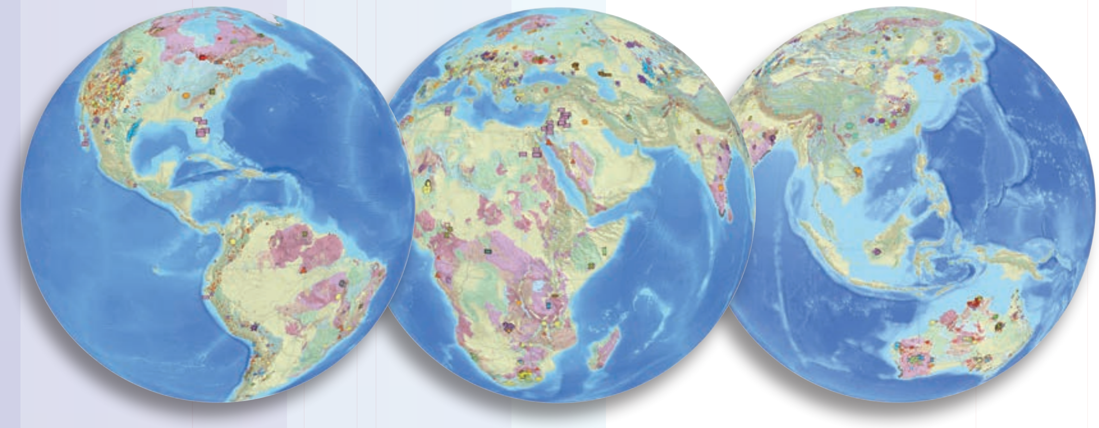
World Uranium Geology, Exploration, Resources and Production



IAEA
International Atomic Energy Agency

WORLD URANIUM GEOLOGY, EXPLORATION, RESOURCES AND PRODUCTION

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
CONGO
COSTA RICA
CÔTE D’IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE’S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency’s Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is “to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world’’.

WORLD URANIUM GEOLOGY, EXPLORATION, RESOURCES AND PRODUCTION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2020

For further information on this publication, please contact:

Nuclear Fuel Cycle and Materials Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

Printed by the IAEA in Austria
June 2020

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: World uranium geology, exploration, resources and production / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2020. | Includes bibliographical references.
Identifiers: IAEAL 20-01333 | ISBN 978–92–0–111520–1 (paperback : alk. paper)
ISBN 978–92–0–111620–8 (pdf)
Subjects: LCSH: Uranium ores — Geology. | Uranium mines and mining. | Prospecting.
Classification: UDC 553.495 | IAEA/WOR/URA

FOREWORD

The principal objective of this publication is to provide a comprehensive compilation of information on uranium geology and potential for uranium mineralization around the world. The information included is based on, and updated from, data compiled within the International Uranium Resources Evaluation Project (IUREP) undertaken by the IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA) from 1978 until the early 1980s. For the sake of completeness, this publication also includes a comprehensive review and comparison of the various outputs of the IUREP, with new data visualization incorporating previously difficult to access information.

The emphasis is on resource related geology, not on uranium markets and supply–demand relationships, which are adequately covered in Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, published in 2006 as part of a joint NEA-OECD/NEA–IAEA project. Nevertheless, a section on developments in the global situation since publication of the Red Book Retrospective is included. In general, information is current to at least 2009, with updates to 2018 where significant developments have influenced world uranium raw material supply.

This evaluation is supported by historic uranium exploration, resources and production data from the 1965 to 2018 editions of the joint OECD/NEA–IAEA publication Uranium: Resources, Production and Demand (commonly known as the ‘Red Book’), compiled, visualized and interpreted by the IAEA. Rather than repeating data verbatim from the latest edition of the Red Book, the analysis is focussed on trends and aggregated information for individual countries over time as a basis for providing insights into future uranium potential. Additional publicly available data supplement this analysis.

To review the complete historic information, it is necessary to refer to earlier editions of the Red Book, many of which may not be readily available. This publication aims to provide a comprehensive overview and interpretation of trends in historic Red Book information, specifically where these trends are relevant to support the assessment of uranium potential, and to make the information more readily available to all users with an interest in uranium.

Countries that are not members of the IAEA and OECD/NEA are included where their uranium geology, resources and production are relevant to adjacent or nearby countries that are, even when low potential for uranium mineralization is indicated based on an assessment of public sources. Remote island States that are interpreted to have negligible uranium potential and no geological relevance to distant countries are not considered.

The IAEA acknowledges the contributions of the experts who participated in the consultancy meetings for the planning and editing of this publication. In particular, the IAEA would like to acknowledge the contributions of the late J. McMurray (United States of America), and to thank J.R. Blaise (France) for extensive reviews and contributions at the various stages of the manuscript preparation and E.J.M. Carranza (Philippines) for comprehensive technical editorial support.

To provide further context for the geological framework of global uranium mineralization, large scale world maps for each of the 15 uranium deposit types currently recognized by the IAEA are included as an annex and are available on-line as a separate supplementary file.

The IAEA officers responsible for this publication were M. Fairclough and A. Hanly of the Division of Nuclear Fuel Cycle and Waste Technology and J. Slezak of the Department of Safeguards.

CONTENTS

CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

World Uranium Geology, Exploration, Resources and Production is a temporal overview of global uranium resource activity at a country level. Uranium 2018: Resources, Production and Demand, also referred to as the 2018 'Red Book' [1.1], uses a cut-off date of 1 January 2017, which is also the cut-off date for much, but not all, of the information used in this publication. In some cases country specific information is taken from a previous or representative Red Book edition for illustrative purposes. Furthermore, it is important to note that this publication should be considered as a snapshot in time. Where significant changes have occurred that could make information compiled during the preparation phase, commencing in 2007, significantly misleading, chapters for some countries have been briefly updated. A world overview has also been provided to reflect these changes and recent global scale trends in exploration, resources and production. Exceptionally, for the few areas with little available information, for example, where a Red Book report was not available for one or more editions, information may have been sourced from another edition of Red Book [1.2] or, occasionally, from other publicly available information.

In 2006, the OECD Nuclear Energy Agency (NEA) published a report titled Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective [1.3]. The intention of that publication was to collect, collate, analyse and publish all of the key data and information collected in the previous 20 editions of the Red Book published between 1965 and 2004. The Red Book Retrospective gives a historical profile of the world uranium industry in the areas of uranium resources, exploration, production, installed nuclear capacity, annual requirements, stocks, price, environmental activities and relevant policies.

This publication differs from The Red Book Retrospective in that it focuses more on the narrative describing uranium geology and deposits, and exploration and production activities over time, and the estimated potential for new discoveries. All current and pending IAEA Member States are included even where uranium potential is relatively insignificant. Furthermore, because geological controls on the distribution of uranium mineralisation is not constrained by political borders and may impact on the potential uranium mineralisation and supply of IAEA Member States, this publication includes reports for countries that have never reported to the Red Book or, where uranium potential is significant, that are not IAEA Member States. Countries are not discussed if they have are currently considered to have negligible uranium potential and share no borders and relevant proximal geology with other countries (i.e. island nations)All information is available in public sources and, in general, available in Red Books in the case of Member States.

1.1.1. Principal reference sources

Publications from the International Uranium Resource Evaluation Project (IUREP) are the primary sources for information in these volumes. Supporting data sources are the joint OECD/NEA–IAEA publications Uranium Resources, Production and Demand (i.e., the Red Book). Twenty-seven editions of the Red Book have been published between 1965 and 2018. Over 100 countries have, in one or more years, reported uranium related activities to the Red Book.

Since 1965, the Red Book has reported on uranium resources worldwide that have been identified or for which there is a high level of assurance of their existence and which can be exploited at the defined production cost ranges prevailing at the time. The Red Book has provided estimates of identified uranium resources, categorized as reasonably assured resources and inferred resources, within cost ranges which have evolved according to uranium production costs. For example, an additional cost category, <US $260 kgU, was added in the 2009 edition, reflecting increasing costs in the industry as well as providing an additional category for when market conditions are favourable enough that such resources may be considered economically viable. As noted above, the cut-off date for temporal information on this

publication is the 2018 Red Book [1.1], but some individual data tables are from earlier editions of the Red Book and are representative only.

The only occasion that undiscovered uranium resources were publicly evaluated on a worldwide basis was under the initiative of the NEA/IAEA Steering Group on Uranium Resources, which conducted an expert study, the International Uranium Resources Evaluation Project (IUREP). The summary results of the evaluation were published in two reports: World Uranium Potential: An International Evaluation (in 1978) [1.4] and World Uranium: Geology and Resources and Potential: Report on Phase I, International Uranium Resources Evaluation Project – IUREP (in 1980) [1.5]. Appendix I comprises a detailed list of these IUREP reports and a review of results.

IUREP was a major investigation of known world uranium resources and potential resources by a team of 24 uranium experts and included a budget for site visits to countries judged to have potential uranium resources. This included meeting with the staff of local geological organizations working with uranium, as well as examination in the field of uranium geology and deposits, and the preparation of detailed reports based on the site visits for select countries judged to have good potential for new discoveries. For some countries, the results of the missions are reported in individual reports.

This publication has some similarities to the IUREP 1978 and 1980 reports and incorporates geological information and the results of historical exploration developed over the 40-year period since the 1978 report was published. In some countries, little or no additional uranium exploration has been conducted since 1978, and for this reason much of the IUREP material is still valid and represents the most current knowledge.

Other sources of information used for this publication include the IAEA's uranium deposit database, World Distribution of Uranium Deposits (UDEPO) [1.6] and publicly available information. This includes technical reports for uranium deposits prepared under the guidelines of the Committee for Mineral Reserves International Reporting Standards and similar national reporting schemes such as the JORC Code (Australasian Joint Ore Reserves Committee) and Canadian National Instrument 43-101. However, the emphasis of this publication is not deposit-scale geology, except where it informs the regional geology and potential for new discoveries.

1.1.2. Special note on resource information for China, the former Soviet Union and Eastern Bloc countries

The 1978–1980 IUREP reports provide little information on uranium resources and production activities for China, the former World Outside Centrally Planned Economic Area group, including the former Soviet Union (FSU), and the Eastern Bloc countries (Romania, Bulgaria, Hungary, Czechoslovakia, German Democratic Republic, Poland). Reports on uranium and related activities for several of the eastern European countries and China were first published in the 1990 Red Book [1.7]. The initial information for uranium resources and activities in the FSU first became available in the 1991 paper titled Uranium Resources of the Union of Soviet Socialist Republics, presented at the IAEA technical cooperation meeting on new developments in uranium exploration, resources, production and demand [1.8]. The first official reports on uranium resources for the Russian Federation and several FSU countries were published in the 1994 Red Book [1.9]. This publication includes reports for most of these countries.

1.2. OBJECTIVES

Providing an estimate of the potential for discovery of new uranium resources is one of the objectives of this publication. Making a formal estimate of the undiscovered uranium endowment and resources is a complex process that requires substantial information and personnel resources, as discussed in the IAEA technical report Methods for the Estimation and Economic Evaluation of Undiscovered Uranium Endowment and Resources: An Instruction Manual [1.10]. Such a systematic evaluation was not conducted for this publication, but several case studies have been published by the IAEA using updated methodologies [1.11].

For most countries with favourable source rocks and geological conditions for hosting uranium deposits, the relative potential for new discoveries is identified with suggested areas, rock types or terrains proposed. No effort was made to make quantitative estimates of undiscovered resources. The estimate of potential provided in the reports is a subjective, qualitative judgement made by the consultancy team. It is important to emphasize that the potential favourability was agreed on by a consensus of IAEA consultants and is not a reflection of official estimates of governments or national authorities, unless they are also reported in the respective Red Book editions.

Unconventional uranium resources, including phosphorite, black shale or schist and monazite bearing sands, are discussed in some Red Book editions, beginning with the 1965 edition. In most cases in this publication, no effort was made to evaluate such unconventional resources.

Thorium resources and related activities are beyond the scope of this report and are not included.

1.3. SCOPE OF THE REPORT

More than 100 countries have, in one or more years, reported uranium related activities to the Red Book. Where information is available, reports in this publication address the following topics:

- Geography: area, population, climate, terrain, and industrial and agricultural activities;
- Geology: regional and local, particularly in relation to potentially favourable uranium bearing areas;
- Exploration: historical review and recent and ongoing developments;
- Uranium occurrences and resources;
- Potential for new discoveries;
- Production centres, production technology and historic quantities;
- Environmental activities related to uranium mining and processing centres;

Geographical information was collected from various sources to provide a background framework for each report. This information is informal and should not be relied on for details regarding the respective areas.

The uranium deposits in this publication are, wherever possible, classified following the system described in the Red Book (see Appendix II) [1.1], and modified by [1.12]. Note that reports of deposits from historical sources or use of other classification systems may vary. All Member States that joined the IAEA after this report's information cut-off date (1 January 2018) and non-Member States that have reported activities related to uranium that may be of interest to Member States are discussed through the reports that make up the chapters in this publication. Technical terms used in this report follow usage in the 2018 Red Book and are defined in Appendix II. Supporting information can be found in more recent IAEA publications [1.13−1.20].

1.4. STRUCTURE OF THE REPORT

In addition to the Introduction, this publication consists of a global overview chapter followed by country chapters. In Chapter 2, the publication provides a summary of the world uranium resources, geology, exploration activities, potential for new discoveries, uranium production, followed by a dedicated global update focusing on the period since publication of the joint OECD-NEA/IAEA Red Book Retrospective in 2006 (containing data up until 2003) .Subsequent chapters present uranium related activities for 172 countries, describing uranium geology and deposits, historical exploration and production activities, the estimated potential for new discoveries.

The Appendices I to II provide a list of the International Uranium Resources Evaluation Project (IUREP) publications and summary data, and a glossary of definitions and terminology as used in the Red Books.

References to Chapter 1

[1.1] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[1.2] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2016: Resources, Production and Demand, OECD, Paris (2016).

[1.3] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[1.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, World Uranium Potential: An International Evaluation, OECD, Paris (1978) 170 pp.

[1.5] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[1.6] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[1.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[1.8] INTERNATIONAL ATOMIC ENERGY AGENCY, New Developments in Uranium Exploration, Resources, Production and Demand, IAEA-TECDOC-650, IAEA, Vienna (1992).

[1.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1994: Resources, Production and Demand, OECD, Paris (1995).

[1.10] INTERNATIONAL ATOMIC ENERGY AGENCY, Methods for the Estimation and Economic Evaluation of Undiscovered Uranium Endowment and Resources: An Instruction Manual, Technical Reports Series No. 344, IAEA, Vienna (1992).

[1.11] INTERNATIONAL ATOMIC ENERGY AGENCY, Quantitative and Spatial Evaluations of Undiscovered Uranium Resources. IAEA-TECDOC 1861, IAEA, Vienna (2018).

[1.12] INTERNATIONAL ATOMIC ENERGY AGENCY, Geological Classification of Uranium Deposits and Description of Selected Examples. IAEA-TECDOC 1842, IAEA, Vienna (2018).

[1.13] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO) 2016 Edition. IAEA-TECDOC 1843, IAEA, Vienna (2018).

[1.14] INTERNATIONAL ATOMIC ENERGY AGENCY, Unconformity-related Uranium Deposits. IAEA-TECDOC 1857, IAEA, Vienna (2018).

[1.15] INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources as Co- and By-products of Polymetallic, Base, Rare Earth and Precious Metal Deposits. IAEA-TECDOC 1849, Vienna (2018).

[1.16] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits map, Second Edition. IAEA-STIPUB1800., IAEA, Vienna (2018)

[1.17] INTERNATIONAL ATOMIC ENERGY AGENCY, World Thorium Occurrences, Deposits and Resources. IAEA-TECDOC 1877, IAEA, Vienna (2019).

[1.18] INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Production Cycle Selected Papers 2012-2015, Proceedings of a Series of Technical Meetings. IAEA-TECDOC 1873, IAEA, Vienna (2019).

[1.19] INTERNATIONAL ATOMIC ENERGY AGENCY, Proceedings of the International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM 2014). IAEA-STIPUB1903, IAEA, Vienna (2019).

[1.20] INTERNATIONAL ATOMIC ENERGY AGENCY, Thorium Resources as Co- and By-Products of Rare Earth Deposits. IAEA-TECDOC 1892, IAEA, Vienna (2019).

CHAPTER 2. OVERVIEW OF GLOBAL URANIUM GEOLOGY AND RESOURCES

2.1. WORLD URANIUM GEOLOGY

2.1.1. Africa

Africa is largely composed of a rigid block of ancient rocks bounded by geologically young mountains at its extremities, which include the Atlas Mountains to the north and the Cape ranges to the south. Between them are a series of plateaux, with extensive level or slightly undulating areas, above which stand more resistant rock masses (Fig. 2.1a) [2.1, 2.2].

Surrounding these plateaux are coastal zones that are mainly narrow, but which widen along the seaward side of Mozambique and the United Republic of Tanzania (hereinafter referred to as Tanzania), north of the Zambezi and Senegal Rivers, and are widest along much of the Mediterranean coastal belt. In proportion to its size, Africa has fewer high mountains and fewer lowland plains than any other continent. There are limited areas over 2500 m in elevation and these are either volcanic peaks or resistant massifs. The basic structure of Africa was established by the end of the Precambrian era (600–500 Ma) and results from a series of relatively brief tectonic events interspersed with extended periods of relative stability. At least seven major orogenic events are recorded in the various mobile belts, the earliest dating to around 3000 Ma; the latest being the Palaeozoic–Early Mesozoic (Hercynian) orogenies of north-western Africa and the Cape Fold Mobile Belt, and the Alpine Orogeny of the Atlas Mountains of northernmost Africa.

Africa has essentially remained stable and emergent since Precambrian time, except in the north where it was occasionally flooded by transgressive Phanerozoic epicontinental seas. The Cape area of South Africa and several coastal basins have also been the sites of limited marine invasion. Numerous sedimentary rock sequences, many of which are terrestrial or marginal marine in origin, rest upon a highly metamorphosed and much intruded Precambrian basement. The sequences of sediments such as the Lubilash of the Congo and the Karoo of South Africa were derived in part from sources beyond the margins of the present continent. This fact, along with the truncation of older structures at the coasts and the similarity with the Palaeozoic and Mesozoic formations in Antarctica, Australia, India and South America, led to the concept of there having once been a southern land mass, Gondwanaland, of which Africa formed a part.

During the Phanerozoic, there were very few orogenic movements; the Atlas Mountains being the only example of Tertiary Alpine mountain building, whereas the Cape Ranges at the southern end of the continent were folded during the Triassic. Palaeozoic folding in the Sahara is minor, in contrast to Precambrian deformation which is widespread and which has been dated to several phases. Deformation outside the mobile belts has usually been epeirogenic resulting in the formation of broad basins separated by axial upwarps, e.g., the Congo, Kalahari and Chad Basins. Such basins are features of all ages from the Precambrian up to the present.

Rift valley troughs extend from the Red Sea to Mozambique and represent the Late Pliocene–Middle Pleistocene. However, these rift valleys are superimposed upon earlier rift structures of Tertiary, Cretaceous, Palaeozoic and probably Precambrian age. Although the adjacent topography rises towards the rifts, so that the flanks frequently reach elevations of almost 3200 m with the floor of the rift standing above the general elevation of the African plateau, the origin of the rifts is usually ascribed to tensional forces. Volcanism has occurred throughout geological time and the majority of rock systems have associated intrusive or extrusive rocks and some of these are on an extremely large scale. For example, the Lebombo basalts and rhyolites capping the Karoo sequence have been estimated to be 8800 m in thickness. In addition, at Calvina and Hopetown in South Africa, individual dolerite sheets cover areas of 9100 km^2 and 13 000 km^2, respectively. In Kenya during the mid-Tertiary, flows of phonolite were extruded to form the plateau topography. Recent volcanism in eastern Africa has been aligned closely along the rift valleys. Volcanic emissions along the Eastern Rift are strongly sodic and those along the Western Rift through the Congo are strongly potassic. Recent volcanism is also recorded in Cameroon and in northern Africa.

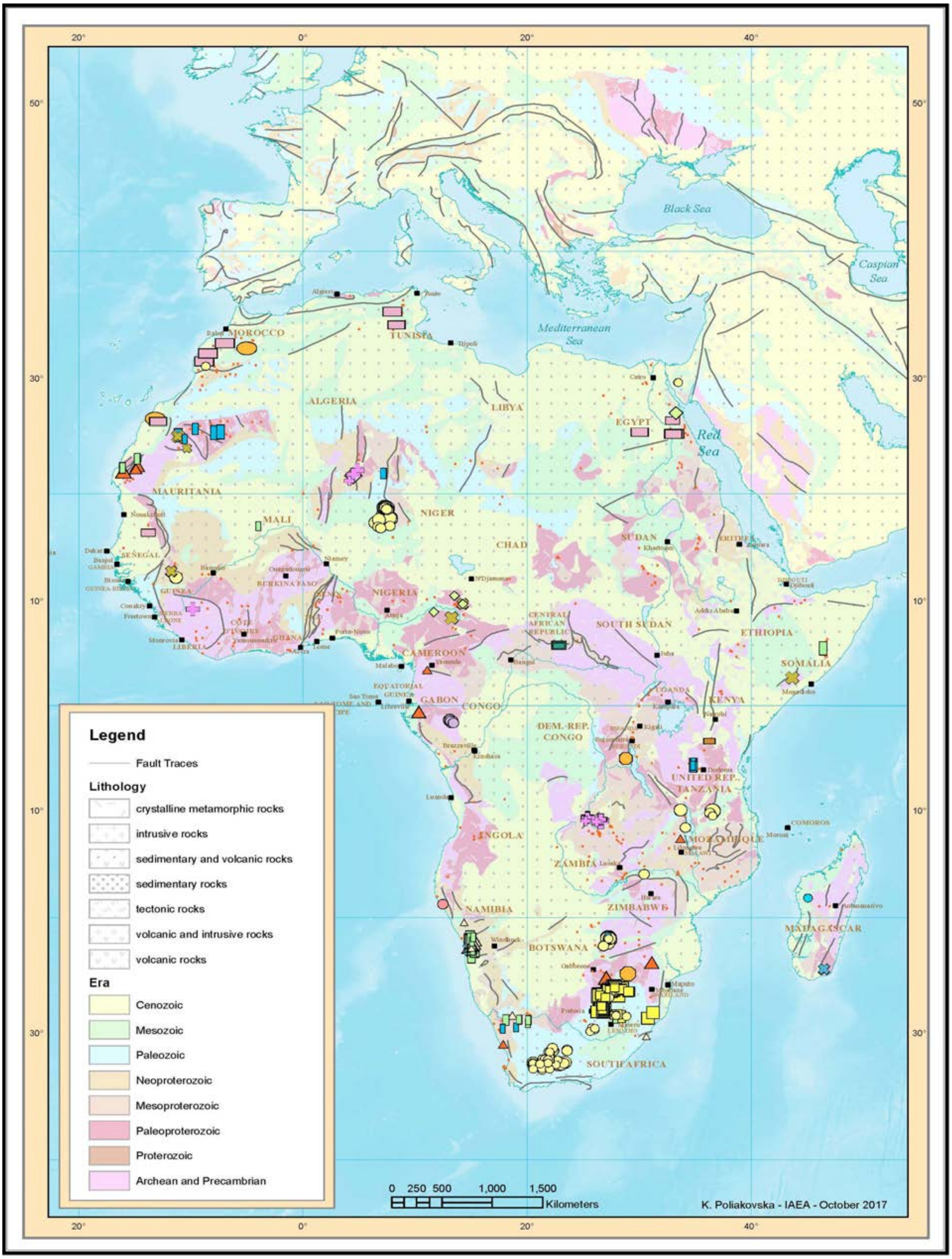


FIG. 2.1a. Regional geological setting of Africa showing the distribution of selected uranium deposits and occurrences. For general uranium deposit legend see Fig. 2.1b. Geological map based upon Geological Survey of Canada [2.1] used under Open Government Licence − Canada (http://data.gc.ca/eng/open-government-licence-canada).

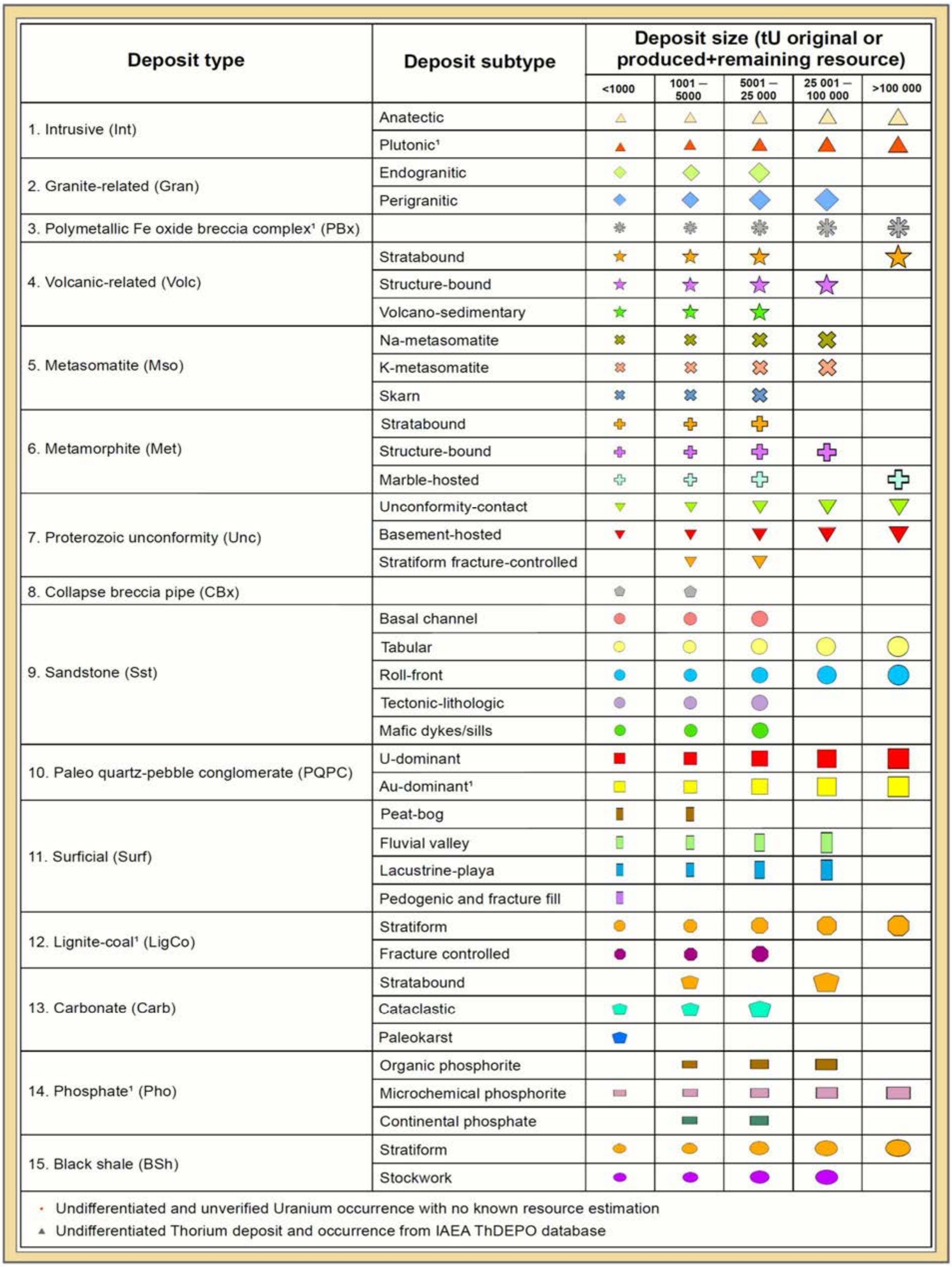


FIG. 2.1b. Deposit type and subtype and deposit size legend for Fig. 2.1a and all regional geological setting maps for country sections in the following chapters.

Archaean

Eight important areas with remnants, or nuclei, of Archaean rocks are observed: Cameroon–Gabon, Côte d'Ivoire–Sierra Leone, Dodoma–Nyanza, Kasai, Mauritania, Transvaal, Zambia and Zimbabwe.

A great variety of metasediments, metavolcanics and plutonic rocks older than 2700 Ma have been recognized in the Transvaal nucleus. This includes the Barberton Mountain Land of the Eastern Transvaal which consists of a complex schist belt of folded sediments and volcanics (greenstones) older than 3000 Ma intruded by basic and ultrabasic rocks and by extensive U-Th rich granites around the margins. These granites are probably the source of detrital minerals found in the Witwatersrand Basin.

In the Zimbabwe nucleus to the north, a similar general relationship exists between remnant schist belts and large bodies of the surrounding granitic rocks. The rocks of the schist belt sequences have been subdivided into several sequences of psammitic and pelitic rocks, ironstones, limestones, some conglomerates, dolomites and some lavas. A minimum age of 2799–2600 Ma is indicated for this succession of rocks.

The Great Dyke, an intrusive body of basic and ultrabasic rocks, transgresses the structure of the schist belts. The dyke lies within the Zimbabwe craton and has been dated at 2.575 billion years old [2.3].

The Dodoma–Nyanza nucleus consists of two contrasting portions: (i) the major part of central Tanzania composed largely of granite, granodiorite, acid gneiss and migmatite associated with folded metamorphic rocks of the Bodoman System; and (ii) a northern portion in northern Tanzania, western Kenya and eastern Uganda where the Nyanzian System, composed of acid and basic volcanic rocks, quartzites, pelites and banded ironstones, is overlain by the Kavirondian System consisting essentially of arenaceous and argillaceous sediments and volcanics.

In contrast to most of the previously discussed nuclei, the nuclei of Kasai, Cameroon–Gabon and West Africa (i.e., Côte d'Ivoire–Sierra Leone and Mauritania) cannot be so precisely delimited. Typical of these is the Kasai nucleus where the ancient rocks consist of gneissic granitic rocks, together with a charnockitic suite of noritic gabbros, enderbites, charnockites, granulites and leptynites. An age of 2700 Ma has been assigned to the granitization and charnockitization.

A similar relationship between granitic and charnockitic rocks has been observed from the poorly defined Cameroon–Gabon nucleus, in which granite occurs over extensive areas.

The Côte d'Ivoire–Sierra Leone nucleus consists largely of a series of micaschists, quartzites, calcareous rocks, ironstones and metamorphosed basic and acid volcanics, intruded by syn- and late kinematic granitic rocks and pegmatites. The sedimentary–volcanic sequences in the Kenema district of Sierra Leone have undergone amphibolite and granulite facies metamorphism. Granitic gneisses, which are structurally conformable with these high grade rocks, yield an age of 2800 Ma.

Similar age patterns have been obtained from the Mauritania nucleus, where a group of metasediments and metavolcanics of the Tasiast Group is associated with migmatitic granites and pegmatites of the Sattle area.

Lower Proterozoic

Subsequent to their orogenic deformation, some of the nuclei were the sites of sedimentation and volcanism and the products were deposited unconformably on the eroded roots of the folded schist belts and their associated granitic rocks. In the Transvaal nucleus, the Dominion Reef, Witwatersrand, Ventersdorp and Transvaal Systems, consisting of a 15 250 m sequence of sedimentary and volcanic rocks, were deposited in the Witwatersrand Basin. Auriferous quartz-pebble conglomerates, some of which are also uraniferous, occur in all four systems. Extrusive igneous rocks form the major part of the

3000–3700 m succession of the Ventersdorp System and also occur in the underlying Dominion Reef and Witwatersrand Systems.

The deposition of the Transvaal System in South Africa was terminated with the intrusion of the great Bushveld Complex of ultrabasic, basic and acid intrusive rocks around 1950 ±200 Ma. The Phalabora carbonatite complex also dates from about the same period. Uranium was recovered from this deposit as a by-product of copper mining.

The Bushveld Complex was intruded about the same time as pronounced orogenic events which affected large parts of the continent (e.g., the Eburnean Orogeny (2150–2000 Ma)). The most conspicuous effects of this orogeny are in West Africa, particularly in Burkina Faso, Côte d'Ivoire, Mali, Mauritania, Morocco and Senegal. In Burkina Faso, Côte d'Ivoire and the surrounding regions, a major part of the Precambrian consists of a strongly folded succession of sediments and volcanics referred to as the Lower Proterozoic Birimian System. These rocks are widely invaded by extensive syntectonic granites and reflect the date of the Eburnean Orogeny. Similar ages have been obtained from granites in Mali and Senegal, which are intruded into supposed correlatives of the Birimian. To the north, in Mauritania, the Amsaga Series of folded gneisses with quartzites, mica schists and calc-silicate rocks contain concordant and discordant granites of about the same age, suggesting that these also were emplaced during the Eburnean Orogeny.

To the south, in Gabon, a series of pegmatites intruding basement gneisses are consistent in age with those of the Côte d'Ivoire and other regions to the north-west. Similar ages obtained from granites in Cameroon and Gabon indicate an extension of this activity.

In the eastern part of Africa, a number of linear orogenic belts have yielded ages in the 2100–1600 Ma range. These include the Kibali, Buganda-Toro, Ubendian-Rusizi (Ubendides) and Limpopo Belts. The Kibali Group consists of schists, quartzites, conglomerates, carbonate rocks and volcanics intruded by granites.

The Buganda-Toro sequences of southern, western and south-western Uganda consist largely of metasedimentary rocks. The NW–SE trending Ubendian-Rusizi Belt of the eastern Congo, southern Tanzania and northern Zambia is largely occupied by crystalline rocks, including metamorphosed sediments, migmatites and biotite gneisses.

In Kasai Province, the Luiza Series, a sequence of metasedimentary schists and gneisses rests unconformably on the basement of the Kasai nucleus and age determinations date the metamorphism and orogenesis of this series to 2100–2000 Ma. To the south of the Kasai region, a fold belt affects the Lukoshi Formation and has been dated as 1845 Ma.

The crystalline rocks of the Limpopo Belt stretch from Botswana eastwards almost to the Mozambique border and consist of metasediments, basic and ultrabasic rocks, granites, gneisses and pegmatites.

Middle Proterozoic

Since the end of the Eburnean Orogeny, a number of segments of Africa have been stable: the Zimbabwe-Transvaal Craton, the Tanzania Craton, the Angola-Kasai Craton and the West African Craton. Within these, later sediments and volcanics up to the present time have been subjected principally to epeirogenic movements. The Transvaal is an excellent example of the long continued stability of these regions, where horizontal and sub-horizontal strata of the Waterberg-Loskop System of quartzites, sandstones, shales, conglomerates and some volcanics overlie the Bushveld Complex.

During the Middle Proterozoic, the Bushveld Complex continued as an igneous province with the emplacement of a series of dolerites and alkali intrusives.

The stable Zimbabwe-Transvaal Craton also recorded sedimentary deposition and igneous activity. The large anorthosite body of southern Angola and northern Namibia was emplaced during this time (1200

Ma). The intracratonic Franceville Basin was the site of deposition of a detrital sequence of sandstones and pelites (Franceville Formation). The Mounana, Boyindzi and Oklo uranium deposits occur in the upper part of the basal Franceville sandstone.

In contrast to some areas of these stable Middle Proterozoic cratons, certain zones were the sites of accumulation of geosynclinal sediments and were affected by the Kibaran Orogeny (1100 ± 200 Ma). Of importance is the Kibaride Belt of central Africa, consisting of 9100 m of geosynclinal sediments of the Kibara and correlative groups. These sedimentary rocks are intruded by pre- and syntectonic granites having ages of 1300 Ma and 1250 Ma, respectively. The Namaqualand-Natal Belt of southern Africa is of the same age but consists mainly of granite and gneiss, with remnants of sediments and volcanic rocks of the Kheis System. The Kabaride Belt and the Namaqualand Belt may have been parts of the same geosyncline.

Upper Proterozoic

After the Kibaran Orogeny, the Kibarides were consolidated with the Angola-Kasai and Tanzania Cratons to form a large single stable unit, the Congo Craton, and the Namaqualand-Natal Belt was incorporated with the Zimbabwe-Transvaal Craton to form the Kalahari Craton. These two stable blocks, together with the West African Craton, were stable during the subsequent Pan-African Orogeny (850–540 ± 100 Ma).

The Pan-African Orogeny resulted in deformation of Upper Proterozoic geosynclinal sediments and also rejuvenation of basement rocks. Zones of orogenically deformed Upper Proterozoic geosynclinal sediments include the Katanga System (central Africa), the Western Congo System (lower Congo), the Hammamat Series (Egypt) the Outjo System (Namibia) and the Pharusian System (southern Sahara). Examples of rejuvenated basement are in central and eastern Africa (the Mozambique and Zambesi Belts), Cameroon, Central African Republic, Madagascar, Nigeria, western Sierra Leone and the Hoggar.

The Katanga System consists largely of a lower (Roan) unit of arkoses, sandstones, shales, conglomerates and dolomites overlain by the Mwashya and the ‘Grand Conglomerate’ tillites, shales and sandstones, and an uppermost (Kundelungi) sequence of conglomerates, limestones, shales, sandstones and quartzites. Copper deposits and some uranium mineralization are found in the Katanga System, in the Zambian Copperbelt and in north-western Zambia. At the Shinkolobwe mine in the Democratic Republic of the Congo, uranium occurs in the Katanga strata. In the Lufilian Arc, the Katanga System is strongly folded, in contrast to the flat lying correlative platform sequences which exist on the Congo Craton to the north.

To the south-west, in the Damaran mobile belt in Namibia, and broadly correlative with the Katanga System, is the north-east trending Outjo System, which consists of two correlative facies, the Otavi and the Damara. The Otavi to the north contains copper deposits and is largely an unmetamorphosed shelf sequence deposited on the southern side of the Congo Craton. The Damara to the south is a regionally metamorphosed eugeosynclinal sequence. The metamorphism of the Lamara culminates in a high grade central zone profusely intruded by granite and pegmatite and it is in this zone that the Rössing uranium orebody occurs. On the south-east side of the Damara facies, and on the same trend (NE–SW) is another shelf facies (Nama Supergroup) similar to, and correlative with, the Otavi. In the lower Congo, the Western Congo System, which is considered to be correlative with the Katanga System, is strongly folded to the west. The rocks of this system consist of a basal Sansikwa System of conglomerates, shales and quartzites, overlain by tillite with interbeds of lava, overlain by a thick succession of clastic and calcareous sediments of the Haut Shiloango. Together, these three systems have strong lithological similarities with the Katanga and Outjo Systems of central Africa and Namibia, respectively.

A number of other sequences in Africa are considered to be Upper Proterozoic in age and are included in this system of Late Proterozoic–Early Palaeozoic orogenic belts (Damaran and Pan-African). These are the Pharusian System of the Hoggar (contains uranium deposits), the Hammamat Series and underlying sequences of Egypt, the Inda Ad Series and parts of the so-called Basement Complex of Somalia and Ethiopia, the Turoka sequence of East Africa, the Rokel River Series of Sierra Leone and the Voltaian-Buem sequence of Ghana. Dated events within all of these units show a broad grouping of ages in the

680–450 Ma range and include the emplacement of synorogenic and late orogenic pegmatite and granite, regional and metamorphic mineral growth or modification and uranium mineralization.

The Mozambique Belt is an important feature of Africa. It has an approximate north–south orientation through Kenya, Tanzania, Malawi, Mozambique and Zimbabwe, and is characterized by ages of 700–400 Ma. This belt contains rocks of Precambrian age, including a number of rejuvenated sequences such as the Nyanzian of Kenya, the Dodoman of Tanzania and the Bulawayan of Zimbabwe. Its trend becomes E–W in Zimbabwe where it is locally known as the Zambezi Belt.

On the western side of equatorial Africa, covering an extensive part of Cameroon and the Central African Republic, a sequence of metasediments, granulites and migmatites intruded by granite and synkinematic dunite and gabbro show a uniform pattern of 650–500 Ma ages.

In West Africa, two regions of Late Proterozoic–Early Palaeozoic activity have been identified, an eastern region extending westwards and northwards from Cameroon through Nigeria, Benin, Mali and into the Hoggar and a western region extending from Sierra Leone northwards through Senegal and Mauritania. The two zones are separated by the West African Craton.

In the southern part of the eastern region, in Benin, Ghana, Mali, Nigeria and Togo, the most extensive rock system within the Upper Proterozoic–Early Palaeozoic belt is the Dahomeyan, consisting essentially of granites, gneisses, migmatites and metasediments. To the north, in the Hoggar region, the structural continuation of this belt is well exposed, and the following tectono-stratigraphic units have been recognized: (i) Suggarian gneisses, marbles and quartzites, (ii) Pharusian metasediments and metavolcanics and (iii) Nigritian molasse. In contrast to the eastern region of Late Proterozoic–Early Palaeozoic orogenesis in West Africa, the western region is less well defined by age determinations.

Phanerozoic craton cover

The area encompassing the Sahara Desert has been a stable platform since the beginning of the Palaeozoic, affected only by epeirogenic movements which produced wide shallow basins and broad uplifts. The pre-Carboniferous Palaeozoic rocks of the Saharan Platform, both marine and continental, are largely clastic. The major transgression began in Morocco with deposition of thick Eocambrian stromatolitic carbonate sediments, with the sea spreading gradually eastwards, reaching its maximum areal extent in the Silurian (Gothlandian). Tectonic movements of Caledonian age (Ordovician–Early Devonian) produced E–W and SW–NE structural alignments and important regressions.

General uplift beginning in the Middle Carboniferous as a result of the Hercynian Orogeny caused the major withdrawal of the Early Palaeozoic sea. Late Carboniferous and all younger transgressions of the sea came from a northerly or north-easterly direction. The Carboniferous sediments are principally continental.

The major topographic feature of the central Sahara, the Hoggar Massif, is a large inlier of Precambrian igneous and metamorphic rocks surrounded by a plateau of principally Palaeozoic clastics. The most severe tectonism affecting the massif occurred in the Precambrian, but in some areas, there are Caledonian structures, and the present appearance of the feature results from early Hercynian movement.

The Adrar des Iforas and the Aïr Massif in Niger are, respectively, the south-western and south-eastern extensions of the Hoggar.

Restriction of the western Tethys Basin and post-Hercynian subsidence along the northern margin of the African landmass resulted in the deposition of a thick series of Triassic and Liassic evaporites. Younger strata of the Saharan Platform are relatively thin, and although continental sands (Continental Intercalaire) were important during certain stages, lagoonal dolomite, evaporite and shale are the dominant rock types. In the north and west of the Sahara platform, the principal later Mesozoic events consisted largely of epeirogenic uplifts with regression and local erosion and transgressive downwarps. Frequent and more intense movements characterized the Early Cenozoic, and local deformation marking the onset of the Alpine Orogeny began in the Oligocene. Stronger orogenic pulses occurred at the end of the Miocene, but the last phase of the Atlas Orogeny took place during the Pliocene–Pleistocene. Thus, the far north-west corner of Africa is a folded zone, Mediterranean and Alpine in nature, joined to continental Africa. The separation is well marked by the South Atlas Fault.

Marine Devonian is present in the southern Cape area of South Africa. This sequence was subjected to Hercynian orogenic movements.

Continental

(1) The Karoo System: In southern equatorial Africa and in Madagascar, Hercynian movements were succeeded by a major glacial period, as indicated by the presence of tillites, followed by continental sediments containing plants and reptiles and covered by basalt flows. This began in the Late Carboniferous and continued through the Permian and Triassic. The Karoo System has been divided into the following series: Dwyka (Late Carboniferous), Ecca (Permian) and Beaufort and Stormberg (Triassic). The Karoo is intruded by one of the largest known networks of basic dykes and sills.

The Karoo covers one half of South Africa, Lesotho, large areas of Swaziland, extends into Mozambique, covers the western part of Zimbabwe and much of Botswana and extends into Namibia. Numerous uranium occurrences and deposits have been discovered in these rocks in Botswana, South Africa and Zambia. Karoo is also present in Somalia, Ethiopia, Angola and DR of Congo.

(2) Carboniferous: In Niger, sandstone type uranium has been discovered in Carboniferous fluviodeltaic sandstones. These clastics are interbedded with marine sediments. Possible Carboniferous correlatives of these uraniferous strata are present farther west, in northern Mali.

(3) Nubian Sandstone: In the absence of a marine transgression at the base of the Palaeozoic, the Precambrian basement may be overlain directly by a continental series such as the Nubian Sandstone. This unit covers a large part of the Sudan and adjacent Chad, Egypt and Libya. The Nubian Sandstone consists largely of cross-bedded, arenaceous and rudaceous units but also includes siltstones, mudstones, sparse lignite, gypsum and some calcareous and ferruginous beds. The subaqueous fluvial and lacustrine sediments were deposited, principally during the Cretaceous, across a broad plain and originated from a source to the south and south-east.

(4) Continental Intercalaire: This term has been used in the past in many parts of Africa for the continental facies of the Late Carboniferous, Permian, Triassic, Jurassic and Lower Cretaceous. In general, the Continental Intercalaire is Lower Cretaceous in age and consists of continental clastics containing silicified wood and dinosaur remains. Continental Lower Cretaceous (overlain by marine Cenomanian) is known from Cameroon, Chad, East Africa, Egypt, Libya, Niger, the Sahara and South Africa. It contains numerous uranium deposits in Niger.

(5) Continental Terminal: This term is applied to Tertiary continental deposits. Wide areas of north equatorial Africa are covered with these continental Tertiary deposits, which locally contain plant remains, freshwater molluscs and vertebrate fossils. In the southern part of Africa, the Kalahari Series of Botswana, Namibia and South Africa would be referred to as the Continental Terminal. Calcretes of the Kalahari are known to be uraniferous in Botswana and Namibia.

Plutonic and volcanic rocks

(1) West African dolerites: The Palaeozoic formations of Côte d'Ivoire, Guinea, western Mali and Mauritania were intruded by prominent dolerite sills (up to 200 m thick) and dykes. The dykes

cut the entire Carboniferous of the Taoudeni Basin but not the overlying Jurassic–Cretaceous. They are probably of Triassic age.

(2) Late Palaeozoic–Mesozoic and Tertiary younger granite ring complexes: The younger granites are high level non-orogenic intrusions. In Niger and Nigeria, they form a group of over sixty massifs lying within a narrow (1500 km × 200 km) N–S strip. The age determinations indicate a Jurassic emplacement (about 160 Ma). In Cameroon and Chad, another group of over twenty plutons, some of which have yielded Tertiary isotopic ages, have a north-easterly alignment.

The most striking petrological feature of this igneous province is the overwhelmingly acid character of the suite and the uniformity of facies found in all areas. Over 95% of the rocks can be classified as rhyolites, quartz syenites, peralkaline granites, hastingsite granites and biotite granites.

Tertiary–Recent alkali volcanism in West Africa is limited to zones affected by younger phases of orogenesis. To the east, the main districts occur in the Hoggar, southern Aïr, Jos Plateau, Biu, southern Cameroon, Ngaoundere and Tibesti. To the west, lavas of the same age and composition have been described from the Dakar region and in the Cabo Verde islands. Basalts of this series are almost invariably related to stratovolcanoes of Strombolian type, whereas the trachytes and phonolites are generally highly viscous and form extrusions, plugs and cumulo-domes, forming distinctive topographical features in the landscape.

(3) Lava flows of East Africa: Despite the number of volcanoes in Africa, volcanic rocks occur only to a limited extent outside East Africa. Extensive lava flows cover large parts of East Africa including Ethiopia, Kenya, Somalia and Uganda. Two series are differentiated: lower basalts (Lower Miocene) and an upper series of trachytes and rhyolites (Upper Pliocene).

2.1.2. Western Europe

The European continent, including Western Europe, is part of the Eurasian continent and is separated from Asia by the late Paleozoic Uralian orogen (Fig. 2.2). The European continent comprises two major sectors, Fennosarmatia in Eastern Europe with an Archean/Early Proterozoic basement and a Middle Proterozoic to Tertiary cover, and Central/Western/Southern Europe with Paleozoic orogens, which accreted since Silurian towards Fennosarmatia.

At present, Europe forms the western part of the Eurasian Plate [2.4]. In the Mediterranean region it abuts against the African Plate to the south which, combined with the broadly SE-directed ridge-push forces of the mid-Atlantic Ridge, and the beginning of an eastward Atlantic plate compression along Iberia, give a broadly NW-SE maximum horizontal crustal compressive stress throughout much of western and central Europe.

Europe comprises various crustal blocks, which have been assembled over geological time. In extreme northwest Scotland, there is a fragment of the late Proterozoic continent of Laurentia, initially part of a North American-Greenland landmass. Otherwise, Europe's continental basement can be divided broadly into two large and distinct regions:

— In the north and east a stable Precambrian craton known as the East European Craton (EEC);
— In the south and west a mobile belt, comprising crustal blocks that have become successively attached to the ancient cratonic nucleus.

The boundary between these two regions is marked by the NW-SE-trending Trans-European Suture Zone (TESZ), extending approximately 2 000 km from the North Sea to the Dobrogea region of the Black Sea. The East European Craton (EEC) comprises Precambrian rocks of the Baltic, Ukraine and Voronezh shields, together with the Russian or East European Platform, where the EEC is covered by relatively thin, undisturbed, Phanerozoic rock sequences. In contrast, the mobile belts to the south and west comprise

Proterozoic-Palaeozoic crustal blocks, which originated as part of the southern Gondwana continent, tectonised by end-Precambrian Cadomian orogenesis that became attached to the south west margin of the EEC in Palaeozoic times. These crustal blocks, belonging to Eastern Avalonia, now form part of the basement of the English Midlands, the southern North Sea, and Armorica extending from western Iberia and Brittany eastwards through central Europe to the Bohemian Massif. The plate tectonic collision of Eastern Avalonia with the East European Craton followed closure of the Lower Palaeozoic Tornquist Sea in late Ordovician to Silurian times. Whereas, the collision of the Armorican micro-continent, with both the EEC and Avalonia, followed the later closure of the Rheic and Theic Oceans probably towards the end of middle Devonian. The southerly European Alpine orogenic belt is mostly of Caenozoic age.

Precambrian

The oldest Precambrian basement provinces of western and central Europe comprise the East European and Hebridean cratons, the stable Cadomian blocks of the London Platform and the East Silesian Massif, and the Caledonian, Variscan and Alpine fold belts. The boundaries between the principal structural elements of the European continental elements are in places poorly defined, partly as a result of a lack of data, and partly because they are concealed by younger rocks. Also, metamorphic overprinting of some older basement areas has occurred during later orogenic cycles. This is particularly the case with the Variscan fold belt, which in places appears to include some Caledonian, as well as the Late Palaeozoic (Devonian-early Carboniferous) orogenic belts. Similarly, throughout the Alps of southern Europe, pre-Alpine basement rocks, including pre-Variscan basement, late-Variscan granitoids and post-Variscan volcaniclastic rocks, occur in many places.

Western Europe has undergone three major orogenic cycles since the Precambrian and an estimated six orogenies during the Precambrian. The older rocks are highly metamorphosed and constitute a crystalline basement in most of Europe.

The Precambrian forms a stable shield area in Finland, Sweden and parts of Norway. Immediately to the west of the shield are mountains folded and uplifted during the Early Paleozoic Caledonian Orogeny. An epicontinental platform lies in the south and east. Farther south the major structures were formed by the Herycynian Orogeny during the Carboniferous and Permian periods. Mountains still farther south were uplifted during the Alpine Orogeny of the Cretaceous and Tertiary. The present continent of Europe stretches from its submarine continental margin in the west to the Ural Mountains in the east, and from the ancient and relatively tectonically stable rocks of the Fennoscandia Shield in the north, to the young, more tectonically and volcanically active zone, of the central and eastern Mediterranean in the south.

Proterozoic and Archaean rocks in Western Europe have ben remobilised during one or more of the Caledonian, Hercynian or Alpine Orogenies in all areas except the Fennoscandian Shield. Study of formations in this relatively stable area has revealed evidence of six orogenic events. The oldest were the Katarchaean Orogeny 3 500 my ago and the Samidie and Belomoride Cycles more than 2 000 my ago. These oldest formations are exposed in the northern part of Finland and Sweden and include volcanic sequences with relatively high uranium content.

The next events dated between 1 850 and 1 700 my ago were the Svecofennain and Karelian. The Svecofennides which are dominant in central Sweden and southern Finland are more highly metamorphosed than the Karelides and originally contained more clays, arenaceous material and basic volcanics. The Karelides contained more sandstones and carbonates, metamorphosed to quartzites and dolomites. Schists and conglomerates occur in both series. The Karelian metasediments stretch in a broad band from the northern part of the Norway-Sweden border across northern Sweden and Finland into Russia. At several locations uranium is associated with sediments intruded by diabase and carbonatite.Later Precambrian orogenic cycles are the Gothide and Ripheide and contain metamorphosed clastic sediments and igneous rocks. The uppermost cycle to the Shield is the Jotnian which contains unmetamorphosed rock and is capped with red sandstone indicative of a post-orogenic series.

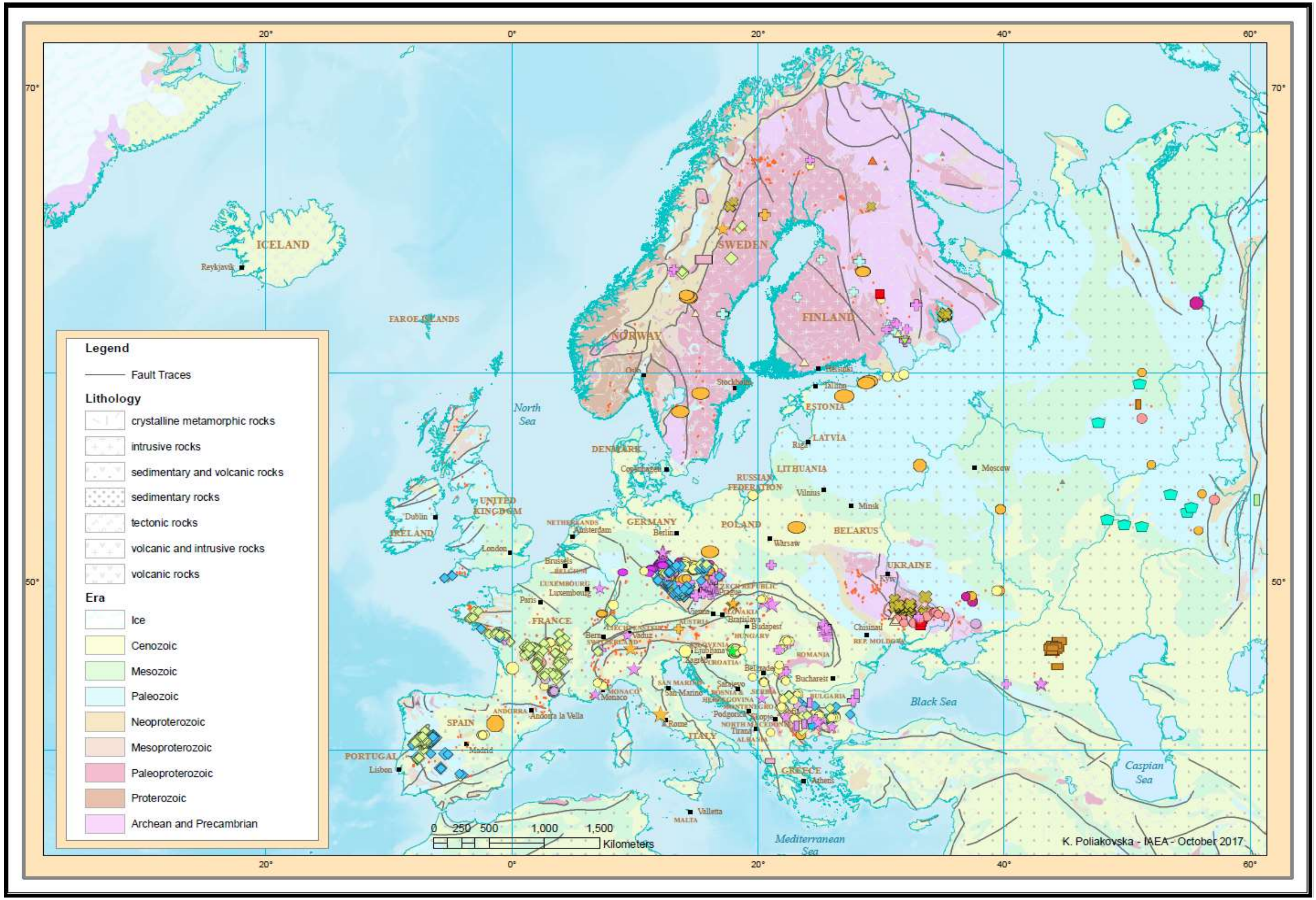


FIG. 2.2. Regional geological setting of Europe showing the distribution of selected uranium deposits and occurrences. For general deposit legend see Fig. 2.1b.

Caledonian

The Caledonides form a belt of uplands from Lapland (northern part of Finland and Sweden) through Norway and the western side of Sweden; his orogenic belt strikes under the North Sea to be observed again in Scotland and Ireland. The geosynclinal stage is recorded in an accumulation of sediments from the late Precambrian to the Silurian. The tectonism was completed in the Devonian.

The earliest Caledonian sediments form the Sparagmite Series which is noted for its arkosic nature and intercalation of layers of till. The till layers are evidence of Late-Precambrian ice ages. The series contains up to 600 m of basal grey and red arkose with some shales. The overlying sediments in the same series are shale, limestone, conglomerate and at the top, sandstone.

Uranium occurrences in Scotland and Ireland are associated with intrusions of the late stages of the Caledonian Orogeny.

The geology of Greenland is similar to that of Norway to the extent that Paleozoic and Precambrian rocks are dominant and have been affected by an orogen coincident with the Caledonian. Uranium is associated with Precambrian sediments and gneisses and with Devonian volcanic and sedimentary rocks. The largest of the known occurrences are associated with the Kvanefjeld portion of the Precambrian Ilimaussaq alkaline intrusive complex. This is a low uranium grade multielement (Rare earth elements, uranium, zinc) deposit.

The Caledonian unconformity is found far from the Caledonide belt in areas affected by the Hercynian Orogen. Metamorphism attributed to the Caledonian had effects as far south as the Alps, and fragments of Caledonian rocks have been preserved in Hercynian structures from the Armorican to the Bohemian massifs.

Caledonian epi-continental platform sedimentation

In southern Sweden and Norway sediments were deposited during the Cambrian, Ordovician and Silurian but without the great thicknesses of the Caledonian geosyncline nor the folding and nappe structures.

In Sweden, dolerite cap rocks, resistant to erosion, have in places preserved sub-horizontal beds of Cambro-Silurian age. Shales and limestones make up most of these strata and at Billingen and other areas uranium occurs in some of the shale beds (alum shales) (Randstad, MMS Vicken, Haggan, … deposits).

In Norway, a north-south trending graben occurs in the Oslo area. The early Paleozoic sediments are preserved under plutonic and volcanic rocks of Permian age.

Quaternary sediments cover most of the epicontinental platform in Denmark, northern Germany, and widen to the east. The underlying strata are not as a rule very thick. Some paleobasins contain economically significant strata, the best known of which are the evaporites of the Triassic and Jurassic Zechstein Basin and the coal of Cretaceous age in Denmark and northern Germany.

Hercynian

The Hercynian front stretches across Western Europe from southern Ireland, across Wales, Belgium and the middle of the Germany. Effects of the orogeny are found in almost all Paleozoic and Precambrian rocks to the south of the front including exposures of crystalline basement in the Alps and Apennines. The present Hercynian massifs are blocks whose structure was determined during the Hercynian Orogeny but were uplifted in the Plio-Pleistocene in Spain and Portugal.

In Devon and Cornwall, southwest England, the Paleozoic sedimentary series contains sandstones, conglomerates, black shales, phyllites and limestones. In places the limestone and sandstone have been intruded by Carboniferous leucogranites. The Ardennes and Rheinisches Schiefergebirge are present in Belgium and the western part of Germany separated by the Rhine River. The Ardennes are composed of Devonian shale, sandstone, conglomerate and some limestone and a cover of Carboniferous limestone. The Rheinishches Schiefergebirge are a similar sedimentary series with volcanics in the Devonian and Lower Carboniferous. Small, tight folds and reverse faults with axial planes dipping to the southeast comprise the principal structural features.

The Amorican massif is located in Brittany and part of Normandy in western France. There is extensive exposure of Precambrian and Early Paleozoic rocks which are not as highly metamorphosed as the rocks of similar age present in other Hercynian and Alpine structures. The Precambrian sediments in the Armorican are composed of clastic material, mainly shales and shaly sand and some sandstone and conglomerate. A series of varved clays and greywackes provide evidence of Late Precambrian ice ages. The Paleozoic sequences have been removed by erosion to a large extent leaving mainly detrital and terrigenous remnants.

Cainozoic to Late Pleistocene volcanics form the centre of the Massif Central. The bulk of the surrounding rocks are sedimentary and igneous rocks metamorphosed to schist, gneiss and granite. A major fault and graben structure, the Sillon Houiller, cuts the Massif Central from north to south. West of the fault, structures tend to strike northwest and southwest. Leucogranites are the dominant Hercynian intrusive rock type. Of the faults, northeast and southwest trends predominate. Uranium is associated with Carboniferous intrusions and overlying Permian sediments. The Montagne-Noire forms a southern extension of the Massif Central. The rocks are not as highly metamorphosed as in the Massif and some unmetamorphosed Early Paleozoic formations remain. Uranium mineralization occurs in Permian continental formations on the border of the Montagne-Noire (Lodève district).

North-East of the Massif Central, the Vosges and the Black Forest massif rise on each side of the border between France and Germany. The granites in these uplands may have supplied the uranium now found in the Permian detrital basins around them. However, they are K-Th-rich granites with refractory minerals, thus uranium is not always released.

The Bohemian Massif rises at the borders between the former West Germany, Austria and the Czech Republic. The Moravian zone along the eastern side of the massif, consists of Precambrian to Devonian schist and Early Paleozoic igneous rock. The southern part of the massif forms the Moldanubian zone containing Precambrian metamorphic rocks intruded by Hercynian granites. Remnants of Permo-Carboniferous molasse sediments overlie parts of these zones. The northern part of the Bohemian massif is covered by post-Hercynian sediments.

High grade metamorphism and granitic plutonism do not appear to have characterized the deeper zones of the Hercynian geosynclines but rather an internal zone of the later Hercynian Orogeny. This internal zone is the Moldanubian which is characterised by a Precambrian basement, often highly metamorphosed and involved in the Caledonian and Hercynian Orogenies. There is usually evidence of a geosynclinal period with neritic facies, a late geosynclinal period with molasse and volcanics, and a post geosynclinal period with fresh water sediments in narrow basins. The type area for the Moldanubian Zone is the Bohemian massif but the zone corresponds to the axis of the Hercynian cordillera extending in an east-west direction across Western Europe. The zone passes south of the Armorican massif via the Vendee, the Massif Central, the southern part of the Vosges and Black Forest to the Bohemian massif.

Most of the known European uranium occurrences are in the Moldanubian. Their size and frequency of occurrence decreases in stages away from this zone coincident with zones of progressively lower metamorphism. These zones of metamorphism are better identified north of the Moldanubian where Alpine events have not obscured the Hercynian. The zone next to the internal zone is the Saxo-Thurigian which is characterised by the presence of Precambrian rocks more or less metamorphosed and intruded by plutons. This basement is usually overlain unconformably by Cambro-Silurian sediments affected by Caledonian folding accompanied by metamorphism and granitic intrusion. The Saxo-Thurignian extends from the Armorican Massif and southern Cornwall under the Paris Basin to the north of the Vosges and eastward to the Thuringian Mountains.

Beyond the Saxo-Thuringian is the Rheno-Hercynian Zone which consists of mainly detrital sediments with limestone facies in the external area away from the Saxo-Thurignian Zone. The Rheno-Hercynian includes the Ardennes, Rheinsisches Schierergebirge and the Harz Mountains. Granitic plutons are exceptional in the Rheno-Hercynian but do intrude the sediments in Devon and in the Ober-Harz region.

The Iberian Peninsula is dominated by the Iberian Meseta which in turn is formed around an axis of Precambrian and Lower Paleozoic schists, quartzites, gneisses and granites. The north-western part of the peninsula is composed of the Cantabria and Asturia Mountains built on Late Hercynian structures. Granite intrusion accompanied the late Hercynian deformation in the Meseta and in the north-western mountains. The areas around the granite intrusions are locally enriched in uranium (Iberian peribatholitic deposits).

Mesozoic and Cainozoic sediments cover the plateaus of the Meseta and are also preserved in valleys in the more rugged areas. To the north and northeast of the Meseta are the Douro and Ebro Basins underlain by Precambrian rock and filled with Cainozoic shallow marine and continental sediments. Some of the intracontinental Tertiary formations contain uranium in lignite-coal beds.

Zones of metamorphism have also been ascribed to Hercynian formations in the Iberian Peninsula. The Galicia-Castille Zone, the belt of the highest grade metamorphism, stretches from the Atlantic Ocean on each side of the Spanish-Portuguese Border in a curve toward Madrid. Three zones of progressively lower-grade metamorphism have been identified on each side of the axis. Uranium mineralisation in crystalline rocks is preferentially associated with the zones of greater metamorphism.

Hercynian rock structures make up the islands of Corsica and Sardinia. The main rock types on both islands are granites intruding a metamorphic basement.

Permian sediments

The more northerly Permian sediments in Europe were deposits in the United Kingdom, Denmark, the Netherlands and northern parts of Germany. In these areas, Permian sedimentation began in depressions with the accumulation of conglomeratic strata commonly accompanied by volcanism.

Farther south, in southwestern England, France and central Germany, the Permian sedimentation began with red fluviatile or limnic deposits in which limestone, coal seams and bituminous shale are common.

For the distribution of uranium concentration, the non-marine Lower Permian strata, particularly sandstones, are important. Uranium occurs in basins around the Massif Central, notably the Lodeve Basin where a basal conglomerate is covered by fine sandstone with bituminous limestone. At the top of the series are psammitic and pelitic deposits.

Alpine

The Alpine Orogeny, principally of Tertiary age, uplifted the Mesozoic sediments, which have been deposited in the Tethys Sea, to form the Alps. The tectonism at the same time and part of the same orogenic event affected all of southern Europe. The mountain systems formed in Western Europe during the Alpine Orogeny are: The Baetic Cordillera, the Iberian Range, the Pyrenees, the Catalanides, the Apennines, the French-Swiss-Italian and Austrian Alps, the Dinarides and the Hellinides.

The Baetic Cordillera consists of an external region with autochthonous neritic sediments of Mesozoic to Miocene age and an internal zone with more deformation and metamorphism. The internal zone consists mainly of Triassic and older schists, quartzites and carbonates.

The Iberian Range is composed of rocks of Paleozoic to Cretaceous age. The older rocks: schists, quartzites and carbonates were mobilised during the Hercynian Orogeny. The younger series is mainly detrital and continental. Uranium occurrences in sandstone are associated with these Mesozoic sequences.

The Pyrénées form a long narrow symmetrical mountain chain with exposure of rocks from Late Precambrian to Tertiary age. The axial zone of the range is composed mainly of the older rocks metamorphosed to gneiss, metasandstones, schists and carbonates intruded by granites. The pre-Pyrénées to the south have Triassic to Eocene carbonate and detrital sediments.

The Catalanides are similar to the Iberian Range but contain Triassic evaporites as evidence of an inland sea and continental origin.

The Apennines are predominantly Mesozoic carbonate in composition but there are outcrops of Paleozoic rocks in Calabria and Sicily. The Paleozoic rocks are gneiss, micaschists, granite and migmatites deformed during the Hercynian Orogeny. The younger rocks are mainly carbonates but also included are Mesozoic and Tertiary flysch and Pliocene and Quaternary clays to silts. Volcanics and intrusive rocks of the Tertiary and Quaternary are prominent in Sicily and the regions around Naples and Rome.

The French, Swiss, Italian and Austrian Alps are composed chiefly of marine sediments deposited in the Mesozoic Tethys geosyncline. These sediments were folded and elevated during the Alpine Orogeny. Continental sediments and crystalline basement of Paleozoic and Precambrian rocks were also uplifted. The structures in the crystalline basement were formed during the Hercynian Orogeny except for intrusion of Permian igneous rocks.

The folds and nappes in the Alps have a common direction indicating tectonic movement toward the continental core, away from an internal zone to the south, or, in the case of the French Alps, to the east. In crossing the Alps from the external zone to the internal zone one can encounter eight schematic zones:

i) In eastern France, the Jura Mountains, where folding has draped Mesozoic sediments over an Hercynian basement. The younger Triassic contains marls and oolitic limestone. The Jurassic sediments are mainly carbonates and are in places covered by Cretaceous marls and Tertiary molasse;
ii) The second zone is a molasse-filled through of Middle Tertiary coarse detritus;
iii) The Pre-Alps consists of Mesozoic strata resting on Early Tertiary flysch as the result of nappe formation. The Mesozoic sediments are mainly marls and limestones;
iv) The High Calcareous Alps formed into recumbent folds and nappes. The major units in the nappes tend to be Jurassic calcareous schists with thinner beds of Triassic dolomites and argillites and Cretaceous limestones and marls. Units of Tertiary flysch are included in the folds;
v) The Hercynian massifs which were uplifted during the Alpine Orogeny. The massifs are crystalline with complex structures following several stages of deformation and metamorphism;
vi) The Pennine Nappes are folded behind the Hercynian massifs. They are composed of Paleozoic and Cretaceous shales and basin igneous rocks. The Pennides lie under a cover of greywacke and limestone in the Eastern or Austrian Alps. Acid igneous intrusions of Triassic and Early Tertiary age in the Eastern Alps are considered favourable for uranium;
vii) The 'Root Zone' is next to the Pennides. The sediments of Mesozoic and Tertiary age were highly metamorphosed and intruded by granites;
viii) The Southern Alps built mainly of Permian ophiolites and Triassic limestone. They broaden toward the east to form the Austrian or Eastern Alps.

The Dinarides butt against the Southern Alps in a line running east-west to the north of Trieste. The Hellenides join the Dinarides in northern Greece and run to the east while the Dinarides continue to the south. The mountains are composed of folded Mesozoic and Tertiary sediments and Precambrian crystalline massifs. The sediments, largely carbonate, are folded toward the west with the Precambrian massifs rising on the eastern side of the ranges and outcropping Macedonia and Thrace.

Greenland

Geologically Greenland belongs partly to North America and partly to Europe. It is located on the Greenland Plate, a sub-plate of the North American Plate. It separated from the European Plate beginning about 55 ma. To the west it is physically separated from Baffin Island by rifts and transform faults. The west coast and the southern third of the east coast consist of Precambrian crystalline rocks. A central Archaen gneiss block is bordered to the north and to the south by early Proterozoic mobile belts. Two mid-Paleozoic fold belts occur in Greenland. The North Greenland Fold Belt is a continuation of the Inuitian Orogeny in the Arctic Islands of Canada, and the Caledonian Fold Belt constitutes a major part of northern East Greenland. Both in North and East Greenland platform areas of Precambrian, Lower Paleozoic and Mesozoic sedimentary formations are bordering the fold belts. In Tertiary time extensive areas were covered by basaltic lavas in central West and central East Greenland. Along the east coast a number of Tertiary igneous complexes were intruded, such as the alkaline mineralised Ilimaussaq Complex. The Quaternary inland ice cap covers the major part of Greenland.

2.1.3. Central, Eastern and South-eastern Europe

2.1.3.1. Geology of Central, Eastern and South-eastern Europe

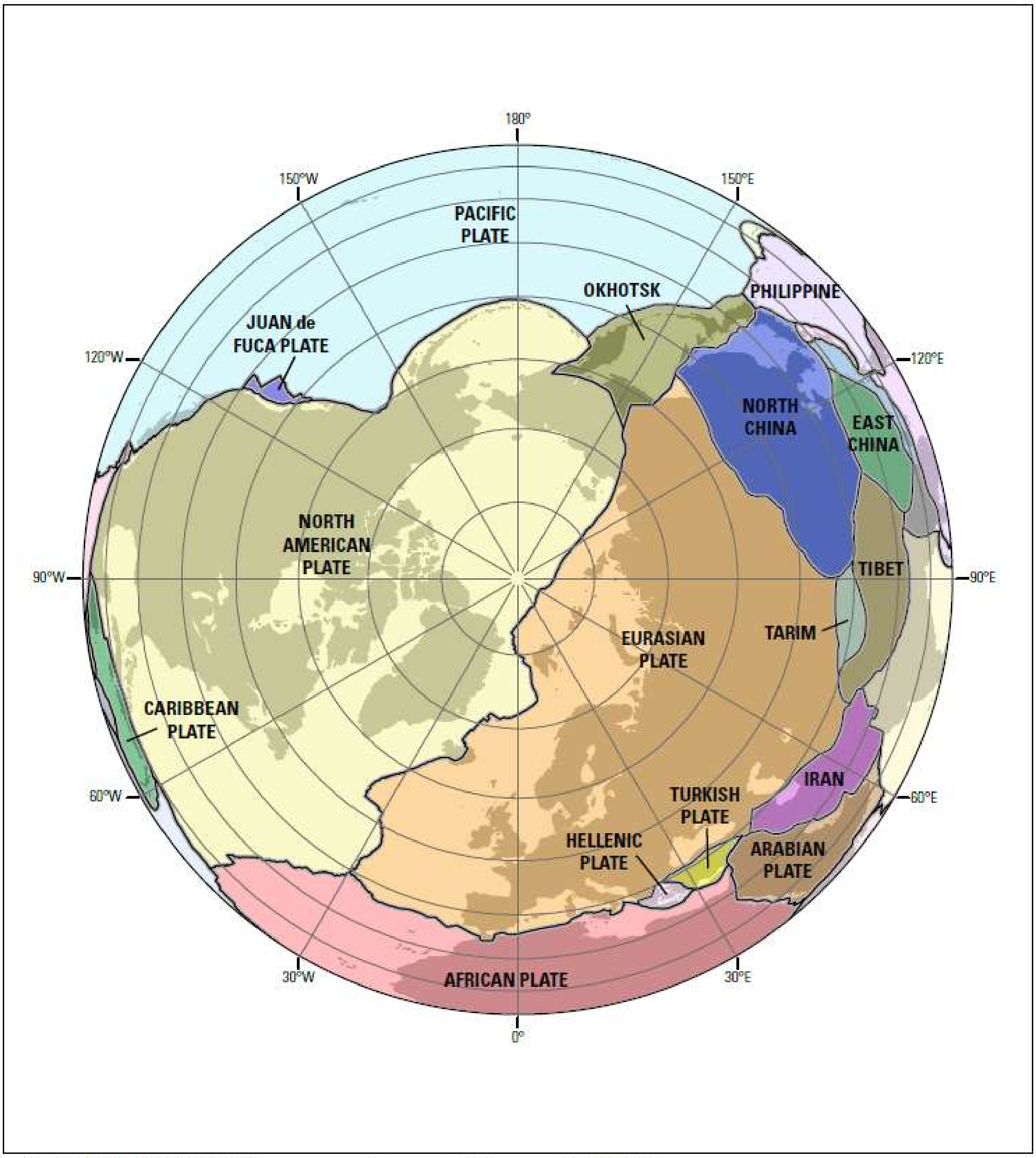
The European continent, including Central and Eastern Europe, is part of the Eurasian continent and is separated from Asia by the mountains of the late Palaeozoic Uralian orogen, which is located within the Russian Federation (Fig. 2.3). The western part of the Russian Federation comprises the central part of the Eurasian Plate to the west of the Ural Mountains (Urals). To the east, the Russian Federation consists of most of the Asian portion of the Eurasian Plate. Recent analysis has shown that the far eastern part of the Russian Federation comprises the North American Plate to the north, whilst the area to the south consists of two microplates: the Okhotch platelet, primarily extending under the Okhotch Sea, and the Amurian platelet located SE of Lake Baikal [2.5–2.6].

The Eurasian Plate is bounded to the north by the Arctic Ocean, which is underlain by the extension of the North Atlantic Ridge and adjacent sea floor, extending from Iceland under the Arctic Ocean to eastern Siberia where it enters the north-eastern Siberian landmass. The Eurasian Plate is bounded to the south (traversing W–E) by the African, Turkish, Arabian, Iranian, Tibetan, Tarim and North China Plates.

The European continent comprises two major sectors: Fennosarmatia (i.e., East European Craton) in eastern Europe with an Archaean–Early Proterozoic basement and a Middle Proterozoic–Tertiary cover, and central/southern Europe with Palaeozoic orogens, which have accreted since the Silurian towards Fennosarmatia.

Europe comprises the western sector of the Eurasian Plate. It adjoins the African Plate in the south-eastern Mediterranean region, which, together with the generally south-easterly trending ridge push forces of the mid-Atlantic Ridge, and the initiation of an east-directed Atlantic Plate compression along Iberia, provides a largely NW–SE maximum horizontal crustal compressive stress field all over most of Europe [2.6].

Europe's geology reflects the plate tectonic processes and the shifting geometry and geography of plates that have been active all through the 3500 Ma of the continent's evolution. The present-day Europe consists of several crustal blocks, which have been amassed through geological time. The basement of the European continental can be split largely into two vast and distinct regions: (i) the stable Precambrian East European Craton in the east and north; and (ii) the mobile Alpine orogenic belt in the west and south, made up of crustal blocks that have sequentially attached to the nucleus of the ancient craton. The border between these two regions is defined by the NW–SE trending Trans-European Suture Zone (formerly known as the Tornquist Line, the Tornquist–Teisseyre Line, or the Trans-European Fault), extending ~2000 km from the North Sea to the Dobrogea region of the Black Sea. The Trans-European Suture Zone is ubiquitously masked and buried beneath Mesozoic and Cenozoic sediments, although it has been rather well defined as an extensive zone of NW–SE trending faults by subsurface geology, drill hole data and geophysical methods, including deep seismic reflection data.



Base map from U.S. Department of State (2009).
Plate boundries modified from Bird (2003).
North Pole Orthographic projection,
Longitude of center 0°., latitude of center 90°.
Datum: WGS 1984.

0 1,500 3,000 KILOMETERS
0 750 1,500 MILES

FIG. 2.3. North polar view of tectonic plates (modified and based upon [2.7]).

The East European Craton consists of Precambrian rocks of the Voronezh, Ukraine and Baltic Shields, together with the East European or Russian Platform, in which the East European Craton is veneered by somewhat thin, undisturbed Phanerozoic rock series. On the other hand, the mobile belts to the west and south consist of Proterozoic–Palaeozoic ‘microcontinents’ (i.e., crustal blocks), which were derived from the southern Gondwana continent, tectonized by the Late Precambrian Cadomian orogenesis that became amalgamated to the SW boundary of the East European Craton during the Palaeozoic. These crustal blocks, belonging to Armorica, extend from western Iberia and Brittany eastwards to the Bohemian Massif. The southerly European Alpine orogenic belt is mostly of Cenozoic age.

The oldest Precambrian basement provinces of Central Europe is composed of the East European Craton and the East Silesian Massif, well as the Variscan and Alpine fold belts. The Bohemian Massif extends over the central Czech Republic, eastern Germany, southern Poland and northern Austria. It is surrounded by four ranges: (i) the Ore Mountains in the NW, (ii) the Sudetes (Sudety Mountains) in the NE, (iii) the Bohemian-Moravian Highlands in the SE, and (iv) the Bohemian Forest in the SW. It consists of crystalline rocks that predate the Permian (>300 Ma) and were deformed during the Variscan Orogeny.

The Precambrian forms a stable shield area in Finland and further west, and an epicontinental platform lies to the south and east. Further south, the major structures were formed by the Hercynian Orogeny during the Permian and Carboniferous periods. Mountains further south still were uplifted during the Cretaceous–Tertiary Alpine Orogeny.

The present European continent extends from the Ural Mountains in the east to its submarine continental boundary in the west, and from the ancient and relatively tectonically stable rocks of the Fennoscandian Shield in the north, to the young, more tectonically and volcanically active, Alpine zone of the eastern Mediterranean in the south.

(1) Precambrian Shield

Proterozoic and Archaean rocks in Western Europe have been remobilized during one or more phases of the Caledonian, Hercynian or Alpine Orogenies in all areas except the Fennoscandian Shield. Study of formations in this relatively stable area has revealed evidence of six orogenic events. The oldest are the Katarchaean Orogeny (3500 Ma) and the Samidie and Belomoride Cycles (>2000 Ma). These oldest formations are exposed in the northern part of Finland and Sweden and include volcanic sequences with relatively high uranium contents.

The next events, between 1850 and 1700 Ma, are Karelian and these have been identified as the eugeosynclinal and miogeosynclinal stages of one orogenic cycle. The Karelides contain more sandstones and carbonates, metamorphosed to quartzites and dolomites. Schist and conglomerate also occur. The Karelian metasediments extend in a broad swathe across northernmost Europe and into the Russian Federation. At several locations, uranium is associated with sediments intruded by diabase and carbonatite.

(2) Caledonian epicontinental platform sedimentation

Quaternary sediments cover most of the epicontinental platform in northern Germany and these widen to the east. The underlying strata are usually not very thick. Some palaeobasins contain economically significant strata, the best known of which are the evaporites of the Triassic and Jurassic Zechstein Basin and coal from the Cretaceous of northern Germany.

(3) Hercynian Orogeny

The Bohemian Massif rises at the borders between Germany, Austria and the Czech Republic. The Moravian Zone along the eastern side of the Massif consists of Precambrian–Devonian schist and Early Palaeozoic igneous rock. The southern part of the Massif forms the Moldanubian Zone containing Precambrian metamorphic rocks intruded by Hercynian granites. Remnants of Permian–Carboniferous molasse sediments overlie parts of these zones. The northern part of the Massif is covered by post-Hercynian sediments.

High grade metamorphism and granitic plutonism do not appear to have characterized the deeper zones of the Hercynian geosynclines but rather an internal zone of the later Hercynian Orogeny. This internal zone is the Moldanubian, which is characterized by a Precambrian basement, often highly metamorphosed. There is usually evidence of a geosynclinal period with neritic facies, a late geosynclinal period with molasse and volcanics, and a post-geosynclinal period with freshwater sediments deposited in narrow basins. The type area for the Moldanubian Zone is the Bohemian Massif, but the zone corresponds to the axis of the Hercynian cordillera, extending in an E–W direction across western Europe.

Most of the known European uranium occurrences are in the Moldanubian. Their size and their frequency of occurrence decrease in stages away from this zone and coincide with zones of progressively lower metamorphism. These zones of metamorphism are more easily identified north of the Moldanubian, where Alpine events have not obscured the Hercynian.

(4) Alpine Orogeny

The Alpine Orogeny (Fig. 2.4), principally of Tertiary age, uplifted the Mesozoic sediments which had been deposited in the Tethys Sea to form the Alps of western Europe. The tectonism affected all of southern Europe. The mountain systems formed in central and south-eastern Europe during the Alpine Orogeny are the Dinarides, extending east and SE into central Europe, including Slovenia and other countries to the south, and the Hellenides, located to the SE in The Former Yugoslav Republic of Macedonia and in the eastern, continental part of Greece.

The Dinarides abut against the southern Alps in a line trending E–W, to the north of Trieste. The Hellenides join the Dinarides in northern Greece and extend to the east whilst the Dinarides continue to the south. The mountains are composed of folded Mesozoic and Tertiary sediments and Precambrian crystalline massifs. The sediments, largely carbonate, are folded towards the west with the Precambrian massifs rising on the eastern side of the ranges and cropping out in North Macedonia and in northern Greece (Thrace).

The Carpathian Mountain system forms a loop extending east across the Czech Republic, Slovakia and Poland, and then strikes SSE through south-western Ukraine and into Romania. The zone then turns WSW across central Romania and into Serbia where it is cut off by the south-easterly trending Alpine Zone. The area enclosed within the loop is the Pannonian Basin of Romania, with the Tisia deposits of Neogene–Quaternary age on the surface. To the east, the foredeep sediments of the Carpathians lap onto the East European Platform. The platform, part of the Eurasian Plate, has an extensive (>3 km thick) Riphean (Middle–Upper Proterozoic) sedimentary cover over its 3000 km width.

The geology of Ukraine forms the transition from the Alpine Carpathian Mountains in the west and SW of the country and the Gorny Crimea in the south through the sedimentary rocks of the respective foredeeps, to the East European Platform of the Eurasian Plate. The Precambrian crystalline massif is in part overlain by large sedimentary basins.

The geologically complex Alpine system extends to SSE through mainland Greece. This includes the sediments and volcanics related to the subduction zone. Nearly continuous to intermittent ophiolites and related rocks occur in twin bands parallel with the tectonic trend. Carbonates occur in a broad 100–180 km wide platform, extending inland from islands along the Adriatic coast from Slovenia southwards to Montenegro and northern Albania. Carbonates are less common southwards through Albania and Greece, although ophiolites continue. In this region, the sequence includes the Pelagonian Zone, believed to be a portion of an older plate caught up in the subduction zone.

In southernmost continental Greece, the Greek islands and Crete form another discrete plate, the Aegean Plate.

FIG. 2.4. Schematic tectonic overview of the Alpine orogenic system of south-eastern Europe [(adapted from [2.8]).

2.1.3.2. Geology of Turkey

Much of Turkey comprises the Anatolian Plate, whilst the Eurasian Plate (separated from it by the Anatolian Fault) includes most of the terrain to the north of Turkey. To the west lies the Aegean Sea, underlain by the Aegean Sea Plate (part of the Eurasian Plate), which hosts most of the Greek islands but excludes the northern mainland of Greece.

The early geological history of Turkey is poorly understood, owing to complex ongoing tectonic processes that have transformed the geology. The African Plate is located to the south of the Anatolian Plate, and the Arabian Plate is adjacent to the south-eastern border (Fig.2.5).

A complicating factor to understanding the geology of Turkey is that the Anatolian Plate consists of several continental fragments which were joined together into a single landmass in the Late Tertiary.

During most of the Phanerozoic, these continental fragments, or terrains, were separated by oceans, whose remnants — ophiolites and accretionary prisms — are widely distributed throughout Anatolia [2.10].

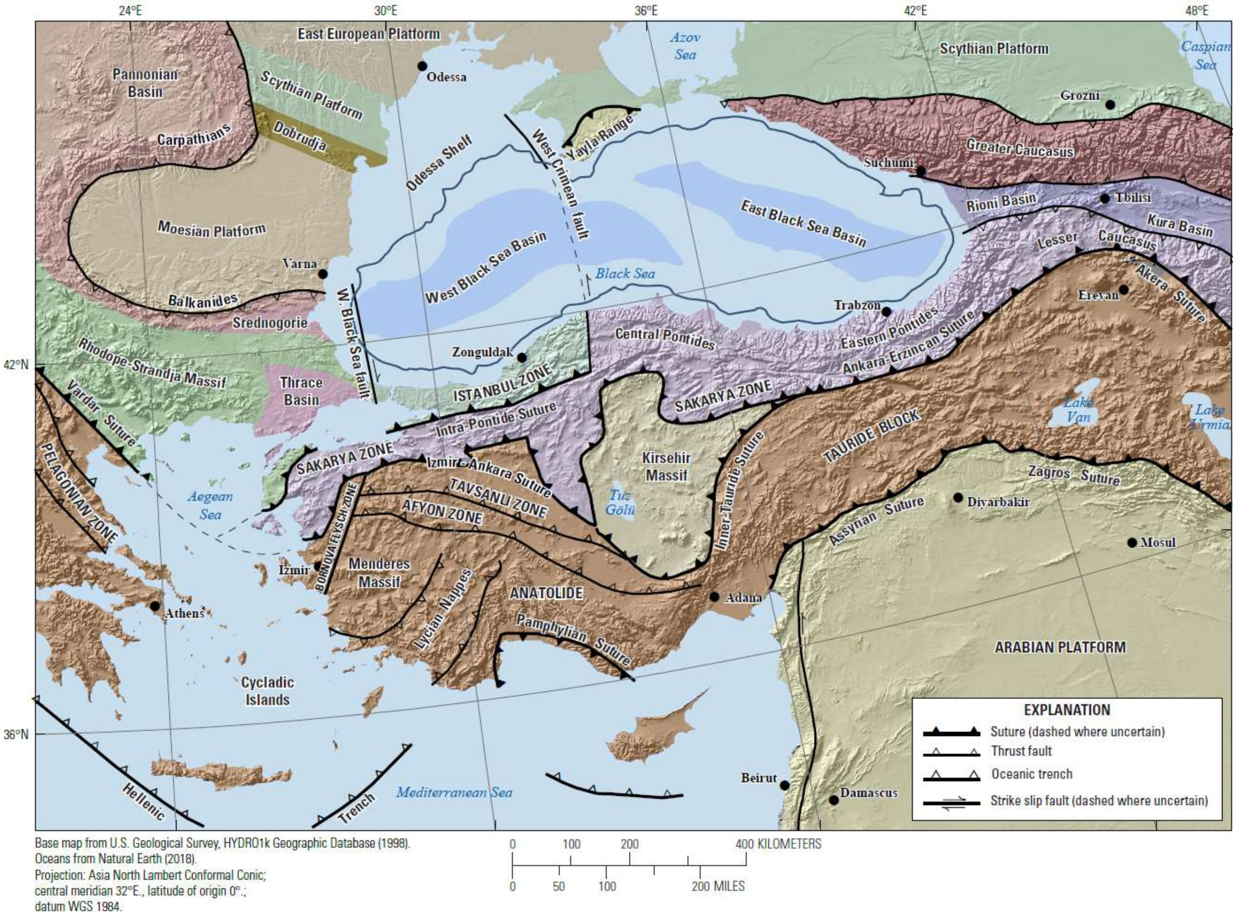


FIG. 2.5. Tectonic map of Turkey and surrounding region (adapted from [2.9)].

Precambrian formations occur in some outcrops as ancient massifs. However, these rocks are extensively deformed and metamorphosed. This is also observed for Palaeozoic strata, now occurring as gneiss, mica schist and quartzite. For most of the country, the Alpine belt is the dominant geological feature. Starting in the Mesozoic, the belt formed a large sedimentary basin known as the Tethys Sea, which separated Gondwana from the Eurasian Plate until the Tertiary. Several episodes of closing and opening of this ocean resulted from movements of the Arabian, African and Indian Plates and initiated the Alpine type mountain building affecting Turkey. Subduction and folding produced a variety of rocks and tectonically mixed blocks, which carry ophiolites, serpentinite and other basic rocks interbedded with chert and metasediments. Intrusion occurred during the pre-Alpine period in the Menderes and Kirsehire Massifs (granites with uranium mineralization).

The Alpine period (Jurassic–Early Tertiary) is characterized by a range of rocks of basic to acidic composition. During the Eocene–Miocene, basalts, andesites and rhyolites were extruded, followed by extensive basaltic volcanism in the Quaternary. Recent studies indicate that the Anatolian Plate, comprising much of Turkey, is wedge shaped to the east and that it is being 'squeezed' westwards as the Eurasian and Arabian Plates come together. These blocks are separated by the North Anatolian Fault to the north and the East Anatolian Fault which runs along the SE of the country.

2.1.3.3. Geology of the Russian Federation

Reflecting its position as the world's largest country, covering an area of 17 075 400 km², the Russian Federation has a commensurately varied and complex geology. Only a short summary is provided here, and the reader is referred to the country report and other sources for more details. With the exceptions of far eastern Siberia, noted below, the Russian Federation comprises the large Eurasian Plate, bounded to the north by seafloor volcanics in the western Arctic which diminish along the Gakkel Ridge to the SE. It is bounded to the south by the African and Indo-Australian Plates, and to the east by the Philippine and Pacific Plates.

The Russian Federation is characterized by a variety of geological regions: the Precambrian of the Russian and Siberian Platforms, the Palaeozoic Uralian and Angara geosynclines, and the Mesozoic and Tertiary geosynclines of the Mediterranean and Pacific Ocean types. In the northern region, the west Siberian lowlands occur, with Quaternary deposits, as well as the Western Arctic and Timan regions, which are thought to be a northern extension of the Uralian geosyncline.

The northern areas of the Russian Federation have a limited infrastructure and road system to provide access for exploration. This is a due to several factors, including several major north flowing rivers, severe cold weather, large areas of permafrost and tundra to the north and widespread boreal forests to the south.

Historically, geologists have divided the Russian Federation into 13 geological regions (Fig. 2.6). Although this provides a basic framework, more recent work highlights diverse geological and tectonic features, as well as providing more detail of this area. With the exception of the extreme NE of Siberia, detailing this is beyond the scope of the present report and the reader is encouraged to review other information sources.

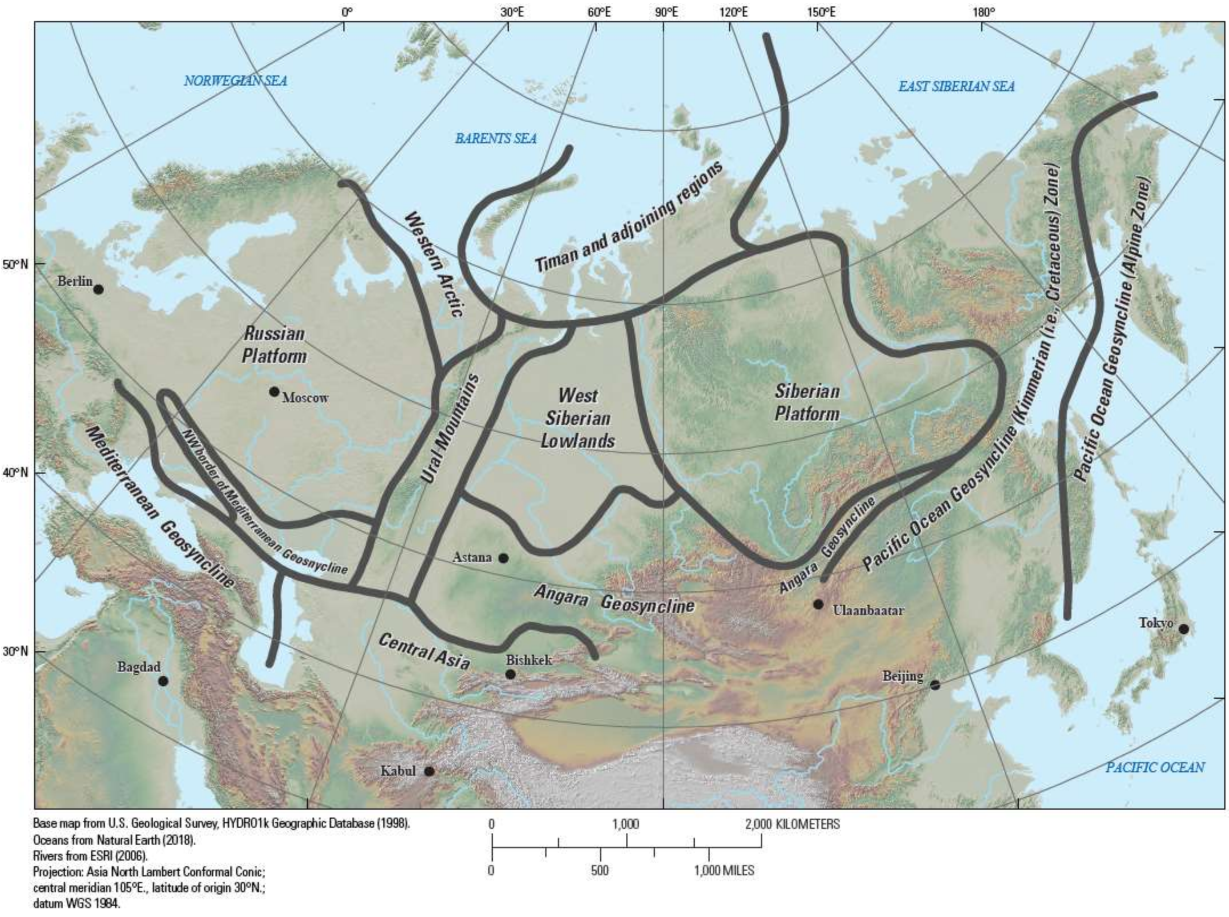


FIG. 2.6. Map of the geological regions of the Russian Federation (adapted from [2.11]). I: Russian Platform; II: Siberian Platform; III: West Siberian Lowlands; IV: Ural Mountains; VA: Western Arctic; VB: Timan and adjoining regions; VI: Angara Geosyncline; VII: Central Asia (see Volume 5 of this series for details of Central Asia); VIII: Mediterranean Geosyncline; IX: North-western border of the Mediterranean Geosyncline; XA: Pacific Ocean Geosyncline (Kimmerian (i.e., Cretaceous) Zone); XB: Pacific Ocean Geosyncline (Alpine Zone).

(1) Russian Platform

The Russian Platform includes Archaean rocks, exposed in the Kola Peninsula and in Karelia, which includes gneisses, migmatites, crystalline schists and granites. The Lower Proterozoic is developed in the Fennoscandian Massif (Kola Peninsula and south of the White Sea). Younger rocks of Palaeozoic, Mesozoic and Tertiary ages occur at various locations over the Precambrian units, as described in the country report on the Russian Federation [2.11].

Geosynclinal folded structures are only developed in the Precambrian deposits whereas the Phanerozoic deposits occur as platform structures. Magmatism was particularly intensive during the Archaean and Lower Proterozoic but subsided in the Upper Proterozoic. Caledonian alkaline intrusions occur in the Kola Peninsula and these contain large apatite deposits.

The East European Craton is composed of Precambrian rocks of the Voronezh, Ukraine and Baltic Shields, together with the East European or Russian Platform, in which the East European Craton is veneered by rather thin, undisturbed Phanerozoic rock series. On the other hand, the mobile belts to the west and south consists of Proterozoic–Palaeozoic ‘microcontinents’ (i.e., crustal blocks), which were derived from the southern Gondwana continent, and were tectonized by the Late Precambrian Cadomian event, becoming amalgamated to the SW boundary of the East European Craton during the Palaeozoic.

(2) Siberian Platform

The Precambrian Siberian Platform is similar to that of the Russian Platform. In the Anabar and Aldan Massifs, the Lower Archaean is represented by gneisses, schists and migmatites, and in the SW by marbles, quartzites and schists with many intrusions. The Lower Proterozoic is developed on the Eastern Sayan Massif as a 10–12 km sequence of folded schist, phyllite, quartzite, crystalline limestone and dolomite. The Middle Proterozoic is similar; the Upper Proterozoic is less folded.

The Lower Palaeozoic and the Silurian are well developed, in contrast to the Devonian and the Lower Carboniferous which are almost absent. Cambrian and Ordovician seas spread over the area of the Siberian Platform and during the Silurian the southern portion was a coastal plain where red sediments accumulated. During the Devonian, the sea occupied the north-western part and during the Lower Carboniferous it had been restricted to the region of Norilsk and Kureika. The Devonian red bed deposits are generally thin. The Lower and Middle Palaeozoic strata are overlain by rocks of the Tunguska coal-bearing suite of sandstone, sand and clay with interbedded marl and coal seams, probably of Upper Carboniferous and Lower Permian in age. The Upper Permian and Lower Triassic consist of basic effusive rocks with a few continental sediments. The lower part of the series is tuffaceous and the upper part has lava flows and dolerite dykes.

Middle and Upper Triassic strata are absent. The Lower and Middle Jurassic strata comprise sandstone, sand and clay and contain bituminous coal. The Jurassic rocks of the Vilui depression contain a marine series and a coal-bearing Upper Jurassic section. During the Cretaceous period, most of the Siberian sedimentation was continental and contains coal measures. The Upper Cretaceous in west Siberia is marine. Tertiary sedimentation is exclusively continental and some of the Miocene beds have coal sequences.

Four Precambrian orogenies and magmatic cycles are developed: the Saamian (Lower Archaean), the Svekofennian (Upper Archaean), the Karelian (Lower Proterozoic) and the Baikalian (Upper Proterozoic). The Caledonian Orogeny was not accompanied by magmatism, unlike the Hercynian Orogeny which includes Upper Permian and Lower Triassic volcanism. An alkaline complex was intruded into the platform in the SE, probably during Jurassic–Lower Cretaceous period, and the Baikal basalts were extruded during the Alpine orogenic period.

(3) West Siberian Lowlands

Nearly the entire area is covered by Quaternary deposits and knowledge of pre-Quaternary geology is heavily reliant on geophysical surveys and data derived from deep drill holes. Results of this work indicate there are 3000–4000 m of Jurassic, Cretaceous and Tertiary marine and continental sediments overlying a Palaeozoic floor. In general, the Upper Jurassic and Lower Cretaceous are marine; the Upper Tertiary and Quaternary are continental.

(4) Urals

The Urals are an excellent example of deformation associated with the collisions of two continents and are similar in this respect to the Appalachians. They form a continuous belt 150–300 km wide and more than 4000 km long. They are overthrust to the west and cover the eastern part of the little deformed Russian (East European) Platform. To the east, they abut the weakly deformed post-Palaeozoic sedimentary rocks of the West Siberian Lowlands that are now largely covered by Quaternary deposits [2.12].

The Urals are the western side of a wider zone of deformation, the Uralides, which underlie the West Siberian Platform, and eastwards crop out again along the western edge of the Siberian Platform. The Uralides underwent maximum deformation during the Late Palaeozoic (Hercynian) as the Russian and Siberian continents converged and sutured, incorporating island arcs and other essentially oceanic fragments that were caught between them. Convergence during the Hercynian produced folding, the intensity of which diminishes towards the west, along with strong westward thrusting of slices of the eugeosynclinal rocks onto the western shelf. Right-slip faulting deformed the Variscan basement and indicates either non-orthogonal convergence or an earlier period of deformation [2.12].

During the Precambrian and Palaeozoic, the Urals were an area of downward movement, with the accumulation of sediments and volcanics exceeding 25–30 km in thickness. The Hercynian Orogeny closed this geosyncline in the Upper Palaeozoic. By the Middle Triassic, the area had been peneplained, but block movements at the end of the Triassic created a new mountain chain which was again peneplained during the Miocene. Block faulting during the Pliocene created the present mountainous topography.

The Archaean consists of gneisses and crystalline schist whereas the Proterozoic comprises schist, quartzite and effusive rocks. The Cambrian occurs in the south as reef limestone. The Ordovician comprises predominantly marine deposits with an arkosic sequence in the SE. The Silurian in the east is divided into a lower shale, sandstone and effusive sequence and an upper limestone sequence. In the west, the rocks consist mainly of coastal continental red beds. The Devonian is represented by a variety of rock types. In general, the succession is marine and is better developed on the eastern flank where lavas and tuffs are common and persist into the Lower Carboniferous.

The Upper Palaeozoic is partly developed on the eastern flanks of the Urals, represented by marine limestone of Middle Carboniferous age followed by limited continental Upper Carboniferous sediments. In the west, however, the Upper Palaeozoic is well developed and consists mainly of a 4–5 km succession of marine sediments. The Middle Permian sequences are continental or lagoonal, with red beds, and contain both salt and coal deposits. The Lower Triassic is developed in the west where it is represented by red beds, the Middle Triassic is absent, and the Upper Triassic occurs in the east as coal-bearing strata. The Lower and Middle Jurassic are predominantly continental, with coal in the latter strata and marine incursions occurring in the Upper Jurassic. The Lower Cretaceous is represented by marine and continental sediments, including lignite. The marine Upper Cretaceous occurs only in the east and the Tertiary sediments are generally thin and mainly of continental origin.

Precambrian magmatism is limited. Basic/ultrabasic intrusions were emplaced during the Caledonian Orogeny, as were several granites and the alkaline intrusives of the Ilmen and Vishnevy Mountains. Acid volcanics were extruded during the Ordovician. The Hercynian Orogeny is characterized by acidic and basic volcanism and emplacement of granitic intrusives in the eastern Urals during the Middle Palaeozoic.

Pegmatite, aplite and granite porphyries are widely distributed. Post-Hercynian igneous rocks are extremely rare.

(5) The Western Arctic and Timan regions

The Western Arctic and Timan regions represent the continuation of the Urals. The tectonic setting of Timan and the region between Timan and the Urals remains controversial. Some geologists believe they are related to the Russian Platform whilst others consider the region to be a peculiar development of a NW branch of the Urals which formed during the Hercynian Orogeny. The post-Silurian stratigraphy is similar to both the Russian Platform and the Western Urals. The tectonics of the Western Arctic are similar to those of the Urals and the magmatism is essentially identical to the latter, especially with respect to the extrusives and the acid intrusions of the Palaeozoic period. There are similarities, with the Lower and Middle Palaeozoic sediments being of marine origin, but with coal-bearing strata and continental sediments being more common in the Upper Palaeozoic. The Mesozoic and Tertiary deposits are geosynclinal in the north Siberian Plain, but mostly absent elsewhere. Quaternary deposits are often well developed.

(6) The Angara Geosyncline (western margin of the Amur Plate)

Archaean and Proterozoic rocks are present in the Angara Geosyncline. Archaean rocks exhibit a higher degree of metamorphism. The Proterozoic comprises a 20 km thick sequence of metamorphic and crystalline rocks which are cut by intrusions. The Cambrian is marine, with the exception of the upper part of the Lower Cambrian. The Ordovician is thick and is made up of marine sediments, including massive limestone, volcanics and flysch type deposits, which were metamorphosed during the Caledonian Orogeny. This orogeny continued into the Silurian in the form of highly variable facies, including marine, lagoonal and continental sedimentation with episodes of acid volcanism.

East of Lake Baikal, the Devonian succession is incomplete and is made up of red beds and volcanics, whereas marine Devonian strata are found in the central and western areas. The Hercynian Orogeny reached its highest intensity in the Upper Carboniferous. Continental sedimentation continued into the Permian, except to the SE of Lake Zaisan, which records varied deposits. Coal measures were developed during this period.

Triassic outcrops are rare, consisting of continental sediments or basalt. The Jurassic is well distributed and contains continental deposits with coal seams. The Lower Cretaceous is a continental sequence containing coal. In some areas, lacustrine marls and clays are rich in bitumen. The Upper Cretaceous is a mixture of continental and marine sediments. The Lower Tertiary is divided into a lower marine sequence and an upper continental sequence. The Upper Tertiary embraces, in the east, the Kuznetzk Alatau, the Minusiusk, the Tuva depression and the Gorny Altai.

The Hercynian zone, which embraces the Rudny Altai, Kulundinskaya steppe and Salair ridge, is distinguished from the Caledonian zone by the intensity of the Hercynian folding, which is more strongly developed than the Caledonian, although both types are present. Hercynian granites strongly predominate over Caledonian granites and are represented by two or three generations of intrusion. The Hercynian was followed by denudation and later by block uplifts during the Jurassic and Lower Cretaceous (Kimmerian). The process of uplift and depression of Precambrian and Palaeozoic massifs began in the Pliocene.

Three Precambrian magmatic cycles have been recognized, the major cycles being the Palaeozoic with the intrusion of Caledonian granites and volcanics predominating in the north, and intrusion of Hercynian granites in the south. Effusive strata of Triassic, Jurassic and Lower Cretaceous age are found in the Kuzbass and Trans-Baikal regions; several small acid intrusives occur in the eastern Trans-Baikal region. Igneous rocks of Alpine age are unknown.

(7) Mediterranean Geosyncline

The Mediterranean Geosyncline consists of the Caucasus Mountain range and adjacent terrain forming the zone where, during the Alpine Orogeny (~25 Ma), a tectonic collision occurred between the Eurasian Plate in the north and the Arabian Plate to the south. Today, the zone is located within the Eurasian Plate, and also marks the geographic boundary between Europe and Asia. The Caucasus range is located in the south-western part of the Russian Federation and extends into Armenia, Azerbaijan and Georgia; forming the border between the Russian Federation, Azerbaijan and Georgia. The Caucasus range trends WNW–ESE between the central west coast of the Caspian Sea and the north-eastern coast of the Black Sea, as shown in Fig. 2.6. The Caucasus consists of two ranges, the Greater Caucasus to the north and the Lesser Caucasus to the south, separated by an intervening basin.

The Mediterranean Geosyncline is of Mesozoic–Cenozoic age; its distinctive features being the intensive development of Kimmerian and Alpine folding and the associated metamorphism and synorogenic intrusions. The Caucasus comprises a geological history, lithologies, tectonics and physical characteristics that are similar to those exhibited by the classical Alpine Orogeny of the Mediterranean region [2.11].

(8) North-western Border of the Mediterranean Geosyncline

The North-western border of the Mediterranean Geosyncline has been considered to be either part of the Russian Platform or a Palaeozoic Hercynian geosyncline or the outer zone of the Mediterranean Geosyncline. The latter viewpoint is the more favoured. The oldest strata are Middle Devonian red beds and basalts which were affected by metamorphic and structural events during the Hercynian Orogeny. In addition, the Jurassic strata have been folded and there has been a weak, but distinctive, folding of Upper Cretaceous and Palaeogene sediments. The Hercynian Orogeny was accompanied by sills and lavas of Devonian age and it is possible that a number of dykes were intruded during the Kimmerian cycle [2.11].

(9) Pacific Ocean Geosyncline (Kimmerian Zone and Alpine Zone)

The Pacific Ocean Geosyncline and the adjacent Kimmerian Zone (Lower Cretaceous) are the least studied regions and only became better known with the advent of plate tectonics, which brought a focus to the region. The region was historically [2.11] divided into the Kimmerian sub-region, characterized by weak manifestations of the earlier phases of the Alpine Orogeny and the absence of the later phases, and an Alpine sub-region, where all phases of the Alpine Orogeny are represented.

The sub-region is situated adjacent to the Pacific Ocean. Strata of all ages occur, although Mesozoic and Cenozoic rocks predominate. Undifferentiated Precambrian rocks are found in many localities and consist of a wide variety of strata ranging from gneiss to shale. In some areas, the Precambrian is subdivided into Archaean and Proterozoic sequences. Large areas are covered by the Sinian complex, a series of shale, quartzitic sandstone and limestone of Upper Proterozoic age. The Lower Palaeozoic is made up of metamorphosed sedimentary and volcanic rocks several kilometres in thickness and intensely folded. The Ordovician consists of a 3–4 km thick sequence of marine limestone, shale and sandstone in the north. The dominant deposits of the Middle Palaeozoic consist of a folded and metamorphosed sequence (>8 km thick) of marine limestone, shale and sandstone. The Devonian includes rare red beds, whilst the Upper Palaeozoic is mainly represented by terrigenous arenaceous and argillaceous strata. In the far east, the Lower Permian includes both continental and marine deposits with coal-bearing strata and volcanics. The Pacific Ocean Geosyncline is characterized by both marine and continental Triassic deposits, several kilometres in thickness. Jurassic rocks consist of continental sediments.

Geological work conducted over the past 20 years or more [2.13] has established the large scale plate tectonic relationships in eastern Siberia and has thereby changed the interpretation of geological maps. Regions once mapped as one terrain with a more or less related history of development are now known to include two or more terrains with different origins and tectonic settings. However, questions remain unresolved and a joint US–Russian workshop on the plate tectonic evolution of the north-eastern part of the Russian Federation [2.14] concluded that the complexity of the Eurasian Plate–North American Plate boundary is one of the major unresolved issues of global tectonics. It is a frontier region about which very little is known, but it is important as it links the tectonics of the Arctic to those of the North Pacific.

The work has demonstrated the terrain north of the Cherskiy Range developed as part of the North American Plate, whilst the Eurasian Plate forms the terrain to the south. In addition, the southern half of the Kamchatka Peninsula is just to the west of the Japan–Kurile Trench, marking a very active tectonic zone with the Pacific Plate undergoing subduction beneath the continental Okhotsk microplate. Twenty-three active volcanoes occur in this region, the largest being the extremely active Kluchevskoy (4750 m). The northern half of the Peninsula and Chukotka, located north of the South Anyui Suture, comprises an inactive portion of the North American Plate with an extinct trench offshore, which abuts against the Siberian Platform part of the Eurasian Plate. This accounts for the major geological contrasts within the historically recognized Kimmerian Zone, as well as with the adjacent and easterly Alpine Zone.

Taking into account current understanding of plate tectonics, the southern Kimmerian Zone lies within the Amurian Plate, the central portion of the Kimmerian Zone lies within the eastern part of the Siberian Platform, whilst north of the Cherskiy Range it forms Chukota, a part of the North American Plate. At the same time, the southern Alpine Zone, south of Stanovoy Range, may comprise part of the Okhotsk Plate (or alternatively the most easterly part of the Amurian Plate), whilst the northern portion of the Alpine Zone is also part of the Chukotka portion of the North American Plate. The western limits of the Amurian Plate form the Baikal Rift, host to Lake Baikal. The Angara Geosyncline located east of Lake Baikal also occurs within the western margins of the Amurian Plate.

The Upper Jurassic of the Eastern Trans-Baikal region consists mainly of volcanic rocks with intercalations of sandstone and shale. A thick volcanic series of porphyrites and quartz porphyries was extruded around the Kolyma Palaeozoic Massif in the NE region. Cretaceous rocks occur, usually divided into two parts. In the NE they occupy extensive areas but are more restricted in the south. The only areas of undivided Cretaceous are to the east of Omolon and in the Koryat region. In the first area, an effusive series of rocks of varying composition attains great thickness, whilst in the second area, marine and coal-bearing sediments occur. The Lower Cretaceous usually consists of thick non-fossiliferous sandstone and shale with some intercalated beds hosting fossils of marine fauna.

The upper part of the Lower Cretaceous in the Kimmerian Zone is continental in origin, whilst the Dzhugdzhur Range is volcanogenic. This far eastern Siberia range extends 1500 km along the entire NW coast of the Sea of Okhotsk.

In the Kimmerian Zone, the Upper Cretaceous is also continental and contains lavas and tuffs in some areas. The Palaeogene in the Kimmerian Zone consists mainly of continental deposits. Volcanic rocks are widespread and coal-bearing sequences are not uncommon.

In the Alpine Zone, the folded and metamorphosed Upper Cretaceous includes marine, lagoonal and volcanic deposits. These deposits are geosynclinal, folded and metamorphosed, though on the western side of Sikhote-Alin, continental deposits, in places coal-bearing, occur. The Neogene deposits are generally very similar to the Palaeogene sediments. Quaternary deposits occupy extensive areas of the NE region, as well as occurring along the shore of the Arctic Ocean. Many active volcanoes are found on Kamchatka and the Kurile Islands. Volcanic rocks and intrusive massifs of Precambrian age are also present.

In the NE, several small nepheline syenite massifs occur. Cambrian age granites have also been recognized. The main effusive phase of the Hercynian is represented by Upper Devonian volcanics, and Hercynian synorogenic intrusions are common in the eastern Trans-Baikal region, in the Dzhugdzhur Range, in the south-western part of Sikhote-Alin and in the Kolyma Massif.

Igneous rocks of the Kimmerian cycle predominate in the Kimmerian Zone but are also well developed in the Alpine Zone. The Jurassic volcanics are widespread and cover large areas. Granites of Kimmerian age are commonly of very large dimension and many are mineralized. Synorogenic intrusions of the

Alpine cycle are absent from the Kimmerian Zone, although acid and intermediate volcanic formations of Upper Cretaceous age occur and cover very extensive areas.

Volcanic rocks of Palaeogene, Neogene and Recent ages are rarely found here but cover large areas of the Alpine Zone. Alpine intrusions are common in the Alpine Zone and exhibit a wide range of compositions ranging from ultrabasic rocks to polymetallic mineralized granitoids, as may be expected onshore from a subduction zone [2.15, 2.16].

2.1.4. South-eastern Asia, Pacific, East Asia

Colliding plates under the Earth's surface make the South-eastern Asia, Pacific, East Asia region, with the exception of Australia, one of the most tectonically active. Existing landforms in Asia are largely the result of the currently active tectonic regime. An extremely complex geological history predates current tectonics (Fig 2.7–2.9) [2.17].

The countries in this volume include the large landmasses of Australia, China and Mongolia, which are major parts of the Indo-Australian, Amur and Indo-Chinese Plates. The Amur and Indo-Chinese Plates are sometimes considered to be parts of the larger Eurasian Plate, which is situated to the W–NW.

Brief summaries of the geology of Australia, China and Mongolia are given. These are the three countries in this volume that are rated by the authors as having high potential for additional uranium resources. More details are found in the individual country reports and in the accompanying references.

Australia

Australia is a large continental mass which has several unique environments favourable for the formation of uranium deposits. Australia can be divided into four orogenic provinces mantled by four platform covers.

The West Australian Orogenic Province is the oldest and contains the Pilbara, Yilgarn and Rum Jungle Blocks, which are belts of metamorphosed sediments and volcanics in predominantly gneiss and granite terrains. The platform cover of the West Australian Orogenic Province comprises Lower Proterozoic basic volcanics and pyroclastics overlain by chemical and clastic sediments.

The North Australian Orogenic Province contains the Pine Creek Block, Tennant Creek Block, Granites-Tanami Block, Nicholson Block and the Halls Creek Belt. These areas generally consist of low to moderately metamorphosed Lower Proterozoic sediments and volcanics which, in some cases, are intruded by granites. The North Australian Platform Cover is largely pelitic with minor dolomites and volcanics.

The Central Australian Orogenic Province consists of several moderately to highly metamorphosed volcano-sedimentary blocks and belts of Lower–Middle Proterozoic age. The Central Australian Platform Cover was deposited over a wide area of western and central Australia from the Middle Proterozoic through the Palaeozoic.

The Arnhem and Litchfield Blocks in northern Australia appear to be Archaean in age. The Arunta Block is poorly exposed and may be associated with the North and Central Australian Orogenic Provinces. The Georgetown Block is Middle Proterozoic and contains high grade gneiss intruded by granite and a younger, less deformed sequence also intruded by granite.

The East Australian Orogenic Province or Tasman Geosyncline, of Cambrian–Late Triassic age, consists of low to medium grade metamorphosed sediments and volcanics intruded by acid plutonic rocks. The Trans-Australian Platform Cover consists of Permian–Tertiary sediments which were deposited over much of the eastern third of Australia.

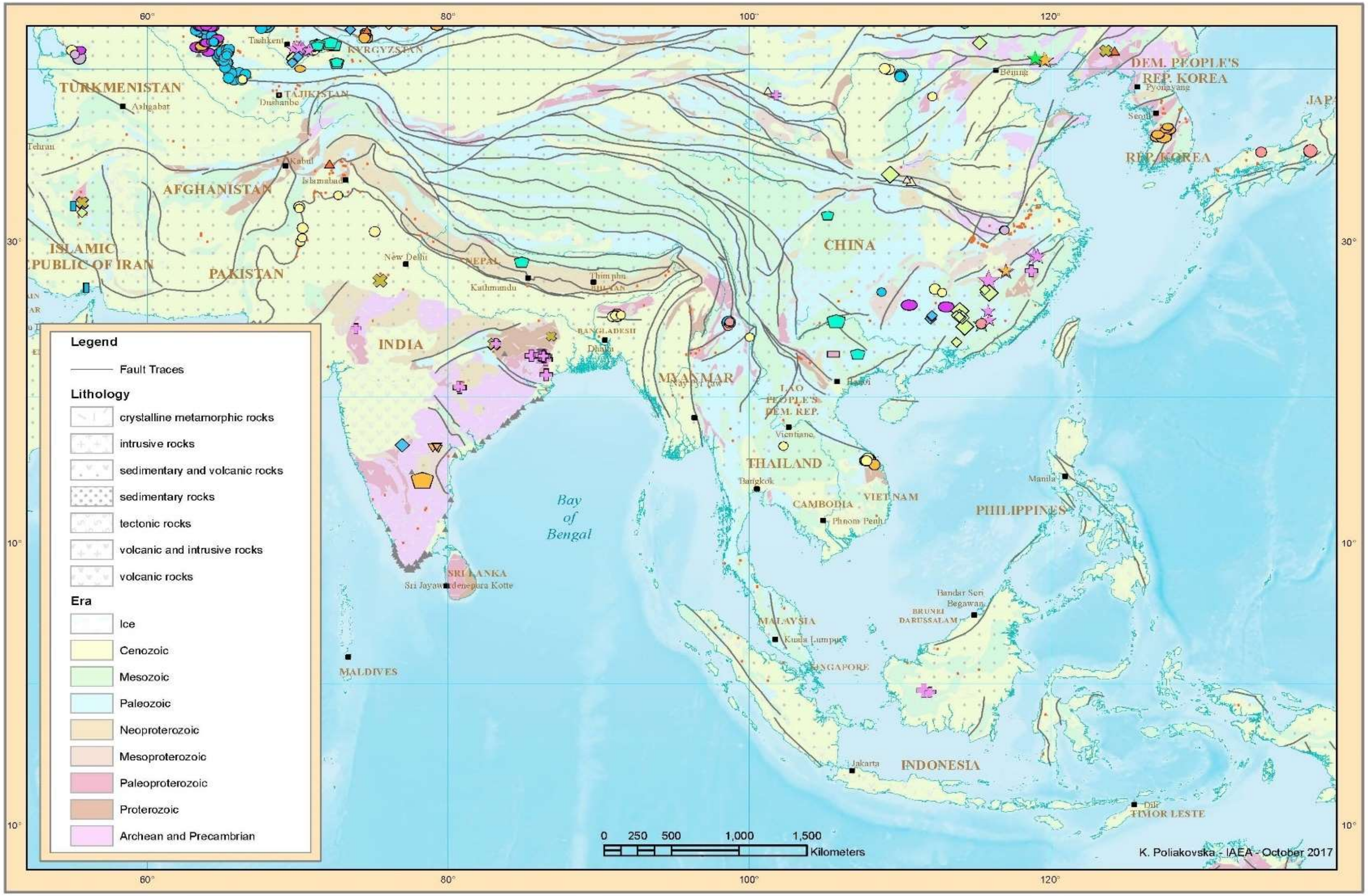


FIG. 2.7. Regional geological setting of South-eastern Asia, Pacific, East Asia region showing the distribution of selected uranium deposits and occurrences. For general uranium deposit legend see Fig. 2.1b.

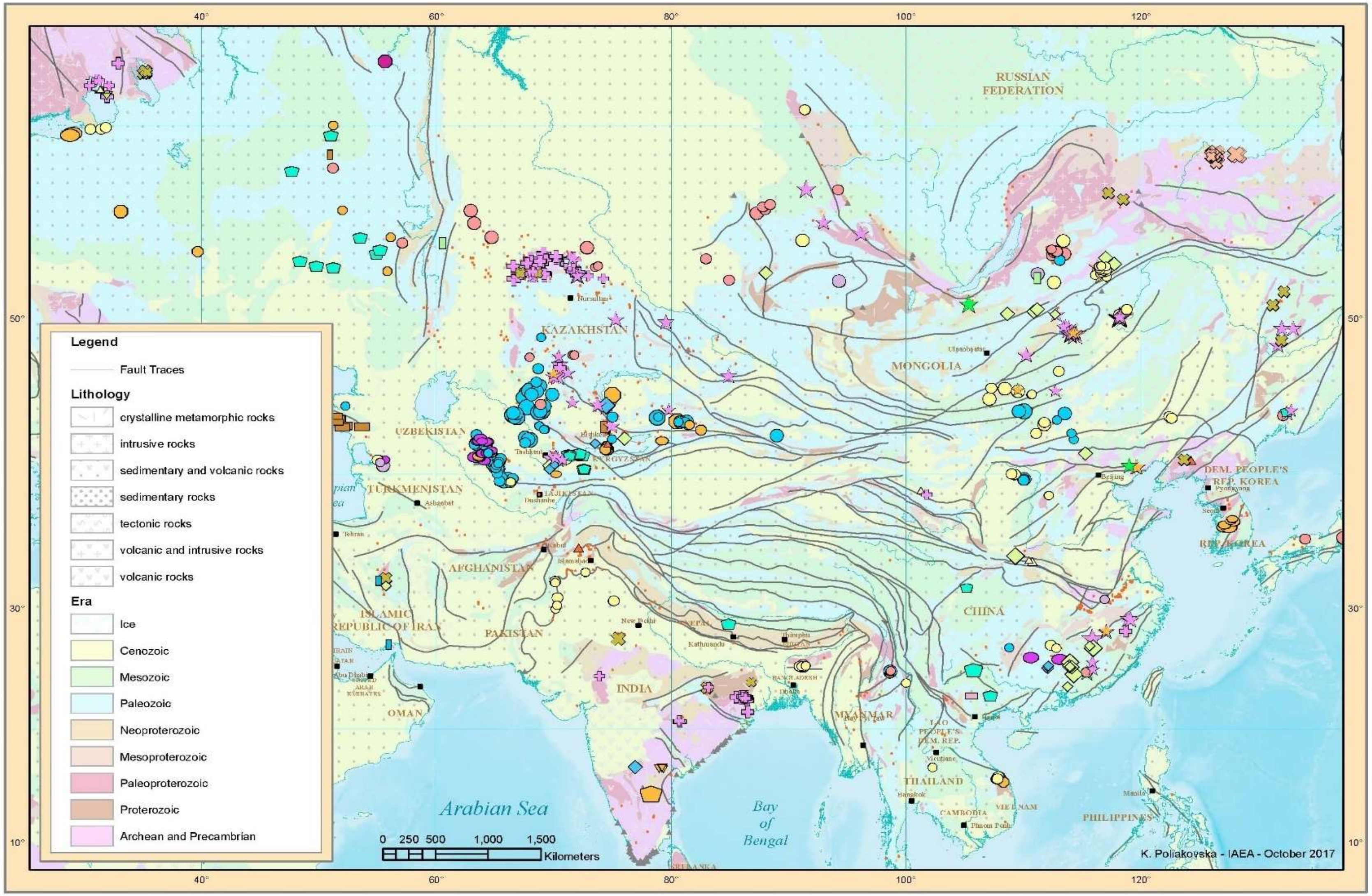


FIG. 2.8. Regional geological setting of Central Asia, part of South-eastern Asia, Pacific, East Asia region showing the distribution of selected uranium deposits and occurrences. For general uranium deposit legend see Fig. 2.1b.

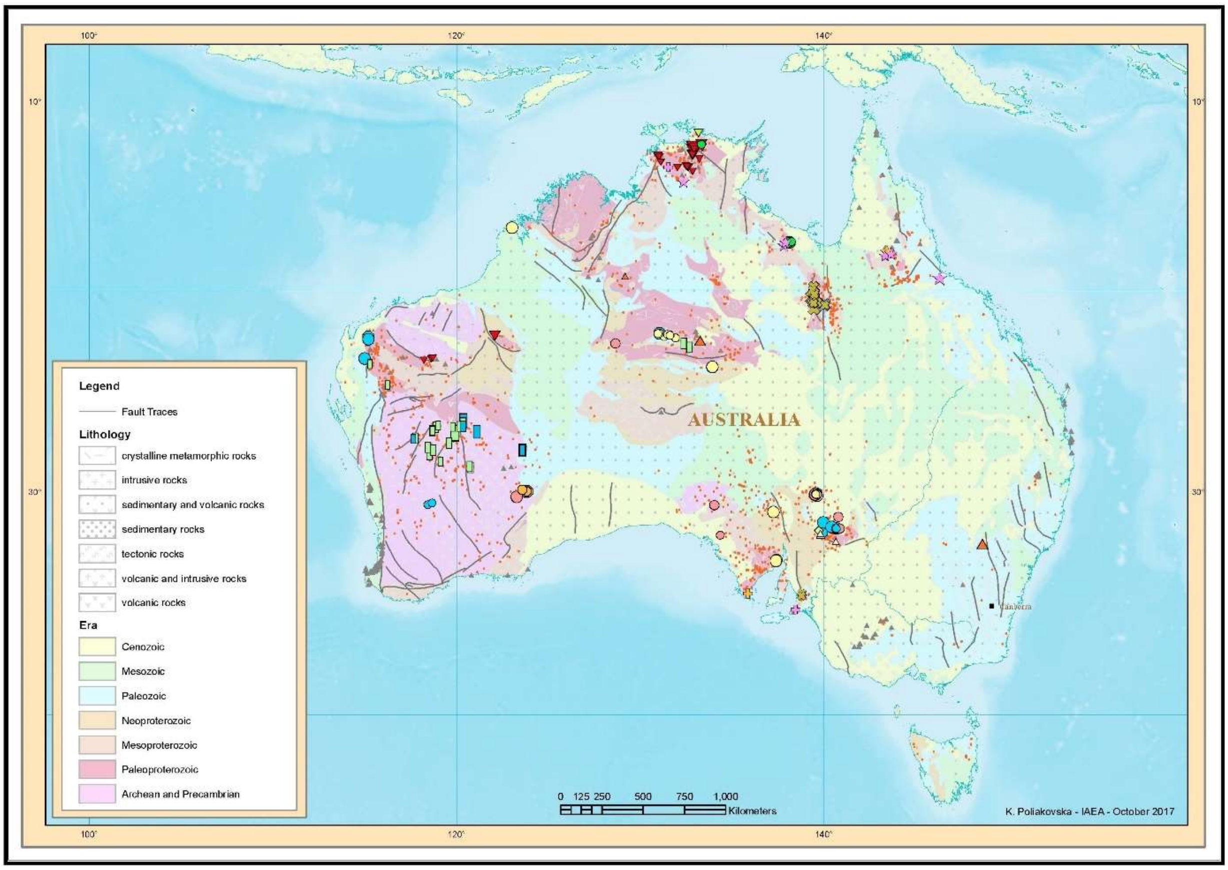


FIG. 2.9. Simplified regional geological map of Australia showing the distribution of selected uranium deposits and occurrences. For general uranium deposit legend see Fig. 2.1b.

Approximately 90% of Australia's initial in situ resources occur in two main types of deposit:

(i) *Haematite breccia complex deposits*: Approximately 70% of the country's resources occur in Proterozoic haematite granitic breccias at Olympic Dam (South Australia), currently the largest individual resource of uranium in the world. Broadly similar haematite breccia mineralization in the same geological province is being evaluated somewhere else at Acropolis, Carrapateena, Oak Dam, Prominent Hill, and Wirrda Well, as are some of the younger breccia hosted deposits in the Mount Painter area;

(ii) *Unconformity related deposits*: About 19% of Australia's resources (Ranger, Koongarra, Jabiluka) are linked with Proterozoic unconformities, mostly in the Alligator Rivers field in the Northern Territory. Kyntyre – a similar type – is located in Western Australia.

Other significant resources occur in:

(a) *Sandstone*: Sandstone deposits comprise 4.4% of total known uranium resources in Australia and are located in South Australia, north-west Queensland, Northern Territory and Western Australia. The uranium fields and basins containing these deposits are the Frome Embayment field, and the Eucla Basin (South Australia), Westmoreland–Pandanus Creek field (Queensland), Amadeus Basin and Ngalia Basin (Northern Territory), Gunbarrel Basin, Carnarvon Basin and Canning Basin (Western Australia). The most important sandstone deposits include the Honeymoon, Beverley and Four Mile deposits in South Australia. The Honeymoon deposit is an example of a deposit hosted in paleochannel sands of the Eyre Formation (Palaeocene–Eocene), whereas the Beverley deposit occurs in sands of the overlying Namba Formation (Miocene). The paleochannels occur in the southern part of the Frome Embayment flank, a structural high in the underlying basement known as the Benagerie Ridge. Beverley North and Four Mile East deposits are in the Eyre Formation. Four Mile West is believed to be hosted in sediments equivalent to the Cretaceous Bulldog Shale;

(b) *Surficial (calcrete) deposits*: These represent about 3.5% of deposits and occur in the Yilgarn Craton, at Centipede, Lake Maitland, Lake Way, and Yeelirrie (Western Australia);

(c) *Other deposits*: The remaining resources are in metasomatite deposits (e.g., Mount Isa uranium field, the Valhalla deposit (Queensland)), metamorphic deposits (e.g., Mary Kathleen (Queensland)), volcanic deposits (e.g., Maureen, Ben Lomond (Queensland)), intrusive deposits (e.g., Radium Hill, Crocker Well (South Australia)), vein deposits in Proterozoic and Phanerozoic host rocks (e.g., Lamboo and Gascoyne Complexes (Western Australia), Barossa and Lincoln Complexes, Peak Metamorphics and Denison Block (South Australia), New England and Lachlan Fold Belts (New South Wales, Victoria and Tasmania) and quartz pebble conglomerates (e.g., Halls Creek Orogen, Hamersley Basin, Pilbara Craton, and Yerrida Basin (Western Australia)).

China

The country report for China describes its tectonic location and aspects of its tectonic evolution that relate to areas favourable for uranium deposits. China is principally a part of the Eurasian Plate, although the margins of the Indian and Philippine Sea Plates have impacted the Himalayas and the Coastal Range of Taiwan, China, respectively [2.18].

Cenozoic collision of the Eurasian and Indian Plates produced deformation and uplift of the Himalayas, which strongly influenced the tectonics of western China. In contrast, Mesozoic–Tertiary evolution of eastern China is typical Basin and Range geology, similar to that of the western United States of America, including development of deep sedimentary basins along with calc-alkaline plutonic and volcanic activity associated with crustal thinning and high heat flow. The complicated tectonic evolution of China is marked by the presence of ophiolites and blueschists in Proterozoic–Tertiary convergent boundaries. These lithotectonic assemblages provide evidence of an extremely mobile history of plate movement [2.18].

The Central Asian Orogenic (or Mobile) Belt is one of the largest accretionary orogens on Earth and dated at 800 Ma (Mesoproterozoic–Early Triassic). The Central Asian Orogenic Belt is an important host to uranium deposits in China and the surrounding region. Chen [2.19] reports on the geological evolution of the Central Asian Orogenic Belt.

The stratigraphy of China is very complex and varied. For more details on the general geology, the reader is referred to references cited in the country report. A discussion of uranium related geology is included in the country report.

The most important geological terrains or environments favourable for uranium deposits in China include granite-related deposits, which include Lantian in central China, Benxi in the north-east and Chongyi production centre in southern China. Expansion of the existing production centre at Chongyi is planned.

The volcanic type is represented by the production centres at Qinglong, in the north-east, and at Fuzhou, in southern China.

Very large clastic filled Mesozoic–Cenozoic intermontane basins are present in north-west China, while smaller basins occur in other areas, including the tectonically disturbed, mobile terrain of western Yunnan, south-eastern China. Yinlin (Yili Basin) is an operational in situ leach (ISL) deposit in north-western China. Other sandstone deposits are being studied to determine their amenability to ISL extraction. Sandstone type deposits hold the greatest potential for resources in China.

Mongolia

Located in the middle of the Central Asian Orogenic Belt, in the interior portion of the Eurasian Plate, Mongolia has grown through the accretion of younger terrains and micro-plates onto the ancient Siberian

Craton. The geology is dominated by the Altaid Orogen, an orogenic collage of subduction and accretion episodes extending from the Ural Mountains to the Korean Peninsula. Uranium mineralization in Mongolia occurs as three main types according to the IAEA classification scheme: (i) volcanic, (ii) sandstone, (iii) lignite types.

The two most economically important deposit types are volcanic and sandstone. Recently, exploration and development have focused on large basins where sandstone deposits amenable to ISL have been identified.

Other Countries

Several countries lying between these large landmasses are situated very close to, and along, active tectonic margins (e.g., Fiji, Japan, Singapore and Taiwan, China). The geology of these countries is dominated by oceanic basalt type rocks, which are unfavourable for the development of uranium deposits.

Other countries, such as Indonesia, Malaysia, Myanmar, Philippines and Thailand are sufficiently extensive that they have some rock types not solely related to the volcanics characterizing plate margins. These countries may exhibit some favourable geology as regards uranium potential, but, to date, exploration and/or favourable results have been limited. Reference should be made to the individual country reports for additional, more detailed information.

2.1.5. Middle East, Central and Southern Asia

This synthesis of the geology of Middle East, Central and Southern Asia is based largely on publications dealing with the geology of individual countries [2.11].

In the context of plate tectonics, the Middle East, Central and Southern Asia is unique in that it is made up by the ‘welding’ of the subcontinent of India and the Arabian Peninsula to the main mass of the Eurasian continent. The violent collision of the Indian Plate with the Asian landmass caused the strong uplift of the Himalayan ranges to elevations of 7000–8000 m. Similarly, the collision of the smaller Arabian Plate is responsible for the Alpine fold belt to the SW and west of the Himalayas.

The Indian and Arabian Plates were parts of Gondwana that have been dislocated from the ‘mother’ continent and pushed northwards against the Eurasian Plate. During this process, a number of continental fragments of Gondwana were abducted in the Mesozoic onto the Eurasian Plate, and finally rejoined in the Late Cretaceous with Gondwana Arabia and India. The region of Central Asia does not belong to one geosynclinal system; in the north it occupies part of the Angara geosyncline whereas in the south it is part of the Mediterranean geosynclines [2.20].

The Shield Areas

The Shield areas in the Indian and Arabian Plates form primeval nuclei of highly deformed and metamorphosed Archaean and Early Proterozoic rocks. The Indian Shield comprises much of India and Sri Lanka but excludes Bangladesh. It is composed of metasedimentary and metavolcanic rocks of Archaean age, which, together with similar metamorphic rocks of Lower Proterozoic age, have been invaded by granitic rocks. The exposed rocks range in age from Archaean to Late Proterozoic (3500–600 Ma). Several structural provinces, each with its own distinct style of deformation, and orogenic trends are recognized:

(a) The NNW Dharwar trend in Karnataka and NW Andhra Pradesh;
(b) The NE trend of Eastern Ghats in Tamil Nadu, Andra Pradesh and Orissa;
(c) The ENE Satpura trend from Gujarat, Madhya Pradesh to the Assam Plateau;
(d) The NE Aravalli trend of Rajasthan.

The first major orogeny, at ~2600 Ma, involved the area of Eastern Ghats folding in western, eastern and southern India and Sri Lanka. These include the Vijayan ‘series’; the charnockite–khondalite Supergroup;

the Peninsular, Singhbhum and Bundelkhand gneissic complexes; the Bellary, Carnatic and Kanara gneisses; and the gneisses of Hyderabad, Karimnagar and the Shillong Plateau. Some of these gneisses show evidence of an earlier phase of metamorphism that occurred around 3500–3000 Ma.

The next major orogeny, occurring ~2000 Ma, is known as the Dharwar–Iron Ore–Aravalli folding and includes the Ayoor, Kolar, Bangalore and Bezwada gneisses; the metasedimentary and metavolcanic rocks of the Dharwar Supergroup; the Bijawar, Agori, Bengpal, Bailadila, Iron Ore and Aravalli Groups; and the Highland 'series' of Sri Lanka. Uranium deposits are hosted in the Iron Ore Group in the Singhbhum thrust belt, as is the Aravalli Group in the Khetu–Kolihan–Ghateshwan and Umra–Udaisagar belts of Rajasthan. Associated syntectonic and tectonic gneisses and granitic intrusions include the Bengpal, Gavalia and other gneisses, and the Closepet, Molakalmur, Dudhi, Dadikar and Ahar rocks and parts of the Singhbhum granites [2.20].

A third orogeny, dated ~1600 Ma (Late Karelian Orogeny), also named the Singhbhum–Sausar–Delhi folding, involved the Singhbhum, Chhotanagpur–Gangpur–Dongargarh–Sausar and Delhi assemblages. This orogeny persisted to 850 Ma. The Late Karelian Orogeny was succeeded by stabilization of the craton and the beginning of Riphean platform development.

The Arabian Shield occupies most of the western part of the Arabian Peninsula. It consists of metavolcanic and metasedimentary rocks that are highly deformed and intruded by granitic bodies. Though rocks older than 1100 Ma are believed to be present, it is unlikely that any of Archaean or Early Proterozoic age occur. The Arabian Shield appears to be similar to the Grenville structural province of Canada, where uranium deposits are found in granitic and syenitic rocks, especially in the pegmatite facies, and in carbonatites that usually carry niobium as the metal of primary value. Similar deposits may be found in the Arabian Shield. In the Shield areas of Asia, Archaean and Early Proterozoic rocks have been deformed and metamorphosed. This environment in other Shield areas of the world has yielded Proterozoic unconformity-related and vein type uranium deposits. Where the basal Early Proterozoic sedimentary rocks are less strongly metamorphosed, there is potential for uranium-bearing quartz-pebble conglomerates to be found, as in the Udaipur area of Rajasthan, India. In the Indian Shield, especially in the southern part (including Sri Lanka), numerous occurrences of uranium in thorium-rich refractory minerals have been reported in pegmatites [2.20].

The Platform Areas

The Indian Shield became stabilized after the Iron Ore Bhilwara Orogeny (2000 Ma). This was succeeded by the development of Riphean platform deposits, comprising the Vindhyan, Cuddapah, Kaladgi and Pakhal Groups. These consist commonly of basal conglomerate, overlain by a succession of arenaceous, argillaceous and calcareous strata. In some places, these strata have undergone open folding and faulting, known as the Semri–Cuddapah folding (~1200 Ma). This was succeeded by anorogenic intrusions of the Ajmer, Umtala, Chhapoli, Erinpura and Dubrajpur granites, Sivamalai syenite, Bengal gneiss, Seringapatam porphyry, Venkatapuram dolerite and pegmatites, all dated prior to 850 Ma [2.20].

There followed, with some overlap, a second period of platform sedimentation of Vendian age, ending at ~650 Ma. The first sedimentation phase resulted in deposition of the Kurnool, Kaimer, Rewa, Bhander, Palnad, Bhima and Sullavai Groups comprising conglomerate, quartzite, limestone, slate and carbonaceous shale. In the central and north-western parts of the Shield, uplift was succeeded by volcanism and associated plutonism.

Finally, before the start of the Cambrian, further platform deposition occurred in which thin arenaceous sediments were deposited in the Chattisgarh–Bastar and Jodhpur–Nagaur Basins.

In the Indian platform, deposits of carbonaceous and phosphatic shales are present and may be uraniferous. Some shales of the Vindhyan System contain carbonized materials, spores and woody remains. Vein or disseminated deposits might be found near to Late Proterozoic intrusions.

On the NE side of the Arabian Shield, Cambrian–Pliocene shelf deposits comprising marine limestone, shale and minor sandstone were deposited. Their total thickness is ~5500 m. The shales are green, red or brown in colour, but no carbonaceous shales that might contain concentrations of uranium are reported. Some of the Permian and Triassic strata are non-marine, but they alternate with marine beds [2.20].

The sandstones, though derived from the Precambrian Shield, are, with a few exceptions, thin and reportedly lacking in plant material; neither are acidic to intermediate tuffs present in the succession.

In the northern part of the Arabian platform, the Great Rift system denotes the boundary between the Arabian Plate and the smaller Sinai Plate in which are located Israel, coastal Lebanon, the Syrian Arab Republic and Cyprus. Within the Sinai Plate, and to the east of it in Jordan, the Syrian Arab Republic and Iraq, the Upper Cretaceous limestone contains extensive deposits of phosphorite, which in many places is uraniferous.

The Mobile Areas

The Himalayan Orogen is one of the most visually significant mobile belts in the world. It is arcuate, over 2400 km long and 230–320 km wide. The belt extends from the easternmost part of India and Tibet through Bhutan, Nepal and Kashmir to northern Pakistan. Crustal shortening across the belt amounts to hundreds of kilometres. The Himalayan Orogen started in the Lower Cretaceous and continued intermittently into the Pleistocene. It can be subdivided into six structural zones, which are, from north to south:

(i) Zone 1, which is bounded to the north by the Tibetan Block, comprises a northwards thrusted mass of Cretaceous flysch with basic and ultrabasic 'exotics', resting upon Palaeogene molasse. The contact of this zone with zone 2 is known as the Indus Suture Line, which is a deep fracture with thrusts to the north and south, the greater displacement being to the south;
(ii) Zone 2, the Ophiolitic Zone, contains associated Jurassic and Cretaceous radiolarites, flysch and ultrabasic rocks deformed by southwards thrusting and gliding. It is characterized by very incompetent folding;
(iii) Zone 3 is a broad thrust belt of regionally metamorphosed Late Precambrian–Cambrian sedimentary rocks and slightly metamorphosed Ordovician–Lower Cretaceous sedimentary rocks. These represent a thick succession of platform sediments laid down in the Tethys Sea. Contact metamorphism has been induced by emplacement of granite plutons of Neogene age;
(iv) Zone 4, the Higher Himalaya, consists of gneiss, schist, marble and calc-silicate rocks, and tourmaline granite. These underlie shale and limestone of Ordovician–Silurian age. The whole sequence is intruded by granitic plutons of Neogene age (16–15 Ma). Pre-existing, post-Lower Palaeozoic rocks have apparently been removed by erosion. The total accumulation of these shallow water, platform sediments is estimated at tens of kilometres. The contact between zones 4 and 5 is the Main Central Thrust, which is directed southwards and has an estimated displacement greater than 80 km, and which has been dated as Miocene–Pliocene;
(v) Zone 5, the Lower Himalaya, contains Precambrian gneiss, schist and granite, Late Precambrian black slates and quartzite, pre-Carboniferous stromatolitic limestone, dolomitic shale and quartzite, Carboniferous tillite, Permo-Triassic limestone and shale, Mesozoic calcareous sandstone and Eocene shale and limestone. This assemblage has been thrust into nappe-like folds. A peculiarity of this zone is that along its length reversed metamorphism occurs in the thrust sheets. For example, in Sikkim, sillimanite gneisses occur at the top, staurolite schists in the middle and chlorite–sericite phyllite at the base, although the succession is not overturned. It has been suggested that this phenomenon could be accounted for if, during the Miocene, large scale subduction occurred along the Main Central Thrust. The Main Boundary Fault, which forms the boundary between zones 5 and 6, is a steep thrust with movement towards the south of more than 30 km. This movement probably commenced in the Pliocene and ended in the Quaternary;
(vi) Zone 6, the Sub-Himalaya, comprises clay, siltstone and brown sandstones of the Lower–Middle Miocene Murree Series and sandstones, some of which are calcareous, siltstone and conglomerate of the Upper Miocene–Pleistocene Siwalik System. Folding began in the Early Pleistocene and

in the Late Pleistocene the eroded Siwaliks were affected by overthrusting and steep reverse faults. The broad Indo-Gangetic Plain lies to the south of zone 6.

Along the Lower Himalaya (zone 5) from Sikkim to Himachal Pradesh, uraninite and pitchblende are widely disseminated and associated with copper mineralization in the Precambrian metasedimentary rocks. Black shales of Carboniferous age, occurring at the base of the Krols, are also slightly uraniferous, as are phosphorites of the same age near Dehra Dun. Uranium mineralization in the Siwalik System, especially in the Upper Siwalik, is widespread, and in Pakistan deposits have been identified.

The Salt Range, which lies east of the Indus River in Pakistan, may be regarded as a southern 'appendage' of the Himalayas. The formations have a westerly trend. This is a south thrust plate, at the base of which is the Cambrian or Infracambrian Salt Range Formation, which contains evaporates and is succeeded by the Middle Cambrian sandstones of the Jhelum Group. The Permo-Triassic beds are marine [2.20]. Above are Eocene limestones, overlain by Lower Miocene sandstones of the Murree Series and those of the Siwalik System, which is of Upper Miocene–Pleistocene age. The Siwalik sandstones are regarded as favourable for hosting uranium in Pakistan and Nepal [2.11].

In the western Himalayas, between the Salt Range and the Pamir Range, the structural trend swings abruptly from north-westerly to south-westerly. The mobile belt that is exposed westwards across Pakistan, Afghanistan and Iran has been subdivided into four major zones on the basis of fundamental differences in crustal character and on the age of basement consolidation. The mobile belt consists of Jurassic–Palaeogene miogeosynclinal beds overlain by Neogene–Quaternary foredeep beds and affected by Alpine folding.

In the main northern fold belt, the rocks comprise schists, slates, quartzites and greywackes of Lower Carboniferous and older ages, and, locally, include deep-sea sedimentary rocks and associated phyllites. After Hercynian deformation and granitic intrusion, Lower Carboniferous strata, in which spilitic volcanic rocks occur locally, and Permian marine sediments were laid down. In the western part, in the Parapamisus Range, red clastics with thick granite boulder conglomerates of Lower Triassic age occur. Early Kimmerian folding and granitization followed throughout the belt.

Within the central zone, which occupies the largest part of the entire region, a crystalline basement that was consolidated in the Precambrian is exposed in fault slices. The Precambrian is overlain unconformably by fragments of Palaeozoic platform cover that were preserved in grabens and the upper part of the sequence comprises geosynclinal sediments with some volcanic flows. Within the sequence, carbonaceous slates have been traced intermittently. Kimmerian deformation was succeeded by more marine sedimentation, from Late Triassic to Lower Cretaceous, and Late Kimmerian and Alpine granites were emplaced. Early Tertiary folding was widespread throughout the central zone; Palaeogene deposits were laid down with marked unconformity. Neogene sediments were deposited in young depressions and these record Pliocene–Pleistocene faulting [2.20].

The axial Ophiolite Belt has been traced with remarkable continuity across the region. It comprises fine-grained shale–sandstone flysch, in part tuffaceous, as well as radiolarites and limestones of Late Cretaceous–Eocene age and Late Cretaceous ophiolite melanges to the north. To the south, and in Iran and separated from it by the Main Zagros Thrust, occur ocean sedimentary rocks of Mesozoic age and extensive blocks of mainly Permo-Triassic limestone and abundant peridotite. Post-ophiolitic granite and diorite bodies were also emplaced. Folding in the Ophiolite Belt is severe, resulting in nappe structures, and took place in the Middle Tertiary.

The southern belt is of continental crustal character, as is the central belt, with a crystalline basement, which may be Precambrian in the western part (Zagros Mountains in Iraq and Iran) and is Precambrian in the Himalayas. A platform character of the succeeding sedimentary rocks persists in the Palaeozoic and Mesozoic strata of the southern fold belt, though epeirogenic movements took place. The Palaeozoic sedimentary rocks are largely marine clastics, becoming dominantly carbonates from the Permian to the

Lower Miocene. This sequence in the post-Triassic differs considerably from that in the Kirthar, Sulaiman and Salt Ranges of Pakistan.

Although diapiric injection of salt domes occurred as early as the Cretaceous, major deformation of the zone did not occur until the Late Alpine period, when folding and intrusion of granites took place.

Throughout this region, the most favourable environment for hosting uranium deposits is regarded as the Siwalik continental beds, which are of Neogene age. Some occurrences are reported in continental beds as old as the Cambrian. Promising grades of uranium have been reported in a carbonatite, Sellai Patti in Pakistan, of Quaternary age that intrudes Neogene beds of the Central Fold Belt. Other such uraniferous carbonatites may be discovered in this region. Pitchblende-bearing veins may be found associated with granites [2.11].

The Oman Mountains are on the eastern side of the Arabian Peninsula, bordering the Gulf of Oman for nearly 600 km and extending from the mouth of the Persian Gulf almost to the Arabian Sea. This folded belt may be regarded as an appendage to the axial Ophiolite Belt as it contains a similar assemblage of rocks. The Jebel Akhdar anticline forms the central core. Precambrian carbonates, quartzite, greywacke and conglomerate underlie Permo-Triassic carbonates, which are thinner and contain increasing amounts of terrigenous clastics towards the south. These are succeeded conformably by limestones of Jurassic–Middle Cretaceous age [2.20].

The limestones are overlain by an extensive mass of intensely deformed shales and radiolarian cherts of Upper Cretaceous age upon which rest extensive blocks of Permo-Triassic limestone. Resting on both the deformed radiolarites and the ‘exotic’ limestones are extensive, nappe-like masses of serpentinized ultrabasic rocks. The structure was originally thought to be due to overthrusting, but authorities now suggest gravity sliding as the mechanism.

It has also been suggested that the ophiolites have been obducted during the collision of the Arabian Plate with the Eurasian Plate. The minimum distance of movement of the ophiolites is more than 200 km. Although occurrences of copper, nickel and cobalt have been reported, and which are often associated with uranium, in this case these are in an ophiolitic suite in which uranium does not occur.
The structures of the Zagros Mountains persist through north-eastern Iraq and westwards into Turkey. There, four structural zones are recognized, comprising, from north to south: (i) the Pontids, (ii) the Anatolids, (iii) the Taurids, and (iv) the Border Folds.

The Pontids, which occupy northern Anatolia, expose in the cores of folds both metamorphic and plutonic rocks of pre-Carboniferous, and possibly in part at least, Precambrian age. These are succeeded unconformably by, or thrust against, Jurassic carbonates and basalts and Upper Cretaceous–Eocene carbonates, clastics, lavas and tuffs. Following the main Alpine Orogeny, Neogene basins were formed.
To the south, the Pontids pass into the Anatolids without evidence of a sharp break. The strike-slip North Anatolian Fault crosses and recrosses the boundary. Again, the Precambrian–Palaeozoic gneisses, amphibolites, schists, marbles and granites are seen in the cores of folds or in larger massifs such as the Mendares, Kirschir and Bilitis Massifs. Devonian–Upper Cretaceous marine carbonates and clastics rest unconformably on the basement. Intercalated with Lower Jurassic sedimentary rocks are basaltic flows.

This succession was deformed during the main Alpine Orogeny, during which ophiolites of probably Cretaceous age were thrust into the Mesozoic assemblage and granites invaded the Cretaceous strata.

South of the Anatolids, the Taurids expose similar rocks, but in addition, nappes of ophiolites, together with abundant ultrabasic rocks, have been emplaced in the main Alpine Orogeny phase, during the Cretaceous–Oligocene.

The southern margin of the zone was affected by thrusting at the end of the Miocene. This overthrust marks the boundary in south-eastern Turkey with the Border Fold Belt, which is characterized by generally open folds and steep reverse faults. Palaeozoic carbonates and clastics of Cambrian–Lower

Devonian age are exposed in tectonic highs. These underwent Hercynian folding, after which marine carbonates and clastics of Permian–Lower Cretaceous age were laid down. Early Alpine folding preceded deposition of marine Cretaceous and Eocene carbonates and clastics, and Oligocene lagoonal and Miocene marine and continental beds were deposited in basins. The final phases of folding and thrusting occurred at the end of the Miocene. Locally, basalts and associated clastics of Pliocene or Pleistocene age occur.

In Turkey, in the fold belts, the pre-Alpine rocks do not seem to be very favourable for hosting uranium. Much more favourable are the Tertiary non-marine sandstones and conglomerates that were deposited in basins formed by taphrogenic movement [2.20].

The Basins

The clastic rocks of the Gondwana System were deposited on the central to north-eastern and eastern central parts of the stabilized Indian Shield. The lower part consists, at the base, of sandstones, shales and tillites, succeeded by a sequence of sandstones ~2400 m thick which contain numerous coal seams of Upper Carboniferous–Lower Triassic age. The upper part was laid down under arid climatic conditions and comprises red and variegated sandstones, clays and shales, with inferior quality coal seams and marine beds at the top. The upper sequence is Middle Triassic–Lower Cretaceous in age.

In north-eastern India, in Maghalaya State, uranium deposits have been explored in sandstone of the Cretaceous Mahadeo Formation, which may be correlated with Upper Gondwana. Although in a marine sequence, the sandstone is non-marine, contains carbonaceous matter and was derived from a radioactive granite source. In the north-western Shield, large areas are covered by Late Cretaceous–Early Eocene Deccan Traps, which conceal much of the Gondwana strata.

At the southern end of the Shield, non-marine sandstone, clays and conglomerates equivalent to part of the Upper Gondwana are exposed over a small area in Sri Lanka. In the north-western coastal Kutch region of India, the marine Jurassic Umia Series grades upwards into plant-bearing Early Cretaceous beds. The Lametas beds in the central part of the Deccan Plateau are Upper Cretaceous estuarine and lacustrine deposits, but those elsewhere are marine [2.20].

Along the southern coasts of India, Miocene marine beds grade upwards into shales containing lignite. In Assam, the Oligocene–Miocene Surma Series contains ferruginous sandstone, conglomerates and shales with some lignite and fossil wood. In Bangladesh, the lower Ganges–Brahmaputra Basin has accumulated perhaps as much as 15 000 m of Tertiary sediments. Unconformably overlying the Eocene Sylhet limestone are Miocene marine sandstones and clays, succeeded by a 2500 m thick sequence of ferruginous sandstone, sandy clay and pebble beds of Pliocene and Pleistocene age, with some lignite seams in the lower part. These may be equivalent to the upper part of the Siwalik System to the NW, which contains significant uranium [2.11].

In Pakistan, knowledge of pre-Siwalik formations of the Indus Basin has been obtained almost entirely from oil wells and from outcrops in the mountains to the west. Post-Jurassic strata range in thickness from 1200 m to nearly 6000 m. Resting unconformably on the marine Winder Group and Zidi Formation are marine shales, sandstones and some limestone of Cretaceous age, overlain by Palaeocene shales and sandstone, with some limestones and conglomerates. The Eocene strata are mainly limestone, with shale and some thin coal seams. Marine shale and sandstone continue, with some limestone and minor gypsum, into the Miocene. The Upper Miocene–Pleistocene continental sandstones, clays and conglomerates of the Siwalik System were laid down unconformably.

In Afghanistan, sedimentary basins of Tertiary age are widespread and range in size from a few hundred to nearly 100 000 km^2. Outcrops of Tertiary rock are not abundant, as the Tertiary strata are, in most places, succeeded by Quaternary deposits. Some of the deposits are as old as Oligocene, as in the Shafa Formation of northern Afghanistan, which consists of red clays, siltstones, sandstones and conglomerates, but most are Neogene.

Carbonaceous material is not common in the sedimentary rocks, which range in thickness in the various basins from less than 1000 m to as much as 7000 m.

Acid volcanic rocks occur across central Afghanistan and are locally associated with Neogene red beds. Uranium anomalies and a few small, low grade deposits have been found in the Neogene, but, in general, the Tertiary basins of Afghanistan are not very favourable for hosting uranium deposits.

In Iran, following epeirogenic movements, intermontane basins and larger desert depressions have been filled with Neogene continental deposits.

In the north, the maximum thickness of Neogene conglomerates, including some sandstone and mudstone, is 1500 m. In the Tigris–Euphrates Basin, which lies mainly in Iraq, but also partly in Iran and Kuwait, the Fars Group, which extends from the type area in the south-western part of Iran, is a Miocene–Pliocene marine sequence, with brackish to freshwater microfauna in the topmost member. It is overlain unconformably by the Bakhtyari Formation of Late Pliocene age and comprising mainly pebble conglomerate with, in the lower part, conglomeratic sandstone and gritstone. It is unfossiliferous and it is not recorded whether there is any carbonaceous matter present. The maximum thickness of the brackish and freshwater beds is 5000 m.

To the NW, in Turkey, after the main Alpine Orogeny ended in Eocene time, Oligocene clastic lagoonal sedimentary rocks were laid down in an eastwards trending belt that extends from north-eastern Turkey through the central part of the country in a narrow belt extending almost to the Sea of Marmara. A small basin of similar sedimentary rocks lies in SW Turkey [2.20].

Gypsum and salt are ubiquitous. Locally, seams of lignite are interbedded. Near the Black Sea and the Mediterranean there are marine facies. The continental sedimentary rocks comprise multicoloured conglomerates, sandstone and sandy clay up to 2000 m thick. Locally, there are red beds with lignite, bituminous shale, lacustrine limestone and marl.

The deposition of Miocene marine sedimentary rocks occurred near the south coast and elsewhere in the interior, where continental sedimentary rocks comprising fanglomerates, conglomerates and sandstones, alternating with lignite beds more than 30 m thick, were laid down. Locally, this sedimentation continued into the Pliocene. Latite, dacite and andesite flows and tuffs were extruded in the Miocene and Pliocene. Taphrogenic movements with vertical displacements of several hundred metres, and in a few places up to several thousands of metres, disrupted the Oligocene and Miocene strata. Uranium deposits have been identified in these Tertiary strata.

In recent or even possibly in primeval semi-arid basins, uranium deposits associated with calcrete or gypcrete may be found. Such basins occur in many parts of Asia Minor, the Arabian Peninsula, Iran, Afghanistan, Pakistan and north-western India.

From the geological point of view, sedimentary basins occupy a very large part of Central Asia. The most important basins are the North Caspian (or Precaspian) and South Caspian Basins, the North Usturt Basin, which occupies the territory between the northern part of the Caspian Sea and the southern tip of the Ural mountain belt, the Mangyshlak Basin located directly east of the Caspian Sea, the Amu-Darya Basin which occupies eastern Turkmenistan and western Uzbekistan, the Syr-Darya Basin in Kazakhstan and the Kyzyl-Kum Basin in Uzbekistan. As with the North and South Caspian Basins, the North Usturt and Mangyshlak Basins are of major interest for potential oil and gas, and the Amu-Darya, Syr-Darya and Kyzilkum Basins countains major uranium deposits [2.11].

The basement of the Amu-Darya Basin represents Hercynian accreted terrain and comprises deformed and metamorphosed Palaeozoic rocks which are overlain by rift grabens filled with compacted Upper Permian–Triassic rocks that have been altered diagenetically. This sequence is overlain by thick Lower–Middle Jurassic, largely continental, coal-bearing rocks. The overlying Callovian–Oxfordian rocks are mainly carbonates. During the Kimmeridgian–Tithonian period, thick sequences of evaporites of the

Gaurdak Formation accumulated. The Cretaceous–Palaeogene sequence comprises mainly marine clastic rocks with carbonate intervals. In the Neogene, the Alpine Orogeny resulted in the deposition of continental clastics, the initiation of new faults and the reactivation of old ones.

2.1.6. North, Central and South America

2.1.6.1. Tectonics of North, Central and South America

The North American Plate makes up the granitic core (craton) of North America and in addition incorporates part of Denmark (Greenland), Cuba, the Bahamas, part of the Russian Federation (Siberia), Iceland and part of Portugal (the Azores). The west coast of the USA and Canada is largely controlled by the offshore subduction of the Pacific Plate as the North American Plate moves in a roughly south-westerly direction away from the Mid-Atlantic Ridge. The Pacific Plate is being subducted under the North American Plate along the southern coast of Alaska. Alaska itself is believed to have been formed from at least seven plate fragments that collided and fused throughout a prolonged period of time. Transform faults form the southern boundary of the North American Plate, with the Cocos Plate to the west and the Caribbean Plate to the east [2.11].

The Cocos Plate comprises mainly oceanic material and underlies Central America and the Caribbean Sea. It borders the North American and Nazca Plates, where seismicity includes frequent earthquakes and occasional volcanic eruptions. In southern Mexico, the geological picture is complicated by the movements of the Cocos and Caribbean Plates relative to each other and to the North American Plate. The interaction of the Cocos, Nazca and Caribbean Plates between the North and South American Plates produces the complicated structural features of the Earth's crust observed in Central America (Figs. 2.10, 2.11).

The current position of the part of Central America to the NW of Costa Rica is interpreted as being the result of a left-lateral translation of 1000 km or more of the southern part of the Cordilleran Orogenic Belt. The South American Plate is moving westward from the Mid-Atlantic Ridge and along the coast of South America. The Nazca Plate, named after the Nazca region of southern Peru, is subducting underneath and this collision accounts for the emergence of the Andes and volcanoes along the coast.

The ongoing subduction along the Peru–Chile Trench of the Nazca Plate under the South American Plate is largely responsible for the Andean Orogeny. The Nazca Plate is bounded to the west by the Pacific Plate and to the south by the Antarctic Plate through the East Pacific Rise and the Chile Rise, respectively. The subducting Nazca Plate, which exhibits unusual flat slab subduction, is tearing as well as deforming as it is subducted. The subduction process continues to form the Andes. Deformation of the Nazca Plate even affects the geography of Bolivia, far to the east. It was on the Nazca Plate that the 1994 Bolivia earthquake had its epicentre.

2.1.6.2. Geology of North, Central and South America

(1) The Geology and Orogens of North America

The North American Craton is bordered by three major geosynclinal complexes that have been deformed at various geological times and which now constitute the Appalachian, Innuitian and Cordilleran Orogens. Partially surrounding these systems are the Gulf, Atlantic and Arctic coastal plains. Canada is divided physiographically into two units: Shield regions and Borderlands.

The Canadian Shield, that is part of the craton that crops out, contains a substantial portion of the Precambrian rocks of North America and comprises nearly half of Canada, as well as parts of the northern USA (Minnesota, Wisconsin and Michigan). The Archaean of the Canadian Shield comprises sedimentary and volcanic rocks that have been folded, metamorphosed and intruded by granitic rocks of the Kenoran Orogeny (2600–2200 Ma). In Canada, the Proterozoic has been divided into three stages: Aphebian, Helikian and Hadrynian.

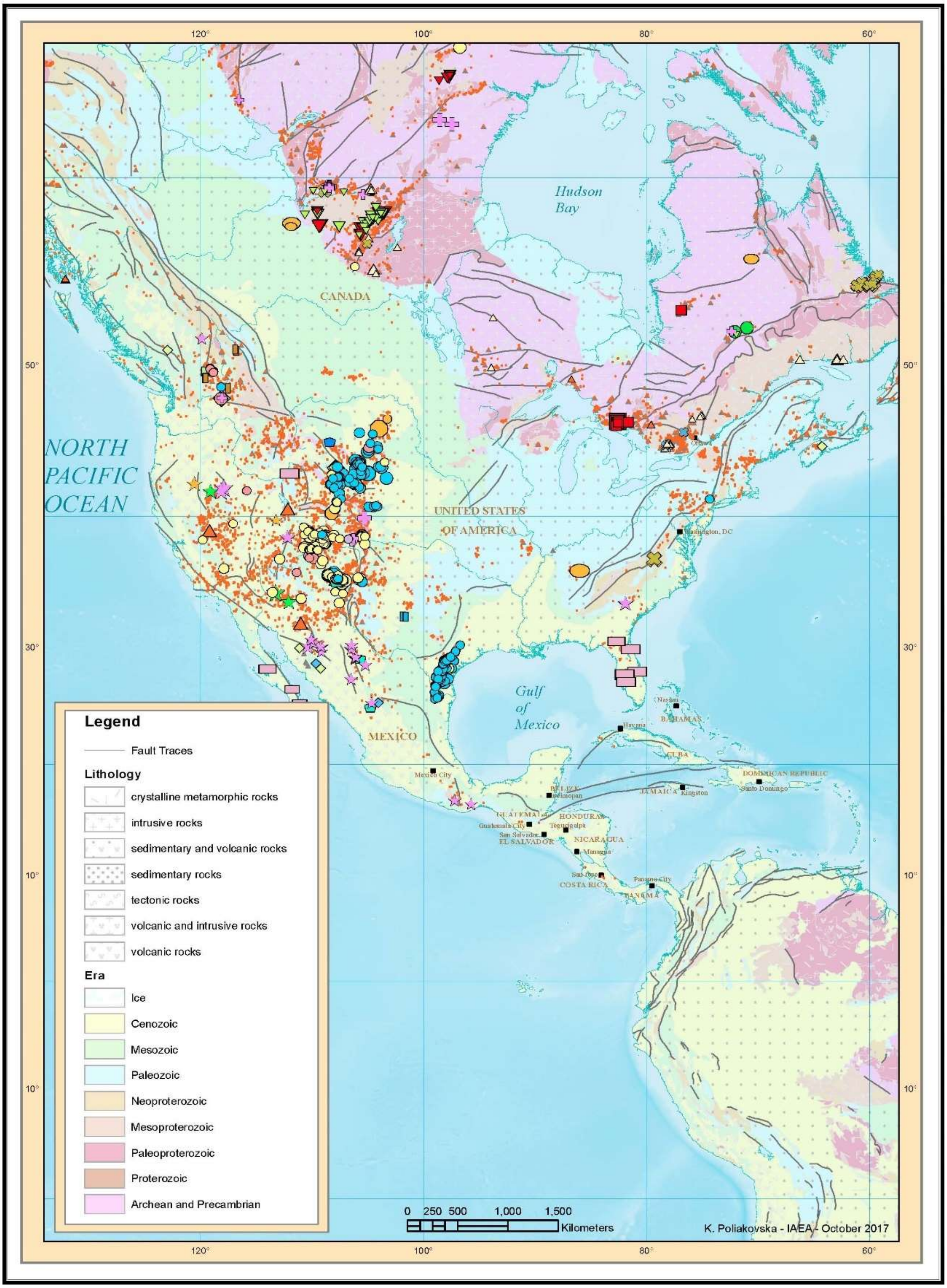


FIG. 2.10. Regional geological setting of North and Central America showing the distribution of selected uranium deposits and occurrences. For general uranium deposit legend see Fig. 2.1b.

FIG. 2.11. Regional geological setting of South America showing the distribution of selected uranium deposits and occurrences. For general uranium deposit legend see Fig. 2.1b.

The Aphebian occurs both as cratonic cover, the clastic sediments of the Cobalt Plate, Bathurst Plate and Mistassini Homocline on the Archaean, and as geosynclinal deposits. The geosynclines border the Superior and Slave Structural Provinces (e.g., Labrador Trough, Cape Smith and Belcher Fold Belts), Churchill Structural Province (e.g., East Arm Fold Belt), and the Bear and Southern Provinces (e.g., Penokean Fold Belt).

The lowermost part of the Aphebian sequence was presumably deposited under oxygen deficient conditions. It contains, in certain areas, large uranium-bearing pyritiferous quartz pebble conglomerate beds (e.g., Elliot Lake). Acidic volcanic centres have been identified in the vicinity of the largest uranium deposits.

The first red beds in the Aphebian are believed to mark the transition between an oxygen deficient atmosphere and one containing free oxygen. ‘Pre-red bed’ uranium deposits have been described as ‘placer type’, as opposed to later ones that have been formed by transport of uranium in solution.

The Hudsonian Orogeny occurred in the Late Aphebian (1850–1650 Ma). The distribution of uranium vein deposits in the Canadian Shield is spatially related to the Aphebian–Helikian unconformity. The Helikian consists mainly of cover rocks resting on Hudsonian Orogens. It occurs in the Churchill Structural Province (e.g., Athabasca Basin, Thelon Plate, East Arm Fold Belt), in the Southern Structural Province (e.g., Lake Superior Basin) and elsewhere. In the Western Nain Province, the Helikian anorthosite plutons were emplaced throughout the Elsonian Orogeny (1370 Ma). Helikian rocks in the Grenville Province were affected by the Grenvillian Orogeny (955 Ma). The uranium deposits related to the Elsonian and Grenvillian Orogenies are mainly of a granitic character (modified by anatexis). Several carbonatite complexes intruded throughout the previous orogenic episode are also uranium-bearing.

The Hadrynian is represented by clastic sedimentary series in which uranium mineralization is uncommon.

The geological structure and evidence of orogenies indicate that the Shield is composed of different parts that were once probably as distinct, physiographically, as the Cordilleran Region and Interior Plains are in the present-day. The chapter on Canada describes the four types of terrain in the Shield, each of which corresponds to, and coincides with, particular geological characteristics: plains, hills, mountains and highlands. Other units are distinguished by less obvious characteristics, and in some places boundaries are arbitrarily drawn to divide units, e.g.: Kazan, Davis, Hudson, James and Laurentian Regions. The Davis Region includes the Canadian Arctic Archipelago, extending off the northern edge of the continent and ‘wrapping’ around north-western Greenland.

The subdivisions of the Shield are depicted and described in the chapter on Canada, as are the following subdivisions of the Borderlands:

- Innuitian Region;
- Arctic Coastal Plain and Continental Shelf;
- Arctic Lowlands;
- Interior Plains;
- Cordilleran Region;
- St. Lawrence Lowlands;
- Appalachian Region.

Continental USA is divided into eight distinct physiographic divisions, several of which are equivalent to those in Canada. The major divisions are:

- Laurentian Upland — part of the Canadian Shield;
- Atlantic Plain — coastal regions of the eastern and southern parts include the Continental Shelf and the Atlantic and Gulf Coasts;

— Appalachian Highlands — on the eastern side of the USA, including several mountain ranges (see Appalachian Orogen));
— Interior Plains and Interior Highlands — part of the interior, including the Great Plains;
— Rocky Mountain System — at the western edge of the Great Plains, extending north to south across the country, reaching elevations greater than 4300 m in Colorado (see Cordilleran Orogen);
— Intermontane Plateaux — include the Columbia Plateau, the Colorado Plateau and the Basin and Range Province (see Cordilleran Orogen);
— Pacific Mountain System — the coastal mountain ranges and features on the west coast (see Cordilleran Orogen).

The geology of Alaska is very complex, owing to its tectonic history. Southern Alaska is a region of high, rugged, heavily glaciated mountain ranges. The interior comprises broad valleys and generally low mountains between the Alaska Range to the south and the Brooks Range to the north.

Hawaii consists of a series of mountain islands which are of volcanic and coral origin:

— The Appalachian Orogen

The Appalachian Mountains and Plateaux extend from northern Alabama to the northern tip of Newfoundland. North of New York, the system can basically be divided into three units comprising, from east to west: (i) an area of schists, gneisses and slates formed from early Palaeozoic sediments and intruded by Devonian granite batholiths; (ii) an area of Middle Palaeozoic sediments folded into open anticlines and synclines, and (iii) an area of gently flexed Palaeozoic rocks of the Allegheny Plateau. The third of these units is not well developed in Canada. South of New York, the system can be divided into four units comprising, from east to west: (i) a region of strongly metamorphosed Palaeozoic sediments invaded by igneous rocks mainly of Late Devonian–Carboniferous age (the Piedmont); (ii) an area of Precambrian basement gneisses, granites, basalts and greywackes with some early Cambrian quartzites, arkoses and conglomerates (Blue Ridge Province); (iii) an area of tightly folded, asymmetrical Cambrian–Ordovician carbonates, sandstones and shales (Valley and Ridge Province), and (iv) an arc of gently flexed Palaeozoic rocks (Appalachian Plateau). The northern part of the system was deformed by the Taconic Orogeny (Ordovician), the majority of the deformation being caused by the latter. The Triassic basins of the Appalachians are the product of post-orogenic normal and strike-slip faulting.

— The Cordilleran Orogen

The North American Cordillera in western North America can be roughly divided into four major physiographic divisions: (i) the Eastern Ranges (including the Sierra Madre Oriental, the Colorado and Southern Rocky Mountains, the Northern Rocky Mountains and the Brooks Range); (ii) the Interior Ranges (including the Basin and Range Province and its Mexican extensions, the Sonoran Desert and the Meseta Central); (iii) the Interior Plateaux (including the Colorado, Columbia and Yukon or Intermontane Plateaux) and (iv) the Western Ranges (the Alaska Range, the Coast Range, the Pacific Coast Range and the Sierra Nevada Range, the Sierra de la Baja California and the Sierra Madre del Sur). It has already been mentioned that the geology of the southern part of the Cordillera, south of the Mexican Transcontinental Rift, is complicated by the movements of two minor plates which have resulted in the Cordillera trending to the east and passing through central Guatemala. The Sierra Madre Occidental and the Sierra de Los Volcanes are discussed separately in this section, as is the Wyoming Basin, which is 'draped' across the Central Rocky Mountains and part of the Great Plain.

— The Eastern Ranges

The Sierra Madre Oriental, located in north-eastern Mexico, consists of folded and faulted Mesozoic sediments, predominantly Cretaceous limestones. In the deep canyons, Precambrian gneisses and Palaeozoic metamorphics are also exposed. Several sedimentary basins contain terrigenous sediments of Late Cretaceous age and the range merges with the geologically similar Meseta Central.

The Colorado and Southern Rocky Mountains include those of southern Wyoming, Colorado and northern New Mexico. The province consists of a series of N–NW trending 'en echelon' ranges formed throughout the Upper Cretaceous–Lower Tertiary. The ranges possess a core of Precambrian rocks bounded by tilted Palaeozoic and Mesozoic sediments.

In the Palaeozoic section, Cambrian–Lower Carboniferous rocks comprise mainly marine quartzite, dolomite and limestone, and Upper Carboniferous and Permian strata consist of siltstone, sandstone and conglomerate, limestone, dolomite, salt and gypsum, some of them marine, others of continental origin. Triassic and Jurassic rocks are continental, but Cretaceous rocks are marginal continental or igneous. Cenozoic rocks include igneous rocks and clastic fluvial strata. Cretaceous and Tertiary volcanic rocks predominate in the San Juan Mountains region. Tertiary and Quaternary sedimentary and volcanic rocks fill the intermontane basins, some of which contain uranium deposits.

The Northern Rocky Mountain region of the USA consists chiefly of complex mountain belts with intervening basins. Upper Precambrian metasediments, intruded by granitic batholiths of Cretaceous–Late Tertiary age, are common. Precambrian felsic intrusives are exposed in several areas and contain uranium deposits in the Owl Creek Mountains.

The Early Palaeozoic rocks of the region consist chiefly of carbonates, quartzites and shales. The Upper Carboniferous is a mixture of shallow marine and continental sediments and the Permian rocks are mainly dark shale, uraniferous phosphorite and chert facies. The lowest Triassic rocks are marine, but the overlying rocks are non-marine Late Triassic–Early Jurassic and comprise continental aeolian sandstones. Middle Jurassic rocks are represented by carbonates, evaporites and red siltstones, while the Upper Jurassic consists of fluviatile and lacustrine sandstones and shales.

Lava flows and pyroclastic rocks of Tertiary and Quaternary age cover a large area of north-western Wyoming and central Idaho.

In the Brooks Range, Palaeozoic limestone, dolomitic limestone, marble and metamorphosed clastic and volcanic rocks are exposed. These have been subjected to complex folding and faulting and are, in places, intruded by mafic and ultramafic bodies, possibly of Jurassic age.

— The Interior Ranges

The Basin and Range region is typical of the interior ranges and in the USA extends from southern Oregon to western Texas. It is characterized by northerly trending block faulted mountains separated by broad, alluvium filled valleys. The mountain ranges are composed of Precambrian and younger sedimentary, metamorphic and igneous rocks. Tertiary volcanic and clastic strata occupy many of the alluvium filled valleys. Mesozoic and Tertiary granitic plutons and Tertiary rhyolitic intrusives are widespread. The Triassic, Jurassic and Early Cretaceous beds in the south and SE are continental, providing potential uranium host rocks in the form of the Chinle and Morrison Formations. Tertiary non-marine sediments, particularly of Miocene and Pliocene age, rhyolitic extrusives and Mesozoic granites are important to uranium deposition. Favourable igneous and metamorphic rocks consist of Miocene rhyolitic plugs, flows and tuffs, Mesozoic and Precambrian intrusives, and Palaeozoic–Mesozoic phyllites and slates near granite contacts.

To the south, in Mexico, major outpourings of acid volcanics throughout the Tertiary have formed the Sierra Madre Occidental, which divides the extension of the Basin and Range Province into two parts. To the west is the Sonoran Desert Province, consisting of a series of block faulted mountains and broad desert plains with exposures of igneous and sedimentary rocks ranging in age from Precambrian to Recent. To the east, the Meseta Central forms a high plains area with widely separated, isolated mountain ranges. The most common rocks here are Triassic sediments and metamorphics, Jurassic sediments and Cretaceous limestones. Volcanic rocks have been extruded in some areas. The Late Triassic Nazas Formation is lacustrine and contains interbedded, intermediate–acid volcanics. Rocks of probable

Palaeozoic age, including metavolcanics and schists, are exposed in the south. Uranium occurrences have been recorded in Tertiary volcanics in the Meseta Central.

— The Interior Plateaux

The Colorado Plateau includes parts of Colorado, Utah, Arizona and New Mexico. Sedimentary, granitic and metamorphic rocks crop out in many places and underlie the Plateau. Sediments range from Palaeozoic to Early Tertiary, with the fluviatile sandstones of Triassic–Jurassic age having the most influence on uranium mineralization.

The western part of the Colorado Plateau is block faulted and structurally transitional between the Basin and Range and the typical plateau-type structure. Flowage of Upper Carboniferous salt beds throughout Late Cretaceous–Early Tertiary deformation has developed broad, NW trending anticlinal structures in the Paradox Basin of the Central Plateau in western Colorado and eastern Utah where numerous uranium mineralization exist. These folds may have contributed to the localization of uranium-bearing solutions.

Tertiary rocks crop out in the northern and south-eastern plateau region in the Uinta, Piceance and San Juan Basins. The Jurassic rocks in north-western New Mexico are intensely mineralized along the southern flank of the San Juan Basin where Mesozoic rocks dip into the basin in a northerly direction off the Zuni Uplift.

The western part of the Columbia Plateau region consists of folded and faulted Palaeozoic and Mesozoic sedimentary rocks, lavas and plutons. More recent marginal marine and marine sediments crop out to the east together with extensive tuffaceous argillite and greenstones. Miocene and Pliocene flood basalts cover large areas. The Snake River Plains consist of basalts of Miocene, Pliocene, Pleistocene and Quaternary age.

The Intermontane or Yukon Plateau consists of lowlands filled principally with Quaternary alluvium, glacial debris, aeolian sand and silt, and uplands consisting predominantly of Precambrian and Palaeozoic metamorphic rocks, except in the west, where Mesozoic sandstones and shales prevail. The area contains intrusions of Mesozoic granites, and Mesozoic volcanic rocks are found in the north while Palaeozoic, Tertiary and Quaternary volcanics occur in the south.

— Western Ranges

The Western Ranges were formed from the Cordilleran geosyncline and consist of intensely deformed Palaeozoic volcanics, greywackes, shales, argillites and cherts. Precambrian metamorphic rocks are exposed in some areas. The areas are intruded by large batholiths of intermediate–acidic composition of Mesozoic and Tertiary age. Coastal California and the Aleutian Ranges on the Alaska Peninsula are underlain by deformed Tertiary sediments, chiefly volcanics and arkoses overlying Mesozoic greywackes, shales, cherts, limestones and older basement rocks.

— Sierra Madre Occidental

The Sierra Madre Occidental is a NW–SW trending range comprising essentially horizontally bedded Tertiary acid volcanics overlying granitic plutons and andesites. The volcanics consist of rhyolitic lavas and ignimbrites, together with relatively young basalts. To the north and NW, Basin and Range faulting divides the range, which grades into the Sonoran Desert. To the south, the province merges into the Trans-Mexico Volcanic Belt.

— Sierra de los Volcanoes

The Trans-Mexico Volcanic Belt is an area in which volcanic activity has continued from Early Tertiary up to the present-day. The volcanics consist of a mixture of lava flows and intrusives, ash falls and volcaniclastic sediments of andesitic and basaltic compositions. Lacustrine sediments are also abundant.

The volcanics are underlain by Triassic metamorphics composed chiefly of slates, phyllites, meta-limestones and greenstones.

— Wyoming Basins

The Wyoming Basins region includes much of Wyoming and smaller parts of adjacent states. It consists of numerous sizeable basins in which the predominant surface rocks are continental strata of Tertiary age, which comprise fine-grained sandstones and siltstones with occasional wedges of coarse arkose derived from the Precambrian granite cores of the surrounding ranges. These sediments are extensively overlain by Middle Eocene–Pliocene tuffaceous sediments which have been eroded where broad regional uplift has taken place. Several basins host uranium as sandstone roll front type deposits.

— The Innuitian Orogen

The Innuitian mountain system crosses the Arctic islands and northern Greenland. The Franklin geosynclines from which these mountains arose received a thick sequence of Early Palaeozoic sediments and were deformed in the Late Palaeozoic. An orogeny in the Cenozoic further deformed the area, together with the Mesozoic sediments of the Sverdrup Basin. The Innuitian Orogen contains areas favourable for uranium mineralization in environments similar to those in the Cordillera.

— The Coastal Plains

The Coastal Plains of the USA and Mexico extend from the Yucatan Peninsula to New Jersey, along the Gulf of Mexico and the Atlantic Ocean. Gently dipping, poorly consolidated terrigenous sediments of Tertiary age cover a large part of the region, particularly along the coastal margins. The Atlantic and Eastern Gulf Coastal Plains consist of Cretaceous continental clays and arkosic sands covered by younger marine clays and marls. The Yucatan Peninsula is a region of low lying Tertiary limestones overlying a thick evaporite sequence at depth and exhibiting karst topography.

The area of greatest potential for uranium mineralization extends along the Gulf of Mexico and curving NE from south Texas to Louisiana and Arkansas where tuffaceous sandstones of Eocene, Miocene and Pliocene age occur in a marginal marine sedimentary environment. South Texas has been the most productive area.

Along the Pacific Coast of the USA and southern Mexico, the marine Tertiary deposits have been deformed by orogenies throughout the Cenozoic, some of which are continuing.

The Sonoran Plain, bordering the Sierra Madre Occidental, contains Late Palaeozoic–Middle Mesozoic low grade metamorphics overlain by Middle–Late Cretaceous andesites and rhyolites intruded by granodioritic batholiths. Red beds have accumulated in the Cretaceous volcanics interbedded with basaltic, andesitic and rhyolitic extrusives.

(2) The Geology and Orogens of Central and South America

A belt of volcanoes (the so-called Ring of Fire) extends along a length of ~1100 km from Mexico to Costa Rica and at a distance of ~200 km from the Middle American trench. The volcanic front is formed by the subduction of the Cocos Plate beneath the Caribbean Plate. Volcanic activity in Central America dates back to Pliocene–Quaternary times. The volcanic arc consists mainly of basaltic and andesitic volcanic rocks (predominantly pyroclastics with subordinate lava sheets). Many of the volcanoes are classified as active.

The South American craton, created in the Late Precambrian, throughout the Brazilian Orogeny, is mostly covered by younger sediments and extrusives. Intrusives of various ages have been emplaced in both the craton and its cover. Towards the Atlantic, the craton breaks off abruptly and this, together with its ‘jigsaw’ fit with the coast of Africa, instigated theories of continental drift and plate tectonics.

The situation is different along the Pacific coast. Here, the craton is bounded by the Cordilleras, an orogenic fold belt which runs north–south. This belt, which contains the remnants of Palaeozoic orogens, was mainly created throughout the Late Mesozoic–Tertiary by westward movement of the continent, which resulted in underthrusting. Volcanism has been widespread throughout the Cordillera and still continues in certain areas.

The South American craton proper is made up of six massifs joined by a series of fold belts: (i) the Guyana Massif, north of the Amazon; (ii) the Guaporé Massif, south of the Amazon; (iii) the São Luis Massif, on the NE coast; (iv) the São Francisco Massif in eastern Brazil; (v) the Rio de la Plata Massif, at the mouth of the Rio de la Plata; and (vi) the Patagonia Massif, in southern Argentina. The Patagonia Massif may be part of the old Antarctic continent.

The geology of many parts of these massifs is poorly understood. A wide range of metamorphosed sediments and igneous rocks make up these areas, including quartzites, metamorphosed dolomites, mica schists, gneisses, itabirites, skarns, diorites, granites and gabbros. Faults, quartz veins, pegmatites and dykes are common. Many of the rocks have been strongly folded. It appears that, towards the south, the crystalline basement of the massifs tends to be somewhat younger than that in the north. This metamorphic basement complex is frequently covered, unconformably, by relatively unmetamorphosed sediments and volcanics. Dykes of Mesozoic age and of acid to basic composition often break through this complex.

The Guyana and Guaporé Massifs are far larger than the others. The connection between these two massifs does not crop out, being covered by the sediments of the Amazonas Basin, and it is possible that they may form one continuous unit.

Throughout the Brazil Orogeny, in the Late Precambrian, the massifs fused together, which resulted in the formation of fold belts separating them. The rock assemblages consist of a wide range of metamorphosed and some slightly metamorphosed sediments deposited in geosynclines, which, in general, are highly folded and frequently invaded by younger intrusives. Younger unfolded sediments cover the craton. Areas of thicker and more continuous sedimentation, from north to south, are the Amazonas Basin, the Piaui Basin in NE Brazil, the Paraná Basin in southern Brazil, Uruguay, Paraguay and Argentina. Smaller sedimentary basins occur at the edges of massifs, some of Cretaceous age.

2.1.6.3. Uranium geology

(1) North America

— Canada

The country report for Canada describes the geology as being directly related to different types of uranium occurrence, which is thought to have some bearing on the location of economic uranium mineral deposits. There are five sources of uranium in Canada:

(i) *Quartz pebble conglomerates*: A substantial proportion of Canada’s historical economic uranium resources were discovered in the basal Paleoproterozoic rocks of the Elliot Lake and Agnew Lake areas;
(ii) *Proterozoic unconformity related deposits in the Athabasca Basin*: most important deposits include those located at Cigar Lake, Cluff Lake, Key Lake, Rabbit Lake, McClean Lake and McArthur River, all of which are located in Saskatchewan, and for most of them, in the east part of the Athabasca Basin. Large deposits have also been recently discovered in the west part of the Basin (Triple R, Arrow);
(iii) *Vein deposits*: Metamorphite structurally-controlled pitchblende deposits in the region surrounding Beaverlodge, north of the Athabasca Basin;
(iv) *Disseminated deposits in igneous and metamorphic rocks*: This type of deposit (Intrusive anatedtic) was historically of economic significance in the Bancroft, Ontario area of the Grenville Province. The Rexspar deposit (Volcanic-related) in British Columbia is similar;

(v) *Volcanic related and other types of deposit*: The Kiggavik uranium deposits occur in close spatial proximity to the unconformity at the base of the Proterozoic Thelon Basin, Nunavut. Gabbro dyke-related uranium mineralization has been discovered at the Matoush locality in the Proterozoic Otish sandstone basin, Quebec. Felsic volcanics associated and shear-related uranium deposits have been discovered in Labrador's Central Mineral Belt. The Michelin deposit occurs in felsic metavolcanics of the Ailik Group and the Kitts deposit is related to epigenetic shear hosted uranium mineralization in granites. Syngenetic uranium accumulations (Amer Lake deposit) are known to occur in the Palaeoproterozoic Amer Group metasediments, Nunavut.

Uranium production is currently derived exclusively from the unconformity-related deposit type. Intrusive and vein type deposits may also hold significant potential. There are no known economic sandstone-hosted uranium deposits in Canada.

— USA

The geology of the USA has been divided into 12 geographical regions, plus Alaska, Hawaii and overseas territories. The 14 regions include discrete areas each with distinctive geological provinces and associated with either identified or speculative uranium resources.

The country report for the USA describes these regions, primarily based on the 1980 US Department of Energy report, An Assessment Report on Uranium in the United States of America [2.21], as well as other related documents, most published in association with the National Uranium Resource Evaluation Program.

The geological provinces, or regions, with a known uranium endowment are: (i) the Colorado Plateau, (ii) the Wyoming Basins, (iii) the Coastal Plain (South Texas portion), (iv) the Northern Rocky Mountains, (v) the Southern Rocky Mountains, (vi) the Great Plains, (vii) the Basin and Range, (viii) the Pacific Coast, (ix) the Central Lowlands, (x) the Appalachian Highlands, (xi) the Columbia Plateaux, (xii) the Southern Canadian Shield, and (xiii) the non-contiguous State of Alaska. No uranium resources or potential resources are known in (xiv) the volcanic Hawaii Islands or in the overseas territories [2.22].

— Mexico

The northern Mexican coast (Caribbean) possesses sandstone roll front type deposits similar to those present in Texas and producing uranium through in situ extraction. The area is little explored and the technology has not been tested in the country. Much of the rest of the country is dominated by volcanic rocks, hosting numerous volcanic-related structurally-controlled uranium deposits.

(2) Central and South America

In Central America, the volcanics and associated intrusives, including recent ones, are related to collisions between plates and are not generally considered as rock types favourable for hosting uranium deposits.

The Shield area in South America covers more than 80% of Brazil and forms part of the Guiana Shield, which extends between the Orinoco and Amazon Rivers and includes eastern Venezuela, Guyana, Suriname, French Guiana and northern Brazil. The crystalline basement is formed principally of igneous and metamorphic rocks, while the coastal plain, which stretches along the northern fringe of the Shield area, is exclusively sedimentary.

Several country reports note that unexplored areas of the larger massifs, in particular the Guyana and Guaporé Massifs, may hold potential for uranium deposits. Several metasomatic granite-related deposits have been discovered in Guyana in the 2000s. The Guyana Shield may also contain uranium deposits in quartz-pebble conglomerates.

Relatively little is known of the detailed geology of some areas such as Paraguay. A large part of the area is covered by Quaternary deposits, which completely conceal the rock basement on which they rest. Sandstone-hosted deposits are present in the Permo-carboniferous formations of the Parana Basin (equivalent of the Karoo formations of Africa). Archaean crystalline rocks dominate the geology of Suriname where the Shield area has been flattened by erosion.

The northern part of the Brazilian Shield crops out in Venezuela. Three general groups of rocks of the Archaean basement complex are recognized, granites, gneisses and schists, and two overlying younger series of sandstones, quartzites, shales, tuffs and mafic intrusions. The two series are separated by a major unconformity. The Precambrian rocks in Venezuela near the border with Colombia have been little studied but are considered to have high potential for uranium, in particular for the discovery of Proterozoic unconformity related deposits below the Roraima Series.

In addition, there appears to be a more limited potential for sandstone, disseminated and vein uranium deposits in the Andean areas.

Large volcanic-related resources have been found in the Macusani area, Peru. They are located in Caenozoic-Quaternary ignimbrite formations.

In Colombia also, little is known about quartz pebble conglomerates in the Guyana Shield, which could have some potential. The Santander and Garzon Massifs have the best potential for new discoveries of disseminated and vein type mineralization. The greatest potential for sandstone uranium deposits in Colombia occurs in Mesozoic sediments, such as the Triassic red beds of the central sector in the Cordillera Central. The Berlin project contains uranium resources in Cretaceous phosphatic black shales.

In summary, unexplored or poorly explored Precambrian Shield areas are potential targets for hosting both unconformity-related, metasomatic and quartz pebble conglomerate type deposits in Bolivia, Brazil, Colombia, French Guiana, Guyana, Suriname and Venezuela.

Basin geology is another important area of study, where the basins may be potential hosts for sandstone type deposits, which may, in some cases, be amenable to in situ leach recovery as, for example, in Argentina, Paraguay and Uruguay.

2.2. WORLD OVERVIEW OF URANIUM DEPOSIT TYPES

Appendix II provides a list and description of the OECD/NEA–IAEA classification scheme for uranium deposit types, which is used in this publication. Table 2.1 indicates that the black shales, phosphate and lignite-coal deposit types make up the highest proportion of the world’s uranium resources, based on the original contained resource. The large number of sandstone and vein (granite and metamorphite-related) type deposits contrasts with the relatively few deposits of the other types owing to the large number of relatively small tonnage sandstone and vein-type deposits. Representing 3.4 % of the total deposits, unconformity-related deposits occur primarily in Australia and Canada and are relatively few in number. However, some unconformity type deposits have very large resources of >100 000 tU, including Jabiluka 2 and Ranger 3 in Australia, and Cigar Lake and McArthur River in Canada, and therefore the total resources associated with this deposit type are large. Additionally, the Cigar Lake and McArthur River deposits also have very high average grades of >10% U. For the haematite breccia complex type, the associated resources primarily occur in the giant Olympic Dam deposit in South Australia, which is the largest exploited uranium resource in the world.

Initial resources associated to unconventional uranium type deposits (black shales, phosphate and lignite-coal) total to 44.96 million tU, 69.3 % of the world total initial resources.

Table 2.2 indicates the worldwide distribution, by region, of the known deposits, according to deposit type [2.23, 2.24].

TABLE 2.1. WORLD URANIUM DEPOSIT TYPES [2.23, 2.24]
(Number of deposits identified and initial uranium resources for ca. 3600 deposits, as of September 2019)

Deposit type	Number of deposits	Proportion (%)	World total initial resource (tU)	Proportion (%)
Unconformity-related	121	3.4	1 691 744	2.6
Sandstone	1430	39.6	5 095 214	7..9
Haematite breccia complex	20	0.6	2 509 262	3.9
Quartz-pebble conglomerate	146	4.0	2 505 965	3.9
Vein (granite, metamorphite-related)	910	25.2	1 256 647	1.9
Intrusive	137	3.8	3 130 599	4.8
Volcanic-related	235	6.5	1 910 722	2.9
Metasomatite	161	4.5	1 079 862	1.7
Black shales	77	2.1	22 866 692	35.2
Carbonate	51	1.4	209 096	0.3
Collapse breccia pipe	20	0.6	19 586	0.0
Lignite-coal	82	2.3	7 421 833	11.4
Phosphate	88	2.4	14 674 442	22.6
Surficial	132	3.7	500 966	0.8
Total	3 610	100.0	64 872 630	100.0

TABLE 2.2. WORLDWIDE DISTRIBUTION OF URANIUM DEPOSITS BY REGION [2.24]
(as of September 2019)

Deposit type	Africa	Central, Eastern and South-eastern Europe	South-eastern Asia, Pacific, East Asia	Western Europe	North, Central and South America	Middle East, Central and Southern Asia	Total
Unconformity-related	0	4	37	0	76	4	121
Sandstone	135	179	109	52	851	104	1430
Haematite breccia complex	0	0	13	0	7	0	20
Quartz pebble conglomerate	114	2	0	1	28	1	146
Volcanic	0	60	60	15	75	25	235
Intrusive	42	13	11	7	59	5	137
Vein	28	223	65	458	65	71	910
Metasomatite	9	74	25	3	42	8	161
Black Shales	2	8	12	28	4	23	77
Carbonate	1	12	4	0	22	12	51
Collapse Breccia Pipe	0	0	0	0	20	0	20
Lignite-coal	2	51	7	4	9	9	82
Phosphate	25	14	2	2	21	24	88
Surficial	53	11	36	0	22	10	132
Total	411	651	381	570	1301	296	3610

2.2.1. Deposit types in Africa

The most frequent uranium deposit types identified to date in Africa are sandstone (135 deposits, 32.8 %) and quartz-pebble conglomerate (114 deposits, 27.7%) types. Surficial, intrusive and metasomatite deposits and uranium associated with phosphorite have also been reported.. Of these, 285 (69.3%) are located in South Africa, Namibia and Niger. Quartz-pebble conglomerate and sandstone types are the most common types in South Africa, intrusive and surficial types in Namibia, sandstone type in Niger (Table 2.3).

TABLE 2.3. URANIUM DEPOSITS BY TYPE (UDEPO [2.24])
(as of September 2019)

Deposit type	Algeria	Angola	Botswana	Cameroon	Central African Republic	Chad	Democratic Rep. of the Congo	Egypt	Gabon
Sandstone	0	0	8	0	0	0	0	0	7
Quartz pebble conglomerate	0	0	0	0	0	0	0	0	0
Intrusive	0	0	0	1	0	0	0	0	1
Vein	4	0	0	0	0	1	15	1	0
Metasomatite	0	0	0	1	0	1	0	0	0
Black Shale	0	0	0	0	0	0	0	0	0
Carbonate	0	0	0	0	0	0	0	0	0
Lignite-coal	0	0	0	0	0	0	1	0	0
Phosphate	3	1	0	0	5	0	2	4	0
Surficial	1	0	1	0	0	0	0	1	0
Total	8	1	9	2	5	2	18	6	8

(cont.)

Deposit type	Guinea	Madagascar	Malawi	Mali	Mauritania	Morocco	Namibia	Niger	Nigeria
Sandstone	0	1	2	1	0	1	1	47	1
Quartz pebble conglomerate	0	0	0	0	0	0	0	0	0
Intrusive	0	1	1	0	0	3	30	0	0
Vein	1	0	0	0	0	0	0	0	3
Metasomatite	0	1	0	0	3	0	1	0	0
Black Shale	0	0	0	0	0	2	0	0	0
Carbonate	0	0	0	0	0	0	1	0	0
Lignite-coal	0	0	0	0	0	0	0	0	0
Phosphate	0	0	0	0	1	4	0	0	0
Surficial	0	1	0	1	10	2	17	1	0
Total	1	4	3	2	14	12	50	48	4

(cont.)

Deposit type	Senegal	Somalia	South Africa	Tunisia	Uganda	United Republic of Tanzania	Zambia	Zimbabwe	Total
Sandstone	0	0	54	0	0	3	8	1	135
Quartz pebble conglomerate	0	0	114	0	0	0	0	0	114
Intrusive	0	0	4	0	1	0	0	0	42
Vein	0	0	0	0	0	0	3	0	28
Metasomatite	1	1	0	0	0	0	0	0	9
Black Shale	0	0	0	0	0	0	0	0	2
Carbonate	0	0	0	0	0	0	0	0	1
Lignite-coal	0	0	1	0	0	0	0	0	2
Phosphate	0	0	3	1	0	1	0	0	25
Surficial	0	1	11	0	0	6	0	0	53
Total	1	2	187	1	1	10	11	1	411

2.2.2. Deposit types in Western Europe

As of September 2019 UDEPO [2.24] reported 570 identified uranium deposits occurring in 12 countries in Western Europe (Table 2.4). The unusually high number (459) and percentage (80.5%) of vein-type deposits (granite-related), as compared with the worldwide frequency (1.9%) is notable. Vein type deposits (granite and metamorphite-related) were the primary source of uranium production in Germany, France, Spain and Portugal. Sandstone type deposits were also significant production sources in Germany and France.

TABLE 2.4. WESTERN EUROPE URANIUM DEPOSITS BY TYPE IN 8 COUNTRIES [2.24]
(as of September 2019)

Deposit type	Austria	Belgium	Denmark	Finland	France	Germany	Italy
Sandstone	0	0	0	2	36	9	0
Quartz-pebble congl.	0	0	0	1	0	0	0
Volcanic	0	0	0	0	1	6	6
Intrusive	0	0	4	2	0	0	0
Vein	2	0	3	8	224	43	0
Metasomite	0	0	0	0	0	0	0
Black Shale	0	0	0	2	4	17	0
Lignite-coal	0	0	0	0	0	1	0
Phosphate	0	1	0	0	0	0	0
Total	2	1	7	15	265	76	6

(cont.)

Deposit type	Portugal	Spain	Sweden	Switzerland	United Kingdom	Total
Sandstone	0	5	0	0	0	52
Quartz-pebble congl.	0	0	0	0	0	1
Volcanic	0	0	1	1	0	15
Intrusive	0	0	1	0	0	7
Vein	100	61	10	4	4	459
Metasomite	0	0	2	0	0	2
Black Shale	0	0	5	0	0	28
Lignite-coal	0	3	0	0	0	4
Phosphate	0	0	1	0	0	2
Total	100	69	20	5	4	570

2.2.3. Deposit types in Central, Eastern and South-eastern Europe

As of September 2019, the IAEA's uranium deposit database (UDEPO) [2.24] reported 651 identified uranium deposits occurring in 14 countries in Central, Eastern and South-eastern Europe (Table 2.5). The most frequent uranium deposit types identified to date in Central, Eastern and South-eastern Europe are vein-type (223 deposits, 34.3%), sandstone-type (179 deposits, 27.5%), metasomatite-type (74 deposits, 11.4%) and volcanic-related type (60 deposits, 9.2%).

In the Czech Republic, 70 % of the total production has been mined from vein type deposits (granite-related and metamorphite). Sandstone type deposits have been mined (and are still mined) using in situ leach technology in the Czech Republic and in the Russian Federation, and by in-situ leaching and underground methods in Bulgaria. Metasomatite type deposits have been the primary production source in Ukraine and it is a major type of identified resource in Ukraine and in the Russian Federation.

Volcanic type deposits are important with respect to the Russian Federation, where 152 700 tU (92.6 %) of all production (through the end of 2016) has come from volcanic type deposits from the Streltsovska caldera, Siberia, and 18 % of the indicated resources are associated to this type of deposits. Lignite-coal deposits constitutes a major type of resources in the Czech Republic (37 deposits).

TABLE 2.5. CENTRAL, EASTERN AND SOUTH-EASTERN EUROPE URANIUM DEPOSITS BY TYPE [2.24]
(as of September 2019)

Deposit type	Bulgaria	Czech Republic	Estonia	Greece	Hungary	North Macedonia	Poland	Romania
Unconformity	0	0	0	0	0	0	0	0
Sandstone	27	14	0	0	4	0	3	9
Quartz pebble conglomerate	0	0	0	0	0	0	0	0
Volcanic	7	0	0	0	1	1	0	1
Intrusive	0	0	0	0	0	0	0	0
Vein	20	128	0	1	0	0	17	13
Metasomatite	0	0	0	0	0	0	0	0
Black Shale	0	0	1	0	0	0	5	0
Carbonate	0	0	0	0	0	0	0	0
Lignite-coal	0	37	0	1	0	0	0	0
Phosphate	0	0	0	1	0	0	0	0
Surficial	5	1	0	0	0	0	0	0
Total	59	180	1	3	5	1	25	23

(cont.)

Deposit type	Russian Federation	Serbia	Slovakia	Slovenia	Turkey	Ukraine	Total
Unconformity	4	0	0	0	0	0	4
Sandstone	69	13	5	1	17	17	179
Quartz pebble conglomerate	0	0	0	0	0	2	2
Volcanic	44	1	4	0	1	0	60
Intrusive	9	0	0	0	0	4	13
Vein	26	11	0	0	4	3	223
Metasomatite	37	0	0	0	0	37	74
Black Shale	2	0	0	0	0	0	8
Carbonate	11	0	0	0	1	0	12
Lignite-coal	8	0	0	0	0	5	51
Phosphate	13	0	0	0	0	0	14
Surficial	4	0	0	0	1	0	11
Total	227	25	9	1	24	68	651

2.2.4. Deposit types in South-eastern Asia, Pacific, East Asia

As of September 2019, UDEPO [2.24] reported 381 identified uranium deposits occurring in ten countries in the region (Table 2.6). Of these 381 deposits, 81.6% are in Australia and China. The high percentage reflects not only the very large areas of the two countries, but also the extensive amount of exploration undertaken, together with favourable geological host environments and relative success in exploration. 165 deposits (43.3% of those in the region) are located in Australia. This includes the haematite breccia complex at Olympic Dam in South Australia, which is the world's largest individual uranium resource. 146 deposits (38.3 %) are located in China. Sandstone is the most common type of deposit and sandstone-hosted deposits have been identified in six countries (49 in Australia, 41 in China, 10 in Mongolia, 6 in Viet Nam, 2 in Japan and 1 in Thailand). The second most common are vein- type deposits (55 in China), followed by volcanic-related type (32 in China, 20 in Mongolia) and unconformity-type (37 in Australia).

TABLE 2.6. URANIUM DEPOSITS BY TYPE [2.24]
(as of September 2019)

Deposit type	Australia	China	Indonesia	Japan	Korea, Republic of	Mongolia
Unconfor-mity	37	0	0	0	0	0
Sand-stone	49	41	0	2	0	10
Haema-tite breccia com-plex	13	0	0	0	0	0
Volcanic	8	32	0	0	0	20
Intru-sive	6	5	0	0	0	0
Vein	4	55	3	0	0	0
Metaso-matite	22	2	0	0	0	0
Black Shales	0	4	0	0	8	0
Carbonate	0	3	0	0	0	0
Lignite-coal	0	4	0	0	0	1
Phosphate	0	0	0	0	0	0
Surficial	26	0	2	0	0	0
Total	165	146	5	2	8	31

(cont.)

Deposit type	New Zealand	Philippines	Thailand	Vietnam	Total
Unconformity	0	0	0	0	37
Sandstone	0	0	1	6	109
Haematite breccia complex	0	0	0	0	13
Volcanic	0	0	0	0	60
Intrusive	0	0	0	0	11
Vein	0	1	2	0	65
Metasomatite	0	0	0	1	25
Black Shale	0	0	0	0	12
Carbonate	0	0	0	1	4
Lignite-coal	0	0	0	2	7
Phosphate	1	0	0	1	2
Surficial	0	0	8	0	36
Total	1	1	11	11	381

2.2.5. Deposit types in Middle East, Central and Southern Asia

As of September 2019, UDEPO reported 296 identified uranium deposits occurring in 14 countries in the Middle East, Central and Southern Asia [2.24]. To date, the most important uranium deposit type identified in the area is the sandstone hosted type (104 deposits, 35.1%), mainly located in Kazakhstan and Uzbekistan. Vein (granite and metamorphite-related) in India and Kazakhstan, volcanic-related in Kazakhstan, types of uranium mineralization, have also been reported (Tables 2.7 and 2.8).

TABLE 2.7. URANIUM DEPOSITS BY TYPE (UDEPO [2.24])
(as of September 2019)

Deposit type	Afghanistan	India	Iran	Iraq	Israel	Jordan	Kazakhstan	Kyrgyzstan
Unconformity	0	4	0	0	0	0	0	0
Sandstone	0	9	0	0	0	0	43	1
Quartz pebble conglomerate	0	1	0	0	0	0	0	0
Volcanic	0	0	0	0	0	0	19	0
Intrusive	1	0	0	0	0	0	0	1
Vein	0	27	1	0	0	0	37	2
Metasomatite	0	4	1	0	0	0	3	0
Black Shales	0	0	0	0	0	0	0	3
Carbonate	0	2	0	1	0	0	0	9
Lignite-coal	0	0	0	0	0	0	2	7
Phosphate	0	0	0	7	1	4	6	0
Surficial	0	0	3	0	0	3	0	4
Total	1	47	5	8	1	7	110	27

(cont.)

Deposit type	Pakistan	Saudi Arabia	Syrian Arab Republic	Tajikistan	Turkmenistan	Uzbekistan	Total
Unconformity	0	0	0	0	0	0	4
Sandstone	7	0	0	0	3	41	104
Quartz pebble conglomerate	0	0	0	0	0	0	1
Volcanic	0	0	0	0	0	6	25
Intrusive	1	2	0	0	0	0	5
Vein	0	0	0	3	0	1	71
Metasomatite	0	0	0	0	0	0	8
Black Shale	0	0	0	0	1	19	23
Carbonate	0	0	0	0	0	0	12
Lignite-coal	0	0	0	0	0	0	9
Phosphate	0	3	3	0	0	0	24
Surficial	0	0	0	0	0	0	10
Total	8	5	3	3	4	67	296

TABLE 2.8. URANIUM DEPOSIT TYPES (UDEPO [2.24])

Deposit type	Morphology	Country	Deposits
Sandstone	Roll front	Kazakhstan	Inkaï, Kanzhugan, Moynkum
		Uzbekistan	Bukinai, Sugraly, Uchkuduk
	Tabular	India	Domiasat
Vein	Metamorphite	Kazakhstan	Vostok, Zvezdnoye
		India	Jaduiguda, Narwapahar
Metasomatite	Na-metasomatite	India	Rohil
		Iran	Saghand
Unconformity	Stratiform structurally-controlled	India	Lambapur, Peddagattu
Black shales		Uzbekistan	Djantuar, Rudnoye
Carbonate		India	Tummallapalle
Phosphorite		Jordan	Al Shedaye

2.2.6. Deposit types in North, Central and South America

As of September 2019, UDEPO [2.24] reported 1301 identified uranium deposits in 12 countries in North, Central and South America (Table 2.9). Of these, 1110 deposits (85.3%) are in Canada and the USA. This high percentage reflects the very large area of the two countries, the very large number of small sandstone-type deposits reported in the USA, as well as the large amount of exploration conducted, together with the favourable geological host environments and the success of exploration programmes.

In Canada, there are an unusually high number of unconformity-related type deposits (76). These represent 62.8% of the world total of unconformity type deposits. Intrusive, vein-type and quartz-pebble conglomerate deposits have also been reported in Canada. In contrast, 799 (89.5%) of the US deposits are of the sandstone-hosted roll front type. Consequently, both unconformity and quartz-pebble conglomerate type deposits constitute the primary source of uranium production in Canada whereas sandstone-hosted type deposits have dominated production in the USA.

TABLE 2.9. DEPOSIT TYPES
(as of September 2019)

Deposit type	Argentina	Bolivia	Brazil	Canada	Chile	Colombia	Guyana
Unconformity	0	0	0	76	0	0	0
Sandstone	19	0	3	11	5	1	0
Haematite breccia complex	0	0	5	0	2	0	0
Quartz pebble conglomerate	0	0	3	25	0	0	0
Volcanic	13	1	0	1	1	0	0
Intrusive	2	0	5	43	3	0	0
Vein	10	0	3	33	0	1	0
Metasomatite	0	0	11	19	6	0	4
Black Shale	0	0	0	3	0	0	0
Carbonate	2	0	0	0	0	0	0
Collapse Breccia Pipe	0	0	0	0	0	0	0
Lignite-coal	0	0	0	0	0	0	0
Phosphate	0	0	1	0	2	4	0
Surficial	5	0	0	6	8	0	0
Total	51	1	31	217	27	6	4

(cont.)

Deposit type	Mexico	Paraguay	Peru	USA	Venezuela	Total for all the North, Central and South American countries
Unconformity	0	0	0	0	0	76
Sandstone	12	1	0	799	0	851
Haematite breccia complex	0	0	0	0	0	7
Quartz pebble conglomerate	0	0	0	0	0	28
Volcanic	26	0	17	16	0	75
Intrusive	0	0	0	6	0	59
Vein	4	0	0	16	0	67
Metasomatite	0	0	0	0	0	40
Black Shale	0	0	0	1	0	4
Carbonate	2	0	1	17	0	22
Collapse Breccia Pipe	0	0	0	20	0	20
Lignite-coal	0	0	0	9	0	9
Phosphate	5	0	1	6	2	21
Surficial	0	0	0	3	0	22
Total	49	1	19	893	2	1301

2.3. WORLD OVERVIEW OF EXPLORATION

World domestic uranium exploration expenditures reported to the 2018 Red Book [2.25] were US $ 877 876 000 and US $ 663 678 000 for 2015 and 2016, respectively (Table 2.10). Information on exploration expenditures is some of the most incomplete and unreliable of data for uranium activities. In several areas with no officially reported expenditures, active exploration programmes are documented. In many cases, the reports discuss exploration without providing the cost of such activities. However, the data on exploration expenditures do provide some indication of the relative amount of exploration, particularly for those areas that regularly report such information.

TABLE 2.10. WORLD DOMESTIC URANIUM EXPLORATION AND DEVELOPMENT EXPENDITURE BY REGION (US $1000) [2.25]
(as of 1 January 2017)

Region	2016	Proportion (%)	2017	Proportion (%)
Africa	15 900	1.81	8 640	1.30
Central, Eastern and South-eastern Europe	25 745	2.93	12 025	1.81
South-eastern Asia, Pacific, East Asia	196 555	22.39	165 782	24.98
Western Europe	9 106	1.04	5 702	0.86
North, Central and South America	509 805	58.07	375 232	56.54
Middle East, Central and Southern Asia	120 765	13.76	96 297	14.51
Total	877 876	100.0	663 678	100.0

Of note is the very low level of exploration and development being conducted in Western Europe, a region whose countries do regularly report to the Red Book. The region accounts for less than 1% of the world's total exploration expenditure. In contrast, high levels of exploration and development have been reported in Central Asia (Kazakhstan), East Asia and Pacific (Australia and China) and North America (Canada and the United States of America). Other areas with reported high expenditure levels are India, Iran and the Russian Federation.

Non-domestic uranium exploration and development expenditures have been reported by 10 countries (Table 2.11). Six of the 10 are Western European countries, each of which has relied, at least in part, on uranium imports to fuel their nuclear power programmes. Belgium, Germany, Spain and the United Kingdom have not reported expenditures in this category for over a decade. Switzerland reported only minor expenditures up until 2001 and has not reported any since. Beginning in 2007 and 2008, respectively, China and the Russian Federation reported large governmental non-domestic expenditures, indicating their high level of interest in obtaining uranium from non-domestic sources.

The only other countries with reported large, continually ongoing, non-domestic exploration and development expenditures are Canada and France. The Canadian expenditures are all non-governmental and were made by the very large number of Canadian based companies with international uranium exploration and development activities. It should be noted that Australia, Canada and the USA do not report non-domestic exploration expenditures, when information is indicated as not being available.

TABLE 2.11. NON-DOMESTIC URANIUM EXPLORATION AND DEVELOPMENT EXPENDITURES FOR SELECTED COUNTRIES (US $1000) [2.25]

Country	Pre-2010	2010	2011	2012	2013	2014	2015	2016	Total to 2016
Australia	n.a.[a]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Belgium	4 500	0	0	0	0	0	0	0	4500
Canada	355 644	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	355 644
China[b]	573 020	94 950	94 740	81 690	599 100	762 980	526 310	378 010	3 110 800
France	1 244 328	61 652	68 670	68 320	71 710	27 600	34 866	30 736	1 607 882
Germany	403 158	0	0	0	0	0	0	0	403 158
Japan[c]	428 490	3 020	3 030	5 371	3 512	5 465	3 922	5 089	457 899
Korea, Republic of	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Russian Federation	n.a.	26 300	31 100	30 100	18 200	4 900	17 100	6 100	133 800
Spain	20 400	0	0	0	0	0	0	0	20 400
Switzerland	29 679	0	0	0	0	0	0	0	29 679
United Kingdom	61 263	0	0	0	0	0	0	0	61 263
USA	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total	3 120 482	185 922	197 540	185 481	692 522	800 945	582 198	419 935	6 185 025

Note: Domestic exploration and development expenses equal total expenses from domestic and foreign sources per country. Expenses overseas are thus a subset of domestic expenses.
[a] n.a.: not available.
[b] Industry expenditures for 2014, 2015 and 2016 only.
[c] Government expenditures only.

2.3.1. Exploration in Africa

The individual reports for 52 African countries in this volume summarize and outline the history of uranium exploration in each country. For countries where more recent exploration has taken place, a recapitulation of reported activities, expenditure and results is given. In order to emphasize the importance of Africa's resources, the following are a few of the highlights from the past few years.

In 2008, six countries worldwide represented 90% of total reported expenditure for world domestic exploration and development. Niger was one of these. Niger focused on resource development in and around the western Arlit area as well as on the evaluation of other deposits under development in this area. A programme of intensive drilling continued in 2009.

Botswana also reported exploration expenditure in 2008 and regulations were introduced with regard to uranium mining and milling.

As regards Namibia, major drilling programmes in support of proposed expansions to the Rössing and Langer Heinrich mines, development of the Trekkopje mine and evaluation of other deposits with a view to possible mine development were reported. Details were provided by the Government of Namibia for Rössing only.

In Malawi, infill drilling was conducted in 2008 on the Kayelekera project and open pit mining began in April 2009.

Eight companies were recorded as actively exploring and developing mine deposits in South Africa. Opportunities for the production of by-product uranium include the Witwatersrand gold reef deposits and recovery from tailings.

In Tanzania, 70 new licences were issued by 2008, primarily to companies interested in uranium exploration and investigations of Karoo age sediments.

During 2007–2008, exploration activities also took place in the Central African Republic, the Democratic Republic of the Congo, Gabon, Guinea, Madagascar, Malawi, Mali, Mauritania, Mozambique and Zambia.

In 2009-2010, exploration activities in Botswana focused on uranium occurrences in the Karoo sandstone formations. Calcrete-type mineralization was a secondary target. In 2011, a JORC compliant indicated and inferred resources, totaling just over 100 000 tU was reported, most of it associated to the Letlhakane deposit.

In Mauritania, exploration started on the Reguibat Craton. Several deposits were defined, in the Bir en Nar and A238 areas, associated to granites. The Reguibat project contains calcrete uranium mineralization.

In Namibia, exploration companies were very active after 2008, which led to the discovery of additional resources, in particular the Husab deposit south of Rossing. Resources reported at Husab, as of August 2014, amounted to 82 883 tU.

In Niger, uranium exploration was revitalized in 2006. New deposits were discovered around Madaouela and in the Dasa area. In November 2017, NI 43-101 compliant resources of Madaouela deposits amounted to 42 615 tU of measured and indicated resources and 10 654 tU of inferred resources. In 2017, indicated and inferred resources at Dasa totaled 41 580 tU. In addition to Dasa, two other deposits, Dajy and Isakanan, were discovered, containing a total of 19 400 tU.

In Tanzania, several companies conducted uranium exploration, mainly on occurrences related to the Karoo sandstones. This works led to the discovery of several deposits, including the Mkuju deposit. In 2013, Mkuju in-situ resources amounted to 58 489 tU. The Mkuju feasibility study was completed in 2013.

TABLE 2.12. DOMESTIC EXPLORATION EXPENDITURES IN AFRICA (US $1000) [2.25]

Country	2015	2016
Mali	774	387
Namibia	9 962	8 253
South africa	5 164	n.a.
Total	15 900	8 640

2.3.2. Exploration in Western Europe

The individual country reports for the 22 countries in the Western European area provide information, where available, on the history of, and current exploration activities for each country. Exploration activities were reported in the 2008-2009 period from Greenland, Finland, Portugal, Spain and Sweden. With only two of the 14 countries reporting expenditures, domestic exploration expenditures totals USD

5.41 and USD 7.02 million, respectively in 2007 and 2008 [2.5]. This was equivalent to only 0.4% of the world total expenditures in both 2007 and 2008. Finland reported (USD 1.51 and USD 2.42 million) and Spain (USD 3.9 and USD 4.6 million), both respectively in 2007 and 2008.

Six Western European countries (Belgium, France, Germany, Spain, Switzerland and the United Kingdom) have historically reported non-domestic exploration and development expenditures (Table 2.12). Their combined expenditures made pre-2002 equalled USD 1 241.607 million, or 63% of all reported non-domestic expenditures. While making no domestic exploration expenditures, France continued major non-domestic expenditures totalling USD 444.349 million from 2002-2008 and averaging USD 63.5 million/year. In 2007 and 2008 French exploration and development activities were reported in Australia, Canada, the Central African Republic, Finland, Kazakhstan, Mongolia, Niger and South Africa. . Furthermore, on June 15, 2007, the French company AREVA agreed to pay over USD 2.5 billion to acquire the 94.5 % of the company UraMin Inc. it did not already own (AREVA Press Release: http://www.AREVA.com/EN/news-6505/AREVA-announces-us-7-75-per-share-friendly-cash-offer-for-uramin.html). The principal assets of UraMin Inc. were the Trekkopje deposit, Namibia, the Bakouma deposit, Central African Republic, and the Ryst Kuil project in South Africa.

In 2007 and 2008, several foreign companies expressed an interest in obtaining mineral rights for the Nisa area in Portugal. In Spain, Berkeley Resources through its Spanish filial Minera de Rio Alagón S.L (MRA, has been actively investigating a total of 11 exploration licences spanning 45 214 hectares. By reassessing historic data and conducting reverse circulation and diamond drilling programs, it developed a JORC complaint resource base of 10 385 tU distributed in four deposits [2.5].

In February 2008 Continental Precious Minerals Inc. reported NI 43-101 compliant Indicated Resources of 2 208 tU at 0.016 % U, and Inferred Resources of 168 095 tU at 0.014 %U in the Alum Shale at its Viken MMS License, Sweden [2.26].

Main exploration activities in Western Europe after 2009 were limited to Greenland and Spain.

In Greenland, following a renewal interest in REE, exploration activities focused on the Kvanefjeld deposit, where a JORC compliant resources was released in 2013, with 221 170 tU of inferred resources, associated to REE, yttrium and zinc

In Spain, exploration activities were conducted in the Salamanca and Caceres provinces., in the areas of historically known uranium projects. In the Salamanca province, projects include Zona 7 and Retortillo deposits, in the Caceres province, the Gambuta deposit. Total resources account for 23 000 tU in the measured and indicated categories, 11 350 tU in the inferred category. In 2015 and 2016, exploration expenditures amounted to US$ 9 106 000 and US$ 5 702 000 respectively.

2.3.3. Exploration in Central, Eastern and South-eastern Europe

The individual country reports for the 25 countries comprising the Central, Eastern and South-eastern Europe area provide information, where available, on historic and current exploration activities. Exploration expenditures were reported in the 2008–2009 period by the Czech Republic, Hungary, the Russian Federation, Turkey and Ukraine (Table 2..13). Only five of the 25 countries reported expenditures. Domestic exploration expenditure totalled US $70.973 million and US $229.762 million for 2007 and 2008, respectively [2.23]. This was equivalent to 5.3% of the 2007 and 14% of the 2008 world total reported expenditures. The Russian Federation accounted for 90% and 96%, respectively, of the totals for 2007 and 2008.

In addition to domestic exploration expenditures, the Government of the Russian Federation reported, for the first time, expenditure of US $49 724 000 on non-domestic exploration in 2008. Information on non-domestic expenditures by the Russian Federation was not made available for the years prior to 2008. A significant proportion of the expenditure was for exploration drilling of the in situ leach amenable Budennovskoye deposit, Kazakhstan, as part of the Akbastau Joint Venture with Kazatomprom. No other country in the Central, Eastern and South-eastern Europe region reported non-domestic exploration expenditures prior to or for 2008.

Russia continued uranium exploration activities, aiming of new deposit discoveries (Buryata, Trans-Baikal and Irkutsk regions), development of earlier discovered deposits and expansion of the resource base near existing production centres (Khiagna, Priargunsky).

In Turkey, activities focused in Yozgat province, with resource evaluation drilling. In 2011, a JORC compliant estimate amounting 6693 tU of indicated and inferred resources was released at Temrezli deposit.

TABLE 2.13. DOMESTIC EXPLORATION EXPENDITURES IN CENTRAL, EASTERN AND SOUTH-EASTERN EUROPE (US $1000) [2.25]

Country	2015	2016
Czech Republic	633	514
Russia	17 581	10 804
Turkey	6 842	223
Ukraine	689	484
Total	25 745	12 025

2.3.4. Exploration in South-eastern Asia, Pacific and East Asia

The 18 individual country reports provide information, where available, on the history of exploration and current exploration activities in each country. Exploration expenditures are reported for Australia, China, Indonesia and Mongolia in 2007 and 2008, and prior to 2008 for the Republic of Korea and Japan (Table 2.14). The countries that report resources include these same countries plus Viet Nam.

China and Japan also reported non-domestic exploration and development expenditures in 2008.

In Australia, exploration activities continued to be developed around known resources in Northern Territory (Alligator Rivers region, for unconformity related deposits), Queensland (Mount Isa region for metasomatite type deposits), South Australia (Gawler Craton/Stuart Shelf region for hematite breccia complex deposits and Frome Embayment for sandstone-type deposits) and Western Australia (Cenozoic paleochannels sands for calcrete deposits). Additional resources have been outlined at Olympic Dam (SA), Carrapateena (SA), Pepegoona (SA), Princess (WA), Yadglin (SA) deposits.

Exploration in China included uranium resources assessment of previously discovered mineralisation. Exploration activities were conducted in northern China, including the Turpan, Yli, Junggar and Tarim basins in the Xinjiang region, the Erdos, Erlian, Badanjili and Bayingebi basins in Inner Mongolia, and the Jiuquan basin in the Gansun province. Exploration in Southern China was mainly directed in identifying mineralization related to volcanic- and granite type deposits.

Recent exploration activities in Mongolia were mainly performed in South Mongolian basins, with the objective of discovering sandstone-type uranium mineralization amenable to ISL mining.

TABLE 2.14. DOMESTIC EXPLORATION EXPENDITURES IN SOUTH-EASTER ASIA, PACIFIC AND EAST ASIA (US $1000) [2.25]

Country	2015	2016
Australia	33 665	29 194
China	152 000	128 000
Indonesia	464	194
Mongolia	7 816	6 600
Vietnam	2 610	1 794
Total	196 555	165 782

2.3.5. Exploration in Middle East, Central and Southern Asia

The individual country reports for the Southern and Central Asia, and Middle East region summarize the history of uranium exploration and production in each country [2.23]. For countries where recent exploration has taken place, the following are a few of the highlights of the past few years. In 2005–2006, a very substantial growth in exploration and development was witnessed, driven by increases in the spot price of uranium. Active programmes have been undertaken in many provinces in India, concentrating on Proterozoic basins, Cretaceous sandstones and other favourable geological settings. Activities in Iran involved exploration and evaluation of uranium resources related with Precambrian metasomatic and magmatic complexes. Uranium occurrences associated to the Gachin salt plug were also investigated. In Jordan, the Jordan Atomic Energy Commission was created in 2008 to promote exploration and exploitation of uranium and other nuclear materials. In Kazakhstan, exploration was conducted in the Chu-Sarysu and Syr-Darya Provinces, where several in situ leach test sites were finalized and mining tests started. Works were also conducted in north Kazakhstan in order to define potential resources related to unconformity and vein stockwork deposits. In Uzbekistan, exploration continued in order to increase uranium production. In 2007–2008, exploration expenditures in the Southern and Central Asia, and Middle East region totalled US $305.8 million, 7% of total world expenditure for the period (Table 2.15).

Exploration activities in India have been concentrated on discovery and resources evaluation of unconformity-related deposits (Cuddappah basin, Rajashtan), carbonatite-type deposits (Tummalapalle), fracture-controlled uranium mineralization (Cuddappah basin, Dehli basin), metasomatite type (Rajashtan) and sandstone-type deposits (Satpura Gondwana basin).

In recent years, exploration activities in Kazakhstan have been related with the development of already discovered deposits, amenable to ISL, in the Shu-Sarysu and Syr-Daria provinces. Geological exploration of sandstone-type deposits is also conducted in the Shu-Sarysu province.

Exploration activities in Uzbekistan are related with the development of already discovered deposits, amenable to ISL, in the Kizylkum province. Exploration is also conducted on the black shale deposits in the Boztau area, in Central Kizylkum, in order to develop these deposits.

TABLE 2.15. DOMESTIC EXPLORATION EXPENDITURES IN MIDDLE EAST, CENTRAL AND SOUTHERN ASIA (US $1000) [2.25]

Country	2015	2016
India	49 858	52 156
Iran	6 276	17 320
Jordan	3 697	2 886
Kazakhstan	60 934	23 935
Total	120 765	96 297

2.3.6. Exploration in North, Central and South America

Individual country reports for the 27 countries comprising North, Central and South America provide information, where available, on the exploration history of, and current exploration activities in, each country. Expenditures for exploration were officially documented in the Red Book in 2008–2009 by only six countries (Argentina, Brazil, Canada, Chile, Colombia and the USA) [2.23]. Historically, 16 of the 27 countries in the region have reported exploration expenditures. Domestic exploration expenditures totalled US $784.962 million and US $760.582 million for 2007 and 2008, respectively [2.23]. These figures represented 59.1% and 46.3% of world total expenditures reported for 2007 and 2008, respectively. Canada reported expenditures of US $532.710 million and US $514.751 million and the USA reported US $245.700 million and US $246.400 million in 2007 and 2008, respectively.

In Argentina, U3O8 Corporation, a Canadian based company, has been working on at least three projects, including Laguna Salada where mineralization has been identified within a metre of the surface in unconsolidated gravels. There was insufficient information up to 2010 to define the resource but evaluation work is ongoing [2.27].

AREVA NC, a French public company, has evaluated its options concerning resources of uranium in southern Argentina and has cooperated with different owners, including Urex Energy Corporation, in supporting a potential central processing facility. The concept envisaged that the mining of a number of satellite orebodies of uranium, owned by various parties, would make available uranium ore feedstock to the central milling facility [2.27].

In Brazil, the domestic fertilizer company Grupo Galvani announced, in July 2009, it was to sign a 25-year contract with INB to develop a uranium and phosphate mine. The contract was worth US $420 million and mining would occur at Itataia, near Santa Quitéria, in Ceará State. The mine would increase Brazil's uranium concentrate production fourfold and its phosphate output by 10%. Drilling and other activities for development in the Lagoa Real province were scheduled for 2009, to establish the size of the Cachoeira and Engenho deposits.

In 2007, there was renewed interest in south-eastern Paraguay, in the western portion of the Paraná Basin. There is potential here for sandstone-hosted roll front type deposits which may be amenable to in situ recovery. Cue Resources Ltd (Canada) investigated this type of deposit in 2008 and filed an updated NI 43-101 technical report for the Yuty uranium project in south-eastern Paraguay, including a significant increase to a historical resource estimate, in 2009 [2.28].

In 2009 and 2010, efforts for exploration in Canada continued to concentrate on promising areas for deposits related with Proterozoic unconformities in the Athabasca Basin, Saskatchewan and, to a lesser extent, in similar geological settings in the Northwest Territories and Nunavut province, in the Thelon Basin. Exploration for uranium was also undertaken in the Otish Basin of Quebec, where Strateco

Resources Inc. has submitted an application for a permit to carry out underground exploration on the Matoush deposit [2.29].

The meteoric increase in the uranium market price after 2003 generated significantly renewed interest in exploration in the USA. This led to expanded exploration for all types of uranium deposit already known to occur in the USA in previously untested areas. Exploration was conducted for deposit types that had not been sought in years, including volcanic targets in the McDermitt Caldera, Nevada, and in Oregon, for example, as well as deposits to be mined conventionally, such as those in the Gas Hills, Wyoming, and in the Grants Mineral Belt, New Mexico. Exploration for breccia pipe targets was also resumed in northern Arizona. The level of exploration decreased significantly with the fall in uranium market prices.

Starting in 2007, there has been an increase in the exploration activities in Argentina, as a consequence of the reactivation of the nuclear programme. Exploration/evaluation works on the Cerro Solo deposit (Chubat province) have been undertaken. Other areas under study are the Sierra Pintada deposits (Chubat province), Laguna Sirven (Santa Cruz province), Urcal, Urcusshun (Rioja Province).

In 2009-2010, exploration activities in Brazil were limited to geological mapping of new targets in the Caetite province. Since 2011, activities focus on albitic formations in the north part of the Lagoa Real province, including geophysical surveys and exploration drillings.

Since 2009, exploration activities in Canada continued to focus on areas favourable for the occurrence of deposits associated with Proterozoic unconformities in the Athabasca Basin of Saskatchewan, and to a lesser extent, similar geologic settings in the Thelon Basin of Nunavut and the Northwest Territories. Surface drilling, geophysical surveys and geochemical surveys continued to be the main tools used to identify new uranium occurrences, define extensions of known mineralised zones and to reassess deposits. In 2009-2011, new uranium discoveries in the Athabasca Basin included Centennial, Shea Creek, Wheeler River, Midwest A and Roughrider deposits.

Drilling conducted on the Triple R deposit in 2013 and 2014 outlined a significant uranium resource which is currently one the largest uranium deposit in the Athabasca Basin.

In 2015-2016, new uranium discoveries in the Athabasca Basin included Phoenix/Gryphon, Arrow and Fox Lake deposits.

In the United States, the decrease in uranium price from 2008 to 2009 lead to a decrease in exploration drilling and in exploration expenditures. In 2009 and 2010, the US government made no exploration and mine development expenditures for uranium. Exploration by private companies continued in the main uranium districts including the Tertiary basins of Wyoming and Nebraska, the Colorado Plateau, Texas and New Mexico. Exploration activities continued to focus on areas favourable for the occurrence of sandstone-type deposits, amenable to ISL mining.

Private industry expenditures for exploration and mine development activities increased in 2011 and 2012, due to generally strong uranium and vanadium prices. Exploration has been for sandstone-type uranium deposits. Most exploration occurred on deposits that were identified in the 1970s and earlier, or on extensions of operating mines.

In 2015, the USGS started a significant assessment of the country's undiscovered resources.

Recent regional exploration expenditures are shown in Table 2.16.

TABLE 2.16. DOMESTIC EXPLORATION EXPENDITURES IN NORTH, CENTRAL AND SOUTH AMERICA (US $1000) [2.25]

Country	2015	2016
Argentina	5 880	3 968
Brazil	224	1 348
Canada	397 249	296 779
Mexico	1 452	1 237
United States	105 000	71 900
Total	509 805	375 232

2.4. WORLD OVERVIEW OF DEPOSIT STATUS

As of 1 January 2009, UDEPO reported 35 countries with one or more deposits under exploration [2.24]. Twenty three of the 35 countries with UDEPO exploration listed projects reported exploration expenditures in 2007-2008 to the 2009 Red Book [2.22]. It is noted that while the deposit type classification changes only rarely, the operational status of deposits may change frequently. Consequently, Table 2.17 provides only a general overview of operational status at any one time.

Since January 2009, UDEPO has been constantly updated, and as of September 2017, the database includes over 3000 deposits. But, as the updates include the geological type of deposit, the uranium resources, the average grade, the deposit status has not always been updated or included for the new deposits. Therefore, information on deposit status in the following paragraphs will only refer to deposits reported to UDEPO as of 1 January 2009.

TABLE 2.17. WORLD DEPOSIT OPERATIONAL STATUS BY REGION [2.24]
(as of 1 January 2009)

Region	Dor-mant	Feasi-bility	Explo-ration	Develop ment	Opera-ting	Stand-by	Closed	De-pleted	Recla-mation	Un-known	Total
Africa	44	1	42	13	11	0	2	15	0	8	136
Central, Eastern and South-eastern Europe	81	0	19	12	17	0	16	44	0	8	197
South-eastern Asia, Pacific, East Asia	54	2	31	3	8	0	0	14	0	0	112
Western Europe	34	0	9	1	0	0	3	53	1	7	108
North, Central and South America	150	6	40	10	10	1	18	82	1	22	340
Middle East, Central and Southern Asia	57	0	11	7	29	1	0	25	0	2	132
Total	420	9	152	46	75	2	39	233	2	47	1025
Proportion of total (%)	41	1	15	4	7	0	4	23	0	5	100

2.4.1. Deposit status in Africa

Of the 142 total UDEPO identified deposits, their operational status as of September 2019 was (Table 2.18): Dormant-43; Feasibility-1; Operating 11; Exploration-49; Development-13; Closed-2; Depleted-15; and Unknown-8.

TABLE 2.18. AFRICA OPERATIONAL STATUS OF 142 DEPOSITS [2.24]
(as of September 2019)

Country	Dormant	Feasi-bility	Explora-tion	Develop-ment	Opera-ting	Stand-by	Closed	Deple-ted	Recla-mation	Un-known	Total
Algeria	5	0	0	0	0	0	0	0	0	0	5
Botswana	0	0	2	0	0	0	0	0	0	0	2
Cameroon	0	0	1	0	0	0	0	0	0	0	1
Central African Republic	0	0	0	1	0	0	0	0	0	0	1
D. R. of Congo	5	0	0	0	0	0	0	3	0	0	8
Gabon	1	0	8	0	0	0	0	8	0	0	17
Madagascar	2	0	1	0	0	0	0	0	0	0	3
Malawi	0	0	1	1	0	0	0	0	0	0	2
Mali	0	0	1	0	0	0	0	0	0	0	1
Mauritania	0	0	1	0	0	0	0	0	0	0	1
Morocco	4	0	0	0	0	0	0	0	0	0	4
Namibia	4	0	15	2	2	0	0	0	0	1	24
Niger	7	0	8	5	4	0	0	4	0	0	28
Senegal	0	0	1	0	0	0	0	0	0	0	1
Somalia	3	0	0	0	0	0	0	0	0	0	3
South Africa	10	0	2	4	5	0	2	0	0	7	30
Tanzania	0	0	3	0	0	0	0	0	0	0	3
Zambia	0	1	5	0	0	0	0	0	0	0	6
Zimbabwe	2	0	0	0	0	0	0	0	0	0	2
Total	43	1	49	13	11	0	2	15	0	8	142

2.4.2. Deposit status in Western Europe

Of the 97 total UDEPO identified deposits [2.24], their operational status as of September 2019 was (Table 2.19): Dormant-29; Exploration-9; Development-1; Closed-3; Depleted-47; Under reclamation-1; and Unknown-7. The data reflects the 47 depleted projects from which the 295 499 tU (96.8%) of Western Europe's historic production was produced in Germany (71.9%) and France (24.8%). There were no projects operating and only 1 undergoing development.

TABLE 2.19. WESTERN EUROPE OPERATIONAL STATUS OF 97 DEPOSITS [2.24]
(as of September 2019)

Country	Dormant	Feasibility	Exploration	Development	Operating	Standby	Closed	Depleted	Reclamation	Unknown	Total
Denmark	0	0	1	0	0	0	0	0	0	0	1
Finland	4	0	1	1	0	0	0	0	1	0	7
France	5	0	0	0	0	0	0	38	0	0	43
Germany	4	0	0	0	0	0	3	8	0	1	16
Italy	2	0	0	0	0	0	0	0	0	0	2
Spain	5	0	5	0	0	0	0	2	0	6	17
Sweden	9	0	2	0	0	0	0	0	0	0	11
Total	29	0	9	1	0	0	3	47	1	7	97

2.4.3. Deposit status in Central, Eastern and South-eastern Europe

Of the 197 UDEPO listed deposits, their operational status, as of September 2019, was as follows: operating — 17; dormant — 81; exploration — 19; development — 12; closed — 16; depleted — 44 and unknown — 8 (Table 2.20).

TABLE 2.20. CENTRAL, EASTERN AND SOUTH-EASTERN EUROPE OPERATIONAL STATUS OF DEPOSITS [2.24]
(as of September 2019)

Country	Dormant	Feasibility	Explora-tion	Develop-ment	Operating	Standby	Closed	Depleted	Recla-mation	Unknown	Total
Bulgaria	3	0	1	0	0	0	10	15	0	0	29
Czech Republic	5	0	0	0	2	0	0	16	0	0	23
Hungary	0	0	0	0	0	0	1	0	0	0	1
Poland	7	0	0	0	0	0	0	0	0	0	7
Romania	8	0	1	0	3	0	5	2	0	0	19
Russian Federation	37	0	15	12	9	0	0	7	0	0	80
Serbia	0	0	0	0	0	0	0	0	0	7	7
Slovakia	0	0	2	0	0	0	0	0	0	0	2
Slovenia	1	0	0	0	0	0	0	0	0	1	2
Turkey	5	0	0	0	0	0	0	0	0	0	5
Ukraine	15	0	0	0	3	0	0	4	0	0	22
Total	81	0	19	12	17	0	16	44	0	8	197

Uranium production in Central, Eastern and South-eastern Europe in 2008 was 4708 tU or 10.7% of world production. About 98% of total regional production in both 2007 and 2008 originated from three countries: the Russian Federation, Ukraine and the Czech Republic. Historically, through 2008, the region produced 431 499 tU, equal to 17.9% of historic world production, with 86.8% of this total produced by the Russian Federation, Ukraine and the Czech Republic. Future uranium production in the region is expected to come primarily from the Russian Federation and Ukraine. Both countries have large domestic nuclear electric programmes. In addition, the Russian Federation is a major commercial producer of uranium fuel for nuclear plants worldwide. Most of these plants are of Russian design and were, or are, built under contract by Russian firms.

2.4.4. Deposit status in South-eastern Asia, Pacific, East Asia

For Australia, UDEPO [2.24] reported 19 exploration projects, 3 projects in development, 3 operational, 7 depleted and 39 dormant projects. China had 10 exploration projects (as of 2009), 5 operating, 7 depleted and 3 dormant deposits. There were 2 exploration projects each in Mongolia and Viet Nam. Dormant projects are also listed for Indonesia (3), Japan (2), Republic of Korea (1) and Mongolia (14).

2.4.5. Deposit status in the Middle East, Central and Southern Asia

The operational status of the 127 total UDEPO identified deposits in the Southern and Central Asia, and Middle East region, as of September 2019, was: dormant (52), exploration (11), development (7), operating (29), standby (1), depleted (25), unknown (2) (Table 2.21) [2.24].

Most of the operating deposits in Kazakhstan and all of those in Uzbekistan are using in situ leach mining to extract uranium.

TABLE 2.21. OPERATIONAL STATUS (UDEPO [2.24])
(as of September 2019)

Country	Dormant	Feasi-bility	Explora-tion	Develop-ment	Opera-ting	Standby	Closed	Depleted	Reclama-tion	Un-known	Total
India	0	0	6	0	5	0	0	0	0	0	11
Iran	0	0	0	1	0	0	0	0	0	0	1
Kazakhstan	39	0	1	5	8	1	0	12	0	1	67
Kyrgyzstan	0	0	3	0	0	0	0	4	0	0	7
Pakistan	0	0	0	1	0	0	0	1	0	0	2
Tajikistan	0	0	0	0	0	0	0	2	0	0	2
Turkmenistan	1	0	0	0	0	0	0	1	0	0	2
Uzbekistan	12	0	0	0	16	0	0	5	0	1	34
Total	52	0	11	7	29	1	0	25	0	2	127

2.4.6. Deposit status in North, Central and South America

The operational status of the 339 UDEPO identified deposits (Table 2.22), as of September 2019, is discussed in the following sections [2.24]. These data reflect the 82 projects that have been depleted and from which much of the 795 710 tU of North, Central and South America region’s historical production was generated. As of September 2019, there were 10 projects operational, 10 under development, 6 undergoing feasibility assessment and 40 being explored.

TABLE 2.22. OPERATIONAL STATUS (UDEPO [2.24])
(as of September 2019)

Country	Dormant	Feasi-bility	Explora-tion	Develop-ment	Opera-tional	Stand-by	Closed	Depleted	Reclama-tion	Un-known	Total
Argentina	5	0	0	0	0	0	0	2	0	0	7
Bolivia	1	0	0	0	0	0	0	0	0	0	1
Brazil	4	1	0	1	1	0	1	0	1	1	10
Canada	38	5	25	2	2	0	10	25	0	12	119
Chile	0	0	0	0	0	0	0	0	0	4	4
Colombia	0	0	1	0	0	0	0	0	0	0	1
Guyana	0	0	1	0	0	0	0	0	0	0	1
Mexico	8	0	0	0	0	0	0	0	0	0	8
Paraguay	0	0	1	0	0	0	0	0	0	0	1
Peru	3	0	2	0	0	0	0	0	0	0	5
USA	91	0	10	7	7	0	7	55	0	5	182
Total	150	6	40	10	10	0	18	82	1	22	339

2.5. WORLD OVERVIEW OF URANIUM RESOURCES

The following tables summarize, by region, identified and undiscovered uranium resources (Figs 2.12 and 2.13 and Tables 2.23 and 2.24)

As of 1 January 2017, reasonably assured resources (RAR), recoverable at <US $260/kg U amount to 4 845 000 tU. Inferred resources (IR), recoverable at <US $260/kgU amounts to 3 173 000 tU.

The South-eastern Asia, Pacific, East Asia region has the largest share of identified resources (reasonably assured resources and inferred resources) at 31.0%, followed by Africa (21.2%), North, Central and South America (16.3%); Middle East, Central and Southern Asia (15.7%); Central, Eastern and South-eastern Europe (13.2%) and Western Europe (2.7%). The regional reports indicate that the majority of identified resources are concentrated within three or fewer countries in each region.

Total undiscovered resources (prognosticated and speculative) are estimated at about 10 401 100 tU. Undiscovered resources are reported by only about one fifth of the countries in this publication. The estimated undiscovered resources are highest where there are formal procedures established to make such estimates of undiscovered resources.

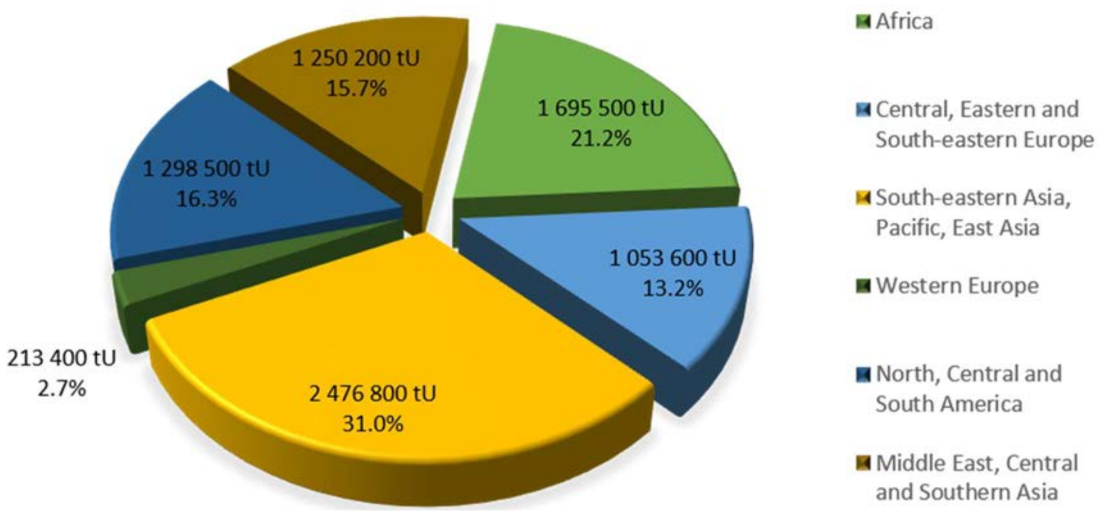


FIG. 2.12. Total identified uranium resources by region as of January 2017.

TABLE 2.23. DETAILS OF IDENTIFIED RESOURCES BY REGION (1000 tU) [2.25]
(As of 1 January 2017)

Region	<US $40/kgU		<US $80/kgU		<US $130/kgU		<US $260/kgU	
	RAR[a]	IR[b]	RAR	IR	RAR	IR	RAR	IR
Africa	0	0	206.2	70.2	921.7	350	1108.8	586.7
Central, Eastern and South-eastern Europe	0	0	82.8	40.4	316.9	322.3	469.4	584.2
South-eastern Asia, Pacific, East Asia	44.3	56.9	153.5	184.1	1468.2	768.2	1599.9	876.9
Western Europe	9.8	0	32.3	13.7	39.9	18.4	109.7	103.7
North, Central and South America	394	10	463.3	132.1	639.6	265.9	880	418.6
Middle East, Central and Southern Asia	265.3	277.5	341.8	359.4	478.7	552.2	647.3	602.9
Total	713.4	344.4	1279.9	799.9	3865.0	2277.0	4815.0	3173.0

[a] RAR: reasonably assured resources.
[b] IR: inferred resources.
Resources in a cost category include resources reported in lower cost categories. Total resources are resources reported in the highest cost category (<US $260/kgU)

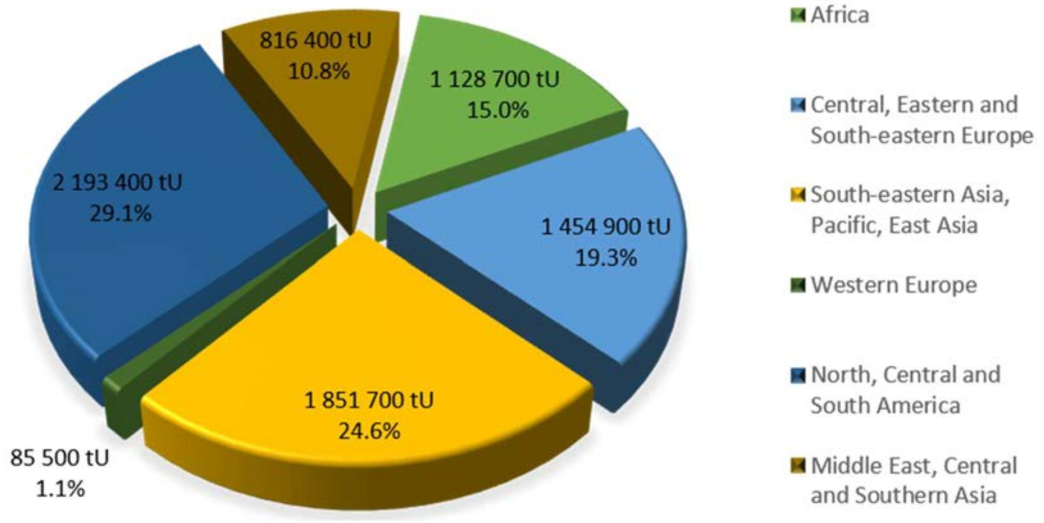


FIG. 2.13. Total undiscovered uranium resources by region as of January 2017.

TABLE 2.24. DETAILS OF UNDISCOVERED RESOURCES BY REGION (1000 tU) [2.25]
(As of 1 January 2017)

Region	Prognosticated			Speculative			Total Speculative
	<US $80/kgU	<US $130/kgU	<US $260/kgU	<US $130/kgU	<US $260/kgU	Unassigned	
Africa	0.0	87.6	229.6	268.0	487.3	411.8	899.1
Central, Eastern and South-eastern Europe	121.1	137.5	448.8	393.1	714.1	292	1006.1
South-eastern Asia, Pacific, East Asia	24.6	24.6	136	1394.1	1394.1	321.6	1715.7
Western Europe	1.0	1.5	1.5	10.0	10.0	74.0	84.0
North, Central and South America	356.6	497.8	500.1	936.7	1016.2	677.1	1693.3
Middle East, Central and Southern Asia	218.9	266.3	382.3	266.9	350.0	84.1	434.1
Total	722.2	1015.3	1698.3	3268.8	3971.7	1860.6	5832.3

2.5.1. Uranium resources in Africa

As of 1 January 2017, total identified resources for Africa (reasonably assured and inferred) amounted to 1 695 500 tU in the <US $260/kgU cost category.

Eighty-four per cent of the resources in the <US $260/kgU cost category are reported by three countries (Namibia, Niger and South Africa) (Fig. 2.14 and Table 2.25). Recently, additional resources have defined in Botswana, Mauritania, Namibia, Niger and Tanzania.

Undiscovered resources (prognosticated and speculative) are estimated to total about 1.13 million tonnes of uranium in the <US $260/kgU and unassigned cost categories. Only six countries reported undiscovered resources (Fig. 2.15 and Table 2.26).

Unconventional resources have significant potential in Africa, mainly associated with uranium in phosphate rocks in Morocco (Table 2.37).

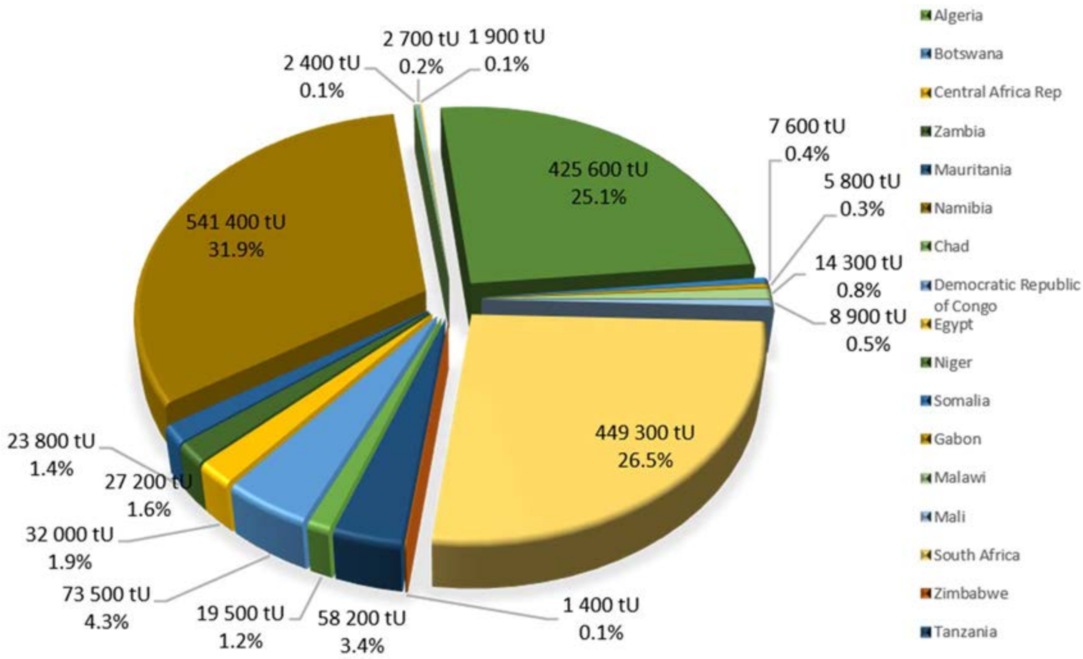


FIG. 2.14 . Total identified uranium resources in Africa of January 2017.

TABLE 2.25. DETAILS OF IDENTIFIED RESOURCES IN AFRICA (tU)
(As of 1 January 2017)

Country	<US $40/kgU		<US $80/kgU		<US $130/kgU		<US $260/kgU	
	RAR	Inferred	RAR	Inferred	RAR	Inferred	RAR	Inferred
Algeria	0	0	0	0	0	0	19 500	0
Botswana	0	0	0	0	13 700	59 800	13 700	59 800
Central Africa Republic	0	0	0	0	32 000	0	32 000	0
Chad	0	0	0	0	0	0	0	2 400
Congo, DemocraticRepublic	0	0	0	0	0	0	1 400	1 300
Egypt	0	0		0		0		1 900
Gabon	0	0	0	0	4 800	0	4 800	1 000
Malawi	0	0	0	0	4 400	1 800	9 700	4 600
Mali	0	0	0	0	5 000	3 900	5 000	3 900
Mauritania	NA	0	NA	0	700	15 700	1 000	22 800
Namibia	0	0	0	0	335 300	106 800	368 500	172 900
Niger	0	0	0	0	237 400	42 600	336 400	89 200
Somalia	0	0	0	0	0	0	5 000	2 600
South Africa	0	0	167 900	61 700	237 600	84 800	259 600	189 700
Tanzania	0	0	38 300	8 500	39 700	18 500	39 700	18 500
Zambia	0	0	0	0	11 100	16 100	11 100	16 100
Zimbabwe	0	0	0	0	0	0	1 400	0
Total	0	0	206 200	70 200	921 700	350 000	1 108 800	586 700

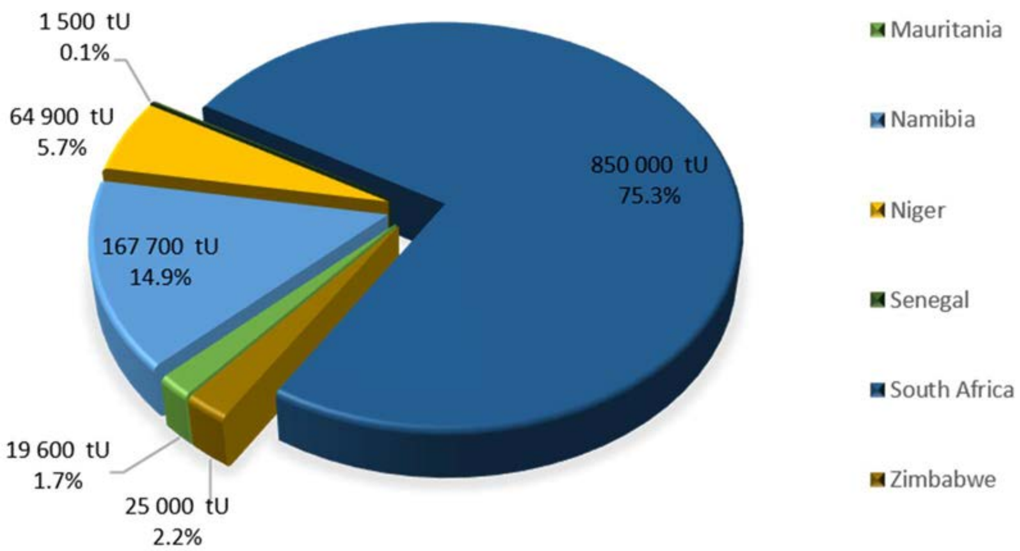


FIG. 2.15 Total undiscovered uranium resources in Africa as of January 2017.

TABLE 2.26. DETAILS OF UNDISCOVERED RESOURCES IN AFRICA (tU)
(As of 1 January 2017)

Country	Prognosticated			Speculative			Total
	<US $80 kgU	<US $130 kgU	<US $260 kgU	<US $130 kgU	<US $260 kgU	Unassigned	Speculative
Mauritania	0	0	0	n.a.	n.a.	19 600	19 600
Namibia	0	0	57 000	0	0	110 700	110 700
Niger	0	13 600	13 600	0	51 300	0	51 300
Senegal	0	0	0	0	0	1 500	1 500
South Africa	0	74 000	159 000	243 000	411 000	280 000	691 000
Zimbabwe	0	0	0	25 000	25 000	n.a.	25 000
Total	0.0	87 600	229 600	268 000	487 300	411 800	899 100

2.5.2. Uranium resources in Western Europe

As of 1 January 2017, total identified resources of Western Europe (Reasonably Assured and Inferred) amounted to 58 300 tonnes of uranium in the <USD 130/kgU cost category and 213 400 tonnes U in the <USD 260/kgU cost category (Fig. 2.16 and Table 2.27). This is only 0.1% and 2.7% of the world identified resources in the respective cost categories.

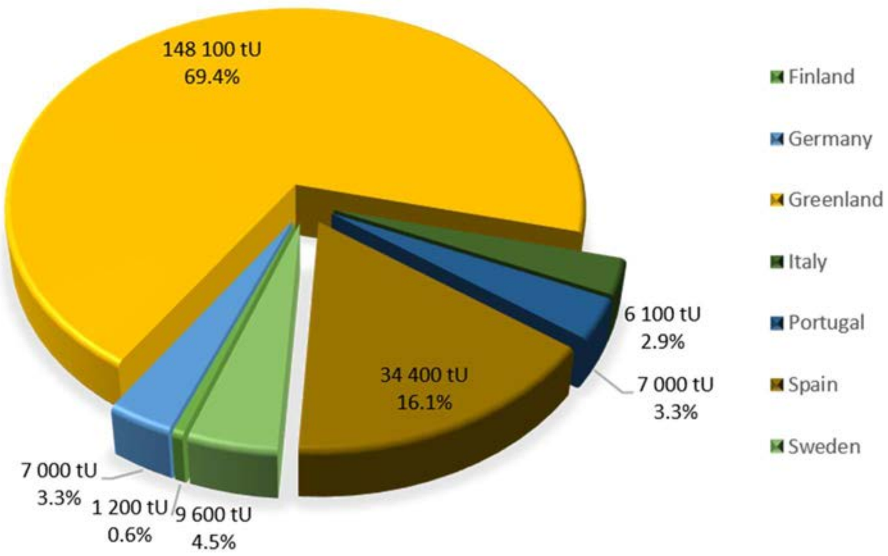


FIG. 2.16. Total identified uranium resources in Europe as of January 2017.

TABLE 2.27. DETAILS OF IDENITIFIED URANIUM RESOURCES IN WESTERN EUROPE
(As of 1 January 2017)

Country	<US $40/kgU		<US $80/kgU		<US $130/kgU		<US $260/kgU	
	RAR	Inferred	RAR	Inferred	RAR	Inferred	RAR	Inferred
Finland	0	0	0	0	1200	0	1 200	0
Germany	0	0	0	0	0	0	3 000	4 000
Greenland	0	0	0	0	0	0	66 800	81 300
Italy	0	0	4 800	1 300	4 800	1 300	4 800	1 300
Portugal	0	0	4 500	1 000	6 000	1 000	6 000	1 000
Spain	9 800	0	23 000	1 1400	23 000	11 400	23 000	11 400
Sweden	0	0	0	0	4 900	4 700	4 900	4 700
Total	9 800	0	32 300	13 700	39 900	18 400	109 700	103 700

In 2017, 7 Western European countries reported identified resources. Nearly 100% of resources in the <USD 130/kgU cost category were reported by 4 countries (Italy, Portugal, Spain and Sweden). Of the 213 400 tonnes identified resources reported in the <USD260/kgU category, 69% are the 148 100 tonnes of inferred resources reported in Greenland's Kvanefjeld deposit. Recently Spain reported additional resources.

Undiscovered resources (prognosticated and speculative) are estimated to total about 85 500 tonnes U in the <USD260/kgU and unassigned cost categories (Fig. 2.17 and Table 2.28). Undiscovered resources are reported by only 3 countries (Germany, Italy, and Portugal).

Unconventional resources (Table 2.37) are associated with uranium in black shale and carbonatite deposits in Finland (37 500 t U) and phosphate rocks and black shales in Sweden (1 054 300 tU).

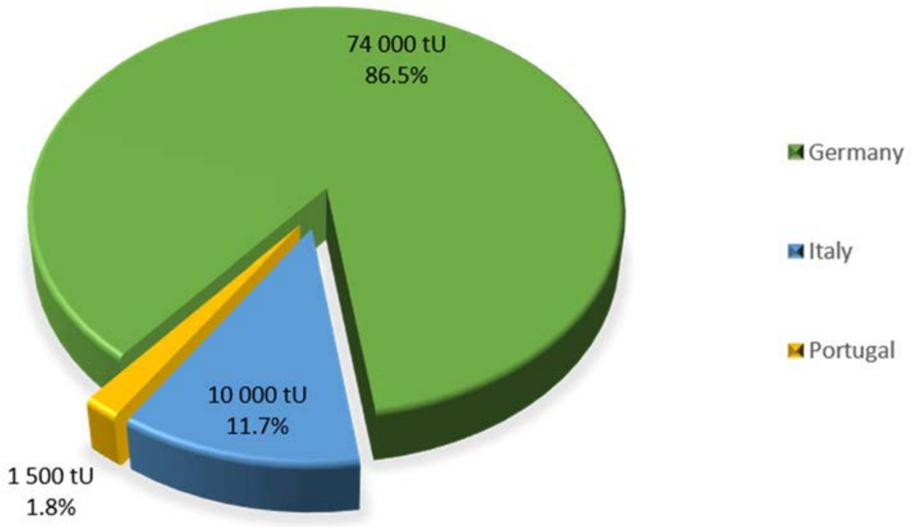


FIG. 2.17. Total undiscovered uranium resources in Europe as of January 2017.

TABLE 2.28. DETAILS OF UNDISCOVERED URANIUM RESOURCES IN WESTERN EUROPE
(As of 1 January 2017)

Country	Prognosticated			Speculative			Total Speculative
	<US $80 kgU	<US $130 kgU	<US $260 kgU	<US $130 kgU	<US $260 kgU	Unassigned	
Germany	n.a.	n.a.	n.a.	n.a.	n.a.	74 000	74 000
Italy	0	0	0.0	10 000	10 000	n.a.	10 000
Portugal	1 000	1 500	1 500	n.a.	n.a.	n.a.	n.a.
Total	1 000	1 500	1 500	10 000	10 000	74 000	84 000

2.5.3. Uranium resources in Central, Eastern and South-eastern Europe

As of 1 January 2017, nine Central, Eastern, and South-eastern European countries reported identified resources (Fig. 2.18 and Table 2.29). About 83 % of total resources in the <US 260/kgU cost category were reported by the Russian Federation and Ukraine.

Undiscovered resources (prognosticated and speculative) are estimated to total 1 298 100 tU in the <US $260/kgU and unassigned cost categories for 10 of the 25 countries in the region (Fig. 2.19 and Table 2.30) [2.25].

Only Greece reports unconventional resources in the region, 500 tU associated to phosphate rocks (Table 2.37).

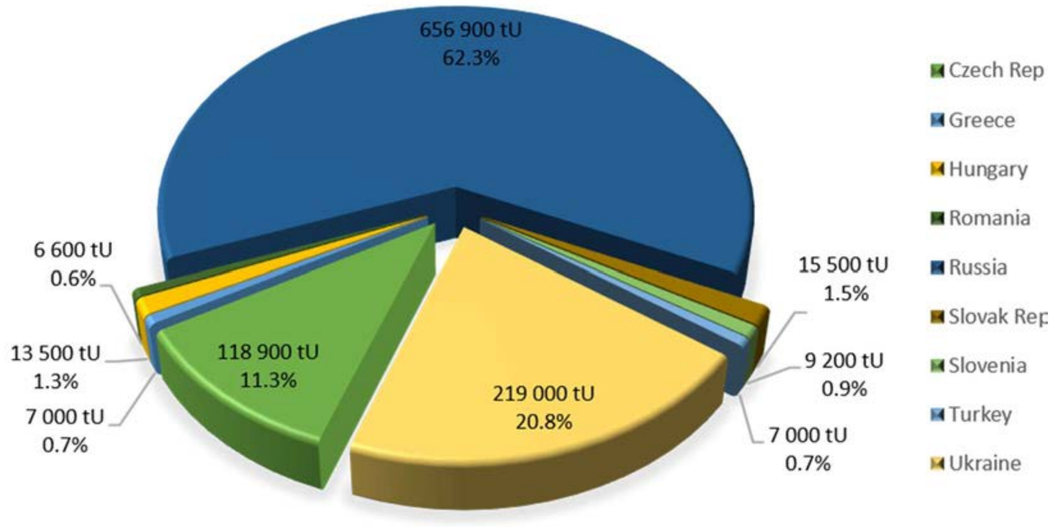


FIG. 2.18. Total identified uranium resources in Central, Eastern and South-Eatern Europe as of January 2017.

TABLE 2.29. DETAILS OF IDENTIFIED RESOURCES IN CENTRAL, EASTERN and SOUTH-EASTERN EUROPE (tU) [2.25]
(as of 1 January 2017)

Country	<US $40/kgU		<US $80/kgU		<US $130/kgU		<US $260/kgU	
	RAR	Inferred	RAR	Inferred	RAR	Inferred	RAR	Inferred
Czech Republic	0	0	0	0	1 200	100	50 700	68 200
Greece	0	0	0	0	0	0	1 000	6 000
Hungary	0	0	0	0	0	0	0	13 500
Romania	0	0	0	0	3 000	3 600	3 000	3 600
Russia	0	0	24 500	15 300	214 500	271 000	260 000	396 900
Slovak Republic	0	0	8 800	3 900	8 800	6 700	8 800	6 700
Slovenia	0	0	1 700	3 800	1 700	7 500	1 700	7 500
Turkey	0	0	6 500	500	6 500	500	6 500	500
Ukraine	0	0	41 300	16 900	81 200	32 900	137 700	81 300
Total	0	0	82 800	40 400	316 900	322 300	469 400	584 200

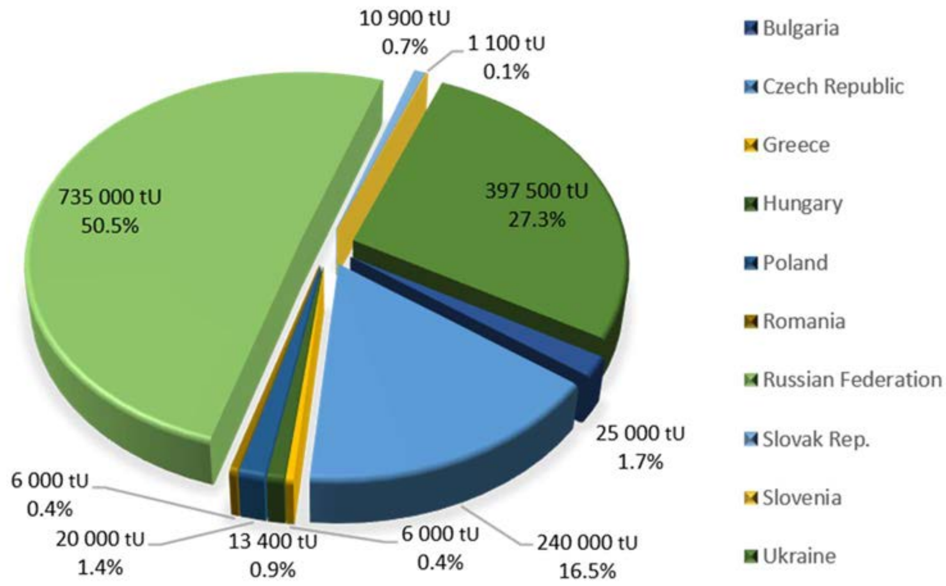


FIG. 2.19. Total undiscovered uranium resources in Central., Eastern and South-Eastern Europe as of January 2017.

TABLE 2.30. DETAILS OF UNDISCOVERED RESOURCES IN CENTRAL, EASTERN AND SOUTH-EASTERN EUROPE (tU) [2.25]
(As of 1 January 2017)

Country	Prognosticated			Speculative			Total speculative
	<US $80 kgU	<US $130 kgU	<US $260 kgU	<US $130 kgU	<US $260 kgU	Unassigned	
Bulgaria	n.a.	n.a.	25 000	n.a.	n.a.	n.a.	n.a.
Czech Republic	0	200 000	223 000	0	0	17 000	17 000
Greece	6 000	6 000	6 000	n.a.	n.a.	n.a.	n.a.
Hungary	0	0	13 400	0	0	0	0
Poland	0	0	0	0	0	20 000	20 000
Romania	n.a.	3 000	3 000	3 000	3 000	n.a.	3 000
Russian Federation	115 100	115 100	143 900	390 100	591 100	n.a.	591 100
Slovak Republic	0	3 700	10 900	0	0	0	0
Slovenia	0	1 100	1 100	0	0	0	0
Ukraine	0	8 400	22 500	0	120 000	255 000	375 000
Total	121 100	137 500	448 800	393 100	714 100	292 000	1 006 100

2.5.4. Uranium resources in South-eastern Asia, Pacific, East Asia

As of 1 January 2017, total identified resources for the South-eastern Asia, Pacific, East Asia region (reasonably assured and inferred) amounted to 2 476 800 tU recoverable in the <US $260/kgU cost category (Fig. 2.20 and Table 2.31). This figure comprised 1 599 900 tU of reasonably assured resources and 876 900 tU of inferred resources. In 2017, only six countries in the South-eastern Asia, Pacific and

East Asia regions reported identified resources to the Red Book. Of the total identified resources, 2 054 800 tU are reported by Australia, equivalent to 83% of the total of the region, mainly associated to the Olympic Dam deposit. Following exploration activies in the southern basins, Mongolia increased significantly its indicated resources [2.25].

Undiscovered resources (prognosticated and speculative) are estimated to total about 1 851 700 tU in the <US $260/kgU plus the unassigned cost categories (Fig. 2.21 and Table 2.32). This represents about 18% of the total estimated world undiscovered resources. Undiscovered resources are reported by only four countries in this region, of which 76% of these occur in Mongolia, 22 % in Vietnam. Australia does not estimate undiscovered resources.

Indonesia and Thailand reports unconventional resources of uranium associated to rare earths (Table 2.37).

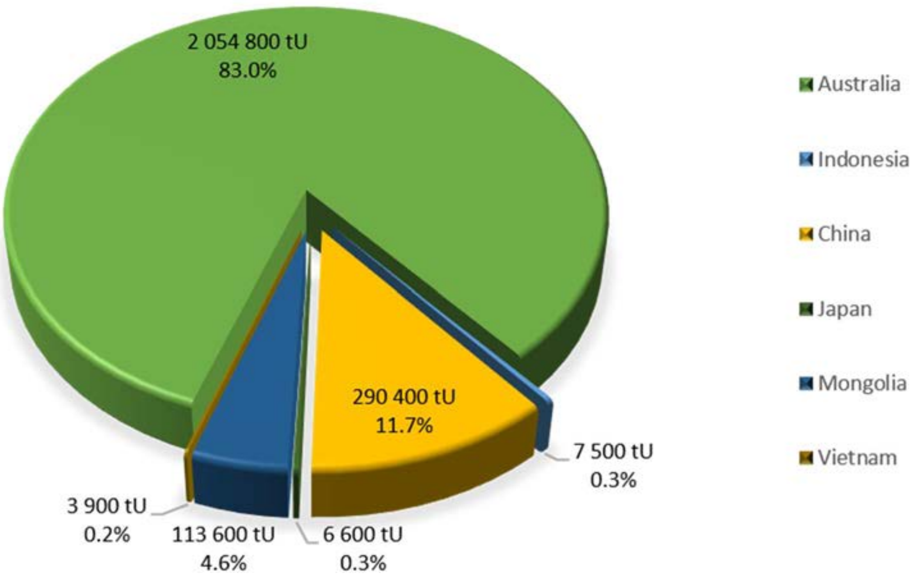


FIG. 2.20. Total identified uranium resources in South-Eastern Asia, Pacific and East Asia as of January 2017.

TABLE 2.31. DETAILS OF IDENTIFIED RESOURCES IN SOUTH-EASTERN ASIA, PACIFIC AND EAST ASIA (tU) [2.25]
(As of 1 January 2017)

Country	<US $40/kgU		<US $80/kgU		<US $130/kgU		<US $260/kgU	
	RAR	Inferred	RAR	Inferred	RAR	Inferred	RAR	Inferred
Australia	NA	NA	NA	NA	1 269 800	548 500	1 400 600	654 200
China	44 300	56 900	102 200	120 300	136 700	153 700	136 700	153 700
Indonesia	0	0	1500	0	5 300	2200	5 300	2200
Japan	0	0	0	0	6 600	0	6 600	0
Mongolia	0	0	49 800	63 800	49 800	63 800	49 800	63 800
Vietnam	0	0	0	0	0	0	900	3 000
Total	44 300	56 900	153 500	184 100	1 468 200	768 200	1 599 900	876 900

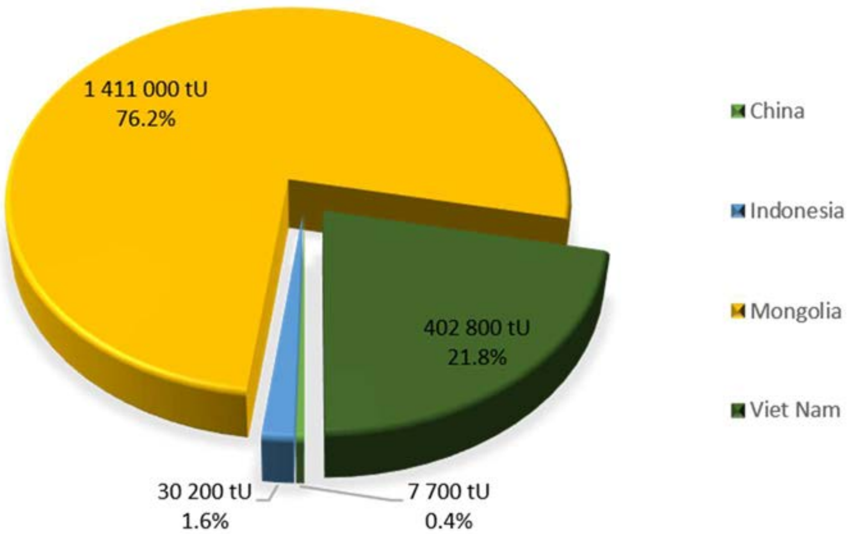


FIG. 2.21. Total undiscovered uranium resources in South-Eastern Asia, Pacific and East Asia as of January 2017.

TABLE 2.32. DETAILS OF UNDISCOVERED RESOURCES IN SOUTH-EASTERN ASIA, PACIFIC AND EAST ASIA (tU) [2.25]
(as of 1 January 2017)

Country	Prognosticated			Speculative			Total speculative
	<US $80 kgU	<US $130 kgU	<US $260 kgU	<US $130 kgU	<US $260 kgU	Unassigned	
China	3 600	3 600	3 600	4 100	4 100	n.a.	4 100
Indonesia	0	0	30 200	0	0	0	0
Mongolia	21 000	21 000	21 000	1 390 000	1 390 000	n.a.	1 390 000
Viet Nam	n.a.	n.a.	81 200	n.a.	n.a.	321 600	321 600
Total	24.6	24 600	136 000	1 394 100	1 394 100	321 600	1 715 700

2.5.5. Uranium resources in the Middle East, Central and Southern Asia

Total identified resources of the Middle East, Central and Southern Asia area (reasonably assured resources and inferred resources) as of 1 January 2017 amounted to 1 030 900 tU in the <US $130/kgU cost category and 1 250 200 tU in the <US $260/kgU cost category. Of the total identified resources, in the <US $260/kgu cost category, 72.3 % are reported by Kazakhstan, 12.5 % by India and 11.1 % by Uzbekistan (Figs 2.22 and Table 2.33).

Undiscovered resources (prognosticated and speculative) are appraised to total 816 400 tU in the <US $260/kgU and unassigned cost categories, with 65 % located in Kazakhstan. Prognosticated and speculative resources are reported by five countries (India, Iran, Jordan, Kazakhstan and Uzbekistan) (Fig. 2.23 and Table 2.34).

Unconventional resources associated with phosphorite are reported by Jordan (although Jordan reports these resources as conventional resources). Resources associated with phosphorite deposits may also exist in Iraq, Israel and the Syrian Arab Republic (Table 2.37).

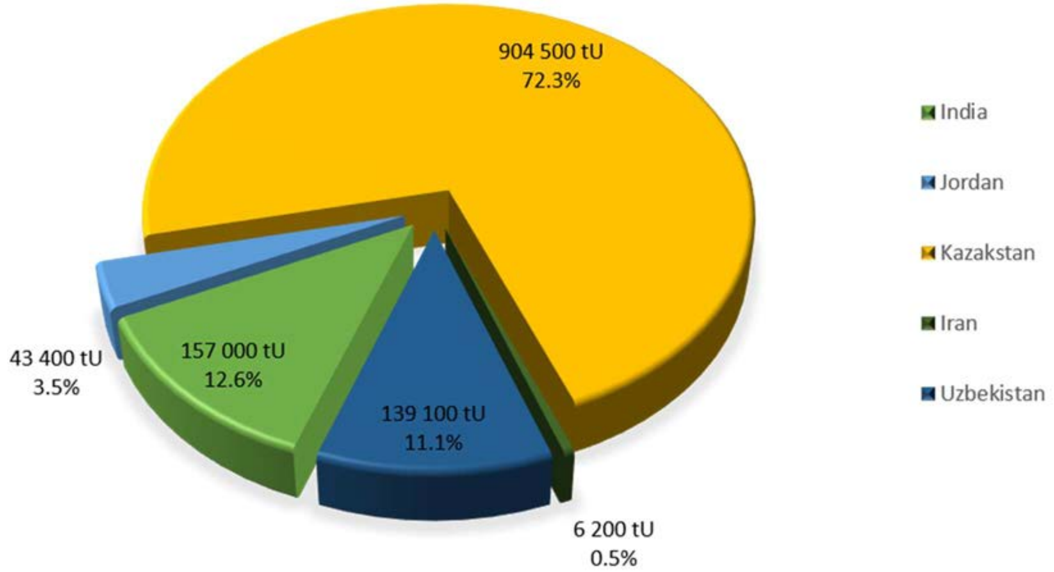


FIG. 2.22. Total identified uranium resources in Middle East, Central and Southern Asia as of January 2017.

TABLE 2.33. DETAILS OF IDENTIFIED RESOURCES IN MIDDLE EAST, CENTRAL AND SOUTHERN ASIA (tU) [2.25]
(As of 1 January 2017)

Country	<US $40/kgU		<US $80/kgU		<US $130/kgU		<US $260/kgU	
	RAR	Inferred	RAR	Inferred	RAR	Inferred	RAR	Inferred
India	NA	NA	NA	NA	NA	NA	149 000	8 000
Iran	0	0	0	0	1 100	5 100	1 100	5 100
Jordan	0	0	0	0	4 800	38 600	4 800	38 600
Kazakstan	227 900	253 200	304 400	335 100	415 200	427 000	434 800	469 700
Uzbekistan	37 400	24 300	37 400	24 300	57 600	81 500	57 600	81 500
Total	265 300	277 500	341 800	359 400	478 700	552 200	647 300	602 900

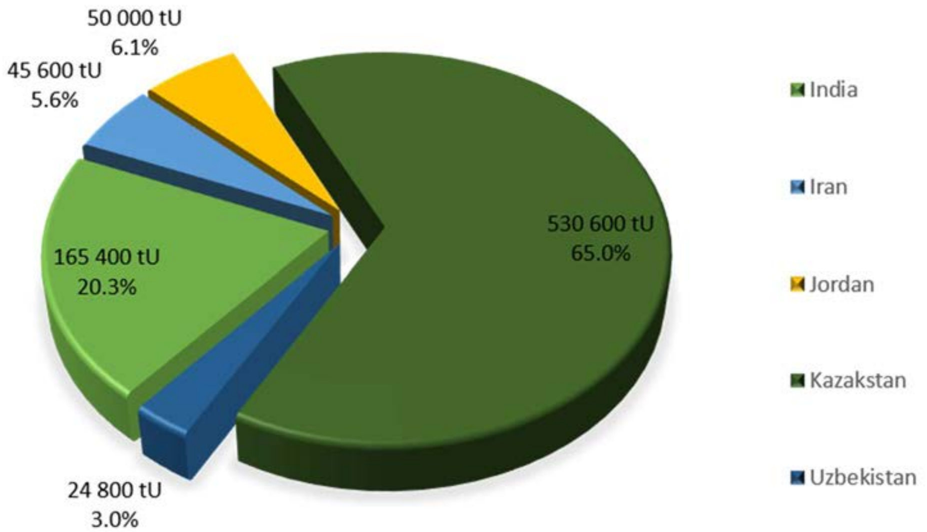


FIG. 2.23. Total undiscovered uranium resources in Middle East, Central and Southern Asia as of January 2017.

TABLE 2.34. DETAILS OF UNDISCOVERED RESOURCES IN MIDDLE EAST, CENTRAL AND SOUTHERN ASIA (tU) [2.25]
(As of 1 January 2017)

Country	Prognosticated			Speculative			Total speculative
	<US $80 kgU	<US $130 kgU	<US $260 kgU	<US $130 kgU	<US $260 kgU	Unassigned	
India	n.a.	n.a.	114 500	n.a.	n.a.	50 900	50 900
Iran	0	12 400	12 400	0	0	33 200	33 200
Jordan	0	0	0.0	0	50 000	n.a.	50 000
Kazakstan	194 100	229 100	230 600	266 900	300 000	n.a.	300 00
Uzbekistan	24 800	24 800	25 000	0	0	0	0.0
Total	218 900	266 300	382 300	266 900	350 000	84 100	434 100

2.5.6. Uranium resources in North, Central and South America

Total identified resources in North, Central and South America (reasonably assured resources and inferred resources), as of 1 January 2017, amounted to 1 298 500 tU in the <US $260/kgU cost category (Fig. 2.24 and Table 2.35). This consisted of 879 900 tU of reasonably assured resources and 418 600 tU of inferred resources. In 2017, only eight countries in North, Central and South America reported identified resources to the Red Book. Of the total identified resources reported, 65% of these are held by Canada and 21% by Brazil.

As a result of exploration activities, additional resources have recently been reported by Canada.

The United States has not historically reported inferred resources. In 2014, the United States began an evaluation of the relative importance of the inferred resource category available in published estimates of US uranium properties.

Undiscovered resources (prognosticated and speculative) are estimated to total 2 193 400 tU in the combined <US $260/kgU plus unassigned cost categories (Fig. 2.25 and Table 2.36). Undiscovered resources are reported by only nine countries (Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Mexico, Peru and Venezuela). A total of 83% of the undiscovered resources occur in Brazil, Canada and Venezuela.

Prognosticated and speculative uranium resources for the United States were last comprehensively assessed in 1980. Records of these estimates are no longer available; therefore they are no longer reported for the United States.

Unconventional uranium resources have significant potential in North, Central and South America owing mainly to the association of uranium with phosphate rock deposits (Table 2.37). Of this deposit type, only the USA in all of North, Central and South America has a history of major commercial production of uranium as a by-product of phosphate production, although Canada has also produced uranium from phosphates.

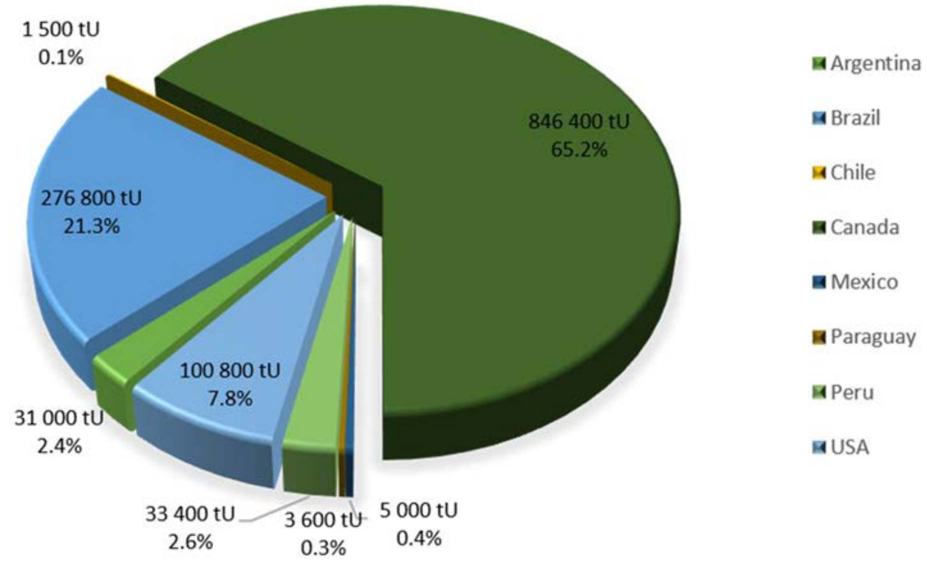


FIG. 2.24. Total identified uranium resources in North, Central and South America as of January 2017.

TABLE 2.35. DETAILS OF IDENTIFIED URANIUM RESOURCES IN NORTH CENTRAL AND SOUTH AMERICA (tU) [2.25]
(As of 1 January 2017)

Country	<US $40/kgU		<US $80/kgU		<US $130/kgU		<US $260/kgU	
	RAR	Inferred	RAR	Inferred	RAR	Inferred	RAR	Inferred
Argentina	0	2400	5100	4000	11 000	19 000	11 000	20 000
Brazil	138 100	0	155 900	73 500	155 900	120 900	155 900	120 900
Canada	255 900	7600	275 200	35 200	409 700	104 700	592 900	253 500
Chile	0	0	0	0	0	0	600	900
Mexico	0	0	0	0	1800	1900	1 800	3 200
Paraguay	0	0	0	0	0	0	2900	700
Peru	0	0	14 000	19 400	14 000	19 400	14 000	19 400
USA	0	0	13 100	0	47 200	0	100 800	0
Total	394000	10000	463300	132100	639 600	265 900	879 900	418 600

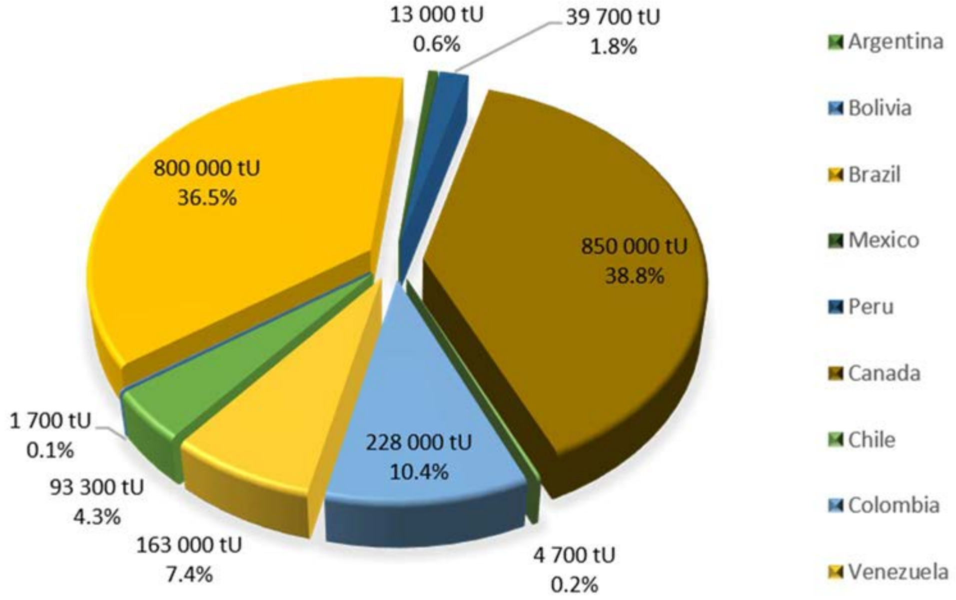


FIG. 2.25. Total undiscovered uranium resources in North, central and South America as of January 2017.

TABLE 2.36. DETAILS OF UNDISCOVERED URANIUM RESOURCES IN THE AMERICAS (tU) [2.25]
(As of 1 January 2017)

Country	Prognosticated			Speculative			Total speculative
	<US $80 kgU	<US $130 kgU	<US $260 kgU	<US $130 kgU	<US $260 kgU	Unassigned	
Argentina	n.a.	13 800	13 800	n.a.	79 500	n.a.	79 500
Bolivia	0	0	0.0	0	0	1 700	1 700
Brazil	300 000	300 000	300 000	n.a.	n.a.	500 000	500 000
Canada	50 000	150 000	150 000	700 000	700 000	0.0	700 000
Chile	0	0	2 300	0	0	2 400	2 400
Colombia	n.a.	11 000	11 000	217 000	217 000	n.a.	217 000
Mexico	n.a.	3 000	3 000	n.a.	n.a.	10 000	10 000
Peru	6 600	20 000	20 000	19 700	19 700	0.0	19 700
United States	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Venezuela	n.a.	n.a.	n.a.	0.0	0.0	163 000	163 000
Total	356 600	497 80	500 100	936 700	1 016 200	677 100	1 693 300

TABLE 2.37. UNCONVENTIONAL URANIUM RESOURCES (tU) [2.25, 2.30–2.43]

Country	Phosphate rock	Non-ferrous ores	Monazite	Carbonatite	Black schist/shales, lignite	Other
Brazil	28–70	2		13.0		
Chile	0.4[a]	0.8[a]				
Colombia	20-60					
Egypt	35-100[b]					
Finland	1			2.5	35	
Greece	0.5					
India	1.7-2.5	6.6-22.9				
Indonesia			27[a]			
Iraq	19-42.8[a]					
Iran, Islamic Republic of						53[a]
Jordan	100a					
Kazakhstan	58					
Mexico	240	1				
Morocco	6 526					
Peru	41.6[a]	0.14-1.41				
South Africa		180[a]			70.7	
Sweden	42.3a				1 012[a]	
Syrian Arab Republic	60-80					
Thailand	0.5-1.5					31.8[a]
United States	576.5[c]	1.8			19 014[c]	
Venezuela	42					
Vietnam					0.5	
Total	7 733.4-7 985.1	192.34-209.91	27.0	15.5	20 132.2	84.8

[a] Updated data from 2011-2017
[b] Includes an unknown quantity of uranium contained in monazite
[c] Secretariat estimate

2.6. WORLD OVERVIEW OF URANIUM PRODUCTION

In 2016, uranium was produced in 19 different countries. World uranium production increased from 39 603 tU in 2006 to reach 62 071 tU in 2016, but started to decline in 2017 as some producing countries limited their production in response to the low price of uranium. In 2016, 95% of the uranium production was produced in only 8 countries.

In 2016, Kazakhstan was the world's largest producer, reporting a production of 24 689 tU (40 % of the world production), more than the combined production of Canada and Australia, the second and third largest uranium producers.

Almost one third (30.3%) of historical world production to 2016 is from North, Central and South America (see Fig. 2.26 and Table 2.38), with 99% of this region's production sourced from North America. This reflects the large production from both Canada (511 321 tU) and the USA (376 204 tU) through 2016.
Historical production from Africa comes mainly from three countries, Namibia, Niger and South Africa. For the Middle East, Central and Southern Asia, two third of the total production is from Kazakhstan, with most of the remainder from Uzbekistan.

In the Central-Eastern and South-eastern Europe region, most of the historical production comes from Czech Republic, the Russian Federation and Ukraine.

For the South-eastern Asia, Pacific, East Asia region, 83% of the total production is from Australia, with most of the remainder from China.

97 % of the historical production in Western Europe is from Germany and France. In 2016, production in Western Europe was only 48 tU, associated to site reclamation.

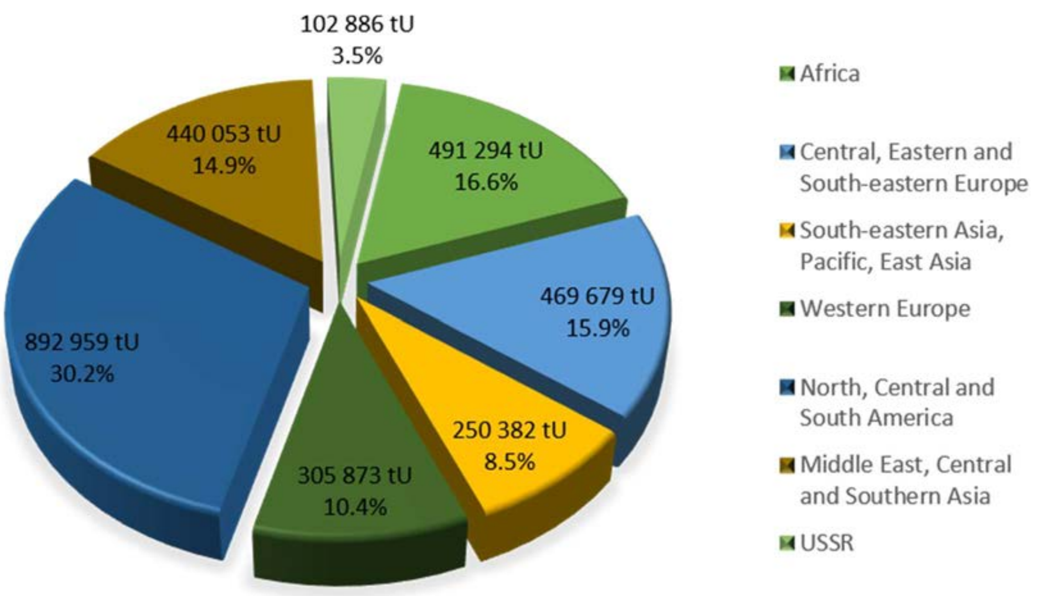


FIG. 2.26. Total world uranium production by region as of January 2017.

TABLE 2.38. DETAILS OF WORLD PRODUCTION BY REGION IN 2015 AND 2016 (tU) [2.25]

Region	2015	2016
Africa	7 501	7 560
Central, Eastern and South-eastern Europe	4 110	3 955
South-eastern Asia, Pacific, East Asia	7 236	7 963
Western Europe	2	48
North, Central and South America	14 796	15 018
Middle East, Central and Southern Asia	26 646	27 527
USSR	0	0
Total	60 291	62 071

USSR; production through the end of 1991

2.6.1. Production status in Africa

Uranium production in Africa amounted to 7 560 tU in 2016, representing 12.2 % of world production. Three countries, Namibia, Niger and South Africa, reported output in 2016 (Fig. 2.27 and Table 2.39).

In Namibia, 2016 production was from 3 different mines, Rossing, Husab and Langer Heinrich. Production at Langer Heinrich started in 2006, but in May 2018 the mine was placed on care and maintenance.

At Husab, production started in 2016, with an objective of 5700 tU/yr production that was completed by the end of 2018.

At Trekkopje, after a limited production in 2012 and 2013, demonstrating the feasibility of the project, the mine was placed on care and maintenance.

Production in Niger come from 2 different mines, Cominak and Somair. Production started at Azelik/Teguidda deposits in 2010 but was stopped in 2015.

Development of the Imouraren mine (5000 tU/yr) was launched in 2009, but the project is now on care in maintenance, due to poor market conditions.

South Africa has been a consistent producer of uranium since 1952. Peak production was achieved at over 6 000 tU/yr in the early 1980s, but in recent years output has declined significantly to around 400-800 tU/year, as a by-product of gold production.

Production commenced at the Kayelekera mine in Malawi in 2009, but the mine was closed up in 2014, and is now on care and maintenance.

Possible production could start in Botswana, Mauritania, Tanzania and Zambia, should market conditions improve.

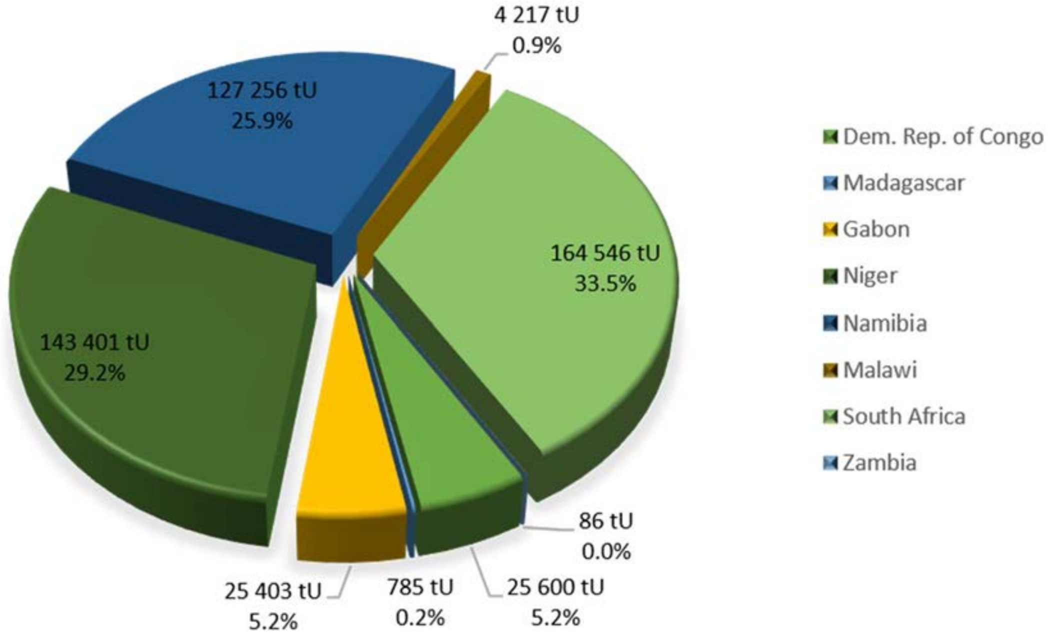


FIG. 2.27. Total uranium production in Africa as of January 2017.

TABLE 2.39. RECENT URANIUM PRODUCTION IN AFRICA BY COUNTRY (tU) (2.25)

Africa	2015	2016
Namibia	2 992	3 593
Niger	4 116	3 477
South Africa	393	490
Total	7 501	7 560

2.6.2. Production status in Western Europe

Uranium production in Western Europe in 2016 was an estimated 48 tU coincident to mine rehabilitation. Historically through 2016 Western Europe produced 310 371 tU, equal to 10.5 % of world production, with 96.9% of this amount produced in Germany and France (Fig. 2.28 and Table 2.40). The future of uranium production in Western Europe is limited with few resources either identified or undiscovered.

Potential uranium mines could be brought into production in Spain, in the Caceres and Salamanca regions.

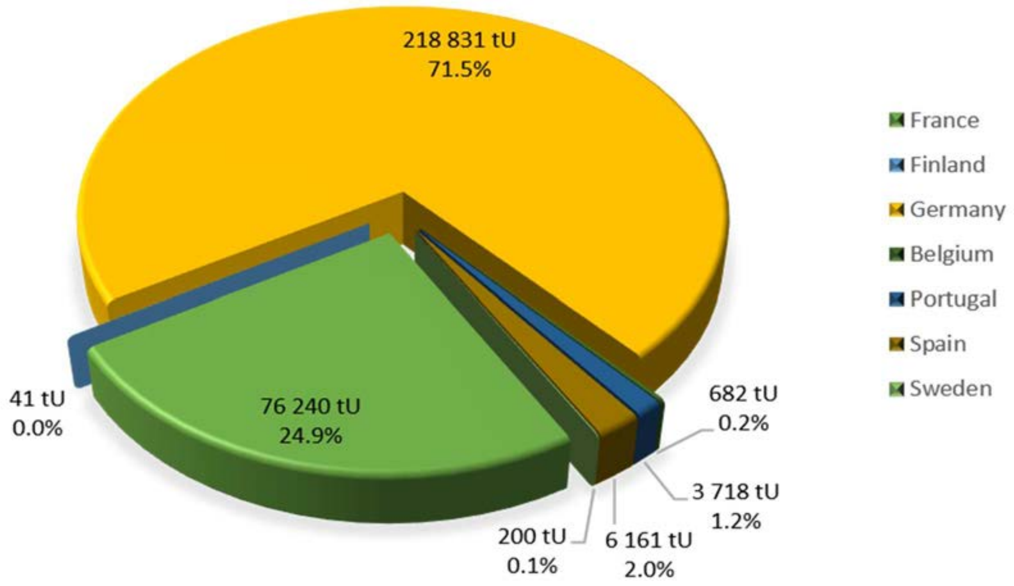


FIG. 2.28. Total uranium production in Western Europe as of January 2017.

TABLE 2.40. RECENT URANIUM PRODUCTION IN WESTERN EUROPE BY COUNTRY (tU) [2.25]

Western Europe	2015	2016
France	2	3
Germany	0	45
Total	2	48

2.6.3. Production status in Central, Eastern and South-eastern Europe

Four countries, Czech Republic, Hungary, Russia and Ukraine, reported production to the Red Book for 2016 (Fig. 2.29 and Table 2.41). Uranium production amounted to 3955 tU. Of this production, 76 % was from Russia, and 20 % from Ukraine.

Production in the Czech Republic came from mine reclamation at Straz, and from the Rozna underground mine which stopped production in 2016 as resources were depleted.

Minor amounts of uranium were produced in Hungary from reclamation of the Mecsek mine.

In Russia, uranium was produced using conventional underground mining methods at the Priargunsky centre and ISL method at Dalur and Khiagda centres.

In Ukraine there are three production centres, all underground mines: Ingulskiy mine, Smolinskiy mine and Novokonstantinovskiy mine where production started in 2011.

In Romania, production ceased in 2016 after the depletion of the Crucea-Botusana deposits.

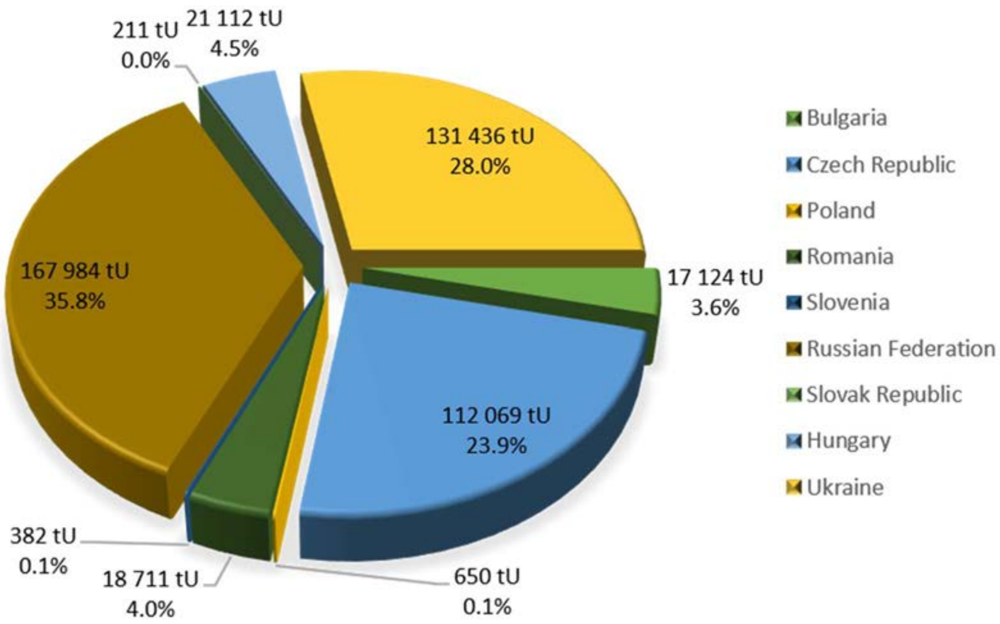


FIG. 2.29 Total uranium production in Central, Eastern and South-Eastern Europe as of January 2017. Production prior to 1992, not included in Russian Federation and Ukraine production.

TABLE 2.41. RECENT URANIUM PRODUCTION IN CENTRAL, EASTERN AND SOUTH-EASTERN EUROPE (tU) [2.25]

Country	2015	2016
Czech Republic	152	138
Hungary	4	4
Romania	75	0
Russian Federation	3 055	3 005
Ukraine	824	808
Total	4 110	2 955

2.6.4. Production status in Southeast Asia, Pacific, East Asia

Two countries in the region (Australia and China) reported production in 2016 to the Red Book 2018 (Fig. 2.30 and Table 2.42). Of this production, 79.3% was from Australia and over 20% was reported by China.

Australia's production, 6 3.13 tU in 2016, represented 10% of world production in 2016. Production in Australia comes from the Olympic Dam mine as co-product of copper-gold-silver, from the unconformity-related Ranger deposit and from the sandstone-type deposits of Beverley and Honeymoon, the latter being mined by ISL. Production at Honeymoon started in 2011, but is on care and maintenance since 2014. Future production centres could include Mulga rock, Wiluna, Kintyre and Yeelirrie. In China, as uranium demand is increasing, several production centres have been developed and put into production. Production increased from an estimated 770 tU in 2008 to 1650 tU in 2016. In 2016, there were seven production centres. The production from underground mines is decreasing significantly, while production from ISL mines is increasing and now dominates the total production. New ISL mines are under study in the Erdos and Erlian basins in Inner Mongolia, and could be developed in the near future.

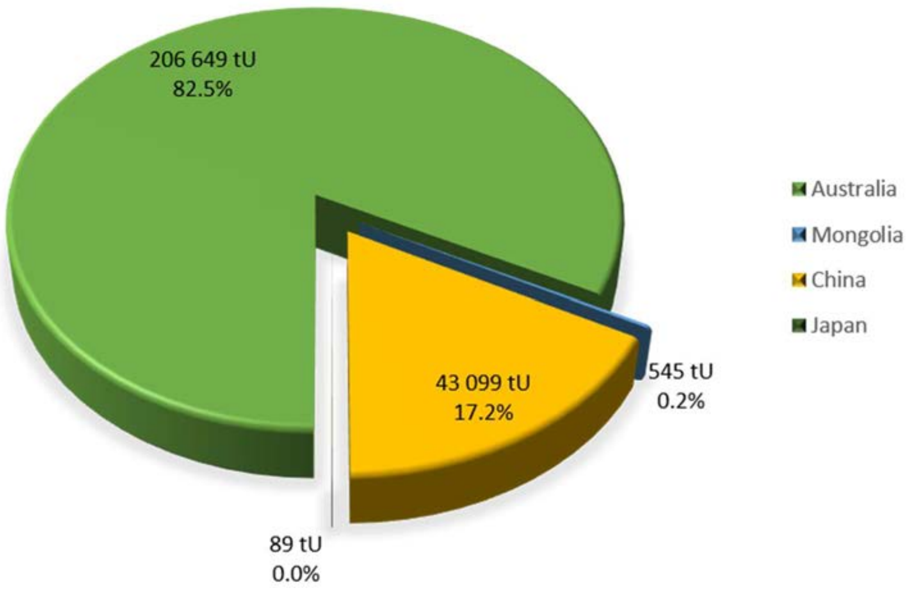


FIG. 2.30. Total uranium production in South-Eastern Asia, Pacific and East Asia as of January 2017.

TABLE 2.42. RECENT URANIUM PRODUCTION IN SOUTH-EASTERN ASIA, THE PACIFIC AND EAST ASIA BY COUNTRY 2015 AND 2016 (tU) [2.25]

Country	2015	2016
Australia	5 636	6 313
China	1 600	1 650
Total	7 236	7 963

2.6.5. Production status in the Middle East, Central and Southern Asia

Production of uranium in the Southern and Central Asia and Middle East region yielded 27 527 tU in 2016, equating to 44.3 % of global production. Five countries (India, Iran, Kazakhstan, Pakistan and Uzbekistan) reported output in 2016 (Fig. 2.31and Table 2.43).

Kazakhstan is the largest uranium producer in the world since 2009. All deposits (14 production centers in 2016), located in the Chu-Sarysu and Syr-Darya provinces, are mined by in-situ leaching acid technique. Production by underground method at Vostok/Zvezdnoe deposits ended in 2013.

In Uzbekistan, uranium is produced by ISL method. Annual production is estimated to amount to 2400 tU/yr. Construction of new uranium mines in the Central Kyzylkum Desert was planned in 2015, with the objective of increasing the production by 40 %, but was suspended due to the high carbonate content of the ore, rendering ISL method inefficient.

India does not report production figures, but production is estimated to be about 385 tU/yr in three operating plants with a total capacity of 8500 t ore/day produced in eight different deposits.

Iran produces small amounts of uranium from the Gachin deposit and plans to start production in the Saghand deposit in the near feature.

Pakiskan does not report production figures to the Red Book, but production is estimated to be about 45 tU/yr.

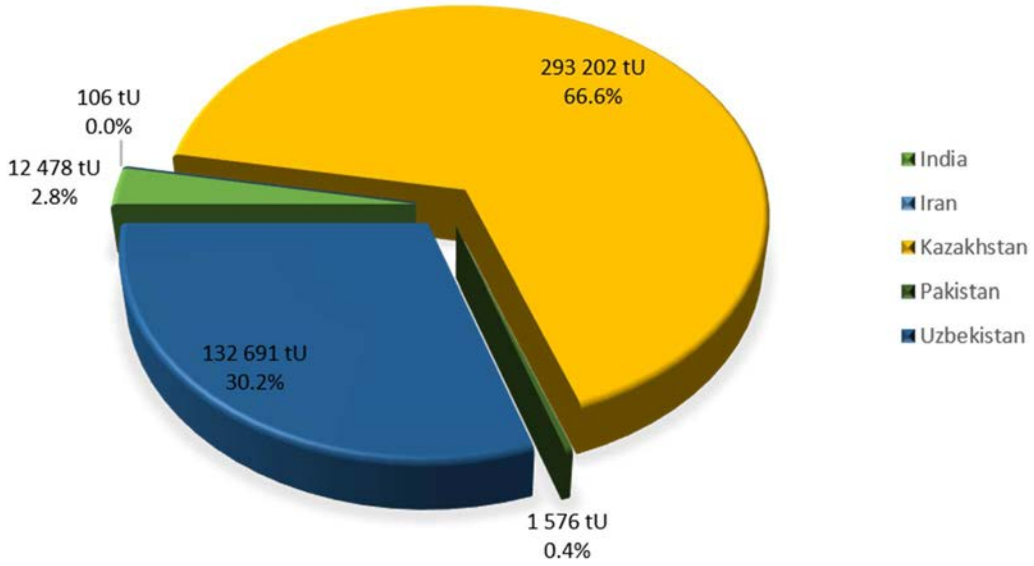


FIG. 2.31. Total uranium production in Middle East, Central and Southern Asia as of January 2017. Production prior to 1992, not included in Kazakhstan and Uzbekistan production.

TABLE 2.43. RECENT URANIUM PRODUCTION IN MIDDLE EAST, CENTRAL AND SOUTHERN ASIA FOR 2015–2016 (tU) [2.25]

Country	2015	2016
India *	385	385
Iran	10	8
Kazakhstan	23 806	24 689
Pakistan*	45	45
Uzbekistan	2 400	2 400
Total	26 646	27 527

[a] Secretariat estimate.

2.6.6. Production status in North, Central and South America

Uranium production in North, Central and South America in 2016 totalled 15 018 tU, from Canada and the USA. Historically, through 2016, North, Central and South America produced 894 372 tU, comprisng 30% of total world production, with 57.2% of this amount produced by Canada and 42.1% by the USA, with minor amounts from three other countries: Argentina, Brazil and Mexico (Fig. 2.32 and Table 2.44) In Canada, production came from the McArthur River, Cigar Lake and Rabbit Lake mines in Saskatchewan. Production started at McArthur River mine in 1999, but was suspended at the end of January 2018 due to low uranium prices. At Rabbit Lake, uranium production was suspended in mid-2016. Production at Cigar Lake started in 2014, the ore being processed at McClean Lake mill.

Two uranium projects could enter into production within the next decade, should uranium prices increase, Midwest and Millennium mines, both in Saskatchewan. Several other exploration projects have identified high-grade uranium deposits.

Historically, the USA is the only country, along with Belgium, Canada and Taiwan, China, to have commercially produced significant quantities of uranium from phosphates. From 1978 through shutdown in 1999, at least 17 000 tU were recovered from phosphates mined in Florida. Extensive resources remain and await an improvement in market conditions to justify production. In the USA, uranium was also recovered from acid solutions from waste dumps at copper mines at Bingham Canyon, Utah, and at Twin Buttes, Sahuarita, Arizona, between 1977 and the late 1980s. Maximum production rates amounted to ~90 tU/year at Twin Buttes, with a total production of 420 tU (1980-1985) , and 420 tU at Bingham Canyon (1978-1989) [2.44]. Production in 2016 was from eight mines, one underground mine in Utah and seven ISL mines in Nebraska, Texas and Wyoming. A number of future production centres are in either permitting or licensing process or under development, where production could start in the near future, depending on uranium prices.

In Brazil, the Caetité centre is the only production facility in operation. The open-pit part of the Cachoeira deposit was mine out in 2014. Licencing of the underground part of the deposit is under way and production could restart in 2026. The Engenho deposit, located 2 km from the mined Cachoeira deposit is under development and is expected to feed Caetité mill after 2019. The phosphate/uranium project of Santa Quitéria is under development. The operation is scheduled to begin in 2026.

Argentina produced about 120 tU/yr from the mid-50s until 1999, from seven production centres. A new production center could potentially be developed in the area of the Cerro Solo deposit.

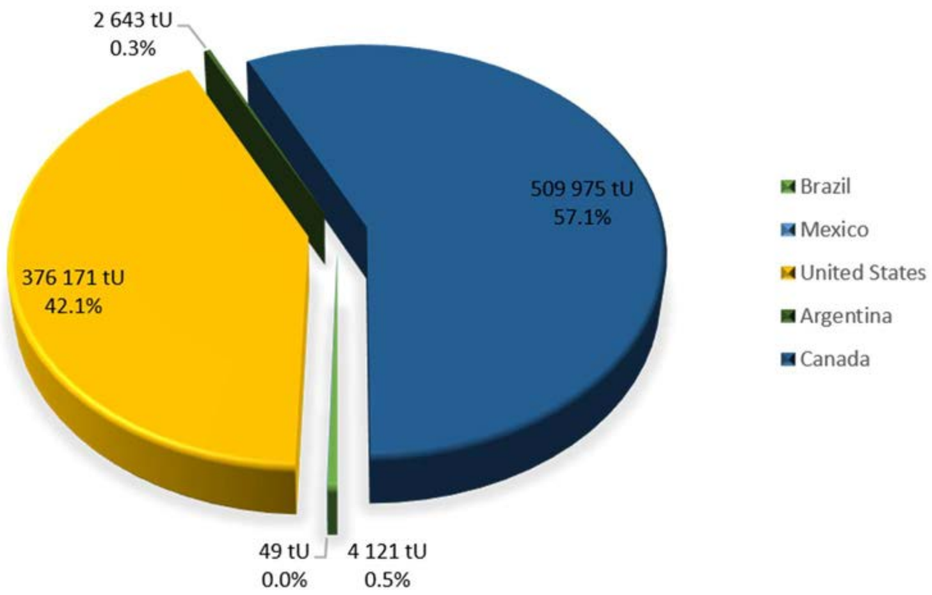


FIG. 2.32. Total uranium production in North, Central and South America as of January 2017.

TABLE 2.44 RECENT URANIUM PRODUCTION IN NORTH, CENTRAL AND SOUTH AMERICA FOR UP TO 2016 (tU) [2.25]

Country	2015	2016	Total to 2016
Argentina	0	0	2 582
Brazil	44	0	4 216
Canada	13 325	14 039	511 321
Mexico	0	0	49
United States	1 427	979	376 204
Total	14 796	15 018	894 372

2.7. WORLD OVERVIEW OF POTENTIAL FOR DISCOVERY OF URANIUM RESOURCES

The IUREP project (1978-1985) (Appendix I) was the earliest attempt at an evaluation of the uranium potential around the world. For most areas possessing the geological conditions favourable for hosting uranium deposits, the relative potential for new discoveries is identified with suggested locations, rock types or terrains proposed. No effort has been made to make quantitative estimates of undiscovered resources. It is emphasized that the potential favourability was agreed on by a consensus of the expert group that prepared the volumes and is not a reflection of official estimates of governments or national authorities. A summary on relative potential is included in the introduction to each regional volume. The reader is referred to the individual reports for estimates of potential for specific areas.

The assessment of prospectivity for the discovery of new uranium deposits in an individual country is based on a consensus of the authors of this publication, following a review of the geology and reported results of exploration and development activities. Terms used range from 'none', 'very limited', 'limited' and 'low', to 'moderate' or 'high'. These terms are not precisely defined but, rather, describe the country's relative potential for additional uranium resources. The assigned description of potential is usually based on the existence of favourable rock types for hosting uranium deposits. The relative size of the country and extent of favourable areas, as well as the extent of exploration conducted, are also taken into consideration in describing the potential rating. It should also be emphasised that these evaluatiosn are necessarily based on incomplete understanding of geology and variable availability of data, and so can (and likely would) change should new information become available. Nevertheless, they are considered to be an appropriate and valid opinion at the time of writing.

2.7.1. Potential for new resources in Africa

There is potential for additional deposits in Africa, including all the types listed in Table 2.45 as well as others. Each report describes the geology and evaluates the potential for locating uranium resources.

Reports on Africa countries include 12 countries with a resource potential that is rated as ranging from none to limited.

Of the remaining 40 countries that have potential for uranium deposits, at least three of them, Algeria, Botswana and Zambia, have moderate to high potential for several types of deposit.
Algeria is described as having a high potential for sandstone, surficial and vein type deposits. Botswana has moderate to high potential for sandstone and calcrete type deposits and low to moderate potential for unconformity type deposits. Zambia has moderate to high potential for sandstone and metamorphic deposits.

There is moderate potential for locating additional sandstone deposits in Chad, the Congo, Ghana, Libya and Mali, and high potential in Gabon, Niger and Nigeria.
Namibia has a high potential for intrusive and calcrete type deposits.

Vein deposits may be located in Chad, the Democratic Republic of the Congo, Egypt, Ethiopia, Libya, Mali, Nigeria and Tunisia.

There is low to moderate potential for quartz-pebble conglomerates in Botswana, Liberia and high potential in South Africa.

Over 6.5 million tU is associated with phosphates in Morocco. There is moderate potential for uranium associated with phosphorite deposits in the Central African Republic, Nigeria and Senegal.

TABLE 2.45. POTENTIAL FOR NEW RESOURCES IN AFRICA

Country	Potential	Remarks
Algeria	Moderate to High	Vein type in Precambrian rocks of the Hoggar and sandstone type and surficial along the fringes of the Hoggar, Eglab and Tindouf Massifs.
Angola	Moderate	Sandstone type in the Karoo and Continental Intercalaire formations, though reporting on exploration limited.
Benin	Limited	Unconformity type deposits along the Dahomeyan Series and the Upper Proterozoic Atacorian Series contact.
Botswana	Moderate to High	Many exposed sedimentary (Karoo) and metamorphic environments. Surficial type
Burkina Faso	None	Neoproterozoic phosphate rocks in the extreme south-east of the country.
Burundi	Low	Vein, granitic, peribatholithic environments.
Cabo Verde	Very Limited	Recent volcanic formations.
Cameroon	Moderate	Sandstone type in continental sediments.
Central African Republic	Moderate	Unconformity type deposit, sandstone type in continental sediments, phosphate type.
Chad	Moderate	Sandstone type in continental sediments, vein type in Precambrian formations.
Comoros	Very Limited	Volcanic formations.
Congo	Moderate	Potential for sandstone and unconformity type deposits. Country relatively small.
Côte d'Ivoire	Moderate	Occurrences in granitic environments. Limited exploration.
Democratic Republic of the Congo	Moderate to High	Overall favourable geological environments.
Djibouti	None	No known exploration. No favourable geology.
Egypt	Limited to moderate	Vein, sandstone and surficial type occurrences but no economic deposits yet located. Phosphate deposits.
Equatorial Guinea	None	No known exploration. Very small country.
Eritrea	Low	Inadequate exploration, several possibilities including sandstone and calcrete deposit types.
Eswatini (Swazilaqnd)	Limited	Sandstone type deposits associated with Karoo strata.
Ethiopia	Moderate to High	Only preliminary exploration, possible unconformity, sandstone and calcrete deposit types.
Gabon	Moderate to High	Several favourable basins. Potential for sandstone type deposits.
Gambia	Low to Moderate	Favourable basins but very small country.
Ghana	Moderate	Metasomatite type associated with Middle Proterozoic formations of the Dahomeyan System, and sandstone type in the Voltaian Basin.
Guinea	Very Limited	Vein type associated with Archaean and Proterozoic metamorphic complexes.
Guinea-Bissau	Very Limited	No favourable geology based on exploration results.
Kenya	Limited	Continental sandstone and volcanic formations.
Lesotho	Low	Favourable rocks but limited channel development in sandstone formations.
Liberia	Moderate	Anomalies identified in quartz pebble conglomerates.

Country	Potential	Remarks
Libya	Moderate	Geology favourable for sandstone, vein, unconformity and surficial type deposits.
Madagascar	Moderate to High	Geology favourable for vein, sandstone (including roll front) and intrusive type deposits.
Malawi	Moderate to High	Additional sandstone type deposits in the Kayelekera area, surficial type and uranium as a by-product of niobium extraction.
Mali	Moderate	Sandstone type deposits in continental sandstone along the fringes of the Adrar des Iforas Massif and in the Faléa area.
Mauritania	Moderate	Unconformity type, vein type, surficial type deposits in north-east Mauritania.
Mauritius	None	Oceanic basalts and reef limestones are unfavourable environments for the formation of uranium deposits.
Morocco	Moderate	Additional phosphates potential. Sandstone and vein type deposits in the Atlas. Surficial type, intrusive type (carbonatites).
Mozambique	Moderate	Vein or unconformity type deposits in Precambrian formations. Sandstone type in Karoo formations.
Namibia	High	Potential for additional intrusive, surficial calcrete, sandstone type deposits similar in size to existing mines and deposits.
Niger	High	Sandstone type deposits in the Agades, Djado Basins.
Nigeria	High	Sandstone type deposits in the Cretaceous in the Sokoto and Chad Basins. Vein type. Phosphates in Cretaceous and Tertiary sediments.
Rwanda	Moderate	Lower Proterozoic pegmatitic and granitic intrusions in the western part of the country.
Senegal	Low	Vein type in granites. Uranium may be associated with sedimentary marine phosphates, possibly in shales.
Seychelles	None	Potential for discoveries based on the rock types found on the islands is regarded as nil.
Sierra Leone	Low	Similarities with the Guyana Shield of northern South America. Metasomatite type.
Somalia	Mod	Sandstone and calcrete type deposits.
South Africa	High	Large areas in western Transvaal favourable for quartz-pebble conglomerate type deposits, sandstone in Karoo Supergroup, large areas for surficial or calcrete deposit types.
Sudan	Moderate	Sandstone type deposits associated with the Mesozoic Nubian Series.
Togo	Moderate	Unconformity type deposits between the Dahomeyan Series and the Upper Proterozoic Atacorian Series.
Tanzania	Low to Moderate	Surficial and Sandstone type deposits associated with Karoo strata.
Tunisia	Moderate	Potential for uranium in phosphates, but low average uranium grade. Vein, disseminated and sandstone type deposits.
Jganda	Moderate	Unconformity type deposits.
Zambia	Moderate to High	Sandstone type deposits in Karoo sediments. Calcrete, igneous or metamorphic deposit types.
Zimbabwe	Moderate to High	Metamorphic in Precambrian Copperbelt and Karoo sediments.

.7.2. Potential for new resources in Western Europe

There is limited potential for additional deposits of significant size in the Western Europe region (Table 2.46). The highest potential is for additional resources of already identified deposit types in Spain.

Andorra, Holy See, Liechtenstein, Monaco and San Marino are countries with small land areas and therefore have no significant potential for uranium discoveries. While Luxembourg is somewhat larger (2 586 km^2), the geology is not favourable for the discovery of uranium deposits.

TABLE 2.46. POTENTIAL FOR NEW RESOURCE DISCOVERIES IN WESTERN EUROPE

Country	Potential	Remarks
Andorra	Very limited	Small country, no exploration reported
Austria	Limited	Vein Bohemian Massif, Permian-Triassic sandstone
Belgium	Very limited	-
Denmark	None	-
(Greenland)	High	Alkaline intrusives, Vein type
Finland	Moderate	Sandstone, Carbonatite, Volcanic & Phosphorite, Metamorphite
France	Low	Very extensively explored ; possible potential at depth
Germany	Moderate	Permian to Tertiary Sandstone
Holy See	None	Small urban country
Iceland	None	Granite-related. Oceanic basalt related rocks unfavourable
Ireland	Very limited	Granitic and Old Red Sandstone
Italy	Very limited	Caledonian granites ; Alpine sandstones ; environmental restrictions
Liechtenstein	None	Small coubtry, no exploration reported
Luxembourg	Very limited	Small country, no exploration reported
Malta	None	No favourable geology
Monaco	None	Small urban country
Netherlands	None	Primarily Quaternary cover predominates
Norway	Limited	Vein type ; Metasediments
Portugal	Moderate	Vein type ; Vicinity of intrusives, sandstones
San Marino	None	Small country, no exploration reportrd
Spain	Moderate	Vein-type, Metamorphite, Alum Shale (<0.03%U)
Sweden	Limited	Vein type
Switzerland	Very limited	Vein type
United Kingdom & Northern Ireland	Very limited	

2.7.3. Potential for New Resources in Central, Eastern and South-eastern Europe

There is potential for additional deposits in Central, eastern and south-eastern region (Table 2.47). The highest potential is for additional resources of already identified deposit types in the Russian Federation.

TABLE 2.47. POTENTIAL FOR NEW RESOURCE DISCOVERIES IN CENTRAL, EASTERN AND SOUTH-EASTERN EUROPE

Country	Potential	Remarks
Albania	Very limited	Unfavourable source and host rock types.
Armenia	Low	Unfavourable source and host rock types.
Belarus	None	
Bosnia and Herzegovina	Very limited	Unfavourable rock types (carbonates, ophiolites, molasse sediments).
Bulgaria	Limited	Potential previously assigned as moderate; these areas have already been explored and mined.
Croatia	Very limited	>50% of country underlain by carbonates.
Cyprus	Very limited	Unfavourable rock types (ophiolite suite and related rocks).
Czech Republic	Low	Very extensively explored; possible potential at depth.
Estonia	Very limited	Alum shale has some low grade potential; no other rocks considered to have potential.
Georgia	None	Unfavourable rock types in Alpine type tectonic setting.
Greece	Low	Potential in NE based on Bulgarian results; sedimentary basins could be explored.
Hungary	Limited	Limited potential on the basis of past exploration results and mostly unfavourable rock types.
Latvia	None	Unfavourable very young rock types; Quaternary cover predominates.
Lithuania	None	Past exploration unsuccessful; basement covered with younger marine sediments and Quaternary strata.
Moldova, Republic of	None	Quaternary with Tertiary (minor) sediments cover infrequent basement outcrops.
Montenegro	None	Unfavourable rock types (mostly limestone).
Poland	Very limited	Sandstone and vein type uranium near intrusives already explored.
Romania	Low	Some potential for deposits at depth in intrusive bodies.
Russian Federation	Moderate to high	Potential in the vicinity of existing large deposits, as well as potential for new discoveries in the very extensive remote areas.
Serbia	Limited to none	Limestone and ophiolite belts are unfavourable; other areas have potential only for limited, low grade mineralization.
Slovakia	Moderate	Past exploration demonstrated additional potential.
Slovenia	Very limited	Limited potential on the basis of past exploration results.
The Former Yugoslav Republic of Macedonia	Very limited	>50% of country covered by Tertiary–Quaternary basins.
Turkey	Limited	Favourable for several deposit types (Sandstone, Metamorphite) although limited to low grade mineralization and relatively deep.
Ukraine	Low to moderate	Exploration for metasomatite type deposits in Shield areas; possible basal channel sandstone type; unconformity, granite-related and haematite breccia type deposits also targeted.

2.7.4. Potential for new resources in South-eastern Asia, Pacific, East Asia

There is potential for additional deposits in the South-eastern Asia, Pacific, East Asia region (Table 2.48). The highest potential is for additional resources of already identified deposit types in Australia, China and Mongolia.

TABLE 2.48. POTENTIAL FOR NEW RESOURCE DISCOVERIES IN SOUTH-EASTERN, PACIFIC AND EAST ASIA

Country	Potential	Remarks
Australia	High	Based on regional geology and knowledge of existing deposits.
Cambodia	Very limited	Potential limited to metamorphic and intrusive formations
China	High	Based on favourable environments, including basins in the north.
Fiji	None	Based on rock types.
Indonesia	Limited	Two areas of volcanics, granites and metasediments have uranium occurrences.
Japan	Very low	Past exploration covered most areas.
DPR Korea	Not rated	Insufficient geological information to evaluate potential. Probably similar to the republic of korea.
Republic of Korea	Moderate	Black shales. Some potential exists for unconformity type deposits.
Lao	Very limited	Potential limited to pre-cambrian metamorphic formations
Malaysia	Limited	Based on exploration to date.
Marshall Islands	None	No favourable geology
Mongolia	High	Based on sedimentary basin geology.
Myanmar	Moderate	Some areas mentioned as having favourable geology.
New Caledonia (France)	Low	Possibly associated with mylonites in shear zones.
New Zealand	Very low	Based on rock types.
Palau	None	Small country. No favourable geology
Philippines	Limited	Limited areas could be explored further.
Singapore	None	Small urban country, no exploration reported.
Solomon Islands	Limited	Phosphates
Taiwan, China	Low	Unfavourable rock types.
Thailand	Low	Some favourable sandstones, exploration has not been encouraging.
Timor-Leste	Very limited	Very small area and unfavourable rock types.
Viet Nam	Moderate	Some potential, including sandstone, coal-lignite and phosphates.

2.7.5. Potential for new resources in Middle East, Central and Southern Asia

There is potential for the discovery of other deposits in the Southern and Central Asia and the Middle East regions. The highest potential is for additional resources of already identified deposit types in Kazakhstan and Uzbekistan (Table 2.49).

TABLE 2.49. POTENTIAL FOR NEW RESOURCE DISCOVERIES IN MIDDLE EAST, CENTRAL AND SOUTHERN ASIA

Country	Potential	Remarks
Afghanistan	Moderate	Tertiary sandstone, carbonatite, volcanic complex. Limited exploration
Azerbaijan	None	—
Bangladesh	Moderate	Permian–Tertiary sandstone
Bhutan	Very limited	Siwalik formations similar to Nepal and Palistan.
India	Moderate	Vein, sandstone, unconformity (low grade deposits), carbonate, metasomatite.
Iran	Low	Sandstone, vein, metasomatite.
Iraq	Moderate	Phosphorite
Israel	Moderate	Phosphorite
Jordan	Moderate to High	Phosphorite
Kazakhstan	High	Sandstone, vein
Kuwait	None	Small country. No favourable geology
Kyrgyzstan	Low to moderate	Sandstone, Vein, black shale
Maldives	None	—
Lebanon	None	No favourable geology
Nepal	Low	Sandstone
Oman	Very limited	Calcrete
Pakistan	Low	Sandstone
Qatar	None	Small country. No favourable geology
Saudi Arabia	Moderate	Vein, Sandstone, Calcrete, Phosphorite
Sri Lanka	Low	Sandstone (limited exploration undertaken)
Syrian Arab Republic	Low–moderate	Phosphorite
Tajikistan	Low	—
Turkmenistan	Low	Sandstone, black shale
United Arab Emirates	None	—
Uzbekistan	High	Sandstone, black shale

2.7.6. Potential for new resources in North, Central and South America

The countries in the North, Central and South Americas designated as having ‘high’ potential are Argentina, Brazil, Canada and Venezuela. All but Venezuela have produced uranium in the past. Another eight countries (Colombia, French Guiana, Guyana, Peru, Surinam, the USA and Uruguay) are described as having ‘moderate’ potential (Table 2.50).

TABLE 2.50. POTENTIAL FOR NEW RESOURCE DISCOVERIES IN NORTH, CENTRAL AND SOUTH AMERICA

Country	Potential	Remarks
Argentina	High	Significant with unexplored areas including fluvial basins. Sandstone, vein, volcanic, surficial.
Belize	Low	Excepting crystalline basement, marine sediments predominate.
Bolivia	Low	IUREP described the existence of attractive unexplored targets, primarily associated with areas underlain by Precambrian strata in north-eastern Bolivia. No deposits have been located.
Brazil	High to very high	Considerable target areas for several deposit types. Particularly important is the Guiana Shield for unconformity, metasomatite and quartz pebble conglomerate type deposits and very large basins for the sandstone hosted type. Numerous alkaline and carbonatite intrusions.
Canada	High	Continued success in identifying unconformity and other deposit types such as metasomatite, metamorphic and black shale.
Chile	Low	Nothing found in highly explored country. Potential for metasomatite.
Colombia	Moderate	Unexplored massif areas and Mesozoic sediments.
Costa Rica	Very limited	Unlikely owing to rock types present.
Cuba	Very limited	Unlikely owing to rock types present.
Dominican Republic	Very limited	Unlikely owing to rock types present.
Ecuador	Limited	Relatively small country and limited rock types present.
El Salvador	Very limited	Unlikely owing to rock types present.
French Guiana	Low	Quartz pebble conglomerate and unconformity type potential.
Guyana	Moderate	Metasomatite, quartz pebble conglomerate and unconformity type potential.
Guatemala	Low	Little exploration undertaken.
Haiti	Low	Unlikely owing to rock types present.
Honduras	Low	Unlikely owing to rock types present.
Jamaica	Low	Rock types related to tectonics unfavourable (dominantly marine and volcanics).
Mexico	Moderate to High	Attractive in situ leach amenable targets exist. Large volcanic areas, Phosphorites.
Nicaragua	Limited	Rock types related to tectonics unfavourable.
Panama	Limited	Rock types related to tectonics unfavourable.
Paraguay	Moderate	South-east region, west Paraná Basin, sandstone hosted type, possibly in situ leach amenable.
Peru	Moderate	Low (excluding Macusani district). Potential environments not investigated.
Suriname	Low to Moderate	Precambrian Shield areas relatively unexplored.
USA	Moderate	Extensively explored. Known deposits have greater resources at higher uranium market prices.
Uruguay	Moderate	Potential in Paraná Basin for sandstone type deposits.
Venezuela	High	Precambrian rocks have high potential for all types except calcrete.

2.8. WORLD OVERVIEW OF INSTALLED AND PLANNED NUCLEAR CAPACITY AND URANIUM REQUIREMENTS

On 1 January 2017, a total of 449 commercial nuclear reactors (390.7 GW(e) net) were connected to the grid in 30 countries and 64 reactors were under construction. Forecasts of future installed capacity are uncertain, but are projected (2017) to grow to between about 331 GW(e) net (low case) and 568 GW(e) net (high case) by 2035. The nuclear capacity projections vary considerably from region to region (see Table 2.51).

The East Asia region is projected to experience the greatest increase, between 30 and 122% over 2016 capacity.

Nuclear capacity in non-European Union countries is also projected to increase considerably, between 9% (low case) and 56% (high case).

For North America, the projections see nuclear generating capacity decreasing by 2035 in both the low and high case.

A similar scenario is reported for the European Union

World annual uranium requirements amounted to 62 825 tU in 2016. Annual uranium requirements are projected to vary between 53 010 tU (low case) and 90 280 tU (high case) by 2035 (see Table 2.51).

As in the case of nuclear capacity, uranium requirements vary considerably from region to region, mirroring projected capacity evolution (Table 2.52).

TABLE 2.51. NUCLEAR CAPACITY AND CAPACITY PROJECTIONS [2.25]
(As of 1 January 2017)

Region	Operating		Under construction
	Reactors	Net capacity (GW(e))	Reactors
Africa	2	1.8	0
Central, Eastern and South-eastern Europe	70	51.9	13
South-eastern Asia, Pacific, East Asia	109	99.3	31
Western Europe	116	111.7	2
North, Central and South America	125	117.9	6
Middle East, Central and Southern Asia	27	8.1	12
Total	449	390.7	64

TABLE 2.52. FORECAST WORLD YEARLY URANIUM REQUIREMENTS (tU) [2.25]

Region	2016	2025		2035	
		Low case	High case	Low case	High case
Africa	290	290	290	540	1 170
Central, Eastern and South-eastern Europe	7 545	7060	7790	7 600	10 850
South-eastern Asia, Pacific, East Asia	13 215	17 040	21 470	20 480	35 300
Western Europe	16 675	14 210	16 860	9 940	18 610
North, Central and South America	23 790	14 270	18 830	9 220	15 270
Middle East, Central and Southern Asia	1310	2 480	3 680	5 230	9 620
Total	62 825	55 350	68 920	53 010	90 820

2.9. UPDATE OF GLOBALLY SIGNIFICANT DEVELOPMENTS 2003–2018

Since 2013, exploration activities have been conducted in countries which continued to explore and develop deposits, but also in countries where no exploration were conducted for many decades, such as Botswana, Mauritania and the United Republic of Tanzania, where new uranium deposits have been discovered. Most of the exploration activities were concentrated in areas where unconformity-related, sandstone type and hematite breccia complex deposits could be discovered. From 2004 to 2016 (13 years), world total expenditures amounted to USD 16.4 billion, or 60% of the amount spent from 1970 to 2016 (47 years). Although data are not complete, in particular for the first years of uranium exploration, average annual expenditures during the 2004-2016 period are 3 times more important than prior to 2004. (USD 1.26 billion/year vs USD 0.40 billion/year). More than 26 % of the total reported world exploration expenditures have been spent in Canada (Table 2.53, compare to Table 5.1 in [2.45]).

TABLE 2.53. COUNTRIES WITH HIGHEST EXPLORATION EXPENDITURES (1945-2016)

Country	USD million	Percentage of world total
Canada	7 985 092	26.7
United States of America (a)	4 341 813	14.5
USSR (b)	3 692 350	12.3
Australia	1 730 314	5.8
Namibia (c)	1 403 831	4.7
China (d)	1 217 000	4.1
Niger	1 048 927	3.5
Russian Federation (e)	1 045 307	3.5
Others	7 483 896	25.0
World total	29 948 530	100.0

(a) Includes reclamation and restoration expenditures from 2004 to 2012;
(b) Includes expenditures in former Soviet Socialist Republics of Estonia, Kazakhstan, Kyrgyzstan, Russian Federation; Turkmenistan, Ukraine and Uzbekistan through the end of 1991;
(c) Expenditures since 1992;
(d) Expenditures since 2000;
(e) Expenditures since 1992.

2.9.1. World exploration and development expenditures

Figure 2.33 shows the direct relation between exploration expenditures, in both OECD and non-OECD countries, and uranium market price (NUEXCO spot price). From 2006 to 2013, when the uranium price increased above USD 100 / kgU, (with an average price of USD 258 / kg U in 2007), expenditures stayed at a high level (more than USD 1.5 billion /year), related to exploration activities, but also development of new projects. From 2004 to 2016, OECD countries spent 64% of total expenditures. Most of the non-OECD expenditures were made by China and Namibia, in particular in 2014 when Namibia spent USD 1.04 billion related to the development of the Husab deposit.

2.9.1.1. World Exploration Drilling and Market Price

Drilling is the largest exploration expenditure. Like exploration expenditures, exploration drilling (km) paralleled the market price changes, with a lag of 1 to 3 years behind uranium price. Annual drilling, during the 2005-2016 period, remained much lower than during the previous period of high uranium price (1975-1980). The fact that expenditures are much higher during the 2003-2016 period than during the previous period (Fig. 2.33 and Fig 2.34), can be partially explained by higher drilling cost related to deeper holes as most of the surface deposits were already discovered, in particular in Canada.

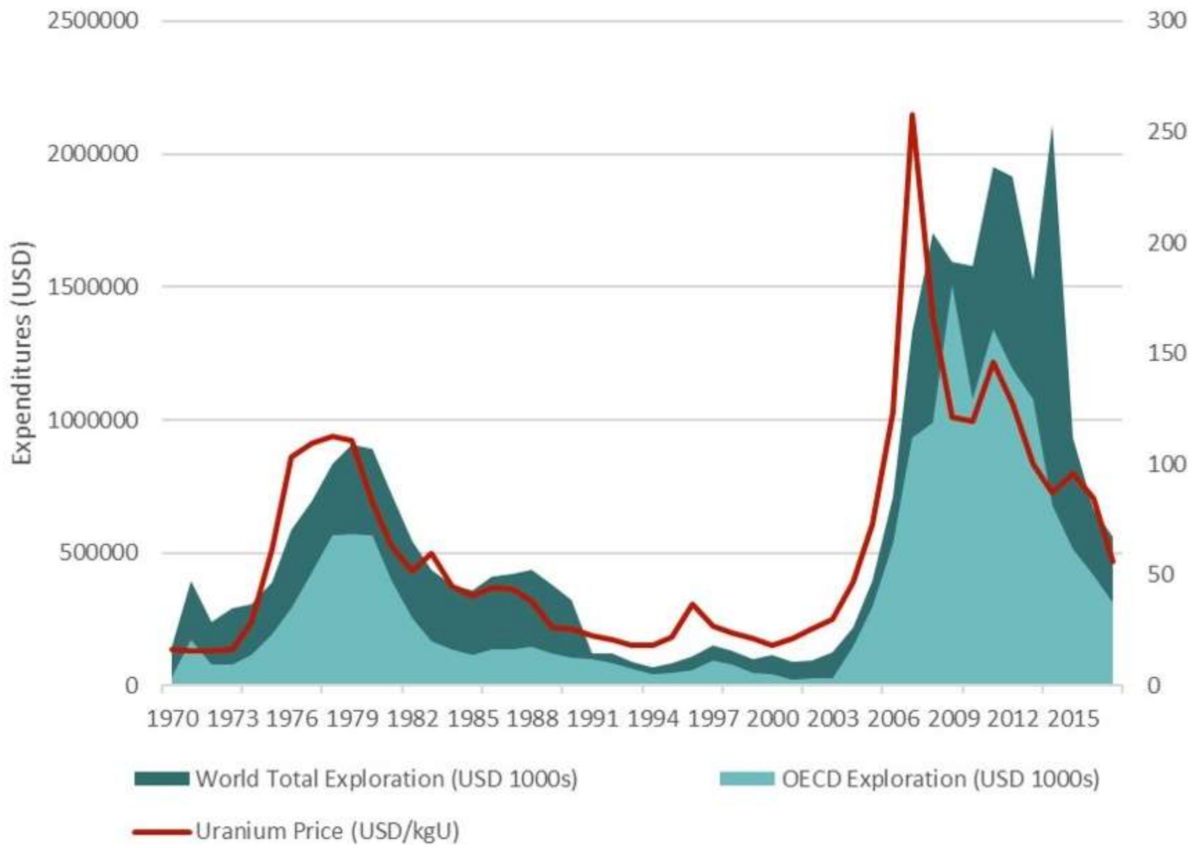


FIG. 2.33. Comparison of annual OECD and worldwide exploration and development expenditures and uranium market price (compare to Fig. 5.2 in the 2003 Red Book Retrospective).

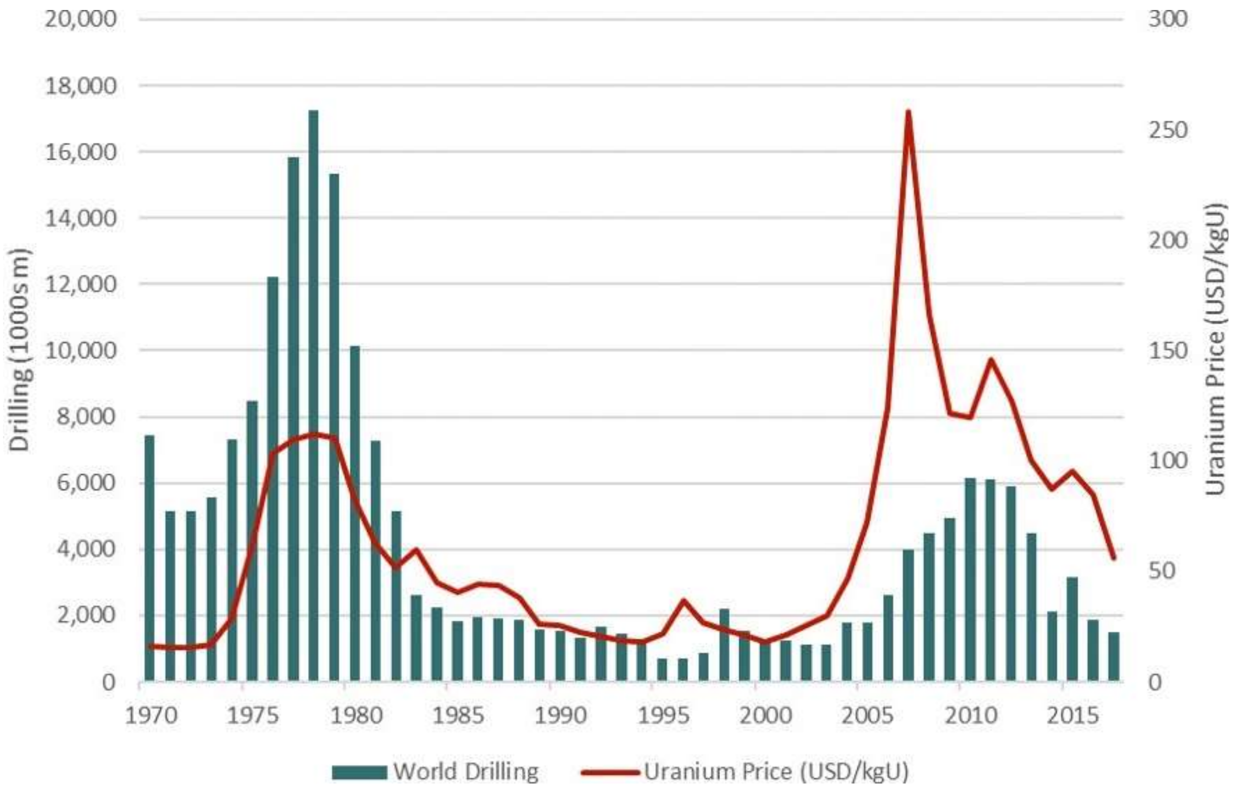


FIG. 2.34. World exploration drilling (km) and market price (compare to Fig. 5.3 in the 2003 Red Book Retrospective).

2.9.1.2. Exploration Activities in Selected Countries

History of exploration trends for six major uranium producing countries, Australia, Canada, China, Kazakhstan, Namibia and the United States of America is analysed below. Annual exploration expenditures for each of these countries are compared with market price and with surface drilling (km) to show both the influence of the uranium market on exploration expenditures and the generally close parallel between overall exploration expenditure trends and drilling.

Australia did not report surface drilling after 2005 (Fig. 2.35). One can see a parallelism between exploration expenditures (and surface drilling until 2005) and the uranium spot price. Exploration tends to lag one to two years behind market price trends, which reflects the time the industry needs to obtain permits and financing and to plan exploration campaigns. As uranium price declined after the peak in 2007, exploration activities decreased significantly in 2012.

The main areas where uranium exploration was carried out from 2005 to 2009 were: Gawler Craton/Stuart Shelf region (South Australia) – exploration for hematite breccia complex deposits; Frome Embayment (South Australia) – exploration for sandstone uranium deposits; Western Australia, exploration for sandstone and surficial deposits; Alligator Rivers region (Northern Territory) – exploration for unconformity-related deposits in Palaeoproterozoic metasediments; Mount Isa Region (Queensland) – exploration for extensions of metasomatite type deposits. As a result of these exploration activities, several discoveries were made during that period (e.g., Four Mile, Pepegoona and Yadglin, deposits of the Wiluna and Mulga Rocks projects, extensions of Olympic Dam, Ranger and of Valhala)

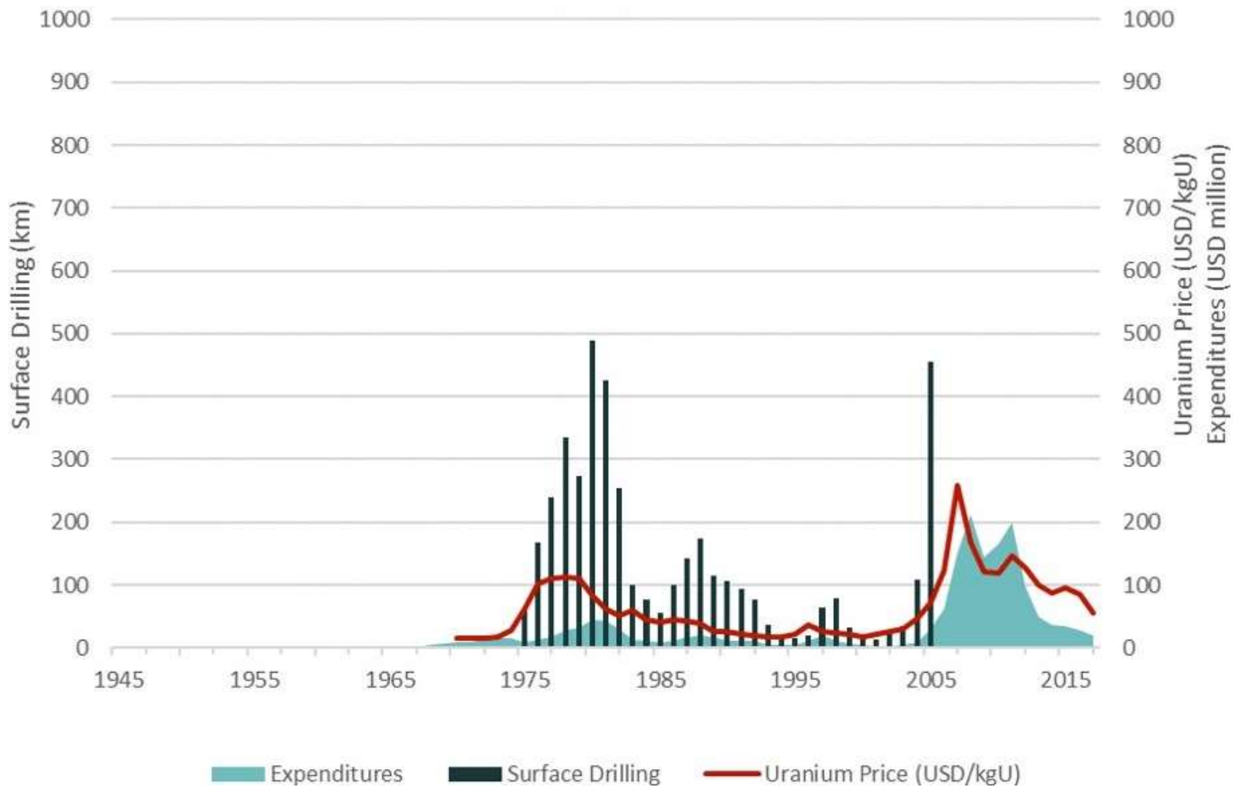


FIG. 2.35. Exploration activities in Australia (compare to Fig. 5.5 in the 2003 Red Book Retrospective).

As in Australia, one can see that Canada's exploration expenditures are linked to the market price for uranium. We also observe the same trend in surface drilling. But in Canada, exploration activities have reacted immediately to the increase of the uranium price. After a continuous decrease in exploration and mine development from 1998 to 2003 (USD 21.7 million), spending began to increase in 2004 reaching a total amount of USD 948.2 million in 2011 (Fig. 2.36). The same year, surface drilling amounted to 516.9 km. Expenditures have been declining since 2011 to USD 297 million in 2016. However, Canada has maintained higher than average expenditures than other countries reporting to the Red Book.

Exploration efforts have focused on areas favourable for the occurrence of deposits associated with Proterozoic unconformities in the Athabasca basin, and to a lesser extent, similar geologic settings in the Thelon basin of Nunavut and the Northwest Territories. Uranium exploration has also remained active in the Otish Mountains of Quebec on the Matoush deposit where mineralisation occurs in mafic dykes associated with Proterozoic sandstones. Exploration activity has led to high-grade uranium mineralisation discoveries in the Athabasca basin, including: Centennial, Shea Creek, Wheeler River, Midwest A, Roughrider. Phoenix/Gryphon, Triple R, Arrow and Fox Lake deposits.

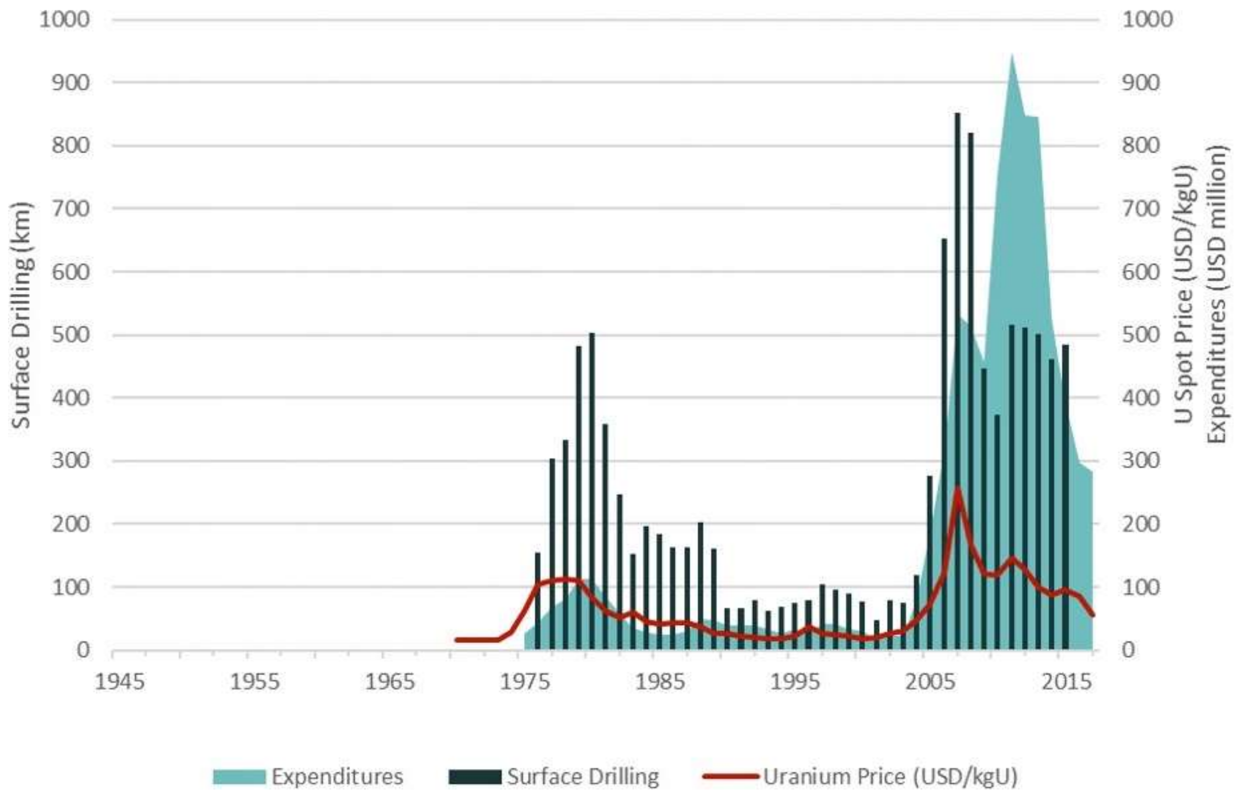


FIG. 2.36. Exploration activities in Canada (compare to Fig. 5.7 in the 2003 Red Book Retrospective).

For China, no data, expenditures and surface drilling were reported before 2000 (Fig. 2.37). Since 2001, China is a major player in exploration and development activities, in particular abroad, in Kazakhstan, Namibia, Niger. Domestic exploration and development expenditures have increased from (USD 7.6 million in 2003, with an all-time high of USD 197.5 million in 2014, then decreased to USD 122 million in 2017. In China, exploration focused on sandstone-type deposits amenable to ISL, but activity also restarted on hydrothermal type deposits in southern China, after more than 10 years of inactivity in these areas. The exploration, including regional uranium potential assessment and further works on previously discovered mineralisation and deposits in northern China, has principally been focused on the Yili, Turpan-Hami, Junggar and Tarim basins of the Xinjiang Autonomous Region; the Erdos, Erlian, Songliao, Badanjili and Bayingebi basins of Inner Mongolia; the Caidaum basin in Qinghai province and the Jiuquan basin in Gansu province. As a result, uranium resources have been dramatically increased, in particular with the large Daying deposit (>25 000 tU) which was discovered in the Erdos basin.

For Kazakhstan, no data, expenditures and surface drilling, were reported before 2000 (Fig. 2.38). Exploration and development expenditures increased from USD 0.7 million in 2004 to USD 94.3 million in 2012, followed by a significant decrease in 2017 to USD 18.5 million (preliminary data). In 2007, Kazakhstan started increasing its exploration and development activities, and consequently its production activities. In 2009, Kazakhstan became the largest uranium producer worldwide. Exploration of sandstone-type deposits was performed in the Shu-Sarysu Uranium Province and in the Syr-Daria Uranium Province. Re-estimation of uranium resources in vein-type deposits was also undertaken in the Northern Kazakhstan Uranium Province. Geological prospecting of sandstone-type deposits amenable for ISL mining was conducted in new perspective areas of the Shu-Sarysu provinces. The decrease in expenditures after 2012 can be partially attributed to a decline in development activities.

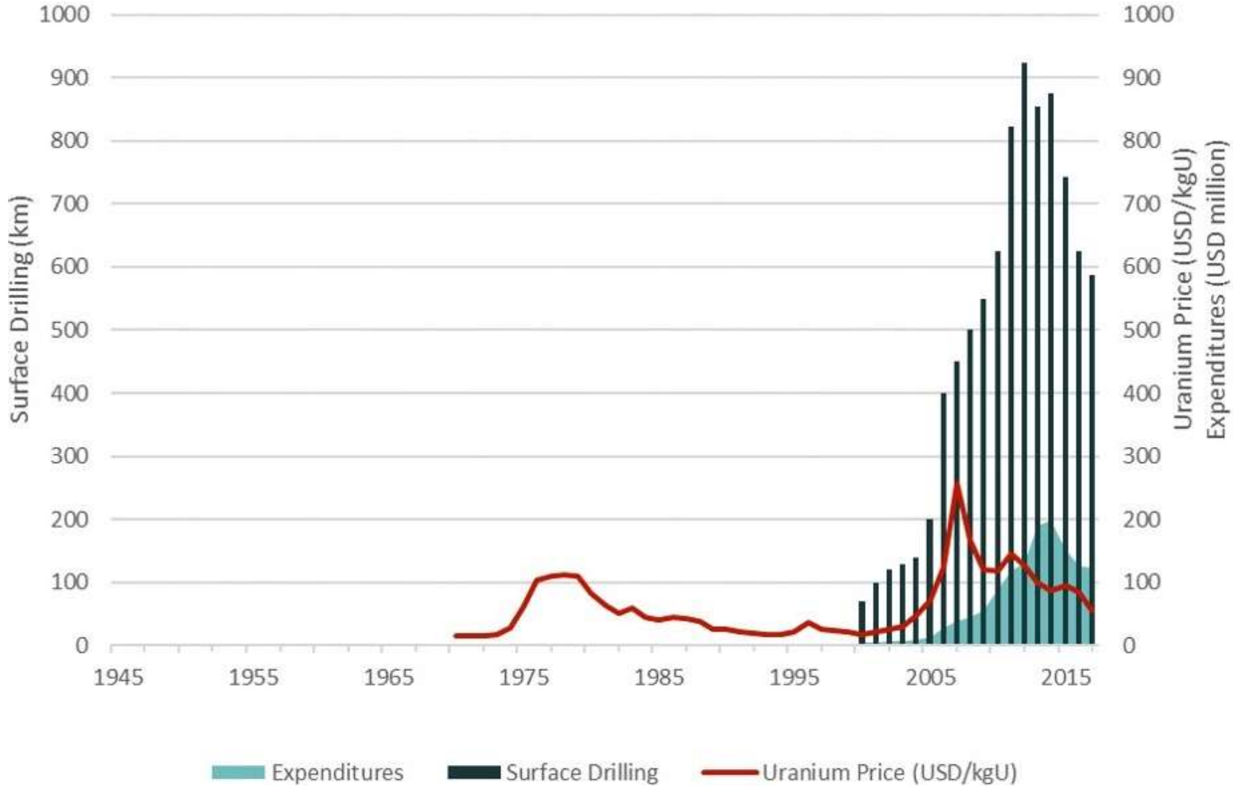


FIG. 2.37. Exploration activities in China.

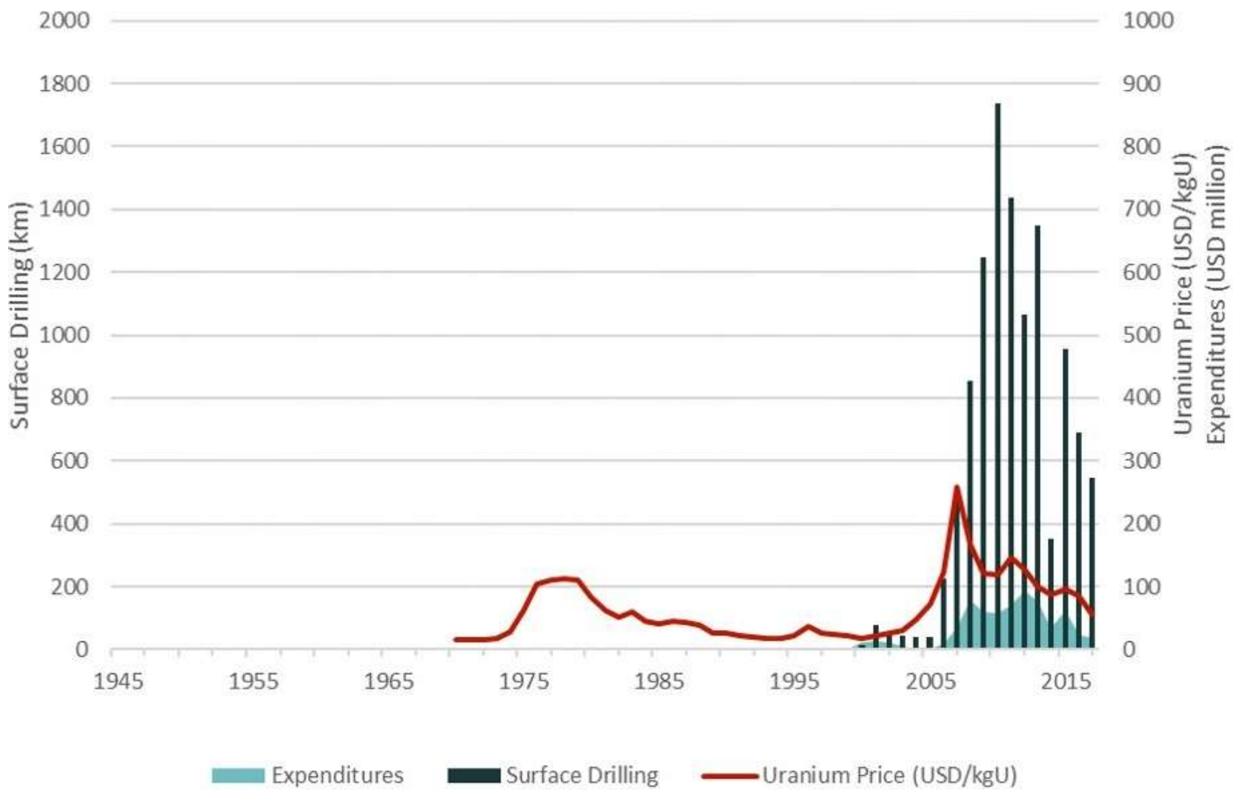


FIG. 2.38. Exploration activities in Kazakhstan.

For Namibia, no data, expenditures and surface drilling, were reported before 2003 (Fig. 2.39). Important drilling programmes started in 2006 in order to develop the Langer Heinrich, Trekkopje and Valencia deposits. Exploration activities targeted two major types of deposits, the intrusive type associated with alaskites, as at Rössing, and the surficial, calcrete type, as at Langer Heinrich and Trekkopje. From 2006 to 2016, intensive exploration activities led to an increase in identified resources in Namibia, at Rossing, Langer Heinrich, Husab, Trekkopje, Valencia and several other areas. In 2014, Namibia reported exploration and development expenditures of USD 1.04 billion, principally related to the development of the Husab mine. Expenditures dropped to USD 10.5 million in 2015.

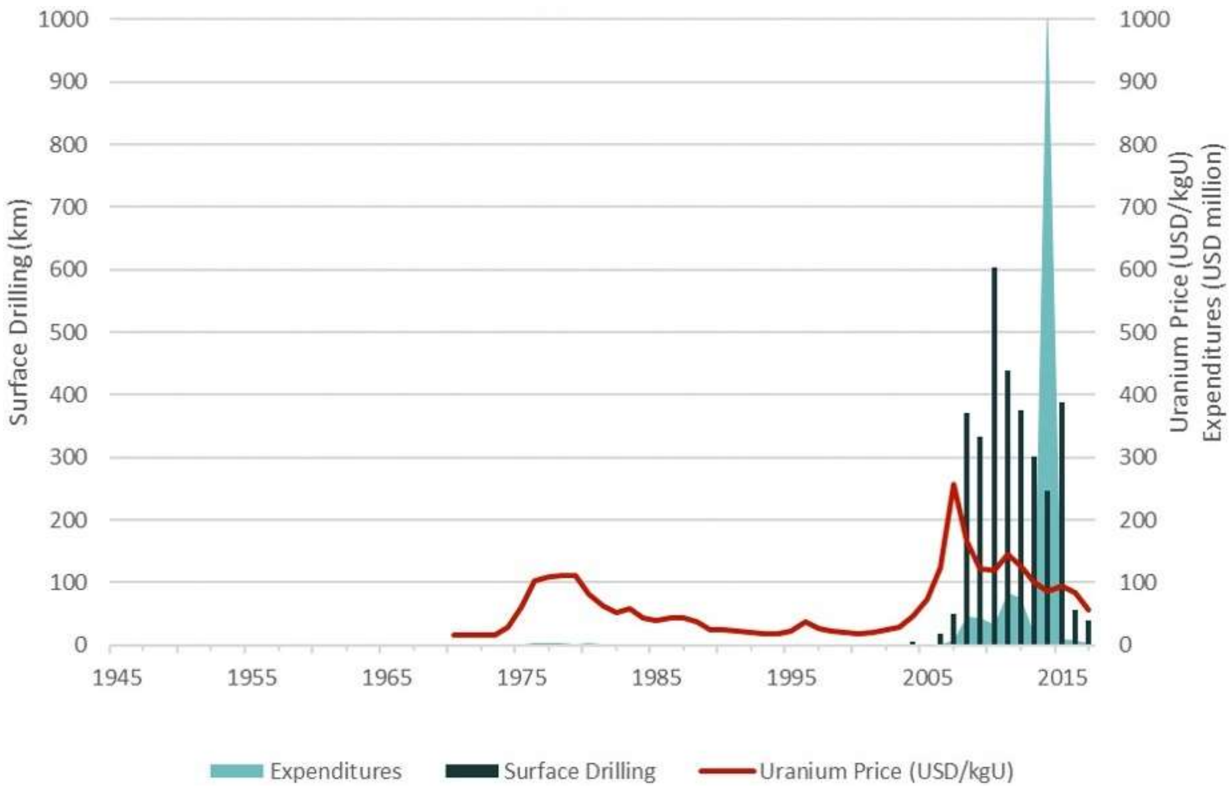


FIG. 2.39. Exploration activities in Namibia.

For the United States of America (USA), expenditures and surface drilling show similarities to those in Australia and Canada, with exploration expenditures sensitive to the uranium price. However, compared to the 1970-1980 period, when the price of uranium increased, exploration activities in the USA, and in particular drilling, have been less important in reaction to the increase of the uranium price in 2006-2008. In 2005, the USA recorded an increase in exploration expenditures, growing from USD 0.35 million in 2002 to USD 77.8 million (Fig. 2.40).

Rising uranium (and vanadium) prices renewed interest in uranium exploration in several states, in particular in Arizona, Colorado, South Dakota, Wyoming and Texas. Exploration expenditures peaked in 2008, with USD 246.4 million spent, then declined to USD 71.9 million in 2016. This decrease is primarily the result of the current depressed uranium market. Exploration and development drilling, the most important part of the expenditures, increased from 381 km in 2004, up to 2 181 km in 2012, then decreased to 231 km in 2016. Exploration has primarily been for sandstone-type uranium deposits, amenable to ISL mining, in districts such as the Grants Mineral Belt and Uravan Mineral Belt of the Colorado Plateau, in the Wyoming basins and in Texas Gulf Coastal Plain region. Most exploration occurred on deposits that were identified in the 1970s and earlier, or on extensions and satellites of operating mines. However, some exploration activities included previously unexplored targets.

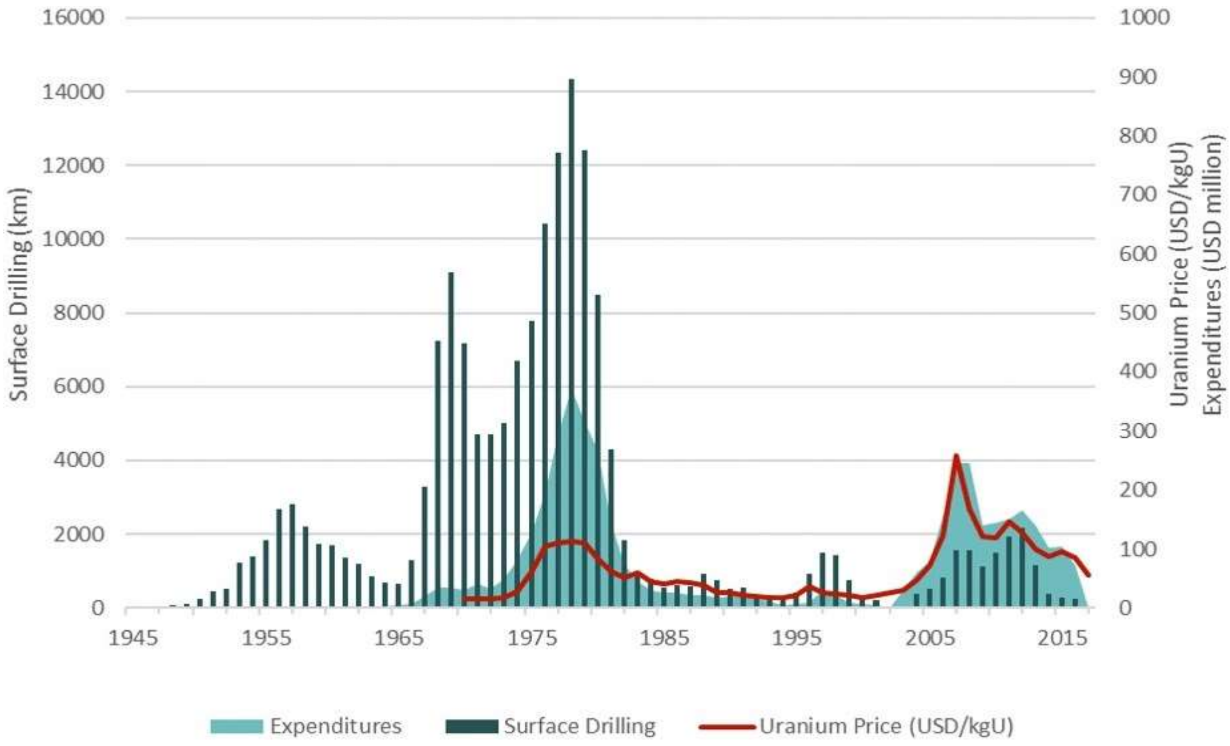


FIG. 2.40. Exploration activities in the United States of America.

2.9.2. Uranium exploration expenditures abroad

Non-domestic expenditures are a subset of domestic expenditures - totals reported on a country by country basis are a total of expenditures from domestic and foreign sources within each country (Table 2.54).

TABLE 2.54. NON-DOMESTIC URANIUM EXPLORATION AND MINE DEVELOPMENT EXPENDITURES (USD 1000)

Country	Pre-2004	2004-2016	Total
Australia	NA	NA	NA
Belgium	4 500	0	4 500
Canada (a)	27 916	327 728	355 644
China (b)	0	3 110 800	3 110 800
France	753 694	854 188	1 607 882
Germany	403 158	0	403 158
Japan(c)	418 158	39 568	457 726
Korea, Rep of	24 049	NA	24 049
Russian Federation	NA	279 137	279 137
Spain	20 400	0	20 400
Switzerland	29 657	22	29 679
United Kingdom	61 263	0	61 263
United States	260 598	NA	260 598
Total	> 2 003 566	> 4 611 443	> 6 614 836

(a) USD 327 728 000, from 2004 to 2007, then data not available;
(b) Since 2007. Government expenditures only from 2007 to 2010. Industry expenditures only from 2014 to 2016;
(c) Data not available in 2004-2006. Government expenditures only.

A very important increase in non-domestic exploration and development expenditures started in 2005 and continued afterwards despite the decline of uranium price after 2007 (Fig. 2.41). As the total exploration expenditures, non-domestic exploration and mine development expenditures are much more important from 2003 to 2016, compared to the 1972-2003 period. Only four countries, China, France, Japan and Russia reported non-domestic expenditures since 2005, with more than 85 % of total expenditures reported by China from 2013 to 2016. Canada did not reported non-domestic expenditures after 2007, although it continued to be an important investor. Australia is also known to make foreign investment, but no figures are reported since 2006.

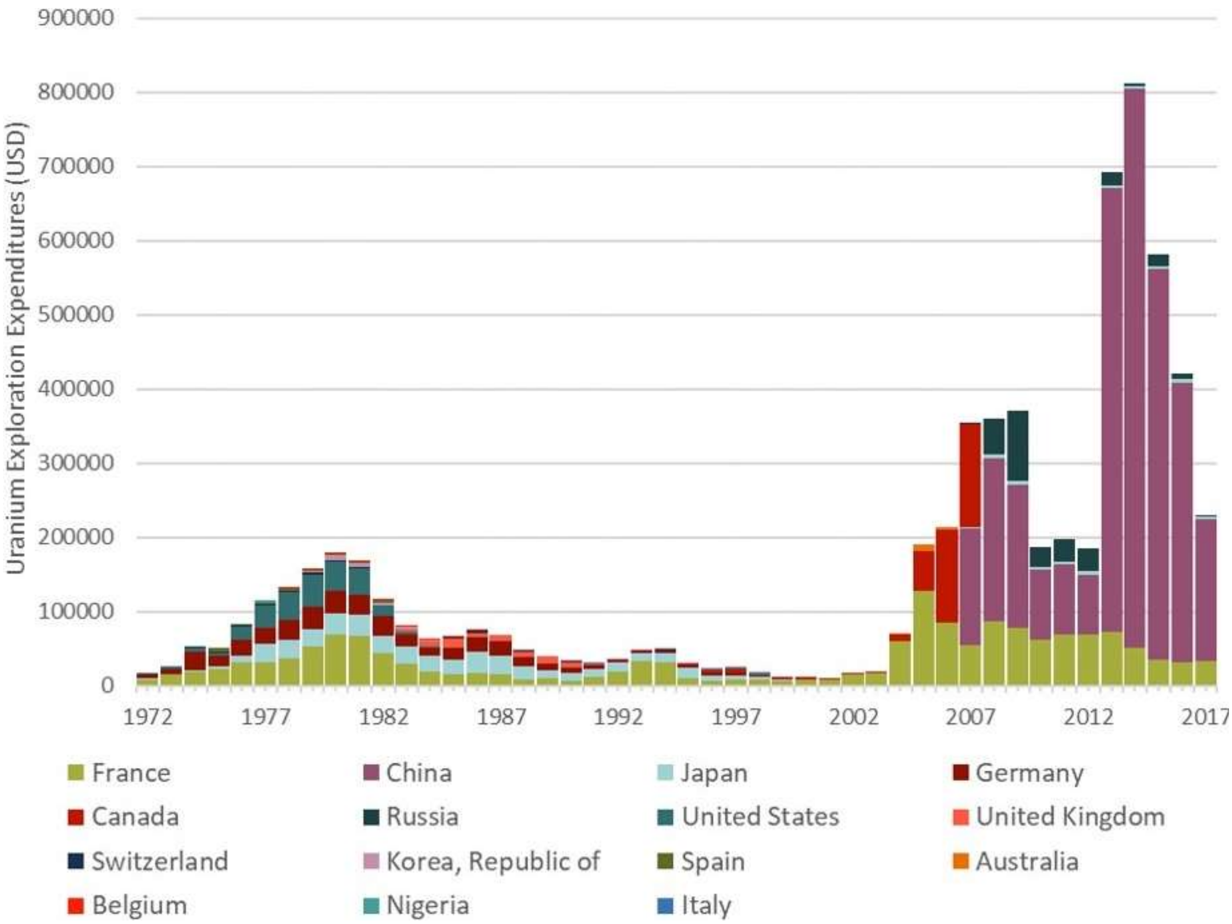


FIG. 2.41. Uranium exploration expenditures abroad (compare to Appendix 5.6 in the 2003 Red Book Retrospective).

2.9.3. Discovery cost

Discovery cost (Expenditures / Resources + production) measures the effectiveness of past exploration activity. Although the expenditures database is incomplete, sufficient data provide a good evaluation of past exploration effectiveness (Table 2.55, Fig. 2.42). In 2003 the known resources recoverable at costs <USD130/kgU amounted to 345 000 tU. As of January 2017, only 62 890 tU are reported in the same cost category. The average discovery cost in the countries listed in Table 2.55 is USD 3.13/kgU, an increase of 61 % compared to 2003 cost (USD 1.88/kgU). The average discovery cost in countries from the former USSR, Kazakhstan, Russia, Ukraine and Uzbekistan is USD 2.15/kgU, a 4% decrease compared to the average discovery cost in 2003 (USD 2.25/kgU).

Compared to 2003 [2.45], all the selected countries show an increase of their discovery cost, in particular Australia (USD 0.43 to 0.84 / kgU), Canada (USD 1.18 to 6.09 /kgU), Niger (USD 0.68 to 1.86 /kgU), the United States of America. (USD3.57 to 9.10 /kgU). The increase in Australia, Canada and Niger are due to important exploration expenditures made in these countries since 2003, proportionally more important than the resources increases, while in the United States of America the increase of the discovery cost is related to important decrease of the known resources.

TABLE 2.55. DISCOVERY COST OF KNOWN RESOURCES + PRODUCTION (RECOVERABLE AT COSTS <USD 260 /KGU) IN SELECTED COUNTRIES
(compare to Table 5.3 and Appendix 5.7 in the 2003 Red Book)

Country	RAR (tU)	IR (tU)	Retrospective)RAR + IR (tU)	Production (tU)	KR + Production (tU)	Exploration expenditures (USD 1000)	Discovery cost (USD/kgU)
Argentina	11 000	20 000	31 000	2 582	33 582	129 745	3.94
Australia	1 400 600	654 200	2 054 800	206 620	2 261 420	1 730 314	0.84
Brazil	149 000	8 000	157 000	12 258	169 258	793 645	5.03
Canada	592 900	253 500	846 400	511 321	1 357 721	7 985 092	6.09
China	136 700	153 700	290 400	43 099	333 499	1 217 000	3.63
Czech Rep	100 800	0	100 800	376 204	477 004	4 341 813	9.10
France	0	0	0	80 976	80 976	907 240	11.20
Gabon	4 800	1 000	5 800	25 403	31 203	102 433	3.28
Germany	1 100	5 100	6 200	84	6 284	341 455	n.a.
India	155 900	120 900	276 800	4 216	281 016	191 304	0.68
Iran	3 000	4 000	7 000	219 731	226 731	2 002 789	8.83
Mali	5 000	3 900	8 900	0	8 900	59 370	6.79
Namibia	259 600	189 700	449 300	160 393	609 693	304 336	0.50
Niger	368 500	172 900	541 400	127 004	668 404	1 403 831	2.35
South Africa	336 400	89 200	425 600	139 776	565 376	1 048 927	1.86
Spain	23 000	11 400	34 400	5 028	39 428	222 998	5.76
United States	50 700	68 200	118 900	112 055	230 955	317 674	1.38
Sub-total	3 599 000	1 755 700	5 354 700	2 026 750	7 381 450	23 099 966	3.13
USSR + Kazakhstan-Russian Fed-Ukraine-Uzbekistan (from 1945 to 2017)*							
	890,100	1,029,400	1,919,500	825,119	2,744,619	5,716,050	2.08
World total	4,489,100	2,785,100	7,274,200	2,851,869	10,126,069	28,816,016	2.85

* Including USD 3 692 350 000 in USSR from 1945 to 1990
Czech Rep[1]. : Exploration expenditures from 1971 to 2017
Germany [2] : Including German Democratic Republic

Discovery cost of Total (identified and undiscovered) Resources (recoverable at costs <USD 260/kgU) and Production in selected countries increased in almost all the countries (Table 2.56, Fig. 2.42- and Fig 2.43) except Argentina (USD 2.66 to 1.04/kgU), Brazil (USD 0.24 to 0.18/kgU), India (USD 3.14 to 2.54/kgU), Spain (USD 8.04 to 5.78/kgU). The average discovery cost from all selected countries increased from USD 0.54/kgU to USD 1.52/kgU. The most important increases are observed in Australia (USD 0.13 to 0.88/kgU), Canada (USD 0.77 to 3.77/kgU), China (USD 0.01 to 3.91/kgU), Namibia (USD 0.08 to 1.68/kgU), Niger (USD 0.66 to 1.66/kgU), Turkey (USD 3.21 to 6.26/kgU), and in the United States of America (USD 0.76 to 8.44/kgU). In the former USSR countries (Kazakhstan, Russia, Ukraine,

Uzbekistan), the average discovery cost decreased from USD 1.07/kgU to USD 1.30/kgU between 2003 and 2017.

Between 2003 and 2017, undiscovered resources decreased significantly in Australia (2 600 000 tU of undiscovered resources were reported in 2003 (Speculative resources in the 1993 edition of the Red Book 1993), 0 tU in 2017), China (1 773 600 tU in 2003, 7 700 tU in 2017), in the United States (2 613 000 tU in 2003, 0 tU in 2017). The increase of discovery cost in Canada, Namibia, Niger and Turkey are due to important exploration expenditures made in these countries since 2003.

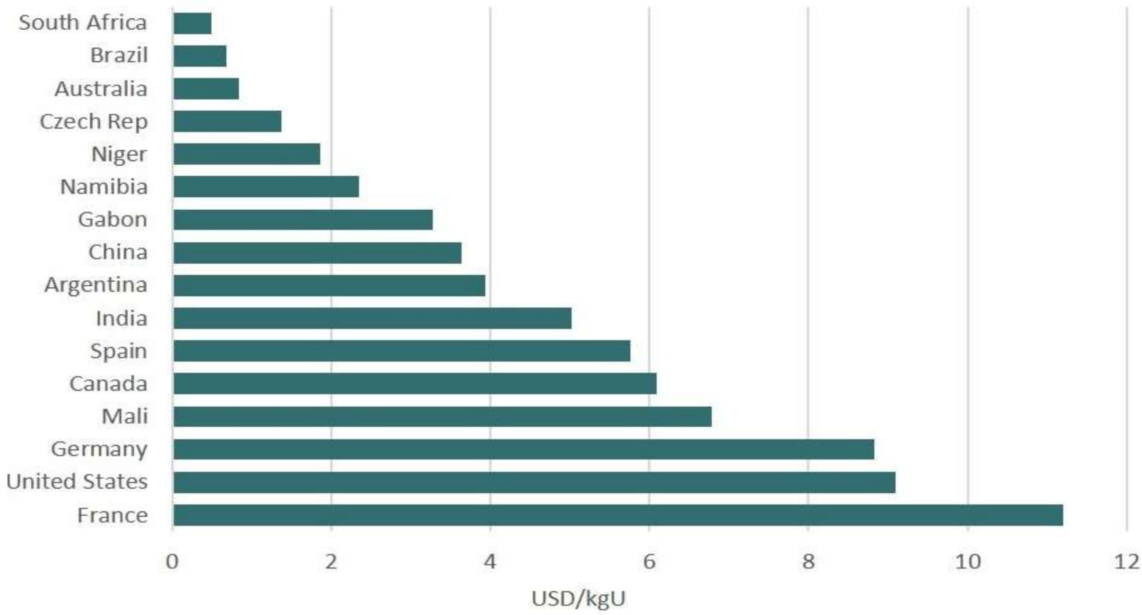


FIG. 2.42. Discovery costs of known resources + production in selected countries.

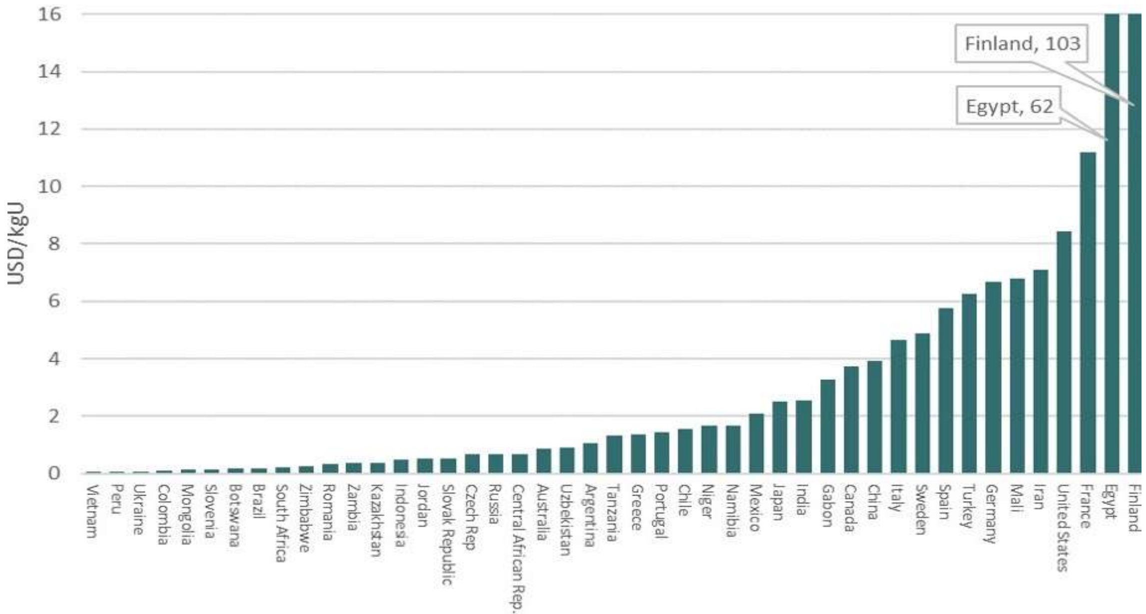


FIG. 2.43. Discovery Cost of Total (Known and Undiscovered) Resources (recoverable at costs <USD 260/kgU) and Production in selected countries.

2.9.4. Resources

In 2005, the terminology of Estimated Additional Resources-Category I (EAR-I) was changed to Inferred Resources (IR), Known Conventional resources (KCR) to Identified Resources, Estimated Additional Resources Category II (EAR-II) to Prognosticated Resources (PR). In 2009, a high cost resource category (USD 130/kgU to USD 260/kgU) was added to complement previous editions that reported resources available at costs up to the USD 130/kgU.

TABLE 2.56. DISCOVERY COST OF TOTAL (KNOWN AND UNDISCOVERED) RESOURCES (RECOVERABLE AT COSTS <USD 260/KGU) AND PRODUCTION IN SELECTED COUNTRIES
(Compare to Appendix 5.8 in the 2003 Red Book Retrospective)

Country	Identified Resources (tU)	Undiscovered Resources (tU)	Total Resources (tU)	Production (tU)	Total Resources plus production (tU)	Exploration Expenditures (USD 1000)	Discovery Cost (USD/kgU)
Argentina	31 000	93 300	124 300	2 582	126 882	132 193	1.04
Australia	2 054 800	n.a.	1 780 800	206 620	1 987 420	1 750 112	0.88
Botswana	73 500	0	73 500	0	73 500	12 629	0.17
Brazil	276 800	800 000	1 076 800	4 216	1 081 016	191 917	0.18
Canada	846 400	850 000	1 696 400	511 321	2 207 721	8 267 219	3.74
Central African Republic	32 000	0	32 000	0	32 000	21 800	0.68
Chile	1 500	4 700	6 200	0	6 200	9 618	1.55
China	290 400	7 700	298 100	43 099	341 199	1 334 000	3.91
Colombia	0	228 000	228 000	0	228 000	25 946	0.11
Czech Republic	118 900	240 000	358 900	112 055	470 955	317 701	0.67
Egypt	1 900	0	1 900	0	1 900	117 271	61.72
Finland	1 200	0	1 200	30	1 230	126 227	102.62
France	0	0	0	80 976	80 976	907 240	11.20
Gabon	5 800	0	5 800	25 403	31 203	102 433	3.28
Germany	7 000	74 000	81 000	219 731	300 731	2 002 789	6.66
Greece	7 000	6 000	13 000	0	13 000	17 547	1.35
India	157 000	165 400	322 400	12 258	334 658	851 030	2.54
Indonesia	7 600	30 200	37 800	0	37 800	18 976	0.50
Iran	6 100	45 600	51 700	84	51 784	367 359	7.09
Italy	6 100	10 000	16 100	0	16 100	75 060	4.66
Japan	6 600	0	6 600	84	6 684	16 697	2.50
Jordan	43 500	50 000	93 500	0	93 500	48 793	0.52
Kazakhstan	904 500	530 600	1 435 100	293 202	1 728 302	667 195	0.39
Mali	8 900	0	8 900	0	8 900	60 403	6.79
Mexico	5 000	13 000	18 000	49	18 049	37 949	2.10
Mongolia	113 500	1 411 000	1 524 500	535	1 525 035	216 796	0.14
Namibia	541 700	167 700	709 400	127 004	836 404	1 408 578	1.68
Niger	425 600	64 900	490 500	139 776	630 276	1 048 927	1.66
Peru	33 400	39 700	73 100	0	73 100	4 776	0.07

Country	Identified Resources (tU)	Undiscovered Resources (tU)	Total Resources (tU)	Production (tU)	Total Resources plus production (tU)	Exploration Expenditures (USD 1000)	Discovery Cost (USD/kgU)
Portugal	7 000	1 500	8 500	3 720	12 220	17 637	1.44
Romania	6 600	6 000	12 600	19 049	31 649	10 060	0.32
Russia	656 900	735 000	1 391 900	164 904	1 556 804	1 051 147	0.68
Slovak Republic	15 500	10 900	26 400	211	26 611	14 003	0.53
Slovenia	9 200	1 100	10 300	382	10 682	1 581	0.15
South Africa	449 300	850 000	1 299 300	160 393	1 459 693	304 336	0.21
Spain	34 300	0	34 300	5 028	39 328	227 189	5.78
Sweden	9 600	0	9 600	200	9 800	47 900	4.89
Tanzania	58 200	0	58 200	0	58 200	78 211	1.34
Turkey	7 000	0	7 000	0	7 000	43 797	6.26
Ukraine	219 100	397 500	616 600	131 436	748 036	60 547	0.08
United States	100 800	n.a.	138 200	376 204	514 404	4 341 813	8.44
Uzbekistan	139 200	24 800	164 000	132 691	296 691	269 715	0.91
Vietnam	3 900	402 800	406 700	0	406 700	23 189	0.06
Zambia	27 300	0	27 300	86	27 386	9 732	0.36
Zimbabwe	1 400	25 000	26 400	0	26 400	6 902	0.26
Sub-Total	7 753 000	7 286 400	14 802 800	2 773 329	17 576 129	26 666 940	1.52
USSR + Kazakhstan-Russian Fed-Ukraine-Uzbekistan (from 1945 to 2017)							
	1 919 700	1 687 900	3 607 600	825 119	4 432 719	5 740 954	1.30
World Total	9 672 700	8 974 300	18 410 400	3 598 448	22 008 848	32 407 894	1.47

* Including USD 3 692 350 000 in USSR from 1945 to 1990

Czech Rep[1]. : Exploration expenditures from 1971 to 2017

Germany [2] : Including German Democratic Rep.

Kazakhstan [3] : Exploration expenditures since 1992

Mongolia [4] : Exploration expenditures from 1992 to 2017

Romania [5] : Exploration expenditures since 1994

Russian Fed [6] : Exploration expenditures since 1990

Ukraine [7] : Exploration expenditures since 1996

Uzbekistan [8] : Exploration expenditures since 1994

Figure 2.44 shows the changes in Reasonably Assured Resources (RAR) over time for different production cost categories. Resources in the lower cost category, <USD40/kgU, shows an important increase from 1995 to 2005, with a maximum of 1 947 000 tU in 2005. This increase, independent of the uranium price, is the result of re-evaluation of deposits and addition of resources that was not previously reported (Russian Federation, Ukraine). From 2007 to 2009, RAR dropped to 570 000 tU, reflecting the increase in the mining costs and the decrease of the U price. Since then, the amount of RAR in that category remains in the range of 500 000 tU, with an increase to 713 400 tU in 2017. Resources in the <USD80/kgU cost category, showed a decrease in 2013, from 2 015 000 tU to 1 212 000 tU, reflecting a continued trend towards higher production costs. Resources in the <USD 130/kgU cost category, continued to increase, independently of the U Price, as a result of resources transfer from lower cost category. Inclusion of the new higher cost category (USD 130/kgU to USD 260/kgU) added 479 000 tU in 2009, 950 000 tU in 2017, to RAR, principally as a result of resources reported in Botswana, Canada, Kazakhstan Namibia, Niger, Russian Federation, Ukraine and the United States of America.

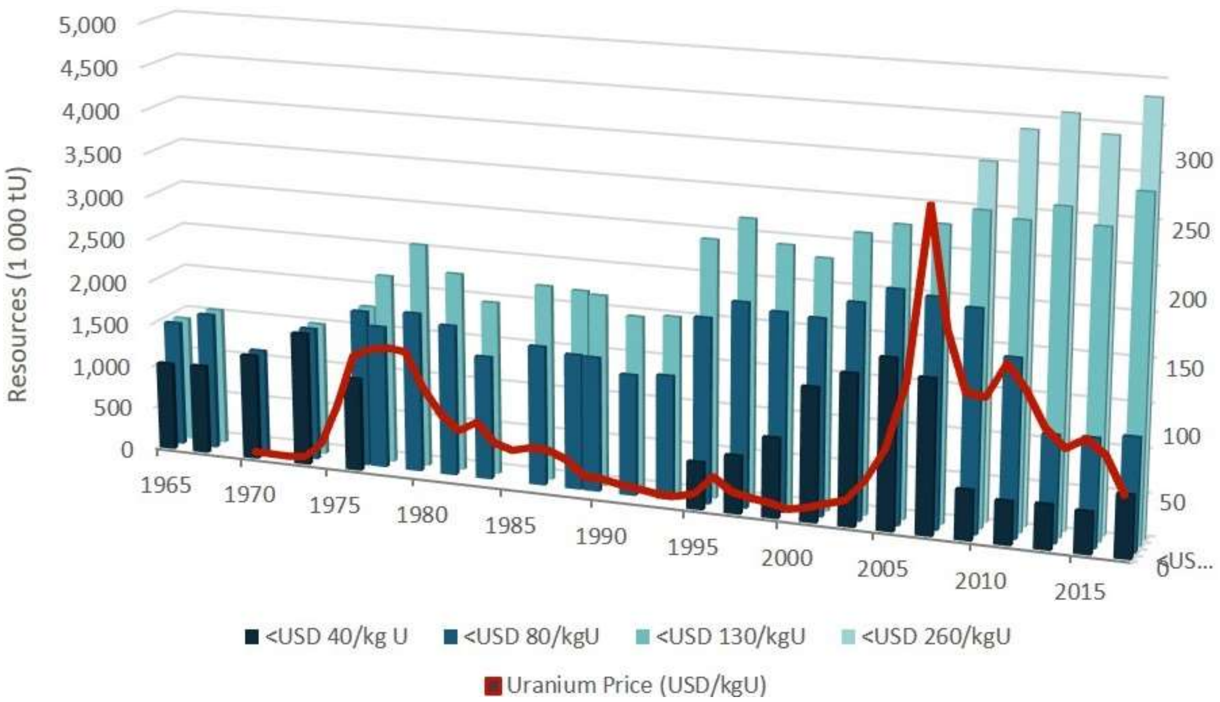


FIG. 2.44. Changes in RAR over time compared to Uranium market price (compare to Table 6.1 in the 2003 Red Book Retrospective).

Figure 2.45 shows the changes in inferred resources over time for different production cost categories. In the <USD40/kgU and <USD80/kgU cost categories, we observe a parallelism between market price and resources. One explanation for this parallelism could be related to exploration activities. A decrease in the market price would affect the level of exploration activities, in particular in 'greenfields' projects, the budgets being affected to delineation works, which tend to convert already identified IR to RAR. In the <USD130/kgU cost category, we see a continuous increase of the resources until 2007, followed by a small decrease in 2009, in parallel to the decrease of the uranium price. From 2013 to 2017, a significant increase of the resources in the <USD130/kgU and <USD260/kgU cost categories came from Greenland with the addition of 86 000 tU and the Czech Republic with 68 000 tU. A reclassification of prognosticated to inferred resources in Kazakhstan also contributed to the increased overall total.

As for the RAR and IR, a new cost category (USD 130/kgU to USD 260/kgU) was added in 2009 for the prognosticated and speculative resources (Fig. 2.46). The 2003-2017 period is characterized by a decrease of the total speculative resources in 2003, when China changed the total speculative resources from 1.77 million tU to 4 100 tU, and a decrease in all categories in 2013, a large percentage of the decline being attributed to the United States of America who did reported undiscovered resources in 2013. Prognosticated and speculative uranium resources for the United States of America were last assessed in 1980. Records of these estimates are no longer available. For this reason, undiscovered resources are no longer reported pending development of new undiscovered resources estimates and/or confirmation of the older estimates. In the SR categories, lower values were also reported in the Czech Republic and the Russian Federation.

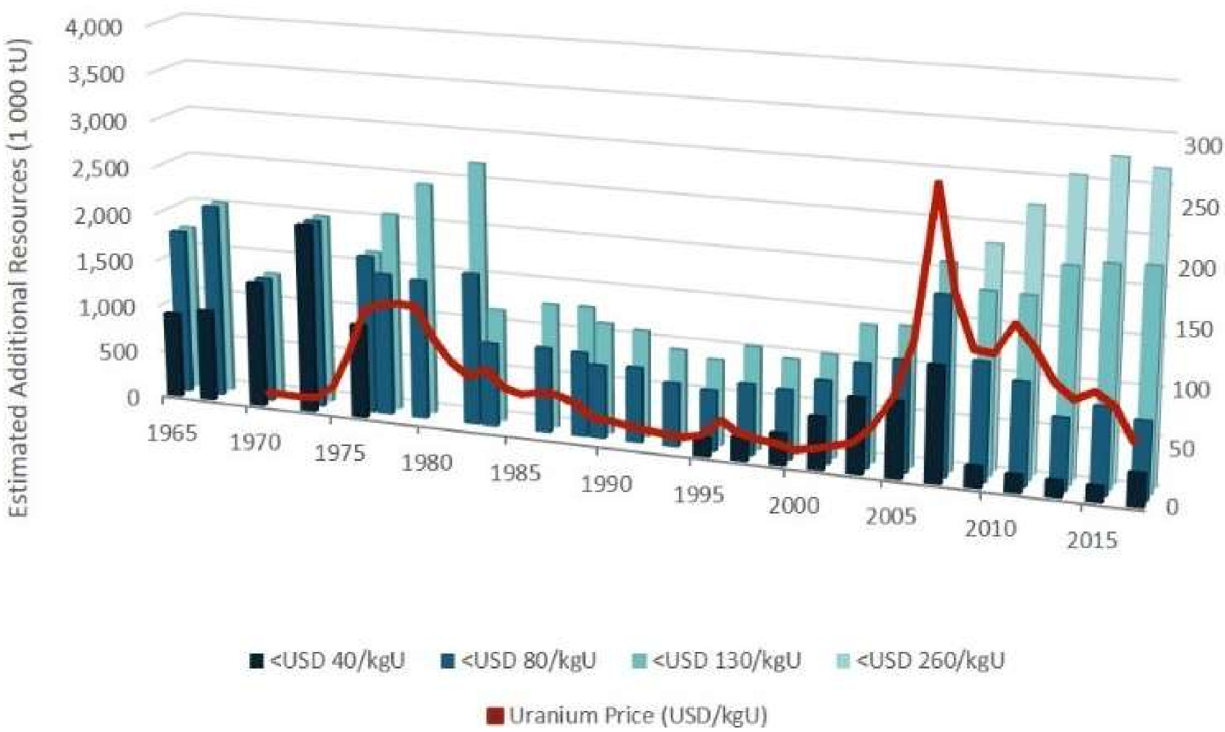


FIG. 2.45. Changes in Inferred Resources over time compared to marked price (compare to Table 6.2 in the 2003 Red Book Retrospective).

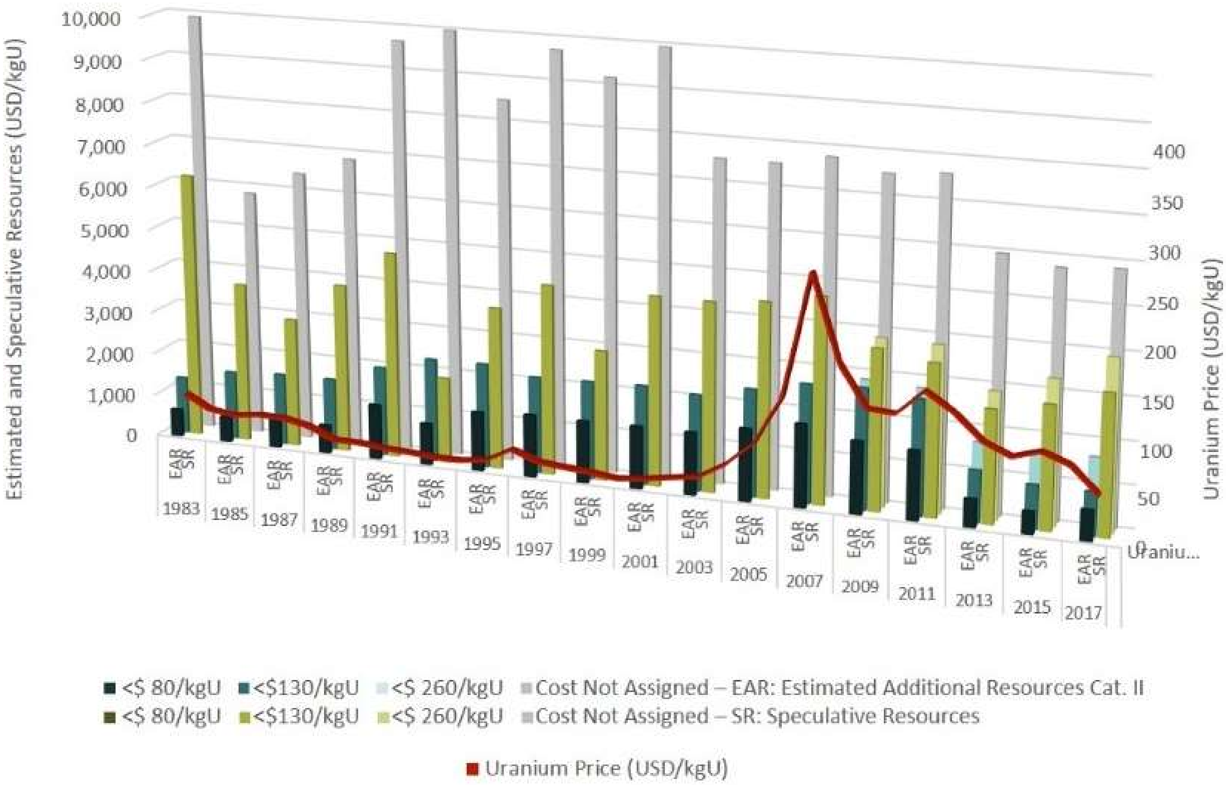


FIG. 2.46. Changes in Undiscovered Resources over time compared to marked price (compare to Table 6.2 in the 2003 Red Book Retrospective).

2.9.4.1. Changes in resources over time for selected countries

Figure 2.47 shows how known conventional resources, adjusted for production, have varied over time in Australia, Canada and the United States. The reasons for these variations are discussed in Figs 2.48 to 2.53. Figs 2.54 to 2.58 provide information on changes over time in identified resources for additonal selected counties (Brazil, France, Namibia, Niger, South Africa).

There are several reasons for changes in resources over time: Production is greater than discovery of new resources, or new resources are greater than production. Following a resource evaluation, resources may change and/or move to a different cost category (as observed in 1983, when resources in Canada and USA decrease following re-evaluations associated to an increase of the mining costs). Resources may be removed from country totals when associated to production centres closures, and/or because of environmental issues.

In Australia, known conventional resources, adjusted for production increased significantly from 2003 to 2009, reflecting discovery of new resources (Fig. 2.48). In Canada, the increase of known conventional resources, adjusted for production, has been regular and continuous since 1983. In the United States, known conventional resources, adjusted for production, stayed at the same level until 2005, when it started to decrease.

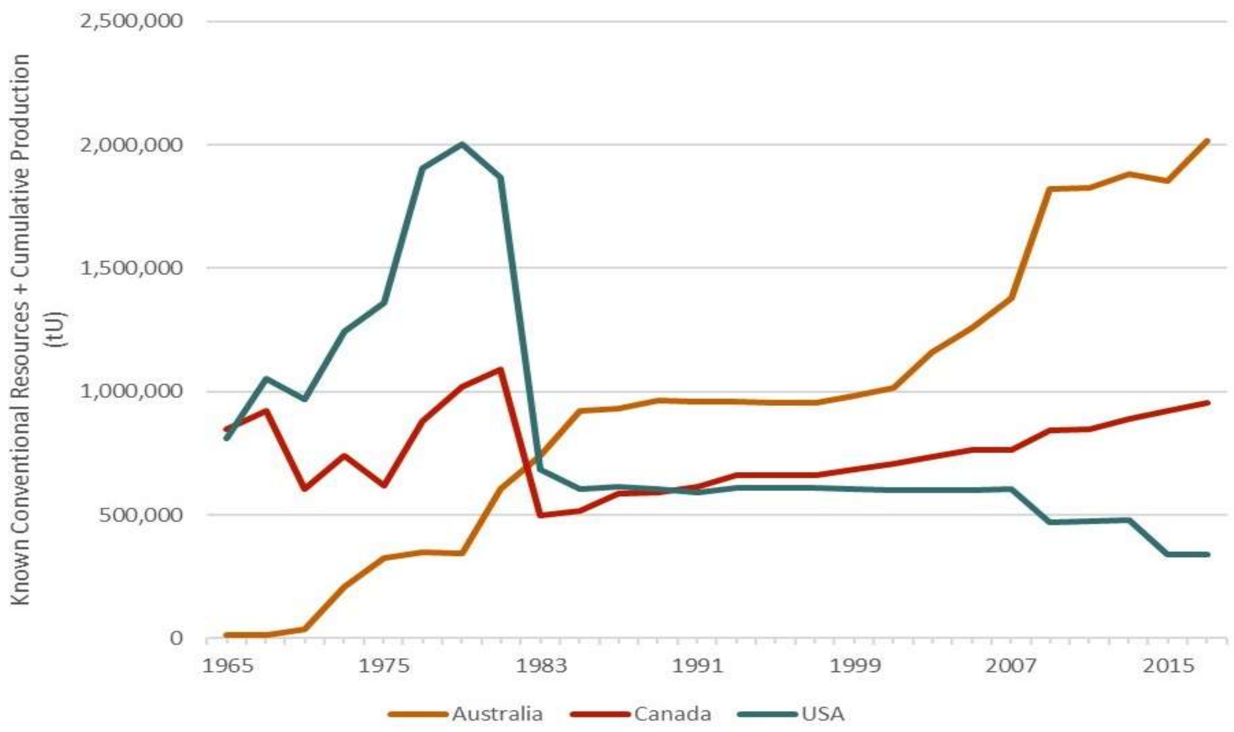


FIG. 2.47. Variations in known conventional resources adjusted for production in Australia, Canada and the United States (compare to Fig. 6.4 in the 2003 Red Book Retrospective).

For the period after 2003, Figure 2.48 shows the parallelism between uranium market price and know resources in the <USD80/kgU cost category, with a lag of 1-2 years between the two. The decrease in 2013 of the RAR and IR could be related to the impact of increasing mining and milling costs. As a result, resources are moved in higher cost categories compared with previous estimates. Since 2015, Australia no longer reports resources in the lower cost categories.

In 2004 and 2005 (Fig. 2.49), drilling in Australia increased considerably (since 2006, Australia no longer report drilling activity). Drilling activities were located in the Frome Embayment, in the region of Honeymoon, in Western Australia and in the south western portion of Olympic Dam. These activities outlined new resources that where reported the following years, in particular at Olympic Dam. As of 1 January 2017, total identified resources recoverable at costs <USD130/kgU amount to 1 818 300 tU, compared to 1 158 000 tU in 2003 (+72%).

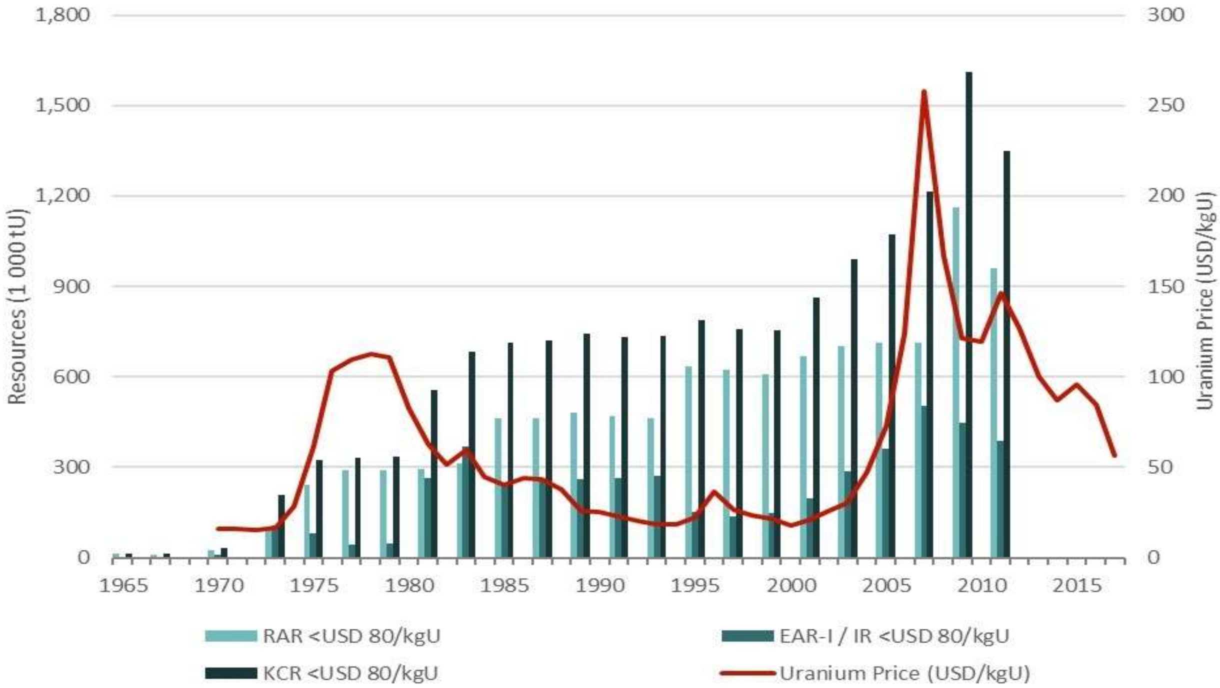


FIG. 2.48. Comparison of resource trends in Australia and uranium market price (compare to Fig. 6.5 in the 2003 Red Book Retrospective).

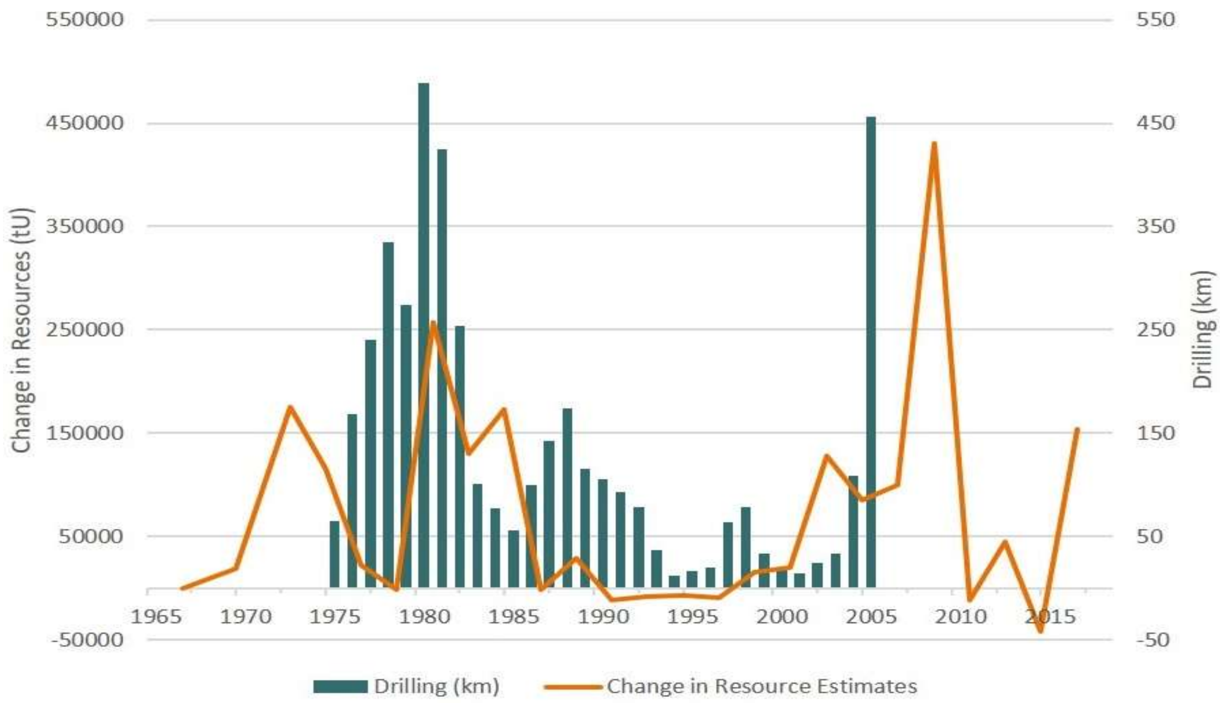


FIG. 2.49. Australian resources (known resources in the <USD130/kgU cost category) and drilling (compare to Table 6.6 in the 2003 Red Book Retrospective).

From 1995 to 2013, there are no major changes of resources in Canada, and in particular no change when the U price peaked in 2007 (Fig. 2.50). In 2015, we observe a significant decrease of the known resources recoverable at a cost <USD 80/kgU, due to mining depletion and transfer of resources into higher cost categories (KR decreased by 23% compared to 2013). Drilling activities in Canada (Fig. 2.51) peaked in 2007 (853 000 m), decreased in 2009, then was steady between 2010 and 2015 (484 000 m). Related to that drilling activity, total resources in the higher cost categories increased, due to the discovery of new deposits (Arrow, Griffon, Phoenix, Tripple R deposits).

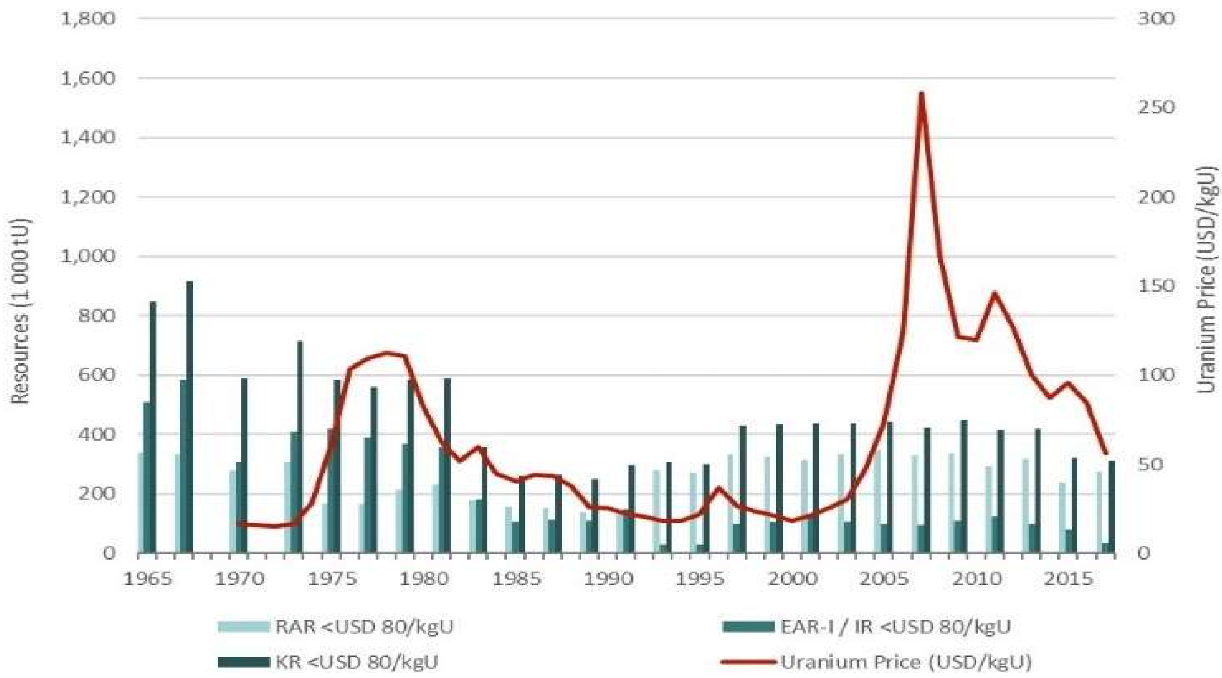


FIG. 2.50. Comparison of resources trend in Canada and uranium market price (compare to Fig. 6.7 in the 2003 Red Book Retrospective).

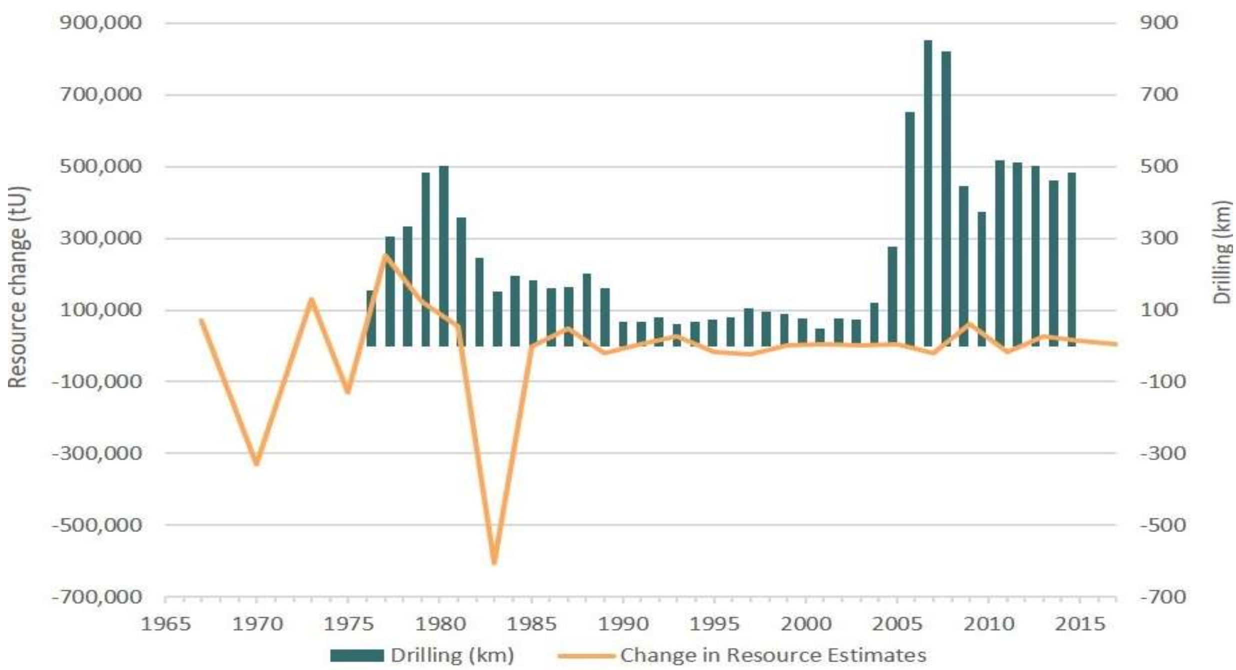


FIG. 2.51. Canada resources (known resources in the <USD130/kgU cost category) and drilling (compare to Fig. 6.8 in the 2003 Red Book Retrospective).

In 2009, the USA updated its RAR estimates (Fig. 2.52). The estimate of RAR for the <USD 80/kgU category as of 1 January 2009 was 39 064 tU, down from the 2003 estimate of 102 000 tU. Differences from the 2003 estimates for the <USD 80/kg U are based on a revised examination of major USA properties, considering increases in mining costs, re-assessments of current resources, newly assessed properties, and mine depletion. In general, higher mining costs over the past several years have resulted in resources being shifted from lower-cost to higher-cost categories (Fig. 2.53). The USA do not report resources in the Inferred category.

Known resources in Brazil did not changed between 2003 and 2013 (Fig. 2.54). In 2015, known resources increased as a result of exploration activities on favourable albititic areas in the north part of the Lagoa Real province.

Following the closure of the last operating uranium mine in 2001, there was no longer known resources recoverable at a cost <USD80/kgU in France (Fig. 2.55).

In Namibia, known resources in the USD80/kgU cost category decreased in 2009 to almost no resources, and were no longer reported in that category after 2011 (Fig. 2.56). But, resources in the < USD130/kgU cost category increased with additional resources defined in all deposits including, Rossing, Langer Heinrich, Husab, Trekkopje, Valencia.

In Niger, known resources in the USD80/kgU cost category increased in 2003-2005 related to re-evaluation of resources following the feasibility study of the Ebba deposit, and transfer of resources previously classified as EAR-II to EAR-I (Fig. 2.57). In 2007, RAR decreased following delineation drilling. After 2001, almost all the existing resources reported in the <USD80/kgU were transferred to higher cost category. Resources in the <USD 130/kgU cost category increased from 227 600 tU in 2003, to 280 000 tU in 2017.

In South Africa, known resources in the <USD80/kgU cost category increased in 2007, then decreased in 2011, in close relation with variations in the uranium price. No changes are observed related to the increase of gold price after 2005 (Fig. 2.58).

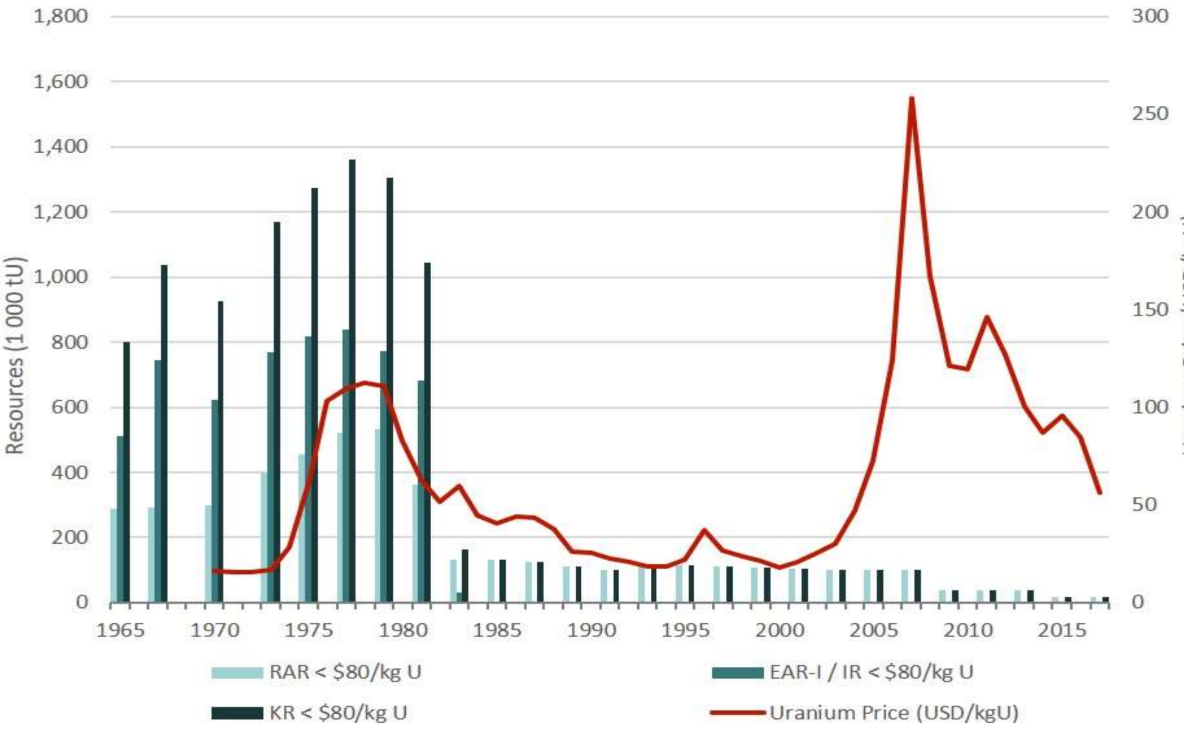


FIG. 2.52. Comparison of resources trend in the United States of America and uranium market price (compare to Fig. 6.9 in the 2003 Red Book Retrospective).

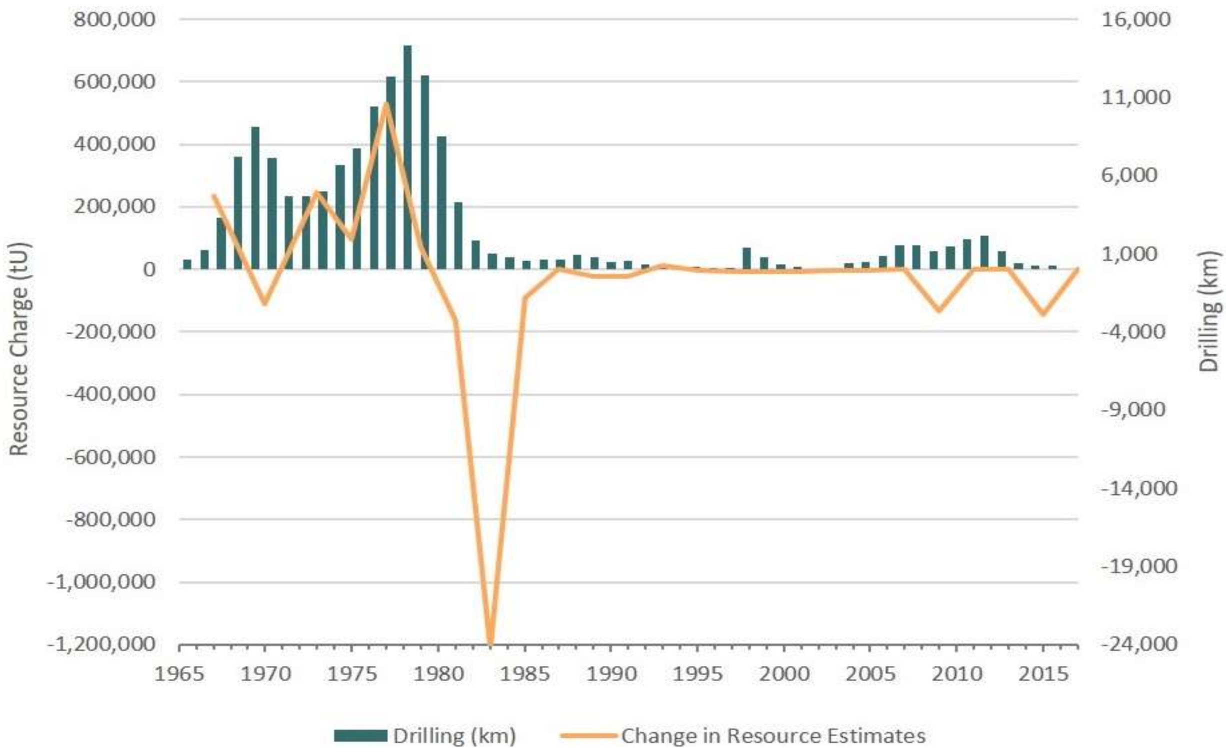


FIG. 2.53. United States of America resources (known resources in the <USD130/kgU cost category) and drilling (compare to Fig. 6.10 in the 2003 Red Book Retrospective).

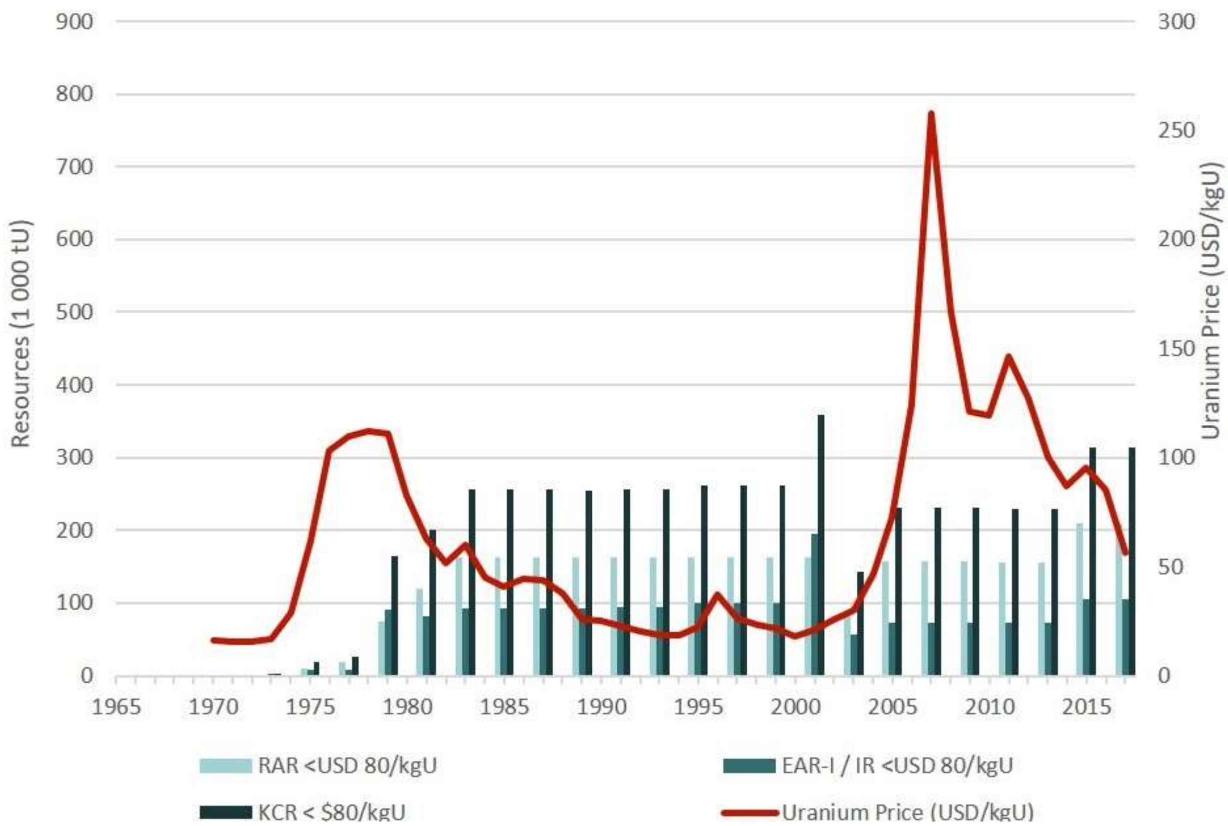


FIG. 2.54. Comparison of resources trend in Brazil and uranium market price (known resources in the <USD80/kgU cost category) (compare to Fig. 6.11 in the 2003 Red Book Retrospective).

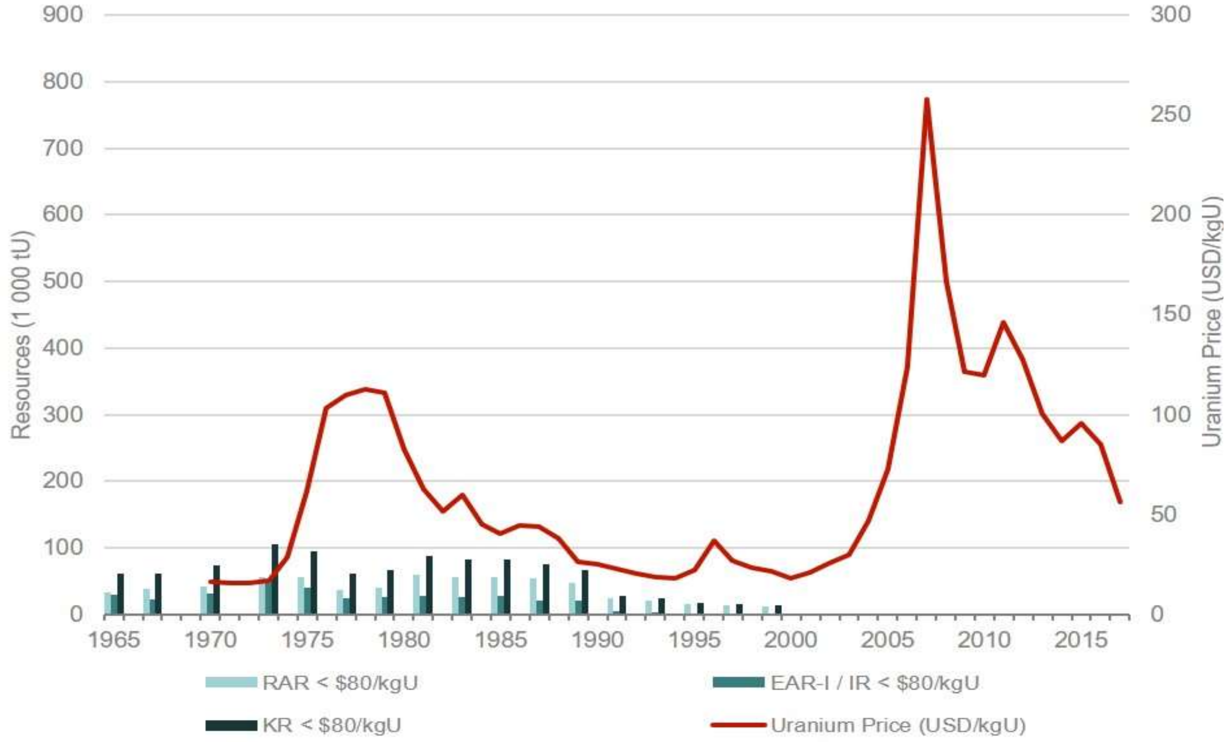


FIG. 2.55. Comparison of resources trend in the France and uranium market price (compare to Fig. 6.12 in the 2003 Red Book Retrospective).

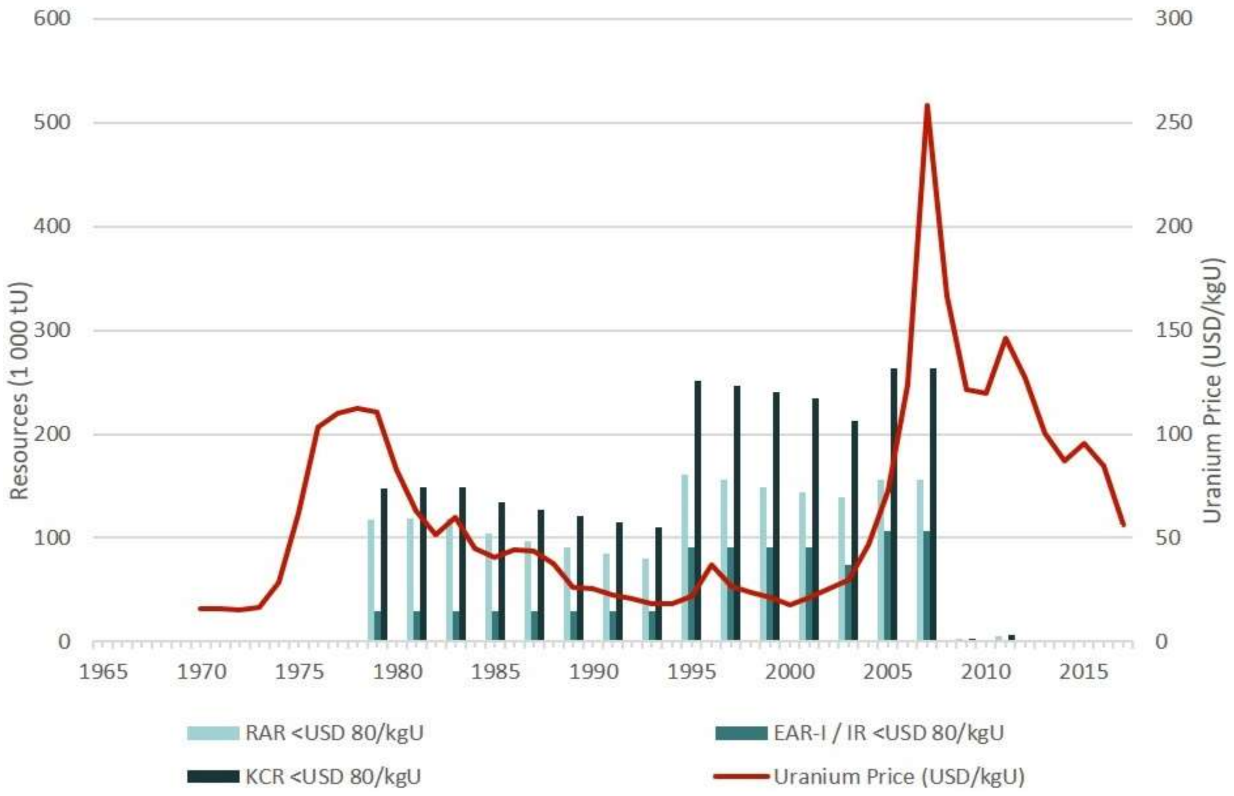


FIG. 2.56. Comparison of resources trend in Namibia and uranium market price (known resources in the <USD80/kgU cost category) (compare to Fig. 6.13 in the 2003 Red Book Retrospective).

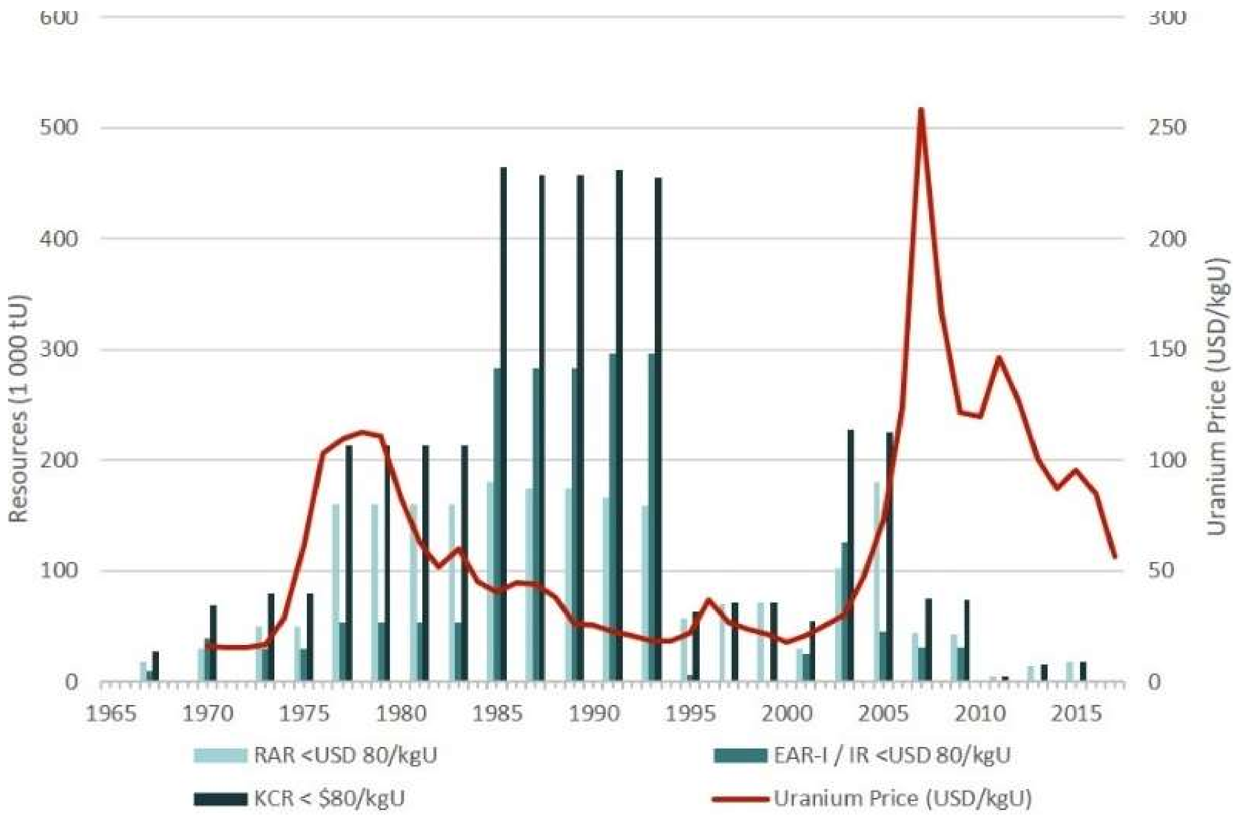


FIG. 2.57. Comparison of resources trend in Niger and uranium market price (known resources in the <USD80/kgU cost category) (compare to Fig. 6.14 in the 2003 Red Book Retrospective).

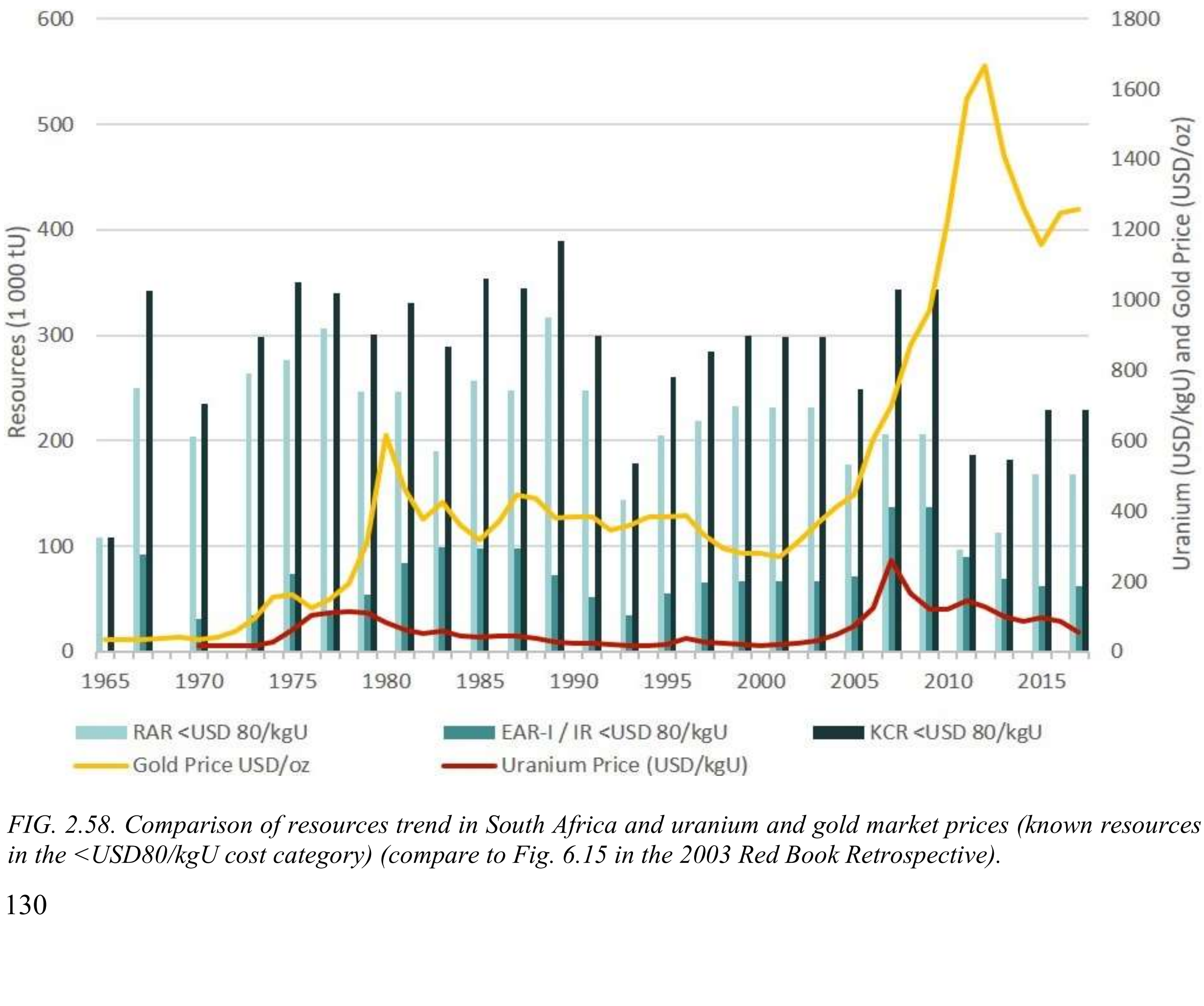


FIG. 2.58. Comparison of resources trend in South Africa and uranium and gold market prices (known resources in the <USD80/kgU cost category) (compare to Fig. 6.15 in the 2003 Red Book Retrospective).

2.9.4.2. *Uranium Resources vs Uranium Requirements*

Comparison between uranium resources and uranium requirements is a key measure of the future balance between supply (mine production) and demand (reactor-related requirements). Figure 2.59 compares the ratio between RAR and KR (reported in the <USD 130/kgU cost category) and annual reactor related uranium requirements.

In 2003, RAR amounted to 3 169 000 tU equivalent to 46 years of uranium requirements (68 435 tU). KR amounted to 4 588 000 tU equivalent to 67 years of uranium requirements. Reactor requirements increased until 2007 (69 110 tU), as the known resources (5 468 000 tU,) then showed a decrease trend. As of January 2017, RAR amounted to 3 865 000 tU equivalent to 62 years of uranium requirements (62 825 tU). KR amounted to 6 142 000 tU equivalent to 98 years of uranium requirements.

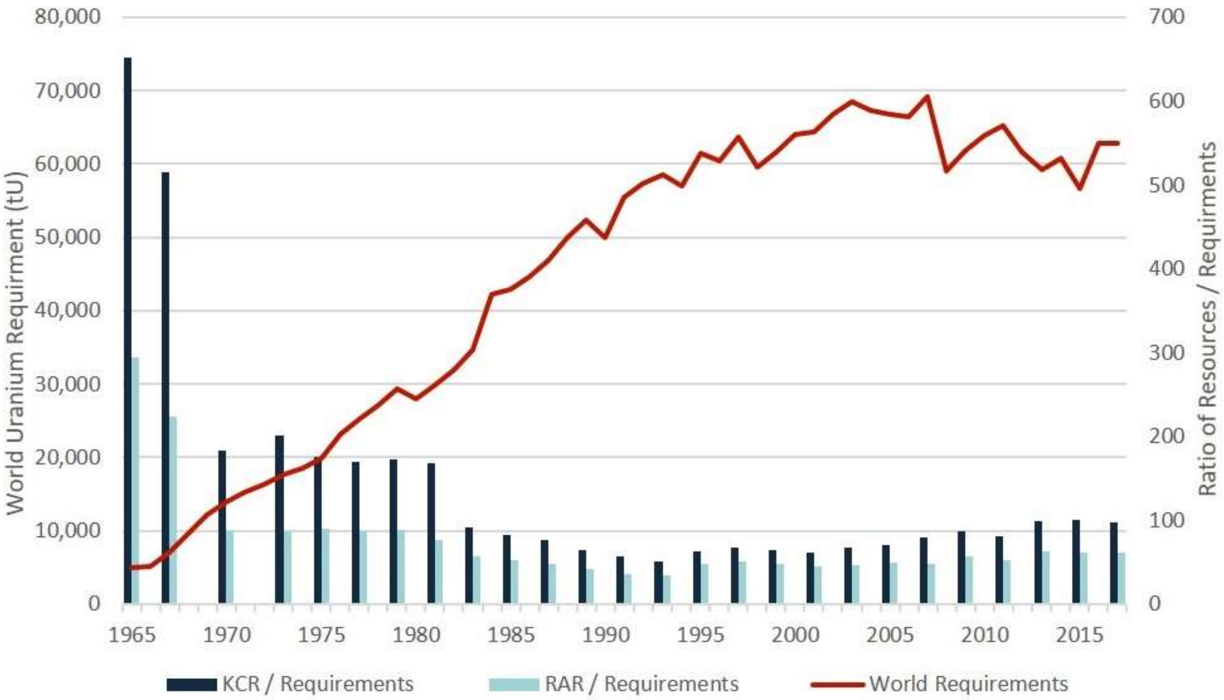


FIG. 2.59. Relationship between uranium resources and reactor-related uranium requirements (compare to Fig. 6.16 in the 2003 Red Book Retrospective).

2.9.4.3. *Relationship between resources and production*

Uranium resources are replenished by exploration and depleted by production. Compared to the situation as of 1 January 2003, total uranium resources + production decreased by 2 530 652 tU, (- 12%) whereas RAR and inferred resources increased (Table 2.57), but this is mainly related to the addition of a higher cost category (USD 80-130 / kgU).

TABLE 2.57. URANIUM RESOURCES AND HISTORICAL PRODUCTION
(As of 1 January 2017) (tU) (Compare to Table 5.2 in the 2003 Red Book Retrospective)

RAR	Inferred resources	Undiscovered resources	Historical production	Total resources + production
4 815 000	3 173 000	7 530 600	2 946 956	18 465 556

Although a higher cost category was added, undiscovered resources decreased from 14 222 290 tU to 7 530 600 tU (- 47%). Prognosticated resources (former EAR-II) increased in Brazil (120 000 tU to 300 000 tU), Russia (104 500 tU to 143 900 tU), South Africa (110 300 TU to 159 000 tU), but decreased in Kazakhstan (310 000 tU to 230 600 tU), in Uzbekistan (85 000 tU to 24 800 tU), and in the United States of America (1 273 000 tU to NA). Speculative resources increased in Ukraine (255 000 tU to 375 000 tU), in Vietnam (230 000 tU to 321 600 tU), but decreased in Kazakhstan (500 000 tU to 300 000 tU), South Africa (1 112 900 tU to 691 000 tU), and United States of America (1 340 000 tU to NA), mainly as a result of re-evaluation of the potential in previously reported areas.

Production in Australia increased between 1995 and 2005 (Fig. 2.60). During the same period, known resources increased at a rate higher than production, which is reflected by an increase of the “total uranium”. Between 2006 and 2014, production decreased. At the same time, total uranium increased in 2009 (+ 413 035 tU, as additional resources were defined at Olympic Dam, Ranger, Mt Fitch, Mt Gee, Westmoreland and Valhalla deposits), but decreased in 2011 (-248 766 tU, as resources were moved into higher cost categories, due to an increase of the mining costs).

In Canada, no major change is observed in the level of production between 2003 and 2013 (Fig. 2.61). Production increased significantly from 9 136 tU in 2014 to 13 325 tU in 2015, related the beginning of mine operations at Cigar Lake in March 2014. The same year, the total uranium decreased by 78 003 tU, related to the decrease of the identified resources in the <USD 40/kgU and USD 80/kgU cost categories, due to mining depletion and transfer of resources into the higher cost categories

In France, following the closure of the last operating uranium mine in 2001, there is no longer known resources (Fig. 2.62). Only a few tonnes of uranium are recovered per year during the water cleaning in the Lodève mine.

In Namibia, from 2003 to 2016, uranium production has increased (Fig. 2.63), but with new resources discoveries higher than production, resulting in an increase of the total uranium, except in 2009. In 2009, Known resources recoverable at cost <USD80/kg U decreased by 260 435 tU, due to the transfer of resources to higher cost categories.

Production in Niger increased in 2010 above 4 000 tU/yr (expansion at Somair and limited production at Azelik), until 2016 when it decreased to 3 477 tU (Fig. 2.64). In 2007, total uranium decreased by 143 527 tU related to resources re-evaluation following delineation drilling and feasibility studies. In 2011, total uranium decreased by 60 455 tU due to the transfer of known resources (recoverable at cost <USD80/kgU) to higher cost categories, despite the identification of new resources in extension to the Imouraren deposit.

Production in South Africa has constantly decreased since 1983, except in 2007 related to the re-opening of 2 gold mines (Fig. 2.65). Since 2003, total uranium has alternately increased or decreased, related to the study of potentially new deposits. In 2005, total uranium decreased due to the re-evaluation of resources and transfer to higher cost categories. In 2007, it increased following the reopening of 2 gold mines, resulting in their uranium resources becoming potentially exploitable, and results of exploration activities. In 2011, total uranium decreased related to the transfer of resources to higher cost categories resulting from the increase of mining costs. In 2015, new resource estimations including additional information from drilling and mining activities led to the increase of total uranium.

In the United States of America, total uranium decreased in 2009 (Re-evaluation of known resources resulting in the transfer of resources to higher cost categories) and 2015 (New resources estimations (Fig. 2.66). Resources estimates are available for only 75 mines and properties, compared to approximately 200 mines and properties in the previous estimates).

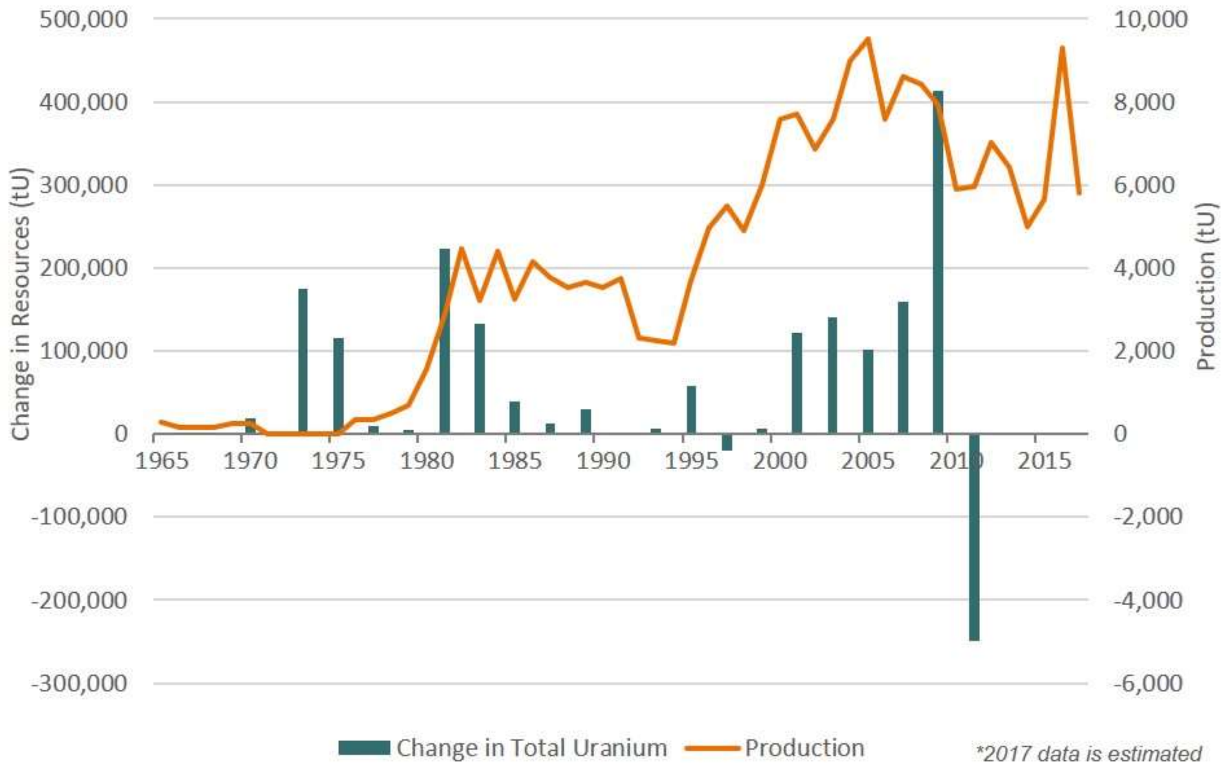


FIG. 2.60. Relationship between changes in total uranium and production in Australia (compare to Fig. 6.17 in the 2003 Red Book Retrospective).

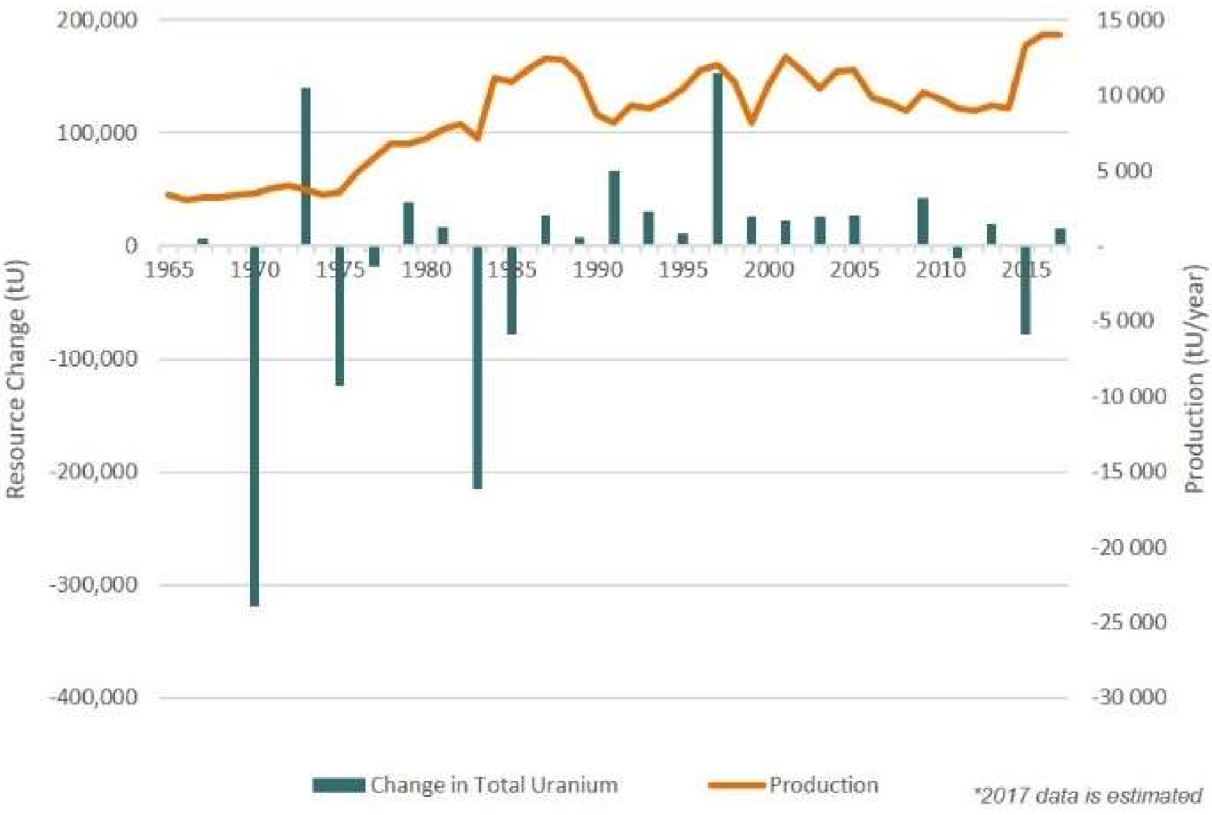


FIG. 2.61. Relationship between changes in total uranium and production in Namibia. (compare to Fig. 6.20 in the 2003 Red Book Retrospective).

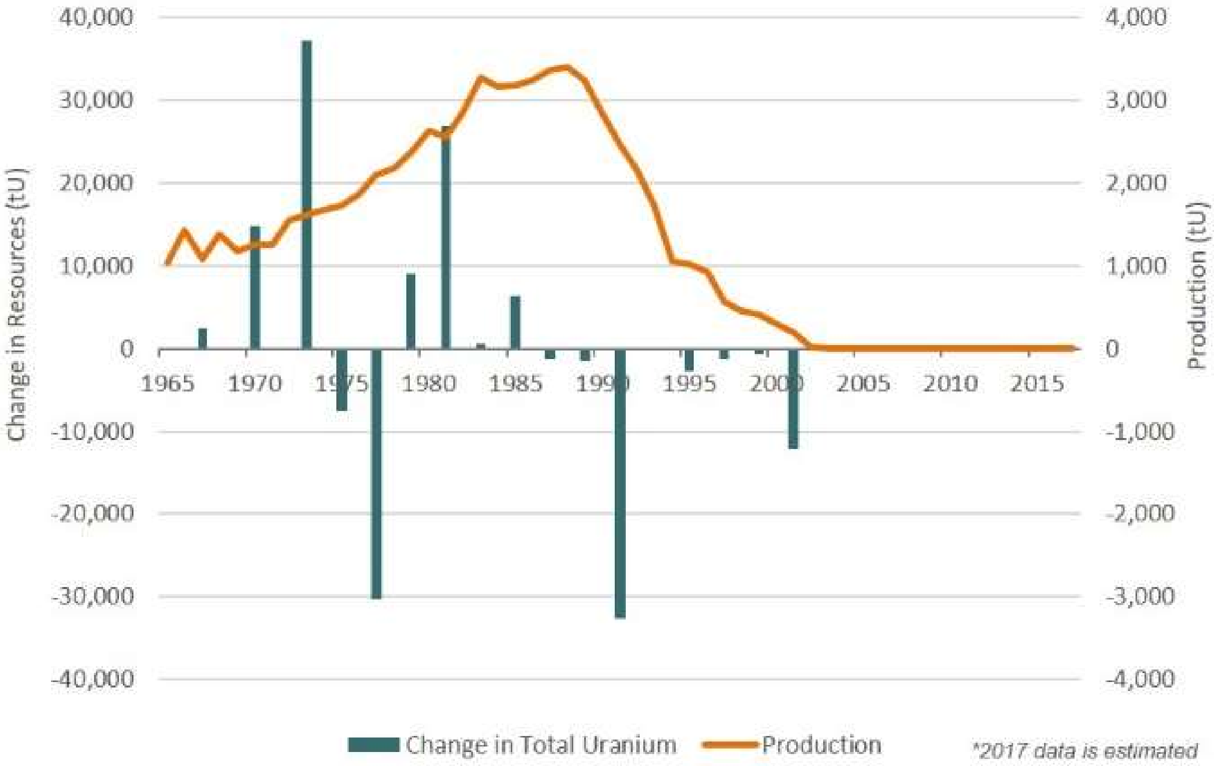


FIG. 2.62. Relationship between changes in total uranium and production in France. (compare to Fig. 6.19 in the 2003 Red Book Retrospective).

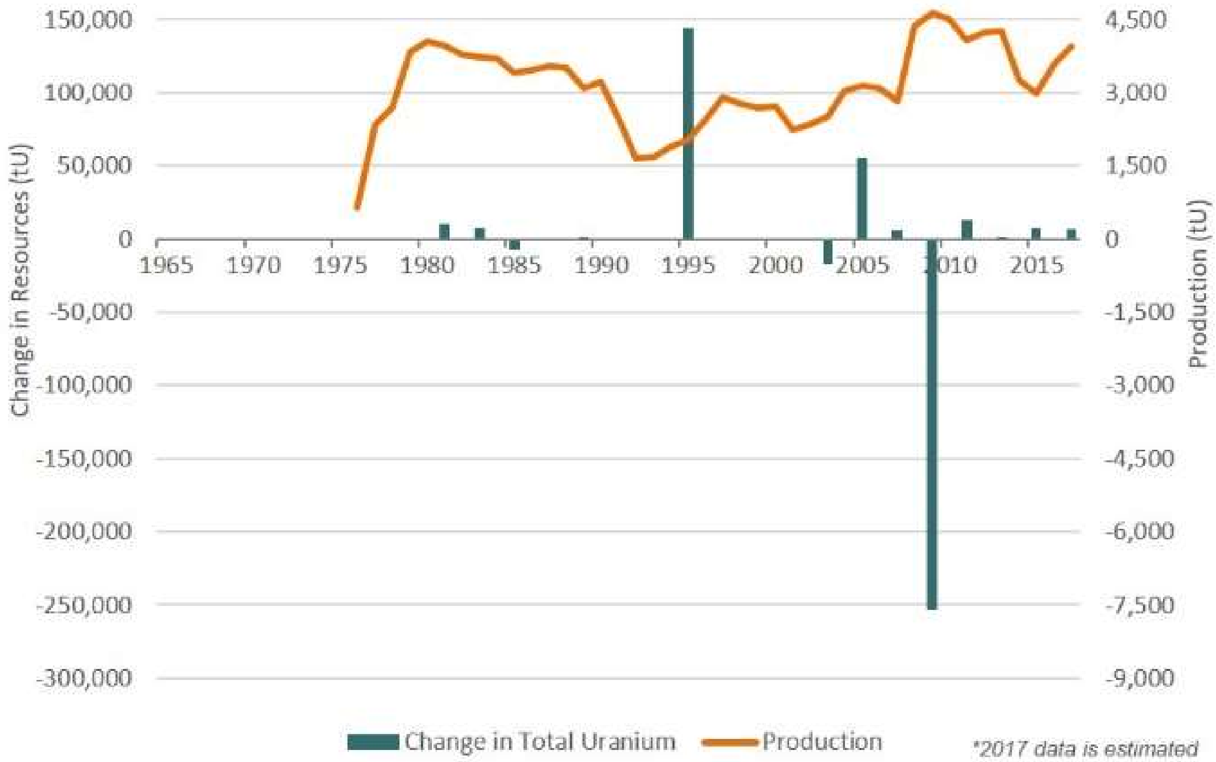


FIG. 2.63. Relationship between changes in total uranium and production in Namibia. (compare to Fig. 6.20 in the 2003 Red Book Retrospective).

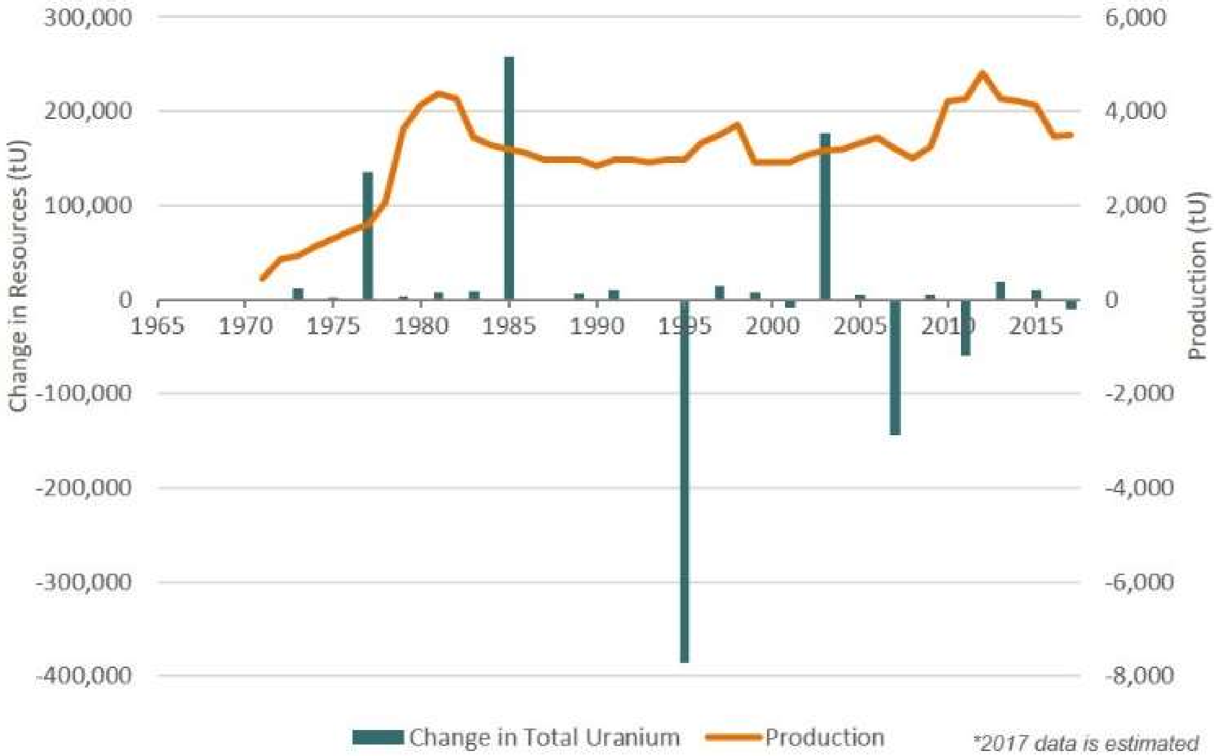


FIG. 2.64. Relationship between changes in total uranium and production in Niger (compare to Fig. 6.21 in the 2003 Red Book Retrospective).

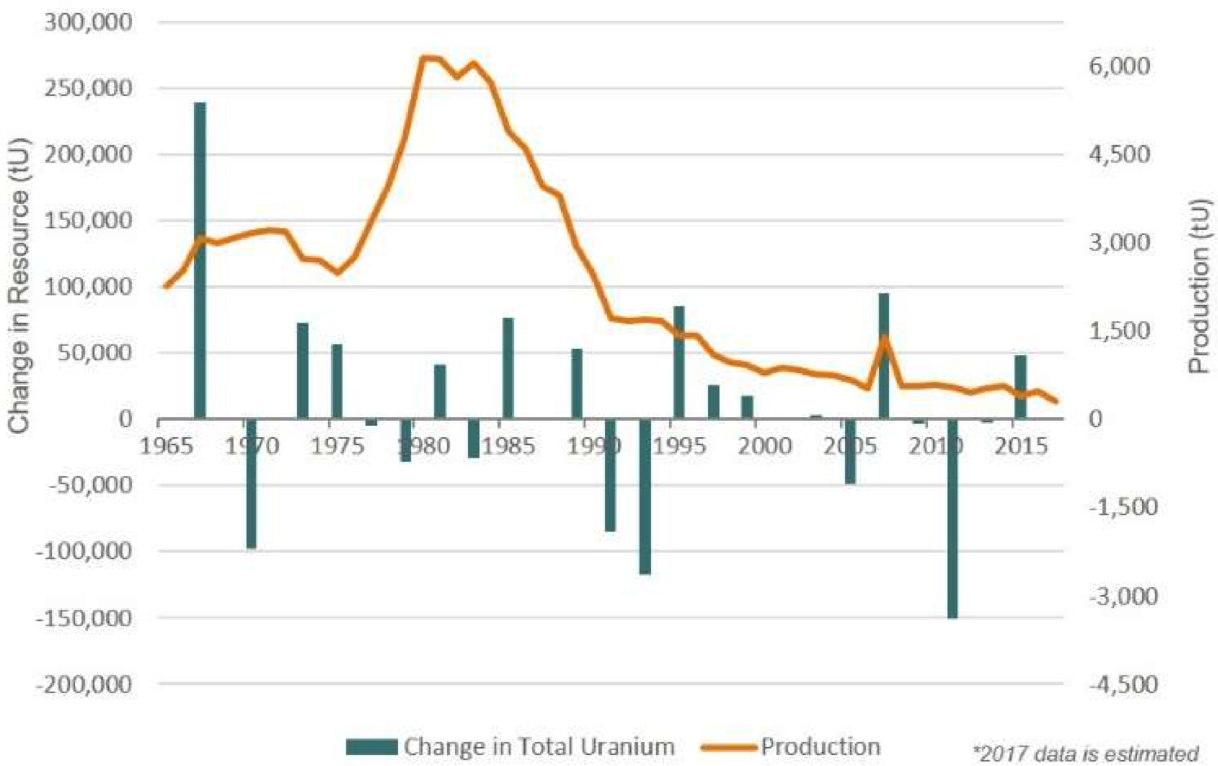


FIG. 2.65. Relationship between changes in total uranium and production in South Africa (compare to Fig. 6.22 in the 2003 Red Book Retrospective).

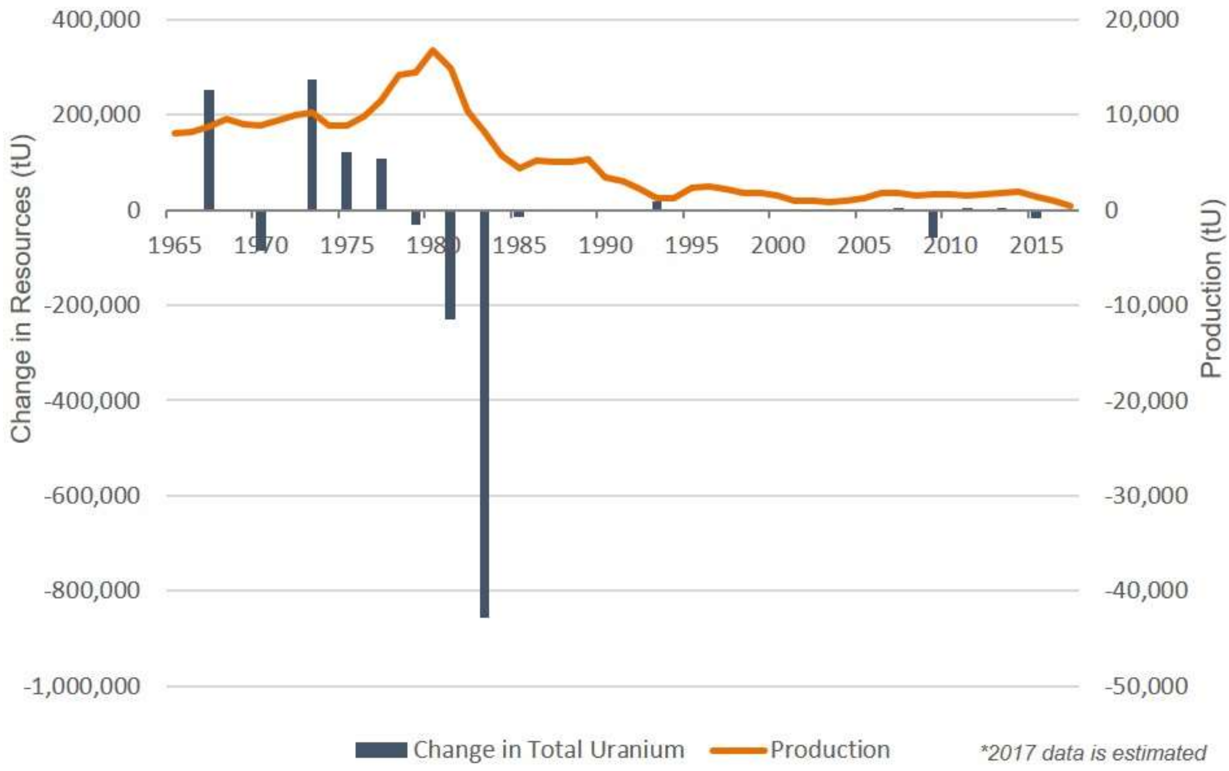


FIG. 2.66. Relationship between changes in total uranium and production in the United States of America (compare to Fig. 6.23 in the 2003 Red Book Retrospective).

2.9.5. Production

Since 1945, uranium has been produced in 41different counties. In 2016, uranium was produced in 18 countries. Production in Kazakhstan (24 689 tU) accounted for 39.8 % of the world production in 2016 (62 071 tU), and only 7 countries (Kazakhstan, Canada, Australia, Namibia, Niger, Russian Federation, Uzbekistan), accounted for about 93 % of the word production (Tables 2.58 and 2.59).

TABLE 2.58. LEADING URANIUM PRODUCER COUNTRIES BASED ON CUMULATIVE PRODUCTION (1945-2016) (compare to Table 7.1 in the 2003 Red Book Retrospective)

Country	tU	Percentage of world total
Canada	511 321	17.4
United States of America	376 204	12.8
Kazakhstan	293 202	9.9
Germany	219 731*	7.5
Australia	206 620	7.0
Russian Federation	164 904	5.6
South Africa	160 393	5.4
Others	1 014 581	34.4
World total	2 946 956	100.0

* Includes production of German Democratic Republic (1946-1989) and Federal Republic of Germany (1961-2016).

Since 1999, there is an almost constant increase of the world uranium production (Fig. 2.67), independent of the uranium price, from 31 929 tU in 1999, to 62 071 tU in 2016 (+ 94 %), the largest increase occurring in 2012 (+ 3673 tU, mainly related to new deposits brought into production in Kazakhstan). During that period, several new production centres were open, the larger ones being in Canada (Cigar Lake), Kazakhstan (Budenovskoye, Irkal, North Kharasan, Semyzbal, Zarechnoye, Zhalpak,), Malawi (Kayelekera), Namibia (Husab), Russia (Khiagda) and Ukraine (Novokonstantinovskoye). Production in Kazakhstan increased from 1 560 tU to 24 689 tU (40% of 2016 world production). In 2017, the world production was expected to amount to 59 282 tU, a decrease of 2789 tU, related to lower production in Australia, Canada, Kazakhstan, Niger and the United States of America. Further decreases in world production are expected for 2018 because of the continued depressed uranium market. In Canada, mining at the McArthur River mine and milling at Key Lake was suspended at the end of January 2018. Kazakhstan, also announced plans to reduce production by a total of 20% over the next three years

TABLE 2.59. HISTORICAL PRODUCTION IN KEY URANIUM PRODUCING COUNTRIES (tU/yr)
(Compare to Table 7.2 in the 2003 Red Book Retrospective)

Country	1970	1980	1990	2000	2005	2010	2016
Australia	254	1 561	3 252	7 579	9 512	5 918	6 313
Canada	3 520	7 150	10 880	10 683	11 628	9 775	14 039
China	500	850	800	700	750	1 350	1 650
Czech Republic (1)	2 627	2 482	2 623	507	409	254	138
France	1 250	2 634	3 189	296	4	9	3
Germany (2)	6 389	5 245	4 470	28	94	8	45
Kazakhstan	x	x	x	1 870	4 346	17 803	24 689
Namibia	0	4 042	3 400	2 715	3 146	4 503	3 593
Niger	0	1 120	3 181	2 914	3 322	4 197	3 477
Russian Federation	x	x	x	2 760	3 285	3 562	3 005
South Africa	3 167	6 146	4 880	798	673	582	490
Ukraine	x	x	x	750	830	837	808
United States	9 900	16 800	4 300	1 522	1 171	1 630	979
USSR (3)	8 300	15 700	15 900	x	x	x	x
Uzbekistan	x	x	x	2 028	2 300	2 874	2 400
Total key producers	35 907	66 720	56 875	35 150	41 470	53 302	61 629
World total	37 736	69 692	60 202	35 755	41 943	54 670	62 071
% of world total	95	96	95	98	99	97	99

(1) Includes production in former Czechoslovakia and Czech Republic;
(2) Includes production of German Democratic Republic and Federal Republic of Germany;
(3) Includes production in former Soviet Socialist Republics of Estonia, Kazakhstan, Kyrgyzstan, Russian Federation, Turkmenistan, Ukraine and Uzbekistan through the end of 1991.

Figure 2.68 shows that since the end of the 1990s, uranium production in OECD countries stays almost at the same level, while the production by non-OECD countries has increased, driven by the increase of the production in Kazakhstan, and at a lesser level in Namibia.

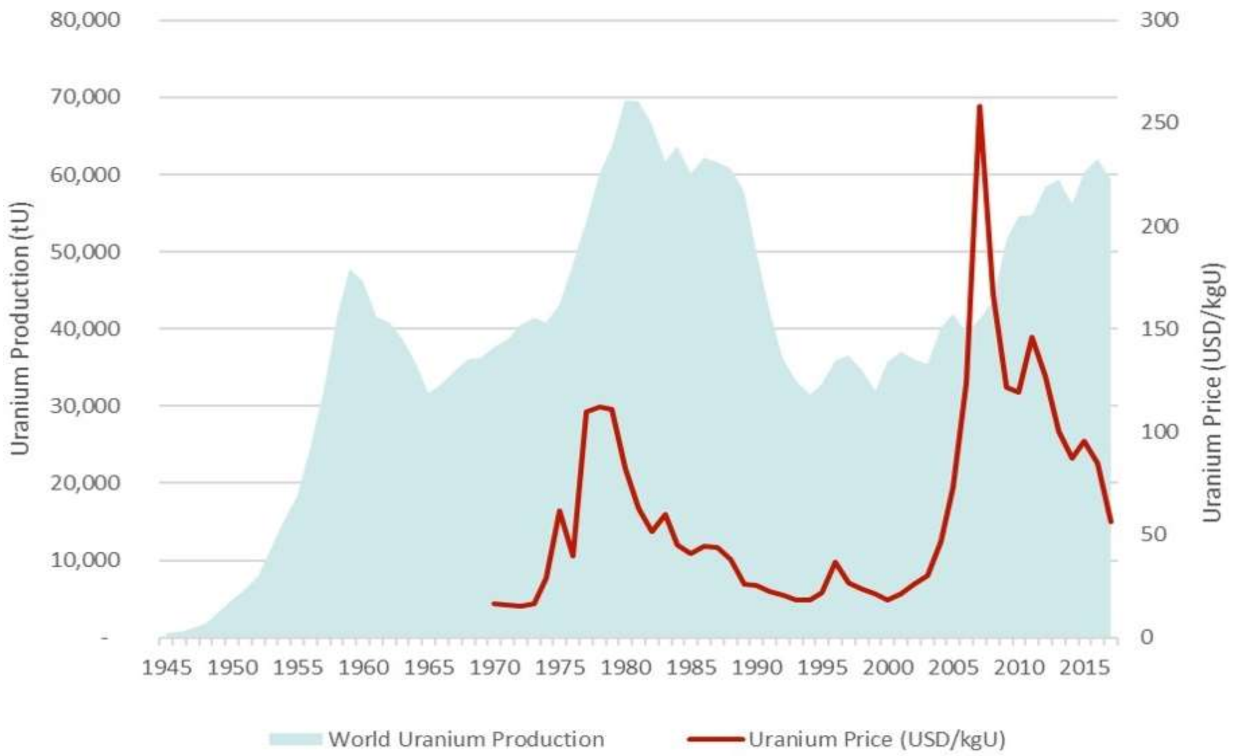


FIG. 2.67. Relationship between historical production and uranium market price (compare to Fig. 7.1 in the 2003 Red Book Retrospective).

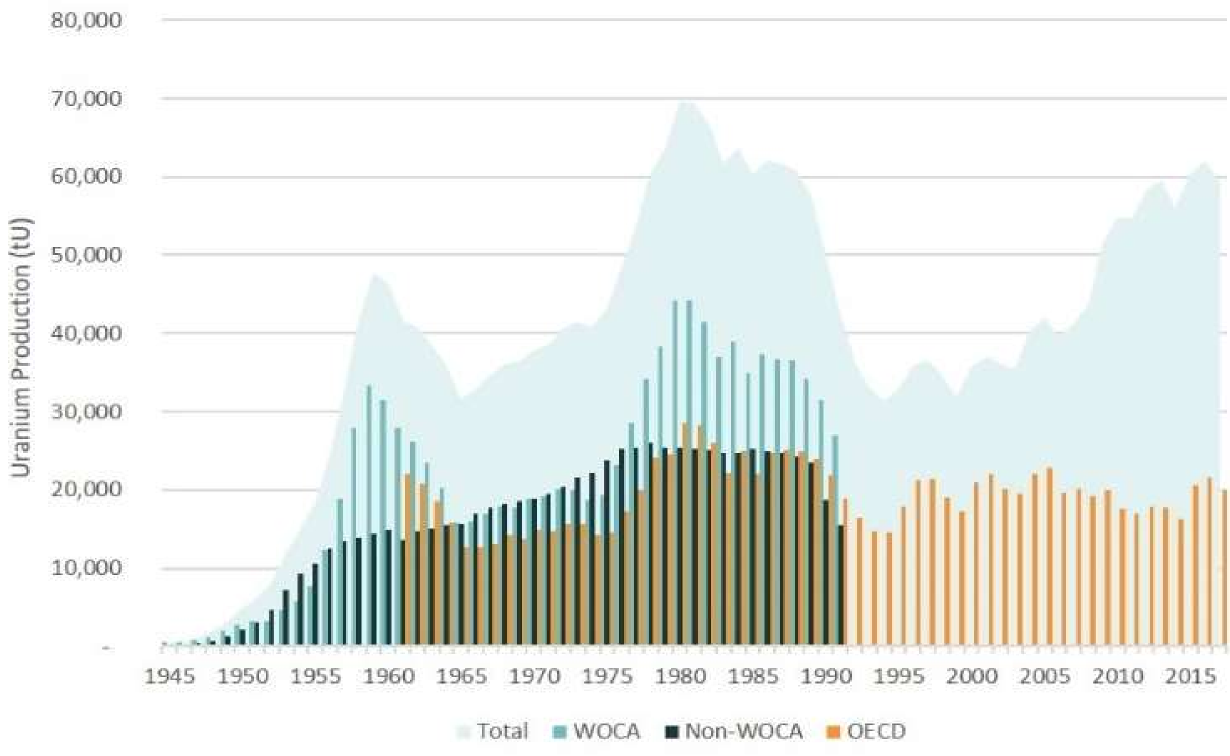


FIG. 2.68. Contributions to Worldwide uranium production by different economic systems (compare to Fig. 7.2 in the 2003 Red Book Retrospective).

From 1993 to 2008, uranium production capacity was below reactor-related requirements (Fig. 2.69). After 2008, with the increase of uranium price, new production centres were planned and constructed, leading to an over capacity as the requirements stayed at the same level. Total world production capacity increased from 50 895 tonnes of U in 2000, in 20 countries, to 97 145 tonnes of U in 2017, in 17 countries, an increase of. 91%. During that period, all existing production centres were closed in 5 countries (Argentina, France, Portugal, Romania and Spain). Mines and processing plants were closed in Canada, China and Kazakhstan. During the same period, production started in 2 countries (Iran and Malawi). (As of 1 January 2017, Kayelekera mine in Malawi is on care and maintenance status). An important increase of the production capacity has been observed in several countries, with the opening of new mines and processing plants. These increases occurred in Australia, Canada, China, India, Iran, Kazakhstan, Namibia, Niger, Russia and Ukraine.

Until 2008, the world production capacity has been under reactor-related uranium requirements (Fig. 2.70). Since then, following the increase of the uranium price, new mine and processing projects have been constructed, mainly in Kazakhstan, Canada and Namibia, raising the capacity/requirements ratio to 1.55. From 2008 to 2016, the production capacity increased from 62 470 tU/year to 97 530 tU/yr (+ 56%).

Until 2007 (Fig. 2.71), the world uranium requirements have increased, then it decreased in 2008 (the decline in uranium requirements in 2008 is likely related to utilities specifying lower tails assays at enrichment facilities and less reactor refuelling scheduled in 2008), and in 2012-2014 (in relation to the accident at the Fukushima Daichi NPP in Japan, all reactors were shut down in Japan). During the same period of time, the annual production slowly increased until 2007, then more importantly from 2009 to 2013. In 2014, after 25 years when production was lower than requirements, production and requirements are at the same level.

As of 1 January 2017, cumulative production amounted to 2 946 956 tU, cumulative requirements to 2 336 772 tU (Fig. 2.72). While production grew quicker than requirements, the gap between production and requirements decreased (610 184 tU in 2017, compared to 691 305 tU in 2003 (- 12 %).

From 1992 to 2007, the ratio of production to reactor-related uranium was less than 0.6 (Fig. 2.73). After 2008, the ratio increased continuously to reach almost 1 in 2013, reflecting the increase in production larger than in requirements. Until that time, the gap between supply and demand was filled with secondary supply. In 2003, production satisfied 52% of reactor-related requirements, 99% in 2016.

Between 2003 and 2017, both uranium production and production capacity continued to increase (Fig. 2.74), but after 2008, the production capacity increase has been higher than uranium production. Consequently, we observe a decrease of the production/capacity ratio from 0.79 in 2009 to 0.61 in 2017. During that period, several mines and processing plants moved to a care and maintenance status (e.g., McArthur River in Canada, Kayelekera in Malawi, Trekkopje in Namibia, Azelik and Imouraren in Niger).

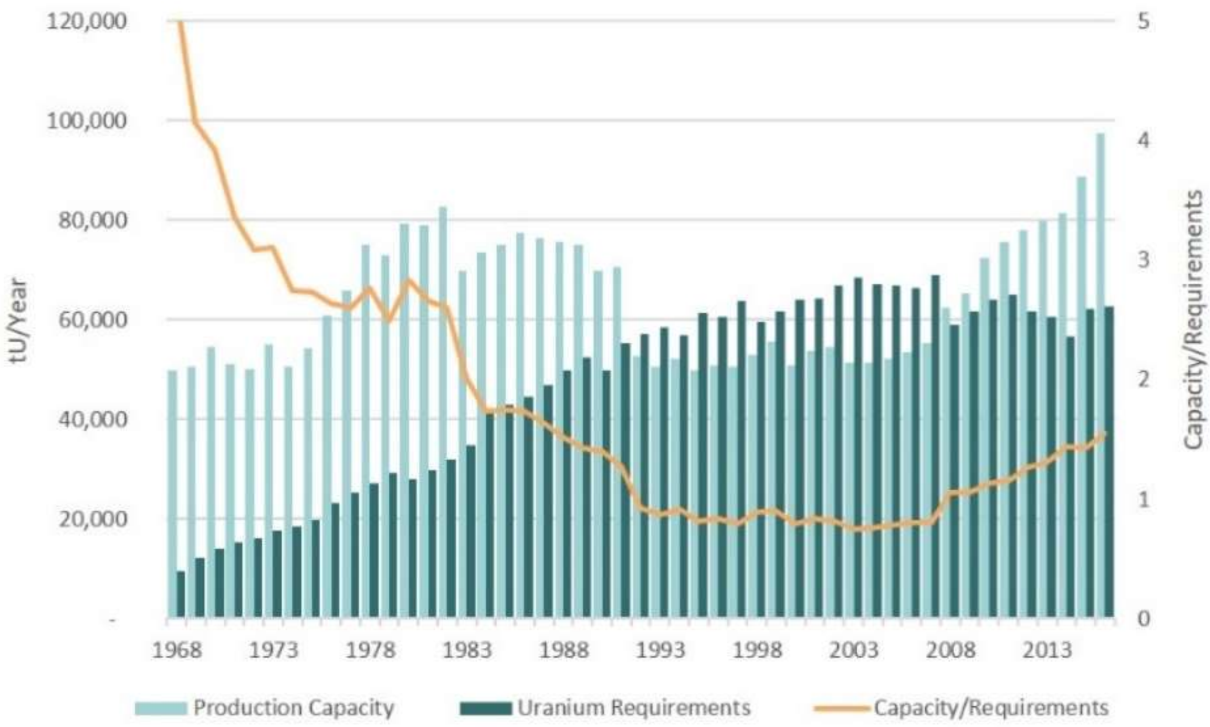


FIG. 2.69. Comparison of annual production capacity and reactor-related uranium requirements (compare to Fig. 7.3 in the 2003 Red Book Retrospective).

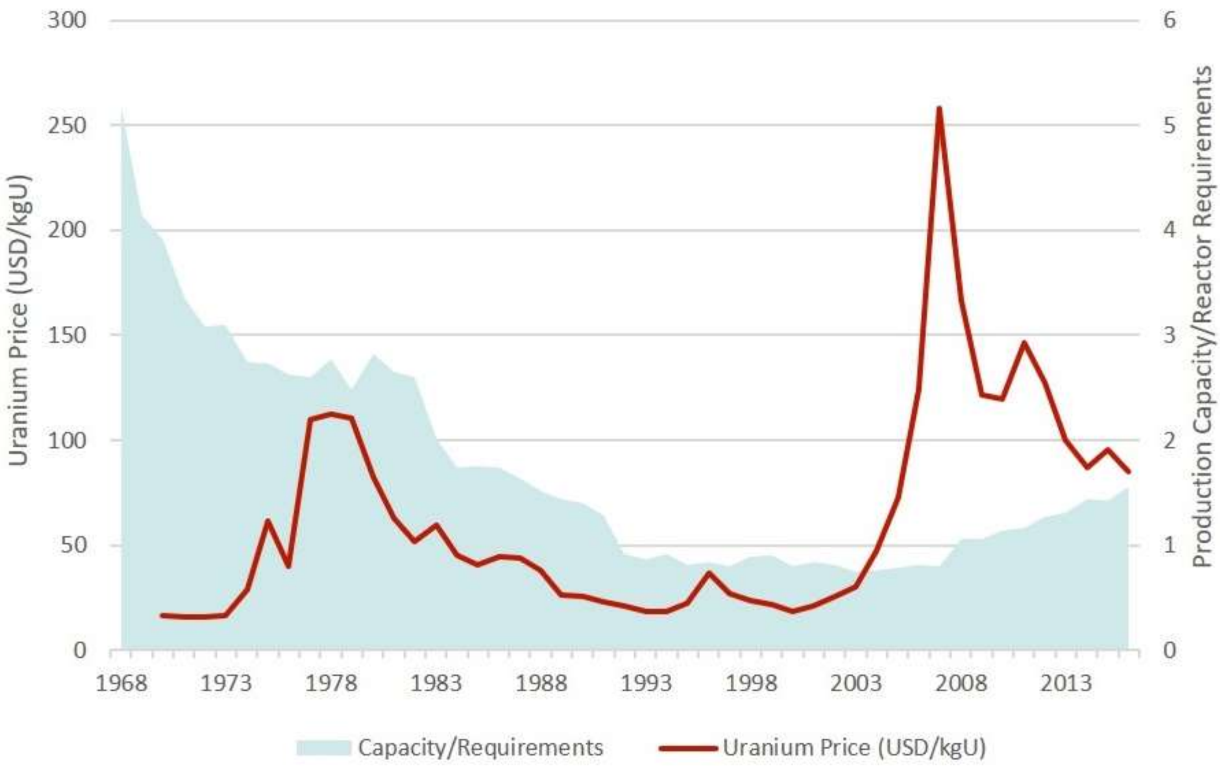


FIG. 2.70. Uranium capacity/requirements vs uranium price (compare to Fig. 7.4 in the 2003 Red Book Retrospective).

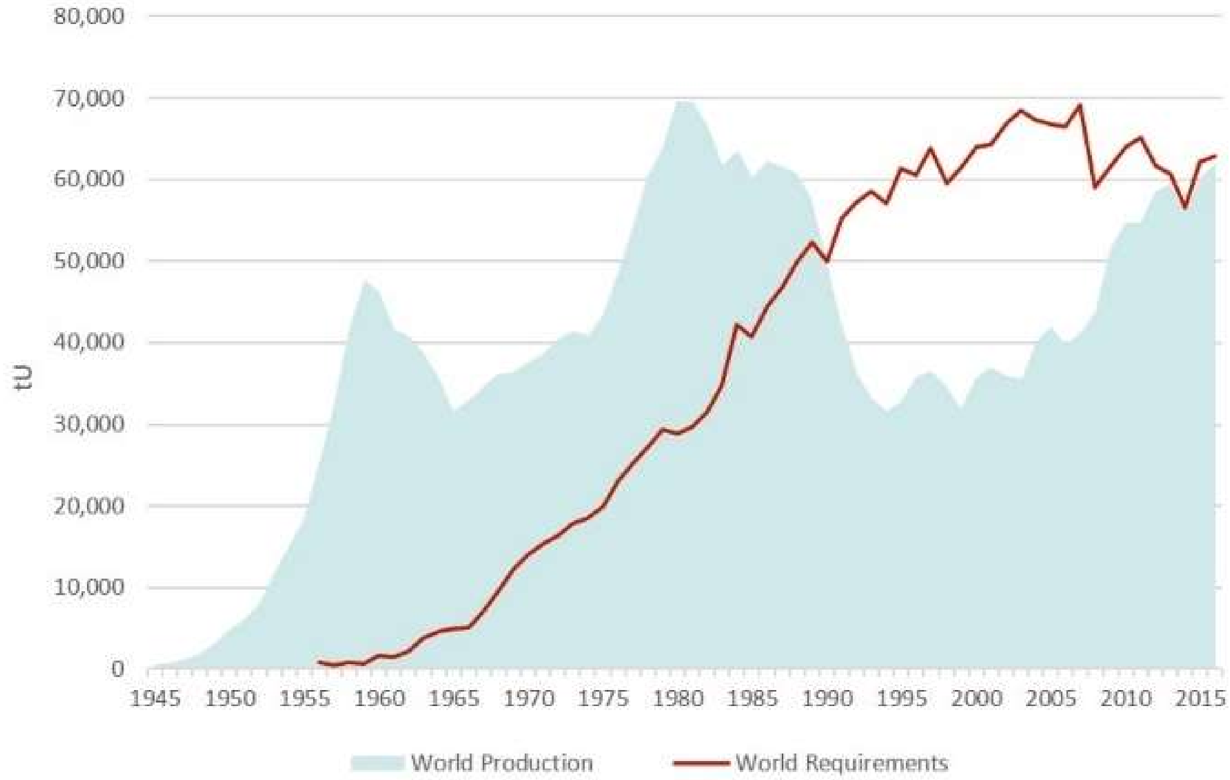


FIG. 2.71. Worldwide annual production and reactor-related requirements (compare to Fig. 7.5 in the 2003 Red Book Retrospective).

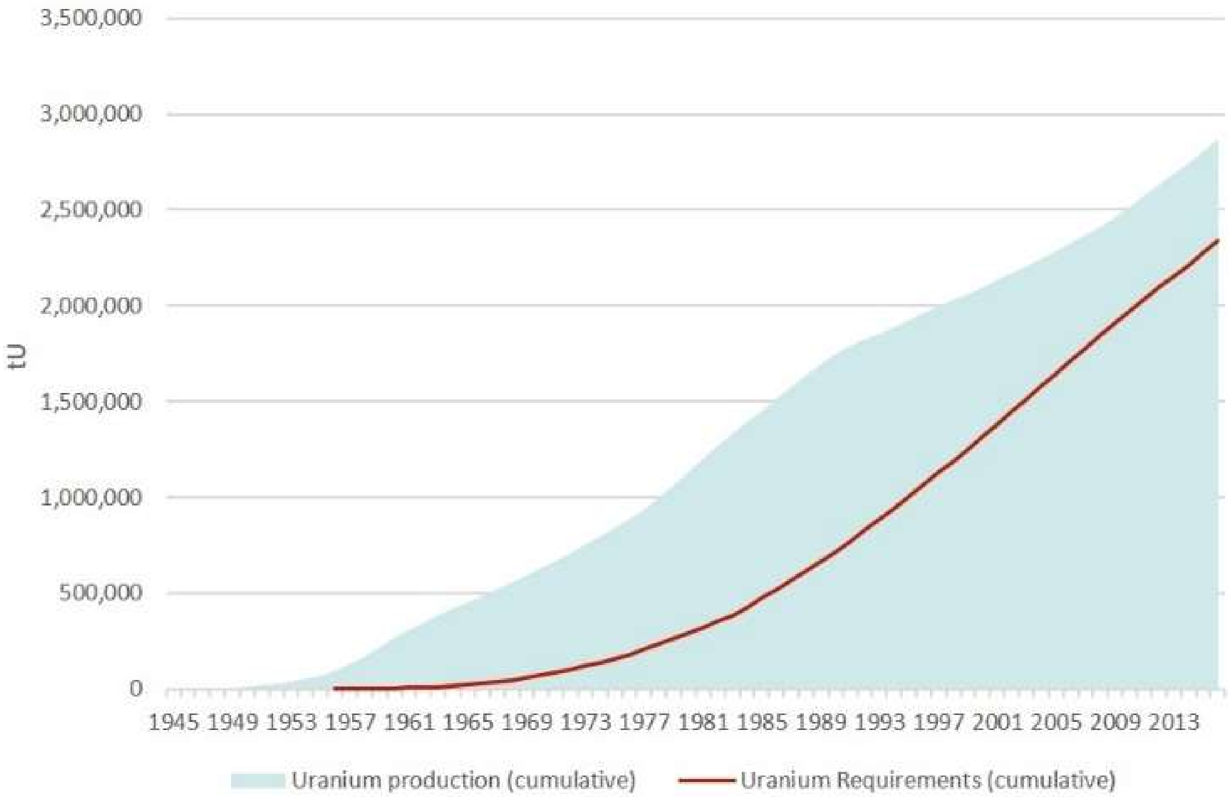


FIG. 2.72. Cumulative worldwide production and cumulative requirements (compare to Fig. 7.6 in the 2003 Red Book Retrospective).

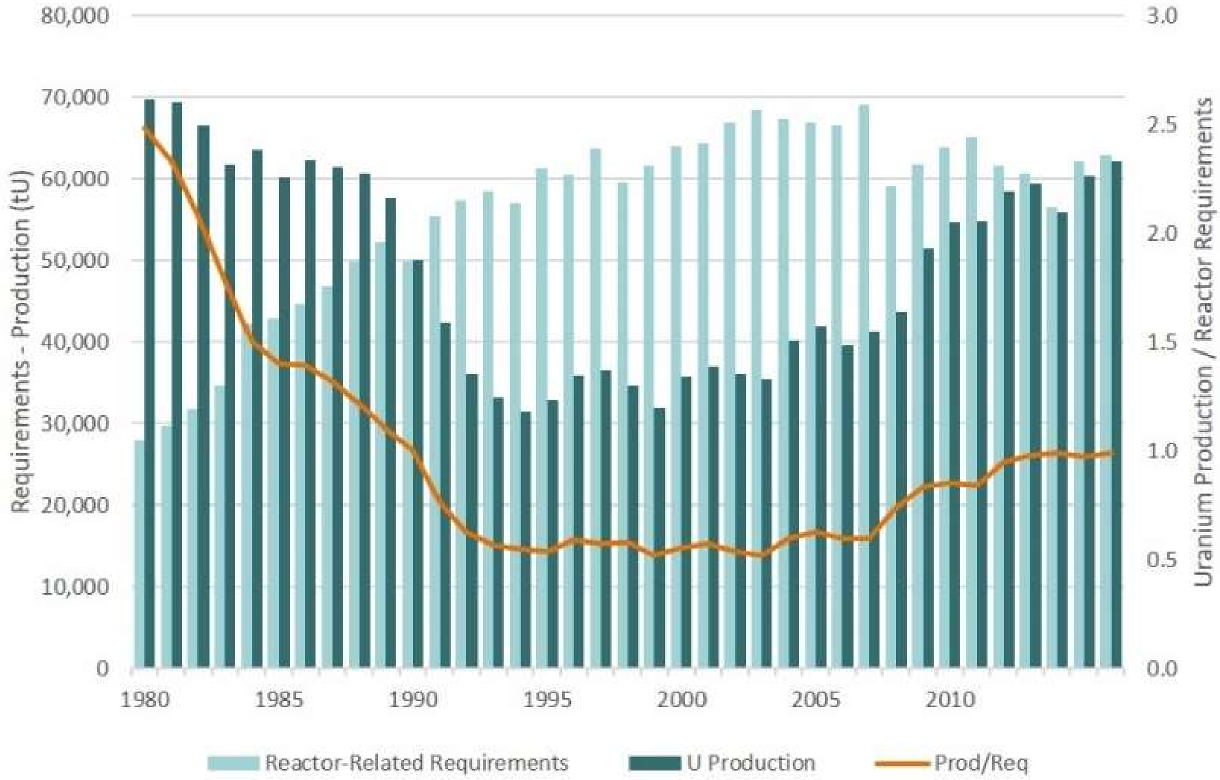


FIG. 2.73. Ratio of production to reactor related uranium requirements (compare to Fig. 7.7 in the 2003 Red Book Retrospective).

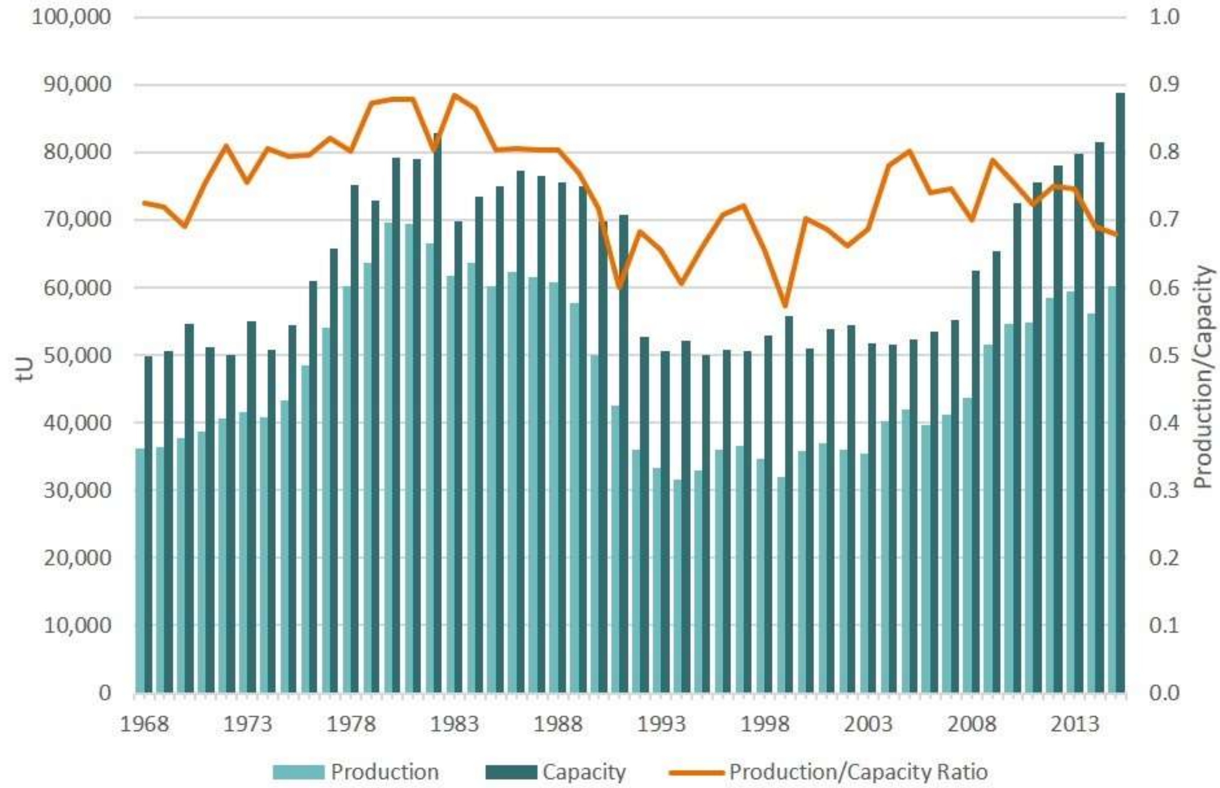


FIG. 2.74. Comparison of worldwide production and production capacity (compare to Fig. 7.22 in the 2003 Red Book Retrospective).

2.9.6. Discovery to mine start-up analysis

Figures 2.75 to 2.78 display the elapsed time between discovery of deposits and start of mining from 1945 to 2017, for all mining methods (open-pit, underground and ISL mining). Since 2000, time between discovery and start of mining has increased for all mining methods, between 20 and 35 years. Several factors control the lapsed time between the start of exploration and discoveries, market price, availability of exploration capital, regulatory requirements and political stability, but today the environmental and social aspects of the uranium production cycle are gaining increasing importance.

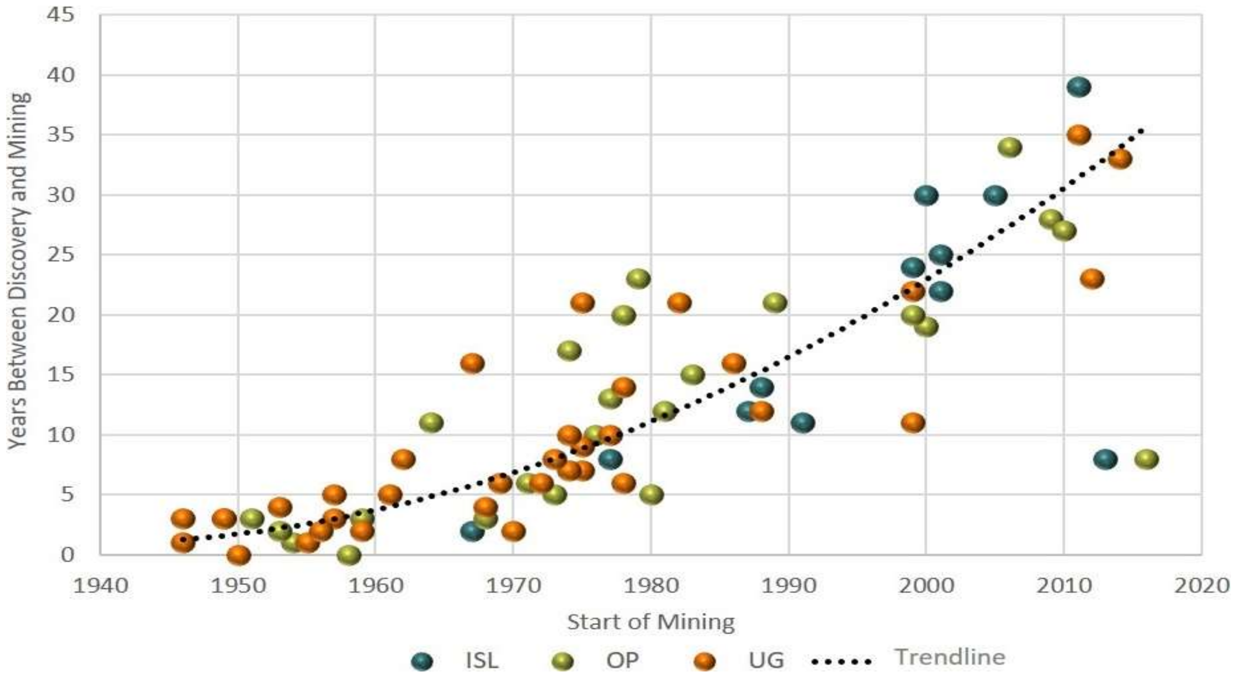


FIG. 2.75. History of elapsed time between discovery and start of mining for all mining methods (compare to Fig. 11.1 in the 2003 Red Book Retrospective).

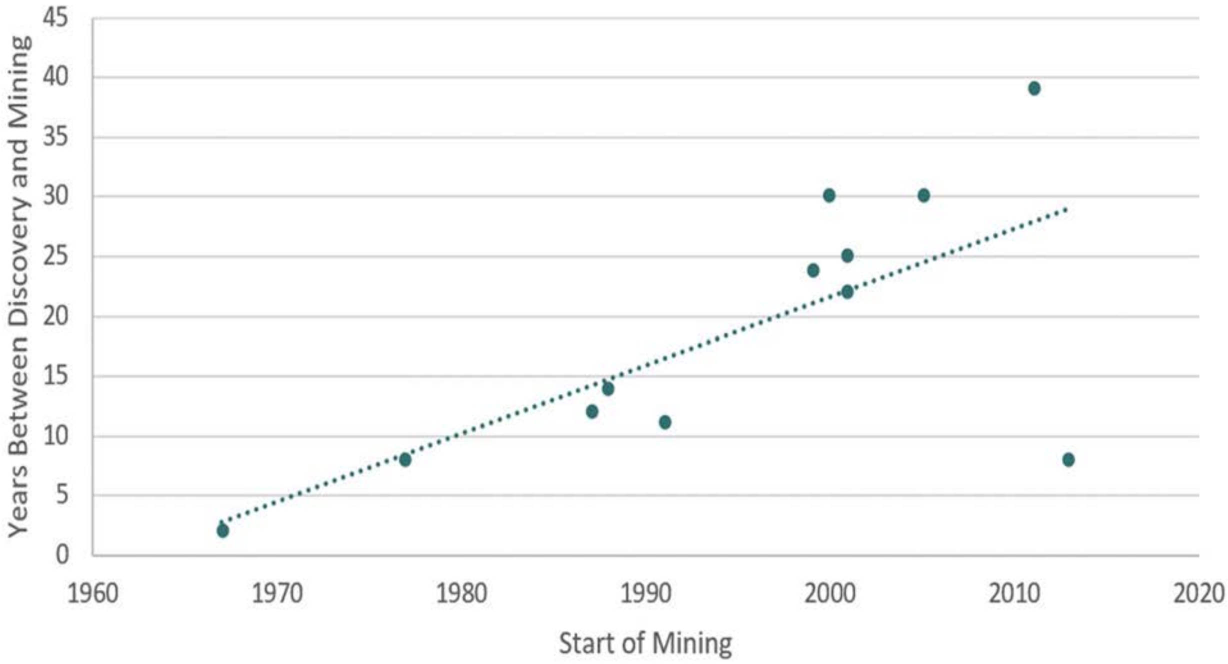


FIG. 2.76. History of elapsed time between discovery and start of mining for ISL mines (compare to Fig. 11.2 in the 2003 Red Book Retrospective).

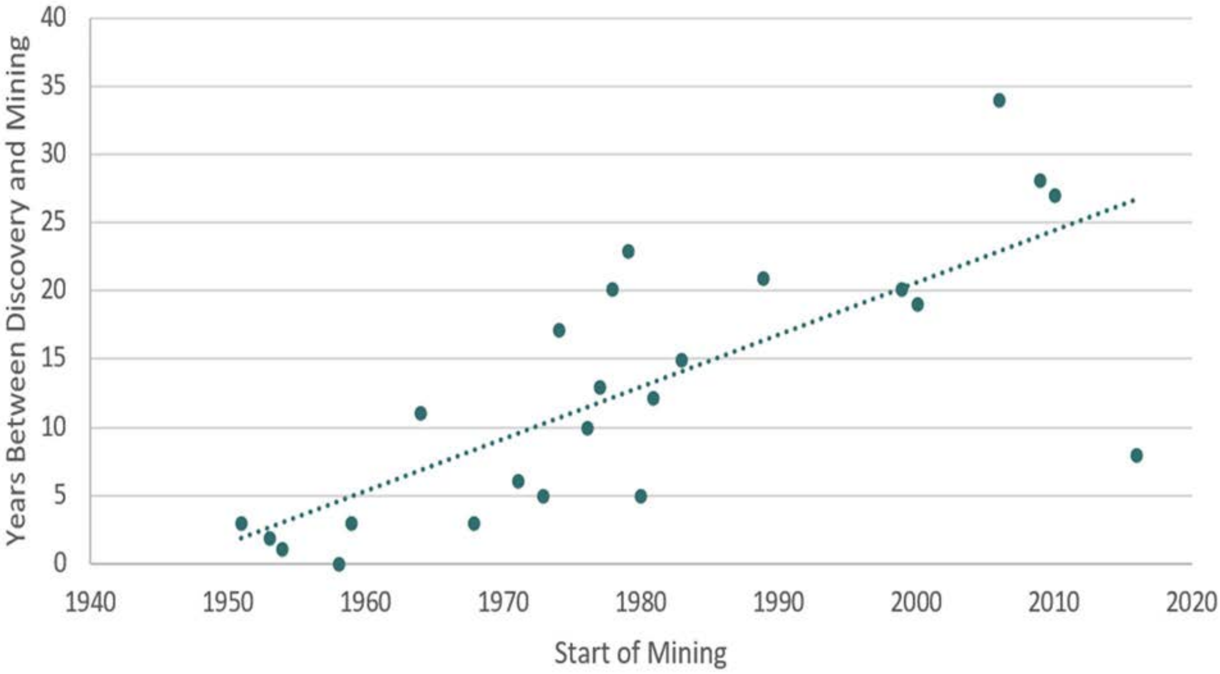


FIG. 2.77. History of elapsed time between discovery and start of mining for OP mines (compare to Fig. 11.3 in the 2003 Red Book Retrospective).

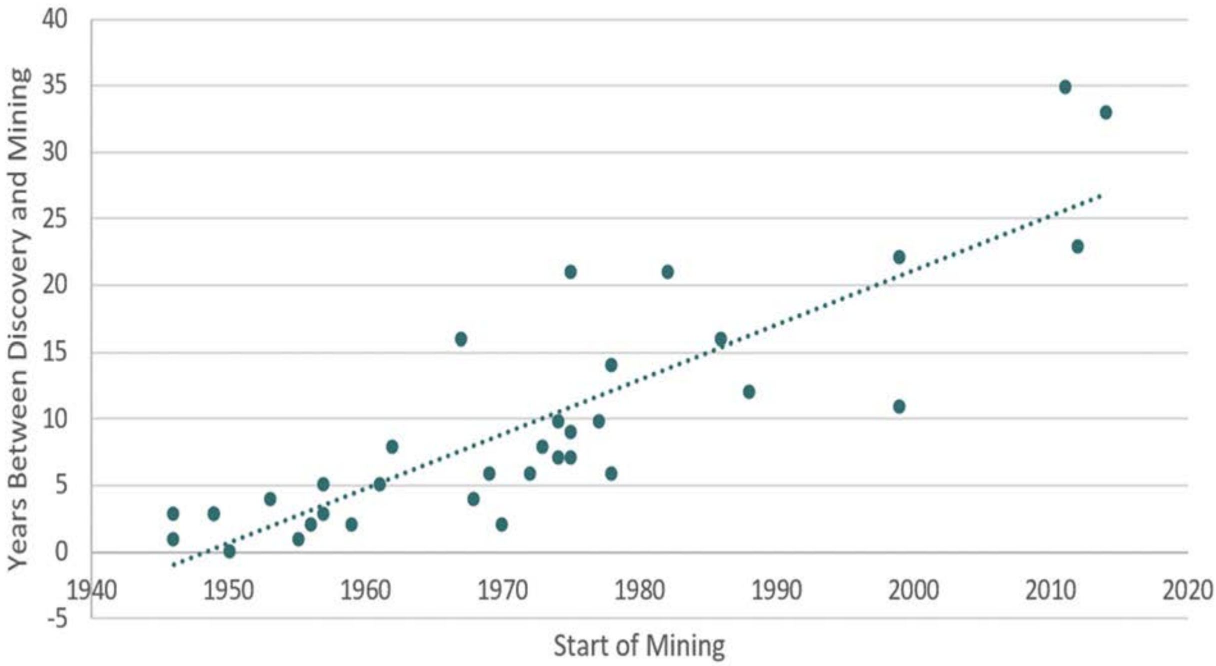


FIG. 2.78. History of elapsed time between discovery and start of mining for UG mines (compare to Fig. 11.4 in the 2003 Red Book Retrospective).

For recent developed mines (Table 2.60), the time between discovery and start of mining has been 28 years at Kayelekera, 34 years at Langer Heinrich (open-pit mines), 33 years at Cigar Lake, 35 years at Novokonstantinovskoye (underground mines), 25 years at Moinkum, 39 years at Honeymoon (ISL mines). Two mines started production 8 years after discovery, Four Mile (ISL) and Husab (open-pit mine).

TABLE 2.60. KEY DATES IN THE DEVELOPMENT OF SELECTED MINES
(compare to Table 11.1 in the 2003 Red Book Retrospective)

Country	Deposit/mine	Discovery of deposit	Beginning of production	Time between discovery and mining	Mining method
Australia	Beverley	1970	2000	30	ISL
	Four Mile	2005	2013	8	ISL
	Honeymoon	1972	2011	39	ISL
	Olympic Dam	1976	1988	12	UG
	Ranger	1969	1981	12	OP
Brazil	Caetité	1977	1999	22	UG
	Lagoa Real	1981	2000	19	OP
Canada	Cigar Lake	1981	2014	33	UG
	Cluff Lake	1975	1980	5	OP
	Key Lake Gaertner	1968	1983	15	OP
	Key Lake Deilmann	1968	1989	21	OP
	McArthur River	1988	1999	11	UG
	McClean Lake	1979	1999	20	OP
	Rabbit Lake	1968	1975	7	UG
Czech Rep	Rozna	1954	1957	3	UG
	Straz	1965	1967	2	ISL
France	Bellezanne	1966	1975	9	UG
	Ecarpière	1952	1957	5	UG
	Fanay	1949	1953	4	UG
	Commanderie	1954	1955	1	UG
	Bernardan	1964	1977	13	OP
	Mas d'Alary	1958	1978	20	OP
	Mas Lavayre	1964	1978	14	UG
Gabon	Mounana	1956	1961	5	UG
	Oklo	1968	1970	2	UG
Germany	Culmitzsch	1948	1951	3	OP
	Johanngeorgenstadt	1945	1946	1	UG
	Lichtenberg	1958	1958	0	OP
	Niedersclema-Alberoda	1946	1949	3	UG
	Oberschlema	1946	1949	3	UG
	Paitzdorf	1950	1950	0	UG
Hungary	Mecsek	1954	1956	2	UG
India	Juduguda	1951	1967	16	UG
	Tummalapalle	1989	2012	23	UG

Country	Deposit/mine	Discovery of deposit	Beginning of production	Time between discovery and mining	Mining method
Kazakhstan	Inkay	1979	2001	22	ISL
	Kanzhugan	1974	1988	14	ISL
	Melovoye	1956	1959	3	OP
	Moinkum	1976	2001	25	ISL
	Mynkuduk	1975	1987	12	ISL
	Uvanas	1969	1977	8	ISL
Kirghizistan	Maili-Su	1943	1946	3	UG
Malawi	Kayelekera	1981	2009	28	OP
Namibia	Husab	2008	2016	8	OP
	Langer Heinrich	1972	2006	34	OP
	Rossing	1966	1976	10	OP
Niger	Akouta	1972	1978	6	UG
	Arlit	1965	1971	6	OP
	Azelik	1983	2010	27	OP
Romania	Avram Iancu/Bihor	1954	1962	8	UG
Russia	Antei	1954	1975	21	UG
	Dalmatovskoye	1975	1999	24	ISL
	Luchistoye	1966	1972	6	UG
	Martovskoye	1964	1974	10	UG
	Oktyabrskoye	1967	1974	7	UG
	Streltsovskoye	1963	1969	6	UG
	Tulukuevskoye	1965	1968	3	OP
Slovenia	Zirovski	1961	1982	21	UG
Spain	Fe	1957	1974	17	OP
Ukraine	Michurinskoye	1964	1968	4	UG
	Novokonstantinovsko	1976	2011	35	UG
	Vatutinskoye	1965	1973	8	UG
USA	Alta Mesa	1975	2005	30	ISL
	Crow Butte	1980	1991	11	ISL
	Lucky Mc	1953	1954	1	OP
	Palangana	1956	1979	23	OP
	Shirley Basin	1957	1959	2	UG/OP
	Smith Ranch	1967	1977	10	UG
	Jackpile	1951	1953	2	OP
	Highland	1968	1973	5	OP
	Mt Taylor	1970	1986	16	UG
Uzbekistan	Uchkuduk	1953	1964	11	OP/UG

References to Chapter 2

[2.1] CHORLTON, L.B., Generalized Geology of the World, Geological Survey of Canada, Open File 5529, 2007.

[2.2] SCHULTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008)

[2.3] OBERTHUER, T., DAVIS, D.W., BLENKINSOP, T.G., HOEHNDORF, A.,. Precise U–Pb mineral ages, Rb–Sr and Sm–Nd systematics for the Great Dyke, Zimbabwe—constraints on crustal evolution and metallogenesis of the Zimbabwe Craton. Precambrian Research, 113, pp 293–306 (2002).

[2.4] Joint Steering Group on Uranium Resources of the OECD/Nuclear Energy Agency and the International Atomic Energy Agency, World Uranium Geology and Resource Potential-Report on Phase I, IUREP, 1980, Miller Freeman Publication, Inc., 524 p.

[2.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, World Uranium Potential: An International Evaluation, OECD, Paris (1978) 170 pp.

[2.6] PLANT, J.A., et al., The Geological and Tectonic Framework of Europe, http://weppi.gtk.fi/publ/foregsatlas/index.php (accessed June 2013).

[2.7] DUTCH, S., Sea Floor Spreading in the Arctic Ocean, https://www.uwgb.edu/dutchs/geolcolbk/arcticbathy-pb.htm (accessed December 2009).

[2.8] ROYDEN, L.H., Late Cenozoic tectonics of the Pannonian basin system, Am. Assoc. Pet. Geol. Mem. **45** (1988) 27–48.

[2.9] OKAY, A., Geology of Turkey, http://web.itu.edu.tr/~okay/AralOkayMapsAndDiagrams.htm (accessed June 2013).

[2.10] OKAY, A., Geology of Turkey: A Synopsis, http://web.itu.edu.tr/~okay/makalelerim/91_geology_of_turkey_anschnitt_2008.pdf (accessed June 2008).

[2.11] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[2.12] NASA Earth Data, http://disc.sci.gsfc.nasa.gov/geomorphology/GEO_2/GEO_PLATE_T-28.shtml (accessed May 2013).

[2.13] STEBLOV, G.M., et al., Imprint of North American Plate in Siberia Revealed by GPS (2003), http://www.earth.columbia.edu/news/2003/story11-11-03b.html

[2.14] STANFORD UNIVERSITY, National Science Foundation Workshop, 9–12 December 2004, (https://pangea.stanford.edu/research/groups/structure/projects/nerussia/presentations.html (accessed May 2013).

[2.15] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[2.16] INTERNATIONAL ATOMIC ENERGY AGENCY, New Developments in Uranium Exploration, Resources, Production and Demand, IAEA-TECDOC-650, IAEA, Vienna (1992).

[2.17] Encyclopedia of European and Asian Regional Geology (MOORES, E.M., FAIRBRIDGE, R.W., Eds), Chapman and Hall, London (1998).

[2.18] ZHANG, Z.M., LIOU, J.G., COLEMAN, R.G., An outline of the plate tectonics of China, Geol. Soc. Am. Bull. **95** 3 (1984) 295–312 (abstract).

[2.19] CHEN, ZUYI, "Regional distribution of uranium deposits in northern Asia", Recent Developments in Uranium Resources and Production With Emphasis on In Situ Leach Mining, IAEA-TECDOC-1396, IAEA, Vienna (2004) 13–24.

[2.20] NAIRN, A.E.M., ALSHARAN, A.S., Sedimentary Basins and Petroleum Geology of the Middle East, Elsevier, Amsterdam (1997).

[2.21] UNITED STATES DEPARTMENT OF ENERGY, An Assessment Report on Uranium in the United States of America, Rep. GJO-111, USDOE, Grand Junction, CO (1980).

[2.22] UNITED STATES GEOLOGICAL SURVEY, Physiographic Regions of the 48 United States, http://tapestry.usgs.gov/physiogr/physio.html (accessed August 2012).

[2.23] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[2.24] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO) https://nucleus.iaea.org/Pages/udepo.aspx (accessed September 2019)

[2.25} OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[2.26] WISE URANIUM, Uranium Mine Ownership, http://www.wise-uranium.org/uoeur.html#SE (Aug. 2008).

[2.27] U3O8 CORPORATION, News release 8 April 2010 and Projects: Argentina, 2010, http://www.U3O8corp.com

[2.28] CUE RESOURCES, Cue Resources Files NI 43-101 Technical Report on SEDAR (29 May 2009).

[2.29] JEFFERSON, C.W., et al., "Unconformity associated uranium deposits of the Athabasca Basin, Saskatchewan and Alberta", Mineral Deposits of Canada: A Synthesis of Major Deposit Types, District Metallogeny, the Evolution of Geological Provinces and Exploration Methods (GOODFELLOW, W.D., Ed.), Geological Association of Canada, St. John's, NL (2007).

[2.30] OECD EUROPEAN NUCLEAR ENERGY AGENCY, World Uranium and Thorium Resources, OECD, Paris (1965).

[2.31] OECD EUROPEAN NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources: Revised Estimates, OECD, Paris (1967).

[2.32] OECD EUROPEAN NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium: Production and Short Term Demand, OECD, Paris (1969).

[2.33] OECD EUROPEAN NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1970).

[2.34] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1973).

[2.35] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1976).
[2.36] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).
[2.37] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).
[2.38] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).
[2.39] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).
[2.40] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).
[2.41] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).
[2.42] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).
[2.43] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).
[2.44] NUEXCO, By-product and co-product uranium resources and production, NUEXCO No. 225 (1987) 21–28.
[2.45] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

CHAPTER 3. AFRICA

3.1. ALGERIA

Located in North Africa, Algeria is bordered by the Mediterranean Sea to the north, Tunisia and Libya to the east, Niger and Mali to the south, and Mauritania and Morocco to the west. With a total area of almost 2.4 million km^2, Algeria is the second largest country in Africa. The country extends roughly 2000 km N–S and around 1800 km E–W.

Climatically, Algeria possesses both arid and semi-arid regions. Rainfall in northern Algeria averages 1000 mm annually. The coastal areas experience mild, wet winters and hot, dry summers. Certain sections of the Sahara Desert may not receive rain for periods of up to 20 years and temperatures can exceed 55ºC.

Mineral resources in Algeria include iron, lead, natural gas (84.5 billion m^3 produced in 2006, ranking it 6th in the world), oil (1.2 million barrels/d produced in 2004), uranium and zinc. Algeria's chief grain crops, which are grown in the more fertile regions, include barley, maize, oats, sorghum and wheat. Vineyards and tobacco plantations in the country export their products. Other crops grown are dates, figs, fruits, olives and vegetables [1.1].

3.1.1. Geology

Algeria has a very diverse geology (Fig. 3.1). From north to south, four regions are morphologically distinct:

(i) The Tellian Atlas combines steep topographic relief and coastal plains where the most fertile areas are the plains around Mitidja in the centre, Chélif in the west and Seybouse in the east. The Tellian Atlas incorporates all 1200 km of the Mediterranean coastline. It is a hilly area, sub-coastal and constitutes a small percentage of the total area of the country. Despite its small size, the Tellian Atlas is inhabited by more than 90% of the population;

(ii) The High Plateau (Highlands) is represented mainly by Oran Meseta in the west. The areas around Aïn M'lila, Sétif and Constantine to the east constitute an extensive region of arid plains;

(iii) The Saharan Atlas is a long succession of NE–SW oriented relief extending from the border with Morocco as far east as Tunisia;

(iv) The Sahara Desert, which contains the bulk of Algeria's hydrocarbon resources, comprises large expanses, sand dunes, stony plains and scattered oases. The oases are all urban centres, e.g., El Oued, Ghardaia and Djanet. The Yetti-Eglab Massif in the south-west and the Hoggar Shield in the south constitute, practically, the southern border of the Algerian Sahara.

Algeria is divided into three major geotectonic areas: (i) in the north, the Alpine field forms the northern border of Algeria, (ii) in the centre, the Saharan Platform dominates the central Sahara, and (iii) in the south lie the Precambrian massifs of the Hoggar and Yetti-Eglab.

3.1.1.1. The Alpine field of the northern border of Algeria

At a continental level, the northern Algeria margin covers the edge of the African Craton, which exhibits two major geological fields which were highly differentiated as a result of Mesozoic and Cenozoic tectono-orogenic episodes. From north to south is the Tellien area, representing an important segment of the Maghrebides chain and the Atlas area, foreland of the Alpine range, constituted by the Saharan Atlas and horsts such as the Oran Meseta.

The Tello-Rif range or Maghrebides chain includes different tectono-stratigraphic zones, which are, from north to south, the Internal areas, the Flysch area and the External areas [1.2].

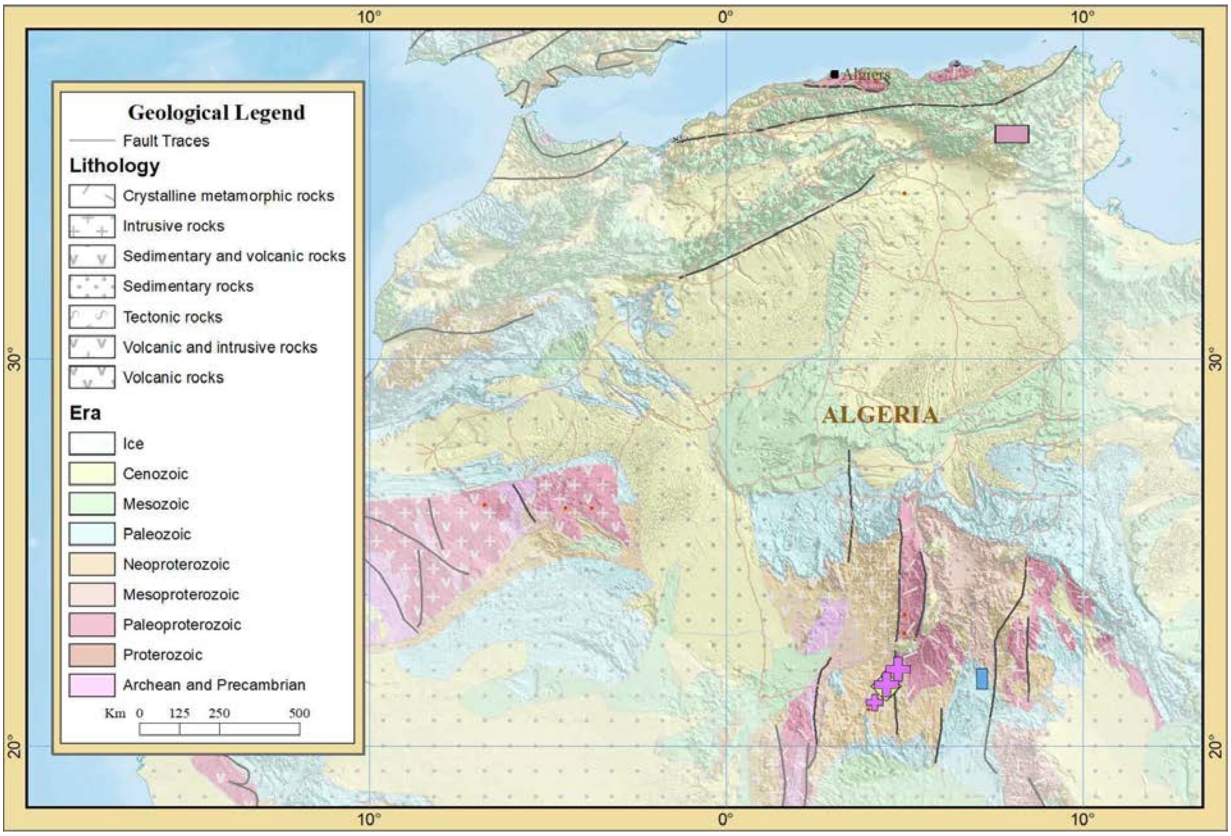


FIG. 3.1. Regional geological setting of Algeria showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

(1) Internal areas: The Kabyle fields

The Internal areas belong in the southern margin of the European Plate and consist of Pan-African and Hercynian crystalline and metamorphic massifs constituting the Kabyle basement. The basement is bordered to the south by the Djurdjuran range, comprised mainly of Mesozoic and Cenozoic transgressive sediments overlying sedimentary Palaeozoic strata and occurring beneath shale [1.3].

(2) Flysch area: Massylian, Mauretanian and Numidian

The area of flysch sheets corresponds to a deep and mobile marine environment from Middle Jurassic to Burdigalian. During the Lower Cretaceous, relatively proximal terrigenous flysch deposits accumulated in the northern part of the basin (Mauritanian flysch) and distal flysch sequences in the south (Massylian flysch) [1.4].

During the Oligocene and Lower Miocene, sandy micaceous flysch strata were deposited unconformably between tectonic units of the Internal areas and the Mauritanian flysch in eastern Algeria. The sandstone series of the Numidian sheet formed during the Aquitanian and basal Burdigalian, probably in the southern Massylian Basin and in the far north of the Tellian external field and/or Rifan [1.4].In the Kabyle region, flysch sheets were thrusted on both External and Internal zone areas and these are found in the northern part of the Tizi Ouzou Basin.

(3) External areas: The Tellian field

In eastern Algeria, and along the Algeria–Tunisia border, the Tellian Series run N–S and comprise [1.5]:

— The ultra-Tellian units;
— The Tellian *(sensu stricto*) units;
— The peri-Tellian units.

The Tellian Atlas sheets, emplaced during the Lower Miocene, are overlapped by some intra-mountainous Neogene basins (Jurassic–Miocene sedimentation of the Chélif). Hodna is a foredeep basin filled with Eocene–Miocene sediments.

In the northern part, the Tellian Atlas is a complex area consisting of Lower Miocene sheets. Some Late Neogene basins, such as Chélif and Hodna, accumulated on these sheets.

The Atlas area extends north of the Saharan area and forms the foreland Tell. It comprises several paleogeographic and structural units, mainly the Oran Meseta, the Highlands and the Saharan Atlas range.

The Highlands (Oran Meseta and Aïn M'Lila blocks) exhibit reduced Alpine foreland sedimentary cover, where overstretching led to the formation of intra-mountainous basins, such as at Telagh and Tiaret.

In the south, the Saharan Atlas range, a subsiding trough filled with a thick sedimentary Mesozoic series compressed during the Tertiary, extends from Morocco to Tunisia.

3.1.1.2. The Saharan Platform

The Saharan Platform represents the stable northern remnant of the African Plate and belongs to the North African Craton. It includes a Precambrian basement that is unconformably overlain by thick sedimentary cover, which developed into several basins during the Palaeozoic. These basins, the Tindouf and Reggane Basins, are located on the northern and north-eastern fringes of the Reguibat Shield.

The Bechar and Ahnet-Timimoun sedimentary basins were developed on the Precambrian bedrock of the West African Craton [1.6]. The Bechar Basin is bordered to the north by the High Atlas and to the south and west by the Ougarta range. The Ahnet-Timimoun Basin is confined to the north by the Oued Namus shoal, to the west by the Ougarta range, to the south by the Tuareg Shield and to the east by the Idjerane-Mzab ridge.

The Mouydir and Aguemour-Oued Mya Basins are restricted to the west by the Idjerane-Mzab ridge and to the east by the Amguid El-Biod ridge. The Ghadames-Illizi syncline is bordered to the west by the Amguid El-Biod ridge and to the east by the Tihemboka uplift and the Tunisia–Libya borderlands. A Triassic basin (the Saharan Mesozoic Basin) occurs in the north-eastern part of the Saharan Platform in the Algeria–Tunisia borderlands.

In the southern part of the Tuareg Shield, the Saharan Platform is represented by the Tin Seririne sedimentary basin, which extends to the Tim Mersoï Basin and into Niger.

3.1.1.3. The Precambrian Hoggar Massif

Located in the extreme south of Algeria, the Hoggar Massif is the central area of the Tuareg Shield, which extends south-west to Adrar des Iforas in Mali and south-east to the Aïr Massif in Niger.

The Tuareg Shield, as a whole, is a dome (uplift) about 1000 km in diameter. It represents the highest relief of the Algerian Sahara. Hoggar elevations range mostly between 1000 and 1500 m, but elevations above 2000 m are common and culminate at Tahat (2918 m).

The main characteristics of the Hoggar are the Precambrian basement occurring in 'terrains' and as a 'metacraton', whose juxtaposition is the result of the Pan-African Orogeny (850–540 Ma) effected through major shear zones. A wide Mesozoic–Cenozoic topographic 'swell' is associated with strong Cenozoic–Quaternary volcanic activity [1.7].

Three major orogenic cycles marked the geological history of the Hoggar during the Precambrian: Archaean (3000 Ma), Eburnean (2150–2000 Ma) and Pan-African (850–540 Ma) [1.6].

3.1.1.4. The Precambrian Yetti-Eglab Massif

The Precambrian Yetti-Eglab Massif, located south-west of Algeria, constitutes the eastern end of the Reguibat ridge, which dominates the northern part of the West African Craton. It forms the Precambrian framework of the western Sahara region and comprises a SW–NE crystalline axis extending for about 1500 km from Mauritania to Algeria. In Algeria, it sinks beneath the Palaeozoic formations of the Tindouf (north) and Taoudeni (south) Basins. In the Yetti and Eglab Shields, it is represented by Palaeoproterozoic formations.

3.1.2. Uranium exploration

Uranium exploration in Algeria has led, so far, only to the discovery of two types of deposit of limited size. Deposits are either associated with hydrothermal veins in the Pan-African granites, in the uranium province of western Hoggar (Pan-African range), or are related to the Precambrian basement and Palaeozoic cover unconformity in the Tin Seririne Basin on the southern edge of the Hoggar.

The four uranium deposits discovered in the Hoggar have been the subject of detailed assessment. Three deposits, Timgaouine, Abankor and Tinef, are associated with fault zones cross-cutting granitic intrusions of the Hoggar Precambrian basement and the fourth one is the Tahaggart sedimentary deposit, which is related to the Precambrian–Ordovician cover unconformity of the Tin Seririne Basin.

The following results have been obtained [1.8]:

— Timgaouine: 5 850 000 t at 0.210% U (C1 + C2 reserves);
— Abankor: 3 351 325 t at 0.209% U (A reserves) and 879 000 t at 0.200% U (C1 + C2 reserves);
— Tahaggart: 800 000 t to 0.215% U (possible reserves).

C1 and C2 reserves, based upon the resource classification scheme utilised in the former Soviet Union, are broadly equivalent to Inferred and Indicated resources in Red Book, while A reserve is broadly equivalent to the highest confidence level within Measured resources category.

Several uranium occurrences discovered by systematic exploration are related to the evolved granites and often host anomalous values of rare metals (e.g., niobium and tantalum). These occurrences have not been studied in detail.

Two extensive areas, the western Hoggar and the southernmost border area, have been the immediate targets of more recent uranium exploration programmes.

The first phase of uranium exploration in the Hoggar was undertaken by teams from France’s Commissariat à l’Energie Atomique (CEA) in collaboration with the Bureau of Mining Research of Algeria during the period 1953–1958. This resulted in the discovery of the uranium occurrences at Timgaouine–Abankor and Aït Oklan–El Bema, which are vein-type deposits hosted in Pan-African granites which are confined to the eastern branch of the Pharusian range (western Hoggar).

In a second phase of exploration (1969–1974), which was marked by a significant investment effort, detailed investigations were undertaken by the national company SONAREM with the assistance of its Romanian partner GEOMIN in a programme of integrated mining research in the Hoggar (uranium–tin–tungsten–gold). These investigations have enabled the development of known uranium occurrences which are now defined as the Timgaouine–Abankor–Tinef deposits.

During the same period, a regional airborne survey (magnetic and spectrometry) for mining and oil exploration was conducted by the US company AEROSERVICE in two phases, in 1969 and in 1971–1974. This survey of the country gave new impetus and direction to uranium exploration in Algeria.

Interpretation of the airborne survey data allowed for the rapid selection of large geographical areas and geological formations considered as having potential for hosting uranium mineralization. The areas identified included the Yetti-Eglab, the Ougarta chain and the Tassili Oua'N Ahaggar of the southern border of the Hoggar (Tin Seririne Basin) in which the existence of the Tahaggart deposit has been confirmed, together with the Tamart-N-Iblis and Timouzeline areas in the central part of the basin.

In parallel and following this investigation, a new phase of exploration was undertaken (1973–1981) which focused mainly on the evaluation of known deposits and enhancement of the Timgaouine and Abankor deposits .

Despite a marked slowdown in the research effort during the period 1984–1997, exploration undertaken on the flanks of discovered fields and surrounding regions enabled the identification of occurrences and mineralized prospects (i.e., Amal in north-western Timgaouine and Tesnou in north-western Hoggar).

In the Tin Seririne Basin (south Tassili Hoggar), the investigation undertaken during 1987–1997 led to the geological mapping of this region with the aim of characterizing the distribution of uranium mineralization in the Palaeozoic sedimentary series.

3.1.2.1. Detailed investigations of the uranium deposits

The Timgaouine deposit is structurally-controlled and hosted by hypovolcanic intrusive batholiths of calc-alkaline granitoids of Upper Proterozoic age.

In the central part of Timgaouine, the deposit consists of a fissured mylonitic breccia in an approximate N–S orientation. The mineralization occurs as veins and stockworks.

The envelope of the mineralized bodies comprises hydrothermal carbonate alteration, with albite, chlorite, epidote, sericite, haematite and clay. Primary mineralization includes uraninite, pitchblende, coffinite, sulphides (e.g., molybdenum), carbonates and chalcedonic quartz. The oxidized uranium mineralization is mainly associated with uranium molybdates.

The uranium deposit of Abankor is located in eastern Timgaouine. The mineralization is of vein- and stockwork-type. It is a part of two systems of fractures, oriented N 10° E and N 40–50° E, respectively [1.9]. The main uranium mineral at Abankor is pitchblende. Yellow oxidation products, uranotile and gummite often accompany the pitchblende. Gangue minerals include pyrite, marcasite, haematite and accessorily molybdenite. The abundance of molybdenum is low, especially when compared with the Timgaouine deposit, which is essentially a molybdenum–uranium deposit. In comparison, Abankor is a monometallic deposit.

The geological setting of the Tinef deposit is the same as Timgaouine which is about 35 km from Tinef. There are two major fault systems (N–S and secondary N–E) which control mineralization. The mineralization is similar to that at Timgaouine: primary mineralization comprises pitchblende, uraninite and occasional coffinite. The oxidized zones contain uranolite, gummite and sporadic autunite and uranium oxides.

The Tahaggart deposit is located at the unconformity between the Precambrian basement and Palaeozoic sedimentary cover. At the contact, sub-horizontal mineralized lenses of 1–8 m in thickness occur and are enclosed in altered gneiss of the Precambrian basement and conglomerates of the Cambrian–Ordovician [1.10].

The secondary mineralization mainly consists of autunite and torbernite associated with iron oxides (haematite and goethite) and a clay matrix (kaolinite). Significant thorium mineralization and rare earth elements also occur, enclosed in a reddish Ordovician conglomerate, and these occurrences are more developed in the north Tassili belt than in the south [1.11]. This mineralization is related to thorium and primary and secondary minerals such as monazite, alumino-phosphates (i.e., crandallite, florencite and brockite), which have high levels of rare earth elements [1.12].

3.1.3. Uranium resources

3.1.3.1. Identified resources

Reasonably assured resources (Tables 3.1 and 3.2) are confined to two geological types of deposit, i.e., those related to Upper Proterozoic unconformities and those related to veins and stockwork. The first type includes deposits associated with weathering profiles (regolith) and deposits associated with the basal conglomerates and sandstones of the sedimentary cover, which are located mainly in the Tin Seririne Basin. The second type of deposit (vein/stockwork) is hosted in the primary fractures associated with faults transecting granitic batholiths. This type of deposit includes Timgaouine, Abankor and Tinef in the south-west of the Hoggar [1.13].

The UDEPO database lists the most significant deposits for Algeria as Bled el Hadba, Djemidjema, Kef es Sennoun, Timgaouine, Tinef, Abankor, Daira South, Tahaggart.

TABLE 3.1. REASONABLY ASSURED (IN SITU) RESOURCES BY DEPOSIT (tU) [1.14]

Deposit	Reserves (1000 t)	Grade (%U)	Resource (tU)
Vein (granite-related) deposits			
Abankor	3 264	0.290	9 450
Timgaouine	7 442	0.157	11 732
Tinef	374	0.100	374
Daira Sud	1 600	0.120	2 000
Total	12 680	0.187	23 556
Surficial deposits			
Tahaggart	781	0.215	1 677
Total	13 461	0.201	25 233

TABLE 3.2. REASONABLY ASSURED (IN SITU) RESOURCES BY DEPOSIT TYPE (tU) [1.15] (as of 1 January 2017)

	Cost category			
	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Surficial	n/a	n/a	n/a	2 000
Vein (granite-related)	n/a	n/a	n/a	24 000
Total	n/a	n/a	n/a	*3.1.1.26 00*

3.2.3.2. Undiscovered resources

Algeria does not report resources in any category other than reasonably assured resources. In 1983, a review of the IUREP estimates reported a range of 50 000–100 000 tU of speculative resources in vein-type and sandstone-type geological environments [1.16–1.18].

3.1.3.3. Unconventional resources

Algeria has also several phosphorite deposits which like those from Morocco contain some uranium (Bled el Hadba, Djemidjema, Kef es Sennoun) as unconventional resources.

3.1.4. Potential for new discoveries

Algeria has moderate to high potential for the discovery of uranium deposits. The Precambrian Hoggar Shield remains the prime target for further investigation and exploration for uranium resources. Three types of mineralization are sought:

(i) Surficial uranium mineralization related to unconformity basement cover;
(ii) Uranium mineralization of stratiform type hosted in sandstones;
(iii) Uranium mineralization of intra-batholithic vein type.

For uranium mineralization related to secondary surficial processes associated to the unconformity basement cover, as at Tahaggart, the Hoggar border region is the target location of choice. This unconformity is developed all around the Hoggar (30 000 km²). Its southern border is represented by the Oua N'Ahaggar Tassili which hosts two very favourable regions for this type of deposit: (i) the Tin Seririne Basin, and (ii) the Tin Rherhoh region (in particular the Débirène, Temaga and In Tabarrekat areas).

Tabular and stratiform mineralization related to continental sandstones (such as at Arlit in Niger) are developed in Devonian sandstone in the Tin Seririne Basin. Tamart N'Iblis and Timouzeline are also favourable for detailed exploration.

The western Hoggar is the most appropriate target area for further exploration of vein type uranium mineralization associated with alkaline granites. Several encouraging prospects were discovered near-by the 3 main deposits.

Three districts have good potential for development of previously discovered deposits and occurrences:

(i) Timgaouine–Abankor–Tinef district;
(ii) Ait Oklan–El Bema–Tesnou district;
(iii) Teg'Orak district.

The Yetti-Eglab Massif in the south-west is expected to be the subject of further exploration of known uranium–thorium–niobium–tantalum and rare earth element occurrences related to alkaline and peralkaline granites in the Djebel Rissa complex ring, as well as uranium occurrences associated with calcrete.

In the Saharan Platform, the Continental Intercalaire (Upper Jurassic–Lower Cretaceous) formations of the Triassic basin are worthy of further investigation of uranium mineralization associated with continental sandstones.

3.1.5. National policies relating to uranium

Act No. 01–10 of 3 July 2001 implementing the Mining Act does not accord any special status to uranium. The Order of 30 December 2002 listing mineral substances and in particular, Section 3 of the Order, classifies uranium as a non-ferrous metallic mineral without any particular strategic character. In accordance with the rules in force, any public, private, national or foreign operator may be authorized to prospect for, and mine, uranium.

On 21 June 2008, France and Algeria signed a civil nuclear cooperation agreement. The deal on the peaceful use of nuclear energy will formalize cooperation in the field of research, training and technology transfer and in the exploration and production of uranium [1.19].

3.1.6. Comments

No uranium has been produced in Algeria and currently no uranium production is planned. Algeria has no nuclear power plant.

References to Section 3.1

[1.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Algeria (2010), https://www.cia.gov/library/publications/the-world-factbook/index.html

[1.2] DOMZIG, A., et al., Searching for the Africa–Eurasia Miocene boundary offshore western Algeria (MARADJA '03 cruise), Comptes Rendus Geosci. **338** 1–2 (2006) 80–91.

[1.3] AITE, M.O., GELARD, J.-P., Distension néogène post-collisionelle sur le transect de Grande Kabylie (Algérie), Bull. Soc. Geol. Fr. **168** 4 (1997) 423–436.

[1.4] WILDI, W., La chaîne tello-rifaine (Algérie, Maroc, Tunisie): Structure, stratigraphie et évolution du Trias au Miocène, Rev. Geogr. Phys. Geol. Dyn. **24** (1983) 201–297.

[1.5] VILA, J.M. La chaîne alpine d'Algérie orientale et des confins algéro-tunisiens, PhD Thesis, Paris Univ. (1980).

[1.6] FABRE, J., Géologie du Sahara occidental et central, Tervuren Afr. Geosci. Coll. **108** (2005).

[1.7] LIEGEOIS, J.-P., BENHALLOU, A., AZZOUNI-SEKKAL, A., YAHIAOUI, R., BONIN, B., "The Hoggar swell and volcanism: Reactivation of the Precambrian Tuareg Shield during Alpine convergence and West African Cenozoic volcanism", Plates, Plumes, and Paradigms (FOULGER, G.R., NATLAND, J.H., PRESNALL, D.C., ANDERSON, D.L., Eds), Geol. Soc. Am. Special Paper 388 (2005) 379–400.

[1.8] SEMIANI, A., ABED, A., BELLAL, M., L'uranium en Algérie: Resources et perspectives, Office National de Recherche Géologique et Minière, Algers (2005).

[1.9] SONAREM, Inventaire et prospective des ressources minérales du Hoggar, SONAREM, Algers (1977).

[1.10] MOKADDEN, M., Le bassin sédimentaire de Tin Séririne et ses minéralisations uranifères (Hoggar, Algérie), PhD Thesis, Paris-Orsay Univ. (1980).

[1.11] HALLALOUCHE, J., Etude de l'altération du socle précambrien à la périphérie du bassin de Tin Séririne (Hoggar-Sud, Algérie) et minéralisation uranifère et thorifère associée, PhD Thesis, Rennes Univ. (1994).

[1.12] SONAREM, Rapport des travaux géologiques exécutés pendant les campagnes 1972–1974 sur le gisement de Tahaggart (Hoggar), Missions 1972–1974, SONAREM, Algers (1974).

[1.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[1.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).

[1.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[1.16] ASKRI, H., et al., "Geology of Algeria", paper presented at Algeria Well Evaluation Conference, Algiers, 1995.

[1.17] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO) with Uranium Deposit Classification: 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[1.18] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[1.19] REUTERS, France, Algeria sign civilian nuclear deal (21 June 2008).

3.2. ANGOLA

Two thirds of Angola correspond to a plateau, the average elevation of which is 1050–1350 m, with higher ranges and massifs exceeding 2000 m. Through the central part of this plateau runs the watershed of Angola's rivers. The coastal plain on the Atlantic is separated from this plateau by a subplateau zone which ranges in width from about 160 km in the north to about 25–40 km in the centre and south. The Namib Desert, extending northwards from Namibia, occupies the coastal plain beyond Mocamedes.

As with the rest of tropical Africa, Angola experiences distinct, alternating wet and dry seasons. In the north, the wet season may last for as long as seven months, usually from September to April. In the south, it begins later, in November, and lasts until February. Temperatures fall with distance from the equator and with increasing elevation and tend to rise with increasing proximity to the Atlantic Ocean. Thus, at Soyo, at the mouth of the Congo River, the average annual temperature is about 26°C, but it is less than 16°C at Huambo on the temperate central plateau. The coolest months are July and August (in the middle of the dry season), when frost may sometimes form at higher elevations.

Angola has substantial mineral resources and hydroelectric power. Oil, chiefly from reserves offshore (1224 million t of reserves), is the most lucrative product, providing about 50% of the country's GDP and 90% of its exports. Diamond mining is also a major industry. In addition, Angola produces natural gas and has deposits of bauxite, copper, feldspar, gold, iron, and phosphates. Industries include metals processing, meat and fish processing, brewing and the manufacture of cement, tobacco products and textiles. Coffee and sugar cane are the most important cash crops. Bananas, corn, cotton, manioc and tobacco are also grown. Fishing is also important, as is livestock farming, notably cattle, goats, pigs and sheep, which are raised on much of the savannah region [2.1].

3.2.1. Geology

Rocks of possibly Neoarchean age outcrop in the northeast of Angola belonging to the Kasai Craton (Fig. 3.2). The country is underlain by Paleoproterozoic, Mesoproterozoic and Neoproterozoic rocks of various composition in the west, which include Neoproterozoic Bembe System basal tillites. Oolitic limestones and stomatolites underlay these. The northern central part of the country is underlain by volcanic and sedimentary rocks of the Karoo Supergroup. Precambrian basement is directly overlain by a thick sequence of Mesozoic to Cenozoic marine sedimentary rocks in the coastal basin. The eastern part of Angola is largely covered by Kalahari Group sands and related deposits.

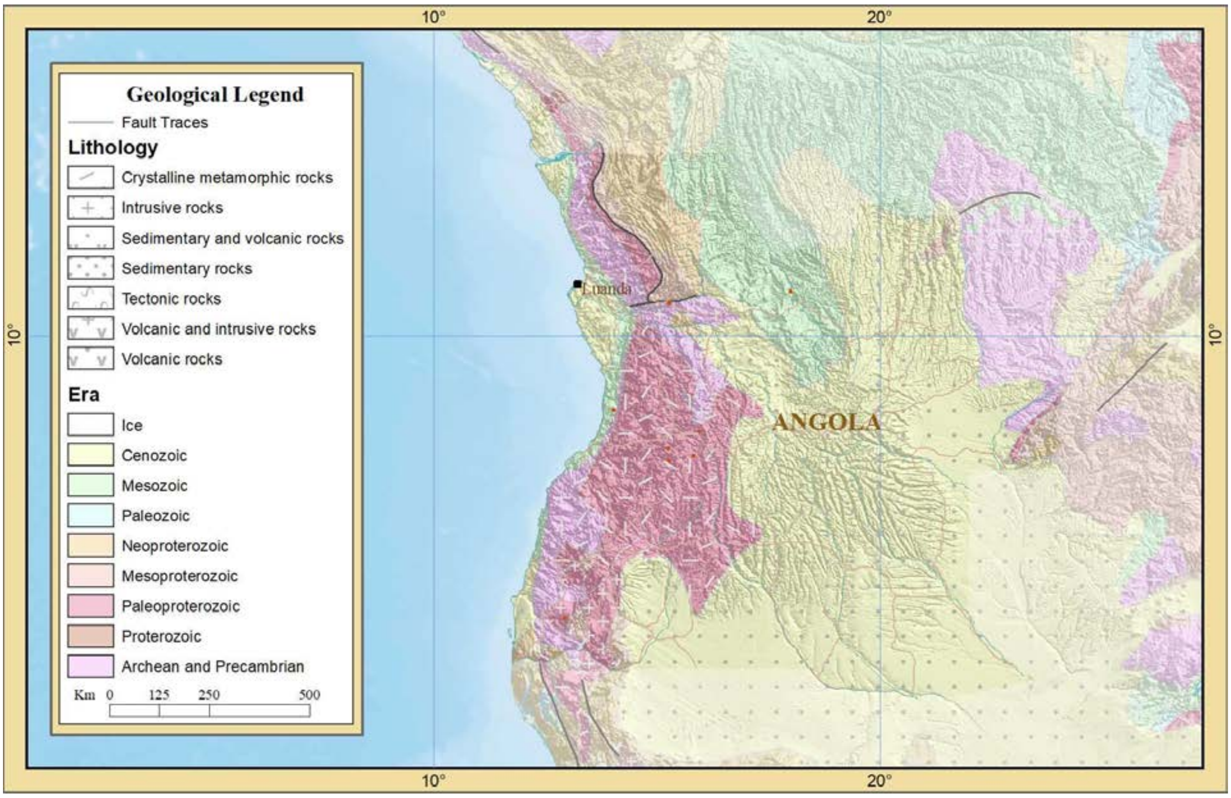


FIG. 3.2. Regional geological setting of Angola.

The oldest formations known in Angola are located in the northeast of the country, related to those more studied in Kasai (Democratic Republic of [the] Congo) and have been affected by metamorphic episodes corresponding to the Neoarchean Moyo and Musefu parts of Kasai. In the basement of western Angola, Isolated Archean rocks are also exposed in some places such as at Dondo, Malanje and south of the River Cuanza near Cariango. Here Archean assemblages show NE–SW and E–W trends, comprising kinzigites, enderbites, charnockites, and granulite gneisses. The volcano-sedimentary Jamba Group South of Nova Lisboa is also of Archean age. Complex greenstone belts of Paleoproterozoic age are present in the southern central part of the country.

It has been concluded that an orogeny affected most of this region at about 2.15 Ga, during which the main metamorphism, granitization and deformation took place, followed by extensive late- and post-tectonic, and anorogenic granitic intrusions and volcanic activity between 2.05 and 1.75 to 1.65 Ga. From Gabon southwards through the Republic of Congo, the Democratic Republic of the Congo, to northern Angola the West Congolian mobile belt extends for over 1300 km. From east to west it contains three structural zones, the external zone with sub-horizontal strata, the median folded zone and the internal zone consisting of intrusive and pre-west basement rocks.

Representing the infilling of a Kibaran-age continental rift, the Mayumbian and the Zadinian Supergroups are the older rocks in the internal zone, which was deformed and thrust eastwards during the Pan-African orogeny in the West Congolian. A sequence of low-grade metasediments of the external and median zones contain the West Congolian Supergroup. The occurrence of high-energy debris flow deposits (mixtites), red beds and basic volcanics in its lower part. Because of its elongate basin geometry sedimentation has been assumed to have started probably at around 1.1 Ga.in a fault-bounded continental rift.

Mainly preserved in the northern central to north-western geological depression are sediments of Paleozoic to Mesozoic age of the Cassanje Graben. These magmatic and sedimentary rocks are correlated with the Karoo Supergroup. Magmatic activities during this period caused the emplacement of diverse volcanic to sub-volcanic bodies, including carbonatites, kimberlites, basalts, syenites, dolerites, trachytes and phonolites. The kimberlite and carbonatite bodies are located along a major trend line, which transects Angola southwest to northeast diagonally.

Cretaceous to Pleistocene marine sediments cover the western margins of Angola. From north to south these basins started developing during Lower Cretaceous times. And are: The Congo, the Kwanza and the Namib marine coastal basins.

Three types of Tertiary to Quaternary rocks can be distinguished, constituting the youngest geological units of Angola. These are Quaternary colluvial and alluvial deposits, Tertiary to Quaternary Kalahari Group continental sediments, and early Tertiary laterite residues. Nearly 50% of Angola is covered by these sedimentary rocks. The Kalahari Group consists mainly of quartzitic sandstones and sand. In the eastern and central part of Angola the lateritic residue forms the substratum of the Kalahari Group. Quaternary colluvial and alluvial deposits in the form of clay, sands, gravels and rubbles occur mainly in river valleys and/or depressions [2.2].

3.2.2. Uranium exploration

The Portuguese began prospecting for radioactive raw materials in Angola in the early 1950s. Small showings of autunite, torbernite and uraninite were noted in a pegmatite area in the basement gneiss at Alto Banda. Euxenite and samarskite, associated with pegmatites in the basement complex, were discovered in 1953, but radiometric surveys and trenching indicated that the mineral occurrences were small.

The Portuguese Junta de Energía Nuclear completed significant prospecting work in Angola during the period 1971–1973 in association with private enterprises. The work included car-borne and airborne prospection and geochemical surveys. Several anomalies were found.

In Cabinda, Companhia dos Fosfatos de Angola carried out reconnaissance drilling work on the phosphate deposits of Maastrichtian and Eocene age, to obtain a better definition of the uranium resources. The distribution of the uranium content was found to be very irregular, but high uranium levels were recorded. Provisionally, the estimated additional resources of this deposit were evaluated at 13 000 tU.

Exploration expenditure data are not available. No recent or ongoing exploration activities are reported.

3.2.3. Uranium resources

No exploitable uranium resources are known in Angola. In 1983, a review of the IUREP estimates reported a range of 50 000–100 000 tU of speculative resources in sandstone (Karoo sediments), magmatic and phosphatic geological environments [2.3, 2.4].

3.2.4. Potential for new discoveries

There are only a few known occurrences of uranium in Angola but there are several areas with potential for uranium deposits. There is the potential for Proterozoic unconformity-related deposits in the rocks of the Oendolongo System, or near the contact of this and the underlying Lower Proterozoic, or in the overlying Bembe System. The Bembe System can probably be correlated with the Katanga System of the Democratic Republic of the Congo and Zambia in which uranium deposits (e.g., Shinkolobwe) and many occurrences of uranium mineralization are known. About 30 ring structures, considered to be correlative with the Karoo volcanic event, are present in a 300 km long NE–SW belt. These ring structure intrusions include carbonatites which may contain significant concentrations of uranium and thorium and may have similarities to the Phalabora carbonatite in South Africa.

There are several environments in which sandstone type uranium deposits could be located:

(a) The Karoo System, which has been divided into three series, underlies large areas of the interior of Angola. Uranium is known in this system in Botswana, South Africa and Zambia;
(b) The Cretaceous Continental Intercalaire is of continental fluvial origin and covers large areas of the northern part of the country. This unit, which is locally known as the Calonda Formation;
(c) In the Angolan coastal basins, Precambrian gneisses are directly overlain by continental and lagoonal Cretaceous beds. These are the Dando and Cuanze Beds, which consist of gypsiferous clays, conglomerates and sandstones with asphaltic coals containing rare plant fossils.

The large area underlain by Kalahari sands in the interior of the country could contain uranium deposits in the fluvial sands or in calcretes.

Uraniferous marine phosphate beds of either Maastrichtian or Eocene age occur intermittently along the coastal basin (Cabinda deposits). These are reported to be of higher uranium grade than other uraniferous marine phosphate beds elsewhere in the world [2.3].

3.2.5. Comments

Angola has not produced uranium. There are no existing facilities and no documented plans to develop nuclear generating capacity. Angola has never submitted a report on uranium activities.

References to Section 3.2

[2.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Angola (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html
[2.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 38–41.
[2.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.
[2.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.3. BENIN

Benin extends from the Niger River in the north-east to the Bight of Benin in the south. Benin's elevation is about the same over the entire country. Most of the population lives in the southern coastal plains, where Benin's largest cities are also located, including Porto Novo and Cotonou. The north of the country consists mostly of savannah and semi-arid highlands.

The climate in Benin is hot and humid with relatively little rain compared with other West African countries, although there are two rainy seasons (April–July and September–November). In the winter, the dust winds of the harmattan can make the nights cooler.

Benin remains underdeveloped and its economy is dependent on subsistence agriculture, cotton production and regional trade [3.1].

3.3.1. Geology

The geology of Benin is comprised of two different domains (Fig. 3.3). The northern region is dominated by crystalline rocks of the Neoproterozoic Dahomeyide Orogen, whereas the southern region consists of sedimentary rocks ranging from Recent to Cretaceous age. In the northeastern part of the country alluvial rocks of Neogene age predominate.

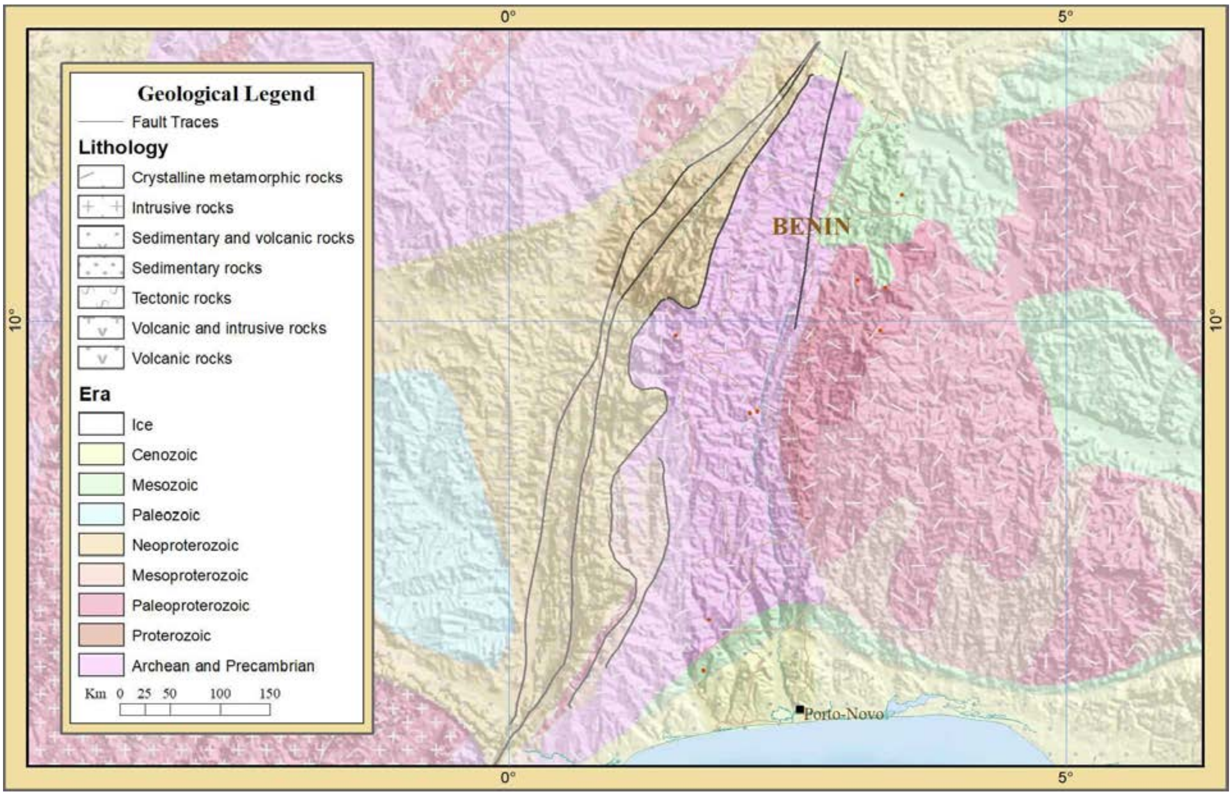


FIG. 3.3. Regional geological setting of Benin. For the general uranium occurrences legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Crystalline rocks in Benin and Togo are generally considered as belonging to the Dahomeyide Orogen, which is located along the southeastern margin of the West African Craton.

Outcropping in the northwestern part of the country are sediments of the Voltaian Supergroup, ranging from Paleozoic to Neoproterozoic times. The Voltaian Supergroup has been divided into three groups.

The lowest comprises sandstones, quartzites and shales with a maximum thickness of 600 m. The middle Voltaian or Oti Group, with a thickness of about 1600m, lies unconformably on the lower Voltaian with conglomerates, interpreted as tillites, at the base, followed by shales, sandstones, limestones and dolomites. The upper Voltaian or Obosum Group is a molasse unit [3.2].

The Neogene formations are best developed in the coastal region and are mostly represented by lagoonal and alluvial deposits. Alluvial deposits are, however, also well-developed along the major rivers within the Proterozoic terrains.

Gold mineralization is known from conglomerates in quartzites of the Togo Group in north-western Benin. Alluvial and eluvial concentrations of rutile are very abundant in an area extending from Kolkonde in the north to Basila in the south. A number of geochemical anomalies of chromium, cobalt, copper and nickel have been detected in the region of Goumpare, east of Parakou [3.3].

3.3.2. Uranium exploration

Very little uranium exploration work has been conducted in Benin. In 1980, France's Bureau de Recherches Géologiques et Minières (BRGM), in cooperation with the Direction Générale des Mines, de la Géologie et du Bureau National de Recherches Minières du Togo and the Office Béninois des Mines, tested the uranium potential of the geological contact between the Dahomey and Atacorian. An area of nearly 2000 km² was covered by radiometric and geochemical surveys (stream sediment sampling density: 1 per km²). The results of this programme did not justify further work.

No recent or ongoing exploration activities have been reported. No information on exploration expenditure is available [3.3].

3.3.3. Uranium resources

Benin does not report uranium resources in any category. In 1983, a review of the IUREP estimates reported a range of 1000–10 000 tU of speculative resources in sandstone and magmatic geological environments [3.4]. The UDEPO database does not list any known deposits for Benin.

3.3.4. Potential for new discoveries

The potential for uranium discovery appears to be limited. The Dahomey/Atacorian unconformity, adjacent to Togo, could have potential as mineralization is known to occur along this horizon [3.3].

3.3.5. Comments

No uranium has been produced in Benin and currently no uranium production is planned. Benin has no nuclear power plant.

References to Section 3.3

[3.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Benin (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[3.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 42–44.

[3.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[3.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.4. BOTSWANA

Botswana is a landlocked country in central southern Africa. It is a predominantly flat to gently rolling tableland. The Limpopo River Basin is the major landform throughout all of southern Africa, including Botswana. Botswana is dominated by the Kalahari Desert, which covers up to 70% of the land surface of the country. The Okavango Delta, the world's largest inland delta, is in the north-west. The Makgadikgadi Pan, a large salt pan, lies to the north.

Botswana has diverse areas of wildlife habitat, including the Okavango Delta, the Kalahari Desert, grassland and savannah. The latter are home to blue wildebeest and many antelope, as well as other mammals and birds.

Botswana's economy has been built on the revenue generated from diamond mining which fuels economic development through fiscal and foreign policies. Debswana, the largest diamond mining company operating in Botswana, is 50% owned by the Government and generates about half of all Government revenues. Several international mining corporations have prospected in Botswana for copper, diamonds, gold, uranium and oil, with some positive results. However, more than half of Botswanan nationals live in rural areas and are dependent on subsistence arable and livestock farming, together with money remitted by relatives employed in urban areas [4.1].

3.4.1. Geology

Rocks of Archean age predominate in the east and southeast of Botswana (Fig. 3.4). Proterozoic orogenic belts, mostly concealed beneath Karoo rocks, young progressively westwards away from the Archean rocks. Karoo strata deposited within the Kalahari Basin underlie central Botswana, whereas in the north and northwest rocks of Meso- and Neoproterozoic age occur [4.2].

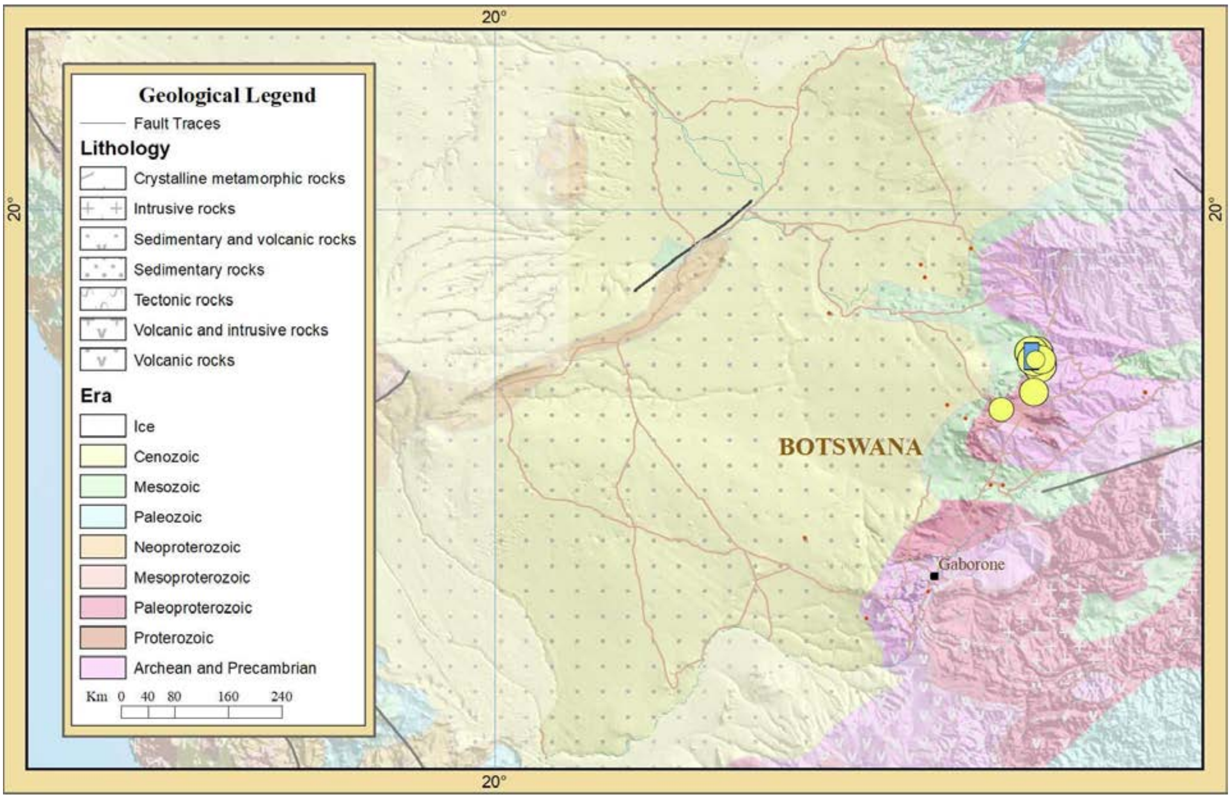


FIG. 3.4. Regional geological setting of Botswana showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

About one eighth of the country in the south-east consists of outcrops of Precambrian rocks. The oldest group of these comprises Archaean gneisses, charnockites and granites with minor in-folded greenstone belts forming the north-western margin of the Transvaal cratonic nucleus and the south-west corner of the Zimbabwe cratonic nucleus. The two cratonic nuclei are unconformably overlain to the west of Gaborone by sediments of the Transvaal Supergroup (shale, quartzite, conglomerate, limestone, dolomite and ironstone). Late Proterozoic Waterburg sediments (conglomerates, sandstones, schists, dolomites and quartzites) overlie this sequence. Both groups of sediments are intruded by ultrabasic and granitic igneous complexes.

In the north-western part of the country, relatively unmetamorphosed Late Proterozoic foreland platform sediments are preserved in small grabens. To the north-west of these exposures, possible eugeosynclinal equivalents of these platform facies of the Damara Supergroup have also been identified. These units are thought to represent the southern side of the Damara geosyncline. Copper deposits are present in the foreland facies on both sides of the Damara geosyncline in Namibia and the Rössing uranium deposit occurs in the granitized eugeosynclinal facies (Damara Supergroup). It is not impossible that the various facies of the Damara orogenic belt in Namibia and Botswana are correlative with the Katanga of the Democratic Republic of the Congo and Zambia.

A large proportion of the southern part of the country, about 200 000 km^2, consists of a major Karoo sedimentary basin, the core of which, at least in the north-east, includes extensive trap basalt sequences in the upper part of the sequence.

The Karoo rocks consist of intercalated shales, mudstones, arenites, arkoses and conglomerates of continental fluvial origin. These are characterized in the unweathered zone below the water table by carbonate cement with the argillaceous elements being pyritic and carbonaceous locally. Parts of the Permian Karoo sequences contain coal. The upper sequences comprise extensive thicknesses of basic trap lavas which cut the lower sedimentary sequences and the basement. Kimberlite pipes also transect all strata. The Karoo sedimentary sequences show many of the characteristics thought to be important in the formation of sandstone-type uranium deposits.

All the rock sequences outlined above are overlain unconformably by Kalahari sands of Eocene–Recent age. Much of the area is in semi-desert terrain, characterized by zones of intermittent water flow and by the development of calcretes, some of which are believed to be uraniferous and therefore targets for extensive prospecting by several organizations [4.2, 4.3].

3.4.2. Uranium exploration

Interest in the uranium potential of Botswana was limited and sporadic during the period 1954–1973. Most exploration activities were carried out in the period 1974–1980 and 2007 – 2013 (Fig. 3.5) for a total of USD $14 609 000, including 68 594 of drilling, 153 650 km^2 of airborne radiometric surveys and 11400 km^2 of other surveys. Exploration data carried out during the period 2013-2017 were not reported by Botswana.

Uranium exploration has been concentrated in three geological environments:

(i) Granitic and syenitic intrusions and high grade metamorphic rocks of Precambrian age;
(ii) Fluviatile sandstones, mainly of Middle Ecca (Permian) age;
(iii) Calcretes of Tertiary and Quaternary age.

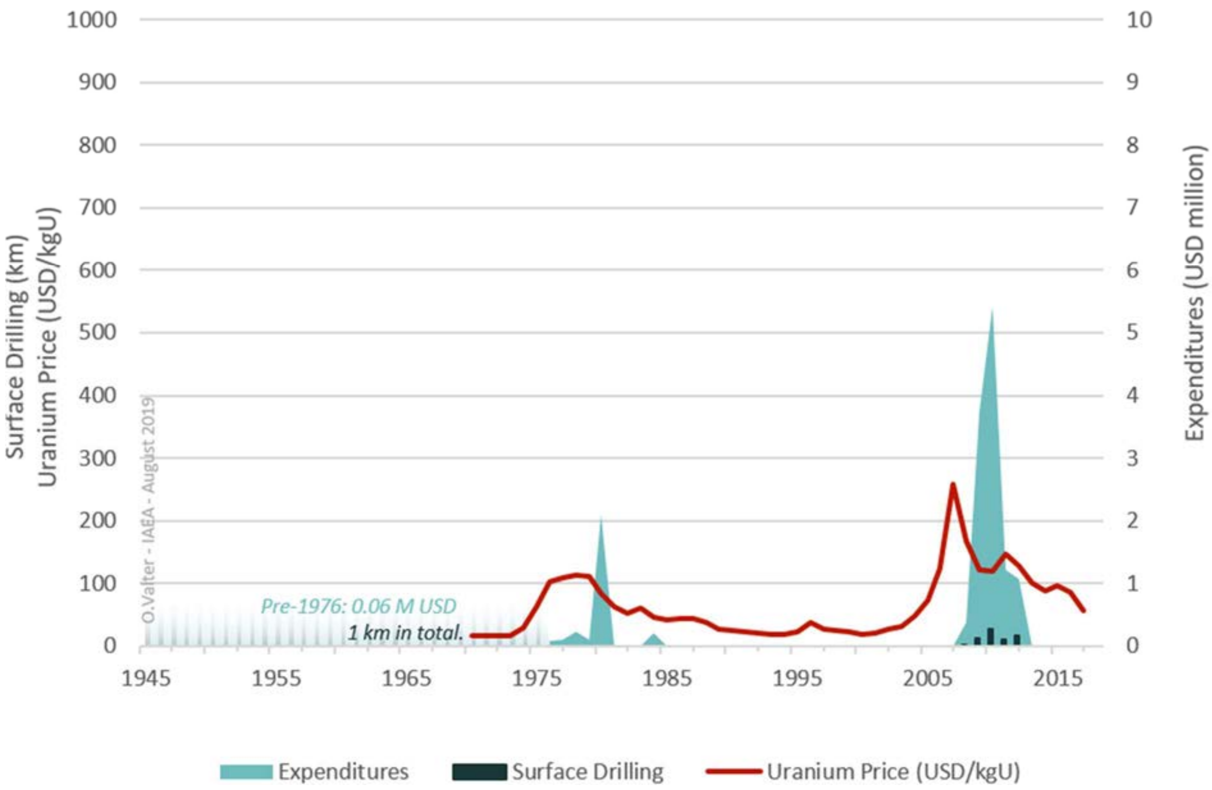


FIG. 3.5. Domestic uranium exploration data for Botswana. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

From 1960 to 1975, regional airborne radiometric surveys were conducted as an adjunct to aeromagnetic or electromagnetic surveys. Areas surveyed were large but often geologically unfavourable or covered by thick Kalahari beds. In 1969, an airborne survey was conducted over a large area in eastern Botswana. Anomalies at Mojabana, Serule and Oukwe were investigated in 1970–1972 and in 1976–1978.

In 1971, the Tuli Block, along the south-eastern border and located mainly in the Central District, was surveyed while water sampling and drilling were conducted in the Mmamabula and Kaiane Tswago areas. In 1976, an airborne radiometric survey using a 4 km line spacing was conducted over an area of 28 000 km² to investigate the areas where Karoo sedimentary rocks crop out between Serowe and Nata (Central District). At the same time, more detailed surveys were flown over known uranium mineralization at Nokobaese and Serule (1400 km² at a 0.5 km line spacing), Dukwe (2400 km² at a 0.5 km line spacing) and Thabatshukudu (500 km² at a 1 km line spacing).

Since 1976, airborne radiometric surveys have been flown for primary exploration of promising areas and followed by ground spectrometer and alpha radiation surveys. Water and outcrop sampling, pitting and drilling have been performed over anomalous areas. These programmes were carried out mainly by Union Carbide, Falconbridge, Bamangwato Concessions, Anglo American and Urangesellschaft.

In 1977, a programme of borehole water sampling in 12 widely scattered areas of Botswana and a programme of car-borne radiometric prospecting along roads and tracks were carried out. In 1978, an extensive airborne radiometric survey was conducted over drainage channels in the central and western parts of the country. Anomalies were checked by ground spectrometer surveys and sampling of duricrusts. Another airborne survey, with a line spacing of 2–10 km, was conducted over eight areas where the bedrock was not obscured by thick Kalahari beds. Ground follow-up was conducted at Mmamabula and Serurume.

In response to the decline in the world uranium market in the late 1970s, all exploration activities, primarily for radioactive minerals, ceased. Four foreign companies exploring for coal in the Karoo sediments, with licences covering over 4000 km², also conducted exploration activities for radioactive minerals as an adjunct to their main target. The Botswana geological survey's activities included the monitoring of exploration projects carried out by the foreign companies and the analysis of uranium in groundwater as a tool for reconnaissance uranium resource evaluation.

No exploration activities have been reported to the Red Book since 1988.

3.4.2.1. Ongoing exploration activities

Uranium exploration has been undertaken by A-Cap Resources Ltd (Letlhakane project), Bannerman Resources Ltd (Serule South, Serule North and Dukwe areas) and African Energy Resources Ltd (Sese Uranium Project in north-east Botswana).

On 17 October 2008, A-Cap Resources Ltd released the results of a scoping study on the Letlhakane project. The preferred project option envisaged the mining of 45 million t of uranium bearing rocks (at a grade of 0.0153% U) containing an estimated 6923 tU. The target annual production rate, assuming a leaching recovery of 80%, is 846 tU [4.3, 4.4].

In 2015, A-Cap Resources, following an important drilling programme (3507 holes, 143.4 km) covering the whole project, released resources in compliance with the JORC code for seven deposits within Karoo tabular sandstones and one surficial deposit. Total resources, using a cut-off grade of 85 ppm U, stand at 140 650 t U at an average grade of 171 ppm U [4.5].

3.4.3. Uranium resources

Exploration for uranium in Botswana has so far failed to discover any economic deposits, but has identified one subeconomic surficial deposit, at Mokobaesi, in a calcrete environment. Weaker indications are widely scattered in promising lithologies and there is considerable potential for further exploration.

The best potential for mineralization would appear to occur where uraniferous Karoo sediments have been subjected to a weathering regime with a fluctuating water table and where a calcrete capping has formed over the uranium source rock, as at Serule and Oukwe. The prospective area where this type of surficial deposit can occur covers approximately 120 000 km² in the south and west of the country.

Additional potential exists in the sedimentary rocks of the Karoo Supergroup of Carboniferous–Jurassic age, which host uranium mineralization in many localities. For the most part, the uranium occurs in fluviatile sandstones of the Middle Ecca Formation and the overlying Upper Ecca shales. Large areas remain unexplored around the A-Cap Resources Letlhakane project.

In addition, the impure dolomites of the Kautse beds, probably equivalent to the Upper Ecca, contain uranium at Thabatshukudu. Exploration, specifically for uranium, has taken place at Mmamabula, Serule, Dukwe and Thabatshukudu, while uranium mineralization has been investigated as a by-product of coal exploration at Letihakeng and Moijabana, and an occurrence has been discovered at Gidikwe.

In the 1979 edition of the Red Book [4.6], Botswana reported the following speculative resources (Table 3.3).

Fig. 3.6 and Fig. 3.7 show historical trends in reasonably assured and inferred resources respectively.

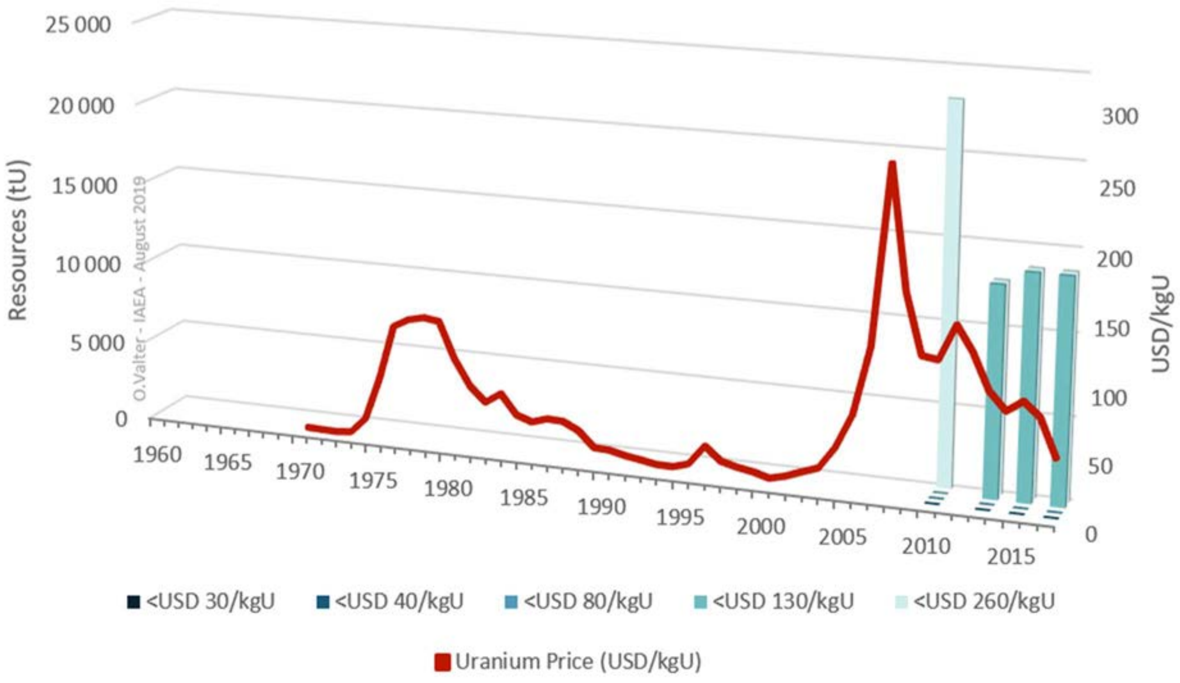


FIG. 3.6. Historical variation of recoverable reasonably assured resources within various cost categories in Botswana. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

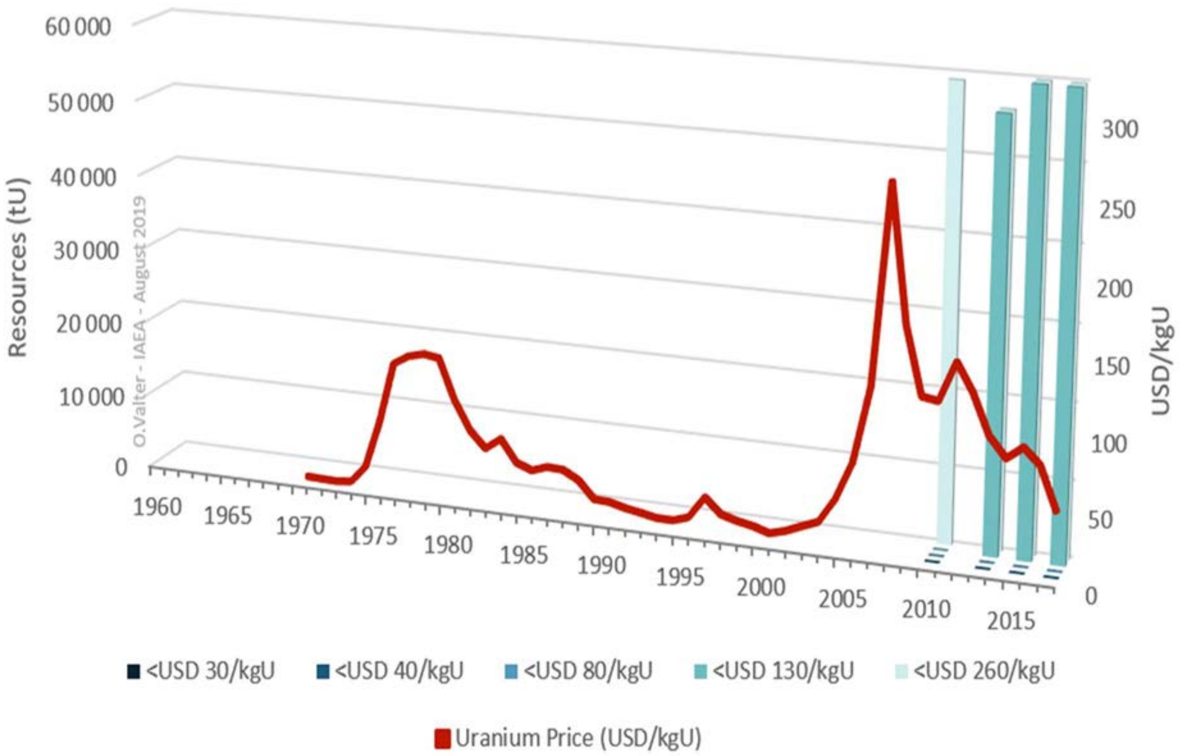


FIG. 3.7. Historical variation of recoverable inferred resources within various cost categories in Botswana. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

TABLE 3.3. SPECULATIVE RESOURCES (tU) [4.4]

Host formation	Cost category	
	US $80–130/kgU	US $130–260/kgU
Karoo sandstones	2000	5000
Syenites	200	400
Calcretes	100	1000
Total	2300	6400

The UDEPO database lists the most significant deposits for Botswana as Gorgon Main, Gorgon West, Serule NW, Gorgon South, Serule West, Kraken, Mokobaesi, Lekobolo, Serule East.

3.4.4. Potential for new discoveries

Botswana should have a moderate to high uranium potential as most of the exposed sedimentary and metamorphic environments are theoretically capable of hosting uranium mineralization.

Quartz pebble conglomerate uranium deposits could exist in Botswana, in the Transvaal and Waterburg Supergroups. These units underlie an area which has extensive cover.

The main Precambrian potential is likely to be in association with Late Proterozoic platform sediments such as the Ghanzi Formation and Damara Supergroup in north-western Botswana, either in favourable sediments within these formations or in proximity to major unconformities with older formations immediately underlying them. Uranium mineralization has been found in the Democratic Republic of the Congo and Zambia in possible correlatives of these strata (Katanga Series).
Uranium is present in ferruginous lenses in coarse, fluviatile Ecca sandstone (Karoo Group) at Serule and Dukwe. Botswana is considered as highly favourable for sandstone uranium deposits in the Karoo Group. At Sua Pan and to the south, uranium is present in grades of up to 420 ppm U in the Kautse Beds of Ecca age (Karoo Group). The uranium occurs in gently undulating dolomite beds of 1–2 m thickness.

Good uranium potential should exist for Yeeleerie type calcrete deposits in the Kalahari sands. A deposit has been found at Mokobaesi in the Serule area of eastern Botswana in nodular calcrete which was formed in a palaeodrainage channel. The uranium mineral is a yellow lead–uranium–vanadium hydrate and the grade averages 380–420 ppm U. The calcrete bed is about 1 m thick and overburden rarely exceeds 1 m. Resources are 2425 t U at 160 ppm. Two minor calcrete occurrences have been reported at Dukwe.

The Kalahari sands, if any fluvial clastic facies are present, could also host roll front uranium deposits, especially in the vicinity of potential source rocks [4.3].

3.4.5. Comments

No uranium has been produced in Botswana and currently no uranium production is planned. Botswana has no nuclear plant and none are planned.

References to Section 3.4

[4.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Botswana (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[4.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 46–49.

[4.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[4.4] A-CAP RESOURCES, Results of nine month scoping study on the Letlhakane uranium project (2008), http://www.acap.com.au/ca2008.htm (accessed October 2008).
[4.5] A-CAP RESOURCES LTD., The Letlhakane Uranium Project, https://acap.com.au/projects/uranium/ (accessed August 2019)
[4.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

3.5. BURKINA FASO

Burkina Faso is a landlocked country in West Africa. Most of the country consists of a peneplain, forming a gently undulating landscape. In some areas, a few isolated hills represent the last vestiges of a Precambrian massif. Burkina Faso is relatively low lying, with an average elevation of 400 m; the differential between the highest and lowest points not exceeding 600 m. The south-west of the country forms a sandstone massif, where the highest peak, Ténakourou (749 m), is located. The massif is bordered by vertical cliffs rising up to 150 m.

Three major climatic zones can be defined:

(i) The Sahel in the north typically receives less than 600 mm of rainfall annually and has temperatures in the 5–47°C range;
(ii) The Sudan–Sahel region is a transitional zone as regards rainfall and temperature;
(iii) The Sudan–Guinea zone farther to the south receives more than 900 mm of rainfall annually and has cooler average temperatures.

Burkina Faso has a range of mineral resources, including limestone, manganese, marble, phosphates, pumice, salt and several small gold deposits.

Agriculture represents 32% of GDP and occupies 80% of the working population. Much of it involves livestock rearing. In addition, corn, cotton, groundnuts, pearl millet, rice and sorghum are also grown, primarily in the south and south-west [5.1].

3.5.1. Geology

Burkina Faso is predominantly underlain by rocks of the Guinea Rise, which borders the Gulf of Guinea and extends from Sierra Leone in the west to Ghana in the east (Fig. 3.8). The rise is generally characterized by granitic gneisses, and north to northeasterly trending belts of metasediments and metavolcanics.

The oldest rocks in Burkina Faso are pre-Birimian migmatites, gneisses and amphibolites underlying the Birimian rocks. In southwestern Burkina Faso the Birimian deposits can often be divided, similarly as in neighbouring Ghana, between predominantly clastic (flysch) formations and volcano-clastic formations. The clastic sequence consists of intensely deformed pelitic and psammitic metasediments. There are three major Birimian greenstone belts in the south and the west of the country, in which volcano-sedimentary sequences are dominant, and a fourth in the central and northeastern regions, besides numerous other smaller greenstone belts, which are found throughout the country. Granites and granodiorites occupy the spaces between the greenstone belts. Proterozoic conglomerates and sandstones of the Tarkwaian Group rest unconformably on Birimian rocks around Essakane in the NE of Burkina Faso. The margins of a large sedimentary basin of Neoproterozoic to Ordovician age emerge at the western border of Burkina Faso. These rocks consist of basal sandstones with overlying shales and dolomites, sometimes carrying bauxite mineralization [5.2].

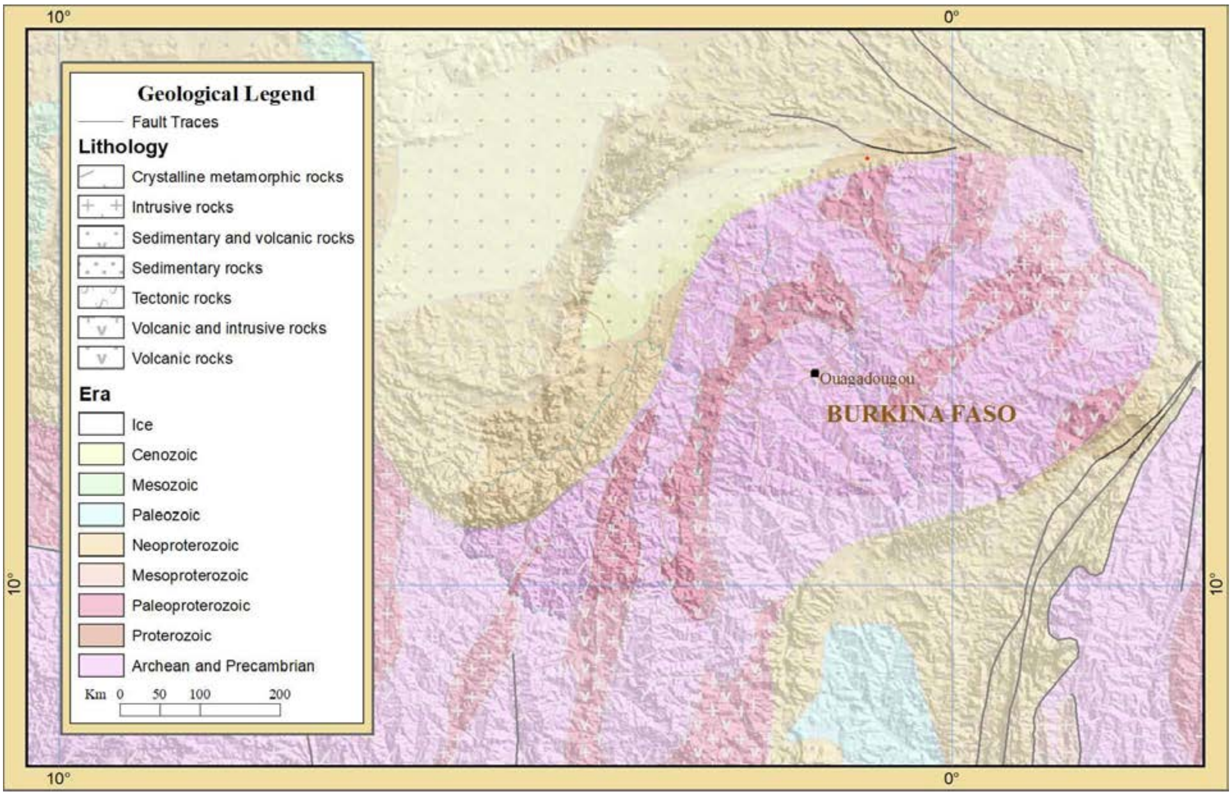


FIG. 3.8. Regional geological setting of Burkina Faso. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Mining contributes only a small amount to Burkina Faso's GDP. The main mineral produced is gold, much of which is extracted by artisanal gold miners. Gold is primarily mined from Proterozoic rocks and alluvial/eluvial deposits.

Burkina Faso has important Neoproterozoic phosphate deposits in the extreme south-east of the country, close to the borders with Benin and Niger. The reserves of the various phosphate rock deposits were, in 1986, estimated at: Aloub Djouana (224 million t at 15% P_2O_5), Kodjari (80 million t) and Arly (4 million t) [5.2].

3.5.2. Uranium exploration

In the 1960s, France's Atomic Energy Commission conducted some exploration in the Bobo-Dioulasso, Djibo and Yako areas. There were no significant results.

In 2008, Crosscontinental Uranium Ltd completed a detailed airborne radiometric and magnetic survey of the Oursi area. The Oursi project tenements, in the north-east of the country, cover a combined area of 500 km² and include a 50 km strike length of an unconformity structure that is considered prospective for uranium mineralization. Known uranium mineralization occurs 50 km along strike and west of the Oursi tenements.

The magnetic data defined the unconformity structure and a number of cross-cutting fault structures. The spectrometer data indicate several discrete uranium anomalies in a favourable geological setting, warranting ground follow-up and investigation. One uranium anomaly is approximately 8–9 times the radiometric background. Ground follow-up was expected to commence as soon as field access could be arranged.

3.5.3. Uranium resources

Burkina Faso does not report uranium resources in any category. In 1983, a review of the IUREP estimates reported a range of <1000 tU of speculative resources [5.3].

The UDEPO database does not list any known deposits for Burkina Faso.

3.5.4 Comments

No uranium has been produced in Burkina Faso and there are no plans to develop nuclear generating capacity. No report has been submitted to the Red Book.

References to Section 3.5

[5.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Burkina Faso, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[5.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 50–52.

[5.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.6. BURUNDI

Burundi is one of Africa’s smallest countries. It is a landlocked country located towards the centre of the continent and forms part of the Albertine Rift, which is the western extension of the Great Rift Valley. The country comprises a rolling plateau, with an average elevation of 1700 m, descending to lower elevations at its borders. The highest peak, Mount Heha (2690 m), lies to the south-east of the capital, Bujumbura. The River Nile is a major river in Burundi and Lake Tanganyika is an important source of water.

The climate is equatorial, with two rainy seasons: hot and humid in the Ruzizi valley (23°C average temperature; 800 mm annual rainfall) and temperate in mountainous regions (16°C average temperature; up to 1200 mm annual rainfall).

Burundi’s largest economic sector is agriculture, with subsistence activities accounting for 90% of the total. Its most important source of revenue is coffee. Other agricultural products include bananas, cotton, maize, manioc, sorghum, sweet potatoes and tea, as well as beef, milk and hides. Some of Burundi’s natural resources include cobalt, copper, nickel, platinum and uranium [6.1].

3.6.1. Geology

Burundi’s geology is mostly made up of rocks belonging to the Mesoproterozoic Kibaran Belt and the Neoproterozoic Malagarasian Supergroup (Fig. 3.9). Tertiary and Quaternary sediments fill parts of the Western Rift at the northern tip of Lake Tanganyika.

Rocks belonging to the Mesoproterozoic Kibaran Belt are widespread in Burundi and are locally termed as the Burundian Supergroup. Generally, the Burundian Supergroup is subdivided into three units. The base of the lower Burundian consists of a quartzitic sequence, which overlies directly the Archean basement. The upper part of this unit contains locally a tuff horizon of intermediate composition. It is overlain by schists of considerable thickness, whose lower part consists of graphitic schists, which are interbedded with quartzitic horizons of minor importance. Higher up, the quartzitic horizons are interbedded with grey schists, sometimes containing volcanic intercalations.

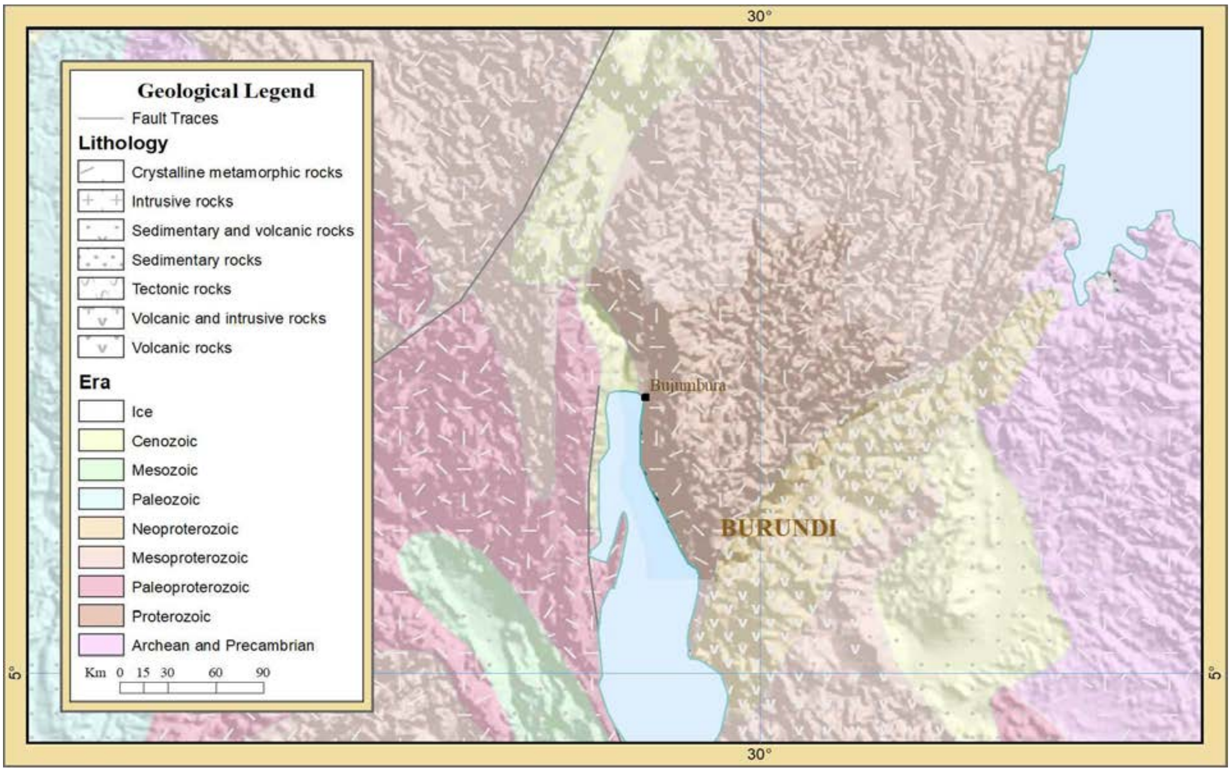


FIG. 3.9. Regional geological setting of Burundi. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The middle Burundian begins with a sequence of quartzites overlain by schists and green phyllites, which are particularly well-represented in the western part of the country, and which in this region contain basic volcanic intercalations overlain by acidic volcanic horizons. These pelitic key horizons are overlain by black graphitic and ferruginous schists, which progress gradually towards the upper Burundian. The upper Burundian is generally characterized by poorly sorted sediments, often containing arenites. Within these arenites occur numerous lenticular conglomeratic bands. Frequently present is an intraformational conglomerate near the base of this formation, which is characterized by the presence of ferruginous lenses. The rocks of the Burundian Supergroup are intruded by granites, and along a 350 km long narrow zone by mafic and ultramafic intrusions [6.2].

Neoproterozoic rocks are represented by members of the Malagarasian Supergroup. The contact between the Neoproterozoic Malagarasian Supergroup and the underlying Burundian sedimentary rocks is either unconformable or faulted. The relatively flat lying and unmetamorphosed Neoproterozoic formations of south-eastern Burundi comprise epicontinental sediments associated with basic igneous rocks. The Malagarasian n Burundi has an overall thickness of about 2000 m and has been subdivided into five units:

(i) The lowest group is the Kavumwe Group, the sediments of which accumulated in local basins and consist of quartzites, sandstones, argillaceous sandstones and shales;
(ii) The Nkoma Group consists of conglomerates, quartzites and sandstones;
(iii) The Musindozi Group contains dolomitic limestones, calcareous shales, lavas, sandstones, quartzites and conglomerates;
(iv) In the Mosso Group, silicified dolomitic limestones and lavas occur;
(v) The top of the Malagarasian Supergroup is represented by the Kibago Group, which is characterized by sandstones, quartzites, shales and a basal conglomerate.

Mostly Neogene sediments fill parts of the Western Rift at the northern tip of Lake Tanganyika and along various rivers [6.2].

3.6.2. Uranium Exploration

Uranium exploration started in Burundi in 1969 when, at the request of the Government of Burundi, the United Nations Development Programme initiated a project of mineral exploration using funds provided by the United Nations and facilities provided by the Geological Survey of Burundi. The programme was divided into four phases:

(i) Phase 1 (1969–1972): General reconnaissance studies and interpretation of geological structures using photogeology and results from an airborne spectrometer survey conducted by Hunting Surveys Ltd;
(ii) Phase 2 (1972–1977): Completion of a combined magnetometer and radiometric airborne geophysical survey covering part of the country by Hunting Surveys Ltd and detailed exploration of specific occurrences;
(iii) Phase 3 (1977–1981): Car-borne radiometric surveys used for infill of areas not covered by airborne surveys and ground follow-up of anomalies. Airborne (electromagnetic and magnetic spectrometer) surveys carried out by German's Bundesanstalt für Geowissenschaften und Rohstoffe. Detailed exploration of specific occurrences located by the airborne survey;
(iv) Phase 4 (1982–1984): Priority given to the delineation of cobalt, copper, iron, nickel, titanium and vanadium mineralization, as well as to feasibility studies. At that time, uranium and rare earth prospects were not regarded as very promising.

From 1981 onwards, France's Bureau de Recherches Géologiques et Minières (BRGM) conducted extensive field work in north-eastern Burundi. The Bundesanstalt für Geowissenschaften und Rohstoffe assessed the potential of the Gakara/Karonge bastnaesite (rare earth) deposit.

No major uranium occurrences are known in Burundi, although a number of small anomalies have been found:

(a) *The Kiganda occurrence*: Assay results of up to 500 ppm U associated with high copper and zinc values were obtained from trenches on radiometric anomalies in an area underlain by Burundian metamorphics at the western periphery of the granite–gneiss Kiganda complex;
(b) *The Musigati occurrence*: Assay results of up to 578 ppm U were obtained from trenches over radiometric anomalies in an area underlain by Burundian and Ruzizian metamorphics (schists and gneisses) and pegmatites. The uranium mineralization occurs as pockets of autunite, irregularly distributed within or at the contact of the partly brecciated and limonite stained pegmatites. The drilling results were not encouraging;
(c) *The Mparamirundi and Kigambi occurrences*: Assay results of up to 2000 ppm U were obtained from trenches over radiometric anomalies in an area underlain by Ruzizian metamorphics and pegmatites. No visible uranium mineralization was reported;
(d) *The Matongo occurrence*: At Matongo, a uraniferous carbonatite, mainly considered for its phosphate potential and probably related to the syenite complex of the Kayanza granite–gneiss complex, yielded assay results of up to 3300 ppm U in its weathered capping. Uranium recovery as a by-product of phosphate mining was considered, but further investigation indicated that the higher grade uraniferous pockets were too small and too sparsely distributed to warrant further effort.

No recent exploration activities have been reported in Burundi.

3.6.3. Uranium resources

There is no official estimate of uranium resources in Burundi. In 1983, the IUREP Orientation Phase Mission to Burundi estimated that speculative resources could range from 300 tU to more than 4100 tU [6.3, 6.4].

The UDEPO database does not list any known deposits for Burundi.

3.6.4. Potential for new discoveries

Speculative uranium resources may possibly be associated with potential vein-like deposits of the Lower Burundian. Other speculative uranium resources could be associated with granitic or peribatholithic environments, possibly in areas of low to medium grade metamorphism or at the faulted contacts between sedimentary arkoses and gabbroic intrusives.

3.6.5. Comments

There has been no uranium production in Burundi. Burundi has no nuclear power plants. No reports have been submitted to the Red Book.

References to Section 3.6

[6.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Burundi, Washington, DC, https://www.cia.gov/library/publications/ the-world-factbook/index.html.

[6.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 54–57.

[6.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[6.4] GEHRISCH, W., CHAIGNE, M., IUREP Orientation Phase Mission Report: Burundi, IAEA, Vienna (1983) 124 pp.

3.7. CAMEROON

Cameroon is located in western central Africa, bordering the Bight of Biafra, between Equatorial Guinea and Nigeria. It also has borders with the Central African Republic, Chad, Congo and Gabon. Cameroon exhibits all the major climates and vegetation of the African continent: mountains, desert, rainforest, savannah, grassland and ocean coastland, and can be divided into five geographic zones.

Cameroon's coastal plain extends 15–80 km inland from the Gulf of Guinea to the edge of the South Cameroon Plateau. The coastal belt is heavily forested and is one of the world's wettest locations. It is extremely hot and humid. The South Cameroon Plateau, which rises from the coastal plain and is dominated by tropical rainforest, has an average elevation of 450–600 m and is less humid than the coast. In western Cameroon, the topography comprises an irregular range of mountains, hills and plateaux. This region enjoys a moderate climate and contains some of the country's most fertile soils, notably around the volcanic Mount Cameroon. From the forested southern plateau the land rises northwards to the grassy, rugged Adamaoua highlands. Extending across Cameroon from the mountainous western area, the Adamaoua forms a barrier between the north and the south. Its average elevation is 1035 m and its climate is equable. The northern savannah plain extends from the edge of the Adamaoua to Lake Chad. Its characteristic vegetation is scrub and grass. This is a region characterized by sparse rainfall and high temperatures.

Cameroon's natural resources tend to be in agriculture and forestry. An estimated 70% of the population farms and agriculture contributed an estimated 45% to GDP in 2006. Crops include coffee, sugar and tobacco. The southern rainforest has major timber reserves, estimated to cover 37% of Cameroon's total surface area. Cameroon also possesses substantial mineral resources (bauxite, iron, petroleum), but these are not extensively exploited. Petroleum extraction has fallen since 1985, but still remains a substantial sector [7.1].

3.7.1. Geology

The oldest Precambrian rocks, the Lower–Middle Proterozoic, have not been differentiated by their age (Fig. 3.10). They consist of gneisses, mica schists and migmatites. The Ayes, Lom, Mbalmayo-Benglois and Poli rock groups are considered to be of Lower Proterozoic age and form a folded complex consisting of amphibolitic schists, lavas and quartzites intruded by granitic bodies. The areas underlain by these rocks could have some potential for uranium, particularly because certain basement granites exhibit relatively high levels of radioactivity along tectonic and altered zones.

The Lower Dja Series, which have been correlated with the Franceville Series of Gabon, contain quartzites, sandstones and shales and could host uranium deposits, despite the lack of success of past surveys.

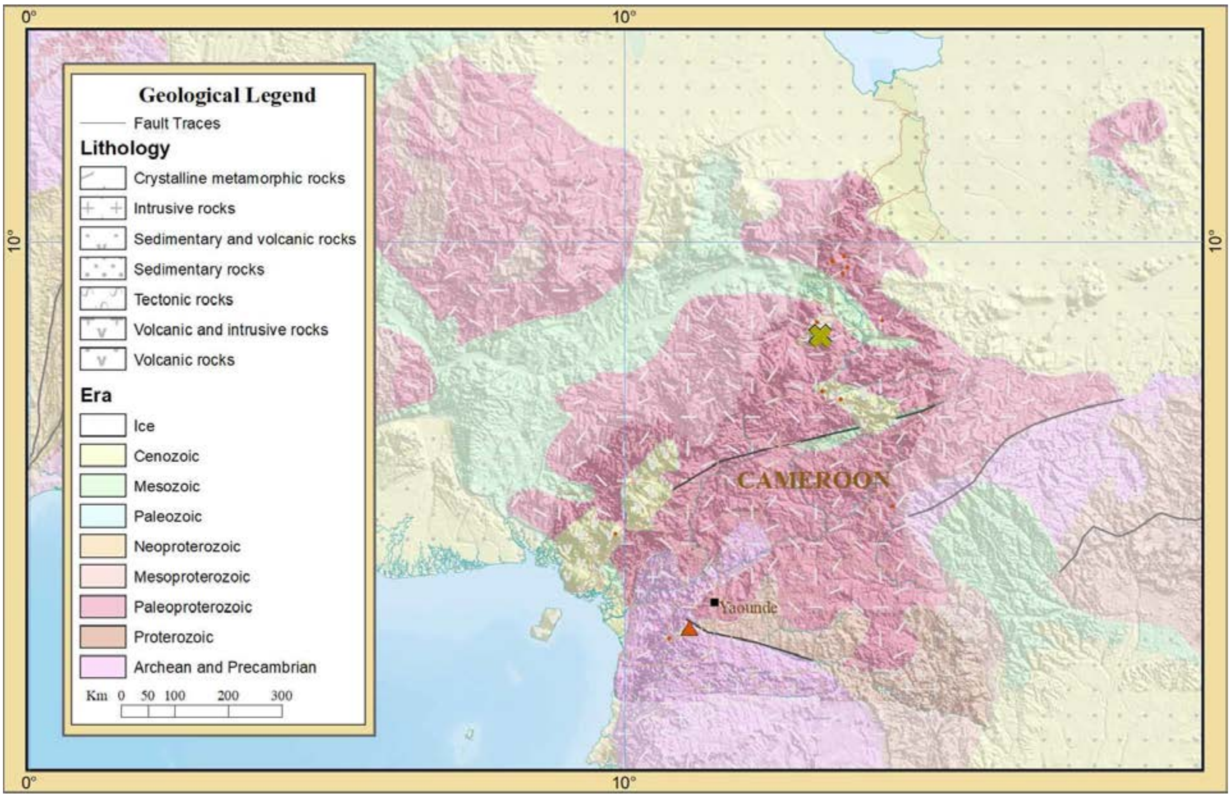


FIG. 3.10. Regional geological setting of Cameroon showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Cretaceous Garoua sandstones (Continental Intercalaire) are present in sub-horizontal beds in a large area on both sides of the Benue River in north Cameroon. Generally, they overlie Precambrian granitic rocks. However, in some localities they are in fault contact with the Precambrian. The sandstones are intruded by volcanic rocks, mainly trachytes. The Garoua is at least 400 m thick and usually has a basal conglomerate overlain by sandstone beds with lenticular shale intercalations. Silicified wood is present in the Garoua sandstone. Uranium deposits could have formed in this geological environment [7.2, 7.3].

3.7.2. Uranium mineralization

Uranium exploration in Cameroon was initiated in 1959 by France's Atomic Energy Commission. During the period 1959–1969, an area of 59 280 km² was investigated by airborne and ground surveys. Anomalies were followed up on the ground at 230 different points. Geologically favourable areas for uranium were detected at several locations. Areas evaluated include: granites and syenites in the basic migmatite complex (Pan-African); areas along the Cretaceous basins in the north of the country; and the formations of the Dja Series in the south-east, which are possibly equivalent to the Franceville System in Gabon and known for its uranium deposits. No significant mineralization was discovered by the Atomic Energy Commission, but a private prospector identified an occurrence at the point of contact with a syenite intrusion, 8 km south of Poli, at Goble.

During the period 1970–1975, the IAEA provided assistance in prospecting an anomalous zone in the Poli–Garona area of northern Cameroon. A total of 277 m was drilled. Small, lenticular occurrences were found to be economically unattractive. Uranium resources of 240 tU metal at 0.1% U were discovered. Also during this period, the Canadian International Development Agency conducted an aeromagnetic survey, not including radiometry, over 168 000 km² (Table 3.4).

TABLE 3..4. URANIUM EXPLORATION DATA [7.4]

	Airborne radiometric surveys (km²)	Other surveys (km²)	Drilling	
			(m)	(Number of holes)
Pre-1977	40 000	168 000	277	11
1977	0	0	0	0
1978	0	0	0	0
1979	0	0	0	0
1980	40 000	0	0	0
1981	0	0	0	0
1982	0	0	0	0
1983[a]	0	0	2000	30
Total	80 000	168 000	2277	41

[a] Planned.

In 1976–1983, three exploration surveys were conducted for metalliferous deposits, including uranium:

(i) Under a United Nations Development Programme project, ground, airborne spectrometry, very low frequency electromagnetics and geochemical surveys were undertaken under an exclusive permit covering 65 000 km² of the Lower Dja Series, which shows great resemblance to the uranium bearing Franceville Series in Gabon and represents a potential target for future exploration;

(ii) The Bureau de Recherches Géologiques et Minières (BRGM) conducted helicopter-borne spectrometry and ground surveys in south-west Cameroon, mainly on a syenite stringer trending E–W and located east of Lolodorf. Anomalies were revealed in a syenite formation lying parallel to the interface with the Old Eratan, possibly a syenite intrusion. Mineralization in the form of uraninite and uranothorite associated with chalcopyrite, galena and molybdenite were discovered. In 1983, BRGM started drilling to a depth of 50–80 m into a fault crossing the syenite stringer. The mineralization appeared to extend irregularly downwards and was estimated to contain 1000 tU at a grade of 0.1% U;

(iii) German's Federal Institute for Geosciences and Natural Resources carried out a survey on uranium mineralization at Goble in the Poli area. The investigations consisted of two short missions, one on granite and syenite intrusions and the other focused on continental Cretaceous basins in northern Cameroon.

The uranium anomalies of the Lolodorf syenite were first discovered during fieldwork undertaken by BRGM in 1979. The arcuate late tectonic syenite occurs in a narrow band along the north-western edge of the Archaean Ntera Complex. It is 2–5 km wide and about 60 km long. On the ground, some samples contained uraninite and uranothorite, associated with minor chalcopyrite, galena, molybdenite and pyrite. Grades of up to 0.1% U have been reported. The mineralization appears to be restricted to a particular layer of fine-grained syenite, parallel to the foliation, and flanked by coarser syenite.

The uranium mineralization at Goble in northern Cameroon (Poli district) was discovered in 1958 by a private prospector and re-examined by IAEA experts between 1970 and 1975. A regional airborne geophysical study covered a large area and all radiometric anomalies were checked. The Kitongo deposit was explored in 1971–1981 and drilled from the surface (14 drill holes) and two adits excavated. Only a fraction of the potential area was explored.

Trenching and drilling revealed uranium mineralization in a shear zone cutting, what was later identified as, an albititized and desilicified granite (episyenite) and Palaeozoic andesites. The intrusive is overlain by Palaeozoic conglomerates. The drill holes recording the highest grade were associated with a mylonite zone in the andesites. The uranium minerals are pitchblende and uraninite, associated with copper sulphides, galena, pyrite, sphalerite and possibly molybdenite. The mineralization is now believed to be related to Palaeozoic volcanism and an albitization process.

Historic uranium resources were identified in three deposits totalling 13 125 000 t at an average grade of 0.08% U (11 130 tU). Prior work by German's Federal Institute for Geosciences and Natural Resources and a report by the Cameroon Ministry of Mines and Energy estimated that the Kitongo deposit contained at least 10 000 tU. However, low grades have been included in this estimate. The subsurface mineralization was investigated via a core drilling programme totalling about 1000 m and excavation of two adits, which indicated a resource of around 380 tU at approximately 0.08% U. For that reason, exploration was terminated at the beginning of 1986. The estimate of 8500 tU is a speculative figure.

Similar deposits are Lagoa Real in Brazil, and Krivoy Rog and Zheltye Vodje in Ukraine [7.3–7.7].

In mid-2007, Nu Energy's detailed airborne magnetic and radiometric surveys highlighted other previously untested radiometric anomalies in all three properties. These anomalies were investigated by a ground radiometric survey and a sampling programme with a view to prioritizing drilling targets.

Canada's Mega Uranium Ltd, through its wholly-owned subsidiary, Nu Energy Uranium Corporation, has a 92% interest in Nu Energy Corporation Cameroon SA, which holds licences for three properties in Cameroon: Kitongo (2700 km^2), Lolodorf (1000 km^2) and Teubang (1000 km^2). Very limited historical drilling in restricted areas of the Kitongo and Lolodorf projects intersected significant uranium mineralization. In February 2008, Mega Uranium commenced a first phase diamond drilling programme in the Kitongo prospect. The planned programme comprises a total of ten drill holes at five sites along a 300 m length of the Kitongo Fault scarp, which marks the contact between the Kitongo granite and the Poli Group metasediments of Middle Proterozoic age. The drill holes are intended to investigate the geological and structural controls to mineralization and are located in the vicinity of uranium mineralization previously intersected in the Kitongo granite by German's Federal Institute for Geosciences and Natural Resources during its exploration programme.

In Mega Uranium's drilling campaign, the highest grade intersections recorded were 3.4 m at 0.085% U, 3.0 m at 0.11% U and 41.9 m at 397 ppm U. The drill holes showed that the uranium mineralization is concentrated in zones of albitized granite lying parallel to the E–NE trending Kitongo Fault and also along cross-cutting NW trending faults. The uranium mineralization is present as disseminated uraninite occurring in wide zones of albitized granite and as high grade veins. Mega Uranium has proposed a drilling programme to test targets elsewhere along the Kitongo Fault scarp.

3.7.3. Uranium resources

Table 3.5 lists Cameroon's uranium resources, as of 1 January 1983. In 1983, a review of the IUREP estimates reported a range of 10 000–50 000 tU of speculative resources in sandstone, magmatic and vein-type geological environments [7.8].

The UDEPO database lists the most significant deposits for Cameroon as Kitongo, Lolodorf.

3.7.4. Potential for new discoveries

Cameroon is thought to have moderate potential for the discovery of uranium resources. At Goble, in northern Cameroon, uraninite occurs as thin coatings on fault planes and fractures of a Precambrian syenite–schist contact. The Middle Proterozoic Lower Dja Series, which has been correlated with the uraniferous Franceville Series of Gabon, is present in the southern part of the country. Cretaceous continental sediments, similar to those in Niger (Garou sandstones), crop out in the north of the country, and the belt of younger granites (Tertiary) could also have uranium potential.

TABLE 3.5. URANIUM RESOURCES (tU) [7.4]
(As of 1 January 1983)

Deposit	EAR-I[a]		Speculative resources
	US $80–130/kgU	US $130–260/kgU	US $80–130/kgU
Poli	240	2000	2000
Lolodorf	1000	2000	2000
Total	1240	4000	4000

[a] EAR-I: estimated additional resource category I.

3.7.5. National policies relation to uranium

The 1983 Policy on Participation of Private and Foreign Companies considers uranium a strategic mineral. Private and foreign companies, therefore, must negotiate special agreements with the Government of Cameroon. While the terms are favourable regarding investment, taxation and the repatriation of profits, the State retains a significant shareholding. The responsible national authorities are the Ministry of Mines and Energy and the National Investment Company [7.9].

References to Section 3.7

[7.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Cameroon, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[7.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 58–61.

[7.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[7.4] DE TREY, M., LENEY G.W., IUREP Orientation Phase Mission Summary Report: Cameroon, OECD, Paris (1983) 20 pp.

[7.5] MEADON, H.M., Geological Review of the Kitongo Uranium Deposit, Poli Area, Northern Cameroon, Nu Energy Corporation, Linden, South Africa (5 May 2006).

[7.6] THOSTE, V., Mineral Exploration in North Cameroon: Region of Poli, Federal Institute for Geosciences and Natural Resources, Hanover (1985).

[7.7] DJAPA, T., THOSTE, V., "The Kitongo uranium occurrence in northern Cameroon", Metallogenesis of Uranium Deposits (Proc. Tech. Mtg Vienna, 1987), IAEA, Vienna (1989) 419–433.

[7.8] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).
[7.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

3.8. CAPE VERDE

Cape Verde is located in the mid-Atlantic Ocean, 570 km off the west coast of Africa. The archipelago consists of 10 islands (Santo Antão, São Vicente, Santa Luzia, São Nicolau, Sal, Boa Vista, Maio, Santiago, Fogo and Brava) and five islets. All but Santa Luzia are inhabited.

Three islands, Sal, Boa Vista and Maio, are generally level and lack natural water supplies. Mountains higher than 1280 m are found on Santiago, Fogo, Santo Antão and São Nicolau.

Rainfall is irregular and this, historically, is the cause of periodic droughts. Average annual rainfall in Praia is 240 mm. During the winter, storms blowing from the Sahara sometimes form dense dust clouds. However, sunny days are the norm year-round. Average daily high temperatures range from 25°C in January to 29°C in September [8.1].

3.8.1. Geology

The Cape Verde islands are located west of the continental margin of the African Plate. The islands are largely of igneous constitution (Fig. 3.11), with basic volcanics and pyroclastics comprising some 88% of the total area and sedimentary rocks forming 9%. Volcanics and plutonics are distinctly basic in character, the archipelago representing a sodic alkaline petrographic province.

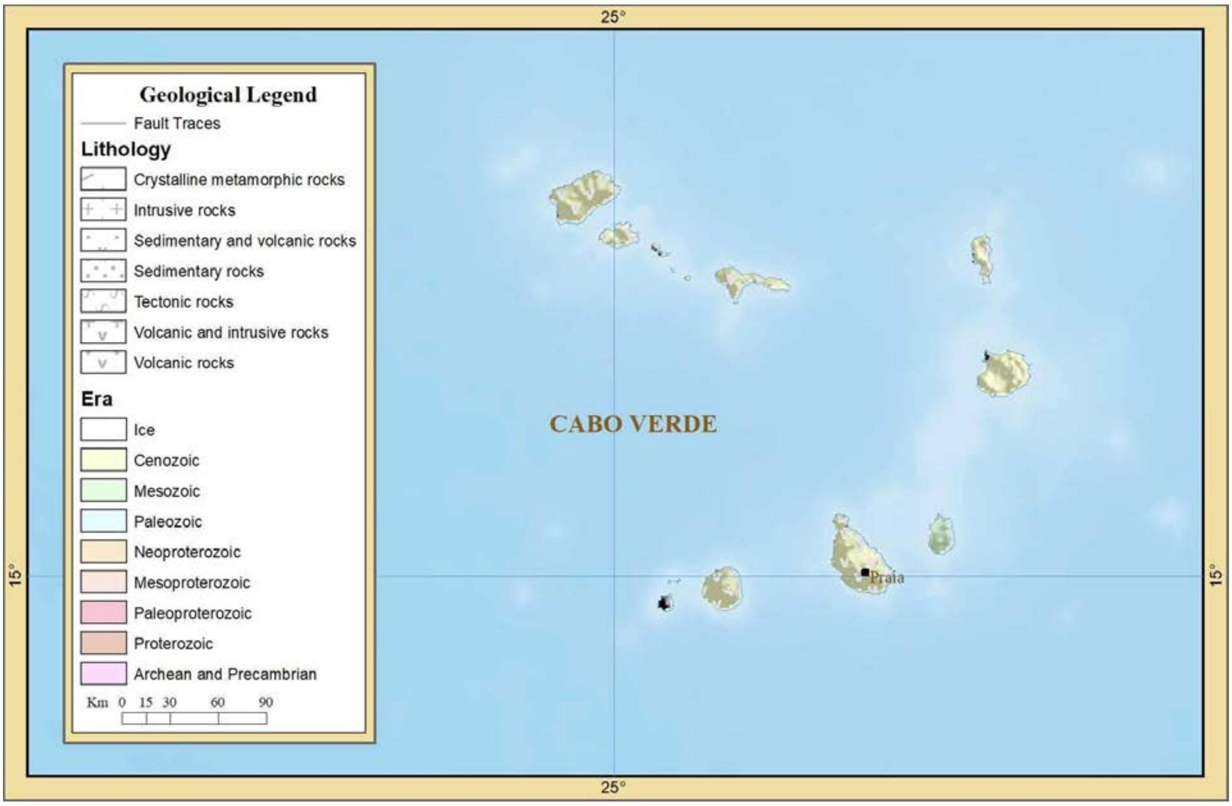


FIG. 3.11. Regional geological setting of Cape Verde. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Rocks perhaps as old as Late Jurassic, most certainly Lower Cretaceous, are present on the nearby island of Male, and here are to be found the steepest dips and greatest thicknesses of sedimentary rocks. Post-Aptian Cretaceous, Palaeogene and Neogene are only sporadically represented.

Fogo is an active volcano, last erupting in 2014. The 8 km diameter caldera, at an elevation of 1600 m and with an interior cone rising to 2829 m, is thought to have resulted from subsidence of a large cylindrical block, with the 'feeding' magma chamber lying at a depth of about 8 km [8.2].

3.8.2. Uranium exploration

No uranium exploration activities have been reported.

3.8.3. Uranium resources

No uranium resources are known in Cape Verde. In 1983, a review of the IUREP estimates reported a range of 0–1000 tU of speculative resources [8.3].

The potential for new discoveries is regarded as very limited, the islands being largely recent basic volcanics.

The UDEPO database does not list any known deposits for Cape Verde.

3.84. Comments

There has been no uranium production in Cape Verde. Cape Verde has no nuclear power plants and none are planned.

References to Section 3.8

[8.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Cape Verde, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed December 2008).

[8.2] SCHLÜTER, T., Cape Verde, Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 66–67.

[8.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.9. CENTRAL AFRICAN REPUBLIC

The Central African Republic is a landlocked country within the interior of the African continent. Much of the country consists of flat or rolling plateau savannah, typically about 500 m above sea level. The Fertit Hills occur in the north-east, and there are also scattered hills in the south-western part of the country. To the north-west is the Yade Massif, a granite plateau which reaches an elevation of 1143 m.

The climate of the Central African Republic is generally tropical. The northern areas are subjected to the hot, dry, dust laden harmattan winds from southern Morocco. The northern regions have been subject to desertification and the north-east is desert. Other parts of the country are prone to flooding by rivers.

The economy of the Central African Republic is dominated by arable agriculture, including cultivation of cassava, groundnuts, maize, millet, plantain, sesame and sorghum. The country has potentially rich, but largely unexploited natural resources in the form of diamonds, gold, uranium and other minerals. Diamonds constitute the most important export of the Central African Republic, frequently accounting for 40–55% of export revenue. However, an estimated 30–50% of the diamonds produced each year leave the country clandestinely [9.1].

3.9.1. Geology

The central and southern parts of the country are mainly composed of undifferentiated basement rocks, reportedly a mixed assemblage of Archaean schists and paragneisses of sedimentary origin and intruded by granites of various ages (Fig. 3.12). Some identified Precambrian areas exist in the east of the country. In the south-west and in some northern and central areas, there are undifferentiated continental Mesozoic sediments and in the north-west, undifferentiated continental Cenozoic sediments. There are a number of Tertiary granites in the north-western part of the country.

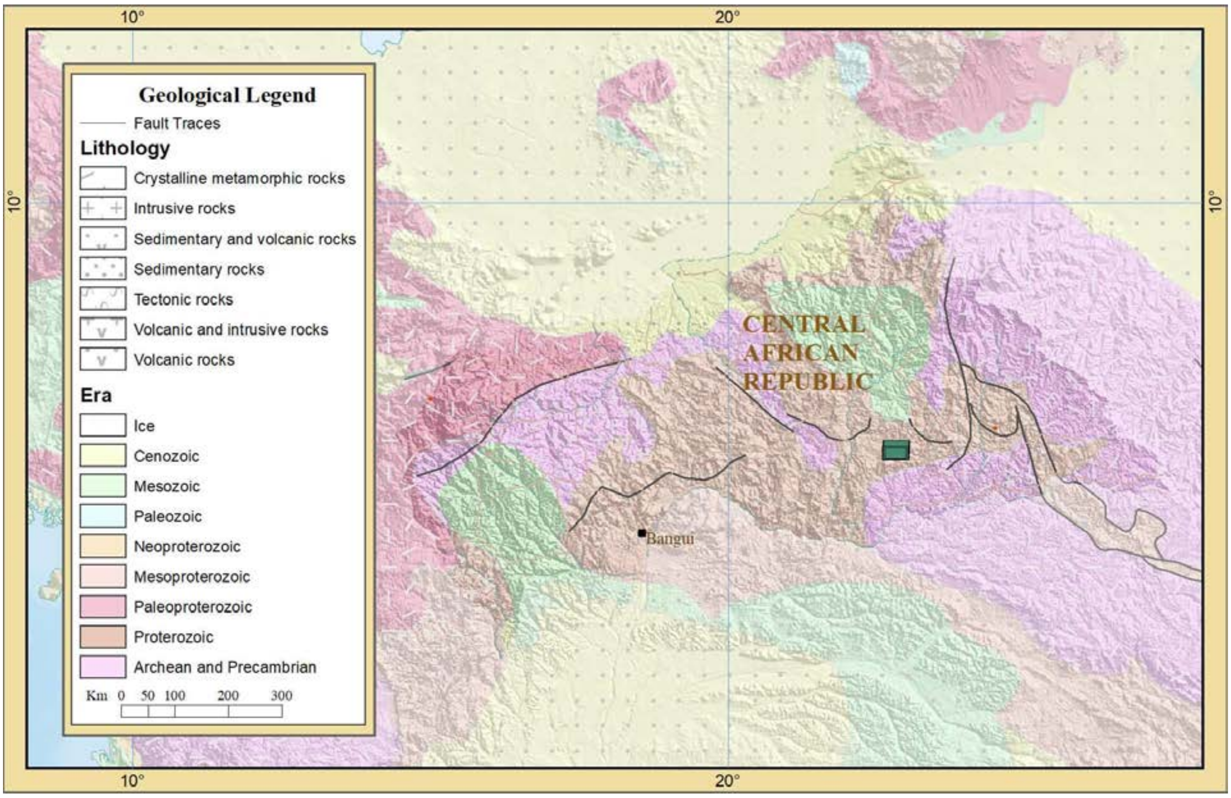


FIG. 3.12. Regional geological setting of Central African Republic showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The granitic summits of the Yade Massif decline eastwards into sandstone plateaux. In the east, gneisses and quartzites predominate, sometimes covered with sandstones, but with occasional isolated granitic knolls. The crest of the main watershed comprises metamorphic rocks and quartzites, which to the north are overlain by Tertiary sandstones of the Chad Basin and more recent alluvium.

For uranium, the main area of interest is the Bakouma region in the east-central part of the country, where the Bakouma uranium deposits were found. The Bakouma region is situated in a mobile Proterozoic zone between the cratonic basin of the Congo in the south and the cratonic area of the Nile in the north. A depositional basin located within this zone contains a Proterozoic platform sedimentary series, which ends in a dolomitic formation containing dykes, sills and doleritic flows, which is known as the Bakouma Formation. This region is marked by a system of fractures having a general orientation of N 65° E. Karst topography developed on the Bakouma dolomite, giving rise to palaeorelief characterized by depressions with steep walls up to 80 m in depth and 70–150 m in diameter, also aligned N 65° E.

During the Cretaceous, coarse detrital sediments with intercalations of red clay were deposited on the slopes of these depressions. A red ferruginous limestone, 50 m thick, was later deposited in some depressions. It is locally siliceous and phosphatic. In a great number of depressions, irregular accumulations of very fine argillaceous, siliceous and phosphatic sediments known as the M'Patou Series were later formed. Phosphate in the form of the microcrystalline carbonate fluorapatite can constitute as much as 50% of the rock. In other depressions, and in the intermediate shelves, the deposits which correspond to this M'Patou Series begin with an agglomerate of siliceous and ferruginous elements cemented by iron oxides and clay, followed by ferruginous sands with illite at the base and kaolinite uppermost [9.2, 9.3].

3.9.2. Uranium exploration

Historical exploration data are given in Table 3.6.

France's Atomic Energy Commission (CEA) was the first organization to prospect for uranium in the Central African Republic. Initial reconnaissance work commenced in 1947 and exploration of the extensive zones of crystalline formations which border the west and occupy the centre of the country was conducted without success. In 1956, prospecting using improved techniques and benefiting from improved knowledge of uranium metallogeny was extended to the detrital siliceous series of the Middle Precambrian–Upper Precambrian (Nbafkl and Fouroumbala Series).

A major radiometric anomaly was discovered in the N'zako laterites, but importantly, a significant geological similarity was noted between the Fouroumbala Series and the Franceville in Gabon, where a uranium deposit had been discovered. Encouraged by this similarity, the CEA intensified its exploration in 1959 with a systematic programme of aerial prospecting, covering the entire eastern region of the country, an area of around 50 000 km². This work led, in 1961, to the discovery of the country's first uranium deposit near the town of Bakouma.

TABLE 3.6. URANIUM EXPLORATION DATA [9.4]

Year	Aerial radiometric surveys (km^2)	Regional geochemical survey (km^2)	Drilling (m)	Expenditure (US$)
Pre-1975	50 000	10 000	45 000	16 300 000
1975			3 000	1 700 000
1976			3 000	1 500 000
1977			4 000	1 200 000
1978			3 000	1 200 000
1979			3 000	-
1980-2017				na
Total	50 000	10 000	61 000	21 900 000

Three deposits were discovered. Geologically, the host is a uranium bearing phosphatic formation of Eocene age. The notable feature is the exceptionally high uranium content for a formation of this type. However, the phosphatic nature of the ore made it difficult to develop a suitable processing method. In 1963, the CEA and the Compagnie Française des Minéraux d'Uranium (CFMU) formed a syndicate to continue exploration and to study the feasibility of mining the deposit. A jointly owned mining company, the Bakouma Uranium Mining Company (URBA), was set up in 1969 between the State and the CEA and CFMU partnership. However, the result of the feasibility study on the mining of the deposit was unfavourable and activities by URBA ceased in 1971.

After the oil crisis in the winter of 1973–1974, numerous foreign companies showed interest in the Bakouma deposit, and Aluminium Suisse S.A. of Zurich resumed studies on the mining of the deposit. In February 1975, a new mining company was set up between Aluminium Suisse and the three original partners of URBA. This new company adopted the name of the Central African Uranium Company (URCA).

Prospecting conducted by the Atomic Energy Commission, URBA and URCA used the following methods:

(a) Geological investigation and cartography;
(b) Airborne radiometric surveys;
(c) Ground radiometric surveys;
(d) Ground verification of selected anomalous zones;
(e) Drilling of boreholes at different spacing intervals;
(f) Geochemical analysis of soil, water and alluvial sediments.

However, subsequent technical, metallurgical and economic studies indicated that the deposits were not economically viable at the then prevailing price of uranium and in 1978 the project was terminated.

In May 2006, UraMin Inc. was granted one mining permit and two research permits for exploration of uranium mineralization in the Bakouma region. Reverse circulation percussion drilling commenced at the Patricia deposit in August 2006 to confirm the presence of uranium mineralization and to increase the known resource. Initial drilling of 66 holes on a 100 m × 50 m grid spacing delineated the extent of the Patricia deposit. Data from these holes were used as the basis for the resource estimate. Reverse circulation infill drilling on a 50 m × 50 m grid spacing commenced and a diamond drilling campaign to acquire additional geological and geotechnical information was also planned. Further reverse circulation and diamond drilling was planned at the other deposits that comprise the Bakouma project.

On 30 July 2007, the owner of Bakouma and other African uranium deposits, UraMin Inc. was acquired by AREVA for US $2.5 billion. This transaction gave AREVA a 90% interest in the project, which included ten discrete deposits, with a 10% carried interest retained by the State.

Start-up of the Bakouma pilot project was planned for 2010. At full capacity, the mine would have a production of 2000 tons U per year. Then, the AREVA group suspended the uranium mining project at the end of 2011 for one to two years. In June 2012, gunmen attacked the Bakouma uranium mine project site and since, all activities were suspended.

3.9.2.1 Geology of the Bakouma deposit

The Bakouma Basin is filled with recent unconsolidated sediments bordered by sandy and quartzitic hills of Precambrian age. The geological section of the Bakouma Basin, as determined from numerous exploratory boreholes, indicates an underlying Precambrian karstic dolomite intruded by dolerites. This depression has served as an erosional corridor which was filled in the Jurassic by the diamondiferous sands of Mouka-Ouadda, which in turn were uncovered and redeposited during the Eocene as the M'Patou Series. The Bakouma Basin was finally covered by laterites and the alluvial deposits of the M'Patou River. Numerous faults cut through all of the formations.

The uranium mineralization of the Bakouma Basin is associated with phosphate lenses intercalated with the silts and siliceous horizons of the M'Patou Series. It is these lenses that have the highest concentrations of uranium mineralization and these are grouped into several small to large deposits: Palmyre, Pama, Pamela, Pâquerette, Patou and Patricia, which make up the Bakouma deposit. Patricia, the best explored deposit contains 11 512 t U at a grade of 0.138%.

3.9.3. Uranium resources

3.9.3.1. Identified resources

The Bakouma uranium deposit, which in 1986 was estimated to contain about 16 000 tU in ore with an average grade of 0.26% U at an average depth of 35–40 m, is described in Table 3.7.

TABLE 3.7. IDENTIFIED BAKOUMA BASIN (IN SITU) RESOURCES (tU) [9.5]

Deposit	RAR[a] <US $80/kgU	RAR <US130/kgU
Palmyre	0	3000
Pama	0	3000
Pamela	0	0
Pâquerette	0	0
Patou	2000	2000
Patricia	6000	6000
Total	8000	16000

[a] RAR: reasonably assured resources.

Inferred resources of 36 475 tU at 0.3% were reported by AREVA at the end of 2016.

The UDEPO database lists the most significant deposits for the Central African Republic as Fosse-Pamela, Patricia, Pama, Pato, Petits Amas.

3.9.3.2. Undiscovered resources

No undiscovered resources have been estimated. In 1983, IUREP estimated a range of 10 000–50 000 tU of speculative resources [9.6].

3.9.3.3. Unconventional resources

There is no report for unconventional resources. While the Bakouma uranium deposit is associated with phosphates, it is classified as a conventional deposit because of the relatively high (0.15-0.30% U) uranium grade [9.6].

3.9.4. Potential for new discoveries

In the central and southern part of the country, undifferentiated basement rocks, comprising mainly a mixed assemblage of Archaean schists and gneisses of sedimentary origin, have been intruded by granites of various ages. Rocks of Precambrian age are also present in the east. There exists the possibility of finding unconformity-related deposits within these Precambrian areas, especially within the Lower, and possibly Middle, Proterozoic rocks.

In the south-west, and in some northern and central areas, undifferentiated continental Mesozoic sediments occur. There are undifferentiated continental Cenozoic sediments in the north-west, in particular the Tertiary sandstones of the Chad Basin. These continental sediments may be prospective for uranium.

Deposits similar to the known Bakouma deposits found in depressions in dolomite could be a possible prospecting target and this deposit type holds the greatest potential for additional discoveries [9.3].

3.9.5. Future projects

On 1 August 2008, AREVA signed an agreement with the Government of the Central African Republic to mine the Bakouma deposit. The Bakouma project was scheduled to start production in the fourth quarter of 2010, using open pit mining and with an envisaged average annual production rate of 2000 tU. The project was indefinitely stopped in 2012 after being attacked by rebels.

3.9.6. Comments

No uranium had been produced in the Central African Republic. The Central African Republic has no nuclear power generation.

References to Section 3.9

[9.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Central African Republic (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[9.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 68–69.

[9.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[9.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[9.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[9.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.10. CHAD

Chad is situated in north central Africa, lying between 8° and 24° N and between 14° and 24° E. The dominant topographic feature is a wide basin bounded to the north, east and south by mountain ranges. Lake Chad, after which the country is named, is all that remains of a lake that occupied an estimated 330 000 km² of the Chad Basin as recently as 7000 years ago. At an elevation of 3414 m, Emi Koussi, a dormant volcano in the Tibesti Mountains, is the highest point.

The annual tropical weather system known as the intertropical front traverses Chad from south to north, bringing the wet season, which lasts from May to October in the south and from June to September in the Sahel. Variations in local rainfall divide the country into three major geographical zones. The Sahara occupies the northern third of the country, where the annual rainfall is less than 50 mm. In the Sahel, a steppe of scrub gradually gives way to savannah in the south. Annual rainfall in this belt is over 900 mm.

Over 80% of Chad's population relies on subsistence farming and raising livestock for their livelihood. The crops grown and the locations of herds are determined by the local climate. The most fertile arable land lies in the southernmost 10% of the country. This area is a major producer of millet and sorghum. The Sahel is ideal pasture for cattle, donkeys, goats, horses and sheep. Prior to development of the oil industry, cotton production was the dominant industry and the major employer of labour, accounting for approximately 80% of export revenue. Oil production began in 2003 with the completion of a pipeline that links the southern oilfields to terminals on the Atlantic coast of Cameroon.

3.10.1. Geology

Precambrian rocks (Tibesti Massif) are present in the north-western part of the country, in the eastern central part of Chad and in the southernmost part of the country, thus defining the north-eastern and southern limits of the Chad Basin (Fig. 3.13). Lower Palaeozoic sandstones, correlative to the Tassili Series of Algeria, overlie Precambrian strata in the Tibesti area in the north and also in the northern part of the eastern central area. Uranium has been discovered in the Hoggar area of Algeria, at the base of the Tassili Series, in channels cut into the underlying Precambrian.

In the Kufra Basin, the Lower Palaeozoic is overlain by the continental Nubian sandstone. Continental Cretaceous clastics overlying Precambrian strata are present in the south-western part of the country and extend northwards into the Chad Basin. The whole of the Chad Basin was covered originally by clastic sediments. Uranium occurrences in the Continental Intercalaire are known in Niger (Arlit area). Cainomanian and Turonian marine sedimentation followed the Cretaceous continental sequence.

Palaeocene continental sandstones are known in the southern part of the country. During the Pleistocene, thick, extensive lacustrine deposits were laid down (Chad Formation). Dune sands immediately overlie the Chad Formation throughout the basin.

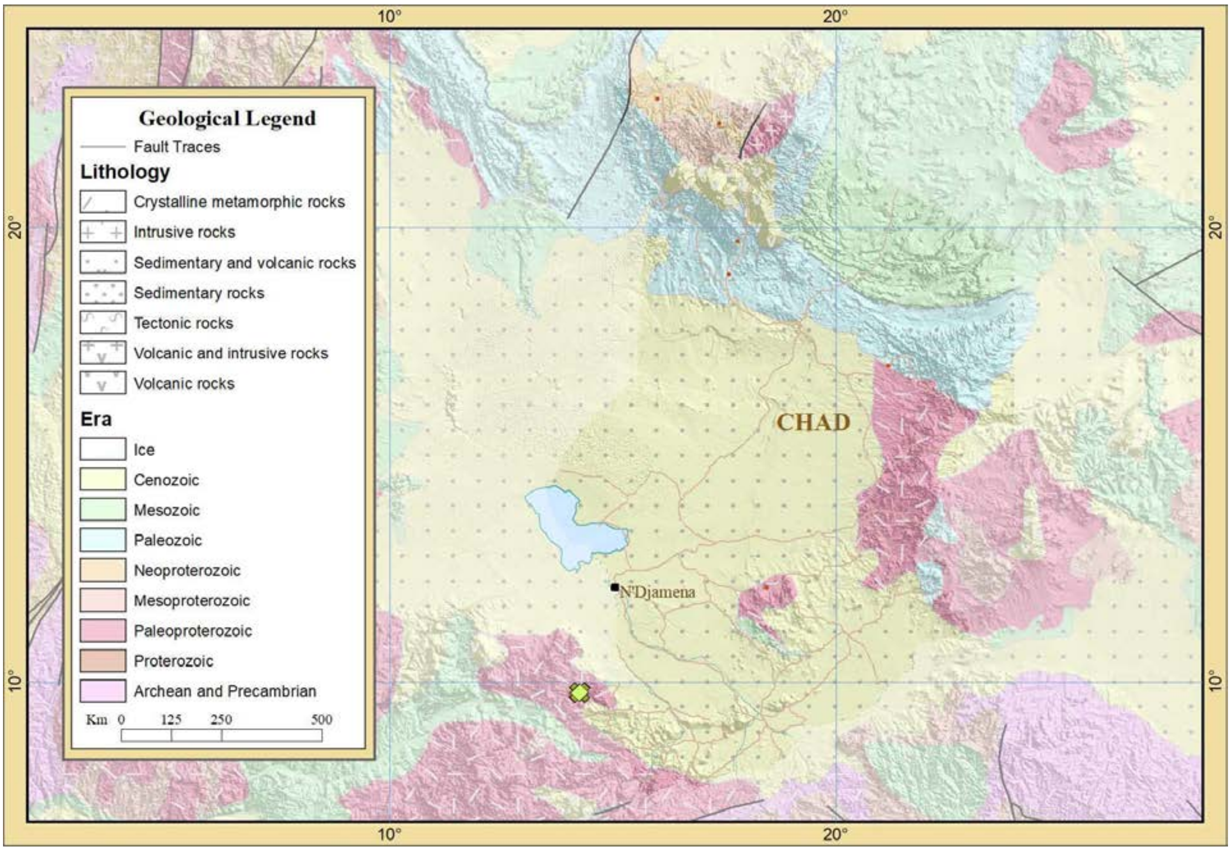


FIG. 3.13. Regional geological setting of Chad showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Uranium has been discovered in the Mayo-Kebbi area (near Lere) of south-western Chad. Uraninite and various uranium oxide minerals occur in veins cutting a granite intrusion of Tertiary age [10.2, 10.3].

3.10.2. Uranium exploration

In 1946, France's Atomic Energy Commission (CEA) sent several missions to various countries in Africa, including Chad. In Chad, the area surveyed was in the north-western part of the country. The work undertaken comprised a preliminary reconnaissance, but the results were negative.

In 1972–1980, the United Nations Development Programme (UNDP) assisted the Government of Chad in an exploration project for metallic and non-metallic mineral resources in the Mayo-Kebbi area of south-western Chad. An area of about 10 000 km² was covered by airborne radiometric and magnetic surveys. Several anomalies were found in granitic and sedimentary terrain. As a result of this survey, vein uranium mineralization was found in the Lere alkaline granite [10.4]. The anomalies in the sediments were not very favourable.

In 1978, the second phase of the UNDP supported project also discovered uranium mineralization in the Mayo-Kebbi area in the south-western part of the country, near the border with Cameroon. Here, the uranium minerals (coffinite and pitchblende) occur as disseminations and veinlets in syenitic rocks. Following a wide spaced airborne radiometric survey, uranium mineralization was discovered at Mandagzang and confirmed by diamond drilling. Exploration drilling had to be discontinued in 1980 as the result of political considerations.

In early 2008, London based Brinkley Exploration SA was granted three exploration licences to explore for uranium, gold and base metals in the Mayo-Kebbi area. The Mayo-Kebbi region covers an area of approximately 8000 km², comprising an exposed basement complex with syntectonic alkaline intrusions and Cretaceous platform cover. Brinkley Exploration conducted a detailed airborne survey which delineated a number of radiometric anomalies. The company ended all uranium exploration activities in Chad in 2008.

Signet Mining Services Ltd has six concessions covering 841 km², including the Lere project, located in south-western Chad near the towns of Lere and Pala. Signet is evaluating the Lere uranium deposit which is hosted in subvertical shear zones and secondary foliation in albitized and silicified granite in a mixed terrain of Precambrian units. Signet classifies the deposit as the intra-granitic variety and has defined a preliminarily in situ inventory estimate of over 2690 tU. A Lere project resource compliant with the South African Code for Reporting of Exploration Results, Mineral Resources and Mineral Reserves was expected by early to mid-2010, based on the drilling of 13 695 m of percussion holes and additional trench samples. Signet reported a high grade drill intercept from the Lere project, including 8 m at 1350 ppm U [10.3–10.8]. UDEPO classify the deposit as metasomatite, Na-metasomatite, granite-derived.

3.10.3. Uranium resources

In 1983, IUREP reported a range of 10–50 000 tU of speculative resources in sandstones, veins and disseminated magmatic geological environments [10.8].

In 2012, resources were 3190 t U at a grade of 0.02%.

The UDEPO database lists the most significant deposits for Chad as Lere, Madadzang

3.10.4. Potential for new discoveries

The Precambrian rocks of the Tibesti Massif, which crop out in north-western Chad, could contain uranium mineralization. This is also true of the Precambrian rocks in the eastern central and southernmost parts of the country.

Lower Palaeozoic sandstones, correlative to the Tassili Series of Algeria, overlie the Precambrian in the Tibesti area and in the northern part of the eastern central area. The base of the series could be prospected for deposits similar to the one at the base of the Tassili Series in Algeria.

The Nubian Series overlies the Lower Palaeozoic in the Kufra Basin in the north-eastern part of the country. These strata, which were deposited mainly during the Cretaceous, contain continental clastic facies which could be conducive to the formation of sandstone-hosted uranium deposits. The continental Cretaceous clastics (Continental Intercalaire), which directly overlie the Precambrian in the south-western part of the country, and the overlying Palaeocene continental sands (Hornodji Series) could hold some potential.

In addition to these areas, the Tertiary 'younger granite' intrusion in the south, which contains uranium in veins, could be prospected further as could areas adjacent to the granite. There is moderate potential for the discovery of additional uranium deposits [10.3].

3.10.5. Comments

There has been no uranium production in Chad. Chad has no nuclear power generation.

References to Section 3.10

[10.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Chad, (2008) https://www.cia.gov/library/publications/the-world-factbook/index.html

[10.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 70–73.

[10.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[10.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[10.5] BRINKLEY MINING PLC, Chad Exploration Permits RNS No. 8816U (20 May 2008).

[10.6] PREMOLI, C., "The Madadzang uranium prospect in the Mayo Kebbi region of Chad", Vein-Type and Similar Uranium Deposits in Rocks Younger than Proterozoic (Proc. Tech. Mtg Lisbon, 1979), IAEA, Vienna (1982) 195–209.

[10.7] SIGNET MINING SERVICES LTD, www.signetmining.com (accessed 2009).

[10.8] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.11. COMOROS[1]

The Comoros form an archipelago of volcanic islands situated off the south-east coast of Africa to the east of Mozambique and the United Republic of Tanzania and north-west of Madagascar. The island group comprises Comoros and the island of Mayotte, which is a French overseas department. The island group consists of Ngazidja (Grande Comore), Mwali (Mohéli), Nzwani (Anjouan), and the disputed Mahoré (Mayotte). These four major islands, as well as several minor islets, comprise the Comoros Archipelago.

The country covers an area of 2235 km². The topography of the islands reflects their volcanic nature and Mount Karthala, an active shield volcano located on Ngazidja, is the country's highest point (2361 m).

The climate is generally tropical and mild, and the two major seasons are distinguished on the basis of rainfall. In March, the hottest month of the rainy season (December–April), the temperature reaches an average high of 29–30°C, and in the cool, dry season (May–November) an average low of 19°C. The islands are vulnerable to cyclones during the rainy season, which are sometimes strong enough to devastate the infrastructure. This occurs about twice every decade.

Agriculture, including fishing, forestry and hunting, is the leading sector of the economy, accounting for 40% of GDP, employing 80% of the labour force and providing most of the country's exports. The country is not self-sufficient in food production, and rice, the main staple, accounts for the bulk of imports [11.1].

[1] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

3.11.1. Geology

The principal steps in geological development include the period ranging from the Permian to the Lower Jurassic, when NE–SW trending Karoo rifting occurred, and from the Middle Jurassic to the Lower Cretaceous, which witnessed the formation of oceanic basins along the N–S trending Davie Ridge. The age of the volcanics of the Comoros (Fig. 3.14) increases eastward, from Grand Comore (0.01 Ma) to Moheli (5.0 Ma), to Anjouan (3.9 Ma) and Mayotte (7.7 Ma), indicating that the Comoros volcanic chain represents a 'hot spot' trace produced as the Somali Plate moves over a mantle plume. The lavas are primarily undersaturated alkali olivine basalts [11.2].

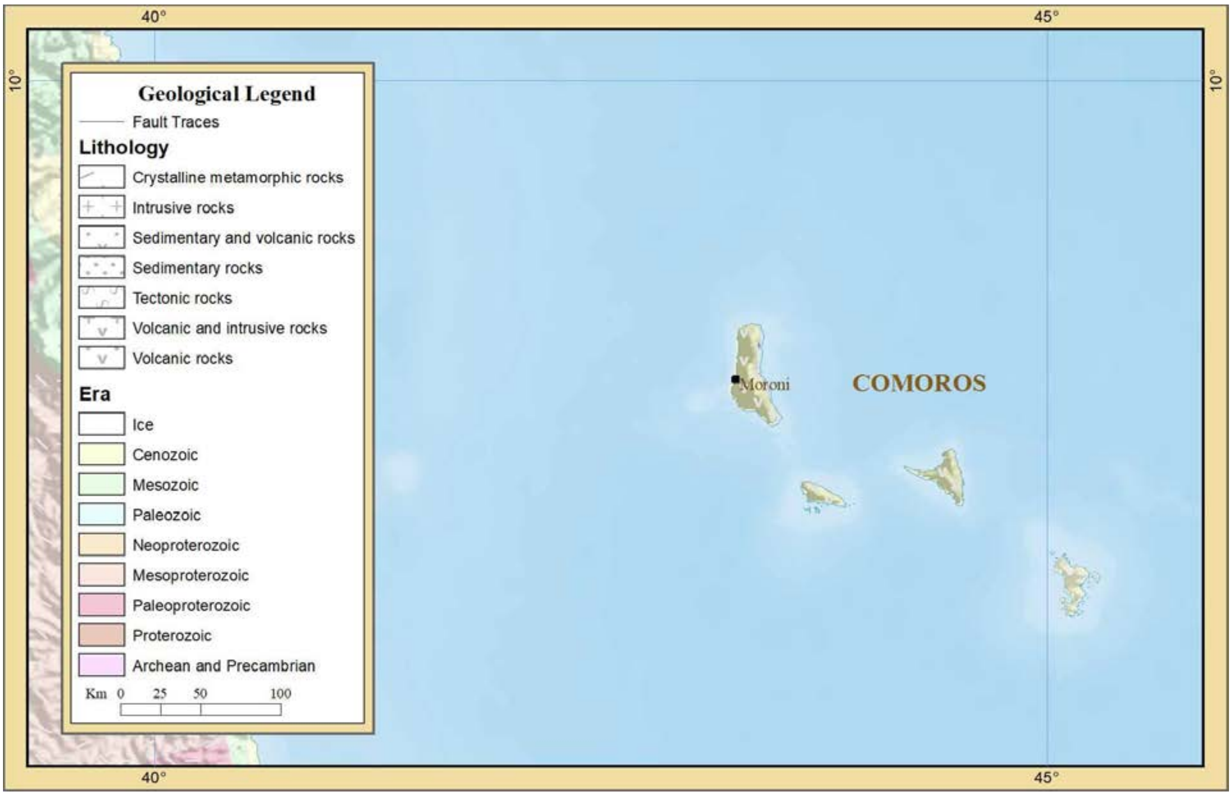


FIG. 3.14. Regional geological setting of Comoros. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.11.2. Uranium exploration

No official information is available on uranium exploration.

3.11.3. Uranium resources

No identified or undiscovered resources are reported.

The UDEPO database does not list any known deposits for the Comoros.

There has been no uranium production in Comoros.

3.11.4. Potential for new discoveries

The potential for new discoveries is regarded as very limited. No plans for exploration have been announced.

References to Section 3.11

[11.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Comoros, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed November 2008).
[11.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 74–75.

3.12. CONGO

Congo is located along the Equator in western central sub-Saharan Africa. The capital, Brazzaville, is located on the Congo River, in the south of the country, and directly opposite Kinshasa, the capital of the Democratic Republic of the Congo. The south-west of the country is a coastal plain drained by the Kouilou-Niari River. The interior of the country consists of a central plateau located between two basins, one to the south and the other to the north.

The economy is a combination of village agriculture and handicrafts and an industrial sector based largely on petroleum extraction and support services. Petroleum extraction has replaced forestry as the mainstay of the economy and contributes a major share of Government revenues and exports. Natural gas and diamonds are relatively recent major additions to Congolese exports [12.1].

3.12.1. Geology

Congo is mostly underlain by Precambrian rocks of Archaean–Neoproterozoic age, especially in the north-west and southern central parts of the country (Fig. 3.15). The east of the country is covered by Quaternary alluvial sediments of the Congo Basin. The coastal basin consists of Cretaceous–Quaternary marine sediments and is bounded by Precambrian rocks of the Mayombe Supergroup.

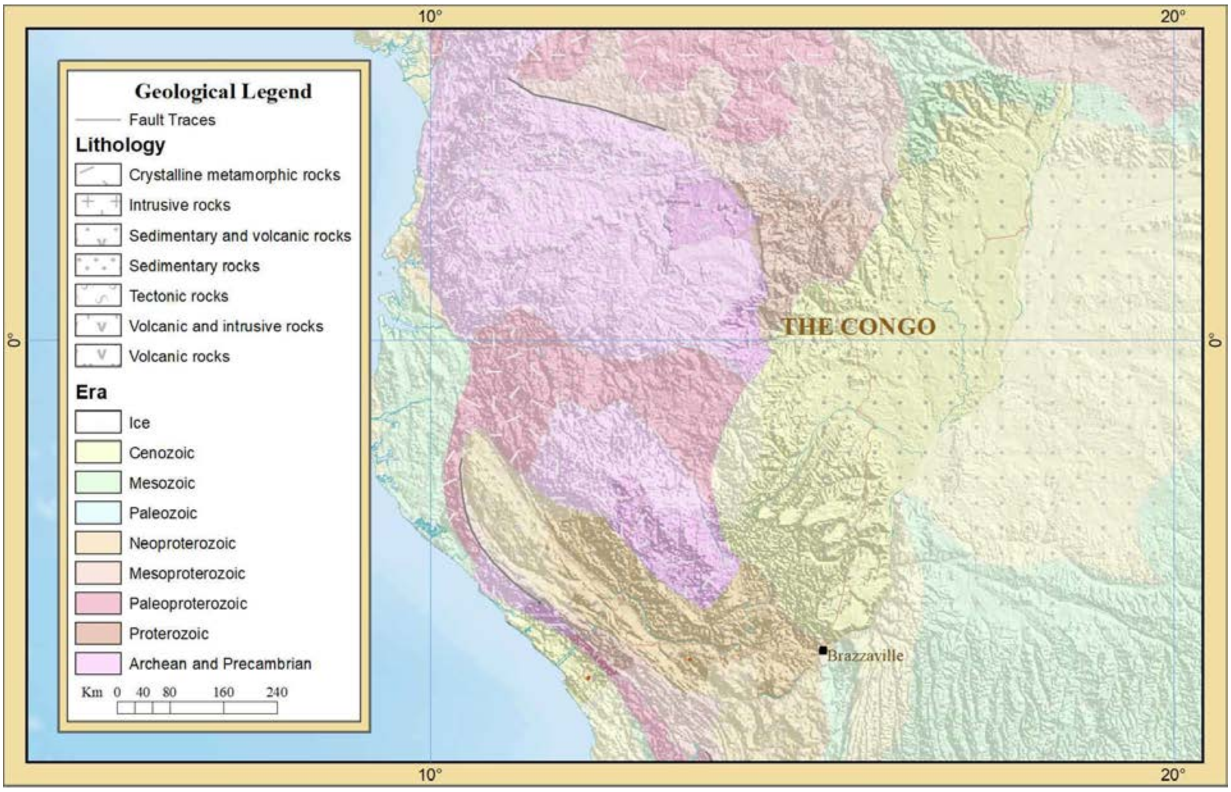


FIG. 3.15. Regional geological setting of Congo. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Mayombe Range forms the western border of the Congo Basin. It extends in a general north-westerly direction parallel to the Atlantic coast from which it is separated by a narrow zone of Cretaceous sediments of the Pointe Noire coastal basin. The oldest crystalline basement is present on the western side of the Mayombe Range, where it occupies a belt 30 km wide. These older rocks may be Lower Proterozoic in age and consist of gneisses, granites and migmatites at the base, with overlying micaceous and non-micaceous quartzites, amphibolites, epidote, mica schists, talc schists and a few porphyritic lavas.

The Upper Proterozoic West Congo System is present in the Nyanga Syncline. On the north-eastern side of the syncline, feldspathic sandstones and argillites are present at the base and these are overlain by chert, dolomite, dolomitic limestones with stromatolites, dolomitic marl and shales. The thickness varies around 600–700 m and the folds are oriented in a NW–SE direction. To the south-east, the West Congo System contains small occurrences of arsenic, cobalt, copper, lead, zinc and uranium.

The Batéké Plateau extends to the north of Congo and is underlain by undisturbed Cretaceous and Tertiary continental strata. The Cretaceous Stanley Pool Series (Continental Intercalaire) crops out around Brazzaville and in the bottom of several valleys. It consists of, from bottom to top, sandstones and red argillites, compact white sandstones and soft kaolinitic sandstones. The Tertiary sequence, overlying the Cretaceous in the Batéké Plateau area, consists of fine-grained sandstones, often silicified with lenses of chalcedony. These Tertiary rocks have been referred to as the 'polymorphic sandstones' and are probably Eocene. The top comprises about 100 m of aeolian sands.

The Pointe Noire coastal sedimentary basin contains about 150 m of Lower Aptian arkose, conglomerate and psammite at the base, which is overlain principally by marine strata. Phosphatic sands are present in the Maastrichtian and Lower Eocene sequences [12.2, 12.3].

3.12.2. Uranium exploration

The Commissariat à l'Energie Atomique (CEA) conducted prospecting and ground reconnaissance in the 1960s. The Italian energy company ENI conducted exploration in 1977 in western Congo.

3.12.3. Uranium resources

There are no known uranium resources in Congo. In 1983, IUREP reported a range of 10 000–50 000 tU of speculative resources, based on general geological conditions, hosted mainly in sandstones (the IUREP report on Congo refers to the Congo area, not Congo specifically). The country may have favourable strata within the Franceville Formation, which hosts high levels of uranium mineralization in neighbouring Gabon [12.3].

The UDEPO database does not list any known deposits for Congo.

3.12.4. Potential for new discoveries

The Mayombe System, which crops out in the Mayombe Range, consists of arkoses, conglomerates, black schists, chlorite schists, micaceous quartzites and volcanics. The system is probably of Middle Proterozoic age and may be correlated with the Franceville Series in Gabon, in which several uranium deposits have been discovered.

The West Congo System, which crops out to the north-east of the Mayombe System, contains feldspathic sandstones and argillites overlain by dolomites, shales, marls, cherts and dolomitic limestones with stromatolites. Several small occurrences of cobalt, copper, lead, zinc and uranium mineralization are known to be hosted in this system, which is stratigraphically equivalent to the uraniferous Katanga System of the Democratic Republic of the Congo and Zambia.

Crystalline basement, of pre-Mayombean age, crops out in a 30 km wide belt on the western side of the Mayombe Range. These rocks, which include gneisses, granites and migmatites at the base with overlying micaceous and non-micaceous quartzites, mica schists, amphibolites, talc schists and lavas, may be of Lower Proterozoic age. The unconformity between the basement and the overlying Mayombe System could be a potential prospection target.

The Cretaceous Stanley Pool Series (Continental Intercalaire), which crops out around Brazzaville and in several valleys on the Batéké Plateau, consists mainly of sandstone. The Tertiary sequence, which overlies the Cretaceous rocks in the Batéké Plateau, consists of fine-grained sandstones of Eocene age. The Pointe Noire coastal sedimentary series contain about 150 m of Lower Aptian arkoses, conglomerates and psammites at its base, and phosphatic sands are present in the Maastrichtian and Lower Eocene sequences. All of these continental sediments may be prospective for sandstone-type uranium mineralization [12.4].

3.12.5. Comments

There has been no uranium production in Congo. Congo has no nuclear power plants.

References to Section 3.12

[12.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Congo, Washington, DC,https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed July 2008).

[12.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 84–87.

[12.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[12.4] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

3.13. CÔTE D'IVOIRE

Côte d'Ivoire is a sub-Saharan nation situated in southern West Africa, on the Gulf of Guinea. Côte d'Ivoire's topography can generally be described as a large plateau rising gradually from sea level in the south to almost 500 m in elevation in the north. The south-eastern region of Côte d'Ivoire is marked by coastal inland lagoons that start at the border with Ghana and stretch 300 km along the eastern half of the coast. The southern region, especially the south-west, is covered with dense tropical forest. The eastern Guinean forests extend from the Sassandra River across the south, central and south-east parts of Côte d'Ivoire and east into Ghana, while the western Guinean lowland forests extend west from the Sassandra River into Liberia and south-eastern Guinea.

The mountains of the Dix-Huit Montagnes region in the west of the country, near the border with Guinea and Liberia, are home to the Guinean mountain forests. The Guinean forest–savannah mosaic belt extends E–W across the middle of the country and is transitional between the coastal forests and the interior savannah. The forest–savannah mosaic interweaves forest, savannah and grassland habitats. Northern Côte d'Ivoire is part of the west Sudanese savannah, consisting of a savannah/scrubland zone of lateritic and sandy soils, with vegetation decreasing from south to north. The terrain is mostly flat to undulating plains, with mountains in the north-west. The highest elevation is Mount Nimba (1752 m) in the far west of the country, near the border with Guinea and Liberia.

The climate of Côte d'Ivoire is generally warm and humid, ranging from equatorial in the southern coasts to tropical in the centre and semi-arid in the far north. There are three seasons: warm and dry (November–early March), hot and dry (late March–May), and hot and wet (June–October). Temperatures average in the range 25–30°C but can vary over the range 10–40°C.

Côte d'Ivoire has a large timber industry based on its dense forest coverage and 8% of the country is arable land. Côte d'Ivoire is the world's largest producer of cocoa, a major cash crop. Other major crops include bananas, coffee and oil palm, which produces palm oil and kernels. Natural resources include bauxite, cobalt, copper, diamonds, gold, iron, manganese, natural gas and petroleum, and hydropower [13.1].

3.13.1. Geology

Almost all of Côte d'Ivoire is underlain by rocks of Precambrian age (Archean and Paleoproterozoic) (Fig. 3.16), belonging to the West African Craton. Only along the southern and southeastern coastal strip occur oil- and gas-bearing, mostly Cenozoic sediments.

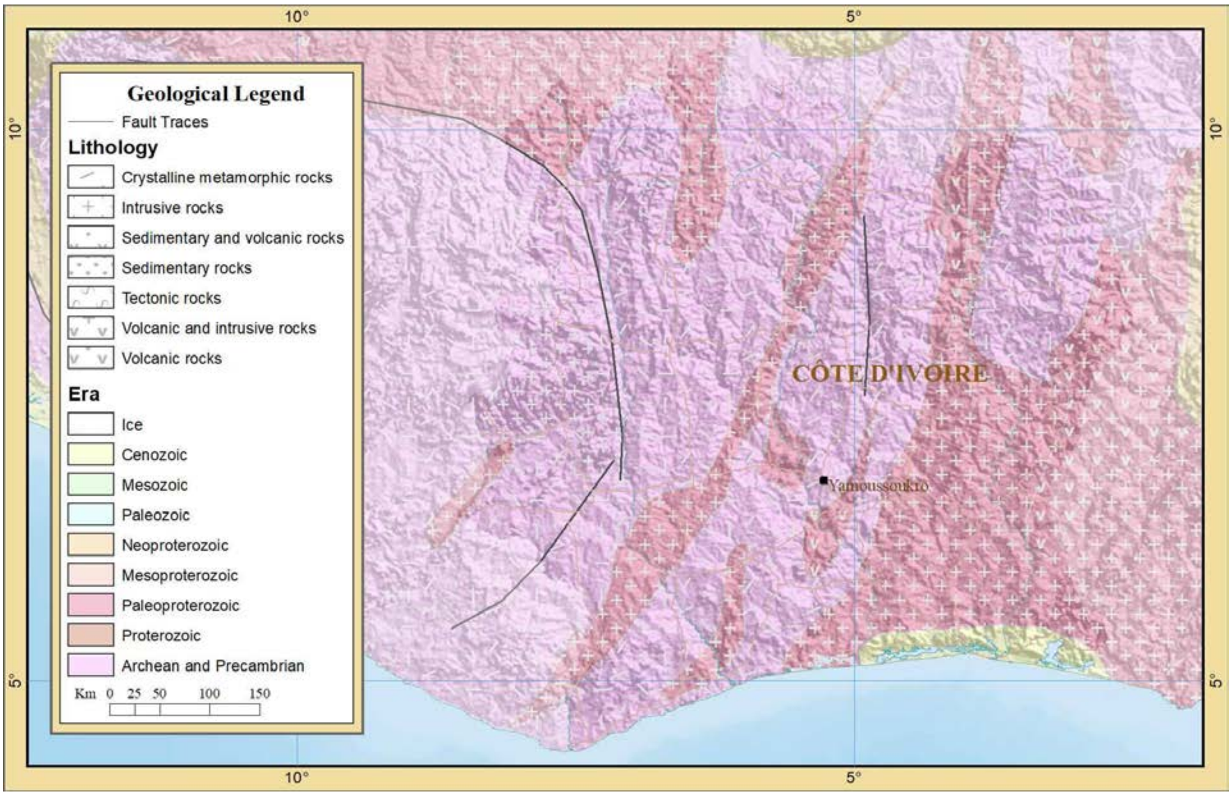


FIG. 3.16. Regional geological setting of Côte d'Ivoire. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Precambrian rocks of Côte d'Ivoire can be subdivided into the Archean Kenema-Man domain in the extreme west of the country around Man, and the Paleoproterozoic Baoule-Mossi domain in central and eastern Côte d'Ivoire. Both are separated by the N–S trending Sassandra mylonitic zone. The Kenema-Man domain consists chiefly of Archean granulitic and migmatitic gneisses with subordinate granitoids and relic supracrustal belts, which are metamorphosed to granulite facies and predominantly composed of banded ironstone formations. Similarly as in Ghana, the Paleoproterozoic terranes of the Baoule-Mossi domain in eastern Côte d'Ivoire consist mostly of NE–SW trending, subparallel volcanic belts and intervening sedimentary basins. These volcanic belts contain chiefly low-metamorphic-grade tholeiitic flow rocks, minor felsic volcaniclastics, some chemical sediments and syn-volcanic granitoid intrusions [13.2].

The sedimentary basins consist of isoclinally folded, mostly dacitic volcaniclastics, greywackes and argillites. The volcanic belts in central Côte d'Ivoire have been dated at about 2100 Ma. Arkoses, sandstones and minor quartz-pebble conglomerates belonging to the Tarkwaian Group are found as relatively small, isolated occurrences, spatially associated with some volcanic belts, the largest one cropping out in the north-east of the country, near Bondoukou.

The Eburnean event is responsible for the formation of high strain zones close to volcanic belt/sedimentary basin boundaries as well as several major, 100 km long, N–S trending shear zones of regional importance.

Mostly Neogene–Recent clastic sediments exist along the shore and offshore on part of the country's Atlantic coast. This sedimentary basin hosts Côte d'Ivoire's modest oil and natural gas reserves [13.2, 13.3].

3.13.2. Uranium exploration

Reports of uraniferous pegmatites led to early reconnaissance missions being carried out by French geologists in 1947. Although indications of uranium and thorium in monazite were found, none were economically viable and work ceased in 1951.

In the 1970s, Société pour le Développement Minier de la Côte d'Ivoire, the State mining organization, initiated exploration programmes in several regions of the country. In 1974–1975, it supervised airborne radiometric and magnetic surveys undertaken by a Canadian company under a joint agreement between the Governments of Côte d'Ivoire and Canada. The survey covered 235 000 km² or about 75% of the country. A total of 470 000 line km was flown at a nominal 150 m terrain clearance and 0.5 line km spacing. Follow-up work found promising indications which led to several exploration permits being issued for areas in the north (Bouna, Bouandougou, Kébi, Sinématiali and Tortiya) and west of the country.

In the late 1970s, a permit covering approximately 20 000 km² was explored by the national petroleum company, Société Nationale d'Opérations Pétrolières de la Côte d'Ivoire, in the north and central parts of the country. Car-borne and field radiometric surveys were used in connection with geophysical and geochemical techniques to evaluate the permit area. Areas selected as being potentially prospective included metasediments of Lower Proterozoic age and granitic rock of Archaean and Proterozoic age.

No exploration activities have been reported in Côte d'Ivoire since the early 1980s.

3.13.3. Uranium resources

There are no quantifiable resources of uranium in Côte d'Ivoire. Supergene uranium enrichment has been observed in laterites and lateritic soils and concentrations up to 0.01% U have been measured in granitic rocks.

In 1983, the IUREP reported speculative resources in the range 0–10 000 tU [13.4].

The UDEPO database does not list any known deposits for Côte d'Ivoire

3.13.4. Potential for new discoveries

Although uranium occurrences were found in the early 1940s, there has been little exploration in Côte d'Ivoire. A number of anomalies and occurrences have been found, particularly in the northern granitic environments. Strata that could be potentially prospective include metasediments of Lower Proterozoic age and granitic rocks of Archaean and Proterozoic age.

3.13.5. Comments

No uranium has been produced in Côte d'Ivoire. Côte d'Ivoire has no nuclear power generation.

References to Section 3.13

[13.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Cote d'Ivoire (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[13.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 128–131.

[13.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[13.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.14. DEMOCRATIC REPUBLIC OF THE CONGO

The Democratic Republic of the Congo (DRC) is situated in the western central part of sub-Saharan Africa. The country straddles the equator and extensive tracts of tropical jungle cover most of the extensive, low lying central basin of the Congo River, which flows towards the Atlantic Ocean in the west. This area is bounded by plateaux that grade into savannah to the south and south-west, by mountainous terraces to the west, and by grasslands extending beyond the Congo River to the north. The extreme north-east of the country is very mountainous.

The tropical climate was instrumental in developing the Congo River system, which dominates the region topographically, along with the rainforest it flows through. The Great Rift Valley, especially the Eastern Rift, has been a major influence in shaping the DRC's geography. Not only is the north-eastern section of the country much more mountainous, as a result of the tectonism associated with rifting, it also experiences volcanic activity. The rifting of the African continent in this area has also produced the renowned Great Lakes, three of which lie on the DRC's eastern frontier: Lake Albert, Lake Edward and Lake Tanganyika. Perhaps most importantly, the rift valley has exposed an enormous amount of mineral wealth throughout the south and east of the DRC, making it accessible to mining. Bauxite, cadmium, coal, cobalt, copper, diamonds (industrial and gem quality), germanium, gold, iron, manganese, radium, silver, tantalum, tin, uranium and zinc are all found in plentiful supply, especially in the DRC's south-eastern Katanga region.

The DRC is the world's largest producer of cobalt and a major producer of copper and industrial diamonds. It also has significant deposits of tantalum [14.1].

Despite its mineral wealth, agriculture remains the main pillar of the economy. The principal cash crops include cocoa, coffee, cotton, palm oil, rubber, sugar and tea. Food crops include cassava, groundnuts, maize, plantain and rice.

3.14.1. Geology

The geology of the country is dominated by the sedimentary Congo Basin which has uplifted rims of Precambrian basement, cut by the rift valley to the east (Fig. 3.17). The basement consists of Archaean acid gneisses and migmatites in early complexes, pre-Mayombean and Ruzizian as well as metamorphosed sedimentary sequences of Middle Proterozoic age. The latter include amphibolites, arkoses, conglomerates, graphite schists, metaquartzites and talc schists and are intruded by alkaline and calc-alkaline granite complexes.

Overlying the basement unconformably are various groups of Proterozoic platform sediments of continental to marginal marine type. These are generally only slightly metamorphosed. The platform sediments include the cupriferous–uraniferous Roan-Kundelungu Series (Katanga System) of Shaba and equivalents such as the Marian, west of Kinshasa, in which minor occurrences of uranium were discovered by France's Atomic Energy Commission in 1954 at Boko Songho in the Congo, close to the border. The age of the Copperbelt sediments is not known definitively, but sedimentation probably dates to 1000 Ma at least. The sediments include cherts, conglomerates, dolomites with stromatolites, graphite schists, sandstones, red and green shales and tillites, which were deformed in the Lufilian (Damaran) Orogeny (650 Ma).

Possible equivalents of the uraniferous Franceville Series of Gabon (1700 Ma) occur unconformably on the basement over large areas of the north of the Congo Basin and parts of the area north of the Katanga (Shaba) Copperbelt. In the eastern part of the DRC, Karoo sediments overstep, unconformably, eroded remnants of the Proterozoic rocks, to rest mainly on the earlier acidic basement. They consist of a poorly described series of Dwyka tillites, shales, coals and arkose–sandstone–shale intercalations, deposited west of the Congo River in a series of palaeovalleys and grabens. They are Carboniferous–Permian. Rocks of similar type and age are uraniferous in Botswana, South Africa and Zambia. Around Kisangani, a 350 m thick series of Jurassic red, brown and green sandstones, with red and green bituminous shales, lies unconformably on the Franceville Series and includes a minor marine limestone incursion. These continental sediments rest on Karoo, Franceville and basement formations.

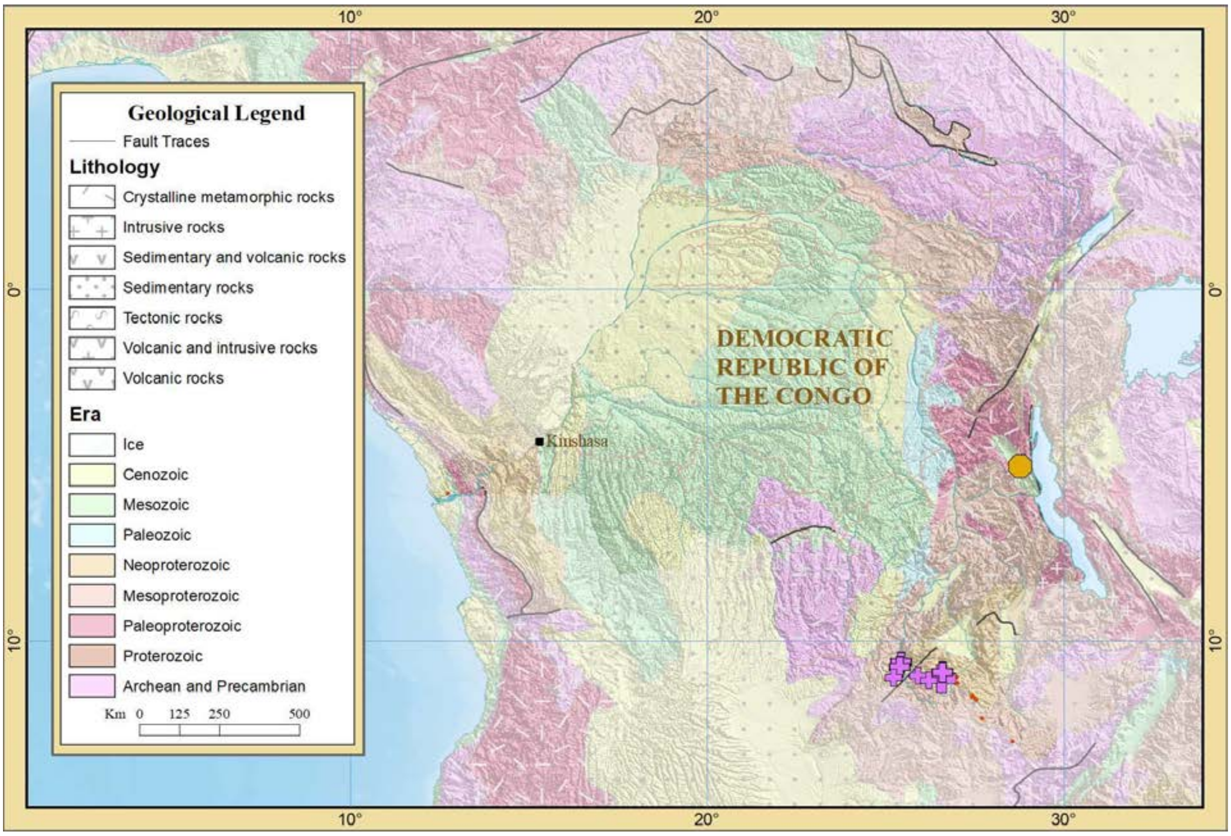


FIG. 3.17. Regional geological setting of Democratic Republic of the Congo showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Much of the remaining rim of the Congo Basin is Cretaceous, principally continental lagoonal sediments and includes arkoses, coarse sandstones (diamondiferous), and red and green shales, in all reaching 250 m in thickness. In the south, these beds rest directly on the acid basement complex while in the east and north, they rest on Franceville and Karoo strata. To the south, these Mesozoic sediments are overlain by 80–100 m of silica cemented and limonite cemented Tertiary Kalahari sands. These overstep to rest directly on the Karoo and basement to the west of Shaba.

The core of the basin is filled with a very thick sequence of Quaternary sediments (sands and shales). In the south, thinner patches of Quaternary sediments rest directly on the basement. Great thicknesses of sediments were deposited at this time in the developing rift valley, together with undersaturated alkaline volcanic lava piles associated with flanking faults [14.2].

3.14.2. Uranium exploration

Exploration in the DRC was initially the sole prerogative of the Union Minière du Haut-Katanga from Belgium. Only the broad outlines of prospecting activities have been released. Records show that some airborne radiometric work was carried out in the Shaba region in the 1950s. This was followed by car-borne prospecting, generally using total count Geiger-Müller instruments, but occasionally employing small scintillometers. Several of the anomalies found as a result of these radiometric surveys had already been located during conventional copper prospecting in the 1920s and 1930s.

In the early 1960s, a few small deposits in the Katanga area west of Shinkolobwe, including Swambo and Kalongwe, were studied. These deposits are similar to the Shinkolobwe deposit except in terms of size, i.e., vein deposits in Precambrian metamorphic dolomites, quartzites and shales associated with cobalt, copper and nickel. In 1969, Hunting Geology and Geophysics Ltd conducted an airborne magnetometer and scintillometer survey on the Générale des Carrières et des Mines (GCM) concession in Shaba Province. In 1982–1985, a joint venture between DRC's Commissariat Général à l'Energie Atomique (CGEA), GCM and France's Compagnie Générale des Matières Nucléaires (COGEMA) conducted exploration work on the Guluwe and Kipese areas, south and west of Shinkolobwe. Ground work was followed by drilling at Guluwe, Kipese and Shinko II in 1984 (10 holes, 2132 m) and 1985 (15 holes, 2793 m).

No exploration expenditure has been reported to the Red Book by the DRC.

In July 2007, the London based Brinkley Mining signed a contract with the DRC's CGEA to obtain the prospecting rights over five key areas which are prospective for uranium. Initial priority targets agreed with the CGEA are Kalongwe, Kasompi, Mindigi, Samboa and Shinkolobwe, all in Katanga Province. These targets all have known uranium occurrences and have been explored previously to various levels of development. Initial work is expected to focus on the remodelling of all existing drill data to establish resource estimates compliant with the Joint Ore Reserves Committee and to provide new drill targets. It is understood this could involve the re-evaluation of over 39 000 m of diamond drilling undertaken prior to 1981. The field work at Shinkolobwe and the other areas will focus on mapping, radiometric surveying and sampling of prospective lithologies along strike and adjacent to the Kundelungu Fault.

On 3 September 2008, Brinkley Mining decided to terminate its operations in the DRC [14.2–14.4].

3.14.3. Uranium resources

The historical variation in identified conventional resources is shown in Fig. 3.18 and Fig. 3.19. Uranium resources in the DRC are associated with the Copper–Cobalt Belt in Shaba Province, between the cities of Kolwesi, Likasi and Lubumbashi (Tables 3.8 – 3.11).

In Red Book 2018, a Secretariat Estimate for recoverable resources was presented for the Democratic Republic of Congo (Table 3.8), although the Member State only reported resources to the 1973, 1977 and 1988 editions of Red Book (Table 3.9).

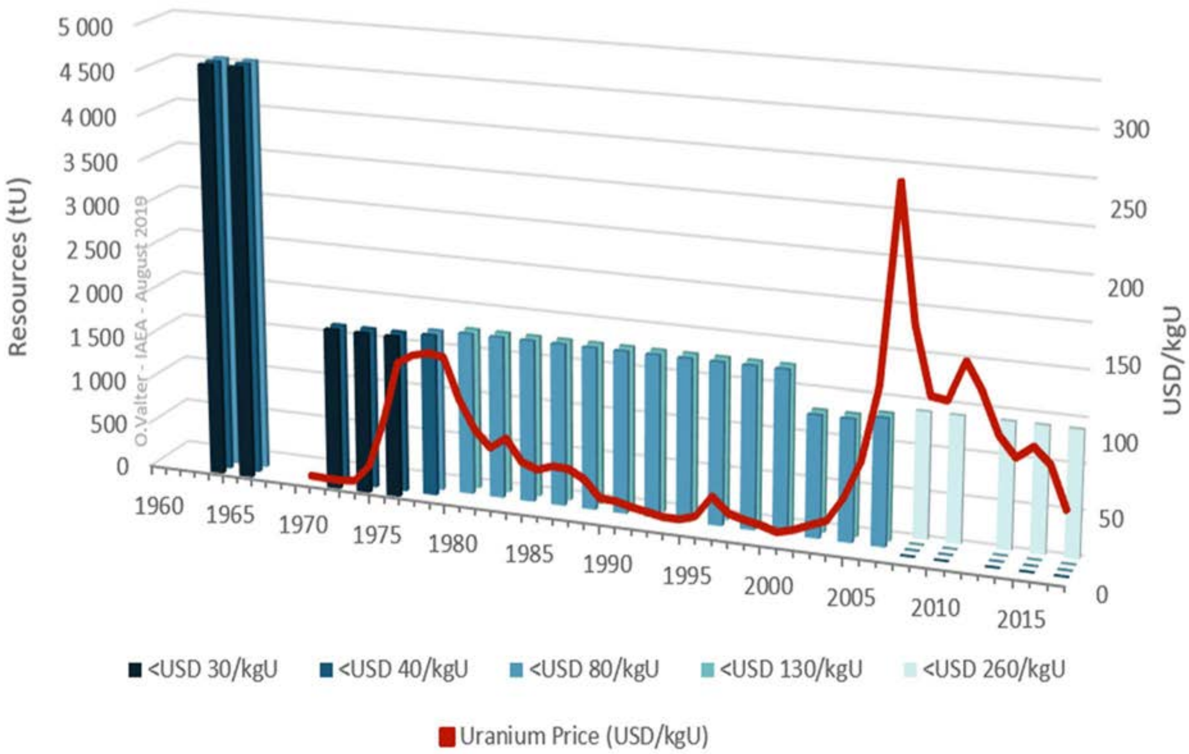


FIG. 3.18. Historical variation of recoverable reasonably assured resources within various cost categories in the Democratic Republic of Congo. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

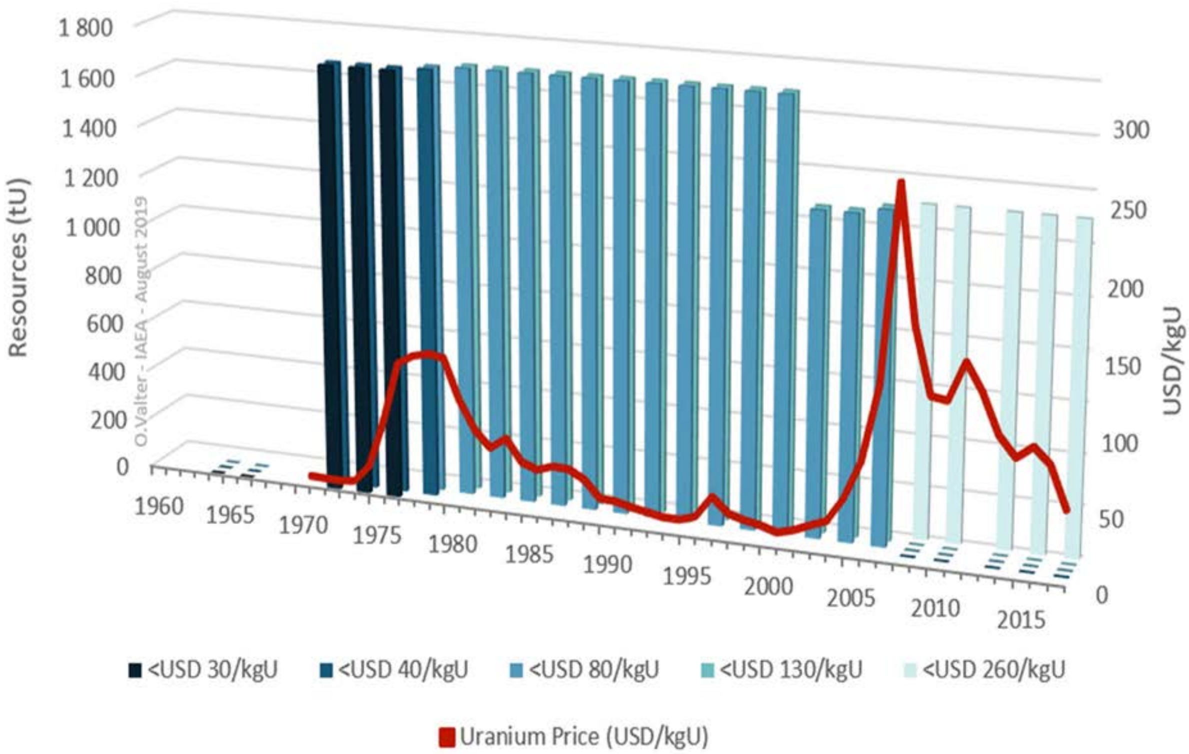


FIG. 3.19. Historical variation of recoverable inferred resources within various cost categories in the Democratic Republic of Congo. Periods where no resources are shown in any cost categories are periods where resources were not reported , either by the Member State or as a secretariat estimate.

TABLE 3.8. IDENTIFIED RECOVERABLE RESOURCES (tU) [14.5]

Category	<US $260/kgU
Reasonably assured resources	1400
Inferred	1300
Identified	2700

TABLE 3.9. CONVENTIONAL URANIUM RESOURCES (tU) [14.6]
(As of 1 January 1973)

Deposit	Ore reserves	Prospected ores	Probable ores	Possible ores
East Kasompi	0	990	0	0
Kiswichi	0	77	0	0
Shinkolobwe	0	0	770	0
Swambo	0	460	0	0
Total	0	1527	770	0

The UDEPO database lists the most significant deposits for The Democratic Republic of the Congo as Shinkolobwe-Kasolo, Kanzi, Luena Basin, Fundu-Nzobe, Musonoi Extension, Kamoto Principal.

3.14.3.1. Undiscovered resources

The DRC does not report undiscovered resources.

3.14.3.2. Unconventional resources

Uranium mineralization has been found associated with copper and is also known in the Upper Cretaceous phosphates at Kanzi and Fundu Zobe, where 30 million t of phosphates (P_2O_5) containing 50–75 ppm U have been identified [14.7].

Table 3.10 was reported in the 1973 edition of the Red Book [14.6].

TABLE 3.10. UNCONVENTIONAL URANIUM RESOURCES (tU) [14.6]
(As of 1 January 1973)

Association/deposit	Ore reserves	Prospected ore	Probable ore	Possible ore
U associated with copper	0	77	77	230
Kalongwe	0	0	540	0
Kamoto	2	8	0	77
Musonoi	0	0	0	0
West Kambova	188	0	0	0
Total	190	85	617	307

The Deomocratic Republic of Congo has not reported to Red Book since 1988, but more recently the UDEPO database reported resource ranges as in Table 3.11.

TABLE 3.11. URANIUM DEPOSITS (UDEPO [14.7])

Name	Type	Status	Resource range (tU)	Grade range (%U)
Kamoto	Vein (metamorphite)	Not developed	1 000–2 500	0.20–0.50
Kasompi	Vein (metamorphite)	Not developed	1 000–2 500	0.20–0.50
Shinkolobwe-Kasolo	Vein (metamorphite)	Not developed	25 000–50 000	0.20–0.50

3.14.4. Potential for new discoveries

The overall geological environment of the country is favourable for the occurrence of uraniferous source rocks and the sedimentary cover of dominantly continental to continental/marginal sequences is suitable for the accumulation of uranium mineralization.

About half of this area is Archaean–Proterozoic metamorphic basement and the remainder is sedimentary platform cover of Proterozoic–Mesozoic age. Uranium occurrences are known in the Upper Proterozoic platform sediments of Katanga in the Copperbelt and were worked at the Shinkolobwe mine. In neighbouring countries, uranium occurrences and deposits are known or have been worked in sedimentary sequences of similar age and type to the Middle Proterozoic rock sequences occurring in the DRC, e.g., the Mounana deposits in the Franceville Series of Gabon, occurrences in the Dja Series of Cameroon, and in the Niari Department and the Boko Songho area in Congo. Potential for discovery of deposits is positive in the following areas:

(a) The south Shaba area, where radiometric anomalies are known in the Mine Series strata;
(b) The north Shaba area and in Kivu Province, where geochemical anomalies (Kobokobo and Lubero) have been found in Middle Proterozoic metasediments [14.2].

3.14.5. Uranium production

It has been estimated that between 23 000 and 28 000 tU have been produced at the Shinkolobwe mine from ore grading 0.38–1.0% U. The mine was officially closed in 1960.

The Shinkolobwe mine was discovered by local copper miners and prospected for copper early in the 20th century. In 1915, uraninite was discovered and from 1921 to 1936 the mine produced radium. Approximately 39 000 m of exploratory and mine development drilling were undertaken during this period. Opencast mining for uranium began in 1944 and underground mining in 1945. The deposit is located in the Mine Series of the Roan (dolomites, sandstones, schists) on a faulted but only moderately transported fold of the Katanga geosyncline. The schist–dolomitic basal series has been overturned against a spur of the higher Kundelungu sediments (arkoses, conglomerates, sandstones and schists) and elongated eastwards. The mineralization is mainly developed in altered (magnesite) dolomites below a shale horizon and between two faults dipping towards each other. Mineralization penetrates deeper, adjacent to the faults. The receptive beds are altered dolomites in the upper parts of the orebody and porous sandstones at subeconomic grade at depth. Uraninite is associated with minor molybdenite, monazite, pyrite, copper–nickel sulphides, selenium and tellurium. Following a phase of tectonic movement which brecciated the ore, chalcopyrite was deposited. Secondary hypogene alteration formed covellite, digenite and siegenite, as well as depositing native gold.

References to Section 3.14

[14.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Democratic Republic of the Congo (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[14.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[14.3] FRANÇOIS, A.P., "Uranium occurrences in Shaba, Zaire", New Developments in Uranium Exploration, Resources, Production and Demand (Proc. Tech. Committee Meeting, Vienna, 1991) IAEA, Vienna (1992) 65–81.

[14.4] THOMSON FINANCIAL NEWS, Brinkley Mining terminates operations in Congo, Chad after review, Thomas Financial News (3 September 2008).

[14.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[14.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1973).

[14.7] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO) with Uranium Deposit Classification: 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

3.15. DJIBOUTI

Djibouti lies in north-east Africa, in the so-called Horn of Africa, on the Gulf of Aden at the southern entrance to the Red Sea. It has 314 km of coastline and is bordered by Eritrea to the north, Ethiopia to the west and south, and Somalia to the south-east. The country comprises mainly stony desert, with scattered plateaux and highlands. The climate is mostly warm and dry. Mountains in the centre of the country divide a coastal plain and a plateau. The lowest point is Lac Assal (155 m below sea level) and the highest is Moussa Ali (2028 m).

The economy of Djibouti is based on service activities connected with the country's strategic location and status as a free trade zone in north-east Africa. Two-thirds of the inhabitants live in the capital city, Djibouti, the remainder being primarily nomadic herders. Crop production is limited to fruit and vegetables and most food must be imported. Natural resources include geothermal energy [15.1].

3.15.1. Geology

Djibouti lies on the narrow gulf linking the Red Sea to the Gulf of Aden (Fig. 3.20). The country is formed of a triangular depression, which is caused by the general tectonic movements of the Great Rift Valleys of East Africa. These trend N–S and NW–SE and have created a complex fragmented relief, composed of high elevated blocks and subsidence zones in which lakes may occur, e.g., Lac Assal. Most of the country comprises Cenozoic sedimentary and volcanic rocks [15.2].

3.15.2. Uranium exploration

No exploration activities have been reported.

3.15.3. Uranium resources

No uranium resources are known in Djibouti. In 1983, a review of the IUREP estimates reported a range of 0–1000 tU of speculative resources [15.3].

The UDEPO database does not list any known deposits for Djibouti.

3.15.4. Potential for new discoveries

The potential for new discoveries is regarded as very limited.

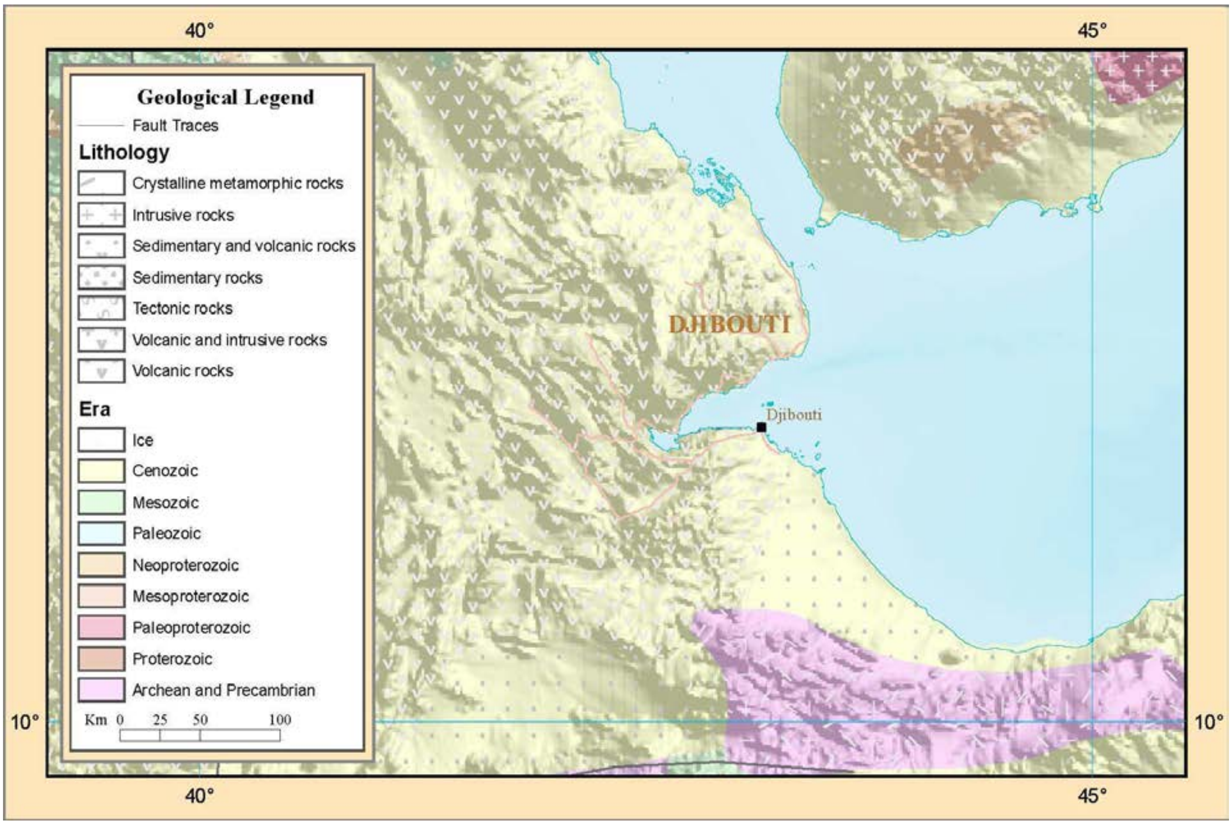


FIG. 3.20. Regional geological setting of Djibouti. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.15.5. Comments

There has not been any past uranium production in Djibouti. Djibouti has no nuclear power generation.

References to Section 3.15

[15.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Djibouti, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2009).

[15.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 88–91.

[15.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.16. EGYPT

Apart from the Nile Valley, the majority of Egypt's landscape is a sandy desert. Egypt includes parts of both the Sahara Desert and the Libyan Desert. Owing to the aridity of Egypt's climate, population centres are concentrated along the narrow Nile Valley and Delta, meaning that approximately 99% of the population inhabits only about 5.5% of the total land area. Egypt's important role in geopolitics stems from its strategic position: a transcontinental nation that possesses a land bridge (the Isthmus of Suez) between Africa and Asia (Sinai Peninsula), which in turn is traversed by a navigable waterway (the Suez Canal) connecting the Mediterranean Sea with the Indian Ocean via the Red Sea.

Egypt receives little rainfall except in the winter. South of Cairo, rainfall averages only around 2–5 mm annually and at intervals of many years. On the very narrow strip along the northern coast the rainfall can be as high as 410 mm, with most of the rain falling between October and March. Temperatures average 27–32°C in summer, and up to 43°C on the Red Sea coast, and 13–21°C in winter.

Egypt's economy depends mainly on agriculture, media, petroleum exports and tourism. Egypt's mineral and energy resources include coal, iron, gold, natural gas, petroleum and phosphates. Petroleum is found primarily in the Gulf of Suez and in the Western Desert. Natural gas is found mainly in the Nile Delta, off the Mediterranean shore, and in the Western Desert. Substantial coal deposits occur in north-east Sinai, which are mined at the annual rate of about 600 000 t. Preliminary exploration in Sinai has also indicated the presence of copper, lead, tin and zinc mineralization [16.1].

3.16.1. Geology

The oldest rocks in Egypt occur as isolated Archean to Proterozoic inliers in the Western Desert, whereas the Egyptian part of the Arabian-Nubian Shield along the coastal Red Sea region is made up of Neoproterozoic Pan-African rocks. Paleozoic sediments often mantle the basement rocks (Fig. 3.21). After a sedimentary hiatus due to the Hercynian orogeny Cretaceous sediments are well exposed in various parts of the country. The Cenozoic history is characterized by transgressions and regressions and their respective sediment types [16.2].

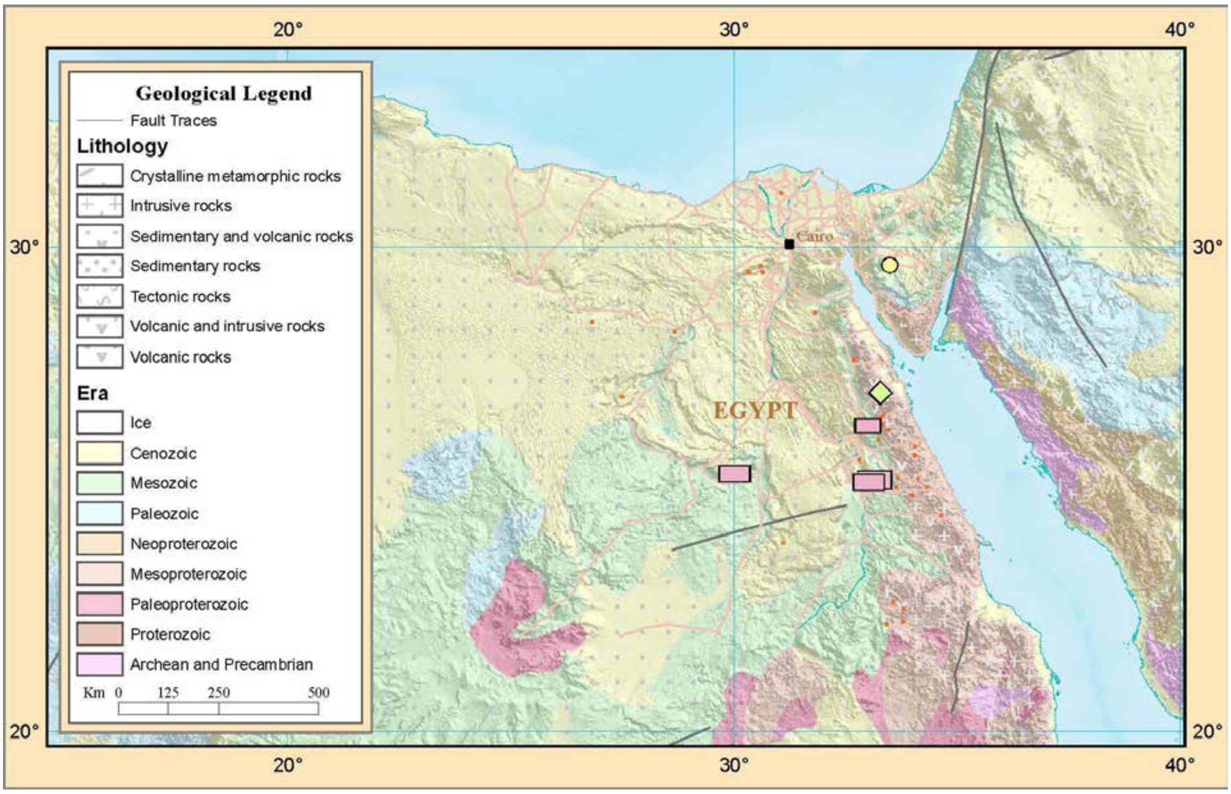


FIG. 3.21. Regional geological setting of Egypt showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Egypt is part of the North African Craton and can be divided into four major geological provinces:

(i) The Nubian-Arabian Shield, which is exposed over large parts of the Sinai Peninsula, the Eastern Desert and in the southern part of the Western Desert. It consists mainly of Precambrian formations, with several stages within the sequences of Archaean formations intruded by plutonic and volcanic rocks;

(ii) The Stable Shelf, which covers the area north-west of the Nubian-Arabian Shield. Its sedimentary cover is essentially represented by continental and epicontinental sandstones;
(iii) The Unstable Shelf, which is situated north of the Stable Shelf. The sedimentary sequence is relatively thick, with a lower part mainly composed of clastic sediments, followed by calcareous sediments and carbonates;
(iv) The Gulf of Suez–Red Sea Graben.

The Gulf of Suez is an area of subsidence within the Stable Shelf and the northern part of the Nubian-Arabian Shield. It was formed during the Early Palaeozoic and was reactivated during the rifting phase of the East African Rift System in the Lower–Middle Tertiary. Extensive accumulations of sediments form this subsiding depression. The Red Sea was formed during the Oligocene and spreading of the Red Sea floor is related to the relative motion of the various tectonic plates in north-eastern Africa [16.2–16.4].

3.16.2. Uranium exploration

Exploration for uranium and other nuclear raw materials started in 1956. Early programmes included:

(a) Airborne radiometric and magnetic surveys over different geological units and geographic regions;
(b) An investigation of black sand deposits along the Mediterranean coast, including estimation of reserves, mineral composition, extraction and processing of rare earths, thorium and uranium;
(c) An investigation of phosphate deposits with regard to uranium content, concentration and extraction.

The airborne surveys covered several hundred thousand square kilometres in the Eastern and Western Deserts, as well as in the Sinai. These resulted in the discovery of a large number of significant anomalies, including the following, where significant work was completed (Fig. 3.22) totalling USD $ 119 001 000 including 15 193 metres of drilling.

El Erediya/El Missikat (central Eastern Desert): Vein-type uranium mineralization is hosted in post-tectonic younger granites. Pitchblende is the primary uranium mineral, which has been intensively oxidized. Exploratory adits were driven and the areas of the El Missikat and El Erediya granite-hosted deposits have been explored by about 4000 m of adits. In both areas, subsurface core drilling was employed to test the uranium bearing veins.

Urn Ara (south-east Aswan): Uranium mineralization has been discovered in younger, pink granites. Surface exploration and shallow trenching confirmed the previously discovered disseminated pitchblende and uranophane mineralization. Drilling was carried out to investigate the extension of the occurrence. The Nuclear Materials Authority of Egypt (NMA) developed a small-scale heap leaching operation at the site. The large granitic mass of Urn Ara is estimated in the speculative resources category as totalling 320 million t at an average grade of 100 ppm uranium.

Gabal Kadabora: In this part of the central Eastern Desert, uranium mineralization is present in a younger granitic mass occupying an area of about 320 km². The uranium is associated with pegmatite veins, particularly along the outer boundary of the granite.

Western Sinai: Uranium is associated with siltstone and shale of Upper Palaeozoic age. The thickness of the uraniferous horizon is in the range 0.5–3.5 m and the uranium content varies in the range 200–500 ppm. Thorium is almost absent and the uranium mineralization is associated with copper and manganese. Some areas have xenotime, which has a high rare earth element content. The extent of the uranium occurrences is about 10 km × 15 km.

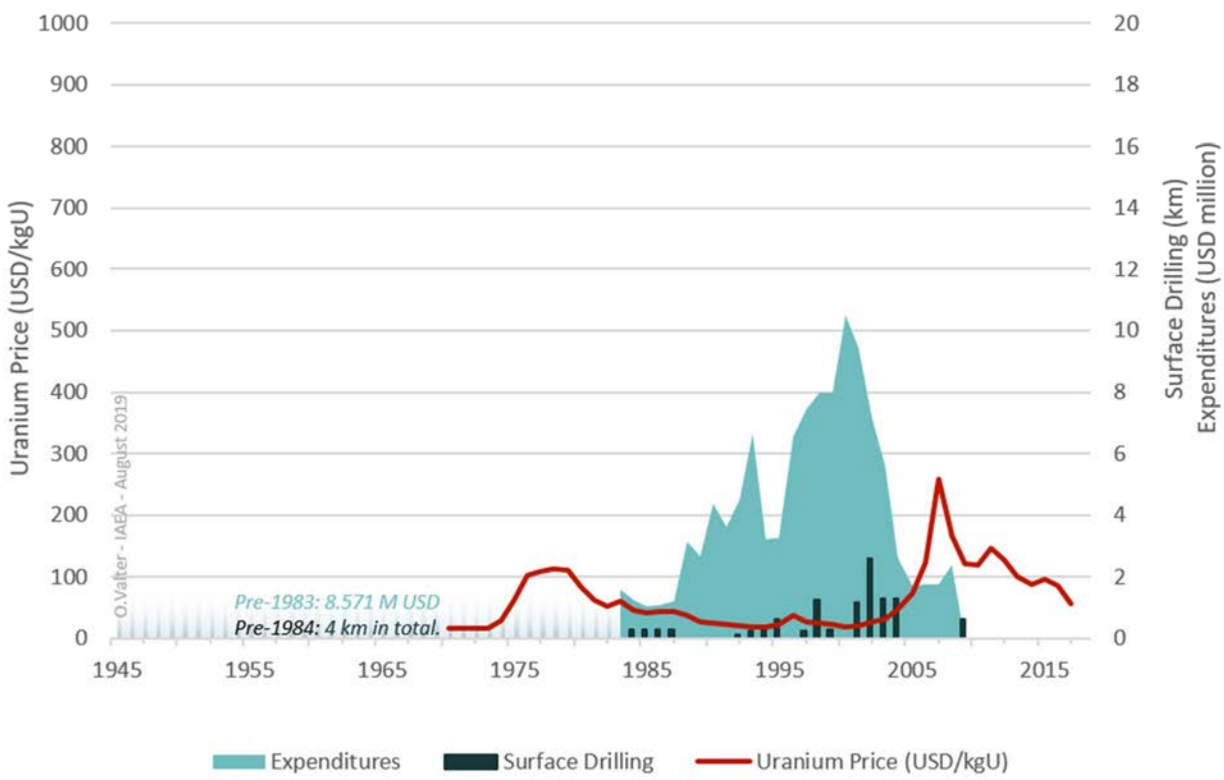


FIG. 3.22. Domestic uranium exploration data for Egypt. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

Bir Nasib (west central Sinai): Carnotite associated with iron–copper–manganese mineralization was found in Middle Carboniferous siltstones. This occurrence has been examined by trenching and drilling.

Wadi Nasieb (west central Sinai): Mineralization is hosted by carbonaceous marls as well as within karstic features in a dolomitic horizon of Carboniferous age. Mineralization has been identified along a network of about 700 m of adits.

Gebel Gattar: Lying about 35 km west of Hurghada, Gebel Gattar is a vein-type fluorine–molybdenum–uranium assemblage occurring in granite. It was discovered in 1985 and has been drilled. Exploratory mining operations were used to follow the uranium bearing shear zone in the granitic mass. A vertical shaft provided access to horizontal adits.

Western Desert: In the Western Desert, the following occurrences have been found in sedimentary formations:

(a) At Gebel Qatrani, where Oligocene black shales and sandstones contain uneconomic amounts of uranium;
(b) At Gebel Hefhuf, in the Bahariya Oasis, where uranium mineralization has been discovered in a kaolinized horizon along a fault zone;
(c) At Wadi Araba, where Carboniferous sandstones and siltstones are radioactive. In addition, phosphate deposits were investigated for their uranium content and recoverability.

The NMA recently (2007–2009) concentrated its exploration activities in selected areas and these activities included exploration for conventional uranium resources in the Eastern Desert and Red Sea region. These activities focused on identifying new target environments, mainly Cretaceous volcanic rocks (e.g., Natash volcanics) and the Cretaceous Nubia sandstone basins (e.g., Kom Ombo Basin) that occur in the southern part of the Eastern Desert, as well as the unconformity contacts between the younger granites and Miocene sediments extending along the Red Sea coast.

Additionally, the evaluation of uranium resources at some occurrences in the Eastern Desert was undertaken. The NMA prepared drilling programmes in the El Sella and Kab Amiri areas of the Eastern Desert. Black sand resources (a potential unconventional uranium resource) are currently considered to be titanium and zirconium resources. In the latter case, the role of the NMA is restricted to the assessment of environmental radiation hazards and mitigation of their environmental impact should the goal of mining these deposits be realized [16.3-16.6].

3.16.3. Uranium resources

3.16.3.1. Identified resources

Some conventional inferred resources have been identified in the Eastern Desert and these are currently under investigation. In Gabal Gattar prospect, approximately 27 000 t of uranium mineralization have been identified grading 0.16–0.20% U (equating to 43–54 tU). In this prospect, rocks hosting the uranium mineralization are mainly represented by Precambrian calc-alkaline granites (late orogenic plutons) referred to in Egypt as the younger granites. The distribution of this mineralization is mainly controlled by shear structures cutting across the granitic masses. In Abu Zenima prospect, an inferred uranium resource of 38 000 t has been identified grading 0.06% U (equating to 23 tU). The uranium bearing rocks mainly comprise Carboniferous sandstones.

The UDEPO database lists the most significant deposits for Egypt as El Sebaeya East, El Sebaeya West, Abu Tartur, Red Sea District, Gabbal Gattar, Abu Zenima.

3.16.3.2. Inferred resources

Details of inferred resources according to deposit types are summarized in Table 3.12.

TABLE 3.12. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [16.5]
(As of 1 January 2009)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	0	103	0
Vein	0	0	2000	0
Total	0	0	2103	0

3.16.3.3. Undiscovered resources

No speculative resources have been identified. The Abu Rushied-Seikat and Sella areas have been identified in the extreme south-eastern part of the Eastern Desert as being geologically favourable environments for prognosticated uranium resources. In 1983, IUREP estimated the speculative resources of Egypt to lie in the range 1000–10 000 tU [16.6].

3.16.3.4. Unconventional resources

The Upper Cretaceous phosphate deposits represent one of the most promising unconventional uranium resources in Egypt and confirmed estimates amount to approximately 700 million t of phosphate. The uranium content in these deposits varies between 50 and 200 ppm, with an average value of 60 ppm. Although no reliable estimate of the uranium resources in Egyptian phosphate deposits has been made, it is possible that the deposits contain up to 42 000 tU.

In the period 1999–2003, the NMA worked on the development of a semi-pilot plant for extraction of uranium from phosphoric acid (purification of phosphoric acid through extraction of uranium). The design capacity of this plant is 15 m^3/d of acid, containing about 60 ppm uranium. This unit was expected to be commissioned in 1999, but unforeseen technical problems arose which caused a delay in obtaining the yellow cake product. The semi-pilot plant for purification of phosphoric acid has since been converted to produce phosphoric acid for agricultural, comestible and other domestic purposes.

Black sands, a potential source of unconventional uranium resource, are considered to be titanium and zirconium resources. The evaluated area is estimated to contain about 6 million t of heavy minerals at an average grade of 4.5%. At some locations, the monazite contains up to 0.46% U and 6.05% Th, as well as 65% rare earth elements.

The following unconventional resources were reported in 1999:

- 4000 tU as estimated additional resource category II (EAR-II), of which 3000 tU occur in phosphates and 1000 tU in monazite deposits;
- 4000 tU as speculative resources, of which 3000 tU occur in phosphates and 1000 tU in monazite deposits [16.5–16.8].

3.16.4. Potential for New Discoveries

Egypt has already witnessed a large amount of exploration work. Despite this, no resources have been discovered. To date, exploration expenditures have totalled more than US $119 million [16.5]. Limited amounts of uranium occur in vein and sandstone-type environments. Egypt has also studied the possibility of extracting uranium from phosphoric acid. However, the project was suspended owing to difficulties relating to the low uranium content of phosphoric acid and failures in the extraction cycle.

3.16.5. Environmental activities

All trial mining, trenching and drilling operations, as well as laboratories, are subject to environmental control and radiation safety regulations in accordance with IAEA regulations. The NMA is responsible for studies to assess and manage the radioactive waste envisaged as arising from the extraction and processing of black sands. This task is currently being addressed in collaboration with the IAEA. In addition, a country regulation makes the NMA responsible for the radiation monitoring of imported and local raw materials.

3.16.6. Comments

Egypt has no uranium production centres.

References to Section 3.16

[16.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Egypt (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[16.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 92–96.

[16.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[16.4] RUSHDI, S., Geology of Egypt, Elsevier, New York (1962) 377 pp.

[16.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[16.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[16.7] HUSSEIN, H.A.M, SAYYAH, T.A., "Uranium potential of the younger granites of Egypt", New Developments in Uranium Exploration, Resources, Production and Demand, (Proc. Tech. Committee Meeting, Vienna, 1991) IAEA, Vienna (1992).

[16.8] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Uranium Reserves/Resources, IAEA-TECDOC-1035, IAEA, Vienna (1998).

3.17. EQUATORIAL GUINEA[2]

Equatorial Guinea is one of the smallest countries in Africa. It is located in western central Africa and essentially comprises two parts: the continental region of Rio Muni, which lies between Cameroon and Gabon and includes the offshore islands of Corisco, Elobey Grande and Elobey Chico; and the insular region comprising Bioko Island (about 40 km from Cameroon) and Annobón Island (about 595 km south-west of Bioko Island).

The discovery of significant petroleum reserves in 1996 and their subsequent exploitation have contributed to a dramatic increase in Government revenue. In 2007, Equatorial Guinea became a major oil producer in sub-Saharan Africa. Oil production has risen to 385 000 barrels/d, up from 365 000 in 2004. In addition, the complex on Bioko Island, operated by Marathon Oil, was completed ahead of schedule and has been producing in excess of its 3.4 million t/year nameplate capacity for almost three years. Farming, fishing and forestry are also major contributors to GDP, although subsistence farming predominates [17.1].

3.17.1. Geology

Precambrian metamorphic sequences underlie most of the central and eastern mainland of Equatorial Guinea. Mesozoic, Neogene and Quaternary sediments are exposed along its coastal and western zone (Fig 3.23). The Atlantic Ocean islands of Pagalú and Bioko are part of the Cameroon Volcanic Line and are of volcanic origin.

FIG. 3.23. Regional geological setting of Equatorial Guinea. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

---

[2] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

Three stratigraphically and lithologically different units can be observed in this part of the Archean Congo Craton of mainland Equatorial Guinea: a basal gneissic complex, a greenstone terrane and an undifferentiated granitoid complex. The basal complex consists of granulitic gneisses of charnockitic character and some gabbros.

The greenstone terrane is made-up of metavolcanics and volcaniclastics, which locally reach amphibolite facies. Quartzitic schists, garnetiferous mica schists, biotite schists and amphibolites are distinguished. The granitoid complex is formed by intrusive rocks ranging from granite to diorite. Most granitoids intrude the gneisses and the greenstones, but some seem to be part of the basal gneiss complex.

The Eastern Gabon and Douala Basins, which underlie the coastal lowlands, are filled with Meso- and Cenozoic successions accumulated during the Atlantic rifting event as well as its later evolution towards a passive margin [17.2].

Pagalú is the southernmost island in the Gulf of Guinea and lies within the Cameroon volcanic line. The island represents the top of a 5300 m high stratovolcano, which is built on oceanic crust and reaches an above sea level elevation of 813 m. The volcano was progressively built, initially as a result of submarine volcanism, with a basaltic flow pile covering the major part of the island. The lava series developed a potassic alkaline trend with basanites, hawaiites, trachytes and tristanites. Bioko Island rests on continental shelf, about 40 km south-west of the coast of Cameroon and is formed of three amalgamated stratovolcanoes.

Pico Biao (San Joaquim) and Pico San Carlos volcanoes are adjacent and form the southern part of the island. The lavas have been dated as being no older than 1.1 Ma, thus, the island is probably of similar age to neighbouring Mount Cameroon. Only basaltic lavas are known on the island [17.2, 17.3].

3.17.2. Uranium exploration

The Government conducted airborne geophysical surveys to locate uranium mineralization and launched a new mining code in 2006 [17.4].

3.17.3. Uranium resources

No uranium resources are known in Equatorial Guinea. In 1983, IUREP reported approximately 0–1000 tU of speculative resources [17.5].

The UDEPO database does not list any known deposits for Equatorial Guinea.

3.17.4. Comments

No uranium has been produced in Equatorial Guinea.

References to Section 3.17

[17.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Equatorial Guinea, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed November 2008).

[17.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 98–100.

[17.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[17.4] PRESIDENCY OF THE REPUBLIC OF EQUATORIAL GUINEA, Law of Mines of the Republic of Equatorial Guinea No. 9/2006, Ministry of Mines, Industry and Energy (November 2006).

[17.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.18. ERITREA

Eritrea is located in East Africa, more specifically on the Horn of Africa. It is bordered to the north-east and to the east by the Red Sea, to the south by Ethiopia, and to the north-west by the Sudan. The country is almost bisected by the Great Rift Valley; the fertile lands to the west giving way to desert in the east.

The Afar Triangle or Danakil Depression of Eritrea is the probable location of a triple junction where three tectonic plates are pulling away from one another: the Arabian Plate and two parts of the African Plate (the Nubian and the Somali Plates) splitting along the East African Rift Zone. The highest point of the country, Emba Soira (3018 m), is located in the centre of the country.

Eritrea's economy is largely based on subsistence agriculture, with 80% of the population involved in farming and herding. According to the Government of Eritrea, artisanal mining produces around 900 kg of gold per year. Western observers have also noted Eritrea's excellent potential for quarrying ornamental marble and granite [18.1].

3.18.1. Geology

Eritrea is underlain by Neoproterozoic terranes and Tertiary to Recent volcanic rocks. Marine sediments of Mesozoic to Recent age are exposed in the coastal area of the country along the Red Sea (Fig. 3.24). All Precambrian rocks occurring in Eritrea have been involved in the Pan-African orogeny.

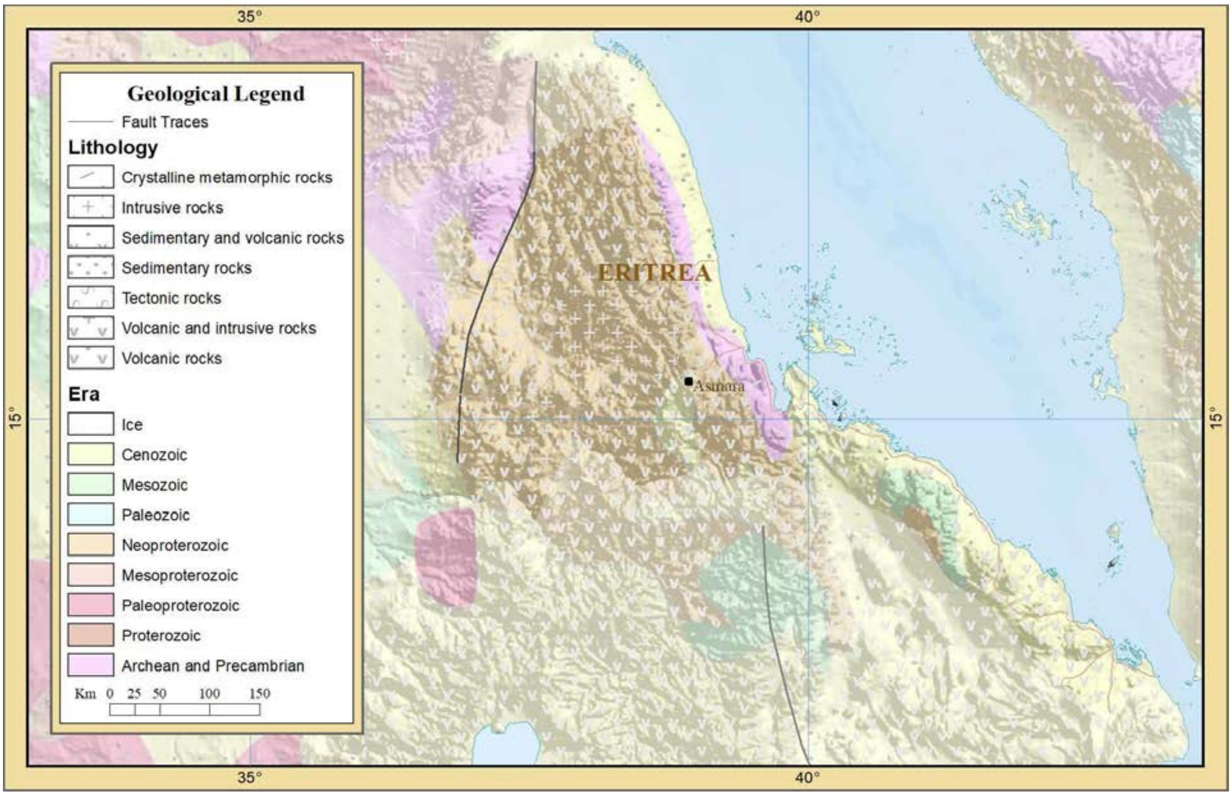


FIG. 3.24. Regional geological setting of Eritrea. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Mesozoic sediments were severely deformed in the present Danakil and Aysha horsts. Near the northern end of the Danakil horst two separate quadrants of ringed intrusions have been observed, which are possibly related to Tertiary granites from the Afar margins. Numerous thin and localized basaltic flows are found in the Miocene sediments of the Red Sea coast. Pliocene welded tuffs were formed prior to the main phase of rifting. The so-called Aden Series basalts range in age from Pliocene to Holocene. The basalts were probably extruded contemporaneously with the major Pleistocene phase of uplifting and rift faulting.

Mesozoic limestones are found east of the Danakil depression, in the Danakil Alps. Most of the Tertiary sediments along coastal Eritrea comprise marine limestones. Large reserves of Neogene evaporites including halites, gypsum and potassium salts exist in the Dallol depression located in Ethiopia and Eritrea. Quaternary gypsum deposits occur along the coast [18.2].

3.18.2. Uranium exploration

No official information is available for uranium exploration in Eritrea. Some work may have been done when Eritrea formed part of Ethiopia.

3.18.3. Uranium resources

No identified or undiscovered resources are reported by Eritrea.

The UDEPO database does not list any known deposits for Eritrea.

3.18.4. Potential for new discoveries

The general lack of known uranium occurrences in Eritrea is a reflection of the inadequate exploration, even of a preliminary nature, in the country. In comparison to similar favourable geological settings worldwide, any uranium exploration in Eritrea should focus on:

— Sandstone hosted mineralization in Mesozoic–Tertiary sediments;
— Calcrete formations in granite terrains within arid and semi-arid areas.

3.18.5. Comments

No uranium has been produced in Eritrea.

References to Section 3.18

[18.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Eritrea (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html
[18.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 102–103.

3.19. ESWATINI (SWAZILAND)

Eswatini (Swaziland) is a landlocked country in southern Africa, bordered to the north, south and west by South Africa and to the east by Mozambique. The terrain consists mainly of mountains and hills, with some moderately sloping plains. The lowest point is the Great Usutu River, at an elevation of 21 m, and the highest is Emlembe, at 1862 m. The climate of Swaziland varies from tropical to near temperate.

Swaziland's economy is dominated by agriculture and subsistence farming. Swaziland possesses a range of natural resources, including asbestos, coal, clay, tin, hydropower, timber, gold, diamonds, stone and talc [19.1].

3.19.1. Geology

The country's geology is dominated in the western part by rocks of Precambrian (mostly Archean) age (Fig. 3.25), whereas in the east these are overlapped by sedimentary and volcanic rocks of Karoo age.

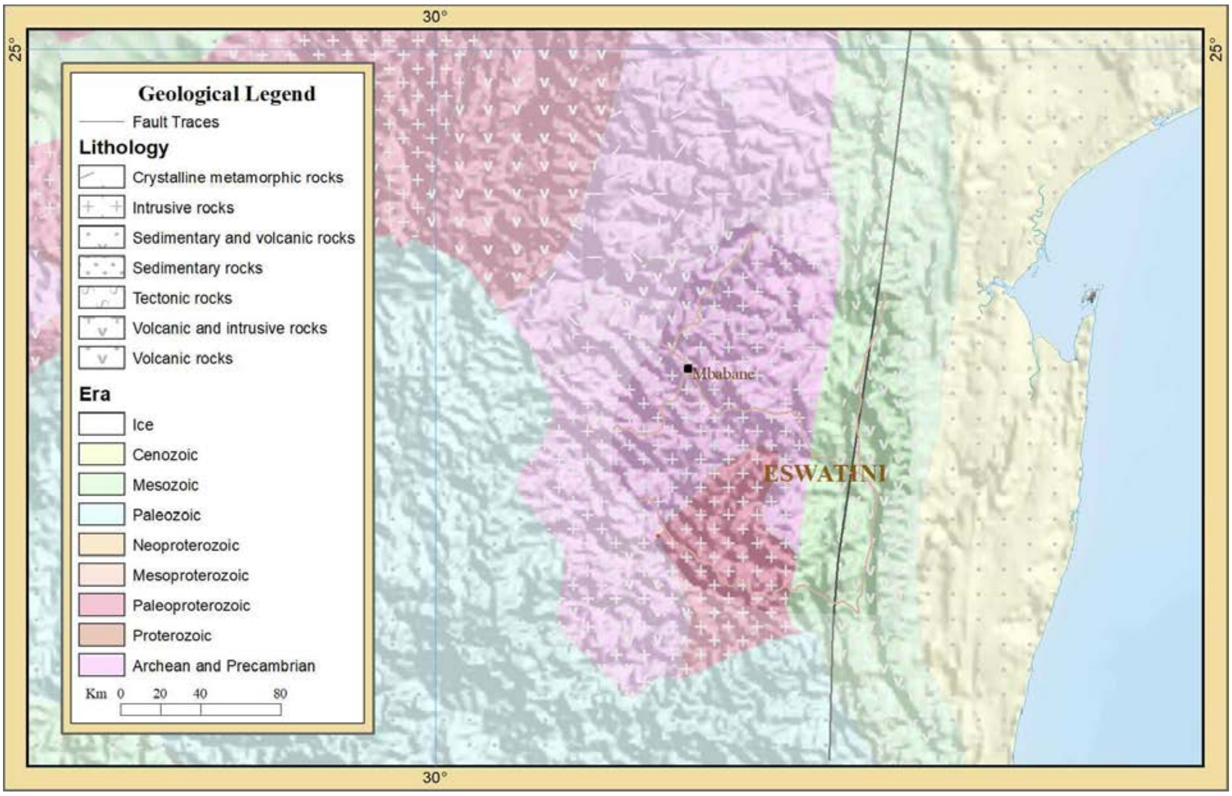


FIG. 3.25. Regional geological setting of Eswatini (Swaziland). A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Swaziland lies on the eastern edge of the Kaapvaal Craton. In the Archean terrain, the oldest rock unit is probably the Ngwane gneiss, which comprises layered, grey tonalitic gneisses with subordinate thin amphibolites. It has a consistently high-metamorphic grade, has suffered the greatest number of deformations, its amphibolites are geochemically distinct from those of other formations, and it is cut by mafic dykes.

Rocks of the tripatite Swaziland Supergroup crop out within the Barberton Greenstone Belt in the northwest of the country.

The base of the Onverwacht Group is not seen but the sequence comprises a greenstone assemblage of mafic and ultramafic lavas, associated serpentinites, and minor sedimentary and acid volcanic rocks. The succeeding Fig-Tree Group yields flysch-type sedimentary rocks associated with ironstones. The Moodies Group lies unconformably on the Fig-Tree and Onverwacht outcrops, both of which together with an igneous/metamorphic terrain supplied the bulk of detritus to the conglomerates of this youngest part of the sequence.

The Mahamba gneiss in southern Swaziland represents high-grade semi-pelitic garnetiferous gneisses. Subsequent to the development of the greenstone belt the Ngwane Gneiss was intruded by hornblende tonalites, the Tsawela and Mhlatuzane gneisses, and by the sheet-like Mponono Anorthosite Suite. The post-greenstone intrusive phase continued with the emplacement of the composite Usutu Intrusive Suite. The Lochiel granite is a major intrusive batholith. Lavas and sediments of the Pongola Supergroup were laid down in the mid-Archean, within a cratonic basin, which lay across the eroded top of the Lochiel batholith. The Insuzi lavas were overlain disconformably by sediments and lavas of the Mozaan Group [19.2].

Some of the Shiselweni amphibolites, which crop out in southern Swaziland, are believed to be metamorphosed lavas as they contain flattened, amygdaloidal quartz blebs. The deposition of the Mozaan sediments was followed by the basic intrusion of the Usushwana complex, which resembles the Great Dyke of Zimbabwe. The Mliba granodiorite is geochemically akin to the older granodiorite plutons, but its stratigraphic age is unclear because it is cut by small leucocratic dykes, which may belong to the Lochiel granite. Subsequently, an increase in the geothermal gradient remobilized the basement, which, together with its Pongola cover, rose diapirically to form a series of mantled gneiss domes, of which the Nhlangano gneiss forms the central core.

The Mkhondo Valley Metamorphic Suite and adjacent outcrops were deformed into a series of dome-and-basin interference folds. The Kwetta and Mtombe granites are rapakivi granites and belong to a formerly continuous post-deformation intrusion. The Hlatikulu granite resembles the Lochiel granite in both its structure and tectonic setting. The Mswati granites are sharply transgressive anorogenic plutons, probably all of similar age. Only a few post-Archaean events can be definitely assigned to the Proterozoic, although much of the Archaean outcrop is cut by innumerable faults and shear zones of varying age, trend and displacement.

The main Karoo outcrop in Swaziland is confined to and draped over the eastern edge of the Kaapvaal Craton. The widespread Lower Ecca claystones were deposited in a shallow marginal-marine basin, but were overlain during the Middle and Upper Ecca by a prograding fluviodeltaic sequence, in which the presence of Gondwana-type coals indicates an amelioration of the climate [19.2].

3.19.2. Uranium exploration and resources

No uranium exploration activities have been reported. No uranium resources, identified or speculative, are reported by Swaziland.

The UDEPO database does not list any known deposits for Eswatini (Swaziland).

3.19.3. Potential for new discoveries

The potential for new discoveries in Swaziland is probably limited to the Karoo strata, as high grade metamorphic terrain appears to be unfavourable for hosting uranium.

3.19.4. Comments

There has been no uranium production in Swaziland. Swaziland has no nuclear power generation.

References to Section 3.19

[19.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Swaziland, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed November 2008).

[19.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 242–245.

3.20. ETHIOPIA

The major portion of Ethiopia lies on the Horn of Africa, which is the easternmost part of the African landmass. Ethiopia comprises a massive highland complex of mountains and dissected plateaux divided by the Great Rift Valley, which trends generally SW–NE, and is surrounded by lowlands, steppes or semi-desert. The great diversity of terrain determines wide variations in climate, soil, natural vegetation and settlement patterns.

Elevation and geographic location produce three climatic zones: (i) the cool zone above 2400 m, where temperatures range from near freezing to 16°C; (ii) the temperate zone at elevations of 1500–2400 m with temperatures of 16–30°C, and (iii) the hot zone below 1500 m which experiences both tropical and arid conditions and daytime temperatures of 27–50°C.

The topography of Ethiopia ranges from several very high mountain ranges (the Semien Mountains and the Bale Mountains) to one of the lowest areas of land in Africa: the Danakil Depression. The rainy season, which extends from mid-June to mid-September (longer in the southern highlands), is preceded by intermittent showers from February or March. The remainder of the year is generally dry.

Ethiopia is the original source of the coffee bean and coffee is the country's largest export commodity. Ethiopia is also the 10th largest producer of livestock in the world. Other important export commodities include leather products and oilseed. Recent development of the floriculture sector could mean that Ethiopia is poised to become one of the world's top flower and plant exporters.

Systematic exploration for mineral resources by the United Nations Development Programme and the Geological Survey of Ethiopia began in 1968. Minerals developed, identified or indicated include precious metals (including both primary and placer gold), rare metals (e.g., niobotantalite), ferrous metals, base metals and radioactive minerals. The country also has significant oil potential in some of the less inhabited regions. However, political instability in the region has limited development of oil resources [20.1].

3.20.1. Geology

The oldest rocks in Ethiopia consist of paragneisses and orthogneisses, as well as large areas of metamorphosed granites (Fig. 3.26). The Wadera Group, consisting of metamorphosed arkoses and shales with subordinate quartzites, was laid down in a shallow basinal environment on the surface of this crystalline basement. The Wadera Group has been strongly metamorphosed and partly migmatized, although only moderately deformed by open folding. The age has been reported as being Lower Proterozoic–Middle Proterozoic. Geosynclinal zones and mobile belts subsequently developed on the crystalline basement during the Upper Proterozoic and possibly the Lower Palaeozoic. Folding, late tectonic and post-tectonic igneous intrusions have been dated at 700–450 Ma.

Following the end of the orogenic movements in the Lower Palaeozoic, a long period of erosion and resultant peneplain generation occurred before the deposition of the pre-Adigrat Glacials in the Blue Nile Gorge, Tigre Province and the Harar area. These have been tentatively correlated with the widespread Gondwana glaciation of the Upper Carboniferous and Lower Permian of Australia, India, South Africa and South America.

The Mesozoic is mainly a period of marine sedimentation over most of Ethiopia, with two main periods of diachronous transgressive continental fluvial or littoral deposition. One occurs in the Upper Triassic–Lower Jurassic (the Adigrat Sandstone), and the other in the Lower Cretaceous (Upper Sandstone or Amba Aradam Formation).

In the western part of the Ogaden Basin, the Gabredare Series of Late Jurassic age has its usual marine limestone facies replaced by a mainly arenaceous assemblage with subordinate limestone interbeds. This may represent a shallow marine coastal environment. In the Tertiary, marine sedimentation continued in the eastern part of Ethiopia. One continental phase has been recorded and is represented by the western exposures of the Jesomma Sandstone in the eastern Ogaden. Basic and alkaline volcanic activity commenced in the Tertiary, associated with rift faulting, and this activity has continued into the present [20.2].

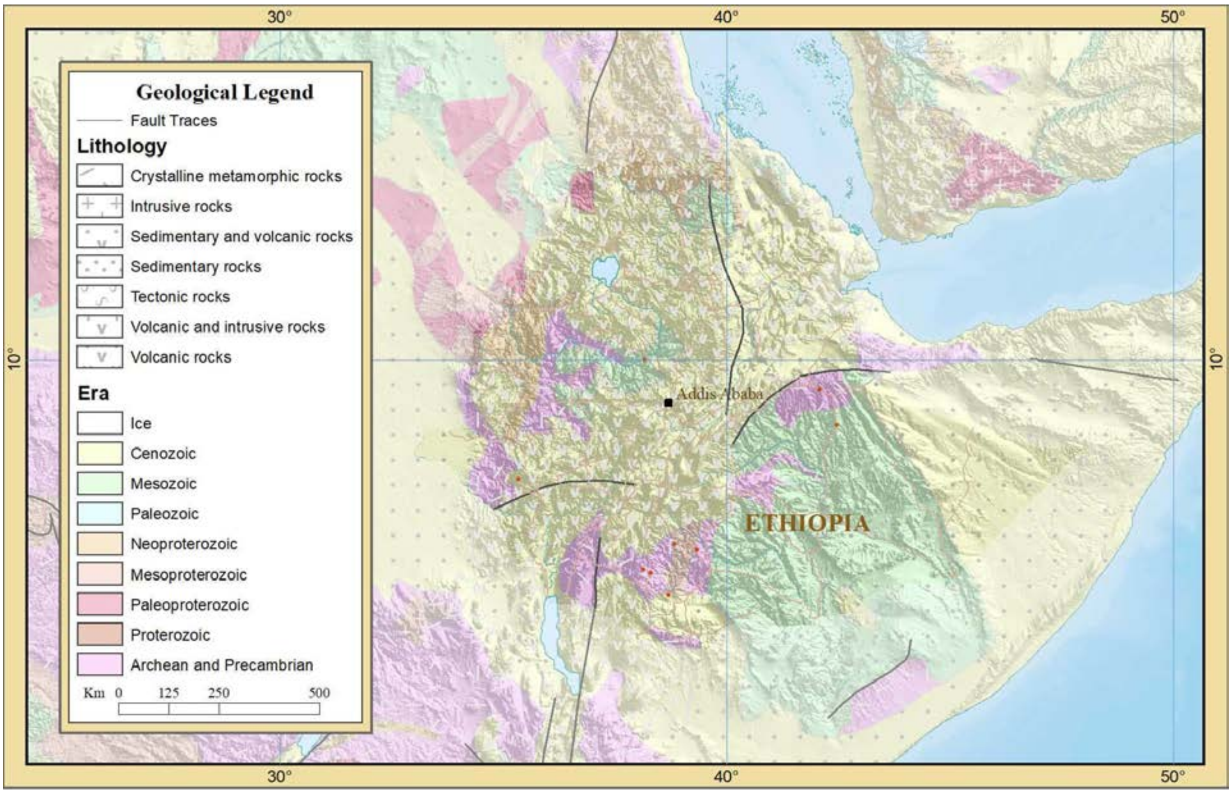


FIG. 3.26. Regional geological setting of Ethiopia. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.20.2. Uranium exploration

Uranium exploration began in the late 1950s. The first surveys were carried out by the US Atomic Energy Commission in 1955. Car-borne scintillometer surveys identified an anomalous zone in gneisses and granites between Harrar and Dire Dawa. An airborne radiometric survey covered the area east of Gimbi (Welega region). In the Akobo area (Kefa region), a granite sample was found to contain 0.01% U. A scintillometer survey completed in 1957 along the Gore-Gecha road in the Ilubador region located three radioactive anomalies.

In 1970, an airborne radiometric survey was undertaken between the basins of the Canale and Awata Rivers, in the southern part of the Sidamo administrative region, under a United Nations Mineral Survey Programme (covering 15 274 km² and 9726 km² in the Welega and Sidamo regions, respectively). Several anomalies were identified but ground follow-up failed to reveal any significant uranium occurrences. The arenaceous meta-arkose of the Wadra Formation in this area initially appeared to have some potential, but ground follow-up failed to reveal any significant uranium occurrences. In 1975–1976, a further scintillometer survey was undertaken at Surupa, Didiga and Wadera in the Sidaroo region. Other areas which have been explored are the Eritrea and Tigray regions.

An airborne survey over Megado and Adola (Sidamo), covering 94 300 km², was conducted in 1993–1994 by Ethiopia and the United Nations Development Programme. Another airborne survey (14 000 km²) over Metekel (north-west Ethiopia) was conducted in early 2000.

A uranium focused ground survey was carried out in the Werri area of south-eastern Ethiopia. Of the 13 anomalies delineated, eight were checked on the ground. The Wadera area was considered the most interesting.

A total of 36 anomalies were delineated in western Ethiopia, six of them checked on ground and these were found to reflect the presence of alkaline phonolitic plugs. Anomalies were found on Gariboro granite ridge and in 2007 some were checked by an orientation survey, but the results were discouraging. Anomalies in connection with restricted uranium bearing pegmatites could be followed up.

3.20.2.1. Identified anomalies

Most known radioactive anomalies of the Sidamo area were discovered in 1968 as the result of an airborne geophysical survey. Anomalies around the Wadera area were found to be interesting. Methods used for the ground survey included:

- Radiometric measurements;
- Trenching;
- Rock samples from trenches and exposures;
- Test borehole drilling at three sites;
- Neutron activation analysis, X-ray fluorescence and X-ray diffraction analysis were undertaken by the Institute of Geological Science in London.

Anomalous radiometric zones were traced over 235 m with radioactive values typically in the range of 300–2000 cps, and locally above 4500–85 000 cps. The anomalous zone is confined to a 0.9–1.2 m thick reddish to yellowish, grey bedded sandstone at the lower part of the Wadera Series. Radioactive anomalies with values of 500–600 cps were also found in 0.2–0.8 m thick pegmatite veins. The host rock is sandstone with up to 1500 cps. One sample recorded 400 ppm U.

Radioactive anomalies with values of 500–600 cps were also recorded in several small granite bodies. X ray fluorescence analysis of samples from the outcrop yielded 0.3–0.94% Th and up to 1.4% Y, and neutron activation analysis indicated U values of 18–36 ppm. The light fraction of samples of yellowish green montmorillonite recorded 1.0% Th and 1.0% Y.

The drill holes did not intersect the expected anomalous zone. Anomalies in the Wadera area are related to bedded sandstone, pegmatites and granite bodies. The overall findings of exploration were not conclusive [20.3, 20.4].

3.20.3. Uranium resources

Although a number of radioactive mineral occurrences have been detected, there are no known uranium resources in Ethiopia. In 1983, IUREP reported a range of 10–50 000 tU of speculative resources in sandstone, surficial (calcrete) and magmatic environments [20.5].

The UDEPO database does not list any known deposits for Ethiopia.

3.20.4. Potential for new discoveries

The general lack of known uranium occurrences in Ethiopia is a reflection of the inadequate exploration, even of a preliminary nature, of the country.

The oldest rocks in Ethiopia consist of paragneisses and orthogneisses, as well as extensive areas of metamorphosed granites. These Proterozoic rocks could be prospected for unconformity-type deposits and also for vein and disseminated types of mineralization.

The Upper Triassic–Lower Jurassic Adigrat Sandstone seems to possess the characteristics necessary for uranium deposition. It is a possible correlative of the Karoo in other areas in Africa which are known to contain significant occurrences of uranium. In the Harar region, secondary copper mineralization occurs near the base of the Adigrat. Brief field reconnaissance by an IAEA consultant indicated that radioactivity levels of three to four times background can be detected locally in the Adigrat rocks. The Upper

Cretaceous Jesomma Sandstone occurs in the eastern Ogaden and its western part is considered to have been deposited in a continental fluviatile environment. Lignitic and pyritic shales have been recorded. This area could be worth further prospection.

Tertiary volcanic plugs, ranging in composition from syenite porphyry to phonolite, occur in the area of confluence of the Blue Nile and Dabus Rivers. A United Nations airborne radiometric survey in 1968 showed that these plugs are quite radioactive (8–12 times background). Radioactive minerals already identified include xenotime and zircon.

A search could be initiated in south-eastern Ethiopia for uranium similar to the secondary uranium deposits of the Mudugh Province of Somalia.

In comparison to a number of favourable geological settings worldwide, systematic exploration in Ethiopia could focus on investigating:

(a) Unconformity-type mineralization in thick Mesozoic sediments of the Ogaden, Abay, Mekele, Gambela and frontier basins;
(b) Sandstone-hosted mineralization in Mesozoic–Tertiary sediments of the above mentioned basins;
(c) Mineralization associated with calcrete formations in granite terrains in the southern, western and eastern lowlands;
(d) Uranium concentrations in acidic volcanic rocks and strata affected by structures and alteration in the main Ethiopian Rift System;
(e) Intrusive related uranium in all Precambrian strata;
(f) Other types associated with metamorphic rocks affected by calcium-rich alteration [20.3, 20.4].

3.20.5. Comments

There has been no past uranium production in Ethiopia and the country has no nuclear power generation.

References to Section 3.20

[20.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Ethiopia (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html
[20.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 104–109.
[20.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.
[20.4] GEBRESELASSIE, M., "Status of uranium exploration in Ethiopia", paper presented at IAEA Tech. Mtg on Uranium Exploration, Mining, Processing, Mine and Mill Remediation and Environmental Issues, Swakopmund, 2007.
[20.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.21. GABON

Gabon is located on the equator, on the Atlantic coast of central Africa. Gabon has an equatorial climate and rainforests cover 85% of the country. There are three distinct regions: (i) the coastal plains (20–300 km from the sea), (ii) the mountains (the Cristal Mountains to the north-east of Libreville, the Chaillu Massif in the centre, culminating in Mount Iboundji (1575 m)) and (iii) the savannah to the east. Natural resources include forests, iron, gold, manganese and oil.

Gabon is more prosperous than most of its neighbouring countries, with a per capita income four times the average for sub-Saharan Africa. This is in large part due to offshore oil production. It is an exporter of iron, manganese and wood. The uranium mines near Franceville closed in 1998. There are plans to exploit the rich iron deposits north-east of Makokou [21.1].

3.21.1. Geology

Gabon is located at the northwestern margin of the Congo Craton. Three major stratigraphic units can be distinguished (Fig. 3.27): the Archean basement and the Proterozoic sediments, which together cover about 75% of the country, and the Phanerozoic sedimentary cover, which is essentially of Cretaceous age or younger.

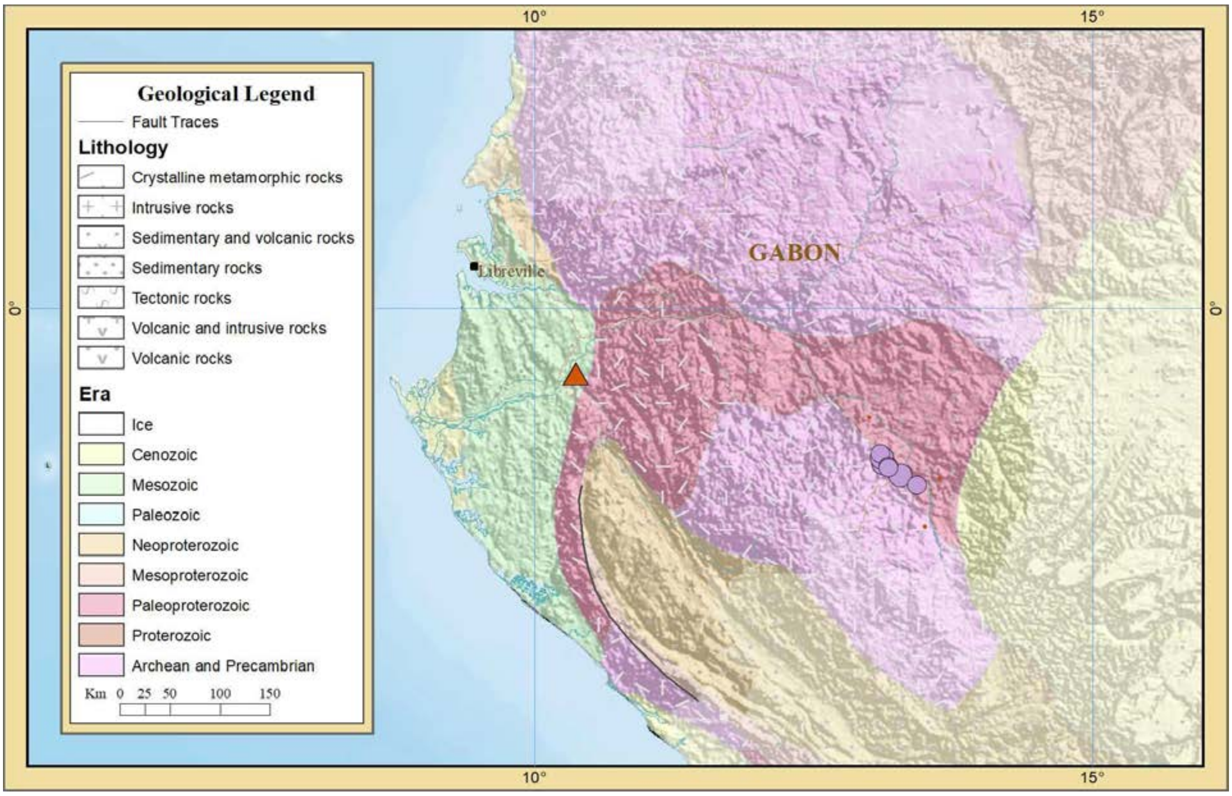


FIG. 3.27. Regional geological setting of Gabon showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The oldest rocks of the country form part of the Archean cratonic basement of Gabon, the Republic of Congo, Cameroon and mainland Equatorial Guinea. In Gabon, this basement is traditionally separated into the southern Chaillu Massif and the North Gabon Massif. The Chaillu Massif is dominated by granitoid rocks, which have given ages of 2800–2600 Ma. The granitoid rocks represent a typical Archean cratonic assemblage of foliated quartz diorite-tonalite-granodiorite suites, with later more potassic rocks of monzonitic, granitic and syenitic compositions. A large charnockitic body has been mapped in the south. The North Gabon Massif appears to show more variation than the Chaillu Masif and includes the Monts de Crystal and Mitzic regions where granulites and charnockites of varying composition are typical. The granitoid terrane in the south, which is a continuation of the Chaillu Massif, contains many relatively small greenstone belts dominated by itabirites and iron-rich quartzites and schists.

Paleoproterozoic rocks consist of the about 2000 Ma old Franceville Supergroup in the eastern central part of the country and the Ogooué orogenic belt in the centre-west. The Franceville Supergroup comprises a thick pile of predominantly sedimentary rocks, which were deposited in three main basins. The syn-Franceville N-Goutou Volcanic Complex has been dated at about 2150 Ma. To the east of the Franceville Supergroup, the Ogooué orogenic belt comprises a number of thrust nappes of highly deformed medium- to high-grade metasedimentary and metavolcanic rocks (the Ogooué Supergroup), that have been considered to be broadly coeval with the Franceville Supergroup. In the southwestern part of the country, the Mayombe-Nyanga terrane comprises medium- to high-grade Paleoproterozoic basement rocks (including the Lambaréné migmatite belt), and metasedimentary rocks of the Doussa Supergroup, along with post-tectonic granites dated at about 1900 Ma.

The Mesoproterozoic geology of Gabon appears to be restricted to the rocks of the Mayombe Supergroup and a suite of post-Franceville dolerite dykes emplaced at about 970 Ma. In the western part of the country, the Neoproterozoic (Pan-African) West Congolian Supergroup is exposed in two regions, the de-la-Noya and Nyanga Basins, which both contain thick low-grade, deformed, volcano-sedimentary sequences [21.2].

The coastal sedimentary basin, which was formed during the Lower Cretaceous, is split into two unequal parts by the horst of the Lambaréné-Chincoua basement rocks. The interior or Eastern Basin, located east of the horst, consists mainly of continental and lacustrine sedimentary sequences dated at Upper Palaeozoic–Middle Cretaceous. The Atlantic or western basin consists of mostly marine sedimentary sequences of Middle Cretaceous–Quaternary age. The Batéké Plateau sequence comprises Tertiary continental facies and lies unconformably on Proterozoic formations [21.2].

3.21.2. Uranium exploration

Prompted by the sudden demand for uranium following World War II, France's then Atomic Energy Commission (CEA) initiated uranium exploration in central Africa and its geologists extended their activities into Gabon.

Uranium exploration in Gabon began in 1948. The first target was the Chaillu crystalline basement area which was thought to contain vein deposits similar to those known in the Hercynian massifs in France. Two campaigns of prospecting were directed at granitic massifs and metamorphic systems.

Following the Canadian discoveries of uranium in Precambrian sediments in 1955, prospecting activities in Gabon concentrated on the Precambrian sedimentary formations where they contacted the granitic base of the Chaillu Massif in the Tchibanga-Mayumba region. Radioactive anomalies were found in a basal conglomerate of the Franceville Formation at Mount Iboundji, near Koulamoutou. This led to a detailed examination of the Francevi1le Basin. In December 1956, only six months after the start of exploration in the area, surface scintillometer surveys led to the discovery of uranium mineralization in Precambrian sandstones of the Franceville Basin, in the vicinity of the village of Mounana.

Exploration during the next four years was concentrated in the Mounana area. In the light of the data obtained in the Mounana region (four deposits representing almost 30 000 tU), a 1150 km² concession was granted in March 1971 to the Atomic Energy Commission, which leased the concession to the Franceville Uranium Mining Company (COMUF) to continue exploration work in this area. Additional uranium deposits were discovered at Mikouloungou (1965), Boyindzi (1967), Oklo and Okélobondo (1974), as well as Bagombe (1982). In 1965, the Atomic Energy Commission withdrew, leaving the Mounana-Mikouloungou region to COMUF to continue exploring for new targets in other parts of Gabon, in most cases through a prospecting group.
Starting in 1960, work was extended to the remaining area of the Franceville Basin. A large number of uranium occurrences were found in the southern part of the basin, which proved difficult to evaluate. Aerial surveys were undertaken in the late 1960s and reconnaissance and general prospecting extended to other parts of the country. Deep geological test holes were drilled in two areas during the early 1970s. One of these areas, the north Leyou zone in the Lastourville region, became an exploration programme which was started in October 1980.

Prospecting work was carried out in the estuary zone east of Libreville, starting in 1965, using a wide grid that covered an area of 10 000 km², followed by more detailed work over an area of 1100 km². This included a shallow drilling programme conducted during 1968–1970, with deeper drilling undertaken from 1970 onwards. A number of radiometric and geochemical anomalies were found in clayey, dolomitic horizons in the Permo-Carboniferous Agoula Formation. A structural analysis of the area concluded that uranium accumulations might exist in tectonically favourable zones. Exploration of these areas, under an agreement between France's Compagnie Générale des Matières Nucléaires (COGEMA), Japan's Power Reactor and Nuclear Fuel Development Corporation and the Government of Gabon, began in 1978, and included plans for drilling a large number of holes over a period of three years. Operations were terminated at the end of 1980.

A programme of general prospecting in the Booué Basin and along the eastern edge of the phyllocrystalline system of the Ogooué area commenced in 1976. Work consisted of geochemical sampling along watercourses and verification of anomalies. A partnership between the Union Carbide Exploration Corporation, COGEMA, the Government of Gabon and the Leon Tempelsman Company carried on this work, but was dissolved at the end of 1979. Studies of the metamorphic and crystalline rocks in the Ndjole-Lintdkö area continued under a new prospecting licence. In 1981, active exploration programmes under a partnership between COGEMA, the Korean Electric Power Company and the Government of Gabon were conducted using deep drilling within the Mounana concession to search for new uranium deposits within the Franceville Formation. The Franceville Formation was also being evaluated outside the Mounana concession in a continuing effort to delineate its uranium potential.

In 1982, exploration programmes run by COGEMA in the north Leyou and south Franceville sectors confirmed the possible existence of further uranium deposits in the north-east and south-east of the Atomic Energy Commission concession. Within the concession, exploration by COMUF provided data on the reserves at the Okélobondo deposit, and new prospects were discovered at Bagombe, just east of the manganese deposit at Moanda, and at Lekedi-M'Berse, south of Okélobondo. In 1983–1984, exploration continued in the Mounana–Franceville area, mainly by COMUF in the Mounana concession, and by the North Leyou Joint Venture (Government of Gabon, COGEMA and the Korea Electric Power Corporation) in close proximity to the eastern border of the Mounana concession. COMUF's activities consisted mainly of drilling, totalling 10 333 m in the following areas: Bagombe deposit (4260 m); Bagombe south-west (2095 m); Lekedi North (1535 m), on favourable structures and associated low grade mineralization; Mounana East (907 m) and other locations (1536 m).

The North Leyou Joint Venture centred its exploration programme in the Suly area, south-east of Leyou, where the Magna and Roma Domes were investigated. Various exploration methods were utilized (geochemistry, radiometrics, seismics, very high frequency, complemented by the drilling of 7301 m). The investigation of the Magna and Roma areas was unsuccessful, and in December 1984 a new exclusive exploration permit 'Leyou-North', covering about 4500 km², was granted by the Gabon authorities.

In 1984–1985, COGEMA undertook a limited programme in the south Franceville area and entered into joint venture negotiations with the Government of Gabon, COMUF and Germany's Urangesellschaft.

Extensive airborne surveys were also carried out in 1971–1984 by various organizations, among them the United Nations Development Programme, France's BRGM, COGEMA and others. A joint venture operated by COGEMA, the Government of Gabon, Urangesellschaft and COMUF started surface prospection and drilling in the area of Lafoube Matoube.

In the early 1990s, most of the exploration effort was devoted to the review of current reserves and drilling for further resource development in the Okélobondo deposit and its satellite orebodies. In addition, some reconnaissance drilling was being carried out in the southern portion of the Lekedi River, referred to as Lekedi-Sud.

Geologically, the deposits are located in coarse sandstones in the lower part of the Franceville Formation (Upper Precambrian). The mineralization is controlled by sedimentary and structural features. The major portion of the uranium mineralization in the Franceville Basin is considered to be hosted by sandstone. In earlier years, the host sandstone for many of the deposits in Gabon had been interpreted as channel sandstone. Under this assumption, the potential for deposits in this environment is considered to be limited to those areas of channel development. A more recent sedimentological study, conducted between 1992 and 1993, concluded that the host sandstone was deposited in a littoral environment. This finding increases the potential of the area because extension of the mineralization is considered a distinct possibility.

In 2007, exploration conducted by Canada's Motapa Diamonds Inc., Pitchstone Exploration Ltd and Cameco Corporation in the Franceville Basin included a 13 352 line km of helicopter-borne magnetic–radiometric survey that covered an area of approximately 1700 km^2 of the licences. Ground geochemical, geophysical and prospecting orientation surveys were also completed. In 2008, an 877 line km helicopter-borne electromagnetic survey, as well as prospecting, rock sampling and stream sediment sampling programmes were completed. Following a campaign of development drilling, AREVA announced in 2013, 5420 tU at 0.027% of inferred resources at the Bagombe deposit.

Figure 3.28. summarises uranium exploration data for a total of USD $92 781 000 expenditure including 436 014 metres of drilling, 8142 km^2 of airborne radiometric surveys and 58 296 km^2 of other surveys.

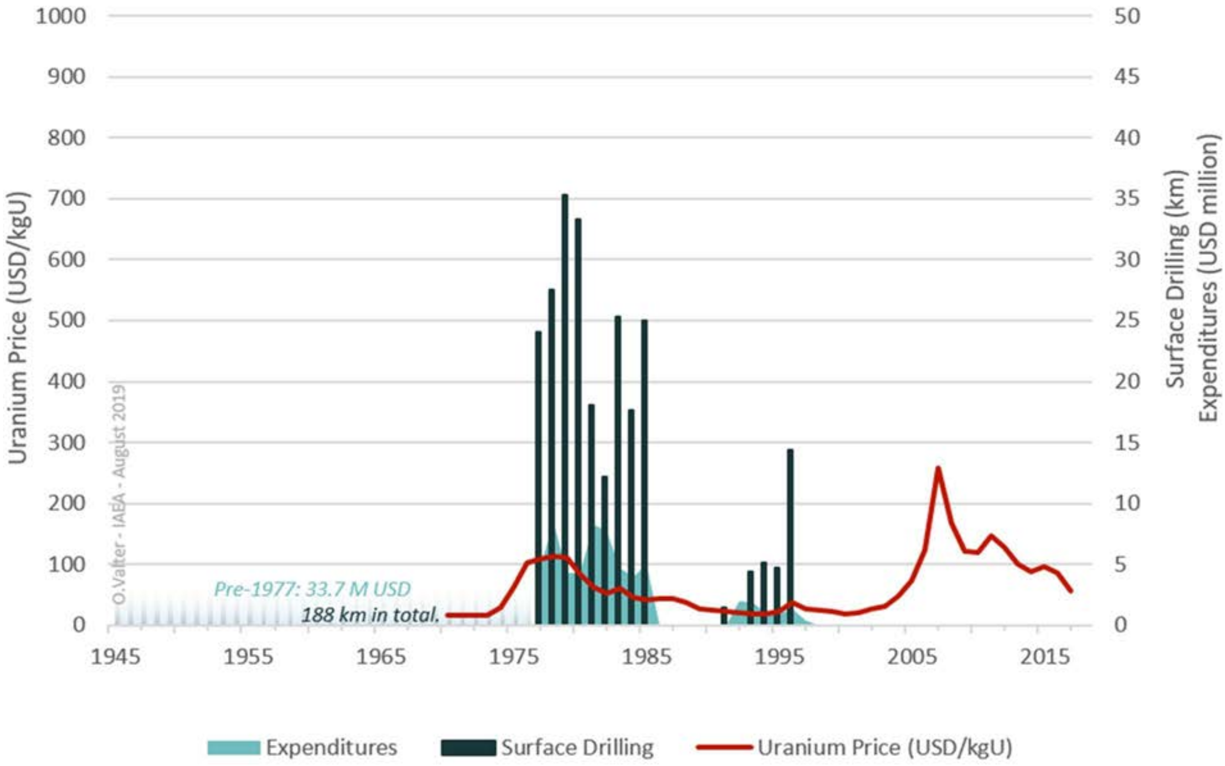


FIG. 3.28. Domestic uranium exploration data for Gabon. Comparison of exploration expenditures, drilling and uranium market price (US$ current) [21.3–21.14].

3.21.2.1. The Oklo phenomenon

In September 1972, the global scientific community was informed of a discovery made by researchers at France's Atomic Energy Commission which indicated the existence of old fission chain reactions in the uranium deposit at Oklo [21.15, 21.16]. The reaction site consisted of several bodies of high grade uranium mineralization and more than 500 tU had been involved in the reaction, with the quantity of energy released roughly equivalent to 100×10^9 kW·h. Samples have been found in which the concentration of ^{235}U is as low as 0.29% (compared with 0.72% in natural uranium). The nuclear reaction control mechanism which has allowed such high rates to be attained must have been quite exceptional.

The state of preservation of the 'fossil' nuclear reactions is exceptionally good and the uranium has retained its configuration over time so faithfully that reaction rate distribution across the formations can be interpreted in terms of neutron physics. In fact, an entire episode in geological history can be studied as a result of the numerous tracers emanating from the nuclear reactions, beginning with the deposition of very high uranium concentrations around 1800 Ma ago. An explanation for the event involves the possibility that the enrichment of ^{235}U at 1800 Ma would have been about 1.8%, compared with 0.72% recorded currently. The half-life of ^{235}U is about 700 Ma. Given a concentrated high natural uranium grade and the presence of groundwater acting as a moderator, the requirements for a natural reactor have been met [21.15, 21.16].

3.21.3. Uranium resources

3.21.3.1. Identified resources

After mine and mill dismantling of Gabon's industry, the remaining reasonably assured resources and inferred resources were moved from the <US $40/kgU cost category to the <US $260/kgU cost category. In-situ reasonably assured resources and inferred resources amount to 6400 tU and 1300 tU respectively, recoverable from underground mining [21.17]. Historical variations in uranium resources are shown in Fig. 3.29 and Fig. 3.30.

The UDEPO database lists the most significant deposits for Gabon as Mabounie, Oklo, Mounana, Bagombé, Boyindzi, Okélobondo Nord, Okélobondo Sud, Mikouloungou.

3.21.3.2. Undiscovered resources

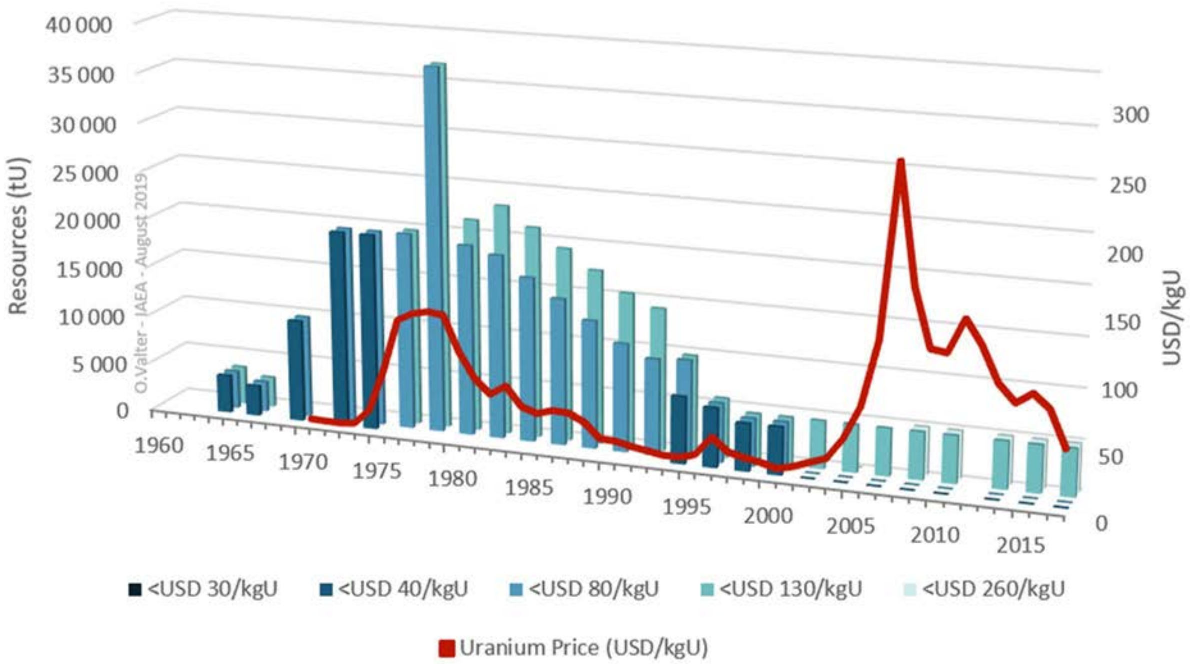


FIG. 3.29. Historical variation of recoverable reasonably assured resources within various cost categories in Gabon. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

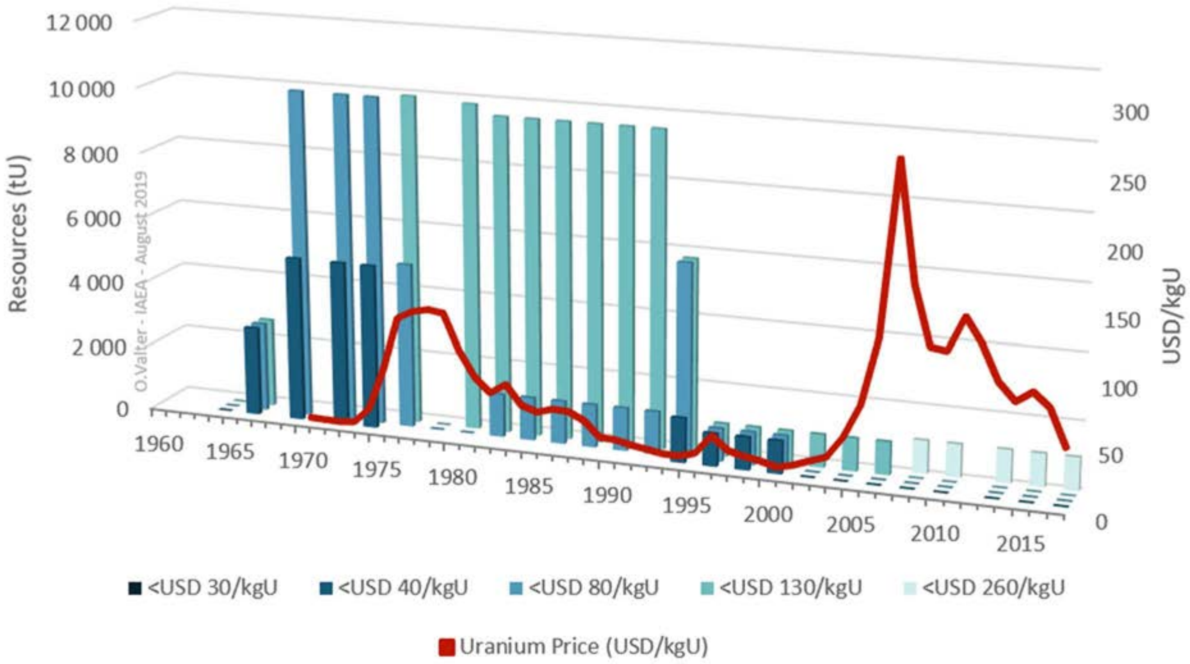


FIG. 3.30. Historical variation of recoverable inferred resources within various cost categories in Gabon. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

With the closure of uranium production facilities in Gabon, undiscovered resource estimates are no longer updated. In 1997, the estimated annual resources (EAR-II) of Gabon were reported to total 1610 tU as in situ resources recoverable at costs below US $40/kgU. Higher cost EAR-II and speculative resources were not reported [21.18].

3.21.4. Potential for new discoveries

There is potential for new orebodies to be found in the Franceville Basin, in similar geological environments to those of the Boyindzi, Mounana and Oklo deposits. The rocks of the Upper Proterozoic West Congo and Noya Systems could also have potential for hosting uranium mineralization. These systems are roughly correlative to the Katanga Series of Zambia and the Democratic Republic of the Congo, and the Damara of Namibia and Botswana. Another area of interest could be in the north-eastern part of the Gabon Coastal Basin (Eastern Basin) between the Lambaréné Basement Horst and the Precambrian basement. The rocks of interest are a several thousand metre thick sequence comprising the Lower Cretaceous Cocobeach Formation.

The Cocobeach consists of alternating sequences of conglomerate, sandstone and thick successions of sparingly bituminous shale. Interbeds of siltstone and limestone with ostracods are also present. Plant remains are common and the environment of deposition is clearly continental and marginal marine. The Lower Cocobeach is underlain by 150–400 m of continental shales, sandstones and conglomerates which rest on the pre-Mesozoic basement complex. These are believed to be of Permian or Jurassic age. The uranium source could be the basement rocks to the east. Some similarities to the US Gulf coast, as regards uranium geological environment, are suggested in the Gabon Coastal Basin. The Batéké Plateau is underlain by continental Cretaceous and Tertiary sediments, and sandstone-hosted uranium deposits could occur in this environment.

3.21.5. Uranium production

Uranium production by COMUF experienced significant fluctuations since the company started producing in 1961 (Table 3.13 and Fig. 3.31) for a total of 25 403 tU up to 2017 [21.13, 21.14, 21.20].

The ore was mined primarily by open cut operations, although underground mining was also employed. There were five discrete orebodies with an average ore grade of 0.37% U. Extraction of the ore began at the Mounana open pit mine (1961–1975), which was followed by production from the Oklo mine (1970–1985). Ore was extracted from underground mines, first at Mounana, then at Oklo (1977–1997) and Boyindzi (1980–1991). The open pit at Mikouloungou, 60 km distant, was mined in 1997–1999.

TABLE 3.13. URANIUM PRODUCTION DETAILS AT MOUNANA [21.19]

Startup date:	1988
Type of ore:	Sandstone
Output:	1300 t ore/d
Average mining recovery:	95%
Type of processing plant:	Solvent extraction
Nominal production capacity:	1500 tU/year

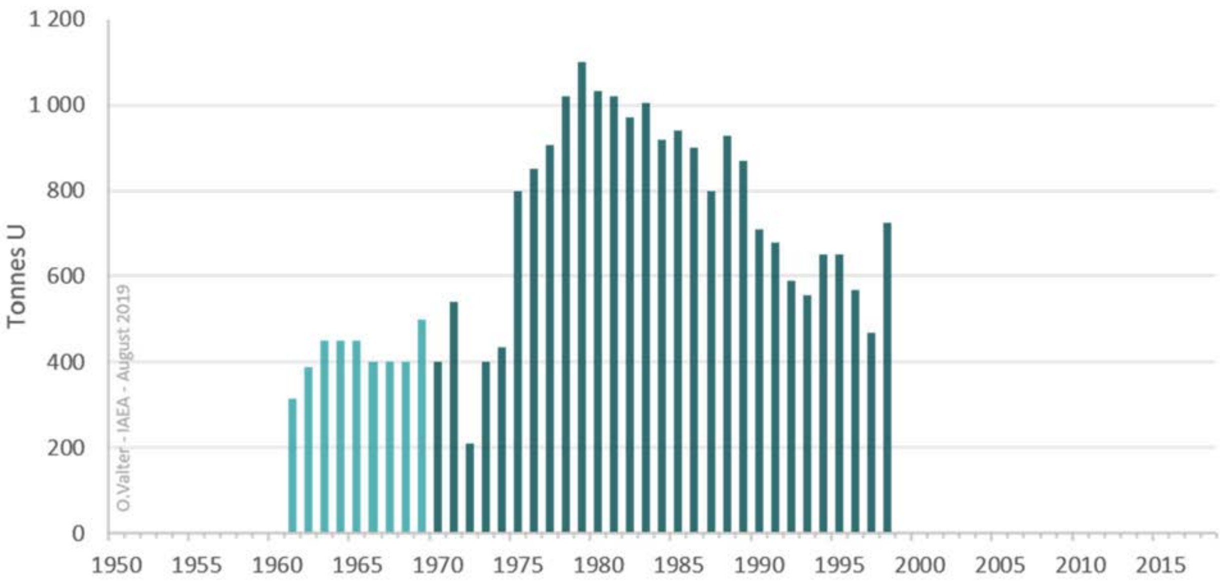


FIG. 3.31. Historical uranium production in Gabon (tU/year) (Data in light green are from the Red Book Retrospective, in dark green from Red Books) [21.13, 21.14, 21.20].

Parameters that impacted the production rate included ore processing capacity, as well as the prevailing international uranium market price. The main changes in production rate were:

(a) 1961–1969: attainment of a production level of approximately 400 tU/year;
(b) 1970–1973: gradual production increase to 500 tU/year;
(c) 1974–1979: rapid production increase to 1250 tU/year;
(d) 1980–1989: production decrease to 900 tU/year;
(e) 1990–1993: further reduction to 550 tU/year;
(f) 1994–1996: maintenance of a production level of 600 tU/year, with the possibility of an adjustment to 550 tU/year;
(g) 1999: termination of uranium production operations and initiation of mill decommissioning.

Following termination of mining and uranium production operations, the plant was dismantled and the site reclaimed. Of the total production, 94 tU were found to be depleted ^{235}U. This uranium was produced from the natural reactor sites of the Oklo deposits [21.15, 21.16].

3.21.6. Status of production capability

Gabon terminated uranium production in 1999. All mining and milling infrastructures have been dismantled and reclaimed.

3.21.7. Environmental activities

The most important environmental concerns relate to the impacts caused by the mining and milling operations. This includes long term management of tailings and waste produced at the mill site [21.19].

With the cessation of all uranium production in the country, the Government initiated a programme of rehabilitation for the entire Mounana mining and milling operation. There were seven sites requiring rehabilitation, covering a total surface area of about 60 ha. The work undertaken consisted of:

(a) Closure of all impoundments for tailings and other residues;
(b) Development of a lateritic cover over the tailings;
(c) Revegetation of the sites.

The objective of this remediation programme was to ensure a residual radiological impact that is as low as reasonably achievable. The work is also intended to ensure the physical stability of the residue impoundments and, if possible, provide for the future utilization of the affected area. The Mounana mill is completely dismantled and restoration of the site was completed in July 2004 at a total cost of €10.7 million, including €7 million provided from EU funds. A programme for long term monitoring and surveillance of the tailings has been implemented [21.19].

3.21.8. Employment in the uranium industry

Table 3.14 provides details of employment within the uranium industry for the period 1988–2003.

TABLE 3.14. TOTAL EMPLOYMENT RELATED TO EXISTING PRODUCTION CENTRES IN THE URANIUM INDUSTRY [21.20]

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Person-year	288	207	193	263	276	259	150	—	—	15	15	15	—

[a] —: data not available.

3.21.9. Comments

Gabon has no existing facilities and no plans to develop nuclear generating capacity. Consequently, it has no reactor related uranium requirements. Gabon has not reported information on national policies relating to uranium, uranium stocks or uranium prices.

References to Section 3.21

[21.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Gabon, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed December 2008).
[21.2] CHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 110–113.

[21.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).
[21.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).
[21.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).
[21.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).
[21.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).
[21.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).
[21.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).
[21.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).
[21.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).
[21.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).
[21.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).
[21.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).
[21.15] GAUTHIER-LAFAYE, F.; HOLLIGER, P.; BLANC, P.-L., Natural fission reactors in the Franceville Basin, Gabon: a review of the conditions and results of a "critical event" in a geologic system", *Geochimica et Cosmochimica Acta*. 60 (25): 4831–4852.(1996)
[21.16] INTERNATIONAL ATOMIC ENERGY AGENCY, The Oklo Phenomenon 1975 (Proc. Symp. Libreville, 1975),, Vienna (1975).
[21.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).
[21.18] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO) with Uranium Deposit Classification: 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[21.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).
[21.20] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006).

3.22. GAMBIA[3]

Gambia is the smallest country in mainland Africa and is bordered to the north, east and south by Senegal. It has a narrow stretch of coastline bordering the Atlantic Ocean to the west. The Gambia River flows the entire length of the country, discharging into the Atlantic Ocean. Gambia is less than 48 km wide at its widest point and has a total area of 11 380 km². Approximately 1300 km² of Gambia's surface area is covered by water.

Gambia's climate is tropical. The period June–November is the rainy season and is characterized by hot weather. In November–May, cooler temperatures and dry conditions prevail.

Agriculture accounts for roughly 30% of GDP and employs about 70% of the labour force. Within agriculture, groundnut production accounts for 6.9% of GDP, other crops 8.3%, livestock 5.3%, fishing 1.8% and forestry 0.5%. Industry accounts for approximately 8% of GDP and services approximately 58%. The limited amount of manufacturing is primarily agriculturally based (e.g., groundnut processing, bakeries, a brewery and a tannery). Other manufacturing activities include soap, soft drinks and clothing.

[3] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

It has been assumed that there might be some potential for the discovery of oil in the basin. Several thousand kilometres of seismic surveys have been run over the past decades and a few petroleum exploration wells, all unsuccessful, were drilled. In the 1950s, titaniferous beach sands were mined. The heavy mineral concentrates average 70.2% ilmenite, 15.9% zircon, 3.3% rutile and 10.6% gangue minerals [22.1].

3.22.1. Geology

Stratigraphically, the Gambia is underlain by sedimentary rocks deposited in a regional basin related to the opening of the Atlantic Ocean. The oldest strata are Tertiary rocks of Oligocene, Miocene or Pliocene age known as the Continental Terminal Series and made up of sands, sandstones, silts, clays and kaolinitic claystones. These occur mostly in the west and centre of the country (Fig. 3.32).

Pleistocene ironstone crusts consisting of iron oxides, gravels, sands, silts and clay matrices predominate in the east of the country as well as Pleistocene alluvium, which is made up of undivided sands, silts and clays. Holocene deposits consist of marine and coastal sands, silts, clays and salts, sometimes with organic intercalations. The Holocene deposits are found along the Gambia River including its tributaries and areas close to the sea [22.2].

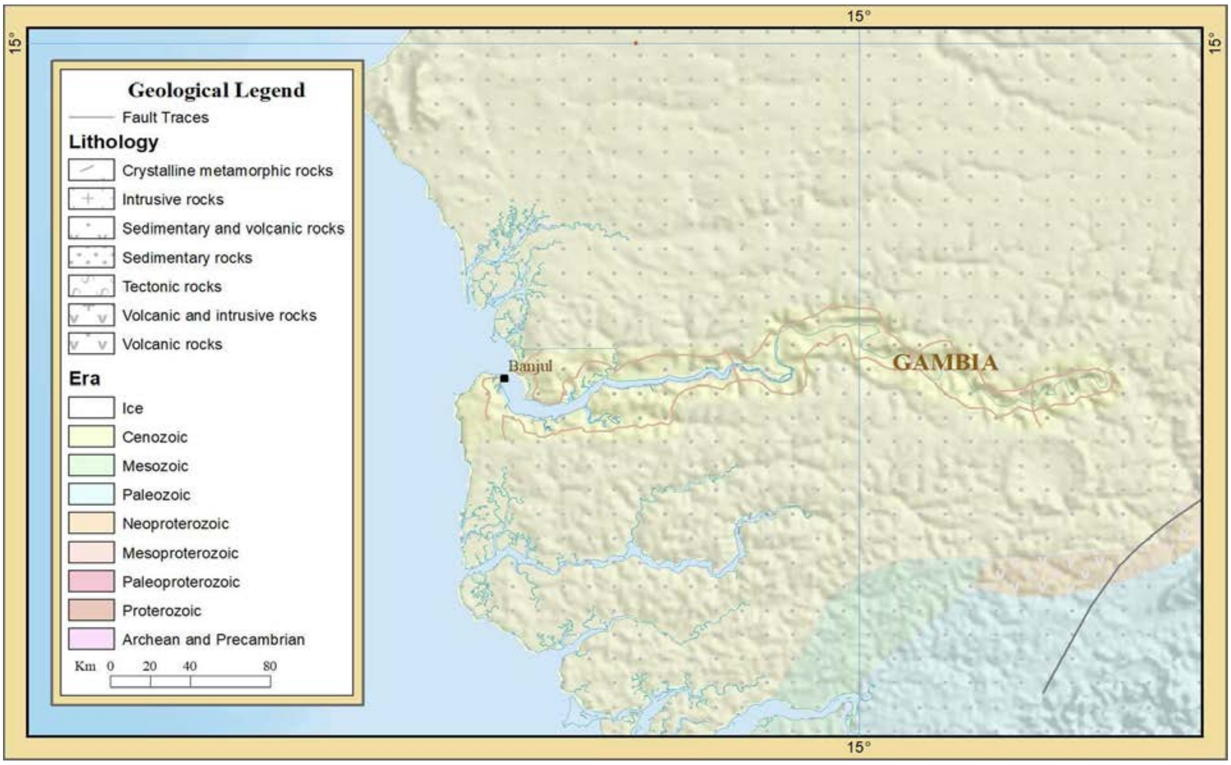


FIG. 3.32. Regional geological setting of Gambia. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.22.2. Uranium exploration

No exploration activities have been reported.

3.22.3. Uranium resources

In 1983, IUREP reported 0–1000 tU of speculative resources [22.3]. No uranium resources have been reported in Gambia. However, there have been some reports that Gambia has commercially exploitable deposits of uranium and other rare minerals [22.4].

The UDEPO database does not list any known deposits for Gambia.

3.22.4. Potential for new discoveries

The sandstones of the Continental Terminal Series or younger strata could host deposits if there is a source for uranium and if favourable reducing environments exist.

3.22.5. Comments

Gambia has no existing facilities and no plans to develop nuclear generating capacity and, consequently, has no reactor related uranium requirements.

References to Section 3.22

[22.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Gambia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed December 2008).

[22.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 114–115.

[22.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[22.4] REUTERS, Gambian leader says uranium reserves discovered (19 January 2008).

3.23. GHANA

Ghana is located on the Gulf of Guinea, a few degrees north of the equator. The coastline mostly comprises a low, sandy shore backed by plains and scrub and intersected by several rivers and streams. Formerly, there was a tropical rainforest belt, but most of this has been felled, leaving scattered remnants that are under protection in the south-west. North of this belt, the land is covered by low bush, savannah and grassy plains.

The climate is tropical. The eastern coastal belt is warm and comparatively dry; the south-west corner hot and humid; and the north hot and dry.

The domestic economy continues to revolve around subsistence agriculture, which accounts for 50% of GDP and employs 85% of the workforce. Gold, timber, cocoa, diamonds, bauxite and manganese exports are also major sources of revenue. An oil field that reportedly contains up to 3 billion barrels of light oil was discovered in 2007. Oil exploration is ongoing and the oil reserves continue to increase [23.1].

3.23.1. Geology

Geologically, Ghana can be subdivided into three different major units: Paleoproterozoic rocks predominate in the southwestern and northwestern part of the country, whereas gneisses and supracrustal rocks of mostly Neoproterozoic age occur in the southeast and east of the country (Fig. 3.33). Flat-lying shelf/marine sediments of very late Precambrian to Paleozoic age are found in the central and northeastern part of the country. Mostly Cenozoic sediments occur in a small strip along the coast [23.2].

The principal rocks of the Late Archaean–Lower Proterozoic West African Craton are the Birimian System, consisting of a strongly folded succession of sediments and volcanics. It consists largely of greywacke and greywacke pelites, now altered to phyllites. No calcareous rocks have been reported in the Birimian. The volcanic rocks, which are predominantly basic, appear in evenly spaced, NE–SW oriented greenstone belts which probably developed in parallel fault-bounded troughs. The Birimian is extensively intruded by syntectonic granites which have been dated at 2150–2000 Ma (Eburnean Orogeny).

Following the intrusion of the Eburnean granites, rocks of the Tarkwa Group were deposited in troughs coinciding with Birimian greenstone belts and were invaded by minor basic and acidic intrusions. The

Tarkwaian has been interpreted as representing a molasse related to the Eburnean orogenic cycle. The coincidence of Tarkwaian and Birimian structural trends and the character of repeated igneous activity associated with the structure, document their persistence during their geological history as well as their taphrogenic character. Auriferous quartz-pebble conglomerates occur in the Tarkwaian sequence.

The West African Craton was not significantly affected by the Katangan-Damaran Orogeny. Folding and metamorphism was restricted to the mobile zone, a part of which occurs in the eastern part of Ghana. A result of this tectonic differentiation is that the contemporaneous and stratigraphically equivalent formations appear as partially metamorphosed geosynclinal deposits (Buem and Togo Groups) in the east and also as a cratonic cover (Voltaian) in the north, which is undeformed and completely unaffected by metamorphism. The rocks of the Volta, Togo and Buem Series are of Upper Proterozoic–Early Palaeozoic age [23.2].

Small remnants of marine sedimentation (Devonian and Tertiary) occur along the coast.

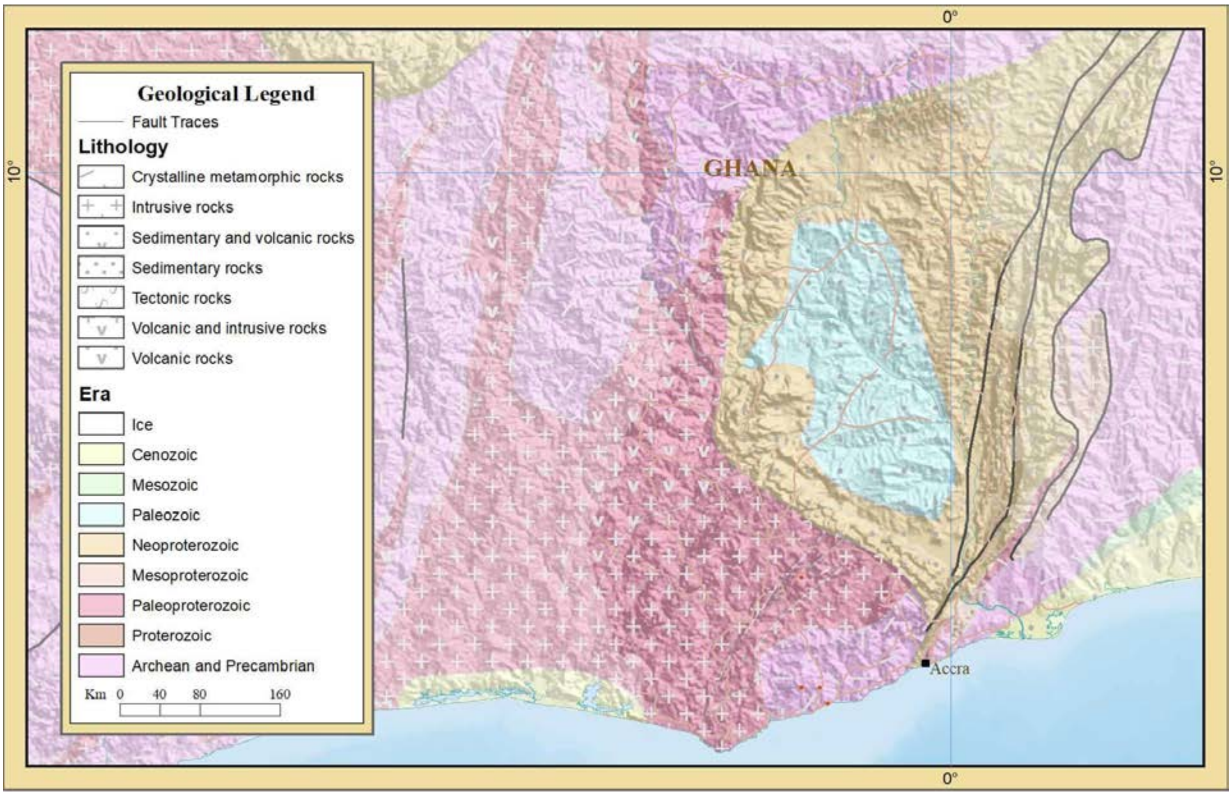


FIG. 3.33. Regional geological setting of Ghana. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.23.2. Uranium exploration

Uranium exploration started in Ghana in 1952 and was undertaken by geophysicists of the Geological Survey Department of Ghana. In 1960–1961, Hunting Surveys Ltd carried out an airborne radiometric survey over the Tarkwaian and the Togo/Dahomeyan/Buem contact. Areas covered in these two regions were 12 430 km² and 4662 km², respectively, a greater part of which was over the gold and sulphide mineralization zone in south-western Ghana.

In 1968, the Government of Ghana granted a prospecting licence to Uranerzbergbau GmbH to explore for uranium and thorium ores in parts of northern and southern Ghana. The areas covered were 59 373 km² in southern Ghana and 18 928 km² in northern Ghana. Another 11 679 km² covering an area considered to be favourable for uranium mineralization was investigated by airborne geophysical methods in northern Ghana. The programme was completed in 1970.

In 1975–1976, at the request of the Government, the IAEA sent an expert to Ghana to evaluate uranium mineralization at Abandzi. However, no mineralization of economic significance was found.

In November and December 1982, IUREP, after consultations with the Government, sent two uranium experts to the country. The experts reviewed all the available documents on past uranium exploration programmes in Ghana and surveyed some parts of the Voltaian Basin with scintillation counters. Their draft report stated that Ghana has no uranium deposits that could be included in the reasonably assured or estimated additional resource categories [23.3].
Past uranium exploration in Ghana revealed only radioactive, partly pitchblende-bearing pegmatites within the Birimian System related to granites of the Eburnean Orogeny, and radioactive refractory minerals within the Togo Series and within sandstones of the Voltaian System. The great number of anomalies in the Dahomeyan is of particular interest, as the northern continuation of the Dahomeyan in Togo is uraniferous. However, all the anomalies are due to thorium mineralization. None of the occurrences found to date are of economic interest.

Some radioactive pegmatites of the Saltpont have been characterized as follows:

(a) The mineralized pegmatites of Ejaa, Akrobadzi and Haseode contain small pods of uranophane and minerals of the euxenite-betafite group;
(b) The Abanzi pegmatite contains pitchblende, uranophane, euxenite (and possibly minerals of the columbite-tantalite series), pyrite and arsenopyrite in an area measuring 10 m × 15 m;
(c) The Amoanda pegmatite contains disseminated green secondary uranium minerals and beryl, tourmaline, garnet and apatite. The strongest mineralization is confined to an area measuring 5 m × 10 m [23.3].

3.23.3. Uranium resources

There are no known uranium resources in Ghana. In 1983, IUREP experts estimated Ghana's speculative resources at 15 000–40 000 tU.The majority of this potential was expected to be located in the Proterozoic Pan-African Mobile Belt and the Palaeozoic Obosum Beds of the Voltaian Basin, the remainder being associated with other geological environments [23.4].

The UDEPO database does not list any known deposits for Ghana.

3.23.4. Potential for new discoveries

The two areas of interest for further exploration are those underlain by the Dahomeyan and Voltaian Systems.

The Dahomeyan System consists of Middle Proterozoic formations, which have been involved in the Pan-African thermotectonic event. It consists primarily of paragneisses with some feldspathic mica schists. The Dahomeyan System is correlated with the Upper Proterozoic Pharusien of the Hoggar Massif to the north and with the rejuvenated mobile belts in Brazil.

The Voltaian System is about 1000 Ma old and about 1500 m thick. It overlies the Lower Proterozoic Birimian System and related granites and the Lower Proterozoic–Middle Proterozoic Tarkwaian System. The Voltaian Basin is correlated with the Taodeni Basin in Burkina Faso, Guinea and Mali.

References to Section 3.23

[23.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Ghana (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[23.2] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[23.3] VOGEL, W., GUELPA, J.P., IUREP Orientation Phase Mission Report: Ghana, IAEA, Vienna (1982).

[23.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.24. GUINEA[4]

Guinea is divided into four main regions: the Basse-Côte lowlands in the west, which run along the coast; the cooler, mountainous Fouta Djalon that runs roughly N–S through the middle of the country; the Sahelian Haute-Guinea to the north-east and the forested jungle regions in the south-east. Guinea's mountains are the source of the Niger, Gambia and Senegal Rivers, as well as the numerous rivers flowing to the sea on the west side of the range in Sierra Leone and Côte d'Ivoire. The highest point in Guinea is Mount Nimba (1752 m).

Guinea possesses over 25 billion tonnes of bauxite; possibly up to one-half of the world's reserves. In addition, Guinea's mineral wealth includes more than 4 billion tonnes of high grade iron ore, and significant diamond and gold deposits, and undetermined quantities of uranium. Guinea has considerable potential for growth in the agriculture and fishing sectors [24.1].

3.24.1. Geology

Major parts of Guinea are underlain by Precambrian rocks, which form the southern portion of the West African Craton (Fig. 3.34). The eastern two-thirds of the country are dominated by rocks of the Kenema-Man domain and the Paleoproterozoic Birimian System. Neoproterozoic and Paleozoic sediments with a basal tillite and overlying sandstones, marls and quartzites form wide parts of northern Guinea. Along the coast occurs a strip of Neogene marine and alluvial sediments.

Crystalline basement rocks in the western part of the Rokelide Orogen are considered to range from Neoarchean (2,700 Ma) to Paleoproterozoic (2,000 Ma) age [24.2]. These are composed of a variety of gneisses, schists, migmatites and mylonites metamorphosed to amphibolite and granulite facies.

To the east, the Ouankifondi Group occurs as a sequence of volcano-sedimentary rocks known as the Bania Group. It is composed of andesites, diabases, spilites and diorites, and exhibits pillow lavas at Mount Binia. In northern Guinea, the Walidiala Group is also of Neoproterozoic age and includes a basal tillite. The Kolente Group, exposed in southern Guinea and also characterized by a basal tillite, is believed to straddle the Neoproterozoic–Cambrian boundary. The Kolente Group is generally composed of greenish clastics and sands near the base of the sequence, the latter becoming finer grained towards the top.

Red sandstones and conglomerates of the Taban Group crop out in several small basins in Guinea immediately south of the Bove Basin. The Taban Group is considered to be of fluviatile origin and is interpreted as a post-orogenic molasse. This unit covers the greatest part of western Guinea.

The Bove Basin strata have been subdivided into three groups:

---

[4] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

(i) The Pita Group is the lowest member and is sub-divided into the Kindia Formation and Mount Gangan Formation. The Kindia Formation, which comprises mostly white, conglomeratic sandstones, probably represents an alluvial plain. The overlying Mount Gangan Formation consists of sandstones with isolated, angular quartz pebbles and argillites with isolated quartz clasts and has the appearance of a diamictite;

(ii) The lower part of the Telimele Group is composed mainly of argillites and siltstones, including green and pyritic sandstones. The upper part of the Telimele Group begins with a sequence of sandstones, which sometimes contain brachiopods. The upper part of this succession comprises black and grey shales rich in various marine fossils, indicating a likely Late Silurian–Early Devonian age;

(iii) The overlying Bafata Group is subdivided into three formations. The lower formation is composed of sandstones, intercalated with argillaceous and silty layers. The middle formation starts with thick yellow sandstone which is overlain by pink siltstones that include brachiopods of Givetian age. The upper formation is composed of argillites and siltstones. The depositional environment of the Bafata Group is shallow marine [24.2].

A narrow strip of marine and alluvial clastic sediments of Cenozoic age occurs along the coast [24.2].

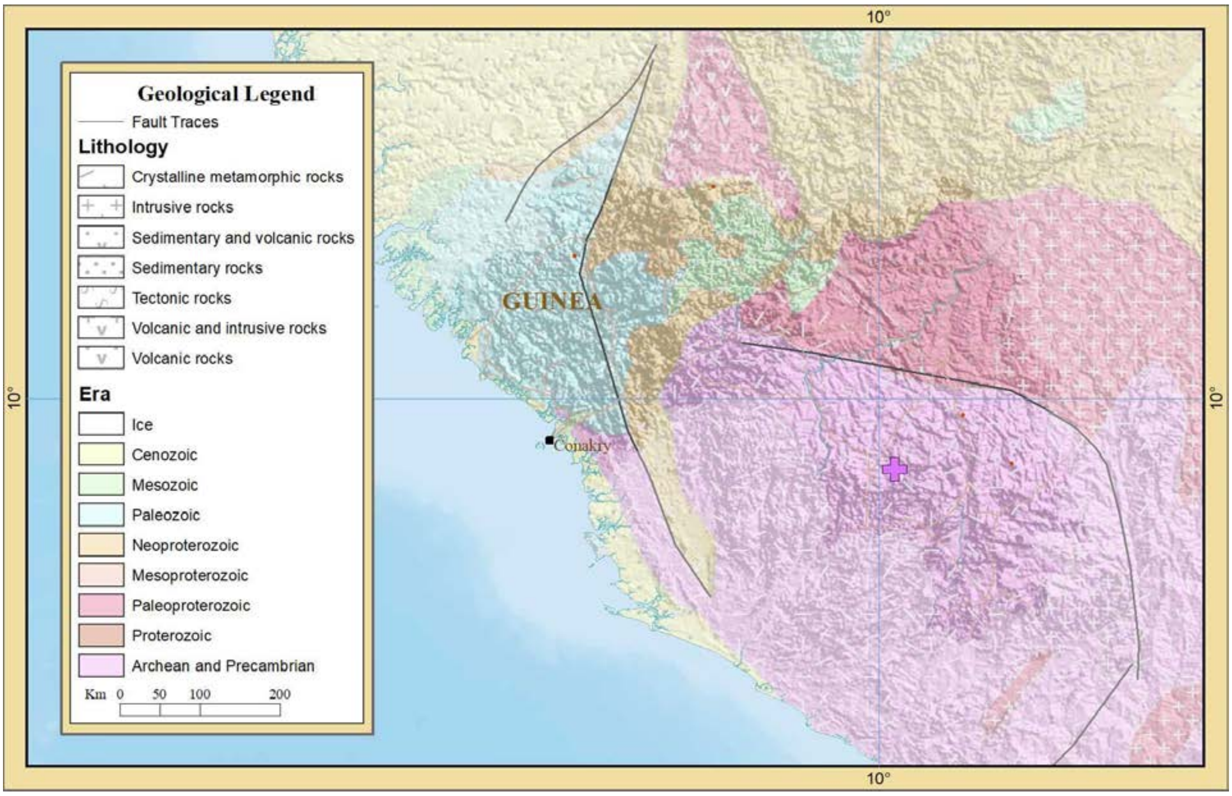


FIG. 3.34. Regional geological setting of Guinea showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.24.2. Uranium exploration

The first uranium exploration was carried out in 1958 by French geologists near Gaoual-Kundara. At this site, conglomerates of rhyolite shingle were explored. In 1961, a Hungarian prospecting group detected minor radioactive anomalies near Cape Zerga. In 1974–1975, Japanese geologists conducted extensive research in central and eastern Guinea. They discovered a large number of promising zones in the Tuge, Dinguiraye, Dabola, Kankan, Beyla and N'Zerekore regions. In 1977, a consortium of the Compagnie Générale des Matières Nucléaires (COGEMA), Japan's PKK and Italy's AGIP used the Japanese research results as background material in their assessment works on 18 anomalies in the north, near the Guinea–Mali border. In total, the consortium drilled 12 000 m.

Prior to 1980, no workable deposits were found. However, in 1980, an airborne geophysical investigation conducted by a West German company discovered two large radiometric anomalies: Firawa (Kisidougou region) and Damaro (Kerouane–Beyla region). The first ground studies identified uranium occurrences in large fractures and adjacent mylonites related to Archaean and Proterozoic metamorphic complexes. Total exploration expenditure exceeded US $15 000 000 by the time work ceased in 1984. Since 2008, Australia's Forte Energy NL has held eight uranium exploration permits in Guinea, covering 3563 km² over three separate concession areas: the Firawa, Bohoduo and Sesse projects [24.3, 24.4].

3.24.2.1. Firawa project

Exploration in the 1980s by Davy McKee identified a 5 km anomaly lying in an E–W direction at the Firawa prospect. Field visits by Forte personnel confirmed the presence of 25-year old deep pits and trenches on the anomaly peaks.

Forte completed an initial drilling programme in May 2007. This programme comprised 29 reverse circulation drill holes totalling 1809 m and targeting a prospective 2 km section within Forte's licence area.

Follow-up diamond drilling commenced in December 2008, targeting a Joint Ore Reserves Committee (JORC) compliant resource estimate for Firawa. The initial 4000 m programme was increased to 5859 m on the basis of encouraging initial results. Firawa is a metamorphite-type deposit.

Using a cut-off grade of 85 ppm U, the initial JORC compliant inferred resource estimate is 17.7 million t grading 250 ppm U for 4460 tU. Using a cut-off grade of 254 ppm U, the resource estimate is 7.7 million t grading 336 ppm U for a total of 2580 tU.

Further drilling was recommended to test for extensions to the deposit, which remains open along strike and down dip. Forte reported encouraging metallurgical test results from Firawa samples, indicating the potential for economic recovery by leaching. Further pre-feasibility and optimization studies were reported to be under way as of 1 February 2010. In July 2012 Forte Energy released a new JORC resource for the Firawa deposit : 7890 t U at an average grade of 283 ppm. Since, the project is dormant.

3.24.2.2. Bohoduo project

Ground work targeted a 700 m long, irregular uranium anomaly at the Bohoduo prospect. Work included diamond drilling and extensive surface investigation which confirmed the presence of uranium mineralization. Airborne geophysical data indicate a 12 km long extension of the anomaly to the east. An initial drilling programme was carried out in May 2008.

3.24.2.3 Sesse project

Historical work at the Sesse prospect was regional in nature and comprised grid geochemistry with radon gas analysis, ground magnetics and electromagnetics.

3.24.3. Uranium resources

3.24.3.1. Identified resources

Guinea has not reported any known uranium resources to the Red Book.

The UDEPO database lists the most significant deposit for Guinea as Firawa.

3.24.3.2. Undiscovered resources

In 1983, IUREP reported 1000–10 000 tU of speculative resources hosted in sandstones and disseminated magmatic geological environments [24.5].

3.24.4. Unconventional resources

Guinea has not reported any unconventional resources.

3.24.5. Comments

No uranium has been produced in Guinea. Guinea has no nuclear power generation capacity.

References to Section 3.24

[24.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Guinea, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed December 2008).
[24.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 122–125.
[24.3] Guinea: Economic analysis, www.guinea.aha.ru/mineral_resources_uranium.htm (accessed December 2008).
[24.4] FORTE ENERGY NL, (accessed December 2008).
[24.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.25. GUINEA BISSAU[5]

Guinea Bissau is a small tropical country in north-western Africa. Topographically, it comprises a low plain, with the highest elevation being 300 m. The interior is savannah and the coastline is swampy plain. Its monsoon-like rainy season alternates with periods of hot, dry harmattan winds blowing from the Sahara. The economy depends mainly on agriculture and fishing. Cashew nuts and groundnuts are its major exports [25.1].

3.25.1. Geology

Geologically, Guinea Bissau can be divided into three tectono-stratigraphic units. Neoproterozoic rocks occur in the extreme north-east, in the eastern part strata of Neoproterozoic–Palaeozoic age occur, and in the west, Cenozoic–Recent sediments (Fig. 3.34).

The oldest rocks of Guinea Bissau are those of the Neoproterozoic (680 Ma) Koulountou Group in the extreme northeast of the country.

The rocks of the Youkounkoun Group are generally unmetamorphosed but slightly folded, originating from sediments of a post-orogenic molasse.

The sediments of the Bove Basin cover the greatest part of eastern central Guinea Bissau. The basin is a gentle synclinal feature filled with Ordovician to Devonian strata [25.2]. Three units are identified:

(i) The Pita Group, of Ordovician age, is 250–600 m thick and consists of conglomeratic sandstones, probably representing deposition in an alluvial plain;
(ii) The Telimele Group is 150–330 m thick and ranges from Llandovery to Upper Devonian in age;

---

[5] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

(iii) The Bafata Group, also of Devonian age, has a thickness of 150–430 m and is considered to have been deposited in a marine shelf environment.

In western Guinea Bissau, these Palaeozoic rocks are unconformably overlain by Cenozoic and younger sedimentary strata, which are mainly of marine origin. Mafic dykes and sills transect all of the above strata [25.2].

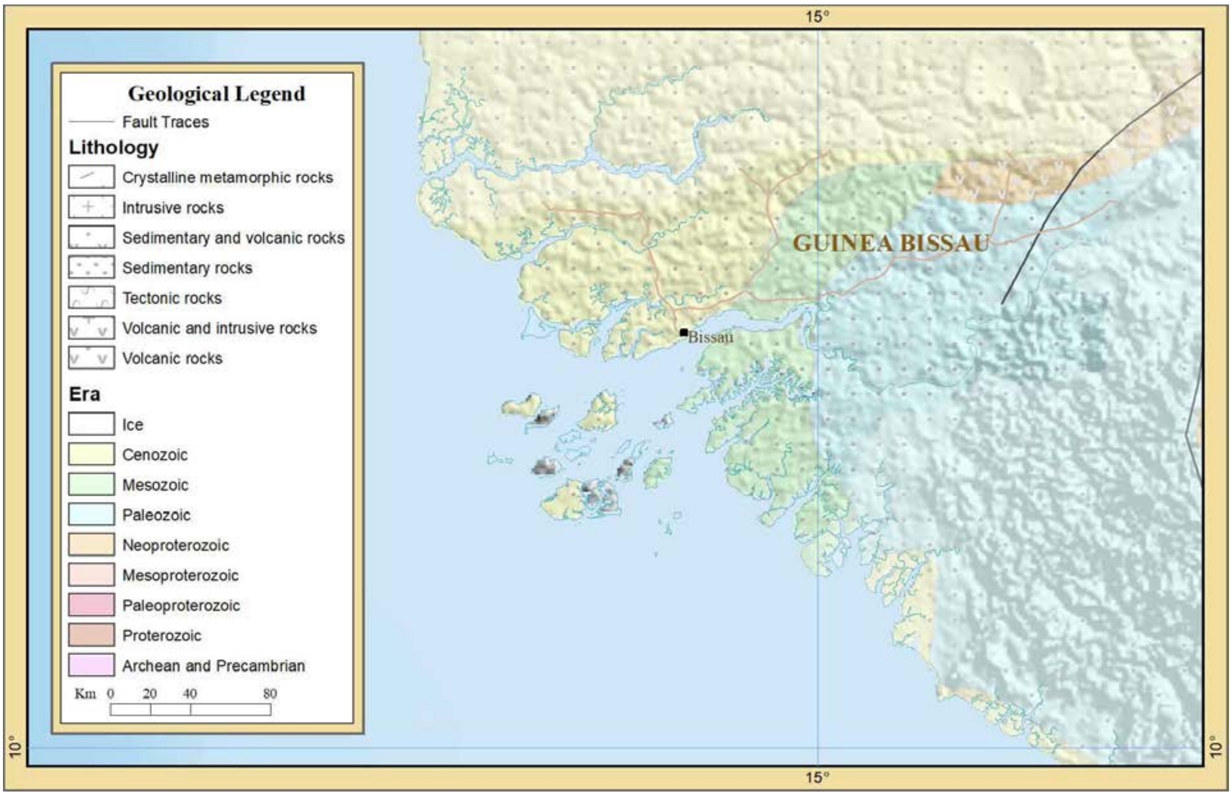


FIG. 3.34. Regional geological setting of Guinea Bissau. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.25.2. Uranium exploration

No exploration activities have been reported.

3.25.3. Uranium resources

No uranium resources have been recorded in Guinea Bissau. In 1983, IUREP estimated speculative resources in the range of 0–1000 tU [25.3].

3.25.4. Potential for new discoveries

Guinea Bissau does not possess significant mineral resources, although exploration has been undertaken. However, the potential for discovery of uranium resources seems to be very limited.

References to Section 3.25

[25.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Guinea Bissau, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed December 2008).

[25.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 126–127.

[25.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.26. KENYA

The geography of Kenya is diverse; it has a coastline bordering the Indian Ocean and a varied topography that includes broad plains and numerous hills and mountains. The central and western parts of Kenya are dominated by the Great Rift Valley. From the coast, the low plains rise to form the central Kenya Highlands, which are bisected by the Great Rift Valley, a fertile plateau in the west. The Kenya Highlands comprise one of the most agriculturally productive regions in Africa and are also the site of the highest elevation in Kenya (and the second highest in Africa): Mount Kenya (5199 m).

The climate varies from tropical along the coast to arid in the interior. It is hot and humid along the coast, temperate inland and very dry in the north and north-east parts of the country. There is, however, considerable rain between March and May. The temperature remains high throughout these months. The long rainy season occurs in April–June. The short rainy season occurs in October–December. Agriculture continues to dominate Kenya's economy. The principal cash crops are tea, horticultural produce and coffee. Horticultural produce and tea are the main growth sectors and the two most valuable export commodities.

Kenya has no significant mineral resources. The mining and quarrying sector makes a negligible contribution to the economy, accounting for less than 1% of GDP. Apart from soda ash, the chief minerals produced are limestone, gold, salt and fluorspar [26.1].

3.26.1. Geology

The geology of Kenya is characterized by Archaean granite/greenstone terrain in western Kenya along Lake Victoria, the Neoproterozoic Pan-African Mozambique Belt, which underlies the central part of the country, and the Mesozoic–Recent sediments which underlie the eastern coastal areas (Fig. 3.35).

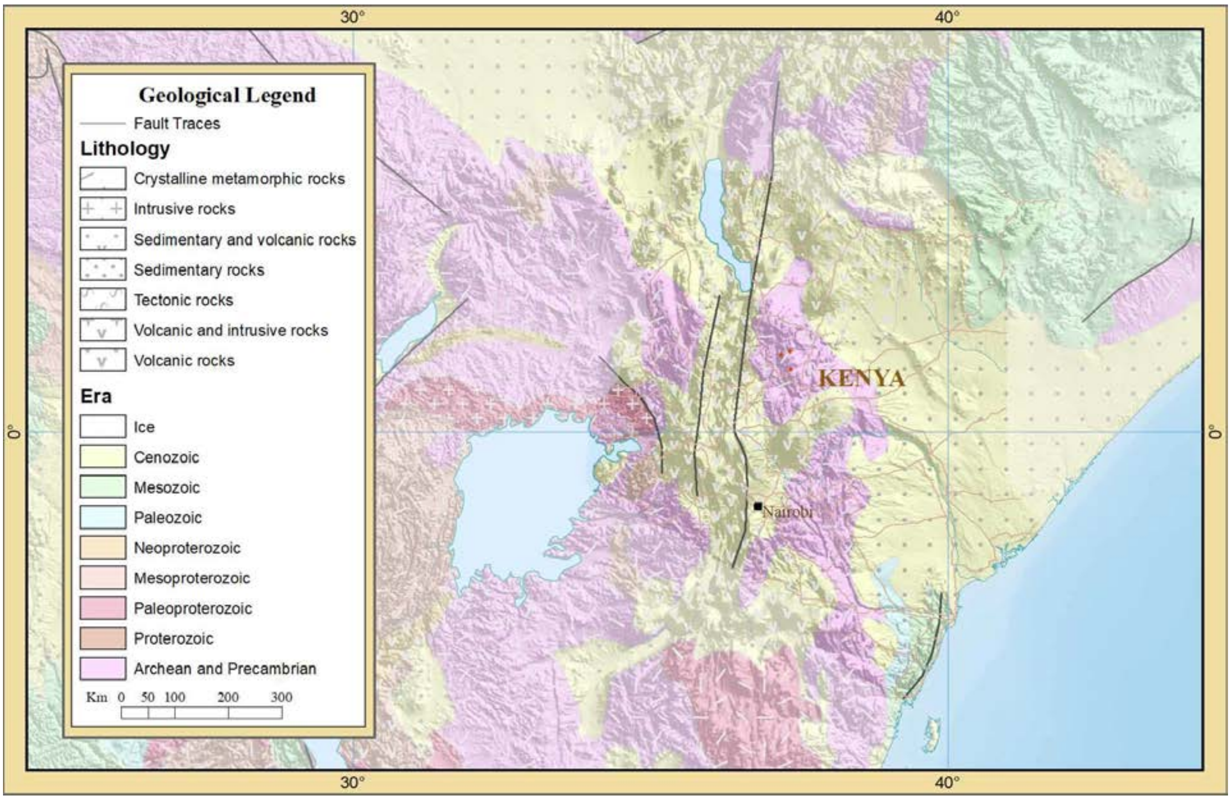


FIG. 3.35. Regional geological setting of Kenya. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Eastern Rift Valley section crosses western Kenya from north to south and the volcanics associated with rift formation mask the generally N–S striking Neoproterozoic Mozambique Belt. Rift valley volcanogenic sediments and lacustrine and alluvial sediments cover extensive tracts of the Eastern Rift.

The geology of Kenya can be grouped into five major geological successions: (i) Archaean (Nyanzian (or Lake Victorian) and Kavirondian), (ii) Proterozoic (Mozambique Belt and Bukoban), (iii) Palaeozoic–Mesozoic sediments, (iv) Tertiary–Quaternary volcanics, and (v) Tertiary–Quaternary sediments.

The Nyanzian and Kavirondian Systems, which comprise the Nyanza Craton portion of the African Plate, are the oldest rocks in the country, with ages exceeding 2500 Ma. The Nyanzian System mainly comprises lavas and pyroclastics, with minor sediments and banded ironstones. The Kavirondian strata, which unconformably overlie the Nyanzian, include sandstones, greywackes and conglomerates. The Nyanzian and Kavirondian Systems host numerous granitic intrusions.

The Mozambique Belt is a structural unit within which a wide variety of metasedimentary and meta-igneous rocks is to be found. It exhibits a broad degree of concordance in terms of both structural style and metamorphic history. In most of these rocks, the degree of deformation is intense and is associated with high grade metamorphism [26.2].

Basic igneous complexes are to be found within the Mozambique Belt and these range in size from bosses to small dykes and occur on both the eastern and western sides of the rift valley. Some of the older basic intrusions have been subjected to both deformation and metamorphism to produce ortho-amphibolites and charnockitic gneisses. Both basic and granitic intrusions are recorded in the Mozambique Belt, whose characteristic feature is its structural trend, which is more or less aligned N–S along its entire length.

Palaeozoic and Mesozoic strata are found near the coast and in the north-eastern part of the country. The oldest of these rocks are Permo-Carboniferous and comprise mostly sandstones and shales of the Duruma Series, which is equivalent to the Karoo System in southern Africa. These strata extend for about 100 km from Taru to Mazeras, west of Mombasa. Mesozoic rocks occur in two separate areas, in the north-east and along the coastal belt. The stratigraphy and fossils in the two areas are very distinct and it is likely that the sedimentary basins in the two areas were connected.

Volcanic rocks cover the central parts of the country from south to north, occurring on the floor of the rift valley and on peneplains to the west and east of the rift. The oldest of the volcanics are Lower Miocene and comprise the eroded lavas and pyroclastic flows of South Nyanza. In the Late Miocene, the Kapiti and Yatta phonolites were extruded and these form extensive flows. Further eruptions, accompanied by faulting, persisted and gave rise to the rift valley and to the volcanic strata comprising Mounts Kenya, Elgon and Kilimanjaro.

Quaternary volcanism occurred mostly within the rift valley and produced the craters and cinder cones that are found on the valley floor (e.g., Longonot, Menengai and Suswa).

There are many deposits of sediments in various parts of Kenya and these ordinarily occur at the base of volcanic successions, intercalated with volcanic rocks, or occurring in tectonic troughs.
Successive episodes of faulting on the floor of the rift valley and the numerous phases of volcanism have generated many short-lived basins with internal drainage in which both lacustrine and fluviatile sediments accumulated.

The most important sediments of the Middle Pleistocene are the Olorgesaillie lake beds, a lacustrine series of strata. These are also comparable to the Kariandusi sediments near Gilgil, and to the Kanjera Beds in the Kavirondo Gulf of Lake Victoria [26.3].

3.26.2. Uranium exploration

Kenya has never reported to the Red Book and no uranium exploration activities have been recorded. Exploration work has been conducted by several Australian companies.

In 2007, Mackay and Schnellmann, a geological consultancy, conducted research and field investigations for Oropa Exploration Ltd with the aim of selecting potential areas for uranium exploration. A number of prospective areas were identified but sovereign risk issues emerged which led to a downgrading of investment interest [26.4].

There are isolated younger sedimentary basins with sediments derived from weathered Mozambique Belt granites and gneisses. These are deposited in tectonically controlled basins. Some of the sediments indicate lacustrine and fluviatile depositional environments. Thick sedimentary deposits in structurally controlled basins have attracted some interest as regards uranium exploration, one example being the Mui Basin in the Kitui district.

The pegmatite-rich hills around Wamba, Barasolai and Maralal, which record radioactive anomalies, are considered to have potential for uranium. These areas lie within the Mozambique Belt's metamorphic formations of north central Kenya.

No records of any exploration completed to date are available. The Government is, however, initiating exploration programmes for uranium. The target areas will initially focus on those prospective areas identified by earlier exploration programmes.

Base Resources has commenced extraction of rutile, zircon and ilmenite from its Kwale mineral sands project [26.5].

3.26.3. Uranium resources

No uranium resources, identified or speculative, have been reported by Kenya. In 1983, IUREP estimated Kenya's speculative resources to be 1000–10 000 tU [26.6]. It is estimated that potential areas worthy of exploration are likely to exceed 10 000 km^2.

No deposits are reported in UDEPO [26.7].

The UDEPO database does not list any known deposits for Kenya.

3.26.4. Potential for new discoveries

Potential for new discoveries in Kenya appear to be limited to continental sandstones, equivalent to the Karoo System in southern Africa, and to volcanic areas.

3.26.5. National policies relating to uranium

All minerals in their natural state (e.g., unextracted) are government property, according to the 2011 Mining and Minerals Bill. As uranium is a fuel for power plants, its exploration and development will be conducted under the mandate of the Cabinet Secretary in charge of Energy. The Ministry of Energy has a mandate to develop all energy minerals in the country.

The Department of Mines and Geology, under the Ministry of Environment and Natural Resources, controls the exploration and exploitation of such minerals [26.8].

3.26.6. Comments

There has been no uranium production in Kenya. Kenya has no nuclear power generation.

References to Section 3.26

[26.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Kenya (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[26.2] KENYAGREECE, http://www.kenyagreece.com (accessed October 2008)

[26.3] KENYA MINES AND GEOLOGY DEPARTMENT, The Geology of Kenya (2008), http://www.minesgeology.go.ke

[26.4] MACKAY & SCHNELLMANN, Non-ferrous metals (2008), http://www.mackayschnellmann.com.au/non-ferrous-metals

[26.5] BASE RESOURCES, Kwale Mineral Sands Operations (2012), http://www.baseresources.com.au/projects/projects-overview/

[26.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[26.7] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO) with Uranium Deposit Classification: 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[26.8] KENYA CHAMBER OF MINES, The Mining and Mineral Bills 2011 (2012), http://www.kenyachambermines.com

3.27. LESOTHO

Lesotho is situated in the southern part of the African continent directly west of Durban. It is a landlocked country that is surrounded by South Africa. It has borders with the KwaZulu-Natal Province in the east, with the Eastern Cape Province to the south and the Free State to the north and west.

The country comprises various distinct and diverse landscape regions all at high elevation. Lesotho boasts one geographical anomaly; it is the only independent State that lies entirely above 1400 m in elevation. In the country, there are high plateaux, mountains and low hills. The highest elevation is Thabana Ntlenyana (3482 m). The crest of the Drackensberg Range forms the border along the south-eastern edge of the country. The lowest point of 1400 m is found at the confluence of the Orange and the Makhaleng Rivers to the south-west.

The climate in the lowlands is generally characterized by cold dry winters and warm summers with occasional rain. In the highland areas, the winters are much colder and longer, while the summers are cooler. Annual rainfall varies in the range 500–1200 mm, with an average annual rainfall of about 750 mm.

Lesotho’s economy is based on exports of water and electricity to South Africa, as well as manufacturing, diamonds, agriculture and livestock, and to some extent, money repatriated by workers employed in South Africa. Lesotho also exports diamonds, semi-precious stones, wool, textiles and footwear. The western lowlands form the main agricultural zone [27.1].

3.27.1. Geology

Lesotho is almost exclusively underlain by rocks of the Karoo Supergroup (Fig. 3.36), comprising sediments, which cover a quarter of the surface area in the northwest and southwest, and volcanics, which dominate in the central and eastern part of the country [27.2].

The economic mineral potential of Lesotho is restricted primarily to the Upper Karoo Supergroup. These strata have potential for diamonds, uranium, semi-precious stones, mercury, coal and industrial minerals. Diamonds are found in the kimberlites and in alluvial gravels [27.2].

Currently, three diamond mines are in operation. Lesotho’s semi-precious stones include agate, amethyst, olivine, zircon and chrome diopside, and these are currently exploited on a small scale [27.2].

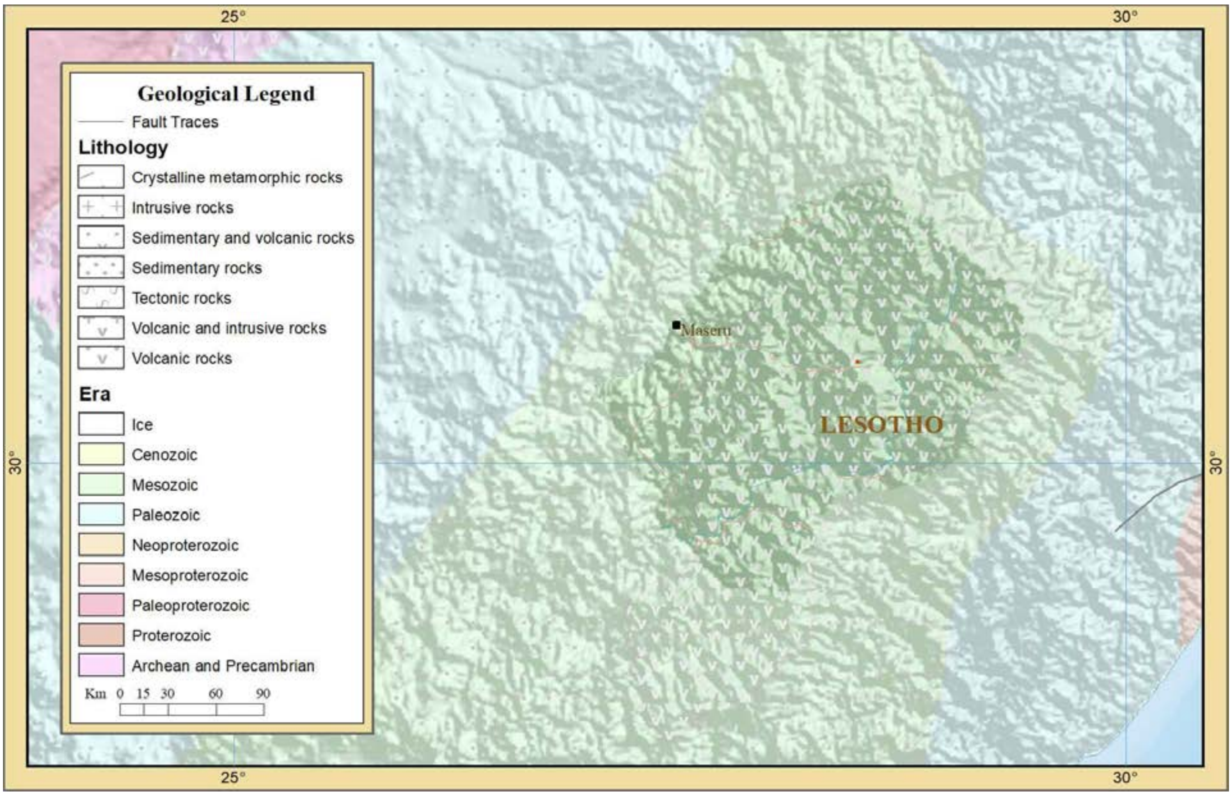


FIG. 3.36. Regional geological setting and uranium mineralisation of Lesotho. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.27.2. Uranium exploration

In 1984–1986, uranium exploration was carried out by the Government in an area covered by strata of the Beaufort and Stormberg Groups of the Karoo Supergroup. On the basis of the results obtained from an airborne spectrometer survey, an area of approximately 6 000 km² was selected for further appraisal. Exploration methods used were ground radiometric, hydrogeochemical sampling and limited drilling. Areas surveyed in 1985 and 1986 measured approximately 625 km^2 and 600 km², respectively. A total of seven areas were identified as targets for further exploration. Tables 3.15 and 3.16 summarize the exploration effort for the period 1984–1986. A total of US $21 500 was spent on uranium exploration in 1984–1986 (Table 3.15). In 1984–1986, seven holes were drilled, totalling 320 m (Table 3.16).

TABLE 3.15. URANIUM EXPLORATION EXPENDITURE (US$) [27.3]

1984	1985	1986
10 000	6500	5000

TABLE 3.16. DRILLING EFFORT [27.3]

1984	1985	1986
3 holes	2 holes	2 holes
150 m	100 m	70 m

3.27.3. Uranium resources

No uranium resources, identified or undiscovered, have been reported by Lesotho.

The UDEPO database does not list any known deposits for Lesotho.

3.27.4. Potential for new discoveries

Throughout southern Africa, rocks of the Karoo Supergroup host low grade, low to medium tonnage, sporadic deposits of uranium. This is also true of Lesotho. However, despite favourable rock formations, limited channel development within the Molteno, Elliot and Clarens Formations mitigates against the genesis of large deposits.

3.27.5. Comments

There has been no uranium production in Lesotho.

References to Section 3.27

[27.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Lesotho, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed November 2008).

[27.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 140–143.

[27.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

3.28. LIBERIA

Liberia is situated in West Africa and borders the Atlantic Ocean. The topography is characterized principally by flat to rolling coastal plains, which rise to a rolling plateau and mountains in the north-east. The coastline is characterized by lagoons, mangrove swamps and river deposited sandbars. The inland grassy plateau supports limited agriculture. The equatorial climate is hot and humid, with wet humid summers and heavy rainfall falling in May–October and dry winters with hot days and cool nights during the months of November–March. Dry, dust laden harmattan winds blow inland from the Sahara. At 1380 m, Mount Wuteve is Liberia's highest elevation and lies in the north-western part of the West Africa Mountains and the Guinea Highlands.

Historically, the Liberian economy depended heavily on the export of iron ore and rubber and through direct foreign investment, as well as the export of other natural resources, such as timber, diamonds and hydropower. While official export figures for commodities declined in the 1990s, during which time many investors left. Liberia's economy during this period featured the exploitation of the region's diamonds. It is also believed that diamonds were smuggled into Liberia from neighbouring States. Liberia has one of the world's largest national register of ships, owing to its status as a flag of convenience [28.1].

3.28.1. Geology

The geology of Liberia is dominated by Precambrian rock formations of the West African Craton (Fig. 3.37). Metamorphosed rocks of the Liberian Province underlie the western two thirds of Liberia, and metamorphites and granites of the Palaeoproterozoic Eburnean Province dominate the eastern part. The iron ore deposits of the Bong Range occur in the Liberian Province. A narrow belt of supracrustal rocks affected by the Neoproterozoic–Lower Cambrian Pan-African Orogeny strikes parallel to the coastline. Unmetamorphosed Palaeozoic–Recent sediments occur along the coast [28.2].

FIG. 3.37. Regional geological setting and uranium mineralisation of Liberia. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.28.2. Uranium exploration

Under the Geological Exploration and Resource Appraisal Programme, jointly undertaken by the Governments of Liberia and the United States of America during 1965–1972, a total count airborne gamma radiation survey was flown over the country in 1967–1968. The survey consisted of approximately 140 000 line km of traverse. It did not indicate the presence of uranium deposits. However, certain high anomalies were identified by a United Nations Mineral Survey. These radioactive anomalies were further investigated on the ground by means of radiometric surveys but were found to be broad, low intensity zones. Zlenzu was investigated in more detail by drilling and trenching. The results of this investigation indicated that the anomalies are due to small amounts of radioactive accessory minerals that have accumulated near the surface as a result of the weathering of felsic rocks.

From 1977 until September 1982, Coastal Liberian Uranium Enterprises, a subsidiary of Coastal Oil and Gas Corporation, undertook uranium exploration in Liberia. A concession area of about 51 200 km^2 was evaluated for uranium potential using airborne radiometric data; radar imagery; reconnaissance and detailed ground radiometrics; geological reconnaissance and mapping; geochemical studies of rock, soil and stream sediment samples; as well as limited drilling. Coastal Liberian Uranium Enterprises was successful in locating a number of uranium prospects within the Archaean Craton of central Liberia (Grand Bassa district). However, no deposit of economic value was discovered.

During 1981–1982, emphasis was placed on reconnaissance and evaluation of airborne anomalies. Detailed follow-up work and further evaluation of core drilling was also undertaken. Airborne evaluation was carried out in two phases. Phase one consisted of the use of geological, geochemical and geophysical surveys conducted along roads, trails and streams. Phase two consisted of the detailed geological, geochemical and geophysical investigation of those anomalies deemed to have significant potential. No new high priority uranium targets were identified. The methods most commonly used included conventional scintillometer surveys and traverses and regional geochemical stream sediment sampling.

Several new, low priority anomalies were detected by field parties, although these were small, isolated, subeconomic occurrences. Stream sediment and heavy mineral concentrate sampling revealed several new anomalous indications of cobalt, copper, gold, lead, nickel and uranium [28.3].

3.28.3. Uranium resources

There are no known uranium resources in Liberia. Speculative resources were estimated by IUREP in 1983 to be in the range of 1000–10 000 tU [28.4]. UDEPO does not list any known deposits for Liberia.

3.28.4. Potential for new discoveries

An airborne radiometric survey over Liberia showed a concentration of anomalies over Precambrian, mainly Archaean rocks. These could be investigated further as some potential may exist for quartz-pebble conglomerate deposits [28.3].

3.28.5. Comments

Uranium has never been produced in Liberia.

References to Section 3.28

[28.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Liberia (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[28.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 144–146.

[28.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[28.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.29. LIBYA

Approximately 90% of Libya is desert and the Libyan Desert, which covers an extensive area in the east of the country, is one of the world's most arid areas, where years may pass without rain. Even in the highlands rainfall is sporadic, occurring only once every 5–10 years. The temperature in the Libyan Desert is similarly extreme. In the west, a number of widely scattered oases, the Kufra group, occur in shallow depressions, and these include Tazerbo, Rebianae and Kufra. Apart from scarps, the overall flatness of the terrain is only relieved by a series of plateaux and massifs rising from the centre of the Libyan Desert, near the borders with Egypt and the Sudan. To the south, rise the granite massifs of Arkenu, Uweinat and Kissu, which are similar to those in the Aïr Mountains and flanked by sandstone plateaux. The area to the north of Uweinat hosts a series of eroded volcanic features. The Libyan economy is heavily dependent on reenues generated by the oil sector. The non-oil manufacturing and construction sectors, which account for about 20% of GDP, have expanded from processing mostly agricultural products to include the production of petrochemicals, iron, steel and aluminium. Climatic conditions and poor soils severely limit agricultural output and as a result Libya imports about 75% of its food [29.1].

3.29.1. Geology

Libya belongs entirely to the Saharan domain forming the northern part of the African Shield. Apart from a few Precambrian outcrops the country is mostly covered by Paleozoic, Mesozoic and Cenozoic sediments and Neogene volcanics [29.2]. Precambrian rocks occur in the south and south-east of the country and in northern Fezzan (Fig. 3.38). Libya hosts thick sequences of moderately deformed Palaeozoic strata and, except in the north-west and the north-east, Mesozoic sediments are comparatively thin. Tertiary rocks occupy the greater part of the Sirte embayment and northern Cyrenaica. Tertiary and

Quaternary extrusive and intrusive rocks occupy large areas in the central part of the country and smaller areas in northern Fezzan and northern Tripolitania.

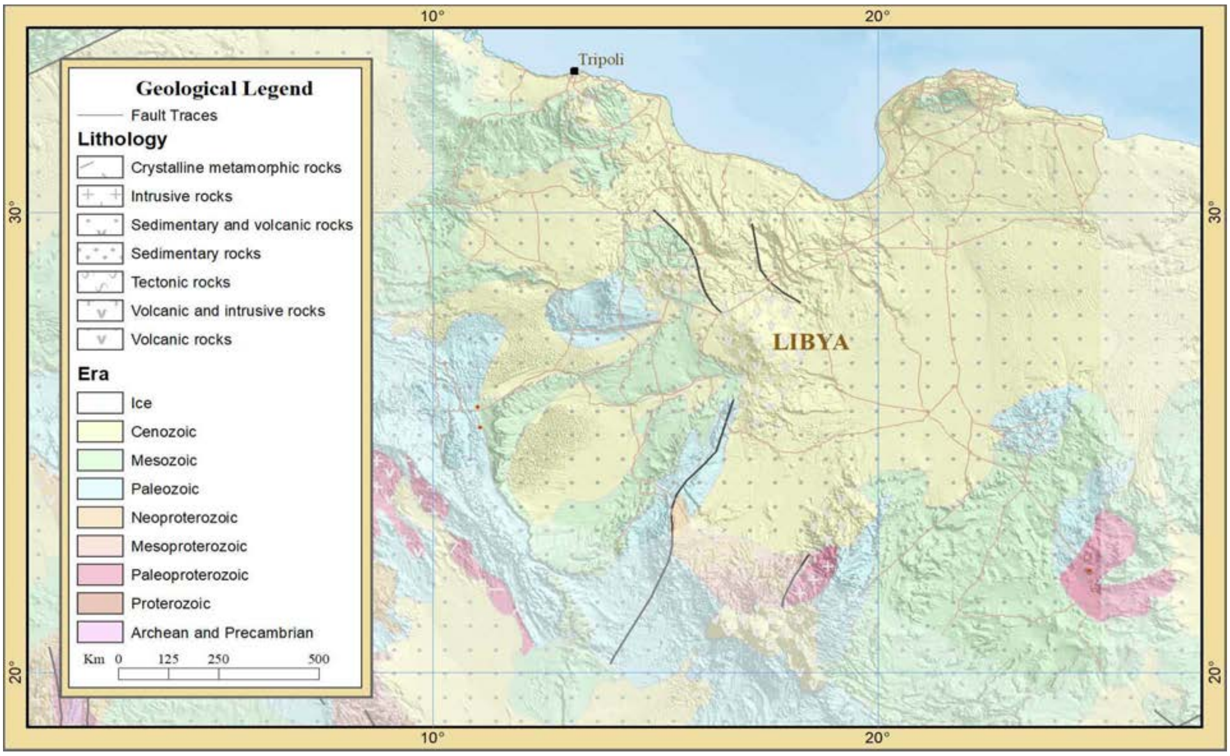


FIG. 3.38. Regional geological setting and uranium mineralisation of Libya. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Continental environments prevailed in southern Libya from the Late Palaeozoic until the Middle Cretaceous, during which several thousand metres of marine sediments were deposited in northern Libya around Sirte. The coastal plains are covered by marine and continental beds of Quaternary age, and the greater part of the Libyan Desert is covered by extensive gravel plains and areas of sand dunes.

There are two extensive basins in southern Libya which appear to have the most favourable characteristics for hosting uranium: the Murzuk and Kufra Basins.

3.29.1.2. Murzuk Basin

The Murzuk Basin is located in south-western Libya and extends into Algeria and Niger. It is bounded on the east by the Tibesti–Haruj Uplift and to the south by the Precambrian Hoggar and Tibesti Massifs. Widespread continental beds are interspersed with strata deposited during several marine incursions. On the flanks of the basin, rocks of all the geological systems from the Cambrian to the Lower Cretaceous are present, assuming that the post-Tassilian–Nubian sequence represents all the systems from the Permian to the Lower Cretaceous. It is probable that most of these units are present throughout much of the basin. To the east, the Dor el Gussa Basin is separated from the main part of the Murzuk Basin by the largely concealed Jabal ben Ghenemeh Uplift. The epeirogenic movements of this subsidiary basin and uplift have caused pronounced irregularities in the thicknesses of the strata from the Cambrian to the Devonian. Regression of the sea, starting in the early Carboniferous, gave rise to widespread continental environments by the end of that period. The resulting continental post-Tassilian–Nubian sequence (Permian–Lower Cretaceous) forms a cuesta about 1450 km long that almost completely surrounds the central area. The Caledonian and Hercynian Orogenies affected considerable areas of this basin.

3.29.1.3. Kufra Basin

The Kufra Basin in south-eastern Libya and adjoining parts of Chad, the Sudan and Egypt is the least known of the Libyan basins. A succession of cuestas on the uplifted northern, western and southern flanks exposes strata ranging in age from Cambrian to Carboniferous. On the north-west side is a 160 km break in the flanking cuestas. The large central part of the basin is occupied by the Nubian sandstone. A few marine sediments have been found in the exposed flanks of this basin. The subsurface section in the central part, together with the geological development of the basin as a whole, remain largely unknown and the structure and stratigraphy are probably complex [29.2, 29.3].

3.29.2. Uranium exploration

The first exploration programme for radioactive minerals in Libya was undertaken in 1969 by the Geological and Mining Department of the Industrial Research Centre of Libya (Table 3.17). A preliminary assessment of the uranium potential of the country was based on the limited geological information available and taking into account the occurrences of uranium mineralization in neighbouring countries. A general plan for exploration, based mainly on the use of airborne radiometric surveys, was decided upon. The plan involved participation of international exploration companies as well as geologists from the Geological and Mining Department and the Atomic Energy Commission. Areas totalling about 350 000 km² were considered geologically favourable for hosting uranium occurrences. About 150 000 km² were surveyed by airborne radiometry, which indicated the presence of numerous radioactive anomalies.

Preliminary field checks of the airborne anomalies were carried out over an area of 100 000 km². The main result of the exploration effort to date is the discovery of small occurrences of uranium in the Carboniferous and Triassic rocks along the western flank of the Murzuk Basin in south-western Libya. These uranium occurrences are hosted by Carboniferous, Permian and Triassic continental sandstones with conglomerate, siltstone and claystone intercalations.

The main uranium mineral present is carnotite, which is locally associated with tyuyamunite. In their form, the deposits strongly resemble roll front uranium deposits. Economic evaluation of these deposits is under way but no information with respect to grades or resources is available. No details of exploration expenditure are available.

In February 2007, Libya's National Bureau for Research and Development was reported to have signed a Memorandum of Understanding with AREVA, under which the latter would help to assess Libya's uranium resource potential.

TABLE 3.17. URANIUM EXPLORATION DATA [29.4]

Year	Aerial radiometric surveys (km²)	Other surveys (km²)
Pre-1977	60 500	60 500
1977	0	0
1978	15 000	15 000
1979	35 000	1 000
1980	0	0
1981	7 500	7 500
1982	30 000	3 000
Total	148 000	87 000

3.29.3. Uranium resources

There are no known uranium resources in Libya. In 1983, IUREP reported a range of 50 000–100 000 tU of speculative resources, mainly hosted in sandstone environments [29.5].

The UDEPO database does not list any known deposits for Libya.

3.29.4. Potential for new discoveries

The country as a whole forms a cratonic basin on the northern fringe of the African Shield. Limited outcrops of Precambrian rocks occur in the south and south-east of the country. Libya contains thick sequences of moderately deformed Palaeozoic rocks. Continental environments prevailed in southern Libya from the Late Palaeozoic to the Middle Cretaceous, during which time a thick marine succession was deposited in the north. The extensive Murzuk and Kufra Basins in the south appear to possess the most favourable characteristics for hosting uranium deposits. The two areas of principal interest are the Murzuk Basin, where the area around the Jabal ben Ghenemeh Uplift may be of particular interest, and the Kufra Basin.

Other areas which could be geologically favourable for the occurrence of additional uranium resources include:

(a) The Tibesti Mountains, which are considered favourable for vein and disseminated type deposits, as well as Proterozoic unconformity related deposits;
(b) The area north of the Tibesti Mountains, which is considered favourable for vein- and sandstone-type deposits;
(c) The Jabal al Uwaynat area for disseminated and vein deposits;
(d) Parts of the Sirte Basin for surficial type deposits [29.3].

References to Section 3.29

[29.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Libya (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html
[29.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 148–151.
[29.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.
[29.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).
[29.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.30. MADAGASCAR

With a surface of 587 041 km^2, Madagascar is the world's fourth largest island and is located in the Indian Ocean, lying 400 km off the east coast of Africa. It is divided into five geographical regions: the east coast, the Tsaratanana Massif, the central highlands, the west coast and the south-west.

The east coast consists of a narrow band of lowlands, about 1 km wide, formed of alluvial soils, and an intermediate zone, composed of steep bluffs alternating with ravines bordering an escarpment about 500 m in elevation, which gives access to the central highlands.

The island's highest peak, Maromokotro (2 876 m), is found in the Tsaratanana Massif, in the far north of the country. The central highlands, ranging from 800 to 1 800 m in elevation, contain a wide variety of topographies: rounded and eroded hills, massive granite outcrops, extinct volcanoes, eroded peneplains, alluvial plains and marshes. The central highlands extend from the Tsaratanana Massif in the north to the Ivakoany Massif in the south. The central highlands include the Anjafy high plateau, the volcanic formations of Itasy and the Ankaratra Massif (which reaches an elevation of 2 643 m) and the Ivakoany Massif in the south.

The west coast, composed of sedimentary formations deposited in several units is more indented than the east coast, especially in the north-west. The south-west is bordered to the east by the Ivakoany Massif and to the north by the Isala Roiniforme Massif.

There are two seasons: a hot, rainy season which lasts from November to April, and a cooler, dry season which lasts from May to October. South-eastern trade winds predominate and the island is occasionally subject to cyclones.

Agriculture, including fishing and forestry, is the main pillar of the economy. Major exports are coffee, vanilla (Madagascar is the world's largest producer and exporter of vanilla), sugar cane, cloves, cocoa, rice, tapioca, beans, bananas, peanuts and livestock products. Industry includes textile manufacture and the processing of agricultural products. Gemstone exports are also important. Several major projects are under way in the mining and oil and gas sectors that will, if successful, provide a significant boost to the economy. In the mining sector, these include the development of coal at Sakoa and nickel near Tamatave [30.1].

3.30.1. Geology

Two thirds of the island comprise igneous and metamorphic terrain of Precambrian age, the remainder consisting of a series of Phanerozoic sedimentary strata (Fig. 3.39). All these units are covered in places by recent volcanic rocks and sediments. The metamorphic grade of the crystalline basement is generally quite high, and for almost the whole island it varies between amphibolite and granulite facies. Greenschists are exceedingly rare.

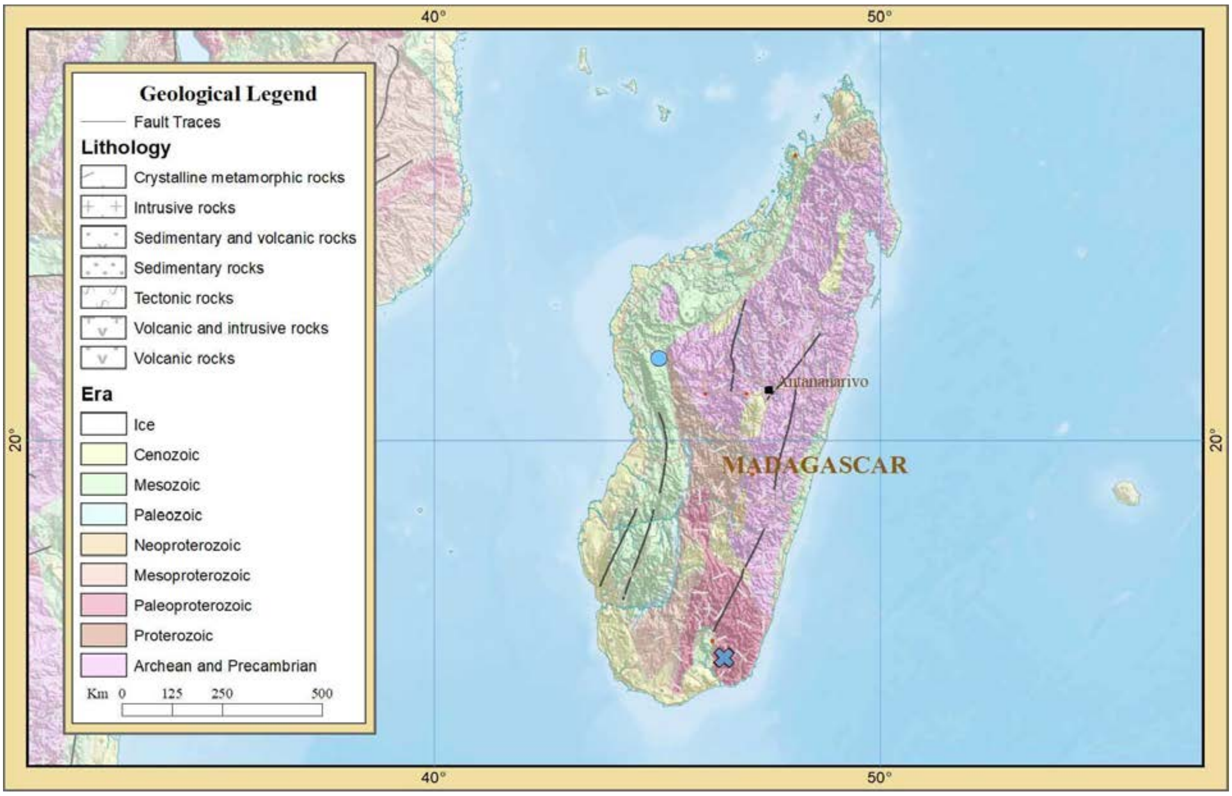


FIG. 3.39. Regional geological setting of Madagascar showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Madagascar underwent three major tectonic periods which can be summarized as follows:

(i) Before 2600 Ma, the era of early craton formation;
(ii) Between 2600 and 300 Ma, the era of intercratonic orogenies and major magmatic reactivations;
(iii) After 300 Ma, the era of platform cover and major tectonic rifts.

The tectonic history and the geology of Madagascar have much in common with both eastern Africa and the Indian peninsula. This fact is explained by the pivotal position which Madagascar occupied in Gondwana's pre-continental drift land mass.

The era of intercratonic orogenies and magmatic reactivations comprise four major orogenies which impacted, to different degrees, part or all of the island:

(i) Kavirondian Orogeny: 2500–2400 Ma;
(ii) Eburnean Orogeny: 2150–2000 Ma;
(iii) Kibarian Orogeny: 1250–1150 Ma;
(iv) Pan-African Orogeny: 850–540 Ma.

The most recent orogeny (Pan-African Orogeny) was responsible for the abundant pegmatization of several areas of Madagascar. The mineral deposits of industrial beryl, gemstones, mica and monazite are related to this episode of thermal metamorphism. Metallogenic similarities are evident between Madagascar, East Africa, India and Sri Lanka.

Madagascar attained complete cratonic stability around 450 Ma. Approximately 150 Ma later, its separation from East Africa began with the deposition of Karoo facies sediments in the newly developed intercratonic channel. Marine ingressions were rare and the sedimentary series are mainly continental. These sediments dip gently to the west.

Madagascar is believed to have separated from India during the Upper Cretaceous by a major strike-slip fault which still forms the eastern coast of the island. This last major tectonic event was marked by extensive outpouring of basalt, particularly along the island's coasts. Since the Mesozoic, the outline of the island of Madagascar has changed only slightly.

The transcratonic platform cover is of relatively little importance in Madagascar and is represented mainly by dominantly marine post-Karoo sediments along the coasts and by Oligocene and Pliocene–Pleistocene volcanic episodes related to tensional stresses in the interior of the island. Several major faults control the general structure of the island and these tend to be roughly parallel to its major axis.

Madagascar is well endowed with radioactive minerals and some of these occurrences have, in the past, been exploited. Uranium mineralization is present in different geological environments, both igneous and sedimentary. Deposits of uranothorianite exist and have been worked in the south of the island, near Fort Dauphin (now Tolanoro). The deposits consist of numerous lenticular zones of uranothorianite occurring within larger lenses and bands of pyroxenite and covering an area of 80 km × 30 km. The age of the uranothorianite has been dated as 485 Ma. The content of the uranothorianite in the ore is in the range 0.1–1.0% U, and averages 0.3% U. The uranium content of the mineral in different deposits varies in the range 5–25%.

Pegmatites, occasionally uraniferous, are widespread throughout the crystalline basement of the island, but they appear to offer only modest economic potential. Their age is correlative with the last Pan-African Orogeny. There are also occurrences of bastnaesite and pyrochlore in tectonically controlled peralkaline intrusions of post-Jurassic age.

Other uranium occurrences are known in the sedimentary platform covers of Madagascar, including carnotite in Karoo formation sandstones at Eolakara and uranocircite (barium autunite) in Pliocene–Pleistocene lacustrine sediments near Antsirabe.

The geological setting of all these occurrences seems to indicate a potential for radioactive raw materials in a variety of environments, most of them comparable in age and geochemical processes with other occurrences elsewhere in the world [30.2].

3.30.2. Uranium exploration

The first studies on uranium occurrences in Madagascar date back to the so-called ‘radium period’ and focused on pegmatites at Itasy and the secondary uranium occurrences at Antsirabe [30.3, 30.4]. The first mission of the French Atomic Energy Commission (CEA) arrived in Madagascar in late 1946. In 1953, the first indications of uranothorianite were found in the Fort Dauphin area, and in 1955, detailed exploration and mining was initiated by the CEA and private companies. An airborne scintillometer survey of all the sedimentary rocks of the island, covering an area of 155 000 km², was started in 1956. The prospecting done by the CEA in 1959 on the sedimentary terrain in the west of the country showed occurrences of carnotite, francevillite and uranocircite. After 1963, the CEA ceased all activity in Madagascar.

In 1971–1973, Government specialists made a survey of radioactive occurrences in the south of the country in order to determine the feasibility of restarting operations. This survey revealed the existence of unworked deposits in the Maudrarean Androy strata. In 1976, Madagascar set up a State organization, the Office for National Mines and Strategic Industries (OMNIS), to resume uranium exploration activities. Scintillometer surveys focused on identifying prospective areas likely to host uranium mineralization were undertaken in the western sedimentary region (Karoo zone), the limnic basins of Antsirabe (centre of the island) and the metamorphic rocks of Fort Dauphin (south-east). The work was jointly carried out by the Directorate for Mines and OMNIS.

In 1977, exploration work concentrated on the uranocircite bearing limnic sediments of Antsirabe (comprising geology, geophysics (spectrometry) and drilling) and on the uranothorianite bearing region of Fort Dauphin (geology, airborne spectrometry followed by magnetometry and ground spectrometry). In 1978, all domestic efforts and resources were focused on further exploration for uranothorianite at Fort Dauphin. This work included:

(a) Geological survey of the zones of interest (scale 1:20 000) and of the deposits found (scale 1:1000);
(b) Ground investigation of the anomalies detected by means of airborne spectrometry;
(c) Mineral sampling and laboratory analysis.

At the same time, foreign companies (from Japan and Italy) contacted Government authorities regarding exploration surveys in Madagascar. Five main areas of potential interest were delineated:

(i) The Fort Dauphin metamorphic area in the south-east. Work concentrated on the anomalies (about 100) detected by airborne spectrometry and included a geological survey (scale 1:1000), detailed spectrometry and drilling (about 50 boreholes to be drilled and core sampled to a depth of 200 m);
(ii) The sedimentary area of western Madagascar;
(iii) The limnic basin of Antanifotsy–Antsirabe in the centre of the island, where a geological survey of the basins and about 1000 m of exploratory drilling had previously been carried out;
(iv) The Ampasindava alkaline intrusive complex in the north-west and the Ambatofinandrahana complex in the centre. At Ampasindava, pyrochlore mineralization occurred in eluvial and alluvial saprolite deposits within an area of 50 km × 250 km. At Ambatofinandrahana, there is a bastnaesite deposit which was evaluated by a geological survey (scale 1:1000) covering 1 km² and detailed geophysical surveys, which included both ground magnetometry and spectrometry;
(v) Pegmatite fields in the centre of the island.

During 1982, various studies and work were carried out. In the Fort Dauphin region, geological exploration continued, in some areas with the assistance of foreign experts. These investigations comprised ground and car-borne radiometric surveys, and emanometric and magnetometric surveys with corresponding maps drawn up. A total of 3 434 m of boreholes were drilled and logged. At Antsirabe, the geological study was extended and a further 470 m of boreholes were drilled.

In the Folakara region, 1943 m of boreholes were drilled, emanometric surveys carried out and three maps drawn up, one 1:10 000 scale geological map and two structural maps on scales of 1:10 000 and 1:5000.

In addition, in 1982, the United Nations Development Programme assisted a project to recover uranium from the sedimentary areas at Folakara and Antsirabe. Exploration continued with geophysical work, geological mapping and drilling on kilometric and hectometric grids over an area of 80 km².

In 1983–1984, activities were concentrated on the Hackay prospect in the Folakara area. An area of 400 km² was covered by emanometry (soil, gas, water) and stream sediment geochemistry.

The 1985–1986 programme was aimed at the determination of a geological model fitting the occurrences of mineralization at Folakara. The activities carried out by OMNIS included geological mapping over 250 km² as well as geophysical exploration. No exploration activities were reported by Madagascar after 1988.

In the 1990s, France's Compagnie Générale des Matières Nucléaires (COGEMA) took out permits in the Morondava Basin in western Madagascar and conducted regional exploration. Exploration was terminated in the late 1990s as a result of the downturn in the prevailing market price of uranium and in demand (see Fig. 3.40). No uranium exploration data has been reported by Madagascar since 1985. Total exploration expenditure was USD $5.293 million inclding 22 387 metres of drilling.

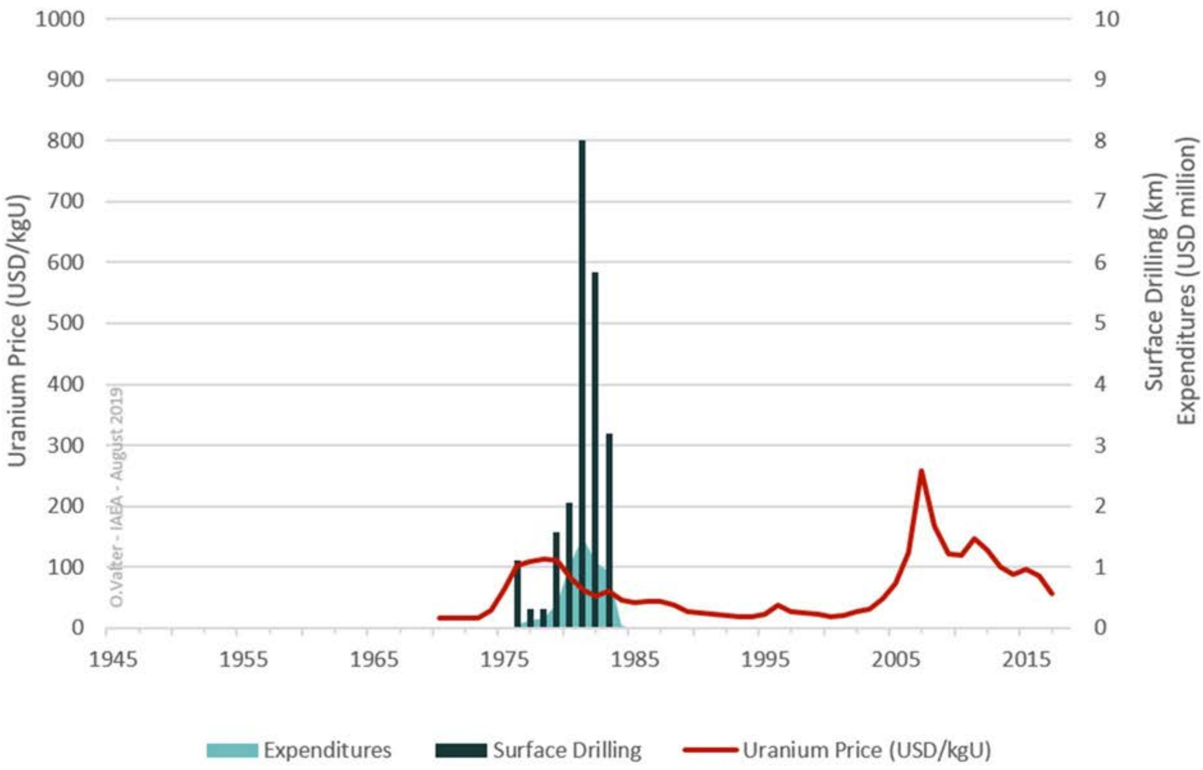


FIG. 3.40. Domestic uranium exploration data for Madagascar. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

Exploration for uranium restarted in 2005. Canada's Cline Mining Corporation and the Uranium Corporation of Madagascar (URAMAD) hold exploration permits, which have been granted for a period of 10 years, expiring in 2015 and 2016, respectively, in the Morondava Basin in western Madagascar. The Morondava Basin is infilled and layered with sediments, most notably the Karoo formation, which hosts uranium mineralization in other countries. The areas were previously identified and explored during the uranium cycles of 1956–1963 and 1979–1982 by the United Nations Development Programme and OMNIS, respectively. Later, COGEMA took out extensive permits and continued regional exploration until this was terminated in the late 1990s. URAMAD is the owner of a database for the Morondava Basin that includes the results of airborne geophysical and radiometric surveys, drill logs for 790 drill holes (equating to approximately 83 000 m of drilling) with indicated uranium values, and visible uranium mineralization associated with targets picked from 7000 radioactive anomalies, recorded and plotted.

Canada's Pencari Mining Corporation [30.4, 30.5] holds eight uranium properties totalling 27 519 km² in the central, western and southern regions of Madagascar that are prospective for uranium, including:

(a) The Betroka property, where recent geological mapping by Germany's GAF AG and Federal Institute for Geosciences and Natural Resources, a United Nations funded geological mapping programme, revealed uranium–thorium mineralization associated with several metamorphic units in this region;
(b) The Northern Morondava Basin uranium properties that comprise four concessions, collectively referred to as the 'Morondava uranium properties', which cover 2093.75 km², including part of a Jurassic–Cretaceous sedimentary basin in western Madagascar in Toliary Province. This sedimentary basin is over 600 km long and is considered to have potential for uranium mineralization;
(c) The Ambatofotsy uranium property, which is an area that has witnessed previous extraction of uranium. Historical records report that France started selectively mining this area in the early 1930s, producing 20 t of betafite from hand-cobbed ore that graded approximately 20–26% uranium oxide. Mining activities were suspended at the start of World War II but were resumed in 1948 by the Atomic Energy Commission. Work carried out during this period included driving 1200 m of underground tunnels and 390 m of drilling.

An assessment was made by OMNIS. Uranium mineralization at Ambatofotsy was found to be associated with a large, zoned pegmatite complex. The mineralization is reported to include betafite (a high uranium content columbium-tantalum mineral) and columbite-tantalite. Both minerals are important sources of tantalum, which is used extensively in electronics. A strong NW–SE trending uranium anomaly has been identified from an aerial radiometric survey. The OMNIS programme has already extended the uranium bearing pegmatite for 3 km beyond the known workings. The zone remains open and high spectrometer readings have been detected by OMNIS along the entire trend. All high spectrometer readings are coincident with a uranium anomaly detected by an airborne radiometric survey undertaken in September 2007 [30.6–30.9].

3.30.3. Uranium resources

3.30.3.1. Identified Resources

There are at present no uranium resources in Madagascar which could be reported in the identified resources category.

The UDEPO database lists the most significant deposits for Madagascar as Tranomaro District, Folakara, Ambatofotsy, Vinaninkarena.

3.30.3.2. Undiscovered Resources

In 1981 and 1983, IUREP estimated Madagascar's speculative resources to be in the range 10 000–50 000 tU [30.9, 30.10].

3.30.4. Potential for new discoveries

There are several geological environments with potential for hosting uranium resources. Four major areas of interest have been delineated:

(i) The Fort Dauphin metamorphic area;
(ii) The Folakara sedimentary region;
(iii) The limnic basins of the Antsirabe area;
(iv) The alkaline intrusive complex of Ampasindava.

In the Fort Dauphin area, uranium occurs in specific horizons in the Tranomaro sequence, which consists of calcium magnesium metasediments. The intense deformation and metamorphism of these rocks has been dated at 500 Ma. Uranium mineralization (uranothorianite) is scattered over an area of about 40 km × 100 km and is hosted in pyroxenite lenses generally enclosed by siliceous, aluminous leptynites and granulites. Some 100 anomalies, including partially exploited deposits, were delineated by airborne prospecting in 1976. These anomalies were shown to have uranium concentrations in the range 300–20 000 ppm U.

The Karoo strata, covering an area of 10 km × 1600 km, has uranium potential, although uranium concentrations found so far are low. The largest accumulation, in the form of carnotite, has been found in channelled sandstone facies in the Folakara and Makay regions, at the base of the Karoo. Correlation of the Karoo strata of Madagascar with its counterpart in mainland Africa suggests the potential for significant accumulations of uranium. Overburden thickness varies in the range 50–100 m.

In the Antsirabe region, uranium mineralization in the form of uranocircite is found in irregularly dispersed clay–sandstone lenses. The geological setting is in limnic basins of Pliocene–Pleistocene age located on the edge of the Ankaratra volcanic mountain chain. The areas covered by the mineralized lenses range from some tens to several hundred square metres, with an average thickness of one metre and uranium concentrations of 600–700 ppm U. The combination of closed basins and adjoining uraniferous pegmatites make this region a favourable target for further exploration.

Uranium mineralization in combination with tantalum and niobium (pyrochlore and microlite) occurs in alkaline granite–syenite intrusions below or within the sedimentary series of northern Madagascar. This geological setting stretches along a 20 km × 200 km strip from the Ampasindava Peninsula to Antogil Bay [30.8, 30.9].

3.30.5. Uranium production

Madagascar was one of the first uranium producing countries. During the period 1909–1921, approximately 57 t of uranocircite, containing about 36 tU, were produced from a deposit in the Pliocene–Pleistocene basin of Antsirabe. In addition, between 1912 and 1927, betafite concentrates containing about 24 tU were produced from pegmatites in the Itasy–Antsirabe–Handoto area.

Between 1953 and 1966, the Atomic Energy Commission and local miners produced uranothorianite from alluvial and primary deposits hosted in the Precambrian metasediments in the Fort Dauphin area. The most important mines were Marosohy, Amboanemba and Ambindrakembe. A total of 3986 t of concentrate was produced. The uranothorianite contained 6–28% U and the uranothorianite content of the pyroxenites was in the range 1–10 ppm U. The total production is estimated at 785 tU and 3 000 tTh (Fig. 3.41) [30.5].

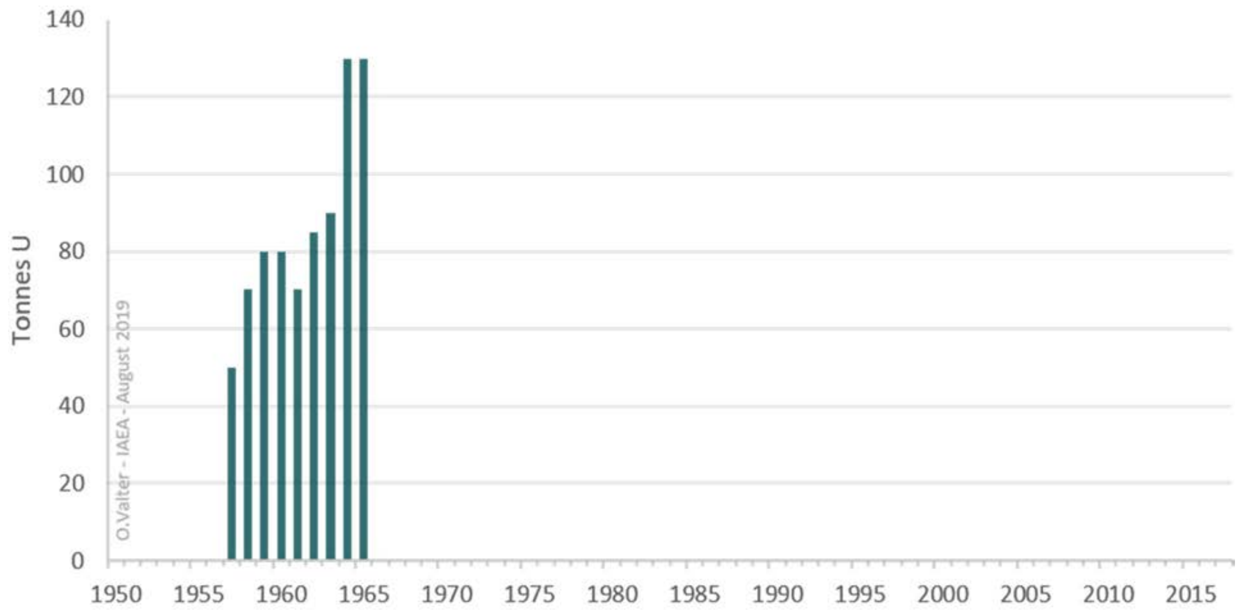


FIG. 3.41. Historical uranium production in Madagascar.

References to Section 3.30

[30.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Madagascar (2010), https://www.cia.gov/library/publications/the-world factbook/index.html

[30.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 152–155.

[30.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[30.4] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO) with Uranium Deposit Classification: 2009 Edition, IAEA-TECDOC-1630, IAEA, Vienna (2009).

[30.5] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006).

[30.6] PENCARI MINING CORPORATION, Ambatofotsy Uranium Property (2010), http://www.pencarimining.com/i/photos/spectrometer.gif.

[30.7] PENCARI MINING CORPORATION, Total Count Ambatofotsy (2010), http://www.pencarimining.com/i/photos/spectrometer.gif.

[30.8] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[30.9] MEYER, J.H., BRINCK, J.W., IUREP Orientation Phase Mission Report: Madagascar, OECD, Paris (1981) 141 pp.

[30.10] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.31. MALAWI

Malawi is a landlocked country in southern central Africa. The Great Rift Valley runs through the country from north to south. Lake Malawi is situated in this deep trough and covers about 20% of the country. The Shire River flows from the south end of the lake and joins the Zambezi River 400 km farther south in Mozambique. High plateaux occur to the east and to the west of the rift valley; generally with elevations of 900–1200 m. The Nyika Plateau rises to 2600 m in the north; south of Lake Malawi lies the Shire Highlands, with elevations of 600–1600 m, rising to the Zomba Plateau and the Mulanje Massif at 2130 m and 3002 m, respectively. In the extreme south, the elevation falls to 60–90 m.

Malawi's climate is subtropical and the rainy season extends from November to April. There is little or no rainfall throughout most of the country from May to October. Malawi is a densely populated country whose economy is heavily dependent on agriculture. Its three most important export crops are tobacco, tea and sugar. Malawi has few exploitable mineral resources [31.1].

3.31.1. Geology

The geology of Malawi is dominated by crystalline Precambrian–Lower Palaeozoic rocks that have been affected by the polycyclic Mozambique Orogeny (700–400 Ma) (Fig. 3.42). Pelitic to semi-pelitic rocks include banded hornblende–biotite gneisses with intercalations of marble, calc-silicate gneisses, quartzites and mica schists which cover much of the country. Two-pyroxene granulites and gneisses, also known as charnockites, form a major proportion of the bedrock in southern Malawi. Granitoid orthogneisses and basic and ultrabasic rocks are scattered throughout the country's rocks. Sedimentary and subordinate volcanic rocks such as basalts and dolerites of Permo-Triassic–Quaternary age lie unconformably on the basement complex rocks. Intrusive rocks of Jurassic–Lower Cretaceous age also occur and are ascribed to the Chilwa Alkaline Province. Large areas of superficial deposits of the Lilongwe, Kasungu and Mzimba plains occur along the major drainage systems such as Lake Malawi and the Shire River.

The structural and metamorphic history of the country is complicated. A number of orogenies, such as the Ubendian Orogeny (2200–1900 Ma), the Irumide Orogeny (~1350–1000 Ma) and the Mozambique Orogeny are known to have affected the country. Faulting, which is mostly related to the rifting, has played a major part in the post-orogenic development of the country [31.2, 31.3].

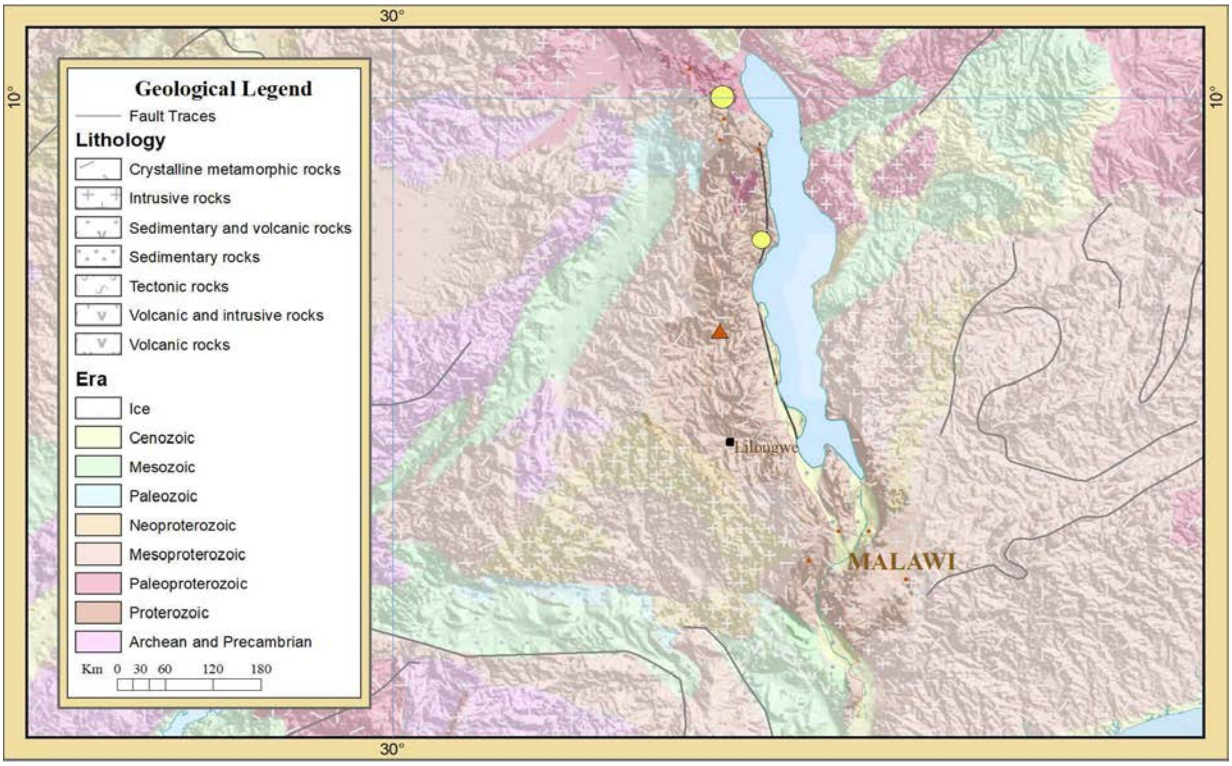


FIG. 3.42. Regional geological setting of Malawi showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.31.2. Uranium exploration

In the early 1980s, the United Kingdom's Central Electricity Generating Board (CEGB) discovered uranium mineralization in sandstones at Kayelekera in northern Malawi. Extensive drilling in 1982–1988 defined an initial inferred resource of 9800 tU at an average grade of 0.13% U. In 1989–1992, geotechnical, metallurgical, hydrological and environmental works were conducted, as was a feasibility study to assess the viability of a conventional open pit mining operation. This work was completed in 1991 at a total cost of US $9 million. The CEGB study concluded that the project was uneconomic using the projected mining model and owing to the low market price of uranium prevailing at that time. The project was abandoned in 1992 [31.4–31.7].

In 1998, Australia's Paladin Resources Ltd acquired an interest in the Kayelekera deposit via its joint venture with Balmain Resources Ltd, which then held exploration rights over the project area. Engineering and financial evaluation work indicated a viable project. In 2004, additional drilling was completed to improve confidence in resource estimates, and the prefeasibility study was updated. Resource drilling and bulk sample drilling for metallurgical test work were completed in 2005, followed by a bankable feasibility study. The feasibility study and the environmental impact study were finalized in early 2007 and a mining licence was granted in April 2007. Construction work on the project started in 2007 and the first mining took place in April 2009. In 2008, Paladin Energy carried out an infill and extension drilling programme of the Kayelekera Project which comprised 132 holes totalling 9955 m [31.4–31.7].

3.31.2.1. The Kayelekera deposit

The Kayelekera uranium deposit is located in the Karonga district of northern Malawi, about 600 km by road from the capital city of Lilongwe.Kayelekera is a sandstone (arkose)-hosted uranium deposit located close to the northern tip of the North Rukuru Basin. The North Rukuru Basin hosts a thick (≥1500 m) sequence of Permian Karoo sandstones preserved in a semi-graben about 35 km to the west of the Lake Malawi section of the East African Rift System and broadly parallel to it. The uranium mineralization at Kayelekera is hosted within the uppermost 150 m of the Muswanga Member, comprising the upper part of the Karoo formation. The Muswanga Member consists of a total of eight separate arkose units with intervening silty mudstones in an approximate 1:1 ratio, which suggests cyclic sedimentation within a broad, shallow, intermittently subsiding basin.

The arkose units contain most of the uranium mineralization. These units, which on average are 8 m thick, are generally coarse grained and poorly sorted and contain a high proportion of fresh, pink feldspar clasts. The basal layer of the arkose units is ordinarily a quartz feldspar pebble conglomerate. Coffinite has been identified as the principal uranium bearing species and occurs together with minor uraninite. Near surface weathering of the primary ore produced a zone of oxidized ore characterized by yellow and green secondary uranium minerals (meta-autunite and boltwoodite). Approximately 40% of the total ore is reduced arkose, 30% oxidized arkose, 10% mixed arkose and 20% mudstone. In November 2008, Paladin reported a resource compliant with Canadian National Instrument 43-101 with probable reserves of 12 312 tU with an average uranium grade of 0.1053% U at a cut-off of 340 ppm U. Total uranium resources were 17 864 t U at a grade of 0.07%.

Historical studies indicate that economically recoverable resources of uranium and coal only occur within the Kayelekera area (Table 3.18). Coal is present in the project tenement area in two deposits: the Nkhachira deposit (850 000 t, recoverable by open pit and underground mining) and in the Kayelekera deposit itself. Coal in the Kayelekera deposit is associated with the uranium resources and is therefore unavailable for commercial extraction. Moreover, this coal is of very low quality [31.3–31.7].

3.31.3. Uranium resources

3.31.3.1. Identified resources

Uranium resources are shown in Table 3.18, and historic variation in recoverable identified resources is shown in Fig. 3.43 and Fig. 3.44.

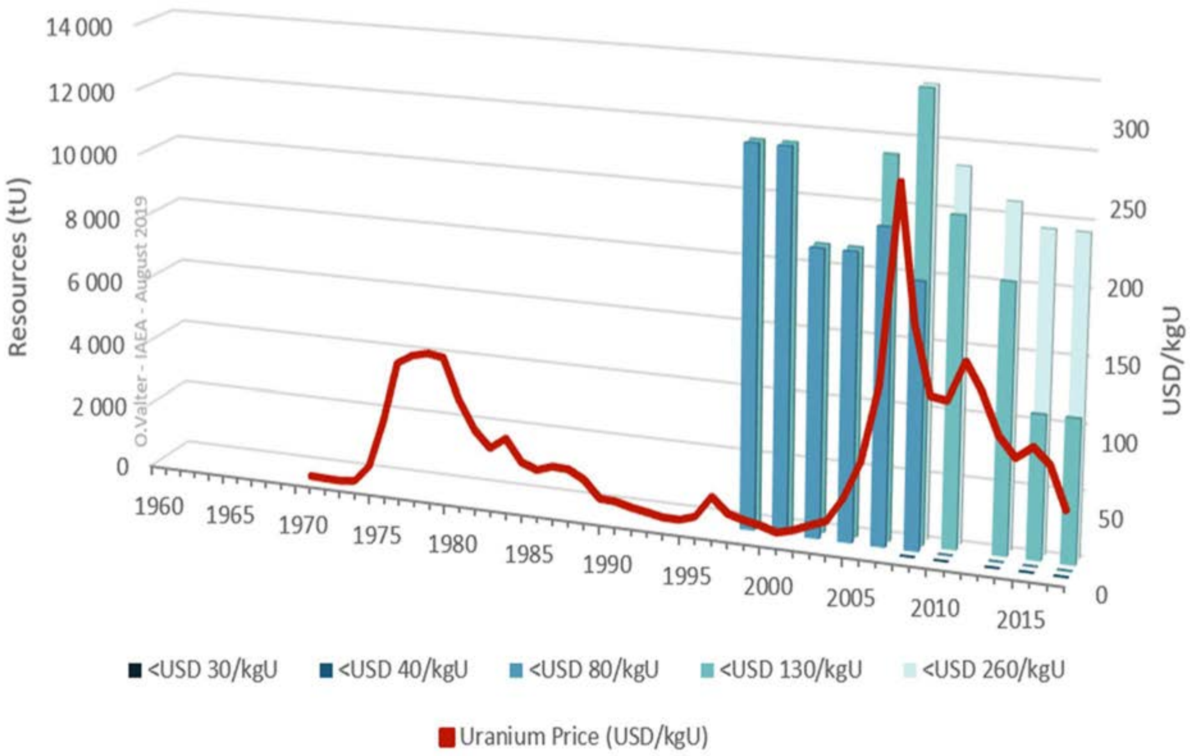


FIG. 3.43. Historical variation of recoverable reasonably assured resources within various cost categories in Malawi. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

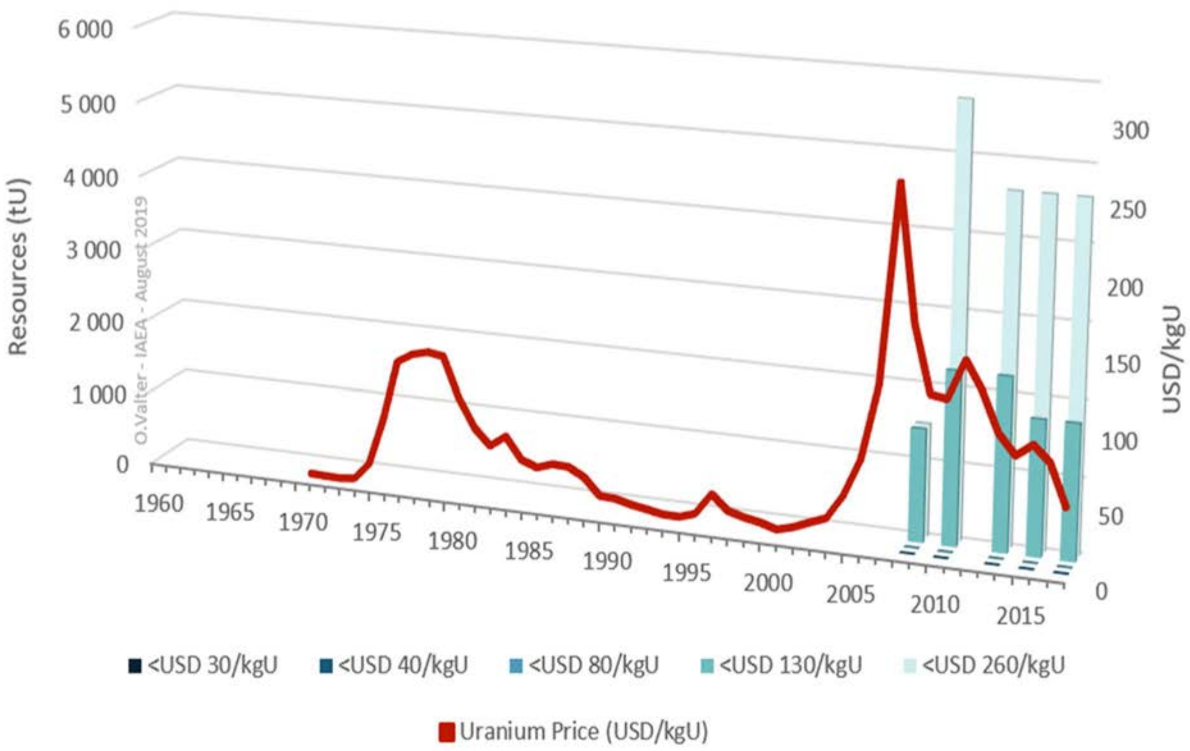


FIG. 3.44. Historical variation of recoverable inferred resources within various cost categories in Malawi. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

TABLE 3.18. IDENTIFIED (IN SITU) RESOURCES (tU) [31.8]
(As of 1 January 2017)

	<US $80/kgU	<US $130/kgU	<US $260/kgU
Reasonably assured resources	0	5500	13 000
Inferred resources	0	2800	6000
Total	0	8300	19 000

The UDEPO database lists the most significant deposits for Malawi as Kayelekera, Kanyika, Chombe.

3.31.3.2. Undiscovered resources

No undiscovered resources are reported by Malawi.

3.31.4. Potential for new discoveries

In addition to the Kayelekera deposit, other uranium mineralization is also known in Malawi from historical records, including uranium and niobium mineralization hosted by nepheline syenite intrusions. In the far north-west of the country, at the Ilomba Hill locality, surface trenching in the 1950s revealed a radioactive zone where rock samples returned analyses of up to 1.82% U and 7.50% Nb_2O_5 associated with uraniferous pyrochlore.

In June 2007, Australia's Oropa Exploration Pty Ltd was granted two exclusive prospecting licences for uranium covering the Mzimba Northwest and Chitunde Projects, which together cover an area of 2365 km². A further two exclusive prospecting licence applications, covering the Chizani and Mankhangala Project areas to the north of Kasungu were submitted to the Ministry of Energy, Mines and Natural Resources.

The Mzimba Northwest Project area is situated in north central Malawi, some 200 km S–SW of Kayelekera. The Mzimba Northwest Project is believed to hold potential for hydrothermal and unconformity style uranium targets and offers the possibility of locating concealed Karroo sediments which could have potential for hosting roll front style uranium mineralization within low lying areas of residual cover.

The Chitunde Project area is situated in the west and central part of Malawi, some 86 km W–NW of the capital, Lilongwe. The focus of exploration within the Chitunde Project area is a prominent circular airborne radiometric anomaly approximately 4 km in diameter, which is coincident with a syenite intrusive complex. Similar intrusions in the north of Malawi, notably the Ilomba Hill locality, are already known to host uranium and niobium mineralization.

The Chizani and Mankhangala Project areas are currently under application. These areas are situated near Globe Uranium Ltd's multi-commodity Kanyika property where core drilling of uranium–niobium–tantalum–zirconium mineralization hosted by alkalic granitoid and pegmatitic zones has been carried out. Recently granted exclusive prospecting licences in the district are also held by CC Mining SA.

The Chizani and Mankhangala Project area applications cover 809 km² and 442 km², respectively, of the structurally complex Malawi basement. This basement complex comprises metamorphosed igneous and sedimentary rocks which belong to the Mozambique Orogenic Belt. A feature of the Chizani Project area application is its coverage, which extends to over 30 km along the strike of the Chimaliro fault zone.

The Lupumba Hills Project area is centred only 37 km N–NW of the Kayelekera deposit. It covers a faulted sequence of Late Palaeozoic–Early Mesozoic Karroo sediments developed on an Early Proterozoic basement complex. Future exploration within this project area will focus on assessing the potential of North Rukuru sandstone and shale units within the Karoo System for hosting roll front style uranium mineralization, based on the analogous geological setting at Kayelekera.

The Machinga property is located just north of Zomba in south central Malawi. An extensive airborne radiometric and magnetometer survey was carried out over Malawi as part of the United Nations Development Programme in 1986–1987. The 1987 United Nations Development Programme report of this survey highlighted two areas worthy of further investigation for uranium mineralization: the Chinduzi radioactive zone and the Machinga radioactive zone. Both target areas form part of the Machinga property.

In 2008, Australia's Resource Star Ltd was granted prospecting licences in two areas: Chintheche in the central east of the country, and Machinga, in the south. High level radiometric targets were identified from an airborne geophysics survey conducted as part of a United Nations Development Programme sponsored project flown across Malawi in the mid-1980s. Anomalies on the Resource Star leases were re-evaluated in late 2006. The Chintheche property is situated immediately to the west of Lake Malawi, about 240 km north of the capital city of Lilongwe. The 1987 United Nations Development Programme report highlighted significant uranium anomalies which may warrant further investigation. Subsequent review by Resource Star confirmed that these anomalies occur over both basement rocks and the younger clastic sediments that overlie them. The younger sediments are prospective for roll front style uranium mineralization and the basement rocks for vein style uranium–niobium–tantalum–rare earth mineralization. Peak airborne radiometric anomalies are of the order of four times higher than background readings within the main target zone in the north-east of the tenement.

On 21 April 2009, Globe Uranium Ltd reported a Joint Ore Reserves Committee-compliant Indicated and Inferred resource of 4430 tU at a grade of 80 ppm U at its Kanyika uranium–niobium–tantalum–zirconium deposit.

By 2009, Resource Star's exploration targets had expanded to include rare earths as well as uranium [31.3–31.10]. In 2011 Resource Star reported 2370 tU at a grade of 275 ppm at Chombe in Karoo tabular sandstones.

3.31.5. Uranium production

Paladin officially opened the Kayelekera mine in April 2009. During 2009, 104 tU were produced.

The Kayelekera uranium deposit is being mined by open pit. Operations are programmed for an approximate nine-year mine life with an annual production of 1270 tU, but could be extended to 12 years with the treatment of marginal ore (bringing the process plant life to a total of 11 years). The final open pit dimensions were expected to be of the order of 300 m × 600 m × 130 m deep. The stripping ratio (waste:ore) is expected to average 2.4:1 [31.5, 31.6].

Uranium is being recovered using a solvent extraction process, with sulphuric acid as lixiviant and a sulphur dioxide/air mixture as oxidant. Expected uranium mill recovery is 90%. Total uranium production was expected to amount to more than 12 300 tU.

From 2009 to 2014, the mine produced 4217 t U before it was put into care and maintenance due to depressed uranium prices. The uranium production history is shown in Fig. 3.45.

FIG. 3.45. Historical uranium production in Malawi.

3.31.6. Comments

It is possible that uranium could be recovered as a by-product during processing of Globe's Kanyika uranium–niobium–tantalum–zirconium deposit. However, with an average grade of 80 ppm U, the deposit is of no interest as a primary uranium producer [31.7].

References to Section 3.31

[31.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Malawi (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[31.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 158–161.

[31.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[31.4] KNIGHT PIESOLD LTD, Kayelekera Environmental Impact Study, Paladin Resources Ltd, Subiaco, Western Australia (2007).

[31.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[31.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).

[31.7] PALADIN ENERGY (2008), http://www.paladinenergy.com.au

[31.8] CARTER, G.S., BENNETT, J.D., The geology and mineral resources of Malawi, Bull. Geol. Surv. Malawi, Zomba (1973).

[31.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[31.10] PATERSON, GRANT, WATSON LIMITED, Interpretation of Airborne Geophysical Survey Results, United Nations Development Programme. Toronto, Canada (1987).

3.32. MALI

Mali is a landlocked country in West Africa. Most of the country lies in the southern Sahara, which produces a hot, dust laden harmattan haze common during the dry seasons. The country extends south-west through the subtropical Sahel to a savannah zone. Mali has a mostly flat topography, rising to rolling northern plains covered by sand. The 250 000 km^2 Adrar des Iforas Plateau lies in the north-eastern Kidal region. The country's climate ranges from subtropical in the south to arid in the north. Most of the country receives negligible rainfall; droughts are frequent. The rainy season extends from June to early December and flooding of the Niger River during this period is common.

Mali's key industry is agriculture and cotton is the country's largest export crop. Mali also produces rice, millet, corn, vegetables, tobacco and tree crops. In 1991, with the assistance of the International Development Association, Mali relaxed the enforcement of mining codes which led to renewed foreign interest and investment in the mining industry. Gold is mined in the southern region and Mali records the third highest gold production in Africa (after South Africa and Ghana). Other mineral resources include kaolin, salt, phosphate and limestone [32.1].

3.32.1. Geology

Precambrian rocks are exposed in south-western Mali and in the north-east, in the Adrar des Iforas Plateau, which is a south-western extension of the Hoggar Massif of Algeria. In the south-west, schists, arkoses, quartzites and volcanics of the Birimian System (Lower Proterozoic) are intruded by both syntectonic (Eburnean Orogeny) and post-tectonic granites (Fig. 3.46). In the Adrar des Iforas Plateau, ancient basement rocks (calc-alkaline granites), which have been stable for over 1600 Ma, are exposed, as well as the Pharusian and Suggarian platform deposits of Upper Proterozoic age. The Late Precambrian is present in the south-western part of the country and consists of schists and stromatolitic dolomites and limestones.

The centre of the West African Craton is gently downwarped to form the Taoudeni Basin and part of Mali extends along the south-eastern side of this basin. Various sedimentary units of Palaeozoic, Mesozoic and Tertiary age are present in the basin. The Palaeozoic rocks of the Taoudeni Basin are Cambrian–Carboniferous in age. The Cambrian and Ordovician are made up mainly of conglomerates and sandstones; the Silurian is composed mainly of marine shales; the Devonian consists of fossiliferous shales and limestones, and the Lower Carboniferous sediments are marine, although the section becomes more continental and clastic in the Upper Carboniferous.

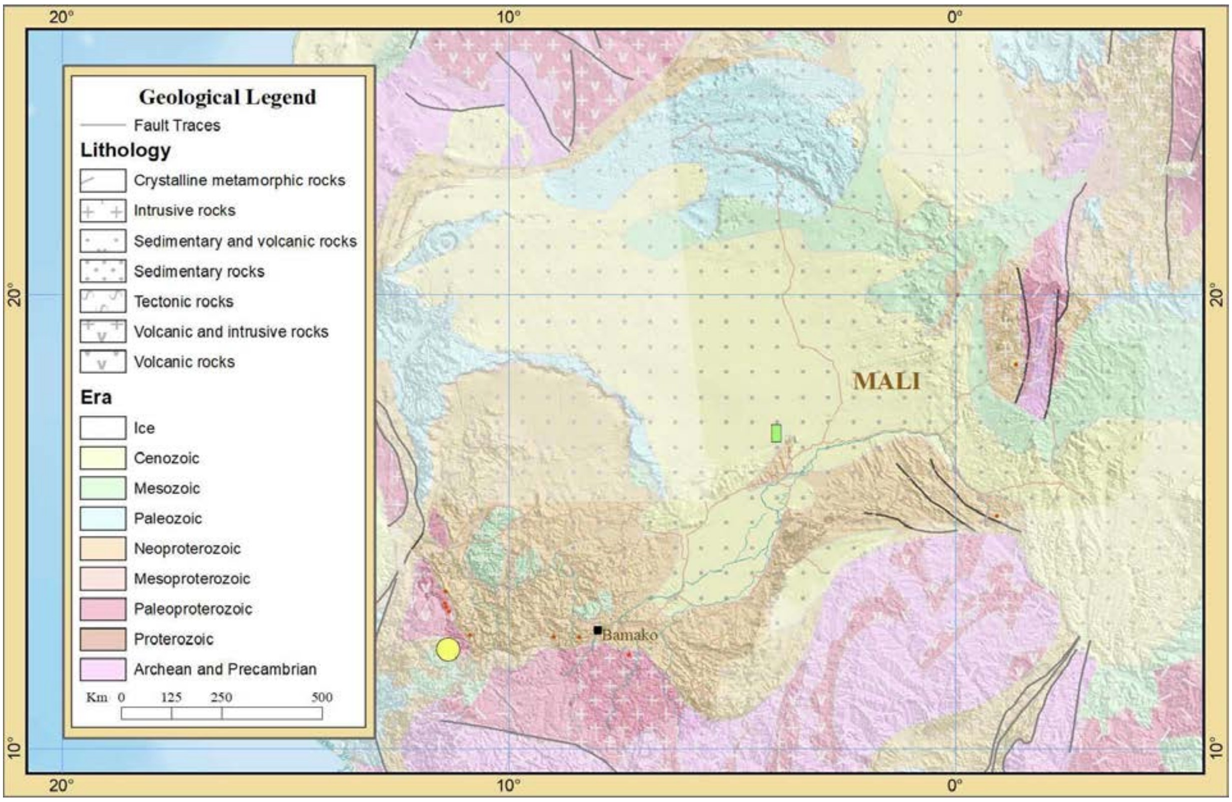


FIG. 3.46. Regional geological setting of Mali showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

At the periphery of the Adrar des Iforas Plateau, Cretaceous formations mapped as Continental Intercalaire lap on to the Precambrian on the western, southern and eastern flanks. Rocks of similar age and character are also present near the centre of the Taoudeni Basin, in north central Mali.

Tertiary sedimentary units in the Taoudeni Basin consist of mud, chalk, sandstone and ferruginous beds. Quaternary sedimentation covers the underlying geology of most of the Niger River valley [32.2].

3.32.2. Uranium exploration

Exploration for uranium in Mali was carried out by France’s Atomic Energy Commission (CEA) but apparently without much success. Prospecting was done along the border with Senegal and, in 1954–1956, in the Adrar des Iforas region, where indications of uranothorianite and thorianite were discovered, hosted by large pegmatite lenses enclosed in highly metamorphosed hornblende and pyroxene schists of the Suggarian sequence. Numerous granites were studied in this area and only the younger granites showed anomalous radioactivity, probably due to the presence of monazite as an accessory mineral. Figure 3.47 summarizes uranium exploration data totalling USD $55.347 million, including 103 783 metres of drilling.

Under an agreement with the Government of Mali, Krupp carried out a reconnaissance survey in the eastern part of the country in 1970, but without any notable success. In 1971, the Geological Survey of the Federal Republic of Germany carried out a hydrogeochemical and radiometric reconnaissance survey in the western part of the country (around Kayes). A few anomalies were detected but their unpromising character precluded further investigation. In 1974, Japan’s Power Reactor and Nuclear Fuel Development Corporation (PNC) initiated an exploration project in the Adrar des Iforas region which also covered parts of the Taoudeni Basin.

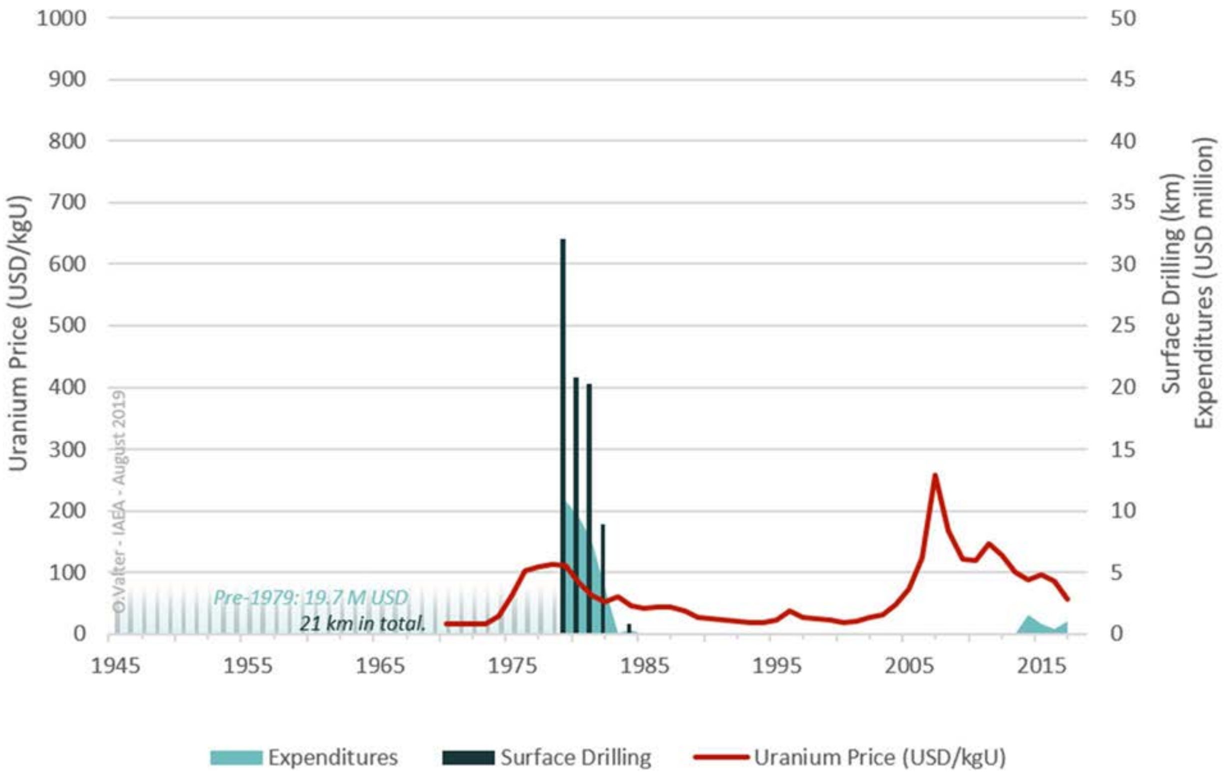


FIG. 3.47. Domestic uranium exploration data for Mali. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

In 1976, the Compagnie Générale des Matières Nucléaires (COGEMA) commenced exploration in the areas of Kenieba, Kayes, Bamako, Sikasso, Hombori, Douentza and Taoudeni. The work included airborne radiometric surveys in Kenieba and Taoudeni, and geophysical exploration as well as drilling in Kenieba (at Faléa and Dabora). In all projects undertaken after 1960, geologists from the National Directorate of Geology and Mines participated in the exploration activities. COGEMA ended its exploration project in 1983. PNC limited its activities to an area of 20 km^2 and continued work during the first quarter of 1985, using emanometry and Very Low Frequency (VLF) geophysics over an area of 14 km^2, before ceasing its activities in the second quarter of 1985 [32.3].

In 2007–2008, several companies conducted uranium exploration in Mali. Canada's Rockgate Capital Corporation was exploring for uranium and copper mineralization at the Faléa property in western Mali in partnership with Delta Exploration Inc. Substantial uranium and copper values were first discovered at Faléa by COGEMA in the late 1970s. However, the project was not advanced owing to low commodity prices prevailing at the time.

Exploration planned by Rockgate Capital and Delta Exploration focused on defining and expanding these initial results. The Faléa epicontinental and intracratonic basin is typical in age and style of sedimentation to known uranium producing basins and overlays Birimian stratigraphy that has been intruded by uraninite bearing Saraya granites. Locally, sedimentation of the Neoproterozoic Faléa Basin is structurally controlled by N–S and E–SE trending structures. On the Faléa project area, the stratigraphic sequences are up to 300 m in thickness. The Kania sequence occurs near a basal unconformity and can be up to 26 m thick. It is this sequence that hosts the uranium and copper mineralization.

In January 2014, Denison acquired the Falea property following completion of the acquisition of 100% of Rockgate Capital Corp. Then GoviEx acquired the Falea property from Denison Mines Corp. in June 2016.

Australia's Oklo Uranium Ltd is conducting uranium exploration in the Kidal area, which is located in the largely underexplored north-eastern part of the country. With an area of 19 930 km^2, the project includes the large crystalline Adrar des Iforas region, which is considered as having potential for palaeochannel hosted uranium, and alaskite pegmatite and vein hosted uranium. There are known occurrences of uranium, gold, copper, lead, zinc and manganese within the project area. Target identification is well under way in the project area, with 47% of an airborne geophysical survey having been completed in 2007. In 2008, Oklo Uranium will attempt to locate and evaluate potential uranium anomalies with ground spectrometry, geochemical sampling and drilling campaigns.

3.32.3. Uranium resources

Mali does not report any uranium resources [32.4]. In 1983, IUREP reported a range of 10 000–50 000 tU of speculative resources in sandstone, vein-type and surficial environments [32.5].

GoviEx interprets the Falea deposit as an unconformity-related uranium deposit associated with the unconformity between the Kania sandstone and the underlying Birimian greenstones. It is also a polymetallic deposit with an association of U-Cu-Ag. Published resources stand at 17 429 t U at a grade of 0.063% [32.6].

As of 1 January 2017, in situ reasonably assured resources and inferred resources, in the < US$ 260/kgU cost category, amount to 6700 tU and 5200 tU respectively [32.7]. The UDEPO database lists the most significant deposits for Mali as Falea, Samit.

3.32.4. Potential for new discoveries

The Precambrian rocks of the Adrar des Iforas are well exposed and offer an attractive exploration target as these rocks correlate closely with those of the Hoggar Massif, where vein and stockwork uranium deposits have been discovered.

In north-western Mali, a belt of NE–SW trending Cambrian–Ordovician clastic sediments occur, which may be equivalent to the Tassili Group in Algeria. This belt is located immediately to the south-east of the Reguibat (Eglab) Massif, which could have been a source of uranium.

Uranium occurrences in similar stratigraphic settings have been evaluated on the southern flank of the Hoggar Massif in Algeria. Other areas of Cambrian clastics may also occur in south-western and south-eastern Mali and these could merit further study.

The most favourable area in Mali for uranium prospecting is probably located east of Bourem and Gao and extending to the Nigerian border and north to the Algerian border. Here, strata mapped as Continental Intercalaire onlap the Adrar des Iforas Plateau. A broad NE–SW trending belt of Cretaceous Continental Intercalaire is also present to the north-west of Tessalit, adjacent to the Algerian border. Uranium deposits are hosted in similar strata in Niger.

Carboniferous sediments are present in north-western Mali and the upper part of this sequence has been mapped as continental. Large sandstone-hosted uranium deposits have been discovered in Niger in similar strata to the south of the Hoggar Massif and west of the Aïr Massif.

The Tertiary continental clastic sediments that are found in the east of the country could be prospective for uranium. In addition, the calcretes which crop out in the Adrar des Iforas region could also be worthy of examination [32.4].

3.32.5. Comments

There has been no uranium production in Mali. Mali has no nuclear power generation capacity.

References to Section 3.32

[32.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Mali (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[32.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 162–165.

[32.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[32.4] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[32.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[32.6] GOVIEX, Goviex Uranium Projects, www.goviex.com/Falea.php

[32.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

3.33. MAURITANIA

Mauritania is located on the north-west coast of Africa. The country is generally flat, with arid plains broken by occasional ridges and cliff-like outcrops. A series of scarps face south-west, longitudinally bisecting these plains in the centre of the country. The scarps also separate a series of sandstone plateaux, the highest of which is the Adrar Plateau, which attains an elevation of 500 m. Isolated peaks, often rich in minerals, rise above these plateaux. The concentric Guelb er Richat (also known as the Richat Structure) is a prominent feature of the north central region. Kediet Ijill, near the city of Zouîrât, has an elevation of 1000 m and is the highest point. Approximately three quarters of Mauritania is desert or semi-desert. To the west, between the ocean and the plateaux, are alternating areas of clayey plains and sand dunes.

Most of the population depends on agriculture and livestock for a livelihood. Mauritania has extensive deposits of iron ore, which account for almost 50% of total exports [33.1].

3.33.1. Geology

Mauritania forms part of the African Plate and, geologically, can be subdivided into four major domains (Fig. 3.48):

(i) The Archaean Reguibat Shield in the north of the country, which continues into both southern Morocco and Algeria;
(ii) The Neoproterozoic N–S striking Mauritanide Belt, folded and thrust during the Variscan Orogeny;
(iii) The Taoudeni Basin, with predominant continental sediments of Neoproterozoic–Phanerozoic age covering most of central and southern Mauritania;
(iv) Parts of the Senegal Basin in the south-west of the country, which have marine sediments of Jurassic–Recent age. Sand dunes cover about 50% of Mauritania and form an extensive peneplain studded with inselbergs over the folded belts [33.2].

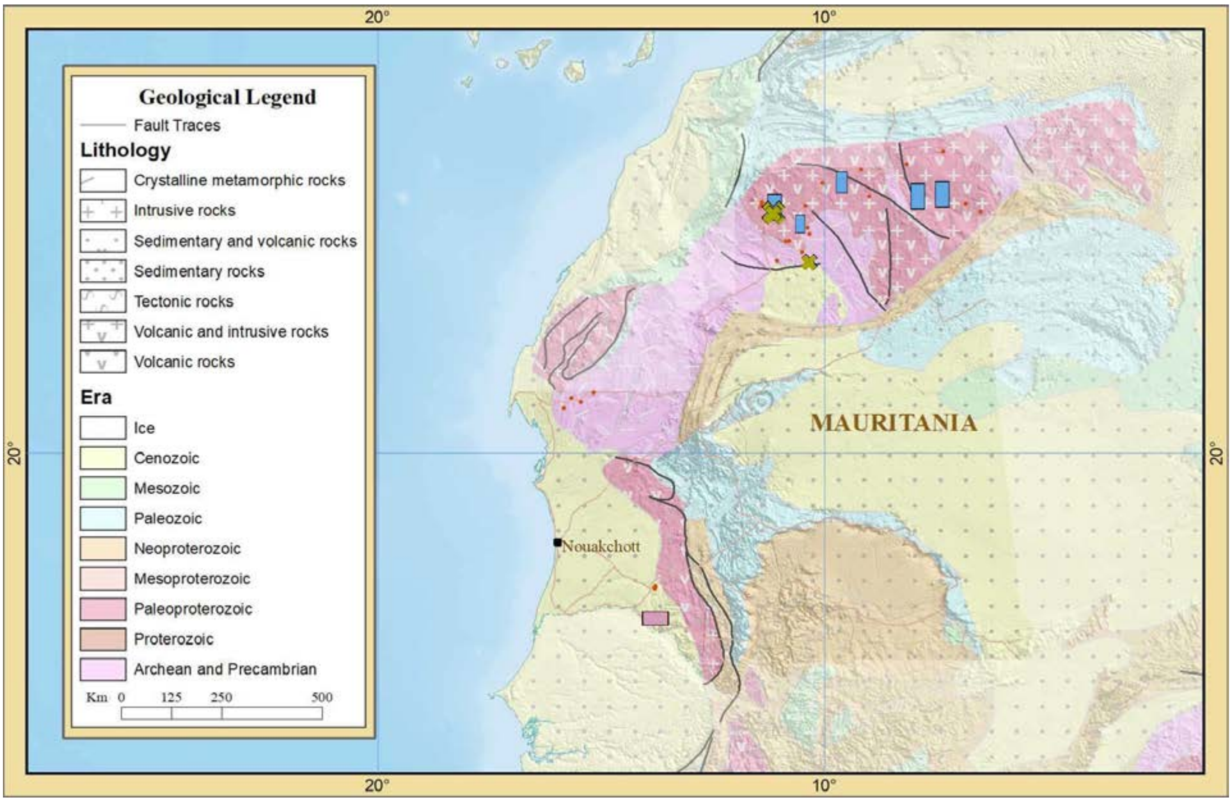


FIG. 3.48. Regional geological setting of Mauritania showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.33.2. Uranium exploration

The first uranium exploration project in Mauritania was carried out in 1959 by France's Atomic Energy Commission (CEA) in the area of the Ogmane Anticline.

In 1972, following the discoveries of surficial type uranium deposits in Western Australia, uranium exploration was initiated in the Reguibat Shield by Total Compagnie Française de Pétrole (in joint venture with the Société Mauritanienne de Recherches Minières, the French Atomic Energy Commission (CEA) and the Tokyo Uranium Development Company). The two exploration permits covered a total area of 164 000 km², divided into four blocks (Chami, Bir Hoghrein, Nouadhibou and Ghallamane). In 1975, the total area was reduced to five blocks totalling 41 000 km². These joint ventures were modified after the foundation of Minatome SA (subsidiary of Total) and Compagnie Générale des Matières Nucléaires.

The joint ventures held the areas up until 1983. Work on the permits was carried out between 1972 and 1975 and again in 1981 and targeted the evaluation of surficial type deposits (Reguibat Shield), as well as occurrences in the Precambrian basement, where radioactive anomalies were found associated with syenites and granites (Bir en Nar, Tigismat, Tenebdar). In 1983, all uranium exploration activities were suspended.

3.33.2.1. More recent exploration activities

Several companies are currently exploring for uranium in Mauritania. In December 2007, Forte Energy NL completed its first drilling programme, a 4006 m reverse circulation drilling campaign of 41 holes, each of 50–150 m depth. The drilling was carried out in the Bir en Nar area of the Zednes region and followed up on the high grade results previously recorded. Downhole radiometric logging results indicated numerous high grade uranium intersections, including 1.55 m at 1.55% U**.** The results of drilling a second group of 21 holes yielded up to 6310 ppm U over a 1 m section, and 576 ppm U over 19 m.

The United Kingdom's Alba Mineral Resources is investigating the uranium potential of areas located in north-east Mauritania. The area is considered prospective for unconformity-type uranium mineralization. The permits cover significant areas of an unconformable contact between Early Proterozoic reworked granitic terrain and overlying sediments of Late Proterozoic–Carboniferous age. Airborne geophysics surveys, flown on behalf of the Government of Mauritania, reveal radiometric anomalies within a mapped, organic-rich unit near the base of this sedimentary sequence, and coincident with its intersection with large, deep penetrating crustal shear structures. Uranium mineralization has been recorded in the north and north-west part of the permit area, hosted by granites and rhyolites that have been cut by these shear structures [33.3, 33.4].

3.33.3. Uranium resources

In 1983, IUREP estimated Mauritania's speculative resources to be 1000–10 000 tU, hosted in sandstone and vein type environments [33.5].

Forte Energy (now Bos Global Holdings) published resources in its 2013 annual report for 3 deposits in the Bir en Nar area. The largest one, A 238-A 238 NW contains 8999 t U at an average grade of 205 ppm in granite-derived metasomatites [33.6]. The project is dormant.

Aura Energy Ltd started exploration on its Reguibat project in 2009 and following two drilling campaigns published a JORC compliant resource estimate in 2011: 19 327 t U at 280 ppm within 8 surficial lacustrine-playa deposits. Carnotite is the main uranium mineral [33.7].

As of 1 January 2017, in situ reasonably assured resources and inferred resources, in the < US$ 260/kgU cost category, amount to 1200 tU and 27 500 tU respectively [33.8].

The UDEPO database lists the most significant deposits for Mauritania as A 238, Bofal-Loubboira, Hippolyte, Ferkik West, Lazare North, Lazare South, Sadi, Hippolyte West, Hippolyte South.

3.33.4. Potential for new discoveries

Areas in north-east Mauritania, where unconformable contacts are known between Early Proterozoic reworked granitic terrains and overlying sediments of Late Proterozoic–Carboniferous age, can be considered prospective for unconformity type uranium mineralization.

Uranium mineralization is known in the north and north-west of Mauritania where it is hosted by granites and rhyolites cut by shear structures.

3.33.5. Comments

There has been no uranium production in Mauritania. Mauritania has no plans to develop nuclear generating capacity and, consequently, has no uranium requirements.

References to Section 3.33

[33.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Mauritania (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[33.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 166–169.

[33.3] FORTE ENERGY NL (2010), http://www.forteenergy.com.au/projects/Mauritania

[33.4] ALBA MINERAL RESOURCES (2009), http://www.albamineralresources.com/text/projects/mauritania.html

[33.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[33.6] FORTE ENERGY, 2013 Annual Report, 30 June 2013, 88 p.

[33.7] AURA ENERGY, First Uranium Resource in Mauritania — 50 Million Pounds. ASX announcement, 14 July 2011, 9 p.

[33.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

3.34. MAURITIUS

Together with La Réunion and Rodrigues, Mauritius forms part of the Mascarene Islands. This archipelago is located in the Indian Ocean, about 1000 km east of Madagascar. The island group was formed as a result of a series of subsea volcanic eruptions occurring when the African Plate drifted over the Réunion mantle plume or ‘hotspot’. The islands are no longer volcanically active. The island of Mauritius itself is formed around a central plateau, with its highest peak in the south-west being the Piton de la Petite Rivière Noire at 828 m. Around the plateau, the original crater can still be distinguished from several mountains.

The local climate is tropical, modified by south-east trade winds; there is a warm, dry winter from May to November and a hot, wet and humid summer from November to May. Anti-cyclones affect the country during May–September. Cyclones affect the country during November–April.

Since independence in 1968, Mauritius has developed from a low income, agriculturally-based economy (sugar cane is grown on about 90% of the cultivated land area and accounts for 25% of export earnings) to a middle income diversified economy with growing industrial, financial and tourist sectors [34.1].

3.34.1. Geology

Geologically, the islands are made up of volcanic rocks between 7.8 Ma (Early Pliocene) and 0.2 Ma in age (Fig. 3.49). The old volcanics are mainly olivine basalts and agglomerates with intrusive trachyte and trachyandesitic plugs. The young volcanics are mainly olivine bearing flood basalts.

The mineral industry of Mauritius is negligible. The main minerals being quarried are basalts for construction purposes with smaller amounts of lime being produced from local coral limestone and coral sand. Potentially important are the polymetallic nodules that have accumulated on the ocean floor at a depth of about 4000 m around the coast of Mauritius [34.2, 34.3].

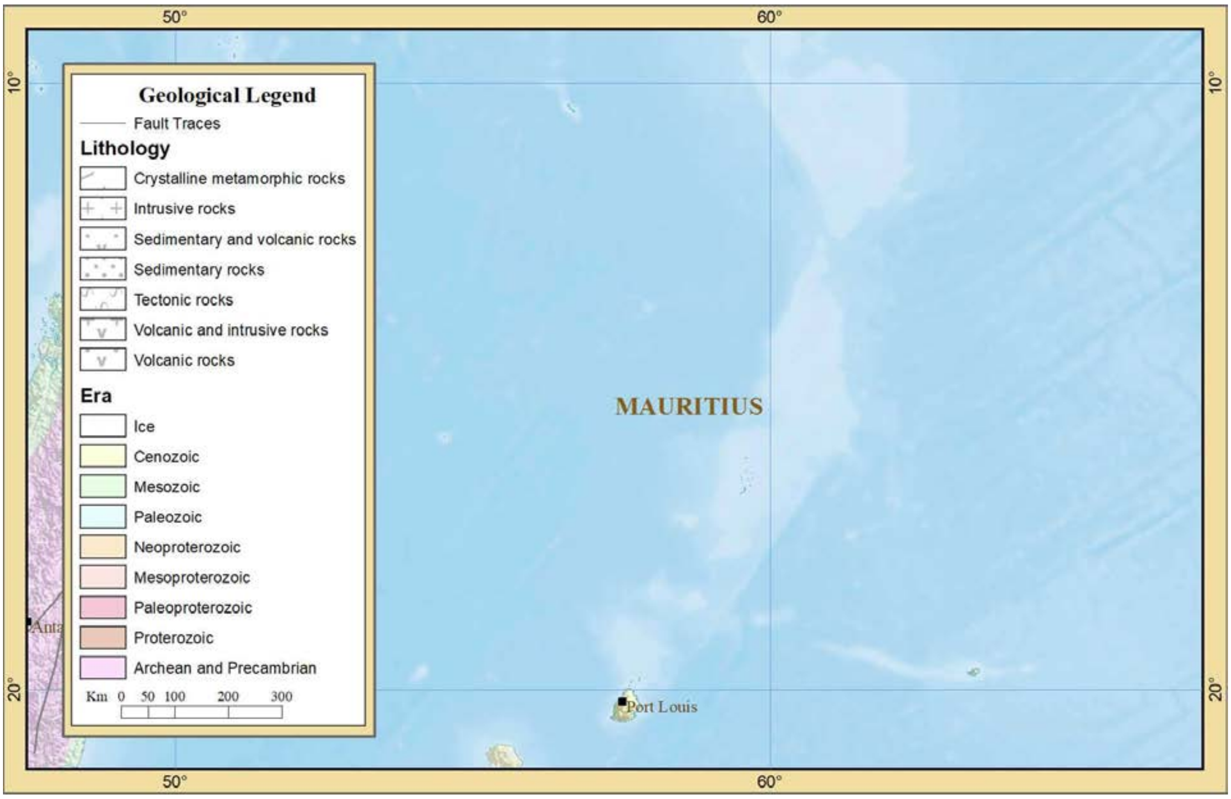


FIG. 3.49. Regional geological setting of Mauritius. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.34.2. Uranium exploration

No official information is available on uranium exploration. Publications do not indicate any information with regard to the presence of uranium mineralization.

3.34.3. Uranium resources

No identified or undiscovered resources are reported.

The UDEPO database does not list any known deposits for Mauritius.

3.34.4. Potential for new discoveries

There is no significant potential for uranium on Mauritius or on any of the other Mascarene Islands. The island group consists of oceanic basalts and reef limestones, neither of which are favourable environments for the hosting of uranium deposits.

3.34.5. Comments

No uranium has been produced in Mauritius.

References to Section 3.34

[34.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Mauritius (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[34.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 170–172.

[34.3] VAN STRAATEN, P., “Geology of Mauritius”, Rocks for Crops: Agrominerals of sub-Saharan Africa, International Centre for Research in Agroforestry, Nairobi (2002) 338 pp.

3.35. MOROCCO

Morocco is situated in north-west Africa, bordering both the Atlantic Ocean and the Mediterranean Sea and lying between Algeria and Mauritania A large part of Morocco is mountainous. The Rif Mountains occupy the region bordering the Mediterranean from the north-west to the north-east. The Atlas Mountains form the backbone of the country, extending from near Agadir to the north-east. They also host the highest point in the country (Mount Toubkal (4165 m)), which is also the highest point in North Africa.

Most of the south-eastern portion of the country forms part of the Sahara Desert and as such is sparsely populated and economically unproductive. The population primarily lives to the north of the mountainous areas; the desert lies to the south. The coastal climate is Mediterranean, becoming more extreme towards the interior mountainous regions.

The south-western portion of Morocco is sparsely populated and consists mainly of desert flatlands. Aside from its rich phosphate deposits and fishing resources, this area has few natural resources and lacks sufficient rainfall for most agricultural activities. The economy is sustained by nomadic herding, fishing and phosphate mining [35.1].

Morocco's agricultural production consists of oranges, tomatoes, potatoes, olives and olive oil. The largest industry is phosphate mining. Morocco is the second largest producer of phosphate in the world after China (33 M tonnes in 2018). It is also the largest silver producer in Africa. Its second largest source of income is from nationals living abroad who repatriate money to relatives living in Morocco. The country's third largest source of revenue is tourism: 12.3 million tourists visited the country in 2018 [35.1].

3.35.1. Geology

The geology of Morocco is extremely varied with numerous geological units and tectonic features ranging from Precambrian to Quaternary in age (Fig. 3.50). Morocco is part of the African Plate and the Atlas Mountain Range is one of the largest intracontinental belts in the world. The igneous rocks include important granite massifs of different ages, basic and ultrabasic rocks, alkaline intrusives and several lava sequences. Tectonically, most of the Precambrian orogenies, as well as the Caledonian, Hercynian and Alpine Orogenies, are in evidence to varying degrees of intensity.

Three principal structural regions, separated by large tectonic uplifts and depressions, may be distinguished from south to north:

(i) The Anti-Atlas region is in part a continuation of the West African Precambrian Shield. It is partially covered in the north and south by Palaeozoic sediments and to the east by more recent rock units. The latest important orogeny in this region is of Hercynian age. However, this event took place without general metamorphism or granitization; only dykes and sills of dioritic and doleritic compositions were intruded;

(ii) The Atlas region consists of a folded Palaeozoic zone, which has been locally metamorphosed and granitized as a result of the Caledonian and Hercynian Orogenies and where the Mesozoic cover has been folded by both pre-Cretaceous and Alpine tectonic events. Gabbros, diorites and alkaline igneous activity resulted from these pre-Cretaceous and Alpine activities. Some of the Hercynian granites are considered to have uranium potential;

(iii) The Rif region principally consists of Mesozoic and Tertiary sediments derived from a northern source and deposited in a geosyncline and subsequently subjected to Alpine tectonics. An older Palaeozoic belt of ultrabasic rocks, surrounded by metamorphic facies, crops out in the northern part of the Rif region [35.2, 35.3].

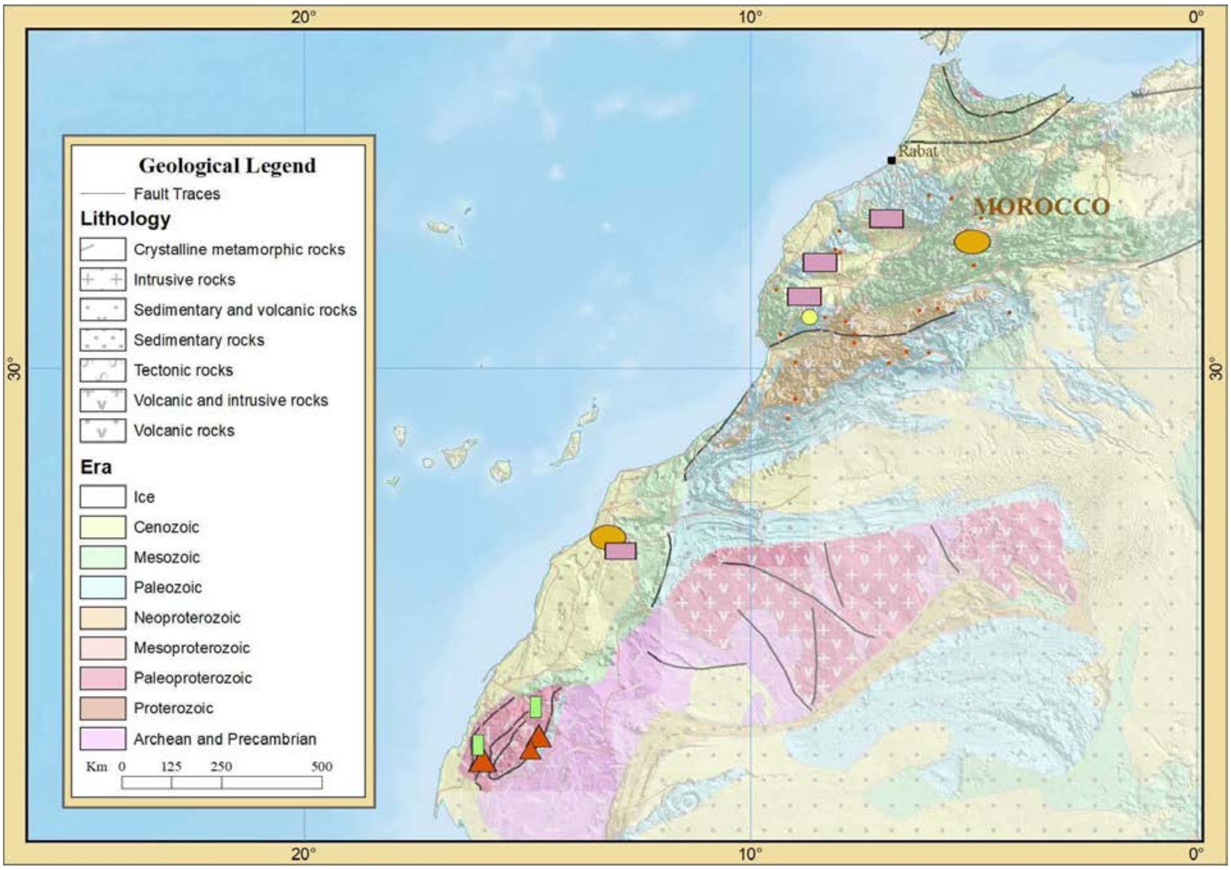


FIG. 3.50. Regional geological setting of Morocco showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.35.2. Uranium exploration

Uranium exploration was first undertaken in Morocco in 1946. In 1946–1953, uranium exploration was carried out by France's Atomic Energy Commission (CEA) in collaboration with Morocco's Mining Research and Investment Office (BRPM). A joint Moroccan–French company, Société Marocaine de Recherches et d'Etudes Minières carried on exploration in 1953–1956. In 1970, a radiometric reconnaissance survey covering 1800 km² was conducted jointly by the United Nations and the BRPM.

After 1974, the BRPM increased its efforts. Two areas were selected for further study. A reconnaissance programme was conducted over the Permo-Triassic of the Haute Moulouya and numerous anomalies were identified at the base of the Triassic, and these were tested by core drilling. In the Haut Atlas Occidental, a uranium-bearing sandstone horizon was discovered in the Cretaceous continental sequence of Imin Tanout (Marrakesh Province). A drilling programme was undertaken along 15 km of outcrops that recorded radioactive anomalies. In 1979 and 1980, exploration activities continued in the Cretaceous of the Haut Atlas Occidental, in the Permo-Triassic of the Haute Moulouya and in the Precambrian areas of the Anti-Atlas. A geochemical programme to investigate the basement of the Nord Mesetien was carried out with the assistance of the IAEA. Another IAEA assisted programme surveyed the area of the Boutonnière de Bou Azzer El Graara.

During 1981–1982, exploration in the continental Cretaceous rocks of the Haut Atlas Mountains (Harrakesh Province) continued. Elsewhere, prospecting was carried out in the Ouarzazate Tertiary Basin, near the middle reaches of the Moulouya River, and in the Precambrian areas of the Anti-Atlas. Car-borne reconnaissance was conducted in north-eastern Morocco. Owing to budgetary constraints in 1983–1984, a planned aerial spectrometer survey of the Haut Atlas Occidental was postponed. Despite this, geological and radiometric surveys and drilling were carried out in selected areas in the Anti-Atlas.

In 1985, a geophysical helicopter survey was undertaken covering an area of 8000 km² in the Haut Atlas, targeting both uranium and base metals, using magnetometric, electromagnetic and spectrometric methods. This resulted in the discovery of numerous uranium and uranium–thorium anomalies. The anomalies detected by the 1985 helicopter survey were evaluated, but the results were discouraging and no economic uranium concentrations were found. As a result, further work was terminated.

In 2007, Australia's Toro Energy Ltd signed a memorandum of understanding with Morocco's Office National des Hydrocarbures et des Mines (ONHYM) for the exclusive rights to evaluate the potential of three areas known to host uranium mineralization. During 2007, these areas were evaluated and one of them, Haute Moulouya, was considered to have potential for sediment hosted uranium. In June 2008, Toro Energy indicated that it planned to terminate the memorandum of understanding with Morocco and focus on its activities in Australia and other areas [35.3].

3.35.3. Uranium resources

No known conventional uranium deposits in Morocco have been reported to the Red Book.

In 2009, a factsheet from ONHYM indicates that the Wafagga uranium occurrence, located 90 km south-west of Marrakesh, has a preliminary resource estimate of 500 tU at a grade of 600 ppm U. It states that the mineralization is likely to be of the roll front type and occurs in the Hauterivien Cretaceous. The estimate is based on results of radiometric and 'track etch' measurements; percussion, rotary and diamond drilling; and underground workings [35.4].

In 2015, ONHYM estimated resources of 35 Mt at 121 ppm U (4273 t U) on the Aghracha prospect in surficial fluvial-valley formations. U-Th-REE-rich granite and carbonatite veins and dykes are also present in the same area. The Taguendest prospect further south in surficial formations is estimated at 1963 t U, 170 ppm. The same document mention large U-Th-Nb-Ta-REE resources associated to intrusive carbonatite plutons: Glibat Lafhouda, 49 Mt at 430 ppm U (43 000 t U); Twihinatte, 560 Mt at 212 ppm U (118 500 t U) [35.5].

The UDEPO database lists the most significant deposits for Morocco as Tarfaya Basin, Oulad Abdoun Basin, Timahdit Basin, Meskala Basin, Gantour Basin, Twihinate, Oued Eddahab Basin.

3.35.3.1. Undiscovered resources

Numerous uranium occurrences are known to exist in the Anti-Atlas, the Haut Atlas Occidental et Central, the Meseta and Moyen Atlas and the Haute Moulouya. Geologically, these occurrences are mainly associated with Precambrian, Cambrian and Palaeozoic granites and sediments of Cambrian–Cretaceous age.

Speculative resources estimated by the 1983 IUREP Orientation Phase Mission were in the 70 000–180 000 tU range [35.6].

3.35.3.2. Unconventional resources

Very large resources of uranium hosted by phosphate deposits are known to exist in Morocco [35.7].

3.35.4. Potential for new discoveries

Morocco offers a number of possibilities for the discovery of uranium resources.
Within the Precambrian, there are both acidic crystalline rocks and volcanics, as well as continental clastic sedimentary rocks such as conglomerates, sandstones and shales. To date, no uranium mineralization has been found. The area underlain by such rocks in southern Morocco is quite extensive and theoretically should be prospective for uranium.

A few uranium anomalies have been found in the continental sandstone facies of the Georgian (Lower Cambrian) in the eastern part of the Anti-Atlas Mountains. Stratiform uranium occurrences have been discovered at the base of the Cambrian–Ordovician continental sediments, just to the south of the Hoggar Massif in Algeria. There are extensive areas of Lower Palaeozoic rocks in the Anti-Atlas and contact zones with Precambrian rocks in the same region that may be favourable for hosting uranium mineralization.

The Carboniferous sediments are principally marine in origin but may include continental facies in the eastern part of the country. A large number of radioactive anomalies and a few occurrences of uranium have been found in the Permo-Triassic rocks of the western and central Haut Atlas region. Copper mineralization often accompanies these occurrences. There are large prospective areas within these stratigraphic units.

The Upper Jurassic sandstones of the Moyen and Haut Atlas contain several radioactive anomalies in association with copper mineralization. These rocks have been little prospected in the past. Uranium in concentrations of 80–200 ppm U is known in central Morocco in phosphatic limestones of Maastrichtian–Lutetian age. The Hercynian granites of the Atlas region should have potential for vein deposits and could also be potential sources of hydrogenic sandstone uranium deposits in various formations. The sequences of acid volcanics interbedded with Miocene sandstones, such as those at Ras Tarf, have potential to host uranium mineralization [35.3]. Potentially large resources of uranium could also be associated with the phosphate deposits.

3.35.5. Uranium production

There has been no uranium production in Morocco. However, in Belgium, 686 tU were recovered during 1985–1998 from phosphates imported from Morocco.

3.35.6. Future projects

On 22 October 2007, AREVA signed an agreement with Morocco's national phosphate company, Office Chérifien des Phosphates, to develop joint cooperation and research initiatives regarding extraction of uranium contained in phosphoric acid produced from Moroccan phosphate ore. The project is terminated.

References to Section 3.35

[35.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook Morocco (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[35.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 174–179.

[35.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[35.4] BENKHADRA, A., Uranium Prospects in Morocco, Royaume du Maroc, Office National des Hydrocarbures et des Mines (2009), http://www.onhym.com/ONHYM

[35.5] OFFICE NATIONAL DES HYDROCARBURES ET DES MINES, Les prospects d'uranium dans les provinces du sud (2015) 4 p.

[35.6] ANIEL, B., HETLAND, D.L., GLASSON, P.J., IUREP Orientation Phase Mission Report: Morocco, OECD, Paris (1983) 22 pp.

[35.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[35.8] WORLD NUCLEAR ASSOCIATION, Emerging Nuclear Energy Countries: Morocco (2009), http://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx

3.36. MOZAMBIQUE

Mozambique is situated along the south-east coast of Africa and shares borders with the United Republic of Tanzania, Malawi, Zambia, Zimbabwe, South Africa and Swaziland. The country is divided into two topographical regions by the Zambezi River. To the north of the Zambezi River, the narrow coastline grades into terrain characterized by hills and low plateaux and farther west by rugged highlands. South of the Zambezi River, the lowlands are wider. The Mashonaland Plateau and Lebomo Mountains are located in the far south. The country is drained by five principal rivers and several smaller ones, the largest and most important of which is the Zambezi River.

Mozambique has a tropical climate with two seasons: a wet season extending from October to March and a dry season which lasts from April to September. Prevailing climatic conditions vary with altitude. Rainfall is heavy along the coastal strip and decreases both to the north and south. Annual rainfall varies in the range 500–900 mm, depending on the region, and averages 590 mm. Cyclones are also common during the wet season.

Subsistence agriculture continues to occupy the overwhelming majority of the country's workforce. The agricultural potential of the country is high, particularly in the fertile northern regions. The principal cash crops are sugar, copra, cashew nuts, tea and tobacco. There are extensive mineral resources, but exploration has been constrained by the civil war (1977–1992) and the lack of infrastructure. Minerals currently being mined include marble, bentonite, coal, gold, bauxite, granite and gemstones [36.1].

3.36.1. Geology

The oldest Precambrian rocks in Mozambique consist of highly metamorphosed gneisses, granites and schists, probably Lower Proterozoic–Middle Proterozoic in age (Fig. 3.51). The most important Precambrian system (Mozambican) comprises gneisses, schists and quartzites and is Upper Proterozoic in age. Granites intrude the entire Mozambican strata. The general fold trend is N–S and forms part of the Mozambique Mobile Belt, which can be traced northwards through eastern Africa into Ethiopia. The youngest Precambrian rocks in Mozambique are represented by the Umkondo Series, which comprise sandstones and quartzites.

There are numerous occurrences of radioactive refractory minerals associated with beryllium, niobium and tantalum mineralization found in pegmatites that are hosted by Precambrian strata. Also, pyrochlore occurs in carbonatites in the Tete district.

There are no known pre-Karoo Palaeozoic sediments in Mozambique. The most complete sections of Karoo are found in the Tete and Fyasa districts. The Tete district has a coal basin with 5–7 m thick seams of exploitable coal. The succession begins with a fluvioglacial conglomerate and passes upwards into sandstones and shales, which contain the coal seams. The succession ends with red sandstones and basalts. In the Nyasa district, the same sequence of sediments is found.

Cretaceous strata crop out in the coastal region and extend inland for a distance of up to 100 km. These stratigraphic units, which are up to 100 m thick, appear to be complete and range in age from Lower Cretaceous to Danian. They are largely marine in origin. The Eocene overlies the Upper Cretaceous between the Zambezi and Sabi Rivers. Lower Miocene and Pliocene strata also occur in the coastal plain. The Tertiary also is largely marine in origin.

The Great Rift Valley of Africa has its southern terminus in Mozambique in the Urema Trough. Here, Precambrian gneisses, granites and Karoo strata bound the trough to the west, and to the east the trough is delimited by a cliff forming the western side of the Gheringoma Plateau (underlain by Cretaceous and Tertiary beds) [36.2, 36.3].

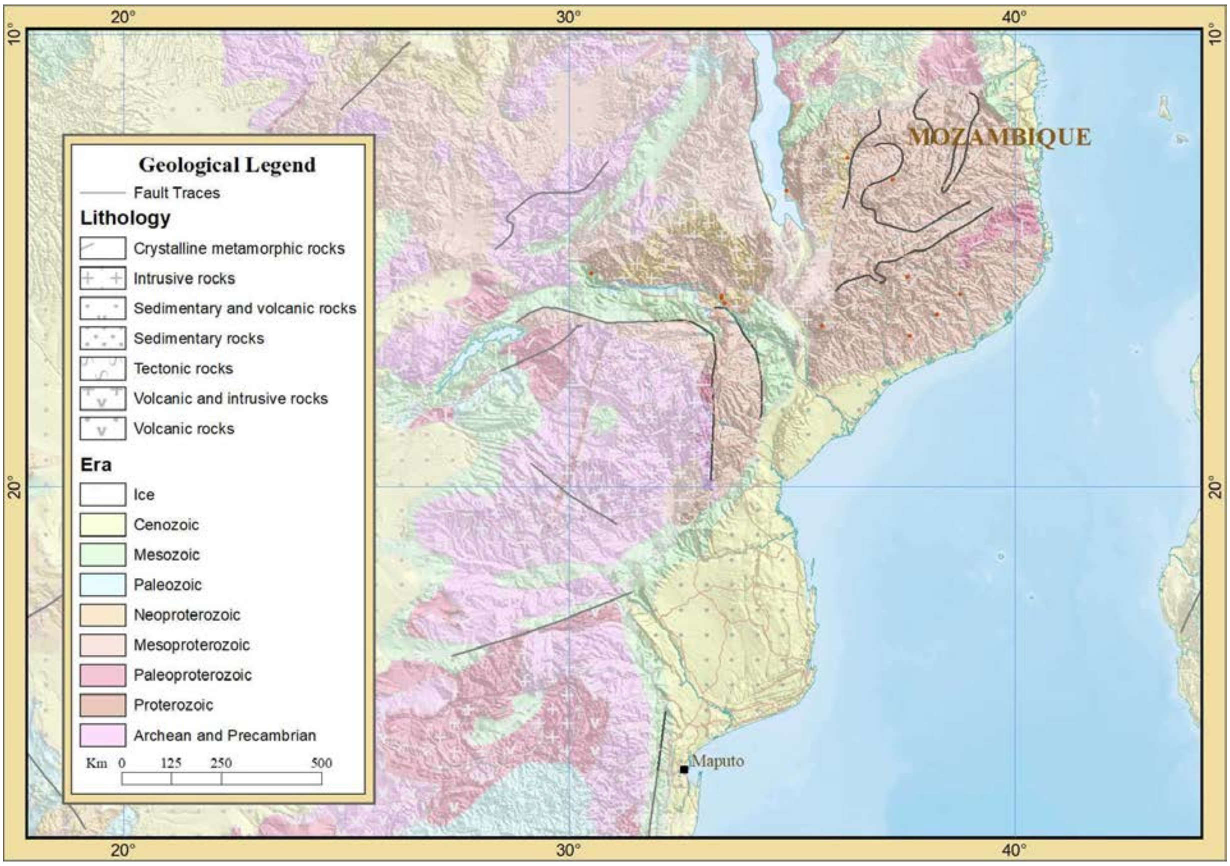


FIG. 3.51. Regional geological setting of Mozambique. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.36.2. Uranium exploration

Exploration for radioactive raw materials was carried out by the Portuguese Junta de Energia Nuclear in the early 1950s. Radiometric and magnetometric aerial surveying was done over four areas totalling 30 000 km². The areas host: (i) continental Karoo cross-bedded conglomerate beds that are rich in carbonaceous material, (ii) granite–gneiss complexes, (iii) gabbro–anorthositic rocks in which radioactivity has been recorded, and (iv) zones in gneisses and granites that have undergone major tectonism. As a result of this survey, together with the follow-up field work, it was concluded that the numerous radioactive anomalies were caused principally by thorium, although some were related to uranium.

From 2005, Australia's Omega Corporation Ltd was exploring the Mavuzi project, which is located roughly 40 km north-west of the provincial centre of Tete in north-western Mozambique and comprises four licences covering approximately 700 km². The central licence covers the historical Mavuzi uranium mine. The company planned a small-scale drilling programme for 2007. By February 2010, the project had been acquired by United Kingdom's North River Resources Plc which was evaluating historical data from a British Geological Survey that was believed to detail rare earth element potential in the Mavuzi area [36.3–36.6].

3.36.3. Uranium resources

There are no exploitable uranium resources in Mozambique. In 1983, IUREP reported a range of 10 000–50 000 tU of speculative resources in sandstone and vein type environments [36.7].

The UDEPO database does not list any known deposits for Mozambique.

3.36.4. Potential for new discoveries

The oldest Precambrian rocks consist of highly metamorphosed gneisses, granites and schists. The occurrences of uranium in the Precambrian suggest that these rocks are 'fertile' and that vein or unconformity-related uranium mineralization could have been formed in these formations.

Good potential exists for finding uranium in the Karoo Series in the western part of the country. The stratigraphic successions appear to be similar to the Karoo strata of South Africa, Zambia and Madagascar, where numerous uranium occurrences are known. Cretaceous and Tertiary sediments crop out in the coastal region and extend inland for a distance of up to 100 km. There is the possibility that continental or marginal marine facies exist in the sequence, which could be prospective, especially where they overly Precambrian strata. The carbonatites in the Tete district could also be worthy of further evaluation [36.3].

3.36.5. Uranium production

The Mavuzi mine was discovered in 1947 and is located approximately 40 km north-west of Tete. A second production centre, the Castro mine, was located 8 km north-west of Mavuzi. Production from the area amounted to approximately 34 tU between 1947 and 1955. Production reportedly continued up to 1974, although no production data are available for the later period [36.4].

References to Section 3.36

[36.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Mozambique (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[36.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 180–183.

[36.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[36.4] DAVIDSON, C.F., BENNETT, J.A.E., The uranium deposits of the Tete district, Mozambique, Mineral. Mag. **29** (1950) 291–303.

[36.5] OMEGA CORPORATION LTD, Strike extensions at Mavuzi mine in Mozambique (25 July 2005).

[36.6] NORTH RIVER RESOURCES PLC (2010), http://www.northriverresources.com

[36.7] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.37. NAMIBIA

Namibia is situated in south-west Africa, bordering the Atlantic Ocean. It shares borders with Angola and Zambia to the north, Botswana to the east and South Africa to the south.

The Namibian landscape consists of five geographical areas, each with its own characteristic conditions and vegetation: (i) the Central Plateau, home to the highest point in Namibia at Königstein (2606 m); (ii) the Namib Desert, a broad expanse of hyper-arid gravel plains and dunes that stretches along the entire coastline; (iii) the Escarpment; (iv) the Bushveld and (v) the Kalahari Desert. Although the climate is generally extremely dry, there are a few exceptions. The cold, north flowing Benguela current passes along the coast and accounts for some of the low precipitation.

Namibia's economy is based primarily on mining and manufacturing and the country is the fourth largest exporter of non-fuel minerals in Africa and the world's fourth largest producer of uranium. Rich alluvial diamond deposits make Namibia a primary source of gem quality stones. Namibia also produces large quantities of copper, gold, lead, manganese and zinc [37.1].

3.37.1. Geology

Namibia's geology encompasses rocks of Paleo-, Meso- and Neoproterozoic and Paleozoic to Cenozoic age (Fig. 3.52). About 46% of the country's surface consists of bedrock exposure, while the remainder is covered by the young surficial sediments of the Kalahari and Namib deserts.

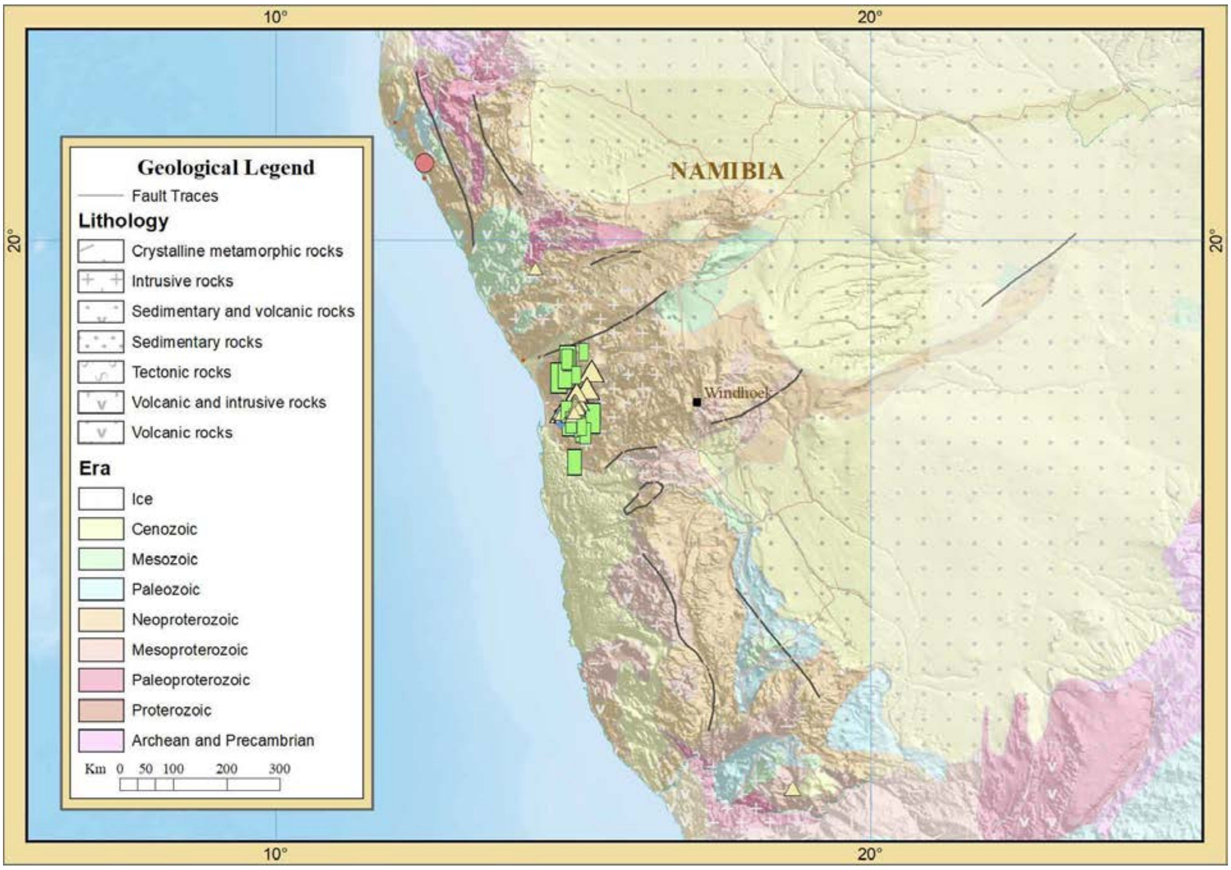


FIG. 3.52. Regional geological setting of Namibia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The geology of Namibia is dominated in the north by metasediments of the Neoproterozoic Damara Orogenic Belt (or Namibian System), while in the south large areas are underlain by the unmetamorphosed, relatively undisturbed sediments of the Cambrian Nama Group. Locally, within the Damaran terrain, inliers of older basement occur, for instance in the extreme northwest at the Kunene River the oldest rocks of the country belong to the Paleoproterozoic (about 2,100 Ma) Epupa Metamorphic Complex. Only slightly younger are metamorphic rocks of the Huab Complex west of Outjo. Similar ages are also recorded from rocks of the Grootfontein Metamorphic Complex in the northeast of the country. The Rehoboth-Sinclair Complex in Namibia's southwest is of late Paleo- or Mesoproterozoic age. The Namaqua Metamorphic Complex consists of metasediments originally eroded from the Congo and Kalahari Cratons [37.2].

Granitic and metabasic intrusions also occur. These are of Mesoproterozoic age and cover large areas in the south and south-west of the country. Rocks of the Damara Orogenic Belt are of Neoproterozoic age and are widespread in central and northern Namibia. They consist primarily of high grade metamorphics, but granitic intrusions are also frequent. The overlying Cambrian age Nama Group rocks in central southern Namibia consist of marine sediments, indicating a shallow shelf environment.

No deposition is recorded of Cambrian tillite, which marks the beginning of the Karoo episode. In its basal phase, the tillite is characterized by glacial sediments of the Dwyka Group. It is followed by continental sediments of the Omingonde Formation in central Namibia. The Permo-Triassic Karoo Sequence is intruded primarily by Mesozoic dolerite sills and dyke swarms, which, together with extensive basaltic volcanism and alkaline subvolcanic intrusions, are related to the break-up of Gondwanaland and the formation of the South Atlantic Ocean during the Cretaceous. The latest episode in Namibia's geological history is represented by the widespread Cenozoic–Recent deposits comprising the Kalahari sequence [37.2].

3.37.2. Uranium exploration

In 1928, G.P. Louw discovered uranium mineralization in the vicinity of the Rössing Mountains in the Namib Desert. Over many years Louw tried unsuccessfully to promote the prospect, but it was not until the late 1950s that Anglo American Corporation evaluated the area by drilling and limited underground exploration. As a result of the erratic uranium values encountered and the poor economic prospects for uranium prevailing at the time, the company abandoned the search.

With an upswing in uranium demand and prices, extensive uranium exploration in Namibia started again in the late 1960s. Three fundamentally different types of uranium deposit were investigated: intrusive, evaporitic and sedimentary. With the exception of some in the latter category, all deposits occur within the narrow coastal tract of desert known as the Namib.

Exploration involved one or more of the following types of campaign:

(a) Airborne and ground radiometric surveys;
(b) Radiometric borehole logging;
(c) Geological mapping;
(d) Percussion and diamond drilling to depths of up to 500 m;
(e) Radon emanometry;
(f) Laboratory research on borehole cores and surface samples;
(g) Open pit and underground bulk sampling;
(h) Pilot plant test work and geological, metallurgical, mining and engineering feasibility studies.

Numerous local and foreign based companies, as well as the Namibian Geological Survey and the South African Atomic Energy Board, were involved in the exploration and research effort.

Several airborne radiometric surveys were conducted by the Namibian Geological Survey during this period and numerous uranium anomalies were identified. One of these developed into the Rössing deposit, for which Rio Tinto had obtained exploration rights in 1966. This deposit was developed by a large scale open pit mine, which started production in 1976 [37.3].

In 1994, the Directorate Geological Survey, Ministry of Mines and Energy, embarked on a programme of high resolution (200 m line spacing, 80 m ground clearance) airborne magnetic and radiometric surveys. The aim of the surveys was to stimulate mineral exploration with the aim of achieving complete national coverage by 2010.

The surveys of particular interest from a uranium exploration perspective were Erongo, flown in 1995 (286 429 line km); Kunene, also surveyed in 1995 (277 532 line km); Aus, flown in 1999 (150 613 line km); Warmbad, flown in 2000 (127 287 line km) and Kuiseb, flown in 2005 (156 670 line km).

The Erongo survey not only provided detailed information over previously known deposits but also identified other potential areas not considered during previous exploration conducted during the 1970s. Similarly, the other airborne surveys also attracted interest but in this instance more for 'greenfield' uranium exploration projects.

The geological history leading to the formation of deposits of the Rössing type is as follows. Arenaceous sediments of the Nosib Group were deposited on an Archaean basement and were subsequently overlain by the pelitic and chemical sediments of the Swakop Group. The Nosib and Swakop Groups make up the Damara Supergroup and were subjected to high grade metamorphism during the Pan-African Orogeny (850–540 Ma). Extensive granitization and granitic intrusion occurred. The red granite–gneiss suite, derived from both the basement and the Nosib rocks, and the Salem granitoid suite, derived from the Swakop rocks, were thus formed. Although these granites may contain anomalous concentrations of uranium, it is the late phase alaskite granites which host the uranium mineralization. In all cases, the deposits are associated with anticlinal or dome-like structures and their sizes and grades are apparently controlled by the first marble band in the Swakop Group, which acted as a trap for the intrusive alaskites. The uranium concentrations in these deposits are erratic and can range from trace amounts up to 1.0% U, but with a comparatively low average grade of around 0.03–0.04% U. Uraninite is the principal uranium mineral.

Development of the Rössing mine, combined with a significant increase in uranium prices, stimulated extensive exploration activity, principally in the Namib Desert. Two major types of deposit were identified, including the intrusive type, associated with alaskite at Rössing, and the surficial calcrete type. Of the intrusive deposits, other than Rössing, only the Trekkopje deposit hosts significant resources, whereas the most significant surficial calcrete deposit is Langer Heinrich. Feasibility studies were carried out on several of these low grade deposits but once again low prevailing market prices led to a cessation of further work.

The occurrence of uranium at a few localities in sediments of the Karoo Supergroup has been known since the early 1970s. In particular, the Engo Valley deposit, occurring in sediments of the basal Dwyka Formation, has been actively prospected.

Figure 3.53 summarises uranium exploration expenditure for a total of USD $1 387 091 364 including 3 595 513 metres of drilling and 351 848 km^2 of airborne radiometric surveys [37.5–37.21]. This is considered a minimum estimate due to confidentiality of some private sector data.

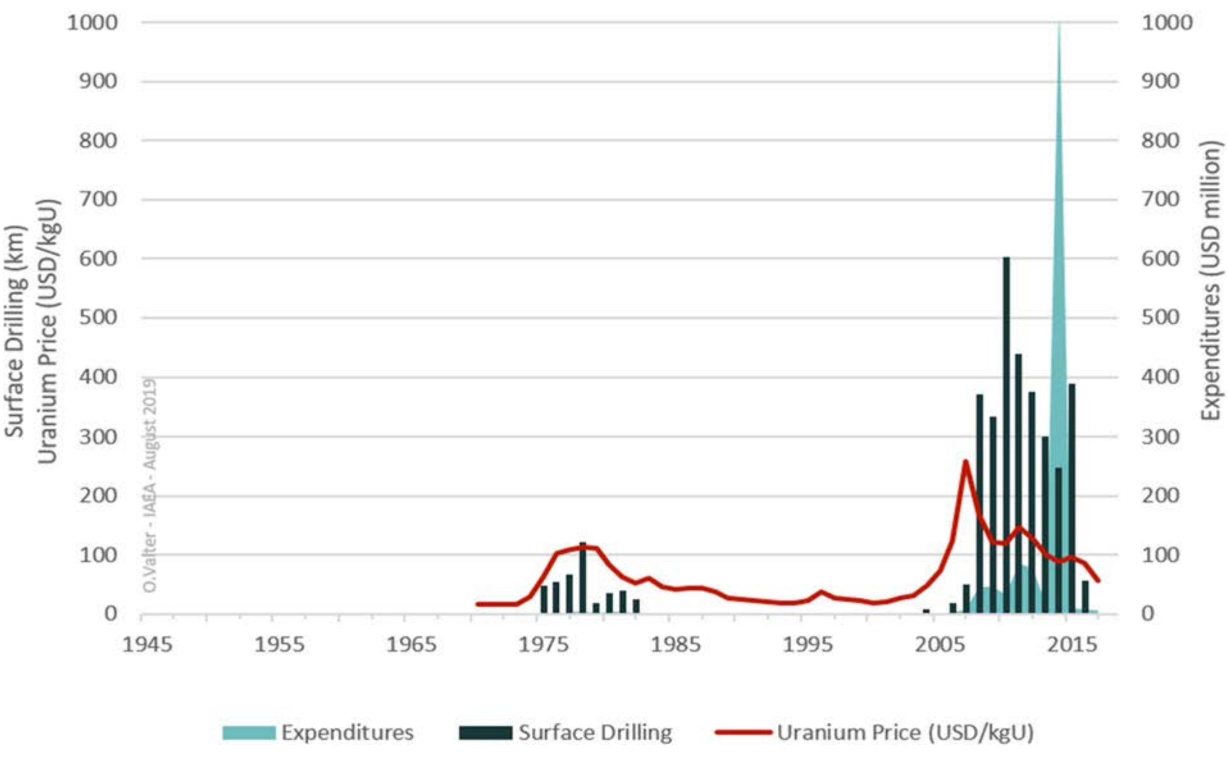


FIG. 3.53. Domestic uranium exploration data for Namibia. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

3.37.2.1. Recent exploration and development work

Major drilling programmes have been conducted in support of proposed expansions of the Rössing and Langer Heinrich mines, ongoing development of the Trekkopje mine and continuing evaluation of several deposits for possible mine development, including Husab, Etango, Marenica, Rössing South and Omahola deposits.

The combined effect of political uncertainty and the decline in uranium prices caused the rapid curtailment of exploration and development work in the early 1980s. This was untimely, as the refinement of exploration techniques, which had proved to be so successful in the Namib Desert, were poised to locate a number of potential new deposits. Prior to the 2002 upturn, the continued weakness of the uranium market discouraged further exploration activities, except in the immediate vicinity of the Rössing mine. However, the post-2002 upturn in demand for uranium stimulated exploration and made possible the development of the Langer Heinrich deposit and the discovery of several large deposits in alaskites and surficial formations [37.4–37.21].

To extend Rössing's mine life beyond 2020, exploration was resumed in 2006 on uranium occurrences within the mining licence area. These had been known since the late 1970s, but were not economic in the past owing to unfavourable market conditions. The evaluation included drilling a total of 70 000 m during 2006–2008. An exercise to determine the level of information available on the various anomalies was carried out during 2005 and culminated in a target list which was scheduled for follow-up work. The main targets were termed the SH and SK areas and potential high priority 'P1' targets, whereas the Z19, Z8 and Z10 areas were identified as potential second priority 'P2' targets.

Follow-up included the setting up of a drilling project to drill the SH and SK anomalies to the Joint Ore Reserves Committee (JORC) inferred resource level which would be used as the basis for deciding on future work in these areas. This campaign involved 14 000 m of drilling. The programme was re-evaluated and the total amount of drilling required for the work revised upwards to 74 000 m, with an expected outcome of identifying a JORC indicated resource.

As of October 2007, 18 000 m (comprising 13 000 m of diamond drilling and 5000 m of reverse circulation) had been drilled. This has resulted in a preliminary evaluation of the SH as a 100 million t deposit with a grade of 140 ppm U. Work is being carried out to ensure that the identified plant process is optimized and that capital cost is evaluated on the basis of a desktop design. The SK area is not yet at the evaluation stage; information is currently only being gathered. However, a feasibility study is in progress on the SK4 section of the SK area to evaluate the potential for developing a starter pit targeting the SK4, 5, 10 and 19 anomalies, all if which had drilling information gathered in a 1977–1978 drilling programme.

The Langer Heinrich project is located in western central Namibia about 45 km south-east of the Rössing mine. It lies 80 km east of the major deep water port at Walvis Bay and the coastal town of Swakopmund.

General Mining and Finance Corporation Ltd (Gencor), now part of BHP Billiton, carried out extensive evaluation work of the Langer Heinrich project over an eight-year period following the discovery of calcrete-hosted uranium mineralization in the early 1970s. Gencor spent approximately US $8.5 million and completed a full project evaluation study in 1980 which was based on conventional open pit mining and alkaline extraction of uranium. Gencor's evaluation included detailed resource definition work and comprehensive mining, metallurgical and mineral processing studies. Approximately 25 000 m of percussion drilling, 2000 m of diamond drilling and excavation of thirty-two 2 m × 1 m exploratory shafts (up to 22 m in depth) were carried out to establish the necessary confidence in the deposit's ore reserve status. The Gencor studies included excavation of about 300 000 t of mineralized rock, the construction of a 300 000 t/year dry screening plant and the completion of an intensive and detailed metallurgical investigation utilizing a purpose-built pilot plant which operated from 1977 to the end of 1979.

While the study indicated that the project had good potential for development, it was subsequently placed on hold owing to the depressed uranium prices prevailing at the time. In 1998, the project was sold to Australia's Acclaim Uranium NL.

Acclaim Uranium NL completed a prefeasibility study at a cost of US $1.26 million that included 2800 m of reverse circulation drilling (107 holes), geochemical, geostatistical, ore resource re-evaluation, metallurgical, engineering and baseline environmental studies. Although the results of the study were favourable, the depressed prevailing market price of uranium again curtailed further development.

In 2005, a reverse circulation drilling programme was carried out in order to increase confidence in resource modelling and to delineate extensions to known uranium mineralization in the palaeochannel. The drilling programme totalled 11 534 m and was confined to selected target areas.

A bankable feasibility study was completed in April 2005 and this confirmed that Langer Heinrich could be developed as a profitable uranium mining operation. Mining licence no. 140 was granted in 2005. Construction at the Langer Heinrich project commenced in September 2005.

In 2006, reverse circulation drilling was carried out in order to establish indicated and measured mineral resources and to increase inferred mineral resources in the eastern portion of the Langer Heinrich orebody. A total of 6355 m was drilled. Since the potential for increasing the resource base was regarded as high, a further resource definition campaign, comprising some 11 000 m of reverse circulation drilling, commenced in 2007 with the aim of determining the extent of all the mineralization occurring within the Langer Heinrich mining lease. At the same time, a reverse circulation resource infill drilling programme of approximately 10 000 m was conducted to upgrade inferred resources.

The mine was officially opened in 2007 and Langer Heinrich achieved a production of 1039 tU in 2008–2009 and stage 2 expansion to increase production to 1423 tU/year was completed in 2010. The stage 3 expansion phase, which further increased production to 2000 tU/year, was completed in 2012.
Langer Heinrich is a calcrete-related uranium deposit associated with valley fill sediments occurring within an extensive Tertiary palaeodrainage system. The calcretes are chemical precipitates that developed under arid to semi-arid climatic conditions. At Langer Heinrich, calcretization has affected a complex sequence of conglomerates, grits, sandstones, silts and clay in a braided stream depositional environment. The uranium mineralization occurs as carnotite, an oxidized secondary mineral containing both uranium and vanadium. The deposit extends over 15 km and consists of seven higher grade pods occurring within a lower grade mineralized envelope. The carnotite occurs as thin films lining cavities and fracture planes and as grain coatings and disseminations in the calcretized sediments. Mineralization varies in thickness in the range 1–30 m and is 50–1100 m wide, depending on the width of the palaeovalley.

After the uranium mineralization event, the calcrete sediments were eroded as a result of uplift and consequential rejuvenated river flow. These drainage channels have dissected and modified both the calcrete and associated mineralization. The deposit is blanketed by up to 8 m of river sands and scree associated with the prevailing ephemeral drainage system.

Trekkopje lies about 80 km north-east of Swakopmund and 35 km north of Rössing. In 2007, South Africa's UraMin Inc. announced an upgrade of uranium resources at the project, comprising two adjacent palaeochannel deposits (Klein Trekkopje being the main one) over an area of about 16 km × 1–3 km. The company was subsequently acquired by France's AREVA. The project will have a shallow open pit mine and a sodium carbonate/bicarbonate heap leach process, the world's first such operation. Around 80% of the ore occurs at a depth of less than 15 m. Water is to be supplied from a coastal desalination plant with an output of about 55 000 m^3/d and requiring 16 MW(e), which is sourced from the grid.

A substantial conversion of inferred resources to reserves occurred as a result of drilling in 2006 and 2007, taking the measured and indicated resource category to 42 000 tU in the main deposit. AREVA quoted 45 600 tU of resources in 2008. Output of over 9000 t of vanadium pentoxide by-product is also envisaged.

A mining licence was granted in June 2008 and production was expected to commence at the end of 2009, ramping up to 3500 tU/year by 2011. However, AREVA announced in October 2012 that it would postpone the launch of the Trekkopje mine until the project's economics improve. Production was 251 t in 2012 and 196 t in 2013 before the mine was put into care and maintenance.

In July 2007, Forsys Metals Corporation of Toronto announced measured and indicated resources of 16 000 tU at its Valencia uranium project, which is located along strike from Rössing and near to Langer Heinrich. Inferred resources are estimated at 8000 tU and the geology is similar to that at Rössing (alaskites). Environmental approval for an open pit mine was granted in June 2008 and a mining licence was granted in August 2008 to Valencia Uranium P/L, a subsidiary of Forsys, allowing production to begin in 2010. In 2014, Forsys Metals resource estimation was 41 580 t U at 130 ppm. The project is dormant since.

In 2007, Canada's Xemplar Energy Corporaton announced a new uranium province in the Warmbad area along the Orange River in the south of the country. The company is drilling two large zones which host similar mineralization to that at Rössing and also Karoo sandstone formations. These outcrops are two among a group of 14 which crop out over an area of 40 km × 28 km [37.5–37.21].

In August 2008, Australia's Bannerman Resources announced indicated resources of 26 000 tU and inferred resources of 15 000 tU at Goanikontes (Anomaly 1 deposit, Etango project), 30 km south-west of Rössing and 40 km east of Swakopmund. The company is proceeding with a definitive feasibility study for mining, effective as of 2011. The alaskite ore is very similar to that at Rössing. In October 2010, Bannerman Resources announced measured and indicated resources of 57 400 tU and inferred resources of 24 800 tU. The company completed its definitive feasibility study for the Etango project in April 2012. The alaskite ore is very similar to that mined at Rössing, although marble is absent. The project is dormant since.

In July 2008, Marenica Energy Ltd announced a 13 000 tU inferred resource in a palaeochannel deposit (surficial fluvial-valley) at Marenica, 40 km north of Trekkopje. In 2017 Marenica Energy Ltd resources stand at 22 060 t U at 80 ppm.

3.37.3. Uranium resources

Tables 3.19 – 3.20 summarize data on Namibia's uranium resources. The historic variation in identified resources is shown in Fig. 3.54 and Fig. 3.55.

The UDEPO database lists the most significant deposits for Namibia as Rossing, Rossing South–Zone 2, Rossing South–Zone 1, Anomaly A (Etango), NUC (Rossing SW), Langer Heinrich, Z 20, Valencia.

3.37.3.1. Identified resources

TABLE 3.19. REASONABLY ASSURED (IN SITU) RESOURCES BY DEPOSIT TYPE (tU) [37.22]
(As of 1 January 2017)

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Intrusive	0	252 057	285 227
Surficial	0	83 262	83 262
Total	0	335 319	368 489

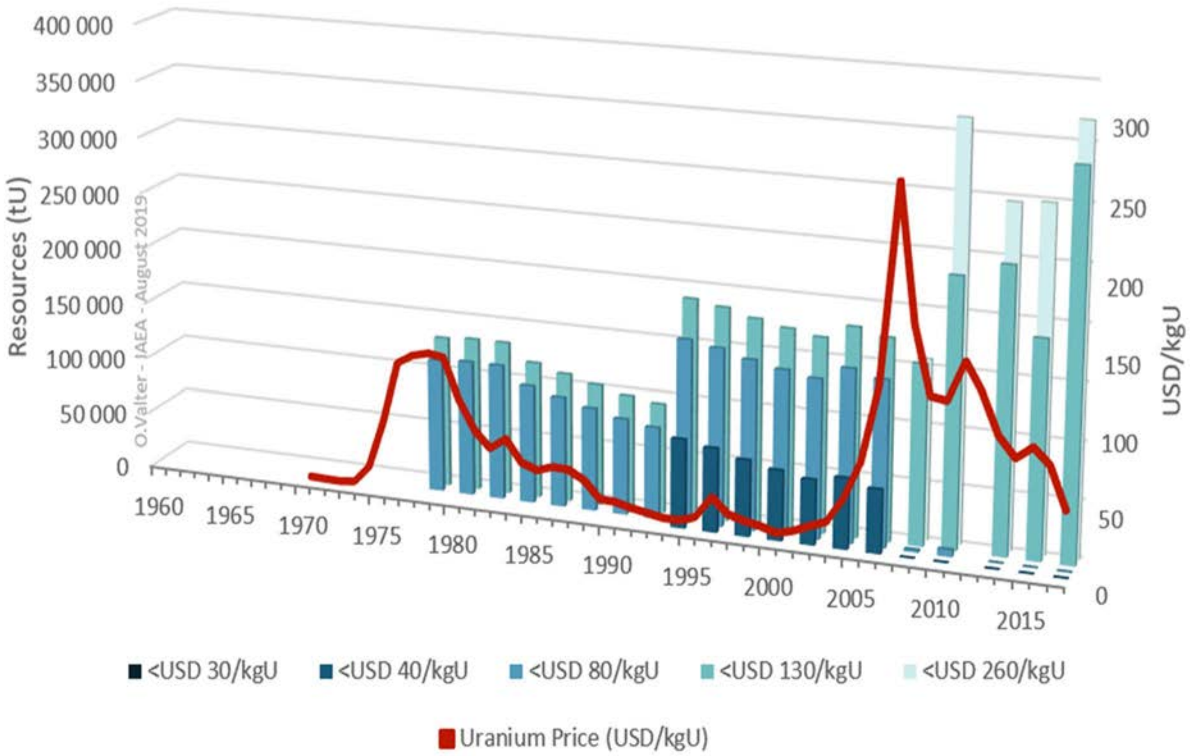


FIG. 3.54. Historical variation of recoverable reasonably assured resources within various cost categories in Namibia. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

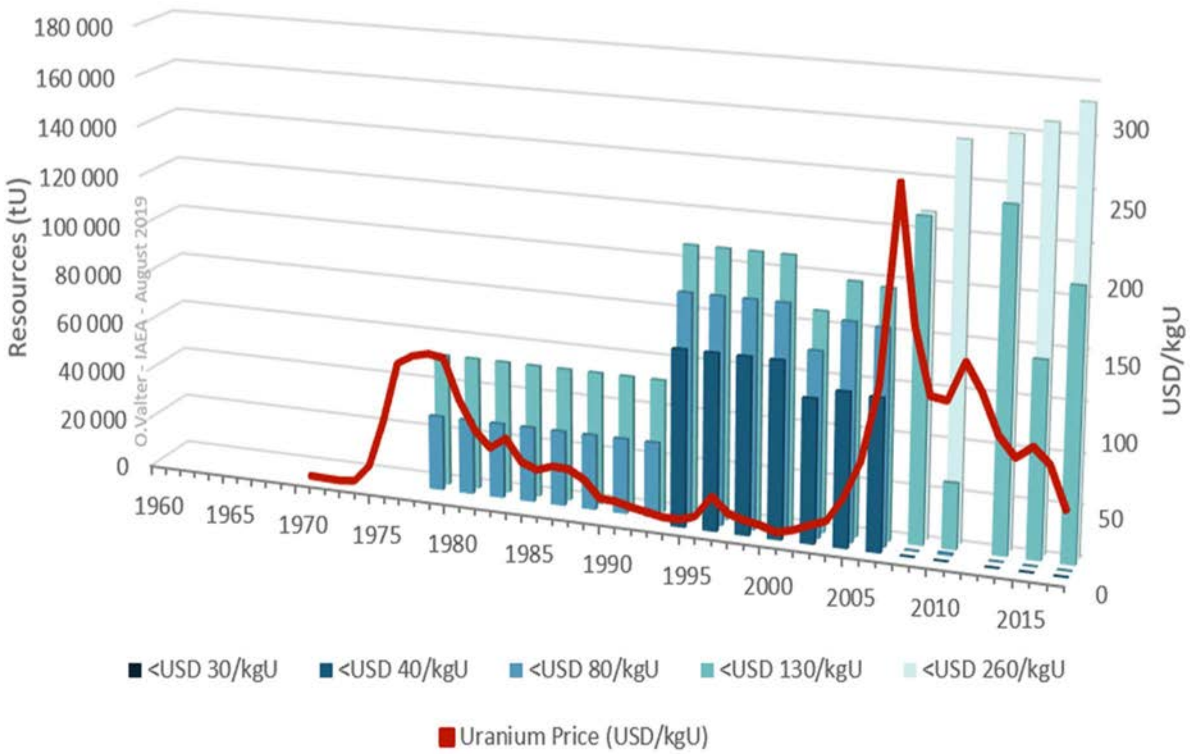


FIG. 3.55. Historical variation of recoverable inferred resources within various cost categories in Namibia. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

TABLE 3.20. INFERRED (IN SITU) RESOURCES BY DEPOSIT TYPE (tU) [37.22]
(As of 1 January 2017)

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Intrusive	0	88 741	129 405
Surficial (calcrete)	0	18 012	43 452
Total	0	106 753	172 857

3.37.3.2. Undiscovered resources

In addition to the identified resources hosted by the Rössing and Valencia alaskite type deposits, which are located in the Precambrian Damara Orogenic Belt, and those resources associated with surficial calcretes (Langer Heinrich and Trekkopje), Namibia has significant potential for undiscovered uranium resources. Namibia does not report prognosticated or speculative resources.

3.37.4. Potential for new discoveries

Although not quantitatively assessed, Namibia's uranium potential is considered greatest in the following geological environments:

(a) The 5000 km² granitic terrain of the Damara Belt is largely overlain by surficial deposits and/or wind-blown semi-consolidated sand. Past investigations focused principally on airborne radiometric anomalies. Substantial additional resources, potentially the size of the Rössing deposit, are suspected of occurring under the surficial cover;
(b) The Tertiary–Recent surficial sedimentary terrains occurring in semi-arid areas, where additional potential for calcrete deposits is thought to exist. Eleven of 38 identified regional airborne anomalies were investigated by extensive drilling, adding identified resources to Namibia's resource inventory. In most cases, the drilling encountered low grade mineralization associated with calcrete filled palaeochannels.

Another potentially favourable geological environment occurs in the sandstone basins hosting Permo-Triassic Karoo sediments. These strata were extensively investigated in South Africa in the early 1970s and have also been explored in Namibia. The Karoo sediments are extensively dissected by river systems in north-western Namibia, and airborne radiometric expressions are consequently very pronounced. Ground follow-up, including substantial drilling, has delineated 1638 t U at 340 ppm in the Engo Valley deposit. However, this was not included in the identified resources owing to high recovery costs.

3.37.5. Uranium production

In August 1966, the Anglo-Australian company Rio Tinto Zinc (RTZ) acquired the exploration rights for the Rössing deposit and conducted an extensive exploration programme that lasted until March 1973. After a feasibility study that included surveying, mapping, drilling, bulk sampling and metallurgical testing in a 100 t/d pilot plant, a production centre was established. Rössing Uranium Ltd was formed in 1970 to develop the deposit. RTZ was the leading shareholder with 51.3% of the equity (at the time of the formation of the company). Mine development commenced in 1974 and commissioning of the processing plant, and initial production took place in July 1976. In 1977, a full design capacity of 3845 tU/year was established, but owing to the highly abrasive nature of the ore, an aspect not identified during the pilot plant testing stage, the production target was not reached until 1979, following major plant design changes. As the result of a sharp increase in the prevailing market price of uranium and a detailed feasibility study, the mine life was recently extended to 2016. In order to prepare the extension of the open pit to access the ore, waste has been removed from the south-east and north-west flanks of the open pit (7.5 million t and 16.8 million t during 2005 and 2006, respectively). The objective was to increase annual production to 3400 tU in 2007, then to 3800 tU in 2008 and to 4500 tU by 2012. To the end of 2017 the Rossing mine has supplied 112 453 tU with an annual 2008-2017 production fluctuating between 1050 and 3500 t/year. In November 2018, Rio Tinto agreed to sell its 68.6% stake in Rössing to China National Uranium Corporation Ltd [37.22].

In August 2002, Australia's Paladin acquired 100% of Langer Heinrich Uranium (Pty) Ltd, the Namibian registered company holding the project rights. Subsequently, a prefeasibility study was completed, followed by a bankable feasibility study. The year-long study was completed in April 2005 by Australia's GRD Minproc (Pty) Ltd. The feasibilty study confirmed that a large body of uranium mineralization exists at Langer Heinrich which could be mined by open pit. The study concluded that both indicated and measured resources support a minimum mine life of 11 years and a process plant life of 15 years. On the basis of a projected mill throughput design capacity of 1.5 million t/year, the feasibility study showed 1000 tU/year could be produced for the first 11 years at a head feed grade of 0.074% U and 340 tU/year over the final four years, using the accumulated low grade (0.027% U) stockpile.

Full scale development of the mining operation proceeded after receipt of a 25-year mining licence granted by the Ministry of Mines and Energy on 15 September 2005. Production at Langer Heinrich started in late 2006. Plans exist for increasing production to 2000 tU/year. In 2014 CNNC Overseas Uranium Holding Limited (CNNC Overseas) bought a 25% joint venture equity stake in the mine. In April 2018 Paladin suspended operations at the mine pending improvement in prices and went into care and maintenance [37.22]. Cumulative production to 2018 is 16 671 t U and remaining resources about 47 500 t U.

Historical uranium production is detailed in Fig. 3.56 for a total of 127 256 tU.

A summary of the operations at Rössing, Langer Heinrich and Trekkopje is given in Table 3.21.

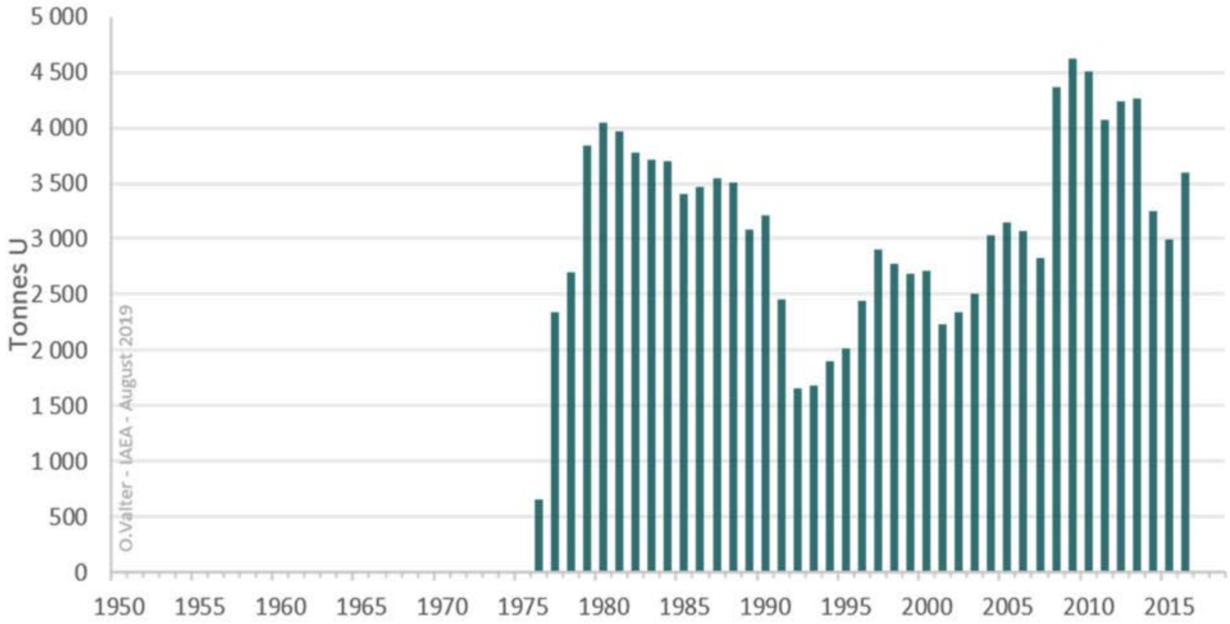


FIG. 3.56. Historical uranium production in Namibia [37.5–37.21].

TABLE 3.21. URANIUM PRODUCTION CENTRE TECHNICAL DETAILS [37.21]
(as of 1 January 2009)

Parameter	Production centre		
	Rössing	Langer Heinrich	Trekkopje
Start-up date	1976	2006	2013
Type of ore	Intrusive	Calcrete	Calcrete
Mining type	Open pit	Open pit	Open pit
Reserves (tU)	75 000	79 000	45 000
Grade (%U)	0.03	0.06	0.011
Average mining recovery (%)	85	90	90
Processing plant	Acid	Alkaline	Alkaline
Type	AL[a]/IX[b]/SX[c]	IX/SX	HL[d]/IX
Size (t ore/d)	30 000	8 000	25 000
Average process recovery (%)	78	85	80
Production capacity (tU/year)	3 817	1 425	1 600

[a] AL: acid leaching.
[b] IX: ion exchange.
[c] SX: solvent exchange.
[d] HL: heap leaching.

3.37.6. Future projects

The Trekkopje mine, located 20 km north of Rössing, was expected to start production by the end of 2011. Although the ore is low grade (averaging 0.011% U), most of it is located at shallow depth and the deposit should therefore be relatively inexpensive to mine. Production is targeted at 1600 tU/year initially, scaling up to 3200 tU/year by 2011. Small quantities of by-product vanadium will also be produced. Heap leach processing is expected to be used over the eight-year operating life of the facility. In 2013, AREVA (now Orano) has taken a decision to postpone the commissioning pending a recovery in the market price of uranium. The mine is under care and maintenance.

Valencia, located 35 km east of Rössing, is another project with near term production potential, although no mine development schedule has as yet been announced. Nonetheless, commissioning could take place in 2011, with initial production amounting to as much as 1000 tU/year. In 2018, the project is dormant.

3.37.7. Environmental activities

The Namibian constitution provides for the protection of the environment and the welfare of all humans. The Minerals Policy of 2003 aims to attract investment in mining by creating an environment conducive to business while also ensuring compliance with national environmental policy and legislation to promote the development of a sustainable mining industry. The Minerals (Prospecting and Mining) Act 1992 (Act No. 33 of 1992) requires every licence holder to conduct environmental impact assessments before they start exploration. Namibia's Environmental Management Act 2007 (Act No. 7 of 2007) came into effect in 2012 and stresses the importance of sustainable management of the environment. The principles of the Act state that any person responsible for damaging the environment must pay the associated costs and mines are required to comply with the regulations and conditions of the Environmental Management Act 2007 (Act No. 7 of 2007).

Namibia implemented a globally unique strategic environmental assessment for the central Namib uranium mining province in 2010. This is a decision making support tool which analyses the cumulative economic, social and environmental impacts of uranium mining and exploration activities in the uranium province and throughout the Erongo region in general [37.23].

The practical implementation of the strategic environmental assessment is based on a multi-stakeholder agreed strategic environmental management plan, which includes 12 environmental quality objectives covering such aspects as socioeconomic development, employment, infrastructure, water, air quality and radiation, health, tourism, ecological integrity, education, governance, facility closure, and land use. A broad stakeholder steering committee oversees and guides the implementation of the recommendations and the monitoring of the environmental management plan.

A strategic environmental management plan office has been established by the Ministry of Mines and Energy (Directorate Geological Survey of Namibia). The overall aim of the strategic environmental management plan process is to gauge whether the region moves towards or away from sustainable development. Political will, enabling policies and mutually beneficial partnerships, in combination with capacity building, transparency and consistency in decision making, will ensure that prospecting and mining in Namibia is beneficial and not detrimental.

Monitoring at the Rössing mine addresses: radiation protection; sealed sources and their control; medical surveillance; air quality, including greenhouse gas emissions; water utilization and seepage management; waste (hazardous and non-hazardous mineral and non-mineral wastes) and dust; biodiversity and occupational hazards related to all operations.

A stability assessment of the tailings impoundment carried out in 2006 confirmed the stability of the facility. There were no changes to the waste rock 'footprint' in terms of land area during the review period, although the heights of the waste dumps had increased. The life of mine plan includes changes that will occur to the waste dump footprint in the period 2008–2016 and is being thoroughly evaluated as part of the environment management plan that is maintained with the Department of Environment.

As Namibia's producing uranium mines are located within the Namib Desert, the principal environmental consideration concerns the management of available water resources. Potable water for the Rössing mine, as well as for the coastal towns of Walvis Bay and Swakopmund, is supplied from aquifers on the deltas of Kuiseb and Omaruru Rivers. To preserve the limited water resources and to save the cost of pumping over long distances, the management of Rössing has undertaken an integrated water management programme. This programme has resulted not only in the reduction of water consumption by the mine but has also minimized groundwater contamination.

Effluent management principally consists of water recycling. Fresh water is added to the processing plant where it is used to produce uranium. The wastewater, together with a much larger volume of recycled water, is then used to pump the tailings to the tailings dam. Some water is lost from the tailings dam owing to evaporation and storage within the tailings material. However, over 60% of the wastewater pumped to the dam is recovered and returned to the processing plant. The volume of fresh water added is determined by the water loss due to evaporation and adsorption. Any additional fresh water is stored in the tailings dam for later use. No wastewater is discharged into the environment. On an annual basis, approximately 60–70% of the fresh water used is recycled. The mine closure plan was updated during 2005, consistent with the new mine plan which extends the mine life to 2016.

Established in 1976, the mining town of Arandis was handed over to the Government of Namibia some two years after Namibia's independence, and became a town with an elected Town Council to manage its affairs. In 2000, with the closure of the mine envisaged as being a few years away, and with the town and its inhabitants still greatly dependent on the mine's economic benefits, Rössing Uranium decided to open a Rössing Foundation office, which came into operation in Arandis and the Erongo region in 2002. In November 2003, the office started to broaden its developmental functions, while actual programme implementation started in earnest in January 2004. Along with the community's input, the Rössing Foundation initially identified six work areas in the Arandis programme, focusing on improving schools, tourism opportunities, business development, local government and infrastructure, and the promotion of recreational, cultural and agricultural activities. The Rössing Foundation's activities were reviewed during April 2006. Following this review, a new reporting structure was introduced and areas of focus identified. The scheme became operational in December 2006. Education became the primary focus area, while work with the Arandis Town Council was regarded as crucial to the sustainability of Arandis [37.24].

Following this, a decision was taken that Rössing would assist the Arandis Town Council in selected infrastructure development projects, while the Rössing Foundation would focus on capacity building. Health and safety became additional operational areas, focusing specifically on HIV/AIDS. The historical costs of environmental management up to 2000 are given in Fig. 3.57 totalling ZAR 44.831 million.

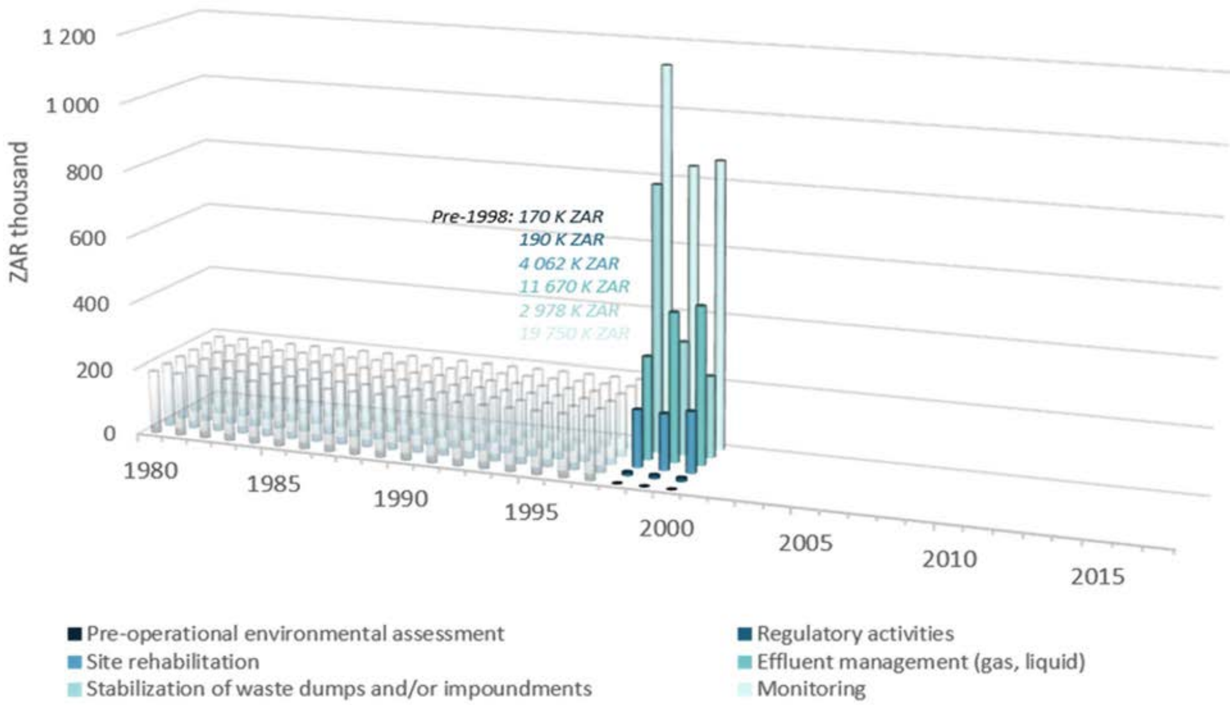


FIG. 3.57. Environmental management expenditures for Namibian uranium mining (in South African Rand, ZAR).

3.37.8. Employment in the uranium industry

Details of employment in Namibia's uranium industry for 1992–2017 are given in Fig. 3.58 indicating a total of approximately 54 000 person -years and 13 300 person-years for production centres and direct uranium production activities respectively.

3.37.9. National policies relating to uranium

The Government of Namibia supports the development of a sustainable Namibian uranium mining sector in line with international best standards and practices. Uranium is defined as a controlled mineral and Section 102 prohibits the export, processing, possession and enrichment of uranium without Government consent.

The Government is in the process of developing effective regulatory frameworks to ensure proper management of exploration, extraction and development of nuclear fuel minerals.

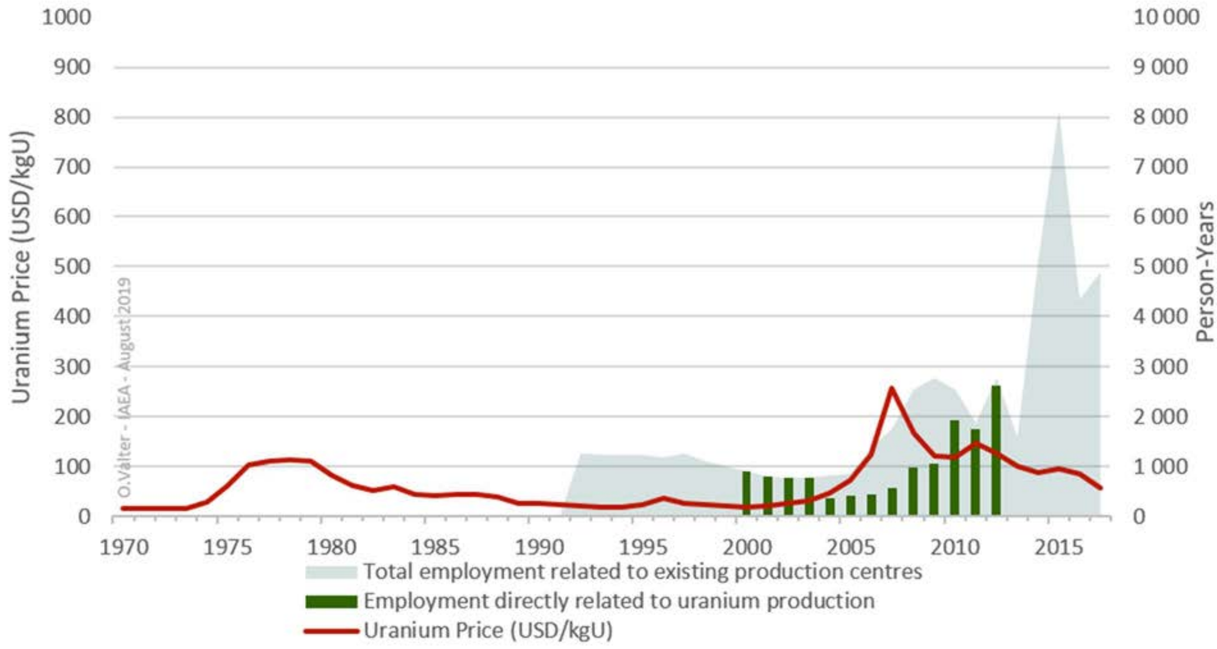


FIG. 3.58. Uranium industry employment at existing production centres (person-years) ZAR South African rand [37.14–37.21].

References to Section 3.37

[37.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Namibia, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[37.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 184–188.

[37.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[37.4] WORLD NUCLEAR ASSOCIATION, Uranium in Namibia (2008), http://www.world-nuclear.org/info/inf111.html

[37.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[37.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[37.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[37.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[37.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[37.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[37.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[37.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[37.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[37.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[37.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[37.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[37.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[37.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[37.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[37.20] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[37.21] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[37.22] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).
[37.23] WORLD NUCLEAR ASSOCIATION, Uranium in Namibia https://www.world-nuclear.org/information-library/country-profiles/countries-g-n/namibia.aspx (2018)
[37.24] MINISTRY OF MINES AND ENERGY, Strategic Environmental Assessment for the Central Namib Uranium Rush, Geological Survey of Namibia and Federal Institute for Geosciences and Natural Resources, Hanover (2010).

3.38. NIGER

Niger is a landlocked nation in West Africa and borders the Sahara and sub-Saharan regions. The country is a transitional region between savannah and desert. The Niger River crosses the south-west corner of the country and north-eastwards from it stretches an extensive plateau area which is mainly desert or semi-desert. In the north of the country, the topography is more accentuated by the Aïr Mountains and the extensions of the Hoggar Mountains from Algeria. The lowest elevation (200 m) is recorded by the Niger River and the highest point is Mont Idoukal-n-Taghès in the Aïr Massif at an elevation of 2022 m. Niger's subtropical climate is mainly very hot and dry. In the extreme south, a tropical climate exists on the edges of the Niger River basin. The terrain comprises predominantly desert plains and sand dunes, with flat to rolling savannah in the south and hills to the north.

Communications are generally difficult and related to the problems incurred by the large expanse of desert terrain. One all-weather road has been built between the coast in Benin and the mining area at Arlit to ensure the supply of mining equipment.

Niger's economy is based largely on subsistence crops, livestock and some of the world's largest uranium deposits. Exploitable deposits of gold are known to exist in the region between the Niger River and the border with Burkina Faso. Substantial deposits of phosphates, coal, iron, limestone and gypsum have also been found. Several oil companies have explored for petroleum since 1992 in the Djado plateau, in north-eastern Niger, and in the Agadem Basin, north of Lake Chad, but to date no discoveries have been worth developing.

Uranium is mined close to the towns of Arlit and Akokan, 900 km north-east of the capital Niamey (more than 1200 km by road), on the southern border of the Sahara Desert and on the western flank of the Aïr Mountains [38.1].

3.38.1. Geology

Precambrian rocks underlie large parts of Niger (Fig. 3.59), but Cenozoic continental weathering products and sand dunes conceal most of the Precambrian rocks. Paleoproterozoic rocks are exposed west of Niamey, forming a continuation of Birimian rocks from Burkina Faso. Other Precambrian rocks occur in the Aïr Massif in the north of the country. Neoproterozoic rocks crop out south of Niamey along the border with Benin and Burkina Faso, in a continuation of the Volta Basin. Paleozoic sediments occupy parts of northeastern Niger and the Agadez Basin west of the Aïr Massif. Cretaceous marine and epicontinental sediments of the Iullemiden Basin occur in central Niger. Volcanic activity, with associated lava, tuff and ash deposition has been recorded from some places intermittently since Devonian times [38.2].

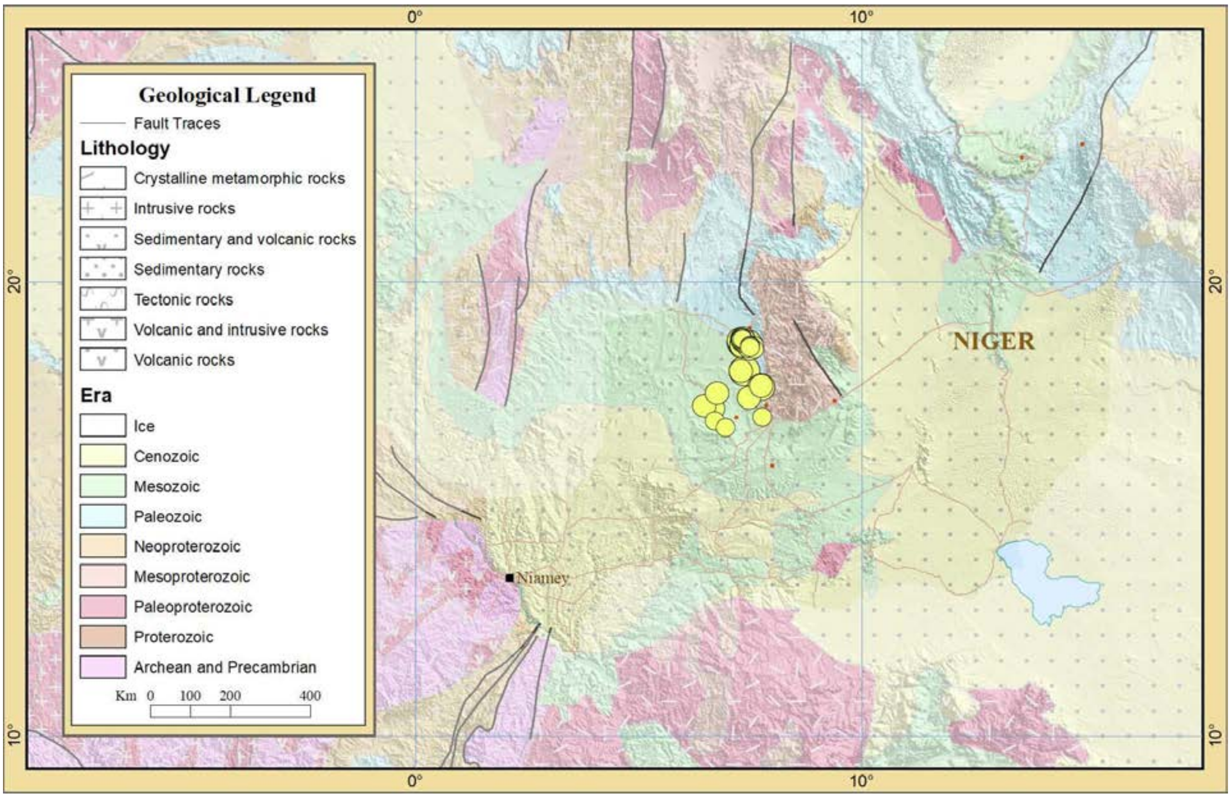


FIG. 3.59. Regional geological setting of Niger showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The broad valley of the Niger River in the south-west of the country lies on a crystalline basement, which, on the eastern bank of the river, dips under sandstones of various ages which form a plateau sloping towards Lake Chad. A large crystalline massif, the Aïr Massif, is mainly formed by Precambrian gneisses and granites, with some Quaternary lavas, tuffs and ashes. The Aïr Massif separates a number of basins, of which the Agades (or Tim Mersoï) Basin is the most important and is situated near the north-eastern part of the extensive Iullemeden Basin. It is bordered to the east by the Precambrian crystalline rocks of the Aïr Massif and to the north and north-west by the crystalline mass of the Hoggar [38.3].

Upper Cretaceous rocks and the Cenozoic rocks of the Iullemeden Basin lie to the west and south. To the east of the Aïr Massif, recent sands overlie the Cenozoic sediments of the Tenere, and in the extreme north-east of the country lie the mountains of the Djado (an extension of the Hoggar). The Djado Mountains have a crystalline core and are surrounded by Carboniferous, Triassic and Lower Cretaceous strata (Continental Intercalaire) similar to those in the Agades Basin, where they host uranium mineralization. The Agades Basin contains an assemblage of sedimentary clastic rocks, 1000–1500 m in thickness, which were deposited on a relatively stable platform. The rocks range from the Silurian, which rests unconformably on the ancient rock basement, to the Upper Cretaceous. This assemblage is arranged in large sedimentary units, each about 200–300 m in thickness. The region had been occupied by the deltas of large rivers, but intercalated in the succession are marine sequences. The sedimentary assemblage is normally characterized by its grey colour, as typified in the Upper Carboniferous stratigraphic units, corresponding to a fluviodeltaic or marginal marine facies.

Beginning with the Cenomanian transgression, the colour of the sediments is generally red. The structure of the area is to a large extent inherited from the Precambrian structural alignments. The volcanic activity which periodically affected the adjacent Precambrian massifs during the Devonian–Jurassic contributed ash and tuffaceous material which was laid down contemporaneously with the sediments. Carbonaceous material and coals exist in the sedimentary series and red bed copper mineralization is found.

Niger's main uranium resources are all hosted by the sediments of the Tim Mersoï sub-Basin, which is mainly the continental part of the sedimentary layers of the Iullemeden Basin. The large deposits mined by Compagnie Minière d'Akouta (COMINAK) and Société des Mines de l'Aïr (SOMAÏR) are located, respectively, in the Guezouman conglomeratic formation of Viséan age and in the younger Tarat sandstone formation which is of Namurian age. Upwards in the sedimentary pile, other mineralization and deposits have been identified, the most important one being the Imouraren deposit located in the Tchirezrine sandstone (Jurassic).

All projections, both laterally and down dip in the Agades Basin, must be regarded as favourable for uranium occurrence. The comparable geology of the Djado region in the extreme north-east must also be considered as being geologically favourable for the discovery of uranium deposits [38.2–38.4].

3.38.2. Uranium exploration

Uranium exploration in Niger was initiated by France's Atomic Energy Commission (CEA) and followed later (1976) by Compagnie Générale des Matières Nucléaires (COGEMA), which initially concentrated exploration on the granites of the Aïr Massif. However, by the end of the 1950s, the target had switched to the sedimentary formations of the Tim Mersoï Basin, on the western side of the Aïr mountain range. Uranium was discovered in sandstone at Abakorum (1959), Madaouela (1963), Arlette, Ariege, Artois, Tassa and Taza, near Arlit (1965), which led to further development work and the formation, in 1968, of SOMAÏR to mine the Arlit deposits.

COMINAK was formed in 1974 to exploit the Akouta deposit and mining started in 1978. Geologically, all of these resources are in deposits of the sedimentary type and hosted in sandstone or continental pelitic formations belonging to the Carboniferous and, to a lesser extent, Jurassic systems (Imouraren).

Exploration was also conducted in the Djado Basin (north-east of Niger), but without success. In subsequent years, both SOMAÏR and COMINAK conducted exploration solely to improve knowledge of existing deposits. SOMAÏR delineated the Taza Nord deposit, while COMINAK evaluated a mineralized area located south-east of the Akola deposit. Exploration activities slowed in 1981 and 1982, and some exploration concessions were cancelled. Work, however, still continued within the Imouraren and Afasto-Ouest joint ventures with Niger's Office National des Ressources Minières (ONAREM).

The Imouraren and Afasto-Ouest joint ventures involved COGEMA, Conoco and ONAREM and COGEMA, the Overseas Uranium Resources Development (Japan) and ONAREM, respectively. The Abakorum-Azelik concession was also explored in a joint venture between Japan's International Resources SA and ONAREM. Similarly, the Sekiret concession was a joint venture between Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC) and ONAREM.

The Afasto-Ouest partners presented a feasibility report in March 1982 demonstrating the existence of a deposit of 25 000 tU of reasonably assured resources and 60 000 tU of estimated additional resources (EAR-I). Between 1983 and 1986, exploration concentrated on the Abakorum, Azelik and Sekiret licence areas. At Abakorum, a mineralized zone was discovered by drilling in the upper part of the Madaouela Series, and at Sekiret, close spaced drilling proved the presence of about 4000 tU, with an average grade of 0.11% U, over a thickness of 2.9 m. In 1987 and 1988, exploration activities decreased. Exploration drilling declined progressively from over 23 500 m in 1986 to 10 000 m in 1987, and to 2200 m in 1988. The area held under exploration licence decreased to 5400 km² in 1988, in contrast to 7390 km² in 1987.

Since 1993, both SOMAÏR and COMINAK have carried out significant drilling campaigns. The results of the drilling led to a reassessment of the resource estimates of the Takriza and Tamou deposits by SOMAÏR, as well as further evaluation of the south Akouta and Akola deposits by COMINAK. In 1997 and 1998, SOMAÏR drilled 598 percussion holes, totalling 47 431 m, focusing on the Tamou deposit. A 25 m drill hole spacing was used to delimit the deposit. The limits of mineralization were established to the north and further reconnaissance was undertaken within the adjacent barren cover. To further investigate the Akola deposit, COMINAK drilled 100 holes, totalling 20 659 m. In 1999 and 2000, COMINAK drilled 82 holes totalling 17 854 m to complete the evaluation of the Akola deposit. In 2002, Niger restarted uranium exploration with the Tagora project. This project aimed, in the first phase, to improve the definition of uranium resources near the SOMAÏR and COMINAK mine sites, and in a second phase, to discover additional resources in the region. A resource of 500 tU was discovered in the Tabelle area, and a potential for 16 000 tU was confirmed at the Ebba deposit. On 1 September 2004, the Government of Niger and COGEMA signed a mining agreement to restart exploration. In 2004, a total of 9657 m of drilling was carried out in COGEMA's Arlit concession. In 2004, SOMAÏR continued the development of the Artois deposit, including conduct of a feasibility study which confirmed a resource of 7921 tU mineable at a grade of 0.30% U, and re-evaluation of the Tabelbelle-Takriza area resource. COMINAK completed development drilling on the Akola deposit. A drilling programme of 83 holes totalling 20 023 m was carried out on the Afasto concession and mineable resources were estimated at 15 737 tU. A potential 21 172 tU was reconfirmed in the Ebba deposit.

3.38.2.1. More recent uranium exploration and mine development activities

The revitalization of uranium exploration in Niger began in early 2006, with a total of six new exploration permits granted that year. Among these, the most advanced were the Imouraren exploration permit granted to AREVA NC Niger, and the Teguidda permit granted to the China National Uranium Corporation (CNUC). AREVA NC Niger conducted intensive drilling campaigns on the Imouraren deposit.

Exploration of the Azelik deposits by CNUC started in 2006 and continued in 2007 to confirm the existing resources. SOMAÏR drilling campaigns were conducted to define the north and south extensions of the Tabele deposit. Mine development of the Tamgak deposit started in 2006 and continued in 2007. Further delineation of the southern part of the Ebba deposit was undertaken by COMINAK.

In 2007–2008, activities focused on resource development in the vicinity of the existing mine sites in an effort to expand the resource base in the western Arlit area. Several deposits in this area were also under development (Ebba, Tamgak and Tabele). New exploration and development projects, which included intensive drilling campaigns on the Azelik, Imouraren and Teguidda deposits, continued through 2009 [38.5–38.25].

In 2007 GoviEx acquired the Madaouella and Anou Melle permits containing some historical resources discovered in 1963-1965 by the French CEA at Marianne and Marilyn. Between 2008 and 2012 a total of 2391 holes for 189 km were drilled on the Marianne and Marilyn deposits and 4680 holes for 504 km on adjacent areas permitting the discovery of new deposits such as Maryvonne, Miriam and La Banane. In 2013, total compliant resources for 7 deposits were standing at 55 481 t U at an average grade of 0.135% [38.26]. A mine permit was granted in 2016.

Also, in 2007, Global Atomic Fuels Corp (GAC) had 2 permits granted for exploration, Adrar Emoles 3 and 4, located about 50 km SW of the Imouraren deposit and where uranium was known at Dajy. In 2011, GAC announced the discovery of a new deposit, Dasa. The mineralization is contained in a horst and graben environment with up-thrust blocks. A mineral resource estimation was published in 2013 for the Dasa deposit: 31 955 t U at a grade of 0.132%. The mineral resource estimation was updated in 2017: 43 582 t U, 0.29%. Total geological resources stand at 74 459 t U, at a grade of 0.072% [38.27].

Figure 3.60 summarizes historical exploration data for an expenditure total of USD $831 688 000, including 1 960 049 metres of drilling.

3.38.3. Uranium resources

Tables 3.22–3.25 summarize the essential details and the status of the different categories of Niger's uranium resources. The historic variation in resources is shown in Fig. 3.61 and Fig. 3.62. The UDEPO database lists the most significant deposits for Niger as Imouraren, Dasa 1-2-3, Akouta Nord, Akola..

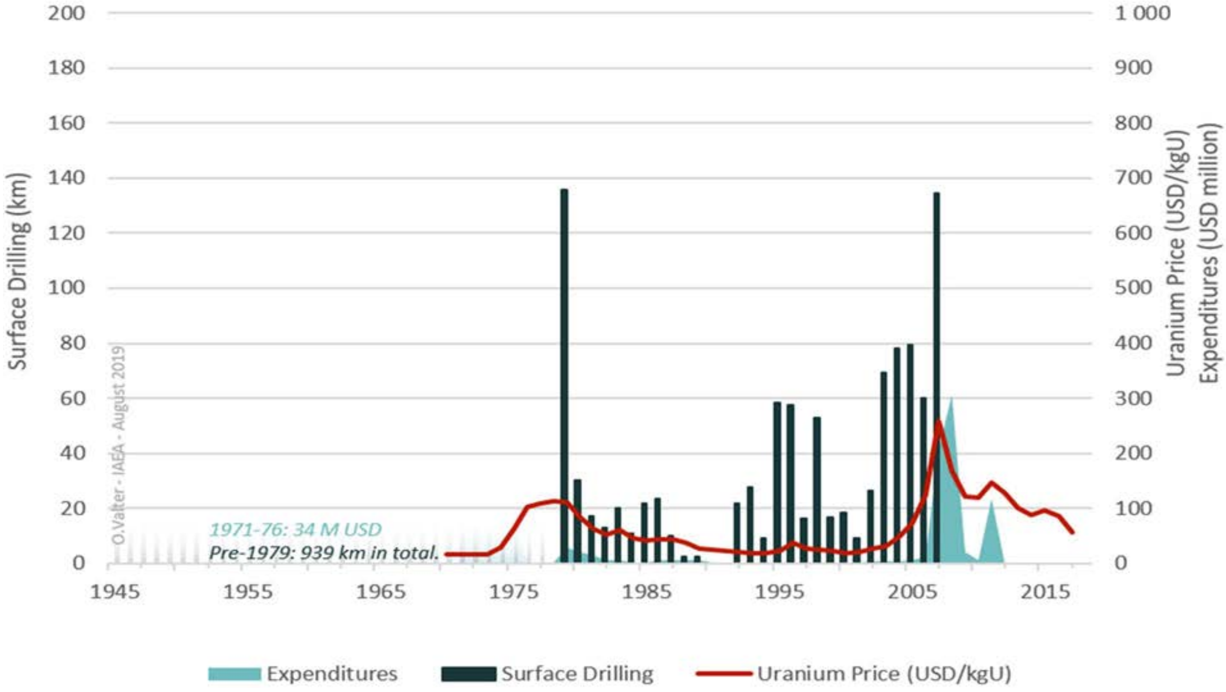


FIG. 3.60. Domestic uranium exploration data for Niger. Comparison of exploration expenditures, drilling and uranium market price (US$ current) [38.5–38.25].

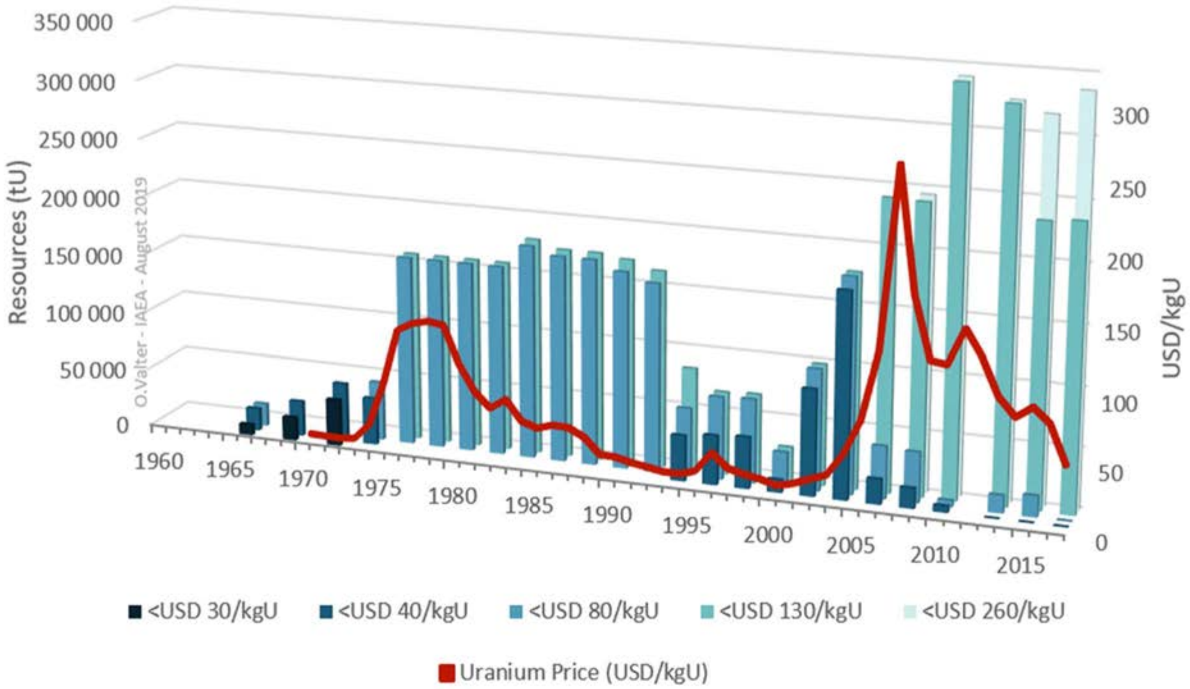


FIG. 3.61. Historical variation of recoverable recoverable reasonably assured resources within various cost categories in Niger. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

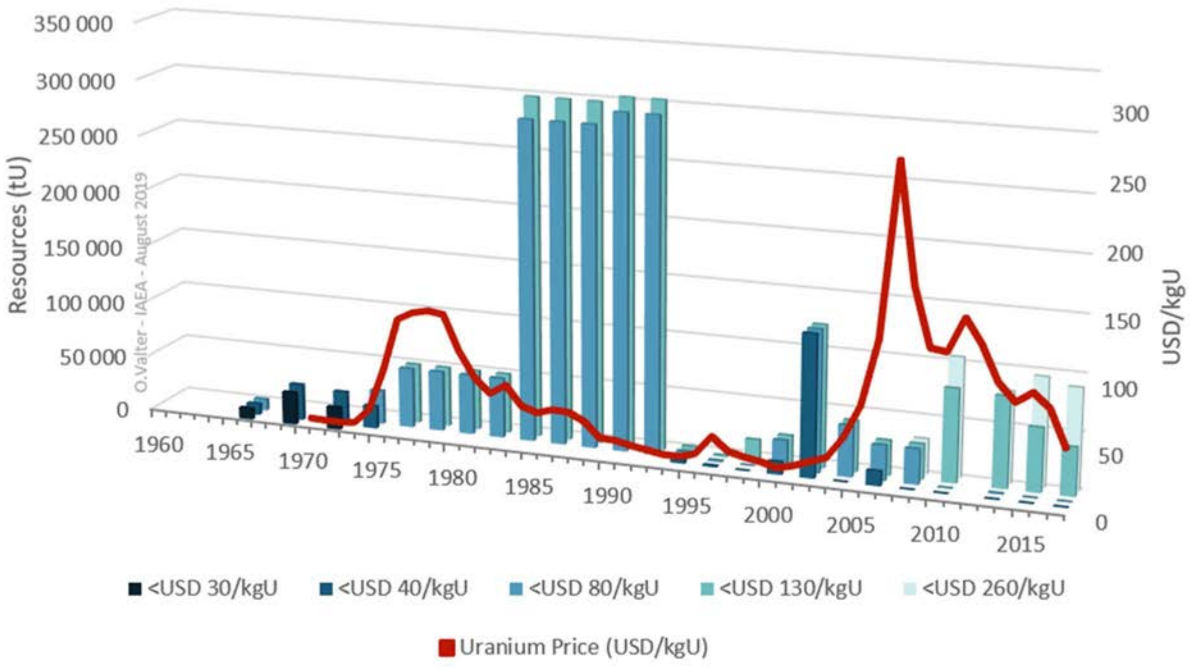


FIG. 3.62. Historical variation of inferred resources within various cost categories in Niger. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

3.38.3.1. Identified resources

TABLE 3.22. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE (tU) [38.25]
(As of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	0	237 449	336 358

TABLE 3.23. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [38.25]
(As of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	0	42 561	89 219

3.38.3.2. Undiscovered resources

TABLE 3.24. PROGNOSTICATED RESOURCES (tU) [38.25]

<US $130/kgU	<US $260/kgU
13 600	13 600

TABLE 3.25. SPECULATIVE RESOURCES (tU) [38.25]

<US $130/kgU	<US $260/kgU
0	51 300

3.38.3.3. Unconventional resources

Niger does not report any unconventional resources.

3.38.4. Potential for new discoveries

The Agades Basin contains the most promising strata for potential additional deposits. Although some exploration work has already been completed, without any significant results, the Djado region in the north-east of the country could also be regarded as favourable. The Djado Mountains, which have a crystalline core, are an extension of the Hoggar and are surrounded by Carboniferous, Triassic and Lower Cretaceous rocks similar to those in the Agades Basin. The area in the south of the country also contains rejuvenated Precambrian rocks surrounded by Cretaceous sediments and these could be worth prospecting. The area to the east of the Aïr Massif also contains Cretaceous and Cenozoic sediments, but these are overlain by recent sands and may be more difficult to explore. The area around Niamey in the south-western corner of Niger contains Palaeozoic platform sediments and Tertiary sediments overlying a Proterozoic mobile belt.

3.38.5. Uranium production

SOMAÏR was formed in 1968 and commenced production from the Arlette deposit in 1971. Open pit mining of ore grading 0.30–0.35% U was undertaken to a depth of 60 m. Capacity was expanded to about 2100 tU/year in 1981. From 2003, production has been increasing, with the Tamou deposit producing 1565 tU in 2006. In 2009 SOMAÏR started laying the groundwork for a new 1.4 million t/year heap leach operation, while planning for the next deposit, Artois. This deposit is deeper (90 m) and has a lower grade (0.20–0.25% U).

Arlette open pit began production in 1968, Ariege in 1976, Taza in 1986, Takriza in 1996 and Tamou in 1998. Through the end of 2017, SOMAIR has already produced more than 70 000 tU.

COMINAK was established in 1974 and commenced underground mining of the Akouta deposit, close to Akokan. Mining is carried out at a depth of about 250 m. Mill capacity is about 2300 tU/year. Through the end of 2017, COMINAK has produced more than 55 000 tU. Production for 2006 amounted to 1870 tU from ore grading 0.45–0.55% U. Production was switched over to the new deposit of Ebba/Afasto [38.5–38.24].

SOMINA (Société des Mines d'Azelik) was established in 2007 to mine the Azelik and Teguidda deposits by open-pit and underground methods. Production started in 2010 with a projected capacity of 700 tU/yr, but was suspended in 2015.

SOMAÏR is 63.4% owned by AREVA NC and 36.6% by ONAREM. COMINAK is 34% owned by AREVA NC, 31% by ONAREM, 25% by Japan's Overseas Uranium Resources Development Co. Ltd and 10% by Spain's Enusa SA. SOMINA is 33% owned by Sopamin (Niger), 37.2% by CNUC, 24.8% by ZXJOY Invest (China) and 5% by Trend Field Holdings SA.

Historical uranium production is given in Fig. 3.63, and Table 3.26 summarize the salient production details. In 2017, Niger produced 3485 tU (2154 t SOMAIR and 1331 t COMINAK). Cumulative production was about 143 421 tU to the end of 2017 for the country.

3.38.6. Status of production capability

In 2008, the total production capability was 3800 tU/year, which was in the process of being increased to 4500 tU/year by the construction of a heap leaching unit. The capacity of the unit will be to process ore at a rate of 1 400 000 t/year from low grade stockpiles (Table 3.27).

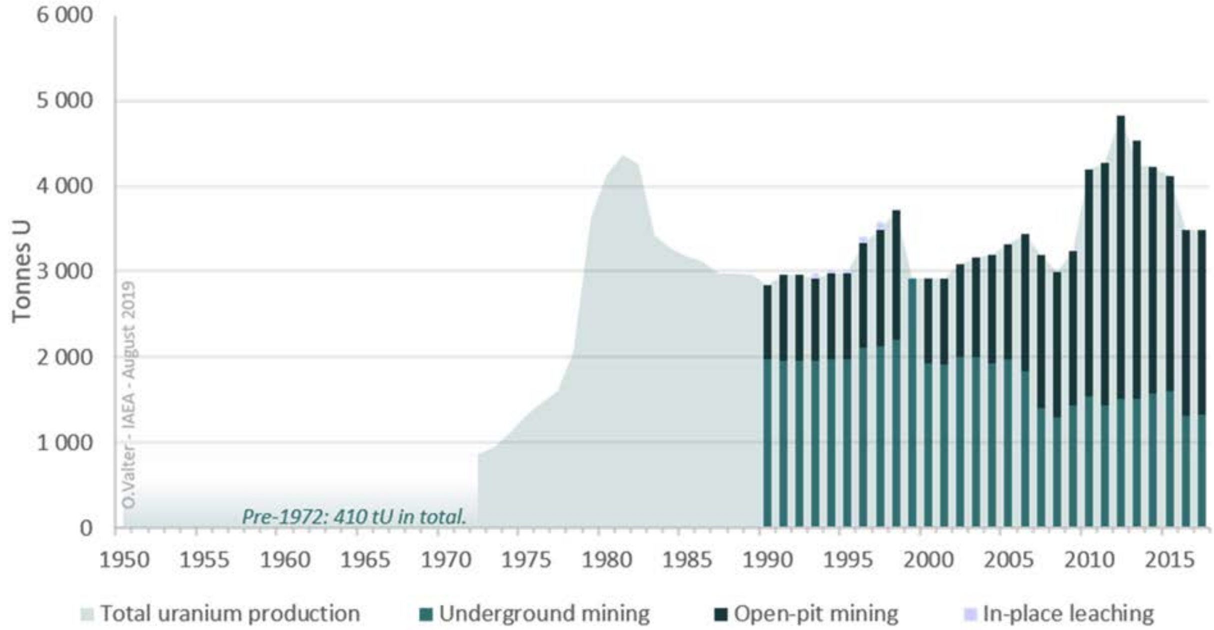


FIG. 3.63. Historical uranium production in Niger[38.5–38.24].

Table 3.26. Uranium production technical details [38.25]

Parameter	SOMAÏR	SOMINA	COMINAK	IMOURAREN
Start-up date	1970	2009	1978	
Type of ore	Sandstone	Sandstone	Sandstone	Sandstone
Mining type	OP[a]	OP/UG	UG[b]	OP
Resources (tU)	43 770	13 770	8978	227 555
Grade (%U)	0.20	0.14	0.31	0.072
Average mining recovery (%)	-	-	-	
Processing plant:				
Type	AL[c]/SX	Alkaline	AL/SX	HP/Acid
Average process recovery (%)	95	85	93	82
Production capacity (tU/year)	1700	700	1800	5000

[a] OP: open pit mining. [b] UG: underground mining. [c] AL: acid leaching. [d] SX: solvent exchange. [e] HP: heap leaching.

TABLE 3.27. SHORT TERM PRODUCTION CAPABILITY (tU/year) [38.25]
(As of 1 January 2009)

2017				2020			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
3500	3500	3500	3500	-	-	3500	3500
2025				**2030**			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
-	-	3500	3500	—[a]	—	5000	5000

[a] —: not available.

3.38.7. Future projects

On 4 May 2009, the Imouraren mine was established, which represented an initial investment of more than US $1.6 billion. The deposit covers 8 km by 2.5 km and AREVA indicated 213 700 t U reserves at 0.07% U, plus 62 500 tU indicated resources. Orebody depth is between 100 and 150 metres and maximum thickness is 60 m. At full production, the project's acid heap leaching facility will process 20 000 tonnes of ore per day with an expected 85% rate of recovery.The projected mine life when operating at full production capacity of 5000 tU/year is 35 years. Production was scheduled to start in 2013, but in May 2014, with uranium prices not sufficient to justify mining, AREVA decided to put the project into care and maintenance [38.28].

3.38.8. Environmental activities

In 2000, both COMINAK and SOMAÏR committed themselves to an environmental management system complying with ISO 14001. They were certified ISO 14001 compliant in 2002. In 2005–2006, three environmental impact assessment studies were completed to gain administrative authorization to mine the Ebba (COMINAK), Artois and Tamgak (SOMAÏR) uranium deposits. At Imouraren, AREVA will spend €6 million annually on health, education and training, as well as providing local people with access to water and energy.

3.38.9. Employment status in the uranium industry

Employment in the uranium industry increased from the start of mining operations in the early 1970s, reaching a maximum of 3935 persons in 2015 with lows during the early 2000s in parallel to the gradual reorganization of the uranium industry from 1990 (Fig. 3.64). The total is 75 677 person-years.

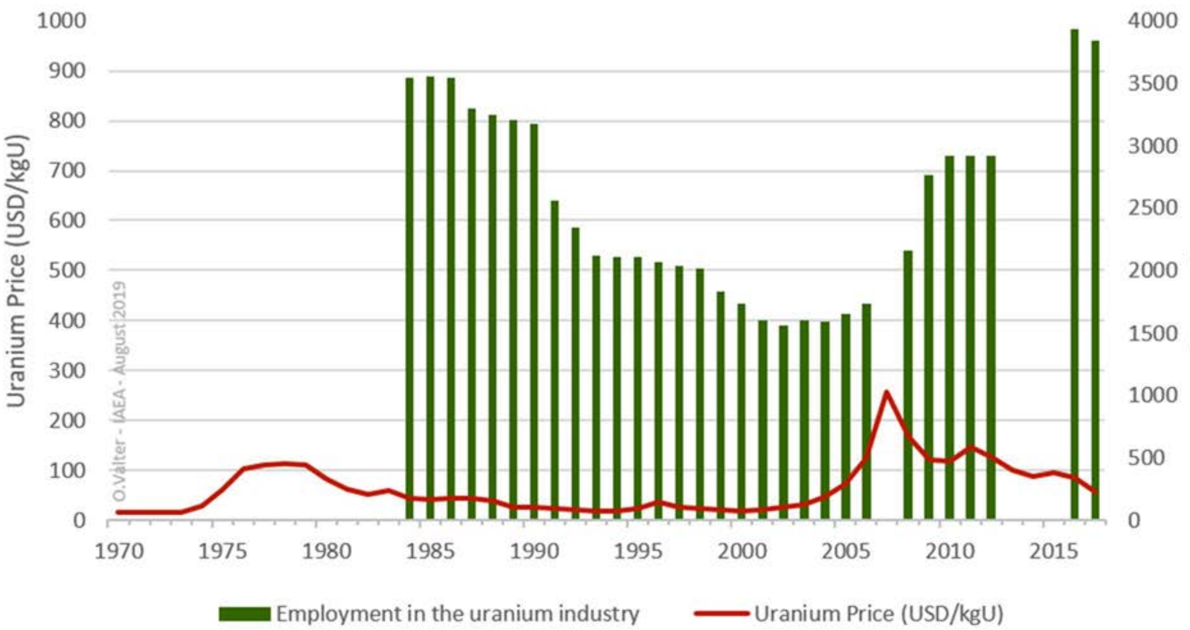


FIG. 3.64. Historical employment in uranium production in Niger [38.10–38.24].

3.38.10. National policies relating to uranium

One of the main objectives of Niger's national uranium policy is to increase the international competitiveness of its domestic uranium industry.

References to Section 3.38

[38.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Niger, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[38.2] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[38.3] CAPUS, G., BOURRELIER, P., SOULEY, M., "Uranium in Niger: Status and perspectives of a top five producing country", paper presented at World Nuclear Association Annual Symposium, London, 2004.

[38.4] OUSMANE, A., "Uranium exploration restarted in Niger", Recent Developments in Uranium Exploration, Production and Environmental Issues, IAEA-TECDOC-1463, IAEA, Vienna (2005) 59–62.

[38.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1970).

[38.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1973).

[38.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1976).

[38.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[38.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[38.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[38.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[38.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[38.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[38.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[38.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[38.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[38.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[38.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[38.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[38.20] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[38.21] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[38.22] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[38.23] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[38.24] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[38.25] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[38.26] GOVIEX URANIUM INC., An Updated Integrated Development Plan for the Madaouela Project, Niger. Prerared by SRK Consulting (2014) 384 p.

[38.27] GLOBAL ATOMIC CORPORATION, NI 43-101 Technical Report – Preliminary Economic Assessment – Dasa Uranium Project, Central Niger (2018) 220 p.

[38.28] WORLD NUCLEAR ASSOCIATION, Uranium in Niger https://www.world-nuclear.org/information-library/country-profiles/countries-g-n/niger.aspx (2018).

3.39. NIGERIA

Nigeria's most expansive topographical region comprises the valleys of the Niger and Benue Rivers. Plains rise to the north of the valleys. To the south-west of the Niger River lies rugged highlands and, to the south-east of the Benue Hills, mountains extend up to the border with Cameroon. A plain extends along the coast. Nigeria is covered by three types of vegetation: forests, savannah and mountainous terrain. Nigeria can be divided into three regions according to climate: the far south, the far north and the rest of the country. The far south is defined by its tropical rainforest climate, where annual rainfall amounts to 1500–2000 mm. The far north is defined by its almost desert-like climate reflected in an annual rainfall of less than 500 mm. The rest of the country is savannah, where annual rainfall is of the order of 500–1500 mm.

Petroleum plays a major role in the Nigerian economy, accounting for 40% of GDP. The country is the 12th largest producer of petroleum in the world, the 8th largest exporter, and has the 10th largest proven reserves. Other mineral resources include coal, tin, tungsten, columbite, tantalite, iron ore, limestone, niobium, lead and zinc. Despite having large deposits of these mineral resources, the mining industry in Nigeria is very underdeveloped [39.1].

3.39.1. Geology

Precambrian rocks cover a sizeable portion of the country (Fig. 3.65). It is commonly described as a large zone of gneisses, mica schists, schists and amphibolites that has been invaded by batholiths of older granites. Tin-bearing pegmatites are associated with the older granites.

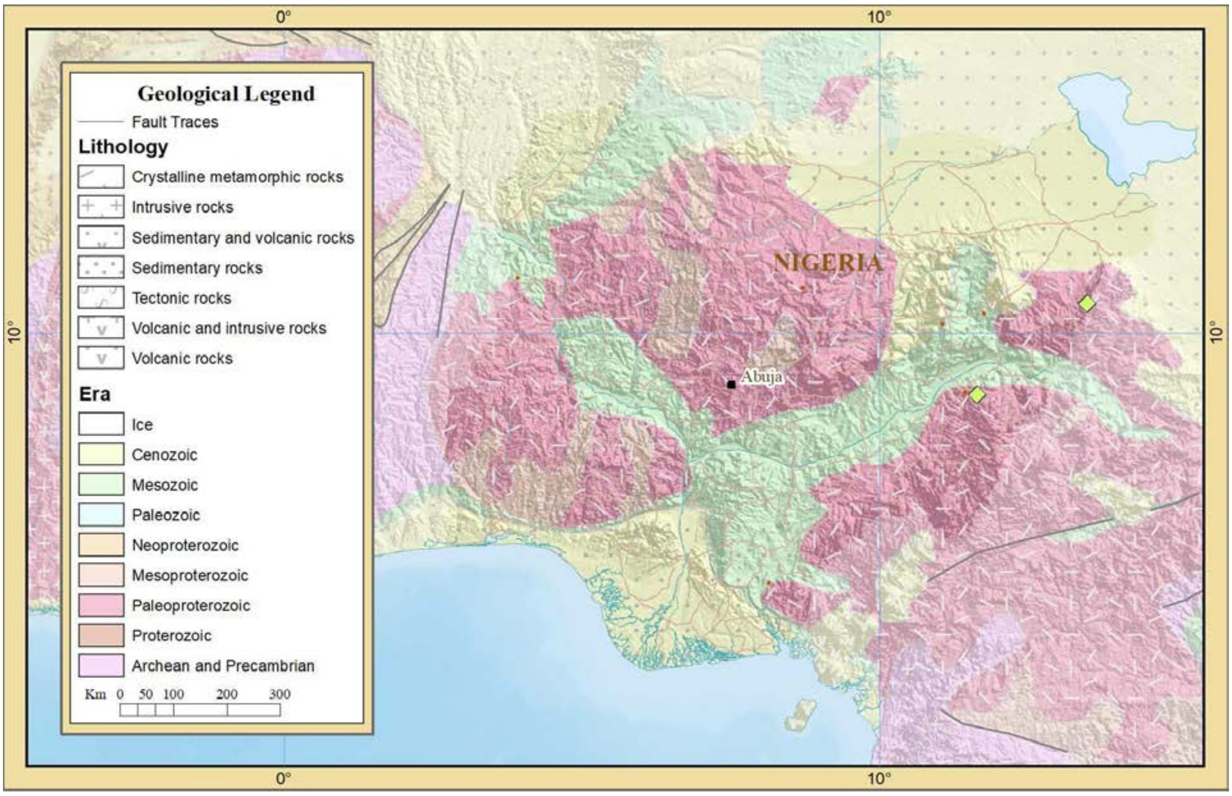


FIG. 3.65. Regional geological setting of Nigeria showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

In the Benue valley, the Lower Cretaceous (Continental Intercalaire) consists of about 500 m of sandstones, marls and variegated shales, which are sometimes saliferous (Lower Grits, Bima Sandstone, etc.). In the west, in Sokoto State, near the Burkina Faso–Niger border, the Lower Cretaceous is represented by the Illo Group, whose shaly sandstones contain silicified wood, and by the Gundumi Group. These Lower Cretaceous continental sandstones are covered in certain places by the transgressive marine Upper Cretaceous and also by Tertiary rocks. The youngest of these Upper Cretaceous strata, in the south-eastern part of Nigeria (Noukka-Enugu Coal Basin), consist of some 1000 m of sandstones and black shales containing five beds of coal, of which the most important is 1.5 m thick.

Southern Nigeria was invaded by the Palaeocene Sea resulting in the deposition of foraminiferal shales, shaly sandstones and phosphatic shales. In the south of Nigeria, there is an undated post-Eocene continental succession, the Lignite Group, which comprises about 25 m of sandstones and shales containing two beds of lignite, one of which is nearly 3 m thick [39.2, 39.3].

3.39.2. Uranium exploration

In 1947, pyrochlore containing uranium was recognized by the Geological Survey Department in small granite bodies on the Jos Plateau. They were surveyed in more detail in 1949–1950 by the Atomic Energy Division of the Geological Survey of Great Britain. The survey conducted considerable laboratory work, while the geological survey of Nigeria completed 12 boreholes (700 m). The pyrochlore contains about 2.8% U but no commercial means of extracting the uranium has yet been developed. In 1959–1960, the Atomic Energy Division carried out road traverses with a scintillometer, but nothing of economic significance was found. In 1969, an airborne radiometric survey covering 85 000 km² was undertaken by the International Resources Corporation on behalf of Ocean Exploration. The survey covered two areas underlain by sediments of the Gundumi and Ilio Formations in Sokoto State, and the Bima and Yolde formations in Bauchi, Borno and Gongola States. Radiometric anomalies were detected, although no ground follow-up was carried out.

In 1973, the Geological Survey Department contracted airborne gamma spectrometer surveys of four contiguous areas:

(i) Sokoto and the middle Niger area (122 000 km²);
(ii) Central north (144 000 km²);
(iii) Lower Benue and adjoining area (120 000 km²);
(iv) Upper Benue and adjoining area (146 000 km²).

The surveys were completed and reports submitted by 1975–1976. In 1976, the Geological Survey Department commenced ground follow-up utilizing its own staff. This programme consisted of traversing with gamma spectrometers and scintillometers followed by radiometric survey gridding, geological mapping, pitting, trenching and diamond drilling. Areas covered included about 20 000 km² in Sokoto State, 10 000 km² in Cross River and Benue States and 8000 km² in the confluence area of the Niger and Benue Rivers, in central Nigeria.

During 1974–1975, Italia's AGIP held two exclusive prospecting licences over essentially the same areas as those covered in the 1969 airborne work. It carried out some photogeological interpretation and very limited ground checking. In 1975, the Nigerian Mining Corporation entered into an arrangement for the preparation of a prefeasibility report on the uranium prospects in Nigeria. Subsequently, France's Office of Geological and Mining Research (BRGM) acted as contractor to the Nigerian Mining Corporation and undertook field work in 1976–1978, with further work planned. This field programme consisted of geochemical and reconnaissance ground traversing with scintillometers, followed by more detailed geological mapping and radiometric surveying. A total area of some 35 000 km² in north-east Nigeria was investigated.

The News Agency of Nigeria reported on 17 October 2005 that uranium deposits of great value had been discovered in six Nigerian States, but no details were given. Deposits have been discovered in the States of Cross River, Adamawa, Taraba, Plateau, Bauchi and Kano, citing a report released by the Ministry of Solid Minerals Development of Nigeria.

Historical exploration data are summarized in Table 3.28.

TABLE 3.28. URANIUM EXPLORATION DATA [39.4]

	Aerial radiometric surveys (km²)	Other surveys (km²)	Drilling (m)	Expenditure
Pre-1975	495 000	0	700	2 250 000
1975	122 000	0	0	900 000
1976	0	20 000	0	600 000
1977	0	24 000	210	1 000 000
1978	0	29 000	0	1 200 000
1979	0	20 000	500	1 000 000
Total	617 000	93 000	1 410	6 950 000

3.39.2.1. Exploration expenditure in other countries

In 1977, Nigeria invested US $2.4 million in the Afasto-Ouest uranium project in Niger [39.3, 39.5].

3.39.3. Uranium resources

There are no known uranium resources in Nigeria. Speculative resources estimated by the 1983 IUREP report are in the range 10 000–50 000 tU, hosted in sandstone and vein-type environments [39.6].

Only small (50-100 t U) vein-type deposits associated to granites at Gumchi, Gubrunde and Mika are mentioned [39.7].

The UDEPO database lists the most significant deposits for Nigeria as Mayo and Zona, Ghumchi, Gubrunde, Mika.

3.39.4. Potential for new discoveries

The geological environments in Nigeria that are considered favourable for the occurrence of uranium mineralization may be summarized as follows:

(a) The Sokoto and Chad Basins, together with the Niger and Benue Troughs, cover some 275 000 km² and contain arenaceous sediments of Cretaceous and younger ages that are being evaluated for sandstone and related deposit types;
(b) Over 300 000 km² of Precambrian terrain occurs within Nigeria and is being investigated for vein, pegmatite and related deposits;
(c) The phosphate bearing sediments of the Cretaceous and Tertiary in both the north-west and southern Nigeria are being investigated for their uranium potential [39.3]. Two phosphate deposits, Sokoto and Ogun, have uranium content of 65 and 23 ppm respectively [39.7].

3.39.5. Comments

There has been no uranium production in Nigeria.

References to Section 3.39

[39.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Nigeria, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[39.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 196–201.

[39.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[39.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[39.5] ALLAFRICA, Nigeria: Uranium Found in 6 States (2005), http://allafrica.com/stories/200510180231.html

[39.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[39.7] OBAJE, S.O., OJUTALAYO, A., OGEDENGBE, O., OKOSUN, E.A., Nigeria's Phosphate and Uranium Mineral Occurrences: Implication for Mineral Investment. Journal of Environment and Earth Science, Vol. 4, N° 1 (2014) 7 p.

3.40. RWANDA

Rwanda is a landlocked country situated in central Africa, two degrees south of the Equator. It has borders with the Democratic Republic of the Congo, Uganda, the United Republic of Tanzania and Burundi. Much of the terrain is grassland which extends over rolling hills. Mountains extend south-east from a chain of volcanoes in the north-west. The divide between the Congo and Nile drainage systems extends from north to south through western Rwanda at an average elevation of almost 2740 m. On the western slopes of this ridgeline, the land slopes abruptly towards Lake Kivu and the Ruzizi River valley, which comprises a section of the Great Rift Valley. The eastern slopes are more moderate, with rolling hills extending across central uplands at progressively lower elevations to the plains, swamps and lakes of the eastern border region.

Although located only two degrees south of the Equator, Rwanda's high elevation makes the climate temperate. The average daily temperature near Lake Kivu, at an elevation of 1463 m, is 23°C. During the two rainy seasons (February–May and September–December), heavy downpours occur almost daily, alternating with sunny weather. Annual rainfall averages 800 mm but is generally higher in the western and north-western mountains than in the eastern savannah.

Rwanda is a predominantly rural country and around 90% of the population is involved in subsistence agriculture. The country has few natural resources and minimal industry, although it records such mineral resources as gold, cassiterite, wolframite, methane and 'coltan', which is a mixture of columbite and tantalite. In addition to minerals, Rwanda's primary exports are coffee, tea and flowers [40.1].

3.40.1. Geology

The geology of Rwanda generally is made up of sandstones alternating with shales, which are all assigned to the Mesoproterozoic Burundian Supergroup (Fig. 3.66), sometimes intercalated by granitic intrusions. In the east of the country predominate older granites and gneisses. Neogene volcanics are found in the northwestern and southwestern parts of Rwanda. Young alluvials and lake sediments occur along the rivers and lakes.

In various localities of Rwanda, for instance to the south and southwest of Butare and in the Congo-Nile watershed to the southwest of Rwengeri, pre-Burundian migmatites and gneisses accompanied by crystalline whitish quartzites occur.

Generally, the stratigraphic sequences established in Rwanda can more or less be identified with those, which appear in neighbouring Burundi.

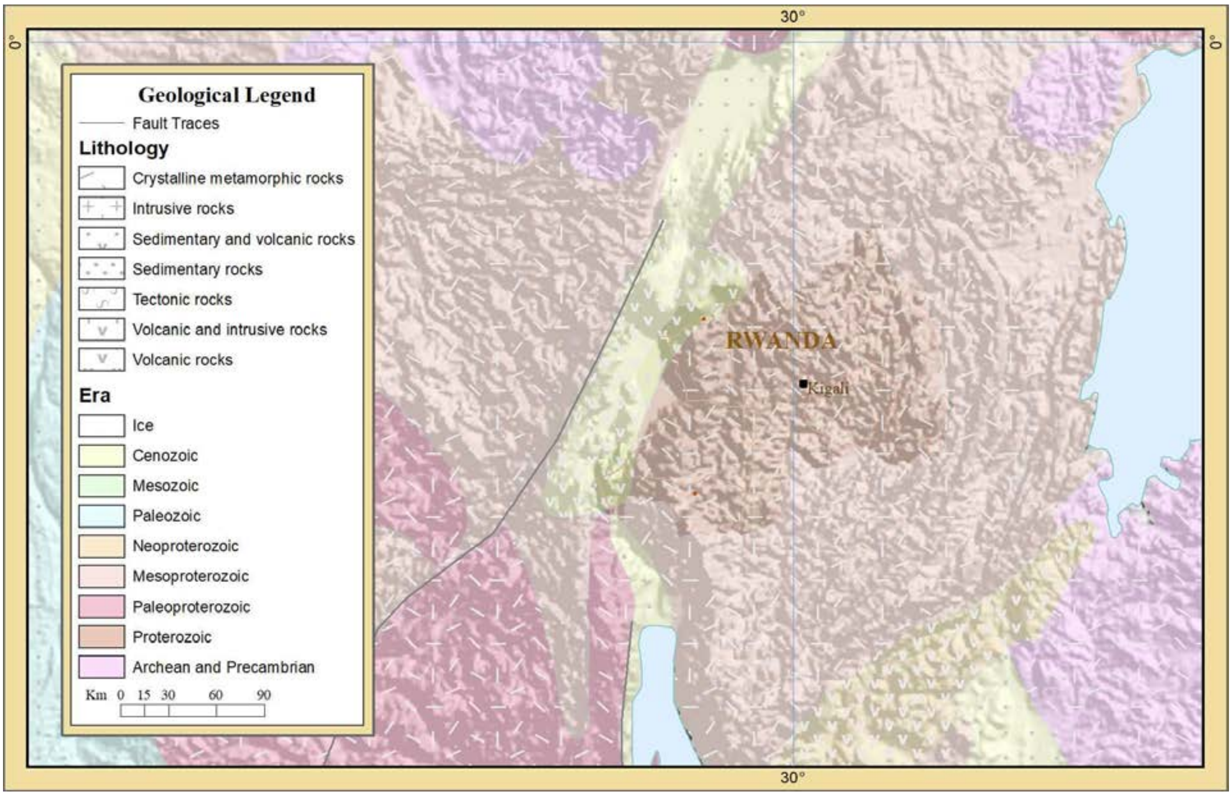


FIG. 3.66. Regional geological setting and uranium mineralisation of Rwanda. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The sedimentary succession of the Burundian Supergroup can be subdivided into the following units: the Lower Series (la Série Inférieure), the Byumba Series, and the Miyove Series; each of these can subdivided into formations of quartzites and various undifferentiated rocks. The base of the Lower Series is the most developed formation, characterized by black sericitic shales. The metamorphic rocks in the east of the country probably represent metamorphosed Burundian formations. All these sedimentary sequences indicate a former shallow marine, high-energetic environment, as often shown by the oblique stratification, the conglomerates and the symmetric ripple marks within the layers.

At least four types of granitic rocks are known within the Kibaran Belt. Of these, the two first are synorogenic and the two last postorogenic. The culmination of the Kibaran orogeny occurred from about 1370 to 1310 Ma; the first of these ages dates early granites in Rwanda. Postorogenic granites are also known from Rwanda and have been dated at about 1136 Ma. Cenozoic to Recent volcanic rocks occur in the northwest and west of the country. Some of these volcanoes are highly alkaline and are extensions from the Virunga volcanic area of southwestern Uganda and eastern Democratic Republic of the Congo. Tertiary and Quaternary clastic sediments fill parts of the Western Rift in the western part of the country [40.2].

3.40.2. Uranium exploration

Before independence in 1962, exploration by small private Belgian companies led to the discovery, in 1954, of the Karago uranium occurrences in the north of the country in Gisenyi prefecture. Around 200 kg of uranium ore grading 20–60% U_3O_8 (34–102 kgU) is estimated to have been produced from pitchblende-bearing quartz veins at the contact between schist and pegmatite. Production apparently stopped in the late 1950s, but detailed prospecting continued into the 1960s and 1970s:

(a) Phase 1 (1968–1973) comprised airborne geophysics and detailed prospecting in localized areas. Total airborne survey coverage was 3300 km^2, flown by Hunting Surveys Ltd. Detailed prospecting, trenching and drilling were carried out at Karago;
(b) Phase 2 (1974–1977) comprised regional stream sediment sampling at 500 m intervals and follow-up of airborne radiometric anomalies. The Nshili area (south-western Rwanda) was radiometrically and geochemically investigated. Uranium, thorium and rare earth element mineralization were discovered at Nshili;
(c) Phase 3 (1978–1980) included general prospecting (scintillometry, geochemistry) and detailed systematic exploration of the most promising anomalies (trenching, pitting, drilling). A stream sediment anomaly 12 km in length with up to 400 ppm U was found in the Mwesa River valley, south-east of Kigali;
(d) Phase 4 (1981–1983) included airborne (helicopter) spectrometry and magnetometry over the whole country. This survey was carried out by Canada's Sander Geophysics Ltd. In this final phase, uranium mineralization, believed to be associated with lamprophyres, was identified in south central Rwanda (Rusatira).

Table 3.29 summarized historical exploration data up to 1985.

TABLE 3.29. URANIUM EXPLORATION DATA [40.3]

Year	Aerial radiometric surveys (km^2)	Other surveys (km^2)	Drilling (m)	Expenditure (US$)
Pre-1979	3300		925	55 530
1979				
1980	23 300	10		1 505 000
1981				
1982		40		20 000
1983				
1984				
1985				
Total	26 600	50	925	1 580 530

3.40.2.1. The Nshili occurrence

The mineralization at Nshili is a combination of uranium and thorium, with probable residual thorium enrichment occurring at the surface. The area is underlain by Lower Proterozoic Ruzizian rocks which thrust to the west against Burundian rocks. The Ruzizian comprises metapelites and metasandstones, mica schists with biotite or muscovite, often with pegmatitic lenses, amphibole schist grading into gneiss, and biotite augen gneiss with large pegmatitic bodies. Granitic intrusions are abundant in the area of the uranium anomaly. Mafic dykes have been reported in its vicinity.

Trenching revealed highly radioactive north-westerly trending, argillaceous zones 1–3 m thick with Th:U ratios of up to 50 or more (up to 19 500 ppm Th and 2000 ppm U), dipping 70° E and followed along strike for 200 m. The mineralization is located at the fault contact between pegmatitic gneiss and a massive pegmatite body. Haematitization is apparent. Drilling revealed a continuation of the mineralization down to a depth of 120 m. Other, less well mineralized zones exist in the area. This type of mineralization clearly offers very good potential for the occurrence of economic uranium deposits.

3.40.2.2. The Karago occurrence

Uranium mineralization at Karago is related to pegmatitic bodies. A 1 cm wide pitchblende vein apparently related to a quartz vein in pegmatite was worked out in the early 1950s, and not far from this location a high grade pitchblende-bearing boulder was found in the late 1950s. However, the most interesting mineralization of this area was found in a subvertical graphitic zone in which visible torbernite occurred. This zone lay within a remnant of biotite mica schist in a pegmatitic to granitic gneiss environment. Siliceous veins with smokey quartz are found close to the contact between granite and mica schist, but faults or shear zones are not evident, although possible. Earthy haematite, probably related to a hydrothermal event, is obvious in the mica schist. However, the zone is only 0.5 m wide and 90 m long. If thicker and more consistent graphite-bearing septas of mica schist could be found in granitic bodies or embayments or close to the granites, this type of occurrence could offer good potential for the occurrence of economic concentrations of uranium mineralization. No recent exploration activities have been reported [40.4, 40.5].

3.40.3. Uranium resources

Rwanda does not report any uranium resources in the reasonably assured resource and EAR categories. Speculative resources, estimated by IUREP in 1983, are in the 500–5000 tU range [40.6]. Most of these resources are expected to be hosted by the Lower Precambrian Ruzizian Formation, consisting of metamorphic sequences (metapelites, metasandstones and mica schists) intruded by granitic and pegmatitic formations. The Nshili and Karago occurrences occur in this environment [40.4, 40.6].

The UDEPO database does not list any known deposits for Rwanda.

3.40.4. Potential for new discoveries

Considering the moderate overall potential of Rwanda for hosting economic uranium deposits, uranium exploration in this country has always been conducted as being incidental to exploration for tin, tungsten, columbo-tantalite, etc. The most prospective target for uranium exploration in Rwanda seems to be the metamorphic Lower Proterozoic Ruzizian Formation, with its granitic intrusives and pegmatitic to pegmatoidal injections, which crops out in northern and southern blocks in the west of the country. No economic deposit has been found to date [40.4, 40.5].

3.40.5. Uranium production

In the 1950s, 200 kg of uranium ore at 20–60% U_3O_8 (34–102 kgU) is estimated to have been mined from the Karago uranium occurrences.

References to Section 3.40

[40.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Rwanda, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2008).

[40.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin Heidelberg (2008) 204–207.

[40.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[40.4] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[40.5] GEHRISCH, W., CHAIGNE, M., IUREP Orientation Phase Mission Report: Rwanda, IAEA, Vienna (1983).

[40.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.41. SENEGAL

Senegal is situated in western Africa and has land borders with The Gambia, Guinea, Guinea-Bissau, Mali and Mauritania as well as a coastline bordering the Atlantic Ocean. The landscape consists mainly of the rolling sandy plains of the western Sahel, which rise to more hilly terrain in the south-east. The northern border is formed by the Senegal River; other important features include the Gambia and Casamance Rivers.

The local climate is tropical with well defined dry and humid seasons that result from north-east winter winds and south-west summer winds. Dakar’s annual rainfall of about 600 mm falls between June and October, when maximum temperatures average 27°C. The December–February minimum temperatures are about 17°C. Interior temperatures can be substantially higher than those along the coast, and rainfall increases substantially farther south, exceeding 1500 mm annually in some areas. In the interior of the country, in the region of Tambacounda, particularly along the border with Mali, temperatures can reach 54°C.

Predominantly rural and with limited natural resources, the economy of Senegal gains most of its foreign exchange from fish, phosphates, groundnuts, tourism and services. Its agricultural sector is highly vulnerable to variations in rainfall and changes in commodity prices.

Production of phosphate rock, fertilizers and phosphoric acid continues to dominate the mineral industry of Senegal. Other mineral resources identified by the Government include clays, copper, diamonds, diatomite, iron ore, titanium bearing sands along the coast and uranium [41.1].

3.41.1. Geology

Senegal is dominated by two major geological units (Fig. 3.67): the folded Precambrian basement in the east of the country and the Senegal Basin comprising Upper Cretaceous–Quaternary sediments in most of the central and western parts. The Precambrian basement comprises the Mauritanides and the Palaeoproterozoic volcano-sedimentary strata of the Kedougou-Kenieba inlier.

The formations comprising the Mauritanides chain are Hercynian in age and constitute one of the mobile areas of the West African Craton. The Palaeoproterozoic volcano-sedimentary sequences, mostly known as Birimian formations, are of significant metallogenic interest as they host the region’s major mineral deposits.

The Kedougou-Kenieba inlier is interpreted as an accretion of north-east trending Birimian age volcanic terrains. It includes two major geological structures, the Senegalomalian Fault and the Main Transcurrent Zone with which gold mineralization is associated. The inlier is divided into three main stratigraphic units, traversing from west to east: (i) the Mako Supergroup, (ii) the Diale Supergroup and (iii) the Daléma Supergroup.

The Mako Supergroup hosts the Sabodala deposits which are located in an area of intense shearing and silicification and associated with pyrite–gold mineralization. Typical lithologies include basalt flows, often with carbonate alteration and minor volcaniclastic intercalations, magnesium basalts or komatiites, ultramafic subvolcanic intrusions (pyroxenites) and numerous massive biotite and amphibole granitoids.

The Diale Supergroup, located between the Mako Supergroup and the western edge of the Saraya granite, has been weakly metamorphosed. It includes extensively folded formations, deposited after those of the Mako Supergroup, consisting of shale, greywacke, quartzite and volcanic strata.

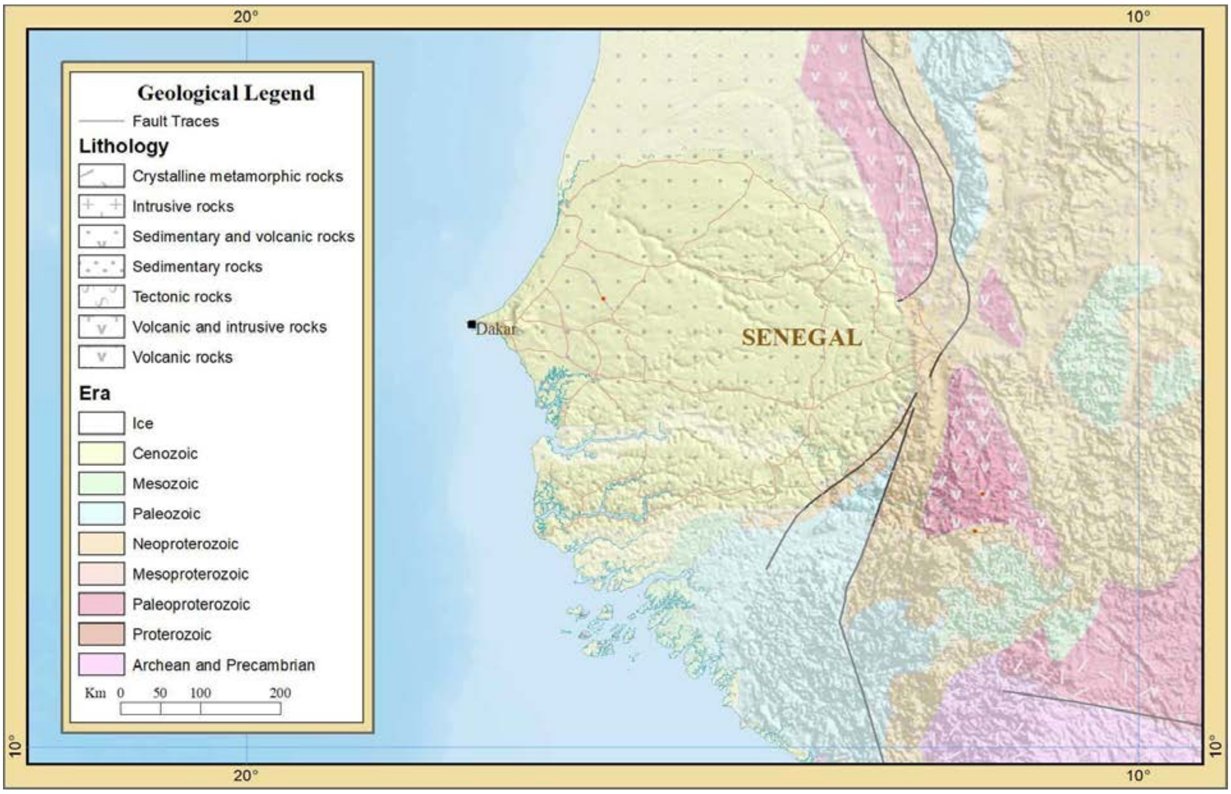


FIG. 3.67. Regional geological setting of Senegal showing the distribution of selected uranium deposits and occurrences. For general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Daléma Supergroup, located between the Saraya granite and the Faleme River, extends into Mali in its eastern part but disappears in the south under the Segou Madina Kouta Series. It is composed of volcano-sedimentary schist and greywacke strata.

These Birimian formations are affected by syn-, late- and post-tectonic granite intrusions. The Precambrian basement is a metallogenic province of major importance for Senegal as it hosts numerous deposits and anomalies of gold, iron, uranium, lithium, tin, molybdenum and nickel in the Birimian formations, and copper and chromium in the Mauritanides range.

The Senegal Basin occupies the central part of the north-west African Coastal Basin, which extends from the Reguibat ridge at the northern end of the Guinea Fault. The Senegal Basin is Mesozoic and has had a complex history in relation to the pre-rift (Upper Proterozoic–Palaeozoic), the syn-rift (Permian–Triassic) and the post-rift (Middle Jurassic–Holocene) episodes of its development. Most of the outcrops are composed of sandy cover of Recent age.

Maastrichtian and Eocene formations crop out in the Cape Verde peninsula, while Eocene strata crop out in the Senegal River valley. They include Maastrichtian sands, clays and sandstones. Tertiary formations hold significant resources of phosphates, limestone, attapulgite and clays. There are four main phosphate deposits in Senegal, although no information on their uranium content is available [41.2, 41.3].

3.41.2. Uranium exploration

Exploration for radioactive minerals has been carried out since 1957, mainly by France's Atomic Energy Commission and Compagnie Générale des Matières Nucléaires (COGEMA). There has been some exploration through the United Nations Development Programme Special Fund projects. Table 3.30 summarizes historical exploration data.

TABLE 3.30. URANIUM EXPLORATION DATA [41.4]

Year	Activity	Expenditure (CFA francs)
1957	General prospecting over 4880 km².	11 750 000
1958	General prospecting over 3752 km². Aerial survey of Senegal Oriental covering 28 000 km² of Birimian strata and granite.	33 250 000
1959	General prospecting over 800 km².	94 900 000
1960	Ground follow-up prospecting of aerial anomalies.	21 350 000
1963	Ground survey of Kedougou granite.	73 100 000
1964	Reconnaissance prospecting of terminal continental formations covering 6600 km² in the area Matarn, Badi, Bassin du Ferlo, Linguere and Podar.	8 650 000
1966	Reconnaissance of Ferlo region (32 000 km²). Radiometric logging of 341 rural wells and geochemical sampling (3365 samples). No positive results.	26 650 000
1974–1978	Reconnaissance and general prospecting of Senegal Oriental over a permit area of 38 600 km², which was reduced to 19 300 km² in 1978.	512 600 000
1979	Exploration drilling at Saraya (3 holes) and Guemedji (19 holes).	153 050 000
1980		43 400 000
Total		978 700 000

Exploration has located several areas where uranium mineralization occurs. In eastern Senegal, a small anomaly has been located near Namel in a phosphatic tillite of Lower Cambrian age. Other anomalies recording 200 ppm U and 15 ppm Th have been found in fragmented Cambrian limestones near Nounomfouka and Guemedji. There are also point anomalies in the complex vein system of the Daléma Series, where low grade mineralization is mainly associated with syenitic rocks. Similar low grade mineralization is found in the Saraya granite near Koudhoko and Fodekouda. Ground radiometric surveys conducted on 100–200 m grids have found other anomalies near Lombel and Walidiala.

The area covered by the mining agreement is described as Saraya East and is 2992 km² in extent. The area was extensively explored by COGEMA and France's BRGM in a three phase programme during the late 1950s, 1970s and early 1980s. Uranium mineralization was identified as being episyenite hosted, which resulted from the hydrothermal remobilization and alteration of the surrounding granites. A historical resource estimate of approximately 1500 tU at an average grade of 0.20% U was reported by COGEMA.

However, the project was uneconomic to mine at the uranium prices prevailing at the time. Over 40 000 m of drilling were completed in the area. Recorded intersections are at depths of 50–220 m.

In 2007, France's UraMin entered into a mining agreement with Senegal to prospect for and, if economically viable, mine uranium and related minerals in the Saraya East region of eastern Senegal.

3.41.3. Uranium resources

There are no reported uranium resources in Senegal. In 1983, IUREP reported speculative resources in the range 1000–10 000 tU [41.5].

A historical resource estimate of approximately 1500 tU at an average grade of 0.20% U was reported by COGEMA at the Saraya deposit.

The UDEPO database lists the most significant deposit for Senegal as Saraya.

3.41.4. Potential for new discoveries

Uranium may be associated with sedimentary marine phosphates. The search for uranium, which received a significant impetus between 1965 and 1984, has witnessed a revival of interest since 2007, with exploration activities undertaken in the Saraya area. The shale sequences of Mako and Diale could also be worthy of investigation.

3.41.5. Comments

There has been no past production in Senegal. There are no existing nuclear facilities and no plans to develop nuclear generating capacity in Senegal.

References to Section 3.41

[41.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Senegal, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[41.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin Heidelberg (2008) 212–215.

[41.3] SALON INTERNATIONAL DES MINES, Senegal's Geology (2012), http://www.simsenegal.com/html/fivepagetwo.html

[41.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[41.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.42. SEYCHELLES

Seychelles is a small island nation located in the Indian Ocean north-east of Madagascar and about 1600 km east of Kenya (Fig. 3.68). The nation is an archipelago of 155 tropical islands, some of them granite and some coral, the majority of which are small and uninhabited. About 90% of the population lives on Mahé and 9% on Praslin and La Digue. Around a third of the land area comprises the island of Mahé and a further third the atoll of Aldabra.

There are two distinct regions: the granitic islands, the world's only oceanic islands composed of granitic rock, and the coralline outer islands. The granite islands are the world's oldest ocean islands, while the outer islands are mainly very young, though the Aldabra group and St Pierre (Farquhar group) are unusual raised coral islands that have emerged and submerged several times during their history; the most recent submergence dating from about 125 000 years ago.

The climate is tropical marine, humid, cooler during the south-east monsoon (late May–September) and warmer during the north-west monsoon (March–May).

Natural resources include fish, copra and cinnamon. In 2000, fishing surpassed tourism as the most important foreign exchange earner. Water supplies depend on catchments to collect rainwater.

Mineral production in Seychelles traditionally consisted mostly of unspecified quantities of construction materials, i.e., clay, coral, stone and sand [42.1].

3.42.1. Geology

The basement of Seychelles comprises a suite of granites emplaced during the Neoproterozoic extension within the Gondwana Supercontinent. Granite is the bedrock of the main island Mahé and of the nearby islands of Praslin, La Digue and Fregate.

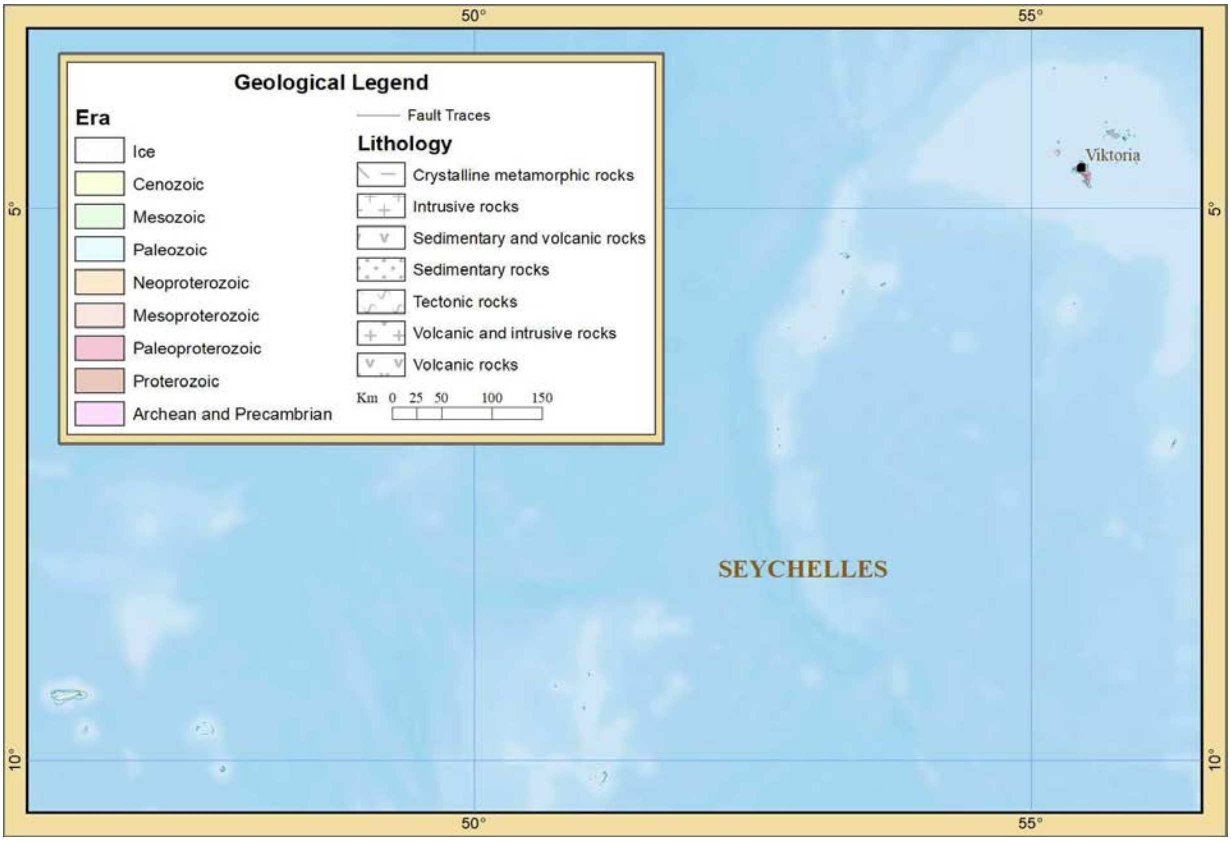


FIG. 3.68. Regional geological setting of Seychelles. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The first Gondwanan rift phase to affect Seychelles took place in the Late Paleozoic forming a series of elongated failed rift grabens. The second phase of rifting, during Triassic to Middle Jurassic, resulted in the deposition of at least 2000 m, and possibly as much as 6000 m, of clastic sediments along the western margin of the Seychelles microcontinent. Following the subsequent split of Gondwana, the Seychelles lay on the passive northwestern margin of eastern Gondwana upon which more than 1000 m of fine marine clastics were deposited as the Somali oceanic basin developed into the Early Cretaceous.

At about 120 Ma the fragmentation of East Gondwana began. During the subsequent northward drift of Seychelles-India, the emergence of the Deccan hotspot at about 65 Ma initiated the Carlsberg Spreading Ridge of the Arabian oceanic basin and completed the isolation of the elongate Seychelles sliver. Silhouette and North islands are early Tertiary (about 63 Ma) alkaline plutonic-volcanic complexes. Maastrichtian and/or Palaeocene volcanics were observed, but their full tectonic significance has not yet been established [42.2].

3.42.2. Uranium exploration and resources

No information is available on uranium exploration in Seychelles. No identified or undiscovered resources are reported. The potential for any discoveries based on the rock types found on the islands is regarded as zero. The UDEPO database does not list any known deposits for Seychelles.

References to Section 3.42

[42.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Seychelles, Washington, DC (2009), https://www.cia.gov/library/publications/the-world-factbook/index.html

[42.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 216–218.

3.43. SIERRA LEONE

Sierra Leone is located on the west coast of Africa, north of the equator. The country has a wide variety of climatic zones. There are some 400 km of coastline and eastwards from the coast are low lying mangrove swamps, rainforested plains and farmland, and finally a mountainous plateau in the east, where Mount Bintumani rises to 1948 m. The climate is tropical, with two seasons determining the agricultural cycle: a rainy season lasting from May to November, followed by a dry season lasting from December to May, when cool, dry winds (harmattan) blow in from the Sahara Desert. About two thirds of the population engages in subsistence agriculture (rice, coffee, cocoa, livestock) and fishing, which collectively account for 52.5% of GDP. Rich in minerals (gold, iron, bauxite, diamonds, rutile), Sierra Leone has relied on mining, especially diamonds, for its economic base. Sierra Leone has one of the world's largest deposits of rutile, a titanium bearing mineral [43.1].

3.43.1. Geology

Sierra Leone forms the central part of the West African Craton. The Archaean rocks of Sierra Leone consist of a granitic basement containing remnants of sedimentary and mafic formations and a group of supracrustal greenstone belts with banded ironstone and detrital sediments (Fig. 3.69).

These strata host significant metalliferous mineralization, including antimony, arsenic, chromite, copper, iron, gold, nickel and tin. They are also intruded by molybdenum-bearing granites. Weathering has produced economic concentrations of diamonds, bauxite and lateritic iron ores and heavy mineral concentrates, most notably rutile. Prospects for lateritic nickel deposits also appear favourable. Only limited exploration has been undertaken in the poorly exposed Late Proterozoic Rokel River Group. These strata, together with those of the Ordovician Saoinya Scarp Group, host glacial sediments in their lower horizons.

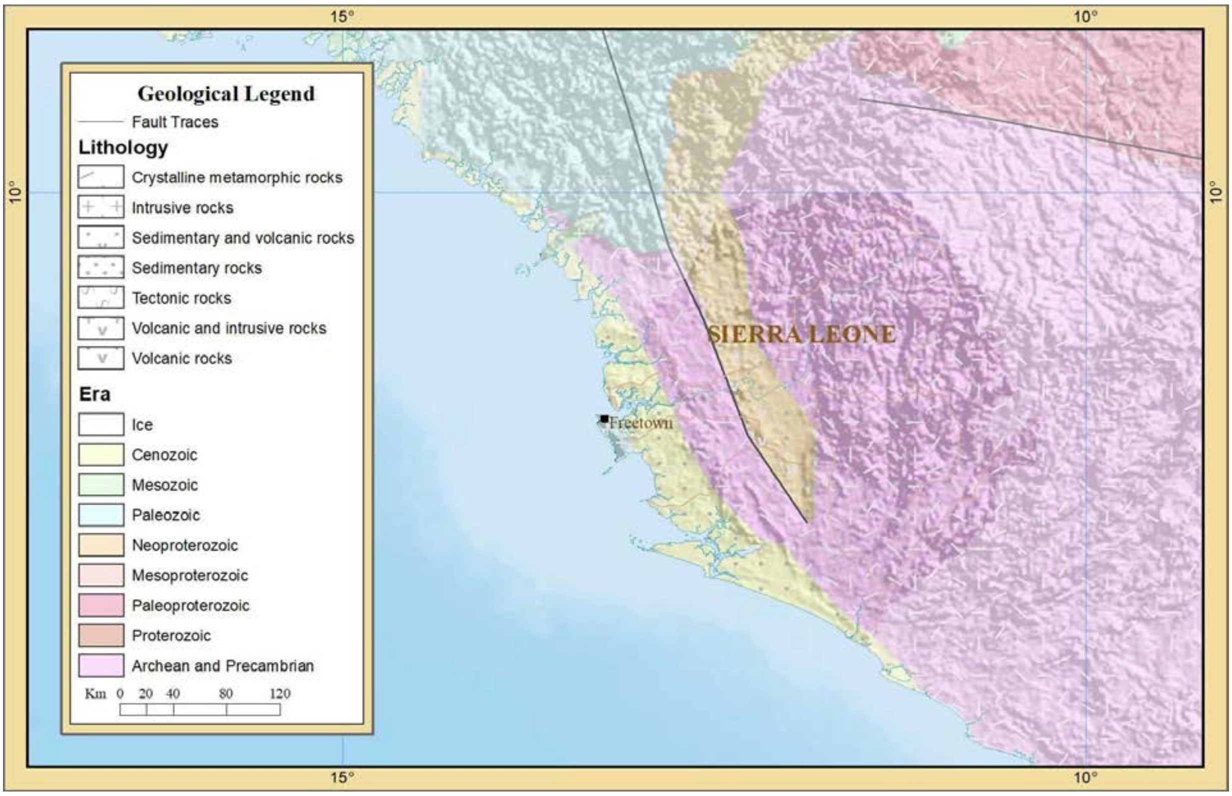


FIG. 3.69. Regional geological setting of Sierra Leone. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Triassic–Lower Jurassic Freetown Layered Basic Complex overlies the continental margin and is considered to have been formed by a series of intrusions of basic magma, which formed a rhythmic sequence of troctolite, gabbro and anorthosite, and which occasionally resulted in an iron-enriched ilmenite–magnetite horizon and acid veining. Some alluvial platinum has been produced from this complex. Kimberlite dykes were emplaced in the Cretaceous period and these are the source of the country's diamonds. The Tertiary and Pleistocene sediments are known to contain horizons hosting lignite and ceramic clays and they may also host economic concentrations of other minerals [43.2].

3.43.2. Uranium exploration

In 2007–2008, uranium exploration was performed in the Lovetta area by African Minerals Ltd.

Located in eastern Sierra Leone, this project is concerned with granite hosted uranium and thorium as well as rare earth elements mineralization. In the immediate project area, seven anomalies of >10 ppm U and >450 ppm Th have been identified by a programme of soil and scintillometer sampling over a 4 km strike length.

These results were followed up by a trenching programme that has recorded elevated uranium, thorium, zirconium and niobium intersections, along with associated rare earth elements such as cerium and lanthanum. The anomalous zone is open to both the north and the south. Grades from the first surface trenches (maximum 3 m depth) have produced results of 28 ppm U and 267 ppm Th over a 66 m continuous interval with a peak grade of 135 ppm U and 1235 ppm thorium over a single 2 m sample interval. African Minerals ended exploration on the Lovetta project at the end of 2008 [43.3].

3.43.3. Uranium resources

No uranium resources, identified or speculative, are reported by Sierra Leone. In 1983, IUREP reported speculative resources of 0–1000 tU [43.4]. The UDEPO database does not list any known deposits for Sierra Leone.

3.43.4. Potential for new discoveries

Sierra Leone constitutes the central part of the split West African Craton, the balance of which is the Guyana Shield, comprising Venezuela (50 000–100 000 tU of speculative resources) and Guyana, Suriname and French Guiana, each with 1–10 000 tU.

3.43.5. Comments

No uranium has been produced in Sierra Leone and there are no existing facilities or reported plans to develop nuclear generating capacity.

References to Section 3.43

[43.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Sierra Leone, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[43.2] MOREL, S.W., The geology and mineral resources of Sierra Leone, Econ. Geol. **74** (1979) 1563–1576.

[43.3] AFRICAN MINERALS LIMITED, 2009 Interim Results (2009), http://us-cdn.creamermedia.co.za/assets/articles/attachments/22827_arm.pdf.

[43.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.44. SOMALIA[6]

Africa's easternmost country, Somalia occupies the tip of a region commonly referred to as the Horn of Africa. Somalia's terrain consists mainly of plateaux, plains and highlands. In the far north, however, the rugged E–W ranges of the Karkaar Mountains lie at varying distances from the Gulf of Aden coast. The weather is hot throughout the year, except at higher elevations in the north. Rainfall is sparse and most of Somalia has a semi-arid to arid environment, suitable only for the nomadic pastoralism practised by well over half the population. Only in limited areas of moderate rainfall in the north-west, and particularly in the south-west, where the country's two perennial rivers are found, is agriculture practised to any extent.

Agriculture is the most important sector of economy, with livestock accounting for about 40% of GDP and about 65% of export earnings. After livestock, bananas are the principal export; sugar, sorghum, maize and fish are products for the domestic market. Natural resources include unexploited reserves of uranium, iron, tin, gypsum, bauxite, copper and salt [44.1].

3.44.1. Geology

Most of Somalia lies within the transitional zone between the great arch of East Africa and the deep sedimentary basin defined from geophysical investigations in the Indian Ocean (Fig 3.70).

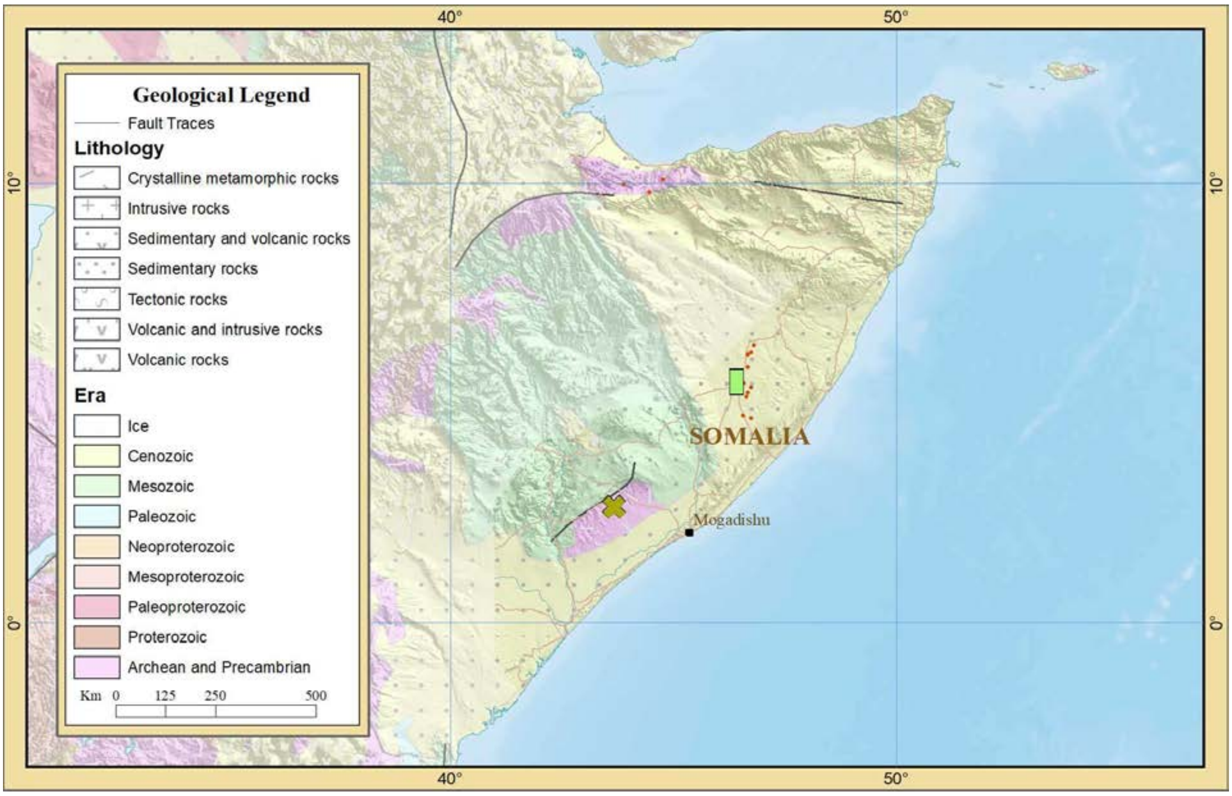


FIG. 3.70. Regional geological setting of Somalia showing the distribution of selected uranium deposits and occurrences. For general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The East African arch, which covers Ethiopia, Kenya, Uganda, the United Republic of Tanzania, Mozambique, the Red Sea, the Gulf of Aden and adjacent territories, is cut by the deep-seated faults of

[6] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

the Great Rift Valley. The largest of the abyssal fractures were formed in the Precambrian and Cenozoic eras and were later affected by numerous tectonic movements and magmatic activity.

Three fault systems are recognized and classified according to their trends: (i) the Red Sea system (N–NE), (ii) the Gulf of Aden system (E–NE), and (iii) the East African system (N–NE). All three systems have determined the block structure of Somalia. Tectonic activity was most active in the northern part of the country.

Metamorphic and magmatic complexes, probably Late Precambrian–Early Palaeozoic, crop out in uplifted blocks (Fig. 3.70). Two areas of such rocks are known, one in northern Somalia, the other west of Mogadishu, in the Bur region. These areas of ancient rocks are structurally different and belong to the different major structural units of Africa.

The Bur region belongs to a large zone known as the Mozambique Belt and consists of Precambrian strata. The northern area is part of an extensive Early Palaeozoic fold belt which occurs along the coasts of both the Red Sea and the Gulf of Aden. Formation of this belt, accompanied by granitic intrusions, has been dated at 470–450 Ma according to radiometric determinations of the granites [44.2].

3.44.2. Uranium exploration

Prior to 1965, the only evidence of radioactive minerals had been from surveys which identified some pegmatites as having minor radioactive mineral occurrences. After 1965, uranium exploration has been carried out in two different areas of Somalia: Bur and Mudug.

The United Nations Development Programme (UNDP) used airborne geophysics to locate radioactive anomalies near Alio Ghelle in 1965 and in the Mudug area in 1968. Between 1966 and 1969, the UNDP conducted extensive ground radiometric surveys in the Bur area, near Alio Ghelle. Further airborne surveying in 1970 led to the delineation of 18 radiometric anomalies in the Mudug area, and between 1972 and 1974, the UNDP conducted detailed ground studies of this area.

In 1969–1976, Nucleare Somalia (Italy's Eni and AGIP) conducted exploration programmes covering approximately 8000 km² of the Bur area, including both airborne and ground radiometrics, trenching, drilling and laboratory analysis, which confirmed the presence of the albitized uranium–thorium deposit first recognized by the UNDP. Detailed studies revealed the mineralized bodies contained around 3% Th but only low grade U, hosted mainly in refractory minerals.

Nucleare Somalia conducted reconnaissance type evaluation studies over two areas of Precambrian and Phanerozoic rocks covering almost 50 000 km² of northern Somalia between 1970 and 1971. These studies consisted of airborne radiometrics and ground follow-up. The results were negative.

White Star Mining Co. also examined the radioactive anomalies in its 2000 km² concession near Yaq Brava in the Bur area in 1969 and 1970. Ground radiometrics outlined five anomalous areas which were subsequently tested by core drilling. No economic deposits were found and White Star admitted to examining only 15–20% of the total concession before withdrawing.

The Uranium Company of Somalia, a subsidiary of a German consortium, examined two concession areas totalling slightly less than 10 000 km² in the eastern and western parts of the Bur area. The study included a 29 000 line km airborne radiometric survey flown by Hunting Geology and Geophysics Ltd, which defined 78 high interest anomalies mainly underlain by Mesozoic limestones. Subsequent ground geological and radiometric studies did not yield positive results. No drilling was conducted by the company.

In 1977, the Government of Somalia, the Government of Iraq and the Arab Mining Company of Jordan formed the Somali Arab Mining Company (SOAMICO) to further explore over 50 000 km² in the Mudug area and to evaluate, develop and mine the calcrete deposits at Wabo, Mirig and Dusa Mareb. SOAMICO contracted for an airborne radiometric survey, metallurgical testing and a prefeasibility study, all of which were completed.

The Geological Survey of Somalia conducted a 9000 km car-borne radiometric survey in northern Somalia in 1980. A single radiometric anomaly was discovered in Hagigarad and follow-up pitting revealed increasing radioactivity at depth within a gypsiferous crust.

3.44.2.1. Bur region

The discovery of radioactive anomalies in the Bur region was made in late 1965 by an airborne magnetometer and scintillation survey conducted under contract by Canadian Aero Service Limited for a UNDP mineral and groundwater project. The survey covered 22 100 km² of mainly Precambrian basement rocks and 38 anomalies were defined. Traversing on foot with Geiger counters followed, and then surface trenching and pitting was undertaken. Six holes were drilled in 1966–1967.

A prospecting licence covering the area around Alio Ghelle was acquired by Nucleare Somalia in December 1969, and this area was then reflown by Hunting Geology and Geophysics Ltd. The work completed during 1969–1975 included an airborne survey; radiometric and resistivity surveys; photographic interpretation; pitting, trenching and drilling; analytical mineralogical and petrographic analysis and determinations; and culminated in a feasibility study. As a result of all of this work, a total of 87 individual anomalies were identified in the Bur area, with Alio Ghelle the most interesting one. The mineralization is related to a particular albitization process resulting from sodium metasomatism of fractured zones in the basement. Estimated resources were 5350 t U at a grade of 0.076%.

3.44.2.2. Mudug province

The original discovery of radioactivity near Dusa Mareb in Mudug Province was made fortuitously in 1969 during a flight in which a gamma ray spectrometer was incidentally being carried. Car-borne scintillometer reconnaissance was then undertaken, followed by some semi-systematic aerial scintillometer surveying. As of March 1971, eighteen anomalies covering an area of about 200 km² had been found and partially explored. The ground radioactivity of this anomalous area was then outlined in more detail by drilling on a grid spacing of 100 m. The subsurface was then explored by the drilling of 1000 holes (principally by auger) and the excavation of 1040 pits.

The mineralization occurs in friable rock, mainly in clays and fluvial sandstone of a Miocene suite which is overlain by a massive gypsum crust.
Data from field operations undertaken between 1969 and the end of 1975 can be summarized as follows:

(a) 8256 km² of airborne survey (21 675 line km flown);
(b) 4109 km² of wide grid ground survey;
(c) 6109 km² of systematic radiometric survey;
(d) 17 637 m³ of pits and trenches;
(e) 11 270 m of core drilling.

Total expenditure for uranium related studies between 1965 and 1982 amounted to about US $14 500 000. No uranium exploration activities have been reported since 1982 [44.3, 44.4].

3.44.3. Uranium resources

Uranium resource data are summarized in Table 3.31.

3.44.3.1. Identified resources

The proven reserves of the Alio Ghelle orebodies amount to 1950 tU with an average grade of 0.076% U and ‘semi-proven’ reserves of 3400 tU. The ore reserves in Mudug Province amount to 5500 tU at an average grade of 0.068% U.

TABLE 3.31. IDENTIFIED RESOURCES (tU) [44.5]
(As of 1 January 1978)

Category	US $80–130/kgU
Reasonably assured resources	5000
Inferred resources	2600
Identified resources	7600

Note: Recoverable resources (in situ resources) were adjusted using a 75% recovery factor.

The UDEPO database lists the most significant deposits for Somaliaas Dusa Mareb-El Bur District (3 deposits), Alio Ghelle.

3.44.3.2. Undiscovered resources

In 1983, a review of the IUREP estimates reported that speculative resources vary in the range 0–150 000 tU. The majority of these speculative resources were related to sandstone and calcrete deposits [44.3, 44.4].

3.44.4. Potential for new discoveries

Only about half of the Bur region, which contains the Alio Ghelle deposit, has been explored. Further work in this area could reveal additional uranium deposits.

The major portion of the Mudug Plateau is underlain by favourable rocks of the Merca Series and is essentially unexplored, except for the area between Adado and El Bur. There is good potential for finding other deposits in this region.

The Upper Cretaceous Jesomma Series, which crops out to the south-west of the Mudug Plateau, consists of red, cross-bedded sandstone with clay bands and conglomerate lenses. These strata could have some potential for uranium mineralization [44.4, 44.6].

3.44.5. Comments

No uranium has been produced in Somalia and currently no uranium production is planned. Somalia has no installed or planned nuclear capacity.

References to Section 3.44

[44.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Somalia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2008).
[44.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 226–229.
[44.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).
[44.4] LEVICH, R.A., MULLER-KAHLE, E., IUREP Orientation Phase Mission Report: Somalia, OECD, Paris (1983) 26 pp.
[44.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).
[44.6] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

3.45. SOUTH AFRICA

South Africa is located at the southernmost tip of the continent of Africa. It has an extensive coastline that stretches more than 2500 km and borders two oceans (the Atlantic and the Indian Oceans).

The interior of South Africa is an extensive, rather flat, and sparsely populated scrubland, including the Karoo, which is drier in the north-west, towards the Kalahari Desert. Free State Province is particularly flat as it lies centrally on the high plateau. Johannesburg, in the centre of the Highveld, lies at an elevation of 1740 m. To the north of Johannesburg, the elevation drops beyond the Highveld's escarpment and forms the lower lying Bushveld, an area of mixed dry forest and an abundance of wildlife. East of the Highveld, beyond the eastern escarpment, the Lowveld stretches towards the Indian Ocean.

South Africa has a generally temperate climate, which is due, in part, to it being surrounded on three sides by the Atlantic and Indian Oceans, to its location in the climatically milder southern hemisphere and to the fact that its average elevation rises steadily towards the north and farther inland. The climatic zones vary considerably, ranging from the desert climate of the southern Namib in the extreme north-west to the lush subtropical climate in the east, along the Mozambique border and the coastline bordering the Indian Ocean. The extreme south-west has a climate similar to that of the Mediterranean region, with wet winters and hot, dry summers. The coldest place in South Africa is Sutherland in the western Roggeveld Mountains, where mid-winter temperatures can drop as low as −15°C. The interior records the highest temperatures.

South Africa has a major agricultural sector and is a net exporter of farming products (sugar, grapes, citrus, nectarines, wine). South Africa has abundant mineral resources and is one of the world's largest producer and exporter of gold, platinum, palladium, zirconium, chromite and manganese. It also exports a significant amount of iron, coal and diamonds. Uranium has been a major commodity in the past, although production has declined during the past decade [45.1].

3.45.1. Geology

South Africa's diverse strata span almost the entire range of the geological time scale. Major areas of the country are underlain by Precambrian rocks (Fig. 3.71), including the granitoid gneisses of the Kaapvaal Craton and several greenstone belts (e.g., Barberton, Murchison Pietersburg, Giyani, Kraaipan), the Limpopo mobile belt and the Witwatersrand Supergroup, all of which are of Archaean age. The Palaeoproterozoic is represented by the sedimentary strata dominated Transvaal Supergroup, the volcanic strata dominated Ventersdorp Supergroup, the Bushveld Complex (mafic/ultramafic and acidic intrusions), the Vredefort Granitic Dome (an ancient meteorite impact structure) and the Waterberg Supergroup. The Namaqualand Metamorphic Province (Northern Cape) and Natal belt are the major terrains formed during the Mesoproterozoic era. The Lower Palaeozoic is characterized by sediments and granites that were folded into the Cape Fold Belt. Approximately two thirds of South Africa's surface comprises strata of the Palaeozoic–Mesozoic Karoo Supergroup, which consists mainly of continental clastic sediments and volcanics. Several alkaline complexes, carbonatites and kimberlites intrude the Precambrian and Karoo strata. Cenozoic terrestrial and freshwater sediments, principally Kalahari Group sands, cover large parts of north-western South Africa along the borders with Botswana and Namibia [45.2].

The country's resources and reserves of uranium occur in five deposit types: (i) quartz-pebble conglomerate, (ii) carbonatite, (iii) sandstone, (iv) coal, and (v) surficial deposits. Other, less significant, uranium occurrences are hosted in granites and gneisses, as well as in marine phosphate deposits.

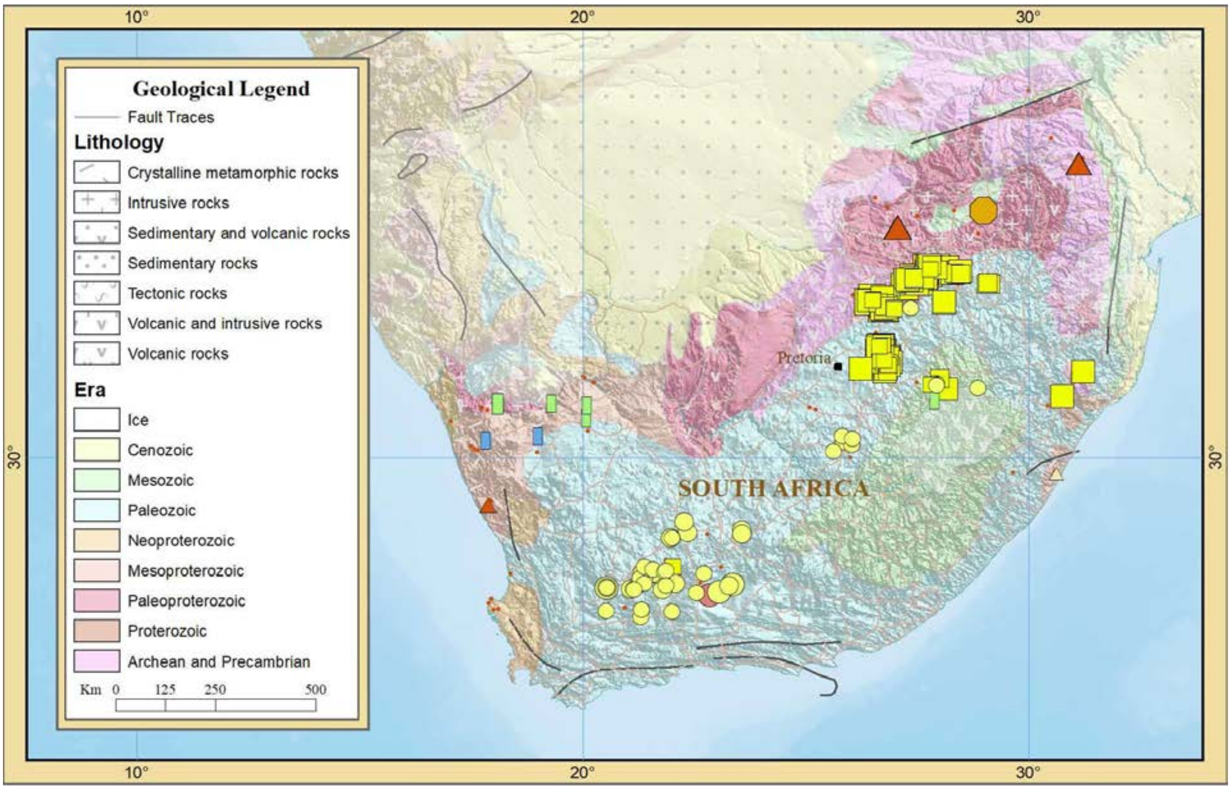


FIG. 3.71. Regional geological setting of South Africa showing the distribution of selected uranium deposits and occurrences. For general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.45.1.1. Uranium in quartz-pebble conglomerates

Important concentrations of uranium minerals occur in auriferous conglomerates present in four Precambrian terrains, namely, the Pongola Supergroup, the Dominion Group, the Witwatersrand Supergroup, and the Ventersdorp Supergroup, of which the Dominion Group and the Witwatersrand Supergroup are important because of their large uranium resources.

The Pongola Supergroup comprises a lower volcano-sedimentary Nsuze Group and the upper, largely sedimentary, strata comprising the Mozaan Group. There are sporadic occurrences of uranium in auriferous quartz-pebble conglomerates within the Mozaan Group in the eastern parts of South Africa. Mineralization is concentrated in the basal part of the Mozaan Group and consists of brannerite, uraninite, thorite and thorogummite as the principal uranium bearing minerals. The uranium potential was investigated by several exploration companies in the mid-1960s and early 1980s. However, the deposits were found to be subeconomic at the time.

The Dominion Group, unconformably overlain by the Witwatersrand Supergroup, is a sequence of volcanic and minor clastic sedimentary rocks which are mostly metamorphosed to greenschist–amphibolite grade. Surface exposures of the Dominion Group are limited, with scattered exposures visible in the Ottosdal area as well as to the west of Klerksdorp.

The Dominion Group consists of the Lower Rhenosterspruit Formation, which is overlain by the Rhenosterhoek Formation and the uppermost Syferfontein Formation. The Rhenosterspruit Formation is largely sedimentary in character, consisting of quartz-pebble conglomerates, arkosic quartzites, grits, sericitic sandstone and sericitic schists. The Rhenosterhoek Formation comprises largely mafic to intermediate lavas, while the Syferfontein Formation is dominated by felsic volcanic rocks. The quartz-pebble conglomerate of the Rhenosterspruit Formation consists of two important horizons, namely, the Lower Reef and the Upper Reef. The Lower Reef is up to 3 m thick in the valleys and thins over the basement high, and in some locations is entirely absent. The Lower Reef is the main gold-bearing horizon, with economic uraninite concentrations virtually absent. The Upper Reef is separated from the Lower Reef by gritty quartzites of variable thickness. The Upper Reef contains significant resources of uranium, with gold being the by-product.

The basal sedimentary units of the Dominion Group represent the earliest sedimentation in the region (3074 ± 6 Ma), pre-dating that of the overlying and economically important Witwatersrand Supergroup in which deposition began around 2970 Ma [45.2, 45.3]. The average grade of uranium in the Upper Reef is roughly between 0.025% U and 0.125% U, but associated gold values are low. Uranium from the Upper Reef has been mined in the past at the Dominion Reef mine, west of Klerksdorp.

The Witwatersrand Supergroup underlies an area of approximately 240 km × 130 km. The Witwatersrand Supergroup consists of the lower West Rand Group and the upper Central Rand Group. The West Rand Group consists of the Hospital Hill, Government and Jeppestown Subgroups. The Central Rand Group consists of the Johannesburg and the Turffontein Subgroups. Each of these subgroups is further divided into a number of formations. Quartz-pebble conglomerates of the West Rand Group are generally depleted in uranium, mostly likely as a result of an 'infertile' source area. However, there are economic concentrations of uranium in the Afrikander Formation (Government Subgroup) and the Buffelsdoorn Reef within the Rietkuil Syncline (Jeppestown Subgroup) that has been exploited. The Central Rand Group consists mainly of quartzites and conglomerates.

Uranium occurs in several quartz-pebble conglomerate horizons within the Central Rand Group, the concentration of which decreases towards the north-east, probably as a result of provenance control on the distribution of detrital uraninite. Therefore, a high concentration of uranium occurs in the Welkom and Klerksdorp goldfields, compared with the Evander goldfield in the north-east of the Witwatersrand Supergroup. Important uraniferous and auriferous conglomerate bands occur on flat planes of intraformational diastems, disconformities and unconformities. Each of these conglomerates represents a deposit formed after a hiatus in the sedimentation process. These obviously consist largely of reworked and resorted detritus derived from the erosion of underlying pebble and quartzite beds. The remarkably close relationship between the concentrations of the gold and uraninite and the sedimentary features strongly suggests that the gold and uraninite were deposited at the same time as the pebbles and other detrital components of the conglomerate.

The Ventersdorp Supergroup unconformably overlies the Witwatersrand Supergroup and comprises the Klipriviersberg Group at the base, followed by the Platberg Group, the sedimentary Bothaville Formation and the volcanic Allanridge Formation. The basal units of the Klipriviersberg Group form the Venterspost Formation, which consists of a quartz-pebble conglomerate up to 8 m thick. This basal Venterspost Formation is widely known as the Ventersdorp Contact Reef. It has been mined for gold in the Klerksdorp, Carletonville and West Rand goldfields, but the low uranium grades have rendered exploitation for uranium alone as subeconomic.

3.45.1.2. Uranium in carbonatite

In 1952, uranothorianite was discovered by the Atomic Energy Board in a carbonatite at Loolekop, which forms the central core of the Phalabora complex. Drilling and prospecting soon proved that the carbonatite body held little promise as a source of radioactive minerals alone, but contained a large body of low grade copper ore to a depth of at least 1480 m, the depth reached by drilling.

The complex consists of pyroxenite, syenite, olivine–phlogopite pegmatoid (altered to serpentine and vermiculite), fennite and carbonatite. Currently, copper, apatite, vermiculite and magnetite are mined, and baddeleyite and uranium were recovered as by-products. Reserves of copper available for an open pit mine to a depth of 400 m and at a grade of 0.7% Cu were estimated at several hundred million tonnes of ore; of thorium, at a grade of 0.01% Th, at 9700 tTh metal; and of uranium, at a grade of 0.004% U, at 11 000 tU metal. Uranium geological resources were estimated at 56 000 t U at 61 ppm.

3.45.1.3. Uranium in sandstone

The Karoo Supergroup covers more than 50% of South Africa. Since 1970, a large number of occurrences of uranium, of variable grades, have been discovered in the Karoo uranium province, in the south-western parts of the Karoo Supergroup. The Karoo uranium province predominantly overlies the Late Permian Adelaide Subgroup, which forms part of the lower units of the Beaufort Group. A small satellite area of the Karoo uranium province, to the north-east of Bloemfontein, is underlain by the Late Triassic Molteno and Elliot Formations. The uranium is sandstone hosted, disseminated and occurs in peneconcordant, tabular orebodies. Most of the exploration work, which includes airborne geophysical and ground surveys (radiometric surveys), trenching and core drilling, has been carried out in the Karoo uranium province and has led to the discovery of numerous uraniferous occurrences and deposits. Significant uranium occurrences and deposits are restricted to the south-western part of the country, around the town of Beaufort West.

The Adelaide Subgroup consists of alternating beds of sandstone and mudstone in the ratio of approximately 30:70. From a maximum thickness of about 5000 m in the south-east, the thickness of the Adelaide Subgroup decreases rapidly to about 800 m in the centre of the Karoo Basin, and thereafter more gradually to around 100–200 m in the extreme north of the basin [45.4]. The sandstones are generally fine-grained and lenticular and generally cannot be traced along strike for more than 3 or 4 km. The sandstones usually average about 5 m in thickness individually (maximum thickness can be up to 60 m) in the Adelaide Subgroup. Thicker sandstones tend to be 'multi-storey', with cut-and-fill features being common. Internally, the sandstones are characterized by horizontal lamination accompanied by parting lineation and less abundant trough cross-bedding and current ripple lamination. The sandstones of the Adelaide Subgroup generally contain quartz, weathered feldspar, calcite, clay minerals, biotite and chlorite. Lensoidal clay–pebble conglomerate, up to 1 m thick, is often developed at the base of the sandstone beds.

The orebodies are normally about 1 m thick, but attain 7 m in places and, where vertically stacked, attain a combined thickness of 20 m. They range up to several hundred metres in length, around two hundred metres in width and are generally elongated along the palaeochannel thalweg [45.5, 45.6]. There are two types of uranium mineralization in the Karoo uranium province: the laminated sandstone type and the carbonate cemented sandstone type [45.6]. The first type is always associated with carbonaceous debris and frequently carries plant fossils and silicified logs. Mineralization appears to be spatially related to major depressions along sandstone–mudstone contacts, which can be ascribed to fluviatile channelling and is frequently found along the edges of these depressions.

The thickest sandstone bodies (up to 60 m thick) contain the greatest proportion of uranium mineralization (i.e., the Poortjie Member). In the Adelaide Subgroup, the Poortjie Member hosts the majority of uranium resources and in the Molteno Formation, all the uranium resources are hosted within the Indwe Member.

The mineralized sandstone is enriched in uranium, copper, arsenic, molybdenum, lead and calcium, but appears to be depleted in iron compared with the unmineralized rocks. Uranium minerals are intimately associated with a variety of sulphides and calcite and are present as discrete grains, predominantly uraninite and coffinite and probably also uranium–carbon complexes. Secondary uranium minerals such as uranophane, beta-uranophane and carnotite are present along bedding planes and joints and result from recent oxidation and weathering. Grades vary from trace amounts to more than 2% U.

The discovery of uranium in the Karoo sediments during oil exploration in 1967 resulted in the diversification of uranium exploration activities. Exploration in the Karoo was at a relatively low level until the oil crisis of 1973–1974, after which it increased significantly. This resurgence in activity, however, was short lived. Uranium exploration in the Karoo declined rapidly and finally ceased in the mid-1980s owing to adverse uranium market conditions. Since then, low key re-evaluations of identified deposits are virtually the only activities to have taken place. However, since 2005, various exploration companies have conducted further exploration in the Karoo uranium province, and currently Peninsula Energy Ltd is the dominant exploration company in the region.

3.45.1.4. *Uranium in coal*

Significant uranium exploration in the Springbok Flats Basin was undertaken in the mid-1970s by companies such as Trans Natal Corporation Ltd following the discovery of uranium during coal exploration drilling in the basin. Uranium was found in the so-called 'Coal Zone' horizon, which consists of alternating coal seams and carbonaceous shales. The Coal Zone occurs in the uppermost part of the Late Permian Hammanskraal Formation (within the Ecca Group) and can attain a thickness of up to 12 m. The Coal Zone conformably overlies a succession of fine-grained to very coarse-grained sandstone beds. Most of the uranium occurrences discovered during this period occurred at depths of between 100 and 200 m. Uranium is concentrated in both the coal and the carbonaceous shale [45.4, 45.5, 45.7].

The Springbok Flats Basin trends NE–SW and has a strike length of approximately 190 km and a width of about 60 km. Exploration has focused in the central and north-eastern parts of the basin, on orebodies containing between 160 and 1000 ppm U_3O_8 over a 1 m width, especially in the Settlers and Roedtan areas [45.5, 45.8]. Uranium is disseminated in both the coal and the carbonaceous shale, the suggested sources being coffinite and auerlite (thorite with phosphorous). However, a high proportion of uranium is found in organo-metallic compounds. Uranium is believed to have originated from the granites of the Bushveld Complex which surround and underlie most of the Springbok Flats Basin.

In 2007, HolGoun Uranium and Power (Pty) acquired prospecting rights in areas such as Settlers and undertook further exploration which included a prefeasibility study. Geological resources are 81 920 t U at a grade of 420 ppm.

3.45.1.5. *Surficial deposits*

Surficial deposits unconformably overlie the African surface of Senonian and Miocene age in many parts of the country, especially in the arid and semi-arid region in Northern Cape Province. These deposits consist predominantly of calcite, quartz, feldspar and mica, together with clasts derived from the underlying country rocks.

Surficial deposits are subdivided into four types, namely, fluvial, lacustrine, pedogenic and ferruginous mudstone. Fluvial, lacustrine and pedogenic deposits predominate in the north-western parts of South Africa, south of the Orange River. These deposits were discovered in the mid-1970s as a result of radiometric surveys. The fluvial, pedogenic and lacustrine deposits have been preserved as a result of a stable crust and low rainfall, while the ferruginous mudstone deposits inhibited the dissolution of carnotite [45.5, 45.9].

Economically, the fluvial and the Henkries lacustrine deposits are the most important of the surficial deposits. Fluvial deposits are situated within sediments filling ancient valleys, with cementitious material being dominated by calcite. Lacustrine deposits normally occur over pans that have impeded drainage outlets. Pan sediments consist of clay, gyspsum/salt, sand, peat and diatomaceous earth.

The principal uranium mineral is carnotite and it is believed that the uranium in these deposits was derived from the granite gneisses of the Namaqualand Metamorphic Complex, which underlies most of the surficial deposits. Of interest are tributary drainage channels, some of ancient origin and now choked by Holocene deposits, which drain parts of Bushmanland and Namaqualand in Northern Cape Province.

In addition, many large shallow depressions, known as pans, are prevalent in Bushmanland, along drainage divides or watersheds. From the Upper Pliocene to the present day, cyclic movements and climatic changes have been responsible for a complicated morphology and many intraformational unconformities are present in the Holocene sedimentary deposits. Seismic surveys indicate accumulations of debris in excess of 100 m in thickness in some of the ancient drainage areas.

A considerable number of uranium occurrences have been found in quarries opened for road metal, in underground water taken from wells and boreholes and in other excavated openings that penetrate the superficial cover, which is often ubiquitous. Currently, exploration by Namakwa Uranium is ongoing in the Henkries deposit. Published resources are 1730 t U at a grade of 345 ppm.

3.45.1.6. Granites and granitic gneiss deposits

Uranium occurs in low concentrations either in disseminated form or associated with fracture zones in the granites and granitic gneisses of the Namaqua/Natal mobile belt (~1200–1000 Ma) in the Northern Cape and KwaZulu-Natal Provinces. These rocks are also found in the Bushveld Complex (~2000 Ma). Exploration carried out to date has indicated the presence of large tonnage low grade ores in a number of localities in Northern Cape and Western Cape Provinces (hosted within the Namaqualand Metamamorphic Complex, Cape Granite Suite, Concordia Granite and George Pluton). However, owing to prevailing uranium market conditions, these occurrences are not considered to be economically viable [45.10, 45.11].

3.45.1.7. Phosphate deposits

Phosphorus bearing sediments containing low grades of uranium (between 10 ppm and 300 ppm U_3O_8) occur on the continental shelf along the western and southern coasts of South Africa. These sediments can be either consolidated or unconsolidated, with relatively higher uranium concentrations in the consolidated, older phosphorites [45.5]. Francolite is the predominant phosphorus bearing mineral in which the uranium occurs. The uranium is believed to have been derived from sea water [45.11]. The low uranium grades in these deposits mean that exploitation will not be feasible for the foreseeable future.

3.45.2. Uranium exploration

The global search for uranium resources in the early 1940s prompted the start of uranium exploration in South Africa in 1944. Attention at that time was focused on the occurrence of uranium in the gold-bearing quartz-pebble conglomerates of the Witwatersrand Supergroup. The discovery of uranium in the Karoo Basin during drilling for oil in 1967 resulted in a diversification of uranium exploration activities in the early 1970s. Although initially conducted at a modest level, exploration activities increased until the accident at Three Mile Island in 1979, which sent the then ‘overheated’ uranium market plummeting. Exploration activities in the Karoo Basin declined rapidly thereafter and finally ceased in the mid-1980s.

Until the oil crisis of 1973–1974, exploration for uranium in the Witwatersrand Basin was always incidental to gold exploration. With the price of uranium increasing more than fivefold over a short period, uranium exploration activities intensified, leading to the establishment, in 1981, of South Africa’s first primary uranium producer: the Beisa mine.

In 1981–1982, prospecting in the Witwatersrand Basin was carried out primarily for gold. As some of this prospecting was being undertaken in uranium-bearing reefs, the beneficial impact was to increase uranium resources. Extensions to the Welkom and Klerksdorp goldfields was the main aim of exploration. Exploration in the Karoo Supergroup was most severely affected and in 1982 only five companies were actively undertaking exploration in these strata. Airborne and ground surveys were conducted by the private sector and Government agencies. The Government agencies limited their activities to geological mapping, airborne surveys and regional hydrological, geochemical and geophysical investigations. The Government sponsored airborne radiometric survey of the Karoo Supergroup, the largest investigation undertaken in the southern hemisphere, was completed in 1982. Three quarters of South Africa was overflown and data processing by computer was completed by mid-1984.

However, the crash in the uranium market shortly thereafter not only resulted in the closure of Beisa’s uranium-only production facility in 1985, but also had a detrimental effect on uranium exploration in general. Incidental discoveries of new uranium resources were nevertheless made during the exploration for gold as a result of the ubiquity of uranium in the quartz-pebble conglomerates. The static gold price in the 1990s furthermore led to a substantial curtailment of gold exploration activities within the Witwatersrand Basin.

Exploration for uranium outside of these two geological basins resulted in the discovery of uranium mineralization associated with coal, carbonatites, granites, marine phosphates and surficial deposits. Such exploration has always been undertaken on a low key basis and has recorded very limited success in terms of the discovery of additional uranium resources.

In 1984, the high gold price, in local currency terms, stimulated exploration activities, with encouraging and positive results. Twelve companies, including all the major South African mining groups, some smaller local companies and foreign companies, were active within the Witwatersrand Basin during 1984. It was estimated that in excess of R 100 million was spent on exploration in the Witwatersrand Basin.

The main areas of exploration activity were to the south of the Welkom goldfield, extensions to the Klerksdorp and Carletonville goldfields, and the Potchefstroom Gap between the latter two areas. Interest was also being shown in proving extensions to the Central, East Rand and Evander goldfields. An important factor in determining target areas was the advancement of deep mining technology, which made deeper reefs accessible for exploitation. Exploring for deep reefs is a very high cost exercise.

Extensive use was made of the sophisticated vibroseismic technique to define targets more accurately before embarking on a drilling programme. The success of the exploration activities was attested by the fact that announcements were made for the opening of five major mines, two of these on the basis of primary uranium production. Exploration outside the Witwatersrand Basin was at a low level, but the expenditure reported for 1984 showed a 50% increase over that for 1983.

Exploration for uranium as a primary commodity was last undertaken in 1988 during exploration activities on the Springbok Flats in Limpopo Province. No exploration for uranium as a primary product was carried out between 1988 and 2005. During this period, exploration activities in the Witwatersrand Basin targeted gold, although the depressed gold market severely constrained these activities. Information regarding uranium exploration undertaken by South African companies both within and outside South Africa is unavailable owing to company confidentiality.

The Karoo research project, initiated by the Atomic Energy Corporation in 1991, was completed in 1994. The data from some of the larger and higher grade uranium deposits were, however, re-evaluated to establish the economic viability of initiating mining operations. The work identified a number of fundamental controls to the uranium mineralization in the Karoo sandstones. The study indicated that significant potential exists for the discovery of additional uranium deposits within the main Karoo Basin.

Outside of the Witwatersrand and Karoo Basins, exploration activities have been directed at the discovery of other types of uranium deposit, including unconformity-related, surficial (alluvial–lacustrine), alaskite breccia, Olympic Dam type and marine phosphate deposits. These activities were always conducted on a reduced scale compared with those in the two main uranium-bearing basins. The activity level peaked in the late 1970s and declined rapidly following the onset of the uranium price decline in the early 1980s. They achieved only very limited success.

The upsurge in the price of uranium from 2005 rekindled interest in uranium exploration and production in South Africa. An increase in the gold price from less than US $12 860/kg towards the end of 2003 to more than US $19 290/kg at the end of 2006 stimulated renewed interest in exploration for gold at several locations along the limb of the Witwatersrand Basin, while the much higher uranium price encouraged some gold mining groups to revert to a routine of recording the uranium concentrations within the reefs during their ore development and mining activities. Some mining companies have also drilled and assayed slimes dams to determine their uranium and gold contents for possible future exploitation. Renewed interest in uranium occurrences in the Karoo Basin has also been evident in recent years.

In 2007–2008, the initiation of a uranium beneficiation programme by the Government, favourable demand/supply fundamentals and a much more positive attitude towards nuclear power helped to underpin rapid uranium price increases, which in turn fuelled investment in both greenfield and brownfield projects.

There were at least eight companies actively engaged in exploration, development or mining. First Uranium Corporation of Canada has been active in South Africa through two operating entities: Ezulwini Mining Company Pty Ltd and Mine Waste Solutions Pty Ltd. Subsequent to the granting of Ezulwini Mining's prospecting licence in January 2008, diamond drilling commenced according to the revised exploration programme. The original plan was to drill 18 surface holes on a 400 m × 400 m grid spacing. This programme was amended to 10 surface holes drilled on a 300 m × 300 m grid spacing, each sunk to a depth of 2000 m. Underground investigations have been deferred to a later date.

UraMin Inc. of Canada (and more recently of France through AREVA) has identified several areas of interest in the Springbok Flats coalfield within its 22 prospecting rights inventory, and has focused on the Leffi and Mocha blocks. The resource for the entire Springbok Flats coalfield is estimated at 77 072 tU at a grade of 0.06–0.1% U (geological resources are 81 920 t U at a grade of 420 ppm in 2010). The most significant constraint to exploitation is the identification of a uranium extraction process that will not detrimentally affect the environment.

UraMin Inc. is also conducting a drilling programme on the largest sandstone-hosted uranium deposit in the Ryst Kuil Channel (19 890 t U at 0.088%), south-east of Beaufort West, as well as in Sutherland, Northern Cape, within its 34 prospect areas. Resources amounting to approximately 10 000 tU have been identified on the properties in Sutherland and in proximate areas.

Little or no exploration activity is recorded in the other uranium resource fields, namely, the surficial fluvial, lacustrine and pedogenic environments in the North West Cape; the Concordia granite in Namaqualand in the vicinity of the town of Springbok; the Natal Group in KwaZulu-Natal, north of Shepstone; and the Mozaan Group in the northern part of KwaZulu-Natal, even though they all have the potential to contain economically viable deposits [45.11].

Figure 3.71 summarises historical exploration data up to 2017 totalling USD $245 299 390, including 3 533 527 metres of drilling and 750 217 km^2 of airborne radiometric surveys.

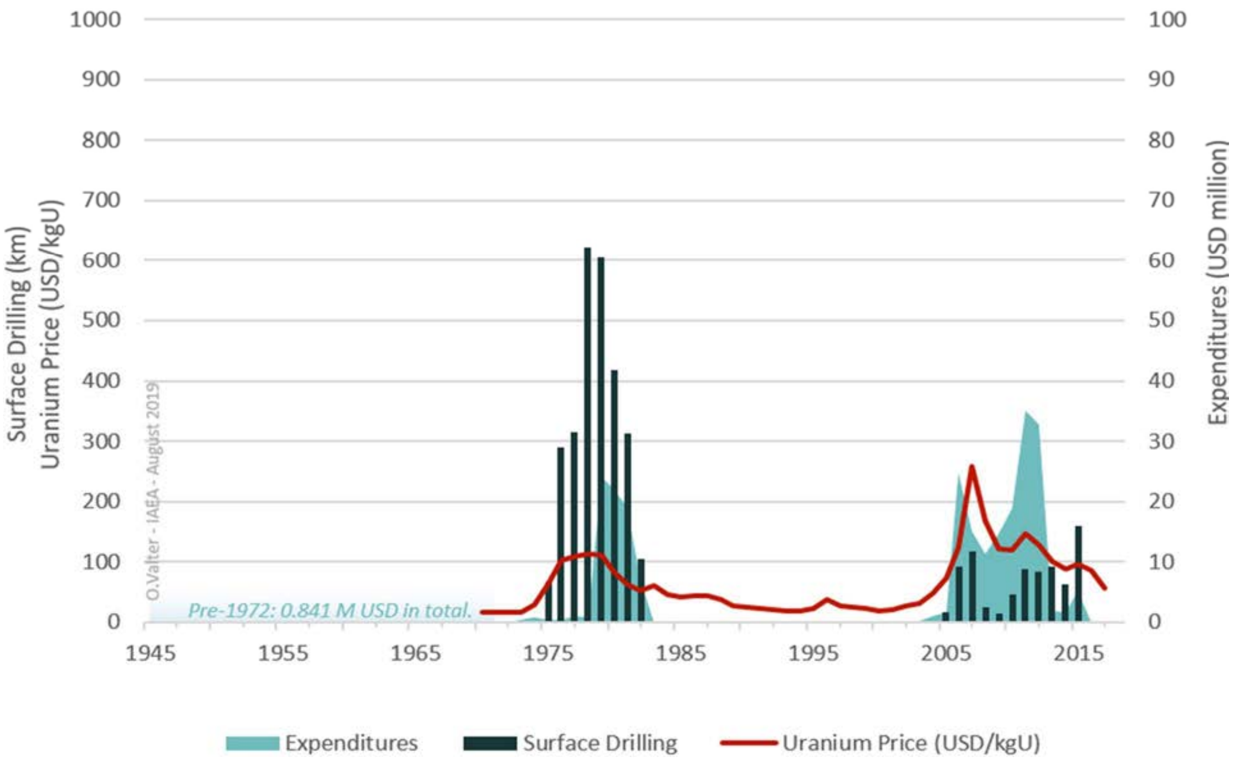


FIG. 3.71. Domestic uranium exploration data for South Africa. Comparison of exploration expenditures, drilling and uranium market price (US$ current [45.12–45.30]).

3.45.3. Uranium resources

South Africa's uranium resources are summarized in Tables 3.32–3.35. The historical variation in identified resources is shown in Fig. 3.72 and Fig. 3.73.

The UDEPO database lists the most significant deposits for South Africa as Pilanesberg - Ledig Zone, Free State Geduld, Vaal Reefs Mine, Durban (Roodeport) Deep, Ezulwini, Freddies.

3.45.3.1. Identified resources

By far the largest portion (about 67%) of South Africa's identified uranium resources comprises low grade concentrations hosted within the gold-bearing Witwatersrand quartz-pebble conglomerates. Where uranium is recovered as a by-product of gold operations, it generally accounts for less than 10% of the total revenue obtained from the total ore mined. Uranium is currently only produced as a by-product of gold mining, and the gold and uranium prices, the Rand/US$ exchange rate, as well as the mining and processing costs have a significant effect on South Africa's uranium resource figures and cost category allocations. The majority (about 73%) of South Africa's identified in situ uranium resources recoverable at less than US $80/kgU is likewise associated with gold resources hosted within the Witwatersrand Supergroup. However, since only one mine (Vaal River Operations) has a uranium recovery plant in operation, significant amounts of uranium are currently being discharged into tailings dams. Recovery of uranium from this source will depend to a large extent on the degree of dilution by non-uraniferous tailings and the possible use of such tailings as backfill in mined-out areas.

3.45.3.2. Reasonably assured and inferred resources

An estimated 61% of South Africa's reasonably assured resources plus inferred resources recoverable at US $40/kgU, or less, are in existing and committed production centres.An estimated 42% of South Africa's reasonably assured resources plus inferred resources recoverable at US$ 80/kgU, or less, are in existing and committed production centres.

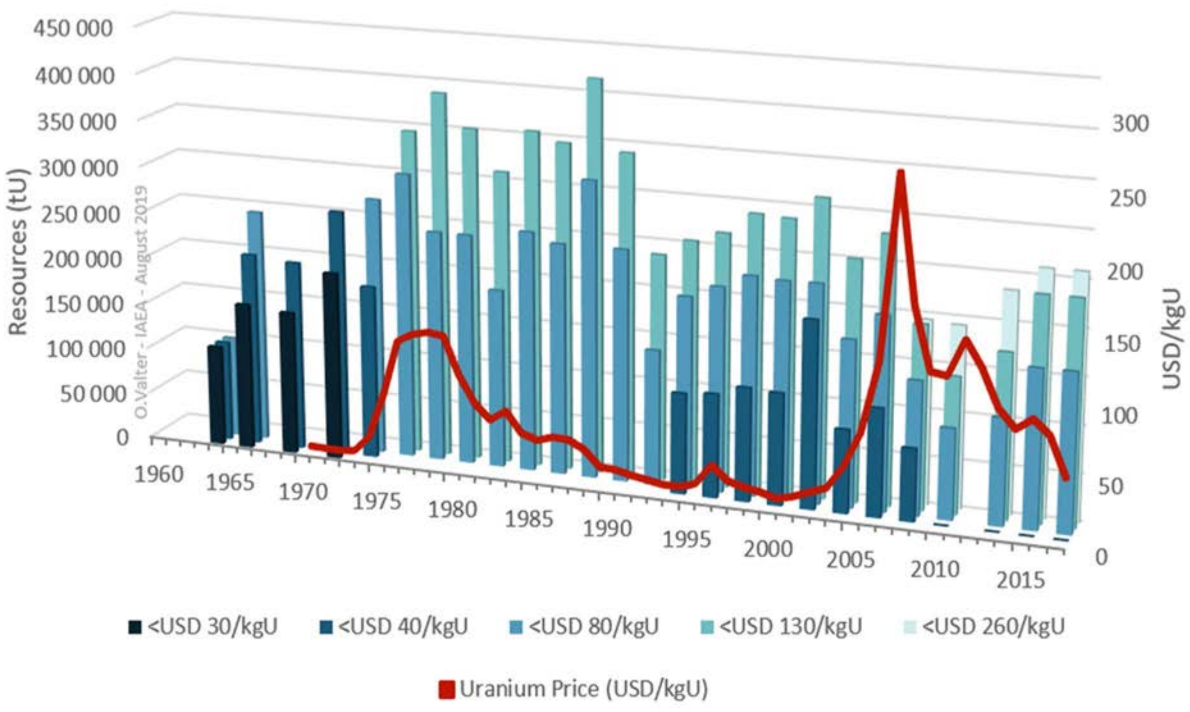


FIG. 3.72. Historical variation of recoverable reasonably assured resources within various cost categories in South Africa. Periods where no resources are shown in any cost categories are periods where resources were not reported.

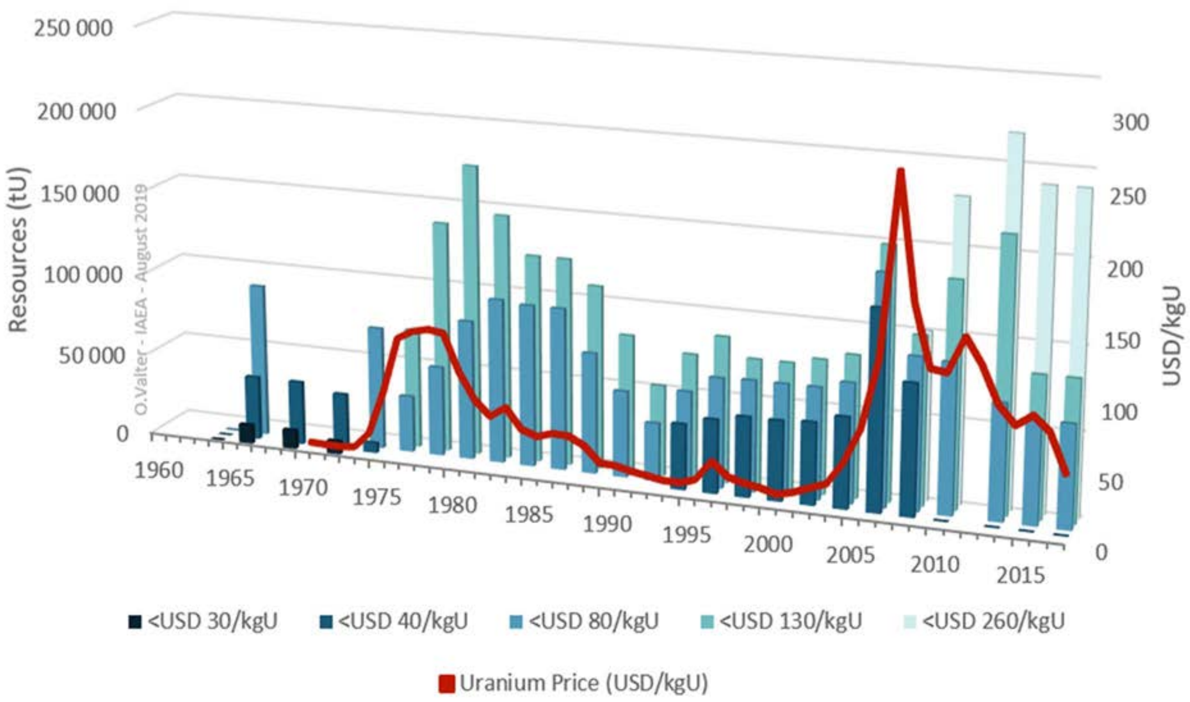


FIG. 3.73. Historical variation of recoverable inferred resources within various cost categories in South Africa. Periods where no resources are shown in any cost categories are periods where resources were not reported.

TABLE 3.32. REASONABLY ASSURED RESOURCES[a] BY DEPOSIT TYPE (tU) [45.31]
(As of 1 January 2015)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	0	7261	8526
Quartz-pebble conglomerate[b]	0	167 874	230 321	249 892
Surficial	0	0	0	1 146
Total	0	167 874	237 582	259 564

[a] Recoverable resources, but depletion is not considered.

[b] Quartz-pebble conglomerate resources include tailings resources

TABLE 3.33. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [45.31]
(As of 1 January 2015)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	0	10 467	13 491
Quartz-pebble conglomerate [a]	0	61 656	74 361	104 861
Surficial	0	0	0	589
Lignite and Coal	0	0	0	70 775
Total	0	61 656	84 828	189716

[a] Includes tailings in the Witwatersrand basin.

3.45.3.3. *Undiscovered resources*

Currently, exploration for uranium deposits outside of the Witwatersrand Basin is ongoing in the Karoo uranium province and Springbok Flats Basin, as well as in the surficial deposits of the Namaqualand region. More than thirty applications for uranium prospecting permits associated with previously discovered deposits within the Karoo Basin were issued in 2006. Most exploration activities for uranium was stopped in 2011-2012.

TABLE 3.34. PROGNOSTICATED RESOURCES (tU) [45.31]
(As of 1 January 2015)

<US $130/kgU	<US $260/kgU
74 000	159 000

TABLE 3.35. SPECULATIVE RESOURCES (tU) [45.31]
(As of 1 January 2015)

<US $260/kgU	Unassigned
411 000	280 000

Limited efforts to identify Witwatersrand type basins outside of the currently known limits of the main basin have met with discouraging results. This has been compounded by a lack of funding for speculative type exploration.

3.45.3.4. *Unconventional resources*

A phosphate field has been identified off the west coast of South Africa which hosts uranium values, although the grades do not exceed 430 ppm U and extraction of uranium from genetically similar offshore phosphate workings has proven to be unfeasible [45.30].

The large areas underlain by rocks of the Dominion Group constitute a promising target area for identifying new uranium deposits. Currently, Shiva Uranium is exploiting these reefs for gold and uranium, even though uranium processing has been temporarily suspended. The company produced approximately 1.6 tU in February 2011.

Sandstone deposits are currently being prospected in the Karoo Supergroup, especially in the Lower Beaufort Group in the south-western part of the country. Peninsula Energy Ltd is the dominant exploration company in the region

Surficial type uranium deposits were prospected for in Northern Cape Province, near to the Henkries deposit. All projects are dormant.

3.45.4. Uranium production

Figure 3.74 details historical uranium production for the period 1952–2017, totalling 163 686 tU.

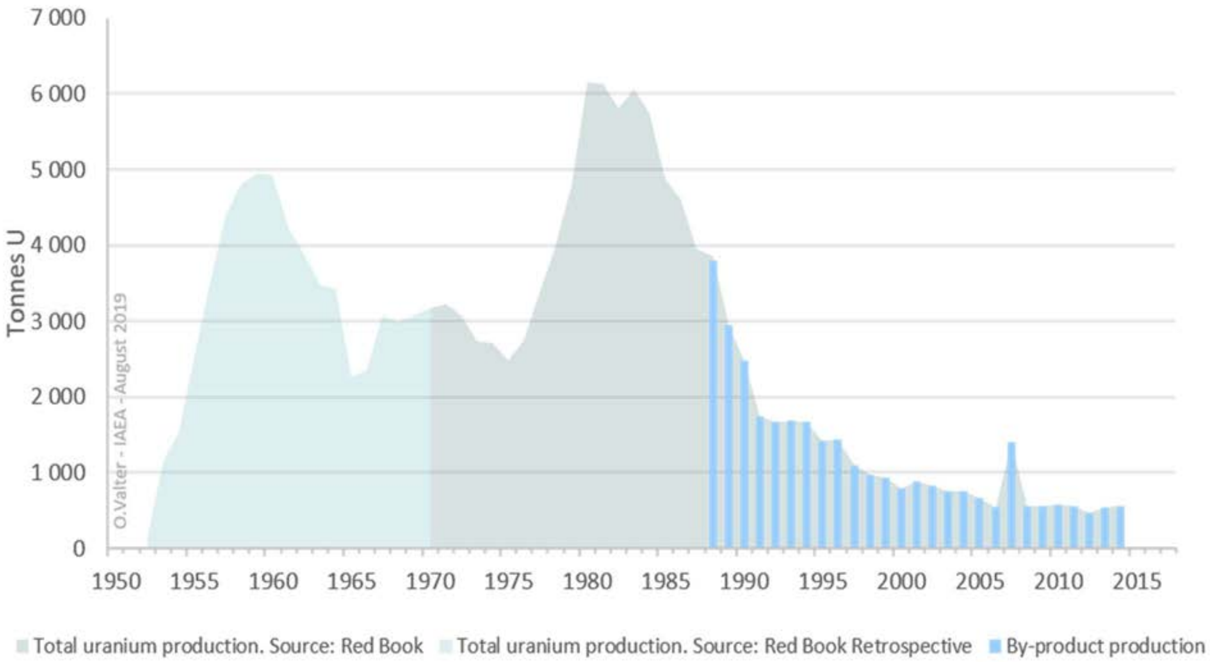


FIG. 3.74. Historical uranium production in South Africa. (Data in light green are from the Red Book Retrospective, in dark green from Red Books) [45.27–45.32].

3.45.4.1. Historical review

Uranium, mainly as a by-product of the mining for gold of quartz-pebble conglomerates of the Witwatersrand Basin, was first produced in 1952 in response to approaches from the Combined Development Agency, a joint US–UK uranium procurement organization. This organization assisted new producers by making loans available to them and by financing the construction of a central calcining plant at the West Rand Consolidated mine for the further processing of uranium slurries prior to shipment. During 1953, a further four plants came into production at various centres. Total uranium production peaked in 1959 when 4957 tU were produced from 17 plants being fed from 26 mines within the Witwatersrand Basin.

Thereafter, as demand for uranium waned, so-called ‘stretch-out’ agreements were made with the United Kingdom and the United States of America and annual production decreased to some 2460 tU in 1965, by which time only 12 mines were producing ore for treatment in 7 extraction plants. Shipments of uranium to the USA under the stretch-out agreements ended in 1966; those to the UK ended in 1973.

In 1971, Phalabora Mining Company became the first non-Witwatersrand uranium producer in South Africa. It produced uranium as a by-product of copper at its open pit mining operation in the north-eastern Transvaal. Uranothorianite was first concentrated in a gravity separation plant, along with other heavy minerals and the uranium recovered using an acid leach and solvent extraction process. Phalabora Mining Company commenced uranium production in 1971 and ceased production in 2002. During its 32-year history of operation, from 1971 to 2002, Phalabora uranium production totaled 3047 t U. Maximum production of 218 t was achieved in 1982.

The oil crisis of 1973–1974 stimulated demand for uranium as an alternative source of energy. The large tailings stockpiles containing uranium which had accumulated over many decades of mining became a readily available source of uranium. These stockpiles were reprocessed at Welkom (Joint Metallurgical Scheme (1977)), on the East Rand (ERGO (1978)) and at Klerksdorp (Chemwes (1979)), which culminated in a record uranium production of 6028 tU in 1980. In 1983, the number of production centres increased to 14.

Since 1983, there has been a steady decline in the number of producers, with only five processing plants producing uranium from only four mines at the end of 1992. In 1984, the Beisa plant was closed completely while the uranium plant at Harmony gold mine and the Blyvooruitzicht plant were placed on a care and maintenance basis. The full effect of the decline in demand was felt in 1985 when production at Western Deep Levels ceased. In 1988, the Driefontein, Randfontein and Chemwes production centres were closed and in 1990 the ERGO processing plant also closed.

The following four mines were producing uranium at the end of 1992:

(i) Hartebeestfontein had one uranium plant with the capacity to treat 3 200 000 t annually. During 1991–1992, the plant operated at a uranium recovery factor of 65%. The production of uranium at the mine used the reverse leach cycle, which also significantly increases the gold recovery and therefore improves the overall profitability of the operation;
(ii) Vaal Reefs has three uranium plants. In 1992, one plant operated near capacity while a second was operated at 50% capacity. The third plant was on a care and maintenance basis. The three plants have a combined capacity to treat 9 000 000 t of ore annually. During 1992, only 6 000 000 t of ore were treated;
(iii) Western Areas is the richest uranium producer in the Witwatersrand and has one plant with the capacity to treat 650 000 t annually. In 1991–1992, Western Areas gold production operated at a loss. However, profits generated by uranium production substantially exceeded these losses. The uranium plant has an annual capacity of 200 000 t of gravity concentrate. The Western Areas plant closed at the end of 1997;
(iv) Phalabora is a large open pit copper producer which produced uranium as a by-product. Uranothorianite was first concentrated in a gravity separation plant, along with other heavy minerals and the uranium recovered using an acid leach and solvent extraction process. Phalabora Mining Company commenced uranium production in 1971 and ceased production in 2002.

The three mines producing uranium at the end of 1998 were Hartebeestfontein and Vaal Reefs at Klerksdorp, and Phalabora in Northern Province. In 1998, for the first time in over 45 years, South African uranium production fell below 1000 tU. At the end of 2000, only two plants were producing uranium from two mines [45.26, 45.27].

3.45.4.2. Status of production capability

AngloGold Ashanti is the largest producer of gold and by-product uranium. Uranium production for 2007 was 530 tU and production for 2008 was 575 tU. AngloGold Ashanti was planning to increase annual uranium production in 2009–2010 and to expand its uranium ore processing plant to 400 000 t/month by 2010.

First Uranium Corporation is focused on the development of its South African uranium and gold mines through the reopening of underground workings in the Ezulwini mine and the expansion of the tailing recovery operation of Mine Waste Solutions (Pty) Ltd. At the Ezulwini uranium and gold mine, it plans to reach an annual production of 130 000 t of ore by 2009 and 180 000 t by 2012 from the Upper and Middle Elsburg Reefs. The uranium plant at the Ezulwini mine is scheduled to start uranium production in early 2009. The first two modules of the uranium plant of Mine Waste Solutions are scheduled to start uranium production in early 2009. The average annual production over the 16-year life of the project is expected to be 349 tU and 3636 kg of gold.

Buffelsfontein Gold Mines Ltd has built a processing plant at the Ezulwini mine, in the Central Rand Group, south-west of Johannesburg. Production started in October 2007 and will increase to an annual production rate of 336 tU between 2008 and 2024.

After extensive exploration and as the result of feasibility studies, SRX Uranium One opened the Dominion Reef mine in June 2007, which has uranium as the primary commodity. Exploration and mine development are currently under way and the mine will have a maximum depth of 500 m and a projected life of 30 years. The processing plant has an annual design capacity of 1460 tU, which is planned to be increased to 1730 tU by 2011. Dominion Reef produced 189 tU and 193 tU in 2007 and 2008, respectively [45.31].

In 2016, uranium production of 490 t was coming from two mines, Vaal River (423 t) and Ezulwini-Cooke (67 t). In 2017 Vaal River was the only producing mine with 308 t.

Total historical production of uranium in South Africa to 2017 is 163 686 t.

In 2007, UraMin Inc. had a feasibility study under way at its Ryst Kuil uranium project. UraMin intended to mine these deposits by open pit. The Ryst Kuil Channel mine, south-east of Beaufort West, was due to open following extensive investigations within the Karoo uranium province (molybdenum was expected to be recovered as a by-product).

In 2012, Australian-based Peninsula Energy, the last operator of the project had reported a JORC-compliant resource of 21 930 tU at its Karoo project. In April 2018, Peninsula announced that it was withdrawing from Karoo in order to focus attention on its Lance project in the USA [45.32]. Production never started and the project is dormant.

3.45.5. Future projects

Since the uranium resources in South Africa occur mainly as a by-product of gold mining, it is difficult to predict whether any prospective operator, other than the existing and committed production centres, could be supported by existing identified resources in the reasonably assured resources and inferred resources categories recoverable at a cost of <US $80/kgU. The cost of producing uranium is determined by the gold content of the ore, the gold price, the working costs and the Rand/US$ exchange rate.

Given favourable conditions in respect of these variables, it is possible for South Africa to achieve annual uranium production levels of more than 6000 tU (last recorded in the early 1980s) within the next decade. South Africa also has significant quantities of uranium contained in mine tailings, which could be extracted given stable and predictable long-term sales contracts [45.26, 45.27]. Future projects could include Dominion Reef, Randfontein and Henkries.

Short term production projections are given in Table 3.36.

TABLE 3.36. SHORT TERM PRODUCTION CAPABILITY (tU/year) [45.30]

2010				2015				2020			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
4860	4860	—[a]	—	4860	6320	—	—	4860	6320	—	—

cont

2025				2030				2035			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
4860	6320	—	—	4860	6320	—	—	4860	6320	—	—

[a] —: not available.

3.45.5.1. Dominion Reef

In 2006, Uranium One obtained its mining permit for the Dominion Reef project, 150 km south-west of Johannesburg. Production commenced early in 2007 and there were plans to increase to 1250 tU/year by 2011. Production costs were expected to be US $32/kgU from the conglomerate reefs to 500 m depth, but these have evidently increased well beyond this. Production for 2007 was 66 tU and that for 2008 was expected to be 123 tU, reflecting slower and more difficult underground development than anticipated.

Dominion Reef has indicated resources of 43 250 tU at a grade of 0.053% U and inferred resources of 53 255 tU at a grade of 0.031% U. However, of these reserves there are only 12 075 tU grading 0.065% U at a production cost of US $102.50/kgU. The mine was closed in October 2008 due to a labour dispute coupled with power shortages and increased project costs in the context of lower uranium spot market prices. Uranium One subsequently announced the mine would be put on care and maintenance pending a possible sale.

3.45.5.2. Randfontein

Newco is reopening part of the Randfontein mine, which produced uranium in the 1980s. It has identified resources of some 41 000 tU both in tailings and underground. Probable reserves of 15 200 tU remain in the Cooke tailings. Production of 1000 tU/year is envisaged.

3.45.5.3. Henkries

The Henkries uranium project is being explored by Namakwa Uranium, which is now 74% owned by Niger Uranium and 26% by the company’s economic development partner, Gilstra Exploration. Anglo American completed a feasibility study for the project in 1979. In 2018, the project is dormant.

3.45.6. Environmental activities

In South Africa, there is some land which has been contaminated by radioactivity, particularly where existing and previous uranium plants are or were located. If development takes place on former mine land, the area is radiometrically surveyed and, where necessary, decontaminated.

The National Nuclear Regulator is the body responsible for the implementation of nuclear legislation related to these activities and for ensuring that the standards conform to international norms. Large areas around gold/uranium mines have been reserved for slimes dams and rock dumps. South Africa has enacted strict environmental legislation which ensures that such areas are suitably rehabilitated after closure.

Environmental issues relating to gold/uranium mining within the Witwatersrand Basin are dust pollution, surface water and groundwater contamination, as well as residual radioactivity. Scrap materials from decommissioned plants may only be sold after these have been decontaminated to internationally accepted standards.

The by-product status of uranium production in South Africa makes it impossible to establish what proportion of the total expenditure on environmentally related activities specifically pertains to uranium. The South African mining industry, however, allocates considerable resources for environmental rehabilitation from the exploration stage through to mining and, finally, mill closure [45.27].

3.45.7. Employment in the uranium industry

Figure 3.75 summarizes employment in South Africa’s uranium industry for the years 2000–2008.

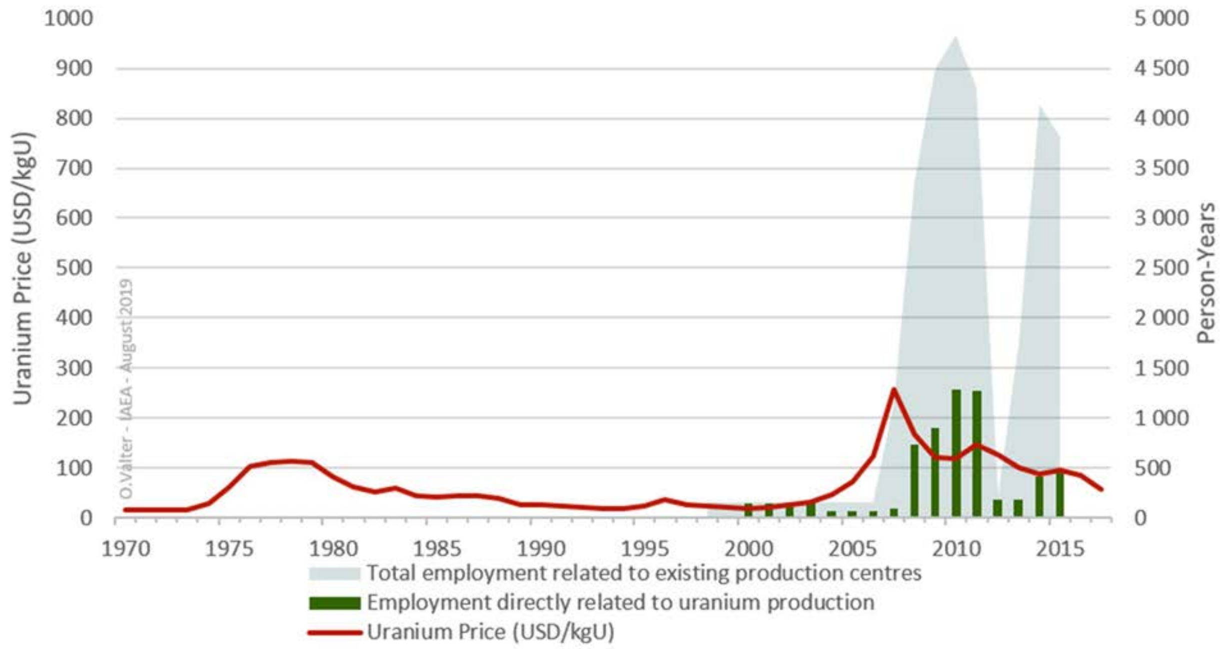


FIG. 3.75. Uranium industry employment at existing uranium production centres in South Africa [45.27–45.31].

References to Section 3.45

[45.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: South Africa, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[45.2] MARSH, J.S., "The Dominion Group", The Geology of South Africa (JOHNSON, M.R., ANHAEUSSER, C.R., THOMAS, R.J., Eds), Geological Society of South Africa and the Council for Geoscience, Pretoria (2006) 149–154.

[45.3] McCARTHY, T.S., "The Witwatersrand Supergroup", The Geology of South Africa (JOHNSON, M.R., ANHAEUSSER, C.R., THOMAS, R.J., Eds), Geological Society of South Africa and the Council for Geoscience, Pretoria (2006) 155–186.

[45.4] JOHNSON, M.R., et al., "Sedimentary rocks of the Karoo Supergroup", The Geology of South Africa (JOHNSON, M.R., ANHAEUSSER, C.R., THOMAS, R.J., Eds), Geological Society of South Africa and the Council for Geoscience, Pretoria (2006) 461–500.

[45.5] COLE, D.I., Uranium in the Mineral Resources of South Africa Handbook (WILSON, M.G.C., ANHAEUSSER, C.R., Eds), Council Geosci. **16** (1998) 642–658.

[45.6] COLE, D.I., WIPPLINGER, P.E., Sedimentology and molybdenum potential of the Beaufort Group in the main Karoo Basin, South Africa, Council Geosci. Mem. **80** (2001) 225.

[45.7] CHRISTIE, A.D.M., Demonstrated Coal Resources of the Springbok Flats Coalfield, Geol. Surv. S. Afr., Johannesburg (1989) 2269–2287.

[45.8] ROBERTS, D.L., The Springbok Flats Basin – A Preliminary Report, Rep. No. 1993-0197, Geol. Surv. S. Afr., Johannesburg, unpublished data.

[45.9] HAMBLETON-JONES, B.B., LEVIN, M., WAGENER, G.F., "Uraniferous surficial deposits in southern Africa", Mineral Deposits of Southern Africa II (ANHAEUSSER, C.R., MASKE, S., Eds), Geol. Soc. S. Afr., Johannesburg (1986) 2269–2287.

[45.10] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 230–237.

[45.11] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[45.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1973).

[45.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1976).

[45.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[45.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[45.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[45.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[45.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[45.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).
[45.20] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).
[45.21] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).
[45.22] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).
[45.23] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).
[45.24] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).
[45.25] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).
[45.26] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).
[45.27] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).
[45.28] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).
[45.29] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[45.30] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[45.31] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2016: Resources, Production and Demand, OECD, Paris (2016).
[45.32] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006).

3.46. SUDAN (SOUTH SUDAN AND THE SUDAN)

Sudan was the largest country in Africa until it split into South Sudan and the Sudan[7]. It is situated in north-eastern Africa, with a coastline of 853 km bordering the Red Sea. The interior is dominated by the River Nile and its tributaries.

The terrain comprises flat plains, broken by several mountain ranges; in the west the Jebel Marra is the highest range; in the south the highest mountain is Mount Kinyeti Imatong, near the border with Uganda; in the east it is the Red Sea Hills. The Blue and White Niles meet in Khartoum to form the River Nile, which flows northwards through Egypt to the Mediterranean Sea. Rainfall increases towards the south. In the north, there is the very dry Nubian Desert; in the south, swamps and rainforest. Sudan's rainy season lasts for about three months (July–September) in the north, and up to six months (June–November) in the south.

Agriculture (cotton, gum arabic, livestock) remains Sudan's most important sector, employing 80% of the workforce and contributing 39% of GDP. However, oil production and exports are taking on greater importance. The country is rich in mineral resources, including petroleum, natural gas, gold, silver, chromite, asbestos, manganese, gypsum, mica, zinc, iron, lead, uranium, copper, kaolin, cobalt, granite, nickel and tin [46.1].

3.46.1. Geology

Sudan is largely underlain by Precambrian rocks (Fig. 3.76), particularly in the southwest, centre and northeast, which were almost exclusively reactivated during the Neoproterozoic Pan-African tectono-thermal event. Large parts in the north of the country are covered by continental clastic sequences of the

[7] Following a referendum held in January 2011, the southern region became independent on 9 July 2011 and is now known as South Sudan. When this chapter was prepared, South Sudan was still part of the Sudan. Therefore, Chapter 46 treats 'Sudan' as one entity, incorporating both the Sudan and South Sudan.

predominantly Mesozoic Nubian cycle and in the south by Tertiary to Quaternary unconsolidated superficial sediments. Some Tertiary and younger basalts occur in the border zone with Ethiopia [46.2].

Precambrian strata crop out over a very wide area in Sudan. The earliest Precambrian includes the most metamorphosed rocks, granite–gneiss and schist, all of which have been intruded by later granites and dolerite dykes. Most of the granitic rocks have an age of 700 Ma. Thus, it appears as if the basement complex in Sudan was probably metamorphosed during the Upper Proterozoic and therefore is related to the Pan-African Orogeny.

Resting unconformably on the basement complex is the Nafirdeib Series, which consists of over 3000 m of gneisses, quartzites, marbles, schists and green andesite flows. These strata are intruded by granites, gabbros, norites and quartz veins which contain free gold values. These veins most commonly occur in granite–gneiss, or gneiss–chlorite schist. The host rocks are often graphitic and sulphides, such as pyrite, arsenopyrite and chalcopyrite, may be associated. A younger Precambrian sequence, the Awat Series, consists of about 1600 m of lavas (varying compositionally from andesites to rhyolites), argillites and conglomerates, which has been intruded by two distinct granites.

A very small area of Lower Palaeozoic sandstones is present near the border with Libya and Chad. These are probably equivalent to the lower part of the Tassili Series of the Hoggar (Algeria), where uranium occurrences have been discovered in channels at the base of the Lower Palaeozoic.

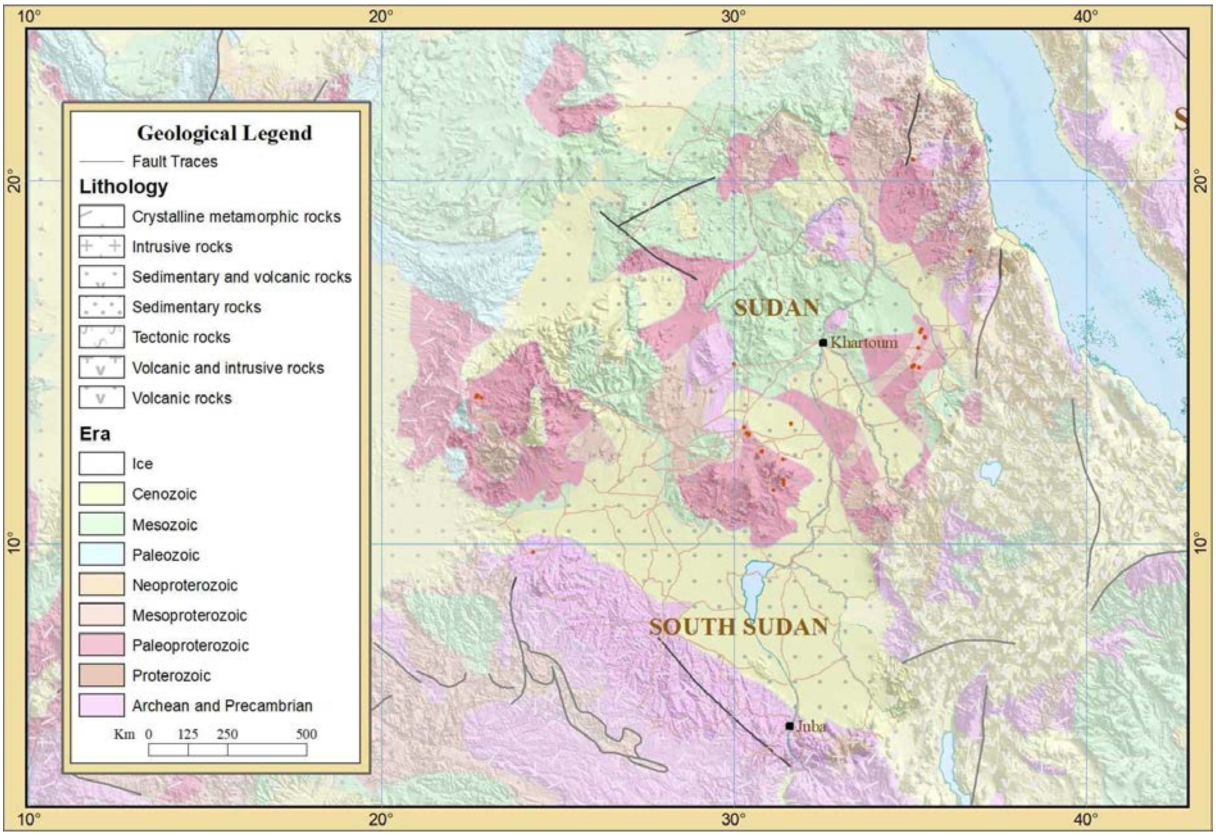


FIG. 3.76. Regional geological setting of Sudan and South Sudan showing the distribution of selected occurrences. For general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

After a long period of erosion, the clastic sediments of the Nubian Series, of mainly Mesozoic age, were deposited. The Nubian covers most of the north-western quarter of the country and rests on the Precambrian. It is dominated by arenaceous and rudaceous beds, but includes siltstones and mudstones, sparse lignite, gypsum, and some calcareous and ferruginous beds. The sandstones consist of generally poorly sorted coarse- to medium-grained layers in which pebbles of quartz and flakes or balls of mudstone may be included. The sandstones are cross-bedded on many scales, ripple marked and poorly graded. The composition is mainly quartz pebbles and grains, chert and feldspar and the clay mineral content is high in some beds. A poorly sorted conglomerate is present at the base in several places. Intraformational conglomerates are common, the beds varying up to a few metres in thickness. The conglomerates contain almost exclusively quartz, chert and siltstone and representative clasts of the underlying metamorphic and granitic rocks comprising the basement are almost entirely absent.

The Nubian Series was deposited in a tropical to subtropical climate under various continental conditions (excluding aeolian) merging intermittently into shallow marine.

Various superficial deposits such as laterites, Quaternary sands and clays, basalt flows and the like often obscure the underlying geology [46.2, 46.3].

3.46.2. Uranium exploration

With the exception of a few areas, very limited systematic exploration for radioactive minerals has been undertaken in Sudan. Only the Hofrat en Nahas copper deposit with associated minerals (gold, molybdenum, uranium) and a few localities in the Nuba Mountains, together with a radioactive pegmatite in the Red Sea Hills Province, have been the targets for uranium prospecting and exploration activities in Sudan.
The Hofrat en Nahas copper deposit has been known for a long time and, until the end of the 19th century, was mined by local indigenous tribes. Geologically, the area lies within the Precambrian Basement Complex and consists of gneisses, various metamorphosed schists, quartzite, metabasic rocks and marble. Up until the early 20th century, the Hofrat en Nahas copper deposit and surrounding areas had been investigated periodically, and, since 1921, prospecting and systematic exploration have been increasingly carried out, principally for copper.

In 1957, the Geological Survey Department of Sudan detected uraninite in a few holes. The uraninite was found associated with copper sulphides but no effort was made to estimate the size of the uranium resource. In 1967–1971, prospecting and systematic exploration were carried out by the United Nations Development Programme (UNDP) with the aim of providing the Government of Sudan with a preliminary commercial estimate of the known deposits and, hopefully, the discovery of new ones.

In 1968, airborne magnetic and total count radiometric surveys (17 000 line km) were flown by Survair. The airborne radiometric survey revealed that most radiation is due to potassium. The strongest radiation was detected at a few places along a line that included Jebel Angwawa (in the south-west), Jebel Morai, Jebel Patapan and Khor Siomo. The airborne radiometric activity did not increase significantly on traverses flown over the Hofrat en Nahas mining area, where outcrops of mineralized veins occur with relatively high grades of uranium mineralization (torbernite). Ground radiometric measurements made over these outcrops revealed high levels of radiation. As a result of this survey, three major structural units and several large intrusive bodies were distinguished.

In 1969, ground geophysical surveys were undertaken over selected areas. A number of anomalies were located against a relatively low background. Geochemical surveys and geological reconnaissance traverses covered about 19 000 km and a total of 26 holes (3380 m) were drilled, 19 of them in the Hofrat en Nahas central area. All the above activities confirmed the ore potential of the deposit, which was estimated at about 9 million t of ore grading 4% copper. No estimates for uranium were given.

On the basis of the results of this work, 10 anomalous areas extending in a south-westerly line from Hofrat en Nahas were also selected for follow-up investigation. Work conducted, mainly drilling, confirmed the ore potential of the deposit and upgraded the reserve estimate calculated in 1971.

Early in 1975, Italy's AGIP approached the Sudanese mining authorities to ascertain uranium exploration policies and collect general information on the geology and known uranium occurrences in the country.

On the basis of available data, two areas of possible interest were located, one in the Hofrat en Nahas area and one in the Nuba Mountains.

A temporary exploration permit for the two areas was granted to AGIP for a period of six months ending April 1976. A preliminary ground radiometric survey in the Hofrat en Nahas mine area confirmed the results obtained by the Sudan Geological Survey Department in 1957–1959 and further indicated that surface radioactivity was fairly coincident with known copper ore distributions. Areas showing low surface radioactivity were also found to contain uranium mineralization at depth. The most significant available drill cores were logged and radiometrically scanned. Two airborne radiometric anomalies located at Jebel Morai, 70 km south-west of Hofrat en Nahas, were surveyed on the ground and evaluated by trenching and pitting to a depth of about 4 m. The largest anomaly strikes for about 10 km, with an average width of about 1 km. Chemical analyses of mostly lateritic material indicated that the radioactivity was due to thorium and potassium. The second anomaly, to the north, was found to occur in potassium-rich porphyroblastic granitic gneisses.

At Jebel Waranga East, 50 km south-west of Hofrat en Nahas, fairly high levels of radioactivity, up to 8–10 times background, were located in an old trench. Samples yielded a copper content of up to 13% and uranium levels of several hundred parts per million. A third, southernmost airborne anomaly, which is the strongest recorded in the area, was not investigated owing to the onset of the rainy season and poor access to the area.

Relevant data and the results of previous investigations of the Hofrat en Nahas deposit were evaluated and an interpretation of the geometry of the deposit was attempted. On the basis of the above considerations, a detailed two-phase exploration programme covering an area of 14 000 km² was prepared by AGIP and submitted to the Sudanese authorities. The area considered consisted of part of the UNDP project area and part of a new adjacent area. The objectives of the exploration programme were to detect uranium–copper mineralization over the project area and to prove and increase the copper ore reserves indicated by the UNDP in the main Hofrat en Nahas area. Subsequent evaluations, however, were disappointing in this regard.

The Nuba Mountains region lies almost in the geographical centre of the country. In September 1979, the Government of Sudan and Minex Inc. (USA) signed a 39 month agreement to explore for uranium and associated minerals in selected areas of central Kordofan Province. Reconnaissance and detailed work, including geological mapping, radiometric traversing, and geotechnical and hydrogeochemical sampling, were undertaken over parts of the project area. Targets included potential vein-type mineralization at Jebel Dumbeir and potential calcrete-type mineralization at Jebel Kon. At Jebel Dumbeir, the uranium mineralization is associated with important quantities of fluorite. Samples show high values of molybdenum and anomalous levels of strontium, barium, rare earths, lead and zinc. At least three subparallel fractures with strike lengths of the order of 1500 m and widths up to 5 m have been located. Little is known about the Jebel Kon occurrences.

In 1979, a Sudanese–German exploration project was initiated in the area which lies between latitudes 10°43' N to 11°00' N and longitudes 30°00' E to 30°26' E (600 km²). Prospecting and mapping work, mainly for radioactive minerals, commenced in 1979. The area is mainly underlain by granite and syenite intrusives and possible multiphase ring complexes. Regional mapping and prospecting have also been conducted by the Geological Department of the University of Khartoum in one area to the north-west of the Sudanese–German exploration project area. This area is located between Kadugli and Lagowa. Polymetallic (chalcopyrite, sphalerite, pyrite and galena) mineralization was found in one locality to the north of the track connecting the two towns. High level radioactivity was associated with fluorite occurrences in a mylonitic zone to the north of the sulphide occurrences. Geochemical soil sampling and reconnaissance radiometric traversing have also been conducted [46.3, 46.4].

3.46.3. Uranium resources

3.46.3.1. Identified resources

The Hofrat en Nahas area is the best known locality for uranium mineralization in Sudan, but exploration has not yielded a separate economic evaluation of the uranium resource.

The UDEPO database does not list any known deposits for Sudan.

3.46.3.2. Undiscovered resources

In 1983, IUREP reported speculative resources of 20 000–40 000 tU [46.3, 46.4].

3.46.4. Potential for new discoveries

The Precambrian crops out over a very wide area in Sudan but is, in general, poorly described. The earliest Precambrian includes granite gneisses and schists which have been intruded by later granites and dolerite dykes, giving isotopic ages of around 700 Ma. The Precambrian is unconformably overlain by over 3000 m of gneisses, quartzites, marbles, schists and andesites comprising the Fafirdeib Series, and later by the Awat Series comprising 1600 m of metamorphosed lavas, argillites and conglomerates. Ultrabasic, basic and acid igneous rocks of various ages are found in these strata.

In Sudan, the known uranium localities occur where Precambrian schists have been intruded by granite. Many similar geological settings occur elsewhere in Sudan and this environment probably holds the greatest potential for deposits in the country. The Precambrian should also be regarded as having some potential for the location of unconformity-related deposits, especially below the base of the Awat Series.

A very small area of Lower Palaeozoic sandstones is present near the borders with Libya and Chad. These are probably equivalent to the lower part of the Tassili Series of the Hoggar region (Algeria) in which uranium occurrences have been discovered.

The predominantly Mesozoic Nubian Series contain many continental sandstone bodies. These sandstones are relatively undisturbed tectonically and could host uranium deposits. In particular, channels at the base of the Nubian Series could be worthy of prospection.

Additional exploration targets are the younger granite and syenite intrusives and possible multiphase ring complexes, and any areas which may be underlain by calcrete [46.3, 46.4].

3.46.5. Comments

No uranium has been produced in Sudan. Sudan has no nuclear power plant.

References to Section 3.46

[46.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Sudan, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[46.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 238–241.

[46.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[46.4] KNEUPPER, G., SCIVETTI, N., IUREP Orientation Phase Mission Report: Sudan, IAEA, Vienna (1984) 128 pp.

3.47. TOGO

Togo is a small, sub-Saharan nation, bordering the Bight of Benin to the south, Ghana to the west, Benin to the east and Burkina Faso to the north. In the north, the land is characterized by a gently rolling savannah, in contrast to the centre of the country, which is characterized by hilly topography. Southern Togo is characterized by a plateau extending to a coastal plain that has extensive lagoons and marshes.

The climate is generally tropical, with average temperatures ranging from 27°C on the coast to about 30°C in the northernmost regions, with a dry climate and characteristics of a tropical savannah. To the south, there are two seasons of rainfall (the first April–July and the second October–November), even though the average annual rainfall is not very high (about 1000 mm in the wet mountainous areas).

Togo's small sub-Saharan economy is heavily dependent on both commercial and subsistence agriculture (cotton, coffee, cocoa), which provides employment for 65% of the labour force. In the industrial sector, phosphate mining is no longer the most important activity (reserves of around 60 million t) as cement and clinker exports to neighbouring countries have supplanted it as the main industry [47.1].

3.47.1. Geology

The oldest rocks of Togo are present in the north-western corner of the country and consist of granites of Lower Proterozoic (Birimian) age (Fig. 3.77). The next youngest Proterozoic sequence is the Dahomeyan, which includes granites, gneisses, mica schists, diorites, gabbros and peridotites, and covers a large area in the centre and east of the country. The Dahomeyan rocks are followed by Middle Proterozoic Atacorian quartzites and pelites. The quartzites are often micaceous and include metamorphosed iron oxide formations (itabirite). Generally, these quartzites are the relief features that form the main part of the Atacora Range.

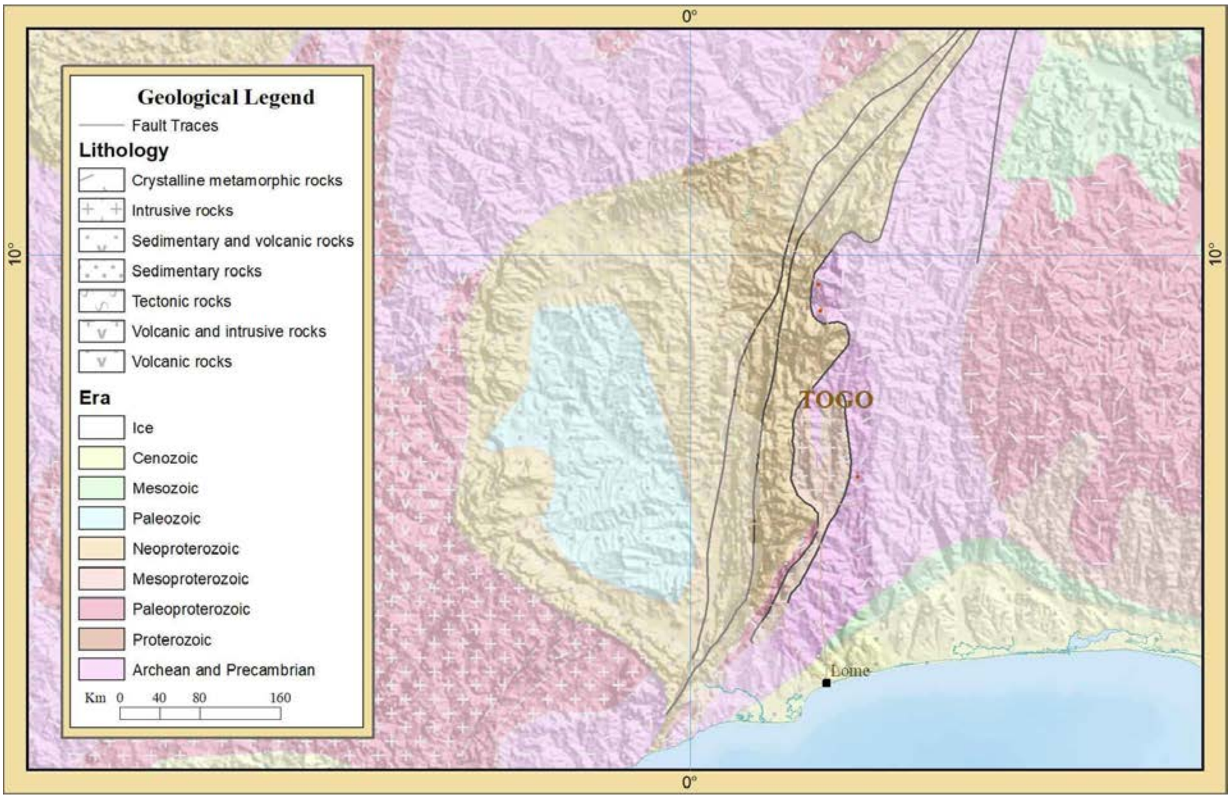


FIG. 3.77. Regional geological setting of Togo. For general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Uranium mineralization occurs sporadically in the Dahomeyan in the northern part of the country in a NE–SW trending belt about 64 km in length. The principal uranium mineral is autunite, along with minor pitchblende. The mineralization occurs in biotite and muscovite schists and in other lithological environments. Shear zones crossing the trend of the schists also influence the mineralization. Proximity to the boundary between the Dahomeyan and Atacorian strata also seems to be another control on mineralization [47.2, 47.3].

3.47.2. Uranium exploration

Exploration for uranium in Togo has been carried out in the past partly by the Service des Mines and partly by France's Commissariat à l'Energie Atomique (CEA). The latter conducted exploration programmes in an area which included Benin, Burkina Faso and the northern part of Togo, but found nothing of significance. In 1963, the United Nations planned a mineral resource survey to cover three areas totalling 20 000 km². Plans for an airborne magnetometer and scintillometer survey on a 1 km flight line spacing were included.

The German company Uranerzbergbau Gmbh conducted exploration for uranium in Togo and found several small mineralized zones in the Dahomeyan. During the intervening ten years, systematic airborne surveys were made. On the basis of these prospecting operations, the Niamtougou region was selected as being of interest from the geological standpoint. Uranium mineralization was first discovered at Niamtougou in 1970. Following this discovery, prospecting operations were concentrated in the Niamtougou and Lama-Kara regions, where several anomalies were detected and subsequently confirmed by the occurrence of visible uranium mineralization. Between 1971 and 1978, more than 60 000 m of percussion drilling and more than 7000 m of core drilling were carried out. The work performed showed that the observed mineralization was not economically viable owing to its low grade and to its occurrence in insignificant quantities.

A programme conducted by the Bureau de Recherches Géologiques et Minières (BRGM) made the initial studies possible in 1970 and resulted in the discovery of radioactive minerals at Konda (in the administrative district of Kioto). In 2008, Zambia's Lithic Metals and Energy Ltd started uranium exploration in the northern portion of Togo, near the regional centre of Lama-Kara. Discovered by Uranerzbergbau in the mid-1960s, uranium mineralization occurs in several locations and appears to be related to a major regional structural feature. Drilling by Uranerzbergbau of surface radiometric anomalies encountered grades of over 400 ppm U.

Lithic Metals found the geophysical exploration surveys over the project area to be old, of poor quality and covering only a small proportion of the prospect areas. Lithic Metals had planned to fly a high resolution radiometric and magnetic survey over the project area as a matter of priority. Lithic Metals became AfNat Resources Limited as of December 2009. No further information was available as of May 2010 [47.3].

3.47.3. Uranium resources

There are no known uranium resources in Togo. The 1983 IUREP report estimated speculative resources of 10 000–50 000 tU, hosted in vein type environments [47.4].

Togo has large phosphate deposits some into production, with resources estimated at more than 2 billion tons. Average uranium content would be in the range of 70 ppm. The UDEPO database does not list any known deposits for Togo.

3.47.4. Potential for new discoveries

The unconformity between the Dahomeyan Series and the Upper Proterozoic Atacorian Series appears to be highly prospective for uranium deposits. The Dahomeyan sequence includes granites, gneisses, mica schists, diorites, gabbros and peridotites, while the Atacorian consists of quartzites and pelites. These quartzites are a topographic feature, forming the main part of the Atacora Range. Uranium mineralization is known to occur close to this unconformity.

The Palaezoic rocks in the north-western part of the country could be evaluated where they overlie the Lower Proterozoic (Birimian) granites of the Eburnean Orogeny. These sediments are an extension of the Voltaian cratonic cover of Ghana. The granites themselves could also be prospected within the same programme [47.3].

References to Section 3.47

[47.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Togo, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed November 2008).

[47.2] SCHLÜTER, T., Geological Atlas of Africa, Springer, Berlin and Heidelberg (2008) 254–256.

[47.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[47.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.48. TUNISIA

Tunisia is situated in northern Africa and borders the Mediterranean. Despite its relatively small size, Tunisia possesses significant geographical and climatic diversity. The Dorsal, an extension of the Atlas Mountains, traverses Tunisia in a north-easterly direction from the Algerian border in the west to the Cape Bon Peninsula. North of the Dorsal is the Tell, a region characterized by low, rolling hills and plains. However, in the north-western corner of Tunisia, the land reaches elevations of 1050 m. The Sahil is a plain stretching along Tunisia’s eastern Mediterranean coast and is famous for its olive monoculture. Inland from the Sahil, between the Dorsal and a range of hills south of Gafsa, are the steppes. Much of the southern region is a semi-arid desert.

Tunisia has a diverse economy, with important agricultural (olives, grain, dairy products, tomatoes, citrus fruit), mining (phosphates, iron), energy, tourism, petroleum and manufacturing sectors [48.1].

3.48.1. Geology

Most of northern and central Tunisia is underlain by sedimentary rocks ranging from Permian to Recent (Fig. 3.78) and belonging to the structural unit of the Atlas Domain. In the south of the country Mesozoic and Cenozoic sediments overlying the Saharan Platform are well developed. Northwestern Tunisia is influenced by the structural unit of the Tellian Domain, which is part of the Alpine orogeny [48.2].

Tunisia is essentially a sedimentary country, with geological formations from Permian to Quaternary in age. Some Miocene magmatic formations occur in the northern part of the country. The metallogeny of Tunisia is related to the structural geology of the country. From north to south, four distinct geological zones can be defined: the Tellian Atlas, the Atlas domain, the Eastern structural platform and the Saharan structural platform.

3.48.1.1. The Tellian Atlas

This area of thrust sheets is characterized by Tellian and Numidian units, which are largely autochthonous. Mineralization found in this area includes:

(a) Copper, lead, zinc, iron, tin and tungsten in the basement formations;

(b) Arsenic, copper, lead, zinc, iron, gold and silver associated with the Neogene volcanism in the Nefza-Sejnane area;
(c) Arsenic, antimony, mercury, lead, zinc, copper and gold associated with structural features in Triassic formations;
(d) Lead and zinc in detritical or Neogene lacustrine limestone basins.

3.48.1.2. The Atlas domain

This area represents the eastern extension of the Saharan domain and consists of large anticlines developed in a north-easterly direction and are often box-folded and separated by large basins. This domain can be subdivided into four areas:

(i) The Diapir zone, Triassic in age, with lead, zinc, barium, strontium and iron mineralization;
(ii) The central Tunisia carbonaceous shelf, with lead, zinc, barium and iron mineralization associated with Cretaceous unconformities;
(iii) The N–S axis, in Zaghouan Province, with lead, zinc, barium and fluorine mineralization;
(iv) The Gafsa Basin, with phosphate and iron deposits.

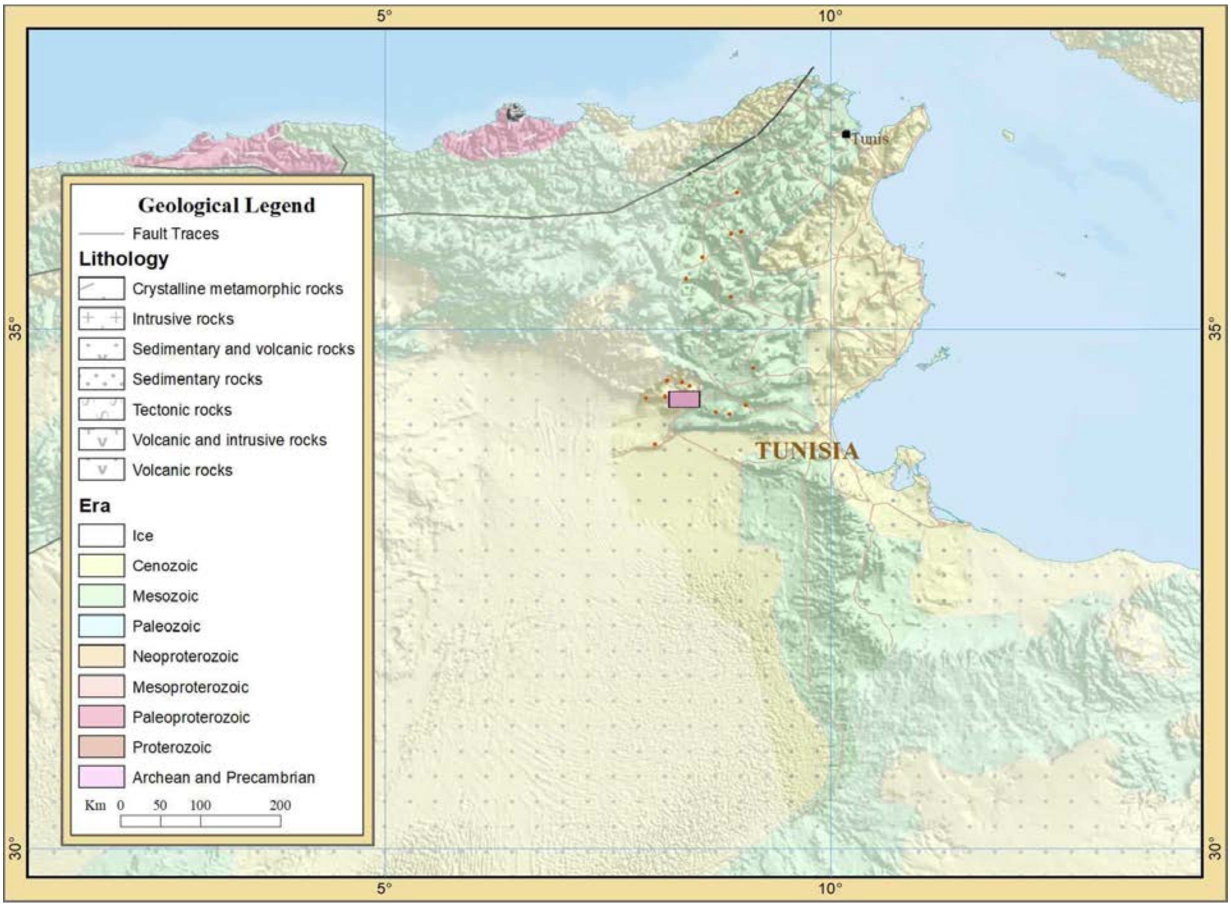


FIG. 3.78. Regional geological setting of Tunisia showing the distribution of selected uranium deposits and occurrences. For general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.48.1.3. The Eastern Structural platform

The Eastern structural platform is characterized by a slow subsidence during the Mesozoic, which became more pronounced during the Cenozoic. The area is marked by a combination of horsts and grabens related to folds of large radius. The Miocene strata are rich in lignite.

3.48.1.4. The Saharan Structural platform

In this platform, occurrences of lead, zinc, iron and manganese mineralization have been described [48.3, 48.4].

3.48.2. Uranium exploration

Follow-up work of the Nefza anomaly in northern Tunisia, which included exploration drilling, was completed in 1982 with the assistance of the IAEA. The result was negative. Discontinuous uranium mineralization (up to 300 ppm U) was found primarily in the breccia zone bordering an elliptical structural basin [48.5].

3.48.3. Uranium resources

No exploitable uranium resources are known in Tunisia. In 1983, IUREP reported a range of 1000–10 000 tU of speculative resources [48.5].In 2008, Tunisia's phosphate reserves amounted to 100 million t, with resources of 600 million t. In 2008, phosphate production was 7.8 million t. The uranium grade of Tunisia's phosphates is low, in the range 12–80 ppm U. Tunisia is planning to launch a research programme focusing on uranium extraction from phosphates of the Gafsa deposit. The extracted uranium would be used to feed the nuclear power plant that Tunisia is planning to build by 2020.

The UDEPO database lists the most significant deposit for Tunisia as Gafsa-Metlaoui District.

3.48.4. Potential for new discoveries

There is some potential for vein or disseminated type deposits in Tunisia. Uranium could also occur in sandstones. Tunisia has some potential for uranium in phosphates, but the low average uranium grade would make development economically challenging.

3.48.5. Uranium production

No past uranium production is recorded in Tunisia. In November 1983, the Government inaugurated a pilot plant to recover uranium from phosphoric acid. The plant was built at Gabes by Uranium Pechiney Ugine Kuhlman under contract to Industries Chimiques Maghrébines. Work on the 120 t/year extraction circuit was scheduled to begin at the end of 1983, with operation projected for late 1985. No further information has been reported.

References to Section 3.48

[48.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Tunisia, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[48.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 258–261.

[48.3] ZARGOUNI, F., ABBES, C., The Structural Zonation of Tunisia, Centre des Sciences de la Terre, Institut National de Recherche Scientifique et Technique, Hamam-Lif (1985).

[48.4] OFFICE NATIONAL DES MINES, Resources Minérales (2012), http://www.onm.nat.tn/fr/index.php?p=ressourcesmin

[48.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.49. UGANDA

Uganda is a relatively small, landlocked country located in east-central Africa. The country is located on the East African plateau, which averages about 1100 m in elevation and decreases steadily towards the

Sudanese Plain to the north. Much of the south is poorly drained, while Lake Kyoga and extensive marshy areas lie in the centre. Uganda lies almost completely within the Nile Basin.

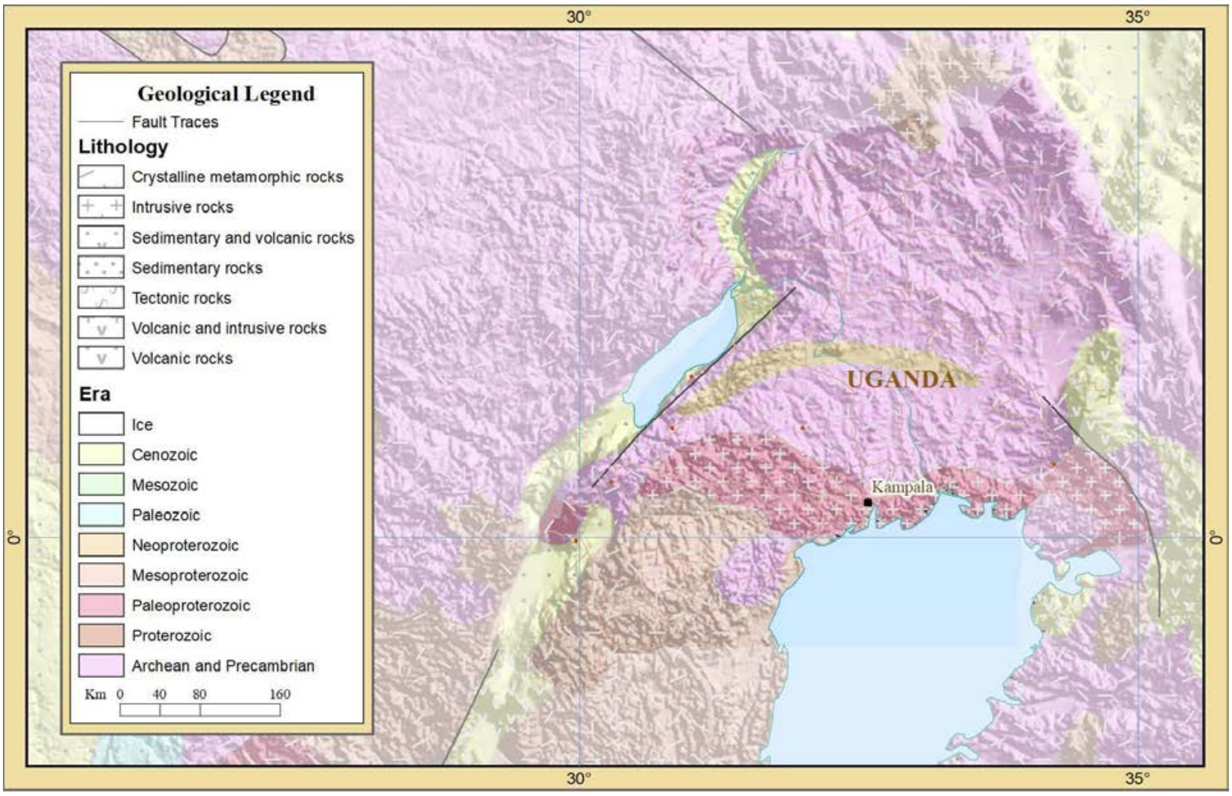
Although generally equatorial, the climate varies according to elevation. The southern and western parts of Uganda are wetter, with rainfall evenly distributed throughout the year. At Entebbe, on the northern shore of Lake Victoria, most rain falls from March to June and from November to December.

Farther to the north, a dry season gradually emerges at Gulu about 120 km from the border with the Sudan. In this area, the period November–February is much drier than the rest of the year. The north-eastern Karamoja region has the driest climate and is prone to droughts in some years. The climate in the south of the country is heavily influenced by Lake Victoria, one of the world's largest lakes. The lake serves to moderate temperatures from varying significantly and influences the local climate and rainfall.

Uganda has substantial natural resources, including fertile soils and sizeable deposits of copper, cobalt, iron, phosphates, tungsten, vermiculite and tin. The country has largely untapped reserves of both crude petroleum and natural gas. Agriculture is the most important sector of the economy, employing over 80% of the workforce, with coffee, tea, fish and cotton accounting for the bulk of export revenues [49.1].

3.49.1. Geology

More than two thirds of Uganda is underlain by Archaean and Proterozoic rocks (Fig. 3.79). These shield rocks are part of the African or Nubian Plate and are located between the eastern branch and the western branch of the East African Rift System. The Western Rift Valley runs the entire length of Uganda.



IG. 3.79. Regional geological setting of Uganda. For general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Apart from the vast Archaean Gneissic-Granulitic Complex in the north there are at least three major Proterozoic belts exposed in the country: the Paleoproterozoic Buganda-Toro System, the Mesoproterozoic Karagwe-Ankolean System and the Neoproterozoic Mozambique Belt. Tabular

Neoproterozoic sediments are also widespread. Tertiary to Recent sediments filled parts of the downfaulted Western Rift. Tertiary carbonatites and Cenozoic volcanics are related to rift activities and occur along the eastern and western borders of the country [49.2].

In Uganda, the Precambrian is divided into wholly granitized formations, including basement and granitized equivalents of the cover formations, partially granitized formations, non-granitized formations and other rocks.

The first group includes metamorphic rocks of the granulite metamorphic facies, acidic gneisses, metamorphic rocks of epidote–amphibolite, biotite and hornblende–biotite facies and marbles and quartzites.
The second group consists of rhyolites, porphyries, tuffs and basalts of the Nyanzian System; argillites, basalts, amphibolites of the Buganda-Toro System (1800 Ma); arenites, siltstones, quartzites, sandstones and conglomerates of the Karagwe-Ankolean System; and shales and quartzitic sandstones of the Kioga Formation.

The third group consists of molasses type sedimentary rocks.
The last group, the ‘other rocks’ category, includes undifferentiated gneisses and mobilized basement, mantled granite–gneiss domes in the south-west and various granites.

The Ecca shales (Karoo formation) occur in small downfaulted outliers on Dagusi Island and also underly part of Entebbe. These outliers are remarkable in being the most northerly occurrences of the Karoo formation in Africa.

The Mesozoic and Cenozoic rocks in Uganda are composed chiefly of rift valley sediments, volcanic formations and more recent alluvial overburden. The eastern volcanic rocks generally comprise soda-rich agglomerates, lavas and tuffs, extruded from central volcanoes. The carbonatite ring complexes at Tororo, Sukulu, Bukusu and Napak, and the syenite complexes such as Zulia, represent the eroded remnants of former volcanoes of a similar rock suite.

The Western Rift Valley sediments are divided into several series and are of Pliocene age [49.2, 49.3].

3.49.2. Uranium exploration

Exploration for radioactive minerals in Uganda began in 1949. However, the early programmes were generally poorly designed and confined to coverage of small areas. Almost all uranium exploration in Uganda has been conducted by the Government and no major mining company has been involved in the search for radioactive minerals. During the early 1950s, radioactivity surveys were conducted over most roads in Toro, Ankole, Kigezi and Mubende and along some of the roads in Mengo, Busoga, Mbale and Masaka. Similar surveys were also conducted throughout all adits in the Kilembe mine and in many of the tin and tungsten pegmatite mines. Radioactive anomalies were discovered at the Sukulu carbonatite complex, in the tuffs of the Ndale volcanic field and at several locations near Kilembe. A drilling programme was conducted at Ndale and additional studies were made on the radioactive pyrochlore at Sukulu. A survey was also completed on radioactive knopite (perowskite containing cerium) in Bugisu district.

In the late 1950s, surveys were completed for known radioactive areas in Busoga and Kyandondo, near Kampala. Airborne prospecting and several ground studies were made in Karamoja and a study was conducted of the radioactivity in the Lunyo granite. Radioactive springs at Dwemkorebe were examined and surveys made of the Buhwezu Plateau’s conglomerates at Kitabi and in the Mubende area.

In 1952, the Atomic Energy Division of the Geological Survey of Great Britain carried out a detailed examination of the west valley soils of Sukulu hills which had recorded a strong radioactive anomaly. The high radioactivity in the west valley soils was due to daughter elements of uranium and thorium dispersed in the slime fraction of soils derived from a ferruginous matrix of sovite breccias flanking the valley [49.4].

In 1955, an airborne geophysical survey showed that the Sukulu district also records strong magnetic and radiometric anomalies. The magnetic anomaly is due to large concentrations of magnetite and the radiometric anomaly is attributed to pyrochlore containing up to 2.73% ThO_2 and 0.66% U_3O_8.

In 1959, Lundburg Explorations Ltd flew a scintillometer survey of around 1100 line km in eastern Uganda, and in 1960, airborne scintillometer surveys were made at Karamoja, along the Aswa shear zone, and at Mubende. Radioactive anomalies were found related to the granites of north-western Uganda and in the Mubende district. In 1962, the United Nations sponsored an airborne geophysical survey, including total count scintillometer measurements of 50 000 line km in three areas: (i) the Karamoja district of north-eastern Uganda, (ii) along the Aswa shear zone in north central Uganda and (iii) east of Fort Portal in the south-western part of the country. No follow-up was conducted on any anomalous localities.

Pyrochlore concentrates from the dismantled pilot plant at Tororo Industrial Chemicals and Fertilizers factory at Tororo, when analysed by the IAEA, were found to contain 0.35–0.5% U_3O_8 and 0.5–1.5% ThO_2. Previous analyses of crystals of brown pyrochlore from the soils of the western valley at Sukulu hills recorded 0.66% U_3O_8 [49.4]. On the basis of the preliminary assessment, the country's potential for the uranium minerals in all the various occurrences was estimated at 89 000 t U.

There is no record of exploration for radioactive minerals having been undertaken between 1963 and 1969. In 1970, detailed pitting was completed at Sukulu. A US oil company conducted an airborne multi-channel gamma ray spectrometer survey over two concession areas in southern Uganda and some ground follow-up examinations were made of selected airborne total count anomalies. Another oil company discovered rift valley sediments containing over 250 ppm U south-east of Lake Albert. In 1976, it was reported that a large area near the Ruwenzori Range was radioactive and the mineral davidite was identified.

Between 1977 and 1979, an IAEA expert visited Uganda and focused attention on known areas of radioactivity. In 1980, Geosurvey International conducted an airborne gamma ray spectrometer survey of all of Uganda south of 1° N [49.3, 49.5].

The World Bank, the African Development Bank, the Nordic Development Fund and the Government of Uganda, through the Sustainable Management of Mineral Resources Project, conducted an airborne geophysical survey, covering 80% of Uganda.

Data interpretation by Paterson, Grant & Watson Ltd indicated 80 targets that are geologically favourable for the discovery of uranium. These anomalies were categorized as 13 first priority areas and 17 second priority areas. The anomalies which are likely to yield economically viable uranium resources are those associated with:

— Karoo Formations in Bugiri and Mayuge districts;
— Unconformity-related deposits in intercratonic or marginal basins in Lower Proterozoic (Buganda-Toro System) metasediments that overlie Archaean basement;
— Deposits in intrusive rocks, including granite, pegmatites, carbonatites and monzonite at Mubende and in eastern carbonatites;
— Volcanic deposits associated with felsic volcanics in continental settings related to faults, with ages varying from Proterozoic to Tertiary, and associated sediments;
— Potential for sandstone uranium deposits exists in the Karasuk strata of the Moroto area.

3.49.3. Uranium resources

There are no known uranium resources in Uganda. In 1983, a review of the IUREP estimates reported a range of 10 000–50 000 tU of speculative resources in sandstone hosted and vein type geological environments [49.6].

The UDEPO database lists the most significant deposit for Uganda as Sukulu.

3.49.4. Potential for new discoveries

The majority of Uganda is underlain by Precambrian rocks but the geology and age relationships of the area are both uncertain. Several major unconformities do occur and these could hold potential for unconformity related uranium deposits. The unconformities between the Buganda-Toro System and later formations are expected to hold the greatest potential.
The Buganda-Toro System consists mainly of argillites, basalts and amphibolites and hosts copper mineralization in association with cobalt in strongly folded schists. Uranium minerals have been identified, together with the copper. Overlying rocks include the arenites, siltstones, quartzites, sandstones and conglomerates of the Karagwe-Ankolean System (1400–1300 Ma) and shales and quartzitic sandstones of the Kioga Formation.

In west central Uganda, sporadic outliers of the Singo Series composed of grits and sandstones with a basal conglomerate and subordinate shale bands occur in the Buganda-Toro System. These, and later unconformities, could merit prospection.

The Mesozoic and Cenozoic rocks of Uganda are chiefly composed of rift valley sediments and soda rich volcanic rocks. The rift valley sediments could merit prospection as local concentrations of up to 300 ppm U are already known. The carbonatite ring complexes at Tororo, Sukulu, Bukusu and Rapal, and the syenite complexes, such as the one at Zulia, may also host some potential [49.3, 49.5].

3.49.5. Comments

There has been no uranium production in Uganda. Uganda has no nuclear power generation.

References to Section 3.49

[49.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Uganda, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[49.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 262–267.

[49.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[49.4] CAMPBELL, C.B., BOWIE, S.H.U., HORNE, J.E.T., Report on the Radioactive Mineral Deposit of the West Valley, Sukulu, Uganda, Rep. No. 127, Geological Survey Museum, Kampala (1952) 19 pp.

[49.5] DE TREY, M., LEVICH, R., IUREP Orientation Phase Mission Report: Uganda, IAEA, Vienna (1977) 53 pp.

[49.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.50. UNITED REPUBLIC OF TANZANIA

The United Republic of Tanzania (hereinafter referred to as Tanzania) is mountainous in the north-east, where Mount Kilimanjaro, Africa’s highest peak (5895 m), is situated. To the north and west are the great lakes of Lake Victoria and Lake Tanganyika. Central Tanzania comprises a large plateau, with plains and arable land.

The climate of Tanzania ranges from hot and humid on the coast to a more temperate climate in the elevated centre of the country. Tanzania has two rainy seasons: a heavy one from March to May, and a lighter one from November to January.

The economy is mostly based on agriculture (coffee, tea, cotton, cashew nuts, sisal, cloves), which accounts for more than half of the GDP, provides 85% of exports and employs 80% of the workforce. Topography and climatic conditions, however, limit cultivated crops to only 4% of the land area. Industry is mainly limited to processing agricultural products and light consumer goods. Tanzania has a sizeable inventory of natural resources, including gold and diamonds, and is also famous for the distinctive gemstone tanzanite. Tanzania has several national parks, exemplified by the world-famous Serengeti and the Ngorongoro Conservation Area, which help to underpin the large tourism sector and generate vital income for the economy [50.1].

3.50.1. Geology

Precambrian rocks underlie most of central and western Tanzania (Fig. 3.80). Archaean granite and greenstone rock assemblages form the central area of the country, the Tanzania Craton, which is surrounded by Proterozoic belts: the Palaeoproterozoic Usagaran–Ubendian Belt and the Mesoproterozoic Kibaran Belt. The Neoproterozoic Mozambique Belt occurs in the eastern part of the country. Parts of the Usagaran–Ubendian Belt were rejuvenated during the Neoproterozoic–Early Cambrian Pan-African Orogeny (850–540 Ma). Shallow water sediments of the Neoproterozoic (900–800 Ma) Malaragazi Supergroup underlie parts of western Tanzania and the Karoo Basin crosses southern Tanzania in a north-easterly direction. Mesozoic and younger marine sediments occur along the coast of Tanzania.

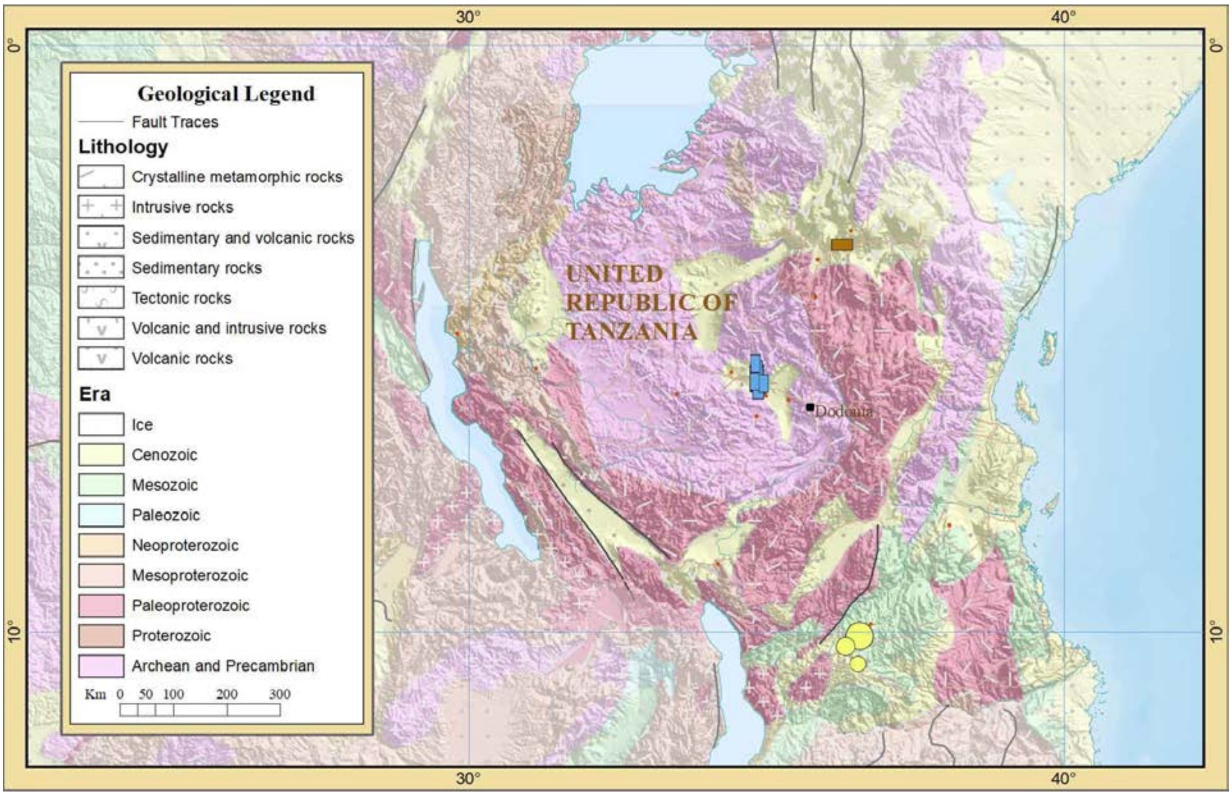


FIG. 3.80. Regional geological setting of United Republic of Tanzania showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Tertiary–Recent Eastern Rift Valley extends into Tanzania from Kenya to the north. Lake Tanganyika and Lake Nyasa (Lake Malawi) form part of the Western Rift Valley. Volcanics and carbonatites are associated with both the Eastern and Western Rifts and lacustrine sediments fill large parts of the valleys.

There are several distinct kimberlite fields in the Archaean Tanzania Craton, including the Mwadui kimberlite pipe in central Tanzania.

A large part of the southern Tanzanian geology comprises strata of Karoo age, terrigenous sediments several thousand metres in thickness that accumulated in basins during the Late Palaeozoic–Early Mesozoic. The basal series comprises glacial deposits, which, in turn, are overlain by fluviodeltaic coal-bearing sediments which are succeeded by arkoses and continental red beds. Transitional carbonaceous shales with coals gradually develop into thick lacustrine series which are overlain by Late Permian bone beds. The Triassic is characterized by a very thick fluviodeltaic succession of siliciclastics unconformably overlying the Permian. This Early Triassic sequence exhibits well developed repetitive depositional cycles. Heightened uranium values are observed in the Triassic arenaceous series, with diagenetic alteration and subsequent cementation [50.2].

3.50.1.1. Uranium exploration

Uranium was first discovered in 1953 at the Chiviligo pegmatite in the Uluguru Mountains. Between 1976 and 1979, an airborne geophysical survey was flown over the entire territory of Tanzania and this identified a number of radiometric anomalies. The results of this survey led to a uranium exploration programme carried out by Uranerzbergbau GmbH in 1978–1983. The targets of this survey were uranium occurrences in Karoo strata (Selous Game Reserve and Mkuju), in younger surficial sediments (Itigi area), in phosphatic sediments of Pleistocene age (Minjingu) and in the carbonatite of Gallapo [50.3].

Detailed information on exploration expenditure incurred in this project is not available. It is reported, however, that about 35 holes totalling 1700 m were drilled.

More recently, uranium exploration is being performed by several companies, mainly targeting mineralization in Karoo sediments in southern Tanzania (the Mkuju River, Mbamba Bay and southern Tanzania projects) and in palaeochannels associated with calcrete and sandstone-hosted uranium targets within the Bahi catchment of central Tanzania (the Bahi North and Handa projects). The Government has issued about 70 licences to companies interested in uranium exploration.

Uranex NL had defined two uranium resources, the Bahi and Mkuju projects, in accordance with the 2004 Joint Ore Reserves Committee (JORC) code guidelines, and further drilling was continuing on these deposits. Uranium was first reported at Bahi in 1954 when drilling for salt at Lake Bahi recorded a 0.15 m interval assaying 0.20% U associated with strontium carbonate. Historic reconnaissance of the country by radiometric survey in the 1970s located uranium mineralization in the form of carnotite associated with drainage systems leading into Lake Bahi. A mineral resource estimate for Likuyu North in 2012 indicated 2350 tU at 200 ppm. In central Tanzania and adjacent to its Bahi deposit, Uranex in 2010 reported inferred resources of 12 000 tU at a grade of 125 ppm in six shallow surficial lacustrine-playa deposits at Manyoni, which were supposed to be mined in 2013. In 2014 Uranex suspended its uranium developments and changed its name to Magnis Resources [50.4].

Mkuju, in southern Tanzania, is another project where auger sampling has revealed near surface uranium mineralization. Both areas record exposure of the prospective uraniferous stratigraphic interval in the Karoo Basin sediments. Uranium mineralization was first evidenced in this geological terrain as a result of exploration carried out during the period 1978–1983 [50.5].

The Mkuju River project was acquired in 2006 by Mantra Resources which started subsequent exploration work resulting in the definition of resources in 2010 for Areas A, C, D, E, F and S of the Nyota Prospect. Mineralization lies in the Supergroup Karoo sediments. Terrestrial sediments with variable proportions of organic matter host the mineralization. The coarse-grained units are interpreted as channels within a braided fluviatile system [50.6].

In 2011, Uranium One acquired 100% of Mantra Resources and published the same year an updated resources estimate after the completion of 62 diamond drilling holes: measured and indicated resources of 35 920 t U at 260 ppm and inferred resources of 10 049 t U at 235 ppm. Uranium One expected to start mining in 2013, with planned production of up to 1400 tU/year but has suspended the project due to low uranium prices [50.6].

Uranium exploration expeditures to 2017 are shown in Fig. 3.81 for a total of USD $78 211 000 including 295 642 metres of drilling.

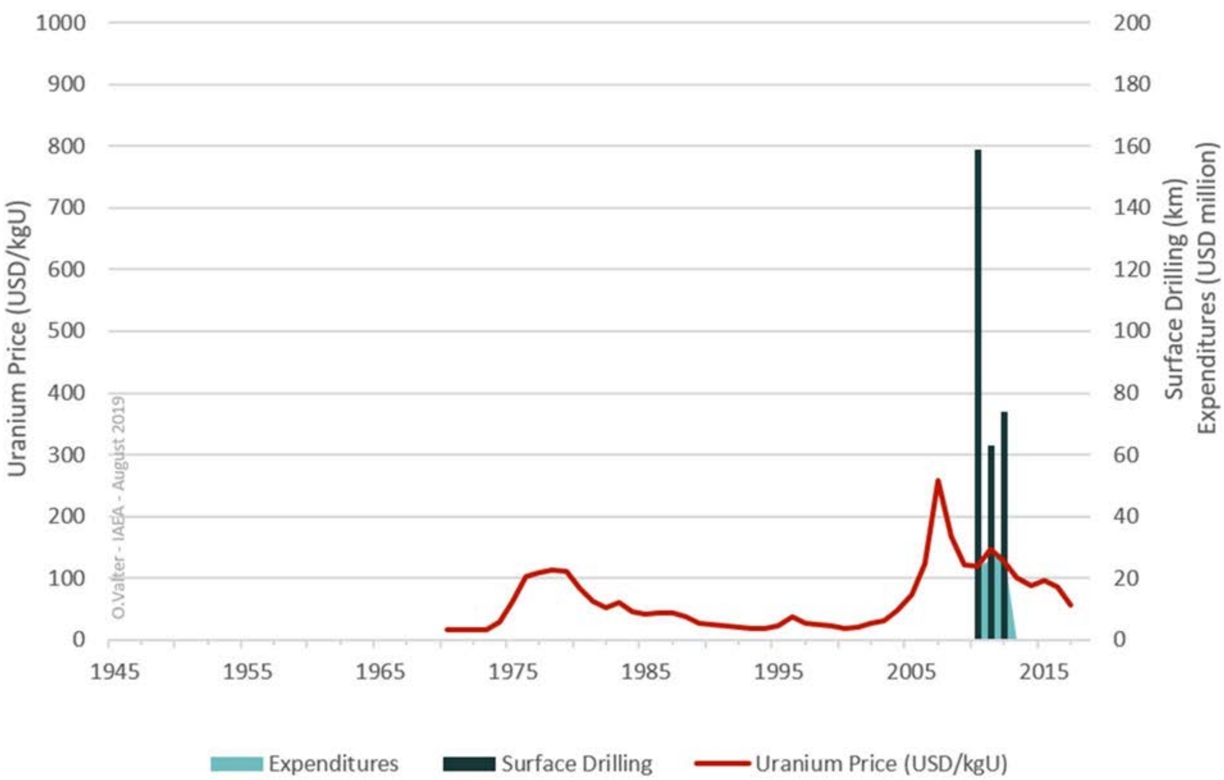


FIG. 3.81. Domestic uranium exploration data for Tanzania. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

3.50.2. Uranium resources

3.50.2.1. Identified resources

The newly discovered uranium resources, based on JORC and Canadian National Instrument 43-101 compliant information from Mantra Resources Ltd and Uranex NL, total about 8900 tU of reasonably assured resources and 19 500 tU of inferred resources categorized as high cost (<US $260/kgU). These sandstone hosted resources are considered to be amenable to open pit mining.

An additional 19 500 tU is reported as inferred conventional resources. Of this, 17 400 tU is in sandstone-hosted deposits and 2100 tU in other types of deposit.

The UDEPO database lists the most significant deposits for the United Republic of Tanzania as Nyota, Manyoni District-Zone C 1, Minjingu, Likuyu North, Manyoni District-Zone E.

3.50.2.2. Undiscovered resources

In 1983, IUREP reported a range of 1000–10 000 tU of speculative resources hosted in sandstones and vein type geological environments [50.7].

3.50.3. Potential for new discoveries

The most favourable area for uranium prospecting is probably in southern Tanzania, in association with Karoo sediments and central Tanzania for surficial deposits.

3.50.4. National policies relating to uranium

A new Mining Advisory Committee was established to advise the Government on all mining related issues. The committee is to advise on matters outlined in the Mining Act of 1998 as well as all matters pertaining to Mining Development Agreements. With the appointment of the new committee, the process for establishing mining policy has been initiated which will lead, eventually, to a new Mining Act and associated regulations [50.3].

3.50.5. Comments

No uranium has been produced in Tanzania. On 20 August 2008, Uranex NL announced the commencement of a prefeasibility study on the Bahi Uranium Project in central Tanzania. Uranex NL may start operating a mine in Tanzania's central Bahi region within two years. In September 2009, South Africa's Mantra Resources and Australia's Uranex NL moved closer to uranium production after they met all environmental conditions mandated by the National Environment Management Council. Mantra Resources (before being acquired by Uranium One) expected to complete a prefeasibility study for its Mkuju River project in southern Tanzania, ahead of the awarding and commencement of a full feasibility study. Uranium production could start within the next three years. Using the current resource estimate as a base case scenario, the projects could support a minimum annual production of 1000 tU which would indicate at least a 10-year mine life [50.8]. As of 2018, due to depressed uranium prices none of these mining projects were started.

References to Section 3.50

[50.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Tanzania, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[50.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 246–252.

[50.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[50.4] WORLD NUCLEAR ASSOCIATION, Uranium in Africa -Tanzania (2018).

[50.5] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, San Francisco (1980) 524 pp.

[50.6] URANIUM ONE INC., NI 43-101 Technical report on the September 2011 Resource Update. Mkuju River Prpject, Tanzania, Africa (2011) 109 p.

[50.7] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[50.8] WORLD NUCLEAR NEWS, Tanzania uranium production nears (14 September 2009). http://www.world-nuclear-news.org/Articles/Tanzanian-uranium-production-nears

3.51. ZAMBIA

Zambia is a landlocked country in southern central Africa whose topography comprises various high plateaux, with some hills and mountains dissected by river valleys. Zambia is drained by two major river basins: the Zambezi Basin in the south, which covers about three quarters of the country, and the Congo Basin in the north, which covers the remainder.

The Zambezi valley, running along the southern border, is both deep and wide. To the east of Lake Kariba it is formed by grabens and comprises a rift valley, as do the Luangwa, Mweru-Luapula, Mweru-wa-Ntipa and Lake Tanganyika valleys.

Western Zambia is very flat and has broad plains and contrasts with eastern Zambia which shows greater diversity in terms of topography. The plateau extending between the Zambezi and Lake Tanganyika valleys is inclined to the south and rises gradually from about 900 m in the south to 1200 m in the centre, reaching 1800 m in the north, near Mbala. In the east, the Luangwa valley splits the plateau in a curve extending NE–SW, extended west into the heart of the plateau by the deep Lunsemfwa River valley. Hills and mountains occur along some sections of the valley, notably in the north-east where the Nyika Plateau (2200 m) on the border with Malawi extends into Zambia as the Mafinga Hills, which host the country's highest peak, Kongera (2187 m).

The Muchinga Mountains form the watershed between the Zambezi and Congo drainage basins. The range runs parallel to the deep valley of the Luangwa River and forms a spine to its northern edge, although it is mostly below 1700 m in elevation. Lake Tanganyika is a major hydrographic feature within the Congo Basin.

Zambia's climate is tropical, although influenced by elevation. Most of the country is classified as humid subtropical or tropical wet and dry, with a semi-arid steppe climate reported in the south-west and along the Zambezi valley. There are two main seasons, the rainy season (November–April), which corresponds to summer, and the dry season (May/June–October/November), which corresponds to winter. Elevation exerts a moderating influence and produces subtropical weather rather than tropical conditions during the cool season of May–August. However, average monthly temperatures remain above 20°C over most of the country for eight or more months of the year.

The Zambian economy has historically been based on the mining of copper. Despite its importance, output of copper had fallen, however, to a low of 228 000 t in 1998, representing a 30-year low. This was the result from a combination of factors, including lack of investment, low prevailing copper prices and uncertainty over privatization. In 2002, following privatization of the industry, copper production recovered to 337 000 t. In 2018, copper production amounted to 861 946 t. The Government of Zambia is pursuing an economic diversification programme to reduce the economy's reliance on the copper industry. This initiative seeks to exploit other components of Zambia's rich resource base by promoting agriculture (corn, soybean, cotton, sugar, sunflower seeds, wheat), tourism, mining (gemstones, nickel, tin, uranium) and hydropower [51.1].

3.51.1. Geology

The oldest rocks of Zambia consist of gneisses, schists, quartzites, phyllites and granites comprising the basement complex (Fig. 3.82). These are overlain in the central part of the country by metasediments (quartzites, phyllites, talc schists and dolomites) of the Upper Proterozoic Katanga System. The Katanga is overlain by a sequence of shales, sandstones and limestones of the Upper Proterozoic Kundelungu Series. During the Carboniferous–Early Jurassic, tillites, sandstones, shales and lavas of the Karoo System were deposited and preserved in downfaulted trough-like structures mostly aligned in a north-easterly direction. Notable examples are the Zambezi valley in the Lake Kariba area and the Luano-Luangwa valley system in the eastern part of the country.

The Lower Karoo comprises basal sandstone overlain by mudstones, including some coal seams. This is followed unconformably by the Escarpment Grit of the Upper Karoo, a coarse pebbly arkose which forms prominent ridges parallel to trough alignments. The overlying sandstones are locally capped by the Batoka basalts of the Stormberg Formation, the uppermost unit of the Karoo Group.

In the extreme west of the country, where outcrops are largely obscured by duricrusts (ferricrete, calcrete, silcrete) and wind-blown sand, the Karoo Group rocks are overlain by Kalahari sands.

Quaternary and Recent deposits occur in depressions in the plateau surface and in basins on the floor of the rift valleys.

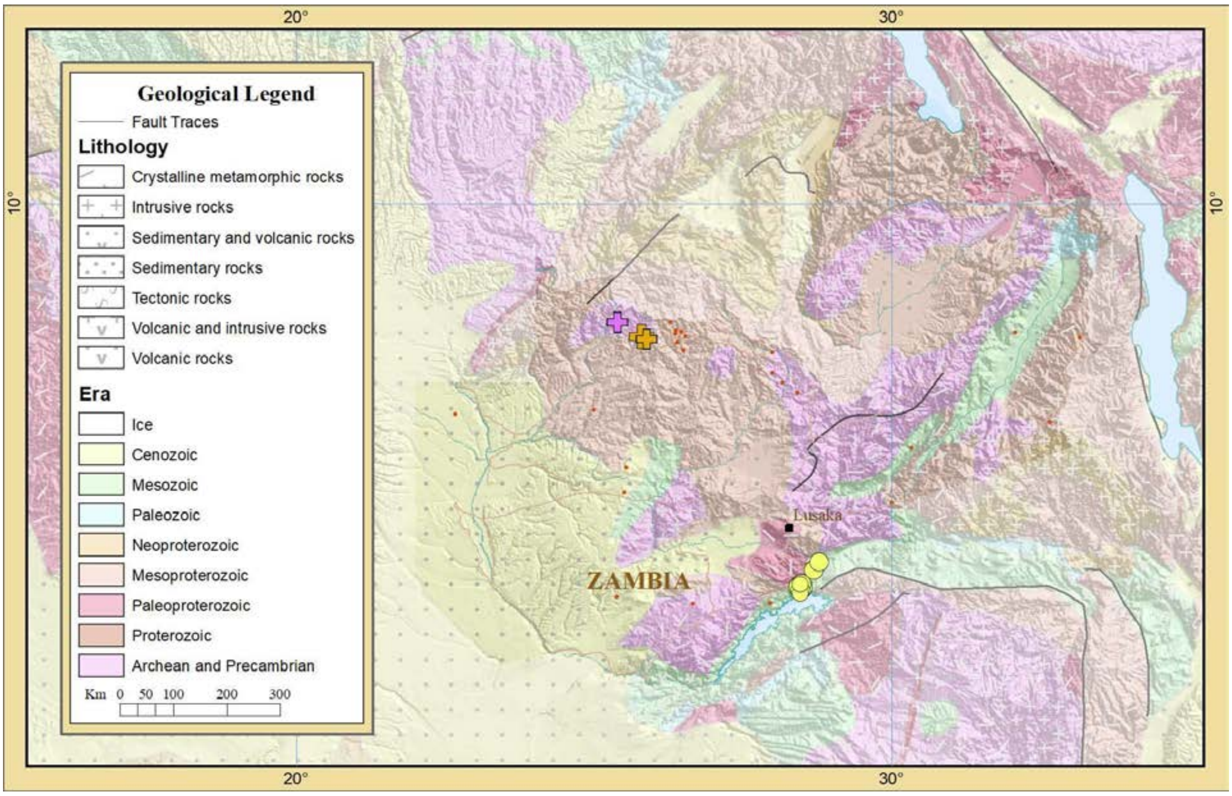


FIG. 3.82. Regional geological setting of Zambia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

3.51.1.1. North-western Province

The North-western Province is underlain mainly by metasediments of the Katanga System, the lowest of which, the Roan Formation, being the host of the Copperbelt mines in Zambia. The principal copper operations in the Zambian Copperbelt are the Chililabombwe, Chingola, Mufulira, Kitwe, Ndola and Luanshya mines. A minor amount of uranium usually accompanies the copper ore (the average grade of the copper ore is 0.004% U). Copper and uranium mineralization are found in the Roan, which was subjected to tectonism during the Lufilian Orogeny and metamorphism related to, and post-dating, the tectonism. As a result, vein uranium deposits were formed by repeated mobilization and deposition. Supergene processes resulted in further redistribution and concentration.

In the Domes area of north-western Zambia, the mineralization occurs mainly in a mica schist underlying a quartzite bed, near the base of the Lower Roan at the margins of the Kabompo, Mwombeshi and Solwezi domes. The Roan dips outwards from the basement cores of the domes at about 15–20°. The mineralization occurs as pitchblende, disseminated or in veins, and as secondary uranium minerals. The pitchblende occurs in discrete masses, generally up to a few centimetres in diameter, although exceptionally large masses have been encountered.

3.51.1.2. Lake Kariba Area

Scattered uranium mineralization hosted in sandstones and mudstones of the Upper Karoo Group, which crop out along the north shore of Lake Kariba, has been known since 1974. The basal member of the Upper Karoo Group, the Escarpment Grit, appears to be especially favourable as a host rock. The known mineralization derives essentially from the oxidized zone and is therefore secondary, consisting of autunite, meta-autunite, phosphuranylite, uranophane, abernathyite, boltwoodite and uranocircite. The shape of the mineralized bodies is essentially lensoid, both concordant and discordant. The source of the uranium found in these sandstone occurrences is thought to be the Katanga System [51.2].

3.51.2. Uranium exploration

3.51.2.1. Historical uranium exploration

Uranium exploration in Zambia dates from the 1950s, when disseminated pitchblende concentrations were discovered in association with the copper–cobalt mineralization at the Mindola mine in the Copperbelt. This deposit was hosted in the lower part of the Proterozoic Katanga Supergroup and was mined out between 1957 and 1959.

In 1958, a car-borne radiometric survey by the Zambian Geological Survey Department detected uranium concentrations in the Karoo sediments of the Zambezi valley, near Zariba. Mwinilunga Mines undertook an airborne radiometric survey in the North-western Province and this led to another uranium discovery in the Katangan metasediments of the Domes area. Radioactivity was noted in a number of hot springs and several minor occurrences of radioactive minerals were recorded at that time in carbonatites, syenites, granites, pegmatites and basement schists.

During the period 1967–1976, the Government undertook a countrywide airborne radiometric survey, with the exception of the Western Province, which is dominated by Kalahari Quaternary sands. The objectives were to speed up mineral exploration in both Karoo and pre-Karoo strata, to attract uranium explorationists and to diversify mining activities away from the Copperbelt to other parts of the country. Parts of the Northern, Central and Southern Provinces of Zambia were also covered with car-borne gamma ray spectrometer/scintillometer surveys. Ground follow-up using geological, radiometric and geochemical techniques led to the discovery of uranium occurrences of both the sandstone type (Siavonga and Sinazongwe in the Southern Province) and the vein type (North-western Province and the Copperbelt).

The Kariba uranium area was identified by several radioactive anomalies, including one anomaly near Siavonga, which is about 15 km long. This anomalous area was selected in 1974 for intensive ground investigation by the Zambian Geological Survey Department. A parallel strip of ground adjoining it on the north-west was later awarded for prospecting to Italy's AGIP. The anomalies are due to the presence of yellow uranium phosphates disseminated in the Escarpment Grit, the basal member of the Upper Karoo System.

The only work done elsewhere in the Karoo was in the Luano-Luangwa valley system where a Japanese company, the Power Reactor and Nuclear Fuel Development Corporation (PNC), was holding prospecting licences at the northern end of Luangwa valley and just west of Lundazi.

Regional prospecting by AGIP in the Domes area of north-western Zambia began in 1972 with the completion of an airborne spectrometer survey. AGIP focused its area of interest on several strips of Lower Roan schist up to 15 km long and fringing a few of the dome-like protrusions of the basement complex, which are a feature of the area.

In 1983–1984, the Government and three foreign companies continued uranium exploration activities in the country.

The Government, through the Geological Survey Department, was involved in the selection of areas considered favourable to hosting uranium mineralization. The selection was based on office studies of available geological and radiometric data acquired previously. Work was continuing on the chemical analysis of available stream sediment samples. Field visits were made to a few selected areas, to study the radioactivity, geology and surficial environment. Davidite mineralization was observed at Chitumbo (east of Lusaka) in a basement environment and meta-autunite at Mwila village (north-east of Mpika).

At the same time, the Government carried out an IAEA assisted project on exploration for nuclear raw materials. Under this project, the Geological Survey Department identified the most favourable areas for the occurrence of uranium and assessed them in order of favourability. The results of the project were assembled in dossiers, which contain geological, radiometric and geochemical information on each of the selected and studied areas.

Foreign companies have investigated uranium occurrences in the following environments:

(a) The Karoo formation, in the area north of Lake Kariba;
(b) The contacts between the basement and Katanga strata (Late Precambrian).

Work included detailed geological mapping, radiometric and electromagnetic profiling, drilling, chemical analysis and petrographic studies.

Private companies exploring for uranium in Zambia include AGIP (since 1970), PNC (since 1973) and Saarberg Interplan Uran GmbH (since 1980). AGIP held prospecting licences in the mid-Zambezi valley (north of Lake Kariba) and in the North-western Province. PNC held only one prospecting licence in the mid-Zambezi valley. Saarberg Interplan also held prospecting licences in the mid-Zambezi valley, as well as in the Luangwa district and the Copperbelt, extending into the North-western Province.

In 1982, the Compagnie Générale des Matières Nucléaires (COGEMA) joined AGIP in a joint venture exploration programme for uranium. Work in the mid-Zambezi valley and the North-western Province (Domes area) involved extensive drilling and proved the existence of uranium anomalies/occurrences in the Upper Karoo sediments. In the Domes area, uranium anomalies/occurrences are found in the lower parts of the Katanga succession. PNC's work in the Lundazi licence area only revealed insignificant uranium mineralization along the contact of the Upper Karoo with the basement strata.

In view of the increased activity in uranium exploration during the 1970s, an act of Parliament was passed which led to the formation of the Prescribed Minerals and Materials Commission (PMMC). The PMMC was charged with regulating and controlling radioactive mineral exploration, mining and marketing, and with the disposal of radioactive wastes in a manner that was beneficial to the country and acceptable to the international community. In 1985, an Orientation Phase Mission of the International Uranium Resources Evaluation Project (IUREP) was published [51.3].

In 1987 and 1988, the only exploration activities in the country were undertaken by Government organizations, as the foreign companies, AGIP, PNC, COGEMA and Saarberg, had either terminated or suspended their projects.

The PMMC and the Geological Survey Department, with assistance from the IAEA, analysed geological, radiometric and geochemical data to define target areas where uranium mineralization could occur. This programme focused on basement and granitic terrains which received little or no attention from private companies in the past.

In 1989, a new programme was initiated whose objective was to produce a uranium geochemical atlas by plotting geochemical results of existing stream sediment samples. These data, in connection with geological and geophysical maps, were planned to be used for the preparation of promotional dossiers to encourage and help uranium exploration companies select areas with the greatest uranium potential.

In 1990, the AGIP–COGEMA joint venture continued uranium exploration in the Domes area in north-western Zambia. A prefeasibility study on the Lumwana copper–uranium occurrence was completed. Resources were reported to be 15 000 tU [51.3–51.6].

Figure 3.83 summarises historical data on exploration in Zambia up to 2017, for a total of USD $9 902 000, including 276 412 metres of drilling and 560 200 km^2 of airborne radiometric surveying.

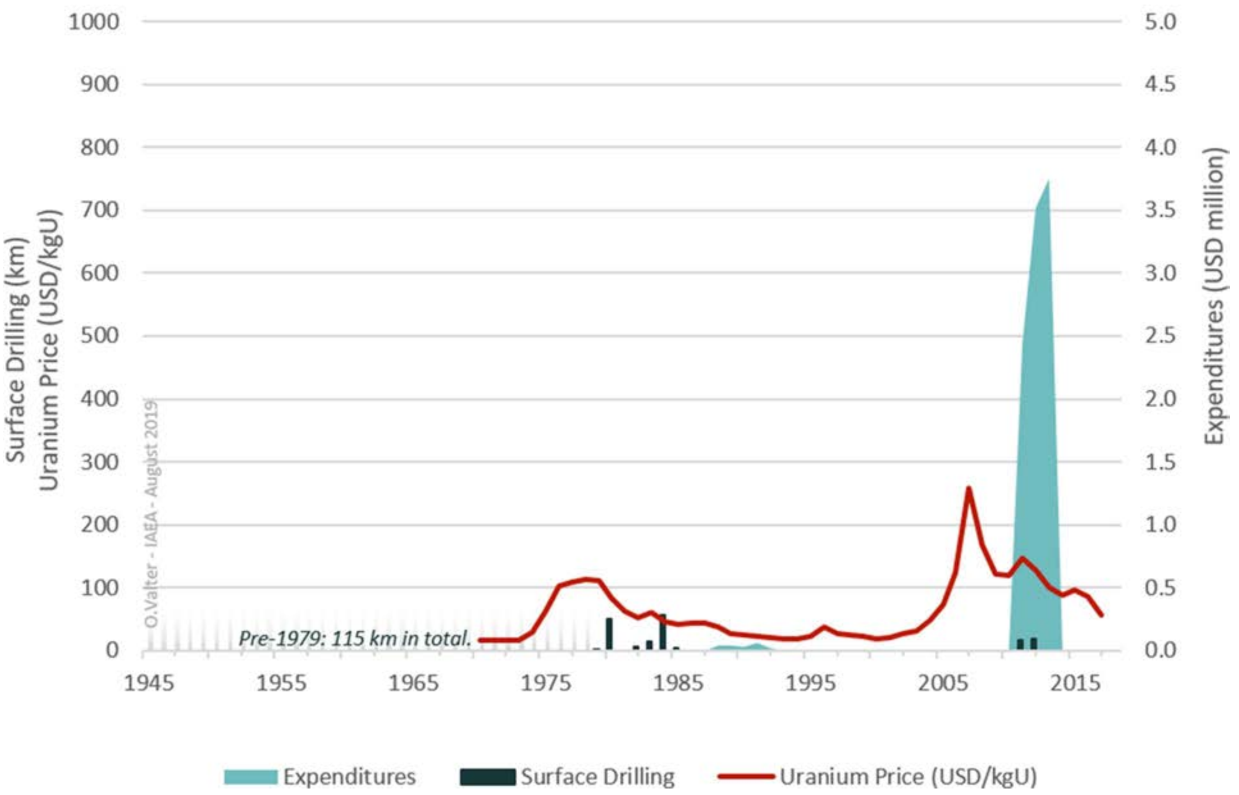


FIG. 3.83. Domestic uranium exploration data for Zambia. Comparison of exploration expenditures, drilling and uranium market price (US$ current) [51.7–51.15].

3.51.2.2. Recent exploration activities

Australia's Equinox Minerals Ltd is developing the Lumwana project in north-western Zambia [51.16]. The mineralization occurs as discrete uranium enriched zones within the Malundwe and Chimiwungo copper deposits. This is primarily a copper project, but following a bankable feasibility study on uranium recovery in 2003, the company announced 7465 tU of indicated resources at an average grade of 0.08% U and 785 tU of inferred resources at an average grade of 0.04% U. The uranium resources occur in discrete zones, separate from the copper. However, they will be mined at the same time as the copper. This facility would cost about US $200 million and could recover approximately 769 tU and 12 800 t of copper concentrate annually.

In 2011, the company said that it had 4.6 million tonnes of uranium ore stockpiled containing 0.09% uranium and 0.8% copper. In mid 2011 Equinox was taken over by Barrick Gold Corp. As to 2018, no uranium has been produced [51.16].

Canada's Denison Mines Corporation planned to bring the Kariba uranium project into production by 2011, based on mining several shallow orebodies (Mutanga, Dibwe, Dibwe East) [51.17]. Measured resources total 766 tU at 0.048% U, indicated resources total 2237 tU at 0.031% U and inferred resources total 5059 tU at 0.025% U. The project named Kariba, was developed by Omega Corporation prior to its acquisition by Denison Mines. Following successful licence renewal, a feasibility study was presented for an open pit mine with acid heap leaching. GoviEx Uranium Inc of Canada acquired the Mutanga project and is planning to develop it [51.16].

Albidon Ltd, based in Western Australia, was exploring the Njame and Gwabe deposits (Chirundu uranium joint venture) and reported indicated resources of 1340 tU at 0.03% U and inferred resources of 1190 tU at 0.02% U.
African Energy Resources was then holding these deposits but in 2017 sold the whole Chirundu project and Kariba Valley tenements to GoviEx, giving it almost contiguous tenements of approximately 140 km in strike length parallel with the border, including three contiguous mining permits. In 2017, combined mineral resources are 5800 tU measured and indicated resources at 0.028%U and 17 400 tU inferred resources at 0.025%U for its Mutanga project including the Chirundu deposits [51.16].

3.51.3. Uranium resources

3.51.3.1. Identified resources

Tables 3.37 and 3.38 summarize the Zambia's uranium resources by deposit types.

TABLE 3.37. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE (tU) [51.17]
(As of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	0	5113	5113
Metasomatite	0	0	6016	6016
Total	0	0	11 129	11 129

TABLE 3.38. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [51.17]
(As of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	0	15 198	15 198
Metasomatite	0	0	951	951
Total	0	0	16 149	16 14

The UDEPO database lists the most significant deposits for Zambia as Dibwe East, Malundwe, Njame, Mutanga Main, Dibwe, Gwabe, Kawanga, Chimiwungo, Njame South, Mutanga Ext-E-W.

3.51.3.2. Undiscovered resources

In 1997, results of the compilation of uranium geochemical maps led to the definition of two new metallogenic provinces with uranium potential. They were defined on the basis of anomalous uranium values found in stream sediments. These metallogenic provinces include the Bangweulu block in northern Zambia and the Kabwe-Mkushi area in central Zambia. In addition, there are known uranium occurrences in the Copperbelt and in the mid-Zambezi valley.

The Bangweulu block is a cratonic unit composed of crystalline basement, acid metavolcanics and granitoids and has an age of 2000–1800 Ma. The Kabwe-Mkushi area is underlain by metasediments of the Katanga Group, which were deposited between 1300 ± 40 Ma and 620 ± 20 Ma.

The uranium potential of these two provinces was assessed at 22 000 tU of estimated additional resources (EAR-II) recoverable at costs below US $130/kgU. Of the total potential, 3000 tU were judged to occur in vein type deposits and 19 000 tU in sandstone type deposits. In 1983, IUREP reported speculative resources in the range of 33 000–100 000 tU [51.18, 51.19], subdivided according to geological environment as follows:

(a) Disseminated magmatic, pegmatitic and contact deposits in igneous and metamorphic rocks (0–5000 tU);
(b) Sandstone type deposits in Karoo and younger sediments (28 000–75 000 tU);
(c) Surficial deposits (0–5000 tU);
(d) Katanga type deposits (5000–15 000 tU).

3.51.3.3. Unconventional resources

Zambia does not report any unconventional resources. The average uranium grade of copper mine ore is about 0.004% U. The leaching of mine dumps or slimes dams may also add to Zambian uranium resources. It is recognized, however, that the carbonate content of the ore makes the cost of acid leaching for uranium prohibitive. Alkaline leaching could not readily be integrated into normal copper leaching practice.

3.51.4. Potential for new discoveries

The potential for discovering uranium resources in Zambia is estimated as moderate to high. Resources could be found in three major uranium hosting environments identified during past exploration: continental sandstones of Karoo age, the Copperbelt and the gneiss domes of North-western Province.

The part of the Katanga System in the Copperbelt, which has been explored for copper, and the Domes area, which has been explored for uranium, represents only a very small fraction of the overall area underlain by rocks of similar age and facies in Zambia. In these areas, the small basement gneiss uplifts protrude through the cover and are resistant to erosion and give rise to exposures or near exposures of the lower mineralized Katanga strata. It is possible that the apparent outcrop distribution distorts the true distribution of uranium in the Katanga strata and, if so, the uranium potential of the inter-dome regions may be greater.

There are areas of Karoo Group outcrop remaining to be explored, such as the Luano-Luangwa Trough and the western part of Zambia. A large area of Zambia is covered by Karoo basalt, but there are probably portions of this basalt zone where normal Karoo clastic sediments are present.

The Kalahari sands, present in south-western Zambia, could be explored for uranium occurrences both for fluvial sands within structural lows and for calcrete deposits.

3.51.5. Uranium production

The only uranium production occurred in 1957–1959 at the Nkana copper mine, Kitwe, in the Copperbelt. From about 100 000 t mined at a grade of 0.19% U, about 100 tU were produced. The uranium mineralization occurred in a barren zone of the stratabound copper deposit in the Lower Roan Formation of Upper Proterozoic Katanga metasediments.
The Lumwana project is primarily a copper project, but the uranium resources occur in discrete zones, separate from the copper. However, uranium is mined at the same time as the copper. In 2011, 4.6 million tonnes of uranium ore were stockpiled containing 0.09% uranium (4140 tU) and 0.8% copper. This uranium-copper stockpile may be treated at a later date [51.16].

3.51.6. Future projects

On 29 April 2008, Equinox announced a positive feasibility study for uranium extraction at its Lumwana copper mine project. As part of the much larger copper mining operation, Equinox is planning the selective mining of 1 million t/year of uranium ore. Approximately 770 tU/year are to be recovered from the ore.

The deposit contains 8250 tU. Equinox is hoping to produce about 150 000 t of copper annually from the Lumwana project when it comes on-line in 2008. The project has a projected mine life of 37 years. An environmental impact assessment has been prepared as part of the uranium feasibility study and was lodged for approval in July 2005 with the Environmental Council of Zambia. Investment in the US $230 million uranium mill has been deferred owing to difficulty in financing. Malundwe will be the first of two uranium mines within the overall project. At Malundwe, the uranium mineralization occurs in discrete veins distributed throughout the copper mineralization. The uranium development will be a separately financed US $150 million exercise. There has been no uranium production to 2018.

Omega Corporation has expressed interest in opening up a uranium mine in Siavonga (Kariba project). The exploration project started in June 2006. Omega intended to start constructing the mine between July 2007 and October 2008, as soon as the Government issues a mine operating licence for which the company has applied. Production of uranium from the mine was expected to start in October 2008 and end in 2015 after operating for a period of seven years. No uranium has ben produced on this project operated by GoviEx in 2018.

On 9 May 2008, Albidon Ltd and African Energy Resources Ltd announced the completion of the prefeasibility study on the Chirundu uranium joint venture project. The prefeasibility study demonstrates that commercially viable mining is possible under the projected price and cost scenarios. A base case for the study is the production of 538 tU/year over an initial five-year mine plan, assuming a uranium price of US $143.3/kgU. Mining would employ open pit mining and acid heap leaching. Production could start in 2010.

Denison Mines plans to bring the Kariba (designated as Mutanga by Denison) uranium project into production by 2011 by mining several shallow orebodies [51.18]. No uranium has ben produced on this project which is operated by GoviEx in 2018.

3.51.7. National policies relation to uranium

Zambia has upgraded its mining legislation to take into account uranium mining. Regulations for Prospecting, Mining and Milling of Uranium Ores and other Radioactive Minerals was drafted in 2007 and submitted to the IAEA for comment. Zambia started issuing uranium mining licences in late 2008.

References to Section 3.51

[51.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Zambia, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[51.2] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[51.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission Report: Zambia, IAEA, Vienna (1985) 20 pp.

[51.4] TAUCHID, M., Nuclear raw materials: Developing resources through technical co-operation, IAEA Bull. **35** 3 (1993) 14–17.

[51.5] MONEY, N.J., “Uranium agreements – Conditions considered fundamental for such agreements: Zambia, a case study”, Contractual Arrangements for Uranium Exploration and Mining, IAEA-TECDOC-468, IAEA, Vienna (1988) 13–18.

[51.6] THE ZAMBIAN PARLIAMENT, Mines and Minerals Act (1976).

[51.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[51.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[51.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[51.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[51.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[51.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[51.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).
[51.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).
[51.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).
[51.16] WORLD NUCLEAR ASSOCIATION, Uranium in Africa -Zambia (2018).
[51.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).
[51.18] EQUINOX COPPER VENTURES LIMITED, Lumwana Copper Project Environmental Impact Assessment (2005) 348 pp, http://www.eib.org/attachments/pipeline/1570_eia_en.pdf
[51.19] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

3.52. ZIMBABWE

Zimbabwe is a landlocked country in south-east Africa. To the south, Zimbabwe is separated from South Africa by the Limpopo River; the north-western border is defined by the Zambezi River. Zimbabwe's highest peak is Mount Nyangani (2592 m), which is located within the Nyanga National Park in the east of the country. Zimbabwe's lowest elevation, 162 m, lies to the south-east, at the junction of the Runde and Save Rivers, on the border with Mozambique.

Zimbabwe's climate is tropical, although this is moderated by elevation. The rainy season extends from November to March. The terrain is mostly high plateau, with a higher central plateau and a mountainous range in the east.

Mineral exports and agriculture are the main foreign currency contributors to Zimbabwe. The country has reserves of metallurgical grade chromite and other commercial mineral deposits include coal, asbestos, copper, diamonds, nickel, gold, platinum and iron [52.1].

3.52.1. Geology

Zimbabwe is underlain by a core of Archean basement known as the Zimbabwe Craton, which is intruded by the famous Great Dyke, a SSW–NNE trending ultramafic/mafic dyke complex. The craton is principally composed of granitoids, schists and gneisses and greenstone belts. It is overlain in the north, northwest and east by Proterozoic and Phanerozoic sedimentary basins [52.2].

The eastern half of Zimbabwe comprises the Archaean Rhodesian cratonic nucleus, a 3600–2600 Ma block of granites, gneiss and charnockite domes containing greenstone belts. The low metamorphic grade greenstone belts are intruded by late potassic granites, porphyries and sodic tonalites.

The cratonic trends are transected by the N–S trending Great Dyke (2530 Ma). The craton is surrounded by Proterozoic mobile belts where, formerly, broadly similar basement rocks have been metamorphosed, deformed and granitized.

In the west of the craton, Lower Proterozoic–Middle Proterozoic sediments rest on the basement. These have been compared to the Katanga–Copperbelt Series of the Democratic Republic of the Congo and Zambia, and with the Nama–Transvaal Series of South Africa. The sediments are somewhat different from the Copperbelt, as no carbonates are reported, although volcanics are present. The degree of metamorphism is also higher, locally reaching amphibolite facies. The rocks consist of basal sequences of conglomerates, overlain by lavas, conglomerates, arkoses, sandstones and schists. Copper is disseminated in the upper arkoses and conglomerates, below the schists and above the lavas.

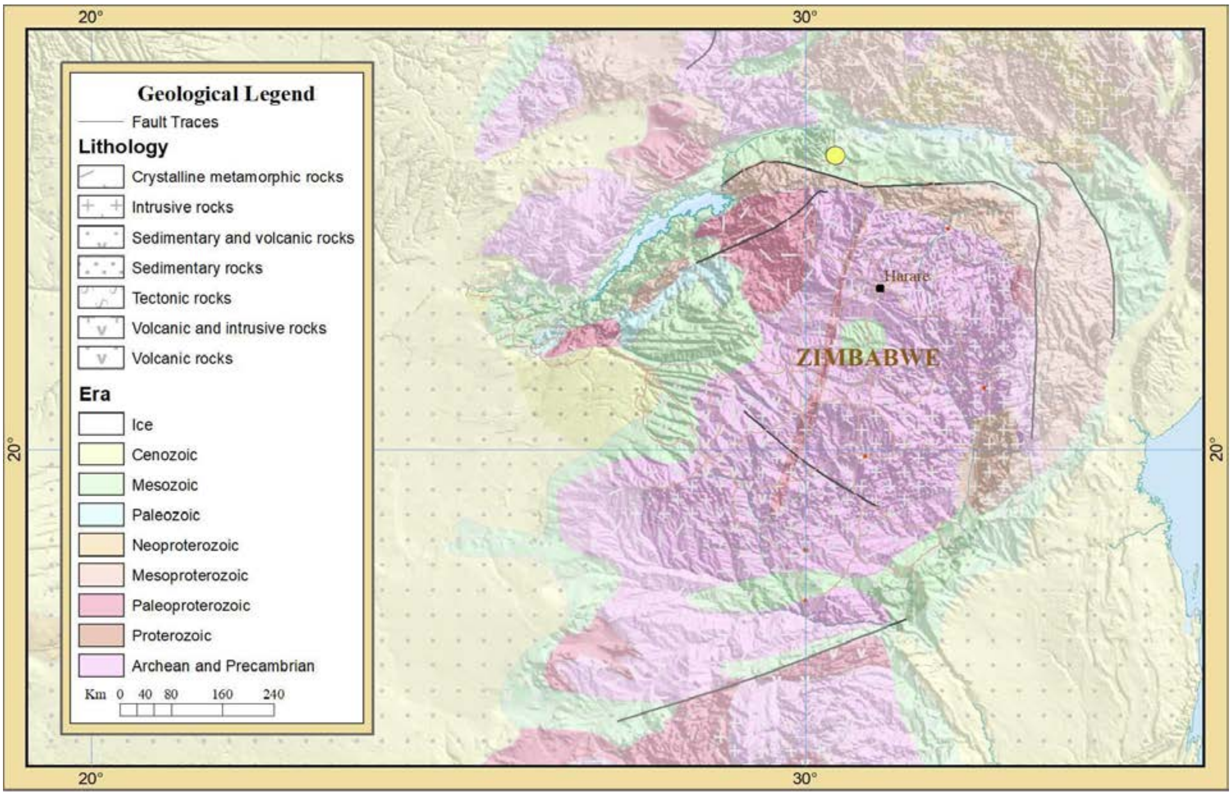


FIG. 3.84. Regional geological setting of Zimbabwe showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The various Precambrian rocks are overlain unconformably by Karoo sediments of Carboniferous–Triassic age. Small outliers occur well into the craton, but the Karoo is largely confined to downfaulted or downwarped grabens and basins. The rocks are mainly arenites, conglomerates, shales and coals, with both oxidized and reduced facies. In the north and west, in the Zambezi graben, they crop out over an area of around 78 000 km². However, in the west and, more particularly, the south, the Karoo consists predominantly of basalts with thin interbedded sedimentary sequences. In the south-east, there is a small area of Jurassic continental and marine sediments, while in the west, Karoo strata are overlain by Eocene aeolian Kalahari sands, which blanket the bedrock geology. Large Tertiary syenite–granite complexes occur in the south-east along the margins of the Limpopo graben. Small, shallow Quaternary sedimentary basins occur in the centre, west and south-east of the country [52.2, 52.3].

3.52.2. Uranium exploration

Uranium exploration was started in Zimbabwe in an ad hoc manner in the early 1950s by numerous private prospectors. Many radioactive anomalies were found at that time, mainly associated with pegmatite in the basement complex and in Proterozoic terrain, as well as within Karoo sediments. In the mid-1950s, the United Kingdom Atomic Energy Authority (UKAEA) commenced a comprehensive search for radioactive minerals but with very limited success. A guarantee purchase programme for uranium ores undertaken to stimulate prospecting and mining generated only one shipment of 300 t of ore grading 0.255% U, yielding 0.77 tU. This came from a mineralized fault zone in granite. The UKAEA programme also included an airborne radiometric survey covering 17 000 km². During this time, private companies also engaged in systematic exploration ventures consisting of airborne and ground surveys and selective core drilling. A variety of geological environments were investigated, although with very little success.

In 1969, Karoo Group sediments were explored under three Exclusive Prospecting Orders. Attention focused on the heavy mineral content of various conglomerates, but the only radioactive mineral found was monazite. In 1972, the Messina Development Co. Ltd discovered a large radioactive anomaly during an airborne survey in the Sabi Valley, but ground follow-up, including drilling, failed to identify the cause of the anomaly. In 1976, Gold Field Prospecting Co. (Pty) Ltd examined the granitic terrain of the Chinamora batholith, located 30 km north-east of Salisbury. Both airborne and ground surveys were conducted. However, the only anomalies detected were from weakly radioactive alaskite dykes.

Modern uranium exploration in Zimbabwe started in 1981, when a gamma spectrometric airborne survey was flown over the entire Zambezi valley using fixed wing aircraft. The purpose of the survey was the evaluation of the Karoo System strata. To verify and screen anomalies identified by the airborne survey, a follow-up helicopter-borne and ground-based survey was conducted in 1982. The German company Interuran, formerly named Saarberg Interplan Uran, was one of the companies involved and it focused work on the Kanyemba area. In 1983–1987, additional work was completed on all verified anomalies. Following discovery of the Kanyemba-1 deposit, a detailed evaluation was initiated. Between 1985 and 1990, exploration and delineation drilling, as well as technical studies on hydrogeology, rock mechanics, ore processing, mining, etc., were completed. A prefeasibility study was also completed using this information.

Exploration activities for the Kanyemba-1 deposit were achieved by the end of 1991. During 1991–1992, a technical feasibility study was completed. An environmental impact study was started, including the collection of baseline data on the hydrogeology, radon flux, dosimetry and micro-meteorology of the area.

Owing to the depressed international uranium market, which adversely impacted the feasibility of the Kanyemba project, all activities were terminated at the end of 1992 [52.3].

Figure 3.85. summarises historical exploration data, for a total of USD \$6.9 million, including 28 562 metres of drilling and 24 400 km^2 of airborne radiometric surveys.

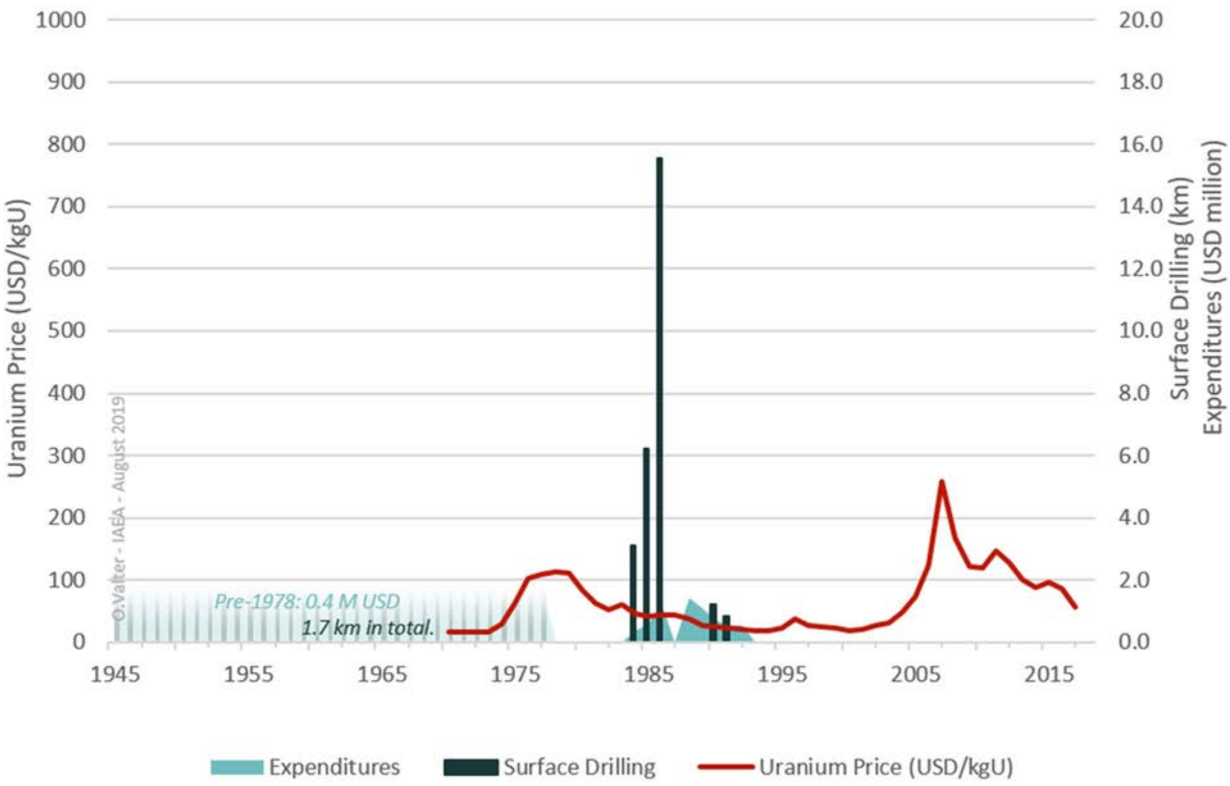


FIG. 3.85. Domestic uranium exploration data for Zimbabwe. Comparison of exploration expenditures, drilling and uranium market price (US\$ current) [52.4–52.11].

3.52.3. Uranium resources

3.52.3.1. Identified resources

Zimbabwe's identified resources (reasonably assured resources) are 1800 tU (in situ) with a recoverable cost of up to US $80/kgU and an average grade of 0.6% U. The resources are associated with the Kanyemba-1 deposit located in the northern part of the country, near the border with Mozambique. The deposit consists of several lens shaped bodies, 0.20–3 m thick, 20–100 m wide and up to 600 m long. It is a tabular deposit occurring in sandstones of the Upper Pebbly Arkose Formation (Upper Triassic) of the Upper Karoo System. The sandstone host rock was deposited by a meandering fluvial system.

The 2018 Red Book indicates 1400 tU as reasonably assured resources recoverable in the $130-260/kg cost category.

The UDEPO database lists the most significant deposit for Zimbabwe as Kanyemba 1.

3.52.3.2. Undiscovered resources

Zimbabwe does not report any estimated additional resources (EAR-II). However, it has reported speculative resources of 25 000 tU recoverable at <US$130/kgU. These resources are associated with sedimentary rocks of the Permian–Lower Jurassic Karoo System. In 1983, IUREP reported speculative resources of 10 000–50 000 tU, hosted in sandstone and magmatic environments [52.12].

The 2018 Red Book indicates 25 000 tU as speculative resources.

3.52.4. Potential for new discoveries

The 7800 km² of overlying Lomagundian platform sediments are regarded as the best Precambrian target. In these, around Sinoia, disseminated copper mineralization occurs in association with metamorphosed lavas and schists at the base of a thick clastic sequence. In the Molly mine, uraninite and secondaries are patchily dispersed, antipathetically to copper in the sediments in the vicinity of intrusive pegmatites. It has been suggested that the rocks of low metamorphic grade in this series possess uranium potential. However, to the north, where the series is metamorphosed up to amphibolite facies, it is likely to be barren. The Karoo Group sandstones crop out over an area of 90 500 km² and must be considered to have some potential based on the general premise for exploration applied in other parts of southern Africa.

Minor occurrences of pitchblende and secondary uranium minerals have been located in the Wankie coalfield and near Sebungwe, in the NE–SW post-Karoo faults. The major problem in prospecting these sediments is poor exposure due to laterization and subdued topography. The Karoo consists of sandstone/shale/conglomerate intercalations of continental origin, in reduced and oxidized facies, with coals and organic debris. This is a highly favourable situation for the concentration of uranium in reduced zones in the porous sections of the sequences. In the west and south of the country, the Karoo rocks are dominantly basalts, but the basal sediments may well be worthy of examination. Small outliers in the craton could also be worthy of examination. In the same general area, two syenite–phonolite complexes could have minor potential for uranium as a co-product with monazite and rare earth minerals.

In the west, the Karoo is overlain by Eocene Kalahari sands. On the basis of the broad observations of increasing aridity towards the Botswana border, and on the intermittent nature of drainage both now and in the past, duricretes could well be developed in this area. If a source of uranium is available for their formation, calcrete deposits of the Yeeleerie–Swakopmund type could occur. However, younger sands could mask orebodies in the Karoo. The coarser zones of Quaternary sediments might be worthy of examination where the underlying rocks can be shown to be uraniferous.

The main uranium potential of Zimbabwe is undoubtedly in the north-western one third of the country, to some extent in low grade metamorphosed Lomagundi (Precambrian) Copperbelt type platform sediments, but more particularly in the extensive areas of poorly exposed Karoo sediments [52.3].

3.52.5. Uranium production

Three hundred tonnes of ore, containing 0.77 tU, were produced in the 1950s. The Kanyemba-1 deposit, with known resources of 1800 tU in the <US $80/kgU cost category, could, under favourable market conditions, support a production centre. Feasibility studies completed in the early 1990s provided plans for the construction of such a centre, with a production capability of 350 tU/year.

On 24 April 2010, a press report stated that the Government of the Islamic Republic of Iran had entered into an agreement with the Government of Zimbabwe to develop and mine the Kanyemba-1 deposit [52.13].

References to Section 3.52

[52.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Zimbabwe, Washington, DC (2008), https://www.cia.gov/library/publications/the-world-factbook/index.html

[52.2] SCHLÜTER, T., Geological Atlas of Africa, 2nd edn, Springer, Berlin and Heidelberg (2008) 274–278.

[52.3] JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Miller Freeman Publications, Inc., San Francisco (1980) 524 pp.

[52.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[52.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[52.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[52.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[52.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[52.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[52.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[52.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[52.12] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[52.13] MUSHEKWE, I., ALEXANDER, H., Iran strikes secret nuclear mining deal with Zimbabwe's Mugabe regime, The Daily Telegraph (24 Apr. 2010).

CHAPTER 4. WESTERN EUROPE

4.1. ANDORRA[8]

4.1.1. Geography

Andorra is a landlocked country in south-western Europe and is situated between southern France and northern Spain. The country straddles the Pyrénées, which form an east–west trending mountain belt. Andorra's northern part consists of Mesozoic sedimentary rocks; the southern part of Tertiary sedimentary rocks and Hercynian basement rocks.

4.1.2. Comments

Uranium exploration activities are not reported. Given the small land area of Andorra, there is very limited potential for discovering uranium.

The UDEPO database does not list any known deposits for Andorra.

4.2. AUSTRIA

4.2.1. Geography

Roughly 60% of the Austria consists of the Alps. The northern part, the area bordering the Czech Republic, is occupied by the Bohemian Forest. The eastern part is formed by lowland, the hilly areas of the Vienna Basin and the flat Pannonian Plain. The southern part, around Graz and Klagenfurt, consists of lowlands known as the South-eastern Alpine Foreland.

Austria stretches from Lake Constance (Boden See) in the west to the Neusiedler See in the east. The main river is the Danube, which rises in Germany and flows through Austria, Hungary and Serbia, forming the border between Romania and Bulgaria, before discharging into the Black Sea. Its major tributary rivers in Austria are the Salzach, Inn and Enns.

The Alps are divided into the Northern Calcareous Alps, the Central Alps and the Southern Calcareous Alps. Both the Northern and Southern Calcareous Alps are formed mainly of limestone and dolomite of Mesozoic and Tertiary age. The Central Alps consist of granitic and metamorphic rocks of Palaeozoic age. The Central Alps extend from Tyrol in the west to Styria/Niederösterreich in the east and possess the highest mountain peaks (3797 m peak of Grössglockner). The higher areas are permanently glaciated, including the Ötztaler Alps at the Tyrol–Italy border and the Hohe Tauern (with Grössglockner and Grössvenediger) in eastern Tyrol and Carinthia. The highland of the Bohemian Forest and Mühlviertel in the north reaches elevations of between 1000 m and nearly 1400 m, which continues into the hilly areas of the Waldviertel and Weinviertel [2.1].

4.2.2. Geology

4.2.2.1. General

Austria occupies the southern part of the Bohemian Massif (Fig. 4.1), where the oldest rocks are exposed. The largest part is covered by the northern and central parts of the Eastern Alps. In the north and east lie the Molasse Basins, which are filled by erosional debris from the Alps, followed by the Vienna and Pannonian Tertiary Basins.

---

[8] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

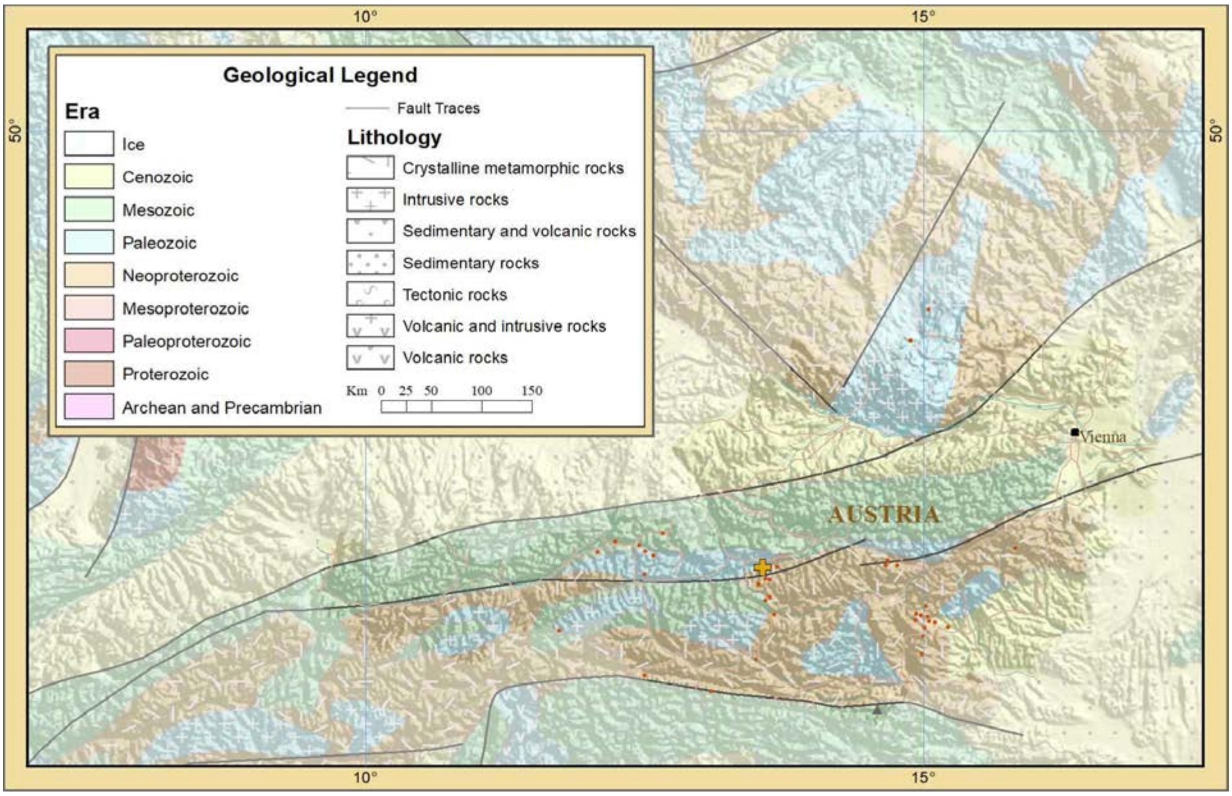


FIG. 4.1. Regional geological setting of Austria showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

In the Bohemian Massif, the metamorphic domains of the Moravian Zone (external) and the Moldanubian Zone (internal) are recognized, representing deeply eroded parts of the Hercynian Orogenic Belt. In the eastern part, the Moldanubian Zone is divided into Archaean–Lower Proterozoic paragneisses, with Hercynian granites in the lower zone and orthogneisses and granulites in the upper zone. The Moravian Zone consists of schists of Upper Proterozoic–Devonian age, intruded by granites. Owing to Hercynian overthrusting, parts of the Moravian underlie the Moldanubian. The late Hercynian granites are unmetamorphosed.

The Eastern Alps consist of several tectonic units (nappes) which have been overthrust on each other throughout different stages of the Alpine Orogeny, starting in the Triassic period and continuing into the Lower Cretaceous. During the Middle Cretaceous, subduction processes resulted in the development of a complicated nappe system. The geological setting is very complex. In the northern part, the Helvetian Zone dominates and comprises limestone, marl and sandstone of Jurassic–Eocene age. The Helvetian is followed by the Flysch Zone, which comprises marine sedimentary rocks (sandstone, marl, breccias and conglomerates) of Upper Cretaceous–Miocene age. The next unit is formed by the Penninic Zone which consists of metamorphosed Palaeozoic and Mesozoic sedimentary rocks and late Hercynian granitoids. The Penninic Zone is followed by three zones of the Austro-Alpine (lower, middle and upper), mainly of pre-Alpidic rocks (so-called metamorphic 'old crystalline' and partly metamorphosed Mesozoic sedimentary rocks) and a variety of unmetamorphosed sedimentary rocks.

To the north and east of the Alps, Tertiary Basins developed. Some of these carry the erosional debris of the uplifted Alps (Molasse Basins) deposited in shallow water throughout the Eocene. Lignite may be present. The Vienna Basin is filled with sedimentary rocks of Miocene age, some of which carry oil and gas. Only the western edge of the Pannonian Basin extends into eastern Austria [2.2, 2.3].

4.2.2.2. *Potentially-favourable uranium-bearing areas*

In the Bohemian Massif, conditions for the formation of vein type deposits are expected. In the unmetamorphosed Permian sedimentary rocks, peneconcordant deposits in the Grödener Sandstein, similar to the Zirovsky Vrh type in Slovenia, may occur.

The continental unmetamorphosed Triassic Buntsandstein may have potential.

In the metamorphosed quartz phyllite and in the Werfener Schichten, favourable conditions are expected. Tertiary Basins may have conditions for the formation of peneconcordant and roll-front type mineralization. Lignite, oil and gas occurring in these basins may have a role as reducing agents at oxidation–reduction fronts.

A description of potentially favourable areas in Permo-Triassic sedimentary rocks was given in 1974 [2.4], and for all formations in Austria the 1981 IUREP report provides guidance [2.3].

4.2.3. Uranium exploration

A detailed report on uranium exploration activities and expenses was only provided to the Red Book in 1977 [2.5]. In view of the exploration activities summarized below, it can be assumed that expenses would total in the range of a few million euros.

According to Ref. [2.4], regional prospecting was carried out by Studiengesellschaft für Atomenergie in 1956–1961 in selected areas of the Bohemian Massif and the Central and the Southern Alps. The main targets were mines, bauxite and phosphorite occurrences, lignite deposits and mineralized spring waters. No follow-up of promising anomalies was made owing to the depressed uranium market prevailing at that time.

In the period 1968–1978, Bergbau und Mineralgesellschaft Pryssok & Co KG (Pryssok) was actively conducting exploration in the Bohemian Massif, in the Upper Carboniferous–Lower Permian of Salzburg, Styria, Kärnten and Tyrol, and in the Tertiary Basins. In 1978, Pryssok was taken over by Salzburger Uranerzbergbau Gesellschaft, a wholly owned subsidiary of the German company Uranerz. Car-borne radiometric surveys were followed by ground surveys over large parts of the Moldanubian and Moravian Zones in the Bohemian Massif, in the Northern and Southern Austro-Alpine Zone and in the Middle and Lower Austro-Alpine Zone [2.3]. Promising anomalies were investigated by trenching and drilling. Most anomalies found in the Bohemian Massif were located in granite porphyries and pegmatitic rocks and were found to be of low economic interest. Some similarities were found with uranium occurrences and deposits in France, Portugal and the Czech Republic.

Metasedimentary rocks and sedimentary rocks of continental origin hosted anomalies in Upper Carboniferous, Permian and Lower Triassic strata. Of interest are parts of the Werfener Schichten, the basal unit of the Permian Verrucano, known for hosting several uranium showings in the Alps. The Violette Schiefer of Upper Carboniferous–Lower Permian also contains minor showings. At Fieberbrunn, in Tyrol, pitchblende has been found in Lower Triassic terrigenous sandstone. In the Mitterberg copper mine (Salzburg), uranium indications have also been recorded along a 4 km strike length. The Permian Grödener Sandstein at Eisenkappel (southern Kärnten) hosts a 3 km zone of uranium–thorium mineralization hosted in conglomerates and black limestone. The Permian Verrucano near Semmering, Styria, hosts uranium occurrences in quartzite.

Since 1970, work has concentrated on the Permian phyllites at Forstau in the Radstädter Tauern near the border of Salzburg and Styria. In 1971–1977, three adits were driven to investigate the underground extent of mineralization which had been found at the surface and in drill core. Between 1975 and 1979, surface and underground exploration was carried out in the southern Radstädter Tauern using an adit at Tweng. All activities were terminated at the end of the 1970s and the sites of underground work have since been reclaimed.

Recent exploration activities for uranium are not reported and none are assumed to be taking place at the present time.

4.2.4. Uranium resources

In the 1977 Red Book, reasonably assured resources for the Forstau deposit were reported as 1800 tU at US $80/kgU. Nothing was reported for other categories and cost classes [2.5].

Experts engaged with the IUREP Orientation Phase Mission Report for Austria reported different results from their work [2.3]. The total for Forstau was estimated in the ABC classification (average grades for the classes of 850 ppm U, cut-off grade of 350 ppm U) as: B: 212 tU, C1: 170 tU and C2: 297 tU, giving a total of 680 tU. Accordingly, the resources at Forstau are equivalent to reasonably assured resources of 210 tU and estimated additional resources of 470 tU. No cost category was given. The Forstau deposit was judged to be too small to be economically viable.

Austria has never officially reported any undiscovered or unconventional uranium resources. The IUREP Orientation Phase Mission to Austria estimated the speculative resources of the Forstau area to be of the order of 1700–2500 tU [2.3].

The UDEPO database lists the most significant deposits for Austria as Forstau, Mitterberg.

4.2.5. Potential for new discoveries

In addition to those areas already mentioned, IUREP reports potential for new discoveries in the following areas:

i) If geological conditions in the Austrian part of the Bohemian Massif are comparable to those in the Central Bohemian Massif at Pribram and to the Eibenstock Massif at Jachymov (10 000–25 000 tU range), then possibly similar ranges of resources may be anticipated. Expectations are for hydrothermal veins (cf. Pribram, Czech Republic (25 000–50 000 tU)) and vein-like deposits (cf. Massif Central, France (1000–10 000 tU));
ii) In the Central Alps, there is potential for the occurrence of deposits in unmetamorphosed sedimentary rocks of Permian (Grödener Sandstein) and Triassic (Buntsandstein) ages of the peneconcordant type (cf. Zirovsky Vrh, Slovenia, and Lodève, France) and tectono-lithological type (Mounana, Gabon);
iii) Deposits in metamorphosed pelitic-psammitic sedimentary rocks, mainly of Permian age (cf. Kitts and Beaverlodge, Canada). These environments can be expected to occur in the Radstädter Tauern where the Forstau deposit occurs. Potential also exists in the Tertiary Basins for peneconcordant (cf. Saint Pierre du Cantal, France) and roll-front deposits (cf. Wyoming, United States of America) [2.3].

According to IUREP, Austria is regarded as having good potential for the finding of uranium mineralization [2.6].

4.2.6. Production

Austria had no commercial uranium production. Future production is not envisaged owing to the restricted size and low grade of any deposits.

4.2.7. Installed and planned nuclear capacity

Austria has no domestic nuclear power generation. A 700 MW(e) BWR nuclear power plant at Tüllnerfeld was scheduled to be built in the early 1970s but was cancelled in 1978 when a moratorium on nuclear power was adopted in a plebiscite. There are no plans to build nuclear power plants.

4.2.8. National policies related to uranium

There is no official report in any Red Book of official Austrian policy with regard to uranium. However, it appears from media reports that permission for exploration would not be easily obtained.

The 1977 Red Book notes that, according to the mining legislation (Bergesetz 1975), uranium and thorium deposits are State property. Exploration and exploitation are only possible under Government contract. More details are given in the IUREP report [2.3]. Permissions for exploration/exploitation can be granted to applicants against a non-fixed amount of payment to the Government. Contracts have to be negotiated with the Federal Mining Authority (Bergbehörde) and with local mining authorities (Berghauptmannschaft). In the application, the usual requirements need to be listed. If discoveries are made, the local mining authority would have to apply for mining concessions (Gewinnungsfelder).

References to Section 4.2

[2.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Austria, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html

[2.2] KUHN, C., Introduction to the Geological Zones of Austria, http://www.8ung.at/geologie/eeinfueh.htm (2006)

[2.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission, Summary Report: Austria, OECD, Paris (1981) 25 pp.

[2.4] PETRASCHEK, W.E., ERKAN, E., NEUWIRTH, K., "Permo-Triassic uranium ore in the Austrian Alps — Paleogeographic control as a guide for prospecting", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 291–298.

[2.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[2.6] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

4.3. BELGIUM

4.3.1. Geography

Belgium can be geographically divided into three main regions: (i) the coastal plain of the NW, (ii) the central plateau area and (iii) the rolling topography of the Ardennes Mountains in the south and SE, which border the mountains of Hohes Venn and Schnee Eifel in the east.

Regionally, the country consists of the landscapes of Flanders and Kempen in the NW and north, Brabant in the central part and Wallonia in the south. The principal rivers are the Maas/Meuse and Schelde/Escaut. Typical features of the coastal plain are polders, similar to those in the Netherlands, where land has been reclaimed from the sea by a system of canals and protected by dykes. The central plateau region is characterized by a nearly flat topography comprising low hills and river valleys. The soil is fertile. The climate is influenced by the proximity of the English Channel, providing moderate temperatures, mild winters and mild summers. In the Ardennes, snow may fall throughout the winter [3.1].

4.3.2. Geology

The oldest rocks are of Cambrian age (Fig. 4.2) and are exposed in the Ardennes Mountains as dark, pyrite-bearing shale, schist and quartzite, followed by a thin zone of Ordovician–Silurian sedimentary rocks. Sedimentation into the Palaeozoic basin continued, interrupted by the so-called Ardennes Phase (a discordance of Upper Silurian–Lower Devonian age), through Devonian, Carboniferous and Permian periods. The Devonian is characterized by the deposition of limestone and dolomite.

During the Carboniferous, sedimentation became shallow marine to lacustrine, with deposition of bituminous coal deposits. Coal mining started in the early 19th century and ceased in the late 20th century. The Carboniferous strata continue towards Brabant in the central part. To the north, in the central region and the coastal plain, the rocks become progressively younger. Large areas are overlain by Upper Mesozoic, mainly Cretaceous, Tertiary and Quaternary sedimentary rocks [3.2].

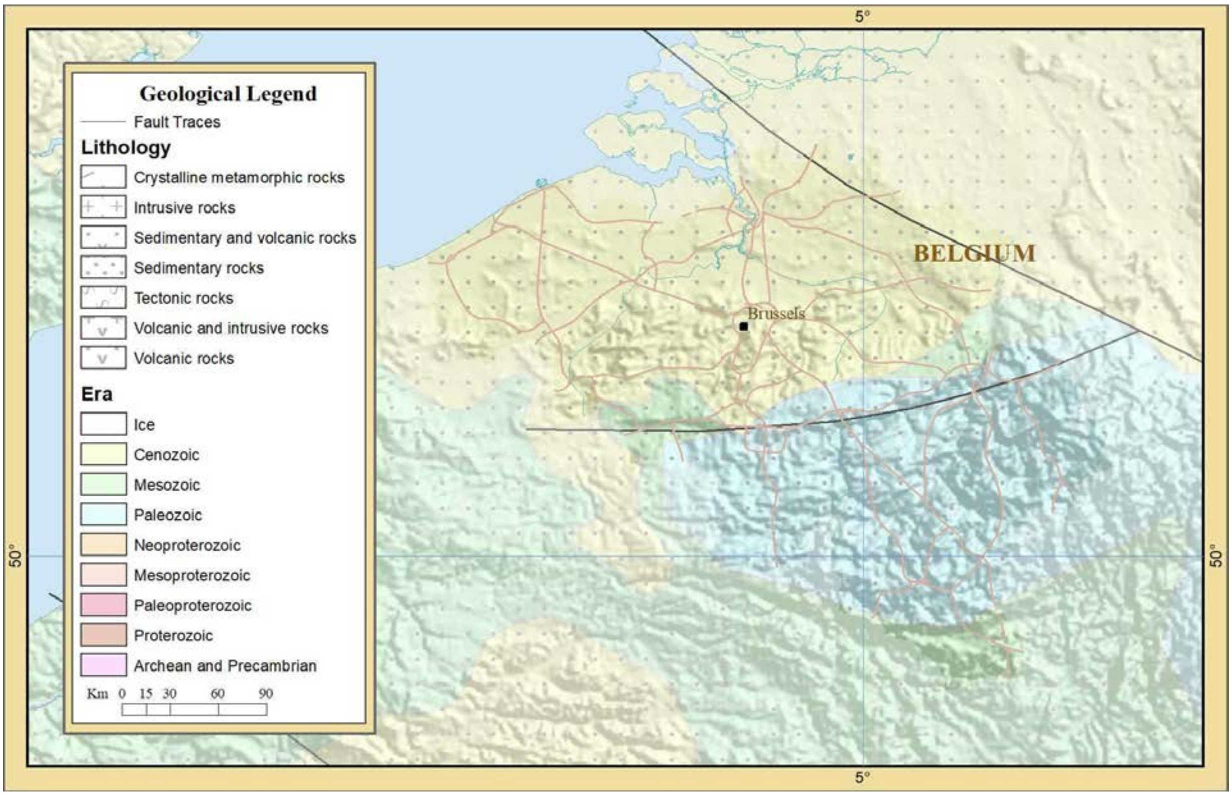


FIG. 4.2. Regional geological setting of Belgium. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.3.3. Uranium exploration

Prospecting for uranium started in 1977, prior to which a few uranium occurrences and showings had been reported in black shale of Carboniferous age (Upper Viséan–Namurian), in Middle Cambrian black schist of the Stavelot Mountains (Ardennes–Hohes Venn) and others possibly related to acidic intrusions, and in breccias of the Upper Devonian–Lower Carboniferous (Visé Mountains in the northern part of Hohes Venn).

Between 1977 and 1979, occurrences in the Visé Mountains and in phosphate in Cretaceous sedimentary rocks of the Mons Basin, SW of Brussels, were studied. Between 1979 and 1981, exploration was funded jointly by the European Commission and the Belgian Ministry of Economic Affairs. Reconnaissance surveys of Palaeozoic formations were carried out by the Universities of Mons, Louvain and Brussels and coordinated by the Geological Survey of Belgium. Approximately 11 000 km² were covered by car-borne gamma, geochemical and hydrogeochemical surveys. The results were published in 1983.

Anomalies in the Carboniferous rocks of Viséan–Namurian and Lower Devonian were studied at Mons in 1985–1988. Shales recorded up to 80 ppm U. Exploration funded by the Underground Resources Service of the Wallonia region resulted in the finding of point occurrences of up to 1% U (eq.) in schistose sandstone of Lower Devonian age, and in exposed formations in the Ardennes Mountains. Anomalies detected by car-borne surveys were studied between 1979 and 1982 by geochemical and geophysical methods, supported by trenching and drilling, core sampling and drill hole logging. This work was financed by the European Commission and the Geological Survey. No economic concentrations of uranium were found throughout the exploration programme. Surface drilling was conducted only in 1987, with 820 m drilled in 26 holes. No drilling was done in later years. Exploration expenses totalled US $2 487 000.

Currently, no exploration or mining activities are being undertaken [3.3, 3.4]. Belgium last provided a country report for the 2007 Red Book.

4.3.4. Uranium resources

Belgium officially reports no identified or undiscovered resources. Occurrences of over 100 ppm U have resources of less than 1 tU. The phosphate deposits of the Mons Basin have been evaluated for their unconventional uranium resources which are estimated to total ~40 000 tU. In areas suitable for phosphate mining, resources of ~2000 tU have been estimated. However, the phosphate content is below 10% P_2O_5 and the uranium is below 100 ppm U (eq.) [3.4].

The UDEPO database lists the most significant deposit for Belgium as Mons Basin.

4.3.5. Potential for new discoveries

In view of previous exploration and geological considerations, the potential for new discoveries appears to be very low. The IUREP report lists Belgium as a country with limited potential for the occurrence of uranium deposits [3.2]. Consequently, further uranium exploration is not envisaged.

4.3.6. Uranium production

Belgium has not produced uranium from domestic resources. However, in 1980–1998, Prayon-Rupel recovered uranium from phosphate imported from Morocco. Total production amounted to 682 tU (Fig. 4.3) [3.5].

Prayon-Rupel's uranium recovery production facility has since been decontaminated and dismantled. There are no plans for new production centres.

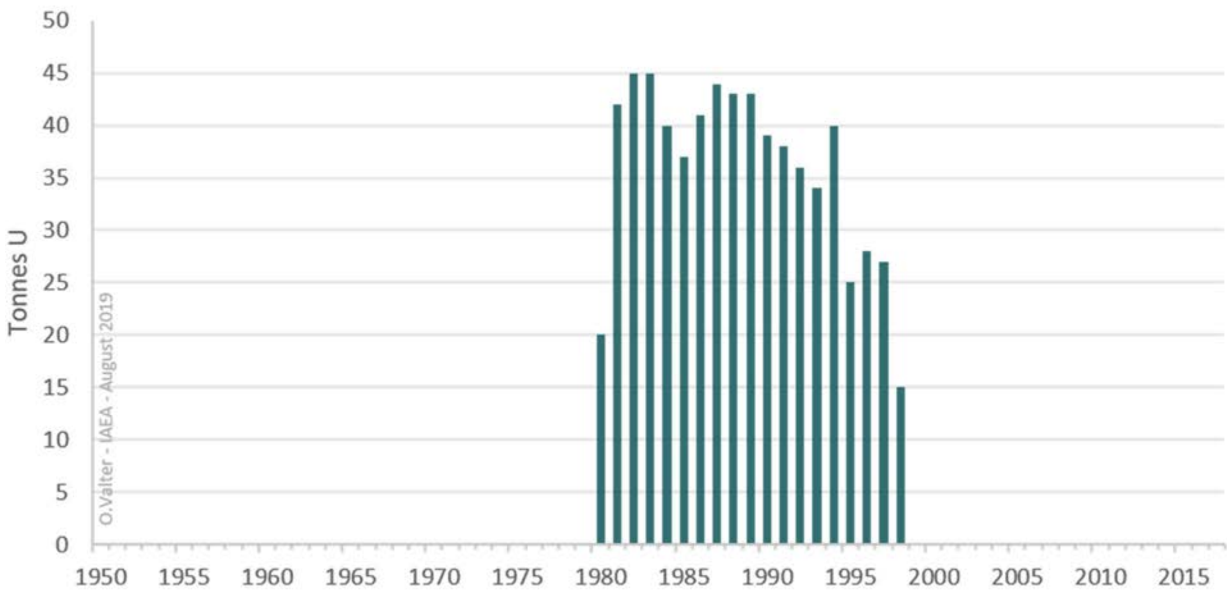


FIG. 4.3. Historical uranium production in Belgium.

4.3.7. Employment in the uranium industry

During the construction (1984) of Prayon-Rupel's uranium extraction facility at the phosphate treatment plant, 30 people were employed. From 1985 to 1996, the uranium extraction facility employed five employees, and from 1997 to 1999, six employees. During decommissioning of the plant, employment was reduced to five in 2000 and to four employees in the final two years, 2001 and 2002.

References to Section 4.3

[3.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Belgium, Washington, DC (2010), https://www.cia.gov/library/publications/the-world-factbook/index.html

[3.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[3.3] OECD-NEA/IAEA: Uranium Resources, Production and Demand (Ed. 1983–2005).

[3.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[3.5] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

4.4. DENMARK

4.4.1. Geography

Denmark consists of the peninsula of Jutland and a number of islands and shares a land border with Germany. The western coast borders the North Sea; the eastern coast the Baltic Sea.

The Faroe Islands and Greenland also belong to Denmark, although these are autonomous territories. Greenland was granted self-government by Denmark in 1979.

Greenland has an area of 2 166 086 km², of which only the coastal region, totalling ~410 449 km², is free of inland ice. The population of Greenland is just over 57 000, consisting mainly of Inuits [4.1].

Greenland, the largest island in the world (2 166 086 km^2), is situated between the Arctic Ocean and the North Atlantic Ocean. A narrow zone along the coast is rocky and mountainous. The highest point (Mount Gunnbjøm) has an elevation of 3733 m. The climate is arctic to sub-arctic, with short cool summers and cold winters.

The population is confined to small settlements. Vegetation is very sparse. There is no appreciable land use owing to a lack of arable land.

The economy depends on fishing and support from Denmark [4.2, 4.3].

4.4.2. Geology

At least 80% of Greenland's total area of nearly 2.2 million km² is ice covered (Fig. 4.4), with only ~410 000 km² that is ice-free. The geology of this area is dominated by Precambrian strata dating to ~4000 Ma. These strata consist of Archaean and Lower Proterozoic rocks which underwent early phases of tectonism. A stabilization phase occurred around 1600 Ma as part of the formation of the Laurentian Shield. Later geological events mainly occurred along the margins of the Shield area. Sedimentary basins were formed and infilled throughout the Proterozoic–Phanerozoic. During the Palaeozoic period, parts were affected by pre-Caledonian and Caledonian orogenic events. Basins dating from the Upper Palaeozoic and Mesozoic were filled by sediments and are related to continental break-up and rifting. The opening of the North Atlantic by seafloor spreading in the Early Tertiary resulted in the extrusion of plateau basalts.

During the various orogenic events, magmatic activity took place, resulting in the emplacement of granitic and alkaline intrusions. Important phases of intrusion emplacement occurred throughout the periods 1850–1800 Ma and 1180–1150 Ma.

Mineral resources that are found include zinc, lead, iron ore, molybdenum, gold, platinum, uranium and thorium. Coal deposits also exist. Mining for lead and zinc was undertaken in the period 1973–1990 and plans are pending as regards reopening the mine [4.3, 4.4].

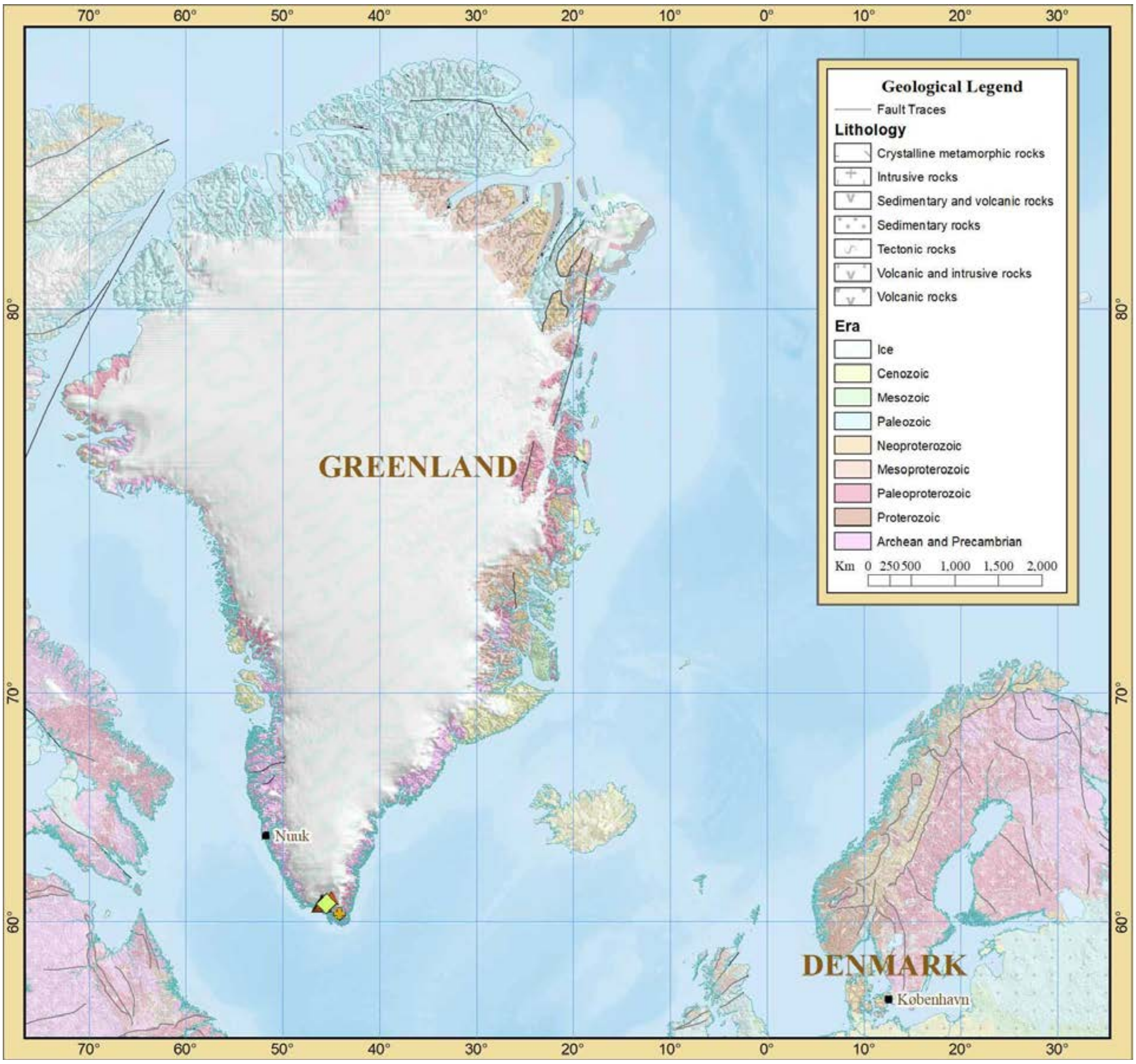


FIG. 4.4. Regional geological setting of Denmark and Greenland showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.4.3. Uranium exploration

Exploration for radioactive minerals has been carried out in southern, western and eastern Greenland. During the exploration phase of 1955–1984, the uranium–thorium Kvanefjeld deposit was the subject of detailed investigation. This deposit is situated in alkaline intrusive rocks.
In 1979–1986, further work was carried out in southern Greenland. Uranium mineralization, as pyrochlore, was found in fractures and veins in alkaline rocks and in hydrothermally altered

metasedimentary rocks. The aggregate resources hosted in these types of occurrence are believed to total ~100 000 tU in the speculative resource category [4.5]. Surface drilling data are summarized as follows: pre-1972: 5000 m in 35 drill holes; 1978: 5000 m in 27 drill holes); 2007: 10 000 m; 2008: 15 000 m. No drilling was recorded in other years.

4.4.3.1. Exploration expenditures

Pre-1998 expenses are reported in the 2005 Red Book as totalling US $4 450 000 (Fig. 4.5) including 20 000 metres of drilling [4.6].

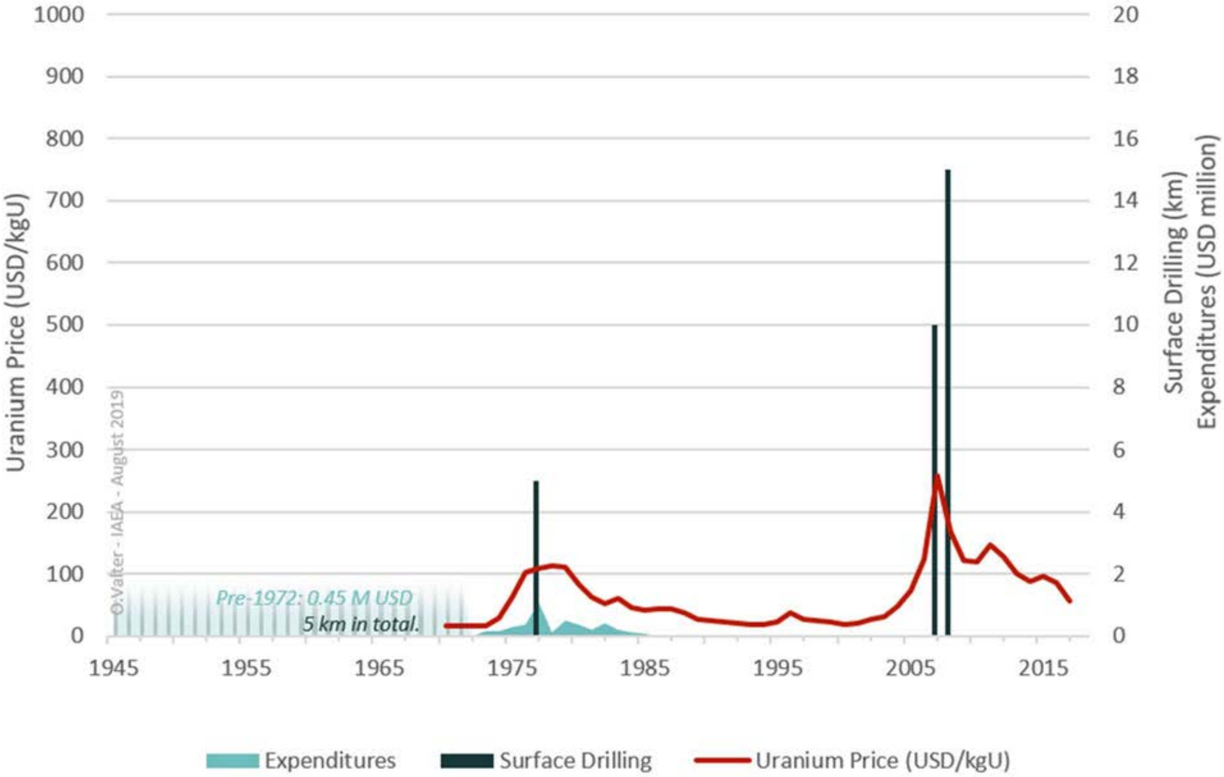


FIG. 4.5. Domestic uranium exploration data for Denmark and Greenland. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

Exploration and development expenses for 2007 and 2008 are reported as €10 million and €15 million, respectively. Expenses for 2006 and 2009 are not available.The total given in Fig 4.5 is lower than that reported to the 2005 Red Book of US $4 350 000 [4.6].

Since 1986, no exploration expenses have been reported in the Red Book. Drilling has been carried out to a limited extent; ~5000 m were drilled prior to 1972 and an additional 5000 m drilled in 1978 to delineate the extent of the Kvanefjeld deposit. In 1979–1980, an adit was driven at Kvanefjeld to excavate ~4000 t of ore for metallurgical test work at the Risø Laboratory.

Currently, Greenland Minerals and Energy Ltd, an Australian based company, is conducting exploration activities in the Kvanefjeld area [4.8]. The 2007 drilling campaign and geological work programme formed the basis for a first JORC compliant resource estimate of the Kvanefjeld deposit. The resource was updated in August 2008 as more assay data from the 2007 drilling campaign became available. The resource was estimated to contain 2.6 million t of rare earth oxides, 2.2 million t of NaF and 85 650 tU. In 2008, the company planned to drill a minimum of 15 000 m of core. The bulk of the campaign focused on the Kvanefjeld deposit. However, numerous other multi-element targets hosted within the Illimausaq intrusion were also scheduled to be drill tested [4.7, 4.8].

In 2009, a budget of A $3–4 (US $2.3–3) million was allocated for ongoing exploration. A budget of A $5 million (US $3.8 million) was allocated to metallurgical test work and other aspects of the pre-feasibility study through 2008 and 2009.

In 2012, two new mineralized zones were recognized in the lujavrite formation of the Ilimaussaq Complex which had resources of 62 370 tU at a grade of 258 ppm U for Zone 2 (now known as Sorensen) with 1.10% REE and 0.26% Zn and 24 250 tU at a grade of 254 ppm U for Zone 3 with 1.16% REE. The project overall resource inventory stands at 228 240 tU, 10.33 Mt REE and 2.25 Mt Zn. A feasibility study was completed with planned production, starting in 2016–2017, of 1100 tU/year with a projected mine life of at least 30 years. [4.9]

The Kvanefjeld project will consist of a mine, a concentrator and refinery. The concentrator will produce a mineral concentrate containing 20-25% rare earth oxide, a zinc concentrate and fluorspar. The refinery circuit will produce high-purity intermediate rare earth products, and uranium as a by-product. Rare earth products are forecast to generate over 80% of the project's revenue, with uranium, zinc and fluorspar by-products contributing to the balance [4.10].

In November 2012 the Greenland government voted unanimously to support the project, including uranium, and in October 2013 it repealed the long-standing policy banning uranium development [4.10].

In 2016, Shenghe Resources Holding Co Ltd, a Chinese company, became the largest shareholder and strategic partner of Greenland Mineral.

4.4.3.2. Potentially-favourable uranium-bearing areas

During reconnaissance surveys, ice-free areas have been investigated for their uranium potential. Focus has been placed on magmatic rocks, mainly those of acidic and/or alkaline composition. Uranium mineralization was found at Kvanefjeld in the nepheline syenite of the Illimausaq intrusion in south-western Greenland. Illimausaq covers an area of ~150 km² and includes a complex of alkaline rocks (fenitization). An early augite syenite intrusion is followed by highly alkaline nepheline syenite (agpaitic rocks) with sodic pyroxenes and amphiboles. These host the accessory silicates (eudialyte and rinkite) which have elevated concentrations of fluorine, chlorine, rare earth elements, niobium, beryllium, lithium, zirconium, zinc, tin, uranium and thorium resulting from magmatic differentiation and later crystallization. The final intrusive phase may be enriched by up to 0.5% Th and up to 0.1% U. Most of the radioactive minerals are of complex composition, e.g., silicates and phosphates with rare earth elements, niobium, tantalum, zirconium and iron. Steenstrupine, a complex sodium–cerium phosphosilicate is the most important carrier of uranium (0.2–1.5% U) and thorium (0.2–7.4% Th). The thorium silicate thorite (3.1% U, 40.5% Th) occurs only in the late stage differentiate lujavrite. In other rock types, eudialyte, a sodium–calcium–iron silicate containing zirconium, is the dominant uranium- and thorium-bearing mineral. The uranium-bearing minerals are refractory, thus extraction of uranium from the ore is difficult [4.3].

4.4.4. Uranium resources

In 2008, Denmark reported a new JORC compliant estimation from Greenland Minerals and Energy Lt based on data gathered throughout exploration aimed at other minerals present in the Kvanefjeld deposit. Following an exploration campaign, Greenland Minerals and Energy reported ~85 650 tU of re-assessed hitherto known inferred resources at the Kvanefjeld deposit in mid-2008. No production cost is included with this resource estimate. These outcomes were put in the high cost category (<US $260/kgU), as the

ore has a complicated mineralogy and treatment is anticipated to be impacted accordingly. Because of these reasons, 65% was used as the recoverability ratio. Resources assigned to lower cost classes are zero.

According to the results of the 2008 field season, which were published in June 2009, the JORC compliant resources were updated as follows: 4.91 million t rare earth oxides, 101 760 tU at grade of 0.022% U, 0.99 million t Zn and 2.21 million t NaF. Of the resources, 79% are indicated and 21% inferred [4.11].

In 2018, the project overall resource inventory stood at 228 240 tU, 10.33 Mt REE and 2.25 Mt Zn.

As of 1 January 2017, in situ reasonably assured resources and inferred resources reported by Denmark in the < US$ 260/kgU cost category amount to 102 820 tU and 125 143 tU respectively [4.12].

The UDEPO database lists the most significant deposits for Denmark as Kvanefjeld, Sorensen, Illimaussaq Zone 3, Motzfeldt, Puissagtaq, Igdlorssuit Area, Illorsuit.

4.4.5. Potential for new discoveries

During IUREP Phase 1, the potential of other areas in Greenland was reported based on the initial work carried out [4.4].

At Randboldal in east Greenland, the area north of Kejser Franz Joseph Fjord was found to have a mineralized zone hosted in kaolinized rhyolites and pyroclastic rocks of Devonian age. Uranium associated with hydrocarbons occurs in joints, veinlets and along grain boundaries, as well as in isolated grains. In these features, the uranium content may attain levels of up to 10% whereas the mineralized rock contains 0.01–0.5% U.

At Arkosedal, south of Kong Oscars Fjord, uranium mineralization was found in a hydrothermally altered breccia and associated with fluorine in fault zones between Caledonian complexes and Permian arkose.

Several other places in east Greenland also host uranium mineralization, which is mainly associated with acid magmatic rocks and surrounding sedimentary rocks [4.4].

4.4.6. National policies relating to uranium

In November 2008, a majority in Parliament agreed to support the extraction of uranium as a by-product from mines where other minerals are the primary target. Siumut, Atassut and the Democrats all support easing the country’s 20-year-old zero tolerance policy regarding uranium mining. Exploration and exploitation of radioactive elements is banned in Greenland. The Inuit Ataqatigiit and Kattusseqatigiit political parties are both opposed to the proposal according to an edition of the Sermitsiaq newspaper dated 27 November 2008. Also in November 2008, the citizens of Greenland elected resolutely in backing of a proposal to assume greater self-rule from Denmark.

On 24 october 2013, the Greenland parliament lifted a decades-long moratorium on mining radioactive elements, which has opened the way for potential future exploitation of uranium [4.13].

4.4.7. Comments

Denmark has no uranium production and no nuclear power generation. It therefore has no requirements for uranium.

References to Section 4.4

[4.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Denmark, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html

[4.2] ABOUT.COM, Geography and Map of Greenland, http://geography.about.com

[4.3] GEOLOGICAL SURVEY OF DENMARK AND GREENLAND, Geological Map of Greenland 1:2500 000, http://www.geus.dk/geuspage-uk.htm
[4.4] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.
[4.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[4.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).
[4.7] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.
[4.8] GREENLAND MINERALS AND ENERGY LTD, http://www.ggg.gl/
[4.9] INTERNATIONAL ATOMIC ENERGY AGENCY, Geological Classification of Uranium Deposits and Description of Selected Examples, TECDOC 1842, Vienna (2018)
[4.10] GREENLAND MINERALS Web Site 2018. www.ggg.gl/
[4.11] URANIUM LETTER INTERNATIONAL, Greenland Minerals and Energy Ltd, Special Situation-August 2009 Update, http://www.goldletterint.com/documents/pdf/GREENLAND_SPU_Aug09Update.pdf (August 2009).
[4.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).
[4.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2016: Resources, Production and Demand, OECD, Paris (2016).

4.5. FINLAND

4.5.1. Geography

Roughly 35% of Finland is situated north of the Arctic Circle. The landscape is predominantly flat, reflecting a topography formed by glacial processes. Finland's highest peak attains 821 m and is situated in the north, near the boundary with Sweden. The glacial landforms include moraines, eskers, drumlins and numerous lakes, which account for ~10% of the territory and which are concentrated in southern Finland. However, the largest lake (Inari) is situated in the north. About 70% of the country is covered by forest.

The climate is influenced by the high latitude of the country. Winter is the longest season. Generally, in the south, the climate is moderated by the Baltic Sea, particularly along the coast. The yearly average temperature in the south is about 5–7°C. This area receives yearly precipitation of 600–700 mm. Snow cover lasts 3–4 months in the south and ~7 months in the north.

The country is divided into four principal regions: (i) the islands, (ii) the coastal region forming the agricultural plain, (iii) the interior region of lakes and forests, and (iv) northern Finland, above the Arctic Circle, which is covered by artic vegetation.

Most of the population lives in the south [5.1].

4.5.2. Geology

Finland is part of the Fennoscandian Shield (Fig. 4.6), which was formed in the Late Archaean and Early Proterozoic. The oldest rocks have an age of 4000–3000 Ma. An Archaean block, the Karelian Craton, forms the nucleus around which Early Proterozoic mobile belts are situated. The Karelian Craton consists of greenstone belts with magmatic, mostly granitic, intrusions. During the Early Proterozoic, the Karelian Craton was subject to rifting processes and mafic volcanism. Apart from the Karelian Craton, throughout the Early Proterozoic a collision with the Svecofennian Oceanic Island Arc has been inferred. These events are believed to date to roughly 2000–1000 Ma [5.2, 5.3]. The 1981 IUREP report [5.3] and the 2007 Red Book [5.4] provide further details on the geology.

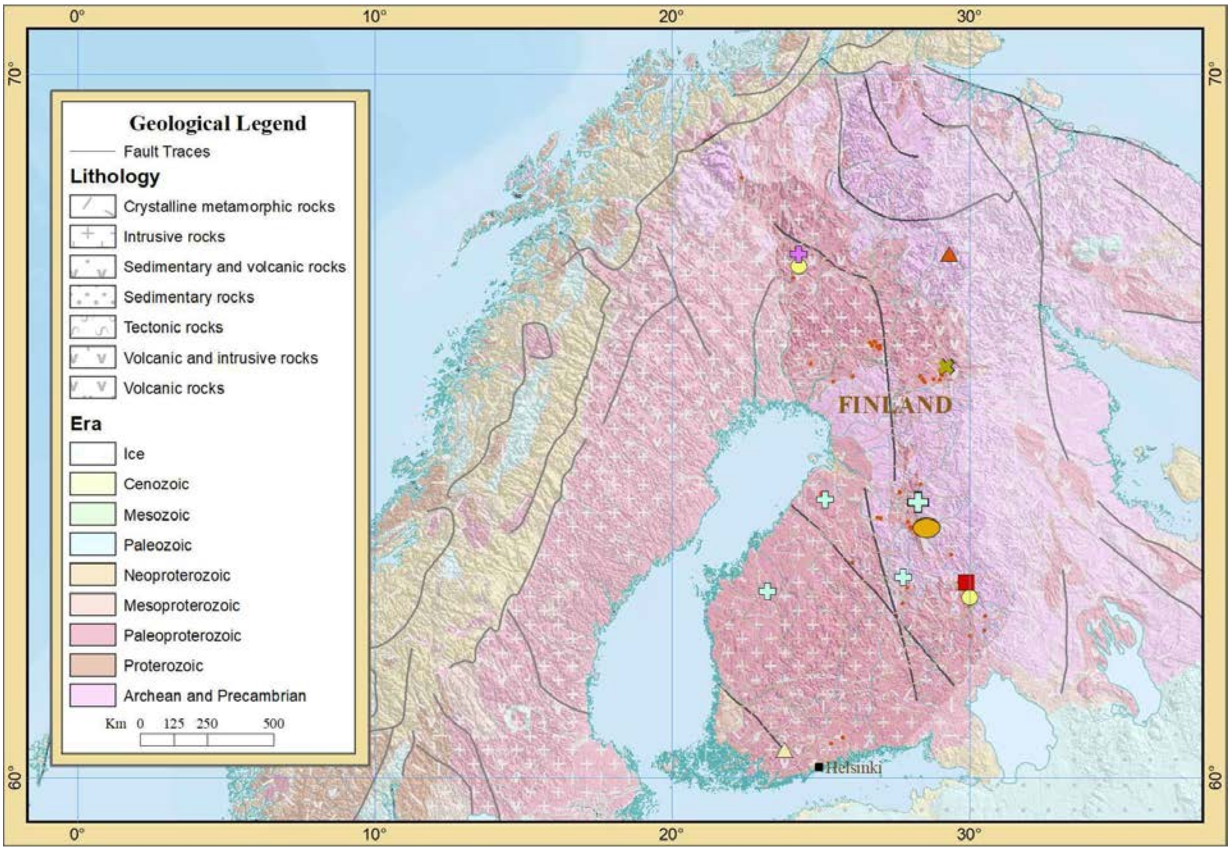


FIG. 4.6. Regional geological setting of Finland showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.5.3. Uranium exploration

4.5.3.1. Historical review

Exploration for uranium in Finland has been conducted by several organization over the period 1955–1989. From the late 1970s, the work was primarily undertaken by the Geological Survey of Finland. Regional airborne geophysical surveys and geochemical sampling programmes were conducted in the early 1970s.

The geological settings of uranium deposits and the distribution of uranium provinces are summarized as follows, with in situ resource, grade and status given in parentheses:

- (i) Kolari-Kittilä Province, west Lapland, including the Kesänkitunturi sandstone deposit (950 tU, 0.06% U, dormant) and the Pahtavuoma vein deposit (500 tU, 0.19% U, dormant) in Palaeoproterozoic quartzite and greenstone-related graphitic schists, respectively;
- (ii) Kuusamo Province, NE Finland, hosts occurrences of metasomatite uranium with Au and Co (e.g., the Juomasuo deposit) in Palaeoproterozoic quartzites and mafic volcanic rocks. In 1987, a description was given of the U–Co–Cu–Au mineralization occurring in the Early Proterozoic Kuusamo Schist Belt [5.5];
- (iii) Koli Province, eastern Finland, has a number of small sandstone-hosted deposits of epigenetic uranium (Ipatti, Martinmonttu and Ruunaniemi: 250 tU, 0.08–0.14% U; and the former Paukkajanvaara mine (reclaimed)) as well as occurrences of thorium- and uranium-bearing quartz-pebble conglomerate in Palaeoproterozoic quartzites, and has potential to host unconformity related deposits in a Palaeoproterozoic regolith;
- (iv) Uusimaa Province, southern Finland, hosts occurrences of uranium in Palaeoproterozoic granitic migmatites, e.g., the Palmottu deposit (1083 tU, 0.106% U, exploration stage) and in the Askola area.

The geological settings also comprise:

(i) Uraniferous phosphorites related with sedimentary carbonates of Palaeoproterozoic series, e.g., the Nuottijärvi deposit (1059 tU, 0.063% U) and the Vihanti-U (Lampinsaari) deposit (735 tU, 0.03% U);

(ii) Uraniferous carbonate veins and uranium mineralization in Palaeoproterozoic albite diabase dykes and albitite, mainly in northern Finland;

(iii) Thorium- and uranium-bearing veins and dykes of Palaeoproterozoic pegmatitic granites;

(iv) Surficial type concentrations of 'young' uranium in recently deposited peat.

Previously, 2900 tU of reasonably assured resources in the >US $130/kgU cost category were reported in several deposits. For various technical and environmental reasons, several of these deposits are not exploitable. Potential by-product uranium has been documented earlier in association with the low grade Ni–Cu–Zn deposit at Talvivaara in central Finland (0.001–0.004% U, development stage), which is hosted by Palaeoproterozoic black shales, as well as in pyrochlore at the Palaeozoic Sokli carbonatite (2500 tU-0.01% U, dormant) in eastern Lapland [5.4, 5.6]. Drilling and expenses are detailed in Fig. 4.7. Drilling and expenses up to 1979 totalled 37.27 km (309 drill holes) and US $9.51 million, respectively. The total to 2014 was USD $126.325 million including 69 705 metres of drilling.

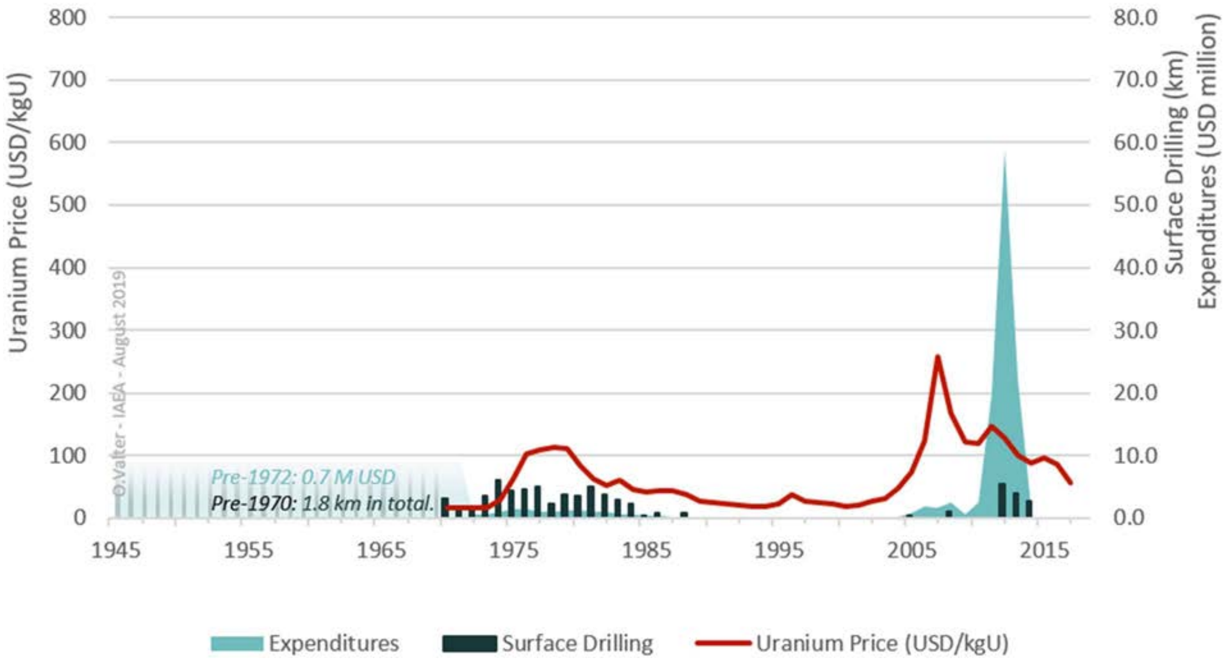


FIG. 4.7. Domestic uranium exploration data for Finland. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

4.5.3.2. Recent and ongoing uranium exploration activities

Exploration by international companies was at a low level in 2005–2006, and those that were active were mainly involved in claim reservation, claim areas and reconnaissance studies. One company carried out trenching and drilling in 2005 on a finding made in northern Finland. During 2005–2006, nearly all of the occurrences of uranium recorded in the deposits database of the Geological Survey of Finland had been catalogued by the firms as reservations for claim. Applications for claims have been submitted to MTI (authority responsible for mining and exploration) with respect to six areas. By the end of 2006, two applications had been rejected and one claim granted by MTI.

Active companies included Agricola Resources, AREVA, Karelian Resource Services, Mawson Resources and Namura Finland (Cooper Minerals). MTI rejected in January 2007 an additional four applications for claims because they did not satisfy the conditions stipulated by law. As of January 2008, a number of other claim applications were pending, including three filed in 2006, 13 filed in 2007 and two in 2008. MTI approved another claim with requirements attached. Five applications for claim were submitted by three firms in March 2006 and, because reservations for claim were expiring, yet possibly more were to be submitted throughout 2007 [5.4].

In January 2008, MTI merged with the Ministry of Labour to form the Ministry of Employment and the Economy, which is responsible for promoting the exploitation of mineral resources by safeguarding a favourable working environment for mineral exploration and mining activities.

Owing to the problems and interruptions in licensing, exploration activities in Finland have been restricted. AREVA conducted an airborne geophysical survey on its target in eastern Finland in 2007 and following the court's judgment, trenching and diamond drilling were conducted in 2008. Activities in general were expected to be reduced from 2009.

4.5.4. Uranium resources

4.5.4.1. Identified resources

Reasonably assured resources amount to 1500 tU (in situ) in the cost range US $130–260/kgU, including Palmottu (intrusive type (1100 tU)) and Pahtavuoma-U (vein deposit (500 tU)). The production method is not specified and the processing method is expected to be conventional.No inferred resources have been reported. The historical variation in reported resources in shown in Fig. 4.8 and Fig. 4.9.

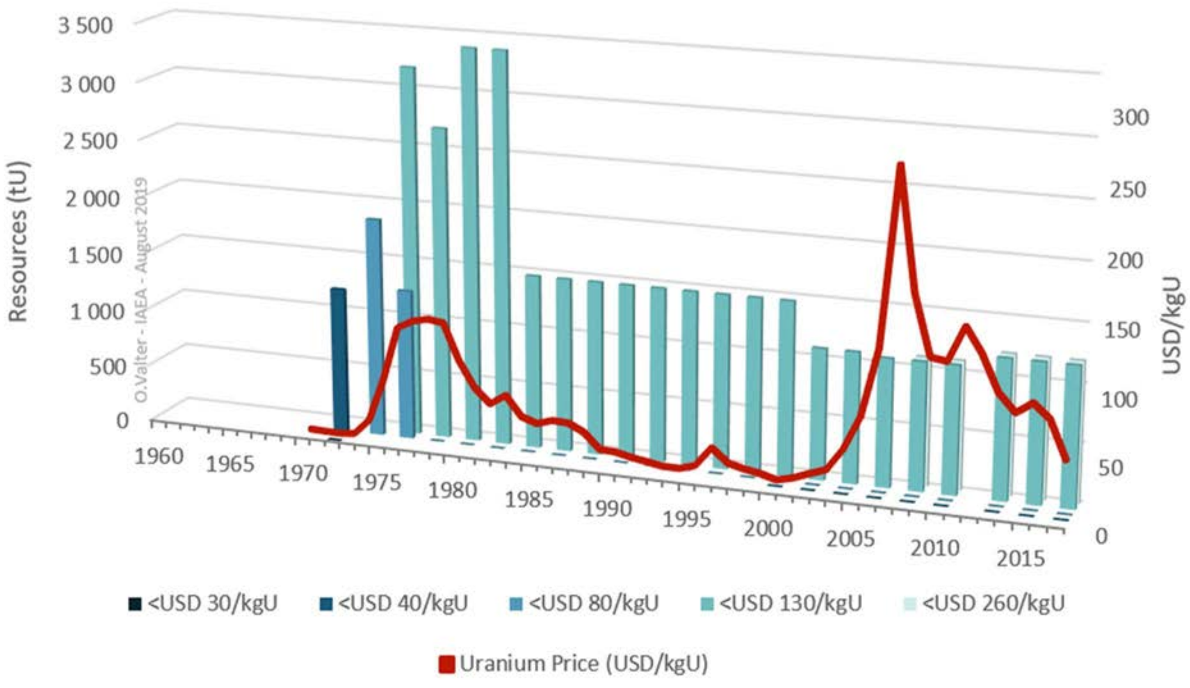


FIG. 4.8. Historical variation of reasonably assured resources within various cost categories in Finland. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

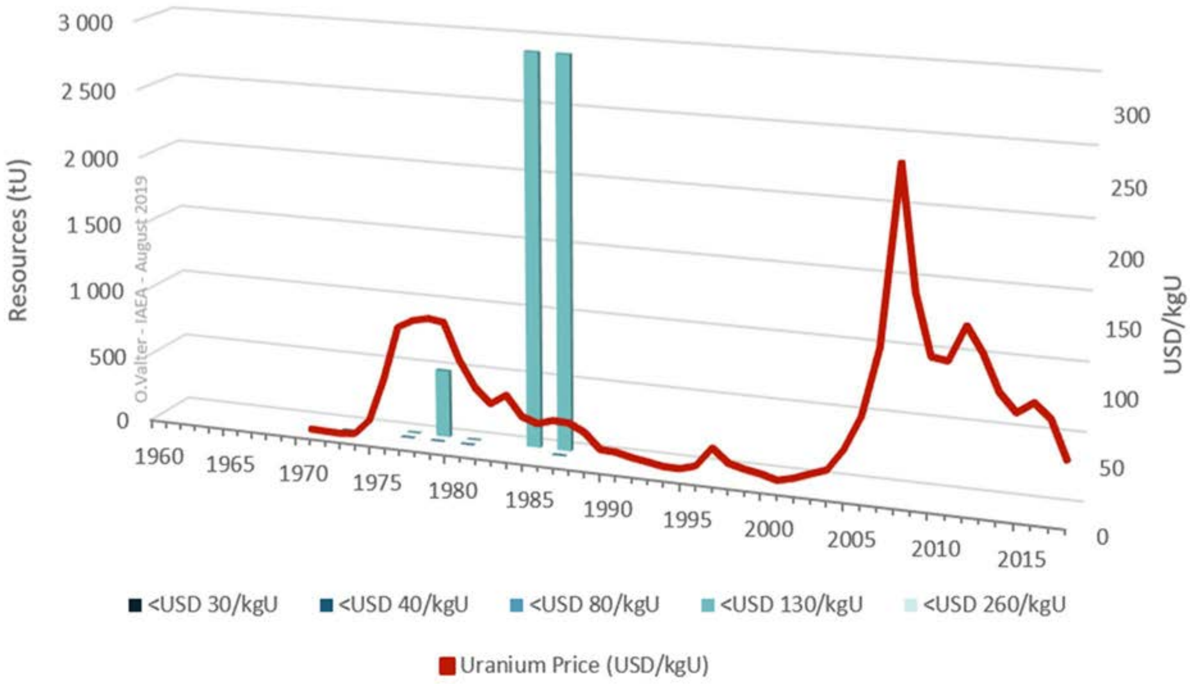


FIG. 4.9. Historical variation of recoverable inferred resources within various cost categories in Finland. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

The UDEPO database lists the most significant deposits for Finland as Kuusilampi, Kolmisoppi, Sokli.

4.5.4.2. Unconventional resources and other materials

In 1981, the IUREP report [5.2] noted that between 3000 and 9000 tU could be extracted from the Talvivaara black shales and another 2500 tU from the Sokli carbonatite as by-product resources. Roughly 340 million t of low grade polymetallic sulphide ores in the Talvivaara black shales are presently being developed for Ni, Zn, Cu and Co using bio-heap leaching. The mine was expected to start up in 2008. The black shales' uranium content is low (according to IUREP of the order of 0.001–0.004% U [5.2, 5.3]), and the mining plan does not make provision for uranium recovery.

In addition, the metamorphic phosphorite deposits of Nuottijarvi (dormant) and Vihanti-U (undergoing reclamation) are of unconventional type [5.3, 5.4].

In 2010, Talvivaara Mining Company Plc announced that it planned to recover 350 tU/yr over 46 years as a by-product of nickel and zinc production from suphidic black shales using bacterial heap leaching at Sotkamo in northeastern Finland. The company signed an agreement with the Canadian company Cameco in 2011 to build a €45 million plant for uranium recovery, using solvent extraction. Cameco would take all uranium production to 2027. In 2014, Talvivaara Sotkamo was declared bankrupt and operations stopped. In 2015, the business and assets of Talvivaara Sotkamo was purchase by the state-owned Terrafame Group Oy and assets were transferred to Terrafame Oy. In October 2017 the company applied for a permit to recover uranium as a by-product. If granted, uranium recovery could begin late 2019 [5.6].

4.5.5. Uranium production

4.5.5.1. Historical review

At Paukkajanvaara mine (pilot plant operative in 1958–1961), ~30 tU were produced from 40 000 t of ore. According to the MTI mining register statistics, historical production (Table 4.1) totalled 41 tU in 1958–1961 [5.4, 5.7]. Currently, Finland has neither production capacity nor plans to develop any.

TABLE 4.1. URANIUM PRODUCTION IN FINLAND (tU) [5.4]

Year	1958	1959	1960	1961	Total
Production	11	2	11	17	41

4.5.6. Environmental activities

The Paukkajanvaara mine area was refurbished in the 1990s. The Finnish Centre for Radiation and Nuclear Safety awarded the official document for environmental refurbishment to the landowner in 2001 [5.8, 5.9].

References to Section 4.5

[5.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Finland, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2008).

[5.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[5.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission: Finland, OECD, Paris (1981) 104 pp.

[5.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[5.5] VANHANEN, E., "Uraniferous mineralizations in the Kuusamo Schist Belt, northeastern Finland", Metallogenesis of Uranium Deposits (Proc. Tech. Mtg Vienna, 1987), IAEA, Vienna (1989) 169–186.

[5.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[5.7] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[5.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999) 88–89.

[5.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002) 205–207.

4.6. FRANCE

4.6.1. Geography

Metropolitan France (European territory) is divided into 13 regions, which in turn are sub-divided into 96 departments. France also has four overseas regions (Guadeloupe, French Guiana, Martinique and Réunion), three overseas collectives (St Pierre and Miquelon, Wallis and Futuna, and Mayotte), one unique country (New Caledonia), one overseas country (French Polynesia), one overseas territory (French Southern and Antarctic Land) and five islands in the Indian Ocean (Îles Éparses, Bassas da India, Europa, Juan de Nova, Glorioso and Tromelin).
The landscape of France is made up of three main geological regions: (i) the remains of ancient mountains making up the Hercynian massifs, (ii) the young, high fold mountains in the south and SE, and (iii) the northern and western plains.

The Paris Basin, in north-western France, includes the Beauce and Brie regions, which are important for agriculture. The elevation increases in the Ardennes and Armorican Massifs. The Aquitaine Basin (Basin of Garonne), which is situated to the SW and borders the Pyrénées, is characterized by plateau of limestone and fertile valleys. A third basin runs north–south and is formed by the valleys of the Rhône and Saône Rivers.

France is mostly flat in the northern and central parts. Towards the south, the central part adjoins the mountainous regions of the Massif Central, attaining elevations of over 1800 m in the Puy de Dome. The northern part has some hilly regions with elevations of 300–400 m.

In the west, a broad flat zone extends inland from the Atlantic coast for ~150 km, or more along the rivers. The south is characterized by the ~400 km long Pyrnees range, (up to 3400 m in elevation), forming the border with Spain and Andorra. The area to the east of the Pyrénées includes the southern part, formed by the coastal area along the Mediterranean Sea, with alternating lowlands, such as the Rhône River delta and the southern extension of the Alps. The east consists in its northern part of alternating lowlands and hilly areas, continuing into the Vosges Mountains (elevations of up to 1424 m), and further south to the Alps and the forelands of the Alps. The Alps attain elevations of 3000–4000 m in France, with a maximum of 4807 m attained at Mont Blanc.

The main rivers in France are:

(i) The Rhône, in the east, which flows north–south, and after flowing through a large delta west of Marseille, enters the Mediterranean Sea;
(ii) The Loire, in the centre, running roughly east–west, and entering the Atlantic Ocean near Nantes;
(iii) The Seine, in the north, running roughly SW–NW and, after crossing Paris, enters the English Channel near Le Havre;
(iv) The Garonne, in the south, flows roughly SE–NW and enters the Atlantic Ocean north of Bordeaux.

The climate varies, depending on geographical location. The western and northern areas are generally influenced by the Atlantic Ocean, with cool, mild winters and moderate summers. In the south, the climate is influenced by the Mediterranean, with mild winters and hot summers.

The country is very fertile and about 35% of the area is arable. Roughly 20% consists of permanent pastures and 27% of forest and woodland [6.1].

4.6.2. Geology

4.6.2.1. General

France is situated in the western part of the Moldanubian zone of the Hercynian Orogenic Belt, which runs from the Czech Republic through southern Germany and into France. From east to west, the Moldanubian comprises the Vosges Mountains, the entire Massif Central and the Vendée. The oldest rocks located in Normandie, are Precambrian (Proterozoic Cadomian domain), and were reactivated by the Caledonian and Hercynian events (Fig. 4.10). During the Hercynian, intensive metamorphism affected the older rocks and this event was followed by acid magmatism.

The Saxo-Thuringian zone is situated north of the Moldanubian and is part of the Hercynian. The Saxo-Thuringian can be traced from the Ardennes Mountains in the east, extending beneath the Paris Basin, and cropping out in the west in the Massif Armoricain of Brittany. Sedimentary basins of Upper Carboniferous–Permian age are filled with the molasse of the Hercynian Mountains. The basins are developed either adjacent to the Hercynian, for example, the Hérault Basin, or as intramontane basins. Sedimentation continued throughout the Mesozoic period, filling large depressions in the older basement, or as the result of marine transgressions. Examples are the Paris Basin, which hosts Cretaceous sedimentary rocks, and the Aquitaine Basin, which is filled by Tertiary sediments. Another Tertiary age example in the Moldanubian is the St. Pierre du Cantal Basin [6.2].

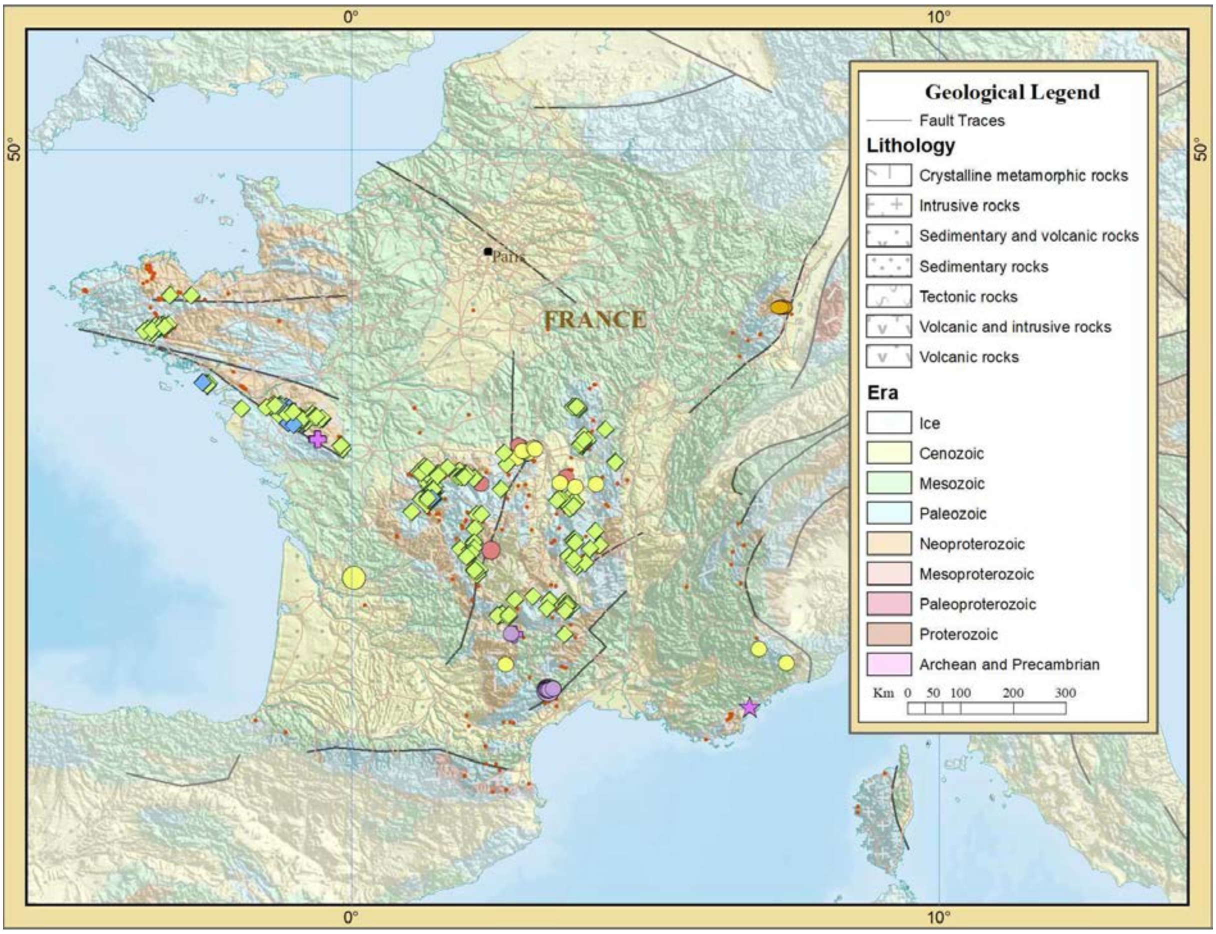


FIG. 4.10. Regional geological setting of France showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Pyrénées and the Alps formed during the Mesozoic, are two prominent features in France.The Pyrénées correspond to a 430-kilometre-long, east–west, intracontinental mountain chain that divide France and Spain. The belt has a long polycyclic geological evolution starting during Precambrian times. The present configuration of the chain is due to the collision between the microcontinent Iberia and the southwestern part of the European Plate. The two continents approached each other since the the Upper Cretaceous 100 million years ago and collided during Eocene/Oligocene, 55 to 25 million years ago. Intense erosion and isostatic readjustments affected the chain. A cross-section through the chain indicate an asymmetric flower-like structure with steeper dips towards France. The Pyrénées are the result of compressional forces and important sinistral shearing.

The French Alps are the southern part of an extensive Cenozoic orogenic belt called the Alpide belt, that stretches through southern Europe and Asia from the Atlantic to the Himalayas. The belt formed during the Alpine orogeny and the Alps arose as a result of the collision between the African and Eurasian plates. The Alpine Tethys, which was located between these two continents progressively disappeared. As a result, the thick sediments of the Alpine Tethys basin and its Mesozoic and early Cenozoic formations were pushed against the stable Eurasian continent by the northward-moving African continent during the Oligocene and Miocene. Great recumbent folds or nappes were pushed northward sliding on top of each other to form very large thrust faults. Precambrian and Paleozoic crystalline basement rocks, which are exposed in the higher central regions, are the rocks forming the Mont Blanc.

More specifically, deposits of economic value occur in three groups:

(i) The Saxo-Thuringian zone of the Variscan Orogeny, mainly in schists at the periphery of granitic areas (peri-granitic type);
(ii) The Moldanubian zone of the Variscan Orogeny in granitoids (intra-granitic) or in metamorphic rocks at the periphery of granites;
(iii) The Mesozoic and Cenozoic sedimentary basins of Cantal, Hérault and Gironde.

Examples of group (i) include deposits in the southern part of the Vendée (La Prée). Examples of group (ii) are: deposits in Brittany (Bonote), Vendée (Commanderie), and Massif Central (Margnac). Examples of group (iii) are: Mas Lavayre (Herault), St. Pierre du Cantal (Cantal), Cerilly (Allier) and Coutras (Gironde).

In the Moldanubian of the Massif Central and in the Vendée, uranium deposits occur in veins associated with leucogranites. In the Massif Central, in the Limousin deposits, uranium veins occur primarily within two-mica leucogranites, whereas in the Vendée, uranium mineralization occurs in the boundary of leucogranites rather than in the surrounding metamorphics. The granites range in age from about 320–300 Ma, whereas the uranium is associated with processes dating from about 280 Ma [6.3–6.5].

The vein systems are complex and vary drastically in size. Uranium mineralization is either associated with the intersections of tectonic trends (the most common type), or with fractures within kersantite dykes and at the leucogranite–metamorphic country rocks contact. The mineralized zones are mostly linear in their morphology. Laterally, the zones can extend to over several hundred metres and have thicknesses ranging from less than 1 m up to 15 m. Stockwork mineralization is also often observed.

Pitchblende is the main mineral of uranium. Gangue minerals comprise sulphides, haematite, quartz, calcite, fluorite and occasional baryte occur.

A typical feature associated with uranium enrichment in granites is episyenitization. This results from leaching of the leucogranites by alkaline solutions and involves the removal of silica (quartz) and the formation of potassium minerals, i.e., potash feldspar. Studies of fluid inclusions related to this process indicate the mineralizing fluids were rich in CO_2 and that mineralization took place at temperatures of ~350°C and at pressures of 700–800 bar [6.3].

The continental sedimentation of Permian age is favourable for uranium accumulation. In the Lodève Basin, Hérault, in southern France, deposition started in the lower part (Autunian), which was swampy and rich in plants, and are now represented as bituminous shales. In the lower section, grey sandstones are overlain by carbonates, followed by grey and red sandstones, shales, carbonates and acid pyroclastics and, finally, mostly red sediments [6.4,-6.7].

The overlying Saxonian comprises a 1000 m thick red-bed sequence. Uranium mineralization is less common and occurs only in reducing zones, which are related to organic matter occurring in the horizons with the finest grain size (pelite), and possibly in association with ankerite, low temperature albite, chlorite and sulphides. Uranium is usually associated with organic matter and mineralization occurs in lenses or rolls in sands or in sequences containing siltstone/claystone that are also rich in organic matter. At Lodève, fault controlled mineralization is also observed. Pitchblende and coffinite are the main uranium minerals. In addition, uranium exists as microscopic disseminations in carbonaceous matter.

Several deposits are located within lower Tertiary sediments such as Saint Pierre du Cantal and Coutras. For Saint Pierre, the mineralization is contained in a small basin of fossil-wood Oligocene sand embedded by faults in the granitic basement. The Coutras deposit, in the north of the Aquitaine Basin, is contained in Eocene organic matter-rich clayey sand and clay between the surface and a depth of 100m. Geological resources are in the order of 20 000 t U at a grade of 0.1%.

4.6.3. Uranium exploration

4.6.3.1. Historical review

<u>Domestic exploration</u>

Uranium exploration started in 1946 around known uranium deposits and at several minor occurrences found during radium exploration. The total expenditure was USD $907 741 000 including 12 982 674 metres of drilling (Fig. 4.11). The early work consisted of geological mapping and radiometry (airborne, car-borne and ground survey) and led, in 1948, to the finding of the small but very rich Henriette deposit (in the Massif Central). Following the discovery of numerous deposits, the area became a major production centre known as La Crouzille. By 1955, deposits had been identified in Hercynian granites at Limousin, Forez, Vendée and Morvan.

During the 1950s and 1960s, exploration was mainly conducted in the vicinity of known deposits, as well as in areas with similar geological settings. Subsequently, work was broadened to terrigeneous formations derived from eroded granite mountains and to sedimentary formations in intra-granitic basins. These are mostly situated south and north of the Massif Central. Basins of Permian age were also of interest and this exploration led to the finding of uranium mineralization in the Hérault Basin.

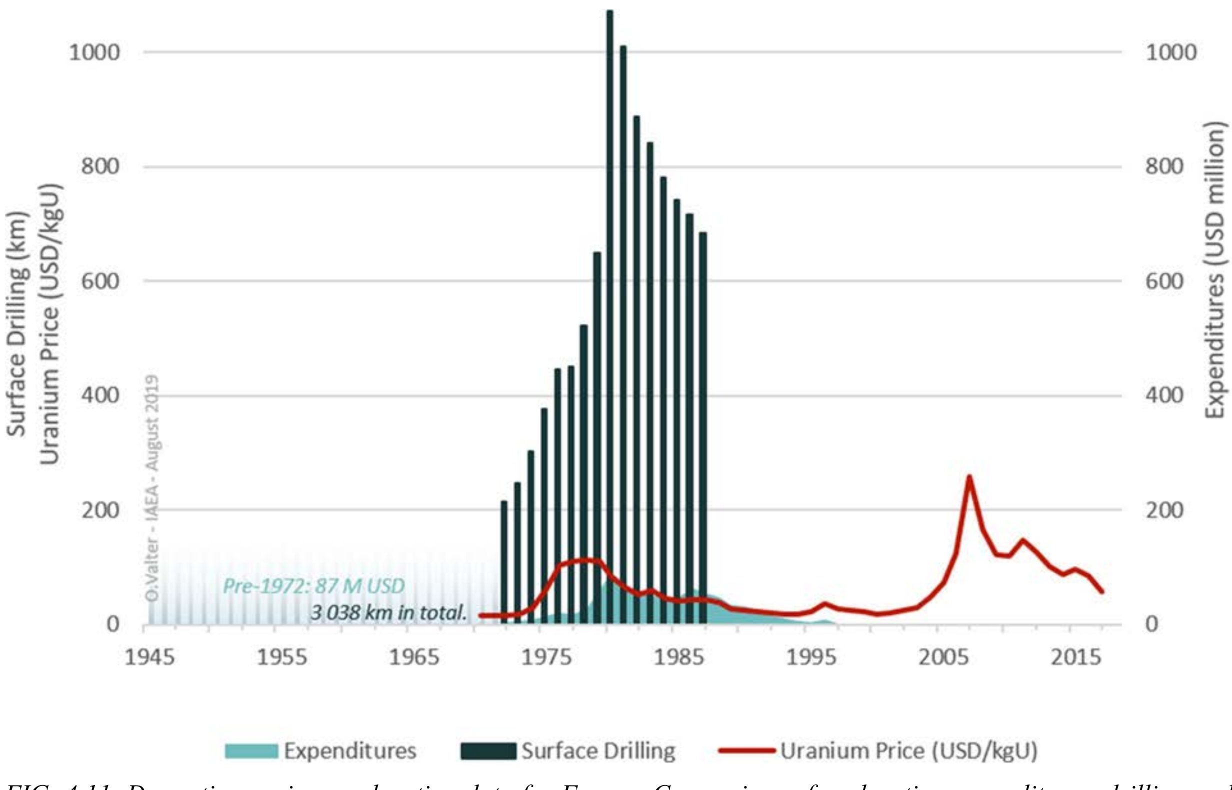


FIG. 4.11. Domestic uranium exploration data for France. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

After the world energy crisis of the early 1970s, the French nuclear programme was accelerated and after 1974 exploration was intensified. Exploration was conducted adjacent to uranium mining districts and around known showings that had not been previously explored owing to economic considerations. New areas, located mainly in Permian and Tertiary sedimentary basins, were also investigated.

Exploration activity continued at high levels until the mid-1980s, even as the spot market price for uranium continued to decline. While exploration expenses expressed in US$ decreased, they remained high in French Francs. Additional exploration was conducted in the Massif Central, as well as to the NW in the Massif Armoricain, in the Aquitaine Basin to the south and in the Alps.

In 1977–1981, the Government supported exploration with an expenditure totalling US $38 million. This financial aid could represent up to 35% of the cost of a project and was provided in both France and abroad. For these subsidized projects, the operator was obliged to reimburse the Government if an economically viable deposit was exploited.

At the end of the 1980s, exploration activities declined and were mainly concentrated in areas adjacent to mines. After 1994, exploration was only conducted in the north-western part of the Massif Central and in the Permian Basin at Lodève. Exploration was terminated in 1996 in the Permian Basin and in 1998 in the Massif Central [6.8, 6.9].

Exploration abroad

To ensure the supply of uranium for the French nuclear programme, French mining companies were encouraged to explore abroad and to this end exploration has been carried out in Australia, Canada, Gabon, Indonesia, Kazakhstan, Niger, South America and the USA. In 1979, exploration was being conducted in 19 different countries. As shown in Table 4.2, yearly exploration overseas increased from less than US $10 million to a maximum of over US $68 million in 1980. The following years show a steady decrease from the maximum reached in 1980 to below US $6 million by 1990. With the exceptions of 1993 and 1994, yearly expenses were below US $20 million and even below US $10 million in the years to 2001. Thereafter, an increase in exploration expenses occurred owing to an increase in the prevailing spot market price of uranium (Fig. 4.12 and Table 4.2) [6.8, 6.9]. As of January 2017, total non-domestic exploration expenditure is USD $1494 million.

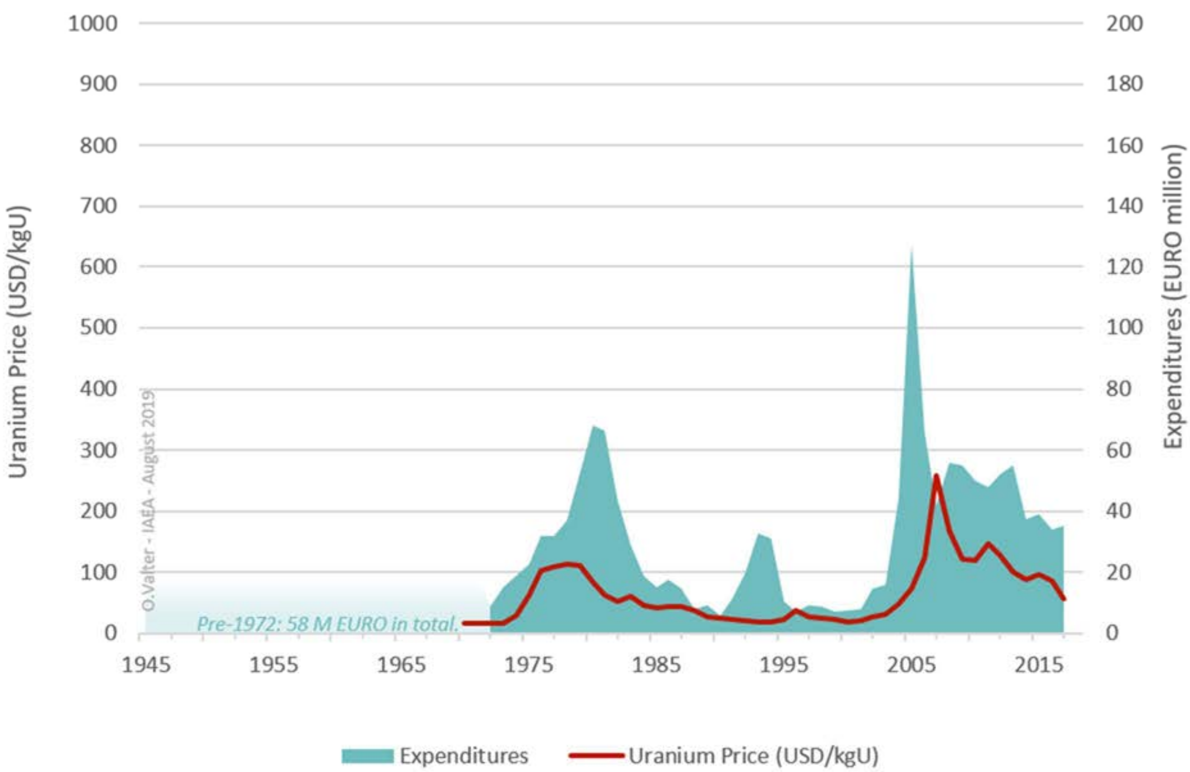


FIG. 4.12. Non-domestic uranium exploration data for France. Comparison of exploration expenditures, drilling and uranium market price (US$ current) [6.8, 6.9].

TABLE 4.2. NON-DOMESTIC EXPLORATION AND DEVELOPMENT EXPENDITURES BY THE URANIUM INDUSTRY FOR 2004–2007 (US$ million) [6.8, 6.9]

Year	2004	2005	2006	2007 (est.)
Exploration expenditure	13	n.a.[a]	40	60
Development expenditure	31	n.a.	45	55
Total	44	127.5	85	115

[a] n.a.: not available.

4.6.2.2. Potentially-favourable uranium-bearing areas

In general, uranium mineralization occurs in rocks formed by the Variscan (Hercynian) Orogeny, in sedimentary basins of Carboniferous–Permian or Tertiary age, formed in Variscan rocks, and in larger sedimentary basins at the periphery of Variscan regions and containing erosional materials from the Variscan regions.

4.6.3.2. Recent and ongoing uranium exploration and mine development activities

From 1999, no domestic uranium activities have been conducted in France. Overseas, Compagnie Générale des Matières Nucléaires (COGEMA, formerly Commissariat à l'Energie Atomique (CEA)), AREVA (formerly COGEMA) and Orano (formerly AREVA) have been focusing on targets in Niger, Mongolia, Kazakhstan, Finland, Canada and Australia. AREVA is likewise directly or indirectly engaged in activities for exploration or development of uranium via its subsidiaries. In 2017, Orano was created as a result of restructuring and recapitalizing of the nuclear conglomerate AREVA. In Niger, Kazakhstan and Canada, Orano is engaged in mining operations and projects for uranium. Besides, without being the operator, it keeps shares in a number of research projects and mining operations in different countries [6.8].

The costs for finding of 1 kgU in total conventional resources, including uranium produced until 2003, amounts to US $10.61. This compares with roughly US $2/kgU for the world average [6.10].

4.6.4. Uranium resources

4.6.4.1. Identified resources

After the shutdown in 2001 of the last uranium mine, any reasonably assured resources no longer exist in France. Inferred resources of 11 740 tU are reported for the Coutras deposits. UDEPO [6.11] lists a total of 43 deposits (or mining areas). Three of which are dormant; the sandstone deposits at Coutras, the vein deposit at Montulat and the Saint Hippolyte black shale deposit. All the others have been depleted. These deposits are minable using open pit [6.8]. Figure 4.10 shows their location. The variations in historical resources are shown in Fig. 4.13 and Fig. 4.14.

The UDEPO database lists the most significant deposits for France as Coutras, Mas Lavayre, Margnac-Peny, Bois Noirs (Les), Bernardan (Le), Bellezane, Commanderie (La), Chardon (Le), Treviels.

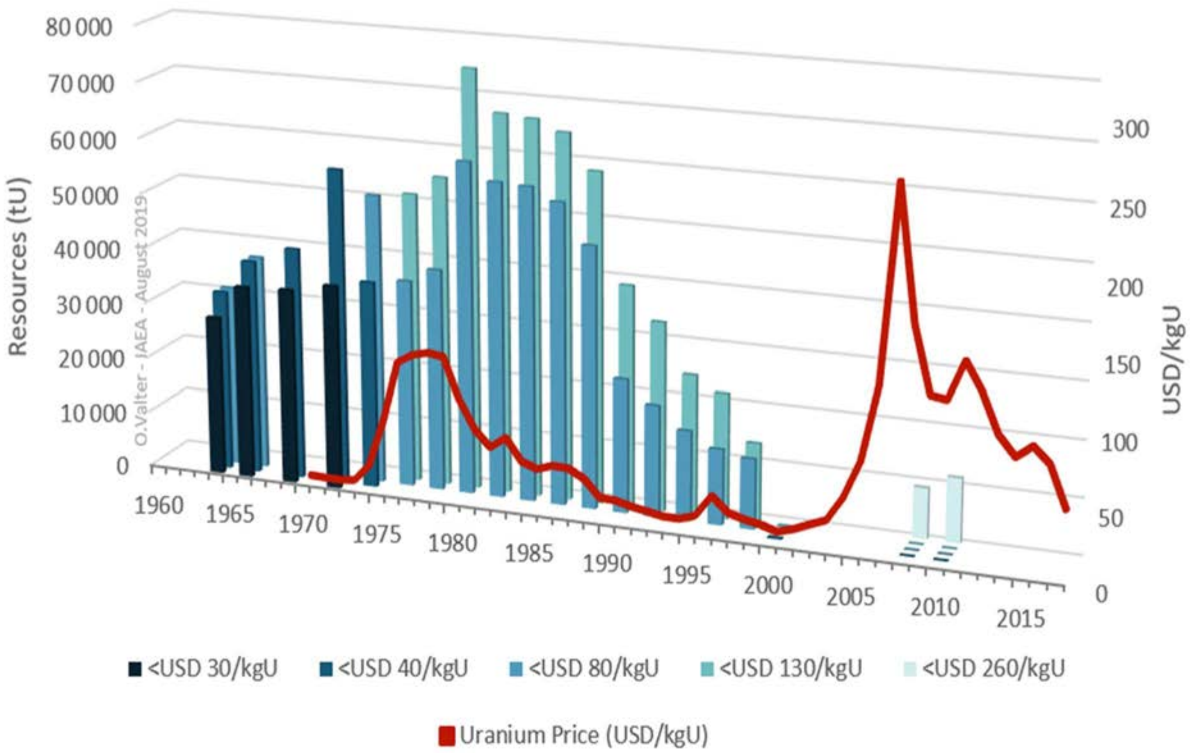


FIG. 4.13. Historical variation of recoverable reasonably assured resources within various cost categories in France. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

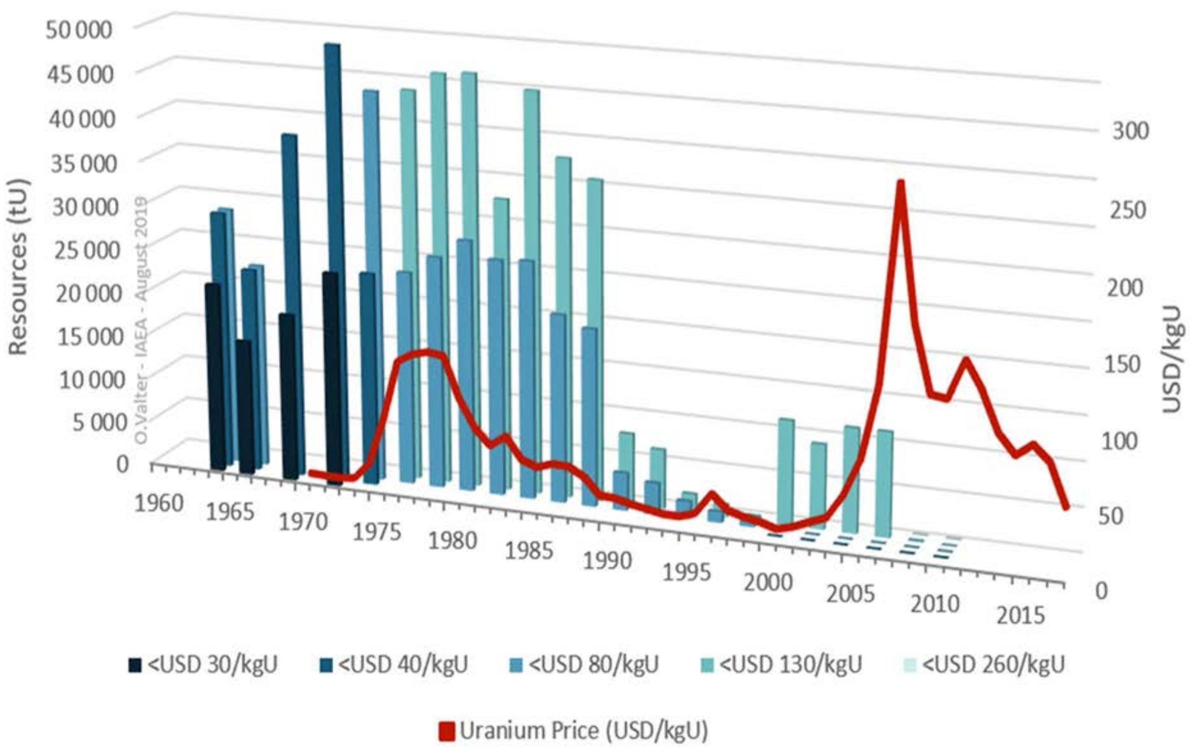


FIG. 4.14. Historical variation of recoverable inferred resources within various cost categories in France. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

4.6.4.2. *Undiscovered resources*

No systematic appraisal has been carried out for undiscovered resources.

4.6.5. Potential for new discoveries

France is one of the most intensively explored countries. With the exception of deposits which are dormant owing to economic and/or ecological reasons, no new exploration areas may be found at a reasonable depth. The deeper parts of fertile granites and sedimentary basins may have some potential. However, at present these are not of economic interest.

4.6.6. Uranium production

4.6.6.1. *Historical review*

Details of historical uranium production are given in Fig. 4.15. Total historical French production to 2016 is 76 240 t.

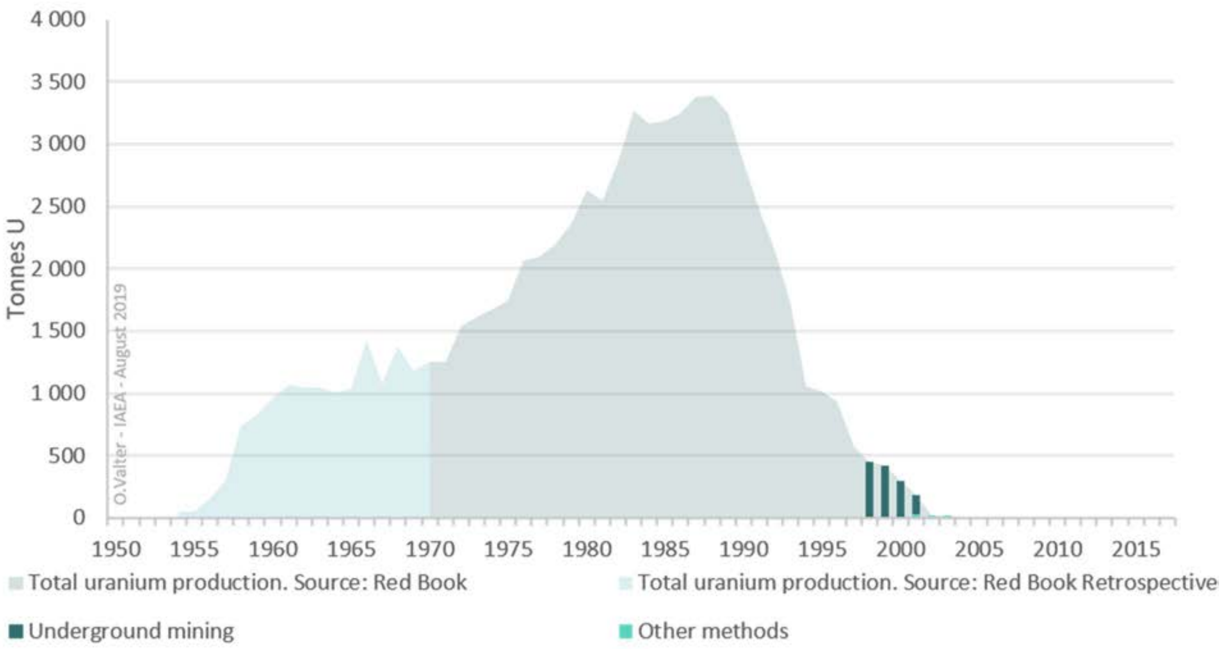


FIG. 4.15. Historical uranium production in France (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

Uranium has been produced from at least 200 different sites, with production ranging from less than 1 tU to at least 5000 tU (Bois Noirs, Le Bernardan, Lodève district, Margnac). Due to mine closures, production of uranium in France has dropped continually after 1990. Because of the shutdown of Lodève and Le Bernardan in 1997 and 2001, respectively, there is currently no uranium producing operation in France. Since 2002, any generation recorded has been achieved as the result of site reclamation.

4.6.6.2. *Status of production capability*

After 2001, all ore treatment plants were closed, demolished and the sites recovered. Just 2-3 tU/year are still recovered on resins used throughout water cleaning processes at the outflow from the former Lodève mine. The resins are eluted at the Malvesi refinery and the uranium recovered.

There are no current proposals to develop addition production centres.

4.6.7. Environmental activities and sociocultural issues

After the shutdown of the last mines in Hérault (1997) and at Bernardan (2001), reclamation and decommissioning efforts focused on these sites. Regulations demand mothballing and restoration of closed mining and milling facilities, including waste dumps and tailings facilities, in order to minimize any release of potentially harmful substances and thereby ensure that a broad range of specific standards are met. Expenses for decommissioning totalled nearly FFr 793 million (US $134 million) through 2000. Monitoring the quality of both air and water in the neighbourhood of these facilities is ongoing.

Additional information on environmental and remediation activities is provided in Refs [6.12, 6.13].

4.6.8. French Guiana

4.6.8.1. Geography

French Guiana is located on the north-eastern coast of South America, bordering the Atlantic Ocean. As an Overseas Department of France, French Guiana is part of the European Union and is the largest landmass in the EU outside of Europe. In contrast, compared with other South American countries, French Guiana has the smallest landmass and the smallest population. The country's economy is heavily dependent on France for subsidies, trade and goods. The main industries are fishing (accounting for three quarters of foreign exports), gold mining and timber. In addition, the Guiana Space Centre at Kourou contributes 25% of GDP and employs ~1700 people.

There is very little manufacturing. Agriculture is largely undeveloped and is mainly confined to the area near the coast, sugar and bananas being two of the main cash crops. Tourism, especially eco-tourism, is growing. Natural resources include bauxite, cinnabar (mercury), gold (widely scattered), kaolin, timber and fishing.

The climate is tropical, hot and humid, with little seasonal temperature variation. Summers are dry and winters rainy. Low lying coastal plains rise to hills and small mountains, the highest point being Bellevue de I'Inini at an elevation of 851 m [6.14].

4.6.8.2. Geology

French Guyana is part of the Guiana Shield, a large massif extending from the Amazon to the Atlantic Ocean (Fig 4.16).

It is composed of old Precambrian formations dated between 3500 and 2700 Ma. The shield comprises several geological units: the southern peneplain, the Inini synclinorium, the central granite massifs and the northern synclinorium. The southern peneplain consists of granito-gneisses corresponding to metagabbros, metagranodiorites and metagranites ('Guyanese Granites') dating from 2075 ± 7 Ma. To the north, the peneplain straddles the Inini synclinorium, mainly composed of the Paramaca series (micaschists, aluminous paragneisses, conglomerates and black quartzites) with a thickness of about 1 km. The Upper Paramaca is made of various lavas (basalt, andesite, dacite and rhyolite). The central granite massifs consist of granites, granodiorites and quartz diorites plutons dating from 2150-2050 Ma. Pegmatite veins are common. The north of French Guiana corresponds to a synclinorium composed of the Paramaca series on which are unconformably overlying sandstones, quartzites, conglomerates and black schists of the Bonidoro and Orapu series. They are intruded by the well represented 'Caribbean Granites'. The largest intrusions are surrounded by migmatites. Pegmatite veins and bodies are common and carry some mineralization. Rocks of the Shield are all dated between 2500-1600 Ma. [6.15]

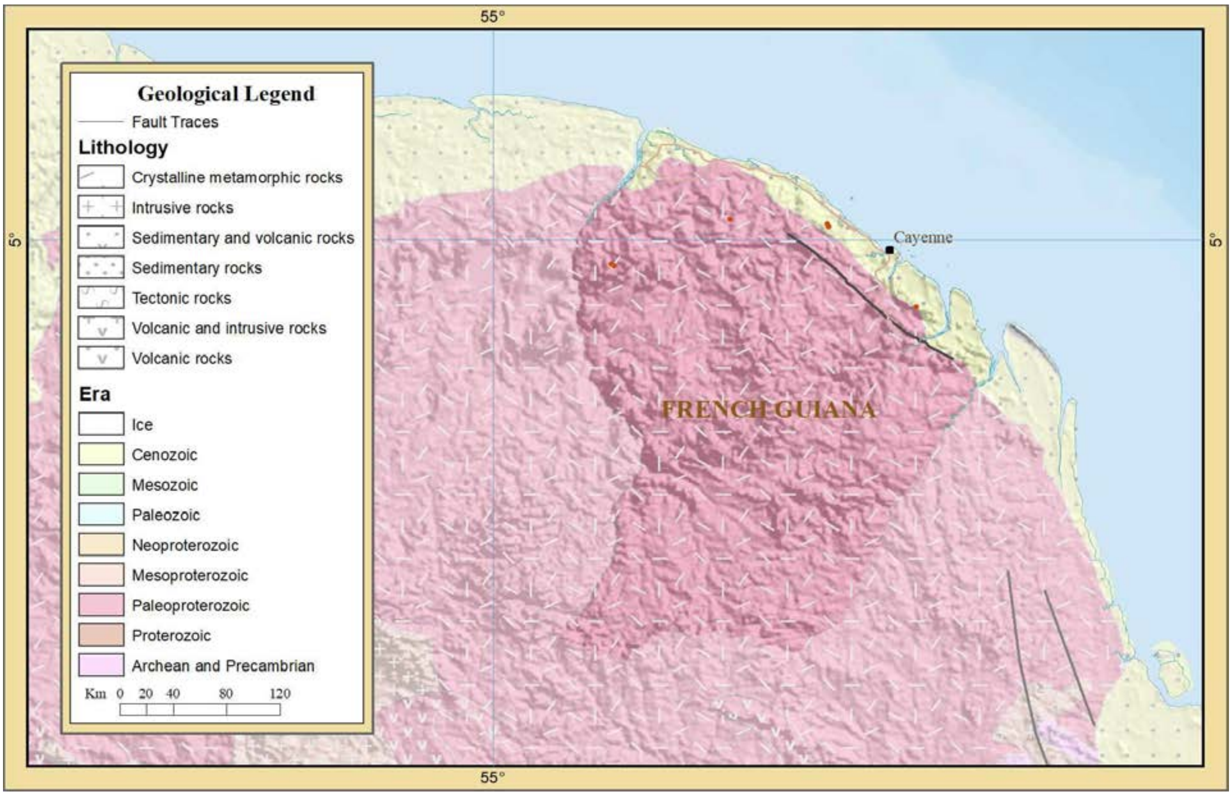


FIG. 4.16. Regional geological setting and uranium mineralisation of French Guiana. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Well developped late dolerite dykes crosscut all the above formations with a NNW preferential direction. Late Cenozoic terranes (carbonates) are very rare and have only been found in drill holes. Dismantled ferruginous and bauxitic laterites formed during Mesozoic and Cenozoic times are present in various topographic levels.

Quaternary formations are located along the coast and are represented by thin layers (8-15 meters) of marine clay, sand and pebbles originating from alteration and erosion of the Precambrian Shield. The youngest contain a large proportion of organic matter (peat and shells).

4.6.8.3. Uranium resources

No reports on previous or current uranium exploration are available. There are no uranium or thorium resources or production reported in UDEPO or in the literature. French Guiana has not submitted any Red Book reports (any uranium related activity reported to the Red Book would be provided in the country report for France).

Within the Montagne de Kaw depression, strong anomalies were found related to radon emanations. Caribbean pegmatites are often autunite-rich. Columbo-tantalates and ilmeno-rutiles are weakly anomalous [6.16].

4.6.8.4. Potential for New Discoveries

As in the surrounding countries, IUREP recognized there is some potential for quartz pebble conglomerate and Proterozoic unconformity related deposits associated with the Shield area [6.17]. Also, vein and disseminated mineralization within pegmatites can be present. Black shales are locally well developed in some areas.

4.6.9. New Caledonia

4.6.9.1. Geography

New Caledonia is a 'special collectivity' or unique portion of France located in the region of Melanesia in the south-west Pacific. It is about 1200 km east of the Australian coast. It comprises a main island, Grande Terre, the Loyalty Islands and several smaller islands.
The climate of the islands is tropical and rainfall is highly seasonal, brought by trade winds that usually come from the east. Annual rainfall averages about 1500 mm on the Loyalty Islands, 2000 mm at low elevations on eastern Grande Terre and 2000–4000 mm at high elevations on Grande Terre. The western side of Grande Terre lies in the rain shadow of the central mountains and annual rainfall averages 1200 mm. There are two main seasons: a dry season, and a warm, wet season. The dry cooler months last from April to November with daily temperatures in the range 17–27°C. During the wet season (December–March) the temperature can reach 32°C.

New Caledonia contains a considerable wealth of industrially critical elements and minerals, including about one-quarter of the world's nickel resources. Mining is therefore a significant industry that greatly benefits the territory's economy [6.18].

4.6.9.2. Geology

For a relatively small island, the geology of New Caledonia is quite complex (Fig. 4.17). The stratigraphic record begins with marine sediments being deposited in the Mesozoic. The succession is quite thin, but a thick Eocene section is present.

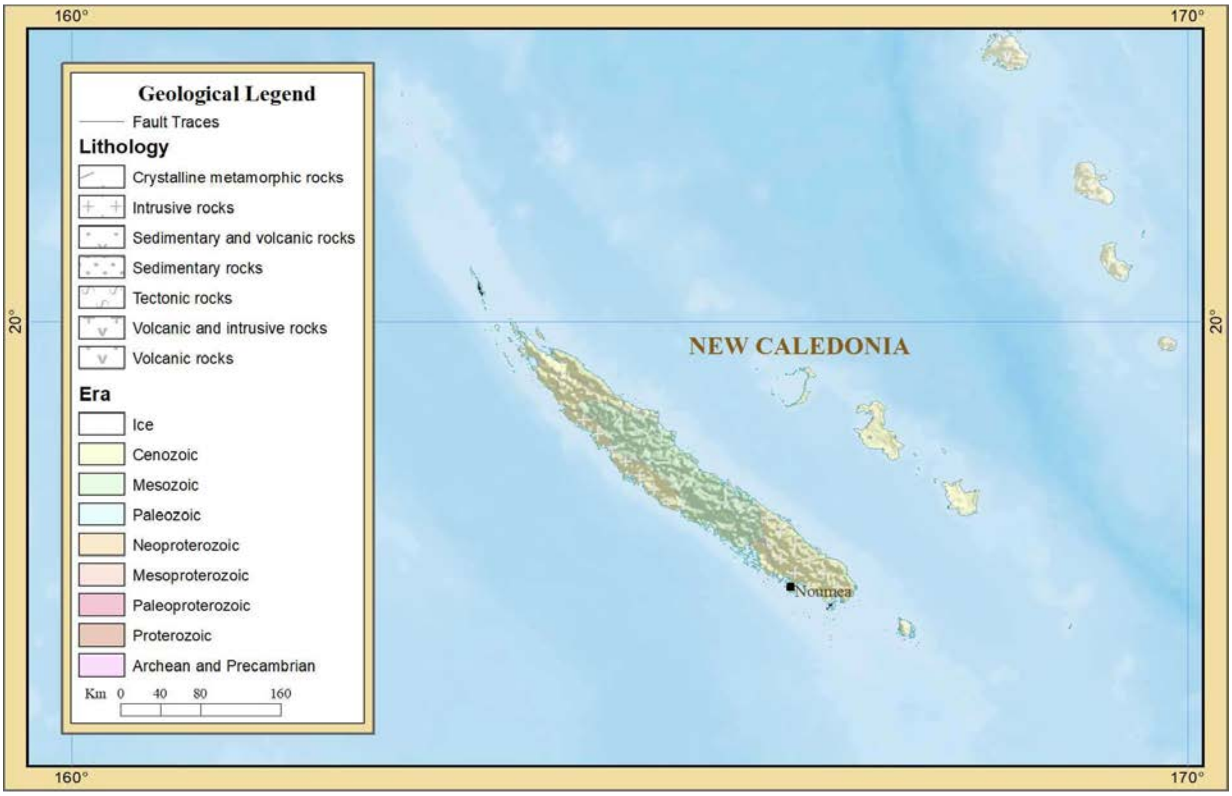


FIG. 4.17. Regional geological setting of New Caledonia (France). A general global geological legend is shown although not all geological units necessarily occur on this particular map.

New Caledonia belongs to the circum-Australian group, along with New Guinea and New Zealand. Thicknesses of up to 13 000 m of Eocene strata are preserved along this trend. Grande Terre consists mostly in sedimentary, volcanic and ultrabasic rocks from Permian (280-225 Ma) to Tertiary (65–1.5

Ma). Metasediments of Cretaceous age predominate in the extreme north-west. Basalt is present in the western portion of the north-western part of the island. Small outcrops of marine sediments of Mesozoic and Eocene age intermix with granites in the central part of the island. Ultrabasic rocks and 'blue schist' glaucophane-bearing metamorphics occupy the south-eastern quarter of the island. Radiometric dating of the metamorphism peak is 44 Ma while the cooling ages range from 40 to 34 Ma. They indicate a rapid unroofing and exhumation of the metamorphic units in the north and a synchronism with the emplacement of the ophiolitic nappe (38-34 Ma). A zone of intense faulting runs the entire length of the island through its centre. The terms of 'geosuture' and "la grande faille" are locally used to indicate the degree of faulting, although the magnitude of movement and relative throw are debated. Shear zones are measured in widths of kilometres, although descriptions of the character of the shears are fragmentary. This fault is correlated to the faulting along the Owen Stanley Mountains of Papua New Guinea.

The island is quite heavily mineralized; several deposits are economic (notably nickel and chromium) [6.18].

4.6.9.3. Uranium Exploration

There has been no reported uranium exploration on New Caledonia. However, given the fact that several French organizations have undertaken exploration for uranium in several States in Africa, it is therefore likely that New Caledonia has already been considered as a target for uranium exploration.

4.6.9.4 . Uranium Resources

There are no known uranium occurrences in New Caledonia. Based on the complexity of the geology and the relative intensity of the mineralization of the island, as well as apparently favourable host rocks, IUREP assigned speculative resources in a range of 1000–10 000 tU to New Caledonia [6.19].

4.6.9.5. Potential For New Discoveries

The shear zones along the 'geosutre' present the best potential host environment for uranium deposits. Mylonite zones within the shear zones appear to have most potential. Primary type deposits may be present in the metamorphics as veins, stocks and pipes, especially where organic-rich (phyllite, etc.) metasediments contact impervious rocks [6.19]. Owing to the country's size and rock types present, the potential for any discovery is rated as low.

4.6.9.6. Comments

There has been no past production in New Caledonia. New Caledonia has no nuclear power generation.

References to Section 4.6

[6.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: France, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed February 2008).

[6.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[6.3] POTY, B.P., LEROY, J., CUNEY, M., "Les inclusions fluides dans les minerais des gisements d'uranium intragranitiques du Limousin et du Forez (Massif Central, France)", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 569–582.

[6.4] DE FRAIPONT, P., MARQUAIRE, C., SIERAK, J.P., HORRENBERG, J.C., RUHLAND, M., "Réseau de fractures et répartition des corps tectoniques élémentaires de fracturation", Vein-Type and Similar Uranium Deposits in Rocks Younger than Proterozoic (Proc. Tech. Mtg Lisbon, 1979), IAEA, Vienna (1982) 87–101.

[6.5] LILLIE, F., HERY, B., "Expression multiscalaire du réseau de fractures minéralisées dans le gisement uranifère de Bertholène (Aveyron, France)", Vein-Type and Similar Uranium Deposits in Rocks Younger than Proterozoic (Proc. Tech. Mtg Lisbon, 1979), IAEA, Vienna (1982) 103–112.

[6.6] HERBOSCH, A., “Factures controlant la distribution des éléments dans les shales uraniferes du basin Permien de Lodève (Herault, France)”, Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna, (1974) 359–380.
[6.7] STAFFELBACH, C., MENDEZ-SANTIZO, J., HORRENBERGER, J.C., RUHLAND, M., WEBER, F., “Fracturing of the uranium ore deposit of Lodève: Mode of formation and filling”, Metallogenesis of Uranium Deposits (Proc. Tech. Mtg Vienna, 1987), IAEA, Vienna (1989) 119–135.
[6.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[6.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).
[6.10] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.
[6.11] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[6.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999) 89–94.
[6.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002) 208–216.
[6.14] CENTRAL INTELLIGENCE AGENCY, The World Factbook: France, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2010).
[6.15] ABOUT.COM, Geology of French Guiana, http://geology.about.com/od/othernationgeomaps/ss/South-America-Geologic-Maps_7.htm (accessed September 2012).
[6.16] CHOUBERT, B., Atlas des D.O.M.. La Guyane. Planche 4 (1978)
[6.17] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.
[6.18] CENTRAL INTELLIGENCE AGENCY, The World Factbook: New Caledonia, France, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).
[6.19] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: New Caledonia, IAEA, Vienna (1977) 9 pp.

4.7. GERMANY

4.7.1. Geography

Roughly 35% of Germany is situated in the Northern European Plain, which extends from the Netherlands through Germany, Denmark, Poland, the Baltic States and Belarus to the Russian Federation. The northern area is crossed by several rivers originating in the southern highlands and mountains: the Ems, Weser, Elbe and Oder. The main river in the west is the Rhine with the major tributaries being the Neckar, Main, Ruhr, Nahe and Moselle. The Danube River originates in the Black Forest and runs in an easterly direction into Austria.

The northern terrain was formed throughout the Ice Age, when glaciers left various features and deposits, including lakes, moraines of various types, and flat, sand covered plains. The central region, or Mittelgebirge, is moderately mountainous. In its northern part, the hilly area extends west to east from the Eifel through the Rheinisches Schiefergebirge and the Wesergebirge to the Harz Mountains (with elevations of up to 1142 m). Further south, the uplands are formed by the Pfälzer Wald (Palatine Forest), Hunsrück, Taunus, Thüringer Wald and Erzgebirge (with elevations of up to 1214 m).

In the southern part, the topography is characterized by the mountains of the Black Forest (Schwarzwald with elevations up to 1493 m)), Swabian Alp (Schwäbische Alb), Franconian Alp (Fränkische Alb), Upper Palatine Forest (Oberpfälzer Wald) and Bavarian Forest (Bayerischer Wald with elevations up to 1456 m)). The southernmost area is formed by the foreland of the Alps, as well as the Alps themselves (the Northern Calcareous Alps, with elevations up to 2963 m, which form the border with Austria.
The climate in the north and NW is influenced by temperate winds from the North Sea and the Baltic Sea, with mild winters and comparatively cool summers. In the east, the climate is continental; winters are cooler and summers are warm. The south has transitional climatic conditions; winters in the uplands may

be cold and snow may persist for several weeks. The summers tend to be warmer than in the north and temperatures may rise above 30°C.

In the south, Lake Constance is the largest lake and extends into Switzerland and Austria. Other major lakes are the Müritz and Chiemsee.

Roughly 35% of the country is arable, with forests and woodlands also covering roughly 35% of the country. Agricultural crops include grain, potatoes and sugar beet. Fruit is grown almost everywhere, except at high elevations. Viticulture is important in the west and south. Mineral resources include hard coal and lignite, potash, kaolin, rock salt and other industrial minerals (baryte and fluorspar) and construction materials. Metalliferous mining ceased several years ago [7.1].

4.7.2. Geology

4.7.2.1. General

Geologically, Germany is divided into three main units (Fig. 4.18). The oldest, the Grundgebirge (basement rocks), consists of folded and metamorphosed rocks, mainly of sedimentary origin, along with a few magmatic types. The Grundgebirge has been intruded by magmatic rocks, which range in age from Late Proterozoic to Upper Carboniferous. The Assyntic Orogeny, which occurred throughout the Cambrian, was probably the first tectonic episode to deform the Grundgebirge. The effects of the Caledonian Orogeny are found in many areas. The Hercynian or Variscan Orogeny (Upper Palaeozoic) was the most prominent orogenic event, and most of the magmatic activity took place throughout this period.

The Grundgebirge is discordantly overlain by less deformed rocks known as the Deckgebirge (cover rocks), which range in age from Permian to Tertiary. These strata consist of sandstone, marl, limestone, dolomite and porphyries, as well as alkaline and basaltic volcanic rocks.

The third unit consists of unconsolidated Quaternary sediments which are glacial products. This unit occurs mostly in the north and NW, as well as in the Alpine foreland.

The differences in composition and tectonic style between the oldest unit and the overlying unit were caused by the Hercynian Orogeny. In Germany, the Alps primarily consist of the limestone and dolomite of the Northern Calcareous Alps. The development of nappes resulted in the overthrust of part of the Northern Calcareous Alps. In the Alpine foreland, thick molasse sediments were deposited in a deep trough [7.2, 7.3].

4.7.2.2. Metallogenic units

Germany shares part of its geological development with central and western Europe. For example, several metallogenic units observed in Germany are similar to those recognized in the Czech Republic and France. From southern Germany, the Moldanubian Zone extends eastwards into the Czech Republic and westwards into France.

In the SE, the Moldanubian Zone occurs in the Bavarian Forest and in the southern part of the Upper Palatine Forest. To the west, the Moldanubian Zone is covered by the rocks of the Deckgebirge and is exposed again in the Black Forest. Here, it is dislocated by the Rhine Graben, which is situated between the Black Forest and the Vosges Mountains in France.

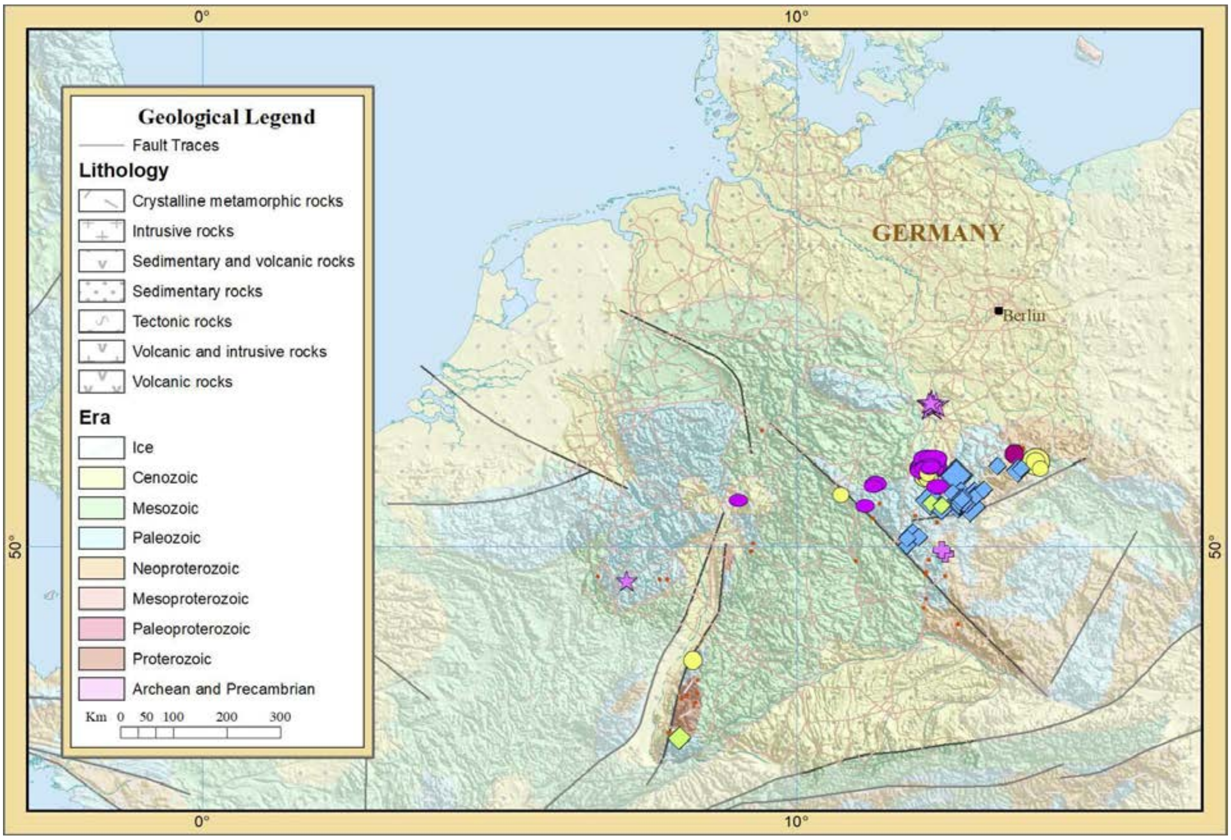


FIG. 4.18. Regional geological setting of Germany showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Moldanubian Zone is intruded by Hercynian granites. Vein deposits with fluorite and baryte occur in the Bavarian Forest, Upper Palatine Forest and Black Forest. In the Czech Republic and France, the Moldanubian Zone hosts several uranium deposits. However, in Germany only a few small vein deposits have been found in Wäldl and Poppenreuth, close to the border with the Czech Republic (associated with fluorite veins in Upper Palatine) and at Menzenschwand in the southern Black Forest. The Müllenbach sedimentary deposit occurs in a small basin of Upper Carboniferous age located on the northern edge of the Black Forest. It is classified by age as Moldanubian or Saxo-Thuringian.

The Saxo-Thuringian metallogenic zone is situated north of the Moldanubian Zone and can be traced from the Czech Republic through the southern part of central Germany to France. In Germany, the NE–SW trending Erzgebirge (Ore Mountains), of which roughly 50% is situated in the Czech Republic (Krušné Hory), forms the north-eastern edge of this metallogenic zone. The Erzgebirge consists of metamorphosed pre-Palaeozoic rocks, and Cambrian and Silurian sedimentary rocks of different metamorphic grade, as well as a number of granite bodies. Many base metal vein deposits are associated with Hercynian granites in the Erzgebirge and these include mineral assemblages containing Bi, Co, Ni, Pb, Zn, Cu and Ag.

Several large (now depleted) uranium deposits in the Erzgebirge were located in Hercynian age granites and in the surrounding metamorphosed country rock. Outside the Erzgebirge, the Saxo-Thuringian strata are developed from Cambrian sedimentary rocks (mainly under cover rocks) through Ordovician (sedimentary rocks and basic magmatic rocks in Saxony and Thuringia) to Silurian and Devonian. The Silurian includes siliceous shales (Kieselschiefer), dark bituminous shales (Graptolithenschiefer) and limestone.

The Thuringian (Ronneburg type) uranium deposits occur in black shales, calcareous shales and limestones/dolomites where they are intruded by diabase dykes of Silurian and Devonian age. In the Saar-

Nahe region, in the western part of the German Saxo-Thuringian zone, uranium mineralization of limited economic value has been found in Permian porphyritic volcanic rocks.

The Rhenohercynian metallogenic zone occurs north of the Saxo-Thuringian zone. This west–east trending zone extends from the border with Belgium into the Rheinisches Schiefergebirge and through central Germany to the Harz Mountains. The Rheinisches Schiefergebirge was formed by sediments starting in the Lower Devonian, consisting of slates and sandstone, overlain by fine-grained dark slates (Dachschiefer) of Middle Devonian age. Within the basin, the grain size of the sediments varies with the depth of deposition. The deeper zones host the argillaceous fraction and calcareous sediments occur on the rises, whereas the shallow water areas are characterized by arenaceous sediments. Massive limestone banks (Massenkalk) were developed in the Middle Devonian. The Upper Devonian consists mainly of reddish shale. In central Germany, the Rhenohercynian occurs in the Thuringian Trough.

In the Harz Mountains, the Rhenohercynian is exposed at the surface. In one small area, a variety of rocks are exposed ranging in age from Upper Proterozoic–Lower Devonian basic intrusions, through to well-developed Devonian, Carboniferous and Permian strata. The rocks of the Rhenohercynian have been explored for uranium, although no economic concentrations have been found.

The Carboniferous sedimentation started with partly argillaceous, partly arenaceous sediments. The greywackes of the Lower Carboniferous Kulm are found in many areas. The hard coal deposits of the Ruhr district occur in the northern part of the Rhenohercynian. Massive sulphide (Cu, Zn and Pb) deposits are developed in the Rheinisches Schiefergebirge (Meggen) and the Harz Mountains (Rammelsberg), the latter having been mined continuously for over a thousand years.

The marine Permian (Zechstein) includes limestone, anhydrite and rock salt/potash in mineable quantities. In the Permian Rotliegendes, which is partly transgressional to the Zechstein, the bituminous/marly Kupferschiefer is developed, which was locally mined for copper. In some parts, the uppermost Kupferschiefer carries uneconomic levels of uranium mineralization.

The Upper Carboniferous–Lower Permian basins that host hard coal are partly uraniferous, including the Stockheim Basin in northern Bavaria. However, these concentrations were not economic to extract. Wismut did, however, recover uranium from coal deposits at Freital, near Dresden. However, this was achieved under centrally planned economics rather than under market conditions.

Large parts of the metallogenic zones are overlain mainly by Mesozoic rocks, starting with the Lower Triassic arenaceous Buntsandstein (Bunter). In some places, the transition from the continental Permian red coloured sandstone to the red Bunter occurs without interruption. In other areas, the continental Upper Carboniferous is transitional to the continental Permian without any discontinuity or unconformity.

The Buntsandstein in the so-called German Basin is formed of erosional debris from the Variscan Mountains. The sandstones are mainly fluviatile, often cross-bedded and/or consisting of fining upwards sequences of sands and argillaceous horizons deposited in a continental/desert climate. The conditions of sedimentation are comparable to those of sandstone-hosted uranium deposits elsewhere, although no economic concentrations of uranium have been found.

During marine transgressions, limestone of the Muschelkalk formation overlies the Lower Triassic sandstones and Palaeozoic strata. After the Muschelkalk, a change of deposition regime occurs, starting with deposition of the arenaceous sediments of the Keuper, indicating a transition from marine to continental conditions. Sandstones were deposited under conditions favourable for the concentration of uranium, similar to some deposits on the Colorado Plateau. The so-called dolomitic arkose of the Keuper was found to contain uranium in the carbonate cement, but the concentrations are uneconomic. Jurassic sedimentation starts mainly with dark bituminous shales (Lias, Black Jura), followed by Middle Jurassic Dogger sedimentary rocks of brown colour and white limestone of the Upper Jurassic Malm.

Sedimentation throughout the Cretaceous is divided into continental to fluviatile arenaceous deposits and marine limestone. Sandstone basins occurring within the basement are favourable for uranium deposit formation. With the exception of the basin in the Elbsandsteingebirge (Königstein) in Saxony, no economic concentrations have been found. Königstein occurs in a similar stratigraphic horizon to the Hamr/Straz deposits of the Czech Republic.

The Tertiary is characterized by both marine and continental sedimentary rocks. In limnic parts, large lignite deposits were formed (e.g., in the Lower Rhine Basin and the Central German Basins of Leipzig and Brandenburg). Small lignite basins in Bavaria, overlying the basement, have been prospected for uranium, although no economic concentrations were found. Other lignite deposits are non-uraniferous.

In the west, volcanic rocks of basic composition are present in the Westerwald, SE of Bonn, in the Vogelsberg area, NE of Frankfurt am Main and in the Eifel district, west of Bonn. Other volcanic rocks of alkaline composition are found in the Upper Rhine Graben, north of Lake Constance, and in a few other places [7.4].

4.7.3. Uranium exploration

4.7.3.1. Historical review

Following World War II, uranium exploration was undertaken in both the Federal Republic of Germany and the former German Democratic Republic.

Former German Democratic Republic

Exploration and mining of uranium were conducted in 1946–1953 by SAG Wismut, the Soviet stock company, and was focused on old mining sites where nickel, cobalt, silver and other metals had been extracted in the Vogtland and Erzgebirge, Saxony. Uranium was first found here in 1789. Uranium mining started at the bismuth and cobalt mines near Oberschlema (a historically famous radium spa) and Schneeberg. Throughout the early period, at least 100 000 people were involved in activities for exploration and mining. Rich uranium ores were hand sorted and transported to the former Soviet Union for treatment. Lower grade ores were processed locally in small treatment plants. The mill at Crossen near Zwickau, Saxony, started operation in 1950.

In 1954, Sowjetisch-Deutsche Aktiengesellschaft Wismut (SDAG Wismut), the joint Soviet–German stock company, was created, held evenly by the two governments. Production of uranium, either hand sorted concentrate, gravity concentrate, or chemical concentrate, was transported to the former Soviet Union. The price for the final product was settled among the two partners. Any ‘incomes’ were utilized for further exploration. At the close of the 1950s, major mining of uranium was shifted to the eastern Thuringia region where exploration for uranium began in 1950, near the radium spa at Ronneburg. By the early 1970s, the mines in eastern Thuringia accounted for roughly 65% of SDAG Wismut’s yearly production.

After unification in 1990, the Federal Government took the decision to terminate uranium production, a decision taken principally on economic considerations as the uranium grades were low and underground mining was expensive. The most favourable part of the Drosen mine in the Ronneburg orefield was evaluated in 1990, with the conclusion that recovery costs were four times the 1990 spot market price.

Between the mid-1960s and the mid-1980s, ~45 000 people were working for Wismut. In the mid-1980s, Wismut’s employment had dropped to ~30 000. In 1990, only 18 000 people employed in mining and milling of uranium.

Exploration for uranium, employing an assortment of ground-based and airborne methods, took place in the south and encompassed an area of ~55 000 km^2. Roughly 36 000 holes were drilled over an area of ~26 000 km^2. Total expenses for exploration of uranium over the life of the exploration programme were GDR Mark 5.6 billion, equivalent to ~US $1.9 billion (Table 4.3, Fig. 4.19).

Federal Republic of Germany before 1990

Since 1956, exploration was conducted in the Hercynian Massifs (Harz, Bayerischer Wald, Oberpfalz, Fichtelgebirge, Frankenwald, Odenwald and Black Forest), in the Palaeozoic sedimentary rocks of the Rheinisches Schiefergebirge, in the Permian volcanic rocks and continental sedimentary rocks of the Saar-Nahe region and in other regions with favourable sedimentary formations.

The first phase comprised hydrogeochemical and car-borne surveys and, to some extent, airborne prospecting. Follow-up work included geochemical stream sediment surveys, radon surveys and detailed radiometric work, then by trenching, drilling and occasionally test mining. During reconnaissance work, both the State and Federal geological surveys were engaged. However, private companies conducted the actual work.

Three economically interesting deposits were discovered: (i) the Krunkelbach high grade hydrothermal deposit near Menzenschwand (southern Black Forest); (ii) the sedimentary Müllenbach deposit (northern Black Forest); and (iii) the Grossschloppen deposit (north-eastern Bavaria). In the Upper Palatine Forest, the Wäldl (Mähring) and Poppenreuth/Höhensteinweg deposits, located close to the border with the Czech Republic, were investigated underground by test adits and the ore treated in both the Ellweiler mill and in a local heap leaching operation. The mineralization was not economic and the work was terminated. Some uneconomic uranium mineralization was also found in the Wölsendorf fluorite deposit in Bavaria. Uranium exploration ended in the Federal Republic of Germany in 1988.

Through 1988, ~24 800 holes were drilled, totalling ~354.5 km. Total exploration expenses were roughly US $96.869 million for the Federal Republic of Germany (including 498 278 metres of drilling) and USD $1905 million for the German Democratic Republic (i.e WISMUT) (Fig. 4.19).

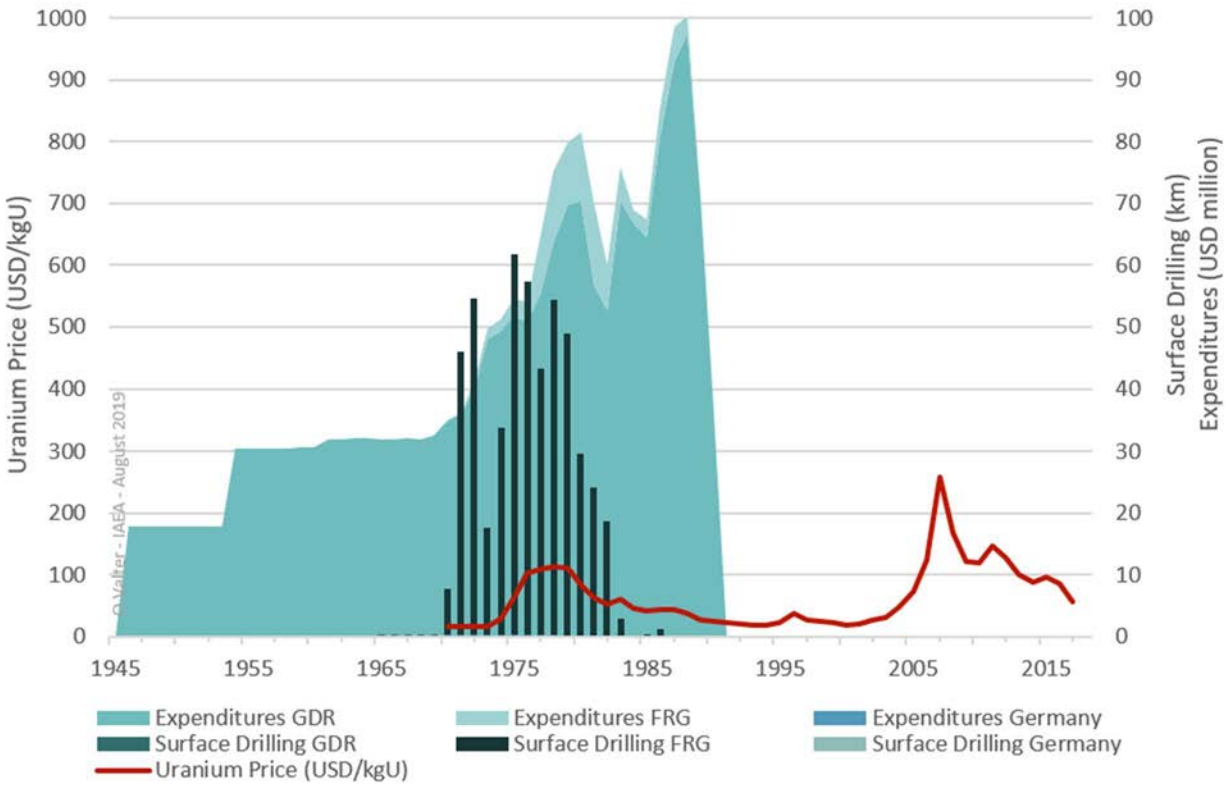


FIG. 4.19. Domestic uranium exploration data for Germany. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

Germany after 1990

Total uranium exploration expenses for Germany amounts to slightly over US $2 billion. Surface drilling was undertaken over an area of 28 000 km^2 and involved the drilling of ~60 000 holes. No exploration activities have been conducted in Germany since the end of 1990.

Several German mining companies undertook exploration overseas up to 1997, mostly in Australia, Brazil, Canada and the USA as well as in several African countries. They also participated in mining, e.g., at Key Lake (Canada), Arlit (Niger), Rössing (Namibia) and Ranger (Australia).

Exploration by companies was subsidized by the Ministry of Economic Affairs over the period 1972–1992. In the event that a uranium project proved successful, the company was obliged to reimburse the Ministry [7.5].

4.7.3.2. Historical uranium exploration in Germany

It should be noted that exploration expenses for Wismut are only reported for combined periods and not for specific years. Thus, for the period 1946–1953, a total expenditure of GDR Mark 600 million was reported and divided into equal yearly amounts of GDR Mark 75 million. For the period 1954–1982, total expenditure amounted to GDR Mark 3.9 billion, again divided into equal amounts of GDR Mark 128 million yearly. The total expenditure by Wismut in the period 1946–1990 was GDR Mark 5.6 billion.

Uranium exploration in the Federal Republic of Germany was terminated in 1988. The deposits found were small and of low grade compared with other occurrences elsewhere. In parallel, German mining companies successfully explored abroad and were also engaged in foreign joint venture mining operations. It was expected that German uranium requirements could be satisfied to the desired level by those activities.

4.7.3.3. Recent and ongoing uranium exploration and mine development activities

There are no current activities for exploration in Germany. Recently, there have been a number of expressions of interest in the Großschloppen deposit by national and international entities and junior mining companies. No reports or proposal are currently known with regard to exploration or drilling. Renewed activities for exploration in the uraniferous Pöhla mine, Erzgebirge, will concentrate on tin and tungsten [7.5].

4.7.3.4. Discovery costs

Total combined exploration expenses for both the Federal Republic of Germany and the German Democratic Republic in the period 1946–1990 are slightly over US $2 billion. This relates to a total of ~220 000 tU mined and total resources (known/identified resources plus undiscovered resources) of ~80 000 tU. The finding cost of total resources plus production are estimated at US $6.67/kgU. This compares to a world average of US $1.95/kgU. The relatively high discovery costs are the result of high exploration expenses in the former GDR.

If only identified resources plus production of ~220 000 tU are considered, the finding costs are US $8.85/kgU, as opposed to the world average of US $1.95/kgU [7.6].

4.7.4. Uranium resources

4.7.4.1. Identified resources

Identified resources, formerly referred to as 'known conventional resources' were last evaluated in 1993. These resources exist mostly in closed mines, which have been decommissioned. Future availability remains uncertain.

As of 1 January 2017, reasonably assured resources recoverable in the < US $260/kgU cost category amount to 3000 tU in unspecified deposits, and inferred resources recoverable in the <US $260/kgU cost category amount to 4000 tU in unspecified deposits.

Identified resources of 7000 tU may not be available owing to the closure of former mines [7.5].

The UDEPO database lists the most significant deposits for Germany as Niederschlema-Alberoda Ore Field, Schmirchau - Reust, Drosen, Paitzdorf, Koenigstein, Beerwalde-Korbussen, Zeitz – Baldenhain.

4.7.4.2. Undiscovered resources

All undiscovered conventional resources are documented as speculative resources of 74 000 tU, with unassigned cost categories.

4.7.4.3. Uranium deposits

As already noted, exploration for uranium was undertaken separately in the Federal Republic of Germany and in the German Democratic Republic. In the German Democratic Republic, exploration started in 1946 and many different deposits were found. These are summarized below according to their geological setting [7.4, 7.7].

In the Erzgebirge (Saxony), exploration was carried out on hydrothermal polymetallic vein deposits where pitchblende was known to occur. The deposits are hosted in peri-granitic veins in folded, faulted and overthrusted contact metamorphic rocks surrounding granitic intrusions of Hercynian age [7.8]. The host rocks are of Proterozoic, Cambrian, Ordovician and Devonian age, and comprise mica shales, banded shales and amphibolites.

Uranium mineralization persists to a depth of 2200 m. Major ore concentrations occur in lensoid bodies of 10–100 m^2 in size in the veins, attaining concentrations of 1–40 kg/m^2 (average 2.8 kg/m^2). The main uranium mineral is pitchblende, associated with quartz, dolomite and calcite. The upper parts of the veins carry sulphides and arsenides of a five element paragenetic suite (Bi, Co, Ni, Ag, U) which had previously been mined for centuries. Similar geological conditions prevail in the deposits situated in the adjacent mining area of Vogtland.

Mining of at least 12 (both large and small) deposits was conducted underground. By using radiometric ore sorting, an average head grade of >0.4% U was obtained. In the early phase of mining, the ore was also hand sorted and then shipped to the former Soviet Union for treatment.

The hydrothermal deposits of the Erzgebirge contained ~96 000 tU, of which ~83 000 tU were extracted. In the Vogtland district, ores containing ~6400 tU were mined, from which 5500 tU were extracted [7.7].

In Thuringia, over ten individual Ronneburg type deposits were exploited in an area covering ~50 km^2. The largest underground mines were excavated in the Ronneburg orefield. Uranium is associated with intensely folded and faulted rocks ranging in age from Upper Ordovician to Upper Devonian. The Upper Ordovician consists of micaceous slates with arenaceous, calcareous and pyritiferous phases (Lederschiefer). The Lower Silurian strata are developed as siliceous, argillaceous, sapropelitic black shales (up to 10% organic) with pyrite and marcasite (Graptolithenschiefer) and as limestone/dolomite (Ockerkalk). Upper Devonian diabase intrusions are also present.

The uranium deposits formed throughout complex, multistage processes. The Silurian black shales contain syngenetic uranium in concentrations up to 60 ppm U. Weathering throughout the Permian period down to a depth of ~100 m resulted in uranium, carbonate and sulphur being leached out and transported along fractures into reducing environments that formed a geochemical barrier favouring the precipitation of pitchblende, carbonate and minor amounts of sulphides of lead, zinc and copper, and arsenides of cobalt and nickel. The formation of uranium mineralization took place about 240–180 Ma and ~90 Ma. The deposits are classified under the IAEA terminology as black shale owing to the source of uranium being derived from Silurian black shales.

The uranium content in the mined ore is typically in the range 0.085–0.097% U, but sometimes exceeds 0.1% U. Initially, some deposits were mined by open pit (e.g., Lichtenberg open pit near Ronneburg), although the majority were mined underground.

The ore mined at deposits of the Ronneburg type (between 1950 and 1990) contained 113 000 tU from which ~97 000 tU were extracted. About 12 000 tU were produced by open pit [7.7].

In Saxony, uranium deposits of the sandstone type were found in Cretaceous sandstones near Königstein/Elbsandsteingebirge. These are similar to the Staz and Hamr deposits in the Czech Republic and occur on the northern extension of a Cretaceous basin.
The sedimentary rocks are Cenomanian and Turonian in age and were deposited under continental lagoonal to marginal marine conditions in sequences up to 50 m thick in the depression of the Elbtal Graben. The orebodies have dimensions of roughly 1500 m × 100–150 m in area and vary in thickness in the range of 0.5–2.5 m. The ore minerals are pitchblende and uranium assemblages related with organic material and pyrite. In the 'stack' ore, uranium is associated with haematite and baryte.

In 1967–1983, conventional underground mining produced ore at a grade of 0.11% U. Beginning in 1971, underground acid stope leaching was applied to low grade zones and from 1983 onwards underground stope leaching was the only mining method used.

By 1990, a total of ~16 700 tU had been produced. Commercial production was terminated in 1990, although since that time some uranium continues to be recovered as a result of the cleanup of contamination associated with the mining operation [7.7].

In Thuringia, deposits of the Upper Permian Zechstein type were mined. These occur in continental to lagoonal sandstone, shale and dolomite. The mineralogical non-defined uranium is very finely disseminated and occurs in the interstitial cement of the sedimentary rocks. Open pit mining was used to recover ~10 000 tU from ores having an average grade of 0.066% U.

Near Dresden, uranium mineralization was found in 1946 in the Lower Permian (Rotliegendes) coal deposit of Freital. Mining of uranium was conducted over two time periods: 1947–1955 and 1968–1989. Uranium occurs as pitchblende and coffinite disseminated with pyrite in three coal seams and grades vary from 0.05% U to as high as 0.25% U on occasion. In the 1947–1955 period, less than 300 tU were extracted; in the second period (1968–1989) ~2600 tU were recovered. Following radiometric sorting, uranium extraction was undertaken in the mills at Crossen and Seelingstadt [7.7]. The deposit is classified as lignite.

UDEPO lists 16 deposits of which 12 are in Saxony and Thuringia (Fig. 4.18). Eight of these are vein deposits. Several mines are actually located at some of the locations, thus the total is greater than 8: Annaberg, Antonsthal, Johangeorgenstadt, Niederschlema–Alberoda, Oberschlema, Schneckenstein, Tellerhäuser and Zobes.

All of the deposits are now depleted and are either undergoing reclamation or have already been totally reclaimed. The Culmitzsch sandstone deposit is depleted and has been reclaimed. The Königstein sandstone deposit is listed as depleted, although some uranium mineralization remains in the mine. While commercial mining has ceased, some uranium is recovered from mine water incidental to the treatment of mine waters throughout reclamation.

The deposits of the Ronneburg type are listed in UDEPO under Ronneburg orefield in which a number of individual mines are dealt with. All are under reclamation or have already been totally reclaimed [7.10].

Table 4.3 lists, in summarized form, the deposits in the Wismut district [7.11]. Further details are provided in Ref. [7.11].

In the Black Forest, the vein type deposit of Krunkelbach, Menzenschwand district, has been investigated underground. After producing 583 tonnes of uranium at a grade of 0.6%, the mine was closed owing to economic and environmental reasons. Remaining resources are estimated at ~1500 tU of reasonably assured resources and ~5000 tU of inferred resources [7.12]. The Menzenschwand District contain a great number of granite-related vein-type uranium showing which have not been investigated in detail [7.13].

Several small deposits in Bavaria were investigated underground in the Fichtelgebirge, Upper Palatine Forest, and in the Bavarian Forest. These comprise vein type mineralization at both Großschloppen/Fichtelgebirge and at Wäldel-Poppenreuth/Upper Palatine Forest. The grades and resources were found to be uneconomic and as a result further underground evaluation was discontinued. According to estimates, the resources remaining at Großschloppen are 1500 tU and those at Wäldel/Poppenreuth are 1000 tU [7.12].

After underground evaluation, the sandstone type mineralization at Müllenbach, which occurs in an Upper Carboniferous sandstone basin in the northern Black Forest, was found to be uneconomic. According to estimates, the remaining resources total ~3000 tU [7.12].

TABLE 4.3. URANIUM DEPOSITS OF THE RONNEBURG DISTRICT [7.11]

Deposit	Identified resources (tU)	Prognosticated resources (tU)
Ronneburg:		
Schmirchau/Reust	6620	1500
Paitzdorf	6190	0
Beerwalde	15 910	0
Drosen	23 100	3760
Others	0	30 140
Total Ronneburg orefield	51 820	35 400
Erzgebirge:		
Schlema orefield	1040	5020
Pöhla	760	4580
Total Erzgebirge	1800	9600
Total Königstein orefield	4300	4250
Total Culmitzsch orefield	0	3350
Aggregate total (Wismut)	57 920	74 000

4.7.5. Potential for new discoveries

Some potential may exist in the Moldanubian, as it has not been explored in detail. However, nature conservation and other ecological restrictions would prevent any such exploration.

In the Ronneburg orefield, uranium mineralization occurs at depth but this remained unexploited when the decision was made to close the mines. In the Königstein mine, some low grade ore remains but will not be mined.

4.7.6. Uranium production

4.7.6.1. Historical review

Federal Republic of Germany before 1990

From 1960, the treatment plant at Ellweiler, in Baden-Württemberg, was ran by Gewerkschaft Brunhilde. Serving as a test mill for various types of ore, its yearly capacity was 125 tU. Ellweiler shut down in 1989 after generating ~700 tU (Fig. 4.20). The ore for this plant was shipped initially from the nearby open pit in limited amounts only. Subsequently, the mill received ore from the vein deposit at Menzenschwand (Black Forest), producing about 10–30 tU yearly. Small quantities also came from the underground mines and heap leach operations at Wäldel/Poppenreuth, near the border with the Czech Republic [7.6].

Former German Democratic Republic

Two processing plants were ran by SDAG Wismut (Fig. 4.20). The plant at Crossen, near Zwickau, in Saxony, began treating ore in 1950. The ore was transported by rail and road from several mines in the Erzgebirge. The ore from the hydrothermal deposits has a composition that necessitated carbonate pressure leaching for processing. The plant's maximum yearly capacity was 2.5 million t ore. Crossen was shut down on 31 December 1989.

FIG. 4.20. Historical uranium production in Germany (in dark green production data from GDR, in light green from FRG, in green from Germany) [7.5–7.14].

The second plant, at Seelingstadt, near Gera, Thuringia, began operations for ore treatment in 1960 using the nearby deposits of the Ronneburg type (black shales, uranium in stockwork and fissures). The plant's maximum yearly capacity was 4.6 million t ore. Siliceous ore was processed by acid leaching until the end of 1989. Carbonate rich ores were processed by the carbonate pressure leaching method. After 1989, operations at Seelingstadt were restricted to the processing of slurry generated at the Königstein mine also using the carbonate route.

From 1992, all production of uranium in Germany has come from cleanup operations at the Königstein mine [7.6]. Total historical production for Germany to 2017 is 218 831 t U.

4.7.6.2. Status of production capability

There is no commercial uranium production. From 1991, uranium has been recovered from cleanup activities at former working mines. Over the period 1991–2008, recovery of uranium from mine water processing and environmental restitution has been estimated at 2431 tU [7.14].

4.7.6.3. Ownership structure of the uranium industry

In August 1998, Cameco and COGEMA completed the purchase of Uranerz USA Inc. and Uranerz Exploration and Mining Ltd, Canada, from Uranerzbergbau GmbH (jointly owned (50%) by Preussag and Rheinbraun) – their German parent company. Urangesellschaft/Interuran was acquired earlier by Compagnie Générale des Matières Nucléaires. Consequently, no commercial uranium industry remains. The Government, through Wismut GmbH, keeps proprietorship of all uranium recovered in cleanup.

4.7.6.4. Future production centres

No future production centres were documented in the 2009 Red Book [7.14]. Owing to the uneconomic status of the remaining resources and Government policy, it is not expected that uranium will be mined.

4.7.7. Environmental activities and sociocultural issues

After reunification in 1990, commercial production of uranium ended. The Government assumed responsibility for restoration of past production sites and allotted €6.6 billion to cover projected costs. Up to the end of 2007, at least €5 billion had been spent, resulting in substantial reduction in undesirable environmental impacts. Expenses linked to USD $2071 million of environmental activities are given in Fig. 4.21 including tailings rehabilitation USD $314 million, monitoring USD $193 million, site rehabilitation USD $284 million, water treatment USD $459 million and waste rock management of USD $821 million [7.5]. Details on environmental activities and expenses are given in Refs [7.15, 7.16]. All employment is engaged in the restoration of previous production facilities totalling 250 000 person–years.

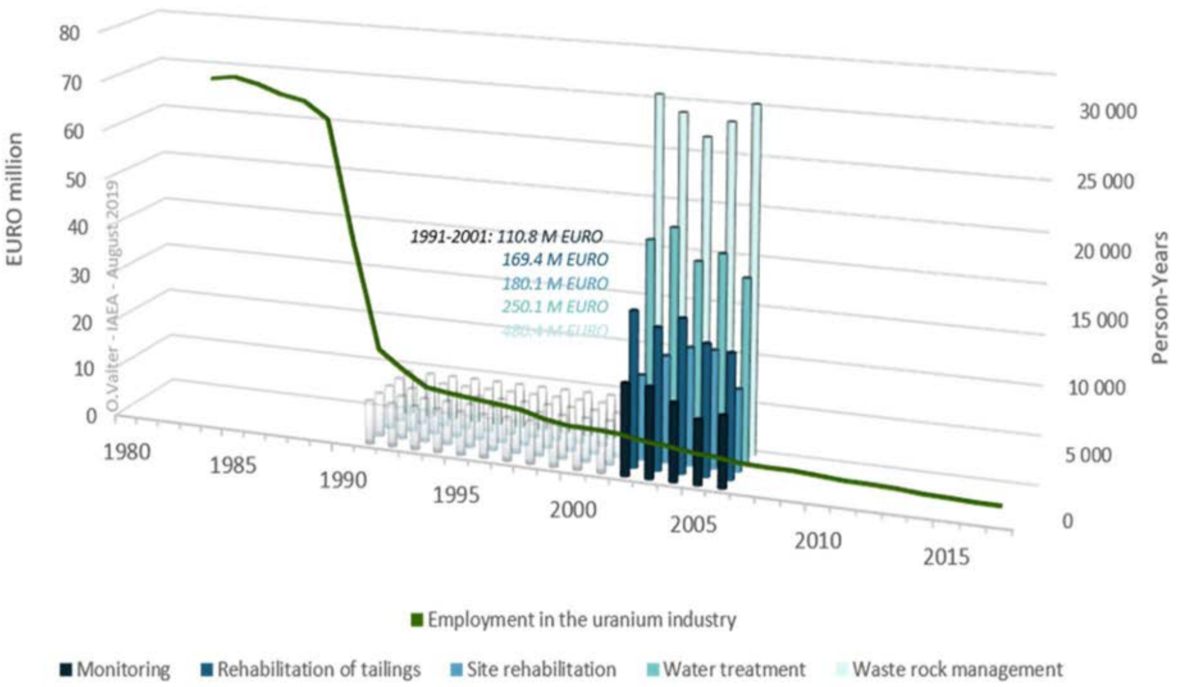


FIG. 4.21. Employment in the uranium industry and rehabilitation expenditures.

References to Section 4.7

[7.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Germany, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed 16 March 2008).
[7.2] HENNINGSEN, D., Einführung in die Geologie der Bundesrepublik Deutschland, F. Enke Verlag, Stuttgart (1976) 119 pp.
[7.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.
[7.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).
[7.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[7.6] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.
[7.7] BARTHEL, F.H., Die Urangewinnung auf dem Gebiet der ehemaligen DDR von 1945 bis 1990, Geol. Jahrb. A **142** (1993) 335–346.
[7.8] DAHLKAMP, F.J., Uranium Ore Deposits, Springer Verlag, Berlin (1993).
[7.9] BARTHEL, F.H., Uran-Prospektion in der Bundesrepublik Deutschland, Naturwis-senschaften **64** (1977) 499–506.
[7.10] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[7.11] WISMUT GMBH, Chronik der Wismut, Chemnitz, CD-ROM (1999) 2738 pp
[7.12] DIEHL, P., Uranabbau im Westen Deutschlands, WISE Uranium Project, Mining and Milling (October 1991).
[7.13] DAHLKAMP, F.J., Uranium Deposits of the World - Europe, Springer Verlag, Berlin (2016) 800 p.
[7.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[7.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999) 104–110.
[7.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002) 222–230.

4.8. HOLY SEE

4.8.1. Geology

The Holy See is underlain by rocks younger than ~3.5 Ma. This includes, from the lowest sequence, marine clays and sands, followed by pre-volcanic gravels, clays and sands deposited by the Tiber River and its tributaries and in turn overlain by pyroclastics and tuffs younger than ~500 000 years, intermixed with syn-volcanic continental gravels, sands and clays.

4.8.2. Comments

There are no known uranium or nuclear activities related to the Holy See. The Holy See has never reported to the Red Book.

The UDEPO database does not list any known deposits for the Holy See.

4.9. ICELAND

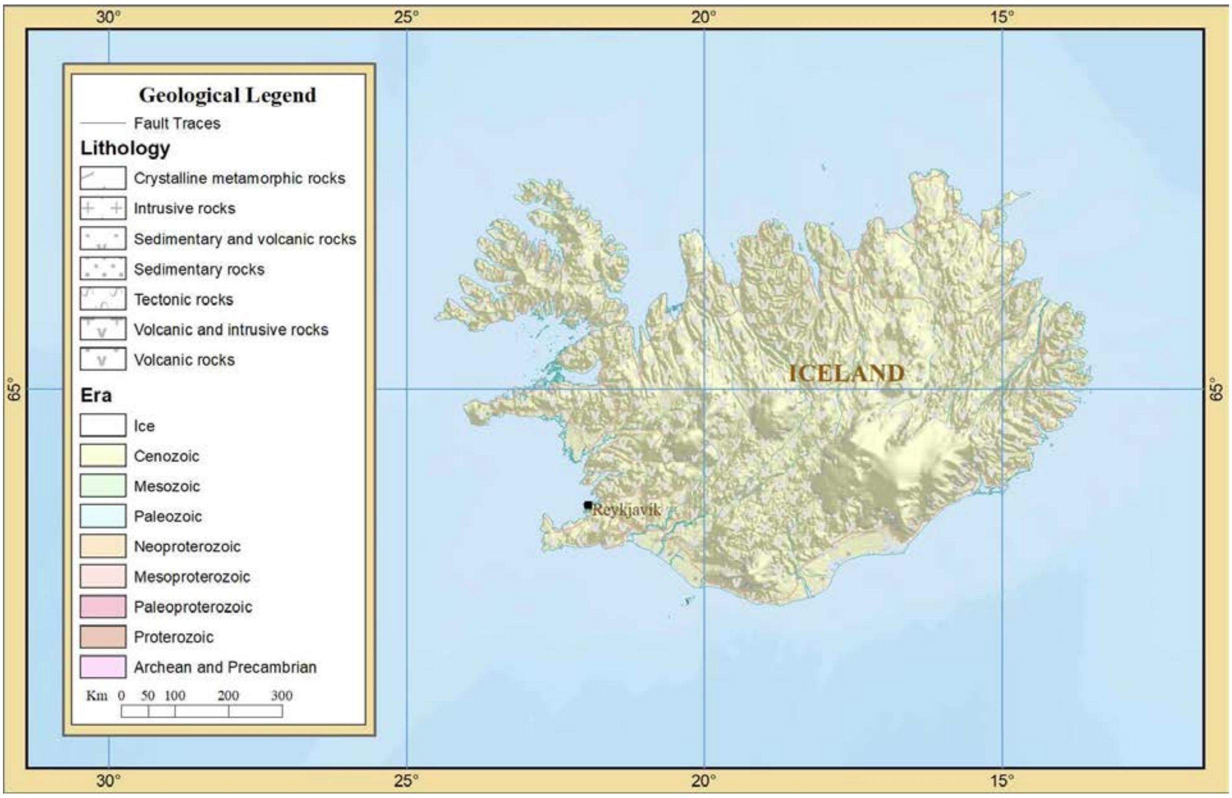
4.9.1. Geography

Iceland is an island located in the North Atlantic Ocean, south of Greenland and immediately south of the Arctic Circle. The island is dominated by rocks of volcanic origin and ~10% of its surface is covered by glaciers (e.g., Vatnajökull in the SE). The terrain is dominated by features related to tectonic rifting and related volcanic activity, including grabens, as well as volcanic peaks and craters. Recent volcanism and ongoing seismic activity are commonplace. For example, throughout the Late Pleistocene and Holocene, 41 mapped volcanic systems have been active within Iceland and on its insular shelf. Geologically, Iceland is a very young country.

Geothermal energy is a widely used resource [9.1].

4.9.2. Geology

Iceland (Fig. 4.22) is the only location where the meeting of two tectonic plates occurs above sea level and is situated on the Mid-Atlantic Ridge, on the boundary of the Eurasian and North American Plates. The ridge trends roughly NE–SW, running through the middle of the island. Iceland also lies at the junction where the Mid-Atlantic Ridge crosses the Caledonian suture, which marks the site of a subduction zone dated to ~400 Ma.



4.22. Regional geological setting of Iceland. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Iceland is also interpreted by some, but not all geoscientists, as being situated over a mantle plume. Seafloor spreading and possibly a mantle plume are the source of Iceland's intense volcanic activity. Rising magma pushes up through fissures around the ridge, creating lava flows that continue to add to the landscape. Active spreading is observed, giving rise to volcanic activity (eruptions, geysers and numerous earthquakes).

Whereas the rift zone volcanic systems produce tholeiitic basalts, the major products of the off-rift volcanic zones are mildly alkaline and transitional (tholeiitic to alkaline) basalts. The tholeiitic rift zone volcanism and mildly alkaline flank zone volcanism in Iceland are equivalent to the main shield building tholeiitic stage and the pre- and post-shield building alkaline stages of the Hawaiian volcanoes. Approximately 75% of the rocks are basaltic, 14% are intermediate and 11% are silicic in composition. The silicic rocks comprise rhyolites, dacites and other acid types.

The elongated central ridge area consists of the youngest rocks and the age of the rocks increases both to the west and to the east, with the oldest rocks dated at more than 3 Ma located furthest from the central zone. Rocks as old as ~15 Ma occur in the far west of Iceland [9.2, 9.3].

4.9.3. Uranium resources

No uranium occurrences or deposits have been reported. The UDEPO database does not list any known deposits for Iceland.

4.9.4. Potential for new discoveries

Owing to the predominance of oceanic basalt and a related series of rocks, Iceland is judged to have little or no potential to host uranium deposits.

4.9.5. Comments

Iceland has no current or planned nuclear activities.

References to Section 4.9

[9.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Iceland, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html

[9.2] TRØNNES, R.G., Geology and Geodynamics of Iceland, Nordic Volcanological Institute, University of Iceland, https://notendur.hi.is/oi/Pdf%20reprint%20library/Geology%20and%20geodynamics%20of%20Iceland.pdf

[9.3] JAKOBSSON, S.P., JÓNASSON, K., SIGURDSSON, I.A., The three igneous rock series of Iceland, Jokull No. **58** (2008) 117, http://www.nattsud.is/skrar/file/Jokull58.pdf

4.10. IRELAND

4.10.1. Geography

Ireland is an island that borders the United Kingdom (Northern Ireland) to the north. It is situated in the Atlantic Ocean and is surrounded by the Irish Sea, Celtic Sea and Atlantic Ocean.

The largest part of the country is covered by the central lowland, which includes numerous lakes and abundant peat bogs. To the east, the lowland extends to the Irish Sea. The lowland is surrounded by hilly areas in the north, west and south and partly in the east. The Wicklow Mountains in the east reach an elevation of 923 m. The highest mountains, however, are located in the SW, in County Kerry, where elevations attain 1041 m. The entire south, extending from the Wicklow Mountains to the SW corner peninsula, is characterized by irregular groups of hills. Heath and pasture are the other characteristics of the country.

Many parts of the country, especially the centre, are underlain by limestone, which produces poor soil and is subject to karst formation (as in the landscape of the Burren, in County Clare). In the north of the island, basaltic flows with columnar jointing have produced a distinctive landscape known as the Giant’s Causeway.

The climate is temperate and has a strong Atlantic influence. Summers are mild but not hot and the winters also tend to be mild, with temperatures usually above 0°C. Rainfall may occur throughout the year. There is a considerable difference in the amount of precipitation between the west and the east; the amount of rain falling in the west may be twice as much as in the east [10.1, 10.2].

4.10.2. Geology

The oldest rocks are of Precambrian age and comprise metamorphics (Fig. 4.23), located in the extreme west and north, which are mostly overlain by younger cover. The Palaeozoic (Cambrian) occurs in the SE and consists of sandstone, slate and quartzite deposited on the shelf. The Ordovician and Silurian consist mainly of arenitic deep water sediments, intersected by basic volcanic rocks of subduction zone processes. Ordovician and Silurian strata can be found in the SE, to the north of Dublin and in the SW. The formations of Cambrian–Silurian age have been folded in the Caledonian Orogeny. The latest phase carries granitic intrusions.

The Devonian is represented by the Old Red Sandstone, which is thought to have been deposited by large river systems under arid to semi-arid conditions. The landscape of the south and SW is dominated by the underlying Devonian sedimentary rocks, which are marine in the south.

Large parts of Ireland comprise marine Carboniferous limestone, which were deposited under tropical conditions. In the upper part of the Carboniferous, the depositional environment becomes lacustrine. Sedimentation turns to become arenitic, where deposition occurs under swampy conditions with the formation of coal beds in southern Ireland. The period is marked by Hercynian Orogeny. The Permian and Triassic are marked by the New Red Sandstone, which comprises arenitic continental sediments deposited under arid to semi-arid conditions.

Most of the Jurassic and Cretaceous strata are not exposed. The Upper Cretaceous is present as shallow marine limestone sediment in the form of chalk.

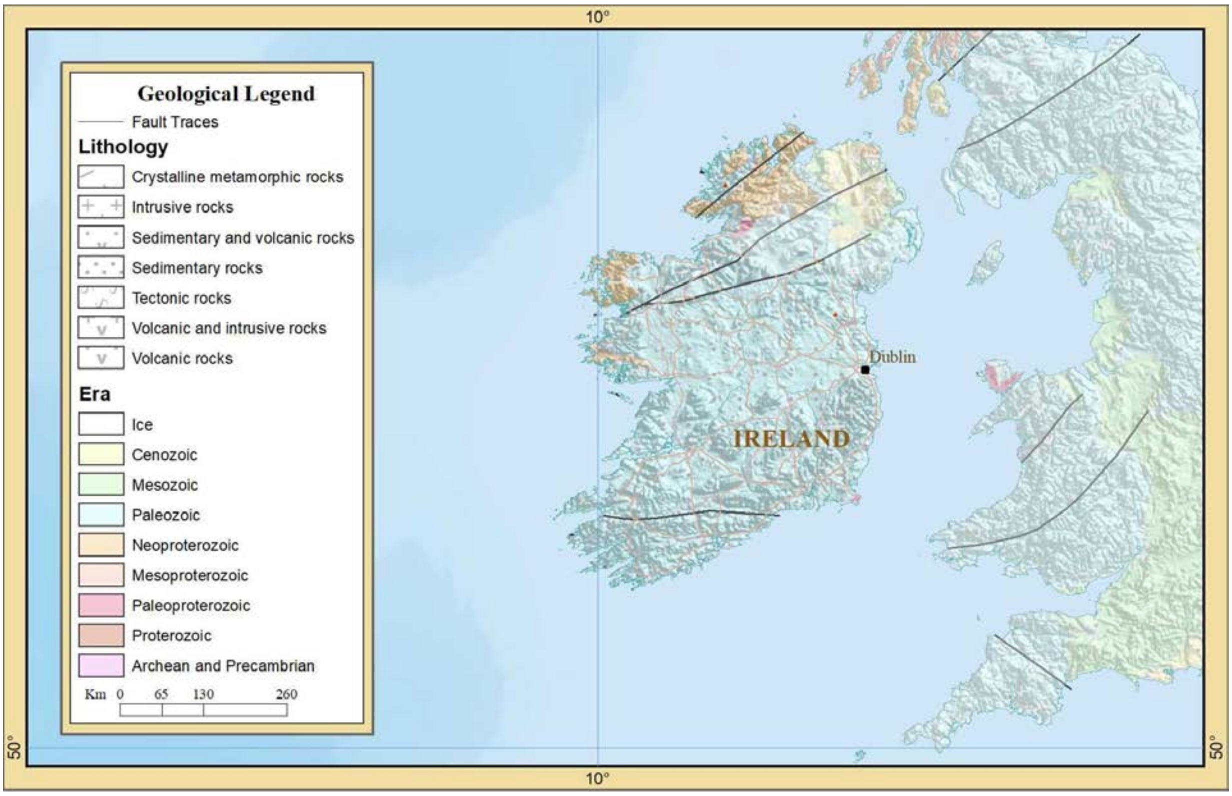


FIG. 4.23. Regional geological setting of Ireland. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Lower Tertiary is characterized by volcanic activity. In the Middle Tertiary, clays were deposited.

Peat is an important natural resource and has been used as an energy source for centuries. Oil and gas are produced offshore. Ireland is an important producer of lead and zinc from three operating mines: Navan, Galmoy and Lisheen. Other known commodities include some gold, silver and industrial minerals and construction minerals [10.1–10.3].

4.10.3. Uranium exploration

Exploration for uranium started in 1973, conducted mainly by the Geological Survey of Ireland, with support from the European Commission. Initial work included reconnaissance with radiometry and geochemical surveys. Airborne radiometry recorded no positive results. Additional ground surveys in Leinster, Connemara and Donegal were conducted over Caledonian granites and the results were deemed worthy of more detailed investigation, which was undertaken by exploration companies. Total exploration expenses in the period 1973–1982 amounted to US $6.2 million (Table 4.4). No economic findings were made and exploration stopped in 1982 [10.4]. No recent exploration for uranium has been reported.

TABLE 4.4. SURFACE DRILLING

Year	1973–1978	1979	1980	1981	1982
Drilling (m)	3000	3480	7793	1300	Not reported
Number of holes	20	161	188	Not reported	

4.10.4. Uranium resources

No uranium resources have been documented.

The UDEPO database does not list any known deposits for Ireland.

4.10.5. Potential for new discoveries

Caledonian granites and favourable lithologies in the continental Old Red Sandstone may have some potential, although the potential is rated as low.

4.10.6. Environmental activities

The occurrence of radon in certain areas was the primary reason that a national survey was carried out, which was announced as having been completed at the end of 1998. No official report has been made available.

References to Section 4.10

[10.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Ireland, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2008).

[10.2] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Ireland, IAEA, Vienna (1977).

[10.3] GEOLOGICAL SURVEY OF IRELAND, Bedrock Geology of Ireland, GSI, Dublin (2004).

[10.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

4.11. ITALY

4.11.1. Geography

Italy extends into the Mediterranean Sea and includes the major islands of Sicily and Sardinia, as well as a number of smaller islands. It has land borders with France, Switzerland, Austria and Slovenia.

The Italian peninsula, with its famous 'boot-like' shape, has a length of ~1000 km and a width of 130–250 km. Sicily is situated at the southern tip of the peninsula. In general, the country is very mountainous, with ~75% covered by mountainous and hilly terrain. Mont Blanc, with an elevation of 4807 m, is the highest mountain massif in the Alps and straddles the border with France. From a morphological and physiographic point of view, from north to south, Italy consists of the Alpine mountainous region, which extends from the north-western part and forms the northern border with Switzerland and Austria, and entering Slovenia in the east. The highest mountains are permanently snow-capped. A number of deep, north–south trending valleys extend south from the Alps and host large lakes, as exemplified by Lake Maggiore, Lake Como and Lake Garda.

South of the Alps, the Po River's wedge shaped plain extends west–east. South of the Po River, the Apennine Mountains run NW–SE through the central part of Italy. Small coastal plains are found in the centre and in the south.

The country has several volcanoes, including Mount Vesuvius, near Naples, and the active Mount Etna, in Sicily. The Aeolian Islands, north of Sicily, are also volcanic, and include the active volcanoes Mount Stromboli and Vulcano.

The island of Sicily is characterized by a mountain chain, with Mount Etna located at its eastern end. On Sardinia, low-range mountains are distributed throughout the island, intersected by several river valleys.

The climate varies according to the geographical location. The northern alpine area has cold winters with abundant snow and temperate summers. In the valleys south of the Alps, the climate is milder. The lowlands generally have mild climatic conditions influenced by the Mediterranean. In the Apennines, the winters can be cold and the summers are temperate to warm. To the south the climate is warmer. In general, winters tend to be mild and summers hot.

Roughly 35% of the country is arable and roughly one quarter is covered by forest and woodland. Depending on the climate and the fertility of the soil, rice and corn are grown. Citrus fruit and grapes are also intensively cultivated in some areas.

Natural resources include marble, building stone, mercury and potash, as well as some natural gas and crude oil. The mountainous terrain poses risk from natural hazards, such as landslides and winter avalanches. Italy is seismically active, and volcanic eruptions and earthquakes pose another natural hazard [11.1, 11.2].

4.11.2. Geology

Italy's geology (Fig. 4.24) is very diverse and therefore in this report only the geology of potentially favourable uranium-bearing areas will be described. For further details refer to Refs [11.3–11.7].

Structural settings are mainly the result of activity throughout the Miocene period which was related to the latest phase of the Alpine Orogeny that resulted from the collision between the northerly moving African Plate and the Eurasian Plate. In the mountain chains, older strata are preserved and these may be of importance as regards ore genesis. The oldest complexes are probably of early Palaeozoic age, deformed by the Caledonian and Hercynian orogenies. Acidic intrusions of both orogenic phases provide pre-concentrations of uranium. In the Alps, throughout the Late Carboniferous and more importantly throughout the Permian period, continental basin-like areas formed which contain the debris of older rocks. The sediments are arenitic, deposited in lagoons in littoral and deltaic environments. Intercalations of Lower Permian intermediate to acid volcanic rocks are common. These strata are favourable for the formation of uranium deposits in the Southern Alps.

In Calabria, Hercynian massifs hosting intrusions of granitic composition have been found to be favourable for uranium ore formation. In the Latium region (west central Italy), basins with continental sediments of Quaternary age and alkaline volcanic rocks are enriched in uranium and have been subjected to detailed exploration. In Sardinia, Hercynian granites, together with volcanic rocks of alkaline composition and of Permian and Tertiary age, were found to be prospective.

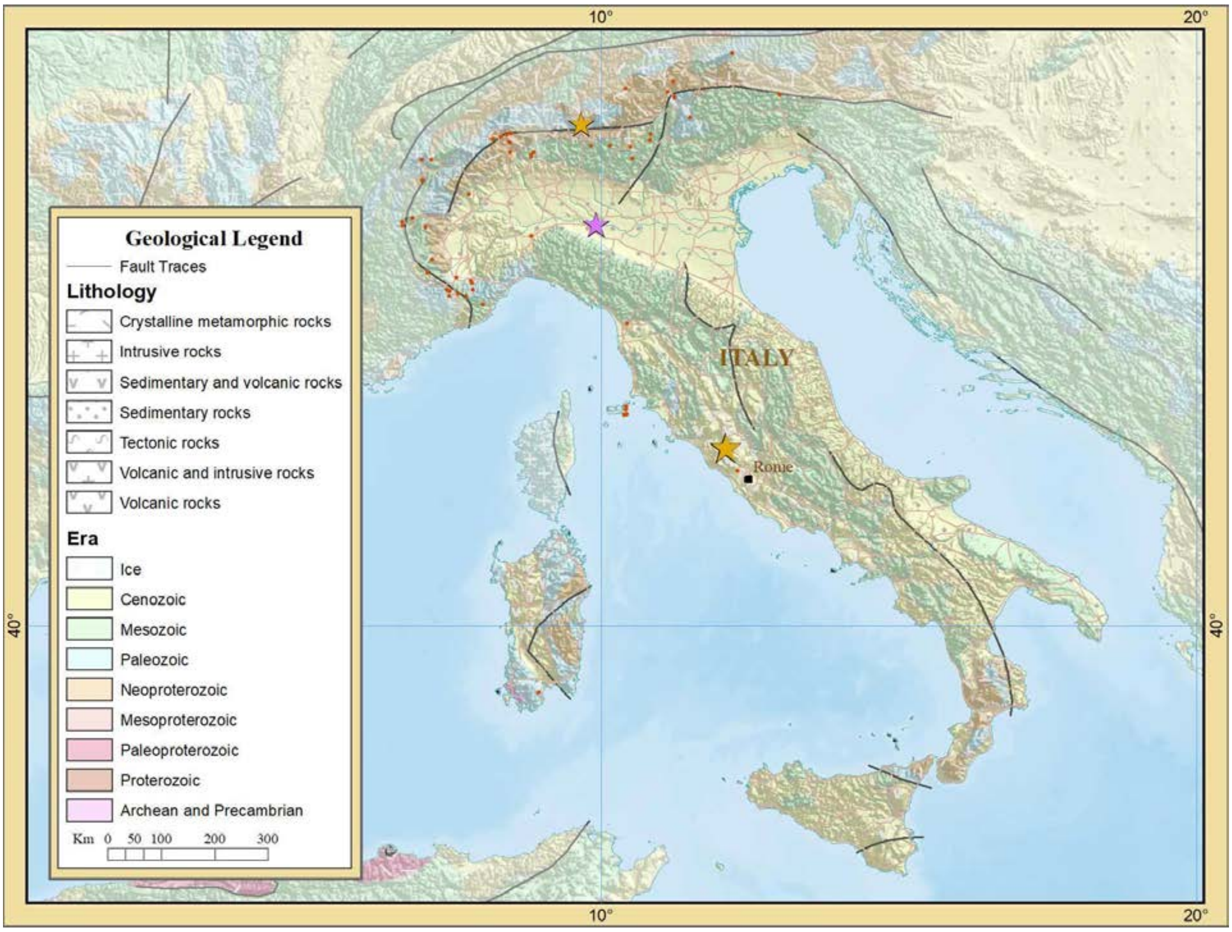


FIG. 4.24. Regional geological setting of Italy showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.11.3. Uranium exploration

Uranium exploration began in Italy in the 1950s with a reconnaissance survey of all favourable areas. This led to the finding of the Novazza deposit between 1954 and 1962. This deposit, located in the Bergamasc Alps, west of Bolzano, consists of volcanic-hosted mineralization of Permian age. A similar deposit was found throughout exploration at Valvedello, near Novazza, in 1975–1983. The Novazza mineralization occurs in a Permian ignimbrite host, which has been subjected to sodic metasomatism. Pitchblende and sphalerite exist in microfractures and were formed at temperatures of between 80° and 100°C. Total exploration expendituirs of USD $ 75 million (including 178 973 metres of drilling) were incurred (Fig. 4.25).

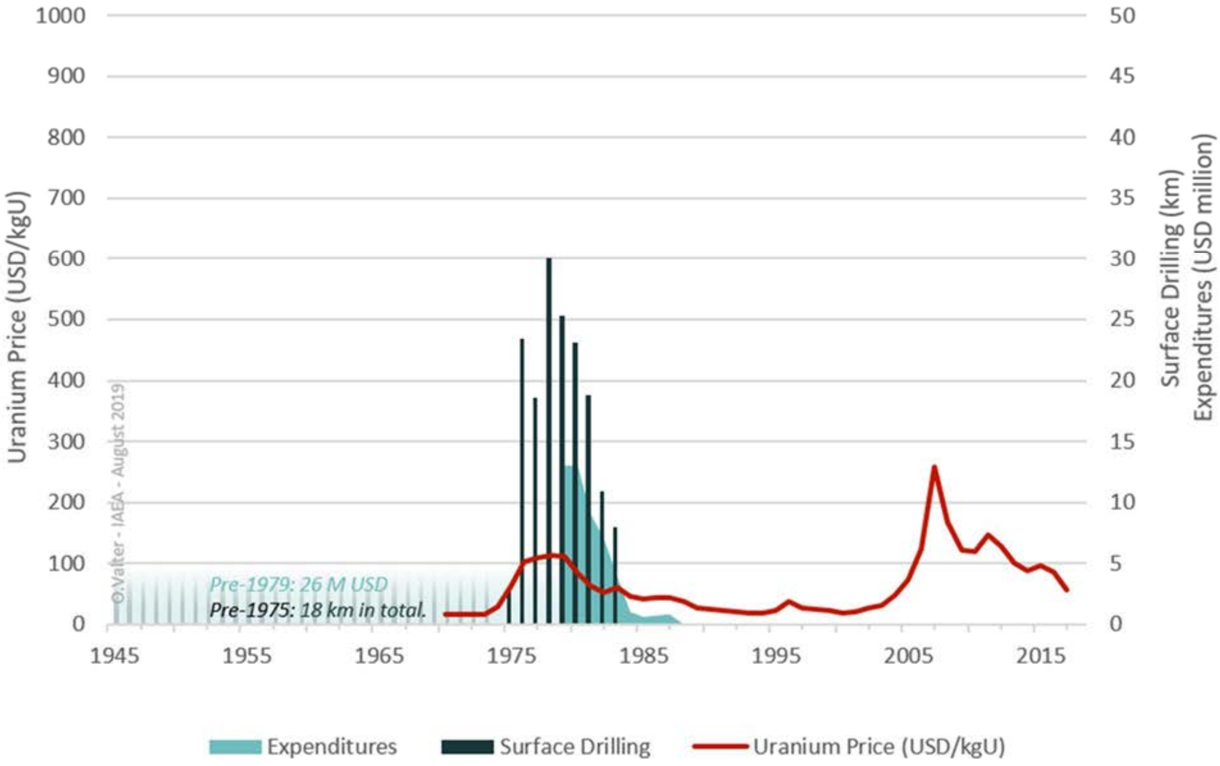


FIG. 4.25. Domestic uranium exploration data for Italy. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

Other mineralization of interest has been found at several places in the Permian of the Southern Alps. The most promising are in the Val Rendena and Val Daone areas in the Trento region of northern Italy. Pitchblende and pyrite occur with organic material in coarse-grained grey sandstone located below red sandstones. Other occurrences of limited interest include veinlets hosting pitchblende and sulphides in Hercynian granites of the Mount Blanc Massif, and small-scale mineralization in the contact metamorphics and granites of southern Sardinia and Calabria [11.8, 11.9].

4.11.4. Uranium resources

Resource estimates made in 1987 were reported in the 1991 Red Book [11.9]. No more recent updates are available. The 1987 estimates are:

(a) Reasonably assured resources at <US $80/kgU: 4800 tU;
(b) Estimated additional resources (EAR-1) at US $80–130/kgU: 1300 tU;
(c) Speculative resources at <US $130/kgU: 10 000 tU.

According to UDEPO and the Red Book, the reasonably assured resources and EAR-1 occur in the volcanic type Novazza and Valvedello deposits. Both projects are currently dormant. UDEPO reports Novazza’s resources as 1000–2500 tU at grades of 0.05–0.1% U and Valvedello’s resources as 2500–5000 tU at grades of 0.05–0.1% U.

IUREP reports reasonably assured resources for Novazza as 1200 tU at a grade of 0.09% U, and EAR-1 and inferred resources at 1000 tU [11.1, 11.8].

The UDEPO database lists the most significant deposits for Italy as Val Vedello, Novazza, Preit Valley, Val Rendena, Val Seriana.

4.11.5. Uranium production

Italy does not produce uranium. The Valvenova production centre, with a yearly output capacity of 260 tU, was built to process ores from underground mines at the Novazza and Valvedello deposits. The plant never operated.

4.11.6. Potential for new discoveries

The potential for new discoveries is believed to lie within the continental series of Permian strata, which are located in the Alps. However, most Alpine areas are in environmentally sensitive zones, such as national parks and tourist destinations or have restrictions as regards mining. The same restrictions would apply to those areas where granitic intrusions have potential, such as in the Alps, as well as in other parts of the country.

References to Section 4.11

[11.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Italy, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed February 2008).

[11.2] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Italy, IAEA, Vienna (1977).

[11.3] LOCARDI, E., PANTANETTI, F., "Search for uranium in Italy: Criteria adopted and results", Exploration for Uranium Ore Deposits (Proc. Int. Symp. Vienna, 1976), IAEA, Vienna (1976) 545–549.

[11.4] BARTHEL, F.H., "Review of uranium occurrences in Permian sediments in Europe, with special reference to uranium mineralizations in Permian sandstone", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 277–289.

[11.5] MITTEMPERGHER, M., "Genetic characteristics of uranium deposits associated with Permian sandstones in the Italian Alps", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 299–312.

[11.6] LOCARDI, E., "Geologic environments of uranium deposits in Quaternary volcano-sedimentary basins in central Italy", Geological Environments of Sandstone-Type Uranium Deposits, IAEA-TECDOC-328, IAEA, Vienna (1985) 83–98.

[11.7] FUCHS, Y.A., "Hydrothermal alteration at the Novazza volcanic field and its relation to the U–Mo–Zn Novazza deposit, Northern Italy", Metallogenesis of Uranium Deposits (Proc. Tech. Mtg Vienna, 1987), IAEA, Vienna (1989) 137–151.

[11.8] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[11.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

4.12. LIECHTENSTEIN

4.12.1. Geography

Liechtenstein is a landlocked country (Fig. 4.26) located in central Europe and is bordered by Switzerland and Austria. It is bordered to the west by the Upper Rhine River and to the east by part of the Raetikon Ridge of the Alps. The country imports 100% of its energy supply.

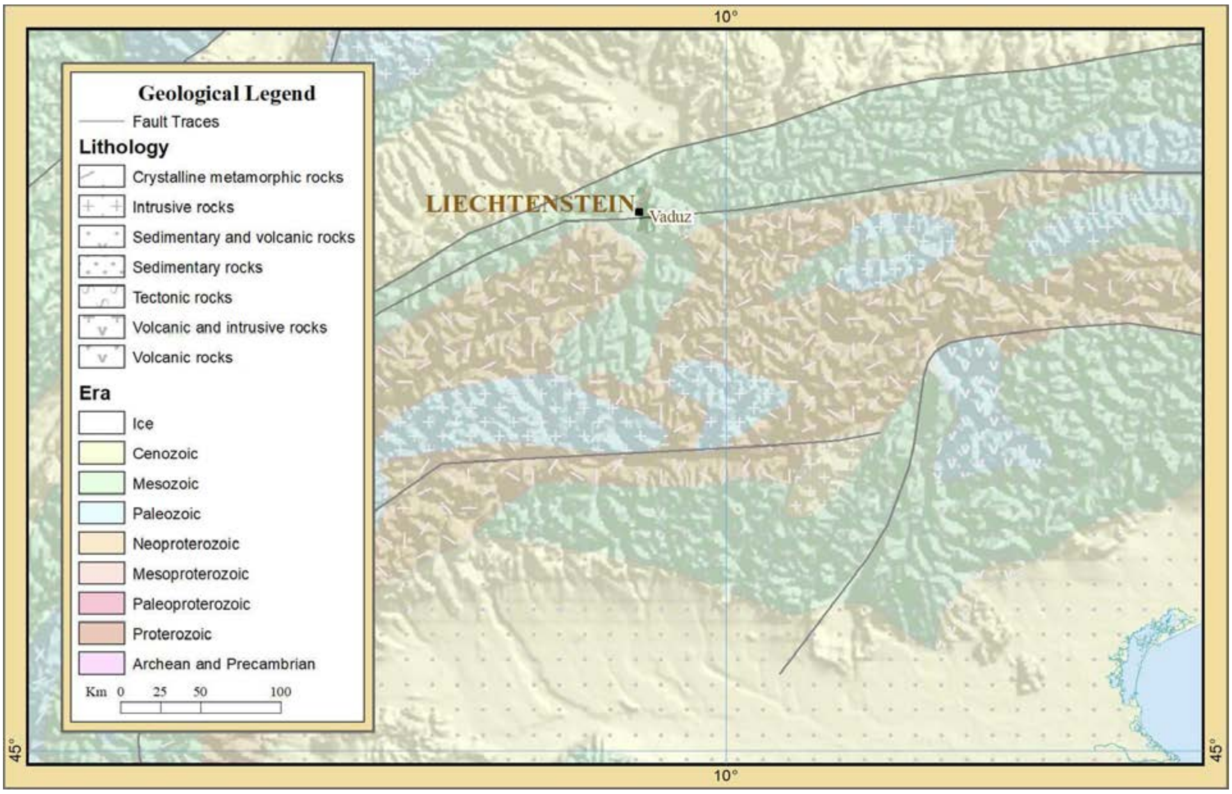


FIG. 4.26. Regional geological setting of Liechtenstein. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.12.2. Comments

No uranium occurrences and/or deposits have been reported. The country has no nuclear power programme.

The UDEPO database does not list any known deposits for Liechtenstein.

4.13. LUXEMBOURG

4.13.1. Geography

Luxembourg is a landlocked country (Fig. 4.27), bordered to the west by Belgium, to the east by Germany, and to the south by France. The northern basement of Luxembourg consists of Devonian schist and quartzite, while the central part includes Triassic and Jurassic limestone, sandstones and dolomites. The minette iron ore of the Dogger (Middle Jurassic) was of historic local significance and is an extension of the formerly important iron ore district in eastern France (Lorraine).

Luxembourg imports 100% of its energy supply.

4.13.2. Comments

No uranium occurrences and/or deposits have been reported. Luxembourg has no nuclear power programme.

The UDEPO database does not list any known deposits for Luxembourg.

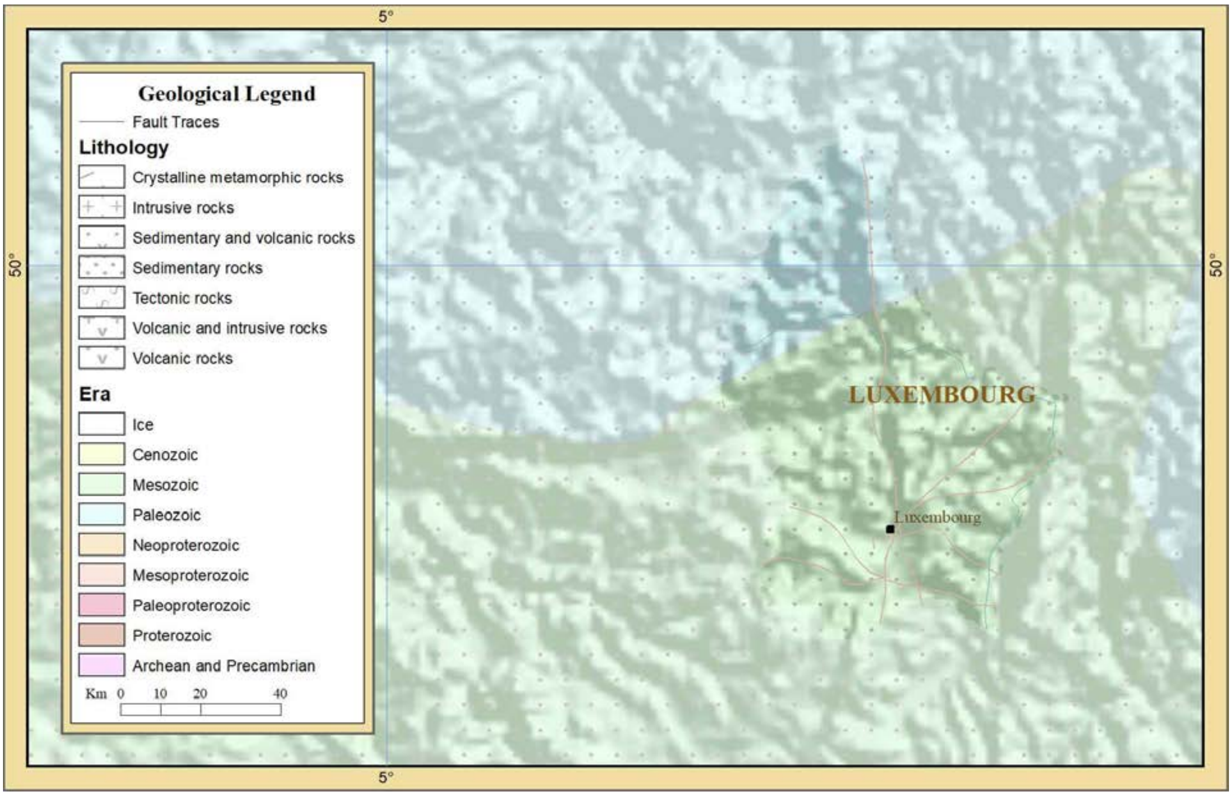


FIG. 4.27. Regional geological setting of Luxembourg. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.14. MALTA

4.14.1. Geography

Malta is an island country in southern Europe (Fig. 4.28). It consists of an archipelago in the Mediterranean Sea. It is situated 80 km south of Italy (Sicily), 284 km east of Tunisia, and 333 km north of Libya. Only its three largest islands, Malta, Gozo and Kemmuna are inhabited.

The country's landscape is characterized by low hills with terraced fields. The highest point in Malta is Ta' Dmejrek, at 253 m, near Dingli. There are a few small rivers during high rainfall, but there are no perennial rivers or lakes on Malta.

Malta has a Mediterranean climate with hot summers and mild winters. Rain occurs mainly in autumn and winter, with summer being generally dry.

Malta's major resources are limestone and a favorable geographic location. The country produces only ~20% of the food it needs, has inadequate supply of freshwater and has no sources of domestic energy, except the potential for solar energy. The country's economy depends on tourism, manufacturing (chiefly textiles and electronics) and foreign trade (serving as a freight trans-shipment point) [14.1].

4.14.2. Geology

The Maltese Islands are all underlain by sedimentary formations, resulting from the deposition of carbonate sediments in a fairly shallow marine environment. Different types of sedimentary rocks relate with different palaeo-environments of deposition. Quaternary sediments were deposited in a terrestrial environment after the emergence of the Maltese Islands above sea level.

The origin of the Maltese Islands is linked to the development of the Mediterranean basin which can be traced to Triassic times when rifting in Pangaea in an east-west trend generated a transverse ocean called the Tethys Sea. Fluvial sediments and reef deposits deposited on this early ocean bed comprise the rocks that form the Maltese Islands. [14.2]

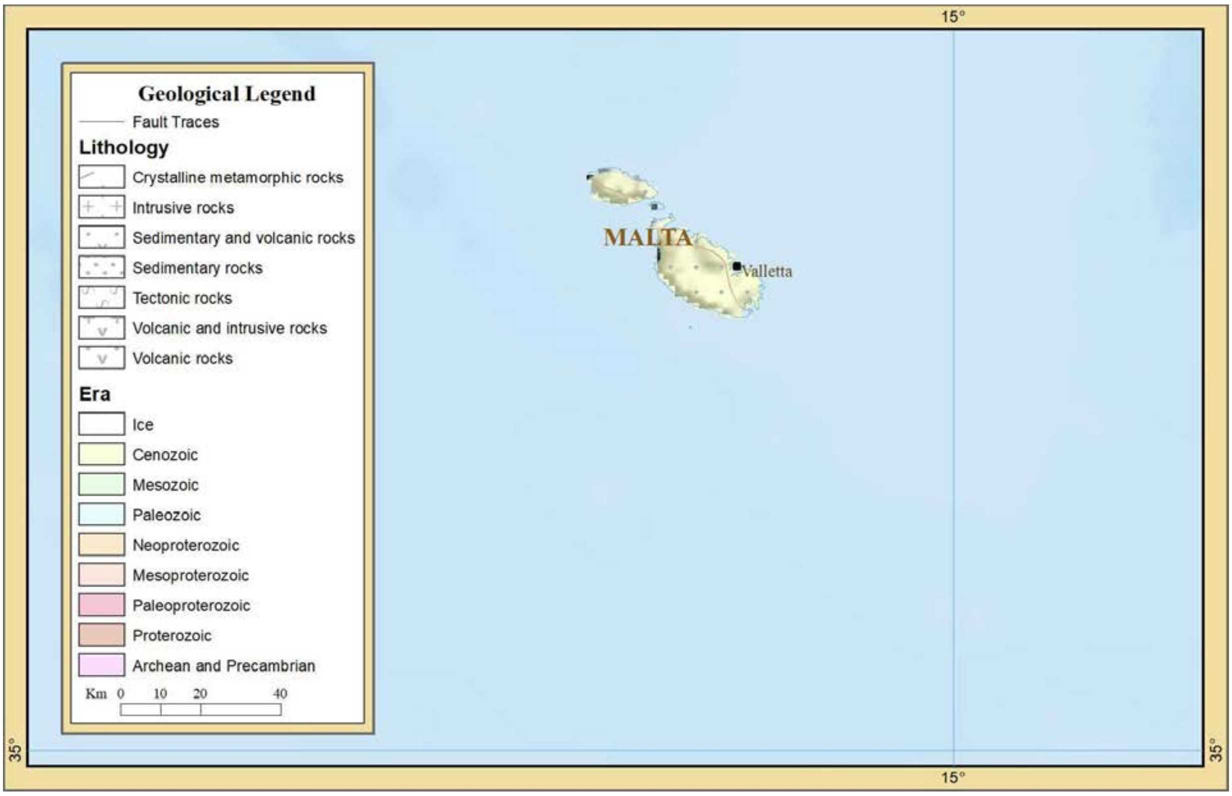


FIG. 4.28. Regional geological setting of Malta. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.14.3. Uranium exploration

There has been no reported uranium exploration in Malta.

4.14.4. Uranium resources

There are no known uranium occurrences in Malta and no resources of uranium have ever been reported. The UDEPO database does not list any known deposits for Malta.

4.14.5. Potential for new discoveries

From a geological point of view, Malta does not have potentially favorable areas for the development of uranium deposits. Owing to the country's rock types present, the potential for new discoveries is rated as nil.

References to Section 4.14

[14.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Malta, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2012).

[14.2] GRIFFITHS V., Geology of Malta (2013), people.bath.ac.uk/exxbgs/journal_articles/01_Malta.pdf.

4.15. MONACO

4.15.1. Geography

Monaco is an urban area in south-eastern France, situated on the coast of the Ligurian Sea. Monaco is underlain by sedimentary rocks of the Languedoc Basin.

4.15.2. Comments

Monaco has no nuclear related activities. There is no record of any uranium exploration.

he UDEPO database does not list any known deposits for Monaco.

4.16. NETHERLANDS

4.16.1. Geography

The Netherlands lies in north-western Europe and has borders with Germany and Belgium, as well as having a maritime border with the North Sea. The Netherlands also includes the overseas departments of Aruba and the Netherlands Antilles, both located in the Caribbean Sea.

The country is situated NW of the lowland which extends easterly through northern Germany and northern Poland to the Baltic countries and further into eastern Europe. Roughly 35% of the country lies below sea level and is protected from inundation by the sea by an extensive system of dams and dykes [16.1].

4.16.2. Geology

The surface of the country is covered largely by Quaternary deposits (Fig. 4.29). In south Limburg, in the SE of the country, a small area of Upper Carboniferous crops out, including terrestrial sediments. In an adjacent area, Cretaceous sedimentary rocks occur that are mainly of marine deposition. North and south of Enschede, both Cretaceous and Tertiary sedimentary rocks can be found, together with some Triassic sedimentary rocks [16.1].

The geology does not indicate any potential for the occurrence of uranium deposits.

4.16.3. Uranium resources

The Netherlands has no uranium resources [16.2].

The UDEPO database does not list any known deposits for the Netherlands.

4.16.4. Comments

Reports on uranium exploration are not available. No exploration is currently being carried out and the country does not produce uranium. The Netherlands reported to every Red Book for the period 1982–2002.

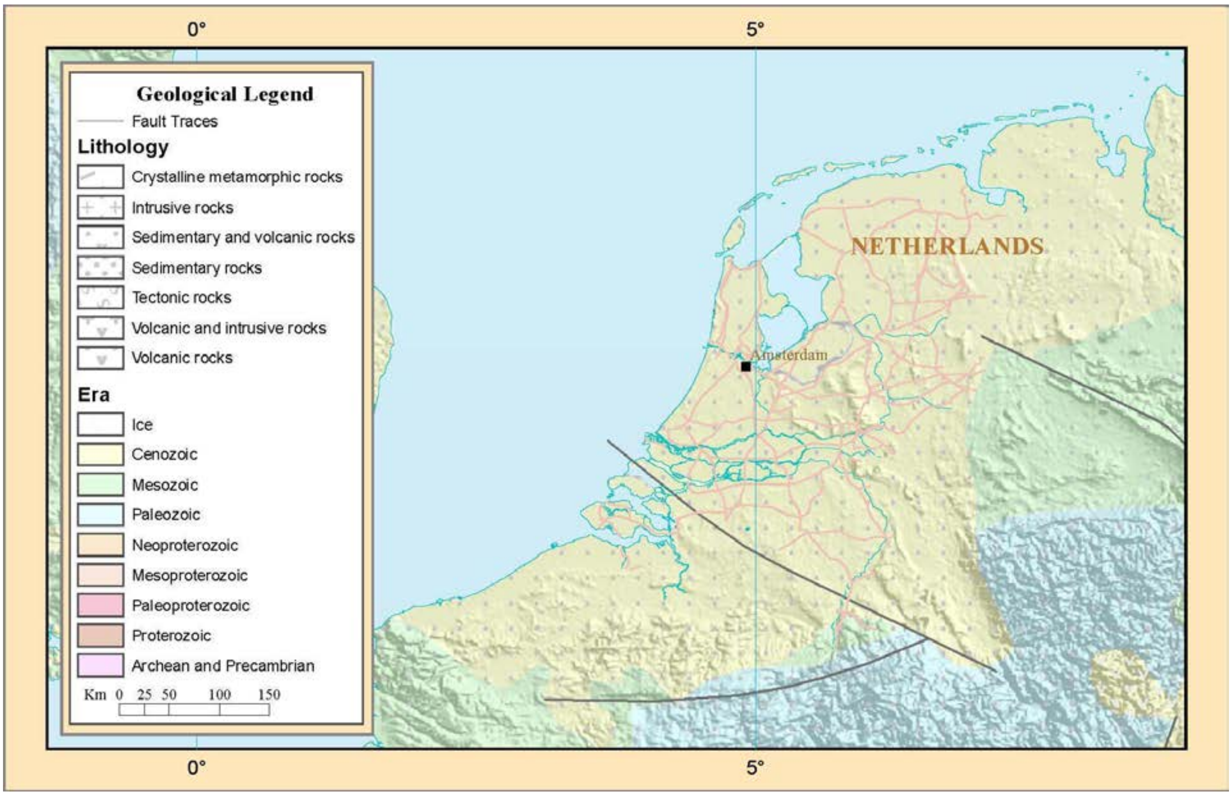


FIG. 4.29. Regional geological setting of Netherlands. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

References to Section 4.16

[16.1] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Netherlands, IAEA, Vienna (1978) 11 pp.

[16.2] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

4.17. NORWAY

4.17.1. Geography

Norway is situated in northern Europe and borders Sweden, Finland and the Russian Federation (Fig. 4.30). It also has maritime borders with the North Sea and the North Atlantic Ocean. The country has a length of ~1800 km.

Norway is one of the most northerly countries and is situated on the western part of the Scandinavian Peninsula. The country is characterized by the Scandinavian Mountains which run from the northern tip to the south in a series of high plateaus (fjells) and dissected by numerous fjords on its western shore, some of which penetrate deep into the interior of the country. The mountains attain their highest elevation of 2470 m north of Oslo. This area covers one of the largest glaciers in Europe. The fjords and numerous valleys are the result of erosion by ice. Many islands are scattered off the coast in the North Atlantic Ocean, e.g., Lofoten Islands.

During the Ice Age, Norway was completely covered by a thick ice sheet. After melting of the ice the country experienced isostatic rebound, an upwards movement after the release of the weight of the overlying ice sheet. Many features of the present-day topography were formed throughout and after the Ice Age. The relatively flat terrain occurring towards the east is countered by very rough topography, with steep cliffs, to the west.

Depending on latitude and elevation, agricultural use of the land differs widely. In the southern lowlands and valleys, crops may be grown, whereas further north, the amount of arable land gradually decreases while the proportion of mountain pasture increases. Only ~8% of the country's surface is arable and nearly 50% consists of mountainous terrain.

Considering the northern latitude of the country, the climate is relatively mild owing to the influence of the Gulf Stream. At the coast, the winters are milder than in the mountains or in the north. Average winter temperatures in the milder areas may be just below 0°C, whereas in the northern polar areas the temperature may reach -40°C. Similarly, the summer temperatures in the Oslo area may average 15–17°C and only 5–10°C in the northern areas. Large differences in precipitation are observed, with the coastal areas having much higher rainfall (up to 3000 mm/year in some areas) than inland areas, some of which have as little as 300 mm/year [17.1].

4.17.2. Geology

Norway is part of the Fennoscandian Shield, which includes Norway, Sweden, Finland and the north-western part of the Russian Federation. In the east and SE, the Precambrian basement forms part of the Fennoscandian Shield, whereas in the west and north, metasedimentary rocks and metavolcanic rocks are of Cambrian–Silurian age. In addition, Carboniferous–Permian rocks are found in the Oslo area. The Precambrian contains Archaean gneisses, migmatites and schists in northern Norway (Kola block). Lower Proterozoic rocks are found in Finmark, on the Lofoten Islands and near Narvik. Middle Proterozoic rocks occurring in southern Norway are highly deformed and were metamorphosed around 1000 Ma. The post-metamorphic period is characterized by granitic intrusions which are overlain by alternately reduced and oxidized sandstones and intercalated with basalts (Trysil Series).

The Fennoscandian Shield was consolidated in the Upper Proterozoic and this episode has been dated at 800 Ma. The Lower Palaeozoic strata start with Cambrian sandstone and shale, followed by Ordovician limestone and shale. During this period, the Caledonian Orogeny (~400 Ma) deformed part of the Precambrian basement and the Cambrian–Ordovician sedimentary rocks. Sedimentary rocks of Devonian, Permian and Mesozoic age are less widespread.

Ore deposits are found in the Precambrian, Caledonides and Permian rocks. In northern Norway, banded iron ore deposits, massive sulphide deposits and iron–titanium deposits occur in Precambrian rocks. In the Ordovician greywacke–greenstone sequence, massive sulphide deposits were formed, such as the Kongsberg deposit (silver), and lead–zinc and porphyry molybdenum deposits.

Rocks and sequences favourable for the formation of uranium deposits include the Trysil Series (with similarities to unconformity-related deposits). Cambrian black shales may be enriched in uranium. The magmatic rocks of the Oslo province are enriched in thorium [17.2–17.5].

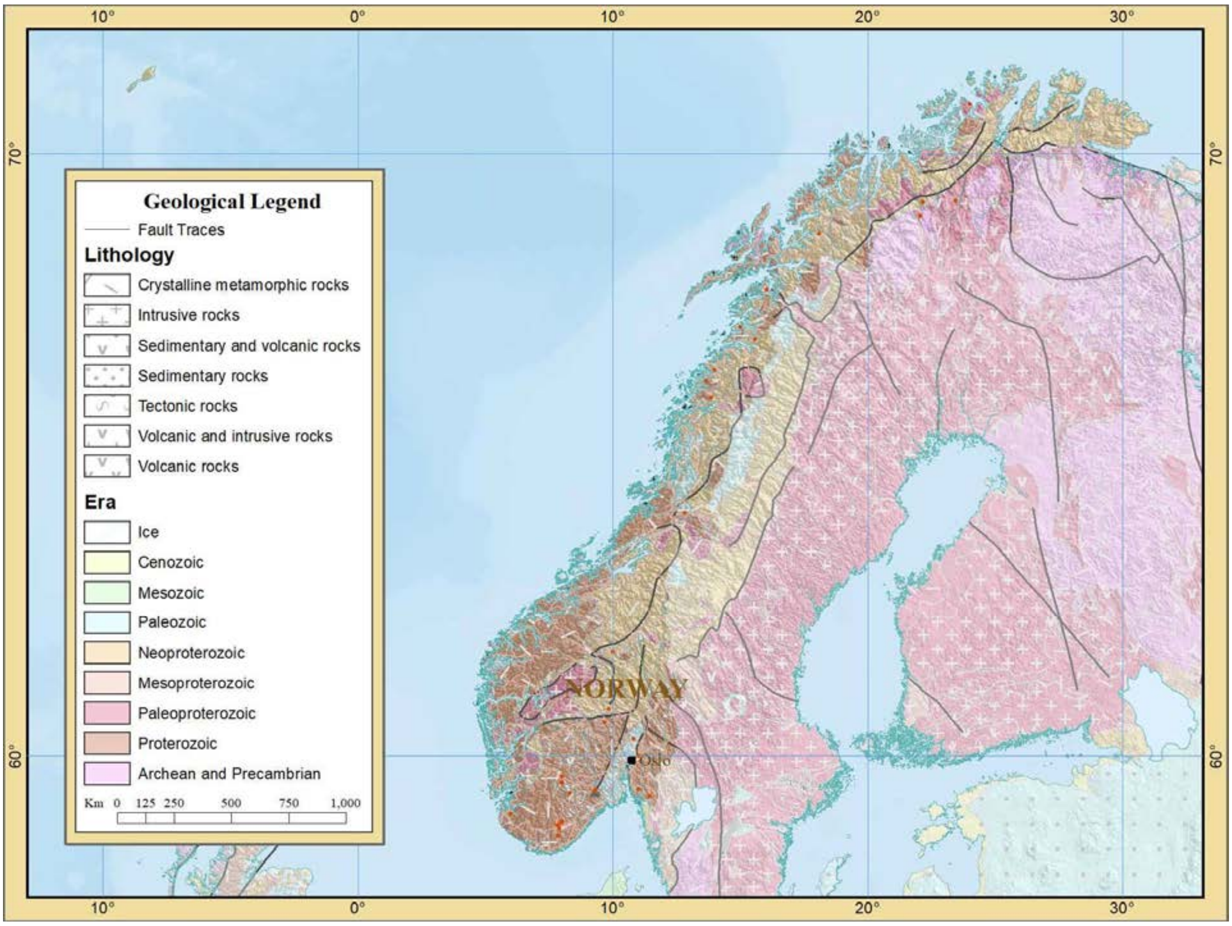


FIG. 4.30. Regional geological setting of Norway showing the distribution of selected occurrences. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.17.3. Uranium exploration

With the exception of the occurrence of small amounts of uranium in pegmatites, which was used for colouring glass in the 19th century, no systematic exploration was conducted before 1945. After 1945, exploration was carried out by several organizations targeting the Cambrian black shales, pegmatites and other previously known showings. The black shales, similar to those occurring in Sweden, are in some locations found to contain up to 300 ppm U.

During the 1950s and 1960s, systematic exploration, including car-borne and air-borne methods, was conducted over ~30% of the country. After 1975, a 10-year programme was started by the Geological Survey of Norway using car-borne, air-borne and geochemical exploration, as well as stream sediment and bedrock sampling. A limited drilling programme was carried out on promising anomalies. However, detailed follow-up was not undertaken and no resources were delineated. In 1997, no uranium exploration activities were reported to the Red Book [17.3–17.8].

Surface drilling in 1977 comprised two holes totalling 400 m and in 1978 six holes and 600 m. No drilling was undertaken after 1978. Exploration expenses in 1976–1983 amounted to US $3.18 million.

4.17.4. Uranium resources

No uranium resources have been documented. The UDEPO database does not list any known deposits for Norway.

4.17.5. Potential for new discoveries

The IUREP missions reported a list of known uranium occurrences and these data were combined with information from the mission experts on potential areas [17.4, 17.5]. This has provided a reasonably complete assessment of the uranium potential of Norway.

Known occurrences, none of which at the time of compilation were of economic interest, include several hydrothermal type mineralized occurrences and pegmatites located in Precambrian rocks. Some of the occurrences are associated with other metals (e.g., Cu, Ag, Mo and Fe).

In addition to Precambrian strata, alum shales were also investigated, but discouraging results and ecological considerations precluded further work being undertaken.

Areas of potential were classified in both IUREP reports [17.4, 17.5], but likely exploration targets were not identified. Some potential may exist in ancient placers of Lower Proterozoic age, as these bear similarities to uranium mineralization found in Finland. Quartz pebble conglomerates are poorly developed. Some hydrothermal type mineralization occurrences are considered to have good potential but as these lie in protected areas that lack ready access, their potential for further investigation is limited. In general, the lack of detailed exploration limits assessment of the uranium potential. Further details are provided in Ref. [17.4].

Speculative resources are estimated at 9000–58 000 tU, excluding the 10 000–50 000 tU of speculative resources hosted in alum shale.

4.17.6. Comments

Norway has never produced uranium and there is no nuclear power industry. Norway's most recent report to the Red Book was in 1998.

References to Section 4.17

[17.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Norway, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2008).

[17.2] SHOWCAVES, Geology of Norway, https://www.showcaves.com (March 2008).

[17.3] INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP, National Favourability Studies: Norway (1977) 9 pp.

[17.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission: Norway, OECD, Paris (1981) 102 pp.

[17.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission, Summary Report: Norway, OECD, Paris (1983) 23 pp.

[17.6] LINDAHL, I., Classification of Uranium Mineralization in Norway, Norges Geologiske Undersokelse **380** (1983) 125–142.

[17.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[17.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

4.18. PORTUGAL

4.18.1. Geography

Portugal is situated on the Iberian Peninsula in south-western Europe. The volcanic islands of the Azores and Madeira, located in the North Atlantic Ocean, are also part of Portugal.

The River Tejo (Tagus) splits the country into two parts. North of the River Tejo, the landscape is mountainous, cut by the east–west running River Douro. Along the valley of the Douro, fertile plains are developed as well as on the coastal plain. Both the Tejo and Douro rivers originate in the central highlands of Spain. The highest elevations (1991 m) in the north are to be found in the Serra da Estrela. South of the Tejo, the landscape is characterized by rolling plains, reaching elevations of 900 m in the Serra de Monchique. The south features the Algarve, Portugal's most popular tourist destination. The southern area is drained by the River Guadiana, also originating in Spain, which enters Portugal near Badajoz and from there turns to the south. The flat areas south of the Tejo and SE of Lisbon are fertile.

Roughly 25% of the country is arable. Agricultural products include vegetables, various fruits and grapes. Cork made from the bark of oak trees is a famous product of the country as well as wine. Fishing and tourism are also important. The climate is Atlantic–Mediterranean and varies according to geographical position, being cooler in the north and warmer in the south. Generally, summer temperatures are high and in winter snow covers the peaks of the higher mountains. Rain is more plentiful in the north (up to 1400 mm/year) compared with the south (700 mm/year). In the south, summers can be hot and dry, although they are moderated by Atlantic winds [18.1].

4.18.2. Geology

Mainland Portugal is situated on the western edge of the Iberian block, which belongs to the Hercynian geotectonic unit and underlies roughly 65% of the country (Fig. 4.31). It is divided into the northern and southern blocks. Roughly 65% of the northern block is underlain by the schist–greywacke complex (the Portuguese part of the Central Iberian Zone) of probable Precambrian–Lower Cambrian age [18.2]. The other third is characterized by Cambrian, Ordovician and Silurian metasedimentary rocks (Ossa Moreno Zone). The northern block is folded and faulted and is intruded by granites of the Hercynian Orogeny. The latest tectonic events occurred throughout Alpine movements. The granites have been dated at ~300 Ma and 280 Ma. The younger granites are considered to be the source of uranium.

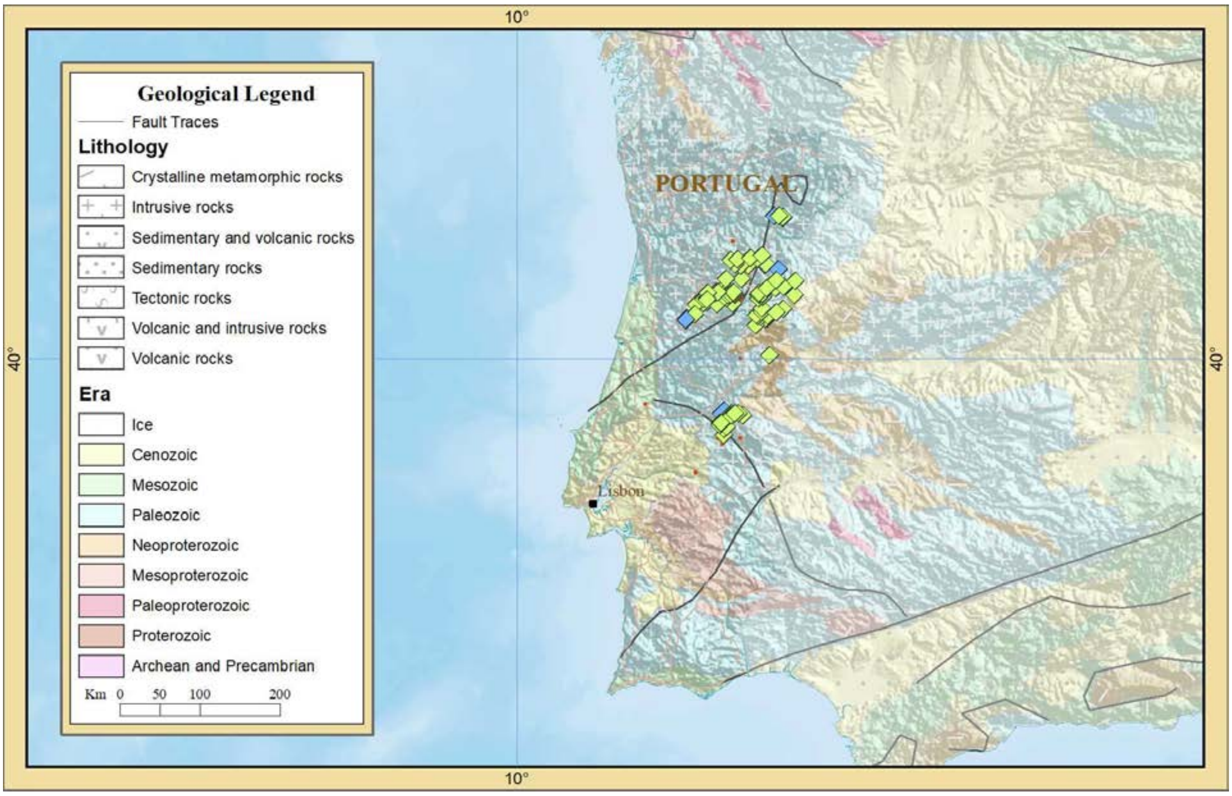


FIG. 4.31. Regional geological setting of Portugal showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The southern block is underlain by marine sedimentary rocks of Upper Devonian and Carboniferous age. West of both blocks, sedimentary cover strata of Mesozoic–Cenozoic age are deposited. At the base, red continental sandstones of Triassic age are deposited, which, in composition, resemble the Bunter Formation found elsewhere in Europe. Lower Jurassic sedimentation starts with marine limestones overlain by fluvial sandstones of Upper Jurassic age. Continental sedimentation prevailed throughout the Cretaceous and Tertiary periods [18.2–18.7].

4.18.3. Uranium exploration

4.18.3.1. Historical review

The first uranium–radium deposits were discovered in 1907 and a mining franchise (Rosmaneira) approved in 1909. At Urgeiriça, extraction of 50 g of Ra from ~500 tU took place over the period 1913–1944. Uranium was mined in 1944–1951. During 1945–1962, a foreign private company, Companhia Portuguesa de Radium (CPR) mined and treated ores from Urgeiriça and other mines in the Beira Alta (central Portugal) region. CPR conducted geological mapping, radiometric surveys, trenching and core drilling together with gamma ray logging in the Hercynian Beiras granitic formations.

In 1954, the State-owned Junta de Energia Nuclear (JEN) was created and in 1955 an exploration programme (geological mapping, car-borne and ground radiometric surveys, geophysics, trenching, and diamond and percussion drilling) was initiated, which boosted the resource inventory. Metasedimentary rocks around granitic formations proved to be the principal targets for economic uranium mineralization. By the exploration programme's completion in 1959, JEN had found ~100 small to medium size deposits in Hercynian perigranitic and granitic formations at Alto Alentejo and Beiras.

The Beiras deposits and the Urgeiriça mill were operated as an integrated uranium production centre. The Alto Alentejo deposits, which comprise the Nisa orebody (~3500 tU), could support an additional production centre, but these deposits have remained unexploited. The last attempt to commence production in this area was cancelled in 1999 after a favourable environmental assessment but an undesirable economic evaluation. The current level of uranium prices in recent years sparked renewed interest in the Nisa deposit by several foreign companies.

Since 1976 until the mid-1990s, exploration in crystalline regions lasted, with new findings being made at a rate which roughly kept pace with exhaustion by mining. Exploration in sedimentary formations during 1971–1982 (geological mapping, geochemistry, emanometry, drilling surveys) in the western Mesozoic–Cenozoic periphery of the Lusitanian Basin was unsuccessful in finding any additional economic resources .

In the 1960s and early 1970s, JEN conducted prospecting works in Angola and Mozambique [18.8].

4.18.3.2. Exploration expenditures

Total exploration expenses, including US $5.594 million incurred in the period prior to 1972, were estimated at US $17.687 million up to the end of 2016. No exploration was carried out in 2000–2006. Yearly exploration expenses totalling USD17.687 million and drilling (totalling 806 168 metres) are shown in Fig. 4.32 [18.7, 18.9, 18.10].

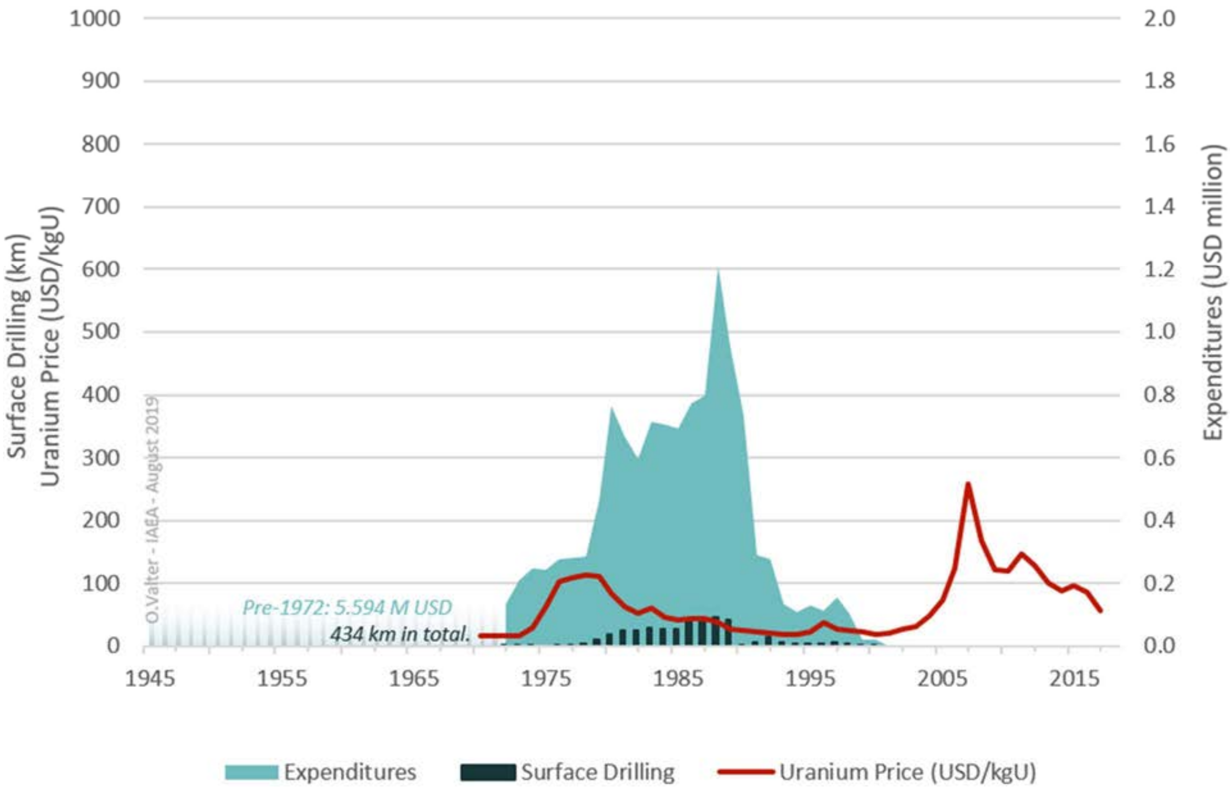


FIG. 4.32. Domestic uranium exploration data for Portugal. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

4.18.3.3. Recent and ongoing uranium exploration and mine development activities

Throughout 2005–2006, no activities for exploration or exploitation of uranium were carried out in Portugal. Several foreign companies submitted applications for mining and exploration rights, with the Nisa deposit being the major target. The Government launched an open bidding process to applicants.

For 2007, exploration expenses were reported as €6.9 million (US $4.42 million) and for 2008 about €6.7 million (US $4.29 million). No estimates were reported for 2009.

The largest individual investment, representing ~60% of the total, was spent on the Cunha Baixa/Quinta do Bispo deposit [18.8–18.10].

4.18.3.4. Discovery costs

The cost of finding of known conventional resources and production amounts to US $1.4/kgU and for total resources (known and undiscovered) and production the cost is US $0.92/kgU [18.9].

4.18.4. Uranium resources

4.18.4.1. Identified resources

Portugal reports 4500 tU of reasonably assured resources hosted in open pit vein deposits, recoverable at costs of <US $80/kgU. Open pit vein deposits have reasonably assured resources of 5500 tU recoverable at costs of <US $130/kgU. In this category, an additional 500 tU are recoverable by underground mining. Total reasonably assured resources amount to 6000 tU at costs of <US $260/kgU and a recovery factor of 75%.

Additionally, 1000 tU are reported as identified resources in vein deposits, recoverable at costs of <US $130/kgU.

Processing and mining losses combined were of the order of ~25% for both resource categories.

The historic variation in identified resources is shown in Fig. 4.33 and Fig. 4.34.

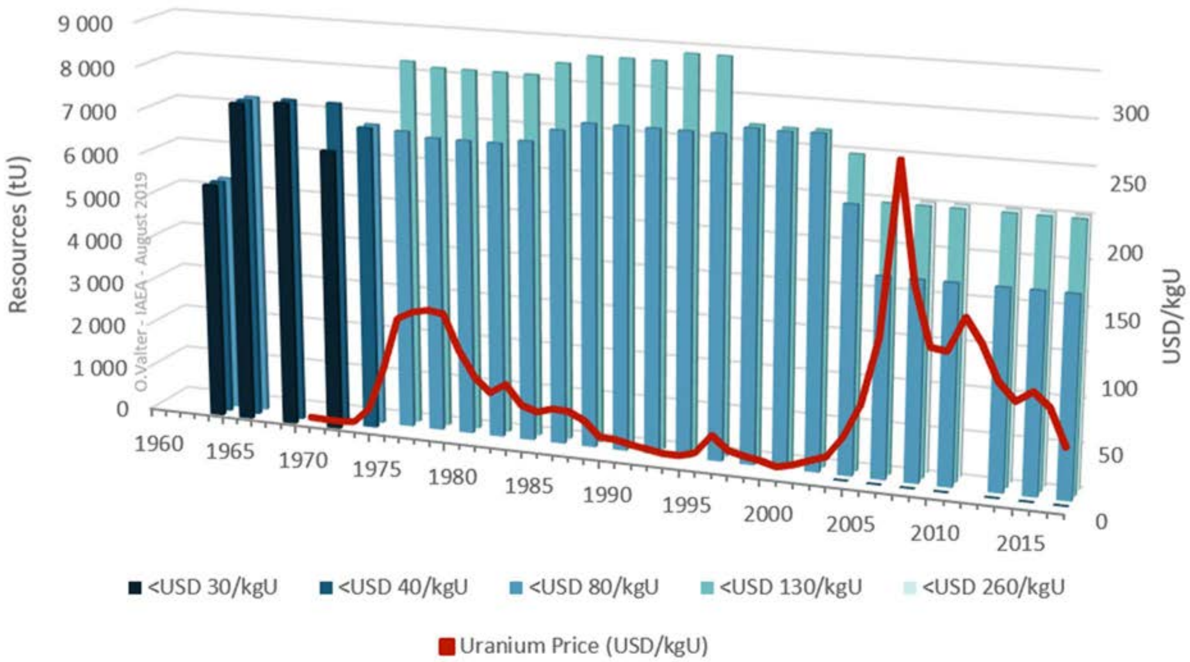


FIG. 4.33. Historical variation of recoverable reasonably assured resources within various cost categories in Portugal. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

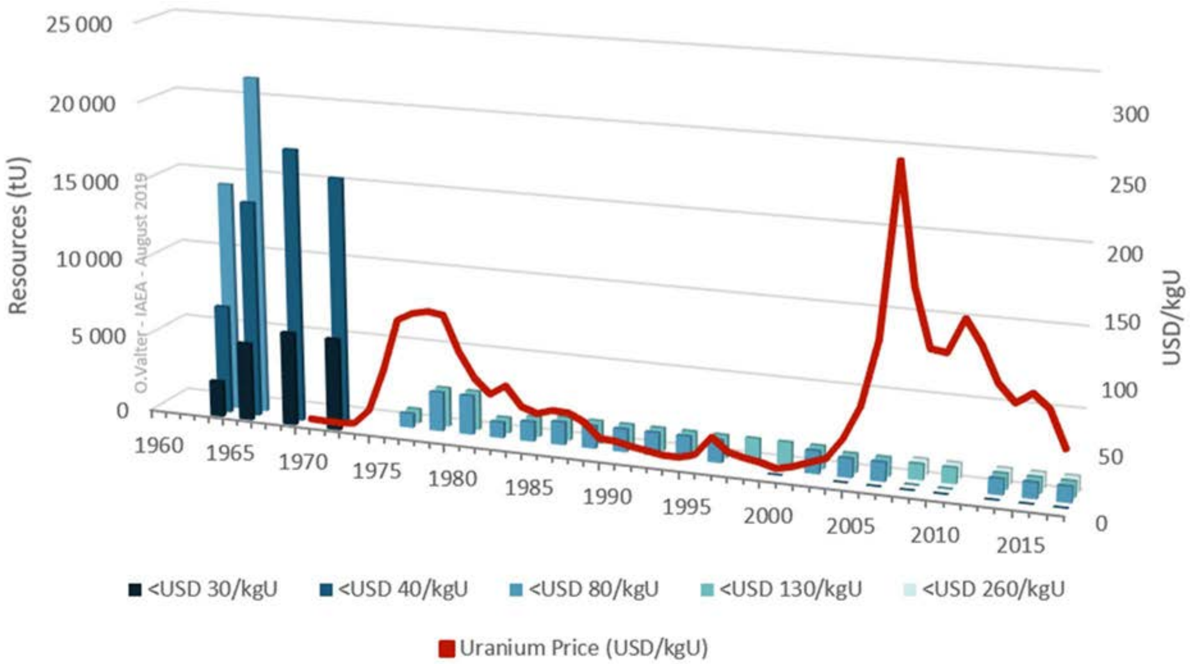


FIG. 4.34. Historical variation of recoverable inferred resources within various cost categories in Portugal. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

The UDEPO database lists the most significant deposits for Portugal as Urgeirica, Nisa, Cunha Baixa, Pinhal Do Souto, Horta Da Vilarica, Palheiros de Tolosa, Quinta Do Bispo, Freixiosa, Maia, Tarabau.

4.18.4.2. Undiscovered resources

A new estimate of undiscovered conventional resources comprises a total of 1500 tU of prognosticated resources in the <US $260 kgU cost category, 1000 tU of prognosticated resources in the <US $80/kgU cost category and 1500 tU in the <US $130/kgU cost category.

Speculative resources recoverable in all cost categories are not documented [18.10], because the original evaluation is out of date. In 2005, a total of 5000 tU was stated as speculative resources in the <US $130/kgU cost category [18.8, 18.10].

4.18.5. Potential for new discoveries

Exploration by private companies is planned in the region around the Nisa deposit. Regions with Hercynian granites are generally favourable for uranium mineralization, although they probably underlie cover rocks. All the 'easy to detect' mineralization would likely have already been found by earlier exploration programmes.

Previous exploration investigated the potential of sedimentary rocks, but the results were disappointing. Perhaps continental sedimentary rocks are worthy of re-examination.

The IUREP reports describe in detail favourable areas and geological targets [18.4–18.6]. It is mentioned that at the time of the IUREP missions (end of 1979) the full potential of deposits belonging to the Iberian vein-type were not fully investigated. No recent reports have been located describing to what extent exploration has followed these recommendations [18.4].

Speculative resources were estimated in the range of 20 000–80 000 tU, of which 9000–30 000 tU were estimated as being hosted in vein-type deposits and 7000–28 000 tU hosted in metasedimentary rocks. Up to 6000 tU were estimated as occurring in Mesozoic–Cenozoic deposits [18.5].

4.18.6. Uranium production

4.18.6.1. Historical review

In 1950–1951, a mill processing 50 000 t of uranium ore yearly was authorized at Urgeiriça. Underground mining at Urgeiriça lasted until 1973, after which extraction was continued up to 1991 by in place leaching. The mine was excavated to a depth of 500 m. In 1951, heap leaching (high sulphide content of the ore) was applied. Five heap leach facilities operated in the period 1953–1959 and throughout this period produced a total of 40 tU.

During 1951–1962, CPR generated a total of 1123 tU from 22 franchises, of which 1058 tU were milled at the Urgeiriça plant and 65 tU were generated at other mines by heap leaching. A low grade concentrate was achieved by precipitation using magnesium oxide.

In 1962–1977, JEN took over activities of mining and milling from CPR, presenting solvent extraction in 1967 to generate ammonium uranate concentrate, increasing processing yearly capacity to 100 000 t ore and then to 200 000 t ore in July 1985. The Urgeiriça mill and the pilot plant at Senhora das Fontes produced a total of 825 tU under JEN administration. From 1977 to 2001, Empresa Nacional de Urânio S.A. (ENU) generated 1772 tU. Production stopped in March 2001. About 25% of the total production was derived from Urgeiriça.

Ore treatment at Urgeiriça was terminated in 1999; the facility was mothballed in March 2001. During 1999–2001, resins charged at the heap leach and leach plants situated at the Bica and Quinta do Bispo mines were treated.

In total, 57 orebodies have been mined, 29 by underground methods, 24 by open pit and four by mixed underground/open pit methods. Local ore processing was used in 18 mines and uranium concentrates were generated on an industrial scale at Urgeiriça. Two pilot processing plants (Forte Velho and Senhora das Fontes) generated restricted quantities of concentrates (sodium uranate).

Proprietorship of the Urgeiriça mill changed and since CPR settled a deal with the Government in 1962, JEN took over until 1977 when the State-owned enterprise ENU obtained exclusive rights for the generate and sale of uranium concentrate. Exploration teams of JEN merged with the Direcção-Geral de Geologia e Minas in 1978. ENU was, in 1992, merged with Empresa de Desenvolvimento Mineiro (EDM) – the State-owned mining entity. EDM decided on March 2001 to liquidate ENU, effective end of 2004 [18.8].

4.18.6.2. Historical production

The production of uranium over a 51-year period totalled 3718 tU (Fig. 4.35). From 1952 onwards, yearly production for 10 years fluctuated in the range 102–127 tU/year, before declining for a period of 13 years to levels of between 8 and 92 tU/year, followed by a period of 16 years (1975–1990) with yearly production of 81–159 tU. As of 1991, most of the deposits were approaching [18.9].

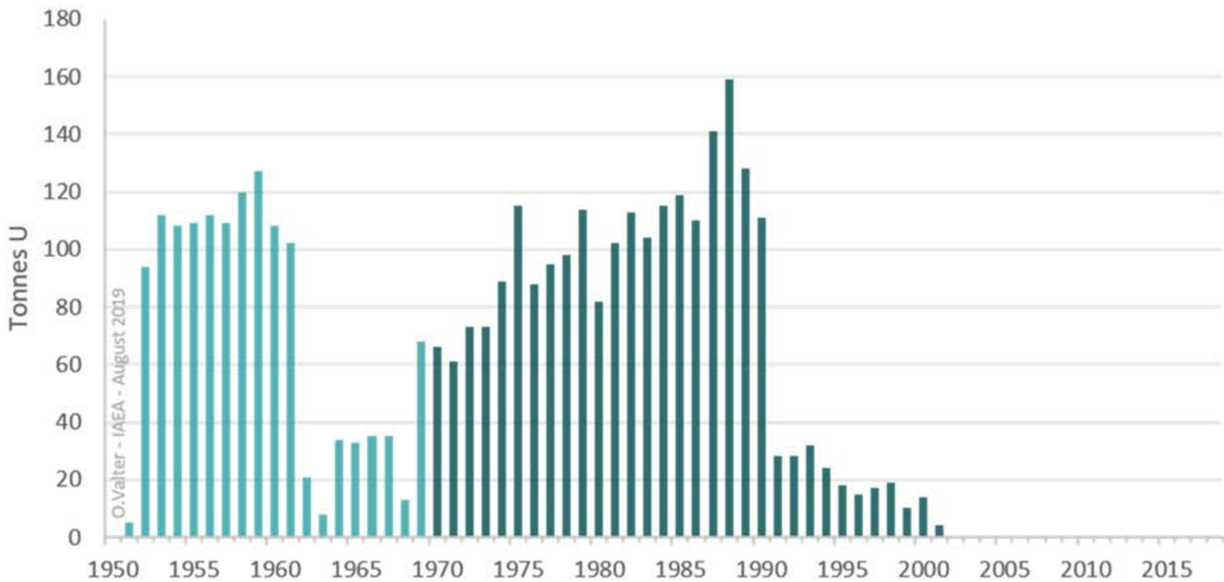


FIG. 4.35. Historical uranium production in Portugal. (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

4.18.6.3. Status of production capability

No facilities for treatment were operational after 2001. Dismantling/repossession of the Urgeiriça mill and other mine sites are at an advanced stage. A €5 million reclamation project of the tailings dam commenced in 2005 since an environmental impact assessment was conducted. Neutralization of acid mine drainage from Quinta do Bispo, Cunha Baixa, Bica and Urgeiriça is continuing.

4.18.6.4. Ownership structure of the uranium industry

As already noted, the uranium mining and processing company ENU was dissolved at the end of 2004. Currently, no company holds exploration or mining rights.

4.18.6.5. *Future production centres*

No future production centres are proposed. The Nisa mine may be brought into operation if mineral rights are granted to interested companies.

4.18.7. Environmental activities and sociocultural issues

Environmental studies have been undertaken by Companhia de Indústria e Serviços Mineiros e Ambientais (EXMIN), which is accountable for the restoration of mine sites. The rehabilitation started in 2005 with the Urgeiriça tailings dam confinement being the main project.

Under Decree 198-A/2001, the State institutionalized the restoration of so-called 'orphan' mine sites, including sites f uranium mining. Resolution 93/2001 of the Council of Ministers established the State subsidiary EXMIN, and as of September 2006, EXMIN was integrated by EDM.

The ongoing programme, enacted under Decree 198-A/2001, is intended to restore mine sites and tackle public health and potential economic development, as well as heritage and cultural issues.

A surveillance programme of old mines has been undertaken by EDM, which has accepted all obligations formerly held by EXMIN. An environmental impact assessment of the restoration project on the old tailings dams was indorsed in 2005. Further information details can be obtained in the reports prepared by expert groups of the OECD Nuclear Energy Agency and the IAEA for the periods 1996–1997 and 1999–2001 [18.11, 18.12].

4.18.8. National policies relating to uranium

The authorities accountable for national policies regarding uranium are the Directorate General for Geology and Energy and the Ministry of Economy and Innovation (as of March 2005). From 2005 to 2006, a number of foreign firms filed applications for rights to explore and mine with Nisa as their principal target. The Government resolved to present a bidding procedure among the applicants in order to grant mineral rights.

4.18.9. Comments

There is no installed nuclear capacity and there are no plans to introduce nuclear energy.

References to Section 4.18

[18.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Portugal, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2008).

[18.2] CAMERON, J., "Geomorphology and the uranium vein deposits of the Beira region of Portugal", Vein-Type and Similar Uranium Deposits in Rocks Younger than Proterozoic (Proc. Tech. Mtg Lisbon, 1979), IAEA, Vienna (1982) 237–277.

[18.3] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project (IUREP), National Favourability Studies: Portugal (1977) 18 pp.

[18.4] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[18.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission, Summary Report: Portugal, OECD, Paris (1977) 28 pp.

[18.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission: Portugal, OECD, Paris (1980) 116 pp.

[18.7] PORTUGAL FERREIRA, M., MATOS DIAS, J.M., "Uranium mineralization and episyenites — A case study in Portugal", Vein-Type and Similar Uranium Deposits in Rocks Younger than Proterozoic (Proc. Tech. Mtg Lisbon, 1979), IAEA, Vienna (1982) 311–321.

[18.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[18.9] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.
[18.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[18.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999).
[18.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002) 241–244.

4.19. SAN MARINO

4.19.1. Geography

San Marino is situated in central Italy and is a landlocked country. It is covered mainly by limestone and lies on the north-eastern side of the Apennine Mountains [19.1].

4.19.2. Comments

Chapter 12 (Italy) briefly describes the geology of potentially favourable uranium-bearing areas, although the area surrounding San Marino is not specifically referred to. San Marino has no uranium resources and no nuclear capacity.

The UDEPO database does not list any known deposits for San Marino.

References to Section 4.19

[19.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: San Marino, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed September 2012).

4.20. SPAIN

4.20.1. Geography

Spain is situated in SW Europe, on the Iberian Peninsula, of which it occupies ~80% (Portugal comprising the remaining 20%). In the NE, Spain is bounded by France and Andorra, where the Pyrénées Range forms a natural frontier. Additional Spanish territory includes the Balearic Islands (Ibiza**,** Mallorca and Menorca) in the Mediterranean Sea, the Canary Islands in Atlantic Ocean, near the Moroccan coast, and Melilla and Ceuta, situated on the Moroccan coast in northern Africa.

Most of the peninsular region of Spain comprises the Meseta Central, a highland plateau bordered and dissected by mountain ranges. Other landforms comprise narrow coastal plains and some lowland river valleys, the most pronounced of which is the Andalusian Plain in the SW.

The Meseta Central, an extensive plateau in the centre of Spain, has elevations of 610–760 m. Bordered by mountains, the Meseta Central slopes gently westward and a series of rivers forms part of the boundary with Portugal. The Sistema Central splits the Meseta into southern and northern subregions, the south being lower in elevation but larger in size than the north. The Sistema Central borders the city of Madrid with peaks that reach elevations of 2400 m north of the city. West of Madrid, the Sistema Central rises to its highest peak at nearly 2600 m. The southern portion of the Meseta is further split by two mountain ranges, the Sierra de Guadalupe to the west and the Montes de Toledo running to the east. Elevations are lower, rarely exceeding 1500 m. The two mountain ranges are disconnected from the northern central part of the Sistema by the River Tagus.

The mountain regions forming the Meseta Central and those which are related with it are the Sistema Iberico, the Cordillera Cantabrica and the Sierra Morena. Comprising the southern border of the Meseta Central, the Sierra Morena joins in the east the southern extension of the Sistema Iberico and reaches westwards along the northern limit of the Rio Guadalquivir valley to merge with mountains in southern Portugal. The massif of the Sierra Morena stretches northwards to the Rio Guadiana, which disconnects it from the Sistema Central. In spite of their fairly low elevations, rarely exceeding 1300 m, the Sierra Morena mountains have a rugged topography.

The Cordillera Cantábrica, a limestone formation, runs parallel to the northern coast adjoining the Bay of Biscay. Its highest points are the Picos de Europa, exceeding 2600 m in elevation. The hills of the NW region lie to the west and the Basque mountains to the east join them to the Pyrenees.

The Sistema Iberico stretches from the Cordillera Cantábrica south-eastwards and, near the Mediterranean, expands from the Rio Ebro to the Rio Jucar. The mountains exceed 2000 m in elevation in their northern region, reaching a maximum height of at least 2300 m east of the headwaters of the Rio Duero.

Beyond the Meseta Central lie the Pyrenees, in the NE, and the Sistema Iberico, in the SE. The Pyrénées, stretching from the eastern limit of the Cordillera Cantábrica to the Mediterranean Sea, constitute a major topographic barrier and a natural boundary between Spain and both Andorra and France. In the central section of the Pyrénées, peaks exceed 3000 m, the highest, Pico de Aneto, exceeds 3400 m in elevation.

From the southern tip of Spain, the Sistema Penibetico stretches NE running parallel to the coast where it joins with the southern extension of the Sistema Iberico close to the Rio Jucar and with the eastern extension of the Sierra Morena. The Sierra Nevada, part of the Sistema Penibetico, south of Granada, includes the highest mountain of Spain, Mulhacen, which rises to 3179 m.

The major lowland regions are the Ebro Basin in the NE, the Andalusian Plain in the SW and the coastal plains. The Andalusian Plain is basically a wide river valley through which the Rio Guadalquivir flows. The Andalusian Plain is bordered to the south by the Sistema Penibetico and to the north by the Sierra Morena. The Rio Ebro valley forms the Ebro Basin, which is surrounded by mountains on three sides, the Pyrenees to the north and east, the Sistema Iberico to the south and the west, and their coastal extensions running parallel to the shore to the east.

The coastal plains regions are narrow strips between the seas and the coastal mountains. They are widest along the Golfo de Cadiz, where the coastal plain connects with the Andalusian Plain, and along the central eastern and southern coasts. The narrowest coastal plain runs along the Bay of Biscay, where the Cordillera Cantábrica descends almost to the shore.

Owing to its southerly geographical location, which exposes only northern Spain to the jet stream's typical path, and to its resulting impacts, the climate is very varied, with three major climatic types: Mediterranean, oceanic and continental.

Spain experiences extremes of temperature and generally low rainfall (less than 610 mm) except in the north. Along the northern Atlantic coast, the climate (oceanic) is usually quite damp and cool. The Meseta Central has very hot, dry summers and drought is common (continental). In Seville, Córdoba and Granada, temperatures can reach 50ºC. On the southern coast, a Mediterranean climate prevails, with Málaga enjoying an average winter temperature of 14°C. Although Spanish soils need careful irrigation and cultivation, they are the country's most valuable natural resource with nearly 35% of the land available for cultivation. Major products include grain, vegetables, olives, tomatoes, grapes, sugar beet, citrus fruit, beef, pork, poultry and dairy.

The country also has many mineral resources, including hard and brown coal, some petroleum and natural gas deposits, iron ore, uranium, copper, fluorspar, gypsum, lead, mercury, potash, pyrite, tungsten and zinc. The principal coal mines are in the NW, near Oviedo; the chief iron ore deposits are in the same area, around Santander and Bilbao. Large mercury reserves are located in Almadén, in south-western Spain, and copper and lead are mined in Andalusia [20.1].

4.20.2. Geology

The geological structure of the Iberian Peninsula is relatively simple (Fig. 4.36). A series of sedimentary formations overlies a platform of ancient crystalline rocks, which had earlier been uplifted into discontinuous ridges and among which exist proxies of most of the geological systems from the older Palaeozoic to the Quaternary.

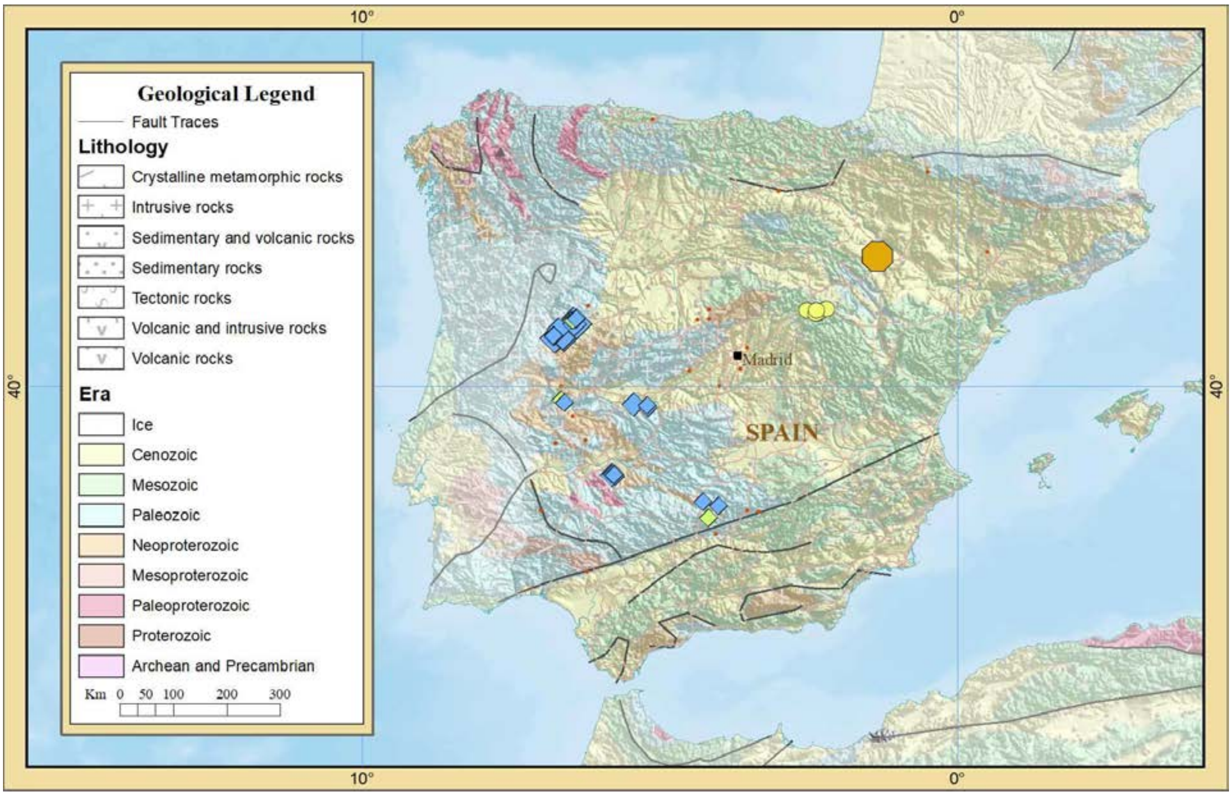


FIG. 4.36. Regional geological setting of Spain showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Archaean rocks are exposed along the great Pyrenean axis, in Serrania de Ronda, Sierra Nevada, Sierra Morena, Estremadura and Galicia. They comprise granite, gneiss and mica schist, with talc schist, amphibolite and crystalline limestone. The oldest Palaeozoic strata are of Cambrian and Silurian age. These strata extend across a large region of Salamanca, Leon, Estremadura, Castile, Asturias and Andalusia, and along the sides of the Cantabrian and Pyrenean chain. They comprise slate, greywacke, quartzite and diabase. Devonian grits, quartzite and shale occur in a few scattered areas, the largest and most fossiliferous of these existing in Asturias.

The Carboniferous rocks of Spain can be divided into three groups, the lowest comprising limestone intercalated with sandstone and shale, the middle comprising sandstones and conglomerates, and the uppermost strata comprising conglomerates, sandstones, shale and coal. They exist in discontinuous basins and are poorly explored. One of the largest areas, in Asturias, extends more or less continuously through the provinces of Santander, Palencia and Leon and covers 6500 km². Another 200 km² tract exists at San Juan de las Abadesas in Catalonia, while a third, covering ~500 km², extends from the province of Córdoba into Badajoz. There are other smaller areas with little or no coal, although, the presence of plant remains indicates that the strata comprise the Carboniferous system.

The Triassic system is well developed in the north of the Peninsula, along the Cantabrian chain and eastwards to the Mediterranean. It comprises red and variegated sandstones, marls and dolomites, crossed in some places by ophiolitic (mafic) rocks, and containing deposits of rock salt, aragonite and gypsum. These rocks underlie Jurassic strata, which are particularly prominent in the eastern part of the Peninsula, between Aragon and Castile, along the Mediterranean border, in Andalusia, as well as along the slopes of the Pyrénées. The Lias is the best represented rock.

The Cretaceous system is represented in four districts, the largest of which stretches across Valencia and Murcia; a second, which extends between the two Castiles; a third one occurring in Asturias and the Basque provinces; and a fourth which extends along the southern flanks of the Pyrenees from the Mediterranean to Navarre. The lower members of the Cretaceous sequences comprise an important freshwater formation (sandstones and clays), which stretches from the Cantabrian coast across the provinces of Logrofio, Soria, Burgos and Santander. This formation is probably equivalent to the Devonian Wealden series in SE England. The higher members include massive Hippurite limestone, and in the Pyrenean district, proxies of the upper subdivisions of the system occur, as well as the Danian (lowermost Palaeocene).

Deposits of Tertiary age overlie slightly at least 35% of the country. They can be divided into two major series, based on their mode of origin: marine or lacustrine. The marine Tertiary accumulations commence with the Eocene series, comprising nummulitic limestones, siliceous sandstones and marls. These strata are developed in the Ebro Basin, and in a belt which stretches from Valencia through Andalusia and Murcia to Cadiz. Marine Miocene deposits occupy some small tracts, particularly on the coast of Valencia. However, the majority of the sandy Tertiary rocks of this district are Pliocene. The Tertiary masses of Andalusia comprise coarse conglomerates (Middle Miocene) at their base, overlain by thick beds of bryozoan molasse and younger (Pliocene) beds. These strata are especially notable for hosting a significant metalliferous deposit, the native silver deposit of Herrerias, which occurs in a Pliocene bed in the form of crystals, needles and flakes. The most interesting and extensive Tertiary accumulations are those of the major lakes, which in the Oligocene and Miocene spread out over a large expanse of the tableland. These freshwater expanses covered the centre of the country, including the basins of the Tagus, Guadalquivir, Guadalaviar, Jucar and Ebro. They deposited thick sequences of limestone, gypsum, marls and clays, in which are preserved the remains of land fauna.

Quaternary deposits cover roughly a tenth of the country. The largest tract occurs to the south of the Cantabrian chain, but another, of barely lesser area, borders the Sierra de Guadarrama and widens out over the plain from Câceres to Madrid. Some of these alluvial deposits signify a previous greater extension of the snowfields that are now very limited in the Spanish sierras. The remains of reindeer have been found in caves in the Pyrénées.

Eruptive rocks of various ages exist in several areas of Spain. The most significant occurrence extends from Coria in Estremadura to Cape Ortegal and stretches across a large area of Portugal. They are also present in Castile, composing the Guadarrama and the Sierras of Gredos; further to the south they are present in the mountains of Toledo, in the Sierra Morena, and through the provinces of Badajoz, Córdoba, Huelva and Seville, and as far as Evora in Portugal.
Granite is the most abundant of the plutonic series. Volcanic rocks include quartz porphyry (Pyrenees, Sierra Morena), diorite, porphyrite, diabase (well developed in the north of Andalusia, where it has a major influence on the structure of the Sierra Morena), ophite (Cadiz, Pyrénées), serpentine (an extensive occurrence in the Serrania de Ronda), basalt, andesite, liparite and trachyte. The last four rock types are distributed in three main areas: (i) Cape Gata, including south-eastern Andalusia and southern Murcia, (ii) Catalonia and (iii) La Mancha.

The majority of Spain's uranium resources are hosted within the contact metamorphic aureoles where Hercynian granites have intruded pre-Devonian shale. This type of deposit is known as the Iberian type and occurs within the Meseta Central. The deposits are located in shales, which are rich in organic material and although they have been little affected by regional metamorphism, they have, however, been altered by contact metamorphism to hornfels.

Three types of mineralization are recognized:

(i) In the immediate vicinity of the granitic contact, a zone, ~1000 m wide, of altered sedimentary rocks occurs which is frequently fractured and may occur as inclusions (xenoliths) within the granite. Mineralization is preferentially located in these pockets, as is the case at the Alameda, Esperanza and Caridad deposits;
(ii) Mineralization which has the appearance of being vein-type occurs in roof pendants of shale in the granite. The most important deposit, at Fe, occurs in hornfels despite being located several kilometres from the nearest granite outcrop. There is a possibility, however, that granites may occur at shallow depth beneath the deposits. In these deposits, the mineralization occurs in fractures and in other heterogeneous portions of the shales which have permitted circulation of volatiles. In the oxidized zone, the mineralization essentially consists of uranium phosphates, including autunite, torbernite, uranocircite, saleeite, sabugalite, phosphuranylite and uranospilite. The mineralization generally extends to limited depths of 15–25 m. The majority of deposits of this type occur in the Ciudad Rodrigo district and include the Fe, Esperanza, Caridad, Alameda and Villavieja de Yeltes deposits. These deposits also occur, together with intragranitic deposits, in the districts of Câceres (Valdelayegua), Andujar (San Valentina, Raso de los Machos) and Zafra (Cabra Baja, Encinalosa);
(iii) Vein deposits, which account for a small percentage of Spain's resources, fall into two categories. The first category contains veins associated with quartz breccias, often with smoky quartz, mineralized by uranium and often associated with uranium–copper phosphates of no economic value. The second category includes veins associated with haematized jasperoid veins, often containing fluorite, where the pitchblende is generally accompanied by very small amounts of iron and, rarely, copper sulphides. Deposits in the latter category occur at Los Ratones in the Câceres district and in the La Virgen deposit in the Andujar district.

The Ciudad Rodrigo District, which is important mainly for deposits associated with schists, hosts several intragranitic vein deposits. These are siliceous breccias containing small amounts of Fe, Pb, Zn and Cu sulphides.

The deposits in the Zafra district exist in the contact aureoles of the Hercynian granitoids. One of these (Monesterio) consists of pitchblende with sulphides and arsenosulphides of Fe, Ni, Co and Cu. The other consists of uraninite/allanite hosted in inclusions within diopside skarn with a later association of sulphides and arsenosulphides of Fe, Ni, Co and Cu in the aureole of the granitoid. The economic value of these deposits appears to be very limited.These deposits contain abundant siliceous gangue and generally exhibit polymetallic associations. However, the vein-type deposits are of minimal importance economically and, given the effort expended on exploration and development of this type, it would appear that their potential is low.

Sandstone deposits in Spain occur in the post-Hercynian continental detrital basins. An exception is the La Plana occurrence in the eastern part of the Spanish Pyrénées.The mineralization at La Plana is hosted in schistose sandstones of Permian–Triassic age, which lie discordantly on folded Devonian formations consisting of black schists and bituminous limestones. The uranium-bearing mineralization is lodged in a brecciated zone and consists of pitchblende, 'carburans' (a pitch-like hydrocarbon containing uranium) and uranium vanadates associated with Cu, Ni and Co mineralization.

Sandstone-hosted mineralization occurs in the Iberian Range. This range has a Palaeozoic basement, with schists, quartzites and carbonates mobilized throughout the Hercynian phase and accompanied by late volcanism. Overlying this basement were deposited the largely detrital and continental Mesozoic and

Tertiary series (Lower Triassic, Lower Cretaceous and intermontane Tertiary basins). The entire range was affected by the Alpine Orogeny, the main phase of which in this area dates from the Oligocene–Miocene transition. Mineralization occurs in sedimentary rocks of several different ages.

From the NW to the SE, four sectors can be distinguished:

(i) The Burgos sector, where the sedimentary rocks of the Wealden and Aptian (Lower Cretaceous) as well as the fluviatile Palaeogene are potentially interesting potential for hosting uranium mineralization;
(ii) The Soria sector, where the mineralized formations are Lower Triassic, consisting of red sandstone in the Mazarete Basin (Guadalajara), which contains significant uranium reserves and resources; the arkosic Lower Cretaceous formations of the Pico Frentes and Sierra Leana Basins; and the zones of Salas de los Infantes, Penelen and Arijo (Maestrazgo);
(iii) The Tervel sector, where the formations of interest are as noted above;
(iv) The Cuenca sector, where uraniferous mineralization has been encountered in the Lower Triassic (in particular), the Lower Cretaceous and the Miocene (Corcoles mineralization).

Four Tertiary basins are recognized in Spain. One includes marine sediments and the other three, the Ebro, Upper Duero and Upper Tagus Basins, host intracontinental sediments. Uraniferous mineralization has been identified in Palencia Province in the north of the Upper Duero Basin. Here, the Palaeogene consists of conglomerates, arkoses and variegated clays which crop out in the western part of the region. Uranium mineralization occurs in the Miocene formations of the Mesa Manchega, east of the Upper Tagus Basin and has also been identified in the Oligocene lignite of the Ebro Basin in concentrations of 300–400 ppm U. Uranium has also been reported in association with titanium and zirconium in refractory minerals in Silurian quartzites, intercalated in schists of the Despenaperros district (at the eastern end of the Sierra Morena). The uranium concentrations vary in the range 300–600 ppm U [20.2, 20.3].

4.20.3. Uranium exploration

4.20.3.1. Historical review

The first studies of radium-bearing ores were carried out in Spain in 1914 by a French company on a deposit in the Monesterio region. This deposit was excavated to a depth of 60 m. In 1939, a private company (BRESA) mined pegmatites in the Sierra Albarrana which contained brannerite mineralization. Domestic exploration expenditure totalling USD $219 981 660 for 1 426 877 metres of drilling is summarized in Fig. 4.37. Non-domestic exploration details are given in Fig. 4.38 for a total of US $20.4 million.

In 1949, the Junta de Energia Nuclear (JEN) revived the Monesterio operation and continued exploration in that region until 1956. The initial targets of exploration were the Hercynian granites of western Spain. However, in 1952, JEN initiated an extensive exploration programme, concentrating mainly on the provinces of Jaén, Córdoba, Badajoz, Câceres, Salamanca and Zamora. It was at that time that systematic exploration in the Badajoz Massif began. In the Andujar region, the first uranium indications in the Los Pedroches Massif were found in 1953, and in May 1954 the most important of these, the La Virgen deposit, was found.

In 1965, exploration in sedimentary strata commenced and resulted in the finding of the Mazarete deposit in Guadalajara province. Near Soria, significant potential for uranium mineralization in sedimentary formations was reported.

Mineralization has also been found in lignite deposits hosted in lacustrine sediments of Oligocene age in the Calaf region. These extensive lignite deposits contain between 0.05 and 0.1% U. In 1976, 8500 tU of estimated additional resources were estimated to be hosted in the Calaf lignites, 12 800 tU in the Santa Coloma de Queralt lignites and 42 500 tU in the Fraga, Mequinenza and Almatret lignites.

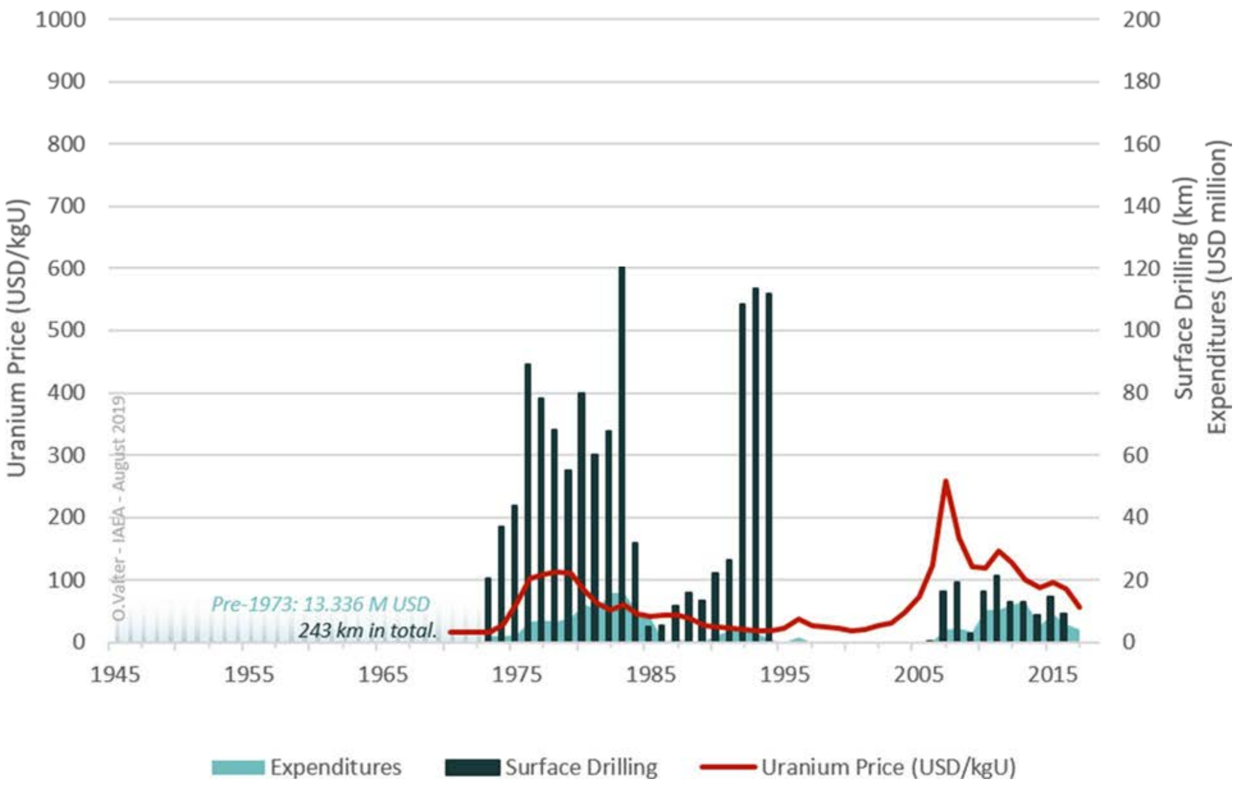


FIG. 4.37. Domestic uranium exploration data for Spain. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

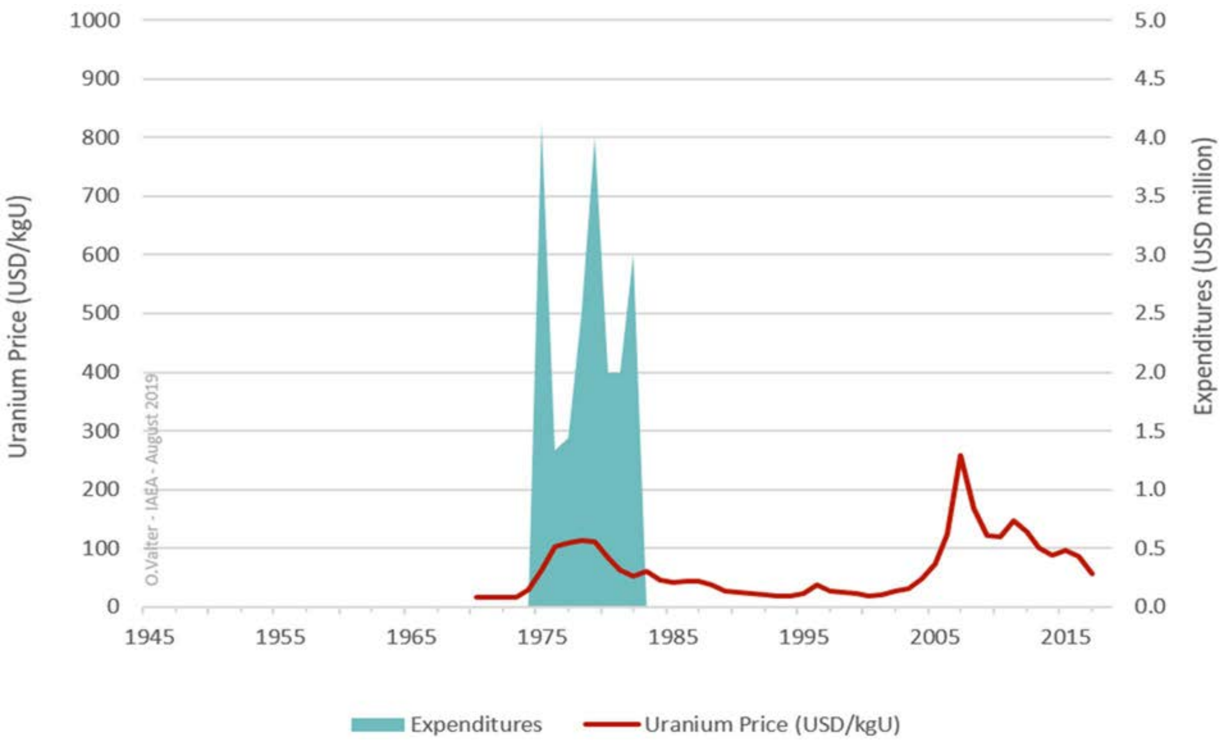


FIG. 4.38. Non-domestic uranium exploration data for Spain. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

In the Calaf Basin, uranium was found in the course of prospecting using car-borne equipment. The lignite-bearing zone is situated within the broad Oligocene band of the eastern sector of the Ebro valley. The formation, 800 m thick, consists of an alternating sequence of limestones, sandstones and marls which incorporate the different types of lignite. The Fraga, Mequinenza and Almatret Basins are the most extensive and homogeneous lignite-bearing basins of the Oligocene terrain to occur in the Ebro Basin. Unlike the Calaf Basin, they are not affected by folding or fracturing. For this reason the lignite layers and the uranium contents are very uniform. The total area of this basin covers ~750 km^2. In the Santa Coloma de Queralt Basin, the lignite-bearing layers occur near the surface. In the crystalline zone of Galicia, near Lugo and Orense, numerous uranium occurrences have also been recorded.

In the early 1970s, emphasis shifted from exploration in granite terrains and the surrounding metasedimentary rocks towards focusing on continental sedimentary formations, essentially Triassic, Lower Cretaceous and Tertiary. By mid-1972, an area of 95 000 km^2 throughout Spain had been covered by field prospecting (with mobile equipment or on foot) and a further 156 500 km^2 examined by airborne survey. Approximately 50% the country has been explored and appropriate general and regional studies have been conducted, with the level of emphasis varying according to the estimated relative potential of each site. Detailed studies have only been partially completed, particularly for the continental sedimentary formations.

During the period 1975–1984, uranium exploration was carried out under the National Plan for Uranium Exploration. The budget for this period totalled US $150 million. Prospecting received fresh impetus in 1975 when the budget for uranium exploration was at least doubled from US $2.6 million to US $6.5 million. This expenditure rose to US $7.1 million in 1976 and to US $8 million in 1978. This prospecting effort mainly targeted the post-Palaeozoic detrital basins of Lower Triassic (Bunter sandstones), Lower Cretaceous (Utrillas sands) and Tertiary age.

The Bunter sandstones attracted most of the attention. These occur along both branches of the Iberian Range, with discontinuous outcrops occurring over a distance of 200 km. They also crop out on the western part of the Mesozoic Cantabrian Basin and are present as a narrow band along the Pyrénées. Other outcrops include those in the Catalan Coastal Range and along the SE edge of the Meseta Central. Although little drilling has been done, a significant orebody was found near Molina de Aragon in the central part of the southern branch of the Iberian Range.

The Utrillas sands are known to occur along both branches of the Iberian Range and the Maestrazgo Basin. Many radiometric surface anomalies have been reported and drilling has been carried out in the area near Soria. Continental Tertiary basins cover extensive areas of Spain; three of them (Tajo, Duero and Ebro) cover an area of 100 000 km^2. A number of smaller basins are also present.

Exploration in 1978 included coverage of 110 000 km^2 in Santander and Zaragoza provinces, the Cordillera mountain ranges and the Ebro, Duero and Jajo river basins. During the period 1983–1984, exploration targets remained the same as in previous years, especially the Precambrian schists in the western part of the country. In 1984, exploration activities declined as a consequence of the Government decision to reduce the budget throughout for that year. The National Plan for Uranium Exploration was terminated at the end of December 1984. In 1989–1990, exploration continued in the Hercynian Massif in western Spain. Exploration was concentrated around the mine at Fe, where the M-Sageras and Esperanza deposits were found.

Activities for exploration by the Empresa Nacional del Uranio, S.A. (ENUSA) were concluded in 1992. Joint venture exploration between ENUSA and other companies resumed until the close of 1994. Throughout this period, most of the country had been investigated using various exploration methods which were suitably adapted. Sufficient coverage using ground and airborne radiometrics to evaluate the most favourable areas has been accomplished.

In 1989, exploration work was started in Câceres province by the ENUSA/COGEMA (Compagnie Générale des Matières Nucléaires) joint venture. Exploration work at the follow-up and detailed stages was, until 1992, concentrated on schist and granite targets north of Câceres city (Cabeza de Araya granite and contact schists), whereas in 1993 exploration was intensified around the Albuquerque granite, SW of Câceres.

Regional and reconnaissance work was carried out in another area around Plasencia, where granites, schists and Tertiary sedimentary rocks south of the Sierra de Gredos were being investigated. During 1991 and 1992, exploration work in Salamanca province was reduced in favour of the development of those deposits that had already been geologically evaluated. Thus, close space drilling, recoverable resource estimation, pit design and feasibility studies were being carried out on the Fe, Palacios (formerly Mina D), M-Sageras and Alameda deposits.

During the period 1993–1996, ENUSA improved its understanding of uranium deposition in the Ciudad Rodrigo area (Salamanca province) and carried out close spaced drilling (at least 100 000 m yearly) as well as updating mining projects and feasibility studies. These studies were focused on those orebodies most proximal to the Fe mining site. In this way, new assessments of reasonably assured resources and EAR-1 resources were achieved.

No activities for exploration were conducted in 1997–1998. Just some close spaced holes were drilled throughout 1998 at ENUSA's Fe mine. The last reported expenses were for 1998, for development work, which resulted in 18 development holes, totalling 641 m, being drilled. Spain (through ENUSA) carried out uranium exploration throughout the period 1975–1982 in the following countries:

(a) Canada, through participation in a joint venture;
(b) South Africa, in the Karoo region;
(c) Colombia, as operator associated with the Instituto de Asuntos Nucleares.

Cumulative exploration expenses of ENUSA in these countries totalled US $20.4 million.

4.20.3.2. Recent and ongoing uranium exploration and mine development activities

No activities for exploration or mine development were conducted throughout the period 1998–2004 (see FIG 4.20.2).Since 2005, international uranium companies have submitted applications for exploration permits in different historical uranium mining regions, e.g., Salamanca, Câceres and Guadalajara.

Total mineral resources in Salamanca province are 20 155 tU at an average grade of 0.037% U. Berkeley noted that confirmatory drilling is well advanced at the Alameda deposits, where it expects to define additional mineral resources. The Salamanca uranium project incorporates the State reserves, including the Aguila area (M-Sageras and Palacios (Mina D)) and Alameda deposits, Berkeley's Retortillo deposits and the Quercus uranium processing plant.

In early 2009, Berkeley entered into a cooperation agreement with Spain's fuel cycle company ENUSA Industrias Avanzadas S.A. under which Berkeley will undertake a feasibility study with a view to recommencing uranium mining based on ENUSA's and Berkeley's assets in Salamanca province. Berkeley commenced a feasibility study on the Salamanca uranium project in May 2009. The study focussed on mining the Aguila and Alameda areas, with output processed through the Quercus plant utilizing heap leaching or dynamic leaching, or a combination of the two. The study also addressed the potential for later sourcing of additional feed for the plant from nearby deposits. Apart from Salamanca, Berkeley has other projects, including Câceres VI, which has 4000 tU of inferred resources (based on ENUSA work), and two others in eastern Spain.

In the 2009 Red Book [20.4], JORC compliant resources provided by Berkeley totalled 10 385 tU distributed in four deposits. The resource data are obtained from reassessment of historical data, as well as from Berkeley's own exploration, which commenced in December 2006.

In March 2010, the Australian company Berkeley Resources Ltd (Berkeley) reported the JORC compliant uranium mineral resources for the Aguila area, including the Sageras, Palacios (previously Mina D) and Majuelos deposits, as totalling 7960 tU at an average grade of 0.035% U. In addition, mineral resources in the Retortillo area total 8650 tU at an average grade of 0.043% U.

In 2013, a pre-feasibility study using only the 13,270 tU estimated resources of Alameda and Retortillo was based on open pit mining with acid heap leaching at both sites, a central processing plant at Retortillo and a remote ion exchange operation at Alameda, with resin trucked to the main plant. In 2014 Berkeley was granted a 30-year mining licence for Retortillo. Possible satellite operations include Zona 7 (11,600 tU, 10 km from Retortillo). In 2015, Consejo de Seguridad Nuclear (CSN) approval represented the first of three steps in authorizing the treatment plant as a radioactive facility in the name of Berkeley Minera Espana, then the company obtained all approvals for project infrastructure. Some infrastructure development started in 2016, major plant items were ordered late in 2016 and full construction of the mine and plant started early in 2017 [20.5].

4.20.4. Uranium resources

Details summarizing Spain's in-situ uranium resources and related costs are given in Tables 4.6 – 4.7. The historical variations in identified resources are shown in Figs 4.38 and 4.39. Table 4.8 gives the discovery cost of uranium in Spain.

4.20.4.1. Identified resources

TABLE 4.6. REASONABLY ASSURED RESOURCES (tU) [20.6]
(as of January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Vein (granite-related)	10 300	24 200	24 200	24 200
Total	10 300	24 200	24 200	24 200

TABLE 4.7. INFERRED RESOURCES (tU) [20.6]
(as of January 2017)

Deposit type	<US$ 40/kgU	<US$ 80/kgU	<US$ 130/kgU	<US$ 260/kgU
Vein (granite-related)	0	11 900	11 900	11 900
Total	0	11 900	11 900	11 900

TABLE 4.8. DISCOVERY COST OF KNOWN CONVENTIONAL RESOURCES AND PRODUCTION [20.6]
(as of January 2017)

Reasonably assured resources (tU)	Inferred resources (tU)	Known conventional resource (reasonably assured plus inferred resources) (tU)	Production (tU)	Known conventional resources plus production (tU)	Exploration expenditures (US $1000)	Discovery cost (US$/kgU)
24 200	11 900	36 100	5028	41 128	222 998	5.42

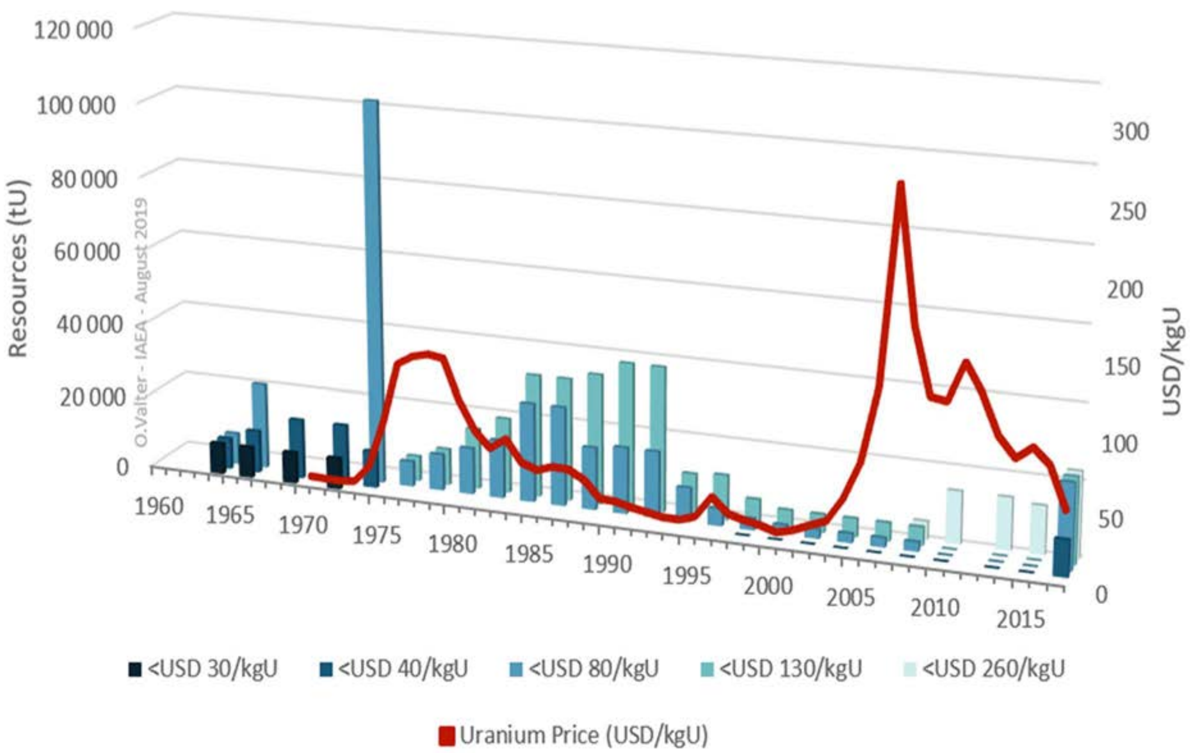


FIG. 4.38. Historical variation of recoverable reasonably assured resources within various cost categories in Spain. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

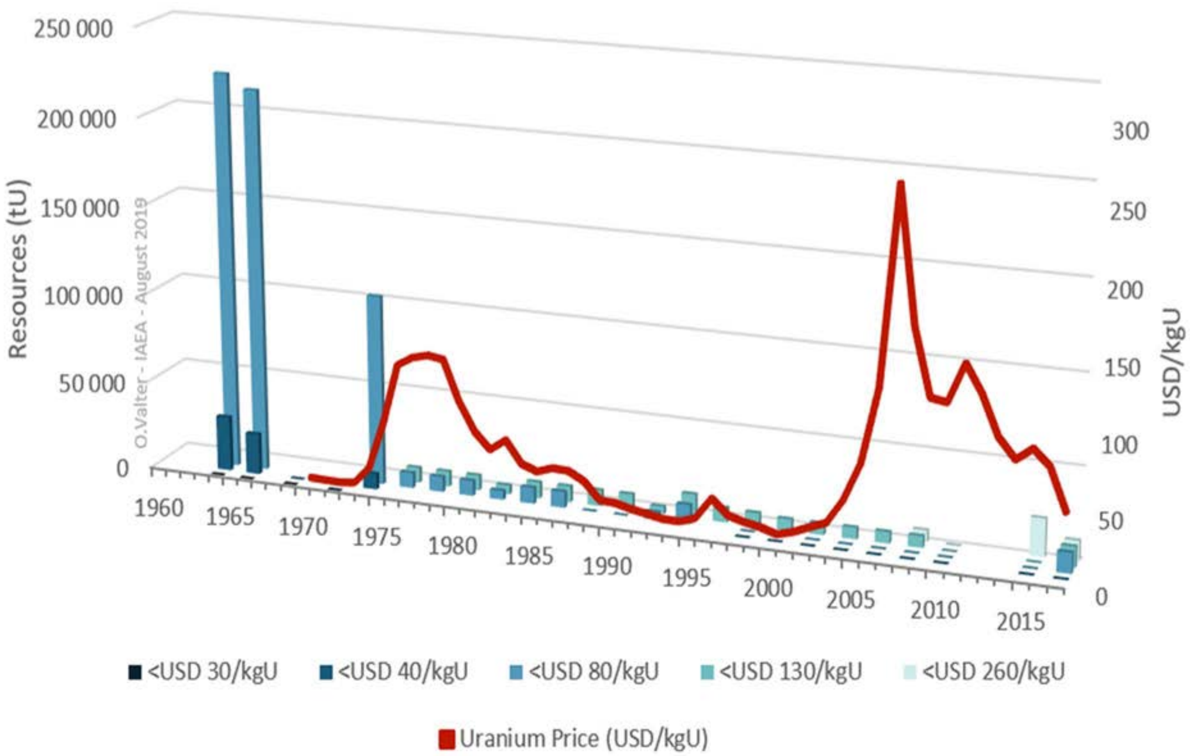


FIG. 4.39. Historical variation of recoverable inferred resources within various cost categories in Spain. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

4.20.4.2. *Uranium deposits*

UDEPO has listed the uranium deposits in Spain [20.7]. Fig. 4.36 shows the location of some of the principal deposits. The most significant deposits for Spain as Almaret-Fraga-Mequinenza, Calaf area, Santa Coloma de Queralt, Alameda South, Mina Fe, Retortillo, Gambuta, Sageras-Zona M.

4.20.5. Uranium production

4.20.5.1. *Historical review*

Spanish uranium production was first started on a semi-industrial scale in 1949–1954, using primary ores with grades of 3.4–17% U (Fig. 4-20.5). The pilot plant at Moncloa (Madrid) was designed based on the experience gained at the time and employed the alkaline process. It operated up to 1959. Details of historical uranium production in the period 1949–1959 are unknown.

Full-scale industrial production began in 1959 at the Andujar plant (Jaén) and lasted until 1981. The Don Benito plant (Badajoz) remained operational in 1983–1990. Production at the Mina Fe operation (Salamanca) began in 1975 with heap leaching (Elefante plant). A dynamic leaching plant (Quercus) commenced operation in 1993 and was closed in December 2000. The treatment plant completed treatment of uranium concentrates in November 2002. The license for a decisive closure of production was filed to regulatory authorities in December 2002 and was awarded in July 2003. Total production amounted to 5028 tU [20.6].

At the end of the 1980s, Fosforico Espanol S.A. and ENUSA planned the construction of an extraction plant at Huelva, designed to extract uranium from phosphoric acid. The plant had a projected processing capacity of 300 000 t/year of P_2O_5, equivalent to a production capacity of 75 tU/year. Start-up was planned for 1987, but the project was never completed.

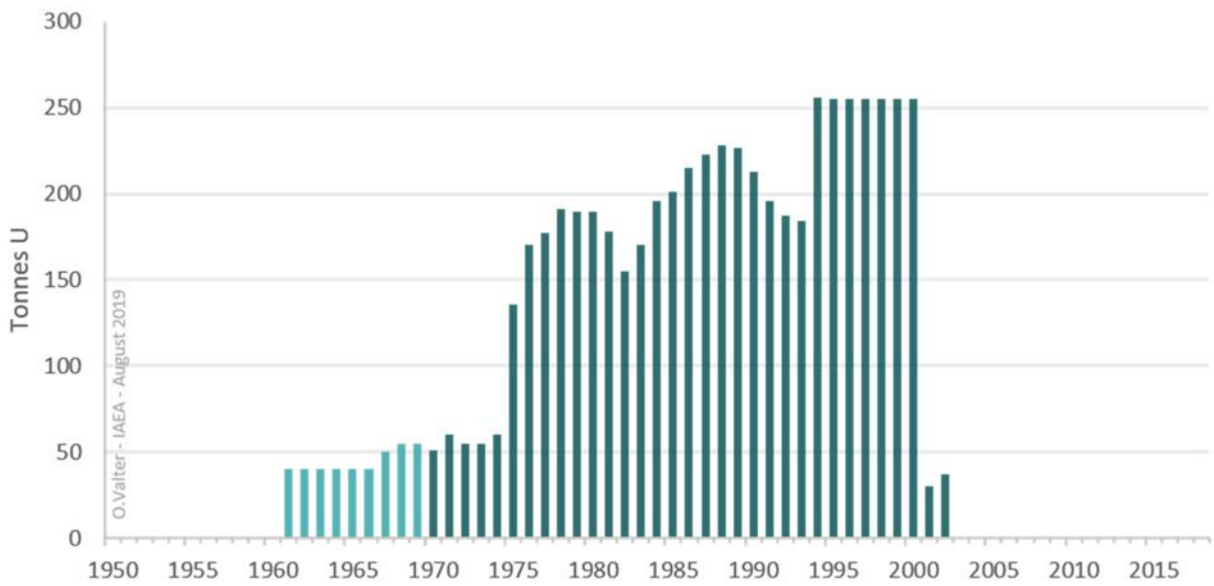


FIG. 4.40. Historical uranium production in Spain (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

4.20.5.2. *Ownership structure of the uranium industry*

The sole production facility in Spain is owned by ENUSA Industrias Avanzadas, S.A., which is owned jointly by Sociedad de Participaciones Industriales (60%) and Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (40%).

4.20.5.3. *Mined deposits*

Mina Fe

Mina Fe [20.8] was the most important uranium deposit in Spain. This uranium deposit was found by radiometry in 1957 and production commenced in 1974. Initially, mining activity focused on the zone of supergene enrichment rich in hexavalent uranium minerals. Subsequently, the primary reduced ore was mined. Yearly production until closure in 2001 totalled 250 tU, which was extracted by dynamic leaching in a plant with a yearly capacity of 800 tU. The grade of the ore mined was 0.06% U.

At present, the non-mineable geological resources at Fe are in excess of 4000 tU, at a cut-off grade of 200 ppm U. In addition, several other uranium deposits of the same type occur west and north of Ciudad Rodrigo (Mina D, M-Sageras, Alameda and Alameda North). Total non-mineable geological resources hosted within these deposits amount to at least 16 000 tU, of which 7600 tU are contained within the Alameda orebody.

Don Benito

The Don Benito uranium mine, composed of several orebodies, is situated in the La Haba district, in the Extremadura region of south-western Spain. Uranium mineralization occurs on the northern flank of a syncline, where an axial plane parallel fault has controlled emplacement of a radiogenic granite intrusion. The mineralization is clearly associated with the granite, following and lying in close proximity to the intrusion contact within an Ordovician shale and schist sequence. Deposit mineralogy is dominated by secondary uranium minerals, including autunite, torbenite and sabugalite, with lesser amounts of pitchblende and uranotile.

Roughly 1000 tU have been extracted by open pit mining throughout two phases of activity. In the period 1960–1975, 650 tU were extracted at a grade of 0.102% U from the El Lobo and El Pedrigal open pits. In 1980–1990, 350 tU at a grade of 0.110% U were extracted from the El Pedrigal, Intermedia and Maria Lozano open pits. A processing plant at the site produced yellow cake in 1983–1990. The project ceased operation in March 1990 owing to an increasing strip ratio and the low uranium price prevailing at that time. Remaining in situ resources are estimated to amount ~2500 tU.

Andujar

The Andujar uranium mill plant operated in the period 1959–1981, producing uranium concentrate from ore extracted from 24 mines located within a 400 km radius of the site (in the provinces of Badajoz, Córdoba and Jaén). Of this total, 22 uranium mines were developed by underground mining and two by open pit mining. Mining operations started about 1950 and were shut down in 1976. The ore was extracted from vein-type deposits hosted in granitic and metamorphic strata. Ore grades varied in the range 0.06–0.23% U. The Andujar plant was designed for processing low grade uranium ore (0.15% U) and produced an 80% concentrate of U_3O_8 in the form of sodium and ammonium uranate at a rate of 60–80 t/year. A total of 1.22 million tonnes of ore were processed from which 1145 tU were extracted.

Los Ratones

Los Ratones, located in the Câceres region, was mined as a small, granite-hosted, vein-type, underground mine in 1959–1975. It was mined to a depth of 160 m and worked along strike for 375 m. A total of 125 000 t of ore were extracted, grading 0.192% U, to produce 240 tU. The principal uranium mineral was massive pitchblende associated with pyrite in quartz veins. Other small mines in the same area include La Carretona, Las Perdizes, La Dehesilla, El Penascal, La Dehesa del Medico and Casa del Gallo [20.5].

4.20.5.4. *Status of production capability*

Activities for mining were concluded in December 2000 and the treatment plant completed producing uranium concentrates in November 2002.

4.20.5.5. Future projects

In December 2008, Berkeley announced an agreement with ENUSA to undertake an 18 month feasibility study on restarting uranium mining, focusing on the Aguila and Alameda areas close to the Quercus mill. Berkeley will have the right to acquire up to 90% of ENUSA's mining and exploration assets, including the Quercus mill, which will form part of its Salamanca Project. The ENUSA assets in the Aguila area include three significant deposits, Sageras, Majuelos and Palacios, two of which have been previously mined as Mina Fe. These have reserves of 8000 tU (JORC compliant), ~50% of this as measured and indicated resources. Also included in the ENUSA agreement are the less advanced but extensively drilled Alameda and Esperanza deposits, the former situated ~10 km west of Aguila. Berkeley has an exploration target of 11 000 tU of reserves for these, based on ENUSA's earlier work. Berkeley's own Retortillo area, comprising Retortillo, Santidad and some smaller deposits, is situated 25 km NE of Aguila [20.4].

Overall, Berkeley (March 2016) claims 34 500 tU resources for the Salamanca project (JORC-compliant) at an average grade of 0.041% U, with 170 ppm U cut-off. An updated pre-feasibility study based only on 23 600 tU measured and indicated resources showed that incorporating Zona 7 transformed the economics of the project. It increased the mine life from 11 to 17.5 years, reduced the operating costs from $24.60 to $15.60 per pound of U_3O_8 produced and reduced the initial capital cost from $95 million to $81 million. A definitive feasibility study in July 2016 showed 1700 tU/yr production over ten years at $15.06/lb. In August 2017 Berkeley arranged through a $120 million investment an agreement with the Oman's sovereign wealth fund to bring the project into production [20.5].

4.20.6. Environmental activities

Following the closure of the mines and processing plants, decommissioning and reclamation efforts focused on the different sites. Status, as of 2005, with regard uranium production facilities are as follows:

(a) Fabrica de Uranio de Andujar (Jaén): This plant was operational from November 1959 to July 1981. In March 1995, the dismantling and refurbishment of the old Andujar uranium concentrate plant were accomplished. This work was conducted by the Empresa Nacional de Residuos Radiactivos, S.A. A 10-year monitoring and control programme (erosion control, groundwater quality, infiltration and radon control), which is a precondition instituted by the Spanish Nuclear Safety Council for the issuance of the ultimate declaration of shutdown, was introduced in 1995 as the dismantling and rehabilitation were completed;
(b) Mine and plant LOBO-G (Badajoz): Mothballing of the waste dump and treatment plant at ENUSA's La Haba production centre (Badajoz) was authorized in November 1995. Demolition and rehabilitation of the site were undertaken throughout 1996 and 1997. The materials have been placed in the tailings dam, which has been covered with a 3–8 m thick layer of waste material with high clay content and which has been capped with soil. The open pit was mothballed throughout 1995, including revegetation. The open pit and mill tailings remediation was followed with a monitoring and control programme (erosion control, groundwater quality, infiltration and radon control) until 2004, which was followed by a long-term stewardship programme;
(c) Old mines in the Andalucía and Extremadura regions: In both regions, 18 open pits and underground mines were rehabilitated, with work accomplished in 2000. The cost of these remediation activities totalled the equivalent of €8 million;
(d) Elefante plant (Salamanca): The mothballing plan for the Elefante heap leaching plant was indorsed by regulatory authorities in January 2001. The plant was demolished in 2001. Stockpiles of ore (used for heap leaching) were regraded, then totally capped with a protective layer in 2004, and a 5-year monitoring and control programme was started;
(e) Open pit mine in Saelices el Chico (Salamanca): The remediation plan in 2004 for the open pit mine in Saelices el Chico (Salamanca) was indorsed by the regulatory authorities. This remediation plan is programmed to be completed in 2008;

(f) Quercus plant (Salamanca): Activities for mining were completed in December 2000 and the treatment plant stopped generation of uranium concentrates in November 2002. A proposal for mothballing was filed to the regulatory authorities in 2005;

(g) Nuclear Safety Council and the Ministry of Industry and Energy: In 1997, the Nuclear Safety Council and the Ministry of Industry and Energy indorsed a plan for the rehabilitation of 22 old uranium mines ran by the former JEN from the early 1950s to 1981. They were operation either as trial or production mines and the ore was processed at the Andujar plant. Of the 22 mines, one is in the Castilla-La Mancha region, five in Andalucía and 16 in the Extremadura region.

References to Section 4.20

[20.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Spain, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed July 2008).

[20.2] 1902 ENCYCLOPEDIA, Geology of Spain, http://www.1902encyclopedia.com/S/SPA/spain.html

[20.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524

[20.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[20.5] WORLD NUCLEAR ASSOCIATION, Nuclear Power in Spain (2018).

[20.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 20018: Resources, Production and Demand, OECD, Paris (2018).

[20.7] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[20.8] MARTIN-IZARD, A., ARRIBAS Sr, A., ARIAS, D., DRUIZ, J., FERNANDEZ, F.J., The Fe deposit, West-Central Spain: Tectonic–hydrothermal uranium mineralization associated with transpressional faulting of Alpine age, Can.

4.21. SWEDEN

4.21.1. Geography

Sweden is situated in north-western Europe and has land borders with Norway and Finland. The western part is mountainous, whereas hilly areas predominate in the south, which also hosts two large lakes, Vaenern and Vaettern. Some areas are covered by glacial features such as moraines and abundant lakes. Agricultural plains are present in the South. Sweden has no important navigable rivers although some lakes are used as navigable waterways. It has two major islands in the Baltic Sea, Gotland and Öland , and a large number of smaller islands lying along the coast.

The north is characterized by an Arctic climate, becoming more temperate in the south. Over 50% of the country is forested. Natural resources include iron ore, base metals and some precious metals [21.1].

4.21.2. Geology

4.21.2.1. General

The general geology can be divided into the Archaean/Jatulian, the Precambrian of the Svecofennian, the Precambrian in SW Sweden, the Precambrian of other areas, as well as the Caledonian and the Phanerozoic (Fig. 4.41).

The oldest rocks in Sweden date to the Archean, more than 2500 Ma ago and are restricted to a few areas in the far north of the country. The Archaean consists mainly of gneisses and metasedimentary rocks. The Svecofennian, with the Svecokarelian Orogeny between 1950 and 1850 Ma, comprises mafic, intermediate and felsic metavolcanic rocks, undeformed basic rocks, intrusive granites of different ages, as well as sedimentary rocks (Jotnian sandstone).

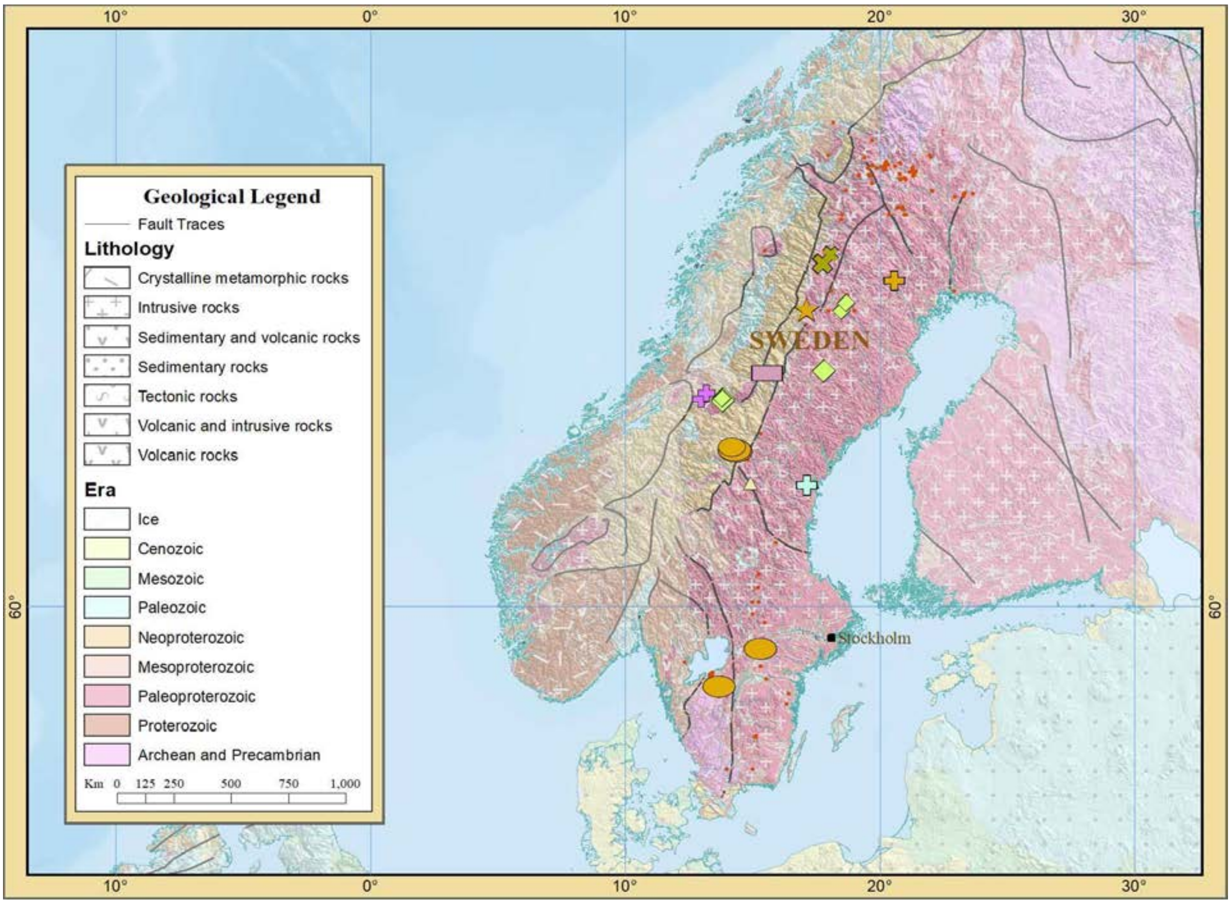


FIG. 4.41. Regional geological setting of Sweden showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

A variety of granitic intrusions, metasedimentary rocks and some basic rocks occur in the Precambrian of SW Sweden. The Precambrian in other areas is mainly characterized by granitic rocks. The Caledonides formed during the Caledonian Orogeny in the early Paleozoic, along the western margin of Sweden 510 to 400 Ma ago. The Caledonides are 900 km long, 120 km wide and are dominated by a series of thrust sheets, on top of the Precambrian allochthon formations. They comprise 200 m thick Cambrian shallow marine quartz arenite, Ordovician black shales and Silurian limestone, sandstone and shale. Of particular interest, are the uraniferous black shales (alum shales) [21.2, 21.3].

The Tornquist Zone, south Sweden, is characterized by deep faults bounding the Fennoscandian Shield. They have been active since the Carboniferous. In this area, Early Paleozoic rocks are up to one kilometer thick, continuing upward into Mesozoic and Cenozoic rocks (shale, siltstone and sandstone). The Late Cretaceous and Lower Cenozoic are made of limestone two to three kilometers thick.

4.21.2.2. Geology of uranium-bearing areas

In the region of Arjeplog-Arvidsjaur, south of the Arctic Circle, a uranium-bearing area was identified in a complex of volcanic rocks, granites and alaskites hosted in Proterozoic rocks 2000–1500 Ma in age. Sodium metasomatism occurred throughout the Svecofennian Orogeny (1754–1735 Ma) and mobilized uranium from the alaskites, depositing it as vein infillings and impregnations. The most significant deposit occurs at Pleutajokk as stockwork fillings.

In central Sweden, north of Ostersund, a ‘window’ of Precambrian rocks in the overlying Caledonides occurs at Hotagen. Veins hosting uranium mineralization transect the Precambrian and Caledonian strata. At Lilljuthatten, pitchblende-bearing veins are found in granite [21.4].

The Upper Cambrian and Lower Ordovician sedimentary rocks in southern Sweden contain black (alum) shales. The best known is the area of Billingen in Västergotland where the Ranstad deposit is situated. Ranstad consists of low grade stratiform uranium mineralization. Limited mining was carried out in the 1960s but was terminated owing to environmental reasons [21.3, 21.5].

4.21.3. Uranium exploration

4.21.3.1. Historical review

Exploration for uranium was conducted during 1950–1985 (Fig. 4.42) [21.6]. At the close of 1985, activities for exploration were halted because uranium became readily obtainable, at low prices, from the world market. Exploration expenses reported for 1971–1985 totalled US $47.9 million.

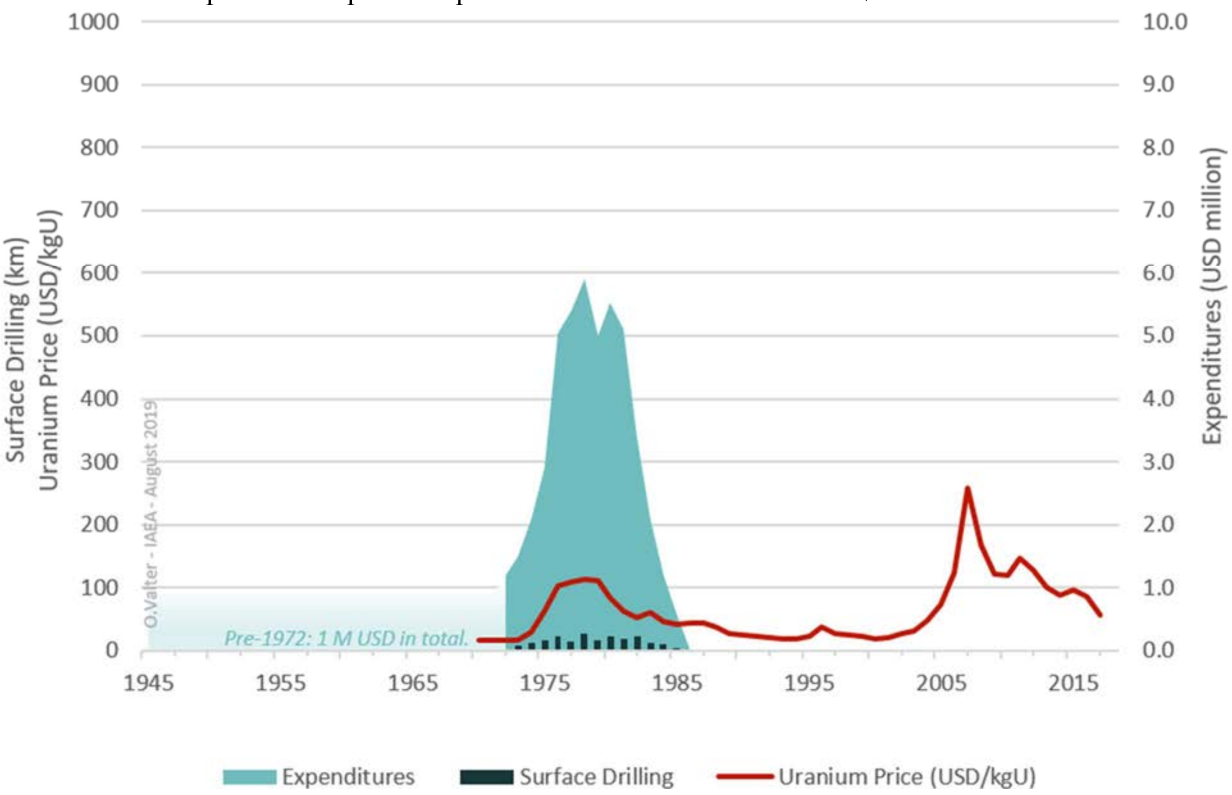


FIG. 4.42. Domestic uranium exploration data for Sweden. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

4.21.3.2. Recent and ongoing exploration and mine development activities

From 2005, several exploration firms have applied for and have been awarded permits for uranium exploration. In some cases, these permits are being questioned by members of local communities. Nevertheless, exploration is proceeding and some companies have reported uranium resource estimates.

The Swedish report to the 2009 Red Book provides the following summary of exploration activities [21.7]. Since the revival of exploration in recent years, at least five companies have been active:

(i) Mawson Resources Inc. of Canada has explored and evaluated data at several small deposits in northern Sweden, including: (a) the Hotagen district, where a NI 43-101 compliant estimate reported 1270 tU of indicated resources at 0.068% U; (b) the Duobblon project, where a Canadian

Institute of Mining, Metallurgy and Petroleum compliant estimate reported a resource of 3385 tU at 0.042% U; and (c) the Tåsjöe project, where a resource of 42 300 tU at 0.042% U has been outlined in phosphatic shale and associated with rare earth elements;

(ii) Uranium International Corporation has been undertaking initial exploration on several small deposits in northern and central Sweden;

(iii) In 2007–2008, Continental Precious Metals accomplished NI 43-101 technical reports on a portion of the Alum Shale Formation;

(iv) Aura Energy has also reported interest in the Alum Shale Formation and has applied for landholdings;

(v) Continental Resources was reported to be investigating the potential of bioleaching to recover metals from black shale. Indicated resources in place for the MMS Vicken deposit:: 3824 tU at 0.016% U; inferred resources: 399 100 tU at 0.0144% U (according to Continental Precious Minerals, Inc. as of March 2009). These deposits also have high values of V (2.55 kg/t), as well as Mo and Ni [21.5];

(vi) In 2012, Aura Energy Ltd in its Haggan project near-by MMS Vicken reports resources of 308 000 t U at 133 ppm with associated V, Ni, Mo.

4.21.4. Uranium resources

4.21.4.1. Identified resources

There are limited uranium resources hosted in granite (vein deposits). The historic variation in identified conventional resources is shown in Fig. 4.43 and Fig. 4.44. As of 1 January 2017 [21.8], in-situ reasonably assured and inferred resources in the cost category <US $130/kgU are 6500 tU and 6300 tU [21.8, 21.9].

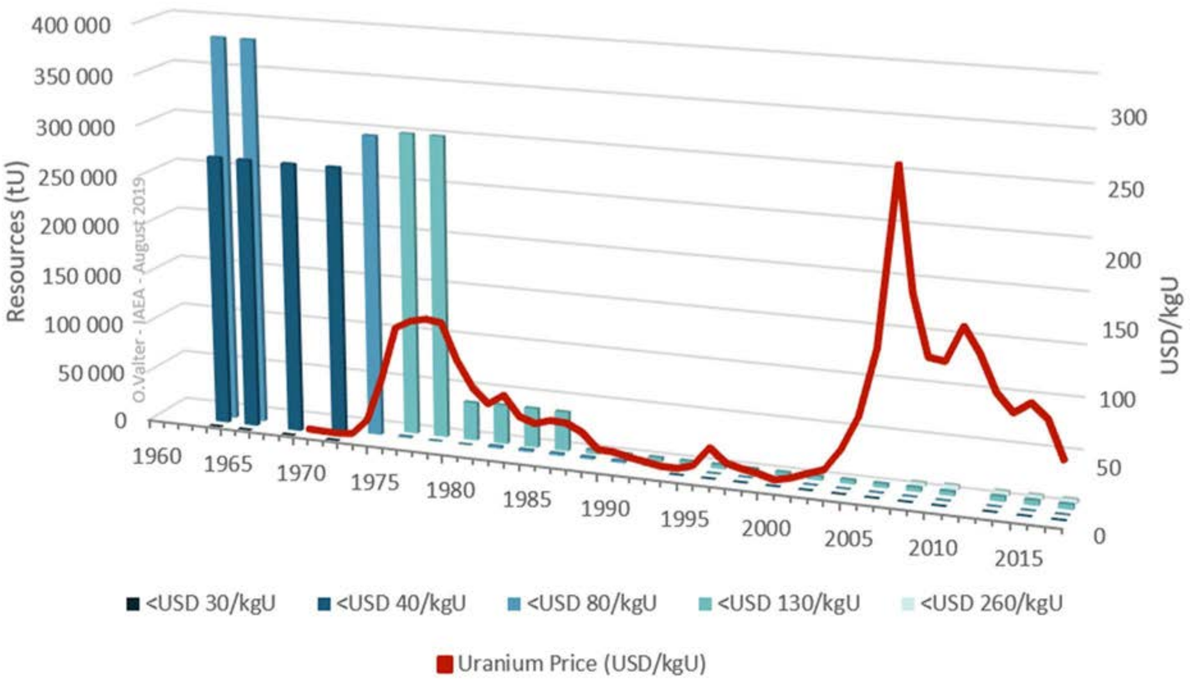


FIG. 4.43. Historical variation of recoverable reasonably assured resources within various cost categories in Sweden. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

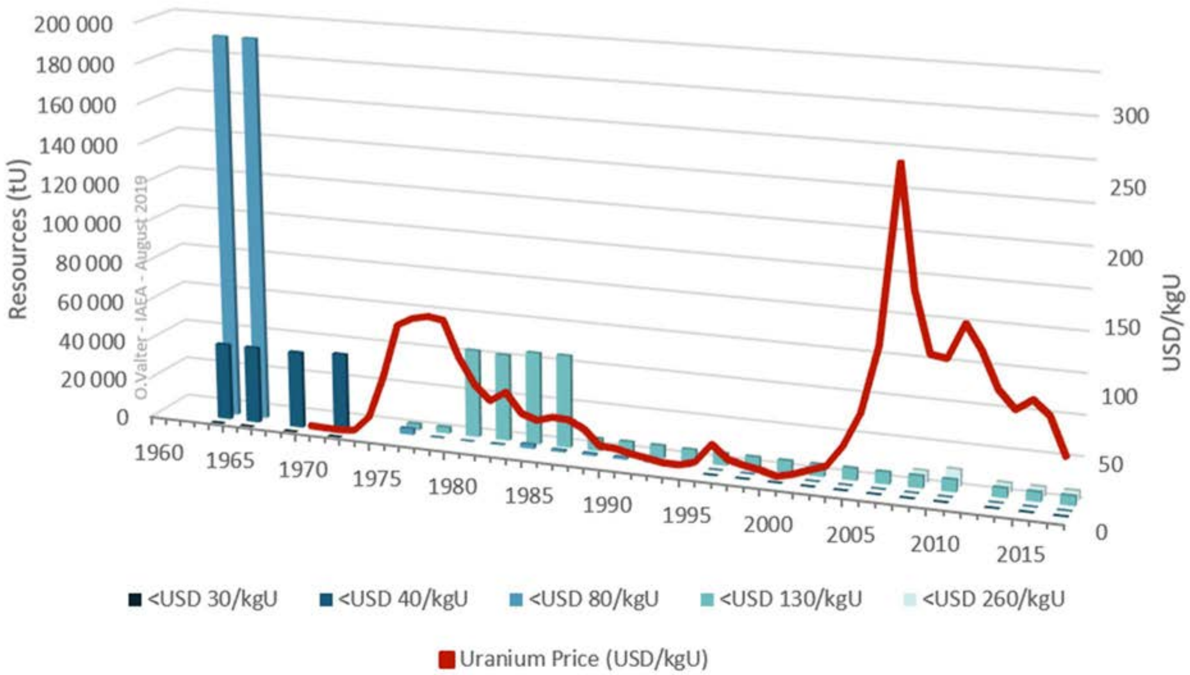


FIG. 4.44. Historical variation of recoverable inferred resources within various cost categories in Sweden. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

The UDEPO database lists the most significant deposits for Sweden as Ranstad, MMS Vicken, Haggan, Narke, Tasjo District, Marby, Duobblon, Pleutajokk, Lill-Juthatten, Palang, Kvarnan.

4.21.4.2. Other uranium resources reported

In 2006, the Wise Uranium Project reports the following resources (Table 4.9), although these data are not official figures [21.4]. In addition, for the MMS Vicken and Klappibaecken deposits, the same source gives indicated and inferred resources (Table 4.10). According to Troeng and Wilson [21.10], the resources of Lilljuthatten were estimated to be at least 1200 tU, reflecting the information available in the early 1980s. In 2011, Continental Precious Metals published resources of 1873 t U at a grade of 0.201% for this last deposit.

TABLE 4.9. URANIUM DEPOSITS [21.4]

Deposit	Resource (tU)	Grade (%U)
Skuppesavon, Norrbotten	688	0.07
Pleutajokk, Norrbotten	2030	0.1
Kvarnan, Norrbotten	1422	0.07
Bjoerkramyran, Västerbotten	1321	0.1
Lilljuthatten, Jämtland	1652	0.2
Noejdfjaellet, Jämtland	438	0.06
Tåsjöe District, Jämtland/Västerbotten	42 308	0.025–0.06
Sågtjärn, Västernorrland	438	0.058
Duobblon, Värmland	4400	0.03

TABLE 4.10. MMS VIKEN AND KLÄPPIBAECKEN RESOURCES [21.4]

MMS Viken, Jämtland (black shales)		
February 2008	Indicated resources	Inferred resources
Size	2208 tU	168 095 tU
Ore grade	0.016% U	0.014% U

Kläppibaecken, Jämtland (granite-related endogranitic)		
July 2008	Indicated resources	Inferred resources
Size	46 tU	1212 tU
Ore grade	0.054% U	0.065% U

4.21.4.3. Unconventional resources

There are potentially large resources of uranium hosted in the Alum Shale Formation. However, these deposits are very low grade and the cost of recovery is estimated to be above US $130/kgU. Owing to restrictions and its unusual nature, the Alum Shale Formation at Ranstad is classified as an unconventional resource. The historic resources were reported as 1 700 000 tU. The ore grade at Ranstad is reported as being <0.03% U.

Total geological resources in the Randstad district are estimated to be 1.7 million t U at a grade of 210 ppm [21.11].

Besides Randstad and the MMS Viken and Haggan projects, alum shales are also known in several other areas such as at Narke (257 000 t U, 175 ppm), Ostergotland, Oland, Gotland, indicating that the geological uranium resources are enormous [21.11].

4.21.5. Potential for new discoveries

Detailed exploration can be expected to define additional resources in the areas described above. The potential for new discoveries is indicated by increased exploration activities by private companies, as already detailed. However, the results to date only indicate the presence of low grade mineralization.

4.21.6. Uranium production

4.21.6.1. Historical review

In the 1960s, 215 tU were produced from the Alum Shale Formation at Ranstad. This represents the country's total historical production. The Ranstad mine site is being restored to protect the environment.

4.21.6.2. Secondary sources of uranium

Sweden does not report the use of mixed oxide fuel or reprocessed uranium. Swedish utilities used re-enriched tails amounting to 230 t and 571 t nat. U (eq.) in 2007 and 2008, respectively.

4.21.7. Environmental activities and sociocultural issues

As already noted, Refs [21.12, 21.13] reported a total production of 215 tU originating from the Ranstad alum shale. The ore grade is reported as 300 ppm U and the shale contains ~22% organic matter and ~15%

pyrite. From a total of 1.5 million t of alum shale mined, the resulting tailings of ~1 million m³ have been deposited over an area of 250 000 m².

The Ranstad mine was rehabilitated in the 1990s. The open pit, originally 2 km long, 100–200 m wide and ~15 m deep was transformed into a lake and the tailings area was covered with a multilayer top to prevent the formation of acid from sulphur in the shale tailings. An environmental monitoring programme is now being carried out. The total cost for restoration of the Ranstad mine has been estimated at SEK 150 million. The current monitoring programme represents only minor costs.

References to Section 4.21

[21.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Sweden, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed December 2108).

[21.2] GEOLOGICAL SURVEY OF SWEDEN, Geology of Sweden, Maps and Metadata (2009).

[21.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[21.4] WISE URANIUM, Uranium Mine Ownership, http://www.wise-uranium.org/uoeur.html#SE (August 2008).

[21.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[21.6] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[21.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[21.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018)

[21.9] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[21.10] TROENG, B., WILSON, M.R., "Geological setting of uranium mineralizations in the Hotagen area, Central Swedish Caledonides", Vein-Type and Similar Uranium Deposits in Rocks Younger than Proterozoic (Proc. Tech. Mtg Lisbon, 1979), IAEA, Vienna (1982).

[21.11] ANDERSONN, A., DAHLMAN, B., GEE, D.G., SNALL, S., The Scandinavian Alum Shales. Sveriges Geologiska Undersokning, Upsalla (1985) 52 p.

[21.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999).

[21.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002).

4.22. SWITZERLAND

4.22.1. Geography

Switzerland is a landlocked country in western Europe and has borders with Austria, France, Germany, Italy and Liechtenstein. The Alps are a dominant feature of the country and cover the central and southern parts. A hilly plateau area north of the Alps is bordered to the NW by the predominantly limestone mountains of the Jura. This plateau area, which borders France, covers roughly 35% of the country and is the most populous area.

The Alps include several mountains with elevations of at least 4000 m and these form the principal watershed. The Alpine chain continues to the west and into France, to the east into Germany and Austria and to the south into Italy. The River Rhine and its tributaries drain roughly 65% of the country, eventually discharging into the North Sea. The River Rhone flows through France and enters the Mediterranean. The River Inn, which originates in Switzerland, is tributary to the river Danube, which flows into the Black Sea. Switzerland has a number of lakes, of which the largest are Lake Constance, Lake Leman (Lake Geneva) and Lake Neuchatel [22.1].

4.22.2. Geology

4.22.2.1. General

The geological history starts with the sedimentation of the Tethys Ocean, which dates to ~500 Ma. Marine limestone was the principal sediment deposited, although this includes numerous intercalations of other types of sediment. Most of the older formations are metamorphosed by later orogenic activity, the ages of which are difficult to determine. The process of Alpine uplift is dated at ~100 Ma and came about as the result of collision with the northward moving African Plate.

The Alps exhibit a very complicated structural development, characterized by nappes. Crossing the Alps in a NW–SE direction, a general geological section is traversed, as follows:

(i) Helvetic nappes built up mainly of folded calcareous sedimentary rocks of Triassic–Tertiary age;
(ii) Pre-Triassic core covered by Mesozoic and Tertiary sedimentary rocks;
(iii) Penninic nappes composed of pre-Triassic metamorphic basement rocks;
(iv) Austro-alpine nappes of pre-Permian igneous rocks and schists, covered by younger rocks of variable composition.

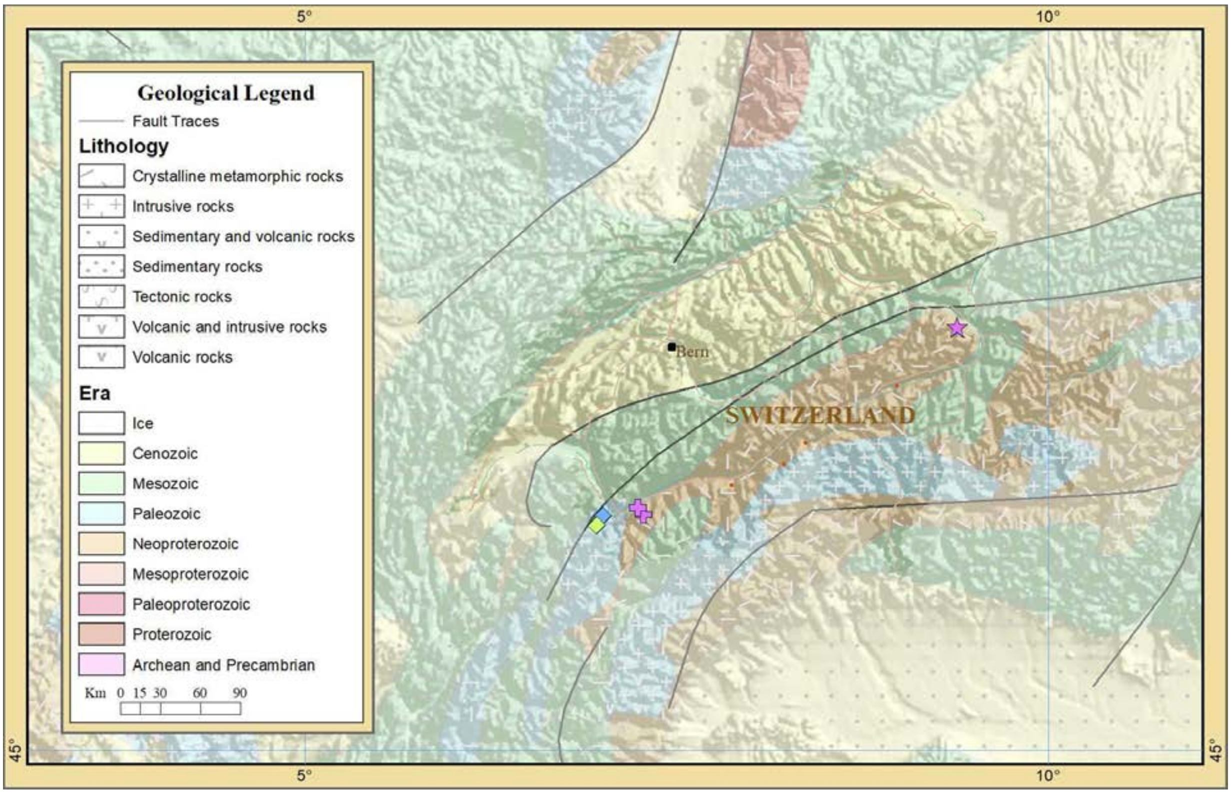


FIG. 4.45. Regional geological setting of Switzerland showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Jura consists of Mesozoic sedimentary rocks folded in the west (Faltenjura, Jura plisse) and tabular sedimentary rocks in the east (Tafeljura). The plateau represents a molasse basin of Oligocene–Miocene age, formed of erosional sediments from the uplifted Alps [22.2, 22.3].

4.22.2.2. *Geology of favourable areas for uranium*

During the Permian period, continental sedimentary rocks intercalated with volcanic rocks were deposited in a basin type environment. This sedimentation, referred to as the Verrucano, hosts some uranium mineralization. Additionally, small uranium occurrences have been found in some of the crystalline massifs.

4.22.3. Uranium exploration

Figure 4.46. summarizes the drilling campaigns conducted in Switzerland. In June 1979, the Government decided to encourage uranium exploration by granting CHF 1.5 million for prospecting over the period 1980–1984. During 1980 and 1981, ~1000 m of galleries were excavated for prospecting by a private company in the Hercynian Massif of Aiguilles Rouges and the surrounding gneisses. The limited work did not provide a complete understanding of the factors controlling the low grade mineralization, which is disseminated in an area of very complex geology.

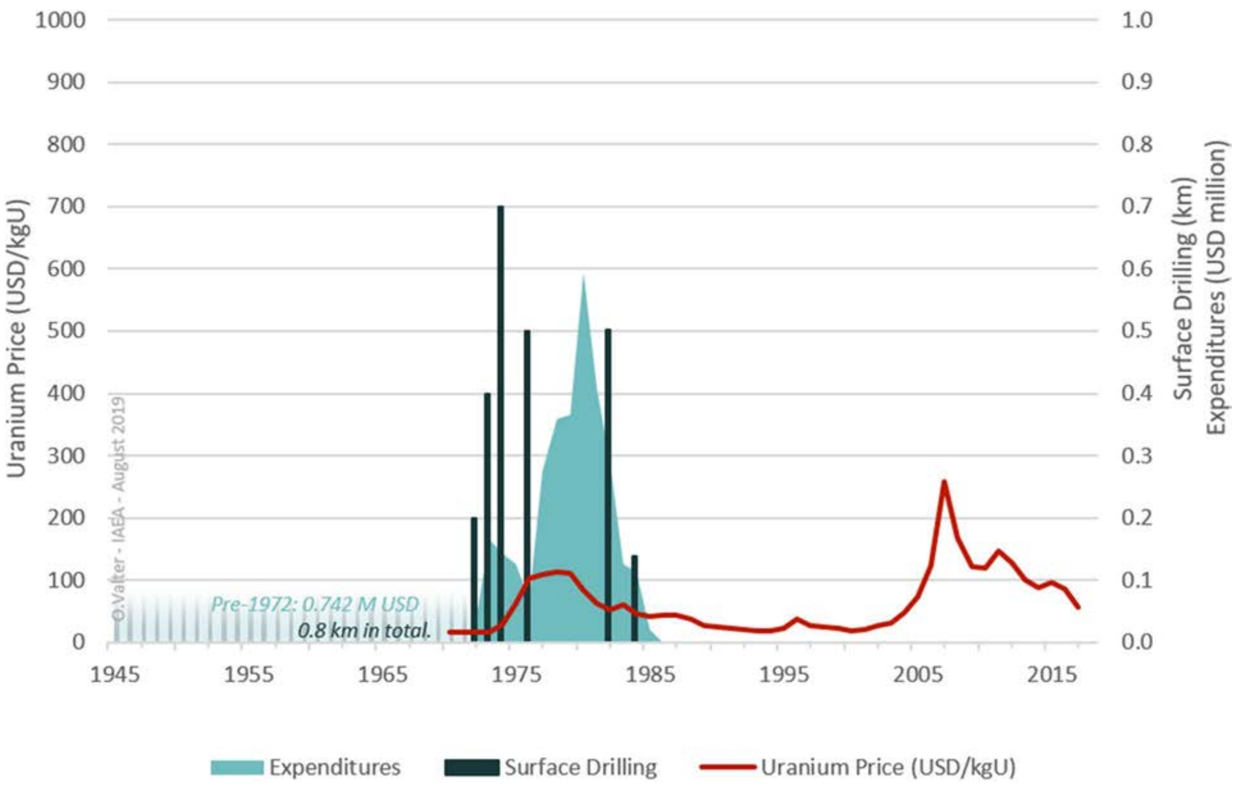


FIG. 4.46. Domestic uranium exploration data for Switzerland. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

In 1982, the Government funded surface prospecting to the south of Iserables and drilling at Naters (Valais). Between 1982 and 1984 (part of a five-year programme financed by the Government), exploration was carried out in the rugged region of the Penninic Bernhard nappe, in the western Valais. The radiometric and geochemical investigations concentrated mainly on the detrital Permian–Carboniferous deposits and schists of older age (Nendaz series and the underlying Siviez series). Owing to strong Alpine tectonism, the uranium is generally irregularly disseminated in the rock. Radioactive anomalies appear to be concentrated in the carbonate and chloritic facies of the Nendaz series, although their economic value could not be confirmed [22.4].

Small deposits (1-300 t) have been reported in granitic and metamorphic rocks such as vein and epysyenite mineralization in the Marecottes project operated by Urania [22.5]..

Some Swiss companies have been engaged in non-domestic uranium exploration, mining and milling projects located in the western United States of America and in Africa, in the period 1983–1995. There were no domestic exploration activities reported after 1985. There are no ongoing uranium exploration and mine development activities.

There was no domestic exploration after 1985. Uranium exploration expenses totalling US $3.359 million were reported for the period 1971–1985 [22.6].

4.22.4. Comments

No uranium resources have been reported. The potential for new discoveries is regarded as modest [22.3]. There has been no production in the past and no future production is envisaged.

The UDEPO database lists the most significant deposits for Switzerland as Col des Mines - Le Fou, Nendaz Reries, Les Marecottes-La Creusat, Oberrer Plattnerboden, Balaye.

References to Section 4.22

[22.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Switzerland, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2009).

[22.2] TRÜMPY, R., Geology of Switzerland: A Guide-book, Wepf, Basel and New York (1980).

[22.3] INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP, National Favourability Studies: Switzerland, IAEA, Vienna (1977) 9 pp.

[22.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[22.5] URANIA RESOURCES LTD., Technical Report on the Marécottes uranium property, Canton Valais, Switzerland (2011) 90 p.

[22.6] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

4.23. UNITED KINGDOM

4.23.1. Geography

The United Kingdom is situated in the north-western part of Western Europe and comprises the island of Great Britain (England, Scotland and Wales), and Northern Ireland and a number of smaller islands. In addition, several Crown Dependencies belong to the UK, including the Channel Islands, the Isle of Man and ~13 Overseas Territories, which are located in the Atlantic, Indian and Pacific Oceans.

The physical geography of the mainland is variable. The south (England) consists mainly of lowlands and hilly terrain, generally gaining in elevation towards the north, bordering Scotland. Scotland is characterized by highlands. Wales also includes highland areas. Numerous lakes are found in Scotland. Hilly terrain and mountains are found in Northern Ireland, as well as the UK’s largest lake, Lough Neagh.

The climate is temperate and is influenced by the Gulf Stream. Depending on the elevation and location, the temperature and the precipitation vary greatly. In Scotland, the lowlands have warmer weather both in summer and winter, compared with the mountains. The average precipitation in the Scottish Highlands may be six times greater than that in south-eastern England. However, rainfall is frequent throughout the year.

The UK is a highly industrialized country. The industry was formerly based on hard coal, although dependence on this energy source has declined over the past decades. This is counterbalanced by the production of natural gas and crude oil, mainly from offshore deposits. Some base metals were mined, although, to a very limited extent. Industrial minerals and rocks are produced. Agriculture is important and highly efficient [23.1].

4.23.2. Geology

4.23.2.1. General

The oldest rocks in the UK are of Archaean age (>2700 Ma) and comprise gneisses found in the north-western part of Scotland, on the Hebrides and at a few other places. The second oldest geological province (~1000 Ma) occurs in the NW Highlands and Grampian Highlands and is composed mainly of gneisses.

The Ordovician is characterized both by argillaceous sedimentary rocks (slates) and volcanic rocks. During the Silurian, the Caledonian Orogeny was followed by deposition of the well-known Old Red Sandstone of the Devonian period. The Carboniferous comprises thick sequences of limestone, indicative of an oceanic environment, a retreating ocean, and formation of deltaic and swampy environments and abundant vegetation which ultimately formed coal seams. The Permian and Triassic are characterized by shallow water sedimentary rocks and, finally, with continental conditions. The Jurassic period shows a marine depositional environment in which abundant algae and other organics were the source of the formation of crude oil and natural gas. During the Cretaceous, the marine environment persisted and chalk with flints was deposited across much of the southern England. In the Tertiary, both volcanic activity (e.g., the Giants Causeway in Northern Ireland and the volcanic rocks of the Isle of Skye) and sedimentation of clay and sandstone were typical. Glaciation throughout the Quaternary formed much of the present topography [23.1, 23.2].

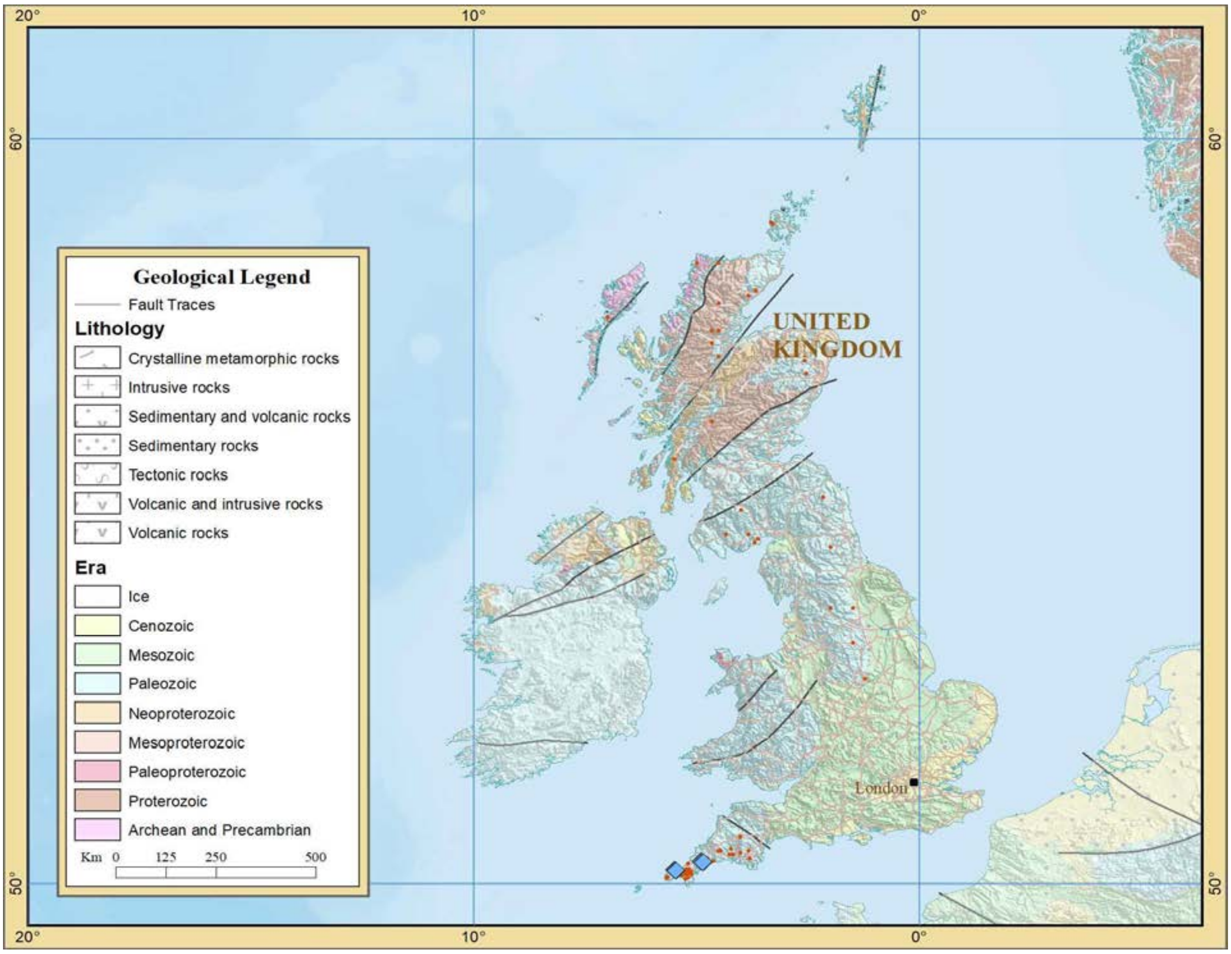


FIG. 4.47. Regional geological setting of United Kingdom showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

4.23.2.2. *Geology favourable for the formation of uranium deposits*

Some uranium has been found as small veins in Caledonian granitoids, Hercynian granites, sandstones of Devonian age and in the Cambrian–Ordovician and Carboniferous black shales. In Cornwall, small quantities of uranium were mined, together with tin, in the last decade of the 19th century [23.2].

4.23.3. Uranium exploration

4.23.3.1. *Historical review*

Some uranium mining was undertaken in Cornwall in the 1890s, produced as a by-product of other metalliferous mining, especially tin. Systematic exploration was carried out in the periods 1945–1951, 1957–1960 and 1968–1982, but no significant uranium reserves were identified (Fig. 4.48) [23.3]. For a limited period in the 1980s, uranium exploration in the UK was funded by the European Commission. Uranium companies based in the UK, or their affiliates abroad, explored for uranium abroad until 1993. Expenses for the period 1983–1993 are shown in Fig. 4.49 totalling USD $54.157 million.

4.23.3.2. *Recent and ongoing uranium exploration and mine development activities*

Non-domestic exploration is carried out by private companies operating through autonomous subsidiaries or affiliated organizations established in the country concerned (e.g., Rio Tinto group of companies). No industry expenses were reported for domestic exploration from 1988 to the end of 2004, nor were there any Government expenses reported for exploration, either domestic or foreign. Since 1983, all domestic exploration activities have been halted.

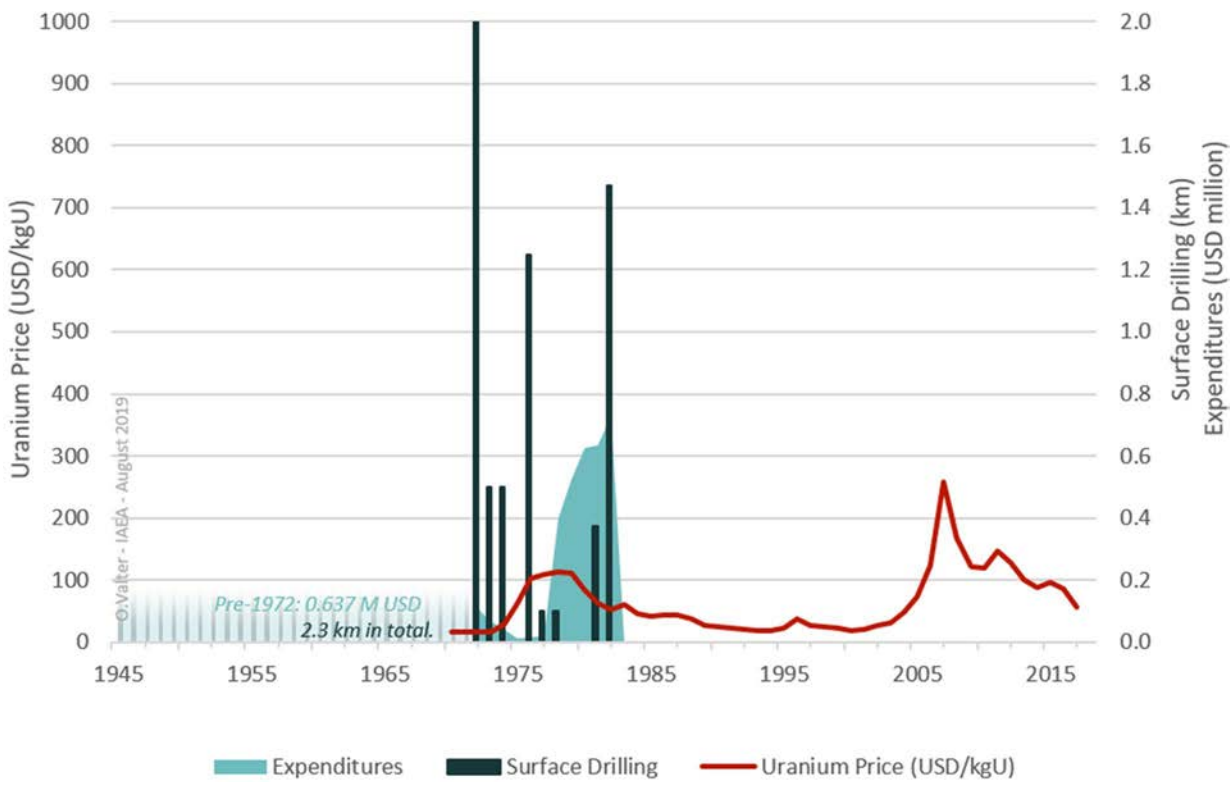


FIG. 4.48. Domestic uranium exploration data for the United Kingdom. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

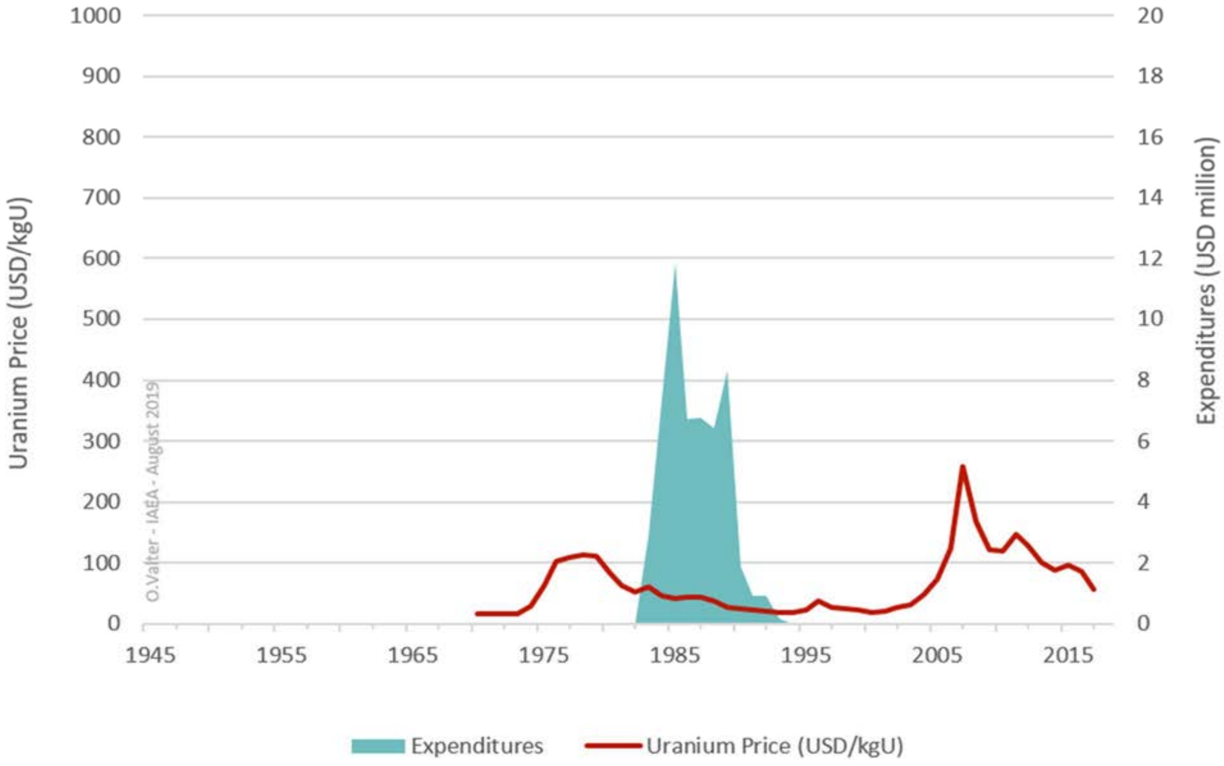


FIG. 4.49. Non-domestic uranium exploration data for the United Kingdom. Comparison of exploration expenditures and uranium market price (US$ current).

4.23.4. Uranium resources

4.23.4.1. Identified resources

Reasonably assured resources and inferred resources are assessed as zero. There has been no geological appraisal of the UK's uranium resources since 1980.

The UDEPO database lists the most significant deposits for the United Kingdom as South Terras, Wheal Trenwith, St Austell Consols, Wheal Providence.

4.23.4.2. Undiscovered resources

There are small quantities of in situ undiscovered resources, as well as speculative resources. Two districts are believed to contain uranium resources:

(i) The metalliferous mining region of SW England (Cornwall and Devon). Uranium occurs in veins and stockworks, often in association with tin and other metals. The veins cut Devonian metasedimentary rocks and volcanic rocks and are related to the margins of uraniferous Hercynian granites. Mineralization is locally of moderate grade (0.2–1% U), although of sporadic distribution. The resource tonnages of individual prospects may be up to several hundred tonnes of uranium;

(ii) North Scotland, including the Orkneys. The Precambrian metamorphic rocks of north Scotland, with intruded Caledonian granites, are overlain by a post-orogenic series of fluviatile and lacustrine Devonian sedimentary rocks. Uranium occurs in phosphatic and carbonaceous sedimentary rocks disseminated in arkosic sandstone (Ousdale) and in faults, both within the sedimentary rocks (Stromness) and in the underlying granite (Helmsdale). Uranium resources of a few thousand tonnes are indicated, with an average grade of less than 0.1% U.

4.23.5. Potential for new discoveries

In the two areas already described, uranium resources in the category of identified resources may be found by systematic exploration. However, previous exploration failed to discover any significant quantities of uranium that would justify their categorization as identified resources.

4.23.6. National policies relating to uranium

No changes have recently been made to the UK's uranium policy. As regards the current policy with respect to participation of private and foreign companies, the UK Atomic Energy Act 1946 gives the Secretary of State for Trade and Industry wide ranging powers in relation to uranium resources in the UK. This includes obtaining information, acquiring rights to work minerals without compensation, acquiring uranium mined in the UK on payment of compensation, and introducing a licensing procedure to control or condition the working of uranium.

There are no specific policies relating to restrictions on foreign and private participation in uranium exploration, production, marketing and procurement in the UK, nor for exploration activities in foreign countries. There is no national stockpile policy. Stocks of UF_6 tails from enrichment are stored as a zero value asset. Utilities are free to develop their own policy. The current policy is to either recycle tails, if economically viable, or to convert the material to a more stable form starting no later than 2020. Stocks of depleted uranium derived from reprocessing of Magnox reactors are stored as a zero value asset. The current policy is to recycle this material when it becomes economic to do so.

Exports of uranium are subject to the Export of Goods (Control) Order 1970 (SI No. 1288), as amended, made under the Import, Export and Customs Powers (Defence) Act 1939.

4.23.7. Comments

The UK is not a uranium producer. No significant mining of uranium has been undertaken in the past. The UK's uranium stockpile practices are the responsibility of the individual bodies concerned and actual stock levels are commercially confidential.

Uranium purchase prices are commercially confidential in the UK.

References to Section 4.23

[23.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: United Kingdom, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2009).

[23.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[23.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

CHAPTER 5. CENTRAL, EASTERN AND SOUTH-EASTERN EUROPE

5.1. ALBANIA

5.1.1. Geography

Albania is located in south-eastern Europe. The majority (~70%) of the country is mountainous, but to the west, towards the coast, lowlands are developed. The Dinaric mountain chain, also known as the Albanian Alps and part of the Balkan Mountains, forms the mountainous landscape in the north. To the south, deeply incised rivers have cut steep valleys into the terrain and highly dissected mountain ranges have been formed.

Five geographical regions are defined: (i) a northern mountain range (north Albanian Alps), up to 2 754 m in elevation (Korabi), very rugged and difficult to access; (ii) a highly dissected mountain region in the northern and central part; (iii) the south-eastern lake district and basins; (iv) the densely populated lowlands, mainly in the west, and (v) the basin and range area of the Albanian Epirus (the coastal region of north-western Greece and southern Albania).

In the south, the main rivers run E–W; the main river in the north, the Drin River, first runs S–N and then turns to the west.

Considering its relatively small size, Albania has a variety of climatic regions. The coastal area, adjacent to the Adriatic Sea, has mild winters. Summer temperatures are moderate to high, with high humidity. The inland climate varies, depending on elevation. Mountainous areas have low winter temperatures, subject to continental conditions. Summer temperatures are lower than in the lowland areas, with lower temperatures at night.

Precipitation varies according to elevation. In the lowlands, the average is 1000–1500 mm annually, with the higher levels in the north. About 95% of rainfall occurs in the winter. The mild climate in the lowlands allows the cultivation of olives, grapes and citrus fruits.

Most of the precipitation is drained by rivers which enter the Adriatic Sea. The seasonal variation in the rainfall, which is concentrated in the winter, limits their use for irrigation. An exception is the Drin River, the country's largest and the one registering the least variation in its flow level. The Drin is fed by snow melt from the mountains [1.1].

5.1.2. Geology

The geology of Albanian is complex (Fig. 5.1). Albania forms part of the Dinaride branch of the Balkan Mountains, a mainly Tertiary orogenic event of Alpine type. Mediterranean plate tectonics are responsible for the formation of the mountain ranges and for the still ongoing tectonic and seismic activity. The oldest igneous rocks (volcanics, intrusives) are of Palaeozoic age, followed by Triassic volcanism of the Verrucano volcano-sedimentary series and Jurassic ophiolitic magmatism. In the Tertiary period, molasse type basins were formed.

Most of the country consists of limestone and flysch deposits. Serpentinites and ophiolites are also present.

Chromite deposits of the Alpine ophiolitic type have attracted some interest (e.g., the Bulqiza deposit). Nickeliferous iron deposits and copper deposits are also known. Other mineral resources include bauxite, coal, oil and natural gas [1.2]

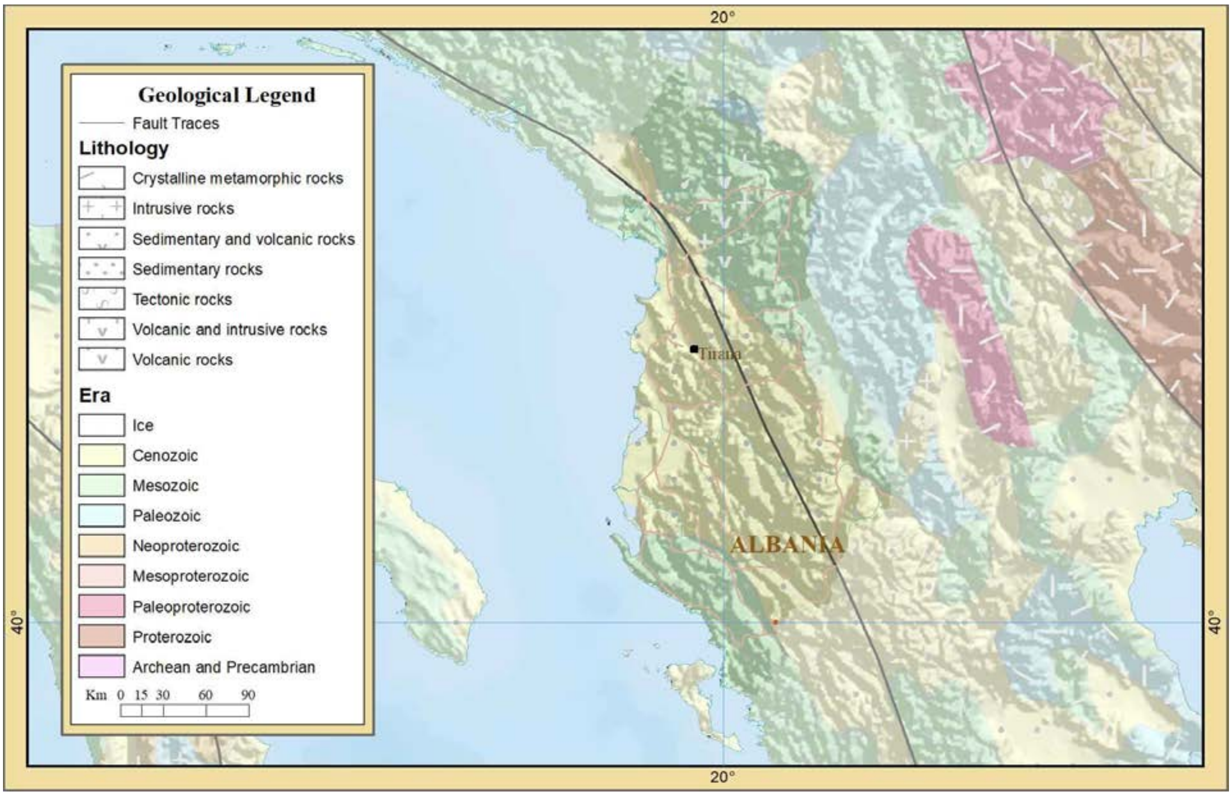


FIG. 5.1. Regional geological setting of Albania. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.1.3. Uranium exploration

No official information is available on uranium exploration and older publications do not include any information regarding the presence of uranium mineralization. According to Ref. [1.3], the uranium potential is unknown. Minor amounts of uranium may occur with cobalt and nickel in bedded copper–magnetite deposits, although a detailed investigation has not been conducted.

A more speculative target for exploration could be the volcano-sedimentary formation of the Verrucano type [1.4]. The Verrucano is exposed near the Drin River in north-eastern Albania and in the Korab and Mirdita zones in central Albania. However, many of the Verrucano sediments are of marine origin and are not favourable hosts for the formation of uranium deposits. The Permian–Triassic Verrucano series is the host strata for small uranium deposits in northern Italy and Slovenia [1.3, 1.4].

5.1.4. Uranium resources

No resources have been reported.

The UDEPO database does not list any known deposits for Albania.

5.1.5. Potential for new discoveries

The potential for new discoveries is regarded as very limited. No plans for exploration have been announced.

5.1.6. Comments

There is no record of past uranium production.

References to Section 5.1

[1.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Albania, https://www.cia.gov/library/publications/the-world-factbook/index.html
(accessed November 2007).

[1.2] MECO, S., et al., Geology of Albania, Gebr. Borntraeger, Stuttgart (2000) 246 pp.

[1.3] KELLY, J., "Exploration opportunities in Albania", paper presented at 15th Calgary Mining Forum, Calgary, 2006.

[1.4] BARTHEL, F.H., HAHN, L., "Sedimentary uranium occurrences in Eastern Europe with special reference to sandstone formations", Geological Environments of Sandstone Type Uranium Deposits, IAEA-TECDOC-328, IAEA, Vienna (1985) 51–67.

5.2. ARMENIA

5.2.1. Geography

Armenia is a landlocked country, located in the southern part of the Lesser Caucasus Mountains, between the Black Sea and the Caspian Sea. Armenia has borders with Georgia to the north, Azerbaijan to the east, the Islamic Republic of Iran to the south and Turkey to the west.

About 90% of the country lies at an elevation of 1000 m. The dormant Aragac volcano (Aragats) has an elevation of 4400 m and is the highest point in the country. The largest lake, Lake Sevan, is located in the central part. The SW part is formed by the Armenian Plateau, which slopes towards the Turkish border. The valleys of the Debet and Akstafa Rivers form the main travel routes. Most of the country is drained by the main system of the Aras River.

The climate in the mountainous area can be severe, but milder in the lowlands. The temperatures depend primarily on the elevation, with typical seasonal variations. The mountains control most of the effects of mild temperatures from the west. The plateau area has average summer temperatures exceeding 25°C, dropping to below 0°C in the winter. Soils developed from volcanic rocks provide fertile land. In the plateau area, Armenia has been populated from the earliest of times.

The Armenian economy is heavily reliant on investment and repatriation of funds from Armenians living abroad. Agriculture accounts for slightly over 20% of GDP (2006 data), although the proportion of the population employed in agriculture is more than 40%. Armenian mines produce copper, zinc, gold and lead. The vast majority of energy is produced with fuel imported from the Russian Federation, including gas and nuclear fuel. The main domestic energy source is hydroelectric. Small deposits of coal, gas and petroleum have not yet been developed [2.1].

5.2.2. Geology

Major aspects of the complex geology of Armenia (Fig. 5.2) are summarized here, which essentially is dominated by Alpine orogenic processes related to the collision of the Arabian and Eurasian Plates. The pre-Alpine basement, mainly exposed in the southernmost part of the country, consists of phyllite, schist, metavolcanics, serpentinite and granite related to Hercynian and/or Caledonian tectonism. In the south and central areas, sediments of Devonian–Triassic age are exposed, followed by Cretaceous sediments, mainly of shallow water deposition. The north-eastern area is dominated by Jurassic and some Cretaceous sedimentary rocks.

Most of the country, however, is covered by Tertiary sediments and the Sevan flysch–molasse trough of Quaternary age. Late Triassic, Late Jurassic–Early Cretaceous and Middle Cretaceous ophiolitic magmatism occurred as the result of folding. Tectonic and volcanic processes of Pliocene–Quaternary age are related to the collision of plates (Arabian and Eurasian Plates), which are responsible for seismic activity (earthquakes).

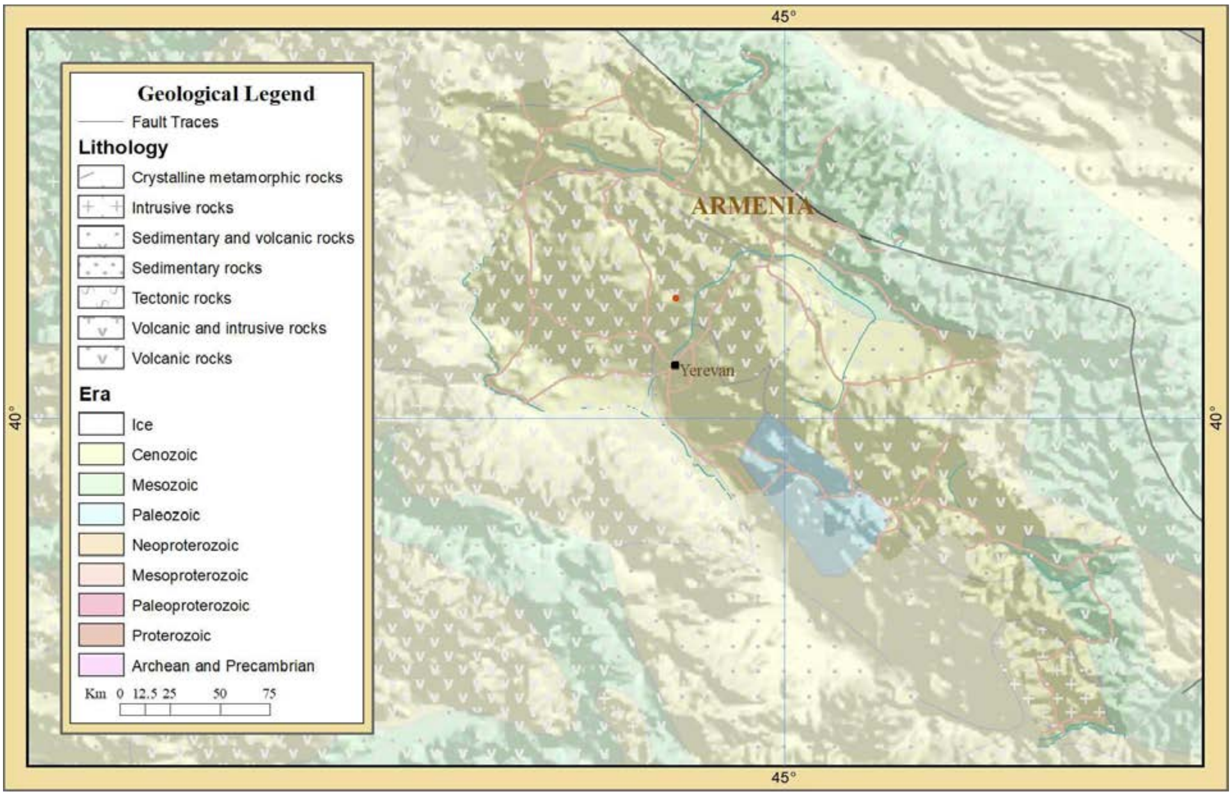


FIG. 5.2. Regional geological setting of Armenia showing uranium occurrences. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Sedimentary basins of Late Palaeozoic–Early Triassic age contain shallow marine carbonates, sandstones, locally bituminous limestone and clay. Geological evolution from Early Jurassic through the Quaternary is characterized by tectonic and increased volcanic activity, probably due to the opening/closure of the Tethys Sea.

During the Mesozoic, Alpine type basins were developed, characterized by occasional rapid changes of sedimentary infill (deep water siliceous carbonate volcanic strata versus shallow marine sediments) with ophiolitic rocks. Acidic volcanism occurred towards the end of the Early Jurassic. The formation of basins and their sediments become increasingly complex, influenced by the processes arising from the opening/closing of the Tethys Sea during the Mesozoic period. The geology became increasingly complex during the Tertiary and Quaternary. The neotectonic stages of the Pliocene and Quaternary are characterized by uplifts and depressions, forming ridges and small troughs [2.2–2.4].

5.2.3. Uranium exploration

Armenia has not reported any information on uranium exploration to the Red Book. According to media reports, an agreement on exploration for gold and uranium was signed between the Government of Armenia and US Global Gold Corporation with respect to the Gegharkunik region in north-eastern Armenia. The exploration area is covered by Cretaceous and Jurassic sediments which are intruded by granites. Historic exploration by Soviet geologists indicated undeveloped uranium resources estimated at 30 000 tU. Armenian officials report the resource may be double this figure [2.4].

In April 2007, an agreement between the Government of Armenia and the Russian Federal Agency on Atomic Energy (Rosatom) was signed for uranium exploration in the Syunik region, south-eastern Armenia. The area includes Jurassic sediments and granites [2.4, 2.5]. On the basis of the agreement of April 2007, an Armenian–Russian joint venture was established in April 2008, the owners being the Government of Armenia and the Russian State owned company “Atomredmetzoloto”. An analysis of the data obtained during previous exploration is given in a report which formed the basis for field work which started in 2009 [2.4–2.6]. The J.V. was unsuccessful and therefore was shut down in mid-2015.

5.2.4. Uranium resources

Identified resources have not been reported. Undiscovered resources have been estimated at 30 000 tU.

The UDEPO database does not list any known deposits for Armenia.

5.2.5. Potential for new discoveries

No other potential areas other than the region described above are known.

References to Section 5.2

[2.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Armenia, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed December 2007).

[2.2] BASHYAN, R., et.al., Geology of Meso-Cenozoic basins in central Armenia, with comment on indications of hydrocarbons (2001), http://www.searchanddiscovery.com/documents/armenia

[2.3] ARMENIA DIASPORA, Russia looks for uranium in Armenia, www.armeniadiaspora.com (23 April 2007).

[2.4] WORLD NUCLEAR ASSOCIATION, Information: Nuclear Power in Armenia (October 2007).

[2.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[2.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

5.3. BELARUS

5.3.1. Geography

Belarus is a landlocked country in eastern Europe. The western part is characterized as east European lowlands, the north is formed by the Polackaja Nizina (lowland), and the central part is characterized by a low hilly area, which transitions to the marshland of the Polessy area. Large areas are covered by sequences of Quaternary age [3.1].

5.3.2. Geology

Belarus is located on the western margin of the East European Craton, the basement of which is composed of Archaean–Lower Proterozoic rocks, whilst the upper basement formations are represented by terrigenous, carbonate and volcanogenic rocks ranging in age from Riphean to Quaternary (Fig. 5.3). The Archaean–Lower Proterozoic age series are composed of crystalline schists, amphibolites and gneisses. These rocks are exposed in central Belarus. In south Belarus, a Lower Proterozoic series exists consisting of chlorite–sericite schists, quartzites, rhyolites, dacites and andesites. Upper Proterozoic formations include Riphean and Vendian rocks. Vendian strata cover around 85% of Belarus and are represented by arkosic sandstones, with underlying gravel and quartzitic sandstones uppermost. The Phanerozoic, which is represented by formations ranging in age from Cambrian to Neogene, is widespread within Belarus.

Large amounts of potash are produced from underground mines in Permian host rocks. Rock salt and limestone are also produced [3.1, 3.2].

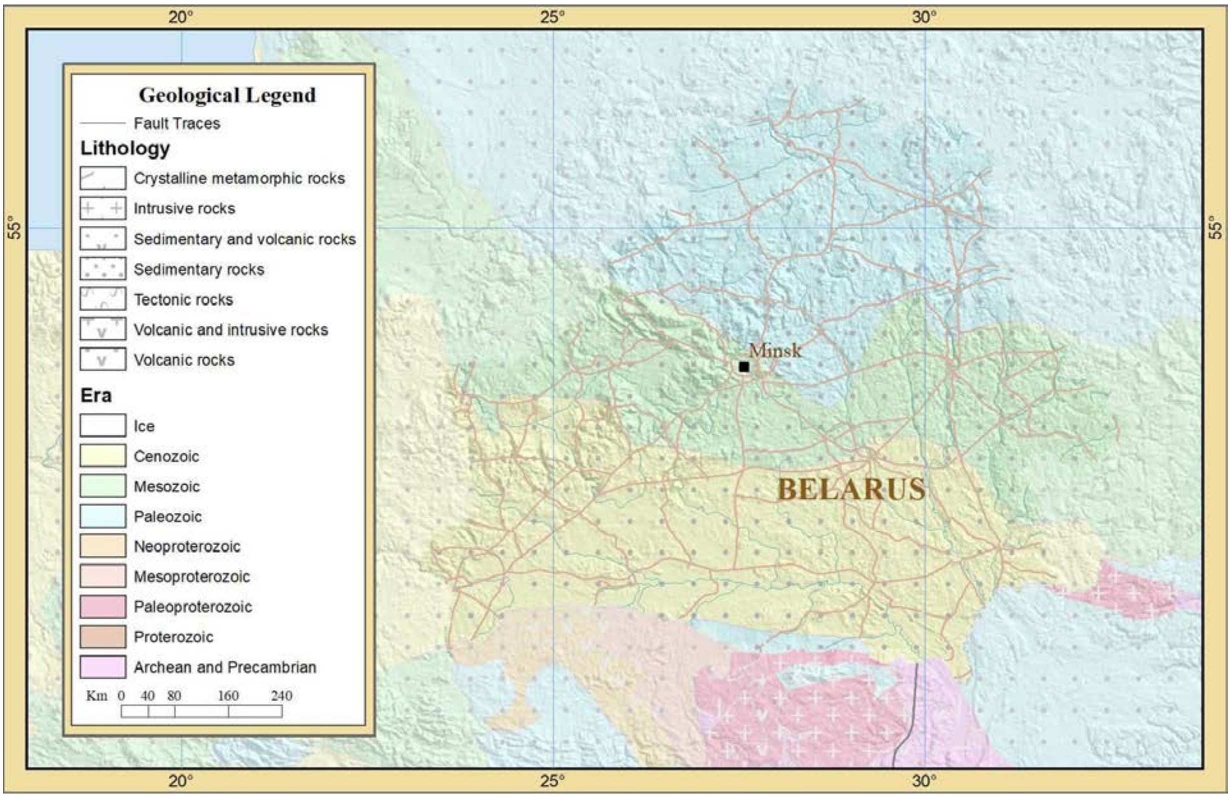


FIG. 5.3. Regional geological setting of Belarus. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.3.3. Uranium resources

No reports on any uranium exploration have been made public. The UDEPO database does not list any known deposits for Belarus.

References to Section 5.3

[3.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Belarus, https://www.cia.gov/library/publications/the-world-factbook/index.html
(accessed December 2007).

[3.2] MOORES, E.M., FAIRBRIDGE, R.W., Encyclopedia of European and Asian Regional Geology, Springer, Berlin and Heidelberg (1998).

5.4. BOSNIA AND HERZEGOVINA

5.4.1. Geography

Bosnia and Herzegovina is located in south-eastern Europe and consists of three political entities with quasi-autonomous status: Bosnian-Croatian Federation, Republika Srpska and Brcko district. Large parts of Bosnia and Herzegovina include the Dinaride Mountains, which cross the western part of the Balkans in a NW–SE direction. Many areas are covered by limestone, characterized by karst, resulting in the subterranean flow of rivers. The country has deposits of lignite, bauxite, iron, manganese, lead and zinc [4.1].

5.4.2. Geology

Three geotectonic belts coincide within Bosnia and Herzegovina (Fig. 5.4). The northern tectonic belt is bordered to the north by the Sava trench; to the south by the Sprečko-Kozara dislocation. In this zone, three tectonic features are observed: horst, basins and Quaternary depressions. Horsts occur at Motajica, Prosara, Majevica, Kozara, Vučjak and Trebava; basins at Prijedor-Omar-Dubica, Prnjavor, Srednjobosanski and Tuzla, and Quaternary depressions at Ivanjsko-Omarska, Bosansko-Podrinjska, Srednje-posavska, Semberija and Spreča. The central tectonic belt is bordered to the north by the Sprečko-Kozarska dislocation and to the south by a zone of high karst. In this zone, several tectonic units are distinguished: a central ophiolitic zone, the Drina Palaeozoic anticline, the Jurassic and Cretaceous flysch zone, the central Bosnian Schist Mountains, the Una-Sana Palaeozoic sequence and a several Neocene basins. The south tectonic belt extends SW from the Bosnian Schist Mountains to the Adriatic Sea. This belt is composed of thick sequences of limestone and dolomite, together with Palaeocene flysch sediments near the Adriatic Basin [4.2].

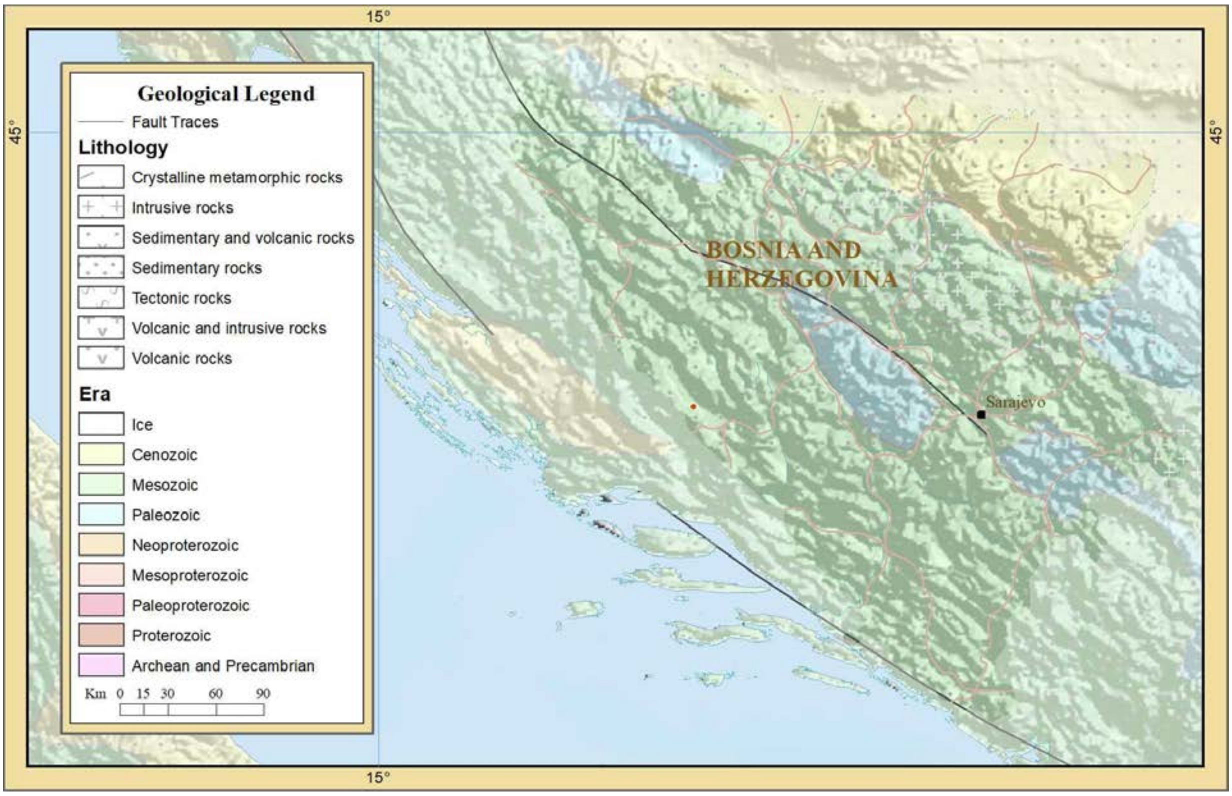


FIG. 5.4. Regional geological setting of Bosnia and Herzegovina showing uranium occurrences. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.4.3. Uranium resources

No uranium occurrences or deposits have been reported and the potential for uranium mineralisation is unknown but probably low. The UDEPO database does not list any known deposits for Bosnia and Herzegovina.

References to Section 5.4

[4.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Bosnia and Herzegovina, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2013).

[4.2] Visit My Country, Geological structure of Bosnia and Herzegovina, www.visitmycountry.net/bosnia_herzegovina/ (accessed January 2013).

5.5. BULGARIA

5.5.1. Geography

The topography of Bulgaria is characterized by both lowlands and mountainous or hilly terrain. In the north, the Danubian plain extends along the Danube River and gradually rises in the south to the Stara Planina or Balkan Mountains (the highest point is Botev (2376 m)). The capital, Sofia, is located in the western part of the mountain ranges. The Balkan Mountains are divided into the west, high and east Balkan, forming watersheds flowing northwards to the Danube ending in the Black Sea, and southwards to the Marica River, which in its southern course forms the border with Turkey and Greece before discharging into the Aegean Sea. The mountains of Sredna Gora and Sarnena Gora are part of the Balkan range. South of the Balkan Mountains, the area extends via the sub-Balkan valleys to the Thracian Plain and to the Marica River. Many parts are hilly. The western extension of this area is formed by the Sofia Basin. The southern part of Bulgaria is dominated by the mountainous regions of Rila (highest peak Musala at 2 925 m), Pirin (highest peak Vihren at 29 15 m) and Rhodope (~2 200 m).

Owing to the ongoing mountain building processes and to the drift of the African Plate towards Eurasia, the country is prone to seismicity. Higher elevations are prone to landslides, especially in areas of deforestation.

The Bulgarian climate varies from continental to Mediterranean. The continental climate, mostly in the northern area and in the mountains, results in cold winters and abundant snow in the mountains, whereas the Mediterranean influence is marked by hot dry weather. In Sofia, the average summer temperature is around 28°C, which drops to below 0°C during winter. The average annual precipitation is ~630 mm in the areas close to the Black Sea and ~500 mm inland.

Industry plays a key role in the Bulgarian economy. Ferrous metallurgy is of major importance. Much of the production of steel and pig iron takes place in Kremikovtsi and Pernik, with a third metallurgical base in Debelt. The country leads its Balkan neighbours in the per capita production of steel and steel products. As well as steel, Bulgaria has major refineries for lead and zinc at Plovdiv, Kardzhali and Novi Iskar, for copper at Pirdop and Eliseina, and for aluminium at Shumen. Bulgaria ranks first in south-eastern Europe in production per capita for several metals [5.1].

5.5.2. Geology

Bulgaria's geology [5.2, 5.3] is complex (Fig. 5.5) and heavily influenced by the collision of the African Plate with the Eurasian Plate. Four principal regions resulted and are defined as the:

(a) Rhodope Massif, mostly comprising Precambrian rocks intruded by Palaeozoic granites;
(b) Marica valley and Tertiary basins;
(c) Balkan Mountains, part of the Hellenide belt of miogeosynclinal sediments, containing volcanics and acid intrusions and related to Alpine orogenic events;
(d) Danubian Platform, covered mostly by Cretaceous limestone and underlain by folded rocks of Hercynian age.

Geological research [5.4] indicates that portions of the Balkan Peninsula have their geological origin as part of Gondwanaland. Two types of terrain are distinguished: the Balkan and the Moesian. The Balkan terrain is characterized by a Precambrian–Cambrian ophiolitic island arc unconformably overlain by a Palaeozoic sequence. The ophiolites have Pan-African features. In the Moesian, the pre-Palaeozoic (Proterozoic–Vendian) consists of metamorphics of continental origin. The proto-Moesian appears to be peri-Gondwanaland.

According to Ref. [5.5], the dating of basement rocks at Sredna Gora indicates Neoproterozoic ages (617 and 595 Ma), corresponding to Gondwana ages elsewhere and the authors suggest that Sredna Gora is Gondwana derived terrain. The ages of the sediments indicate their deposition between the Ordovician and the Early Carboniferous. During the Carboniferous, metamorphism affected most of the older rocks.

Studies of plate tectonics [5.6] have shown that the Balkanides is a mobile belt in the microcontinent formed by the Moesian Platform and the Rhodope Massif. In a complex development, rotation of the microcontinent and sea-floor spreading occurred together with ophiolitic magmatism in the Vardar Trough. During the Middle and Late Cretaceous, island arcs with adjacent marginal basins were formed. In the Vardar Trough, sedimentation took place between the Triassic and the Eocene. The Rhodope Massif in both Bulgaria and Greece is believed to be a Mesozoic nappe stacked within an active Alpine margin environment [5.2, 5.7].

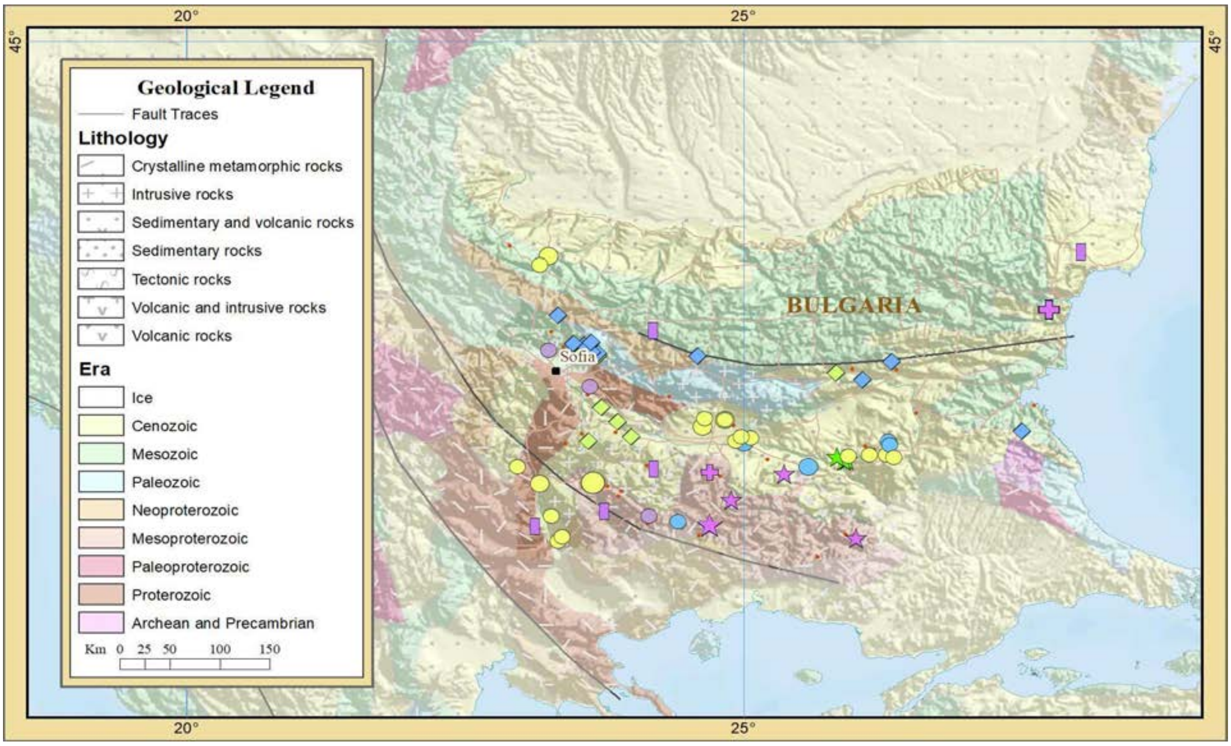


FIG. 5.5. Regional geological setting of Bulgaria showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.5.3. Uranium exploration and description of deposits

Uranium mineralization at Buhovo (also Bukhovo) has been known since 1920. Detailed mining studies were undertaken during 1938–1939. Buhovo hosts high grade uranium in Ordovician black schists, intruded by quartz syenite stocks and dykes. In 1939, ~300 t of ore was mined.

Systematic exploration was started after 1945 by Bulgarian and Soviet geologists. In 1946–1956, a joint Bulgarian–Soviet company was responsible for uranium exploration and mining. After 1956, the Bulgarian uranium company 'Rare Metals' replaced the latter organization and was assisted by Soviet consultants until 1990. In the early 1950s, the deposits of Eleshnitsa, Smolian and Planinetz were discovered. Reconnaissance and general exploration, using all available methods, were carried out over ~80% of the country. Buhovo, Momino and Eleshnitsa contain several individual deposits. Mineable deposits of uranium are small to medium in size (up to 20 000 tU).

Exploration resulted in the discovery of 39 deposits of four principal types:

(i) Several are vein type deposits, similar to Buhovo, with tonnages of 500–5000 tU, and of similar grade. These include Proboinitsa, Kurrilo, Gabra, Biala Voda, Kostenetz, Partisanska Poliana (grade >1% U), Beli Iskar, Dospat, Narretshen and Sborishte;
(ii) Fifteen are sandstone-type deposits of Permian, Oligocene and Pliocene age. Grades generally vary in the range 0.03–0.07% U (with one exception of 0.1% U). The most important deposits are

hosted in Tertiary sandstone and include Eleshnitsa, with several horizons of Oligocene age and total resources of 5000–20 000 tU and Momino, a roll front type hosted in a Pliocene sandstone of the Thrace Basin, between 100 and 260 m deep, with total resources of 5000–20 000 tU. Other deposits include Smolianovtzi, Simitli, Gradovo, Pripetshen-Deltshevo, Melnik, Belosem, Pravoslaven, Haskovo, Marritsa, Navasen-Troian, Orlov Dol, Isgrev and Okop-Tenebo;

(iii) Deposits of the volcanic type occur mainly in Cretaceous (Sliven and Rosen deposits) and Miocene volcanics (Smolian, Sarnitsa, Planinetz deposits) in the form of veins and stockworks. Resources are in the range 500–5000 tU, with grades of 0.01–1.0% U;

(iv) Surficial type deposits occur in river valleys draining granitic terrains. These include Igralishte, Senokos, Beslet and Selishte deposits, which have low to medium tonnages (500–5 000 tU) and grades of 0.1–1.0% U [5.8–5.11].

Details of exploration efforts, for example, drilling and expenditures, are not available. Exploration activities ceased in 1990. Fig. 5.5 indicates the deposits locations.

5.5.4. Uranium resources

Details of uranium resources are shown in Figs 5.6 and 5.7 respectively. In recent years, Bulgaria did not reported identified resources to the Red Book, as the tonnages previously reported were categorized as uneconomic. The following description of resources was submitted to the 2007 Red Book [5.11].

The UDEPO database lists the most significant deposits for Bulgaria as Eleshnitza District, Simitli, Smollian, Momino, Zdravetz, Haskovo, Pravoslaven, Tzarimir, Smolianovtzi, Biala Voda, Rakovski.

5.5.4.1. Identified resources

Identified resources as of 1991 amounted to 20 565 tU and were categorized as uneconomic. A recalculation (as of 1 January 2007) undertaken by the National Geo Fund identified in situ resources of 19 809 tU. Of this total, 11 908 tU could be extracted from underground mining and 7901 tU by in situ leaching (ISL) at 16 sites, assuming a mean recovery factor of 65%. These resources are hosted within 67 small deposits which are currently not considered viable, either economically or technologically.

5.5.4.2. Undiscovered resources

Prognosticated and speculative resources amount to 18 200 tU at a recovery cost of <US $130/kgU (Table 5.1). No unconventional resources have been reported.

TABLE 5.1. URANIUM RESOURCES (tU) [5.12]
(As of 2005)

	<US $40/kgU	<US $80/kgU	<US $130/kgU	Cost unassigned	Total
Reasonably assured resources	1 665	5 870	5 870	n.a.[a]	5 870
Inferred resources	1 650	6 300	6 300	n.a.	6 300
Prognosticated resources	n.a.	2 200	2 200	n.a.	2 200
Speculative resources	n.a.	n.a.	16 000	0	16 000

[a] n.a.: not available.

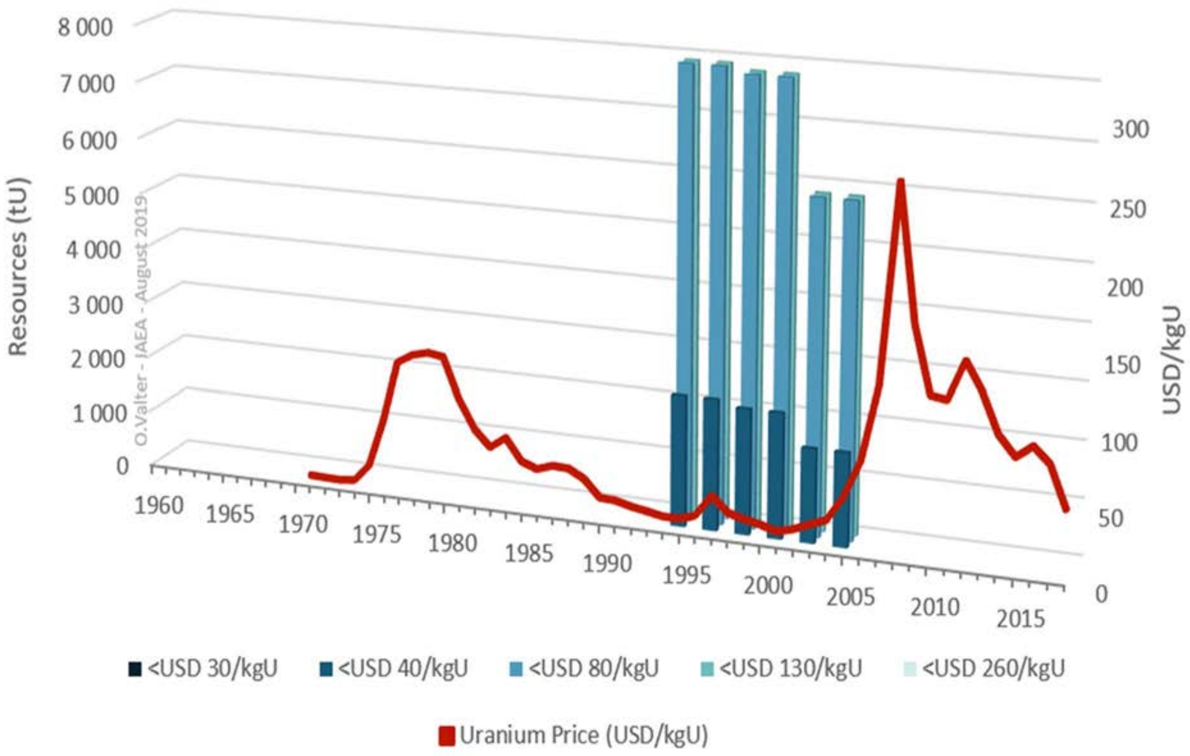


FIG. 5.6. Historical variation of recoverable reasonably assured resources within various cost categories in Bulgaria. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

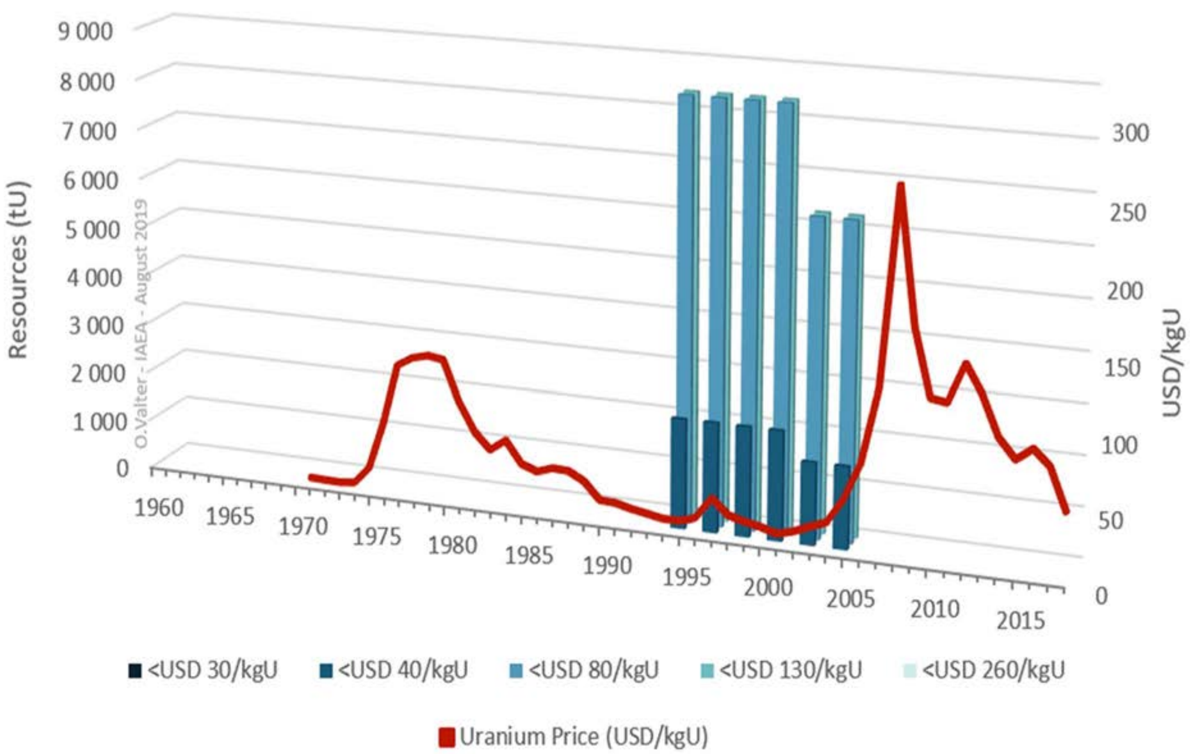


FIG. 5.7. Historical variation of recoverable reasonably assured resources within various cost categories in Bulgaria. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

5.5.5. Potential for new discoveries

According to Ref. [5.5], moderate potential exists in the country. It is believed that the Rhodope Massif and the Balkan Mountains have potential for vein, disseminated and possibly sedimentary deposits. At the time of compilation of the report, limited knowledge was available owing to the political situation prevailing at that time. Official reports for various Red Books since 1990 indicate a great variety of deposits have been found in the areas formerly assigned as having potential. However, it should also be noted that there are areas that were assessed as having the potential to contain deposits owing to their previous exploitation. Currently, no deposits are being mined and no exploration is being carried out. It is likely that only limited potential exists for finding new economic deposits.

5.5.6. Uranium production

Uranium mining began in 1946 with the opening of an underground mine in the Buhovo district, ~20 km NE of Sofia. Individual deposits at grades varying in the range 0.1–1.0% U were delineated and mined. The ore was shipped to the former Soviet Union for further treatment.

Additional underground mines operated in the mid-1950s. Underground mining was the predominant production method until 1979. The first ISL operation was tested in 1967 on the sandstone hosted deposit at Orlov Dol, in south-eastern Bulgaria. After 1979, ISL was applied. In 1981, stope leaching was introduced in underground mines to extract lower grade ores. Since 1981, 23 deposits have been exploited by underground mining, 17 by ISL and 11 using leaching in association with conventional mining.

During the late 1980s, four conventional mines closed and by 1989 ~70% of production came from the ISL mining of sandstone-hosted deposits, mainly using sulphuric acid leaching. The ISL method was mainly applied in those deposits with grades too low for conventional underground mining. In the early 1990s, three ISL operations (Orlov Dol, Madrets and Vladimirovo) were exhausted.

During 1991–1992, 15 well fields, comprising 14 000 wells, were in operation with four satellite ion exchange recovery units and one resin enrichment unit. The resins were hauled by road to the Eleshnitsa plant (~120 km south of Sofia) for concentrate production.

In 1993, several underground deposits were mined out, including: Buhovo, Partisanska Polina, Beli Iskar, Melnik, Beslet, Dospat, Narretshen, Sarnitsa, Planinetz, Sliven and Rosen. The mines using underground mining and stope leaching at Igralishte and Selishte and the ISL production facility at Orlov Dol were also closed. Underground mining continued at Proboinitsa, Kurillo, Eleshnitsa, Simitli, Smolian and Sborishte. Underground mining and ISL production were conducted at Biala Voda. ISL production continued at Momino, Belosem, Provoslaven, Haskovo, Navasen-Troian, Isgrev and Okop-Tenebo and in one open pit was in operation at Senokos.

Ore extracted from vein deposits in underground mines and resins from ISL were treated at the Buhovo plant. Ores and ISL resins from sandstone deposits were treated at Zvezda near Eleshnitsa. Up to 1990, 60 000 tU had been discovered and ~16 500 tU produced. Production had increased steadily from 150–200 tU/year in the 1950s to 430 tU/year by 1975. With the advent of ISL mining, production increased further to 660 tU in 1989, when 70% of uranium production was by ISL. After 1994, no production was reported [5.8–5.11]. Details of uranium production are summarized in Table 5.2 and in Fig. 5.8.

TABLE 5.2. URANIUM PRODUCTION FOR 1946–1990 BY PRODUCTION TYPE (tU) [5.11]

Open pit[a]	Underground mining	ISL[b]	Heap leaching	In place leaching	Co-/by-product	Uranium from phosphate	Other	Total
0	11 526	4 272	0	549	0	0	14	16 361

[a] No open pit production is reported, although seven open pit mines are mentioned in the country report.
[b] ISL: in situ leaching.

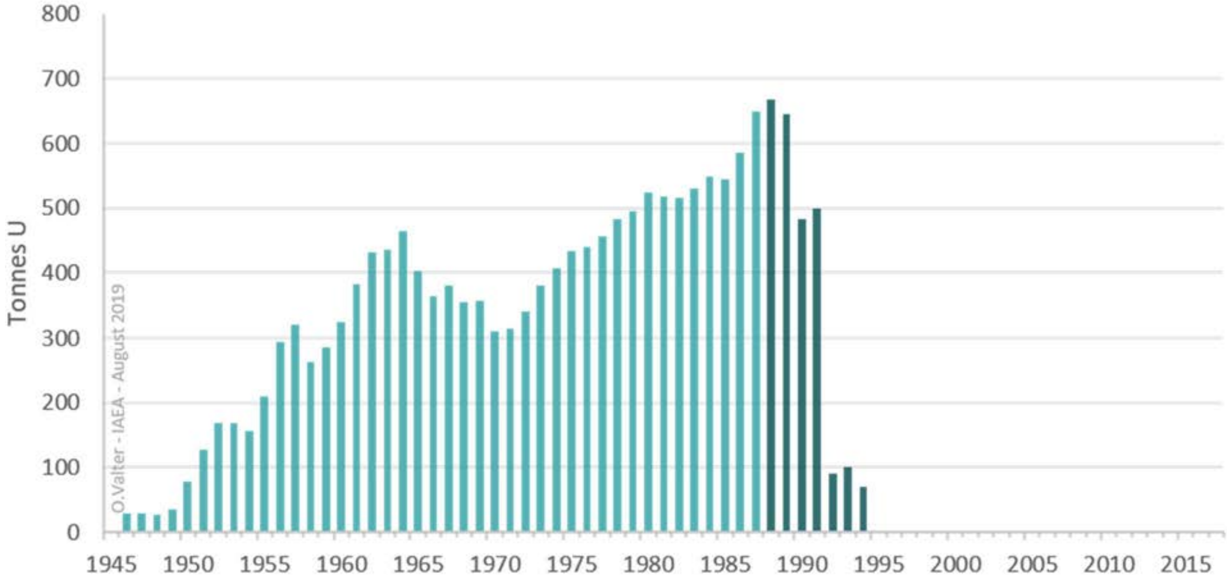


FIG. 5.8. Historical uranium production in Bulgaria (Data in light green are from the Red Book Retrospective, in dark green from Red Books) [5.11, 5.13].

After 1990, uranium was also extracted by mine water treatment during site rehabilitation. At Zvezda, on the site of the past processing plant, an installation for ion exchange resins is used to recover uranium from contaminated mine water. In the period 1991–2009, 5.5 tU was recovered.

5.5.7. Status of production capability

No uranium production centres exist. According to Government policy, were uranium production to restart, then all facilities and processes would have to be operated by private companies. Currently, at the erstwhile Zvezda ore processing plant, the ion exchange resin plant is operational and is being used to purify mine waters. It has a capacity to process ~742 m^3 of resin annually. From 1992, activities have concentrated on disassembling facilities, closing mining works, re-cultivating contaminated areas, purifying contaminated mine waters and conducting environmental monitoring.

5.5.8. Environmental activities and sociocultural issues

Environmental activities are summarized in a short contribution in Ref. [5.13], reflecting the status as of the end of 1998.

Uranium production officially ceased in 1992. Remediation activities include liquidation, biological and technical re-cultivation, decontamination of mine waters and environmental monitoring of former mine sites, provision of technical documentation on hydro-ecological and radiological assessments and prognoses, and conduct of pre-project investigations. Remediation of subsurface and open pit production centres of uranium has been accomplished. Mine adits have been closed and vertical shafts backfilled and covered by concrete slabs. Remediation was completed in seven open pit mines.

Facilities for production by ISL have been disassembled and associated soils re-cultivated, except for 26.5 ha of concrete and foundations. Currently, technical remediation at all sites listed in the Governmental decree has been accomplished, except the Gabra shaft close to Novi Han. Remediation was completed in 54 sites. Of the existing 21 vertical shafts owned by Rare Metals, 19 have been filled and capped and over 600 horizontal mine adits sealed (including galleries totalling over 600 km in the Buhovo deposit). A total of 37 re-cultivation projects were accomplished and 1172.7 ha of agricultural land were re-cultivated biologically and reverted to their owners after remediation was approved by the concerned commissions for land property.

Assessment and categorization of risk was accomplished for 37 facilities. The Metalurg/Buhovo plant, owned by Rare Metals, was sold. The tailings facility at this plant is being investigated for re-cultivation. The plant at Zvezda/Eleshnitsa is nearly wholly disassembled and all buildings have been razed. The tailings facilities have been closed and re-cultivated. The capacity of the decontamination facility has been lessened to meet the requirements for water decontamination. Biological and technical re-cultivation on the waste banks close to the mining sites are continuing. Concurrently, monitoring, chiefly of waters, is continuing at some sites and where polluted mine waters are penetrating to the surface, water decontamination is continuing.

According to Government decrees issued between 1992 and 1998 on the termination of uranium production, a total expenditure of ~26.6 million Bulgarian Lev had been incurred.

By 2007, the majority of environmental remediation of the mining impacts of uranium were considered to be thorough. A project on closing and re-cultivation of the tailings facilities and contiguous areas in Buhovo was completed by 2009. Projects for remediation at former exploration sites and at locations of small- scale mining activities are likewise essentially complete. The overall cost was BGN 35.653 million (USD $15.673 million) (Fig. 5.9) [5.8–5.11, 5.14].

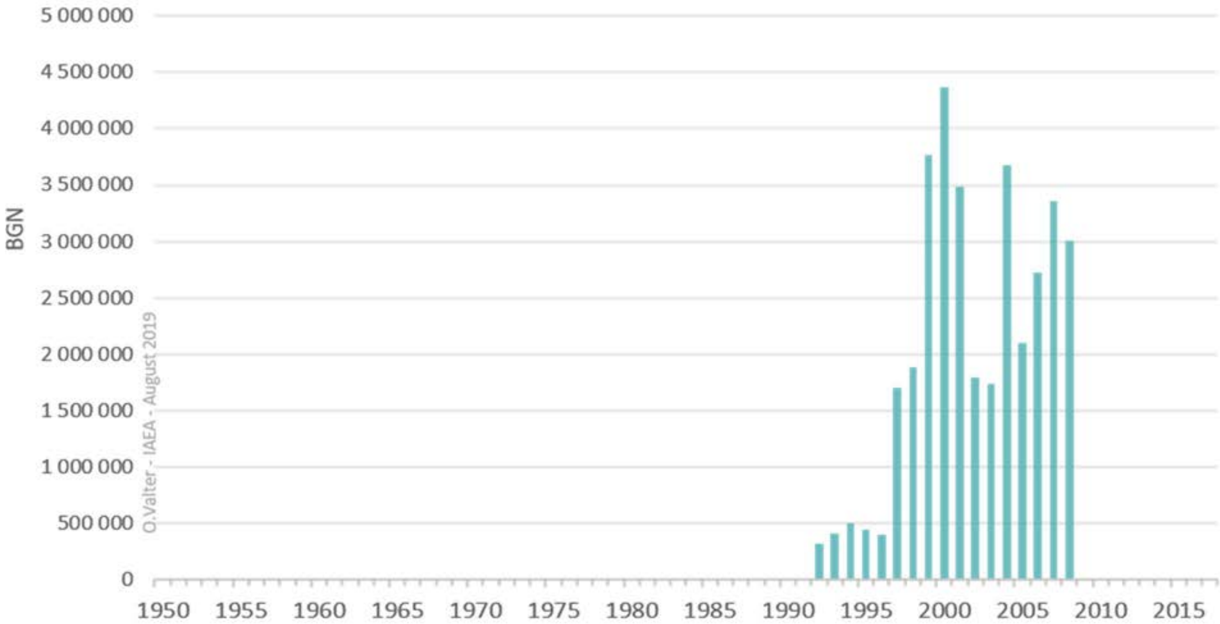


FIG 5.9. Annual environmental expenditures (in Bulgarian Lev).

5.5.9. National policies relating to uranium

Currently, Bulgaria has no intention to renew mining activities for uranium. In view of the building of the Belene nuclear power plant project, this policy may be reviewed.

References to Section 5.5

[5.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Bulgaria, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2013).

[5.2] VISO, Geology and Mineral Resources of Bulgaria, http://viso.jre.it http://viso.jre.it/peco-mines_ext/events/bu

[5.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[5.4] HAYDOUTOV, I., YANEV, S., The Proto-Moesian microcontinent of the Balkan Peninsula – a Peri-Gondwanaland piece, Tectonophysics **272** (1997) 303–313.
[5.5] CARRIGAN, C.W., MUKASA, S.B., HAYDOUTOV, I., KOLCHEVA, K., Neoproterozoic magmatism and Carboniferous high-grade metamorphism in the Sredna Gora Zone, Bulgaria: An extension of the Gondwana-derived Avalonian-Cadomian Belt, Precambrian Res. **147** 3–4 (2006) 404–416.
[5.6] HSÜ, K.J., NACHEV, I.K., VUCHEV, V.T., Geologic evolution of Bulgaria in light of plate tectonics, Tectonophysics **40** (1977) 245–256.
[5.7] RICON, L.-E., et al., Rhodope and Vardar, Geodinamica Acta **11** (1998).
[5.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).
[5.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).
[5.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).
[5.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[5.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).
[5.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999) 63–64.
[5.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

5.6. CROATIA

5.6.1. Geography

Croatia is located in south-eastern central Europe at the transition to the SE European Balkans. Croatia's coast on the Adriatic Sea is rugged and rocky and is characterized by numerous islands of which the largest are Cres and Krk [6.1]. The Croatian part of the Dinaric Alps is forested and arable land covers 26% of the country. The country is prone to seismic activity.

The climate along the coast is Mediterranean, whilst the northern and eastern areas have a continental climate. The Dinaric Alps are characterized by cold winters with a typical highland climate.

Northern and eastern Croatia are lowlands between the Save and Drava Rivers; the Drava forms the border with Hungary and the Save the border with Bosnia and Herzegovina.

5.6.2. Geology

Croatia has no major mineral deposits. Some small oil deposits have been found. Small coal deposits occur, as well as low grade iron ore.

Limestone and dolomite cover ~54% of the entire surface of the country (Fig. 5.10). Most of western Croatia, formed by the NW branch of the Dinaric Alps, is underlain by limestone, which is subject to karstification and extensive dissolution to form caves. Within the karst of the Dalmatian region, more than a thousand deposits of bauxite located within a 150 km long belt were mined during the second half of the 20th century.

The Dalmatian region is also an area that records high output of primary (industrial minerals and construction materials, including sand, gravel and dimension stone) and secondary aggregates (debris from dimension stone production). Aggregates and natural stone are quarried at 155 sites and there are 73 abandoned sites [6.2]. These materials are extracted for domestic use.

The extensive karst geology is not favourable for the formation of uranium deposits. Croatia has no major mineral deposits.

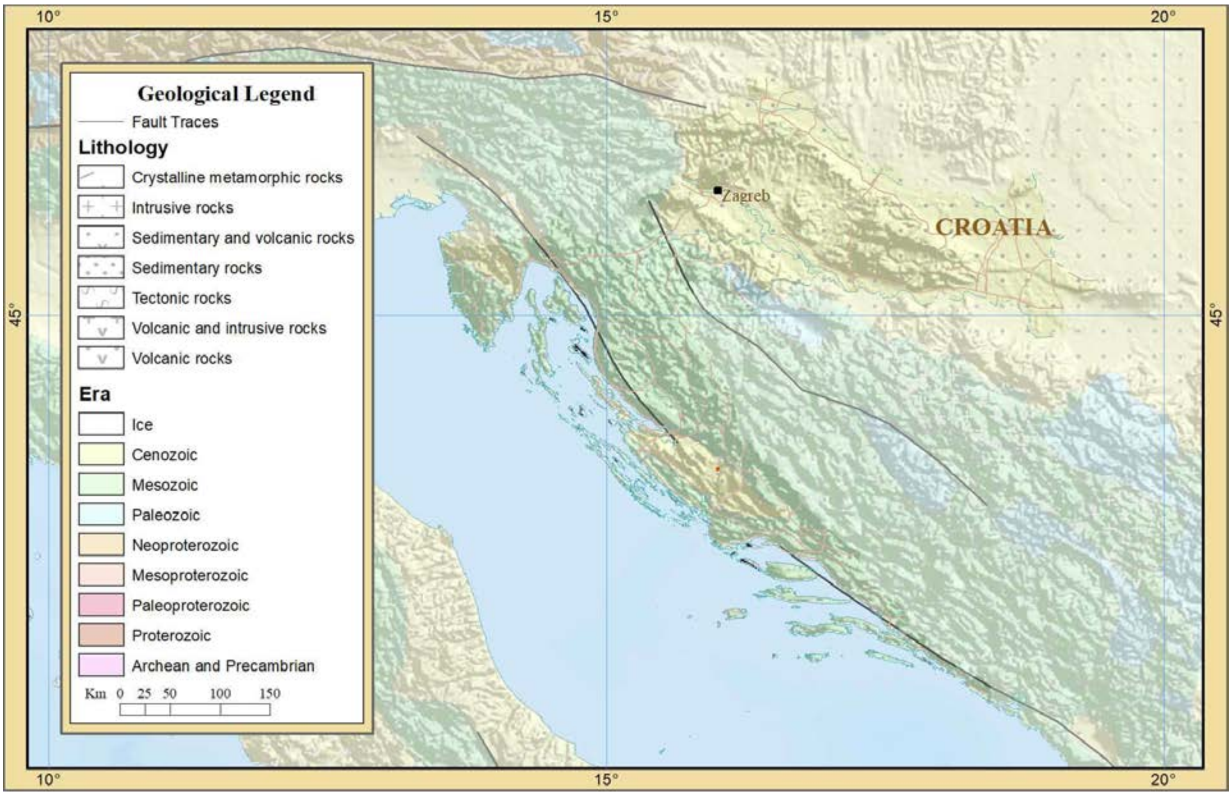


FIG. 5.10. Regional geological setting of Croatia showing uranium occurrences. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.6.3. Uranium exploration

Airborne surveys and geochemical prospecting for uranium were carried out in the area south of the Save River, but no deposits were found. Exploration expenditures are not reported separately for Croatia but may be included in work done in the former Yugoslavia.

5.6.4. Uranium resources

No identified or undiscovered uranium resources are reported. There are no indications of unconventional resources. The potential for uranium discoveries is considered to be very low. The UDEPO database does not list any known deposits for Croatia.

References to Section 5.6

[6.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Croatia, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2013).

[6.2] KOVACEVIC, E., et al., "Past mining and present quarrying: Impact on the Dalmatian karst environment, Croatia", paper presented at 15th Mtg Assoc. Eur. Geol. Soc., Tallinn, 2007.

5.7. CYPRUS

5.7.1. Geography

Cyprus is situated in the eastern Mediterranean Sea (Fig. 5.11), south of Turkey and west of the Syrian Arab Republic [7.1]. The island has two mountain ranges, the Kyrenia Mountains to the NE and the

Troodos Mountains in the SW. The highest point is Mount Olympus (elevation 1 952 m) in the Troodos Mountains.

5.7.2. Geology

The geological features result from the closing of the Tethys Sea during the Mesozoic, which occurred as the African Plate was subducted beneath the Eurasian Plate. Rocks of the Alpine Orogenic Belt are exposed in the north, whilst the rest of the country consists of rocks of the Eastern Mediterranean Basin. The SW is dominated by volcanic peaks of the Troodos Mountains.

Part of the country is intruded by ophiolites (volcanic rocks of alkaline composition), which carry volcanogenic massive sulphide ore deposits. The volcanogenic massive sulphides are associated with volcanic hydrothermal events that occurred in a submarine environment. Cyprus is well known for its base metal deposits, mainly copper and zinc (Cyprus type volcanogenic massive sulphides) [7.2].

FIG. 5.11. Regional geological setting of Cyprus. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.7.3. Comments

No uranium occurrences and/or deposits have been reported. The potential for uranium discovery is low as many of the rock types typically have very low uranium contents. Cyprus has no nuclear programme and has not reported to the Red Book. The UDEPO database does not list any known deposits for Cyprus.

References to Section 5.7

[7.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Cyprus, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed July 2012).

[7.2] GEOLOGICAL SURVEY DEPARTMENT, Geology of Cyprus, http://www.moa.gov.cy/moa/gsd/gsd.nsf/dmlIndex_en/dmlIndex_en?OpenDocument

5.8. CZECH REPUBLIC

5.8.1. Geography

The Czech Republic is a landlocked country in central Europe and has borders with Germany, Poland, Slovakia and Austria. Geographically, the country is divided into Bohemia (west) and Moravia (east). Bohemia is surrounded by the Sudety Mountains in the NE, which form the border with Poland.

In the Krkonose (Riesengebirge) part of the Sudety, the highest point, Snezka, has an elevation of 1 602 m. The north-western mountains, bordering Germany, are formed by the Krušné hory (Erzgebirge), which rise to 1 244 m (Klinovec). In the SW, the mountains of the Sumava (Bohemian Forest) and the Bavarian Forest border Germany, reaching and elevation of 1 378 m (Plechy). In Moravia, the border with Slovakia is formed by the Lesser Carpathian Mountains.

The central part of Bohemia is undulating, with alternating hills and basins. Bohemia is drained by the Labe (Elbe) River and its tributaries: Vlatava (Moldau), Berounka and Ohre (Eger). The main river in Moravia is the Morava (March), a tributary of the Dunaj (Danube). The source of the Odra (Oder) River is in Moravia. Waters from the country flow into three different seas: the Labe, via the Elbe, into the North Sea; the Morava, via the Danube, into the Black Sea; and the Odra, via the Elbe, into the Baltic Sea.

The climate is temperate continental, with warm summers and cold, snowy winters. Variations according to elevation are typical. In the mountains, the winters are colder, with a number of weeks with snow and with temperatures below 0°C. Moravia is normally milder. Summer temperatures in the lowlands may exceed 25°C.

The Czech Republic has one of the most developed industrialized economies in central Europe. The principal industries are heavy engineering and general engineering, iron and steel production, metal working, chemical production, electronics, transportation equipment, textiles, glass, brewing, ceramics and pharmaceuticals. Its main agricultural products are sugar beet, fodder roots, potatoes, wheat and hops [8.1].

5.8.2. Geology

The western part of the Czech Republic mainly comprises the Bohemian Massif (Fig. 5.12), which was stabilized during the Hercynian Orogeny. The Bohemian Massif is characterized by its complicated structure and genesis and is divided into the metallogenic units of the Moldanubian zone, the Saxo-Thuringian zone and the Sudetic-Moravian zone. These zones are surrounded or covered by sediments of Permian–Carboniferous age, by post-Hercynian sediments and by the products of late stage volcanism.

The Moldanubian in the south extends into Austria and Germany and consists of sediments of probably Late Archaean–Early Proterozoic age which are folded and metamorphosed and show some anatectic mobilization. Of limited extent are sediments of the Upper Proterozoic and Palaeozoic, which overlie the basement and which were folded during the Hercynian Orogeny. It is these strata that have intrusions of granite. Sediments of Permian, Upper Cretaceous and Neogene age were deposited in basins.

The Saxo-Thuringian zone is found in the Krušné hory (Erzgebirge) and consists of pre-Palaeozoic rocks, intensively metamorphosed, overlain by Cambrian and Silurian quartzites and slates, which were metamorphosed during the Hercynian Orogeny. Post-metamorphic granites show hydrothermal activity. Active volcanism occurred during the Tertiary.

The Sudetic-Moravian zone is located to the NE and its geological units are the most complex part of the Bohemian Massif. Late Proterozoic–Early Palaeozoic rocks are highly metamorphosed. The Lusitanian pluton was intruded during the Caledonian Orogeny. Probably of Ordovician–Silurian age are the slightly metamorphosed graphitic phyllites. There are also Devonian–Carboniferous shales, quartzites and limestones. During the Carboniferous, granites of the Krkonose-Jizera were intruded. The remainder of the Sudetic-Moravian zone has had an equally complex geological evolution. In some parts, sedimentation took place during the Carboniferous, Permian and Cretaceous periods.

Carboniferous and Permian sediments fill the basins formed on the Bohemian Massif. The Carboniferous is partly marine, partly continental, whilst the Permian sediments are continental in origin. During most of the Mesozoic, the pre-Mesozoic rocks were exposed at the surface and subject to erosion. Upper Cretaceous sequences record that a marine environment existed in some areas, whereas others have sediments that are fluviatile to lacustrine in nature.

The Tertiary is characterized by sedimentation of psammitic to slightly pelitic rocks, and by volcanic extrusions of alkaline composition, particularly in northern Bohemia [8.2].

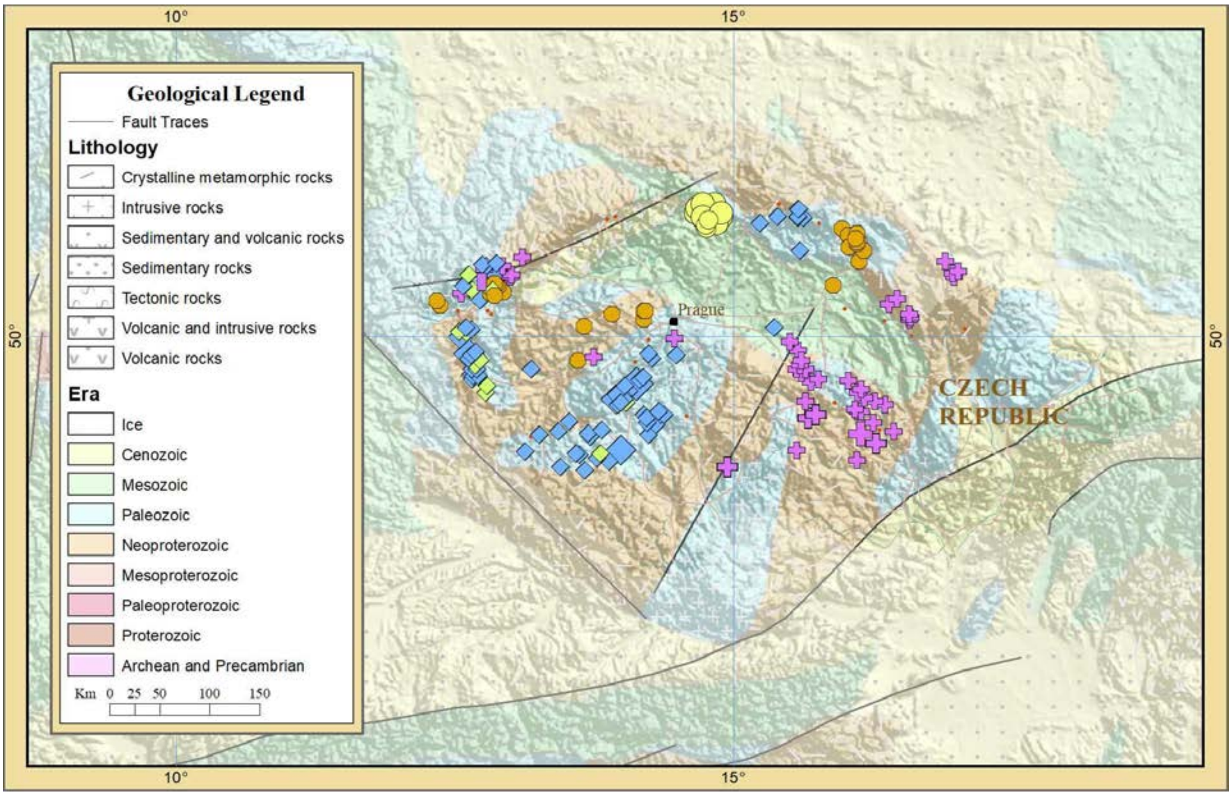


FIG. 5.12. Regional geological setting of Czech Republic showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.8.3. Uranium exploration

5.8.3.1. Historical review

After 1946, exploration in former Czechoslovakia was conducted to support the country's uranium mining industry. Systematic exploration was carried out to assess the entire country's potential for uranium. Drilling and underground methods were used to explore in detail areas with identified potential. Systematic exploration sustained until 1989, with expenditures for exploration in the range of US $10–20 million/year and with drilling campaigns totalling around 70–120 km/year.

Exploration focussed on vein deposits in metamorphic complexes of the Bohemian Massif (Jachymov, Horni Slavkov, Pribram, Zadni Chodov, Rozna), in granitic rocks (Vitkov) and on sandstone-hosted deposits in north-western and northern Bohemia (Straz, Hamr). Exploration expenditures incurred in CZK

(Czech crowns) remained nearly constant, around CZK 240–290 million/year. After 1989, all activities related to uranium were reduced. Since the beginning of 1994, no field exploration has been undertaken.

Data prior to 1971 are not reported [8.3–8.11]. Fig. 5.13 summarizes details of historical exploration expenditure totalling USD $3.18 million for 2 048 540 metres of drilling.

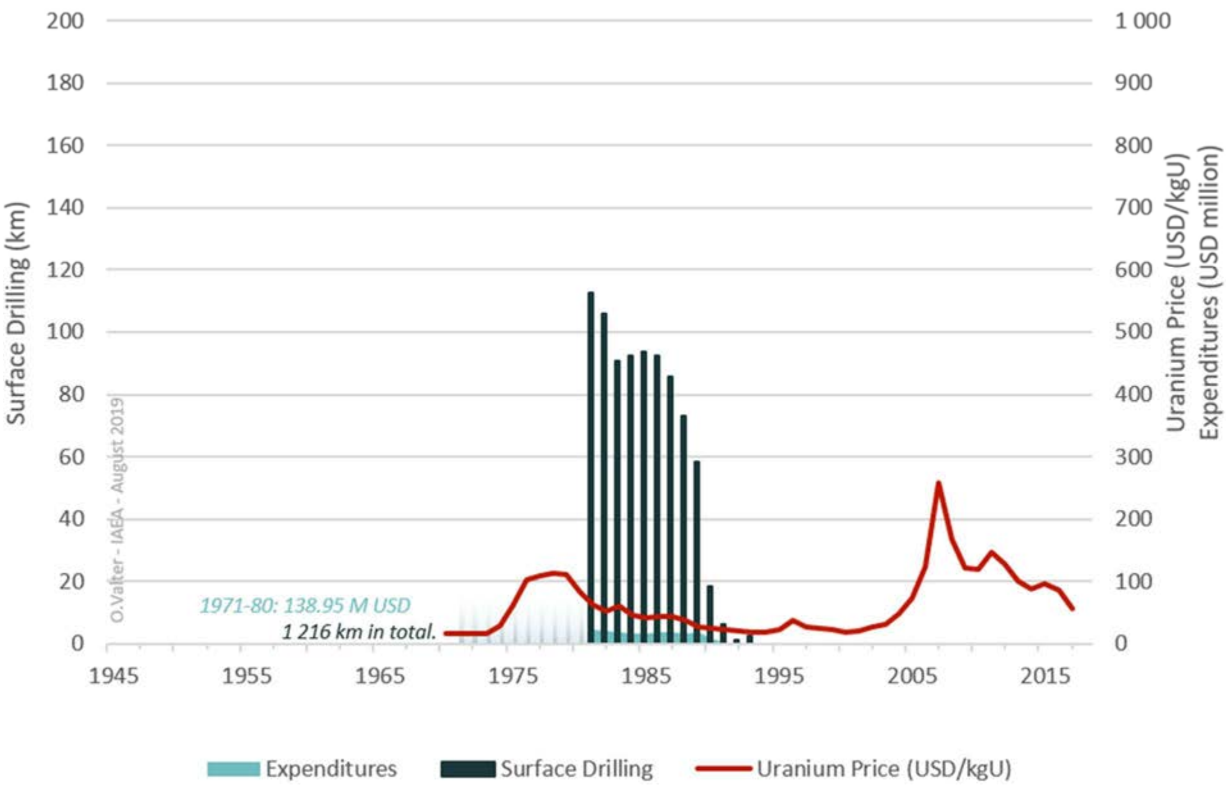


FIG. 5.13. Domestic uranium exploration data for Czech Republic. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

5.8.3.2. Recent and ongoing uranium exploration and mine development activities

Recent exploration activities have been centred on the maintenance and processing of previously collected exploration data. A drilling campaign was undertaken in 2008 at Rozna to delineate and verify resources. Processing the exploration data and constructing the exploration database was planned to carry on in 2009. From 2009 to 2016, underground exploration drilling was carried out to identify additional uranium resources in the deepest parts of the Rozna deposit (to a depth of 1100 m). These works confirmed economically mineable resources. As mining of these resources became unprofitable, it was decided to cease the mining activities and to start the decommissioning of the Rozna mine as of 1 January 2017 [8.12].

Discovery costs, as of 1 January 2003, were estimated at US $2.87/kg U [8.4–8.11]. In considering changes up to 1 January 2007, costs changed only slightly, to US $2.85/kgU.

5.8.4. Uranium resources

Most of the identified resources occur in 23 deposits, of which 20 have either been mined out or have closed. Of the three remaining deposits, two – Brzkov and Osecná-Kotel – have resources that are not recoverable because of considerations of environmental protection, and one is being mined (Rozna). It is believed that undiscovered resources exist in the Brzkov and Rozna vein deposits in the metamorphic complex of western Moravia, as well as in the sandstones in the Hermánky region, Straz and Tlustec blocks in the northern Bohemian Cretaceous basin.

As of 1 January 2009, identified resources shrank by 178 tU relative to the past estimate. Reasonably assured resources at <US $80/kgU decreased by 128 tU as the outcome of the re-evaluation of resources during mining at the Rozna deposit. Reasonably assured resources, as of 1 January 2009, total 432 tU at <US $80/kgUand the same for <US $130/kgU. These resources are exploitable by underground mining of the Rozna vein deposit, with a recovery factor of 90%.

Reasonably assured resources at <US $40/kgU are not reported. Reasonably assured resources at >US $80/kgU are no longer registered.

Inferred resources at <US $80/kgU decreased by 50 tU at Rozna. As of 1 January 2009, inferred resources amounted to 70 tU, exploitable by underground mining of the vein deposit at Rozna, with a recovery factor of 90%. Inferred resources at <US $40/kgU are not reported. Inferred resources at >US $80/kgU are not reported anymore. All identified resources at <US $80/kgU, as of 1 January 2009, total 502 tU. These are offshoots from the existing Straz and Rozna production facilities. Mining losses of 5% have been considered in estimating reasonably assured resources and inferred resources [8.4–8.11].

The Straz production centre has assigned uranium 'reserves' of 1 320 tU in the technical details tables of the 2005 and 2007 Red Books [8.10, 8.11]. However, it should be noted that these resources do not appear in the resource tables listed in the 2009 Red Book [8.12]. These former 'reserves' should therefore probably be considered as speculative resources with no assigned production cost.

As of 1 January 2017, in-situ reasonably assured resources in the cost category <US $260/kgU are reported as 83 700 tU and inferred resources at <US $260/kgU as 113 400 tU [8.13]. Historical variations in resources are shown in Figs 5.14 and 5.15.

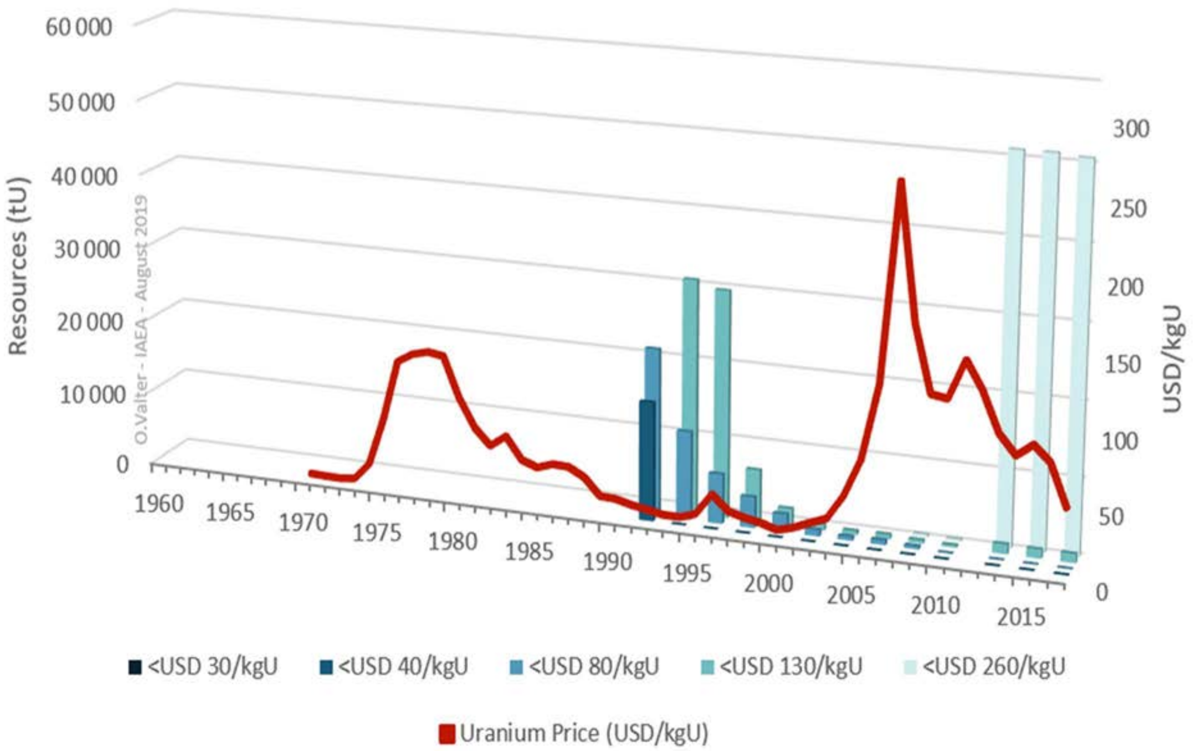


FIG. 5.14. Historical variation of recoverable reasonably assured resources within various cost categories in Czech Republic. Periods where no resources are shown in any cost catergories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

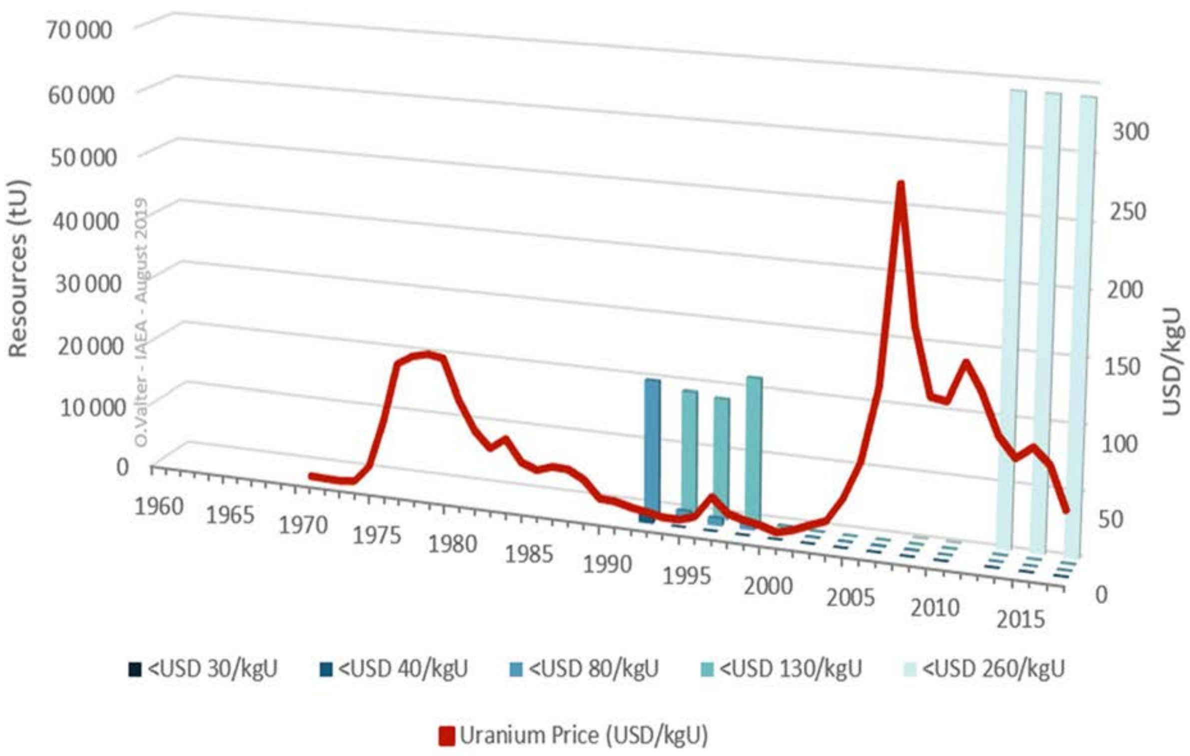


FIG. 5.15. Historical variation of recoverable inferred resources within various cost categories in Czech Republic. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate..

The UDEPO database lists the most significant deposits for the Czech Republic as Bytiz 4, 22-40, Straz, Hamr North (Hamr I) -Krizany, Rožná, Hamr South (Hamr II), Osecna-Kotel, Brevniste, Mimon.

5.8.4.1. Undiscovered resources

As of 1 January 2017, the undiscovered resources category (prognosticated resources and speculative resources are summarized as follows:

— Prognosticated resources at <US $260/kgU total 222 915 tU;
— Speculative resources with costs unassigned total 17 000 tU [8.13].

5.8.5. Potential for new discoveries

Exploration and mining in the Czech Republic has been undertaken extensively and potential areas have been explored, at least superficially. The potential for new discoveries may exist in granitic intrusives and in favourable sedimentary environments. However, these potential areas may be buried under barren strata and thus any new exploration would necessitate both high capital expenditures and the use of sophisticated methods.

Undiscovered resources may occur in the vein deposits of Rozna and Brzkov, in the metamorphic complex of western Moravia. Sandstone-hosted deposits are believed to occur in the Straz block as well as in the Tlustec block and Hermanky region in the Cretaceous basin of northern Bohemia.

Based on its former exploration and mining history, the overall potential for new discoveries in the Czech Republic is considered to be low.

5.8.6. Uranium production

5.8.6.1. Historical review

Uranium production started in 1946. Since then and until the disbanding of the former Soviet Union, all uranium produced was shipped to the former Soviet Union. The first production was derived from the Horni Slavkov and Jachymov mines, in which operations were finished in the mid-1960s. The principal vein deposit – Pribram – was exploited during 1950–1991. The Straz and Hamr sandstone deposits began operation in 1967. Production peaked at ~3000 tU in 1960 and remained between 2500 and 3000 tU/year from 1960 until 1990, when it began to decline.

During 1946–2008, the Czech Republic produced a total of 110 427 tU. About 84% was produced by both open pit and underground mining methods, and ~16% was recovered by ISL [8.4–8.13]. Production during 1946–1992 related to the former Czechoslovakia, whereas production from 1993 to the present relates to the Czech Republic only. Only a few tonnes of uranium were produced in Slovakia (see country report).

Figure 5.15 summarises historical uranium production for 1946–2017. In the period 1946–2017, a total of 112 069 tU (as reported in Refs [8.3–8.13]) was produced, of which ~84.2 was from underground mining, 15.8% was from ISL, ~125 tU were produced by heap/in place leaching and ~2 500 tU were from mine water treatment and environmental restoration.

Historical production came from deposits in the resource range 25 000–50 000 tU (Pribram (vein, depleted), Straz (sandstone, operating)) and several deposits in the range 10 000–25 000 tU. A number of deposits in the resource range 2500–5000 tU have also contributed to the production (UDEPO [8.14]).

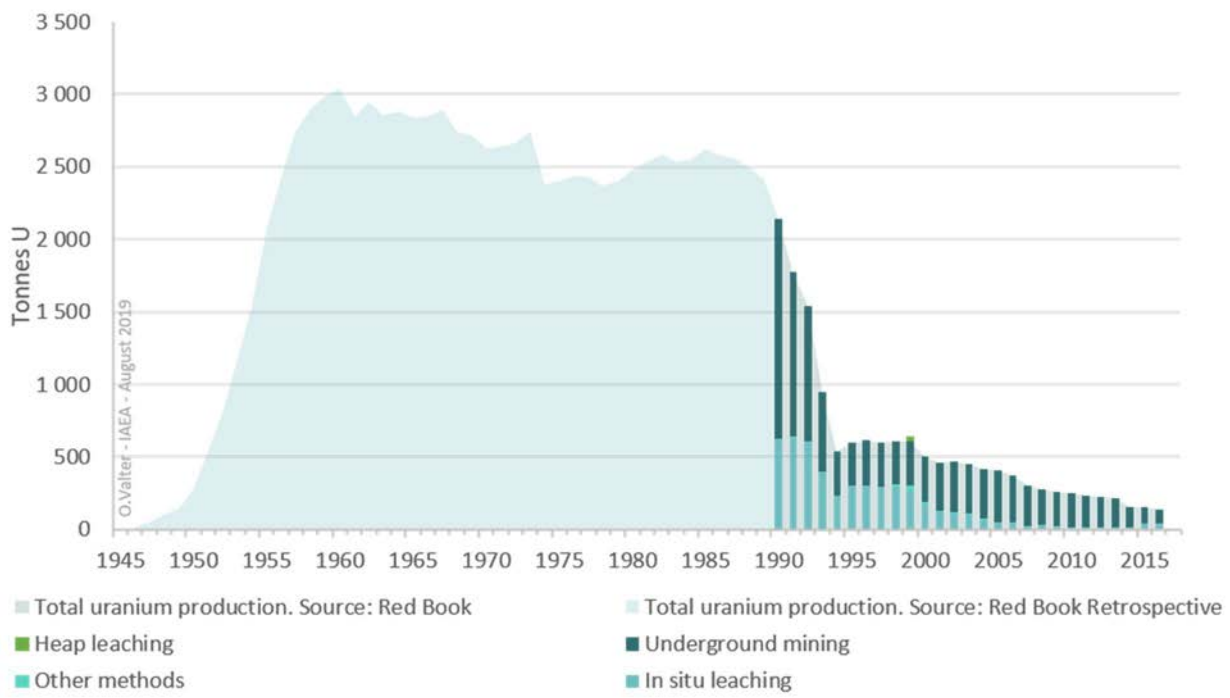


FIG. 5.16. Historical uranium production in Czech Republic (Data in light green are from the Red Book Retrospective, in dark green from Red Books) [8.3–8.11].

The grades of the deposits mined varied from rich (1.00–5.00% U, as at Horni Slavkov, Jachymov and Pribram (all vein deposits)), to medium (0.20–0.50% U, mainly derived from seven deposits) to low grade

(0.05–0.10% U, mostly sandstone deposits where uranium is extracted by ISL mining). Total production was 112 055 t U until 2017 and the closure of the Rozna mine [8.13].

5.8.6.2. Status of production capability

There are production facilities at Rozna (stoping ~1100 m underground) in Dolni Rozinka and at the ISL mining centre currently under remediation in Straz (~180 m underground). Owing to higher uranium prices and uranium resources at the Rozna deposit, the plan was to carry on with the mining activities so long as they are money-making. Production of 230 tU was projected for 2009. This level is anticipated to be continued in future years, even though increase is possible.

In Straz, the ISL facility produces uranium as a result of environmental remediation. Production decreases as the result of lower uranium concentration in the solutions. Production of 25 tU was expected in 2009, possibly decreasing thereafter. Uranium from mine water treatment is expected at 12 tU in 2009, down from 19 tU in 2007. Recovery is from a water treatment plant at the depleted Pribram deposit after flooding of underground workings in 2006.

In Dolni Rozinka, production started in 1957 and the operation has a current capacity of 530 t ore/d. The ore is received from Rozna, (resources of 680 tU, grading 0.378% U). The recovery at the mine averages 95%. The mill uses crush-wet grinding, feeding an alkaline atmospheric leaching circuit followed by ion exchange. Around 550 t of ore can be processed daily. The recovery at the mill is 92.5% and the nominal production capacity is 400 tU/year.

The production centre at Straz started in 1967. It operates as an acid ISL and exploits the Straz sandstone deposit (which has reported resources of 1320 tU). The grade averages 0.03% U. Recovery is by acid leaching with ion exchange. A total of 20 000 kl/d of solution are processed. The capacity is 100 tU/year. Currently, the well fields are under remediation.

5.8.6.3. Ownership structure of the uranium industry

Exploration and production of uranium have been undertaken by DIAMO s.p. — the State-owned enterprise — which is based in Straz.

5.8.6.4. Employment in the uranium industry

All production facilities are State owned. At the end of 2008, employment totalled 2 287, up from 2 251 in 2006. These personnel are involved in production of uranium as well as in decommissioning and restoration activities in the Straz and Dolni Rozinka production centres. Employment directly related to uranium production was 1 122 persons at the end of 2008, compared with 1 213 in 2006 and 1 106 in 2007 [8.4–8.13].

5.8.6.5. Short term production capability

Short term production capability was projected to be 500 tU/year by 2010, decreasing to 50 tU/year by 2015 and continuing at 50 tU/year to 2030, decreasing thereafter to 30 tU/year by 2035.

5.8.6.6. Future production centres

No other production centres are planned or committed in the near future.

5.8.6.7. Environmental activities and sociocultural issues

The contraction programme, which started in 1989, consists of both environmental activities and solving social issues. Activities for environmental remediation consist of planning, administration, environmental impact assessment, decommissioning, remediation of tailings impoundments, waste rock management, water treatment, site rehabilitation and long-term monitoring. These are carried out at current centres of production, as well as at sites of past uranium facilities.

Environmental projects include the following:

- Remediation after ISL in Straz (including treatment of 266 m^3 of groundwater over a surface area of 600 ha);
- Rehabilitation of the tailings impoundments at Straz, Pribram, Mydlovary and Rozna, as well as the waste rock dumps at Olsi, Rozna, Licomerice, Krizany, Hamr, Pribram and others, totalling 19 sites covering 576 ha;
- Treatment of mine water at uranium facilities at Pribram, Licomerice, Horni Slavkov, Straz, Olsi and others (totalling ~11 million m^3/year). The major component (i.e., more than 90%) of the environmental projects receives funding from the State budget. The projects are expected to carry on up to 2040 or thereabouts and are expected to cost at least CZK 60 billion.

The contraction programme consists of addressing the decrease in employment and developing substitute projects to address social-related issues. The social component of the contraction programme (rents, damages, compensation, etc.) is funded from the State budget. The work on behalf of the Czech uranium industry is undertaken by DIAMO, the State-owned environmental engineering company. More details on activities related to environmental remediation are given in Fig. 5.16 and in Refs [8.1.- 8.16]. A total of CZK 44.743 million and CZK 9.748 million were spent on environmental remediation and social programs.

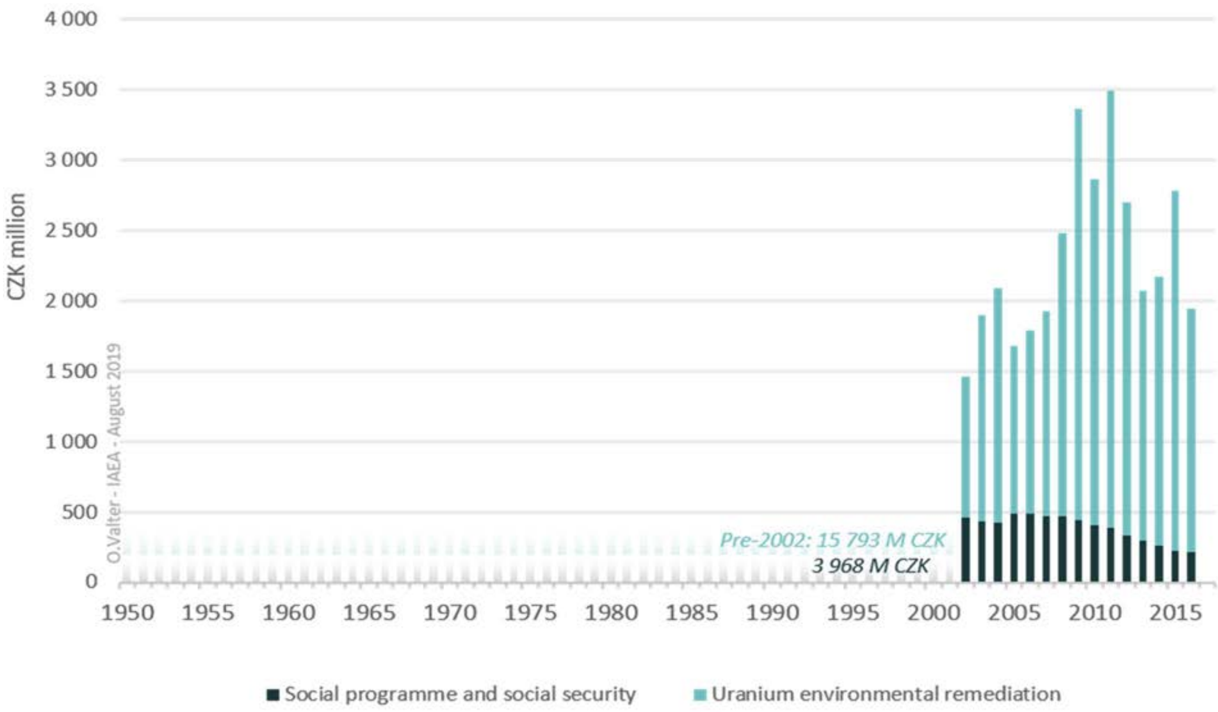


FIG 5.17. Expenditures related to social issues and environmental activities in the the Czech Republic [8.14–8.16].

References to Section 5.8

[8.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Czech Republic, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2013).

[8.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[8.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.
[8.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).
[8.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).
[8.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).
[8.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).
[8.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).
[8.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).
[8.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).
[8.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[8.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[8.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).
[8.14] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[8.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999) 80–86.
[8.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002) 170–201.

5.9. ESTONIA

5.9.1. Geography

Estonia is located in north central Europe and borders the eastern side of the Baltic Sea. The terrain is mostly flat to slightly hilly and the highest elevation is only 318 m (Suur Munamägi). Estonia shares Lake Peipus with the Russian Federation. The Baltic Sea is formed by the Gulf of Finland to the north and in the west by the Gulf of Riga, in which several larger and smaller islands are located. About 44% of the country is covered by forest and ~25% is arable land.

The climate is temperate and is influenced by the Baltic Sea. During the winter, the temperature may fall below -5°C over several weeks. During the summer, the average is above 15°C. The annual rainfall is ~600 mm [9.1].

5.9.2. Geology

5.9.2.1. General

Situated in the NW part of the east European Platform (Fig. 5.18), Estonia is close to the Fennoscandian Shield, which forms large parts of Scandinavia, Finland and the north-western part of the Russian Federation. In Estonia, the Proterozoic basement is covered by younger sediments, which are erosional products derived from Finland. The Proterozoic basement, consisting of gneisses, quartzites, slates and granites, is not exposed. In the north, the basement lies at a depth of ~100 m; in the south it is much deeper.

The sediments overlying the basement are Palaeozoic in age, ranging from Cambrian to Devonian, and were deposited during a marine ingression. Surface exposures of Palaeozoic age are rare and occur mainly along riverbanks. The most prominent exposure is the Estonian Glint of Cambrian–Ordovician age, which comprises sandstone at the base, shale (Dictyonema Shale) in the middle and limestone at the top. The Glint is exposed at the coast near Tallinn. Compositionally, the Dictyonema Shale tends to be more a siltstone than a shale.

The Estonian kukersite, forming the lowest part of the Upper Ordovician, is a very large oil shale deposit and can be compared with the Swedish alum shale. It is characterized by both its high bitumen content and its elevated uranium content.

The youngest formations are Quaternary deposits, mainly limestone and sandstone, which cover most of the country. Mineral resources include oil shale (kukersite), peat, phosphorite, blue clay, limestone, dolomite and amber. The oil shale is mined for its bitumen content and is used in thermal power plants and for local heating. Peat, which covers ~8% of the country, is also a major energy source [9.2].

5.9.2.2. Potential uranium-bearing areas

The only formation containing uranium is the alum shale (kukersite), which occurs near Sillamäe, on the Gulf of Finland. The alum shale was mined underground for uranium from 1948 to 1963 and processed at the Sillamäe plant. The uranium content of the shale is variable, with an average of ~0.03% U and a maximum of 0.1% U.

No exploration has been reported.

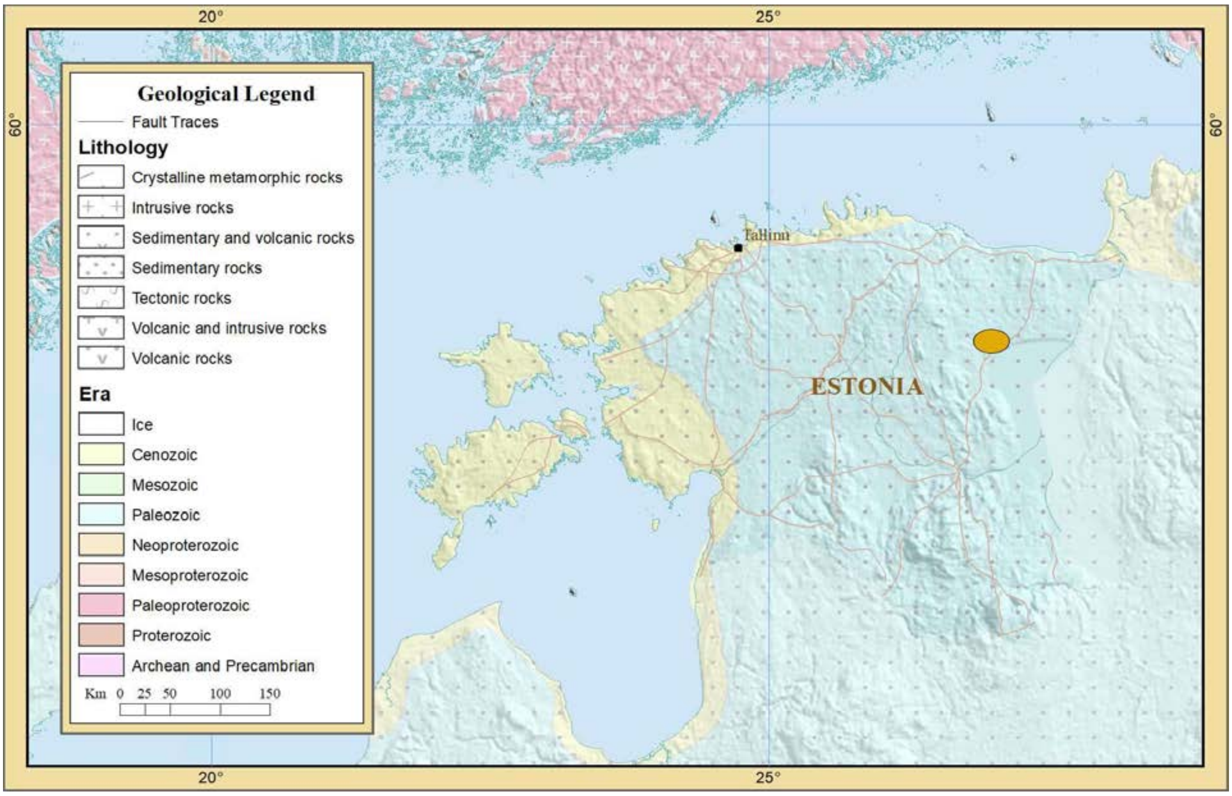


FIG. 5.18. Regional geological setting of Estonia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.9.3. Uranium resources

No uranium resources are reported, as all resources are considered to be either depleted, uneconomic or subject to environmental restrictions. UDEPO indicates unconventional resources of 5 667 000 t U at a grade of 85 ppm in the alum shales [9.3, 9.4].

The UDEPO database lists the most significant deposit for Estonia as Baltoscandia District.

5.9.4. Potential for new discoveries

The Alum Shale may have some low-grade uranium potential, but no other formations are of interest.

5.9.5. Uranium production

About 240 000 t of locally mined alum shale were formerly processed at the Sillamäe processing plant, yielding ~65 tU. The plant is 185 km east of Tallinn and operated in 1946–1963. Mining operations were terminated in 1963 owing to the difficulty of extracting uranium from the low-grade ores.

After 1963, uranium ores containing up to 1% U were imported for processing. An estimated 2.2 million t of ore came from deposits in the former Czechoslovakia and 1.2 million t of ore from Hungary. Smaller amounts were shipped from Poland, Romania, Bulgaria and the former German Democratic Republic. It is estimated that ~4 013 000 t of imported ores were processed at Sillamäe and the total production is estimated to be ~23 000 tU.

The Sillamäe plant was also used in 1970 to process loparite ore from the Kola Peninsula (Russian Federation) to recover niobium, tantalum and rare earth elements. The ore contained ~0.03% U and ~0.6% Th, but neither of these elements were recovered [9.5].

5.9.6. Environmental activities

The tailings from the Sillamäe mill were deposited in a tailings pond close to the Gulf of Finland. The repository was uncovered and therefore radon and its daughter products were released to the atmosphere and the hydrosphere. The radiological impact to the township of Sillamäe was estimated at an individual annual dose of the order of 0.2 mSv. Water leaking from the tailings pond and the closed mine and entering the Gulf of Finland is estimated to have had a smaller impact on the dose rate. A major concern arises from the possibility of a collapse or a landslide affecting the integrity of the impoundment dam.

In 1992–1994, the conditions at Sillamäe were evaluated by an international cooperation project, jointly with Estonian specialists. The results were used for reclamation planning. In 1997, remediation was initiated by the Government and, beginning in 1998, a pilot project was initiated with support from the European Union’s PHARE programme and assisted by Wismut GmbH. In 2003, it was estimated that the reclamation would be completed by 2006. General information on environmental activities has been reported in various publications, although many of these are concerned with the problems resulting from the mining of oil shale [9.5, 9.6].

References to Section 5.9

[9.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Estonia, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[9.2] RAUKAS, A., TEEDUMÄE, A., Geology and Mineral Resources of Estonia, Estonia Academy Publishers, Tallinn (1997) 436 pp.

[9.3] SOESOO, A., Black shale of Estonia: moving towards a Fennoscandian-Baltoscandian database, Hade Instituteof Geology, Tallinn University of Technology (2014) 13 p.

[9.4] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[9.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004) 128–129.

[9.6] PUURA, V., PUURA, E., “Origin, composition and technological and environmental problems of utilization of oil shale”, paper presented at 15th Mtg Assoc. Eur. Geol. Soc., Tallinn, 2007.

5.10. GEORGIA

5.10.1. Geography

Georgia is located on the eastern coast of the Black Sea (Fig. 5.19), extending easterly towards the Caspian Sea. Georgia is subdivided into the mainland and three autonomous regions, Abhazija, Adzharia and Jugo (South) Osetja. The country is surrounded by the Caucasus (to the north) and the Lesser Caucasus Mountains.

The topography is defined by the Caucasus Mountains (the highest peaks are Janga (5 059 m) and Kazbek (5 047 m), with several others over 4 000 m in elevation) to the north, lowlands near the Black Sea and to the SE (Jorskoye Ploskogore), and the Lesser Caucasus Mountains to the south.

Seismic activity is frequent [10.1].

5.10.2. Geology

Georgia is located between the Eurasian and Afro-Arabian Plates at the junction of European and Asiatic branches of the Mediterranean (Alpine Himalayan) fold belt. Its geological structure is built up mainly by Mesozoic and Cenozoic deposits. Early Precambrian and Palaeozoic formations spread over a smaller area. The mountains were formed during an orogenic process dated at 28–23 Ma, which resulted from the northward moving Arabian Plate colliding with the Eurasian Plate. Tectonic activity continues with a number of volcanic peaks occurring on the Jarakheti Volcanic Plateau in the Lesser Caucasus. Three major tectonic units comprise the geological structure of Georgia:

(i) The fold system of the Greater Caucasus;
(ii) The Transcaucasian intermountain area;
(iii) The fold system of the Lesser Caucasus.

The oldest strata, of Precambrian and Lower–Middle Palaeozoic ages, are exposed in all the tectonic units. They are represented by gneisses, migmatites, crystalline schists and amphibolites within the Main Range zone of the fold system of the Greater Caucasus, the Georgian Block and the fold system of the Lesser Caucasus. Palaeozoic rocks are exposed in the central part of the south slope of the Greater Caucasus. They are represented mainly by black shales, sandstones, turbidities, olistrostromes, marbles and calc-alkaline andesitic–dacitic volcaniclastics. Comparatively weakly metamorphosed Palaeozoic sediments are also exposed in the Dzirula Massif. Upper Palaeozoic rocks are also present in all tectonic units. In the Main Range Zone, crystalline rocks are overlain by weakly metamorphosed sandstones, conglomerates and argillites. Continental and coastal calc-alkaline rhyolitic volcanics and coal-bearing argillites with lenses of reef limestone occur in the Dzirula and Khrami Massifs. Lower–Middle Carboniferous corals, brachiopods, foraminifera and terrestrial flora have been found in this formation of the Khrami Massif.

Triassic sediments are observed in the Dizi Series of the Svanethi Zone, in addition to Upper Palaeozoic formations. Triassic dacitic–rhyolitic volcanics, quartz sandstones and siltstones of variable thickness crop out in the Dzirula Massif. Lower Jurassic Aalenian sediments, which everywhere occur transgressively, are present throughout all the tectonic units of Georgia. In the central and eastern parts of the south slope of the Greater Caucasus (Mestia-Tianeti Zone), the Upper Jurassic sediments which follow conformably Middle Jurassic slates consist mainly of clastic limestone flysch. In the western and eastern parts of the Gagra-Java Zone, an Upper Jurassic marine facies is present. In the lower part, it is represented by sandstones and clays and in its upper part by reef limestones. There is a variety of Cretaceous formations in Georgia. Within the Greater Caucasus fold system, the Lower Cretaceous is developed in the form of clastic limestone and greywacke siltstone flysch. In the Upper Cretaceous sediments of the Mestia-Trileti Flysch Zone, greywacke siltstone (in the lower part) and clastic limestone (in the upper part) flysch prevail. In Adjaria-Trialeti Zone, the Upper Cretaceous is represented by a volcanogenic suite with calc-alkaline basaltic composition, which in the lower part also contains the Albian stage.

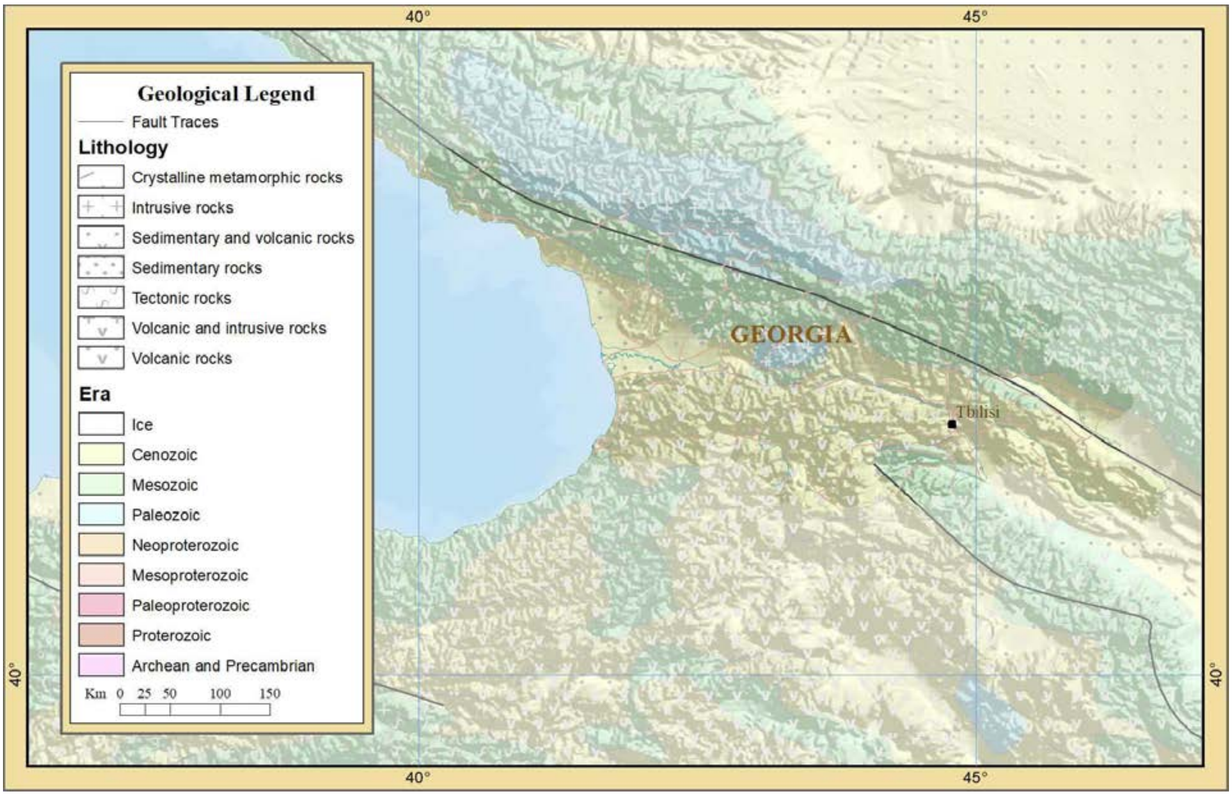


FIG. 5.19. Regional geological setting of Georgia. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Palaeogene deposits are found in all tectonic units. In the south slope of the Greater Caucasus, the Palaeocene–Eocene is represented by greywacke–siltstone flysch. In the southern part, the Upper Eocene is built up of olistrostomes [10.2].

Georgia has iron and manganese ore deposits, and small copper, lead, zinc, tin, cobalt, astatine, and molybdenum deposits. Oil, coal and peat are found in some parts of the country.The UDEPO database does not list any known deposits for Georgia.

References to Section 5.10

[10.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Georgia, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[10.2] RYONO.NET, Geology of Georgia, Ryono.net/ealpha/armenia2.htm

5.11. GREECE

5.11.1. Geography

Greece is located in south-eastern Europe and consists of the mainland, the Peloponnese (connected to the mainland by the Isthmus of Corinth) and over 1400 islands scattered in the Aegean and Ionian Seas. The largest islands are Crete and Euboea and in total the islands comprise 20% of the country in terms of land area. Topographically, Greece consists of ~80% mountains, the highest being Mount Olympus (2 911 m). In the Peloponnese, elevations reach over 2 200 m and in Crete 2 450 m.

Owing to the mountainous terrain, arable land is limited to ~20% of the total land surface. Crops are grown mainly in the lowlands, which are located along the coast and alongside the rivers. About half of the country is covered with forest and woodland. The climate varies according to topography. A Mediterranean climate is found in the lowlands, with mild winters and hot, dry summers. In the mountains, the climate is cold during the winter, with snow, and mild during the summer.

Citrus fruits, grapes and olives are grown primarily in the coastal lowlands and alongside the rivers. Corn is grown where arable fields are available. Mountain meadows are used to pasture sheep and goats [11.1].

5.11.2. Geology

5.11.2.1. General

The Mediterranean area is an active converging plate rim, where the European (Eurasian) Plate and the northwards moving African Plate collide. Greece is located within the active zone of collision. The northern part (Fig. 5.20), bordering Bulgaria, has many similarities to the geology described for the Rhodope Mountains in the Bulgaria chapter of this report.

In general, two main geological zones can be distinguished:

(i) The Rhodope Massif (see Bulgaria) in the provinces of Thrace and Macedonia is formed of Precambrian metamorphics, partly affected by Alpine tectonics. This zone is part of the larger Serbo-Macedonian Massif, extending over parts of the Balkans. The metamorphics consist of gneisses, mica schists and marbles and were intruded by granites during the Hercynian period. The basement rocks are discordantly overlain by Jurassic neritic sediments and terrigenous sediments of molasse type by the Eocene transgression. Alkaline and granodiorite bodies were intruded during the Oligocene and Miocene. The Rhodope Massif is structurally complex and, sensu stricto, is equivalent to the Serbo-Macedonian Massif to the west, which has been intensely affected by the Alpine Orogeny;

(ii) The Hellenides, an Alpine type mountain range belonging to the Dinaride branch of mountains, covers large areas in former Yugoslavia and Albania. The western part of the mountain range in Greece is known as the Pindos. The transition from the Rhodope to the Hellenides is marked by the Vardar Zone. The Hellenides consist of sediments deposited primarily in a geosyncline and are folded, faulted and overthrust. The Hellenides are composed of the so-called ‘coloured melange’, radiolarite, marls and flysch sediments mixed with ophiolites. In detail, the geological development is very complicated and is subject to intensive debate by experts. The Hellenides were formed by processes starting in the Early Tertiary which occurred during Tethys sedimentation and are the result of the collision of the African (Gondwana) continent with Eurasia.

The interplate collision began in the Mesozoic and in Greece all the processes of rifting, sea-floor spreading and subduction can be observed. During the Permian and Triassic periods, rifting occurred which resulted in the formation of several microcontinental landmasses, surrounded by the Tethys Sea. Ophiolitic magmatism occurred during the Jurassic and Cretaceous periods. In subsiding areas, very thick layers of limestone were deposited and in some areas, granitic intrusions are present. In the Late Tertiary, crustal extension took place, resulting in the formation of the Aegean Sea with associated volcanism. The islands of Los and Naxos contain metamorphic complexes similar to those found on Crete. A deep graben south of Crete separates the island from the African continent.

Natural resources include bauxite, lignite, magnesite, marble, bentonite and some base metal deposits.

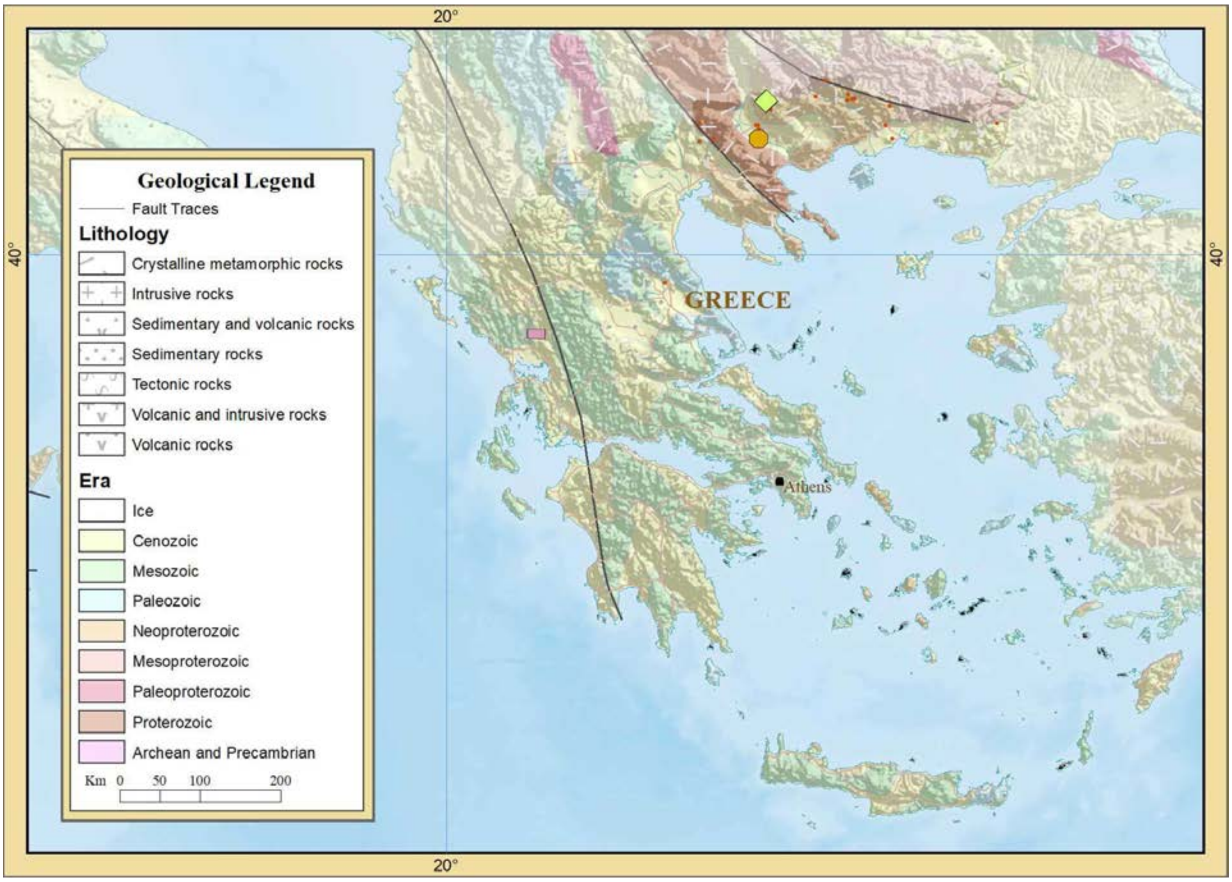


FIG. 5.20. Regional geological setting of Greece showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.11.2.2. Potential uranium-bearing areas

Areas favourable for the formation of uranium mineralization are found in the northern part of the country, in the area adjacent to the deposits in the Rhodope Mountains in Bulgaria [11.2, 11.3].

5.11.3. Uranium exploration

Uranium exploration started in 1955 and continued until the late 1990s. Airborne and carborne radiometric surveys were conducted in the northern part of Greece during the period 1966–1977. In 1971, a follow-up investigation of favourable occurrences in Macedonia and Thrace was started by the Greek Atomic Energy Commission in cooperation with the IAEA and the United Nations Development Programme. Reconnaissance work over the country continued from 1978 onwards. In areas of successful exploration, detailed follow-up work (trenching, drilling, test mining) has been performed since 1978 by the Greek Atomic Energy Commission and the Greek Geological Survey. Detailed exploration included investigation of the Tertiary lignite deposits of Serres and of coal-bearing shales.

Small deposits of uranium mineralization are located mainly in the provinces of Thrace and Macedonia. They were subject to test mining of pitchblende mineralization in the Paranesti area (close to the Bulgaria-Smoljan deposit) and at Mavrorema in Thrace. Surface drilling campaigns were reported for 1977–1996; data for 1997 and 1998 are unavailable (Fig. 5.21) [11.4–11.15]. Prior to 1997, the estimation of potential areas included work on several islands. No work was reported after 1996.

Total expenditures in Greece prior to 1998 amount to US $17.5 million. About 83.5 km of surface drilling was recorded from ~800 holes.

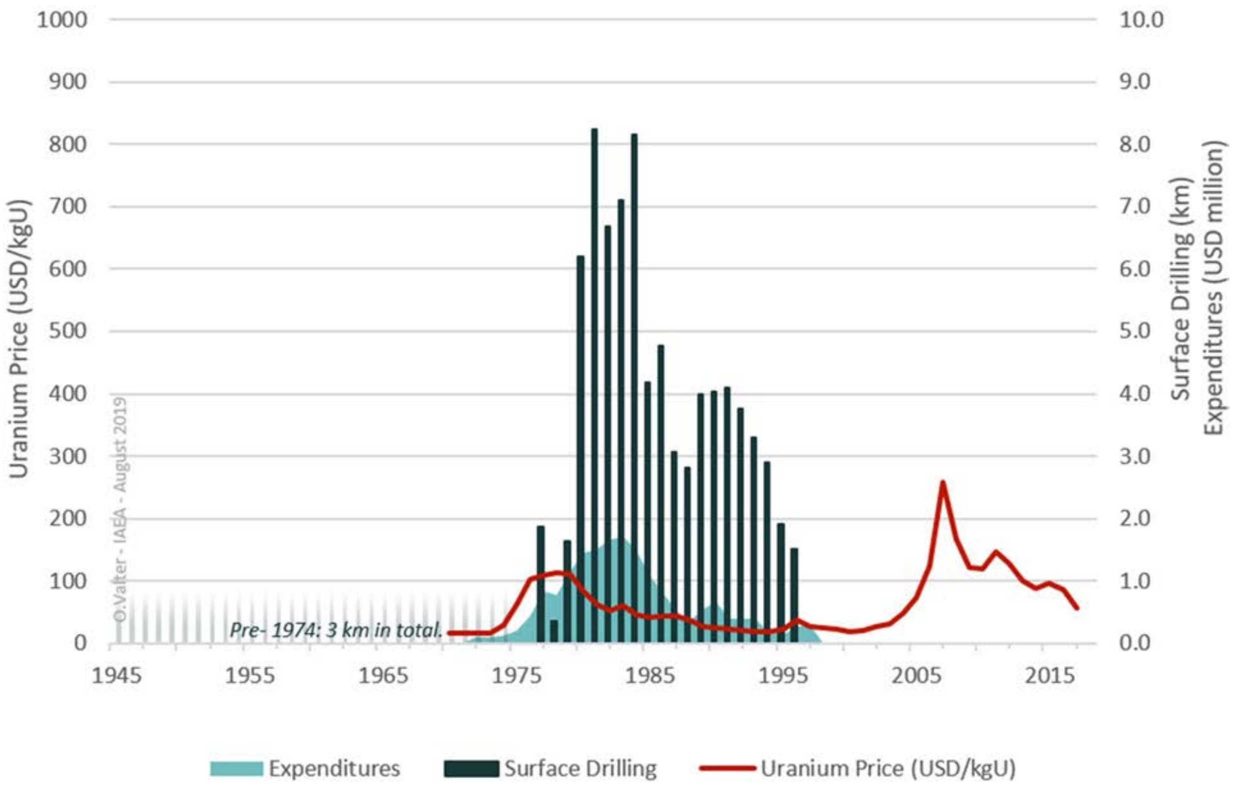


FIG. 5.21. Domestic uranium exploration data for Greece. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

5.11.4. Uranium resources

5.11.4.1. Identified resources

The 1997 Red Book [11.14] includes estimates for reasonably assured resources, inferred resources and prognosticated resources (Table 5.4). Speculative resources have not been reported.

Identified resources (reasonably assured and inferred resources) are located in the uraniferous region of northern Greece (Paranesti region), which is part of the Rhodope Mountains that straddle the border with Bulgaria, and in the Serres lignites. The deposits of the Paranesti area (Archontovouni, Spilia) are of the disseminated vein type in granitic basement rocks. The Serres lignites are hosted by Tertiary sandstone and carbonaceous silts. The uranium grades of the deposits vary in the range 0.03–1% U.

The UDEPO database lists the most significant deposits for Greece as Serres Basin, Archontovounis, Drimon.

TABLE 5.4. IDENTIFIED URANIUM RESOURCES (tU)
(As of 1997 [11.14])

Cost category	Reasonably assured resources	Inferred resources	Prognosticated resources
<US $40/kgU	1 000	n.a.[a]	n.a.
<US $80/kgU	1 000	6 000	6 000
<US $130/kgU	1 000	6 000	6 000

[a] n.a.: not available.

5.11.4.2. Undiscovered resources

Prognosticated resources have been estimated mainly as result of surface exploration and limited drilling. Occurrences in this category have been found in the Paranesti region (Andiro, Fteroto (disseminated type)), in the SE extension of the Rhodope Mountains (Alexandroupolis (pitchblende)) and on the islands of Xanthi and Lesbos, where mineralization has been found in Eocene volcanic rocks. Concentrations of uranium, thorium, rare earth elements and titanium are reported from Florina in the Greek province of Macedonia (Tertiary sandstone), the island of Ikaria (silcrete of Quaternary age) and near the Strymon Gulf (Quaternary clastic sediments).

5.11.5. Potential for new discoveries

Basement rocks and acidic magmatic intrusions in the Rhodope Massif still may have some potential for uranium. Results and knowledge gained in Bulgaria could lead to prospective targets being identified in this area. In addition, sedimentary basins containing favourable host rocks could be further explored. Granitic intrusions in the Hellenides (Alpine type) may have potential for mineralization in rocks younger than Palaeozoic. Lignite deposits may also have some limited potential. Whilst these areas are assigned limited potential, the overall potential for significant new discoveries is rated as low.

5.11.6. Comments

Greece has not produced any uranium. No reports are available for environmental activities in or around known uranium deposits.

References to Section 5.11

[11.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Greece, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed March 2008).

[11.2] HIGGINS, M.D., HIGGINS, R., A Geological Companion to Greece and the Aegean, Cornell University Press (1996) 240 pp.

[11.3] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Greece, IAEA, Vienna (1977) 9 pp.

[11.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[11.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[11.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[11.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[11.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[11.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[11.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[11.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[11.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[11.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[11.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[11.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

5.12. HUNGARY

5.12.1. Geography

Hungary is a landlocked country situated in central Europe (Fig. 5.22). The country is characterized in the eastern and central parts by lowlands and plains. The plain east of the Danube (Alföld) River is part of a large basin that extents into Serbia. It is crossed by the Tisza (Theiss) River, a major tributary of the Danube. The central part extends on both sides of the N–S running Danube. The river is important both as a waterway and for its fertile sediments. The area west of the Danube (Transdanubia) gradually rises to the mountains of the Bakony Forest (highest elevation 513 m). The largest lake in the country, Lake Balaton, is located SE of the Bakony Forest. The part north and NE of Budapest to the border with Slovakia is formed by mountains with elevations of up to 1 000 m (Matra). The Mecsek Mountains are located to the south. The climate is continental. Summers can be hot (>30°C) and winters cold (-25°C). The average annual rainfall of ~600 mm falls throughout the year. In terms of cultivation, about one half of the country is arable. Corn, wheat, barley, vegetables and fruits are grown. Wine production has a long tradition in the country. About 20% of the country is covered with forest. The 'puszta', a treeless plain in eastern Hungary, is renowned for livestock rearing [12.1].

5.12.2. Geology

The basement rocks are not exposed at the surface, but have been located as a result of deep drilling during hydrocarbon exploration. Along the foothills of the Bakony Forest, at the NW shore of Lake Balaton, a complex of Cambrian–Silurian phyllite and acidic lavas and pyroclastics was penetrated by drill holes. This is overlain by a sequence of Permian and Triassic sedimentary rocks. These sediments are composed of argillaceous schists (the Permian Verrucano) and red sandstone in the lower part, and by sandstone, dolomite, limestone and bituminous marls of Triassic age in the upper part. The Triassic sediments contain some uraniferous and fluorite-bearing beds (Fig 5.22).

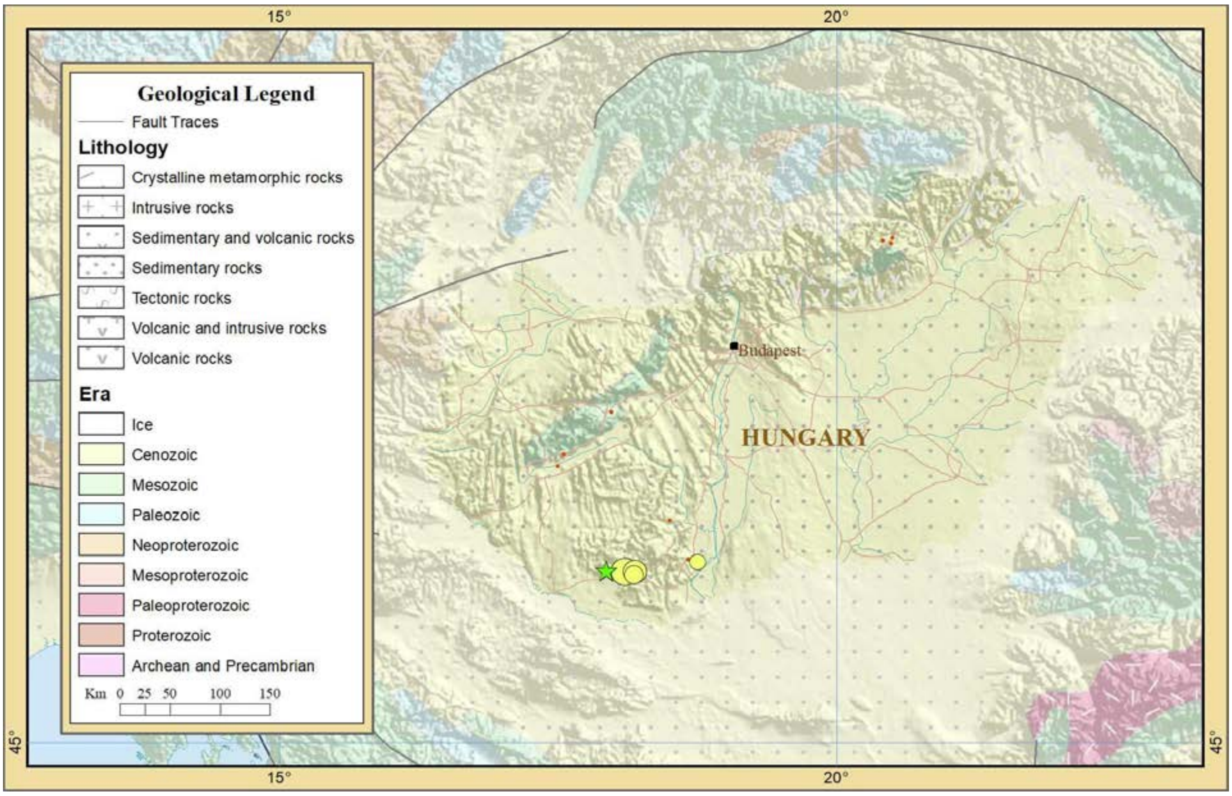


FIG. 5.22. Regional geological setting of Hungary showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Mecsek Mountains are composed of Permian marine and terrigenous sediments, Triassic and Jurassic limestones and intrusions of granites, diorites and a variety of other igneous rocks. The Permian has been studied for its uranium potential and a detailed description is given in Ref. [12.2]. The Lower Permian is mainly composed of sediments of marine origin, marls and clays. The Middle Permian consists of grey, green and red sandstones which were deposited under shallow marine, lacustrine and fluviatile environments. The Upper Permian comprises grey arkosic sandstone, siltstone and thin bedded argillites. The arkose is cemented by clay and carbonate. These strata contain the principal uranium deposit.

The geology of Mesozoic and Cenozoic period strata is complicated owing the influence of the Tethys Sea. Hungary is enclosed by the Alps, the Carpathian Mountains and the Dinaride Mountains. Nappes of these ranges are found in Hungary. The formation of two terrains, the Alcapa (Alpine–Carpathian–Pannonian) and the Tisza have their roots in the Mesozoic. However, they were emplaced in their current positions during the Late Tertiary. The complex geological developments are described in detail in Refs [12.3, 12.4].

5.12.3. Uranium exploration

5.12.3.1. Historical review

Uranium exploration began in 1952 with Soviet participation. Deposits of coal were tested for radioactivity. The outcomes led, in 1953, to a geophysical exploration campaign carried out (surface and airborne radiometry) over the western sector of the Mecsek Mountains. The Mecsek deposit, located near Pécs, was discovered in 1954 and follow-up survey included evaluation and development of the deposit. The first two shafts were sunk in 1955 and 1956. In 1956, the Hungarian–Soviet uranium joint venture was disbanded and the project became the exclusive accountability of the Hungarian State. Uranium production began in the same year.

No details are available for exploration expenditures. The only data are for 1988 and 1989, amounting to US $2.5 and US $1.2 million, respectively [12.5, 12.6].

5.12.3.2. Recent exploration activities

On 6 August 2008, Wildhorse Energy Ltd announced that it has signed an exclusive cooperation agreement with Mecsekérc, with the aim of restarting uranium mining at Pécs. The first stage of this cooperation was to complete a technical and economic review of the entire Mecsek Mountains area. This work was to include:

- Consolidation of the geological model of the entire mineralized area;
- Refinement of a conceptual underground mine design;
- Preliminary evaluation of the environmental impacts of any future mining scenarios;
- Completion of a socioeconomic study on the implication of future mining in the region.

On 13 October 2009, Wildhorse Energy announced a new cooperation agreement had been signed with Mecsek-Öko and Mecsekérc, State owned entities responsible for uranium mining, exploration and rehabilitation activities within Hungary, with the express aim of working towards restarting uranium mining in the Mecsek Hill uranium project area.
At about that time, Wildhorse Energy reported that its Mecsek deposit has a current Joint Ore Reserves Committee (JORC) inferred mineral resource of 17 000 tU at 0.07% U. The in situ inferred resource at <US $260/kgU is 11 500 tU at a cut-off of 0.034% U.

The Mecsek deposit extends into Mariakemend, which covers an area of 177 km², and is displaced from the historic deposit by a strike-slip fault. No exploration has been conducted at this location or in the NW part of the Mecsek Mountains.

The 2009 Red Book [12.7] reports exploration activities on the Bataszek deposit. The roll front type mineralization was discovered in 1989 and occurs in Pliocene sediments, currently covering an area of ~188 km². After airborne exploration, four holes were drilled in 2008. Additional drilling is planned.

The Dinnyeberki prospect was discovered in 1982 and occurs in organic-rich tuffaceous sediments of Miocene age. In 2008, one hole was drilled.

Exploration expenditures are reported as HUF 20.79 million ((Hungarian forints) equivalent to US $0.112 million) for 2007 and HUF 37.087 million (US $0.239 million) for 2008. Reported exploration is available only for two years, which amounts to US $2.6 million. Thus, insufficient information is available to estimate discovery costs [12.5, 12.6].

5.12.4. Uranium resources

Uranium resources reported in the Red Book are restricted to the Mecsek deposit and the adjacent area. The deposit is hosted in Upper Permian sandstones, which attain thickness of up to 600 m, overlying a very thick Permian siltstone and underlying a Lower Triassic sandstone. The sandstones were folded into the Permian–Triassic anticline of the Mecsek Mountains. The green-grey ore-bearing sandstone (Köragoszöllös sandstone) exists in the upper 200 m of the unit, is locally called the 'productive complex' and ranges in thickness from 15 m to 90 m. This unit occurs between grey and red sandstones. The ore minerals include uranium oxides and silicates associated with marcasite and pyrite. The ore-bearing suite is derived from the erosion of granitic rocks and enriched in bismuth, cobalt and nickel. Deposition took place along the banks of a meandering river with abundant flora (from fossil evidence), along with the formation of pools and flooded areas and changes from coarse-grained arkosic to fine-grained clay sediment [12.5, 12.8, 12.9].

The historical variation in identified uranium resources is shown in Fig. 5.23 and Fig. 5.24.

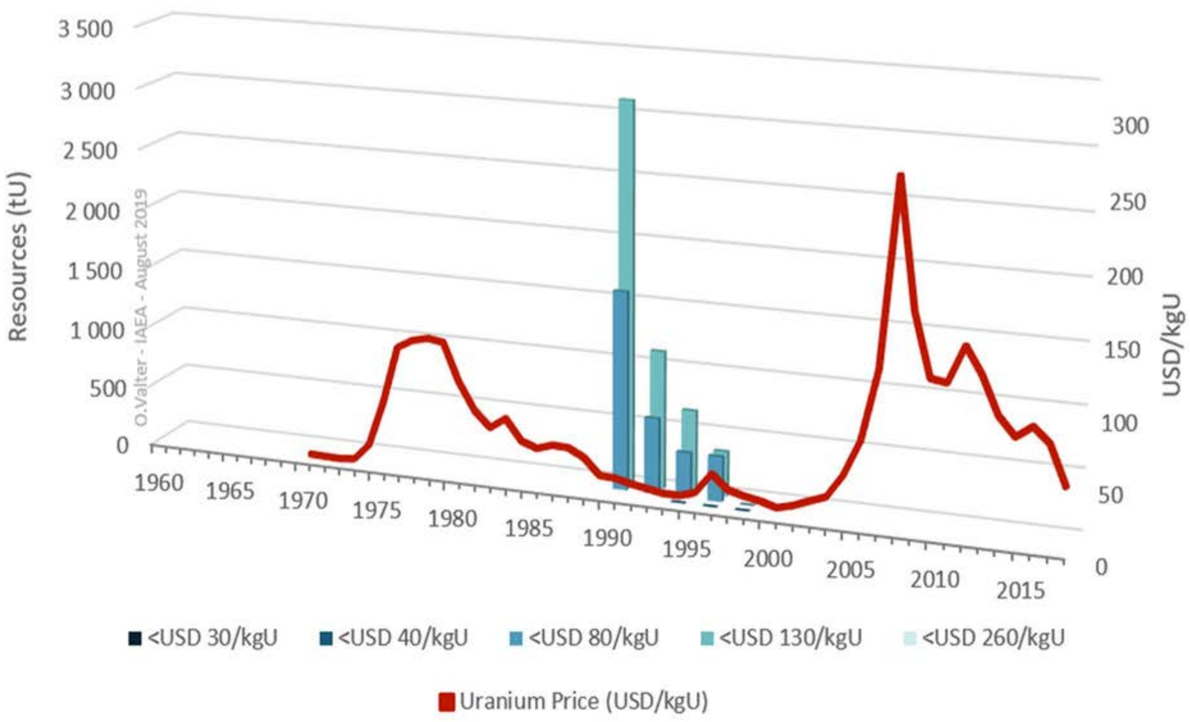


FIG. 5.23. Historical variation of recoverable reasonably assured resources within various cost categories in Hungary. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

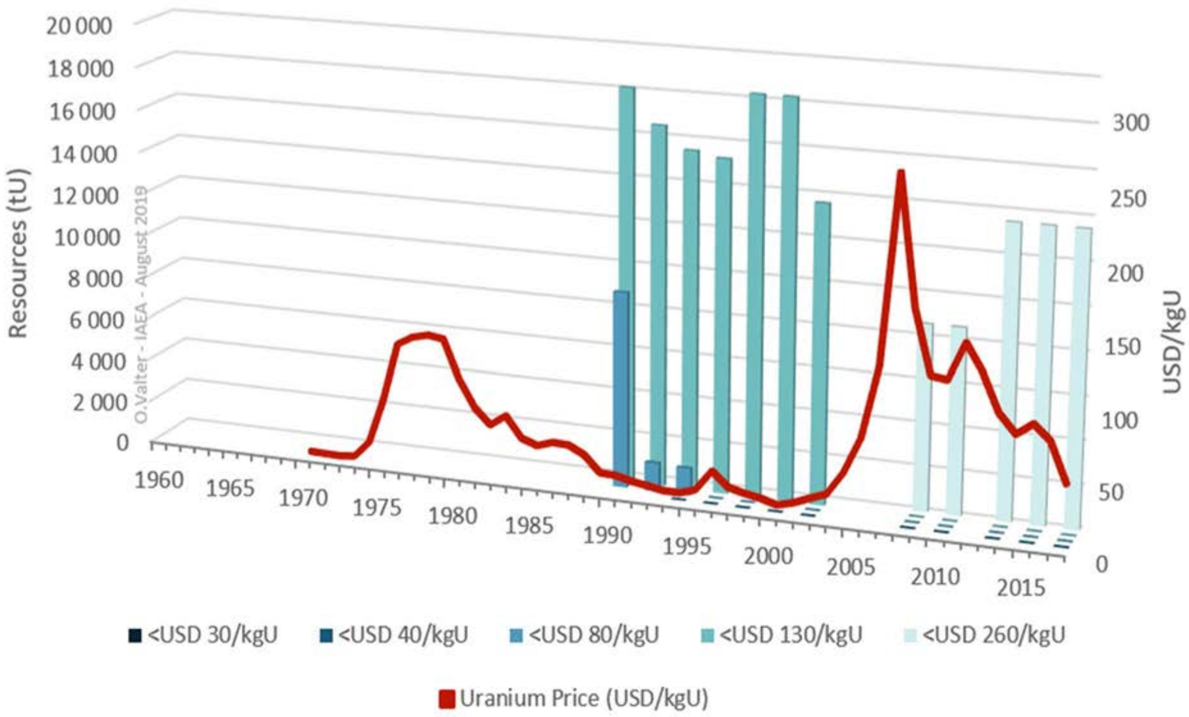


FIG. 5.24. Historical variation of recoverable inferred resources within various cost categories in Hungary. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

The UDEPO database lists the most significant deposits for Hungary as Mecsec Mine, Pecs, MML-E, Bataszek, Dinnyeberki.

5.12.4.1. Identified resources

According to Ref. [12.5], taking into account the JORC amenable resource estimate by Wildhorse Energy, a re-estimation and re-categorization of resources was reported in the 2009 Red Book [12.7]. The resource, classified as in situ inferred resources recoverable at <US $260/kgU, is 11 500 tU. The sandstone type deposits can be mined using conventional mining and unspecified production methods.

5.12.4.2. Undiscovered resources

Speculative resources are not estimated. Uranium resources of 18 399 tU were reported in the 2007 Red Book [12.5]. These are recoverable at costs of <US $130/kgU and are tributary to the area of the now dismantled Mecsek production centre.

Prior to the dismantling of the Mecsek mine and processing plant, these resources were classified as EAR-I recoverable at costs equal to or below US $130/kgU (as of 1 January 1999).

In 2009, prognosticated resources were re-estimated at 12 800 tU, recoverable at <US $260/kg U.

5.12.5. Potential for new discoveries

At present, the potential for new discoveries is judged to be limited. Potential areas have been explored and the deposit found in the Mecsek Mountains was the only economic deposit located. However, as the result of re-estimation and re-evaluation of previous exploration results, new exploration areas have been reported, as described in the section outlining recent exploration activities.

5.12.6. Uranium production

5.12.6.1. Historical review

The Mecsek underground mine was Hungary's sole uranium producer. Before 1 April 1992, it operated as the State owned Mecsek Ore Mining Company. The company started operation in 1956, producing ore from 100–800 m depth until it finally closed in 1997. Whilst still in operation, the company produced annually between 500 000 and 600 000 t ore at an average recovery of 50–60%. The Mecsek mine consisted of five sections with the following history:

- Section I: operating in 1956–1971;
- Section II: operating in 1956–1988;
- Section III: operating in 1961–1993;
- Section IV: operating in 1971–1997;
- Section V: operating in 1988–1997.

The processing plant of the company had a daily capacity of 1300–2000 t ore and it employed radiometric sorting, agitated acid leach (and alkaline heap leaching) with ion exchange recovery. The supposed annual production capacity of the plant was ~700 tU. The processing plant came into operation in 1963. Before that, raw ore was shipped to the former Soviet Union. A total of 1.2 million t of ore was exported to the Sillimae metallurgy plant in Estonia. After 1963, concentrates of uranium were exported to the former Soviet Union. The mine and mill ceased to operate and were shut down at the end of 1997 due to shifts in the market situations during that time. The total production from the Mecsek site, including heap leaching, was ~21 000 tU [12.5].

It should be noted that official annual production figures are only available from 1988 onwards. The pre-1988 production total was given as 19 370 tU. This amount was used to estimate the annual production between 1956 and 1987 [12.6]. Figure 5.25 summarises historical production.
Of the total of 21 112 tU produced, ~97% (20 501 tU) was by underground mining, 525 tU was recovered by heap leaching and 86 tU recovered from mine water treatment since 1998. Some uranium reported as originating from underground mining prior to 2004 may have been recovered by heap and in place leaching. However, the amounts recovered have not been reported.

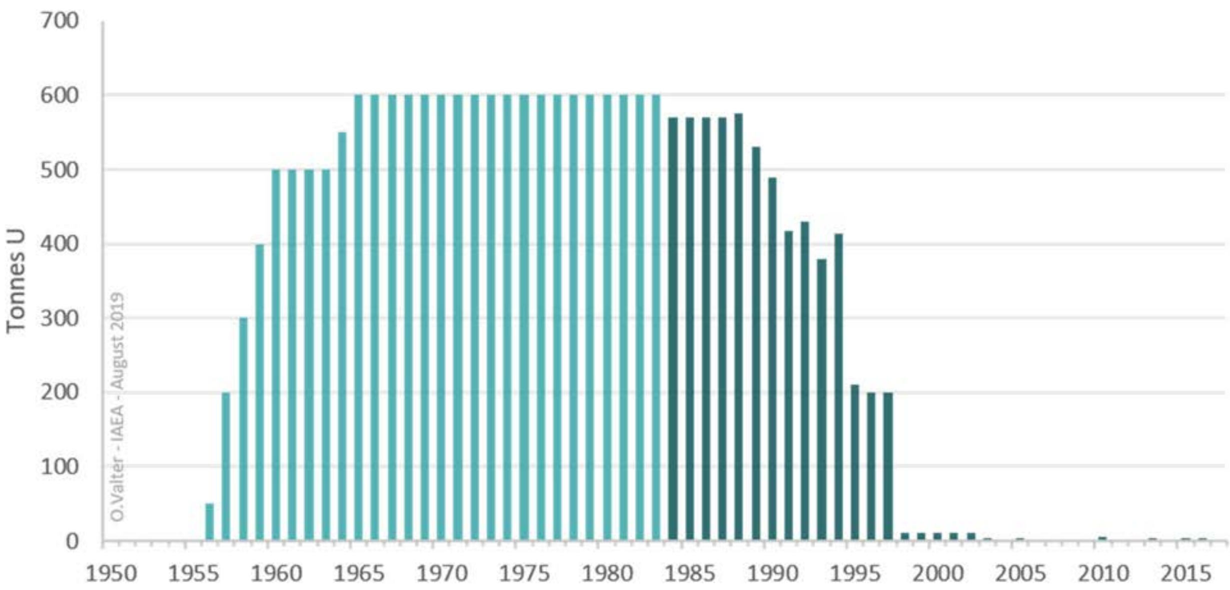


FIG. 5.25. Historical uranium production in Hungary (Data in light green are from the Red Book Retrospective, in dark green from Red Books) [12.5–12.7, 12.10].

5.12.6.2. *Status of production capability*

In 1998 and 1999, annual production of uranium was 7 and 4 tU, respectively, as a by-product of water treatment activities. All uranium produced is owned by the Government.

5.12.7. Environmental activities

After the closure of the mine in 1998, stabilization and remediation work started, based on a conceptual plan proposed by the company and approved by the authorities. The Government funded those activities and established the date of finishing the work as being the end of 2002. Owing to financial constraints, the deadline was revised to year end 2008. The activities included:

- Closure of underground mines;
- Remediation of contaminated water flows, heap leaching sites, waste rock piles and tailings ponds;
- Decommissioning of open pit sites and milling plant;
- Operation of a monitoring system;
- Treatment of contaminated water.

The most vital work involved covering the tailings ponds and addressing the vertical drainage, as well as the conditioning and placement of precipitation waste from water treatment.
The legitimate successor of the erstwhile Mecsek mine was likewise accountable for compensating former workers engaged in mining. This compensation takes the form of payments to those having work-related disease, income and pension supplements, repayments of approved costs and dependent expenses. Figure 5.26 summarizes the costs of environmental management amounting to HUF 23 318.766 million. (approximately USD $77.5 million).

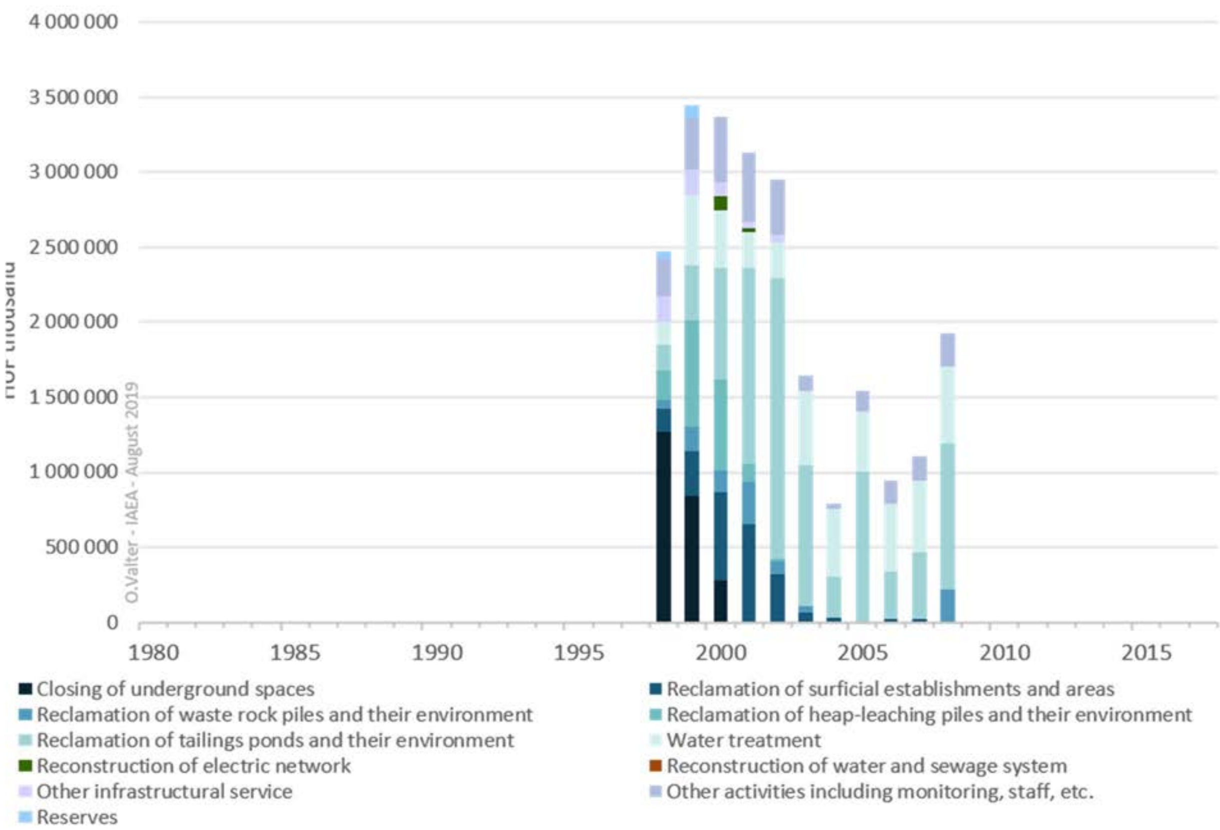


FIG 5.26. Environmental management expeditures for uranium mining in Hungary in Hungarian forint (HUF).

5.12.8. National policies relating to uranium

The 2009 Red Book [12.7] reports that since the cessation of uranium mining in 1997, there are no uranium related policies.

References to Section 5.12

[12.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Hungary, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed February 2008).

[12.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[12.3] TRUNKO, L., Ungarn: Sammlung Geologischer Führer, Gebr. Borntraeger, Stuttgart (2000) 158 pp.

[12.4] KAZMER, M., Synoptic Geology of Hungary, Eur. J. Mineral. **11** Stuttgart (1999) 1–6.

[12.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[12.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[12.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[12.8] BARTHEL, F.H., “Review of uranium occurrences in Permian sediments in Europe, with special reference to uranium mineralizations in Permian sandstone”, Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 277–288.

[12.9] BARTHEL, F.H., HAHN, L., “Sedimentary uranium occurrences in Eastern Europe with special reference to sandstone formations”, Geological Environments of Sandstone Type Uranium Deposits, IAEA-TECDOC-328, IAEA, Vienna (1985) 51–67.

[12.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[12.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999)110–111.

[12.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002) 230–233.

5.13. LATVIA

5.13.1. Geography

Latvia is located in north-eastern Europe on the eastern side of the Baltic Sea. Quaternary age rocks cover most of the country [13.1] (Fig. 5.27).

5.13.2. Comments

Uranium occurrences and/or deposits are not reported. Latvia has no nuclear power plant. The country is considering participating in a joint plan to construct a nuclear power station with Estonia, Lithuania and Poland. The plant would replace the Ignalina reactor after it is shut down. Ignalina is located in Lithuania [13.2].

The UDEPO database does not list any known deposits for Latvia.

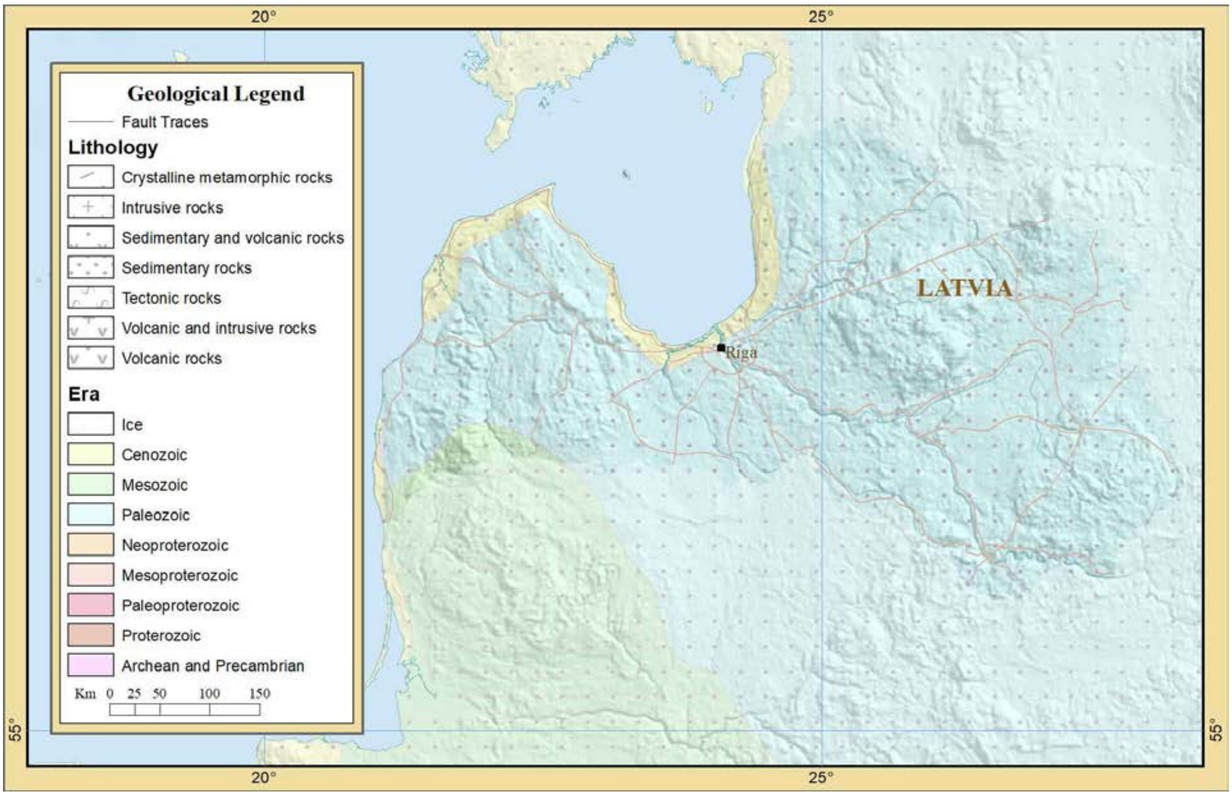


FIG. 5.27. Regional geological setting of Latvia. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

References to Section 5.13

[13.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Latvia, https://www.cia.gov/library/publications/the-world-factbook/index.html
(accessed January 2010).

[13.2] WORLD NUCLEAR ASSOCIATION, Emerging Nuclear Energy Countries (February 2008).

5.14. LITHUANIA

5.14.1. Geography

Lithuania is located in the north-eastern part of Europe on the eastern side of the Baltic Sea. The country lies at the edge of the North European Plain. The northern and south-eastern parts are characterized by low, hilly terrain. Between these areas, along the Baltic coast and inland, the country is flat. The topography is the result of the last glaciation, which left sand, gravel and lakes as remnants. The country has several small rivers. The climate is transitional, influenced by both the Baltic Sea and continental climate to the east. Generally, the climate at the coast is milder than inland. Arable land occurs comprises about one third of the country [14.1].

5.14.2. Geology

Precambrian rocks of the Baltic complex are not exposed at the surface (Fig. 5.28). Geological maps indicate that the bedrock consists of Devonian sediments, mainly limestone. Marine sedimentation continued during the Triassic, Jurassic and Cretaceous periods. Tertiary deposits are also found in several areas. Potential areas suited to the formation of uranium mineralization have not been identified [14.2].

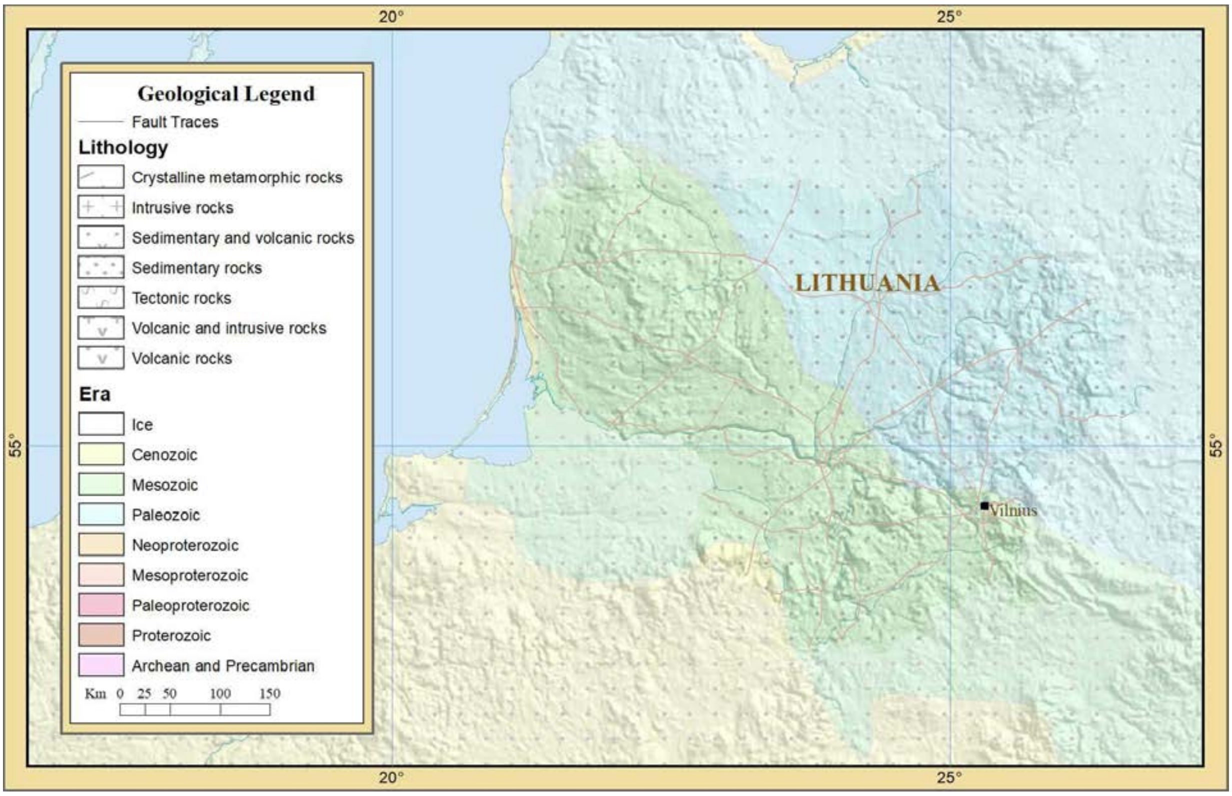


FIG. 5.28. Regional geological setting of Lithuania. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.14.3. Uranium resources

Past exploration programmes to identify uranium mineralization have been unsuccessful. Lithuania has neither uranium resources nor production and no exploration is currently being undertaken [14.3].

There is no potential for any discoveries on the basis of the known geology. No secondary sources of uranium are reported.

The UDEPO database does not list any known deposits for Lithuania.

References to Section 5.14

[14.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Lithuania, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[14.2] GASIUNIENE, V.E., "Lithuanian mineral resources and their usage: Today, future and problems", paper presented at 15th Mtg Assoc. Eur. Geol. Soc., Tallinn, 2007.

[14.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008) 252–253.

5.15. MONTENEGRO

5.15.1. Geography

Montenegro was formerly part of the former Yugoslavia and became independent in June 2006. Montenegro is a small country located in SE Europe, bordering the Adriatic Sea. Montenegro has land borders with Albania, Bosnia and Herzegovina and Serbia. It forms part of the mountainous region of the Balkan Peninsula at the southern end of rugged high limestone mountains (the Dinarides).

The terrain in Montenegro ranges from high mountains in the northern part of the country, through karst in the central and western parts, to a narrow coastal plain. The coastal plain disappears completely in the north, where Mount Lovćen and other mountain ranges plunge abruptly into the inlet of the Gulf of Kotor. The high mountains of Montenegro constitute some of the most rugged terrain in Europe. The peaks average more than 2 000 m in elevation, with the highest peak, Bobotov Kuk, reaching 2 523 m [15.1].

5.15.2. Geology

Over two thirds of the territory of Montenegro comprises the karst landscape of the south-eastern Dinarides (Fig. 5.29). The karst in Montenegro varies over the territory according to its distribution and its position in relation to the non-karstic terrain and the Adriatic Sea. The major tectonic units have a north-westerly trend. Karst development and distribution is detailed in Ref. [15.2].

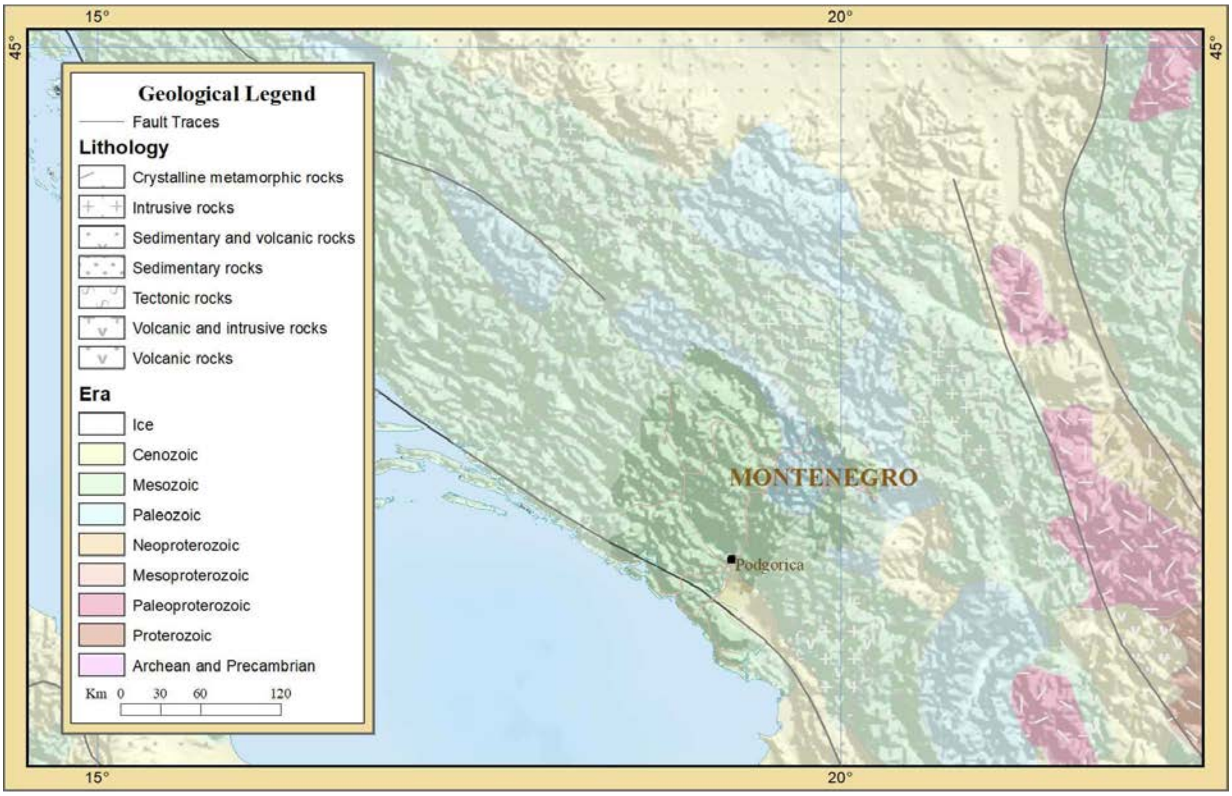


FIG. 5.29. Regional geological setting of Montenegro. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.15.3. Potentially favourable uranium-bearing areas

Uranium occurrences are not reported and the landscape, dominated by karst topography developed over rugged high limestone mountains and plateaux, is not favourable for the development of uranium deposits. This strongly suggests that the potential for uranium resources is very low to non-existent.

5.15.4. Comments

There is no installed nuclear generation capacity in Montenegro. There is no history of any uranium related activities.

The UDEPO database does not list any known deposits for Montenegro.

References to Section 5.15

[15.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Montenegro, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2009).

[15.2] RADULOVIC, V., RADULOVIC, M., "Karst of Montenegro", 100 Godina Hidrogeologije u Jugoslaviji (100 Years of Hydrogeology in Yugoslavia), Belgrade (1997) 147–185 (in Serbian).

5.16. NORTH MACEDONIA

5.16.1. Geography

North Macedonia is a landlocked country in south-eastern Europe (Fig. 5.30). It forms part of the Balkans and is a mainly mountainous area, often affected by seismicity. North Macedonia has some low-grade iron, as well as base and precious metal deposits. Industrial mineral deposits are also reported [16.1, 16.2].

5.16.2. Geology

Little useful historical information on the country's geology has been found. However, reports in the literature indicate some uranium exploration was undertaken when the country formed part of the former Yugoslavia [16.3, 16.4].

The basement underlying the Cenozoic basins has had a complex geological history and consists of a wide variety of rock types. The rocks consist of NW trending terrain comprising a mixture of very low to high grade metamorphics, including both Palaeozoic and Mesozoic rocks, as well as Proterozoic. The rocks vary from sedimentary to igneous in origin. Some portions of these tectonic units are deformed subduction related units. The pre-Cenozoic basement comprises five major tectonic units which are, from east to west: (i) the Serbo-Macedonian Massif; (ii) the Vardar Zone; (iii) the Pelagonian Massif; (iv) the Western Macedonian Zone; and (v) the Chukali-Krasta Zone.

The Serbo-Macedonian Massif is comprised of Early Palaeozoic phyllite and schist and Riphean/Cambrian mafic volcanic and plutonic rocks, all intruded by large bodies of Palaeozoic granite. Exception for the north plunging nose of the Pelagonian anticlinorium, the prevalent structures in the pre-Cenozoic basement rocks are NW trending faults, foliation and folds that form a significant crustal anisotropy that controlled many of the basin bounding faults in the Cenozoic period.

The Vardar Zone signifies a Triassic–Early Cretaceous ocean that had a protracted and complex subduction history. It started to close in the Late Jurassic and the earliest deformation is of Late Jurassic–Early Cretaceous age. The upper part of the Vardar Mesozoic sequence comprises Aptian to Turonian flysch, deformed in the Late Turonian–Early Senonian time (a sub-Hercynian phase in European literature), and unconformably overlain by Senonian and Maastrichtian fine-grained flysch with limestone and rare 'wild' flysch units in its upper part. The Cretaceous series exceed 4000 m in thickness. Rocks within the Vardar Zone were strongly deformed into narrow NNW trending belts of various rock types bounded by faults that developed in the Late Cretaceous–Palaeocene (the Laramide phase).

The Pelagonian Massif occupies the high-grade metamorphic core of a large NW trending and plunging anticlinorium that also incorporates the lower grade rocks of the Western Macedonian Zone on the western and northern flanks. The anticlinorium's core is comprised of schist, augen gneiss and amphibolite grade gneiss formed from Precambrian metasedimentary rocks, characterized by a thick section of marble in the upper part that partially borders the anticlinorium, and abundant granitic plutons.

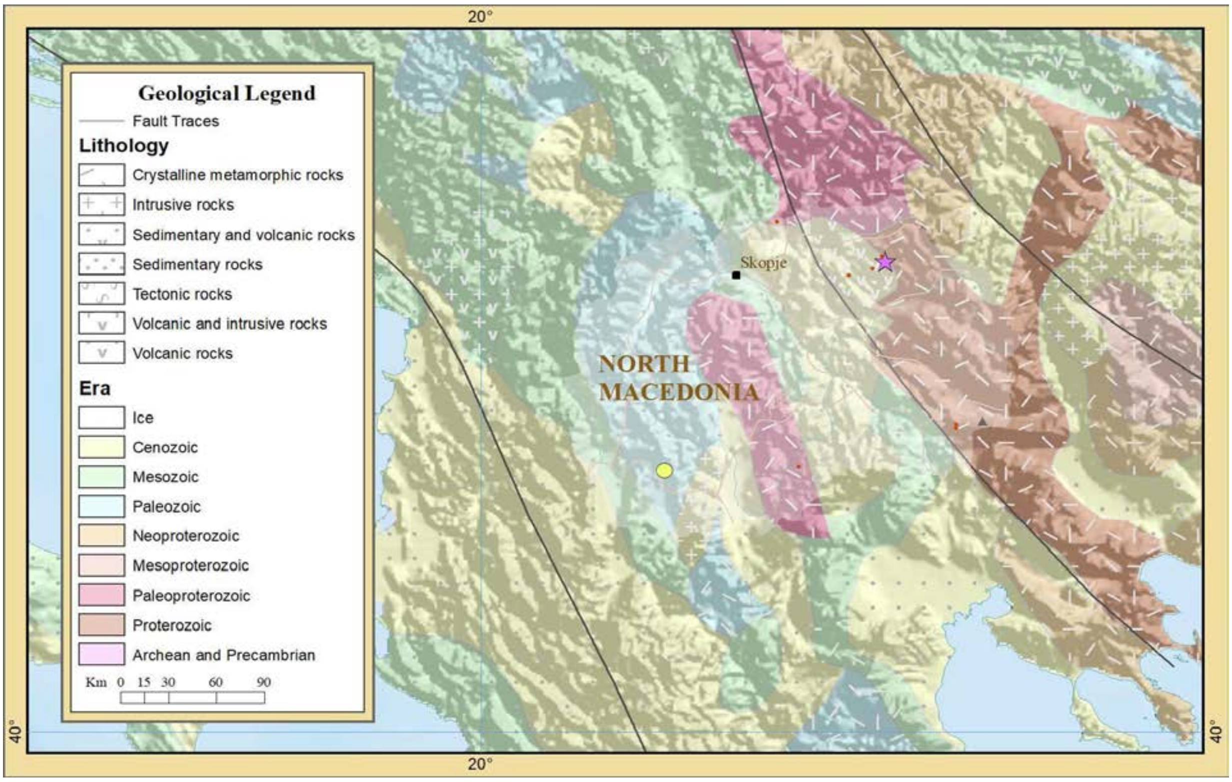


FIG. 5.30. Regional geological setting of North Macedonia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Western Macedonian Zone comprises low grade to localized medium grade metamorphosed Palaeozoic igneous and sedimentary rocks and Mesozoic, mostly Triassic with some Jurassic, sedimentary rocks. The Chukali-Krasta Zone comprises sheared, very low grade metamorphosed Late Cretaceous–Early Tertiary sedimentary rocks that were thrust eastwards below Mesozoic ophiolites and Mesozoic and older metamorphic rocks.

Cenozoic sedimentary basins cover nearly 50% of the surface area of the country (Fig. 5.31). Two main groups of sedimentary basins were formed in the Late Eocene–Recent period. They resulted from two important episodes of extensional deformation split by a rapid episode of shortening. The majority of the basins are associated with extensional faulting and some are grabens, whilst others are more complex. There is a variety of basin types. Many of the deeper parts of the basins are covered by Quaternary sediments and are poorly exposed. Reference [16.3] provides a detailed discussion of the sediments in all the Cenozoic basins. The basins include a variety of rock types, including fault placed limestone and magmatic rocks. The Tikves-Ovchepole basins in the central part of the country include volcanic rocks as well as a 3 500 m thick sequence of red, brown and yellow sandstones, siltstone, mudstone and conglomerate deposited in complex lacustrine, fluvial and marine environments.

In summary, during the Late Cretaceous–Palaeocene, oceanic crust in the Vardar zone was closed and the basement units in most of the country became amalgamated. Pre-Cenozoic basement tectonic units have a NNW trending structural grain, except in the north-central part of the country, where structures and foliations bend around the north plunging Pelagonian anticlinorium. Structures in the basement have had a very intense control on the orientations of Cenozoic faults and related basins.

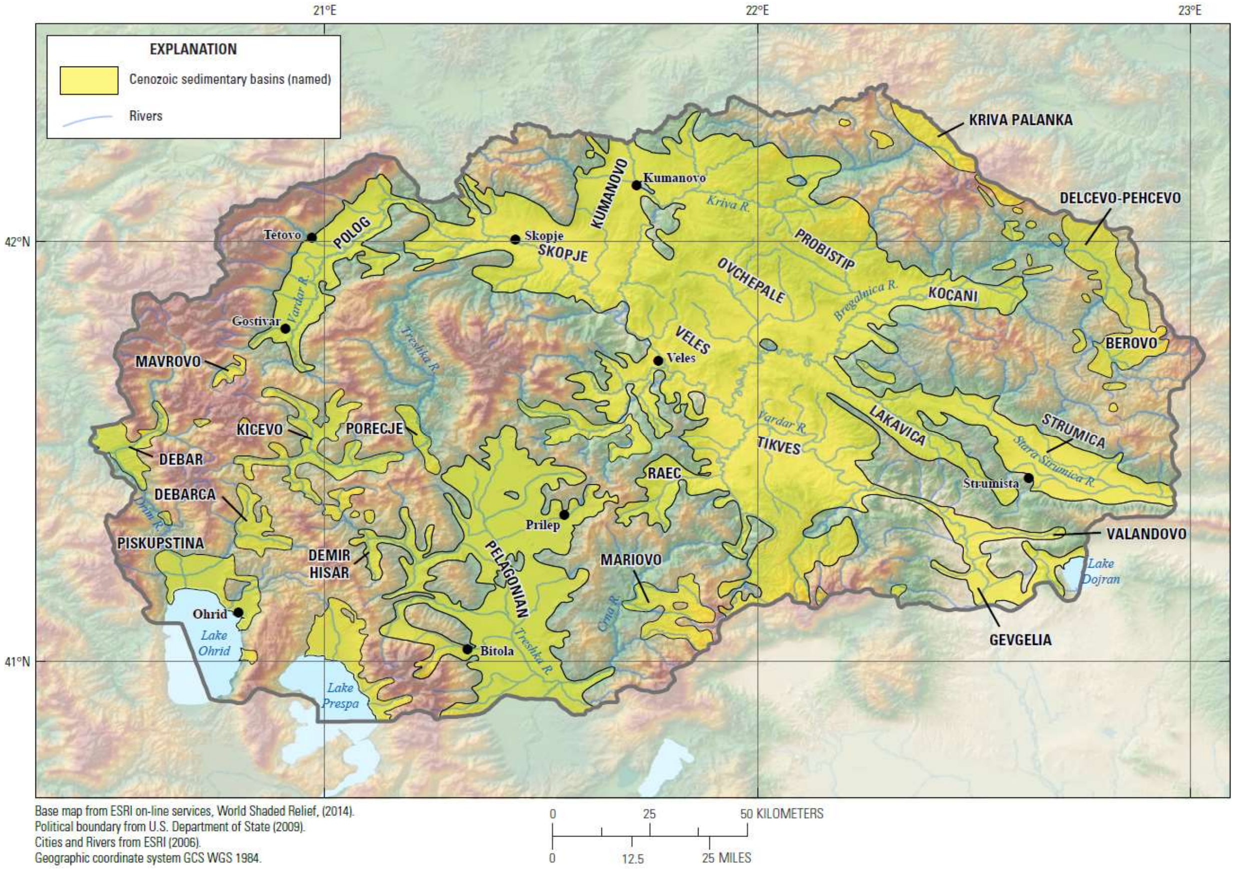


FIG. 5.31. Cenozoic sedimentary basins in North Macedonia [Adapted from 16.4].

5.16.3. Uranium occurrences and deposits

Uranium exploration was mainly reconnaissance, although investigations of known metallic deposits were also conducted. Airborne radiometric surveys, ground radiometric surveys and geochemical surveys were all carried out. A number of occurrences and mineralized sites have been detected, many of them in hydrothermal veins. Most are low grade (0.03–0.08% U) and of small size.

With the exception of the Zletovska Reka vein type deposit, all others are estimated to have resources totalling ~1000 tU. The Zletovska Reka deposit is located in the Kratovo-Zletovo Tertiary volcanic complex, ~75 km east of the capital Skopje, close to the Bulgarian border. Zletovska Reka has estimated resources of 550 tU proven and 450 tU indicated. The deposit is epithermal in nature, fault- controlled and polymetallic. The mineral succession started with deposition of copper sulphide, followed by sulphides of lead–zinc and finally by uranium oxide. It is believed that the zoned mineralization and differentiation resulted in enrichment of uranium during the latest stages of hydrothermal activity. Supergene processes have been observed up to a depth of ~60 m, followed by a zone of ‘cementation’ with sooty pitchblende, and beneath that, primary mineralization extending to a depth of 200–300 m [16.5].

Other vein type deposits include Bajlovce, Spancero, Preseka, Podares, Karatas Lozanica, Crni Kamen and Selce. In addition, in the south, towards the border with Greece, Tertiary clastic sediments at Sudoval and Stavica carry low grade mineralization (0.03–0.08% U), but these occurrences are of small size (several hundred tonnes of uranium).

The intensity of exploration work appears to be rather low and more detailed work would be required to confirm any economic potential. At present, the country is judged to have a low potential for uranium exploration. This may increase with improved understanding of the geology that has developed over the past few years [16.2, 16.5, 16.6]. The UDEPO database does not list any known deposits in Macedonia.

5.16.4. Comments

The country has no existing or future plans to develop nuclear power. It has no other nuclear related activities. The country has not reported to the Red Book. Prior to 1991, information for North Macedonia may have been reported when it was part of the former Yugoslavia.

References to Section 5.16

[16.1] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Yugoslavia, IAEA, Vienna (1977) 9 pp.

[16.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[16.3] DUMURDZANOV, N., SERAFIMOVSKI, T., BURCHFIEL, B.C., Evolution of the Neogene-Pleistocene basins of Macedonia, Geol. Soc. Am. Digital Map and Chart Series, http://gsamaps.gsajournals.org/gsamaps/toc.

[16.4] DUMURDZANOV, N., SERAFIMOVSKI, T., BURCHFIEL, B.C., Cenozoic tectonics of Macedonia and its relation to the South Balkan extensional regime, Geol. Soc. Am. 1 1 (2005) 1–22.

[16.5] RADUSINOVIC, D., "Zletovska Reka uranium deposit", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974).

[16.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

5.17. POLAND

5.17.1. Geography

The northern part of the Poland is characterized by lowlands, which are part of a large plain extending from the Netherlands through northern Germany and northern Poland, then continuing through the Baltic countries into Belarus and the Russian Federation. The lowlands are narrow in the west and expand towards the east to a width of over 200 km. The area was formed by glaciers during the Ice Age and is characterized by numerous lakes (Pomorskie lakes, SW of Gdansk, and Mazurskie lakes around Olsztyn). Remnants of the glaciation include the low hills in the Pomorskie and Mazurskie areas.

South of the lowlands, the Lesser Poland Uplands form a belt of gently sloping terrain at the base of the Sudety Mountains and the Carpathian Mountains. The Sudety Mountains (Sudetes) form Poland's SW border with the Czech Republic, reaching elevations of 1 603 m in the Sniezka of the Karkonosze Mountains, which are shared with the Czech Republic. In the south, the Beskide chain, part of the Carpathian Mountains, border Slovakia, reaching elevations of 2 000 m in the Tatra Mountains.

The country is drained by two major S–N flowing rivers, the Vistula and the Oder. The Vistula originates in the Tatra Mountains, forming a large basin in the eastern part of the country, and flows through Warsaw before entering the Baltic Sea near Gdansk. Its major eastern tributary, the Bug, partly defines Poland's eastern borders with Belarus and Ukraine. The Oder originates in the Czech Republic, flows through the Lower Silesian Basin and enters the Baltic Sea at Szczecin. The major eastern tributary to the Oder, the Warta, drains a large part of western Poland. The Oder and its tributary, the Lusitian Nisa, form Poland's western border with Germany.

The climate is influenced by oceanic air in the west creating quite moderate temperatures. In the east and SE, the climate becomes more continental, with warmer summers and colder winters. In the north, the climate is influenced both by cold air from Scandinavia as well as by the moderating influence of the Baltic Sea. About half of the country is devoted to agriculture; nearly 30% is wooded. There are several national parks in the mountains [17.1].

5.17.2. Geology

The northern and central parts are covered by sediments of the Quaternary glaciation, underlain by Mesozoic and Tertiary sediments (Fig. 5.32). Lying underneath the Mesozoic sediments in north-eastern Poland is the Precambrian Baltic Shield of the Eurasian Plate. These strata were located during drilling.

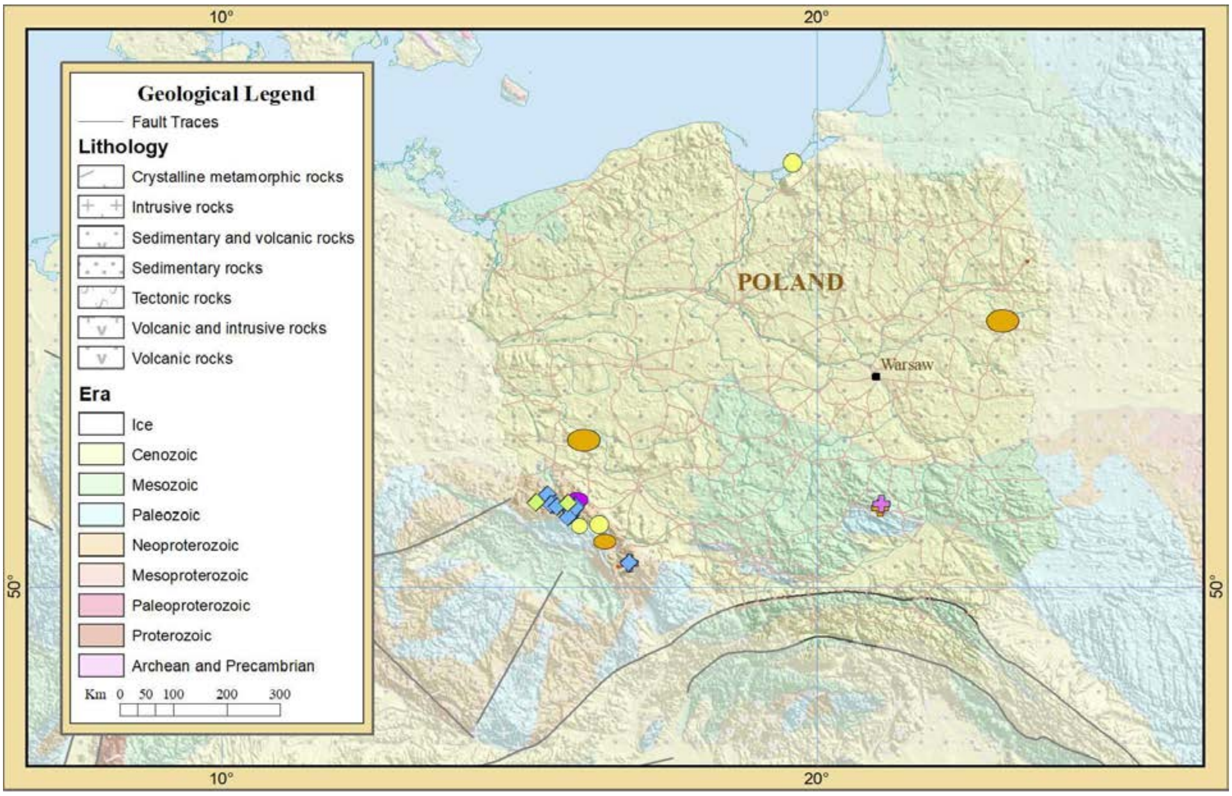


FIG. 5.32. Regional geological setting of Poland showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

In the SW, the Sudety Mountains are built by the tectonic processes accompanying the Caledonian and mainly Hercynian (Variscan) Orogenies and contain rocks of Lower Palaeozoic–Upper Palaeozoic age. The Sudety Mountains form the northern and north-western parts of the Bohemian Massif (detailed in the reports for the Czech Republic and Germany). Rocks of the Lower Palaeozoic are intruded by Hercynian (Variscan) granites which are mineralized.

Within the Sudety Mountains, the Inner Sudetic Depression or Lower Silesian Coal Basin is developed as an intramontane basin. NE of the mountain range, the Fore Sudetic Monocline is filled by erosional products from the hinterland. The Palaeozoic platform extends to the north and NE, forming the Pomeranian Trough.

In the Fore Sudetic Monocline and the North Sudetic Depression, copper-bearing sediments of Zechstein age (Permian Kupferschiefer) are mined for copper and other metals. Some copper horizons are uraniferous. The main mineral is thucolite, a hydrocarbon containing thorium and uranium. Uraninite also occurs [17.2].

The southern area is formed by the Alpine type topography of the Beskide/Carpathian Mountains. In the eastern part of the High Tatra Mountains, Lower Palaeozoic schists are intruded by granites of Hercynian age. Palaeozoic rocks are covered by Mesozoic strata, mainly Upper Triassic and Lower Cretaceous sediments. The sequence was uplifted during the Alpine Orogeny and shows complicated tectonic features. North of the Carpathian Mountains, an Alpine fore deep is developed via mountain building.

The oldest rocks containing some low-grade uranium mineralization are black shales of Lower Ordovician and Silurian age [17.2, 17.3]. These black shales were discovered in boreholes drilled in the Podlasie Depression of eastern Poland, as well as in Lower Silesia.

Other sedimentary concentrations of uranium have been found in the upper parts of the Carboniferous coal-bearing formation in the Upper Silesian Coal Basin.

In the Inner Sudetic Depression, uranium has been found associated with sandstones and clay–carbonate cemented conglomerates. The hard coal of this basin shows uranium enrichment in the form of veinlets which may be associated with acid volcanism of Upper Carboniferous age.

More importantly, perhaps, are the vein type uranium concentrations occurring in the Karkonosze granite of the Sudety Mountains and in the iron ore deposits in the Holy Cross Mountains. Detailed descriptions of these deposits are given in Refs [17.2–17.5].

5.17.3. Uranium exploration

5.17.3.1. Historical review

Prospecting for uranium was started in 1948 by the 'industrial plant' in Kowary/Lower Silesia, which exploited and processed uranium deposits. Since 1956, the Polish Geological Institute investigated the Carboniferous of the Upper Silesian Coal Basin, as well as the phosphorite formations and conducted research on borehole data from the Polish lowlands. Uranium mineralization was found in Lower Ordovician rocks of the Podlasie Depression (Rajsk deposit) and in Triassic rocks of the Peri-Baltic Syneclise and the Sudetes (Grzmiąca, Okrzeszyn, Wambierzyce). The metamorphics of Ladek and Snieznik Klodzki (Lower Silesia) carry minor occurrences of uranium mineralization, in addition to the Kopaliny-Kletno deposit from which ~20 tU was extracted.

Exploration expenditures have not been reported [17.4, 17.5].

5.17.3.2. Recent and ongoing uranium exploration and mine development activities

No concessions for uranium have been granted and currently there are no prospects for the discovery of economically viable uranium mineralization [17.4, 17.5].

5.17.4. Uranium resources

According to the 2009 Red Book, in situ uranium resources totalling 7 270 tU have been identified in the regions listed in Table 5.5. Recovery costs are not reported [17.4, 17.5].

Prognosticated resources are estimated to amount to more than 100 000 tU in the regions listed in Table 5.6. No recovery costs are available for these resources.

TABLE 5.5. URANIUM (IN SITU) RESOURCES (tU) [17.5]

Region	Resource (tU)	Uranium content (%U)
Podlasie Depression (Rajsk deposit): black shale	5 320	0.025
Peri-Baltic Syneclise: Triassic sediments		
Okrzeszyn (Sudetes): Veins (granite-related)	940	0.05–0.11
Grzmiaca (Sudetes): sandstone	790	0.05
Wambierzyce (Sudetes): black shale	220	0.0236

TABLE 5.6. PROGNOSTICATED RESOURCES [17.5]

Region	Prognosticated (tU)
Podlasie Depression (Rajsk deposit): black shale	88 850
Peri-Baltic Syneclise: Triassic sediments	10 000
Wambierzyce (Sudetes): black shale	2 000

The UDEPO database lists the most significant deposits for Poland as Lubin-Sieroszowice, Rajsk, Krynica Morska, Wambierzyce, Okrzeszyn, Grzmiaca, Radoniow, Kowary-Podgorze (Schmideberg).

5.17.5. Potential for new discoveries

The variety of vein type deposits shows that exploration was sufficiently successful to discover deposits of limited size. However, these deposits are now depleted and of no further economic interest. In 1980, the uranium potential of Poland was estimated to be moderate [17.6]. The extent of uranium mineralization in the Permian Kupferschiefer of Lower Silesia [17.2] is not reported. If economically justified, some uranium may be recoverable as a by-product of copper recovery.

Prognosticated resources reported for black shales in the Podlasie Depression (Rajsk deposit) are probably of Ordovician age and can be compared with similar deposits in northern Europe, including the challenges they pose, in terms of low grade, depth, environment, etc., to economic extraction. Some potential may be associated with the prognosticated resources of the Peri-Baltic Syneclise. According to Ref. [17.2], this potential is associated with sandstones of the Bunter Formation.

On the basis of existing information, the potential for new discoveries in Poland is considered to be very limited.

5.17.6. Uranium production

In 1948, a government operated plant in Kowary (Lower Silesia) began processing ore mined from local uranium deposits (Table 5.70).

TABLE 5.7. PRODUCTION DATA [17.4, 17.5]

Deposit name	Resources (tU)	Exploited (tU)
Wolnosc	94	94
Miedzianka	14.7	14.7
Podgorze	280	199
Rubezal	0.5	0.5
Mniszkow	4.5	4.5
Wiktoria	0.28	0.28
Majewo	0.96	0
Wolowa Gora	2.5	2.5
Radoniow	345	214
Wojcieszyce	14.4	12.3
Total	756.84	541.78

Exploitation of vein deposits in the Karkonosko-Izerski Block (Majewo, Miedzianka, Mniszkow, Podgorze, Radoniow, Rubezal, Wiktoria, Wojcieszyce, Wolnosc, Wolowa Gora) and of metamorphic deposits at Ladek and Snieznik Klodzki (where minor occurrences of uranium and the Kopaliny-Kletno deposit were found) continued up to 1967, by which time the deposits were nearly entirely exhausted [17.4, 17.5]. At that time, all uranium production was exported to the former Soviet Union. Estimated production recovered from underground mining in the Sudetes in 1948–1967 amounted to 650 tU.

Low grade ores were chemically treated started since 1969 at Kowary, the only uranium processing plant in Poland, and that continued until 1972. The process generated a substantial quantity of waste, which was disposed of in a tailings pond [17.4, 17.5].

5.17.7. Environmental activities and sociocultural issues

Uranium mining and processing activities were performed in 1948–1976 by now non-existent companies. It is stipulated in the Geological and Mining Law that the State Treasury is to assume liability for remediation of uranium production activities in the past. Therefore, it is the Government's responsibility to fund remediation, either from the district or the national Environmental Protection Fund.

Regional authorities (Voivodships) are responsible for remediation. Approval of remediation plans and supervision of their execution must be done by the local authorities. Environmental monitoring is generally the responsibility of the Inspectorates of the Environmental Protection of Voivodship. The President of the National Atomic Energy Agency is responsible for radiological monitoring.

Poland has, since 1996, participated in the European Union's PHARE Remediation Concepts for Uranium Mining Operations in Central and Eastern European Countries. The situation is characterized by several small-scale liabilities as a result of exploration of uranium, localized at various spots in the countryt.

A restricted number of mining and milling sites are thought to have had a severe impact. The most significant is a 1.3 ha tailings pond in Kowary, which was surrounded on three sides by a dam 300 m long with a maximum height of 12 m. The tailings pond has been filled with ~250 000 t of fine-grained material (averaging 30 ppm U). In the early 1970s, Wroclaw University of Technology (WUT) became the owner of both the site and the facilities of the previous uranium mining company. Later, a company owned by WUT used the existing chemical plant for several experimental processes on rare metals, galvanic processes and chemical production. Consequently, ~300 t of the remainders of rare metals processing and 5 000 m^3 of post-galvanic fluids, with up to 30 t of solids with high contents of nickel, aluminium, sodium and zinc sulphates, have been disposed of in the pond. The remediation was concentrated on the construction of the drainage systems, the building of the tailings pond cover and the final site reclamation. The WUT organised the remediation programme in 1997 and successfully implemented it under the PHARE programme until 2003 [17.4, 17.5].

References to Section 5.17

[17.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Poland, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[17.2] BANAS, M., MOCHNACKA, K., "Genetic types of uranium mineralization in Poland and their metallogenic relationships", Metallogenesis of Uranium Deposits (Proc. Tech. Mtg Vienna, 1987), IAEA, Vienna (1989) 187– 200.

[17.3] BARTHEL, F.H., HAHN, L., "Sedimentary uranium occurrences in Eastern Europe with special reference to sandstone formations", Geological Environments of Sandstone Type Uranium Deposits, IAEA-TECDOC-328, IAEA, Vienna (1985) 51–67.

[17.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[17.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[17.6] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

5.18. REPUBLIC OF MOLDOVA

5.18.1. Geography

The Republic of Moldova shares borders with Ukraine to the NE and south, and to the west with Romania. The surface geology mainly consists of Quaternary sediments, whilst some Tertiary sediments are also present (Fig. 5.32). Proterozoic rocks of the Moldovan Platform can be found in river valleys [18.1].

5.18.2. Uranium resources

Uranium occurrences and/or deposits or related activities are not reported. On the basis of the rock types present, there is no potential for any discovery of uranium resources. The UDEPO database does not list any known deposits for the Republic of Moldova.

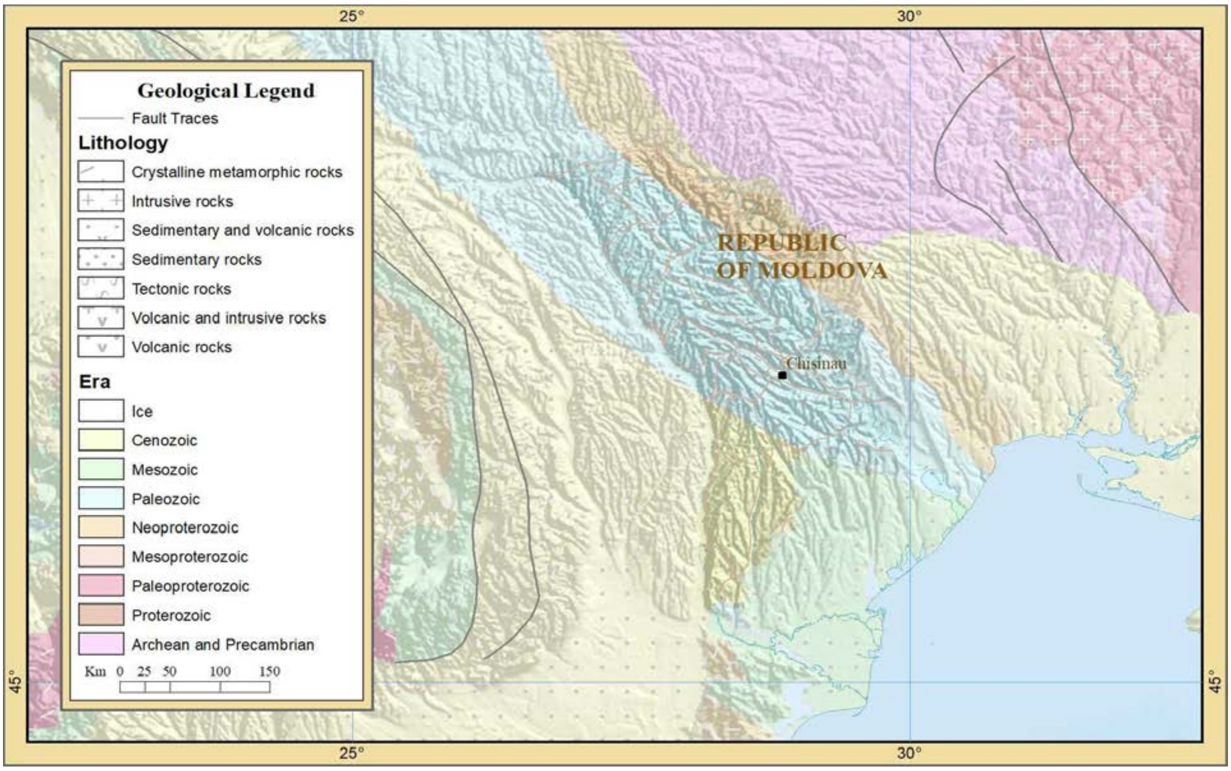


FIG. 5.32. Regional geological setting of Republic of Moldova. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

References to Section 5.18

[18.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Moldova, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

5.19. ROMANIA

5.19.1. Geography

Located on the Balkan Peninsula, Romania has borders with Ukraine, the Republic of Moldova, Bulgaria, Serbia and Hungary. To the east, it borders the Black Sea. The Danube River forms the border with Bulgaria and part of the border with Serbia.

The territory is about one third each covered by the Carpathian Mountains, hilly terrain and lowlands. The Carpathian Mountains are divided into the East and South Carpathians. The highest elevations, above 2 500 m, are to be found in the South Carpathians; the East Carpathians attaining elevations of 2 300 m. Typical topographic features of the Carpathian Mountains are the depressions and valleys formed by ancient river channels.

North-west of the Carpathian Mountains are the undulating plains and lowlands of the Transylvanian Plateau. Transylvania is an important agricultural region. In the western part, the Pannonian Plain extends from Hungary into Romania.

The south features the rolling terrain of the Getic Tableland, to the SE and the east lie the Moldavian and Dobruja Tablelands, and in between the plain of the River Danube. Major tributary rivers flow into the River Danube, which is not only an important waterway, but is also used for hydroelectricity generation, such as at the so-called ‘Iron Gate’, one of the largest hydroelectric power stations in Europe.

The climate is continental but receives temperate influence when Atlantic air passes over Europe. The winter can be severe (below -20°C) whereas the summer temperature can be exceed 30°C. The differences vary considerably, depending on altitude and location.

Agriculture plays an important economic role. Grain, vegetables, fruits, sunflowers and grapes are grown. In recent times, both agriculture and industry have been undergoing progressive modernization. Crude oil and natural gas are important natural resources. The textile industry is also important [19.1].

5.19.2. Geology

A characteristic feature of the country is its complex geology (Fig. 5.33). The geological history of surface exposure dates from the Mesozoic. Rocks of the Precambrian and Palaeozoic periods are covered by younger sediments. In parts of the Apuseni Mountains, nappes of pre-Mesozoic metamorphics are exposed by thrusting. In the Bihor Mountains, Precambrian metamorphics crop out along with Mesozoic sediments, Precambrian intrusives and Mesozoic volcanics. Permian continental sedimentary basins are developed in the Apuseni Mountains.

Nappes are typical are typical features of the geological evolution. Alpine type mountain building processes evident in the Carpathians Mountains started during the early Mesozoic, continuing into the Tertiary and Recent periods. Evidence of the Alpine Orogeny is observed across the territory. The foreland and depressions of the mountains are filled by sediments, often of flysch character. Tertiary and Recent volcanism is typical for Romania. Details of the geological evolution of Romania are described in Ref. [19.2].

Romania has a number of small- to medium-sized mineral deposits, including coal (hard coal and lignite) and polymetallic deposits (including epithermal gold–silver deposits and porphyry copper deposits) [19.3]. Gold, silver and copper have been mined since ancient times. The country also has large resources of rock salt. Numerous quarries are operated for construction materials and dimension stone. Deposits of crude oil and natural gas are well known. Uranium is found in different geological environments. In the Apuseni Mountains, deposits occur in Permian sediments [19.4] in grey to greenish coloured sandstone and conglomerate and are controlled by a change from coarse- to fine-grained sedimentation [19.5, 19.6]. In addition, uranium mineralization has been recorded in association with the polymetallic vein (copper, lead, zinc, molybdenum, bismuth, cobalt, nickel) deposits of the Apuseni Mountains [19.2–19.4, 19.7].

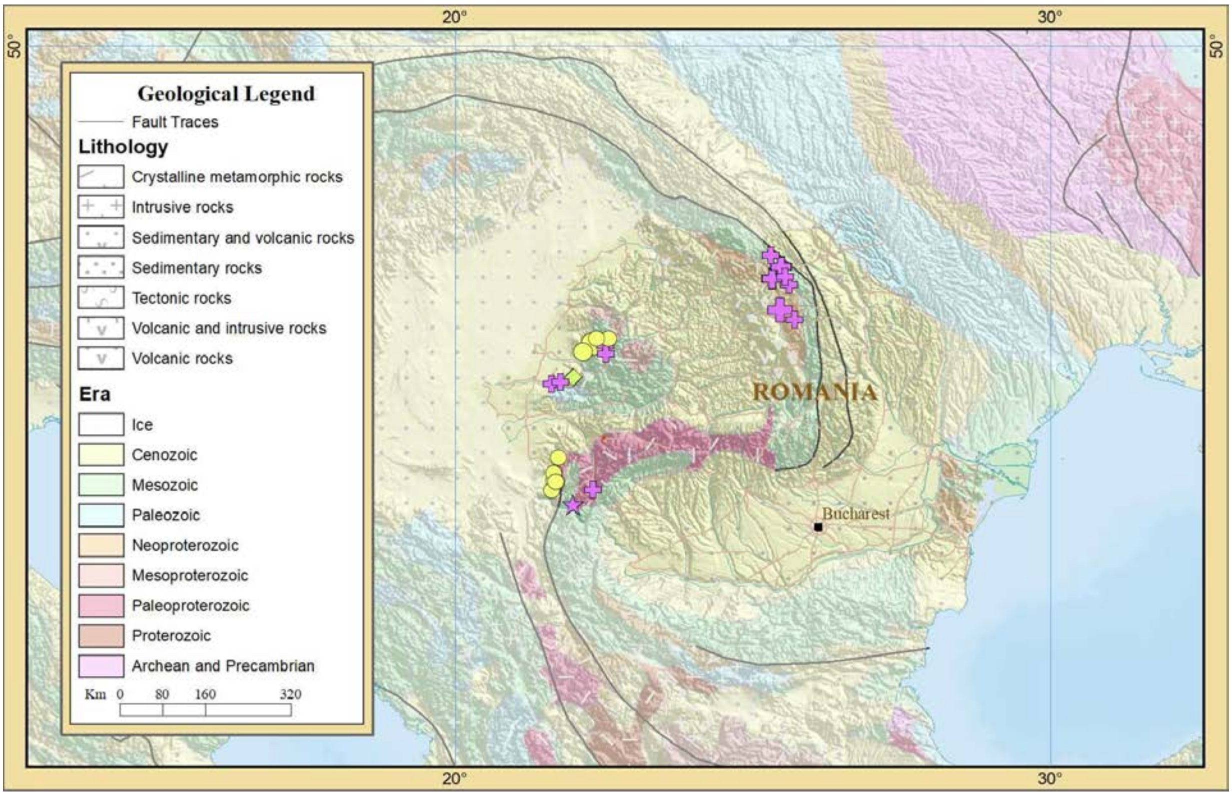


FIG. 5.33. Regional geological setting of Romania showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.19.3. Uranium exploration

5.19.3.1. Historical review

Exploration for uranium was started in 1950 by the Romanian–Soviet company SOVROMCUARTIT. In 1951, high grade mineralization in Permian sediments was found in the Apuseni Mountains, which was the most favourable target. Uranium was found in veins in metamorphic rocks in association with cobalt, nickel, copper, lead and zinc, and in stratiform deposits in close association with meta-rhyolites in which uranium occurs with molybdenum. Low grade copper deposits in tabular sandstones also carry uranium [19.4, 19.8].

A second uranium district was discovered in the Banat Mountains in sandstone of Permian age, in which uranium is associated with bituminous material (anthraxolite) [19.4, 19.7]. The mines at Baita Bihor, in the Apuseni Mountains, and at Ciudanovita, in the Banat Mountains, started production in 1952. The mine at Avram Iancu started production in 1962. During 1961 and 1962, exploration was carried out in the East Carpathian Mountains, where uranium occurred as pitchblende in veins in metamorphic rocks. Mining started in 1983.

Exploration expenditures in the early period have not been released. However, it can be assumed that they might have been substantial, perhaps similar to expenditures in other former Eastern Bloc countries. Official figures on expenditures have only been made available for 1994–2000 (Table 5.8) [19.8].

TABLE 5.8. URANIUM EXPLORATION EXPENDITURES (US$ million) [19.8]

Year	1994	1995	1996	1997	1997	1999	2000	Total for 1994–2000
Expenditures	2.998	2.448	1.776	1.198	0.934	0.549	0.157	10.060

5.19.3.2. *Exploration drilling*

Figures are available for only three years (1998–2000), and these show a decrease from 3 521 m in 1998 to 1 390 m in 1999 and then to only 70 m in 2000 [19.8]. Development drilling for this three-year period was: 5 126 m (1998), 5912 m (1 999) and 3 179 m (2000).

5.19.3.3. *Recent exploration activities*

Exploration after 2000 is not reported. Exploration data are not sufficient to calculate discovery costs.

5.19.4. Uranium resources

The latest resource figures were given for the 2001 Red Book [19.8]. The UDEPO database lists the most significant deposits for Romania as Baita Bihor, Tulghes-Grinties, Crucea, Botusana, Ranusa, Dobrei South, Natra East and West, Dobrei North, Mehadia, Dobrei East.

5.19.4.1. *Identified resources*

Figures of 4 547 tU at <US $130/kgU for reasonably assured resources and 4 686 tU for EAR-I (inferred resources) give a total of 9 233 tU for identified resources. In the 2007 Red Book [19.9], identified resources are given as 6 700 tU. The difference of 2 533 tU between both estimates cannot be explained by production only, which amounted to an estimated 535 tU in 2001–2007. Resource estimates in the identified categories in cost ranges of <US $40/kgU and <US $80/kgU are not officially reported. Historical trends in identified resources are shown in Fig. 5.34 and Fig. 5.35.

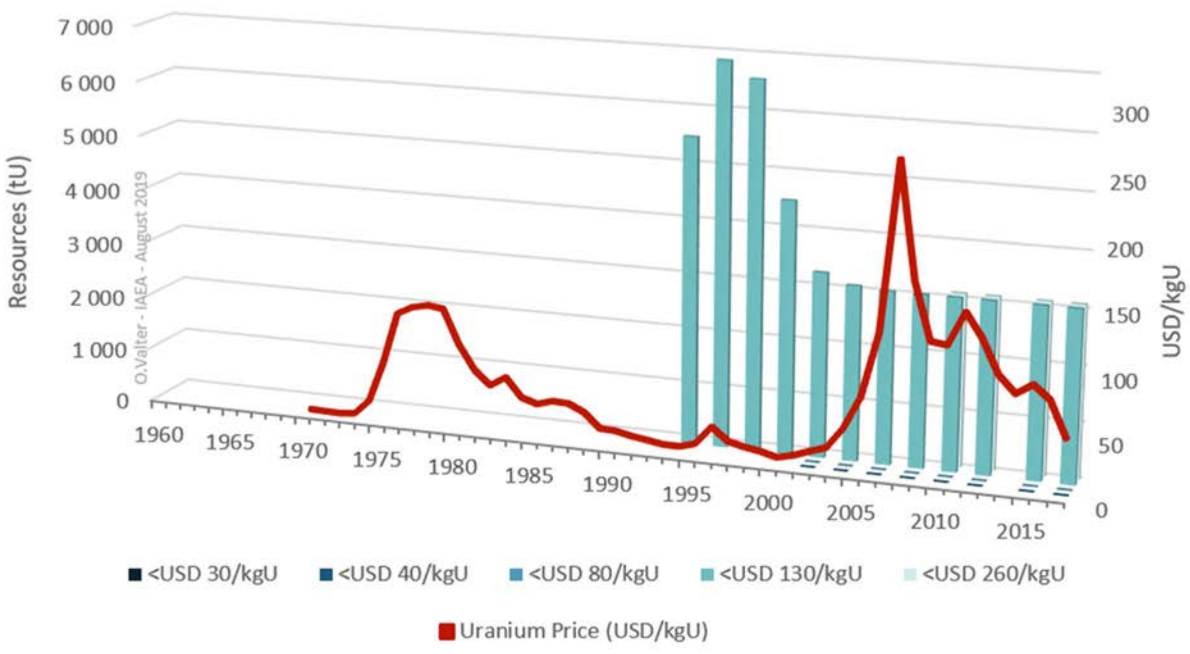


FIG. 5.34. Historical variation of recoverable reasonably assured resources within various cost categories in Romania. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

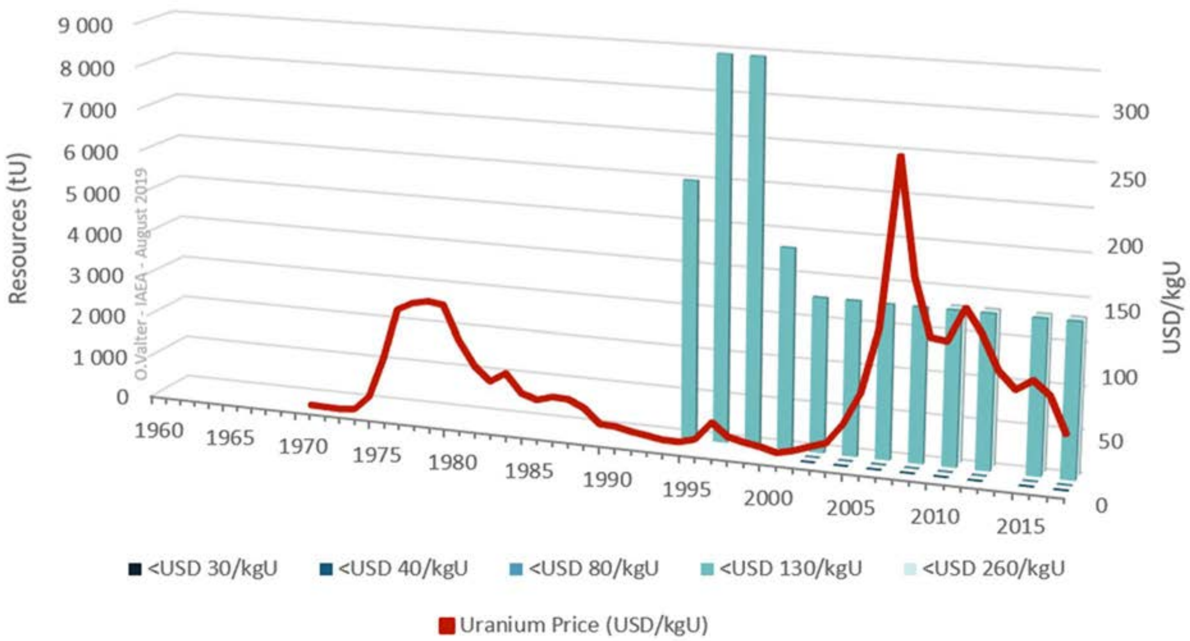


FIG. 5.35. Historical variation of recoverable inferred resources within various cost categories in Romania. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

5.19.4.2. Undiscovered resources

In the 2001 Red Book [19.8], estimates for EAR-II (now prognosticated resources) are given as 3 344 tU and those for speculative resources in the cost range <US $130/kgU as 3 000 tU. There are no estimates for other cost ranges.

The following figures are given in the 2007 Red Book [19.9]:

— Prognosticated resources at <US $130/kg U: 3 000 tU;
— Speculative resources at <US $130/kg U: 3 000 tU.

5.19.4.3. Unconventional resources

No figures are reported. Romanian delegates to IAEA technical meetings have reported research being conducted on uranium recovery from phosphate. Phosphate deposits are not reported for Romania. It can therefore be assumed that any such research on uranium extraction was conducted on imported phosphate.

5.19.5. Potential for new discoveries

During the past 50 years of exploration and mining, all the easily located deposits have been discovered. It is not known whether promising areas in intrusive bodies have been investigated in detail. If not, then possibly there exists some potential (rated as low) for uranium mineralization at depth.

5.19.6. Uranium production

The first production of uranium was recorded in 1952 at the Baita Bihor open pit mine and in 1953 at the Ciudanovita underground mine, both sandstone-hosted deposits. Until 1962, uranium ore was shipped to the former Soviet Union. High grade ore was shipped to the Sillamäe mill in Estonia, as was uranium ore from other former Eastern Bloc countries (see Estonia).

From 1962 onwards, shipments to the former Soviet Union were stopped and the mined ore was stockpiled at the mine site until 1978, when the mill at Feldioara commenced operations. The mill is located north of the city of Brasov.

The Feldioara mill was modified in 1985 to produce uranium oxide, which is used as fuel in Romania's CANDU type reactors.

Romania operates two CANDU type reactors, which use non-enriched uranium. Production from 1978 to the present-day is used for domestic purposes only. The Feldioara mill has a capacity of 300 tU/year. Ore is provided from one mine, Botusana, a vein deposit in the East Carpathian Mountains. Other mines have been closed due to depletion or for other economic reasons. The mine at Tulghes was developed in cooperation with the IAEA under the project Restructuring of the Uranium Industry, which involved introducing modern technology amongst other things. This mine is now closed. Romania produced 75 t U in 2015 before closure of the last uranium mine Crucea-Botusana. Total historical production recorded by the Red Book is 18 711 t U [19.13]. Future mine projects are not currently envisaged [19.8, 19.9, 19.10]. Figure 5.34 illustrates historical uranium production for the period 1952–2017.

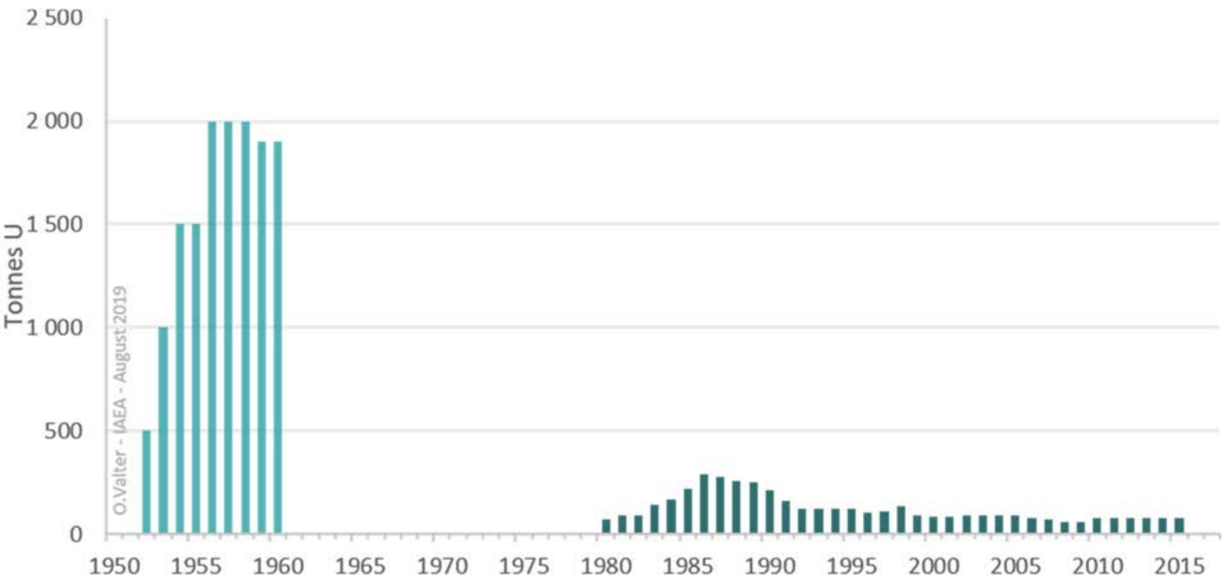


FIG. 5.36. Historical uranium production in Romania (Data in light green are from the Red Book Retrospective, in dark green from Red Books) [19.9, 19.11, 19.12]. Note: Most of the production figures are estimates made by the IAEA and OECD Secretariats.

5.19.7. Environmental activities

Environmental protection programmes are focused on control, treatment and monitoring of mine water effluents and effluents from mill tailings impoundments, monitoring of sediments and vegetation, rehabilitation of environments affected by old uranium mining and milling activities, and improvement of the long-term stability of tailings ponds and waste dumps, including remediation. The Government has assumed responsibility and in connection with its integration into the European Union, the European Union's PHARE programme is actively involved in the Remediation Concept for the Uranium Mining Operations in CEEC. Detailed descriptions of governmental policies and regulations, along with laws regulating safe and ecologically sound processes of environmental remediation, are given in Refs [19.8, 19.10, 19.14].

5.19.8. Employment in the uranium industry

In Ref. [19.8], the following employment figures were given for existing production centres: 3 300 (1998), 2 800 (1999), 2 150 (2000) and 2 070 (2001 estimated). Recent official figures are not available. In Ref. [19.9], estimated employment was 2 000 persons for each year from 2001 through 2007.

5.19.9. National policies related to uranium

The Romanian Law of Mines restricts activities related to uranium exploration, mining, production and marketing to Government agencies.

References to Section 5.19

[19.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Romania, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[19.2] BURCHFIEL, B.C., BLEAHU, M., BORCOS, M., PATRULIUS, D., SANDULESCU, M., Geology of Romania, Geology **2** 8 (1974) 392.

[19.3] FODOR, D., Mining industry of Romania, Erzmetall **56** 10 (2003) 601–606.

[19.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992) 181–182.

[19.5] BARTHEL, F.H., HAHN, L., “Sedimentary uranium occurrences in Eastern Europe with special reference to sandstone formations”, Geological Environments of Sandstone Type Uranium Deposits, IAEA-TECDOC-328, IAEA, Vienna (1985) 51–67.

[19.6] BARTHEL, F.H., “Review of uranium occurrences in Permian sediments in Europe, with special reference to uranium mineralizations in Permian sandstone”, Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 217–227.

[19.7] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[19.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002) 236–243.

[19.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[19.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[19.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[19.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[19.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[19.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999) 123–124.

[19.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002) 245–248.

5.20. RUSSIAN FEDERATION

5.20.1. Geography

The Russian Federation stretches ~8000 km from Eastern Europe in the west through the Ural Mountains (Urals) across northern Asia (Siberia) to the Pacific Ocean in the east. The N–S trending Urals form the border between Europe and Asia.

The Russian Federation has extensive maritime borders in the north to the Arctic Ocean (Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea) and in the east to the North Pacific Ocean (Bering Sea, Sea of Okhotsk). About two thirds of the frontiers are bounded by water. The territory is divided into five natural zones: the tundra, taiga (forest zone), steppe (plains), arid zone and mountains.

Most of the European portion is covered by the East European Plain, which extends from the Netherlands, northern Germany, northern Poland, the Baltic area and Belarus and continues east of the Urals to the plains of Siberia.

Tundra covers ~11% of the territory and extends from the Finnish border in the west to the Bering Strait in the east. This part is characterized by dwarf vegetation over permafrost. The main fauna is reindeer. Population centres include Murmansk (an important port on the Kola Peninsula), Archangelsk and Norilsk (a major centre for nickel and platinum group metals). The area has immense oil and gas resources ('supergiant' fields in the Ural district and in western Siberia).

The taiga occurs south of the tundra and also extends across the country. The southern extensions reach Lake Baikal. The taiga contains the largest expanse of forest in the world. The northern part has very cold winters. Wildlife is extensive.

South of the taiga is an area of mixed and deciduous forest. Extensive areas are also given over to agriculture. The forest area is transitional to the steppe. The steppe consists of grassland with few trees and is important for agriculture.

There are several mountain ranges. The Urals, having low relief, only form a modest geographical barrier. The highest elevation is ~1900 m. The Urals are an important host to a variety of mineral deposits.

The Alpine type Caucasus Mountains are located in the south of the 'European part' of the Russian Federation, between the Black Sea and the Caspian Sea. The crest of the Caucasus Mountains forms the border between the Russian Federation and Georgia and Azerbaijan. The highest elevation is Mount Elbrus (5642 m).

Southern Siberia is also characterized by mountain ranges. The Altai Mountains (highest elevation of 4500 m), at the border with Kazakhstan and Mongolia, are well known for their mineral deposits. The Altai Mountains transition in the east to the Sayan Mountains (3200–3300 m in elevation) and extend to Lake Baikal, the deepest lake in the world (1700 m). East of Lake Baikal, mountain ranges continue with the Jablonovy, Stanovoj and Aldansk Mountains, and eastern Siberia hosts the N–S trending Verkhoyansk Mountains. In the Far East, the region varies between mountain chains, reaching elevations in excess of 3000 m in the Moma Mountains, and areas of low relief. The traverse ends at the Kamchatka Peninsula, which borders the Pacific Ocean. It is characterized by many active volcanoes, with 29 of the 160 total being active, including Klyuchevskaya Sopka (4750 m).

Except for tropical rainforest, the Russian Federation contains almost all of the other vegetational regions. The climate is characterized by a rapid change of two distinct seasons: summer and winter. Large parts are located north of latitude 60° N, which are characterized by having a short summer season, with temperatures sometimes attaining 30°C. There is a distinct difference between regions close to the influence of the moderating maritime climate provided by the Baltic Sea in the west and by the Pacific Ocean in the east. Most of the country, however, has a continental climate. In most northern parts, permafrost dominates soil conditions, causing problems during warmer periods when the surface areas melt and become spongy. Average summer temperatures in the Arctic area are only +4°C, whereas in the south these can rise above +20°C. In January, the average for St. Petersburg is -8°C, in western Siberia -27°C and in central Siberia -43°C. The record winter minimum of -70°C was measured at Verkhoyansk (north central Siberia) and the highest summer temperatures of +38°C have been recorded in several southern areas [20.1, 20.2].

5.20.2. Geology

5.20.2.1. General

The Russian Federation is characterized by its variety of geological regions (Fig. 5.37): the Archean and Proterozoic of the Russian and Siberian Platforms, the Palaeozoic Uralian and Angora geosynclines, the Mesozoic and Tertiary geosynclines of the Mediterranean and Pacific Ocean type and Central Asia with its complex structure. In the northern part occur the West Siberian Lowlands, with Quaternary deposits, and the Western Arctic and Timan regions which are probably a northward continuation of the Uralian geosyncline [20.3].

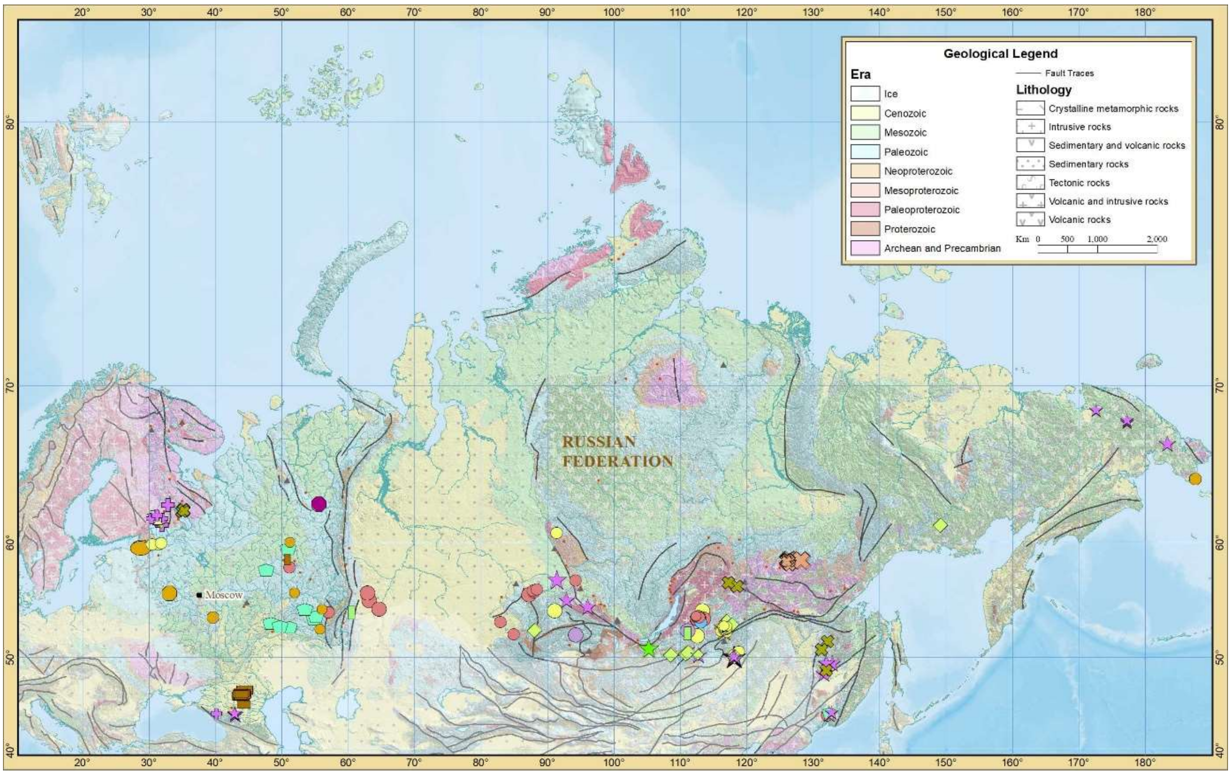


FIG. 5.37. Regional geological setting of the Russian Federation showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Significant occurrences of uranium are reported from fifteen uranium-bearing districts which include more than 100 uranium deposits. Five of them are in the European part of the Russian Federation and ten in the Asian part.

The most important resources can be found within four uranium-bearing districts: (i) the Streltsovsk district, which comprises deposits related to volcanic caldera and where underground mining is ongoing; (ii) the Trans-Ural district and (iii) the Vitim district, both of which comprise sandstone basal channel type deposits which are being developed by in situ leach (ISL) mining; and (iv) the Elkon district, which contains large metasomatite type deposits that are planned to be mined in the future.

Ten other uraniferous districts possess mainly small vein, volcanic and metasomatite type deposits with high cost resources (>US $130/kgU) and low uranium grades. These are currently unfavourable for exploitation.

Stavropol district is renowned for its historical mining heritage. It contains two depleted vein type uranium deposits, Beshtaugorskoye and Bykogorskoye. Current activities are connected with their restoration and rehabilitation.

The UDEPO database [20.4] list a total of 79 deposits, of which 36 were not explored or were not considered of economic interest (dormant). Fifteen deposits were at that time in the exploration phase and 12 in the development phase. Nine deposits were operating and 7 deposits were depleted.

In terms of frequency, the majority of deposits are classified as either sandstone hosted (comprising a total of 21, of which 13 are basal channel, 6 roll-front and 2 tabular) and vein-type deposits (20). The volcanic type accounts for a total of 15 deposits and the metasomatite type for 10 deposits. The remaining are: lignite (6), surficial (5) unconformity-related (1), and phosphorite (1).

UDEPO also indicates that most operating deposits are of the volcanic type (5), followed by vein deposits (3) and sandstone-hosted (1). The volcanic-type deposits are the largest in the Russian Federation, of which the area of Streltsovsk is the most important. Under recent development are the large metasomatite deposits in the Elkon region of the Far East Sakha Republic, in the Archaean Aldan Shield (Druzhnoye, Yuzhnoye). Other exploration has mainly concentrated on sandstone-hosted deposits, preferentially those amenable to ISL.

5.20.2.2. Streltsovsk district

The Streltsovsk district is located 12 km SE of the Krasnokamensk town in eastern Transbaikalia, Chita province, ~40 km west of the Chinese border. The Streltsovsk district encompasses 19 deposits with an average grade of ~0.2% U within an area of ~150 km^2. Total geological resources stand at 270 000 tU.

The principal mineralization type is related to volcanics and is in the main structurally controlled, as characterized by the largely vein and stockwork ore lodes. Therefore, the deposits are considered to be structure-bound volcanic type deposits. Two main ore varieties are recognised: polymetallic uranium–molybdenum and monometallic uranium.

Uranium mineralization exist at depths of ~1100 m and below. Roughly 75% of the resources of the Streltsovsk district occur at depths of 200–600 m, where orebodies are distributed at various levels in stratified sedimentary volcanogenic rocks of Jurassic–Cretaceous age. The largest deposits in this depth range include the Octyabrskoye, Tulukuyevskoye and Streltsovskoye orebodies. These are chiefly confined to two large high-grade deposits, Argunskoye, which is hosted by marble of the Lower Proterozoic basement, and Antei, which is hosted by Palaeozoic basement granite.

Since uranium was discovered in the Streltsovsk district in 1963, 10 deposits have been developed into production, two as open pits and eight as underground mines. Mining by open pit was undertaken at Tulukuyevskoye (>35 000 tU) and at Krasny Kamen (<5000 tU). Both deposits are depleted. Underground mining exploited the large deposits at Streltsovskoye (>60 000 tU original resources), Antei (>30 000 tU) and Oktyabrskoye (>15 000 tU), as well as the medium-sized (5000–15 000 tU) deposits at Luchistoye Martovskoye, Vesennee, Yubileinoye, Novogodneye and Malo-Tulukuyevskoye. In situ ore grades of these deposits typically vary between 0.01% and 0.3% U but may be as high as 1% U in specific orebodies.

Up until around 2000, the main mining operations were concentrated at Antei, which is hosted in granite, and at Streltsovskoye, which is hosted in trachydacite. Antei is the deepest mine with workings at depths ranging from 400 to 900 m. The Antei deposit is practically a depth extension of Streltsovskoye, which ranges from near surface to ~400 m in depth. A basal conglomerate horizon separates both at the unconformity between the granitic basement and the volcanic cover.

Historically, uranium mining started with an open pit and this predominated over underground mining until 1983. Production peaked in 1986 at 5 447 tU. After 1986, production declined and by 1995 totalled 1 960 tU. In the past 10 years production averaged 2 500–3 000 tU. Annual production at Priargunsky from 1996 to 2000 averaged 2500 tU. The dominant tonnages come from underground mining, with a limited amount produced from low grade ores by heap leaching and in place leaching methods.

Application of the three extraction techniques is based on ore grades:

(i) For high grade ore with grades in excess of 0.2% U, conventional mining is applied with subsequent processing at the milling plant. Average mine recovery is 97%;
(ii) For ores with intermediate grades of 0.1–0.2% U, acid heap leaching is applied. Uranium recovery is ~60%;
(iii) For low grade ores grading 0.1–0.15% U, underground acid block leaching is applied on a very limited scale.

Located ~5 km from Krasnokamensk is a hydrometallurgical plant with a sulphuric acid leach circuit. It has a nominal capacity of ~3 500 tU/year and a throughput of 4 700 t/d of ore. Up to 1995, the plant also treated ore from the Dornod uranium district located ~500 km to the south, in north-eastern Mongolia. The JSC Priargunsky Mining and Chemical Production Association (PPGHO), which has its headquarters at Krasnokamensk, is the mine and mill operator. It had ~16 000 employees in 1992–1993, which was reduced to 12 000 by the 2000s.

Geological setting of mineralization

The district coincides with the Streltsovsk caldera, an Upper Jurassic–Lower Cretaceous volcano-sedimentary complex of the Mongolian–Argunian intracontinental volcanic belt, which was formed during Mesozoic tectono-magmatic activation. Basement rocks in the Streltsovsk district comprise Proterozoic metamorphites (dolomitic marble, schist, gneiss) intruded by Palaeozoic granites of the Zabaykalsky Massif, a separate tectonic block of the Palaeozoic Ural–Mongolian Fold Belt.

The Streltsovsk caldera measures ~15 km in diameter and covers an area of ~150 km^2. The principal rocks include mafic to felsic volcanics and intercalated clastic sediments which are separated into an upper unit (Turgin suite) of Lower Cretaceous felsite, rhyolite, ignimbrite and tuff intercalated with sandstone, and a lower unit (Priargun suite) of Upper Jurassic andesite, basalt, dacitic tuff and ignimbrite interbedded with sandstone and conglomerate. The total thickness of this suite ranges from several hundreds of metres to 1200 m and the intercalated sediment beds vary from a few metres to 100 m thick. Numerous faults cut the caldera.

Major structures trend NE–SW, N–S, NW–SE and E–W.

Host rock alteration

Host rocks were affected by a variety of alterations, including silicification, sericitization, hydromicatization, chloritization and carbonatization. The mode of alteration is dependent on the lithology and can also display a certain zoning. The prevalent alterations in the volcanic and sedimentary rocks are hydromicatization, sericitization and silicification, whereas albitization is prevalent in the crystalline basement. The forms of wall rock alterations are also correlated with the three types of ore mineral association.

Characteristics of mineralization

Pitchblende is the chief uranium mineral, whilst brannerite and coffinite are subordinate. Associated metalliferous minerals include molybdenite (femolite), galena, marcasite and pyrite. In oxidized intervals, primary uranium minerals are altered largely to ‘sooty’ pitchblende and uranophane, whereas molybdenite is altered to ilsemannite and uranium molybdates (mourite, umohoite, iriginite). Gangue minerals comprise sericite, chlorite, quartz, calcite, ankerite and fluorite.

Mineralization consists of structurally controlled disseminations, veinlets and partially massive aggregates of ore minerals. Mineralization exists at various stratigraphic levels in the sedimentary and volcanic units, and extends into the basement where it occurs in fractured granite and dolomitic xenoliths in the upper parts of granitic bodies.

Three principal uranium mineral associations are, from oldest to youngest: (i) albite–coffinite–brannerite, (ii) quartz–molybdenite–pitchblende, and (iii) chlorite–carbonate–pitchblende. Isotope dating of pitchblende yields a formation age of 130 Ma.

General shape and dimensions of deposits

Deposits comprise one or several orebodies. The shapes, internal structures and dimensions of the orebodies are highly variable. They may extend, irregularly, over a vertical interval of ~800 m, a width of up to 160 m and a length of up to 300 m. The upper levels of the ore lie at depths of ~50 m (Tulukuyevskoye) and 200 m (Antei). Drilling has intercepted uranium mineralization in the granitic basement at a depth of 2400 m.

Three main outlines of ore arrangement are distinguished and these are typified by the following features:

(i) Veins vary from several centimetres to ~1 m in thickness and from a few metres to 400 m in length and height. Grades can reach up to 1% U. Dip varies from shallow to steep and may vary suddenly. The most significant accumulations of ore exist in intensely fractured host rock intervals. Veins exist in nearly all of the sedimentary and volcanic rocks and continue locally into the basement, particularly where the basement rocks are heavily fractured. Veins extending into the basement are thickest near contacts with overlying volcanics;

(ii) Stockwork orebodies possess complex linear or isometric configurations. Dimensions are of the order of up to 500 m in terms of width, length and height. Grades can reach up to 0.6% U. Stockwork orebodies are commonly developed in favourable single lithological units;

(iii) Tabular/stratiform orebodies vary in thickness from some tens of centimetres up to several metres thick, and up to 600 m in length and width. Grades are of the order of 0.1–0.3% U. Reserves are limited. Tabular mineralization is commonly hosted by permeable clastic or pyroclastic layers composed of sandstones, conglomerates and tuffs in which ore preferentially occurs adjacent to steeply dipping faults. Tabular mineralization also occurs along unconformities between subvolcanic intrusions and volcanic units. Minor tabular mineralization occurs in sediments filling grabens peripheral to the Streltsovsk caldera.

Major deposits are largely of stockwork or vein style whereas stratiform style deposits are typically smaller.

Streltsovskoye deposit

Streltsovskoye is the largest deposit in the district and contains ~20% of total known resources. It was discovered in 1963 and has been exploited by underground mining from 1969 up to the present-day. Original resources were estimated to amount 62 170 tU at 0.18%U.

The deposit occurs in the eastern part of the Streltsovsk caldera in a volcano-sedimentary complex and covers an area of ~10 km^2 (~4 km long and 2.5 km wide). Some isolated ore areas (central, western, eastern, Glubinny, Golub and Flangovy) represent separate deposits.

The basement corresponds to Palaeozoic leucogranite containing small pegmatoid and aplitic bodies affected by potassium metasomatism.

The volcano-sedimentary complex, varying up to 1 000 m in thickness, consists of the Upper Jurassic Priargun suite and the Lower Cretaceous Turgin suite, dipping gently to the SW at 5–10^o.

The Streltsovskoye deposit is situated within the regional Argun NW fault zone, at the intersection of the N–S central fault zone with NE and NW trending faults. Intensive tectonic activity has conditioned the block structure of the volcanic sequence. Amplitudes of vertical displacement can be tens of metres. Four systems of steep faults are determined (from ancient to recent): latitudinal, north-eastern, longitudinal and north-western. Faults occur as intraformational dislocations.

Uranium mineralization occurs in five isolated zones: central, western, eastern, Glubinny and Golub. Their position is determined by the intersection of tectonic zones. The principal resources are concentrated in relatively narrow (200–300 m) north-easterly trending zone, which includes the western, eastern and central areas.

Glubinny is an isolated part of the Streltsovskoye deposit, occurring at deeper levels in the trachydacite sheet, ~400 m to the NW of the central site or 500 m to the north of the western site. The central ore zone is 2 300 m long and 100–500 m wide. The western ore zone is 1 700 m long and 50–170 m wide. The eastern ore zone is 1 800 m long and 100–500 m wide.

The vertical range of mineralization extends to 480 m. About 80% of reserves occur within the 300–550 m depth interval.

Orebodies consist of contiguous steeply dipping ore-bearing fractures ‘feathering’ large faults. The dimensions of single orebodies are a few hundreds of metres, at grades of 0.15–0.50% U. The shape of individual orebodies includes large and small vein-like bodies, flat stockworks, and flat and tabular-like bodies. The vertical extent of mineralization within an individual orebody varies from 30 m to 90 m and is controlled by the thickness of the horizon containing the fault zone.

A significant portion of the reserves is contained in numerous veins and stockwork orebodies within a 750 m long and 6 m thick ore fault zone (N1) of the central sector with an average grade of 0.33% U. However, the main part of the reserves is concentrated in stockwork-like orebodies in the lower trachydacite sheet and the high-grade ores are hosted in basalt.

Some 77% of resources relate to trachydacite, 16% to basalt and the rest to quartz porphyry and conglomerate. High grade mineralization occurs within large tectonic faults and fractures complicated by feathered jointing.

The largest tabular orebody of the Streltsovskoye deposit occurs in the Golub sector at the bottom of a felsic sheet adjoining the southern flank of the eastern portion at a depth of 145–270 m. Mineralization is hosted by andesite and quartz porphyry in a ‘conglo-breccia’ (ore zone 2). The thickness of the ore strata averages 1.5 m and uranium grades vary in the range 0.2–0.24% and up to 2.2% at some intersections.

The principal uranium mineral is pitchblende. Coffinite is of minor importance and uranium titanites occur dominantly as disseminations in low grade ores in trachydacite. Molybdenum minerals are represented by jordisite which has been transformed to ilsemanite in oxidized areas.

Host rock alteration is manifested by the occurrence of hydromicatization, albitization, carbonatization, silicification and pyritization.

Antei deposit

The Antei deposit was discovered in 1974. It is situated directly under the Streltsovskoye deposit at a depth of 350–1 400 m and is hosted by Late Palaeozoic basement granites. Underground mining started in 1976 and continues to the present-day. Total primary resources was 30 750 tU at 0.293% U.

Orebodies are hosted by the Late Palaeozoic granite basement and in the overlying basal sequence conglomerate (up to 70 m thick) at the base of the volcanic sequence. Two granite varieties are distinguished: a coarse porphyrytic granite and a medium-grained biotite and leucocratic granite. The surface of the basement is complicated by having experienced erosive and tectonic arch-like uplifts.

The principal ore control structures are NE trending faults (numbered 13, 160 and 190), which, together with a group of smaller faults, form ore fault zone 6A.

The major orebody, 6A, contains 94% of the reserves and is located in a large tectonic NE trending joint 1 000 m long and ~900 m deep. A gently dipping fracture zone at the contact between the structural granite eluvium and the overlying dacite, which hosts the Streltsovskoye deposit, represents its upper border. Up to 50 m of stockwork-like swells alternate with a vein varying up to a few metres in thickness.

The distance between faults 160 and 13 determines the thickness of the ore zone, which varies from around 10–50 m in the central part of the zone to 80–100 m at the flanks. The vertical extent of mineralization occurs at a depth of 1 000–1 300 m. Most of the uranium resources are concentrated in the central part of the deposit in a chimney shaped body, which is 200 m deep and 300 m long. The grade is ~0.7–0.9% U, reaching 4% U and more at some intersections. Molybdenum occurs in subeconomic amounts.

The principal uranium mineral is represented by pitchblende; coffinite is a minor component. Insignificant quantities of uranium titanites (brannerite) relate to disseminated low grade mineralization in albitization aureoles and dominate in the deeper levels of the deposit.

Tulukuyevskoye deposit

The Tulukuyevskoye deposit was one of the largest and richest deposits in the district (35 350 tU at 0.349% U). It was operated for almost 30 years by open pit and is currently almost depleted. The deposit is located in the central part of the caldera within the NW strike shear zone and is hosted by stratified Upper Jurassic volcanites. Mineralization occurs in a series of contiguous, steeply dipping fractured/veined and stockwork-like orebodies of complex morphology.

The deposit is 1 300 m long. The ‘richest’ part is 400 m long and 150–250 m wide. The section containing ore is 180–270 m in height. The upper parts of the deposit occur at a depth of 30–50 m. Some 60–70% of total resources occur in ore-bearing zone 5. Felsite hosts the principal mineralization and the underlying basalt and trachydacite also contain some low-grade resources.

The average grade exceeds 0.4% U and ranges from cut-off to 7% U over some intervals. Some intersections contained 30% U over a thickness of 5 m. The thickness of individual orebodies varies from a few tens of metres to 60 m. Molybdenum was recovered as a by-product.

Uranium mineralization is represented by pitchblende, which forms metasomatic and streaky segregations. Coffinite occurs in minor quantities.

Wall rock alteration is represented by silicification, haematitization, hydromicatization, carbonatization and albitization.

Argunskoye deposit

The Argunskoye deposit (resources >30 000 tU) is the only deposit of the Streltsovsk district where most of the uranium resources are hosted by carbonate rocks. It is situated in the western part of the caldera, on the northern side of the volcanic neck. The deposit was discovered 16 years after exploration started, as the upper level of mineralization occurs at a depth of 140 m, underlying a basalt sheet.

The deposit is located on the northern limb of a metamorphic anticline; Proterozoic granites comprise the core and southern limb. Metamorphic rocks are represented by a 200 m thick sequence of steeply dipping dolomitized limestone.

The major host for uranium mineralization is a thick breccia zone (50–100 m) at the base of the limestone horizon. Its width is 200–300 m and the vertical extent of mineralization exceeds 1 000 m. Granites underlying limestones are of less importance. The upper limit for orebodies is a fracture zone running along the contact between basement rocks and volcanites.

Uranium mineralization is irregular; grades vary from cut-off to 3.5% U. Thickness of ore intersections is in the range 16–70 m. About 30% of the reserves are concentrated in relatively high-grade ores (>0.3% U). Pitchblende and minor coffinite are the principal uranium-bearing minerals in the ores. The molybdenum grade in carbonate ores is ~0.15% and in silicate ores up to 0.26%.

Ore related host rock alteration is represented by argillization and silicification. Chlorite and montmorillonite metasomatites are observed along faults to a depth of 2500 m.

5.20.2.3. Transural district

The Transural (or Zauralsky) district stretches for 600 km southwards to the Tobol River in south-western Siberia and extends further south and south-eastwards for several hundreds of kilometres beyond the Russian Federation and into Kazakhstan. Major towns are Kurgan and Chelyabinsk.

Several occurrences and deposits of the basal channel sandstone type are reported. The most important ones, which exist in the southern portion of the district, to the south of Kurgan, include Dalmatovskoye (RAR of 10 200 tU), Dobrovolnoye (RAR and IR of 7 400 tU) and Khokhlovskoye (RAR and IR of 3 451 tU). Two small deposits are Vinogradovskoye and Cherepanoskoye, each containing less than 1 000 tU. Ore grades vary in the range 0.01–0.05% U.

A sandstone type deposit, Sanarskoye, situated in the western margin of the Transural district was mined by open pit during 1968–1980, producing 440 tU. The ore grade was 0.08% U. Quaternary carbonaceous sandy sediments that fill a valley hosted the depleted uranium deposit, which was associated with organic matter.

The Dalmatovskoye deposit in the Kurgan region has been exploited by the Dalur mine using the sulphuric acid ISL mining method. For the Khokhlovskoye deposit, the first phase of exploration and pilot testing was completed in 2012. At these two deposits, the recoverable resources were estimated at ~11 000 tU. The Dalur mine produced 529 tU in 2012. Further investigation and ISL testing are still required for the Dobrovolnoye deposit. The planned maximum annual production is 700 tU.

The Transural uranium district is situated in the SW part of the West Siberian Platform. The northern margin of the uranium district coincides with the northern limit of the Late Jurassic–Early Cretaceous pink sediments, which in turn is conterminous with the boundary between the Late Jurassic humid and semi-arid climatic zones to the north and south, respectively.

The district is characterized by Middle–Upper Jurassic palaeochannel systems occupying the south-western alluvial coastal plain of the Jurassic sea in the eastern foreland of the Caledonian Urals. The channels were cut down to a basement of Devonian felsic volcanic rocks and marine and continental sedimentary rocks. The palaeodrainage systems comprise 1–5 km wide channels filled with 30–120 m thick, permeable alluvial–fluvial sediments of Bathonian–Kimmeridgian age. Lithologies comprise mud, silt, sand, conglomerate, and beach gravel with high levels of plant debris (average 0.5–3% C_{org}). The three recognised sedimentary cycles are ascribed to weakening movements during the final uplift and folding phase in the Urals. Following the close of orogenic activity, the river valleys transformed to chains of drainage lakes into which proluvial and limnic sediments were deposited during Late Jurassic–Early Cretaceous. These sediments comprise 30–150 m thick impermeable, pink, carbonaceous clay, silt, and sand containing 100–300 ppm U in the form of syngenetic uranium associated with dispersed plant remains. A 300–700 m thick sequence of Cretaceous and Tertiary sediments, thinning to the west, south and north, overlies the Jurassic strata.

The uranium-bearing grey alluvial–fluvial sediments were altered by oxidation and re-reduction. Neither alteration facies contain either iron oxides or carbonaceous matter. Downstream influx of oxygenated waters resulted in a redox interface. Re-reduction associated with bleaching is thought to post-date the deposition of the overlying, impermeable pink facies. Plant debris, originally present at elevated levels of up to 3% C or more, comprise the reducing agent.

Colloform coffinite and uranium oxides are the chief uranium minerals. Associated minerals comprise chalcopyrite, ferriselite, jordisite, marcasite, native selenium, pyrite, sphalerite, rhenium and vanadium oxides. Other elements present in syngenetic detrital minerals include lanthanides, scandium and yttrium. The uranium and associated minerals are present as disseminations along the redox interfaces. The age of the uranium minerals based on isotope dating is 135 ± 7 Ma.

Resources in individual deposits range from several hundreds to 12 000 tU, most of which are contained in several orebodies. The grades of ore vary from 0.01 to 3% U and average 0.03–0.04% U. Deposits occur at depths of more than 300 m, and measure <1–25 km in length, 50–1 500 m in width and up to 50 m in thickness. Individual orebodies measure <1–7 km in length, 50–700 m in width and 1.5–20 m in thickness. In plan view, orebodies exhibit lensoid or ribbon-like configuration; in cross-section, they are largely lenticular or hardly roll shape. Lenses occur en echelon or singularly arranged at various levels and disconnected by aquicludes. Some of the orebodies follow the channel axes whilst others trend obliquely.

Mineralization is largely geochemically and lithologically controlled. For deposits in the Transural district, important recognition criteria or ore controlling parameters include:

Host environment:

- Basement of Devonian volcanics and marine and continental sediments;
- Palaeosurface weathered during semi-arid climate;
- Old peneplain cut by Middle–Late Jurassic palaeodrainage systems;
- Valleys filled with continental clastic sediments of Middle–Late Jurassic age;
- Cover of Late Jurassic–Early Cretaceous impermeable, pink proluvial–limnic sediments overlain by thick Cretaceous–Recent sediments providing protection against erosion of ore-bearing hosts.

Host rocks:

- Alluvial–fluvial sediments 30–50 m thick composed of very permeable mud, silt, sand, conglomerate and beach gravel of Middle–Late Jurassic;
- Grey coloured reduced facies with high carbonaceous matter content (average 0.5–3% C_{org}) and minor sulphides.

Alteration:

- Oxidation with formation of redox fronts;
- Re-reduction reflected by bleaching.

Mineralization:

- Sooty pitchblende/uranium oxides and coffinite;
- Numerous associated elements;
- Disseminated texture of mineralization;
- Roll shaped and lensoid orebodies trending both parallel and obliquely to channel axes;
- Ore restricted to grey facies with more than 0.2% C_{org};
- Regional distribution of deposits linked with expanse of pink proluvial–limnic cover facies.

Geochemistry:

- Reduction potential provided largely by organic matter and partly by sulphides;
- Redox fronts developed downstream from channel by vadose waters;
- Potential uranium sources assumed to be rhyolites with 4–5 times background uranium content.

Deposits are of epigenetic origin and derived from oxygenated meteoric waters, which must have infiltrated the permeable grey alluvial–fluvial horizon at the valley heads in the western uplands. Elsewhere, impermeable sediments of the pink proluvial–limnic facies halted the downward percolation of mineralizing solutions. The initially reduced grey facies were oxidized by oxygenated solutions and redox fronts developed, along which uranium and associated elements (molybdenum, vanadium, selenium, rhenium) were set in a zonal distribution that is common for these deposits. Ore concentration was limited to lithological units with 1.5–2.5% C_{org}.

Because the mineralizing solutions could only have infiltrated the alluvial horizon at the exposed valley heads, the source of uranium is most likely situated in this region of the Ural foreland. Rocks in this region comprise rhyolites with 4–5 times background uranium values.

Dalmatovskoye deposit

The deposit is located in the Kurgan district ~50 km south of Dalmatovo. Resources amount to 10 200 tU (RAR). The ore grade is 0.039% U. Several orebodies occur at depths of 360–500 m in a major palaeovalley and tributary 11 km long and 8 km long, respectively. Both are up to 1.5 km wide. Single orebodies measure 400–4 500 m in length, 50–700 m in width and 2–12 m in thickness. The thickness of the front part of roll can reach 20 m.

Channel facies are Middle–Upper Jurassic alluvial sediments consisting of pink oxidized and grey reduced conglomerate, sandstone and sandy gravel interbedded with silty mudstone. The channels are cut up to ~100 m into schists and, towards the headwaters to the SW, into Devonian rhyolite porphyry and rhyolite. Faults trend E–W, NW–SE and NE–SW.

Uranium occurs as pitchblende and coffinite. The grade varies in the range 0.01–3% U. High grade parts may contain scandium, rhenium, molybdenum and rare earth minerals. The distribution of uranium is controlled by redox boundaries in sand–gravel aquifers. In map view, majority of orebodies are roll shaped or lenticular and distinctly elongated along the valley axis. In cross-section, mineralization exists as discrete lenses or piled at numerous levels disconnected by argillaceous aquicludes.

5.20.2.4. West Siberian district

The district covers as a relatively narrow curvilinear belt running along the south-eastern margin of the West Siberian Platform, from south of Novosibirsk eastwards for ~900 km to beyond Krasnoyarsk. The belt overlaps largely with the alluvial coastal plain of the Jurassic sea.

Known deposits are of the basal channel sandstone type. Deposits with resources estimated to be of the order of 1 500–5 000 tU include Prigorodnoye, located some 10 km NE of Novosibirsk, Smolenskoye, in the south-western sector of the district, both hosted in Tertiary palaeochannels, and Bystroye, which occurs in a Jurassic palaeochannel close to the eastern margin of the district.

Total resources of the West Siberian district, including Prognosticated and Speculative Resources in the <US $80/kgU cost category, are estimated at ~40 000 tU and related mainly to the Malinovskoye deposit. The uranium grades of all the deposits are of the order of several hundred ppm.

Malinovskoye deposit

Malinovskoye is a basal channel sandstone type deposit located in the Kemerov region ~60 km SW of the town of Mariinsk. Resources are estimated at ~20 000 tU. The average grade of ore is less than 0.05% U.

This deposit is located in the N–S trending channel, measuring 50 km in length and 1–3 km in width, in the Malinovskaya Jurassic palaeovalley. The depth increases from 70 m at the headwaters to 300 m in the downstream sector. The channel is cut into a basement of Cambrian volcano-sedimentary rocks into which diorite and granite were intruded, whereas Devonian continental and terrigenous volcanic sediments were intruded by post-Devonian syenite and granite.

A sequence of Mesozoic sediments up to 300 m in thickness overlies the channel facies. This sequence starts with a 50–110 m thick unit of pink Lower Cretaceous clays which are covered by up to 200 m of Lower–Middle Cretaceous sands, interbedded with kaolinitic clays.

The palaeovalley is occupied by 70–120 m thick, alluvial sediments of the Late Jurassic–Early Cretaceous Bazhenovsky horizon. The mineralized lithological facies comprise grey, carbonaceous sands of erratic grain size alternating with silt and clay beds and conglomerates. Carbonaceous remains in the form of coal are abundant, especially in the basal part of the channel. Thin lignite seams, measuring 0.1–0.5 m in thickness, are locally intercalated. The filtration factor in the aquifer varies from 0.65 to 17.

Mineralization extends over an 18.5 km long channel interval, which encompasses a 2.5 km long, 100–300 m wide and up to 50 m thick ore zone at depths of 100–300 m. The 2.5 km long interval in the central part of the deposit hosts an estimated 2 200 tU of resources at a grade of 0.05% U and this zone was subject to more detailed investigation. Within this area, mineralization occurs generally in two ore zones relating to two mineralized horizons, separated by aquiclude. The first ore zone is located in the eastern part of the palaeovalley at a depth of 247–300 m. It is 1.8 km long, 16–90 m wide (average 52 m) and 1–15 m thick (average 6 m). The second ore zone is 2.5 km long, 50–250 m wide (average 70 m) and 0.7–20 m thick (average 6 m), occurring at a depth of 277–300 m.

Single orebodies are tabular, lensoid or roll shaped and mineralization is composed mainly of coffinite and pitchblende. Ore grades range from 0.013 to 0.139% U, but locally can reach 1.32% U. The average grades of associated elements are: 0.01–0.15% Cu, <0.02% Ge, <0.045% Mo, 0.01–0.15% Pb, <0.002% Sc, <0.1% V, <0.015% Y and 0.01–0.15% Zn. The carbonate content is 0.5% CO_2. The clay fraction averages 17%.

5.20.2.5. Vitim district

The Vitim district lies ~140 km north of Chita town in the NE section of the Buryatia Autonomous Republic of the Russian Federation and lies on the Amalat Plateau in the upper part of Vitim River. It includes the Khiagda orefield and some deposits and occurrences hosted by recent palaeochannel structures. All deposits are of the basal channel sandstone type. Resources of the Vitim district are estimated at 52 000 tU classified as RAR and IR, whilst speculative resources are of the order of 100 000 tU.

The Khiagda orefield is situated 160 km north of Chita and covers an area of 250 km^2. It includes eight closely associated deposits with similar geology: Khiagdinskoye, Tetrakhskoye, Vershinnoye, Dybryn, Namary, Koretkondinskoye, Istochnoye and Kolichikan. The distance between deposits varies in the range 1.5–6.0 km. RAR and IR are estimated at 44 800 tU at 0.042% U. Prognosticated resources are ~60 000 tU. Khiagdinskoye, the largest deposit, contains ~15 500 tU at an ore grade of 0.05% U. The resources of Tetrakhskoye are in excess of 5 000 tU and the others have between 1 500 and 5 000 tU each. Their grades average between 0.05 and 0.3% U. However, there are no exact boundaries between the deposits. Each of them includes several closely occurring orebodies.

The Radinovskoye and Vitlausskoye deposits are situated outside of the Khiagda orefield, within Neogene palaeovalleys in the Ingur and Kholoi areas. Mineralization crops out at both deposits in the permafrost zone (partially at Radinovskoye and completely at Vitlausskoye). Prognosticated resources are estimated at 5 284 tU for Radinovskoye and 8 984 tU at Vitlausskoye.

The Zheglovskoye deposit is situated in the Eravninsky region of Buryatia, 100 km north of Chita. It is located in two adjacent palaeo-tributaries of the Khushida valley. Resources are estimated at 8 000 tU.

The deposits are possibly amenable to ISL extraction; the Khiagda company has been developing the Khiagdinskoye deposit for ISL mining since 2006. Production in 2012 was 332 tU, an increase of 25% with respect to 2011, 540 tU in 2016, 693 tU in 2017. In 2011–2012, the Khiagda company continued infrastructure development. The planned annual production capacity is 1 000 tU with the potential to increase this to 2000 tU/year.

Proterozoic metamorphic rocks intruded by Palaeozoic granite constitute the basement. The ancient peneplain was weathered deeply during a semi-arid to arid climate and cut by a palaeo-drainage system. The system comprises tributary channels draining into two major ancestral rivers which flowed at the boundaries of the Buysiuchan plain. Oligocene–Miocene sedimentary rocks, at least 50 m in thickness, largely of colluvial and, along thalwegs, alluvial origin, fill the palaeochannels. The sedimentary rocks are composed of grey and multicoloured carbonaceous tuff, conglomerate, sandstone and clay–siltstone, with some intercalated lignite seams. Grey facies contain pyrite and are enriched in plant debris. The average carbon content is ~0.8% C_{org}. The older rocks are overlain by Quaternary tuff-bearing sand and gravel cover, measuring mostly 10–30 m, locally up to 250 m, in thickness, which is intercalated with or overlain by basalt lenses or sheets.

Grey host rocks originally oxidized to multicoloured facies in which siderite, pyrite and organic matter are replaced by iron hydroxides. Bleaching (due to re-reduction) produced a whitish facies along the interface of grey and multicoloured rocks.

The principal uranium minerals are uranium oxides and coffinite. Some uranium is adsorbed onto rock constituents. Age dating of the minerals yields ages ranging from 25 Ma to Recent. Associated elements present in the orebodies include molybdenum, zinc, cobalt, zirconium, copper, yttrium, scandium and lanthanides. The uranium deposits are confined to channel sections underlain by granite. The channels in metamorphic terrain are barren of uranium but may contain gold. The ore minerals occur as disseminations along the interfaces. Individual deposits contain from several hundred to more than 5 000 tU. These consist of orebodies which, in plan view, are of ribbon-like configuration, trending along channel axes and in sections of elongated roll or lens shape. The orebodies measure up to 3 km in length, 150–400 m in width and vary in thickness from less than a metre up to a maximum of 23 m. They are present commonly at depths of 150–200 m. Ore grades vary in the range 0.01–0.5% U. Mineralization is chiefly geochemically and lithologically controlled. For the deposits in the Vitim district, important recognition criteria or ore control parameters include:

Host environment:

- Proterozoic metamorphic basement intruded by Palaeozoic granite;
- Palaeosurface deeply weathered during semi-arid climate;
- Ancient peneplain cut by Tertiary rivers;
- Valleys filled with continental clastic sediments of Tertiary age;
- Cover of Quaternary basalts and tuffaceous sediments provide shield against erosion of ore strata.

Host rocks:

- Alluvial and proluvial sediments up to 50 m thick composed of conglomerate, siltstone and sandstone of Oligocene–Miocene age;

- Reduced facies of grey colour and characterized by pyrite and high levels of carbonaceous matter (1–8% C_{org});
- Oxidized multicoloured facies characterized by iron hydroxides and the high permeability of the ore hosting facies.

Alteration:

- Oxidation with formation of redox fronts;
- Re-reduction related bleaching along reduced and oxidized facies.

Mineralization:

- Coffinite and uranium oxides;
- Numerous associated elements;
- Disseminated texture of mineralization;
- Roll shaped and lensoid orebodies;
- Orebodies elongated along channel axes;
- Restriction of deposits to channel sections underlain by granite.

Geochemistry:

- Reduction potential provided by organic matter and sulphides;
- Redox fronts developed by vadose waters migrating downwards from channel margins;
- Potential uranium sources provided primarily by granite with elevated background.

Khiagda (Khiagdinskoye) deposit

The Khiagda deposit is the largest in the district and contains ~12 000 tU at average ore grade of 0.05% U. Mineralization exists in permeable, poorly indurated Neogene fluvial sediments that fill the palaeovalleys of narrow streams. Palaeozoic granite represents the basement. Neogene–Quaternary basalt overlap with ore hosting sediments. The ore hosting horizon's thickness varies from several metres up to 120 m. The mineralization depth varies from 60 to 240 m (average of 170 m). Mineralization occurs in lens and lenticular (ribbon-like) orebodies. Single orebodies are 850–4 100 m long, 15–400 m wide and 1–20 m thick. Uranium minerals occur as disseminations and are principally coffinite, pitchblende and sooty pitchblende.

In 1999, pilot ISL production was started at the Khiagda deposit.

Zheglovskoye deposit

The total resource of the Zheglovskoye deposit is estimated to contain 7 900 tU. The deposit is located in two tributaries of the Khushida palaeovalley and filled by Neogene volcano-sedimentary rocks with a total thickness typically in the range 120–150 m (locally up to 250 m).

Two ore zones are related to two tributaries. Ore zone 1 in the northern tributary is 5.8 km long, 70–300 m wide and occurs at a depth of 8–180 m. Its average thickness is 3.2 m and it has a grade of 0.062% U. Ore zone 2 is located at a depth of 10–180 m in the parallel tributary 1.5 km to the south of ore zone 1. It is 3.6 km long and 100–300 m wide. Average thickness is 3.4 m and the grade is 0.062% U.

Uranium mineralization is represented by sooty pitchblende, pitchblende and coffinite. The deposit is still being explored.

5.20.2.6. *Aldan (Elkon) district*

The Aldan district is located ~100 km NE of the Aldan town in the Sakha Republic, in the east of the Asian part of the Russian Federation. After the first uranium occurrence was discovered in the early 1960s, ~80 more gold–uranium–(silver) occurrences, which include nine deposits of vein stockwork type, were discovered in discrete structural zones. The most important deposits were found along the Yuzhnaya Zone.

Between the 1960s and the early 1980s, five deposits were investigated by drilling to a depth of 2 000 m and four deposits by underground workings. During the latter investigations, some uranium was produced. In 2007, after 22 years 'on standby', 'Atomredmetzoloto' (ARMZ), started a re-evaluation of the deposit which focused on resource estimation, delineation drilling, mining and processing technologies aimed at facilitating a feasibility study.

The recent Russian estimates (as of 1 January 2013) give a total resource of 383 000 tU of in situ RAR and IR attributed generally to the US $130–260/kgU cost category. This makes Aldan (Elkon) the second largest uranium district in the world. Most of the significant uranium resources of the Aldan (Elkon) district were identified as occurring in five deposits of the Yuzhnaya Zone, totalling 296 000 tU, including 100 000 tU of RAR (C1). The uranium grade averages 0.15%. Gold, silver and molybdenum are by-products. Gold values range from less than 1 g/t to several g/t.

The known quality of the Elkon deposits, their remoteness and their requirement for deep mining prohibit their economic exploitation at present. However, the Elkon district is deemed a favourable target for further exploration. This evaluation is based on the potential for additional high-grade uranium orebodies which also contain sufficiently high concentrations of gold.

The Aldan Shield is basically comprised of Archaean–Lower Proterozoic crystalline basement which outcrops in a several uplifts, including the uranium- and gold-bearing Elkon horst. Vendian–Lower Cambrian limestone and dolomite, which are nearly 700 m thick and subhorizontally bedded, overlie the basement to the north, whereas coal-bearing continental deposits and pyroclastics of Lower Jurassic age fill grabens.

The Elkon horst is a NW–SE elongated uplift, measuring 60 km in length and up to 40 km in width, situated in the southern sector of the Aldan Shield. The main lithologies are Archaean marble, quartzite, schist, gneiss, amphibolite and granulite. Intense granitization during Late Archaean–Early Proterozoic spawned leucocratic biotite–microcline granite and migmatite. Only relics of schist and gneiss are observed in the granitized rocks.

Small laccolith-like bodies, stocks, dykes and sills of calc-alkaline and alkaline rocks of the Aldan volcano-plutonic complex were intruded in three episodes into the aforementioned units in the Jurassic and Cretaceous strata, especially within the western sector of the Elkon horst. Repeated faulting affected the region, especially during the Early Proterozoic and Mesozoic, resulting in three sets of prominent faults: (i) ancient, NE–SW and NW–SE trending faults developed during the Early Proterozoic, (ii) ancient faults reactivated during the Mesozoic, and (iii) neotectonic submeridional and NW–SE trending faults of Mesozoic age. The last set of faults triggered block movements, resulting in the development of grabens and horsts.

Uranium deposits are related to the upstanding block of Archaean granite–gneiss basement which is intruded by Jurassic alkaline rocks and crossed by faults. Uranium mineralization is related to both young and reactivated faults.

Various types of alteration include, from oldest to youngest:

(a) Post-granitization potassium siliceous metasomatism formed in a zonal distribution in the Early Proterozoic granitoids;

(b) Multistage Mesozoic, pre-uranium alteration produced different mineral assemblages which were overprinted on each other in the ore-bearing zones. The oldest mineral assemblage is an albite–sericite–chlorite facies;
(c) A younger and very prominent pre-uranium pyrite–carbonate–potassium feldspar alteration assemblage occurring with disseminated gold, and surrounding all ore-bearing structures. This facies has telescoped other strata, especially the albite–sericite–chlorite aureoles, and developed micro-veinlets for several hundreds of metres along and down dip of reactivated ancient faults and which frequently persist for 6–10 m and locally up to 20 m into the wall rocks;
(d) In the outer zone, mafic minerals are completely replaced by marcasite, pyrite, ankerite and dolomite, whereas plagioclase is substituted by carbonate and sericite, quartz by calcite, and magnetite by pyrite. The proportions of pyrite and carbonate are extremely variable. As in the Yuzhnaya Zone, carbonate values reach up to 50%. Pyrite contains disseminated gold with values reaching 4.5 g/t Au in pyrite concentrates;
(e) In addition to the aforementioned alterations, the inner halo exhibits noticeably increased potassium feldspar content. This resulted in an facies composed of 40–75% potassium feldspar, 35–50% carbonate, 5–15% pyrite and minor apatite, sphene and sericite. Gold values reach up to 80 g/t Au in pyrite concentrates;
(f) Late and post-ore alteration includes oxidation, fluoritization, silicification, sulphidization and carbonatization. Fenitization of earlier facies was caused by the post-ore emplacement of Mesozoic alkaline intrusions.

The only primary uranium mineral is a low–medium temperature uranium–titanium phase classified as brannerite-A. This frequently exists in massive, colloform aggregates that enclose small host rock fragments or, as prismatic crystals up to 0.08 mm in length. Associated minerals are marcasite and pyrite, which are mostly younger than brannerite; merely a small proportion of them is coeval with brannerite.

Alteration products of brannerite include secondary brannerite, more or less uraniferous TiO_2 phases, uranium oxides and, in oxidized interludes, hexavalent uranium minerals which developed after renewed cataclastic intervals.

Gold is a typical constituent of most of the ores, but it tends not to be syngenetically associated with uranium. Gold mineralization both predates and postdates the brannerite formation.

A final phase of endogenic mineralization comprises veinlets of dark quartz, calcite, dolomite, fluorite, marcasite, pyrite, and minor baryte, galena, sphalerite and chalcopyrite.

In most deposits of the Elkon district, oxidation of primary ore is persistent to a depth of some tens of metres below the current surface but may extend to 600 m in depth in some ore-bearing structures. Typical minerals include manganese and iron hydroxides, clay minerals, carbonates, chrysocolla, opal, jarosite, azurite, malachite, uranyl phosphates, various products of decomposed brannerite and uranium adsorbed by iron hydroxides and other minerals.

Uraniferous mineralization textures are dominated by veinlet breccia and fine to microclastic breccia. Dissemination and veinlet textures are less common. Coffinite characteristically occurs in disseminated uranium mineralization as coatings on iron sulphides contained in fissures and voids and as replacement of pyritized mafic minerals.

Three uranium ore varieties are distinguished: (i) gold–brannerite, (ii) gold–uraninite, and (iii) brannerite–silver–gold mineralization. In addition, there are three types of gold ore which may or may not contain minor uranium. The main ore zones and deposits of the three types of uranium ore are:

(i) Gold–brannerite mineralization is common for deposits along the Agdinsk, Vesennyaya, Pologaya, Sokhsolookhsk, Severnoye and Yuzhnaya Zones. Blastomylonites, imposed on Early Proterozoic metadiorite dykes, characterize the mineralized zones. Archaean–Early Proterozoic ultrametamorphic lithologies comprise the country rocks. Gold–brannerite mineralization occurs as veinlet disseminated type and typically hosted within auriferous pyrite–carbonate–potassium feldspar altered zones. Brannerite is the only primary uranium mineral. Substantial concentrations of gold and silver are intimately associated with pyrite in two pre-brannerite stages of the pyrite–carbonate–potassium feldspar alteration;

(ii) Gold–uraninite mineralization is known from the Interesnaya and Nadezhda zones in the north-western section of the Elkon district where Mesozoic dykes and stocks abound. Geological setting and ore control are alike to those of the gold–brannerite mineralization although the uraninite is confined to thermal metamorphic zones. Unlike the gold–brannerite assemblage, the gold–uraninite mineralization has higher grades of uranium. Native gold is essentially hosted in early pyrite. Early pyrite concentrates contain 9.1–24.5 ppm Au;

(iii) Brannerite–silver–gold mineralization is found in the Zvezdnaya, Mramornaya, Marsovaya and Fedorov Zones in the south-western Elkon district. Geological setting and ore control are alike to those of the gold–brannerite deposits. Lodes of ores consist of gold-bearing metasomatic rocks cut by thin stringers of brannerite and late small quartz and carbonate veinlets with acanthite, native silver, native gold and pyrite.

The internal structure, dimension, shape and location of uranium–gold and uranium–gold–silver deposits are genetically controlled by NW–SE striking and steeply SW dipping faults.

Deposits comprise sporadically distributed orebodies that are disjointed by barren or intermittently mineralized strata and comprise irregularly mineralized disseminations, joints and fractures, the dimensions, intensity and distribution of which are influenced by the degree of brecciation of the host.

Lodes of ore have a columnar or vein-like formation and are frequently 0.2–5 m in width in neotectonic Mesozoic faults, but they can attain widths reaching to 10 m in reactivated Proterozoic faults. The internal stockwork structure of ore lodes is made up of tightly spaced stringers and impregnations of brannerite that combine, en échelon, into linear orebodies 500–700 m in length and from 0.5 m to at least 10 m in width. Within these orebodies, ore shoots also carry gold and, locally, molybdenum.

Orebodies seldom outcrop at the surface. Most orebodies occur at depths greater than 200 m. Ore has been intersected by drilling down to depths of 2 000 m; however, ore mineralogy does vary with depth throughout the whole vertical range, implying that mineralization likely persists at greater depth.

The uranium content of brannerite–gold ore varies in the range of 0.02–0.2% U or more, and the average is in the range of 0.1–0.15% U. The gold tenor averages 1–2 g/t and that of silver is 8–15 g/t. Grades of molybdenum are in the range of 0.01–0.1%.

Uraninite–gold ore has a uranium content greater than that of the brannerite–gold ore, and it averages 10–20 g/t Ag and 0.5–1 g/t Au. Brannerite–gold–silver ore has uranium grades ranging from 0.02% to 0.2% but can exceed 0.5%, and it has average tenors of 15–200 g/t Ag and 3–10 g/t Au and, although locally the gold and silver grades can be considerably higher. The ore's carbonate content ranges from 1.5% CO_2 in silicified ore to 10% CO_2 in other types of ore, whereas the sulphur content ranges from 1% to 4%, but can be greater than 20%.

Primary brannerite yielded a U–Pb isotope age of 135–130 Ma, which is consistent with the age of the Early Cretaceous intrusions.

Dimensions, shape and location of uranium–gold–silver and uranium–gold deposits are genetically controlled by rejuvenated ancient and neotectonic NW–SE trending and steeply SW dipping faults of Mesozoic age and by neighbouring zones of pyrite–carbonate–potassium feldspar alteration. Important recognition criteria and ore controlling parameters of the major deposits in the region include:

Host environment:

— Archaean–Early Proterozoic granitoids and metamorphic lithologies;

- Granitoids with high uranium background;
- Rejuvenated ancient and neotectonic NW–SE trending, steeply SW dipping faults of Mesozoic age.

Alteration:

Pre-uranium multistage Mesozoic alteration processes are dominated by sulphidization, feldspathization, desilicification, carbonatization and silicification and include, from youngest to oldest, the following assemblages: fenitization related to Mesozoic alkaline intrusions; late and post-ore alteration, including carbonatization, silicification, fluoritization, sulphidization and oxidation; local baryte–quartz with minor iron, copper, lead and zinc sulphides; pyrite–carbonate–potassium feldspar with dispersed gold; and albite–sericite–chlorite.

Mineralization:

- Main ore assemblages are brannerite–silver–gold, gold–uraninite and gold–brannerite;
- Early gold is disseminated in pyrite–carbonate–potassium feldspar alteration facies;
- Brannerite, the only primary uranium mineral, is overprinted on earlier mineralization of gold;
- Uraninite substitutes for brannerite in thermometamorphic aureoles;
- Late stage veinlets of native silver and gold locally telescope older mineralization;
- Restriction of uranium ore to zones of pyrite–carbonate–potassium feldspar alteration cut by NW–SE striking and steeply SW dipping faults;
- Dimensions, shape, location of deposits mostly controlled by brecciated intervals of faults;
- Deposits comprise erratically distributed orebodies having vein-like or columnar shape and internal stockwork structure of orebodies comprises variably mineralized breccias, fractures, joints and disseminations;
- Internal structure, dimensions and distribution of orebodies are influenced by the degree of brecciation of the host rock.

The ore formation began with the auriferous pyrite–carbonate–potassium feldspar alteration stage with most of the gold being hosted in pyrite. Then, uranium was brought in by hydrothermal fluids to the earlier altered rocks. Both alteration and mineralization stages occurred during the Mesozoic tectono-magmatic activation of the Aldan Shield. Uranium was precipitated as brannerite under conditions of medium–low temperature at medium–shallow depth and developed deposits that are structurally controlled in reactivated ancient and neotectonic Mesozoic fault zones.

Due to spatial and temporal correlation of intrusions and deposits, it has been suggested that Mesozoic magmatic activity initiated the hydrothermal process. Uranium is likely sourced from Archaean granitized rocks with elevated contents of uranium. Dissolution of uranium was caused by the interaction of ascending moderate temperature sulphide–carbonate solutions with granitized rock. Subsequently, as typified by the Fedorov zone, the gold–silver mineralization, consisting of native silver and gold, formed in some of the earlier formed uranium–gold zones in areas with Mesozoic intrusions.
It is worth noting the absence of vertical zonation in the uranium-bearing zones of the Elkon district although the upper parts of the deposits are characterized by extensive quartz accumulation. In the Yuzhnaya Zone, the ores' chemical and mineralogical compositions are quite uniform throughout the drill intercepted interval down to ~2000 m, indicating fairly stable conditions during ore formation, perhaps due to a homogenous environment.

Thermobarometric studies signify marked changes in temperatures throughout the whole metallogenic evolution of the Elkon ores and the separate stages of mineral paragenesis. Successive stages of mineral paragenesis began steadily with higher temperatures compared to those at the end of a preceding stage, implying multiphase inflow of ore forming fluids.

All post-brannerite processes just altered the initial brannerite and then redistributed uranium to develop coffinite; they did not provide new uranium.

Yuzhnaya Zone

The Yuzhnaya (southern) Zone has been investigated by up to 2 000 deep drill holes and by underground workings, and thus is the most thoroughly explored uranium zone of the Elkon horst. It contains a number of large, north-westerly plunging gold–brannerite orebodies which are discontinuously distributed over ~20 km along the central section of the zone and are subjectively considered as individual deposits, namely the Elkon, Elkon Plateau, Kurung, Neprokhodimoye and Druzhnoye deposits.

Ore control is exercised by the ancient NW–SE trending and steeply SW dipping Yuzhnaya Fault, which is ~30 km in length and several hundred metres in width, which was rejuvenated during the Mesozoic, and by pyrite–carbonate–potassium feldspar altered rocks. Archaean–Early Proterozoic ultrametamorphic lithologies comprise the country rocks. Blastomylonites imposed on Early Proterozoic metadiorite dykes characterize the mineralized sections.

Most of the ore in the Yuzhnaya Zone is made up of brannerite and gold and associated alteration products in breccias and, more seldom, in fractures intersecting the altered host rocks. Orebodies comprise closely spaced brannerite impregnations and stringers that combine, en échelon, into linear orebodies 500–700 m in length and from 0.5 m to more than 10 m in width.

The orebodies' upper limit lies between 200 and 500 m depth. Depth persistence surpasses 2 000 m. Low ore grades reaching to ~0.1% U occur in the upper levels and extend down to ~500–600 m. Grades increase downwards to 0.2% U and more at a depth of ~1000 m and below. Depth related variation in ore mineralogy is absent throughout the entire vertical range, implying that mineralization likely persists at greater depth.

Uranium and gold are intimately spatially correlated along both strike and dip and exhibit no indications of mineral variations and pinch-out with depth. The spatial correlation is also sustained by the fact that 72% of the entire gold of the Yuzhnaya Zone is hosted in massive pyrite–carbonate–potassium feldspar alteration facies, and 62% of those gold is associated with uranium ore. Late carbonate–quartz and baryte–quartz veins and veinlets together with molybdenite mineralization exist in the upper, near surface, low gold and uranium intervals of the south-eastern flank of the Yuzhnaya zone.

The Druzhnoye deposit and adjacent sections of the Yuzhnaya zone additionally contain high contents of molybdenite associated with a uranium mineral that was temporarily identified as a uranium oxide. The minerals occur in flattened stockworks ranging in width from a few centimetres to 2.5 m and composed of veinlets and black earthy coatings, crusts and masses within breccias.

5.20.2.7. Transbaikal district

The Transbaikal district stretches for ~500 km from the NE to the SW of Chita in central Transbaikalia. Fifteen deposits of uranium have been discovered there but none of them have been mined yet. The deposit types are volcanic vein–stockwork (referred to as Streltsovsk type mineralization), sandstone-hosted deposits and granite-related vein deposits.

The largest deposit is Olovskoye, a volcanic type deposit containing 13 772 tU of high cost category resources at ore grades of less than 0.1% U, where the uranium mineralization occurs in ore lenses stacked in Lower Cretaceous rhyolitic tuff and clastic sediments. Deposits of higher grade, with ~0.2% U, include the vein deposits Gornoye (4382 tU) and Berezovoye (3561 tU). Most other deposits have resources ranging from some hundreds to upwards of one thousand tonnes of uranium at grades of less than 0.1% U. Estimated total resources of the central Transbaikal district are ~40 000 tU. All resources lie within the <US $130/kgU cost category

The central Transbaikal/Chita area includes part of the Mongolian-Okhotsk zone. The zone is located at the border between Hercynian and Caledonian orogenic terrains which underwent tectono-magmatic reactivation during the Mesozoic period. Crystalline rocks of Precambrian–Lower Palaeozoic age constitute the basement. During the Early Jurassic, granite was intruded and volcanics extruded. Regional faulting generated NE–SW oriented grabens which were filled with Upper Cretaceous terrigenous carbonaceous sediments. Depressions evolved by renewed tectonism during the Quaternary contain terrigenous sediments and basalt.

The reported deposits include (traversing NE to SW):

(a) Olovskoye (13 772 tU at 0.083%U (discovered in 1957)): volcanic type tabular/stratiform, vein-like and stockwork mineralization along strata contacts, in porous pyroclastic rocks and in liparite and dacite of Upper Jurassic–Lower Cretaceous age;
(b) Stepnoye (15 500 tU at 0.049%U): tabular sandstone type in Lower Cretaceous lignite-bearing sandstone and conglomerate filling a graben structure;
(c) Imskoye (23 553 tU at 0.058%U (discovered in 1964)): tabular sandstone type in Lower Cretaceous lignite-bearing sandstone and conglomerate filling a graben structure;
(d) Berezovoye (2 605 tU at 0.104 %U) and Gornoye (4382 tU at 0.239 %U): vein type hexavalent uranium mineralization in highly radioactive Mesozoic granite.

5.20.2.8. Yenisey district

The Yenisey uranium region is in the upper Yenisey River–Altay–Sayan area, the centre of which is the town of Abakan. Early records dating back to 1925 report the occurrence of vanadium–uranium mineralization in Permian coal beds at Abakan and Minussinsk in the Minussinsk depression, which extends over 16 000 km^2 and which is underlain by Devonian–Permian sediments. Exploration after World War II discovered several deposits and occurrences of uranium. Ten deposits of different types have been reported.

Representative deposits of sandstone type include Ust-Uyuk and Primorskoye, that of volcanic type, Solonechnoye, and that of vein-type, Labyshkoye. The Primorskoye and Ust-Uyuk deposits have resources in excess of 5 000 tU and ore grades in range of 0.1–0.3% U, whilst the others contain between a few hundred and a few thousand tonnes of uranium at grades of less than 0.1% U.

The estimated total resources of the Yenisey region are ~40 000 tU in the >US $130/kgU cost category. Since the mining of the small, low grade deposits is only possible at high cost, no exploitation is envisaged for the foreseeable future.

The Yenisey uranium region is an orogenic terrain characterized by depressions and uplifts. The cores of the uplifts are occupied by Proterozoic–Lower Palaeozoic granite–metamorphic complexes. These are locally mantled by early orogenic mafic and felsic continental volcanics of Lower Devonian age. Late orogenic continental sediments, predominantly pink sandy siltstone of Upper Devonian–Carboniferous age, fill the depressions. Portions of the older rocks are covered by Jurassic sediments. Major faults trend ENE–WSW, NNE–SSW, and N–S to NNW–SSE.

Primorskoye deposit

Primorskoye, which was discovered in 1970, is located 75 km north of Abakan. It is a tabular sandstone type deposit. Estimated resources are 7 600 tU with an average ore grade of 0.265% U.

Uranium exists in an alternating series of Upper Devonian claystone, siltstone and sandstone of lacustrine origin in the Minussinsk Basin. Mineralization is confined to 0.3–0.5 m thick lenses of grey, highly carbonaceous (up to few per cent carbon) sediments. The orebodies exhibit two patterns, ribbon-like in fluvial clay and sand facies within channel systems, and lenticular or irregular tabular associated with argillaceous limnic facies. Coffinite is the chief uranium mineral, with pitchblende occurring in minor amounts. The ore texture is finely disseminated. Grades of ore vary from 0.05 to 2% U. Isotope dating of the ore yielded an age range of 340–370 Ma.

Ust-Uyuk deposit

Ust-Uyuk, located ~300 km SE of Abakan, is a basal channel sandstone type deposit similar to Malinovskoye in the West Siberian region. Resources are estimated at 13 160 tU at 0.092 %U and assigned to the >US $130/kgU category.

A palaeochannel within the Tuvinsky Basin hosts the Ust-Uyuk. Host rocks are Upper Devonian alluvial sediments consisting alternating tuff, mudstone, siltstone and sandstone. The uranium phases are dominated by fine disseminations of coffinite; sooty pitchblende and pitchblende exist in minor quantities. Mineralization exists as elongated lenses as well as roll-shaped bodies often set at the boundary between grey and pink facies.

5.20.2.9. Ergeninsky district

The Ergeninsky region is in the Kalmyk Autonomous Republic in the SE of the European part of the Russian Federation. Elista is a major town in the region.

Thirteen deposits of uranium, 37 occurrences of uranium mineralization and numerous showings are clustered together in six ore fields covering an area of 70 km × 90 km. The mineralization is categorised as organic phosphate type. The geological setting and mineralization type are akin to similar deposits in the Pricaspian (Mangyshlak) district in western Kazakhstan, where this kind of uranium ore was mined earlier.

Estimated total resources in the Ergeninsky region are ~50 000 tU in the high cost category. Grades average 0.05% U but can be as high as 0.16% U. The Stepnoye deposit is the largest deposit in the district, with resources estimated at 19 100 tU.

Because of high recovery costs, the uranium deposits at Ergeninsky can just be regarded as a potential uranium resource, but its significant rare earth element and phosphate contents may constitute valuable by-products.

The Ergeninsky region is at the Karpinskiy swell in the northern sector of the Skifskaya Platform. Marine sediments of Lower Tertiary age are the main stratigraphic facies. These include lenses and seams of highly pyritic Upper Oligocene clays enriched in fossil fish bone detritus, chiefly from herring type fish and to a lesser extent from larger species such as sharks. These rocks are termed ‘fish strata’. The deposits consist of stratiform, tabular or lensoid orebodies situated at different horizons within the fish strata, in which uranium and other metals are confined to the phosphatic fish bones. Mineralization displays roughly the same features as similar deposits in the Pricaspian district in Kazakhstan.

Deposits vary in size from hundreds of metres to tens of kilometres in length and from a few hundreds of metres to a few kilometres in width. The uraniferous beds of most deposits vary from 0.2 to 1.5 m thick, except for Stepnovskoye which has a thickness of several metres. Most deposits have resources of the order of several hundred to several thousand tonnes of uranium.

Grades of ore generally range from 0.03 to 0.08% U but can reach up to 0.16% U. Associated components have average ranges of 0.15–0.70% rare earth elements, 0.008–0.06 % Mo, 0.02–0.16 % Ni, 0.01–0.03 % Co, 13–25 ppm Sc, 0.2–4 ppm Re. Phosphate ranges from 3.9 to 17.8% P_2O_5. Pyrite contents are high, as reflected in the presence of 5–18% S, increasing locally in some horizons to as high as 30% S.

The deposits are grouped in six ore fields, of which the Stepnovskoye deposit contains the most significant mineralization.

Stepnoye orefield

The Stepnoye orefield is situated in the SW part of the region and contains several uranium deposits or occurrences. The largest deposit is Stepnovskoye, which is very similar to deposits in the Pricaspian region of Kazakhstan. Mineralization is typified by high levels of pyrite, which is reflected in an average of 16% S and up to 25% S in some horizons. Other ore components include phosphorite, baryte, dolomite and ankerite. The Stepnovskoye deposit measures 11 km in length, 0.4–2.5 km in width and up to 6 m in thickness. Orebodies exist at depths of 170–700 m. Resources amount to ~20 000 tU. The ore comprises an average of 0.05% U, 0.23% rare earth elements, 0.12% Ni, 0.031% Co, 0.024% Mo, 1–4 ppm Re and 18 ppm Sc. The phosphate content is 4.8% P_2O_5.

5.20.2.10. Onezhsky (Lake Onega) district

The Onezhsky district, located near the towns of Petrozavodsk and Medvezhyegorsk in the Karelian Republic, extends along the northern shore of Lake Onega, ~400 km NE of St. Petersburg. Five vein–stockwork polymetallic vanadium–uranium deposits typified by high grades of vanadium and precious metal are reported: (i) Srednaya Padma, the largest and most extensively explored deposit, (ii) Vesenneye, (iii) Verhnaya Padma, (iv) Tsarevskoye, and (v) Kosmozero.

Reserves of the five deposits are cumulatively estimated at 9 000 tU in the high cost category, 351 000 t V_2O_5, 11 000 t Mo, 34 000 t Cu, 2850 kg Au, 3 650 kg Pd and 230 kg Pt. Average ore grades are 2.89% V_2O_5, 0.08% U, 0.48% Cu, 0.14% Mo, 0.2 ppm Au, 0.28 ppm Pd and 0.02 ppm Pt.

Exploitation of the Onezhsky deposits is based on vanadium and uranium recovery. Although not currently economically viable, the co-production of uranium, vanadium and precious metals may constitute a viable alternative.

The vanadium–uranium deposits in the Onezhsky district exist in the Onega epicratonal trough, a basin incised into the Archaean–Proterozoic metamorphics of the south-eastern Baltic Shield. The trough is filled by Lower Proterozoic volcano-sedimentary rocks. Dominant basin lithologies include bituminous shale (aleuroite, shungite), silty sandstone (aleurolites) or silty arkose, tuff and dolomite, which are weakly metamorphosed. The country rocks are cut by countless dolerite sills and dykes.

The volcano-sedimentary suite is folded and, locally, severely faulted. Fold axes are oriented roughly NW–SE. Anticlines measure 2–4 km in width and can be followed for 30–90 km. The anticline core is occupied by dolomite whereas the anticline limbs are comprised of schists. The dominant trends of major faults are E–W, N–S and NNW–SSE. They include both shallow and steeply dipping faults.

The deposits' position tends to be controlled by intervals of fold–fault dislocations where cataclastic and breccia zones have formed along northerly trending, steeply dipping faults and where they intersect with shallow dipping thrust faults.

Srednaya Padma deposit

Srednaya Padma is a polymetallic vein–stockwork type vanadium–uranium deposit. Estimated resources in the US $80–130/kgU cost category are 3 100 tU at an ore grade averaging 0.074% U.

Strongly altered arenitic and shungitic facies (aleurolites) host the deposit. These rocks rest on dolomite to the east of the deposit. A NNW–SSE oriented fault zone up to 20 m wide, steeply dipping to the west, shows a marked flexure and this inflicted intense fracturing on the aleurolitic rocks. Cataclasis is particularly marked where this structure is cut by a shallow easterly dippling fault. At this site, the cataclased terrain has formed into a wedge-shaped body, which is the main site of ore formation.

Shaly and silty host rocks (aleurolites) are pervasively altered by micazation, carbonatization and albitization as well as by pyritization and haematitization, forming halos around orebodies. Albitization is most widespread and commonly extends beyond mineralization. Products of carbonatization are largely ferruginous dolomite together with minor traces of ankerite and calcite. Authigenic micas are represented by a vanadium phlogopite (i.e., roscoelite) and a green chrome-bearing mica (i.e., chromian phengite).

Alteration exhibits a zonal pattern depicted by the following mineral assemblages, from the centre to the periphery: (i) mica–carbonate; (ii) albite–haematite–mica; and (iii) pyrite–dolomite–quartz–albite. The principal host to ore is the mica–carbonate zone whereas ores with low–medium grade exist in mica altered rocks of zone (ii). Albitized rocks of zone (iii) are typically devoid of ore.

Up to 85% of the alteration minerals is comprised by mineralized facies. Albite, comprising 14–61% and averaging 37%, is typically the most abundant alteration mineral in the ore-hosting rock. Carbonate contents range from 1% to 44% and average 21%. Ferruginous dolomite constitutes 1–41% of the carbonates, whilst the remainder is ascribed to ankerite and calcite. Micas range from 10 to 57% (average 26%), chlorite from 0 to 15% (average 3.5%), quartz from 1 to 31% (average 9%) and haematite from 1 to 8% (average 3%).

Mineralization at Srednaya Padma is polymetallic and includes uranium, vanadium, molybdenum, copper, bismuth, selenium, gold and platinum group metals. Associated gangue minerals are mostly carbonates (mainly ferruginous dolomite), albite and micas formed by the alteration phases described in the previous section. The following are the characteristic features of the ore components:

(a) *Uranium*: The chief uranium mineral is pitchblende. Hexavalent uranium minerals (vanadium–uranium minerals of the carnotite group, silicates of the uranophane group, hydrous uranates of the curite group) and coffinite exist in minor amounts. Flaky aggregates of uraniferous titanates are present intermittently; these contain 5–10% U. The following are the proportions of uranium minerals in ore: pitchblende ~65%, hexavalent uranium minerals ~20%, coffinite ~15%, and uraniferous titanates <5%. The proportion of pitchblende increases in high grade ore whereas the proportion of hexavalent uranium minerals and coffinite increases in low grade ore. Pitchblende displays a colloform habit. Aggregates of pitchblende fragments cement the mica and carbonate grains. Coffinite is quite pervasive and exists together with pitchblende as well as independently to form low grade ore. Streaks and nests of hexavalent uranium minerals are prevalent along oxidized fracture zones;

(b) *Vanadium*: The chief vanadium mineral is vanadium phlogopite (roscoelite), which contains 8–22% V_2O_5. Phlogopite exists as consistent disseminations and intimately linked with dolomite. Some vanadium occurs in chromium phengite as streaky and disseminated forms. A small amount of vanadium ore is related to vanadium-bearing haematite, containing 1–10% V, to vanadium oxides (karelianite, nolanite) and to uranylvanadates (calcio-carnotite, carnotite). The proportions of vanadium minerals in ore are as follows: vanadium micas 90%, haematite 7% and uranylvanadates 3%;

(c) *Molybdenum–copper*: The ore minerals include molybdenite, chalcopyrite and chalcosine, which are associated with pyrite, marcasite, sphalerite and galena. Molybdenum–copper mineralization is of erratic distribution. It tends to occur in the borders of low-grade vanadium–uranium ore lodes but can also occur away from these;

(d) *Precious metals*: These minerals include native gold, bismuthides (polarite, froodite), selenides (weibullite), and sulpho-selenides of palladium and bismuth, which exist as inclusions in clausthalite and other silver, lead and bismuth selenides. Precious metal mineralization is highly irregularly distributed, with the highest concentrations existing in mica–carbonate veins.

The ore minerals form interlinked stockworks and veins with interfering disseminations of ore within and contiguous to a steeply west dipping fault zone that splits dolomite from bituminous shale.

Dating of ore formation yielded an age of 1740 ± 30 Ma.

The total length of the Srednaya Padma deposit is 3 km. The deposit consists of two major orebodies set en échelon along a joint. Orebody 1 is cigar-shaped in plan with a wedge-shaped cross-section and a gentle dip. The orebody measures 1 060 m in length, up to 100 m in width and 50 m in height, and exists at depths of 100–200 m. The ore grade averages ~3% V_2O_5 and 0.13% U. Orebody 2 is confined to the steeply dipping fault zone in aleurolites and in some cataclastic bulges continuing from orebody 1. Orebody 2 measures 1 840 m in length, up to 20 m in width and persists at depths of 100–450 m. The grades average 2.4% V_2O_5 and 0.11% U. Orebody 2 accounts for 63% of the total vanadium and uranium resources but is unlike orebody 1 characterized by its lower ore grades.

5.20.2.11. Ladozhky (Lake Ladoga) district

The Ladozhky district is located to the NE of St. Petersburg in the north-western part of the Russian Federation. Two uranium deposits, Karkhu and Ratnitskoye, supposedly unconformity-type, are known.

Exploration dates back to the late 1970s when information on the high-grade unconformity-related deposits in the Athabasca region in Canada, and in the Alligator Rivers orefield in Australia triggered a search for this type of uranium deposit in the Baltic Shield area of the former Soviet Union. The above mentioned deposits were discovered as a result of this exploration. Although small in size, they indicate a potential for more deposits of the same kind.

The Ladozhky district is in the south-eastern part of the Precambrian Baltic Shield. The Karkhu occurrence is related to the Archaean–Middle Proterozoic unconformity. Mineralization occurs preferentially in arkosic sediments overlying weathered Archaean basement lithologies but extends, albeit in a limited way, into overlying Riphean sandstone and underlying basement. The principal uranium mineral is pitchblende. Associated minerals are sulphides of iron, zinc, molybdenum and copper. Wall rocks are altered by chloritization and carbonatization. Orebodies are 300–500 m long and 2–7 m thick. The average grade is 0.1% U but there are intervals which record 0.5% U over 7 m and sites with values of 8% U. Resources at Karku are estimated to be 10 080 tU at 0.132 %U. Prognosticated resources amount to 40 000 tU.

5.20.2.12. Bureinsky district

The district is located to the NW of the town of Chabarovsk in the Far East uranium region of the Russian Federation.

Nine small deposits of uranium are reported. Five of the deposits (Tigrovaya Pad, Svetloye, Skalnoye, Kamenushinskoye and Lastochka) are of volcanic vein–stockwork type and associated with Cretaceous felsic volcanics (felsite and rhyolite), akin to the deposits in the Streltsovsk district. Four of the deposits (Sularinskoye, Sentyabrskoye, Osenneye and Molodezhnoye) are of metasomatite vein–stockwork type hosted in Upper Palaeozoic rocks altered to albitite and beresite.

The estimated total resources of the Bureinsky district are ~29 000 tU in the high cost category, 4 000 tU of which are reasonably assured resources contained in the underground explored Lastochka deposit. The ore grades range from ~0.03 to 0.15% U.

The limited resources and low grades of the known deposits preclude further consideration with regard to economic viability. It would require a substantial increase in the world market price of uranium for these deposits to be rendered economic.

<u>Lastochka deposit</u>

Lastochka was discovered in 1965 in the southern part of the Bureinsky Massif, north of the Amur River. Khabarovsk is the closest town, 100 km SE of the deposit. The deposit is of volcanic vein–stockwork type. Resources have been estimated at 4 646 tU at a grade of 0.1–0.2% U.

Lastochka is associated with a small Upper Cretaceous caldera. Palaeozoic granites form the basement. Orebodies are hosted by felsite. The principal uranium minerals include pitchblende, sooty pitchblende, β-uranotile and uranophane

5.20.2.13. Khankaisky district

The Khankaisky district is located NE of Vladivostok in the Far East region of the Russian Federation. Four small deposits have been explored. The resources of separate deposits vary in size from several hundred to several thousand tonnes of uranium. Grades are less than 0.1% U. Speculative total resources of the Khankaisky district are reportedly 25 000 tU.

Fenix and Sinegorskoye are volcanic vein type deposits. These comprise uranium–molybdenum mineralization in quartz–sericite–hydromica/beresite altered Devonian rhyolite near a leucogranite body. Lipovskoye is a metasomatite vein–stockwork deposit contained in an albitized cataclastic zone measuring 50 m in width and situated within skarn altered Cambrian continental carbonate rocks adjoining Devonian granite. Rakovskoye is a basal channel sandstone type deposit and comprise elongated ore lenses measuring 1 km in length, 100 m in width and 5–10 m in thickness hosted in Cenozoic lignite-bearing sandstone filling palaeochannels incised into a granitic basement. Coffinite and sooty pitchblende are the principal ore minerals.

5.20.2.14. Volga–Ural region

The Volga–Ural uranium region, in the eastern central part of the Russian Federation, lies between the Urals to the east and the upper course of the Volga River to the west. In the eastern part of the area is the major town Ufa.

Numerous occurrences of uranium are known in the region. There are four types of deposit. All deposits contain uranium resources that are uneconomic were they to be mined by conventional methods. Whilst ISL might be feasible for some of the sandstone-type deposits, the commonly used sulphuric acid leaching process is not applicable for the bituminous carbonate deposits.

Uranium mineralization of the basal channel sandstone-type is present as ribbon-like, lenticular or tabular bodies hosted by fluvial channel and lacustrine sediments of Upper Permian age and composed of sandstone with interbeds of mudstone and siltstone. Grades typically do not exceed 0.01% U but can locally reach 1% U. Examples of deposits in fluvial channel and lacustrine sediments, respectively, are Cherepanoskoye and Vinogradovskoye. Both contain resources of a few thousand tonnes of uranium.

Vinogradovskoye is hosted in an aquifer within a palaeovalley comprising yellow and grey pyritic and carbonaceous permeable sandstone. The chief uranium mineral is coffinite, which is intergrown with concretionary pyrite and organic matter. Orebodies with grades of at least 0.01% U have elongate tabular shapes. The orebodies measure hundreds of metres in length, 100–200 m in width and up to 3 m in thickness. The average grade is 0.2% U. The ore also contains1–80 ppm Ag, 10–100 ppm Sc and 0.005–0.5% Mo.

Cherepanoskoye consists of low-grade mineralization (<0.03% U) of supposedly syngenetic origin hosted in black clay.

Uranium mineralization of bituminous carbonate type is represented by uraniferous bitumen filling joints and fractures either in limestone (e.g., Badielskoye) or in dolomite (e.g., Repyevskoye). Other occurrences of this type are Sukhobezvodnenskoye, Polomskoye, Chekanskoye, Neftyanik, Noznesenskoye, Zolnoye and Syzranskoye. The resources of separate occurrences vary between a few hundred and several thousand tonnes of uranium. Grades of uranium average several hundred parts per million.

Repyevskoye is hosted by a 10–20 m thick Upper Carboniferous dolomite horizon at the base of which occurs a clayey–sandy limestone layer several metres thick. The Carboniferous is overlain by Middle Jurassic strata comprising 10–15 m thick, interbedded mudstones, siltstones and sandstones which are overlain by Upper Jurassic argillaceous sands.

Mineralization exists at depths of 100–130 m in a zone of broken dolomite more than 1 500 m wide which is intersected by steep northerly dipping faults. Erratic sulphidization by iron disulphides and bitumenization by kerite and asphaltite are typical components of the zone. Uranium phases are ningyoite, coffinite and pitchblende, which associate with sulphides and bitumens.

The relationship between uranium and bitumens implies syngenetic formation. Oil is believed to be the source for the bitumens. The ore minerals coat or fill joints, fissures and other voids within roll-shaped or lensoid orebodies. Lensoid bodies measure 1–10 m in thickness and exist peneconcordantly at one or more superjacent levels. At faults, the lenses increase in thickness to as much as 20 m and become stacked roll-shaped bodies.

The structure of orebody is depicted by thin bands of higher grade ore with values reaching 0.4% U bound in low grade mineralization or barren rock. Ore grades range from 0.01% to 0.4% U and average 0.032% U. The ore also contains 0.01–0.6% V, up to 0.05% Ni, up to 0.05% Mo and up to 0.09% Se. Estimated resources are 1 500–5 000 tU.

Lignite type occurrences such as Mayachnoye, Babaevskoye, Golyusherminskoye and Gavrilovskoye consist of fracture-controlled epigenetic uranium in lignite of Quaternary age. Occurrences are small, with several hundred tonnes of uranium at grades of the order of 0.01% U.

Karinskoye represents surficial peat type mineralization, which is hosted in recently deposited peat. Grades are ~0.01% U and total resources are a few hundred tonnes of uranium.

5.20.2.15. Chukotsky district

The Chukotsky district lies in the extreme NE of the Russian Federation between the Bering Sea and the Arctic Ocean. Five deposits are recorded, four of them of the volcanic vein–stockwork type associated with Jurassic calderas (Severnoye, Keef, Chaika and Katumskoye), and one of the lignite type (Chaplinskoye) which is hosted in continental sediments of Jurassic age. All deposits have low ore grades not exceeding 0.1% U and are small, containing a few hundred to a few thousand tonnes of high cost uranium. Severnoye, located near the coast of the East Siberian Sea east of the settlement of Pevek in NE Siberia, was previously mined and is depleted now.

5.20.2.16. Stavropol district

The Stavropol district is located at the upper Kuma River in the northern foothills of the Caucasus region, to the south of the town of Stavropol, in the southern Russian Federation. Even though radioactivity had been reported here as early as 1907, uranium was discovered only in 1946. Mining began in 1951 and stopped in 1989.

The deposits are of the structurally-controlled volcanic type. Two of the larger deposits, Beshtau and Bykogorskoye (or Byk), and the small Zmeika deposit were exploited. Mining was achieved by two underground and one open pit mines. Total production was 5 700 tU, 1 770 tU of which were recovered by underground block leaching and 3 930 tU by conventional mining. Beshtau was depleted in 1975, Bykogorskoye in 1989. A mill exists at Lermontov (Zheleznovodsk), which not only treated ore from the Stavropol district but also from the Melovoye deposit in Kazakhstan and the Vatutinskoye deposit in Ukraine. Uranium beneficiation stopped in 1991 and since then the plant processed apatite concentrate. The operator, a State-owned company, is S.C. 'Almaz Lermontov Mining and Chemical Production Enterprise'.

The uranium district is situated within the uplifted basement block of Palaeozoic metamorphics, which is enveloped by Mesozoic–Cenozoic sediments and intruded by Late Miocene subvolcanic laccoliths and intrusive bodies. The magmatic rocks vary in composition from largely trachyrhyolite and rhyolite to quartz syenite, granosyenite porphyry and granite porphyry.

Uranium mineralization is associated spatially and temporally with the Miocene volcanics. Orebodies are controlled by structures and exist as stockworks and veins that especially concentrated within and contiguous xenoliths of bituminous sediments within the apex of rhyolitic bodies.

Pronounced supergene alteration affected the ore-bearing structures and intensely oxidized the mineralization to a considerable depth. Consequently, uranium mainly exists in hexavalent uranium minerals. Primary coffinite and pitchblende exist as scarce remnants.

Trachyrhyolite and rhyolite are regarded as the source of uranium. These lithologies have a uranium background 4–5 times higher than the respective Clarke values.

5.20.2.17. Beshtau deposit

Uranium exists in the Beshtau Mountains. The Beshtau deposit comprises a 12 km^2 laccolith of trachyrhyolite and rhyolite with xenoliths of Middle–Upper Palaeogene marl, limy clay and grey clay with fish bones and Lower Cretaceous limestone and sandstone. Faults strike NE–SW and N–S. A major N–S fault divides the Beshtau area into two portions. Agillitization and oxidation are the major modes of wall rock alteration.

Uranium ore occurs in stockwork and vein systems, locally termed ‘skala’, where the major N–S fault intersects NE–SW faults with high angle. Four of these structural systems, i.e., Diagonalnaya, Bezymyannaya, Galenite and Otenite, contained the bulk of the Beshtau reserves.

The Galenite vein system measures 1 000 m in length and continues over a vertical interval of 300 m. The largest orebody has a stock-like shape, with dimensions of 40 m × 70 m and 120 m deep.

The bulk of the ore occurs within the oxidized parts of the orebody. The chief uranium mineral at depth is sooty pitchblende, which is associated with fluorite and clay minerals. At the upper levels, uranophane, torbernite and autunite prevail. Primary coffinite and pitchblende exist only as remnants within hexavalent uranium minerals. Only a few small veins in sedimentary rocks consist exclusively of coffinite and pitchblende.

5.20.2.18. Geological areas favourable for uranium ore formation

During the different phases of exploration, which became more intensive after World War II, a total of over 100 uranium deposits of different sizes and grades were discovered in 15 districts. Not all of them are commercially viable. However, their features are important as a guide for use in detecting economic deposits.

The UDEPO [20.4] report for the Russian Federation lists 79 uranium deposits. Of this total, 21 are sandstone deposits (basal channel (13), roll front (6), tabular (2)) and 20 are vein deposits. The next most common type are volcanic deposits (15). Ten deposits are assigned as metasomatite and five each as surficial and lignite type. One deposit each is assigned to the unconformity and phosphorite type, and there is one unassigned type.

By region, the most important geological environment is located within the Streltsovsk uranium district, which is located near Krasnokamensk in the Transbaikalia region. The district coincides with the Streltsovsk caldera, a volcano-sedimentary complex of Upper Jurassic–Lower Cretaceous age in the Mongolian-Argunian intracontinental volcanic belt, which formed during Mesozoic tectono-magmatic activation.

The 2007 Red Book [20.5] identifies 19 deposits of the volcanic caldera-related type. The uranium ore occurs as vein–stockwork type mineralization in an Upper Jurassic caldera filled with acid to intermediate volcanic and volcanogenic sediments. Uranium was discovered in the area in the 1960s and PPGHO commenced mining in 1968. The first deposits were mined by open pit and these are now depleted. Currently, all mining is underground.

In Archaean basement host rocks in the south of the Republic of Sakha Yakutia, a number of large metasomatite type deposits were found in 1960s. These are centred on the Elkon uranium district. The most significant uranium resources of the Elkon district were identified as being hosted by five deposits in the Yuzhnaya zone, with resources totalling 296 000 tU. The uranium grade averages 0.15%. Gold, silver and molybdenum are by-products.

The location, shape and dimensions of uranium orebodies are primarily controlled by NW–SE oriented and steeply SW dipping ancient faults that were reactivated during the Mesozoic and also by feldspar metasomatic alteration. The country rocks are Archaean gneisses. Exploration has been conducted recently.

Deposits of the unconformity-related type are rare. So far, only one mineralized zone at the Karhu (Karkhu) deposit in the Baltic Shield has been identified. However, there is some potential for deposits of this type in Eastern Siberia (i.e., Yenisey Ridge, Eastern Sayan, Nichat, Torgoy, Bulbukhta, Akitkan).

Sandstone type basal channel deposits amenable to ISL mining are located within the Transural and Vitim uranium districts. The most significant deposits of the Transural district exist in the southern part of the district, south of Kurgan. These include Dalmatovskoye (10 200 tU of reasonably assured resources), Dobrovolnoye (7 400 tU of reasonably assured resources plus EAR-I) and Khokhlovskoye (10 000 tU of speculative resources). Ore grades vary in the range 0.01–0.05% U.

The Transural uranium district lies in the SW sector of the West Siberian Platform. The district is typified by Middle–Upper Jurassic palaeochannel systems occupying the south-western alluvial coastal plain of the Jurassic sea in the eastern foreland of the Caledonian Urals. The channels were cut into a basement of Devonian marine and continental sediments, and felsic volcanics

The uranium deposits in the Vitim district are located within the Khiagda orefield, which is situated 160 km north of Chita in the Republic of Buryatia. The orefield includes eight closely spaced deposits with similar geology. The distance between deposits is 1.5–6.0 km. Khiagdinskoye, the largest deposit, contains ~15 500 tU at a grade averaging 0.05% U. However, there are no exact boundaries between deposits. Each of them includes several closely situated orebodies. Mineralization exists in permeable poorly indurated Neogene fluvial sediments which fill the palaeovalleys of rather narrow streams. The basement is represented by Palaeozoic granite. Neogene–Quaternary basalt overlap with ore hosting sediments.

5.20.3. Uranium exploration

5.20.3.1. Historical review

Systematic exploration for uranium began in 1944. In 1946, the first deposits were found in the Stavropol district in the Caucasus and in the Yenisey area of western Siberia. Subsequently, in 1961, uranium was found in the Aldan district and, in 1963, in the Streltsovsk district in the Transbaikalia district. These discoveries were followed by others in the Transural and Vitim districts in the late 1960s and 1970s. The last major prospects were found in the Onezhsky and Ladozhky districts in the early 1980s.

Data for exploration undertaken in the individual republics that comprised the former Soviet Union are not available. Estimates of exploration expenditure that are available for the period 1945–1990 for the former Soviet Union total around US $2.6 billion [20.5].

Tables 5.11 and 5.12 provide details of annual exploration expenditures and drilling campaigns for the Russian Federation [20.5–20.7].

5.20.3.2. *Drilling effort*

Information for the period prior to the dissolution of the Soviet Union are available only for multi-year periods. For 1945–1950, drilling totalled 403 km; for 1951–1960: 7 784 km; for 1960–1970: 20 277 km and for 1970–1990: 88 151 km [20.7]. A breakdown of drilling effort for individual republics became available after this period. For the Russian Federation, details of exploration drilling are given Fig. 5.38 indicating a total of USD$1 087 million and 3 477 447 metres of drilling.

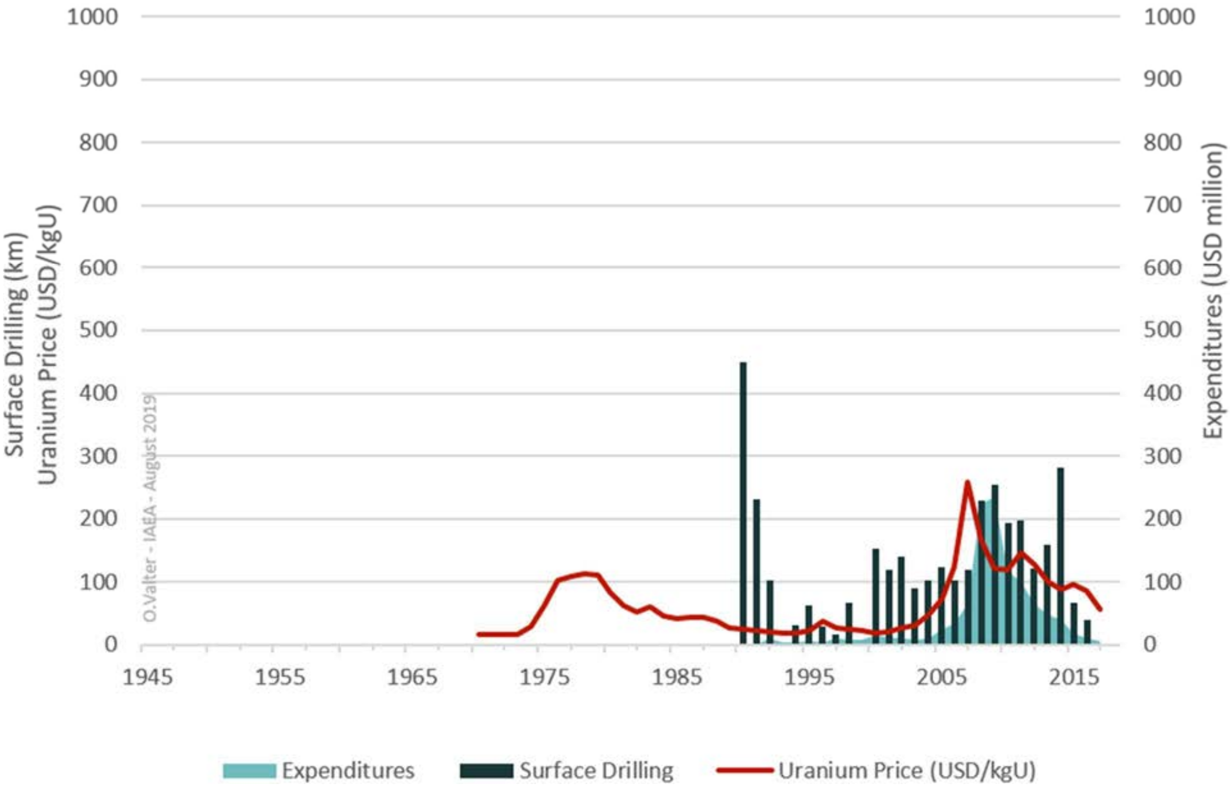


FIG. 5.38. Domestic uranium exploration data for Russia, including former Soviet Union. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

5.20.3.3. *Recent and ongoing uranium exploration activities*

Exploration for uranium is funded from the State budget by the Federal Subsoil Resources Management Agency. Funding in 2005 increased more than threefold compared with 2003. In 2006, the financing increased by yet another 35% to US $33.5 million. In subsequent years, further increases were made, reaching US $253.4 million in 2009. The executing organizations were the territorial subsidiaries of the 'Urangeologorazvedka' – the Federal State Enterprise – as well as Sosnovgeo, 'Chitageologorazvedka' and 'Koltsovgeologia'. Exploration for uranium was carried out as part of the Long-Term State Programme of Subsoil Exploration and Mineral Resources Replenishment (8 June 2005, Ministry of Natural Resources of the Russian Federation). Operations since the early 2000s up to the present-day have focused on the following three deposit types:

(i) Sandstone basal channel type, amenable for ISL mining in the Vitim (Republic of Buryatia) and Transural (Kurgan region) uranium ore districts, at the Balkovskoye deposit (Republic of Kalmykia) and on the Chukotka Peninsula;
(ii) Unconformity type in Eastern Siberia (Akitkan, Bulbukhta, Nichat-Torgoy, Eastern Sayan and Yenisey Ridge districts), the north-western (Baltic Shield) and central (Voronezh Massif) regions of the western Russian Federation;

(iii) Vein–stockwork and volcanic types in the southern Priargun district (Chita region).

Exploration generated promising outcomes in those areas favourable for the occurrence of sandstone type deposits. New favourable areas for vein–stockwork and unconformity types of mineralization were likewise identified in eastern Siberia. Exploration in 2007 and 2008 resulted in increases in prognosticated resources to 182 000 tU (<US $130/kgU) and speculative resources to 633 000 tU (unassigned costs).

In addition to the geological exploration activities in new areas undertaken by the Federal Subsoil Resources Management Agency, the uranium producer ARMZ conducted, in the period 2005–2012, detailed exploration of existing deposits to re-evaluate their resources and move them to higher confidence categories. As a result of detailed exploration, a significant increase in RAR (C1 in Russian classification) was noted for the Khokhlovskoye deposit in the Transural district, for the Khiagda orefield deposits in the Vitim region, and for some promising deposits in the newly developed Elkon district. Exploration activities in the Streltsovsk district were targeted on the discovery of new deposits.

The ARMZ, through its joint venture with Kazatomprom Akbastau, explored in 2008 areas 1 and 3 of the Budennovskoye deposit in Kazakhstan and generated a resource database. The Akbastau planned in 2009 to finish exploration in area 1, as well as resume exploration in area 3 and of the Budennovskoye deposit [20.5, 20.7].

5.20.3.4. Recent mine development activities

Since 2000, JSC Khiagda has carried out plot test work at the Khiagda deposit (Vitim region of the Republic of Buryatia). In 2006, 26.5 tU was produced and in 2007 and 2008, Khiagda produced 26 and 61 tU, respectively. In 2008, exploration started in the adjoining Namaru and Vershinnoye deposits. JSC Khiagda’s feasibility study with regard to achieving a 1 000 tU/year capacity is under review by State authorities. In 2008, the capacity at Khiagda was expanded. Commercial mining is planned for 2012 with production expected to reach 1 000 tU by 2014 and 1 800 tU by 2018.

At Dalur (Khokhlovskoye deposit), pilot ISL operations started in October 2007, thereby confirming the viability of ISL technology.

In 2006–2007, work centred on the pre-feasibility study of the Elkon region (assessment of mining and processing technologies, development of production facilities, environmental monitoring plans and preparation for public hearings). In November 2007, ARMZ established the Elkon Mining Company. A feasibility study of the Yuzhnaya Zone, where the principal resources are located, is continuing. The Lunnoye Company was established in 2006 to exploit a gold–uranium deposit in the area. A preliminary technical and economic assessment for the Berezovoye, Gornoye and Olovskoye deposits in eastern Transbaikalia has been carried out and in December 2007 ARMZ established mining companies for each of the three deposits.

Since 2009, Russia continues uranium exploration activities, aiming of new deposit discoveries (Buryata, Tans-Baikal and Irkutsk regions), development of earlier discovered deposits and expansion of the resource base near existing production centres (Khiagda, Priargunsky). Large resources (>300 000 t U) continued to be defined in metasomatites of the Elkon District were uranium is associated to gold.

Abroad, through Uranium One, Russia performs exploration activities in Kazakhstan (at Akdala, Southern inkai, Khorasan and Zarechnoye) and in Tanzania (Mkuju River project).

5.20.4. Uranium resources

5.20.4.1. Identified resources

On two occasions, in 2005–2006 and again in 2007–2008, resources were re-classified as the result of a comprehensive technical and economic evaluation of deposits explored in the past 50 years and classified as so-called ‘non-balance sheet’ resources, which were excluded in the national inventory of the State Committee for Resources. Their re-evaluation led to a reclassification of those which have the potential to be economically viable. The historical trends in identified resources are shown in Fig. 5.39 and Fig. 5.40.

As of 1 January 2017, recoverable identified resources (RAR and IR) recoverable at a cost of <US $260/kgU amounted to 656 000 tU, of which 39 800 tU are recoverable at a cost of <US $80/kgU. In 2017, no resources were classified as recoverable at <US $40/kgU.

Reasonably assured resources amount to 214 500 tU, recoverable at <US $130/kgU (Table 5.11). The bulk of this total is likely be mined by conventional methods. Nearly all resources in this category are ascribed to the existing and committed mining centres [20.5, 20.8].

Inferred resources amount to 396 900 tU, of which ~4% are recoverable at costs of <US $80/kgU and are mineable by conventional underground and ISL methods (Table 5.12) [20.8].

The UDEPO database lists the most significant deposits for the Russian Federation as Kotlovskoe, Druzhnoe, Elkonskoe Plateau, Streltsovskoe, Severnoe, Kurung, Neprokhodimoe, Elkon, Argunskoe.

TABLE 5.11. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE (tU) [20.8]
(As of 1 January 2017)

Deposit type	<US $40/kg U	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	24 535	24 535	24 535
Vein (granite-related)	0	0	1550	1550
Intrusive	0	0	0	45 424
Volcanic and caldera-related	0	0	75 628	75 628
Metasomatite	0	0	103 982	103 982
Phosphate	0	0	8850	8850
Total	0	24 535	214 544	259 968

TABLE 5.12. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [20.8]
(As of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	0	15 293	15 293	52 075
Vein (granite-related)	0	0	2686	5689
Intrusive	0	0	0	34 701
Volcanic and caldera-related	0	0	29 036	42 683
Metasomatite	0	0	221 252	256 268
Phosphate	0	0	2775	5475
Total	0	15 293	271 042	396 891

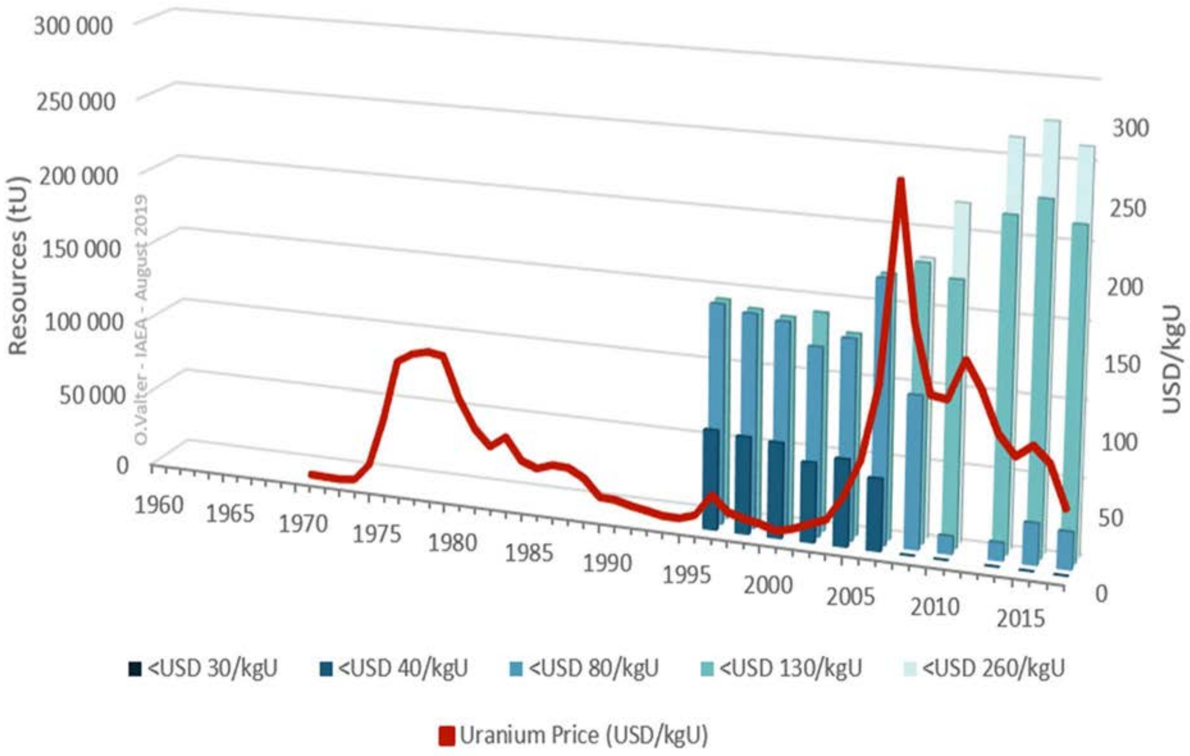


FIG. 5.39. Historical variation of recoverable reasonably assured resources within various cost categories in the Russian Federation. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

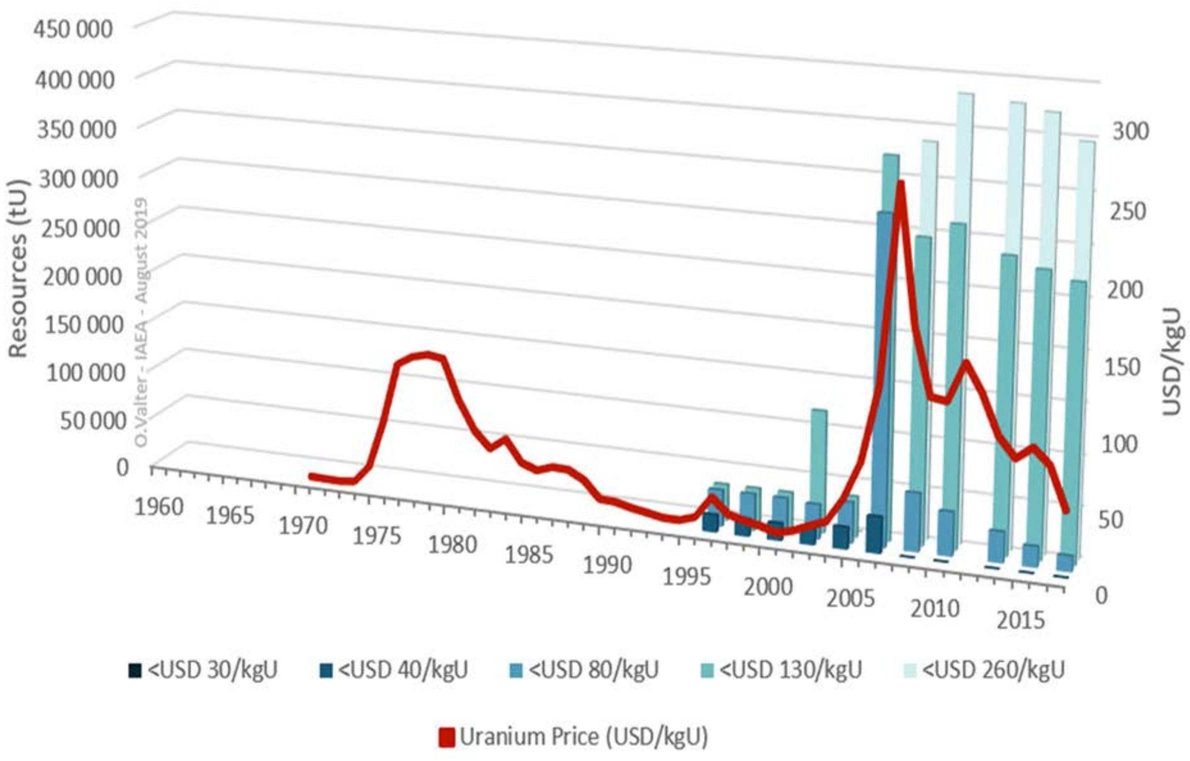


FIG. 5.40. Historical variation of recoverable inferred resources within various cost categories in the Russian Federation. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

5.20.4.2. Undiscovered resources

As of 1 January 2017, prognosticated resources totalled 143 900 tU and speculative resources totalled 591 100 tU. Most of the prognosticated resources exist in the Chita region (east Transbaikalia and Streltsovsk districts), the Republic of Sakha Yakutia (Elkon district), the Republic of Buryatia (Vitim district), and the Republic of Kalmykia. Some prognosticated resources occur in the regions of Leningrad and Kurgan.

5.20.5. Uranium production

5.20.5.1. Historical review

Uranium was first produced by the Lermontov complex (‘Almaz Lermontov Mining and Chemical Production Enterprise’). Almaz is situated 1.5 km from the Lermontov town, in the Stavropol district. This district includes the Byk and Bestau vein deposits, which have been depleted. Their original resources totalled 5 300 tU at an average grade of 0.1% U. Extraction, which started operation in 1950, was effected by two underground mines. The Beshtau mine ceased operation in 1975 and the Byk mine in 1990. The ore was processed locally using sulphuric acid leaching. This plant has been operational since 1954. In the period 1965–1989, block or stope leaching was also utilized.

Since the 1980s until 1991, uranium ore shipped from Kazakhstan and Ukraine was likewise processed at Almaz. Production from local deposits amounted to 5 685 tU, with 1 755 tU extracted by a combination of different leaching technologies and 3930 tU by underground mining. During 1968–1980, 440 tU was generated by ISL from the Sanarskoye deposit in the Transural district. This project was operated by the Malyshevsk Mining Enterprise.

Priargunsky Production Mining and Chemical Association (PPGHO) is located in the Chita region, near Krasnokamensk. Production has been derived from 19 volcanic deposits in the Streltsovsk uranium district (an area of 150 km^2), which have an global average grade of ~0.2% U. Mining started in 1968 with extraction from two open pits (now both depleted) and the currently active underground mines 1, 2 and 4. Milling and processing has been undertaken since 1974 using sulphuric acid leaching, with recovery effected by a combination of solvent extraction and ion exchange. Since the 1990s, low grade ore has been processed by block and heap leaching.

Greater than 100 000 tU has been generated from the Streltsovskoye deposits, one of the world’s most productive uranium districts. Cumulative production through 2007 totalled around 135 000 tU, making the Russian Federation the fifth largest uranium producer in the world, based on historical production (Fig. 5-19.5) of 74 004 tU.

A breakdown for 2007 is given as: Streltsovskoye (3 037 tU), Dalmatovskoye (350 tU) and Vitim (Khiagda) (26 tU). For 2008, the following production is reported: Priargunsky (3 050 tU by conventional mining and 219 tU by heap leaching), Dalur (Kurgan) (410 tU by ISL) and Khiagda (61 tU by ISL). The total to the end of 2008 includes production prior to 1992, for which details are not reported officially; however, estimates are given in Ref. [20.8-20.11].

5.20.5.2. Status of production capability

Uranium production is administered by Rosatom, the Federal Agency for Nuclear Energy. Until 2007, three Russian uranium producing companies (Khiagda, Dalur, Priargunsky) were the spin-off companies of TVEL Corporation, whose principal trade is fabrication of nuclear fuel. Techsnabexport (TENEX) – the Russian exporter of low enriched uranium – has a 49% share in JV Zarechnoye, a joint venture between the Russian Federation, Kyrgyzstan and Kazakhstan. The joint venture is based in Kazakhstan. TENEX has also been involved, since 2006, in new uranium exploration and mining projects in the Russian Federation and elsewhere. As part of the Russian nuclear industry restructuring programme, the State company Atomenergoprom was established in 2007 to combine all entities of Rosatom which operated in the civil nuclear sector, from production of uranium to generation of power.

Atomredmetzoloto, designated as the chief producing company for uranium, is accountable for uranium supply and uranium mining activities. As such, it will administer the uranium mining assets owned formerly by TENEX and TVEL. Atomredmetzoloto is now a section of Atomenergoprom.

In 2008, production totalled 3521 tU, of which 471 tU was generated by ISL and 3050 tU by conventional underground mining methods. For 2009, estimated production totalled 3611 tU.

Historical uranium production in the Russian Federation after the dissolution of the Soviet Union (from 1992 to 2017) amounts to 74 004 tU. Total production, including those during 1950–1992 at all Russian centres, amounted to nearly 164 904 tU.

PPGHO is the major production centre, producing from the volcanic deposits of Streltsovskoye from a resource base of 130 000 tU (in situ). Production of uranium in 2009 generated 3 565 tU. Uranium ore is extracted from three underground mines. Most of the ore is processed at the local hydrometallurgical plant using traditional ion exchange resin sorption and sulphuric acid leach technology. Some uranium (190 tU per year) is generated by in place and heap leaching methods. A new radiometric ore sorting plant was commissioned in 2006, and the expansion of heap leach processing and completion of a new sulphuric acid plant was planned in 2008.

Since 2004, a commercial ISL operation has been under development by the Dalur Company, in the Kurgan region, and initially focused on the Dalmatovskoye deposit. The new processing plant, with an annual capacity of 1 000 tU, became operational in 2006 and production of uranium had increased to 500 tU by 2010. The processing unit built on the central site will form the basis for development of the other nearby deposits. It will process production solutions from the Dalmatovskoye deposit and pregnant eluates from the local sorption units of Khokhlovskoye and Dalmatovskoye deposits. The Dalur Company produced 410 tU in 2008, and it is anticipated to produce 460 tU in 2009. It has also commenced design and engineering works to prepare the Khokhlovskoye deposit for pilot development.

In 2008, pilot ISL production started at the Khiagda mine with a plant with a capacity of 300 tU/year.

Figure 5.41 and Tables 5.13 and 5.14 summarize the salient technical details at the various production centres.

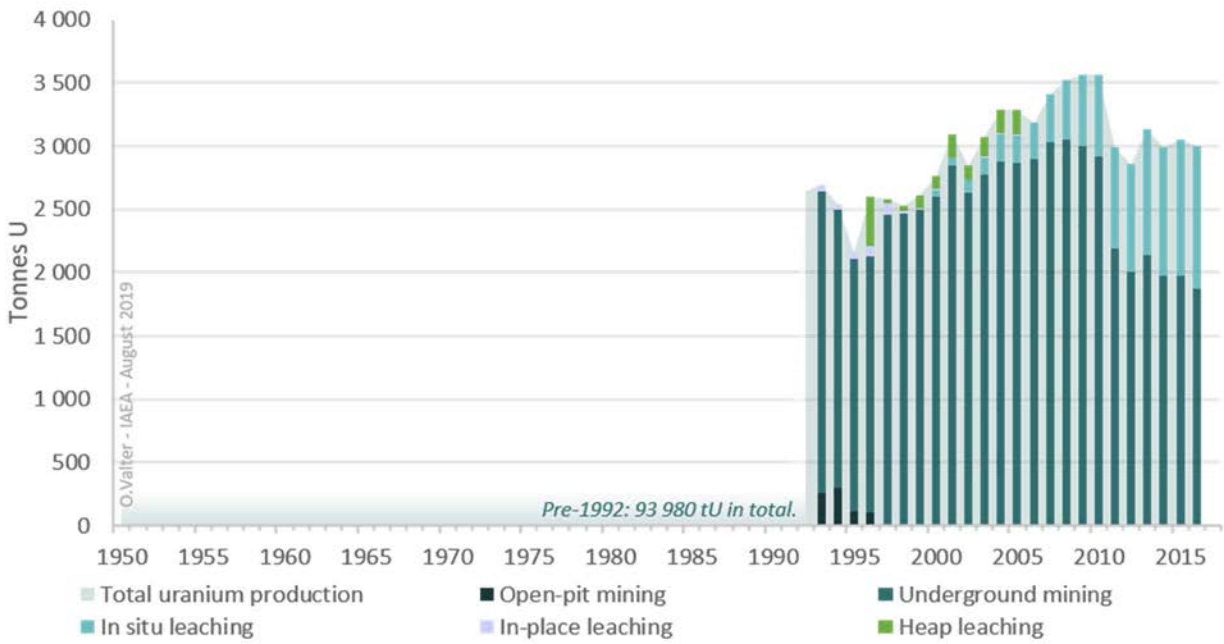


FIG. 5.41. Historical uranium production in Russia according to production methods [20.5, 20.7–20.10, 20.12–20.14].

Total production has been 167 904 tU including 59 686 tU from underground mining, 9 018 tU from in situ leaching (ISL), 1 503 tU from heap leaching, 766 tU from open cut mining and 391 tU from in-place block leaching. All production is owned by the Government.

5.20.5.3. Short-term production capability

The present level of production of around 3 500 tU/year may be increased to more than 4 000 tU/year by 2020. An increase to 7 600 tU/year is estimated beyond 2020 and a level between 5 000 and nearly 10 000 tU/year could be sustained if planned expansions are achieved.

TABLE 5.13. URANIUM PRODUCTION (CENTRES 1–3) TECHNICAL DETAILS [20.7]
(As of 1 January 2009)

	Centre #1	Centre #2	Centre #3
Name of production centre	PPGHO	Dalur	Khiagda
Production centre classification	Existing	Existing	Existing
Startup date	1968	2004	2011
Source of ore:			
Deposit name	Antei, Streltsovskoye, Oktyabrskoye, etc.	Dalmatovskoye Khokhlovskoye, etc.	Khiagda, Vershinnoye, etc.
Deposit type	Volcanic (in caldera)	Sandstone (basal channel)	Sandstone (basal channel)
Resources (tU)	129 530	10 970	26 805
Grade (%U)	0.18	0.04	0.05
Mining operation:			
Type	UG[a], HL[b], IPL[c]	ISL[d]	ISL
Size (t ore/d)	6 700	n.a.[e]	n.a.
Average mining recovery (%)	95	75	75
Processing plant (acid/alkaline):	acid	acid	acid
Type	IX[f]	IX	IX
Size (t ore/d)	4700	No data	No data
Average process recovery (%)	95	98	98
Nominal production capacity (tU/year)	3 000	800	1 000
Plans for expansion (t/year)	3 500	None	1 800

[a] UG: underground mining.
[b] HL: heap leaching.
[c] IPL: in place leaching.
[d] ISL: in situ leaching.
[e] n.a.: not available.
[f] IX: ion exchange.

5.20.5.4. Future projects

To increase production of uranium, PPGHO is preparing a feasibility study of a new mine (No. 6) to extract uranium from three deposits with a total resource of ~43 900 tU (in situ), including the Argunskoye vein deposit (37 400 tU). The feasibility study will consider the construction of a mine complex and heap leaching unit, as well as a mill upgrade and erection of a new autoclave carbonate leaching circuit. To increase the resources of uranium, PPGHO is undertaking geological exploration at the flanks and at deeper levels in the southern Priargun province and in the Streltsovsk orefield. The new developments include the Gornoye vein deposit (17 000 tU at 0.25% U) and the Olovskoye volcanic deposit.

In the Vitim area of the Republic of Buryatia, the Khiagda Company continues with the development of ISL operations to treat basal channel type mineralization. Startup is due in 2011. The nominal capacity is set at 1 000 tU/year with the potential to expand to 2 800 tU/year.

The principal source of uranium supply to 2010 will be derived from the development of uranium production at prevailing mining sites [20.7]. As a consequence of a major upgrade of the current facilities and commissioning of the No. 6 mine, the yearly production of PPGHO is anticipated to rise to 5 000 tU by 2015. By 2011, Dalur is anticipated to reach a yearly capacity of 1 000 tU, and by 2015 Khiagda should achieve a yearly capacity of 2 000 tU. Therefore, the total yearly production of uranium by the three companies should amount to 8 000 tU by 2015 [20.7].

In 2016, uranium production was 1 873 tU from PPGHO (underground mining) and 1 132 tU from Dalur and Khiagda (ISL mining) [20.15].

The largest uranium producing centre in the Elkon uranium district was originally planned for a yearly capacity of 5 000 tU by 2020 [20.7]. Established in 2007, the Elkon mining company was to carry out the entire spectrum of work related to mining, milling, sorting, processing of uranium ore, and production of uranium oxide. It was intended that the company undertake underground development of the Druzhnoye, Neprokhodimoye, Kurung, Elkon Plateau and Elkon deposits

TABLE 5.14. FUTURE URANIUM PRODUCTION (CENTRES 4–6) TECHNICAL DETAILS [20.7]
(As of 1 January 2009)

	Centre #4	Centre #5	Centre #6
Name of production centre	Elkon	Gornoye	Olov
Production centre classification	Stand-by	Standby	Standby
Startup date	n.a.[a]	n.a.	n.a.
Source of ore:			
Deposit name	Yuzhnoye, Severnoye, etc.	Gornoye, Beryozovoye	Olovskoye
Deposit type	Metasomatite	Vein in granite	Vein in granite
Resources (tU)	319 594	7 918	11 726
Grade (%U)	0.15	0.2	0.082
Mining operation:			
Type	UG[b]	UG, HL[c], IPL[d]	UG, HL, IPL
Size (t ore/d)	8 000	1 900	3 000
Average mining recovery (%)	85	70	70
Processing plant:	Acid	Acid	Acid
Type	IX[e]	IX	IX
Size (t ore/d)	No data	No data	No data
Average process recovery (%)	95	80	80
Nominal production capacity (tU/year)	5 000	600	600
Plans for expansion	Exploration of the Elkon district deposits	None	None

[a] n.a.: not available.
[b] UG: underground mining.
[c] HL: heap leaching.
[d] IPL: in place leaching.
[e] IX: ion exchange.

Two mines in Transbaikalia are anticipated to attain by 2016 a total yearly capacity of up to 1 200 tU [20.9]. One mine, with an annual capacity of 600 tU, will exploit the Beryozovoye and Gornoye deposits in Transbaikalia (Chita region) using traditional underground mining techniques and heap leaching. The other mine, also with an annual capacity of 600 tU, will exploit the Olovskoye deposit (also in the Chita region) using open pit and underground mine and heap leaching. After a pre-feasibility study, a feasibility study was prepared in 2008 and construction was anticipated to commence in 2010. Two mining companies (Gornoye and Olovskoye) were established in 2007. However, both projects were mothballed owing to unfavourable market conditions. The resultant shortfall in production will be made up from the development of other deposits in the Russian Federation.

Aside from the expanded domestic supply of uranium, production increases may come through a Canadian based company, Uranium One, which is a wholly owned subsidiary of Uranium One Holdings N.V., which, in turn, is an entirely owned subsidiary of Rosatom, the Russian Federation's State Corporation for Nuclear Energy.

In Kazakhstan, Uranium One has a 70% interest in the Betpak Dala joint venture, which owns the Akdala and South Inkai mines. The company also owns a 50% interest in the Karatau joint venture, which owns the Karatau mine, and a 30% interest in the Kyzylkum joint venture, which owns the Kharasan project. In December 2010, Uranium One acquired a 50% interest in the Akbastau joint venture, which owns the Akbastau mine, as well as a 49.67% interest in the Zarechnoye joint venture, which owns the Zarechnoye mine. In the United States of America, the company owns 100% of the Willow Creek Project and has several development projects in the Powder River and Great Divide Basins in Wyoming. In Australia, the company owns a 100% interest in the Honeymoon Uranium Project.

5.20.6. Environmental activities

Detailed descriptions of environmental activities are given in Refs [19.11, 19.16, 19.17]. In the Stavropol region, uranium mining was carried out by the 'Almaz Lermontov Mining and Chemical Production Enterprise' between 1950 and 1990, producing a total of ~5 300 tU from the Beshtau mine (closed 1975) and the Byk mine (closed 1990). Uranium was recovered from ore by sulphuric acid leaching, heap leaching and ISL. In addition, ores from the deposits of Vatutinskoye (Ukraine) and Melovoye (Kazakhstan) were processed. The total production was 5 685 tU.

Environmental activities carried out at the sites included control of emissions to air and water and management of waste rock dumps. Rehabilitation activities continued until 2005–2006. Monitoring for radionuclides and toxic components is ongoing.

In the Chita region, PPGHO has been involved in the ongoing mining of several deposits at Streltsovskoye since 1974. To protect the mine/mill sites and the town of Krasnokamensk, located 10–20 km from the mine/mill sites, extensive environmental activities are carried out. More than 100 000 tU have been produced, which created large quantities of tailings (more than 40 million t) and waste rock (more than 150 million t). All contaminants originating from the various sources have been controlled by environmental assessment projects over many years and these have been intensified in recent years. Monitoring programmes target the release of contaminants to the atmosphere, groundwater and land surface.

5.20.7. Employment in the uranium industry

The total count of personnel engaged in uranium producing companies in the Russian Federation in 2006 was 12 575, of which 304 worked for Dalur and 12 271 for PPGHO. Of the PPGHO personnel, 4 804 were involved directly in uranium production and processing, whilst the others laboured in support units (production of coal, manufacture of acid, machinery and other services) (Fig. 5.42)

FIG. 5.42. Uranium industry employment at existing production centres in the Russian Federation [20.7–20.17].

References to Section 5.20

[20.1] BUNDESANSTALT FÜR GEOWISSENSCHAFTEN UND ROHSTOFFE, Russische Föderation, Rohstoffwirtschaftliche Länderstudien **3**, Hannover (2003) 230.

[20.2] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Russia, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[20.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524.

[20.4] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[20.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[20.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[20.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[20.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[20.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[20.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[20.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).

[20.12] [BOYTSOV A., "ARMZ (Atomredmetzoloto), Status and Plans for Uranium Mining Development", World Nuclear Association Nuclear Fuel Cycle Plenary Session, London (3 March 2008).

[20.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[20.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[20.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[20.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999).

[20.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002).

5.21. SERBIA

5.21.1. Geography

Serbia is a landlocked country on the Balkan Peninsula in south-eastern Europe. It borders Romania, Bulgaria, the Former Yugoslav Republic of Macedonia, Montenegro, Bosnia and Herzegovina, Croatia and Hungary. Serbia consists of fertile plains of the Vojvodina province in the north, limestone ranges and basins in the east and the mountainous ranges of the Dinaric Alps (Dinarides) to the south. The north is dissected by the River Danube, on which Belgrade is located. Other important rivers are the Tisa, entering the country from Hungary, and the River Morava running S–N. Both are tributaries of the Danube. About 22% of the country is arable and a similar proportion is forested [21.1].

5.21.2. Geology

5.21.2.1. General

The geology of Serbia is characterized by different tectonic units (Fig. 5.42), including the sedimentary Pannonian Basin to the north; the Dinarides with karst limestones; the Vardar Zone, including ophiolite belts; the Serbo-Macedonian block; the Carpatho-Balkanides (with karst limestones) and the sedimentary Dacian Basin to the east. The geological development of the different regions is complicated and influenced by mountain building processes of Alpine type, which is reflected in the high rugged limestone of the Dinarides.

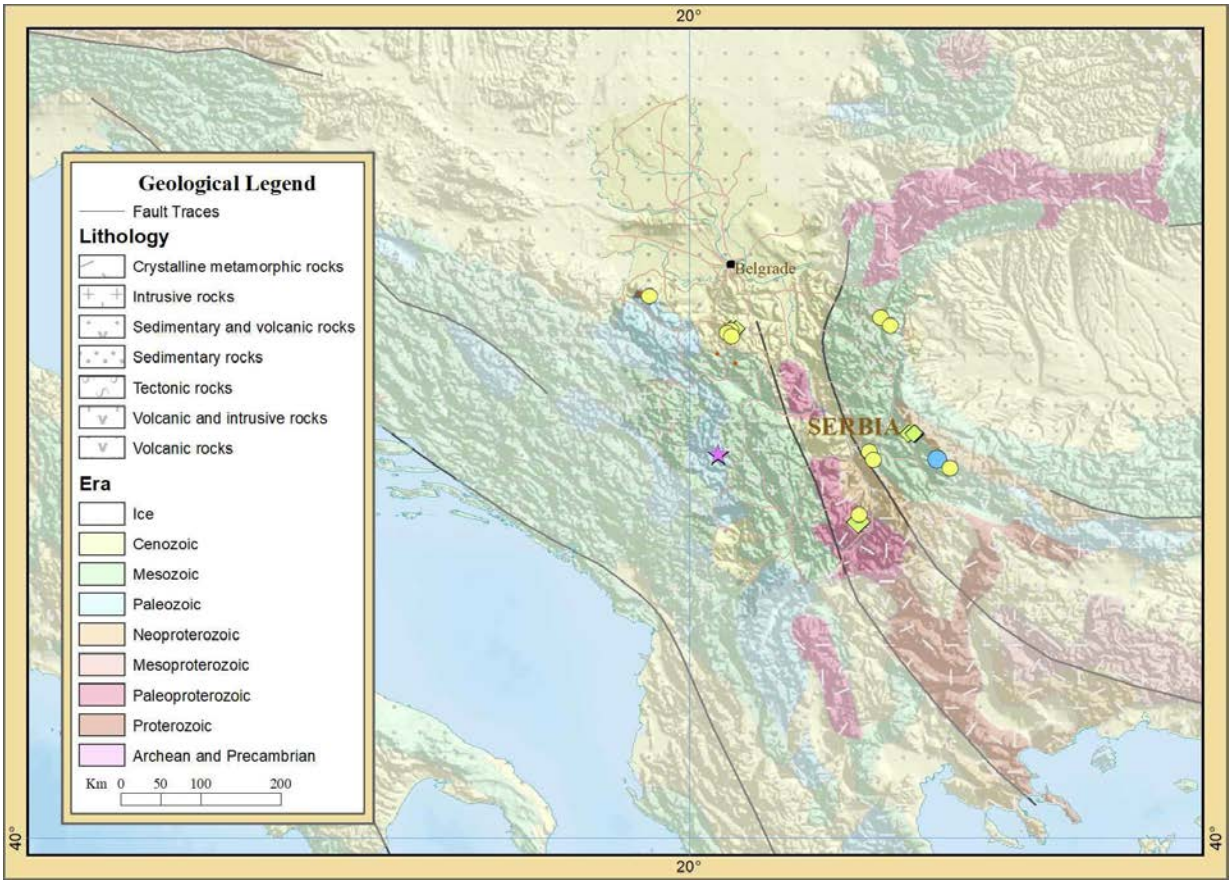


FIG. 5.42. Regional geological setting of Serbia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The oldest elements are represented by Palaeozoic rocks affected by Hercynian tectonics. Nappes and overthrusts are typical features, mostly of Triassic age, and composed of limestone. Permian sediments of limited thickness are observed at the base of some of the nappes. The Jurassic and Cretaceous units are mainly carbonates. In synclinal cores, flysch sedimentation is common.

An ophiolite belt of the Vardar Zone separates the East Bosnian-Durmitor Block from the Drina-Ivanjica element. This belt carries large blocks of Triassic limestone, gravitationally transported from the NE and the east (Devetak, Zlatibor, Zlatar, Giljeva, Mokra Gora, Zljeb). Large masses of ultramafites (Krivaja-Konjuh, Zlatibor) and blocks of oceanic crust (Dobrun) are embedded in the ophiolitic melange and overlie it. In its southern part, this belt separates the Dinarides from the Hellenides and is thrust over Mirdita [21.2, 21.3].

5.21.2.2. Geology of uranium-bearing areas

According to a classification by Radosevic et al. [21.4], the following types of uranium-bearing strata and occurrences are identified:

- Hydrothermal mineralization in granitic rocks ranging in age from Palaeozoic to Tertiary, and in volcanic rocks of pre-Cretaceous and Tertiary age;
- Crystalline schist of diverse lithology and metamorphic grade, older than Upper Carboniferous;
- Continental sandstones of pre-Tertiary age with deposits of roll front type;
- Tertiary classic sediments of Miocene–Pliocene age [21.4].

5.21.3. Uranium exploration

The State owned 'Geoinstitut' began exploration activities in two phases in 1948 and included airborne gamma spectrometry, ground follow-up, hydrogeochemistry and emanometry. The first exploration phase was undertaken for strategic purposes and in the second phase civil reactor use was the prime purpose. Exploration ended in 1990 mainly as the result of the Government decision forbidding the construction of nuclear power plants.

The results of exploration were discouraging. The deposits and mineralized occurrences found were small and of low grade. However, two hydrothermal deposits, Gabrovnica and Mezdreja, both hosted in granitic rocks, were mined in 1960–1966. Details of exploration, including expenditures and extent of work done, are not reported.

A report on the environmental impact of uranium mine waters in eastern Serbia also reports that uranium exploration began in eastern Serbia in 1948. The first location investigated was Aldina reka, whilst in 1951 uranium mineralization was discovered at Mezdreja. In 1951–1956, geological and geophysical investigations were carried out, as well as the partial exploration of the Stara Planina mountain granitoid complex. During what is described as 'incomplete prospecting' of the terrain in 1957, the Grabovnica deposit was discovered, as well as several other locations which would later serve as orientation for further exploration. In 1960, the reclamation of the tailings dumps was undertaken. During 1962, a structural geological map of uranium deposits was made at a scale of 1:10 000. The Janja granite complex was part of the study area where exploration was the most extensive (during 1949–1966). During this period, three deposits were discovered (Mezdreja, Gabrovnica and Srneci Do), as well as several other radioactive occurrences [21.4–21.6].

5.21.4. Uranium resources

The Mezdreja and Gabrovnica deposits in the Janja granite were mined under the name 'Kalna mines' in 1960–1966, and have reasonably assured resources of 220 and 34 tU, respectively, and average grades of ~0.03% U. The only other deposit with resources equivalent to the reasonably assured resource category is the hydrothermal deposit Srneci Do, located in the Janja granite, which has ~40 tU at a grade of 0.34% U, and the Ribarice deposit in the Iverak Tertiary Basin, which has 175 tU at a grade of 0.025% U. The total reasonably assured resource equivalent in the four deposits amounts to ~470 tU, all with low grades. These deposits are not economically viable.

The total inferred resources (equivalent) in all deposits reported are 3585 tU with ore grades of around 0.02–0.03% U.

Resources equivalent to prognosticated are reported at around 1500 tU and of low grade, and speculative resources of around 1000 tU are also reported as low grade.

The UDEPO database lists several deposits in Serbia [21.7]. However, this list may be incomplete owing to insufficient information. The list includes:

- Janja granite: Mezdreja, Gabrovnica and Srneci Do;
- Bukulja granite: Cigankulja and Paun Stena;
- Permian–Triassic strata of Stara Planina: Dojkinci;
- Plavna Liassic: Plana;
- Tertiary Basin of Belanovica: Srednje Brdo;
- Tertiary Basin of Iverak: Ribarice.

Other very small deposits or occurrences are mentioned in Ref. [21.4], such as in the Bukulja granite (Cer, Kukavica, Jastrebac and Slatinska Reka). Mineralization in crystalline schist includes the infiltration type (Trepetljak, Klokocevac and Turija) and hydrothermal type (Nekudovo and Resavica). In pre-Tertiary continental sandstone, additional mineralization has been reported at Lokve, Senokos and Porecka Reka. The only mineralization reported in volcanic rocks is at Muhovo [21.4].

The UDEPO database lists the most significant deposits for Serbia as Dojkinci, Srneci do, Paun stena, Cigankulja, Kamensko, Srednje brdo, Barbes, Ribarica, Mezdreja, Javorski do, Janjska reka, Lokve.

5.21.5. Potential for new discoveries

Both the limestone and ophiolite dominated terrains have little or no potential to host uranium deposits. In 1977, it was estimated that hydrothermal deposits and those associated with continental sediments have additional potential for new discoveries [21.5]. The results obtained by the 'Geoinstitut' show that all of the indications and mineralization found are of small size and of low grade [21.4]. Thus, the potential for discovering economically viable deposits is very limited to non-existent and any such potential can only be expected in the deeper parts of the more promising geological units, such as hydrothermal veins and in continental sandstones.

In some areas described as having potential, anomalously high values of uranium and other radionuclides have been found, both in the natural environment as well as at the sites of previous uranium mining activity [21.4].

5.21.6. Uranium production

During the period 1960–1966, Kalna mines produced uranium from the Mezdreja and Gabrovnica deposits [21.4]. Production amounted to 30.2 tU at an average grade of 0.032%U [21.5].

Kalna was the first uranium mine established in the former Yugoslavia. In 1960, the Nuclear Energy Commission began operating the mine and mill. Between 1964 and 1966, the Kalna mine extracted an estimated 900 kg of UO_2. The Kalna ore was of poor quality, contained very low levels of uranium and required the use of higher cost mining and refining methods.

The semi-industrial plant at Kalna was constructed to separate ore extracted from Stara Planina. In 1960, it was operating with a capacity to process ore at a rate of 23–50 t/d. During the 1960s, the plant operator conducted ‘large scale’ uranium ore processing experiments to familiarize itself with the technologies and processes and to obtain the necessary information to design industrial scale facilities. In particular, the plant investigated alkaline leaching and filtration methods in order to obtain a 70% UO_2 end product. In the general vicinity of the plant are facilities for semi-industrial research into precipitation of uranium from solution through hydrogen reduction. The current status of these facilities and that of the pilot plant is unknown, although they are presumed to have been shut down [21.4–21.9].

5.21.7. Comments

Serbia has no operating mines. No nuclear power stations are operated and none are planned owing to a Government ban on nuclear energy. As a result of this national policy, no future projects are envisaged. Serbia has never reported to the Red Book. The former Yugoslavia (including Serbia) provided a country report to the 1992 Red Book [21.10]. However, the report provided information only on the area which is now Slovenia.

References to Section 5.21

[21.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Serbia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2009).

[21.2] DIMITRIJEVIC, M.D., Geological Map of Serbia (in Serbian) translated by Z. Stojadinovic, http://www.asak.org.rs/karst/yugeo.html (accessed August 2009).

[21.3] KOMATINA-PETROVIC, S., Geology of Serbia and Potential Localities for Geological Storage of CO2, http://www.geology.sk/co2neteast/documents/workshop_zagreb/Snezana_Komatina-Petrovic-Geology_of_Serbia_and_potential_localities_for_geological_storage_of_CO2.pdf (accessed August 2009).

[21.4] RADOSEVIC, B., KOVACEVIC, J., JOVIC, V., Natural occurring uranium in Serbia and possible environmental effect, J. Environ. Prot. Ecol. **3** 3 (2002) 706–718.

[21.5] TOSOVIC R, JELENKOVIC R., Uranium mineral resources of Serbia and their potential economic importance, Acta Montanistica Slovaca Volume 21 (2016)

[21.6] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Serbia, IAEA, Vienna (1977) 9 pp.

[21.7] MILENIC, D., DRAGISIC, V., SAVIC, N., VRANJES, A., Environmental Impact of Uranium Mine Waters in Eastern Serbia, http://www.imwa.info/docs/imwa_2008/IMWA2008_067_Milenic.pdf (accessed August 2009).

[21.8] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[21.9] NUCLEAR THREAT INITIATIVE, Country overviews, Yugoslavia Nuclear Facilities Mining and Milling, http://www.nti.org/country-profiles/former-yugoslavia/facilities/ (accessed August 2009).

[21.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1992: Resources, Production and Demand, OECD, Paris (1993).

5.22. SLOVAKIA

5.22.1. Geography

Slovakia’s landscape is characterized by the Beskide and Carpathian Mountains (Tatra Mountains) to the north, the centrally located Slovenske Rudohorie (‘ore mountains’) and the Pannonian Basin to the south. Large parts of the country are drained by the River Danube and its tributaries, the Vah and the Tisza. About 31% of the country is arable land and ~41% is forested. The higher areas in the mountains are used for pasture. The highest elevations are in the Tatra Mountains, culminating at Gerlachovsky stit (2655 m). Most of Slovakia’s mineral deposits have now been depleted. The country is famous for its past mining of precious metals and the mining school at Kosice is still well recognized [22.1].

5.22.2. Geology

5.22.2.1. General

The country is marked by two distinct geological features (Fig. 5.43): the Carpathian Mountains and the lowlands. Young tectonic processes have formed most parts of the country, e.g., the uplift of the Alpine type Carpathian Mountains. In addition, volcanism during the Tertiary period was another feature. The lowlands are filled with the erosion products of the uplifted mountains, a process starting in the Late Mesozoic.

Parts of the country belong to the Inner West Carpathian and Outer West Carpathian Mountains. In the Inner West Carpathians, Mesozoic sediments and the cores of Palaeozoic and Precambrian rocks have been folded and uplifted by Cretaceous Alpine type mountain building. In depressions and in the lowlands, sediments of Palaeogene and Neogene age have been deposited. The Outer West Carpathians are composed of flysch sediments, which were folded in the Late Tertiary by the Alpine type processes [22.2].

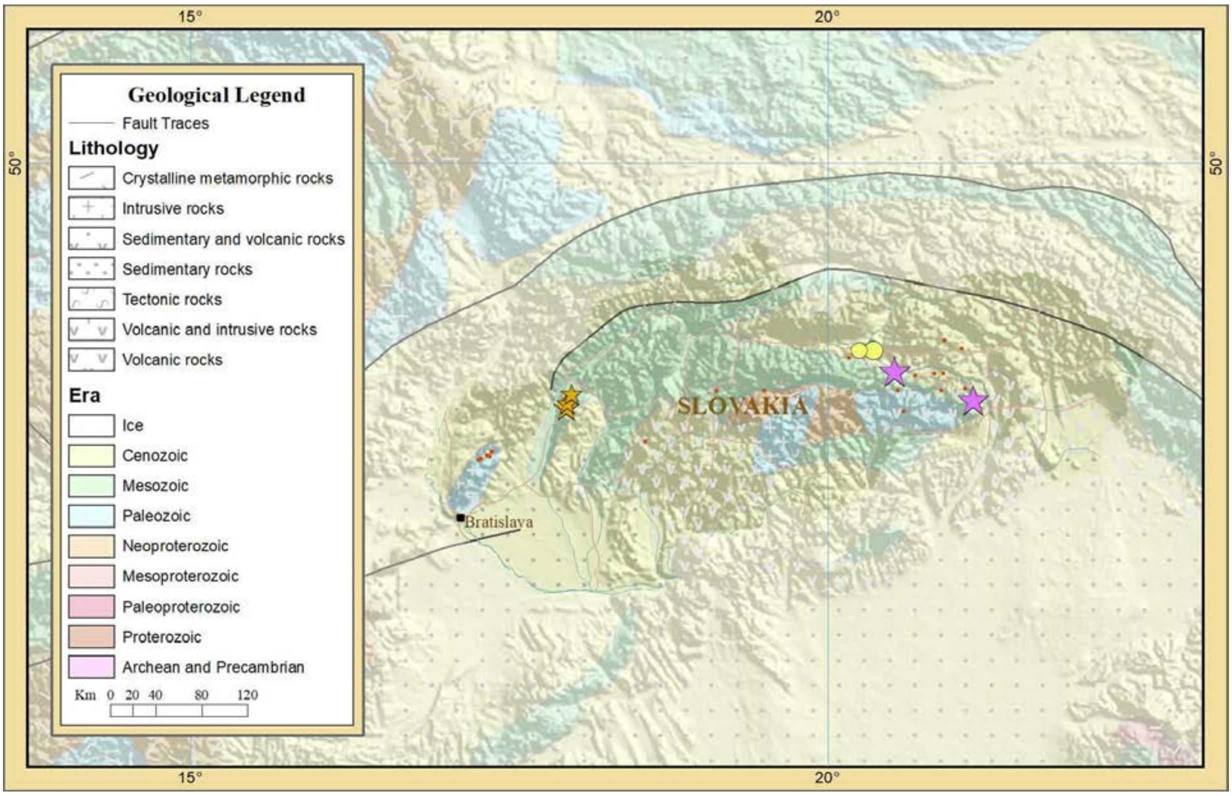


FIG. 5.43. Regional geological setting of Slovakia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.22.2.2. Geology of uranium-bearing areas

The sedimentary processes responsible for the Inner West Carpathians, also deposited ore-bearing rocks of Permian age. The sedimentary sequence consists of conglomerates, sandstone, siltstone and effusive rocks. Uranium is associated with copper and molybdenum mineralization and is linked to tuffaceous rocks, quartz porphyries and shales.

Some uranium deposits found during exploration conducted prior to the dissolution of the former Czechoslovakia into the Czech Republic and Slovakia occur in this geological environment, as exemplified by the Novoveska Huta and Muran deposits in the Slovenske Rudohorie, NW of Kosice [22.3].

5.22.3. Uranium exploration

5.22.3.1. Historical review

Uranium exploration has been carried out since the 1950s in several different regions. The activities used conventional methods of exploration. On the basis of the results, it was concluded at that time that no uranium resources of economic interest existed. No exploration was carried out during 1990–2005.

5.22.3.2. Recent and ongoing uranium exploration and mine development activities

The Canadian company Tournigan Energy Ltd ('Tournigan') secured in a licence in 2005 for exploration for an area of 32 km^2 around the uranium mineralization discovered near Jahodna in eastern Slovakia. A technical report issued in March 2006 stated a mineral resource estimate of 7000 tU ore grading 0.56%U.

The results at Jahodna (Kuriskova) were issued in a NI 43-101 technical report in April 2009, estimating the resources at the deposit at 12 500 tU in ore grading 0.25% U (cut-off of 0.05% U) [22.4, 22.5]. The Slovak company Ludovika, a 100% subsidiary of Tournigan, is ongoing with exploration at this and other less advanced properties (Spisska Teplica, Novoveska Huta) in eastern Slovakia.

In January 2009, Tournigan announced the results of exploration at the deposit of Kuriskova (Jahodna). According to an update of July 2008 which was based on additional drill hole data, indicated resources were estimated at ~2 500 tU in ore grading 0.435% U and inferred resources estimated at ~11 500 tU in ore grading 0.299% U. The report mentions that 23 drill holes totalling 9 267 m have been completed.

Reference [22.6] provides the following details:

— Jahodna (Kuriskova) deposit: indicated resources of 2 527 tU in ore grading 0.37% U and inferred resources of 11 589 tU in ore grading 0.25% U;
— Novoveska Huta: inferred resources of 6 527 tU in ore grading 0.064% U;
— Svabovce: indicated/inferred resources of 2 396 tU in ore grading 0.19% U;
— Spissky Stiavnik: indicated/inferred resources of 433 tU in ore grading 0.17% U;
— Kalnica-Selec: historic resource estimate of 2 112 tU in ore grading 0.053% U.

5.22.4. Uranium resources

As of 1 January 2017 [22.7], reasonably assured resources recoverable at <US $260/kgU are reported at 8800 tU hosted in volcanic deposits and mineable by conventional underground methods. Inferred resources of the same characteristics as reasonably assured resources amount to 6 700 tU.

The UDEPO database lists the most significant deposits for Slovakia as Kuriskova, Novoveska Huta, Svabovce, Kalnica-Selec, Kranjna Dolina, Spissky Stravnik, Cierny Vah, Kravany, Vitartovce.

5.22.5. Potential for new discoveries

In addition to the NI 43-101 compliant resource already delineated at Kuriskova, there is significant exploration upside in the surrounding licences, also controlled by Tournigan. The current resource at Kuriskova is 6 670 tU_3O_8 (5 656 tU) indicated, contained in 1.2 million t grading 0.558% U_3O_8 (0.473 %U) and 8 120 tU_3O_8 (6 846 tU) inferred contained in 3.8 million t grading 0.215% U_3O_8 (0.182 %U) (cut-off of 0.05% U).

Tournigan's uranium licences include the Novoveska Huta uranium deposit, where the company is re-evaluating the geological model of the deposit to determine whether there is potential to improve the grade from that of the historic resource, as well as numerous prospective exploration targets [22.8].

Slovakia is therefore assigned a potential rating of moderate.

5.22.6. Uranium production

No uranium mining has taken place in Slovakia since its formation as a sovereign State (1 January 1993), but during the period when it was a part of the former Czechoslovakia, some uranium mining was undertaken in the area around Novoveska Huta [22.9]. The mine, with both open pit and underground operations, was shut down in the early 1990s owing to the low uranium prices prevailing at that time.

Production reported in Ref. [22.9] for the Novoveska Huta–Hnilcik region during 1954–1957 totalled 1.4 tU; and for several localities (i.e., Novoveska Huta, Muran, Kravany, Svabovce, Vikartovce) production during 1961–1990 totalled 210 tU [22.5].

5.22.7. Comments

Slovakia has no uranium mining industry or production capability. As regards secondary sources of uranium, Slovakia does not produce or use mixed oxide fuels, re-enriched tails or reprocessed uranium. Slovakia does not keep an inventory of uranium. The Government retains a small reserve of enriched uranium in the form of complete fuel assemblies. The Slovak utility does not have any special uranium contracts and does not disclose prices paid for uranium [22.10].

References to Section 5.22

[22.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Slovakia, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[22.2] ECOSYSTEMS, Slovakia: Geology and Geomorphology, http://www.ecosystems.sk/pages/geo.html.

[22.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[22.4] MORAN, A., DAVIES, F., SHARMA, R., Updated NI 43-101 Technical Report on Resources, Kuriskova Uranium Project, Eastern Slovakia (16 April 2009).

[22.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[22.6] WISE URANIUM PROJECT, Uranium Mine Ownership- Europe (30 August 2008)

[22.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[22.8] INVESTORS HUB, Tourignan Energy (29 April 2009), http://investorshub.advfn.com/boards/read_msg.aspx?message_id=37278006.

[22.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[22.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

5.23. SLOVENIA

5.23.1. Geography

Slovenia is situated in southern Europe. It has a small coastal strip bordering the Adriatic Sea and also shares borders with Hungary, Croatia, Italy and Austria. The northern part is covered by the Alps and the Pannonian Plain extends into Slovenia from Hungary. Most parts of the country are hilly. The Karst Plateau, a limestone region famous for underground caves, dominates the south-western part of the country. The country is drained by the Drava and Sava Rivers.

The main mineral resource includes lignite, with some lead, zinc and mercury [23.1].

5.23.2. Geology

5.23.2.1. General

Geologically, the country is located between the Eastern Alps in the north, the Southern Alps in the west and the northern branch of the Dinarides (Fig. 5.44). Its geological evolution has been strongly influenced by Alpine movements during the mountain building processes and nappe formation caused by the collision of the northwards moving African Plate with the Eurasian block. During the Mesozoic period, the Dinaric and Julian carbonate sediments were deposited. Permian continental and marginal marine sediments are found at several places below the marine Mesozoic.

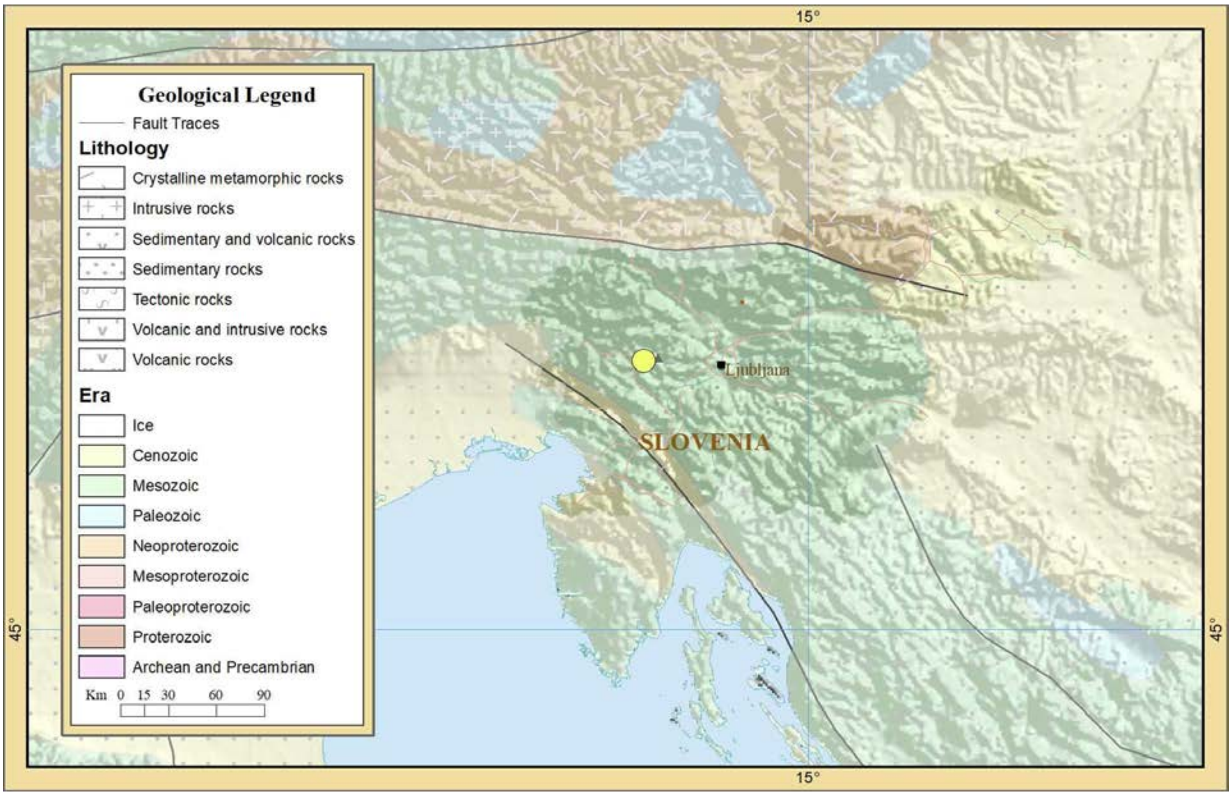


FIG. 5.44. Regional geological setting of Slovenia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

As a result of the complex geological evolution, the sedimentary basins were separated. This includes Jurassic flysch sedimentation upon which the Cretaceous flysch was deposited. These rocks are present as the Julian Nappe. The Mesozoic rocks are overlain by thick sequences of Tertiary sediments [23.2].

5.23.2.2. Geology of uranium-bearing areas

The Lower–Middle Permian Groeden sandstone contains the Zirovski Vrh uranium deposit in the Gorenja Vas region, near Ljubljana. The host sequence is composed of red, grey and greenish coloured sandstone, siltstone and conglomerate. Uranium mineralization is restricted to the grey-greenish facies and is a result of reducing conditions. Mineralization consists of bands or lensoid bodies, grading 0.01–5% U in a 20 m thick stratum [23.2–23.6].

5.23.3. Uranium exploration

5.23.3.1. Historical review

Exploration of the Zirovski Vrh area started in 1961. In 1968, an adit was developed providing access to the orebody. Mining at Zirovski Vrh commenced in 1982 and production of uranium concentrate (as yellow cake) started in 1985. Exploration expenditures and the extent of the work undertaken are not reported.

5.23.3.2. Recent and ongoing uranium exploration and mine development activities

In 1990, expenditure on exploration ended. There are no recent or continuing exploration activities for uranium in Slovenia.

5.23.4. Uranium resources

5.23.4.1. Identified resources

The 1994 resource assessment for the Zirovski Vrh deposit estimated reasonably assured resources of 2 200 tU in the <US $80/kgU category with an average grade of 0.14% U. Inferred resources were estimated to total 5000 tU in the <US $80/kgU category and 10 000 tU in the <US $130/kgU category at an average grade of 0.13% U. The deposit exists in several bodies of varying size and hosted in the coarse-grained grey sandstone of the Permian Groeden Formation. The mineralization exist as linear arrays of elongated lenses within the folded sandstone [23.7]. Historical variations in identified resources are shown in Fig. 5.45 and Fig. 5.46.

The UDEPO database lists the most significant deposit for Slovenia as Zirovski Vrh.

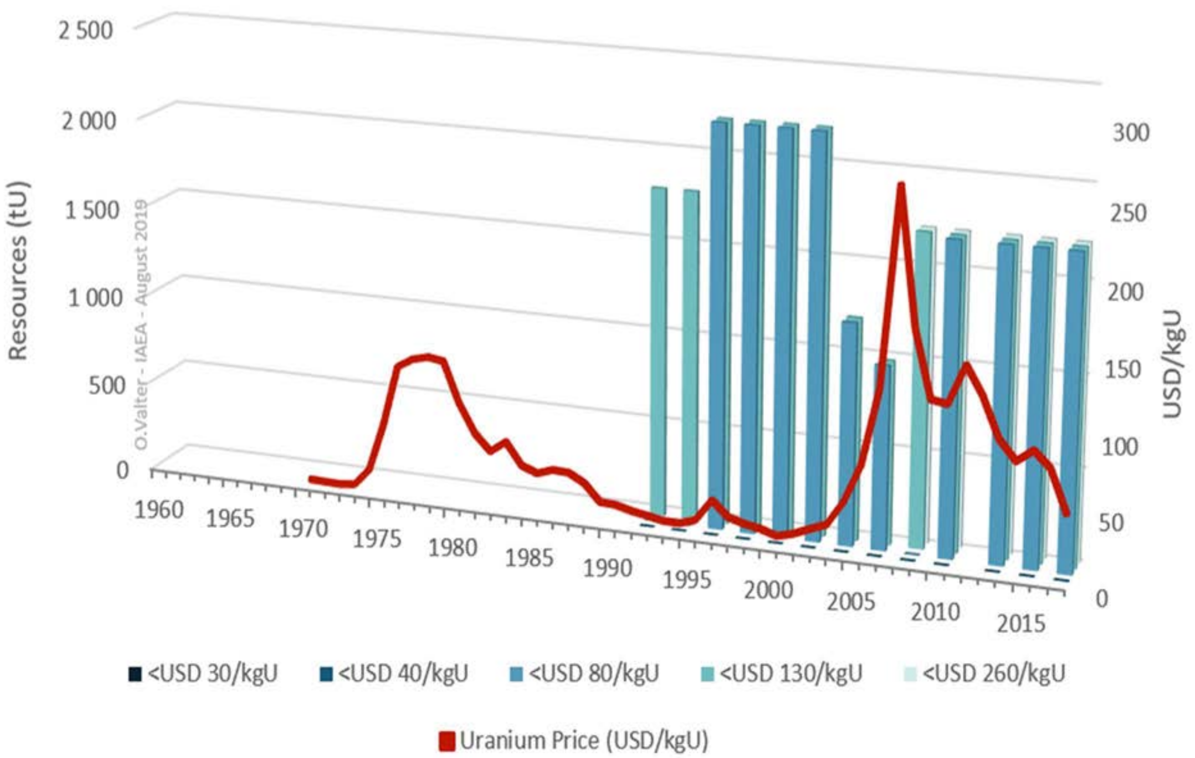


FIG. 5.45. Historical variation of recoverable reasonably assured resources within various cost categories in Slovenia. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

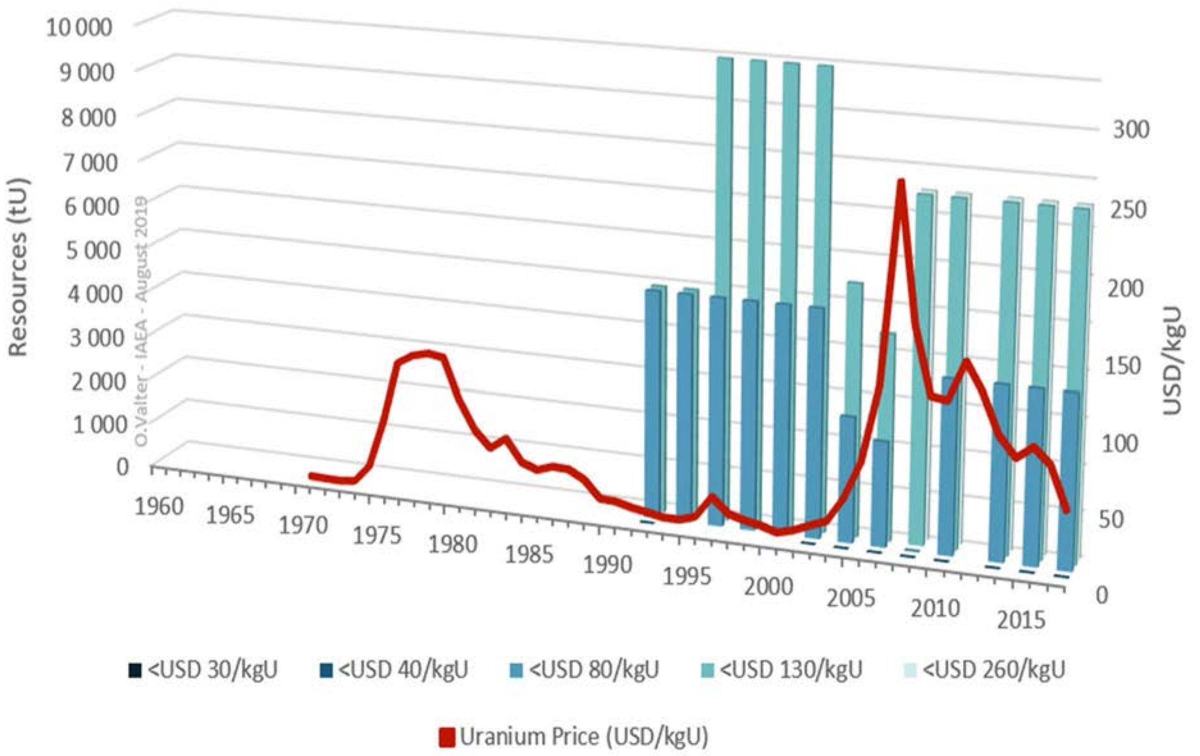


FIG. 5.46. Historical variation of recoverable inferred resources within various cost categories in Slovenia. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

5.23.4.2. Undiscovered resources

Prognosticated resources have been estimated at 1 060 tU in the <US $130/kgU cost category [23.7]. No speculative or unconventional resources are reported.

5.23.5. Potential for new discoveries

The only geological formation with some additional potential would be the sandstone of the Permian Groeden Formation. However, the potential for finding additional uranium resources is limited, as the target is believed to have been evaluated in the past but without success.

5.23.6. Uranium production

5.23.6.1. Historical review

The uranium mine located 20 km SW of Škofja Loka was the sole producer of uranium in Slovenia. Mine production commenced in 1982 and the associated processing plant, which had a yearly production capacity of 102 tU, commenced operation in 1984, first treating stockpiled ore. The ore was mined selectively using a conventional underground operation employing cut and fill, and room and pillar methods. Operations were stopped in 1990. Cumulative production from the Zirovski Vrh mine–mill complex totalled 382 tU (620 000 t ore at an average grade of 0.072% U).

5.23.6.2. Status of production capability

A decision on the final closure and decommissioning of the Zirovski Vrh mine and mill was taken in 1992 and since then there has been no production. The plan for decommissioning the facility was accepted by Government authorities in 1994.

5.23.6.3. Ownership structure of the uranium industry

The Zirovski Vrh production centre is owned by the State. No changes in ownership have occurred since 1988.

5.23.6.4. Employment in the uranium industry

All current employment is concerned with decommissioning and rehabilitation, and the number of persons engaged decreased from 42 in 2004 to 20 in 2007.

5.23.7. Environmental activities

The State owned Zirovski Vrh Mine Company manages the rehabilitation activities of the former site of production for uranium. It acquires the required permits, monitors the impact of mine effluents to the environment, and maintains the area to avert damage to the environment.

The yearly effective dose contribution attributable to all mine objects has been lowered as a consequence of remediation activities to 0.2–0.4 mSv, compared to 0.5 mSv during operation. In the area surrounding the mine, background annual effective levels are 5 mSv. Associated with the facility are 80 000 t of mine waste and 620 000 t of tailings (70 gU/t), located on hillslope, covering an area of 4.5 ha. The site's stability is the critical factor. The mine effluents are monitored every month as they contain radium, uranium, and other contaminants. The mine site's remediation is anticipated to be finished by 2010. Turning over the property over to the community was planned and its development as an industrial centre has been proposed [23.6].

5.23.7.1. Environmental impact assessment

The three long term targets of Rudnik Zirovski Vrh has for remediation are: (i) the underground mine, (ii) the mine waste pile (Jazbec), and (iii) the mill tailings (Borst). All other mine liabilities and past production areas will be decontaminated and returned to society for future use. A safety report has been prepared for the mine waste pile (Jazbec) and mill tailings (Borst).

5.23.7.2. Monitoring

The water effluents and mine air have been monitored consistently from the beginning of production in 1982. The programme is ongoing. Emissions to air and surface waters are monitored and dosages to the critical group of inhabitants have been computed since 1980. Plans for long term monitoring and stewardship of the location are in place.

5.23.7.3. Tailings impoundment

There is a 4.5 ha site designed especially for long term impoundment of tailings (Borst), which has a capacity of 700 000 t. The wastes are stored dry due to infiltration and evaporation of the leached liquor. Borst will be covered with 2 m thick engineered multilayer soil cover with a clay base to avert leaching of contaminants.

5.23.7.4. Waste rock management

All piles of waste will be moved to the central mine waste pile at Jazbec. All other sites will be decontaminated to a high level. The 5 ha Jazbec facility will contain 1.8 million t of mine waste and debris and it will also be covered with a 2 m thick engineered multilayer soil cover.

5.23.7.5. Effluent management

Treatment of mine effluent is not planned because of the low concentration of radioactive contaminants.

5.23.7.6. Site rehabilitation

The mine personnel is responsible for managing the remediation of the mine site. The mine is nearly remediated and the areas with provisional piles of waste have been dealt with. In 2007, work on remediation of the pile of mine waste (Jazbec) was in ongoing and the remediation of the mill tailings (Borst) were planned to start. All works are expected be completed by 2010.

5.23.7.7. Regulatory activities

The company directs the acquisition of all required permits and consensuses for site remediation. The principal regulations for these activities are the Act on Nuclear Safety and Mining and the Act on Safety Against Radioactive Radiation.

5.23.7.8. Sociocultural issues

The principal social problems have been the loss of employment opportunities and the reduction in local economic activity resulting from mine closure in 1990. These problems were addressed through pensions, compensation and agreements with companies in the vicinity. The State is assisting to develop and support the economic growth of the past mining community.

References to Section 5.23

[23.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Slovenia, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[23.2] MIOC, P., Outline of the Geology of Slovenia, Acta Geol. Hung. **46** (2003) 3–27.

[23.3] LUKACS, E., FLORJANCIC, A.P., "Uranium ore deposits in the Permian sediments of northwest Yugoslavia", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 313–329.

[23.4] MARKOV, C., RISTIC, M., "Caracteres mineralo-geochimiques et genese du gisement d'uranium de Zirovski Vrh", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 331–341.

[23.5] BARTHEL, F.H., "Review of uranium occurrences in Permian sediments in Europe, with special reference to uranium mineralizations in Permian sandstone", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 277–289.

[23.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[23.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

5.24. TURKEY

5.24.1. Geography

Turkey has territory covering ~756 000 km² in Asia (Anatolia, Asia Minor) and ~23 000 km² in Europe (Thrace). The country is divided by the Bosporus, the Marmara Sea and the Dardanelles (Fig. 5-24.1). About 10% of the population lives in the European part where Istanbul, the largest city in the country, is located. Anatolia has a roughly rectangular form and has been historically considered the 'bridge' between Europe and Asia.

Anatolia is a mountainous region, characterized by the Pontus Mountains to the north and the Taurus Mountains to the south. The highest elevations are found in the east, along the borders with Armenia and the Islamic Republic of Iran, where the volcanic cone of Mount Ararat reaches an elevation of 5166 m. Central Turkey is also mountainous and hosts several lakes. Geographically it is separated into five regions: Black Sea, Aegean, Mediterranean, central Anatolia and east/SE Anatolia.

Owing to the mountainous nature of much of the country, agricultural land use is primarily limited to the intermontane plains and coastal areas. In these areas, olives, fruit, vegetables and corn are grown. In those areas where cotton is grown, a major textile industry has developed. Woodlands are found on mountain slopes and in coastal areas. On the plateaus, domestic animal grazing is common.

The country is seismically active and prone to earthquakes and landslides. The climate varies with the geographical position. The coastal areas feature warm summers and temperate winters. Central and eastern Anatolia experience hot summers and cold winters [24.1].

5.24.2.1. General

The early geological history of Turkey is poorly understood owing to the manifold geological processes that have formed the country. Precambrian strata are found in some outcrops in ancient massifs, although these rocks are extensively deformed and metamorphosed. This is also observed for rocks of Palaeozoic age, which occur as gneiss, mica schist and quartzite.

Turkey and the surrounding terrain are fundamentally impacted by plate tectonics. Much of Turkey is comprised of the Anatolian Plate, whilst the Eurasian Plate comprises much of the terrain to the north of Turkey. The African Plate is located to the south of the Anatolian Plate, whilst the Arabian Plate is adjacent to the SE border.

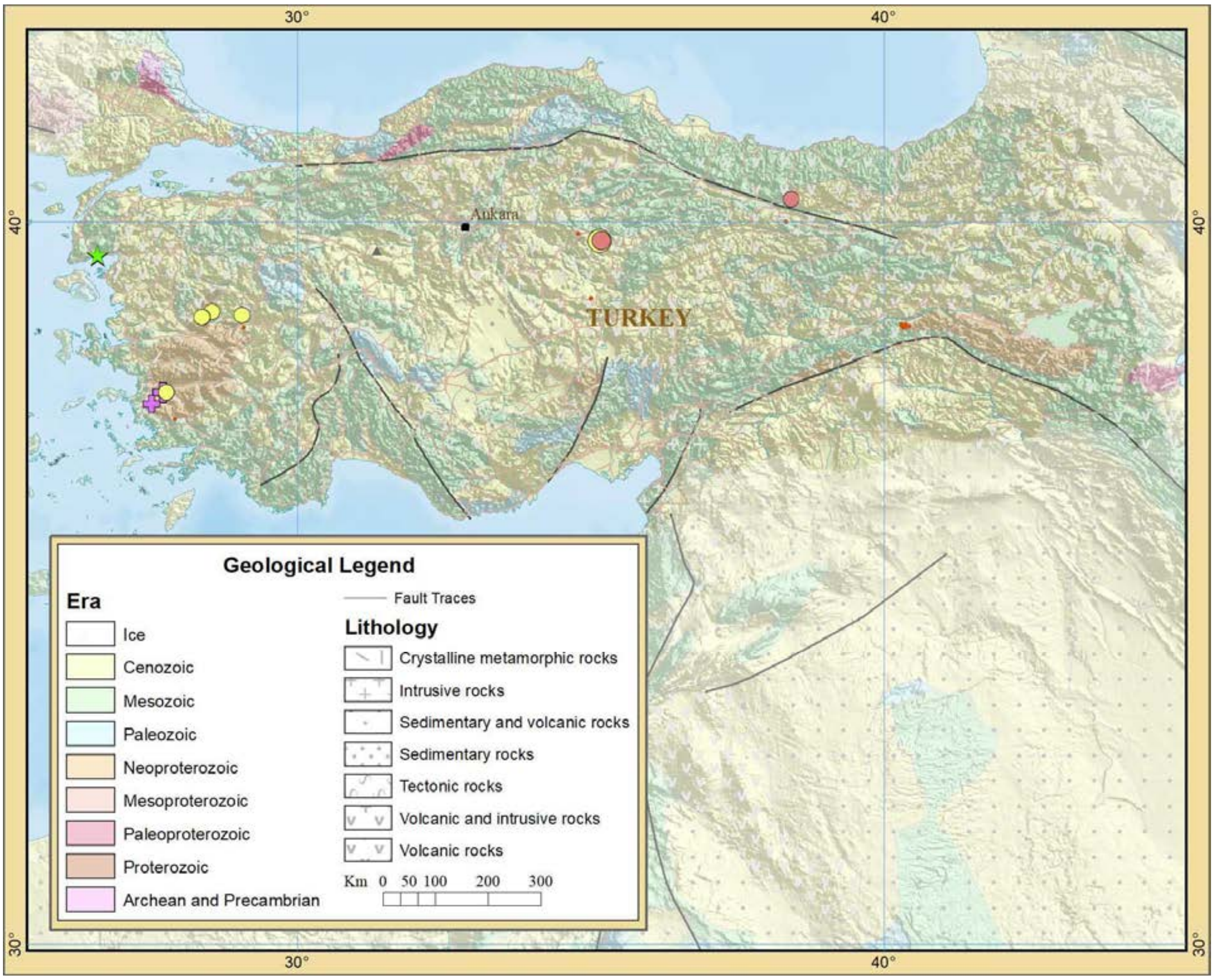


FIG. 5.47. Regional geological setting of Turkey showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

5.24.3. Geology

For most of the country, the Alpine belt is the dominant geological feature. During the Mesozoic, the belt formed a large sedimentary basin known as the Tethys Sea, which separated the continents of Gondwana from the Eurasian Plate until the Tertiary period. Several episodes of closing and opening of this body of water resulted from movements of the Arabian, African and Indian Plates and caused the Alpine type mountain building that affected Turkey. Subduction and folding have produced a variety of rocks and tectonically mixed blocks, which carry ophiolites, serpentinites and other basic rocks interbedded with cherts and metasediments. Intrusion occurred during pre-Alpine time in the Menderes and Kirsehire Massifs (granites with uranium occurrences).

The Alpine period (Jurassic–Early Tertiary) is characterized by a range of basic to acidic rocks. During the Eocene–Miocene, basalts, andesites and rhyolites were extruded, followed by extensive basaltic volcanism in the Quaternary. Modern studies indicate that the Anatolian Plate, comprising much of Turkey, is wedge-shaped to the east and that the entire Anatolian Plate is being squeezed westwards as the Eurasian and Arabian Plates come together. These blocks are separated by the North Anatolian Fault to the north and the East Anatolian Fault to the SE of the country. This is the mechanism responsible for most of the frequent faulting in this unstable region [24.2].

5.24.3.1. Geology favourable for the formation of uranium deposits

Acidic rocks, mainly granite, of various ages may be favourable targets for hosting vein type, disseminated magmatic type and pegmatite mineralization. Small deposits of the disseminated magmatic type are reported from Demirtepe and Kargicak. Vein deposits of small size are known to occur in granitic gneisses and in granites. More important are deposits found in sandstone of Neogene age [24.3–24.5].

5.24.4. Uranium exploration

5.24.4.1. Historical review

Uranium exploration in 1956–1957 was aimed towards the discovery of vein type deposits in acidic igneous and metamorphic rocks. During the exploration, several uneconomic occurrences of pitchblende mineralization were found. Since 1960, sedimentary rocks which surround the crystalline rocks have been investigated. Small mineralized bodies containing torbernite and autunite were discovered in various parts of the country. The first deposit of uranium with 'black ore' was found in the Köprübaşı area in the mid-1970s. Recent exploration also discovered uranium mineralization in Neogene sediments in the Yozgat-Sorgun region of central Anatolia [24.4].

5.24.4.2. Recent and ongoing uranium exploration and mine development activities

Surveys were conducted in the central part of the country in 2003–2004 but proved unsuccessful. In 2005 and 2006, sedimentary rocks, acidic intrusive rocks and granites were explored in a 7000 km^2 area in the Sulakyurt (Kirikkale)–Kaman (Kirşehir) region. In 2007 and 2008, sedimentary rocks, acidic intrusive rocks and granites were explored in a 10 000 km^2 area in the Kirşehir–Nevşehir–Aksaray–Ankara region.

A preliminary economic assessment of the Temrezli ISL uranium project was completed in June 2013 and updated in 2014, based on NI 43-101 figures. Measured resources at Temrezli are 2 351 tU at 0.117%U, indicated resources 2 004 tU at 0.092%U, and inferred resources 732 tU at 0.075%U [24.6].

For 2009, planned exploration was to be carried out on granitic and acidic intrusives as well as on sedimentary rocks in the Kütabya–Usak–Manisa region, covering an area of 50 000 km² [24.7].

Figure 5.48 summarises historical exploration data. Exploration expenditure reports are available for the periods pre-1970–1990, 1997–1998 and 2003–2017 and total about US $ 43.804 million and 419 984 metres of drilling [24.2, 24.7–24.25].

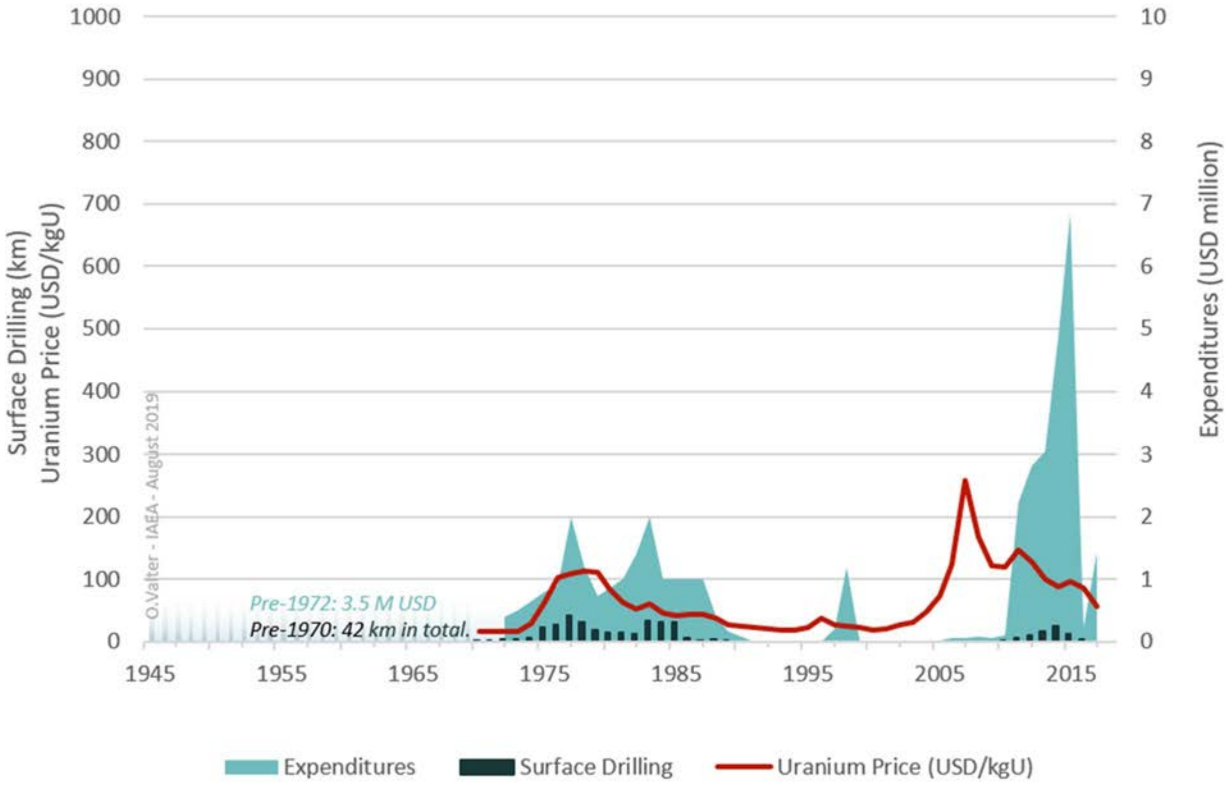


FIG. 5.48. Domestic uranium exploration data for Turkey. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

5.24.5. Uranium resources

5.24.5.1. Identified resources

As of 1 January 2017, reasonably assured resources, recoverable at costs of <US $260/kgU, amount to 6 500 tU and are mineable by conventional open pit methods and treated using heap leaching [24.26]. Indentified resources , recoverable at costs of <US $260/kgU, amount to 500 tU.

There are resources at the following localities (Fig. 5.47):

— Salihli (Manisa)–Köprübaşi: a total of 3 011 tU occurs in ten orebodies at grades of 0.03–0.04% U in fluvial Neogene sediments;
— Usak-Esme: 415 tU at a grade of 0.044% U occurs in Neogene lacustrine sediments;
— Aydin-Koçarli: 176 tU at a grade of 0.04% U occurs in Neogene sediments;
— Aydin-Soke: 1 466 tU at a grade of 0.07% U occurs in fracture zones in gneiss;
— Yozgat–Sorgun: 5110 tU at a grade of 0.09% U occurs in Eocene deltaic lagoonal sediments.

In total, these resources amount to 5550 tU occurring in sandstone hosted deposits and 1060 tU occurring in metamorphite deposits and 390 tU in carbonate deposits.

The UDEPO database lists the most significant deposits for Turkey as Temrezli, Yozgat-Sorgun, Salihli-Koprubasi (Manisa-Koprubasi), Demirtepe, Soke, Tasharman, Kasar, Fakili, Ecinlitas, Kocaduz, Usak.

5.24.6. Potential for new discoveries

Exploration in recent years in both magmatic and sedimentary rocks has not been successful. Both deposit types are considered to have potential for additional deposits and are subject of ongoing exploration. Potential for additional vein type mineralization exists in the Menderes and Kirsehir Massifs in central Anatolia. Neogene continental sediments, which cover extensive areas in Anatolia, are described as having favourable lithologies for the formation of uranium deposits. The deposits found so far could be used as guiding parameters. Limitations to be considered include the rather low grade of the known sedimentary deposits and the possible depth of any favourable targets.

5.24.7. Comments

Turkey has no uranium production. Currently a stock of 1.9 tU (natural) is held by the Government.

References to Section 5.24

[24.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Turkey, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed January 2010).

[24.2] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[24.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission Report: Turkey, IAEA, Vienna (1985).

[24.4] TOKAY, M., ERENTÖZ, C., Uranium and Thorium Possibilities in Turkey, http://www.mta.gov.tr/english/dergi/dergi.

[24.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[24.6] WORLD NUCLEAR ASSOCIATION, Country report, Nuclear Power in Turkey (2018).

[24.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[24.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1973).

[24.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1976).

[24.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[24.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[24.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[24.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[24.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[24.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[24.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[24.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[24.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[24.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[24.20] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[24.21] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1992: Resources, Production and Demand, OECD, Paris (1992).

[24.22] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[24.23] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[24.24] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[24.25] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[24.26] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

5.25. UKRAINE

5.25.1. Geography

Ukraine is located in Eastern Europe and has borders with the Russian Federation, Moldova, Romania, Hungary, Slovakia, Poland and Belarus. It also has an extensive coastline bordering the Black Sea. Large areas of the country are almost flat, making up the steppe north of the Black Sea. The steppe is underlain by fertile black soil. Mountains are found in the west (Carpathian Mountains). The Crimean Peninsula located on the Black Sea to the south is also mountainous. The Dnieper River divides the country from north to south. The Donetz River drains the eastern part. The Donetz Basin is an important industrial area with deposits of hard coal. The coal is found together with iron ore, and as a result the area became important for steel production [25.1].

More than half of the country is devoted to agriculture. Grain, potatoes, sugar beet, sunflowers and a variety of fruits and vegetables are cultivated.

5.25.2. Geology

Most of the territory of Ukraine is situated on the SW part of the East European Platform, close to the zone of geodynamic interaction between the Eurasian and African lithospheric plates. Several terrains are identified (Figs. 5.49 and 5.50): the Ukrainian Shield, the Voronezhskiy Massif, the Dneprovskiy–Donetskiy Depression, the Prechernomorskiy Depression and the Volinskiy–Podolskiy Plate. Almost all uranium deposits are concentrated on the Ukrainian Shield.

The Ukrainian Shield is a massif rising out of the Proterozoic foundations of the East European Platform, which is located close to the south-western border and separated as an independent structure in the Proterozoic and Palaeozoic during the formation of the Dneprovskiy–Donetskiy depression. The Ukrainian Shield lies in the central part of Ukraine and extends from the Sea of Azov in the south to the border with Belarus, for a distance of almost 1 000 km, whilst the width, including the slopes, fluctuates from 150 to 450 km. The total area of the Ukrainian Shield is 250 000 km^2.

The Ukrainian Shield is comprised of a folded Proterozoic crystalline foundation, which is formed of metamorphic and magmatic rocks and an overlying sequence of sedimentary rocks, which covers most of the Ukrainian Shield. The overlying rocks are Mesozoic–Cenozoic in age. The thickness of cover is not more than 100–200 m in the centre of the Ukrainian Shield but increases to 500 m on the slopes. The Proterozoic foundation of the Ukrainian Shield consists of six blocks:

(i) Pryazovskiy (granulite–amphibolite–gneiss with greenstone structures);
(ii) Srednepridneprovskiy (granite–greenstone);
(iii) Kirovogradskiy (granite–amphibolite–gneiss);
(iv) Bila Tserkovskiy (granite–amphibolite);
(v) Podolskiy (granulite–gneiss);
(vi) Volynskiy (granite–amphibolite–gneiss).

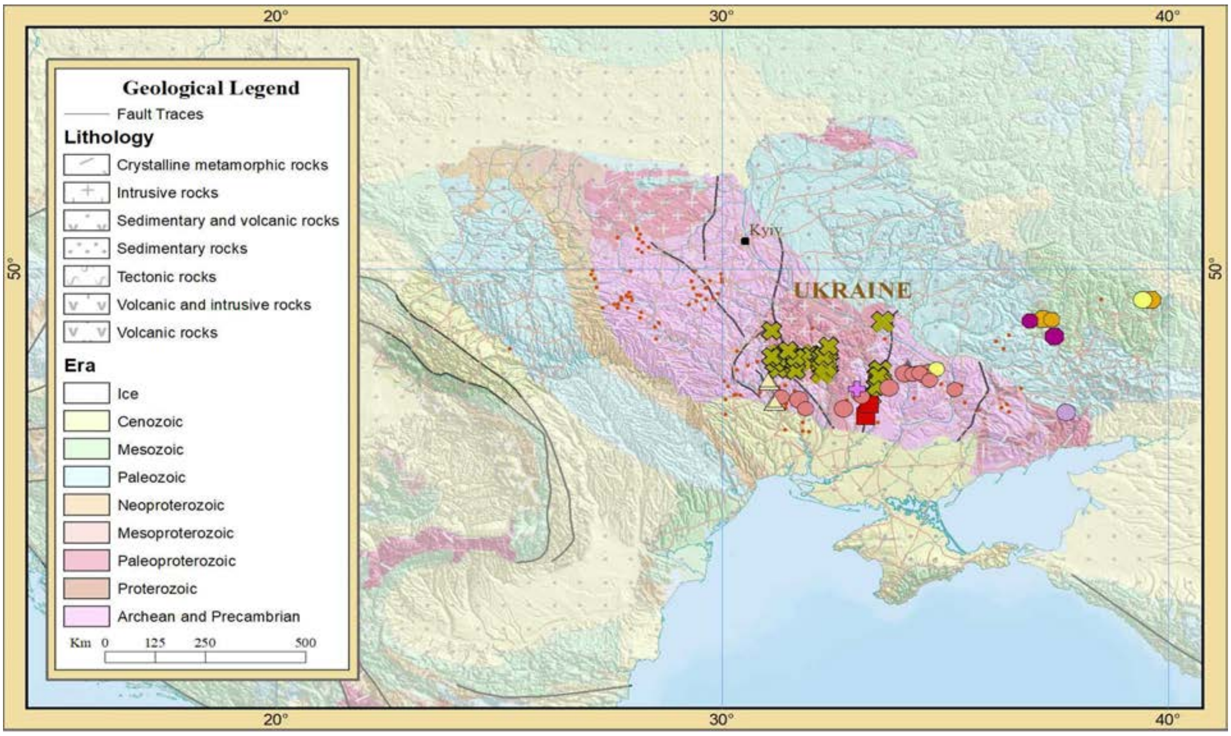


FIG. 5.49. Regional geological setting of Ukraine showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

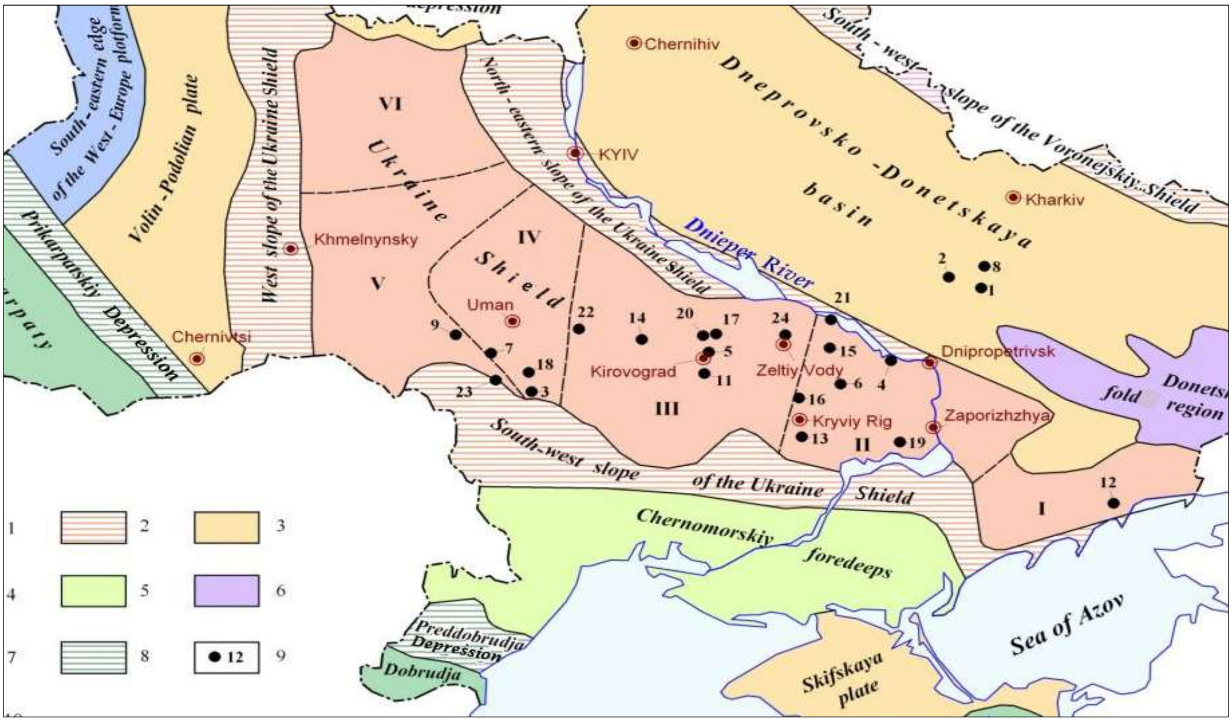


FIG. 5.50. Tectonic map of Ukraine. Legend: (1) Ukrainian Shield, (2) slopes of the Ukrainian Shield and Voronezhskiy Massif, (3) Volynskiy–Podolskiy and Skifskiy Plates framing the Ukrainian Shield, (4) south-eastern edge of East European Platform, (5) Chernomorskiy foredeep, (6) Donetskiy fold region, (7) Karpaty (Carpathian), Dobrujan and Crimean fold systems, (8) Karpaty (Carpathian) and Dobrujan foredeeps, (9) uranium deposits (10) blocks of the Ukrainian Shield**:** (I) Pryazovskiy, (II) Sredepridneprovskiy, (III) Kirovogradskiy, (IV) Bila Tserkovskiy, (V) Podolskiy, (VI) Volynskiy.

All commercial uranium deposits are concentrated in the Kirovogradskiy block and all sandstone hosted uranium deposits have been found in the sedimentary cover of the Srednepridneprovskiy and Bila Tserkovskiy blocks.

(i) Kirovogradskiy district: This includes the central Ukrainian uranium region with metasomatite deposits, including the sodium–uranium genetic type (Michurinskiy, Novokonstantinovskiy, Vatutinskiy), the potassium–uranium genetic type (Kalinovskiy, Lozovatskiy, Uzhniy) and the vein type (Chervonoshahtarskiy);

(ii) Srednepridneprovskiy district: This includes the Krivorozhskiy–Kremenchugskiy metallogenic zone, which has metasomatite deposits, including iron–uranium formations (Zheltorechenskiy, Pervomayskiy) and a non-commercial deposit in a quartz pebble conglomerate (Nikolokozelskiy).

In the central part of the Ukrainian Shield occurs the Dneprovskiy region which hosts sandstone type uranium deposits (Figs 5.50 and 5.51). These coincide with the Dneprovskiy lignite basin.

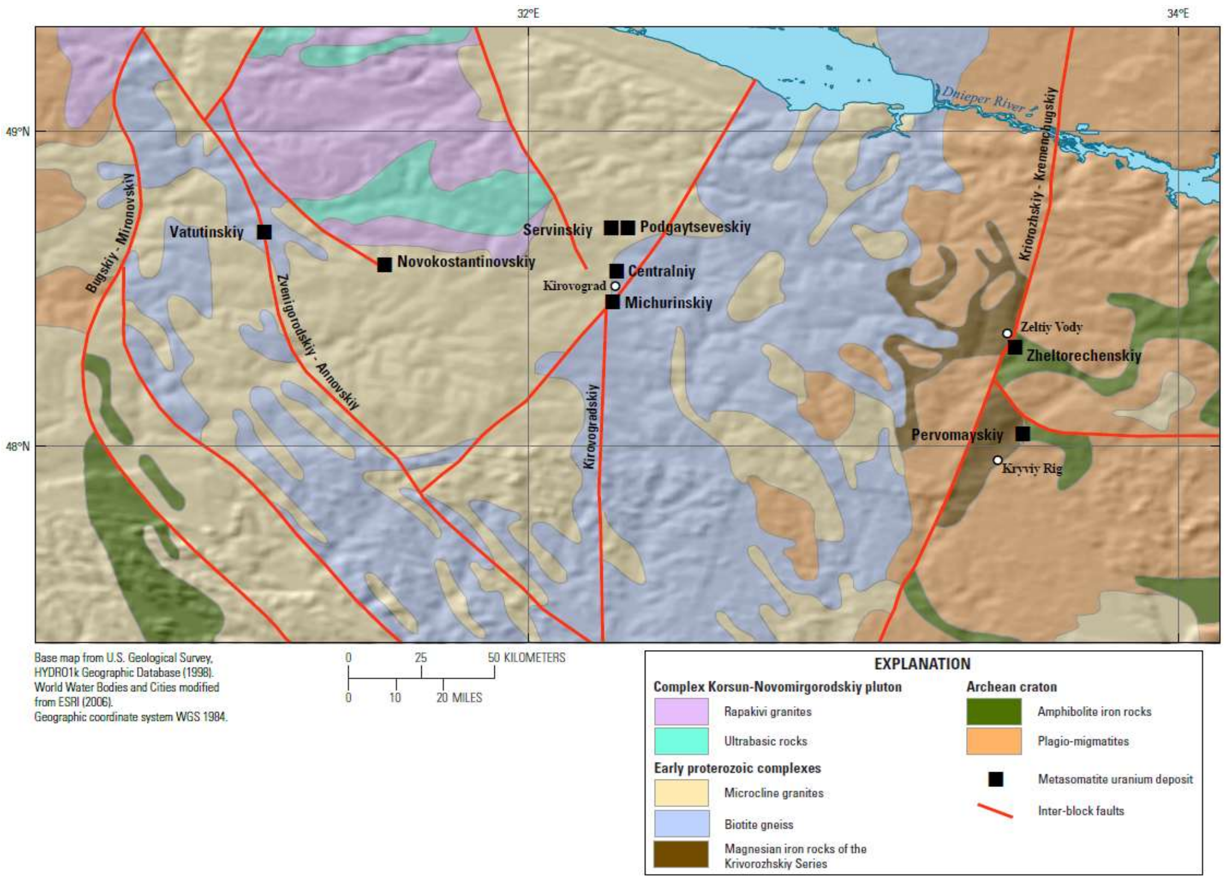


FIG. 5.51. Geological map of the central part of the Ukrainian Shield.

5.25.2.1. Metasomatite deposits

Sodium–uranium type

The main uranium deposits in Ukraine are metasomatite type deposits of the sodium–uranium variety (uranium-bearing albitites), examples of which include Michurinskiy, Novokonstantinovskiy and others. The genesis of the deposits is connected to the process of alkaline metasomatization in the granite–gneiss substratum in the areas of Palaeoproterozoic tectono-magmatic activation. Alkaline metasomatization preceded and aided the process of uranium mineralization. The main episode of uranium mineralization occurred between 1850 and 1700 Ma and followed the main phase of granitization (2000 Ma).

As regards structural geology, the deposits and ore fields are controlled by regional tectono-metasomatite zones (Kirovogradskiy and Zvenigorodskiy–Annovskiy) at their point of intersection with north-westerly and sub-latitudinal faults.

Sodium metasomatites are represented by albitites of differing compositions, such as chlorite–epidote, riebeckite, hydromica–phlogopite, carbonate–haematite. These albitites are developed in different hosts (gneiss, migmatite, granite, pegmatite), but each deposit has a dominant albitite of one type or another. The size of the albitite formations and their saturation by uranium depends on the extent of the tectonic process, the type of ore-bearing rock and other factors. Some formations are traced for several hundreds of metres (up to a kilometre), with a width ranging from 10 m to a few hundred metres and a depth of up to 3 200 m. Uranium mineralization occurs towards the central part of the albitite body and forms fine disseminations or micro-veins in the zones of fine fracturing or places of accumulation of mafic minerals. The morphology of the orebodies includes tabular formations, lenses and stocks.
Uranium mineralization is represented by pitchblende, hydropitchblende, coffinite, brannerite and others. The average uranium grade of the ore is 0.08–0.2% U.

5.25.2.2. Sandstone-hosted uranium deposits

Sandstone-hosted orebodies are located in water saturated sandstone horizons in the palaeovalleys of the Ukrainian Shield. These horizons are not deep, which is positive from a mining perspective. Palaeovalleys are incised into the crystalline rocks of the Ukrainian Shield and into weathered crust to depths of 70–90 m. Palaeovalleys are formed by rivers which flowed from the Ukrainian Shield to the north into the Dneprovskiy–Donetskiy marine basin and to the south into the Tethys Sea basin. In the central part of the country, these deposits are part of the Dneprovskiy uranium ore region which is related to Middle Eocene coal-bearing sediments. Coal-bearing sediments are covered by marine sediments of Eocene–Oligocene age or by sands of Miocene age. The thickness of the sediments is 30–60 m. There are three types of ore lithology: coal–sand, coal–clay and brown coal. Usually, uranium mineralization is concentrated in the coal and clay strata.

Uranium formations occur throughout all strata of the river sediments, but the highest grade orebodies occur in the lower and middle parts of the stratigraphic section. In the river sediments of the southern and central parts of the region, the main uranium deposits are Safonovskiy, Bratskiy, Devladovskiy and Novoguryevskiy, among others. The main ore minerals occur absorbed onto clay minerals and carbonaceous material.

The average grade of the ore is 0.015–0.04% U. The deposits have resources varying from 800 to 3500 tU and these occur at depths of 60–120 m and can thus be mined by the in-situ leach (ISL) method.

Geology of uranium-bearing areas

The Proterozoic rocks, mainly granite and gneiss, of the Ukrainian Massif were transformed by sodic metasomatism into albitite and, to a lesser extent, by potassic metasomatism. The metasomatic process introduced uranium into the system, ultimately forming uranium deposits. The Michurinskiy, Severinskiy and Vatutinskiy deposits are albitic, whereas the smaller Yuzhniy, Kalinovskiy and Lozovatskiy deposits are related to potassic metasomatism affecting intrusive anatectic rocks. These deposits are all located in the Kirovograd region [25.2].

A second group of deposits, also associated with alkali metasomatism, occur in Proterozoic schist and iron quartzite. Examples include the Pervomayskiy and Zheltorechenskiy deposits, where uranium mineralization is fault-related.

The Quaternary Devaldovskiy and Bratskiy deposits are of the sandstone-hosted basal channel type. They were mined using acid ISL technology and are now depleted.

5.25.3. Uranium exploration

5.25.3.1. Historical review

Prospecting first started in 1944 in the north Krivoy Rog orefield. The uranium exploration company 'Kirovgeology' was founded in 1947. The Pervomayskiy and Zheltorechenskiy uranium deposits, discovered during these early activities, were mined out in 1967 and 1989, respectively [25.3].

The first sandstone type deposit, Devladovskiy, was discovered in 1955. In the mid-1960s, geological exploration was concentrated in the Kirovograd orefield and targeted metasomatite type uranium deposits. As a result, the Michurinskiy, Vatutinskiy and Severinskiy deposits were discovered [25.3].

5.25.3.2. Recent and ongoing uranium exploration and mine development activities

Currently, metasomatite type deposits with grades of 0.1–0.2% U comprise the major proportion of resources and these are amenable to underground mining. The second most important type of economic deposit is the sandstone-hosted type, but these comprise a smaller proportion of total resources. The uranium grades of these deposits are in the range 0.02–0.06% U and are amenable to ISL extraction [25.3]. Figure 5.52 summarize details of uranium exploration campaigns totalling USD $60.547 million for 1 072 478 metres of drilling.

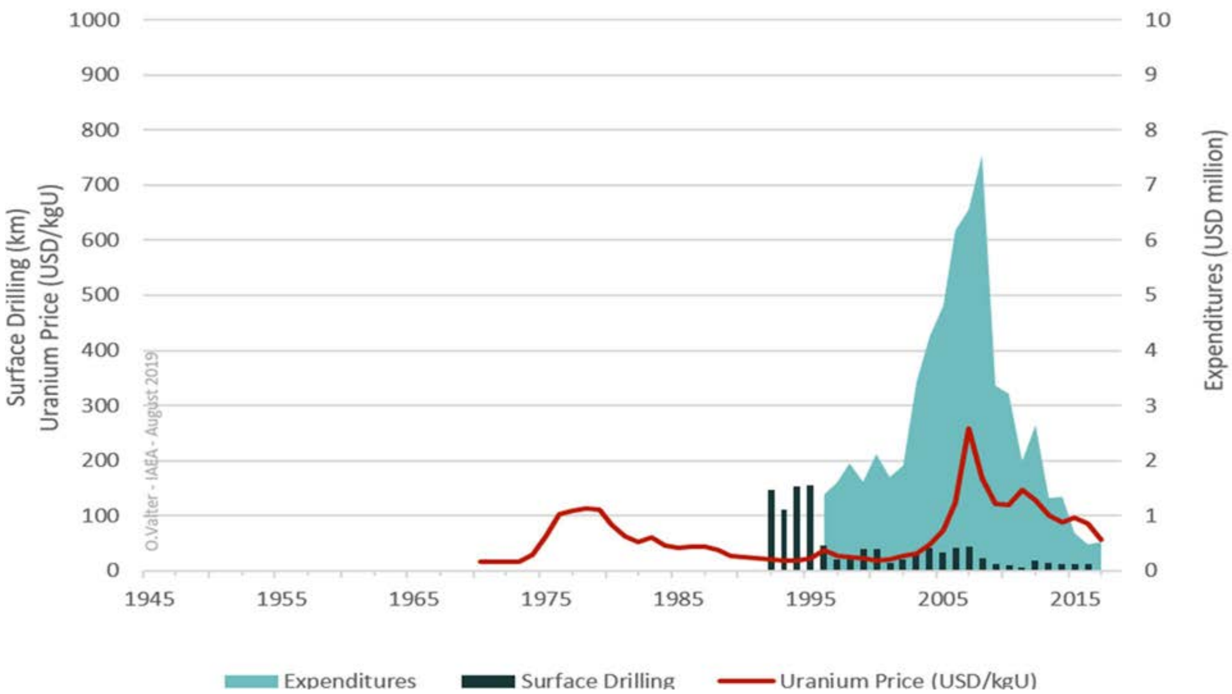


FIG. 5.52. Domestic uranium exploration data for Ukraine. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

'Kirovgeology' has compiled a map indicating the locations of potential ore deposits of the unconformity-related vein type, haematite breccia type and volcanic type. These exploration targets are expected to be of higher grade than the currently known metasomatite type deposits. In 2005–2006, exploration for deposits hosted in different geological environments was conducted [25.3].

Unconformity type deposits were discovered within the western slope of the Ukrainian Shield, in zones of the Riphean unconformity. Exploration activities within the Verbovskaya and Khotynskaya areas have been completed and exploration has been started in the Drukhovskaya area (450 km^2). In zones of the

Vendian unconformity, exploration activities were conducted in the south Podolian area (840 km^2) on the south-western slope of the Ukrainian Shield.

Exploration work was also conducted for vein type deposits in the Zelenovskaya and Mikhaylovskaya areas of the West Inguletskaya zone of the Ukrainian Shield. No mineralization of economic interest was found in 2005–2006. In 2006, evaluation of the Dibrovskiy rare earth–thorium–uranium deposit in the Pryazov block of the Ukrainian Shield was started in order to assess the prognosticated resources of uranium and thorium [25.3]. In 2007–2008, exploration continued in the Drukhovskaya area in the central part of the Suchano Perzhanskiy zone, where 19 holes were drilled to study the epigenetic mineralization processes.

Work to review prognosticated resources in vein type deposits was also conducted. In the Rozanovskaya area, 18 holes were drilled, in the Gayvoronskaya area, 28 holes were drilled and radioactive anomalies were discovered, and in the Khmelnitskiy area, 19 holes were drilled and radioactive anomalies were also discovered. However, none of the results obtained suggested the presence of economically viable levels of mineralization.

Against the background of rising prices for uranium, further exploration is being planned for metasomatite type deposits, mainly in the areas around operating mines. No Ukrainian State or private company is involved in any exploration activities for uranium in another country. Neither foreign governments nor foreign private companies conduct exploration activities for uranium in Ukraine. Additional details are given in Table 5.15, which summarizes details of exploration campaigns conducted between 2004 and 2007, expressed in local currency (UAH: Ukraine Hryvnia).

TABLE 5.15. DOMESTIC URANIUM EXPLORATION AND DEVELOPMENT EXPENDITURES (million UAH[a]) [25.3- 25.13]

Expenditure (million UAH[a])	2004	2005	2006	2007	2008	2009
Government exploration expenditures	22.7	24.1	30.3	31.8	35.4	25.8
Government development expenditures	0	0	0.6	1.0	0	0
Total expenditures	22.7	24.1	30.9	32.8	35.4	25.8
Government exploration drilling (m)	40 938	32 297	37 720	35 213	23 316	12 660
Number of exploration holes	261	206	241	226	151	81
Government development drilling (m)	0	0	4494	7380	0	0
Number of development holes	0	0	74	134	0	0
Total drilling (m)	40 938	32 397	42 214	42 593	23 316	12 660
Total number of holes	261	206	315	360	151	81

[a] UAH: Ukraine Hryvnia.

5.25.4. Uranium resources

5.25.4.1. Identified resources (reasonably-assured resources and inferred resources)

As of 1 January 2009, reasonably assured resources and inferred resources in the <US $80/kgU cost category totalled 61 573 tU, compared with 230 580 t U as of 1 January 2007. The reasonably assured resources and inferred resources recovered at a cost of <US $40/kgU amounted to 6 427 tU and 43 140 tU in 2009 and 2007, respectively. These significant changes are principally the result of a re-evaluation

of mining costs in Ukraine, combined with the subtraction of the uranium production at Michurinskiy and Vatutinskiy (1 630 tU in both 2007 and 2008) (Tables 5.16 and 5.17).
The main economic resources are concentrated within deposits of two types:

(i) Metasomatite type, located within the Kirovograd block of the Ukrainian Shield. The deposits are monometallic and the grade of the ore is 0.1–0.2% U. These deposits are suitable for underground mining;
(ii) Sandstone-type, located within the Dnieper–Bug metallogenic area (17 300 km^2). In addition to uranium, the ores contain molybdenum, selenium and rare earths of the lanthanide group. The grade of the ore is 0.01–0.06% U. These deposits are suitable for mining by ISL.

As of 1 January 2017, recoverable reasonably assured resources and inferred resources in the <US $260/kgU cost category totalled 137 700 tU and 81 300 tU respectively (Tables 5.16 and 5.17).

TABLE 5.16. REASONABLY ASSURED (IN SITU) RESOURCES (TU) [25.12]
(as of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	< US $130/kgU	<US $260/kgU
Sandstone	0	6 730	6730	6730
Metasomatite	0	34 606	74 443	131 001
Total	0	41 336	81 173	137 731

TABLE 5.17. INFERRED (IN SITU) RESOURCES (tU) [25.12]
(as of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	< US $130/kgU	<US $260/kgU
Sandstone	0	897	897	897
Metasomatite	0	16 035	31 982	80 437
Total	0	16 932	32 879	81 334

Historical variations in conventional identified resources are shown in Fig. 5.53 and Fig. 5.54.

The UDEPO database lists the most significant deposits for Ukraine as Novokostyantynivske, Tsentralne, Severinivske, Vatutinske, Zhovtorichenske, Michurinske, Litne, Pidhajtsivske.

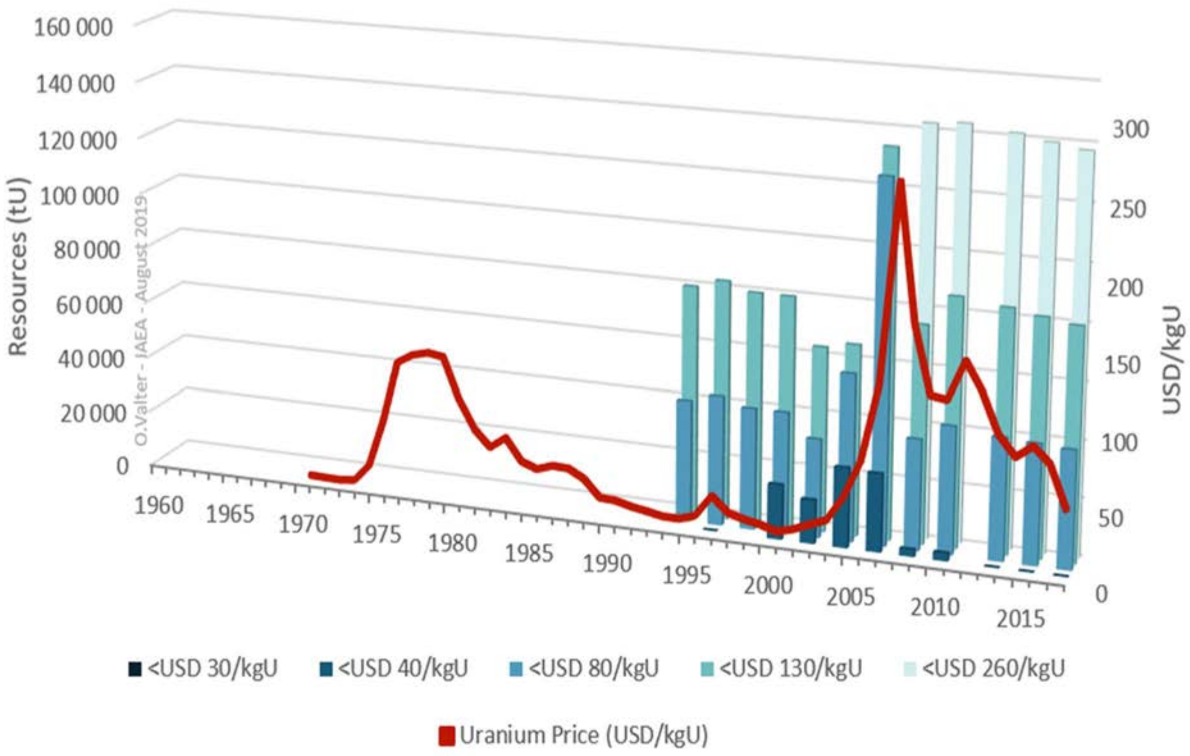


FIG. 5.53. Historical variation of recoverable reasonably assured resources within various cost categories in Ukraine. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

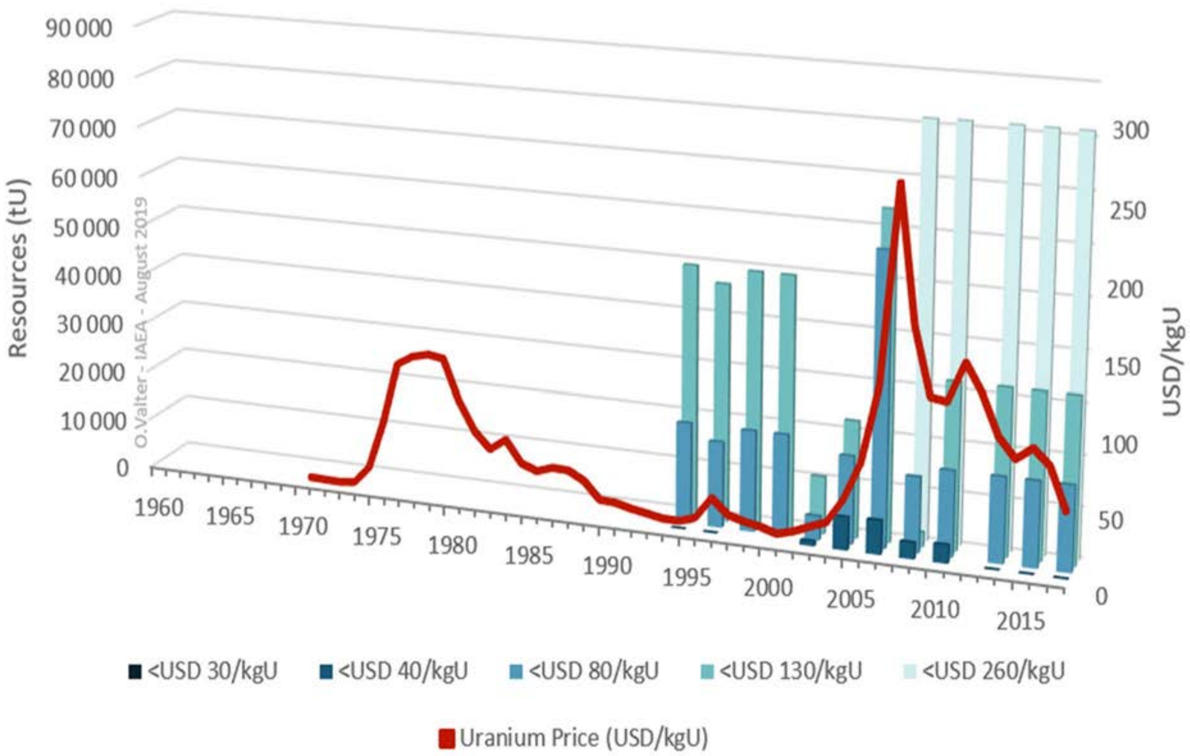


FIG. 5.54. Historical variation of recoverable reasonably assured resources within various cost categories in Ukraine. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

5.25.4.2. Undiscovered resources (prognosticated resources and speculative resources reported as in-situ resources)

Following reassessment, the in-situ resources total 270 300 t U. Prognosticated resources confined to the flanks of the Severinskiy deposit total 15 300 tU. The prognosticated resources total 8350 tU at <US $80/kgU and 22 540 tU at <US $130/kgU.

Speculative resources have been assessed in the central Ukrainian metallogenic area, which is shown on the uranium prognostication map compiled by 'Kirovgeology' (1:500 000 scale). These resources amount to 255 000 tU and are hosted in a variety of environments:

- Metasomatite type (133 500 tU);
- Sandstone type in sedimentary cover of the Ukrainian Shield (20 000 tU) and deposits of sandstone type outside the Ukrainian Shield (in bitumen) (16 500 tU);
- Unconformity type (40 000 tU);
- Vein type (30 000 tU);
- Intrusive type deposits in potassic metasomatites (15 000 tU).

The speculative resources total 120 000 tU at <US $130/kgU and 135 000 tU at an unassigned cost category.

As of 1 January 2017, Ukraine reports 219 000 tU of recoverable resources, 58 000 tU of these recoverable at a cost under $80/kgU. Reasonably assured resources amount to 137 731 tU, nearly all in metasomatite deposits and will require underground mining [25.12].

5.25.4.3. Unconventional resources

No unconventional resources have been reported.

5.25.4.4. Potential for new discoveries

As already noted, the potential for new discoveries is highest for the metasomatite type, mainly in the areas of known deposits in the Ukrainian Shield. Exploration efforts are also being made on deposits of the unconformity-type and the haematite breccia type, primarily in the Ukrainian Shield area. Potential for sandstone-hosted deposits may exist in the sedimentary basins either in or adjacent to the Ukrainian Shield.

5.25.5. Uranium production

The construction of the Pridneprovskiy Chemical Plant (PHZ), near Dneprodzerzhinsk, for uranium ore milling began in 1949. First mining operations began in 1947. PHZ processed ore from the Michurinskiy deposit, but also treated phosphate ores from the Melovoye deposit in Kazakhstan and raw concentrates from the former German Democratic Republic, Hungary and Bulgaria. In 1951, the Government created the Vostochnyi Mining and Processing Combinat (VostGOK), in the city of Zheltye Vody (Dnepropetrovsk region), which had responsibility for mining and processing ores from the Pervomayskiy and Zheltorechenskiy deposits. Pervomayskiy was mined out in 1967 and Zheltorechenskiy in 1989 [25.3].

Construction of a second processing plant began in 1956 at Zheltye Vody, and uranium concentrates from this plant were first produced in 1959.

VostGOK now operates mines in the deposits of the central Ukrainian metallogenic province at Michurinskiy, 3 km south of Kirovograd, and at Vatutinskiy, near the town Smolino. VostGOK is also committed to mining the Severinskiy deposit, 4 km north of Kirovograd [25.3].

The Michurinskiy deposit was discovered in 1964 and construction of the Ingulskiy mine began in 1967. The ore grade is ~0.1% U. Radiometric ore sorting helps to increase the uranium concentration. Two shafts are in operation, one for ore hoisting and one for personnel transportation. In addition, a ventilation shaft is in use. Mining is conducted in blocks 60–70 m high and at depths of 90, 150 and 350 m [25.3].

The Vatutinskiy deposit was discovered in 1965 and construction of the Smolinskiy mine began in 1973. The industrial area is situated near the town Smolino, 80 km west of Kirovograd. Ore hoisting is conducted by the ‘main’ and ‘assisting’ shafts sunk to a depth of 460 m. The lower part of the deposit (at a depth of 640 m) is accessed by two ‘blind’ shafts.

The ore is mined by blasting, mucking and hauling, followed by backfilling. The mines are operated by three shifts totalling 850 workers. The ore is crushed before hoisting and radiometric ore dressing is done at the surface. The backfilling is done by hydropacking.

The Novokonstantinovskiy deposit, with about 90 000 tU of resources at 0.14%U, is situated in the Kirovograd region. It is developed as an underground mine. First production of 99 tU was in 2011. Mine nominal production capacity is 1 500 tU/yr. [25.3, 25.13].

ISL has been employed in Ukraine since 1961. In the period 1966–1983, three deposits (Devladovskiy, Bratskiy and Safonovskiy) were mined by sulphuric acid ISL at a depth of ~100 m. However, ISL mining was stopped, mainly for environmental reasons. Monitoring the conditions of mined out deposits is ongoing. Development of two deposits using ISL mining with alternative leaching reagents is being planned. Construction of a uranium mining centre is planned for the Safonovskiy deposit, with a production capacity of 250 tU/year.

Production for the period 1992–2003 is estimated (Fig. 5.55). Annual production prior to 1992 was included in the total production of the former Soviet Union and was not reported separately. Total cumulative production to 2017 from Ukrainian deposits is estimated at 125 212 tU with 21 074 tU since 1992, mostly from underground mining.

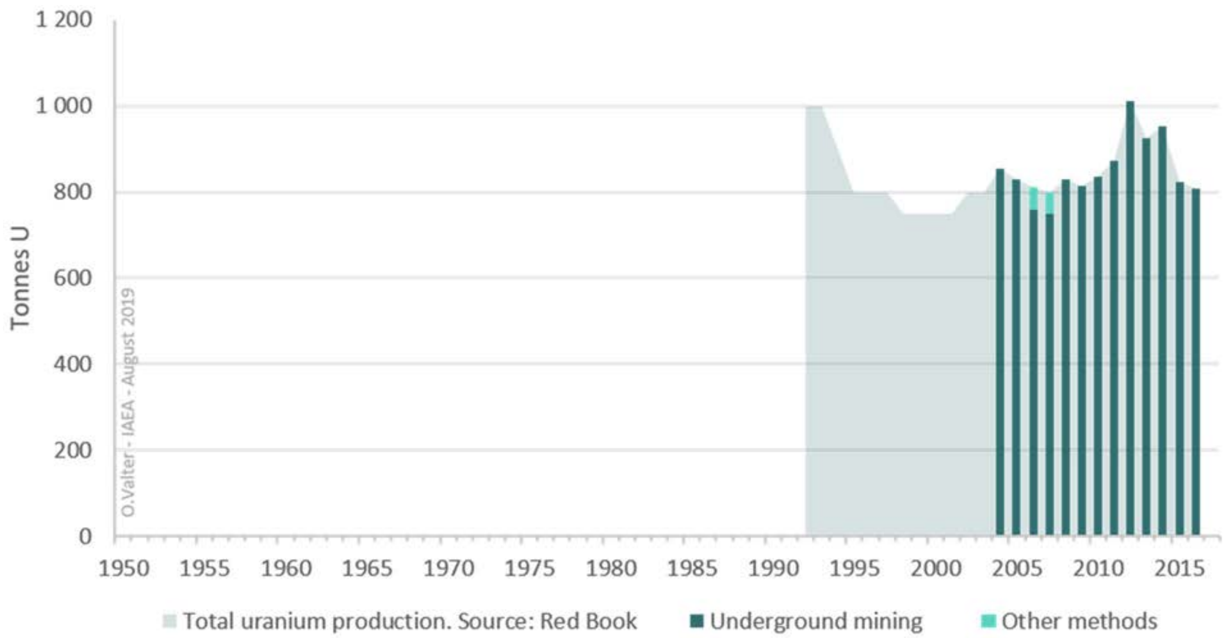


FIG. 5.55. Historical uranium production in Ukraine post-Soviet Union.

The hydrometallurgical processing plant of the VostGOK/Zheltye Vody region has an annual capacity of 1.5 million t ore. The ore is transported from the Ingulskiy and Smolinskiy mines, which are situated 100 km and 150 km to the west, respectively. After crushing and radiometric sorting, the ore is leached in autoclaves using sulphuric acid at a temperature of 150–200°C and a pressure of 2026.5 kPa for four hours. Acid expenditure is 80 kg/t ore. Uranium is extracted by ion exchange. After washing with a mixture of sulphuric and nitric acids, the uranium-bearing solution is subjected to further concentration and purification through extraction with solvents, with ammonia gas used for precipitation. The dewatered precipitate is calcined at 800°C (Table 5.18).

TABLE 5.18 URANIUM PRODUCTION CENTRE TECHNICAL DETAILS [25.3]
(As of 1 January 2007)

	Centre #1	Centre #2
Name of production centre	Hydrometallurgical Plant Zheltye Vody	Hydrometallurgical Plant
Production centre classification	Operating	Committed
Startup date	1958	2015
Source of ore:		
• Deposit name	Michurinskiy, Centralniy, Vatutinskiy	Novokonstantinovskiy
• Deposit type	Metasomatite	Metasomatite
• Resources (tU)	77 070	93 630
• Grade (%U)	0.1	0.14
Mining operation:		
• Type	UG[a]	UG
• Size (t ore/d)	4 500	7 500
• Average mining recovery (%)	81	82
Processing plant:	Sulphuric acid	Sulphuric acid
• Type	Ion exchange	Ion exchange
• Size (t ore/d) for ISL (L/d or L/h)	n.a.[b]	n.a.
• Average process recovery (%)	92	n.a.
Nominal production capacity (tU/year)	1 500	1 500
Plans for expansion		2 500

[a] UG: underground mining.
[b] n.a.: not available.

5.25.5.1. Innovative techniques in uranium production

In metasomatite type deposits, the ore grade is ~0.1% U (consisting of disseminated uraninite, brannerite, coffinite, nasturan (i.e., pitchblende)). The orebodies are steeply dipping. The mines are situated ~100 and 150 km from the hydrometallurgical plant. After underground mining, the ore is crushed and uranium is leached by sulphuric acid in autoclaves. In order to lower the costs of production from these low-grade uranium ores, innovative production technologies have been introduced, such as underground radiometric sorting, in place leaching (IPL), heap leaching and reprocessing (reclamation) of dumps, and these techniques have been employed at operating mines.

Multistage radiometric separators are used for both mined ore and the rock mass in mine dumps. In the case of mined ore, the grade may reach 0.03–0.3% U. In contrast, the uranium content in tailings is less than 0.006%.

If waste material in the dumps has an average specific activity of 1500–1600 Bq/kg, then the tailings obtained after radiometric separation only have 350–650 Bq/kg and therefore can be used as construction material (second class), which has a specific activity within the limits 370–740 Bq/kg.

Separators or ore sorters are installed both on the surface and underground in the mine. The output of a system of two separators is 150 000 t ore/year. Three products are obtained during the radiometric separation of dump material:

(i) 30% – uranium concentrate for processing (0.05–0.06% U);
(ii) 55 – tailings with a specific activity <740 Bq/kg, for use as construction material;
(iii) 15% – inert material, for use as backfill.

Uranium extracted by heap leaching costs 62% as much as that produced at a hydrometallurgical plant. Orebodies with a uranium grade of 0.04–0.06% U are mined using IPL. The uranium concentration in pregnant solutions changes from 1 000 mg/L at the start of IPL to 50 mg/L at the end. Recovery of uranium during heap leaching is ~70–75% per year of leaching. The cost is 58% that for conventional technology.

Ores of metasomatite type deposits are amenable to heap leaching. The degree of rock breakage is the most important parameter as it determines the permeability of the material during heap leaching and the degree of uranium recovery possible. The minimum size of the broken rock is usually between 1 and 5 mm. The optimum size of ore material is 10 mm, which typically yields 80–90% uranium recovery after the two to three months of processing.

The heaps are either formed of ore with a grade of 0.05–0.08% U, or of concentrate obtained as a result of dump sorting with a uranium content of 0.5–0.6%. The size of a heap corresponds to around 40 000 t of ore with a height of up to 6–8 m. The site for heap leaching consists of four heaps with a total processing volume of 160 000 t ore/year.

Efforts to improve the technology of radiometric ore dressing at the radiometric processing plants are ongoing. Previously, at the Smolinskiy radiometric processing plant, specific activity in the tailings was 1 900 Bq/kg, which was subsequently improved to ~1 100 Bq/kg. A new generation of ore sorters will reduce the specific activity of tailings to between 500 and 600 Bq/kg, which corresponds to the specific activity for construction materials (second class). As such, tailings may be used as construction materials for highways and industries and this reduces the quantity of mine waste requiring storage.

5.25.6. Ownership of the uranium industry

The uranium industry (mining, ore dressing, nuclear fuel) is State owned and is subordinate to the Department of the Atomic and Industrial Complex of the Ministry of Fuel and Energy. All uranium produced is owned by the State.

VostGOK, founded in 1951, is responsible for mining and processing of uranium ores and is subordinate to the Department of Atomic and Industrial Complex. In addition, VostGOK runs a plant for production of sulphuric acid, a mechanical repair plant, a ‘scientific production’ complex and a transportation unit.

The State enterprise ‘Kirovgeology’ is responsible for exploration and evaluation of uranium mineral reserves (exploration, assessment and delineation of uranium deposits). It is subordinate to the State Geological Survey of the Ministry of Environmental Protection.

In December 2006, the Government founded 'Ukratomprom' to operate within the Directorate of the Ministry of Fuel and Energy. Management of current activity in external economic and investment relations is the responsibility of another State enterprise, the National Atomic Energy Generating Company ('Energoatom').

5.25.7. Environmental activities

The main environmental impacts of uranium production (related to the Ingulskiy and Smolinskiy mines) occur at ore storage sheds, tailings dumps, waste rock dumps, and transport sites and paths.

The main environmental impact factors arising from uranium production (hydrometallurgical plants, heap leaching sites) concern harmful chemical and ore dust emissions, wind transportation of aerosols and groundwater contamination from tailings impoundments. To ensure any environmental impact is minimized, permanent monitoring is conducted.

At the mined out Devladovskiy and Bratskiy deposits, monitoring of groundwater conditions has been conducted since 1988. Results indicate that the halo of residual leaching reagents does not extend beyond the historic halo of the mined-out orebodies, although diluted and reduced in volume.

Treatment at the hydrometallurgical plant results in the removal and storage of processing wastes, clearance of the liquid fraction and use of recycled water in the technological process. Two tailings impoundments, one situated 9 km from the hydrometallurgical plant and consisting of two sections covering 135 and 163 ha, and the second, 0.5 km from the plant (covering 55 ha), receive the tailings. The second tailings impoundment is filled to capacity and reclamation is ongoing.

There are also environmental issues arising from the decommissioning of uranium mining and uranium processing enterprises [25.3].

The PHZ chemical plant in Dnieprodzerzhynsk produced uranium concentrate from 1949 to 1991. Nine tailings impoundments were used during uranium production (total area of 268 ha containing 42 million t of waste), which have a total activity of 2.775 million TBq.

The radioactive pollution within the production site of the plant covers an area of 25 ha. Some buildings and other facilities are contaminated by radioactivity. The Cabinet of Ministers of Ukraine issued the State programme for putting unsafe objects from the PHZ chemical plant into an environmentally safe condition and providing protection to the population from the harmful impact of ionizing radiation. The funding for this has been taken from the State budget and since 2005 has totalled UAH 22.3 million (about US $4.5 million).

The State programme was approved in 1995 to improve radiation protection at all nuclear industry enterprises, spanning all contaminated areas resulting from the mining and processing of uranium. The cost of this has been assessed at US $360 million. The programme will include decontamination of polluted soils, environmental monitoring, installation of monitoring systems where necessary, and improvement in technology of management with regard to water flows, radioactive waste in dumps, and polluted equipment and land areas. Further details are given in Refs [25.14, 25.15].

5.25.8. Employment in the uranium industry

The total employment in the uranium industry between 2004 and 2007 decreased slightly from 4380 in 2004 to 4 310 in 2007. Employment directly related to uranium production was 1 720 in 2006, 1 690 in 2007 and 1 460 in 2009.

5.25.9. National policies relating to uranium

On 29 December 2006, the Cabinet of Ministers passed Resolution No. 1854 on the improvement of the administration of the Atomic and Industrial Complex. This Resolution founded the State enterprise

'Ukratomprom', which comprised all enterprises and scientific and research institutes connected with the nuclear fuel cycle. The Resolution is also aimed at improving the investment environment.

Government policy is aimed at increasing uranium production and attracting foreign investment for the development of uranium mining projects within Ukraine.

References to Section 5.25

[25.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Ukraine, https://www.cia.gov/library/publications/the-world-factbook/index.html
(accessed July 2009).

[25.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[25.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[25.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[25.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[25.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[25.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[25.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[25.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[25.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[25.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[25.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[25.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[25.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, OECD, Paris (1999) 139–147.

[25.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002) 267–270.

CHAPTER 6. SOUTH-EASTERN ASIA, PACIFIC, EAST ASIA

6.1. AUSTRALIA

6.1.1. Geography

Australia, in the Southern Hemisphere, is comprised by the Australian continent mainland, the Tasmania island and several smaller islands in the Pacific and Indian Oceans. It is the sixth largest country in the world. Neighbouring countries include Papua New Guinea, Timor-Leste and Indonesia to the north, New Caledonia (France), Vanuatu and the Solomon Islands to the north-east, and New Zealand to the south-east.

Australia's size confers a wide variety of landscapes and climatic zones, with a dry desert at its centre, mountain ranges to the south-east, south-west and in eastern areas, and subtropical rainforests to the north-east. It is the 'flattest' continent, with the oldest and least fertile soils. Mount Kosciuszko on the Great Dividing Range is at 2 228 m, the highest mountain of the country. Commonly known as 'the outback', desert or semi-arid land makes up by far the largest portion of country. With only 2.8 inhabitants per square kilometre, it is among the lowest population density in the world, although along the temperate south-eastern coastline lives a large proportion of the population.

Eastern Australia is marked by the Great Dividing Range that runs parallel to the coast of Queensland, New South Wales and much of Victoria. Parts of the range consist of low hills and the 'highlands' are typically no more than 600 m in height. The Great Barrier Reef, the largest coral reef in the world, extending for over 2000 km, lies close to the north-east coast.
In the northern part of the country, the landscapes, with their tropical climate, consist of grassland, woodland and desert. At the north-west corner of the continent are the sandstone cliffs and gorges of the Kimberley, and below them, the Pilbara. At the heart of the country are the uplands of central Australia.

The climate of Australia is significantly influenced by ocean currents. A tropical climate typified by summer rainfall pertains to most of the northern part of the country. A Mediterranean climate pertains to the south-west corner of the country. A temperate climate pertains to most of the south-eastern part of the country, including Tasmania.

Australia, being rich in natural resources, is a major exporter of agricultural products, particularly wool and wheat, as well as minerals such as iron, gold, bauxite, base metals and diamonds, and energy in the forms of natural gas, coal and uranium. The mining sector represents 10% of GDP and the 'mining related economy' (exploration, mining equipment) represents 9% of GDP. Although accounting for only 3% and 5% of GDP, agriculture and natural resources, respectively, contribute considerably to exports. The service sector of the economy, accounting for ~70% of GDP, includes tourism, financial and educational services [1.1].

6.1.2. Geology

6.1.2.1. General

Australia can be divided into four orogenic provinces mantled by four platform covers (Figs. 6.1 and 6.2).

The West Australian Orogenic Province is the oldest province and contains the Pilbara, Yilgarn and Rum Jungle Blocks, which are belts of metamorphosed sediments and volcanics in predominantly gneiss and granite terrains. The platform covers of the West Australian Orogenic Province, consisting principally of the Hamersley Basin, mantles the Pilbara Block and comprises Lower Proterozoic basic volcanics and pyroclastics overlain by chemical and clastic sediments.

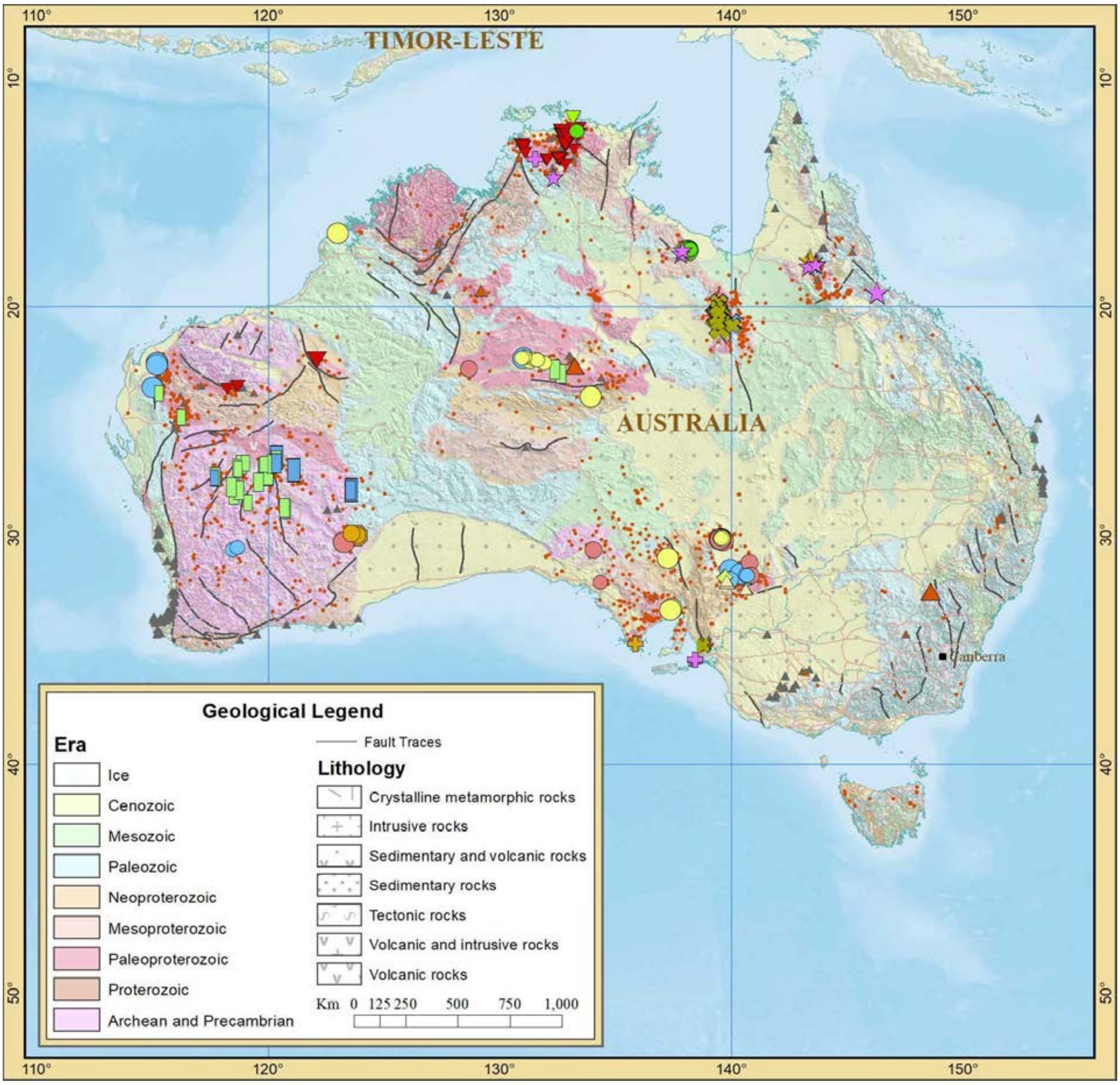


FIG. 6.1. Regional geological setting of Australia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The North Australian Orogenic Province contains the Pine Creek Block, Tennant Creek Block, Granites-Tanami Block, the Nicholson Block and the Halls Creek Belt. These areas generally consist of low to moderately metamorphosed Lower Proterozoic sediments and volcanics which, in some cases, are intruded by granites. The North Australian Platform Cover was deposited in the Middle Proterozoic and is preserved in the Kimberley Basin, the McArthur Basin and around the Tennant Creek, Granites-Tanami and Nicholson Blocks. This platform cover is largely pelitic with minor dolomites and volcanics.

The Central Australian Orogenic Province consists of several moderate to highly metamorphosed volcano-sedimentary blocks and belts of Lower–Middle Proterozoic age. In the west, there are the Ophthalmia-Gascoyne, Northampton and Albany-Fraser Blocks; in the centre there are the Musgrave and Gawler Blocks; and to the east the Mount Isa Belt and the Willyama, Mount Painter and Wonaminta Blocks. The Central Australian Platform Cover was deposited over a wide area of western and central Australia from the Middle Proterozoic through the Palaeozoic.

In the west, there are the Carnarvon, Bangemall and Canning Basins, in the centre the Officer, Amadeus and Ngalia Basins, and in the east the Georgina Basin and the Adelaide Geosyncline.

Several orogenic blocks have not been assigned to any province. The Arnhem and Litchfield Blocks in northern Australia appear to be Archaean in age. The Arunta Block is poorly exposed and may be associated with the North and Central Australian Orogenic Provinces. The Georgetown Block is Middle Proterozoic and contains high grade gneiss intruded by granite and a younger, less deformed sequence, also intruded by granite.

The East Australian Orogenic Province or Tasman Geosyncline, of Cambrian–Late Triassic age, consists of low to medium grade metamorphosed sediments and volcanics intruded by acid plutonic rocks.

The Kanmantoo Belt is the oldest part of the province. Other belts within this province are the Lachlan Belt and its age equivalent, the North Queensland Blocks, and the Holdgkinson and New England-Yarrol Belts.

The Trans-Australian Platform Cover consists of Permian–Tertiary sedimentation which was deposited over much of the eastern third of Australia.

Figure 6.2 illustrates the principal geological elements.

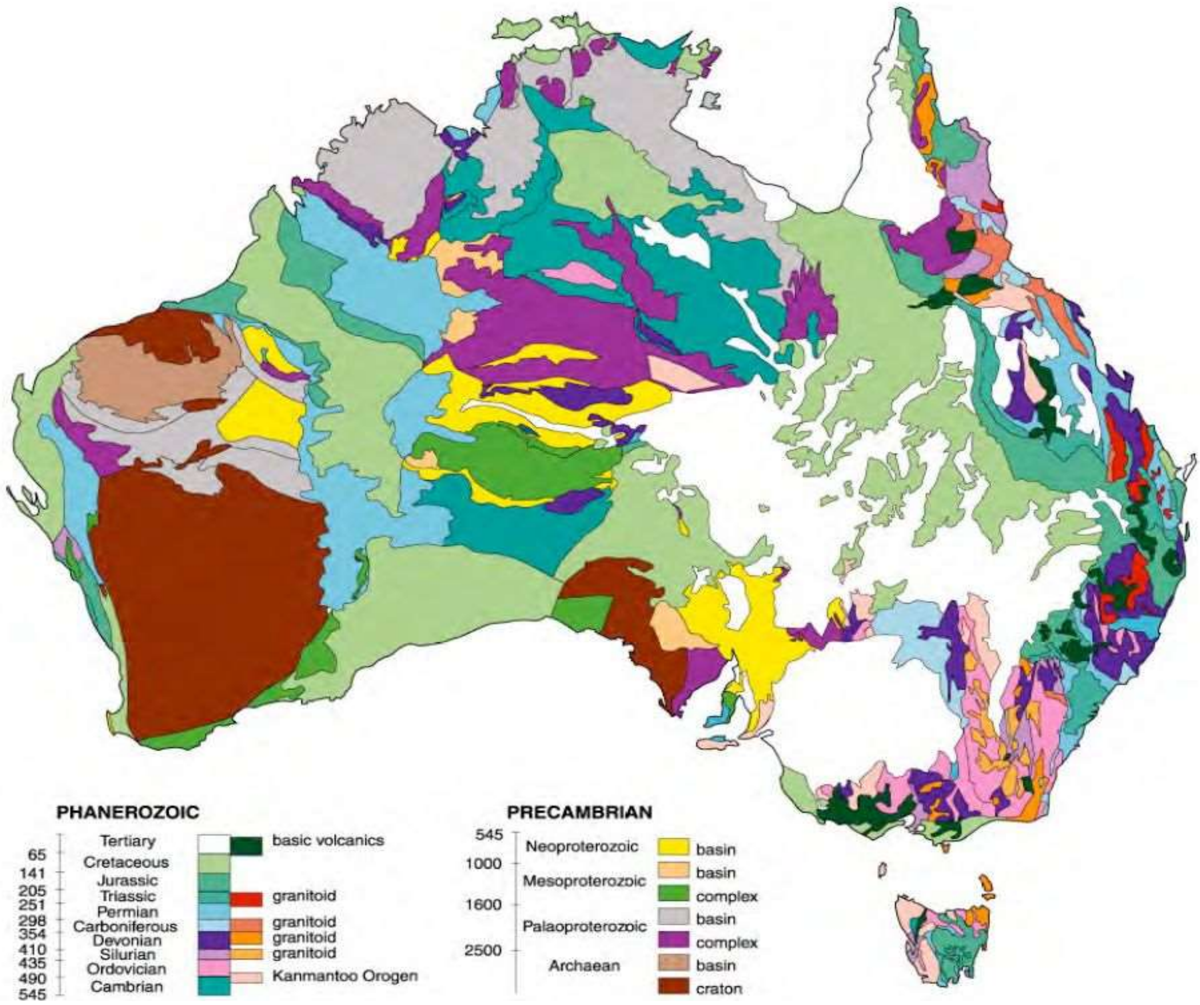


FIG. 6.2. Major geological elements of Australia (map courtesy of, and with permission from, Geoscience Australia).

6.1.2.2. Geology related to uranium-bearing areas

Approximately 90% of Australia's initial in-ground resources occur in two main types of deposit: haematite breccia complexes and unconformity-related deposits. In addition, there are other types of deposit, including sandstone hosted and surficial (calcrete) deposits, which also contain significant resources.

Haematite breccia complex deposits

Approximately 70% of resources exist in Proterozoic haematite granitic breccias at Olympic Dam (South Australia), the largest uranium resource in the world. Broadly similar haematite breccia mineralization in the same geological province is being evaluated somewhere else at Acropolis, Carrapateena, Oak Dam, Prominent Hill and Wirrda Well, and at some of the younger breccia-hosted deposits in the Mount Painter area.

The Olympic Dam deposit, occurring in a haematite-rich granite breccia complex in the Gawler Craton, underlies ~300 m of flat-lying sedimentary rocks of the Stuart Shelf geological province [1.2]. Formed in a post-orogenic tectonic setting [1.2], the breccia complex is linked with a plutonic intrusion and co-magmatic continental felsic volcanics of Mesoproterozoic age.

The Olympic Dam Breccia Complex occurs entirely within the Roxby Downs Granite intrusion of Mesoproterozoic age. The margins of the Olympic Dam Breccia Complex are gradational with the Roxby Downs Granite. The Olympic Dam Breccia Complex includes a complete gradation from granite breccias through haematite–granite breccias to haematite-rich breccias. The zone of haematite-rich breccias is enveloped by granitic breccias, which extend ~3 km beyond the margins of the haematite-rich breccias. There is an extensive zonal distribution of the major types of rocks within the Olympic Dam Breccia Complex, and almost all of the economic Cu–U mineralization is hosted by haematite-rich breccias (haematitic breccias and heterolithic haematite breccias) [1.3].

Intrusive tuffs and dykes of felsic, mafic and ultramafic rock types intrude into the Olympic Dam Breccia Complex, particularly its southern and eastern portions. These intrusive rocks are intimately linked with volcanic diatreme structures. Localized zones of volcaniclastic rocks widen upwards, and close the unconformity they comprise surficial volcaniclastic rocks consisting chiefly of conglomerate (containing fragments of Gawler Range volcanics) and laminated ash together with reworked hydrothermal breccias.

The Olympic Dam deposit contains Fe, Cu, U, Au, Ag and rare earth elements (mainly Ce and La). Only Cu, U, Au and Ag are currently being recovered [1.2]. Uranium mineralization at Olympic Dam occurs as disseminations, microveinlets and aggregates of fine-grained pitchblende intergrown with Cu-sulphides within haematitic breccias and heterolithic haematite breccias. Pitchblende also occurs as small aggregates intergrown with or replacing breccia material. Minor abundance of brannerite and coffinite are intimately related with the pitchblende. Zones of narrow, higher grade uranium frequently occur in zones of bornite–chalcocite, particularly with haematite breccias [1.4]. Some zones of high-grade uranium mineralization cut the bornite–chalcopyrite interface. As of 1 January 2017, total recoverable reserves for the Olympic Dam deposit were reported as 918 256 tU at an average grade of 0.025 %U [1.5].

Unconformity-related deposits

Approximately 19% of resources are linked with Proterozoic unconformities, especially in the Alligator Rivers field in the Northern Territory (Ranger, Koongarra and Jabiluka). The Alligator Rivers Uranium Field (ARUF), which lies within the Pine Creek Inlier, is located ~220 km east of Darwin. The area's mineral potential was recognized in 1967, when the Bureau of Mineral Resources published a revision of the 1:500 000 scale geological map of the Katherine–Darwin region, which depicted probable Archaean basement in the Alligator Rivers area [1.2, 1.6]. The Archaean rocks were portrayed to be overlain unconformably by metamorphosed and deformed Palaeoproterozoic strata, which, in turn, were overlain by Mesoproterozoic sandstones of the McArthur Basin. The map underscored similarities to the deposits of uranium in the Archaean–Palaeoproterozoic–Mesoproterozoic setting at Rum Jungle. The cover sandstones in the Alligator Rivers area were dated to Late Palaeoproterozoic age [1.7, 1.8].

The Koongarra, Jabiluka and Ranger 1 deposits and most of the major prospects of uranium occur adjacent to the Archean Nanambu Complex forming a regional dome. They are hosted in the lower member of the Palaeoproterozoic Cahill Formation, which is characterized by the existence of metamorphosed carbonate rocks and includes interlayered chloritized feldspathic quartzite, quartz schist, mica schist, para-amphibolite and calc-silicate rock. The Myra Falls metamorphics, which host the Nabarlek deposit, are likely metamorphosed equivalents of the lower member of the Cahill Formation [1.2]. The deposits of uranium were formed after the main period of regional metamorphism. According to U–Pb isotope dating, the age of mineralization at Ranger is 1737 ± 20 Ma age whereas that at Jabiluka is 1437 ± 40 Ma [1.9]. Rb-Sr, U-Pb, Pb-Pb and Sm-Nd analysis of uraninite and minerals from the inner alteration zone produced ages of primary mineralization in the range 1650-1610 Ma at Jabiluka and Nabarlek [1.10].

Unconformity-related deposits have also been found in the Pine Creek Uranium Province, in the South Alligator River Valley Mineral Field (SARMF), 220 km south-east of Darwin and in the Rum Jungle Mineral Field (RJMF), 90 km south of Darwin. Four deposits have been mined in the RJMF — Mount Burton, White's, Dyson's, and Rum Jungle Creek South — two of which produced Cu as well [1.4]. Production of uranium from the was taken from 14 small deposits, including Coronation Hill, Rock Hole, El Sherana and El Sherana West, Palette and Saddle Ridge [1.2, 1.6, 1.11].

The Kintyre deposit in the Rudall River area (Western Australia) exists in metasediments of the Yandagooge Formation in the Rudall Complex next to the unconformity with the Neoproterozoic Coolbro Sandstone. The deposit shares similar characteristics with the deposits in the Alligator Rivers region. The favourable lithologies for mineralization are interbedded chlorite schist and chert. Mineralization occurs within a system of narrow, closely spaced veins. These veins occur along the cleavage of a major NW trending shear zone, which has faulted the Coolbro Sandstone. Ore zones are formed by multiple sets of tightly spaced mineralized veins. The ore zones are divided into five ore bodies, which together make up the Kintyre deposit and include the Pioner, Kintyre and East Kintyre, Nerada, Whale and East Whale deposits [1.2, 1.12].

Sandstone-hosted uranium deposits

Sandstone-hosted uranium deposits account for 4% of resources. The known sandstone hosted uranium deposits are located in Western Australia, South Australia, Northern Territory and Queensland. The basins and uranium fields containing these deposits are the Canning Basin (Western Australia), Carnarvon Basin (Western Australia), Gunbarrel Basin (Western Australia), Ngalia Basin (Northern Territory) and Amadeus Basin (Northern Territory), Westmoreland–Pandanus Creek field (Queensland), Eucla Basin (South Australia) and Frome Embayment field (South Australia).

The Frome Embayment is a lobe on the southern portion of the Callabonna Sub-basin in the south-western part of the Lake Eyre Basin [1.13]. The Callabonna Sub-basin contains shallow water sediments of Tertiary age. The Barrier Ranges, Olary and Flinders bordering the embayment are comprised chiefly of Precambrian and Cambrian sedimentary and metamorphic rocks which comprise widespread occurrences of disseminated uranium mineralization and many small uranium deposits [1.1].

In Early Tertiary, well sorted sand (Eyre Formation) was deposited as a thin, laterally continuous horizon occupying the full width of the northern part of the Sub-basin. The equivalents of the Eyre Formation to the south (i.e., angular, poorly sorted fluvial sand and interbedded silt and clay) were deposited in major stream channels of limited areal extent [1.14]. The channels were incised into Precambrian basement and Late Cretaceous Marree Subgroup marine clay. Dolomite, sand and clay of the Mioene Namba Formation form a continuous sequence disconformably overlying the channel sediments. A thicker sequence of the Namba Formation was deposited near the Flinders Ranges, forming the small Poontana Sub-basin.

The Goulds Dam, Yarramba, East Kalkaroo and Honeymoon deposits are hosted in palaeochannel sands of the Palaeocene–Eocene Eyre Formation, whereas the Beverley deposit lies within the sands of the overlying Miocene Namba Formation [1.2]. The palaeochannels in the southern part of the Frome Embayment border a structural high in the underlying basement known as the Benagerie Ridge. The Beverley North and Four Mile East deposits are in the Eyre Formation, whereas the Four Mile West is believed to be hosted in sediments equivalent to the Cretaceous Bulldog Shale.

The Tertiary sands were sourced from Precambrian granitic and metamorphic rocks in the neighbouring uplands and were deposited in the channels together with abundant plant matter. Uranium contained in rock fragments and mineral detritus was deposited together with the channel sands [1.2, 1.14].

Two genetic models have been proposed. One model suggests that oxidizing groundwater, flowing sluggishly through the channel sands, leached uranium and reprecipitated it, down-gradient, at the redox interface. Roll front deposits developed at the redox interface, especially where groundwater flow was hampered by lower permeability and thinner sand units towards the channel banks. The migration of groundwater resulted in oxidation of pyrite and organic matter, imparting red and orange coloured iron oxide stains on the sands [1.2]. The second model suggests that uranium was introduced in solution rather than in rock fragments and mineral detritus, was transported through the palaeochannel and was precipitated in favourable reducing settings [1.2].

In the Eucla Basin, uranium exists in the basal Eocene palaeochannel sediments overlying the Archaean and Proterozoic gneiss, granites and volcanics of the Gawler Craton [1.2]. Low grade mineralization of significant extent is known in the Wynbring and Warrior palaeochannels. In addition, mineralization is known to be present further south in the Narlaby and Yaninee palaeochannels.

The Westmoreland deposits are located in the Palaeoproterozoic-Mesoproterozoic McArthur Basin, north-west Queensland, 400 km NNW of Mount Isa, in an area adjoining the Pandanus Creek area in the Northern Territory. The McArthur Basin is a 6-10 km thick sequence of sedimentary and volcanic rocks that were deposited between 1 800 and 1 575 Ma. The four main geological settings of the deposits and occurrences of uranium in the Westmoreland–Pandanus Creek field are as follows [1.2, 1.6]:

(i) Stratabound mineralization in the uppermost sandstone unit of the basal Westmoreland Conglomerate, subparallel to the contact with overlying basic volcanics of the Seigal Volcanics (Redtree, Junnagunna, Long Pocket deposits, Southern Comfort occurence);
(ii) Discordant, steeply dipping zones of mineralization contiguous to the contact with intrusive basic dykes and sills coeval with the overlying mafic Seigal Volcanics (Wanigarango, Oogoodoo occurences, and Mageera Huarabagoo deposit);
(iii) Mineralization associated with fractures in altered basic volcanics (King’s Ransom, El Hussen, Old Parr occurences and Cobar 2 deposit); and
(iv) Mineralization related with shear zones within altered acid volcanics (Pandanus Creek occurence).

In the Amadeus Basin, the Angela and Pamela uranium deposits lie within the Undandita sandstone member of the youngest unit (i.e., Brewer Conglomerate) in the Amadeus Basin. This sandstone member is the uppermost unit of a thick sequence of terrigenous sediments (i.e., the Pertnjara Group) of Late Devonian–Early Carboniferous age [1.15]. The Undandita Member consists of medium- to coarse-grained lithic arkose interbedded with thin mudstone units, and fine- to coarse-grained lithic sandstones. South of the MacDonnell Ranges, this sequence interfingers with the Brewer Conglomerate. In the Missionary Syncline, 15 km south of Alice Springs, the sequence attains a maximum thickness of 3000 m. The sediments are mostly oxidized, although preserved within the sequence if a wedge-shaped zone of reduced sandstone [1.16]. The area of the reduced sandstones within the Undandita Member is defined by a redox boundary, the upper part of it is where the uranium deposits are located [1.15].

The Ngalia Basin is an elongate, intracratonic basin filled by continental and marine strata – chiefly arenaceous with interbedded dolomite and shale – of Neoproterozoic and Palaeozoic age. The basement is comprised of highly deformed metamorphics, granites and sediments of the Palaeoproterozoic Arunta Block. The sequence is made up of 11 formations with maximum cumulative thickness of ~7500 m. Most formations are separated by unconformities [1.17].

Uranium mineralization occurs in the lower part of the Mount Eclipse Sandstone, which is of Late Devonian–Late Carboniferous age, and hosted by medium- to coarse-grained feldspathic sandstones commonly cemented by carbonate [1.2]. Drilling in 1980–1988 identified three deposits, together called the Mulga Rock deposits, hosted by Eocene palaeochannel sediments of the Gunbarrel Basin [1.2]. Peat and clayey peat, which occur just beneath the redox limit at the bottom of the weathered zone, host the uranium mineralization. The mineralized zones are horizontal and occur at a depth of 20–50 m, dependent on variations in surface topography and changes in the level of the redox limit [1.2].

A major unconformity exists between the Carnarvon Basin shelf strata and the Archaean(?)–Mesoproterozoic metasedimentary and granitic basement rocks [1.2]. Basal conglomerate in palaeochannels is followed by other formations that cut the basement to the east. The Yarraloola conglomerate is overlain by the Cretaceous shallow water/marine Birdrong Sandstone, which, in turn, is overlain by marine shale and radiolarite. The Cretaceous strata are overlain by Cenozoic calcareous gravel, clay and siltstone with an erosional hiatus. Uranium mineralization occurs in the basal parts of the Yarraloola Conglomerate and the Birdrong Sandstone, and is related with strong oxidation of the erst while sediments are reduced by groundwater flowing along the confined aquifer beneath the Muderong Shale [1.2].

Within the Yampi Embayment of the Canning Basi, the Early Carboniferous Yampi Sandstone hosts the Oobagooma deposit [1.2]. The embayment is a NW-trending fault-controlled graben bordered on three sides by Proterozoic metamorphics. The Yampi Sandstone was deposited in a deltaic environment influenced by fluvial and tidal processes. Mineralization is hosted by sandstones rich in pyrite and organic matter. Higher grade mineralization occurs in two zones: a 1–6 m thick lower band lying at depths of 65–85 m, and a 1–5 m thick upper band lying at depths of 48–55 m [1.2]. In the upper band, mineralization forms a roll front deposit and is controlled by a combination of structural, sedimentological and redox factors [1.2].

Surficial (calcrete) deposits

Surficial (calcrete) deposits account for 4% of Australia's uranium resources and occur mostly in the Yilgarn Craton, at Centipede, Lake Maitland, Lake Way and Yeelirrie (Western Australia).

Calcretes have been forming since Pliocene under semi-arid to arid climatic conditions. Carnotite mineralization is extensive in calcreted trunk valleys of the Tertiary drainage system that developed over an area of 400 000 km² of south-western Australia [1.18]. However, the significant prospects and known calcrete hosted deposits of uranium are restricted to the granitic rocks in the northern sector of the Yilgarn Craton [1.2]. Anomalous concentrations of surficial uranium mineralization in calcreted drainage channels spread north of the Yilgarn Craton and exist in the Proterozoic Bangemall Basin and Gascoyne Complex, in the Archaean Pilbara Craton, and in portions of the Northern Territory and South Australia. The Yilgarn Craton, the 'Menzies line' to the south and the 'Meckering line' to the west controlled the extent of the distribution of the principal calcrete uranium deposits [1.19].

In the northern part of the Yilgarn Craton, the Yeelirrie deposit, located 650 km north-east of Perth, is hosted within valley calcretes sitting on the drainage channel of a broad flat valley [1.2]. The Yeelirrie catchment area is underlain nearly wholly by highly weathered granitic rocks. The uranium deposit is a horizontal sheet ~1.5 km wide and ~9 km long. The bulk of the mineralization is restricted to the interval 4–8 m beneath the surface, with ~90% existing beneath the water table. The mineralized material assaying 0.08% U or greater has an average thickness of 3 m [1.20]. Roughly 90% of the mineralization exists at the 4 m thick transition zone between the clay–quartz and the calcrete [1.2].

The Lake Way deposit, 16 km south-east of Wiluna, is at the north-eastern margin of Lake Way. Mineralization occurs in clay and earthy calcrete in the lower levels of a Tertiary drainage channel where it enters the north-east margin of Lake Way. Carnotite exists in clay–gravel, on bedding planes, on slickenside surfaces, and as coatings on broken calcrete blocks at the interface between water table and air, extending down to 2 m below the interface and up to 1 m above it [1.21]. There exist four areas of ore grade mineralization linked by areas of sub-economic mineralization. The average thickness of the mineralization is 1.5 m, varying from a few centimetres to a maximum of 5 m [1.2].

There are several uranium calcrete deposits at Lake Maitland, 102 km south-east of Wiluna. The deposits, extending in a N–S trending zone, underlie the northern part of Lake Maitland. The mineralized zone is 300–600 m wide and ~6 km long, 0.2–2.0 m thick (maximum 3.75 m) and lies 1.5–2.0 m below the surface [1.2]. The mineralization occurs as the mineral carnotite within 'slabby' calcrete, but is also present in clay, silt, and sand [1.2].

In the Hinkler Well–Centipede drainage system, which enters the south-western side of Lake Way, valley calcretes cover a distance of 33 km [1.22]. The valley calcrete is over 2 km wide in the western part of the system, but narrows to 0.5 km before widening into a chemical delta inward to Lake Way. The calcrete's thickness increases from 5 m to 15 m up-drainage. The Centipede deposit consists of three separate lenses of higher-grade mineralization, with carnotite existing in a carbonate matrix. The thickness of mineralized zones varies from 1 to 5 m thick and they sit below overburden that is 0–6 m thick [1.23].

Other deposit types

The remaining resources occur in a variety of deposits [1.24]:

- Metasomatite (Mount Isa uranium field with the Valhalla deposit (Queensland));
- Metamorphic (Mary Kathleen (Queensland));
- Volcanic (Maureen, Ben Lomond (Queensland));
- Intrusive (Crocker Well, Radium Hill (South Australia));
- Quartz-pebble conglomerates (Pilbara Craton, Halls Creek Orogen, Yerrida Basin and the Hamersley Basin (Western Australia)).

6.1.3. Uranium exploration

The existence of uranium in Australia has long been known even before it became the target of any systematic exploration. It was first noted in Australia from Carcoar (New South Wales) in 1894, where torbernite was discovered associated with cobalt mineralization. Two important occurrences of uranium were found in Mount Painter (South Australia) in 1906 and at Radium Hill (South Australia) in 1910.

Uranium exploration in Australia began in 1944 in reaction to appeals from the Governments of the United States of America and the United Kingdom. The known deposits at Radium Hill and Mount Painter were investigated by both State and Federal Government geologists. To encourage exploration, tax incentives were introduced by the Federal Government in 1948 for the discovery of uranium orebodies. Further stimuli to explore and develop resources of uranium were presented in 1949 when a 6-year uranium ore buying pool in Australia was approved which guaranteed fixed prices for uranium ore. Tax breaks were granted in 1952, especially around known mineral fields.

Significant discoveries of uranium were made at Rum Jungle (Northern Territory) in 1949, in the South Alligator Valley (Northern Territory) in 1953, at Mary Kathleen (Queensland) in 1954 and at Westmoreland (Queensland) in 1956. Small occurrences were discovered at several locations throughout the continent. Prospectors using Geiger counters were the ones who made most of the significant discoveries during those years. As the present sales contracts were met, there seemed small hope for further sales and exploration practically ceased in the late 1950s.

Uranium exploration resumed in 1966, owing chiefly to the exceptionally strong world perception that utilization of nuclear energy for the generation of electricity would intensify abruptly. To encourage exploration, the Federal Government relaxed the existing export policy for uranium in 1967 and, as a result, expenditures for exploration of uranium rose quickly during the period 1967–1972. However, the costs of exploration uranium diminished during 1972–1975, as the policies of the then Labor Government actively discouraged exploration for uranium by private companies. In the later part of 1972–1975, Government funded uranium exploration was conducted by the Australian Atomic Energy Commission.

After the election of the Liberal–National Party Coalition to Government in late 1975, exploration increased gradually to a record level of AU$94 million (in constant 2000 AU$) in 1980. Some of the factors attributed to this revival of exploration for uranium were:

— Sharp rises in uranium spot market prices. Prices negotiated for sales under long term contracts also rose since the mid-1970s;
— Release in 1976 and 1977 of findings from the environmental inquiry on Ranger uranium;
— The Federal Government's announcement of Australia's uranium policy in 1977, which promoted the continued growth of Australia's uranium mining industry under stringent regulated conditions.

Unlike earlier uranium exploration by prospectors, exploration from 1966 onwards was carried out by major companies employing state-of-art equipment and techniques, and which had respectively huge budgets. The advancement of multi-channel gamma ray spectrometers with large volume crystal detectors amplified the efficacy of airborne radiometric surveys.

In the 1970s, mapping and exploration led to improved understanding of the distribution of uranium, and so the search could be focused more effectively on those geological environments regarded most likely to host deposits of uranium. The regional mapping carried out by the Bureau of Mineral Resources and the State geological surveys was exploited effectively by exploration teams in target selection, and companies carried out airborne radiometric surveys using multi-channel gamma ray spectrometers. This phase of exploration was highly successful and practically all of the significant deposits in Australia were discovered during 1969–1980. Important discoveries during this period were Ranger (1970), Nabarlek (1970), Koongarra (1970) and Jabiluka (1973) in the Alligator Rivers area of the Northern Territory; Beverley (1969) and Olympic Dam (1975) in South Australia; and Yeelirrie (1972) in Western Australia [1.2].

From the peak level reached in 1980, costs of exploration for uranium dropped abruptly to AU$28 million (in constant 2000 AU$) in 1983. This was brought by the economic recession in the major industrial nations, the execution of energy conservation policies in response to the oil shocks of the mid-1970s and the abrupt decline in spot market prices of uranium from 1976 onwards. In 1983, the then Labor Government presented the 'Three mines' policy, under which exports of uranium were allowed only from the Olympic Dam, Ranger and Nabarlek mines. Likewise, in the early 1980s, the State Governments of Victoria and New South Wales enacted legislation to ban exploration for, and mining of, uranium. As a consequence, no uranium exploration has been carried in these States since then.

Despite of the reducing effect of the 'Three mines' policy on exploration for uranium, the discovery of the Kintyre deposit (Paterson Province, Western Australia) in 1985 led to an increase in expenditures for exploration during 1985–1988. The goal of that was to locate similar deposits elsewhere in the Paterson Province. Subsequently, exploration waned from 1989 onwards and reached an historic low in 1994.

In January 1994, the Native Title Act 1993 was enacted by the Federal Government. The Act obliged exploration companies inform and discuss with Native Title parties prior to granting of exploration tenements over lands where Native Title exists, or which are subject to a registered Native Title claim. The Act obliged the formulation of complementary State/territory legislation — a process that has hindered the authorization of exploration licence applications for all minerals, including uranium. This has had a significant impact on exploration for uranium in Western Australia, where large tracts of Crown land are affected by Native Title land claims.

After the abolishment of the ‘Three mines’ policy by Liberal–National Party Coalition in 1996, uranium exploration increased even as demand for uranium improved. However, during 1998–1999, exploration later waned when numerous large companies ceased to explore for uranium in Australia in response to continued low prices.

During the late 1990s, two factors strongly affected the focus of exploration for uranium. Firstly, the economic success of both the Olympic Dam mine (haematite breccia complex type deposit) and the Ranger mine (unconformity-related deposit) proved that these deposit-types of uranium are significant targets for exploration. Secondly, fruitful advance, in the past decade, of low cost in situ leach (ISL) technology for developing sandstone-hosted uranium deposits rekindled the exploration for this deposit-type of uranium.

The areas chiefly explored for uranium in the late 1990s are the following:

- Arnhem Land (Northern Territory): exploration targets are unconformity-related deposits in Palaeoproterozoic metasediments overlain by thick sandstone cover of the Kombolgie Subgroup;
- Paterson Province (Western Australia): exploration targets are unconformity related deposits in Palaeoproterozoic metasediments of the Rudall Metamorphic Complex, which hosts the Kintyre orebody;
- Gunbarrel, Canning and Carnarvon Basins (Western Australia) and Frome Embayment (South Australia): exploration targets are sandstone-hosted uranium deposits;
- Olympic Dam area (South Australia): exploration targets are breccia complex type deposits in Mesoproterozoic granitoids of the Gawler Craton, overlain by the Stuart Shelf sedimentary sequence;
- Westmoreland area (Queensland): exploration targets are sandstone type deposits in Proterozoic sediments of the McArthur Basin;
- Mount Isa Inlier (Queensland): exploration targets are metasomatite type deposits in Proterozoic metasediments;
- Tertiary palaeochannel sediments overlying the Yilgarn Craton (Western Australia): exploration targets are calcrete type deposits;
- Mount Gee area (South Australia): exploration targets are breccia complex type deposits in Palaeozoic haematite breccias.

In 2001–2002, the areas chiefly explored for uranium were the Gawler Craton/Stuart Shelf region, the Frome Embayment and Arnhem Land. In November 2001, Minotaur Resources Ltd publicized the discovery of gold, copper, rare earth and uranium mineralization in haematite breccias at the Prominent Hill prospect (South Australia). This mineralization exists in Proterozoic basement, which is covered by at least 100 m of younger sedimentary rocks. The geological setting, the overlapping magnetic and gravity anomalies and the style of mineralization are apparently generally similar to the Olympic Dam deposit, located roughly 150 km to the south-east. Precious metal, copper, uranium and rare earth assemblages are also apparently similar to those at Olympic Dam, but uranium concentrations are fairly lower. Indeed, when the Prominent Hill mine was developed uranium was not recovered.

During 2003–2004, exploration activities in the Frome Embayment intensified. Drilling tested the target areas, which had been delineated by airborne electromagnetic surveys that established the limits of buried palaeochannels. Heathgate Resources publicized the discovery of a new uranium-mineralized zone, called Deep South zone, roughly 3 km south of the Beverley deposit. The Deep South ore zone occurs in sands, like those that host the Beverley deposit, and was mined together with the other deposits there.

Southern Cross Resources has endured exploration in the region of the Goulds Dam, East Kalkaroo and Honeymoon deposits. A new low–medium grade uranium-mineralized zone was found in an area of the

Yarramba palaeochannel, ~1.5 km north-west of the Honeymoon deposit. The new zone, called Brooks Dam prospect, has been tested by drilling over a distance of 1 km along the palaeochannel, and the company thinks that it may stretch farther to the south like the main Honeymoon deposit.

In 2004, WMC Resources conveyed that exploration drilling in the south-eastern part of the Olympic Dam deposit has delineated considerable additional resources, close to 30% increase over the resources to December 2003. Minotaur Exploration Pty Ltd has endured exploration drilling of the copper–gold–uranium–rare earth mineralization at the Prominent Hill deposit (South Australia).

Important discoveries during 2005 and 2006 included: extensions of the Valhalla and Skal deposits (Mount Isa region (Queensland)), major extensions of the Olympic Dam deposit (South Australia), and Four Mile deposit (8 km north-west of the Beverley mine (South Australia)).

At Four Mile deposit, in the Frome Embayment, drilling has delineated an extensive mineralized area measuring 5 km^2 in Palaeogene (Tertiary) sands along the flanks of Proterozoic basement rocks of the North Flinders Ranges. Within this extensive area are two deposits. As of 2012, the East and West deposits were estimated to contain inferred resources of 11 000 tU and 16 000 tU, respectively [1.5]. A third deposit, Four Mile North-East is being investigated.

The principal areas where exploration for uranium was undertaken during 2007 and 2008 were the Mount Isa region (Queensland), the Alligator Rivers region (Northern Territory), the Gawler Craton/Stuart Shelf region (South Australia) and the Frome Embayment (South Australia). Several discoveries were announced, including the N-147 project in the Alligator Rivers region (Northern Territory), the Thunderball deposit in the Pine Creek geosynclines (Northern Territory), the Blackbush deposits (South Australia) and the Double 8 deposit in Tertiary palaeochannel sands (Western Australia).

Drilling and exploration delineated considerable extra resources in the south-eastern part of the Olympic Dam deposit. As of June 2010, total measured and indicated plus inferred resources (JORC code) amounted to 9075 million t with average grades of 0.87% Cu, 0.023% U (2 078 000 tU), 0.32 g/t Au and 1.5 g/t Ag [1.5].

In 2009, Heathgate Resources found two new sandstone-hosted deposits, Pepegoona and Pannikan, in the Frome Embayment, near Beverley. Exploration drilling continued at Carrapateena, a haematite breccia complex deposit similar to Olympic Dam. Total inferred resources are 203 million t with average grades of 1.31% Cu, 0.027% U, 0.56 g/t Au and 6 g/t Ag [1.5].

Historical exploration data are given in Fig. 6-3, reflecting a total of 4 208 536 metres of drilling within a total expenditure of USS $1 751 397 000.

6.1.3.1.Foreign exploration and development expenditure

In 1967–1971, expenditures reported by Australian companies engaged in exploration for uranium in foreign countries amounted to US $210 000, nearly all of which was spent in New Zealand.

In 1999, Paladin Resources Ltd (an Australian exploration company) bought the Kayelekera uranium deposit in Malawi, and in 2002, the Langer Heinrich uranium deposit in Namibia. At both projects, engineering and feasibility studies were undertaken during 2001 and 2002.

A comprehensive drilling programme and feasibility study on the Langer Heinrich deposit during 1997 and 1998 was completed by another Australian exploration company, Aztec Resources Ltd, which is the previous owner of the deposit. In 2004, a broad exploration drilling programme delineated areas of extra resources contiguous to the Langer Heinrich deposit. In May 2005, the company opted to ensue with development of the deposit. During 2005 and 2006, Paladin finished the development of an open cut mining operation at Langer Heinrich. Mine production commenced in early 2006 [1.25, 1.26]. Paladin also conducted further exploration at the Kayelekera deposit in Malawi. During 2007 and 2008, Paladin finished the development of an open cut mining operation at the Kayelekera deposit. Mine production commenced in May 2009. Production reached 681 t in 2010 and 846 t in 2011. The project was put into care and maintenance in 2015.

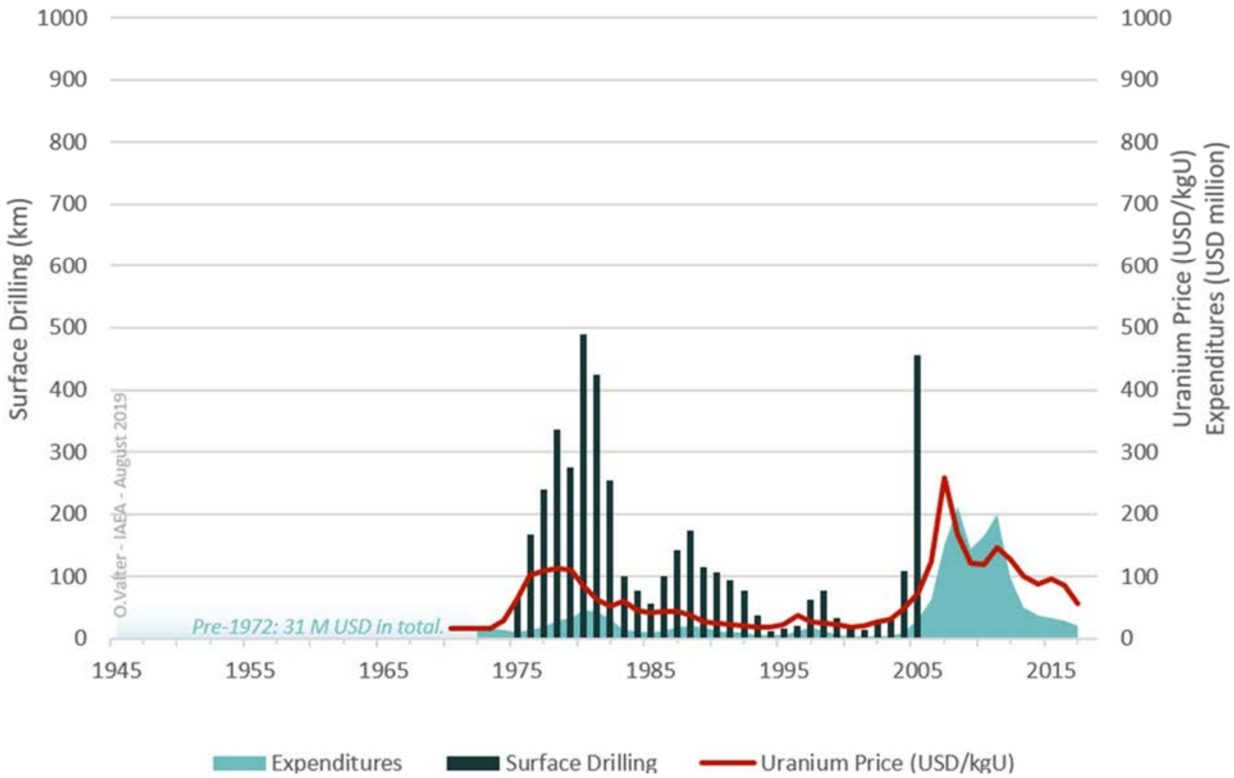


FIG. 6.3. Domestic uranium exploration data for Australia. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

6.1.4. Uranium resources

6.1.4.1. Identified conventional resources

The historical variation in reasonably assured resources and inferred resources are shown in Fig. 6.4 and Fig. 6.5 respectively [1.5]. Australia's identified conventional resources recoverable at costs of <US $260/kgU amounted to 2 054 800 tU as of 1 January 2017 [1.5]. The resources are summarized in Tables 6.1 – 6.3 and their locations shown in Fig. 6.1.

Most of Australia's identified conventional resources, recoverable at <US $130/kgU, are contained within the following six deposits:

(i) *Olympic Dam*: This is a haematite breccia type deposit and is the largest uranium resource in the world. Based on ore reserve and mineral resource data described by BHP Billiton, as of June 2018, it was estimated that the total resources of the deposit amount to 2 064 480 tU at an average grade of 192 ppm U [1.27]. Uranium is a co-product of copper mining at Olympic Dam; silver and gold are likewise recovered;

(ii) *Ranger*: The orebodies (Ranger 1 n°1 and Ranger 1 n°3) were found in 1970 by a joint venture of the Electrolytic Zinc Company of Australia Limited and the Peko Wallsend Operations Ltd (Peko). As of 1 January 2017, ERA estimated that the total resources of the Ranger deposit amounted to 47 463 tU [1.28] The mineralized zone has a strike length identified to date of about

1.2 km, lying at a depth of between 250 and 550 m, immediately east of the pit, and remaining open to the north.

(iii) *Jabiluka 1*: This uranium deposit was discovered by Pancontinental Mining Limited in 1973 in the Northern Territory. Additional drilling outlined the uranium orebody of the larger Jabiluka 2 deposit some 1 km to the east. Jabiluka is located 20 km north of Ranger and 230 km east of Darwin. The deposit is located within the Kakadu National Park, although the area of the mine lease is excluded from the National Park and is adjacent to the Ranger lease. In 2000, after intensive drilling in the underground access to the Jabiluka orebody, the overall resource was revised by the Energy Resources of Australia, with some decrease in actual reserves. The project has been abandoned;

(iv) *Koongarra*: This is a relatively high grade but small uranium deposit in the Alligator Rivers area of the Northern Territory. It is located roughly 30 km south of Ranger, the lease area being on Aboriginal land. Koongarra is an unconformity-related type deposit. The project has been abandoned;

(v) *Kintyre*: This deposit is a medium- grade uranium orebody with a limited surface outcrop in the remote Rudall region of Western Australia. This is on the western edge of the Great Sandy Desert in the eastern Pilbara region of Western Australia, roughly 1200 km north-east of Perth and some 70 km south of Telfer. It was found in 1985 by Rio Tinto Exploration through surface follow-up of several radiometric anomalies detected as the result of an airborne survey. Cameco bought the project in 2008;

(vi) *Yeelirrie*: This deposit is located between Leinster and Wiluna, Western Australia, some 420 km north of Kalgoorlie. It is the largest and richest sedimentary calcrete deposit in the world. Uranium is present as carnotite (hydrated potassium uranium vanadium oxide). The deposit extends for 9 km, is up to 1.5 km wide, up to 7 m thick and is overlain by overburden with an average thickness of 7 m. The Yeelirrie uranium deposit was acquired by Cameco from BHP Billiton in 2012.

The UDEPO database lists the most significant deposits for Australia as Olympic Dam, Ranger 1 n°3, Carrapateena, Jabiluka 2, Ranger 1 n°1, Yeelirrie, Ranger Deeps, Valhalla, Mount Gee, Kintyre.

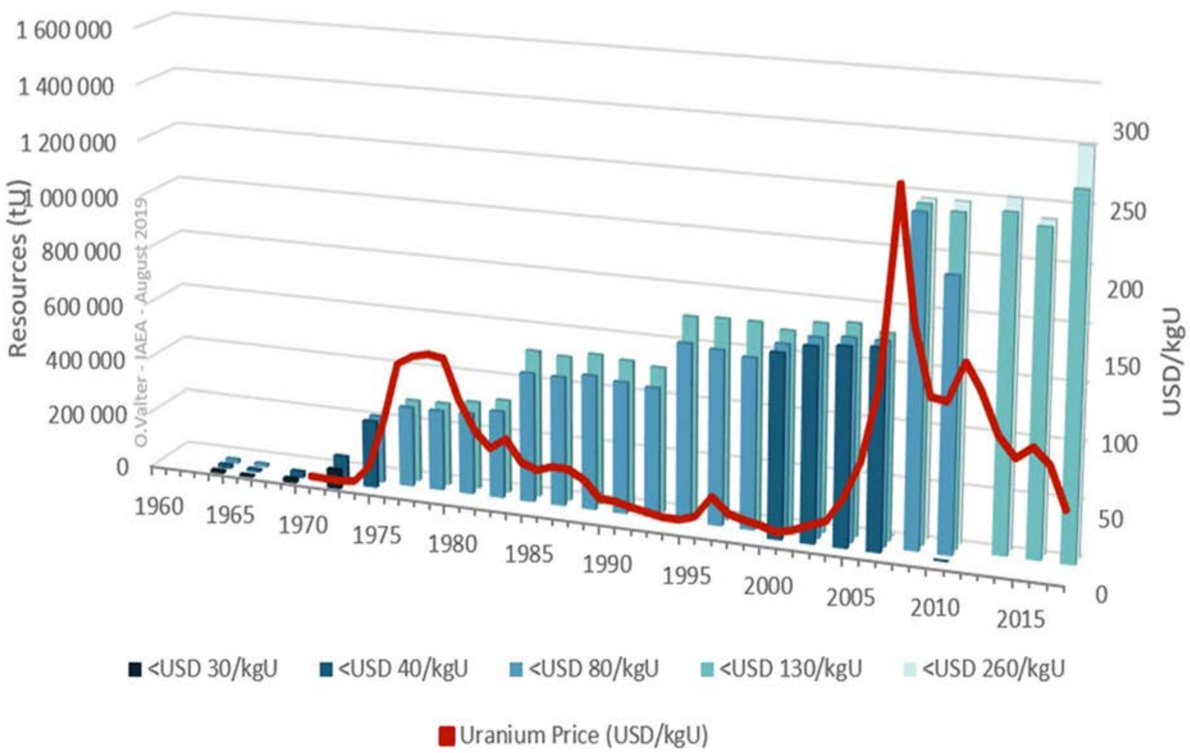


FIG. 6.4. Historical variation of recoverable reasonably assured resources within various cost categories in Australia. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

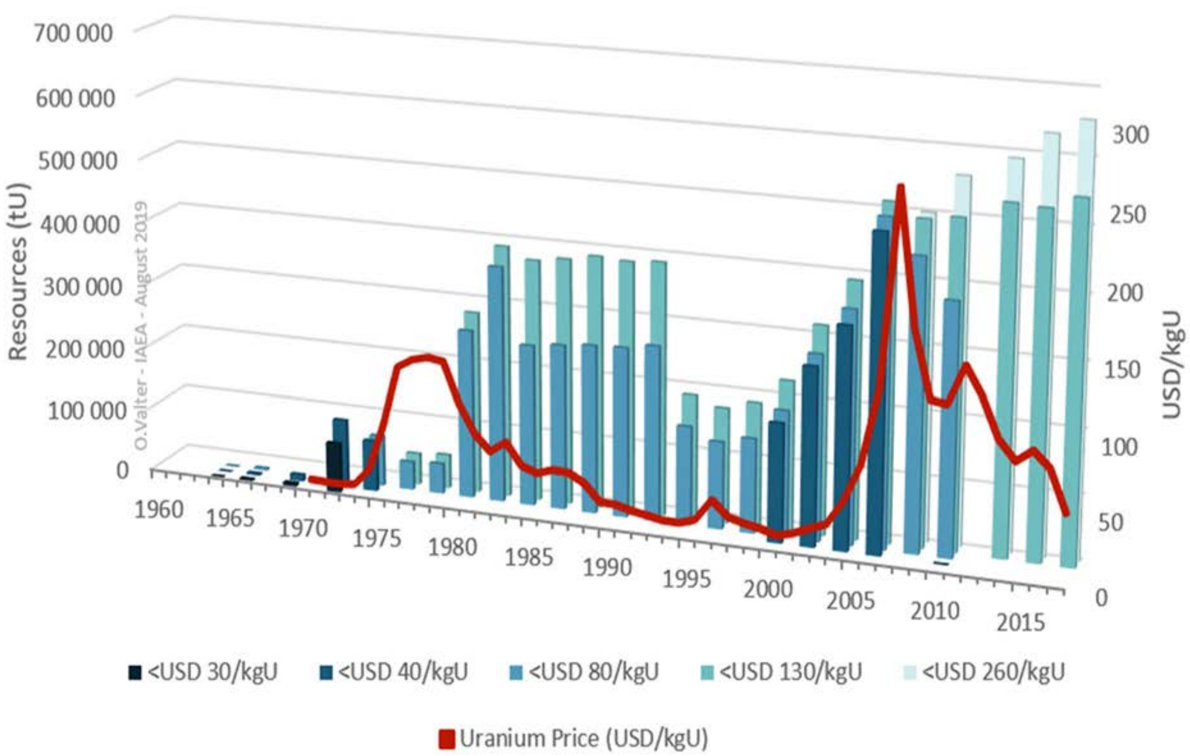


FIG. 6.5. Historical variation of recoverable inferred resources within various cost categories in Australia. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

TABLE 6.1. KNOWN URANIUM RESOURCES IN OTHER DEPOSITS-DISTRICTS [1.2]

Deposit	Grade (%U)	Resource (tU)
Angela (Northern Territory)	0.11	11 860
Ben Lomond (Queensland)	0.193	4120
Beverley (South Australia)	0.152	18 320
Bigrlyi/Ngalia (Northern Territory)	0.082	10 346
Carapateena (South Australia)	0.0155	144 000
Crocker Well (South Australia)	0.0244	4 490
Four Mile deposits (South Australia)	0.27	46 603
Goulds Dam (South Australia)	0.043	9 625
Lake Maitland (Western Australia)	0.047	10 180
Manyingee (Western Australia)	0.072	9 960
Maureen (Queensland)	0.077	2 530
Mount Fitch (Northern Territory)	0.03	5 580
Mount Gee (South Australia)	0.052	26 590
Mulga Rock district (Western Australia)	0.048	34 690
Mullaquana district (South Australia)	0.025	15 770
New Well (Napperby) (Northern Territory)	0.032	3 092
Nolans Bore (Northern Territory)	0.017	9 300
Nyang, Carley Bore (Western Australia)	0.027	6 545
Oobagooma (Western Australia)	0.102	8 345
Ponton, Double 8 (Western Australia)	0.025	6 615
Prominent Hill (South Australia)	0.01	10 300
Skal, Andersons, Bikini, Watta (Queensland)	0.045	17 025
Thatcher Soak E and W (Western Australia)	0.024	8 925
Valhalla (Queensland)	0.069	29 340
Westmoreland district (Queensland)	0.07	19 980
Wiluna district (Western Australia)	0.048	14 010

TABLE 6.2. REASONABLY ASSURED RESOURCES (tU) [1.5]
(As of 1 January 2017)

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Unconformity-related	n.a.[a]	118 600	130 600
Sandstone	n.a.	60 578	71 578
Haematite breccia complex	n.a.	988 980	1 080 947
Granite-related	n.a.	0	200
Intrusive	n.a.	3100	4300
Volcanic-related	n.a.	2700	5200
Metasomatite	n.a	21 200	21 200
Surficial	n.a..	74 621	80 621
Total	n.a.	1 26 779	1 400 646

TABLE 6.3. INFERRED RESOURCES (tU) [1.5]
(As of 1 January 2017)

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Unconformity-related	n.a.[a]	48 300	52 800
Sandstone	n.a.	86 350	106 800
Haematite breccia complex	n.a.	371 800	426 100
Intrusive	n.a.	800	5 000
Volcanic-related	n.a.	1 000	1 500
Metasomatite	n.a.	14 600	16 900
Surficial	n.a.	25 670	45 100
Total	n.a.	548 520	654 200

[a] n.a.: not available.

6.1.4.2. Undiscovered conventional resources and nonconventional resources

Estimates are not made of Australia's undiscovered conventional resources. Estimates are also not made of Australia's uranium resources in the categories of unconventional resources and other materials.

6.1.5. Potential for new discoveries

Australia does not report undiscovered resources (prognosticated or speculative) to the Red Book. However, based on geological knowledge of previously discovered deposits and regional geological information, there is significant (high) potential for additional uranium deposits to be found, including:

- Unconformity-related deposits, including high grade deposits at the contact and immediately above the unconformity, particularly in Arnhem Land in the Northern Territory but also in the Granites–Tanami region (Northern Territory and Western Australia), Paterson Province (Western Australia) and in the Gawler Craton (South Australia);
- Haematite breccia deposits, particularly in the Gawler/Stuart Shelf region of South Australia;
- Sandstone-hosted deposits in sedimentary strata in various regions adjacent to uranium enriched basement, in particular in the Frome Embayment region (South Australia);
- Metasomatite type deposits in the Mount Isa region of Queensland;
- Calcrete type deposits in Cenozoic palaeochannel sands in Western Australia.

6.1.6. Uranium production

Uranium was first recovered in Australia as a by-product of ore mined for radium at Radium Hill and Mount Painter (South Australia). About 2 000 t of ore were treated and the uranium content had minor commercial interest for use in ceramic glazes. As only a fraction of the uranium content of the ore was recovered and this production can be considered insignificant. Between 1954 and 1971, Australia produced some 7 732 tU from plants at five locations. The first phase of uranium production in Australia ceased after the closure of the Rum Jungle plant in 1971

Uranium production details, including historical data, are given in Tables 6.4 – 6.5 and Fig. 6.4 reflecting a total production of 206 649 tU up to 2017. This is comprised of 75 235 tU, 54 761 tU, 10 116 tU and 8 810 tU from open pit, co/by-product (Olympic Dam underground), *in situ* leach and other underground mining respectively.

TABLE 6.4. URANIUM PRODUCTION PHASE 1: 1954–1971 [1.2]

Mine	Rum Jungle (NT[a])	Radium Hill (SA[b])	Mary Kathleen (Qld[c])	South Alligator Valley (NT) (United Uranium)	South Alligator Valley (NT) (South Alligator Uranium)
Mining method	OP[d]	UG[e]	OP	OP–UG	UG
Operational period	1954–1971	1954–1962	1958–1963	1959–1964	1959–1962
Average grade (%U)	0.24–0.34	0.09-0.13	0.13	0.30–0.58	0.95
Production (tU)	2 993	721	3 460	441	117

[a] NT: Northern Territory.
[b] SA: South Australia.
[c] Qld: Queensland.
[d] OP: open pit.
[e] UG: underground mining.

TABLE 6.5. URANIUM PRODUCTION CENTRE TECHNICAL INFORMATION [1.5]
(As of 1 January 2011)

Production centre	Ranger	Olympic Dam	Beverley
Operational status	Operating	Operating	Operating
Startup date	1981	1988	2000
Source of ore:			
• Deposit name	Ranger 3	Olympic Dam	Beverley
• Deposit type	Unconformity	Haematite breccia	Sandstone
• Reserves (tU)	22 100	212 900	763
• Grade (%U)	0.10	0.05	0.10
Mining/milling operation:			
• Type	OP[a]	UG[b]	ISL[c]
• Mining recovery (%)	100%	85%	65%
• Size	4.5 M t/year	12 M t/year	1.62 M L/h
Processing plant:			
• Acid/alkaline	Acid	Acid	Acid
• Type	CWG[d], SX[e]	CWG, FLOT[f], SX	IX[g]
• Average process recovery (%)	88	85	
• Nominal capacity (tU/year)	4 660	3 820	850

[a] OP: open pit.
[b] UG: underground mining.
[c] ISL: in situ leaching.
[d] CWG: crush wet grind.
[e] SX: solvent extraction.
[f] FLOT: flotation.
[g] IX: ion exchange.

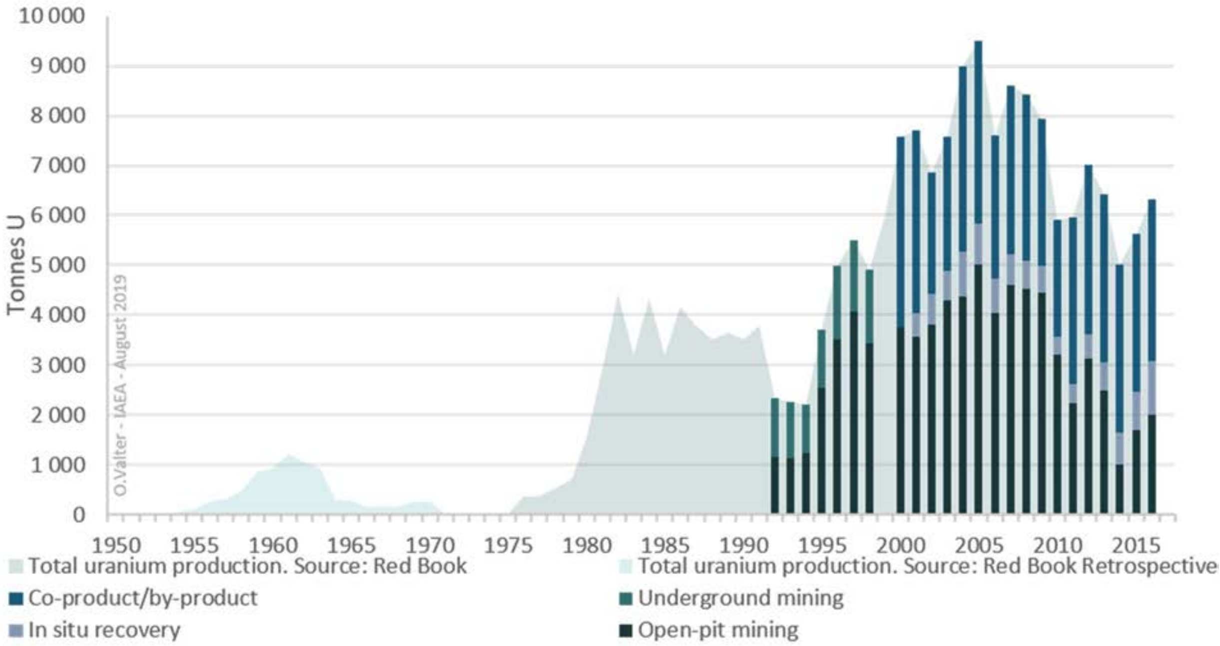


FIG. 6.6. Historical uranium production in Australia (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

Uranium production in Australia resumed in 1976. During this second phase, production was recorded from the operations at Mary Kathleen (4 072 tU in 1976–1982), Nabarlek (9 208 tU in 1979–1988), Ranger (since 1981), Olympic Dam (since 1988), Beverley (since 2000) and Honeymoon (since 2011). From 1976 to the end of 2010, production from these operations totalled 162 546 tU.

The Ranger mine is about 230 km east of Darwin, in the Northern Territory, and is surrounded by the Kakadu National Park. The mine (Ranger Pit 1) opened in 1981 at a production rate of approximately 2 800 tU/year, which has since been expanded to 4 660 tU/year capacity. Mining at the second pit (Ranger Pit 3) commenced in 1997 and finished at the end of 2012, although production continued from large ore stockpiles. Treatment is conventional acid leach. Future development may be underground.

The Olympic Dam mine lies about 560 km north of Adelaide, in an arid part of South Australia. Olympic Dam is the largest single uranium resource in the world and mining operations commenced in 1988. The deposit is mined underground at a depth of 350 m. The mine produces copper, with gold and uranium as major by-products. Annual production capacity has been expanded from 1 500 to 3 820 tU.

About 80% of the uranium is recovered by conventional acid leach of flotation tailings derived from copper recovery. Most of the remaining 20% is from acid leach of the copper concentrate, but this concentrate still contains up to 0.15% U.

There are plans to greatly increase the mine's size and output by accessing the orebody through excavation of an open pit measuring about 4.1 km × 3.5 km and 1.0 km deep. As of 2009, BHP Billiton is investigating the feasibility of expanding the capacity of the Olympic Dam operations to produce 16 100 tU (19 000 t U_3O_8) annually. It is proposed to mine the southern portion of the deposit by open pit in conjunction with underground mining (sub-level stoping) in the northern portion of the deposit.

A draft environmental impact study was released on 1 May 2009. Following feedback, a supplementary environmental impact study was submitted to the Federal Government in December 2010 and approval of the proposal was announced in October 2011. BHP Billiton moved the project to the feasibility study

stage in March 2011. However, a decision to postpone the expansion and undertake further studies was announced in late 2012.
The Beverley uranium deposit is situated 520 km north of Adelaide, on the plains north-west of Lake Frome. It is a relatively young sandstone deposit, with uranium mineralization leached from the Mount Painter region, and was Australia's first commercial ISL operation. Mine construction started in 1999. The deposit consists of three mineralized zones (north, central and south) located within a buried palaeochannel (the Beverley aquifer) in Tertiary sediments of the Frome Basin. Groundwater salinity ranges from 3 000 mg/L total dissolved solids in the north to 12 000 mg/L total dissolved solids in the south.

As the main orebodies became depleted, the Beverley North project was initiated in 2009 and in 2010 a field leach trial at Pepegoona was successful. This became a satellite operation, with loaded resin being trucked to the treatment plant. In 2011, mining commenced at nearby Pannikin with the installation of a second satellite plant [1.3, 1.26].

6.1.6.1. Future projects

Several future projects are summarized in Table 6.6.

Uranium production at Honeymoon, an ISL mine, started in late 2011 and is anticipated to increase progressively to 340 tU/year.

At Yeelirrie, BHP Billiton undertook drilling to upgrade the resource estimate (total current resources are 44 500 tU at an average grade of 0.13% U) and started a feasibility study for development of the deposit. The project was sold to Cameco in 2012. When the acquisition is complete, Cameco intends to conduct its own mineral resource estimation to generate an NI 43–101 compliant value.

The Wiluna project comprises four shallow calcrete hosted deposits: Lake Way, Lake Maitland, Centipede and Milipede. In 2010, Toro Energy excavated an evaluation pit at the Centipede deposit to increase confidence both in the resource estimates and in the proposed mining method. Environmental approvals were well advanced by the end of 2012. In 2018, the Wiluna Uranium Project has received federal and state government environmental approvals for mining uranium at the four deposits.

At Kintyre, Cameco commenced an environmental impact assessment and in 2012 completed a prefeasibility study and signed a mine development agreement with the relevant Aboriginal group. A detailed feasibility study is yet to be undertaken. The deposit is intended to be mined by open pit. The proposed annual production will be between 2 300 and 3 000 tU. The project received environmental approval in 2015.

6.1.7. Environmental activities and sociocultural issues

6.1.7.1. Northern Territory

The Federal Government has responsibility for supervising the environmental management of uranium mining in the Alligator Rivers region, which is Federal land. The Ranger mine, Jabiluka mine (on care and maintenance after initial development work) and Nabarlek mine (mined out and nearing completion of remediation work) lie within this region. The Northern Territory Government has responsibility for the day-to-day regulation of mining activities, with the responsibilities determined by a suite of legislation and agreements between the two Governments (Federal and State) to minimize any environmental impacts arising from uranium mining. Environmental supervision and oversight of operations in the Alligator Rivers region are provided by the Supervising Scientist, a statutory officer of the Federal Government, who derives authority from the Environment Protection (Alligator Rivers Region) Act.

TABLE 6.6. FUTURE URANIUM PRODUCTION CENTRES [1.25]
(As of 1 January 2009)

	Centre #4	Centre #5	Centre #6
Name	Honeymoon	Four Mile	Yeelirrie
Status	Existing	Existing	Planned
Startup date	2010	2010	Unknown
Source of ore:			
• Deposit name	Honeymoon and East Kalkaroo	Four Mile	Yeelirrie
• Deposit type	Sandstone	Sandstone	Calcrete
• Reserves (tU)	3 230	[a]	44 500
• Grade (%U)	0.17		0.13
Mining operation:			
• Type	ISL	ISL	OP
• Size (Mt ore/year)	n.a.	n.a.	n.a.
• Average mining recovery (%)	65[g]	65[g]	n.a.
Processing plant:			
• Acid/alkaline			
• Type	Acid		Alkaline
• Size	SX	[l]	n.a.
• Average mining recovery (%)	Not reported[g]		[m]
Nominal production capacity (tU/year)	340	[l]	n.a.
Expansion plans	n.a.		
Other	n.a.		[q]

[a] Four Mile West has total resources of 16 110 tU (19 000 t U_3O_8) averaging 0.29% U. Four Mile East has inferred resources of 11 025 tU (13 000 t U_3O_8) averaging 0.14% U and Four Mile North-East has resources of 19 550 t at 0.254%..
[b] OP: open pit mining.
[c] UG: underground mining.
[d] ISL: in situ leach.
[e] Capacity to mine a total of 4.5 million t/year of ore and waste rock.
[f] n.a.: not available.
[g] Recovery includes combined losses due to ISL mining and hydrometallurgical processing.
[h] CWG: crush wet grind.
[i] SX: solvent extraction.
[j] FLOT: flotation.
[k] IX: ion exchange.
[l] Uranium-bearing resin from Four Mile will be treated at the Beverley plant to recover uranium.
[m] BHP Billiton is investigating several options for processing the ores, including tank leaching and heap leaching with ion exchange.
[n] Processing lateritic ores is scheduled to commence in 2009 and will produce approximately 340 tU (400 t U_3O_8) annually. In addition, a new radiometric ore sorter will allow an additional 930 tU (1100 t U_3O_8) to be produced from existing low grade stockpiles. Energy Resources of Australia proposes construction of a heap leach facility for the extraction of up to 20 000 t U_3O_8 contained in low grade mineralized material.
[o] BHP Billiton is investigating the feasibility of expanding the capacity of Olympic Dam operations to produce 16 100 tU (19 000 t U_3O_8) annually. It is proposed to mine the southern portion of the deposit by open pit in conjunction with underground mining (sub-level stoping) in the northern portion of the deposit.
[p] Approval has been granted to extend the capacity of the Beverley plant to produce 1270 tU (1500 t U_3O_8) annually when the company decides it is commercially viable to do so.
[q] BHP Billiton has commenced the environmental approvals process.

The Federal Government's Office of the Supervising Scientist has overseen the environmental aspects of uranium mining operations in the Alligator Rivers region since mining commenced at Nabarlek and Ranger. It is also discharging this role in relation to the potential development of Jabiluka. The Supervising Scientist, supported by the Environmental Research Institute of the Supervising Scientist, coordinates and supervises measures for the protection and restoration of the environment of the Alligator Rivers region in response to the effects of uranium mining. The Office of the Supervising Scientist measures environmental performance at the mines, including the rehabilitation of Nabarlek, through twice yearly audit exercises.

6.1.7.2. South Australia

The South Australian Government has responsibility for regulating the Olympic Dam, Beverley and Honeymoon projects. Olympic Dam is principally regulated under site specific South Australian State Government legislation — the Roxby Downs (Indenture Ratification) Act 1982 as amended (the Indenture). Beverley and Honeymoon are regulated under a range of South Australian legislation applicable to mining, including mining of radioactive substances.

The Department for Manufacturing, Innovation, Trade, Resources and Energy regulates day-to-day mining activities, with the Environment Protection Authority responsible for radiation protection issues.

6.1.8. National policies relating to uranium

The Federal Government supports the development of a sustainable Australian uranium mining sector in line with world's best practice environmental and safety standards and allows the export of uranium to those countries which observe the Treaty on the Non-Proliferation of Nuclear Weapons and which are committed to non-proliferation and nuclear safeguards. Non-nuclear-weapon States must also have in force an Additional Protocol.

In November 2008, the Government of Western Australia overturned the ban on uranium mining put in place by the previous State Government. Mining of uranium in Western Australia is subject to strict safety and security provisions, including meeting all the necessary international safeguards and rigorous environmental approvals for mining and transporting uranium. A decade's long ban on uranium mining was reversed in Queensland in 2012.

References to Section 6.1

[1.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Australia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2012).

[1.2] McKAY, A., MIEZITIS, Y., Australia's Uranium Resources, Geology and Development of Deposits, AGSO Mineral Resource Rep. 1, Geoscience Australia, Canberra (2000).

[1.3] REEVE, J.S., CROSS, K.C., SMITH, R.N., ORESKES, N., "Olympic Dam copper–uranium–gold deposit", Geology of the Mineral Deposits of Australia and Papua New Guinea (HUGHES, F.E., Ed.), Australasian Institute of Mining and Metallurgy, Melbourne (1990) 1009–1035.

[1.4] CROSS, K.C., DALY, S.J., FLINT, R.B., "Mineralization associated with the GRV and Hiltaba Suite granitoids — Olympic Dam deposit", The Geology of South Australia, Vol. 1: The Precambrian, Geological Survey of South Australia, Adelaide (1993) 132–138.

[1.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[1.6] LALLY, J.H., BAJWAH, Z.U., Uranium deposits of the Northern Territory. Northern Territory Geological Survey, Report 20 (2006).

[1.7] SWEET, I.P., BRAKEL, A.T., CARSON, L., The Kombolgie Subgroup — a new look at an old 'formation', AGSO Research Newsletter 30, Geoscience Australia, Canberra (1999) 26–28.

[1.8] LUDWIG, K.R., et al., Age of uranium mineralisation in the Jabiluka and Ranger deposits, Northern Territory, Australia, Econ. Geol. **82** (1987) 857–874.

[1.9] FOY, M.F., "South Alligator Valley uranium deposits", Economic Geology of Australia and Papua New Guinea, Vol. 1: Metals, Monograph 5, Australasian Institute of Mining and Metallurgy, Melbourne (1975) 301–303.

[1.10] POLITO, P.A., KYSER, T.K., THOMAS, D., MARLATT, J., DREVER, D., Re-evaluation of the petrogenesis of the Proterozoic Jabiluka unconformity-related uranium deposit, Northern Territory, Australia. Miner. Deposita 40 (2005) 257-288.
[1.11] McKAY, A.D., Kintyre Deposit: Estimation of Identified Uranium Resources, Bur. Min. Res. Geol. Geophys, Canberra (1992) (unpublished).
[1.12] CALLEN, R.A., ALLEY, N.F., GREENWOOD, D.R., "Lake Eyre Basin", The Geology of South Australia, Vol. 2: The Phanerozoic, Geological Survey of South Australia, Adelaide (1995).
[1.13] BRUNT, D.A., Uranium in Tertiary stream channels, Lake Frome area, South Australia, Proc. Austral. Inst. Min. Metall. **266** (1978) 79–90.
[1.14] LINDSAY, J.F., KORSCH, R.J., "The evolution of the Amadeus Basin, Central Australia", Geological and Geophysical Studies in the Amadeus Basin, Central Australia, Bur. Min. Res. Geol. Geophys Bull. 236, Canberra (1991) 7–32.
[1.15] BORSCHOFF, J., FARIS, I., "Angela and Pamela uranium deposits", Geology of the Mineral Deposits of Australia and Papua New Guinea (HUGHES, F.E., Ed.), Australasian Institute of Mining and Metallurgy, Melbourne (1990) 1139–1142.
[1.16] WELLS, A.T., MOSS, F.J., The Ngalia Basin, Northern Territory: Stratigraphy and Structure, Bur. Min. Res. Geol. Geophys Bull. 212, Canberra (1983).
[1.17] GASKIN, A.J., BUTT, C.R.M., DEUTSCHER, R.L., HORWITZ, R.C., MANN, A.W., "Hydrology of uranium deposits in calcretes of Western Australia", Energy Resources of the Pacific Region (Proc. Int. Conf. Honolulu, 1978), American Association of Petroleum Geologists, Tulsa (1981).
[1.18] BUTT, C.R.M., HORWITZ, R.C., MANN, A.W., Uranium Occurrences in Calcrete and Associated Sediments in Western Australia, Rep. FP16, CSIRO Research Laboratories Division of Mineralogy, Commonwealth Scientific and Industrial Research Organization, Canberra (1977).
[1.19] WESTERN MINING CORPORATION, Yeelirrie Uranium Project, Western Australia, Draft Environmental Impact Statement and Environmental Review and Management Programme, WMC (1978).
[1.20] BRIAN LANCASTER & ASSOCIATES, Draft Environmental Impact Statement, Lake Way Joint Venture Environmental Review and Management Programme, Melbourne (1981).
[1.21] CRABB, D., DUDLEY, R., MANN, A.W., "Hinkler Well and Centipede deposits", Surficial Uranium Deposits, IAEA-TECDOC-322, IAEA, Vienna (1985) 133–136.
[1.22] BRUNT, D.A., "Miscellaneous uranium deposits in Western Australia", Geology of the Mineral Deposits of Australia and Papua New Guinea (HUGHES, F.E., Ed.), Australasian Institute of Mining and Metallurgy, Melbourne (1990) 1615–1620.
[1.23] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[1.24] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.
[1.25] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[1.26] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).
[1.27] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[1.28] BHP, 2018 Annual report. https://www.bhp.com/-/media/documents/investors/annual-reports/2018/bhpannualreport2018.pdf (2019)
[1.29] ERA, Annual Statement Of Reserves And Resources Reserves, https://www.energyres.com.au/operations/reserves-resources/. January 2018

6.2. CAMBODIA

6.2.1. Geography

Cambodia is situated in Southeastern Asia, between Lao to the North, Thailand to the West and North, Vietnam to the East, and bordering the Gulf of Thailand to the South.

Country's landscape is characterised by a flat central plain surrounded by low mountains and uplands. Extending from this central region are transitional plains, rising to elevations of 200 metres. To the north a sandstone escarpment defines the southern edge of the Dangrek Mountains.The Mekong River, which flows southward, crosses through the eastern region. East of the Mekong valley, the transitional plains progressively join with the eastern highlands, a region of high plateaus that extend into Lao and Vietnam.

About 70% of the country is forested, surrounding the central plain which is largely rice paddies and cultivated.

Cambodia has a tropical climate, with a monsoon season during May–November, and a dry season during December–April. Temperatures range from 25° C in January to a maximum of 35°C in April.

Cambodia has shown a strong economic growth over the last decade; GDP grew at an average annual rate of over 8% between 2000 and 2010. Major developing sectors include tourism, garment, construction, timber and agriculture Mining is attracting investor interest.as Cambodia could present opportunities for bauxite, gold, iron and gems mining [2.1].

6.2.2. Geology

Only a small part of Cambodia shows outcrops, the mountains on the south bordering the Gulf of Thailand and the highlands bordering Vietnam. Most of the country is covered by alluvium (Fig. 6.7).

Mesozoic sandstone dominates most of the basement geology in Cambodia. Outcrops in the south are Mesozoic and Paleozoic. Rocks of the same age are present in the east and orogenic deformation has left intrusive and extrusive formations of late-Tertiary to recent age. Like all countries of south eastern Asia, Cambodia has been subject to several periods of deformation, with metamorphic rocks occurring in the east. Recent geological surveys on the Cambodian Shelf area of the Gulf of Thailand, have identified sedimentary basins favourable for oil and gas exploration.

The uranium, potential of Cambodia is not considered great. Limited outcrops restrict prospecting areas, so exploration would have to be carried out almost entirely by drilling through the alluvium [2.2].

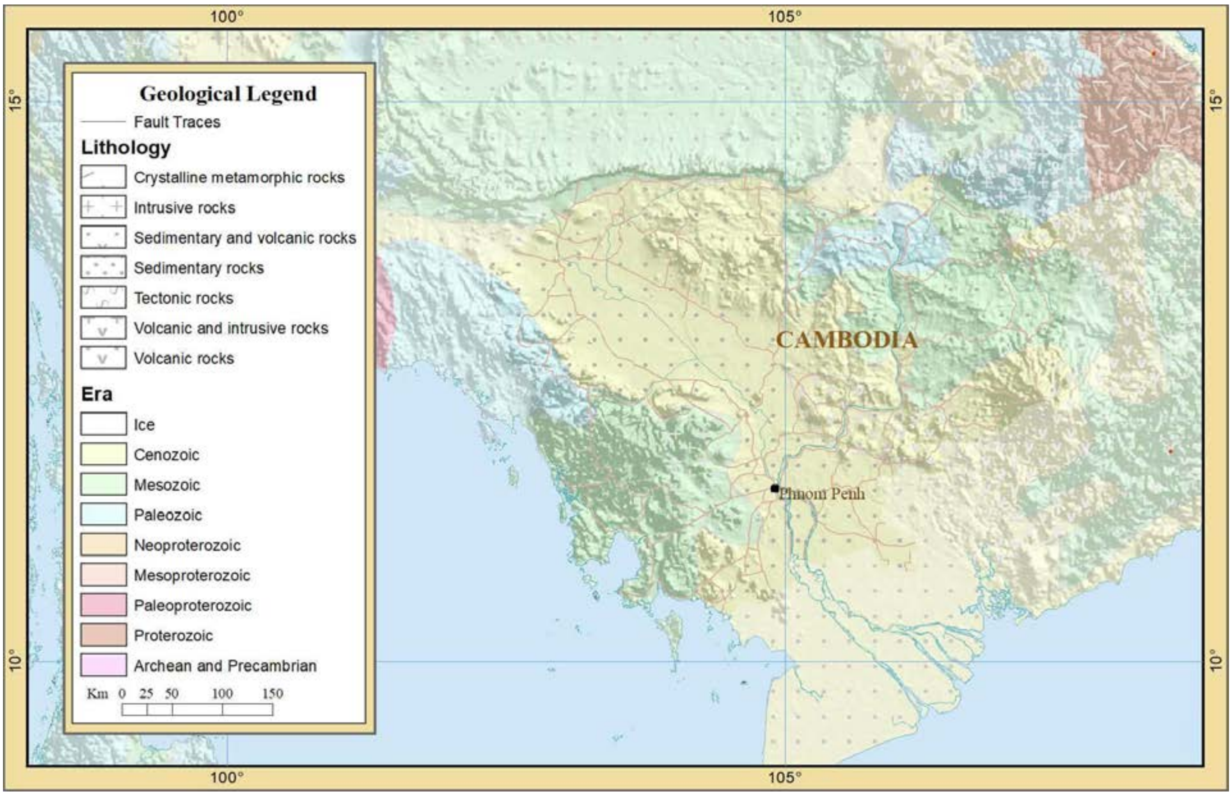


FIG. 6.7. Regional geological setting of Cambodia. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.2.3. Uranium exploration

There has been no reported uranium exploration in Cambodia.

6.2.4. Uranium resources

There are no known uranium occurrences in Cambodia and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for Cambodia.

6.2.5. Potential for new discoveries

Available geological descriptions of Cambodia don't show great encouragement as for the uranium potential of the country.

The uranium potential of Cambodia is limited to the metamorphic and intrusive formations in the Krâvanh and Dâmrei Mountains areas in the south.

The 1977 IUREP study estimated the uranium potential of Cambodia to less than 1000 t U.

6.2.6. Comments

There has been no past uranium production in Cambodia. Cambodia has no plan to produce nuclear energy.

References to Section 6.2

[2.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Cambodia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2012).

[2.2] HANSEN M.V., BOWMAN J. I U R E P NATIONAL FAVOURABILITY STUDIES N.F.S. No. 100. Democratic Kampuchea (Cambodia) (1977).

6.3. CHINA

6.3.1. Geography

Located in eastern Asia, on the western side of the Pacific Ocean, China has a land area of about 9.6 million km^2 and is the third largest country in the world, surpassed only by the Russian Federation and Canada. China's population numbered 1 393.6 million in 2018.

From north to south, the territory of China reaches from the centre of the Heilong River north of the town of Mohe to the Zengmu Reef at the southernmost tip of the Nansha Islands, a distance of 5 500 km. From east to west, it extends from the confluence of the Heilong and Wusuli Rivers to the Pamir Mountains, a distance of 5 200 km.

China has land borders totalling 22 800 km and has borders with the Democratic People's Republic of Korea to the east; Mongolia to the north; the Russian Federation to the north-east; Kazakhstan, Kyrgyzstan and Tajikistan to the north-west; Afghanistan, Pakistan, India, Nepal, Sikkim and Bhutan to the west and south-west; and Myanmar, the Lao People's Democratic Republic and Viet Nam to the south.

China's topography was determined by the emergence, over the past several million years, of the Qinghai–Tibet Plateau, the country's most important geological event. The terrain gradually descends from west to east in a series of 'steps'. As a result of the collision of the Indian and Eurasian Plates, the young Qinghai–Tibet Plateau rose continuously to become the highest region, averaging more than 4 000 m in elevation and often referred to as 'the roof of the world'.

The second step includes the gently sloping Inner Mongolia Plateau, the Loess Plateau, the Yunnan–Guizhou Plateau, the Tarim Basin, the Junggar Basin and the Sichuan Basin, which have an average elevation of between 1 000 m and 2 000 m. The third step, dropping to 500–1 000 m in elevation, begins at the Greater Hinggan, Taihang, Wushan and Xuefeng mountain ranges and extends eastwards to the Pacific coast. Here, from north to south, are the Northeast Plain, the North China Plain and the Middle–Lower Yangtze Plain. The areas of mountains, hills and plateaus accounts for 65% of the total land area of China.

China has over 1 500 rivers, the most important being the Yangtze, which, at 6 300 km in length, is the longest river in China and the third longest river in the world, surpassed only by the Nile (6 670 km) and the Amazon (6 400 km). In its upper reaches, the Yangtze is channelled through steep, forested gorges and in its middle and lower reaches flows through important agricultural regions that have a warm and humid climate and plentiful rainfall. The other major rivers are the Yellow, Heilong, Pearl, Liaohe, Haihe and Huaihe.

China's many rivers can be categorized as exterior and interior systems. The catchment area for the exterior rivers that empty into the various seas accounts for 64% of the country's total land area. The Yangtze, Yellow, Heilong, Pearl, Liaohe, Haihe and Huaihe rivers flow eastwards and discharge into the Pacific Ocean. Other rivers flow into neighbouring countries. The catchment area of the interior rivers that flow into inland lakes or disappear into deserts or salt marshes makes up about 36% of China's total land area.

China's territory includes numerous lakes, both freshwater and saline, most of which are found on the Middle–Lower Yangtze Plain and on the Qinghai–Tibet Plateau. Freshwater lakes mostly lie on the Middle–Lower Yangtze Plain whereas the saltwater lakes tend to be found on the Qinghai–Tibet Plateau.

Cultivated land, forests, grasslands, deserts and tidelands are distributed widely across China. Cultivated land is mainly located in eastern China, grasslands are mainly located in the north and west, and forests mainly in the remote north-eastern and south-western areas.

Currently, 130.04 million hectares of land are under cultivation, mainly on the Northeast Plain, the North China Plain, the Middle–Lower Yangtze Plain, the Pearl River Delta and the Sichuan Basin. The fertile black soil of the Northeast Plain, the largest plain in China with an area of more than 350 000 km^2, is used for the cultivation of wheat, corn, sorghum, soybeans, flax and sugar beet. The deep, brown topsoil of the North China Plain is planted with wheat, corn, millet and cotton. The Middle–Lower Yangtze Plain's flat terrain and many lakes and rivers make it particularly suitable for rice cultivation and for rearing freshwater fish. This area also produces large quantities of tea and silkworms.

Forests cover 158.94 million ha. The Greater Hinggan, Lesser Hinggan and Changbai mountain ranges in the north-east are China's largest natural forest areas. Grasslands cover an area of 400 million hectares.

China is rich in mineral resources and these include energy related minerals, including petroleum, natural gas, coal and uranium; metallic minerals, including antimony, iron, manganese, molybdenum, copper, bauxite, tin, mercury, lead and zinc; and non-metallic minerals, including rare earth elements, graphite, phosphorus, sulphur and sylvite. The reserves of the major mineral resources, such as coal, iron, copper, bauxite, antimony, molybdenum, manganese, tin, lead, zinc and mercury are among the largest in the world. The national reserves of rare earth elements far exceed the combined total for the rest of the world [3.1].

6.3.2. Geology

As befits a country of its size, China has extensive exposures of strata spanning all geological ages from the Archaean to the Quaternary (Fig. 6.8). In the context of this publication, a summary of the regional geology would not do justice to the complexity of China's geology nor to the tectonic events which have shaped it. In view of this, discussion of the geology confines itself specifically to reviewing the uranium metallogeny of the country.

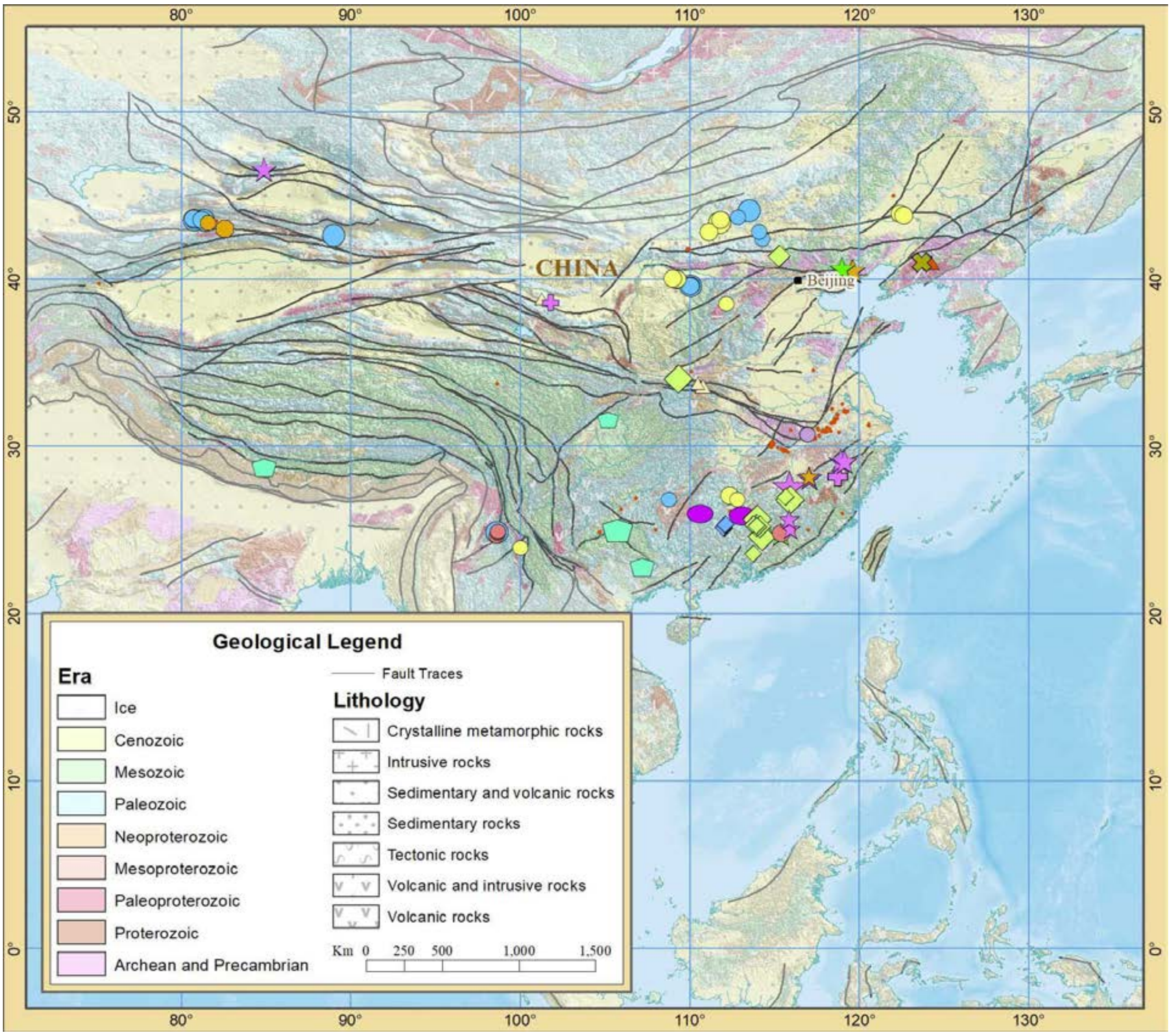


FIG. 6.8. Regional geological setting of China showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Uranium metallogeny

Much of China's uranium inventory is classified as a State secret and therefore information on this subject is scant, and what is available may be unreliable. Much of the information condensed here has been reported by Dahlkamp [3.2]. The information given here draws extensively from Dahlkamp's comprehensive review of China's uranium deposits. Approximately two thirds of deposits, irrespective of type, are of low to medium grade (0.05–0.2% U). In addition, many of the deposits are relatively small, often several hundred to several thousand tonnes. Around 30% of deposits have reserves of less than 1 000 tU and another 30% have reserves of 1 000–3 000 tU. A few locations have much higher reserves, of the order of 10 000 tU.

Five uranium provinces have been recognized [3.3], plus several other areas. The five main provinces are:

(i) Junggar-Tien Shan (north-west China);
(ii) Yinshan-Liaohe (north-east China);
(iii) Qilian-Quinling (central China);
(iv) South China;
(v) West Yunnan (south-west China).

In addition, several uranium occurrences are recorded elsewhere, including the Da Hinggan–Erguna zone in north-eastern Inner Mongolia and the Ordos Basin in central north China.

The majority of uranium mineralization occurs in four types of deposit: (i) granite-related deposits (37%), (ii) sandstone type deposits (24%), (iii) volcanic-related deposits (19%), and (iv) carbonaceous–siliceous–pelite deposits (16%). The remainder comprise metasomatite, intrusive, lignite and phosphorite deposits [3.2].

(i) *Granite-related deposits:*

Granite-related deposits are typically hydrothermal veins, often structurally controlled by silicified fault/fracture zones. They generally occur within granite batholiths of Mesozoic age and in the sedimentary rocks comprising the contact aureole. The principal mineral is pitchblende, together with minor coffinite. With regard to size, these deposits are mostly small to medium sized (<500–3000 tU) and are low to medium grade (0.05–0.2% U). The majority of these deposits occur in the Nanling tectono-magmatic zone and in the Jiangnan granite belt in southern China. Some also occur in central (Xi'an), north-east (Lianshanguan Dome) and south-east China (Lower Yangtze granite belt) [3.2].

(ii) *Volcanic-related deposits:*

Volcanic-related deposits are structurally bound and stratabound deposits that are controlled by volcanic systems and faults. The host rocks are felsics, including lavas and pyroclastics, of Mesozoic age. The mineralization comprises complex polymetallic assemblages containing uranium, molybdenum and silver, the molybdenum and silver being recovered as by-products. These deposits are generally small (<500–1000 tU) and of low grade (0.03–0.1% U). These deposits occur in the south-east (Jiangxi–Zhejiang–Fujian), north-west (Tien Shan) and north-east (Hebei and Inner Mongolia) [3.2].

(iii) *Sandstone-hosted deposits:*

Sandstone hosted deposits occur as roll front and basal channel type mineralization in intermontane basins of Mesozoic age. The basements of the uranium-bearing basins contain granite and felsic volcanics. The host rocks are carbonaceous and comprise arkosic sandstone and conglomerate with variable clay contents. These rocks are commonly interbedded with lignite/coal seams and argillaceous strata. The deposits are predominantly small- to medium-sized but, exceptionally, can exceed 10 000 tU. Grades are low (0.03–0.1% U). The deposits occur in the north-west (Yili and Tarim Basins), north (Eren Basin), north-east (Jianchang and Qinglong Basins), south-west (Yunnan Basin) and south (Hengyang and Jingan Basins). Other areas that have yielded promising results are the Turpan–Hami, Ordos, Junggar and Qaidam Basins.

(iv) *Carbonaceous–siliceous–pelite type deposits:*

These include the black shale stockwork type deposits, which are stratabound and associated with black shale sediments of Upper Proterozoic–Palaeozoic age. The uranium mineralization is structurally controlled and occurs in fracture stockworks or occasionally in solution cavities in carbonate rocks filled with collapse breccias. The uranium mineralization is disseminated and is confined to altered fracture zones. The host rocks are sedimentary lithologies comprising siliceous carbonate or pelitic strata which are enriched in carbonaceous material. Some of the strata may be weakly metamorphosed. These deposits are small- to medium-sized and have low to medium grades (<0.1–0.2% U). Deposits of this type occur in the south (Guangxi, Hunan, Jiangxi and Guizhou Provinces) and centre (Sichuan Province) of the country.

(v) *Other deposits:*

Metasomatite, intrusive, lignite-coal and phosphorite deposits also occur. Metasomatite deposits occur in north-east (Lianshanguan Dome) and central China (Longshoushan and North Qilian fold belts). Intrusive type deposits include the uraniferous pegmatite at Danfeng in central China and a peralkaline syenite in the north-east (Liaoning Province). Uraniferous lignite-coal is found in several sedimentary basins of Mesozoic age [3.2].

Uraniferous phosphorite deposits also occur in Guizhou, Xinjiang, Gansu and Ningxia Provinces. Grades are generally low, of the order of 0.01–0.03% U. The Yankong deposit in central Guizhou has a grade of about 0.02% U.

6.3.3. Uranium exploration

6.3.3.1. Historical review

Uranium exploration in China was initiated in 1955. Prior to the 1990s, China's uranium resource exploration activities were mainly carried out for hydrothermal, granite and volcanic-related uranium deposits in Jiangxi, Hunan and Guangdong Provinces and Guangxi Autonomous Region in southern China. Over several decades of exploration, the Bureau of Geology (BOG) and the China National Nuclear Corporation (CNNC) had been successful in discovering significant uranium deposits such as the Xiangshan and Xiazhuang orebodies and the Chengxian deposit in the southern China fold belt.

These deposits mainly occur in intermediate to acid magmatic rocks such as granitoid and volcanic rocks. A number of these deposits are of relatively small size and of low to medium grade. They occur in relatively remote locations and are not readily accessible as regards transportation and access to power supplies. The mining costs therefore are much higher than could be accepted by the commercial nuclear reactor operators.

At the beginning of 1990s, when China initiated its nuclear energy programme, the demand for uranium from China's nuclear power plants was not urgent. In addition, in the mid-1990s, China's currency strength deterred further uranium exploration activities, a situation that prevailed up to the end of the decade.

In responding to financial pressures, as well as rising to the challenge of meeting the demand of an economically affordable uranium resource for the country's medium and long term nuclear energy development plan, the BOG decided to change its prospecting focus from the 'hard rock' type to the in situ leaching (ISL) type in northern and north-west China.

From the mid-1990s, China increased the rate of construction of nuclear power plants at coastal sites and, accordingly, the demand for uranium steadily increased. As the known low cost uranium resource decreased, the BOG, starting in the early 1990s, used limited funding to initiate regional reconnaissance geological and drilling projects in the Yili, Turpan–Hami, Junggar, Erlian and Songliao Basins in northern and north-west China.

During the 1990s, the limited budget funded an average annual drilling programme of only about 40 000 m. In 1999, the Government undertook a significant structural reform of China's mineral exploration sector. As a result, a large number of personnel who had been involved in geological exploration were transferred to local government. After the transfer of most of the geological organizations, BOG staff were reduced from more than 45 000 to around 5 500. At the end of 1990s, the Government recognized the importance of increasing the economic uranium resource in order to meet domestic demand for uranium from the nuclear power industry. Investment in uranium exploration has steadily increased since 2000. Annual drilling rebounded from 40 000 m to 70 000 m in 2000, and gradually increased to 130 000 m in 2003 and 140 000 m in 2004. All drilling was focused on prospecting for ISL amenable sandstone-hosted type uranium deposits in northern China. Important target areas include the Yili, Erdos, Turpan–Hami, Erlian, Junggar and Songliao Basins.

6.3.3.2. Recent and ongoing uranium exploration and mine development activities

Domestic uranium prospecting and exploration has been intensified by increasing financial support, resulting in an increase in actual work accomplished during 2007–2008. The active project areas have been expanded to include the potential prospects that were selected after the regional prognosis and assessment, as well as those identified from continued prospecting and exploration within those mineralized areas and belts related to previously discovered uranium deposits. The exploration focus is on the sedimentary basins in northern and western China, as well as on several projects investigating possible extensions to existing orebodies in southern China.

The exploration programmes, including the regional uranium potential assessment and follow-up work on the discovered mineralization and deposits in northern China, are being carried out in the Yili, Turpan–Hami, Junggar and Tarim Basins of Xinjiang Autonomous Region, the Erdos, Erlian, Songliao, Badanjilin and Bayingebi Basins of Inner Mongolia, the Caidamu Basin in Qinghai Province and Jiuquan Basin in Gansu Province, and elsewhere. Different evaluation methods, such as EH-4, CSAMT and some drilling, are used for the initial assessment. Follow-up drilling is used in the mineralized areas to discover both ISL amendable sandstone-hosted deposits and conventional hard rock sandstone and mudstone-hosted deposits.

Exploration for hydrothermal vein type uranium deposits related to volcanic and granitic rocks in southern China has been carried out in the Xiangshan and Taoshan uranium fields in Jiangxi Province; in the Xiazhuang and Zhuguang uranium fields in Guangdong Province; in the Ziyuan uranium field in Guangxi Autonomous Region; and in the Lujing and Daqiaowu uranium fields in Zhejiang Province.

The total drilled in the past two years amounted to 950 000 m (450 000 m in 2007 and 500 000 m in 2008), including 700 000 m drilled in sedimentary basins in northern China. The uranium resources and reserves in northern China have increased significantly as a result. Meanwhile, progress has also been achieved in southern China.

The future exploration focus will be on exploring sedimentary basins in northern China to discover more ISL amenable uranium resources.

Apart from domestic development, Chinese companies have also been active abroad. CNNC is developing a mine in Niger, China Guangdong Nuclear Power Corporation is involved in Kazakhstan and Sinosteel Corporation is present in Australia (the Crocker Well and Mount Victoria projects). At the same time, uranium is being imported from Australia and the Russian Federation, as well as from African and central Asian countries, and elsewhere. In conclusion, China's uranium supply will be secured through a combination of domestic production and overseas exploration and mining, as well as through foreign trade.

6.3.3.3. Uranium exploration expenditures

Domestic and non-domestic uranium exploration expenditures and additional details are summarized in Fig. 6.9 (reflecting a total of 8 127 200 metres of drilling within an expenditure of USD $1 339 000 000) and Table 6.7.

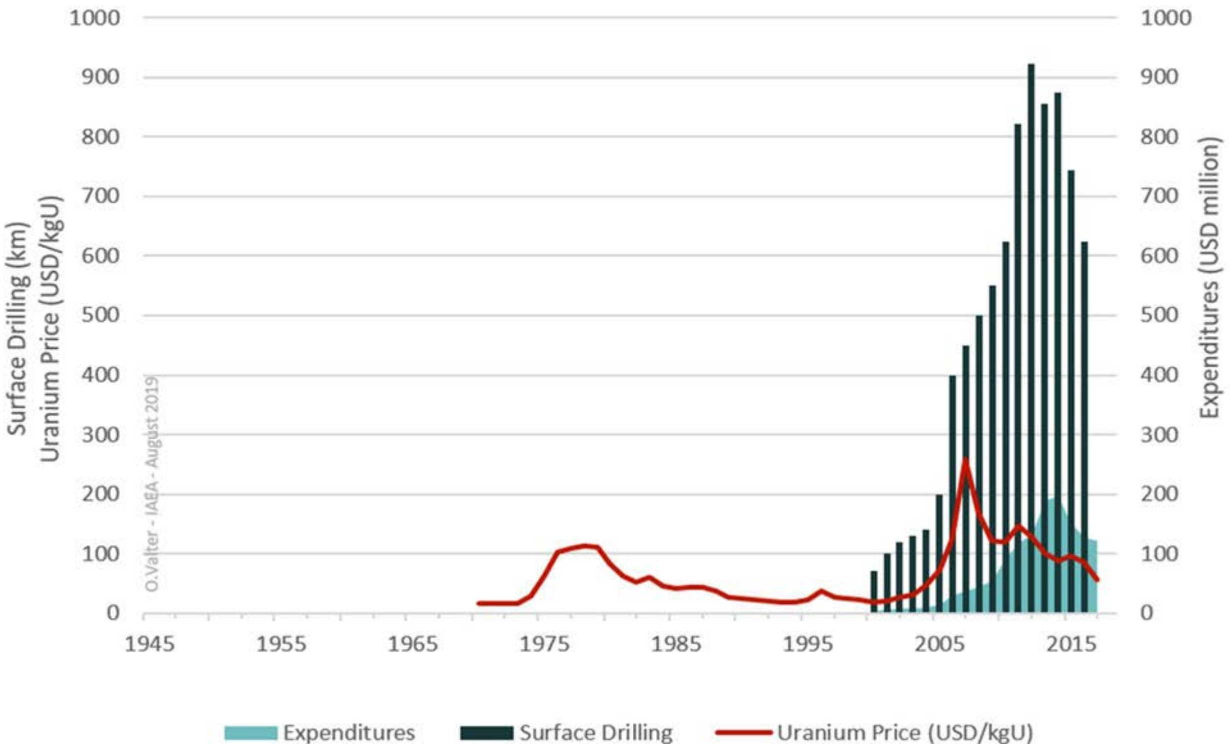


FIG. 6.9. Domestic uranium exploration data for China. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

TABLE 6.7. NON-DOMESTIC URANIUM EXPLORATION EXPENDITURES (US$ million) [3.4]
(US $1 = 6.83 RMB Yuan (as of 1 of April 2009))

	2006	2007	2008	2009
Industry (non-Government) exploration expenditures	0	0	0	0
Government exploration expenditures	n.a.[a]	n.a.	n.a.	n.a.
Industry (non-Government) development expenditures	0	0	0	0
Government development expenditures	n.a.	160	220	n.a.
Total	n.a.	160	220	n.a.

[a] n.a.: not available.

6.3.4. Uranium resources

China's in-situ uranium resources, as of 1 January 2017, are summarized in Tables 6.8 – 6.11 and the variation in historical resources are shown in Figs 6.10 and 6.11.

TABLE 6.8. REASONABLY ASSURED CONVENTIONAL RESOURCES (tU) [3.5]

Production method	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Underground mining	8 100	56 000	79 300	79 300
ISL acid	21 100	38 200	55 400	55 400
ISL alkaline	29 000	39 600	43 000	43 000
Total	58 200	133 800	177 700	177 700

TABLE 6.9. INFERRED CONVENTIONAL RESOURCES (tU) [3.5]

Production method	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Underground mining	12 300	57 400	85 400	85 400
ISL acid	50 500	80 900	94 600	94 600
ISL alkaline	6 800	12 100	13 200	13 200
Total	69 600	150 400	193 200	193 200

TABLE 6.10. PROGNOSTICATED RESOURCES (tU) [3.5]

Cost range		
<US $80/kgU	<US $130/kgU	<US $260/kgU
3 600	3 600	3 600

TABLE 6.11. SPECULATIVE RESOURCES (tU) [3.5]

Cost range		
<US $80/kgU	<US $130/kgU	Unassigned
4 100	4 100	n.a.[a]

[a] n.a.: not available.

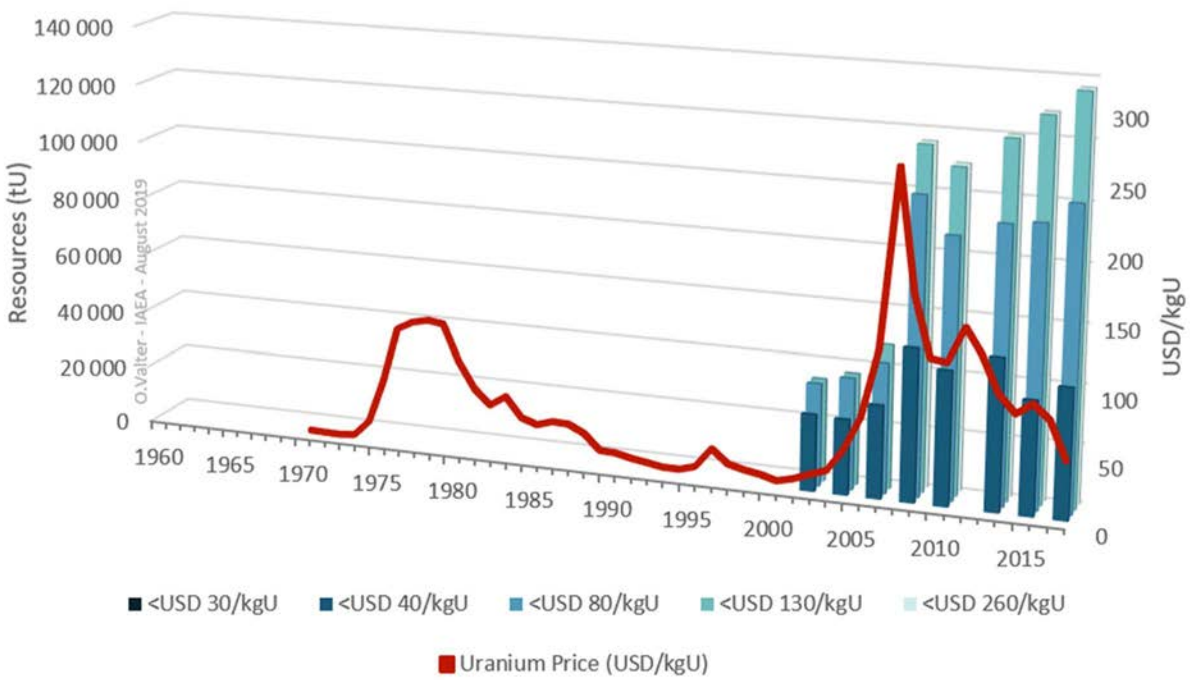


FIG. 6.10. Historical variation of recoverable reasonably assured resources within various cost categories in China. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

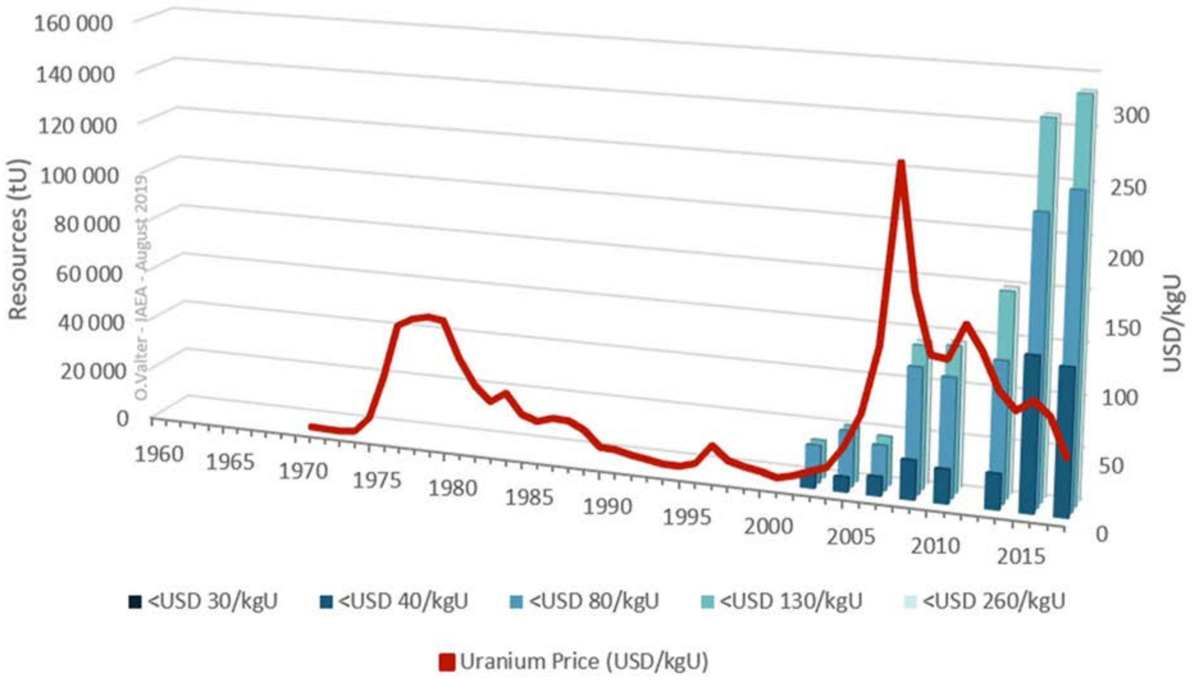


FIG. 6.11. Historical variation of recoverable inferred resources within various cost categories in China. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

The UDEPO database lists the most significant deposits for China as Huayangchuan, Daying, Nuheting, Bayinwula, Kujiertai (512), Nalinggou, Mengqiguer 2, Taoshan District, Zoujiashan.

6.3.5. Potential for new discoveries

China is believed to have a great potential for additional uranium resources. The results of statistical analysis by several institutes in China estimate that potential resources could be in the range 1.2–1.7 million tU. Favourable areas, including the Erlian and Erdos Basins and the Inner Mongolia Autonomous Region, have been identified in the past two years. Other areas, including the Tarim and Junggar Basins in the Xinjiang Autonomous Region and the Songliao Basin in north-east China are also regarded as having favourable potential. Additional uranium resources may also be added to the known uranium deposits in southern China, as prospecting and exploration work have been restarted in the region.

6.3.6. Uranium production

The 50-year history of China's uranium industry has experienced both a boom in activity during the first two decades followed by a decline in the late 1980s and 1990s. In the early years of the 21st century, there has been a resurgence, driven principally by the ambitious new nuclear power programme announced by the Government and the surging uranium spot price. As a result, uranium production has once again been a focus of attention. Several production centres are under construction, including the Fuzhou and Chongyi uranium mines. A new Chongyi production centre, located on a different site, is to be built, subject to the results of ongoing pilot tests. In addition, the former Qinglong uranium mine has been rehabilitated and brought back into operation. Feasibility studies are also being carried out on other selected uranium deposits.

Construction of two new production centres was completed in 2009. The facilities are awaiting final approval from the relevant authorities. One conventional underground mine, Qinglong, belongs to the Benxi uranium mine. The other is an expansion of the Yining ISL mine. The two facilities will add a further 200 tU/year of nominal capacity once they reach full operation. China's other uranium production centres remain the same. No production centres have been shut down in the past two years.

The uranium industry in China is 100% owned by State companies. Figure 6.12 details employment at existing production centres and Tables 6.12 and 6.13 summarize the technical details at the five production centres. Figure 6.13 shows the historical production trends reflecting a total of 26 159 tU with 7 920 tU and 3 780 tU of undergound and in situ leaching mining respectively during the period of 2000-2017.

TABLE 6.12. URANIUM PRODUCTION CENTRE TECHNICAL DETAILS (Centres 1–4) [3.4]
(As of 1 January 2009)

	Centre #1	Centre #2	Centre #3	Centre #4
Name of production centre	Fuzhou	Chongyi	Yining	Lantian
Production centre classification	Existing Committed	Existing	Existing	Existing
Startup date	1966	1979	1993	1993
Source of ore:				
• Deposit name			Deposit 512	Lantian
• Deposit type	Volcanic	Granite	Sandstone	Granite
Mining operation:				
• Type	UG[a]	UG	ISL[b]	UG
• Size (ore t/d)	700	350	n.a.[c]	200
• Average mining recovery (%)	92	90	n.a.	80
Processing plant (acid/alkaline):				
• Type	Conventional	Heap leach	Heap leach	Heap leach
• Size (ore t/d)	IX[d], AL[e]	IX, AL	IX, AL	IX, AL
for ISL (L/d or L/h)	700	350	n.a.	n.a.
• Average process recovery (%)	90	84	n.a.	90
Nominal production capacity (tU/year)	300 200 (committed)	120	300	100
Plans for expansion	n.a.	Expansion to 270 t/year		n.a.

[a] UG: underground mining.
[b] ISL: in situ leaching.
[c] n.a.: not available.
[d] IX: ion exchange.
[e] AL: acid leaching.

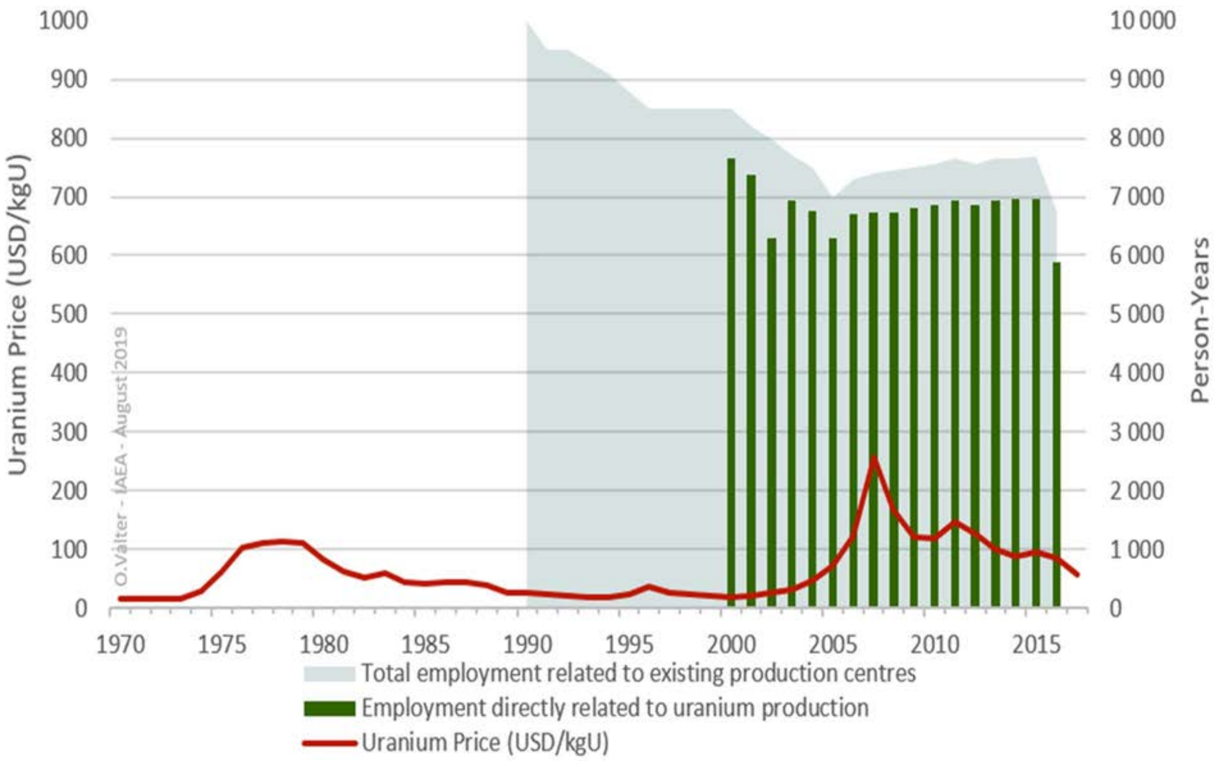


FIG. 6.12. Uranium industry employment at existing uranium production centres in China.

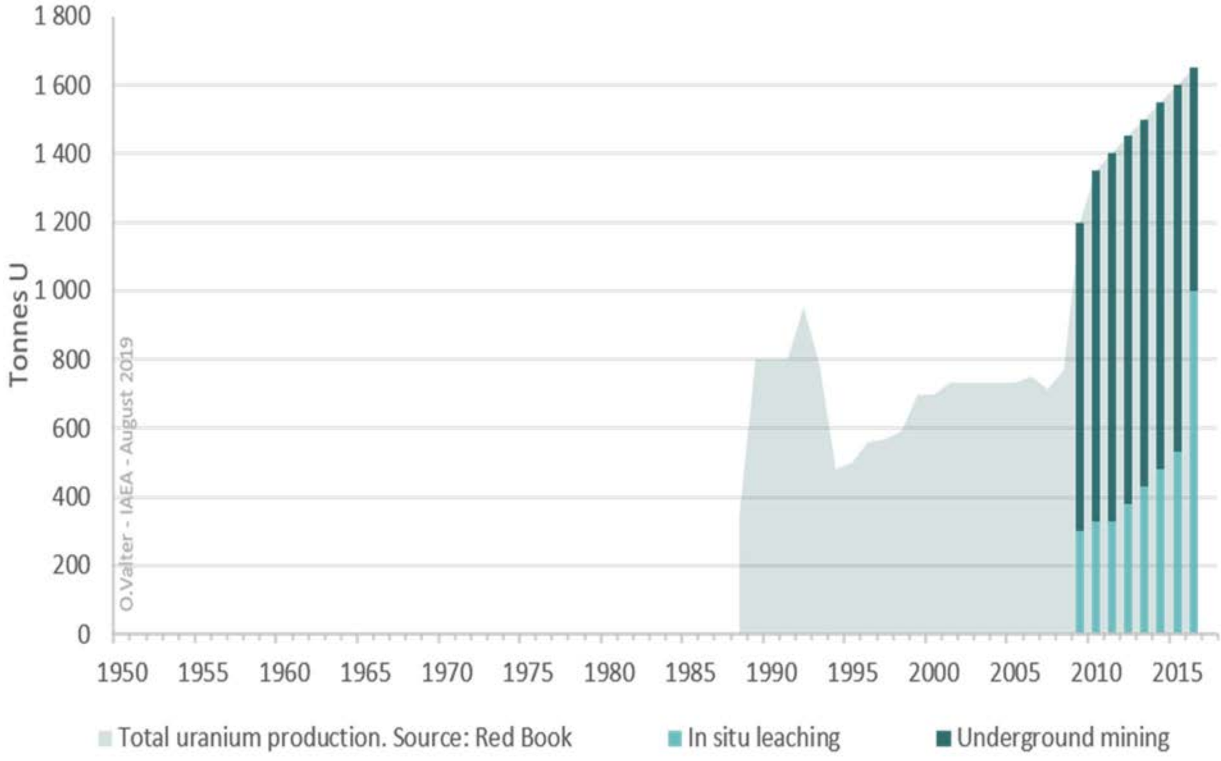


FIG. 6.13. Historical Uranium production in China.

6.3.7. Production centres

TABLE 6.13. URANIUM PRODUCTION CENTRE TECHNICAL DETAILS (Centre 5) [3.4]
(As of 1 January 2009)

	Centre #5	
Name of production centre	Benxi	Qinglong
Production centre classification	Existing	Existing
Startup date	1996	2007
Source of ore:		
• Deposit name	Benxi	Qinglong
• Deposit type	Granite	Volcanic
Mining operation:		
• Type	UG[a]	UG
• Size (ore t/d)	100	200
• Average mining recovery (%)	85	85
Processing plant (acid/alkaline):	Heap leach	Heap leach
• Type	SX[b], AL[c]	IX[d]
• Size (ore t/d) for ISL (L/d or L/h)	n.a.[e]	n.a.
• Average process recovery (%)	90	96
Nominal production capacity (tU/a)	120	100
Plans for expansion	n.a.	n.a.

[a] UG: underground mining.
[b] SX: solvent extraction.
[c] AL: acid leaching.
[d] IX: ion exchange.
[e] n.a.: not available.

A new production centre at the Fuzhou uranium mine is under construction. Another production centre is also under construction at the Chongyi uranium mine, which will employ in-stope leaching, a new mining method at Chongyi. The use of this method will eliminate the cost of hoisting ore at the mine. It will also reduce the land area required for tailings disposal.

Pilot testing of ISL technology at the Shihongtan deposit is continuing. Pilot testing at the Dongsheng uranium deposit is also ongoing. Results at Dongsheng have led to the decision to abandon the ISL method in the eastern part of the deposit owing to low rock permeability. ISL testing is still under way in the western portion.

Feasibility studies are being prepared for several deposits, such as the Liaohe sandstone type uranium deposit and the Guyuan granite-hosted uranium deposit.

6.3.8. Environmental activities

Owing to new environmental regulations recently put in place, new technologies are being widely used in uranium mines in China. Mine liquids are collected, treated and recycled. To meet the discharge regulations and standards, only very small amounts of wastewater are discharged after treatment. The treated water is not discharged directly but maintained in a storage pond for a sufficient period of time before being checked again to verify that it meets discharge standards according to the new regulations enacted in the past two years.

The regulation covering the radiation protection of the uranium mine and mill (EJ 993-2008) came into force in 2008. All workers in uranium mines and mills are required to be equipped with radiation monitors during working hours.

Three closed mines have been rehabilitated. One has been approved by the responsible Government authority and approvals for the other two are expected in 2009.

6.3.9. National policies relating to uranium

To meet the increasing demand for uranium driven by the fast growth of China's nuclear power industry, the Government has recognized the importance of securing the supply of uranium fuel and has taken several measures to safeguard this. The measures taken by the Government include the intensification of uranium exploration in China, promotion of domestic production, introduction of regulations to allow non-government organizations to explore for uranium in China and the introduction of a 'two markets and two resource systems', meaning including both overseas purchases and production of uranium.

6.3.10. Taiwan

6.3.10.1. Geography

The island of Taiwan, China, is located in the western Pacific Ocean and lies 125 km off the south-east coast of mainland China, from which it is separated by the Taiwan Strait. The island is 394 km long and 144 km wide at its widest point and its most prominent geographic feature is its 270 km long central mountain range, which has more than 200 peaks over 3000 m high. At 3952 m, Mount Jade is the highest peak in East Asia. Foothills from the central mountain range lead to tablelands and coastal plains in the west and south. The eastern shoreline is relatively steep and mountains over 1000 m high dominate the island in the north.

Crossed by the Tropic of Cancer, Taiwan, China has a subtropical climate except for its extreme southern tip, which is tropical. The island has an average annual rainfall of 2471 mm. However, the distribution of water resources is uneven, putting constraints on the water available for use on a per capita basis. Summers are long and humid, while winters are short and usually mild. During the coldest months, snow falls on the island's higher mountains [3.6, 3.7].

6.3.10.2. Geology

Taiwan, China is situated on the edges of the Eurasian and Philippine Sea Plates (Fig. 6.14). The Huatung Longitudinal Valley marks the boundary between the two plates; to the east is the Philippine Sea Plate and to the west is the Eurasian Plate. The Philippine Sea Plate is moving westwards and is being subducted under the Eurasian Plate. The uplift of the island's Coastal Range is a product of this plate movement.

The island was formed from a geosyncline, a large, trough-like depression in the ocean floor containing sequences of sedimentary and volcanic rocks, and is part of an island arc. This arc is short in length and high in elevation and is located at the junction of the Ryukyu Island Arcs and Luzon Island Arcs. As such, it is one of the few islands among the many in the East Asian region which 'arcs' towards the Asian continent, i.e., the 'convex surface' faces the mainland. Its geology is closely related to that of mainland China.

Taiwan, is an island with both geosyncline and island arc features. Its geosyncline environment, which has already gone through several transformations, is very complex. Its location at the meeting point of the Eurasian and Philippine Sea Plates is characterized by folds, faults and uplift movements.

The strata of the western flank of the Central Mountain Range, facing the Taiwan Strait, are underlain by marine sedimentary rocks of Tertiary age. The eastern flank, facing towards the Pacific Ocean, is underlain by metamorphic rock of Mesozoic and Palaeozoic age. Other areas, such as Tatun Shan in the north, the Coastal Mountain Range in the east and many outlying islets, such as the Penghu Archipelago, comprise lava flows and agglomerated masses of volcanic rock fragments fused by andesite and basalt. Strata are distributed in long and narrow strips, almost parallel to the island's axis.

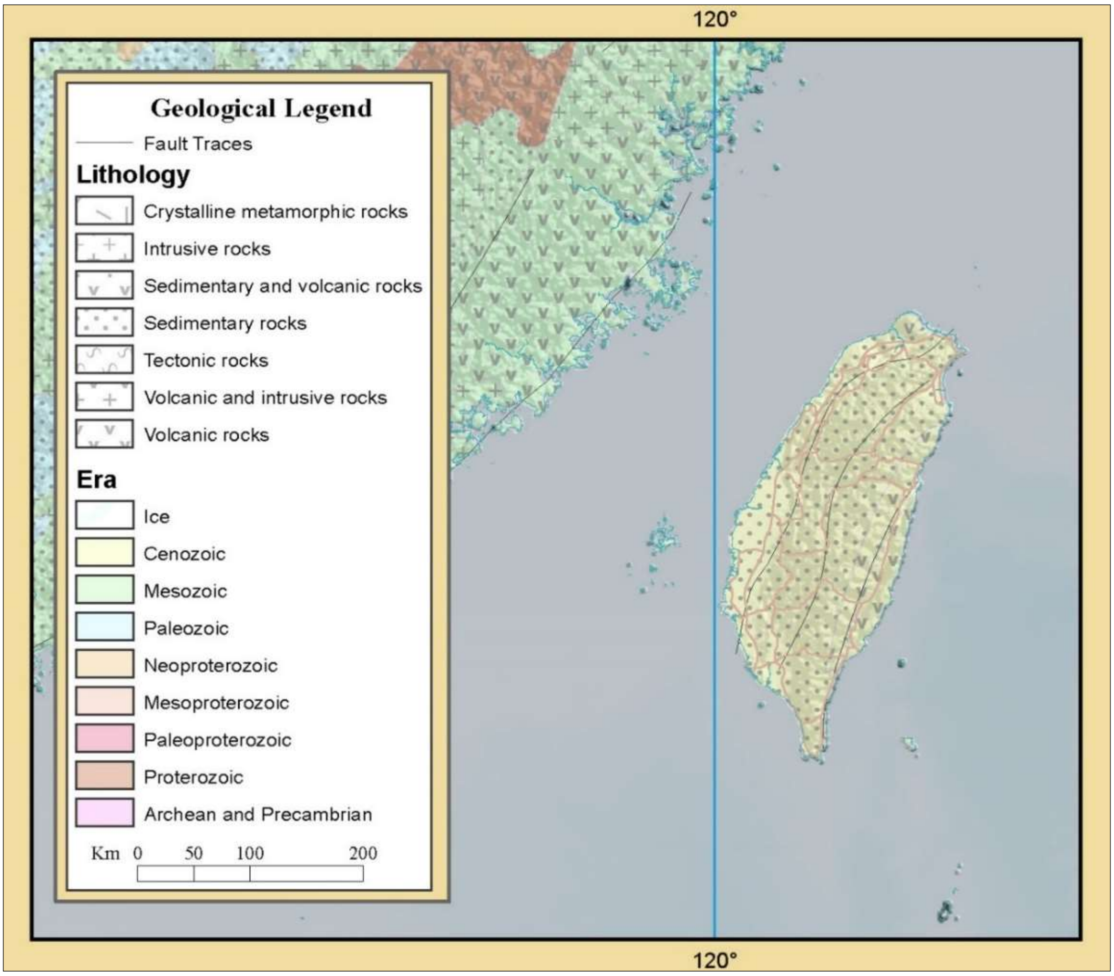


FIG. 6.14. Regional geological setting of Taiwan (China). A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Taiwan has more volcanic rock than plutonic rock. Dacite makes up the strata of the Tatun and Keelung volcanoes, as well as the Coastal Mountain Range, whereas basalt forms the Penghu Archipelago.

These rock types are not favourable for hosting uranium deposits.

No information on uranium exploration has been reported and no uranium resources have been recorded. Given the geology of the island, the potential for any discovery is regarded as very low [3.8].

References to Section 6.3

[3.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: China, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2012).

[3.2] DAHLKAMP, F.J., Uranium Deposits of the World, Springer, Berlin (2009).

[3.3] LIU XINGZHONG, ZHOU WEIXUN, "Uranium provinces in China and their distribution", Uranium Geol. **6** 6 (1990) 326–337.
[3.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[3.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).
[3.6] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Taiwan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2010).
[3.7] ASIAN INFO, Taiwan's Geography and Climate, http://www.asianinfo.org/asianinfo/taiwan/pro-geography.htm (accessed August 2010).
[3.8] TWGEOG, The Geology of Taiwan, http://twgeog.geo.ntnu.edu.tw/english/geology/geology.htm (accessed August 2010).

6.4. DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA[9]

6.4.1. Geography

Located on the Korean Peninsula, the Democratic People's Republic of Korea (DPRK) borders China and the Russian Federation to the north and the Republic of Korea to the south. The Sea of Japan lies to the east and the Yellow Sea to the west.

Topographically, the country is characterized by hills and high mountains into which deep valleys have been incised. In the central part, the Rangnim Sanmaek mountain ridge forms the backbone of the country. The highest peak is the Baekdu (2 744 m), located close to the Chinese border. West of the mountainous area, a broad coastal plain is developed, whereas to the east of the mountains the coastal plain forms only a narrow strip.

The longest river is the Amnok, with a length of 790 km, which forms the border with China and flows into the Yellow Sea.

Most parts of the country are characterized by a continental climate with four distinct seasons. The winter can be cold and the summers are generally short, hot and humid.

About 14% of the country is arable and 60% is covered by forests and woodland [4.1].

6.4.2. Geology

According to the literature, granitic intrusions of various ages are reported, ranging from Proterozoic to Late Mesozoic (Fig. 6.15). This indicates magmatic activity during the orogenic events which may be dated as being equivalent to the European Caledonian, Variscan and later episodes. Sedimentary formations have accumulated in the periods between. In general, the geology is not reported.

According [4.1], the natural resources of the DPRK include base metals, fluorspar, gold, graphite, iron, magnesite, salt and tungsten. Energy resources, notably coal and petroleum, are also reported.

Over 50% of the country's territory is underlain by rocks of Archaean and Proterozoic age, Palaeozoic rocks make up around 30% and Mesozoic–Tertiary formations comprise the rest.

Three main geological elements are recognized: a stable platform, geosynclines and younger sediment and volcanic (basalt) covers. Granitic intrusions of Archaean–Mesozoic age occur. As in many parts of

[9] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

East and South-east Asia, the Cretaceous granite is considered important in relation to uranium potential. Uranium mineralization in sedimentary, hydrothermal (vein), metamorphic (stratabound), skarn and pegmatite hosts are known in the country. However, only those associated with the Cambrian black shale are considered important. Sizeable resources from this type of deposit have been outlined in and around Kumchon and several prospects have been evaluated throughout the country [4.2].

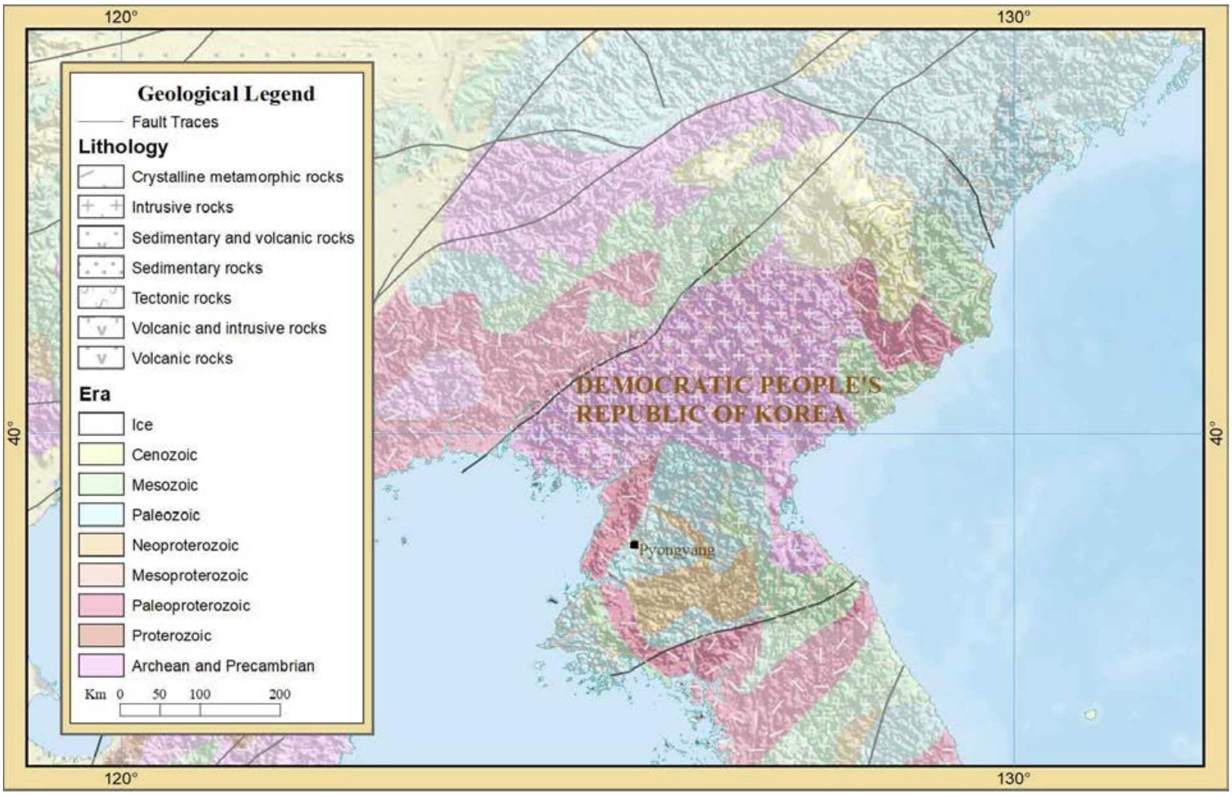


FIG. 6.15. Regional geological setting of Democratic People's Republic of Korea. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.4.3. Uranium resources

Uranium resources are not officially reported. The DPRK has never supplied uranium resource information to the OECD/NEA–IAEA Uranium Group. Uranium experts who have visited the DPRK's uranium facilities state that according to an analysis conducted in the 1960s, the country possessed natural uranium resources amounting to about 200 000 t of ore. More detailed exploration activities in the 1970s increased the uranium resource estimate to 300 000 t of ore.

The deposits are uraniferous black shale occurrences (possibly similar to that at Okchon in the Republic of Korea) occurring at a depth of about 200 m. The ore grade is about 0.2% U. Some orebodies have been mined by low cost open pit techniques. There are five known mines: (i) Sunchon–Wolbingson, (ii) Kusong, (iii) Pyongsan, (iv) Sunchon, and (v) Unggi.

No data are available on the production figures (tonnage, grade, production cost).

One expert who visited the mines estimated that the DPRK's mining and milling capabilities could currently support an annual production of 2000 t of natural uranium.

In Ref. [4.3], the following mines are mentioned:

— Sunchon–Wolbingson;
— Kusong, north Pyongan Province;
— Pyongsan, north Hwanghe Province;
— Sunchon, south Pyongan;
— Unggi;
— Yongchon deposit, Songhak-ri, Hoiryeong.

According to Ref. [4.3], total resources are estimated at 3.6 million t of ore at an estimated grade of 0.8% U. Assuming an average grade similar to that at the Okchon deposit in the Republic of Korea suggests that uranium resources would amount to about 7 200 tU.

If this grade were correct, then resources would amount to ~30 000 tU [4.3, 4.4].

The UDEPO database does not list any known deposits for the Democratic People's Republic of Korea.

6.4.4. Potential for new discoveries

Only when additional geological information becomes available will an accurate assessment of the potential for additional uranium resources be possible.

6.4.5. Comments

The annual production of uranium remains unknown, but it can be estimated at a few hundred tonnes per year, with a cumulative production of several thousand tonnes.

References to Section 6.4

[4.1] ENTRAL INTELLIGENCE AGENCY, The World Factbook: Democratic People's Republic of Korea Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed July 2012).

[4.2] MATOLIN, M., TAUCHID, M., Uranium Prospecting DRK/3/003, Laboratory gamma-ray spectrometry, Report to the Government of the Democratic People's Republic of Korea, Evaluation Mission of May 1987 (1990).

[4.3] FEDERATION OF AMERICAN SCIENTISTS, North Korea Special Weapons Guide (November 2006), http://www.fas.org/nuke/guide/dprk/

[4.4] HAYES, P., North Korea's uranium exports: much ado about something, Nautilus Institute (25 May 2004).

6.5. FIJI

6.5.1. Geography

Fiji consists of about 320 islands in the southern Pacific Ocean, of which about 110 are permanently inhabited. The largest islands are Viti Levu (10 429 km²) and Vanua Levu (5556 km²). The island group is distributed in a crescent shaped area around the Koro Sea between the Equator and the Tropic of Capricorn (Fig. 6.16). The archipelago extends over an area of about 1.3 million km². Apart from the main islands of Viti Levu and Vanua Levu, other larger island groups are associated with the Northern Lau Group and the Southern Lau Group. To the south, the uplift in the Pacific Ocean continues in the Kermadec High, which continues further south to New Zealand. To the east of the Kermadec High, the more than 10 000 m deep Kermadec and Tonga Graben system is located. The largest islands are rugged, made up of volcanic material and surrounded by coral reefs. The shores of the islands are mostly flat and sandy, forming beaches. The highest point is Mount Tomaniivi (1320 m), located on Viti Levu.

The climate is tropical with temperatures seldom below 16°C or above 32°C.

Agriculture is dominated by production of sugar cane and the products of coconut palms, rice and bananas. The forests produce rare woods. Fishery is also important. Tourism has become a major source of income. Development of a few mineral deposits is at an early stage. Mining of gold is reported at the Emperor Deposit in north-western Viti Levu where 146 000 kg were produced between 1933 and 1994. Gold mineralization at Tuvatu, near Emperor, is being investigated. Other commodities include manganese and silver, and mesothermal–epithermal arsenic and copper sulphide mineralization occurs on Vanua Levu.

The major source of energy is hydropower [5.1].

6.5.2. Geology

Fiji is located along a set of transform faults offsetting the complex boundary between the Pacific and the Indo-Australian Plates by over 1500 km. It lies at the midpoint of the opposing Tonga Kermadec and New Hebrides convergence zones, separated from these actual convergence zones by two extensional back-arc basins, the North Fiji Basin to the west and the Lau Basin to the east, and a series of transform faults including the Fiji Fracture Zone and the Matthew Hunter Ridge. This boundary is recognized in other areas as the locus of several major world class porphyry copper–gold and epithermal gold systems.

Much of the younger (Late Miocene–Pliocene) structural and volcanic features of the Fiji Platform can be related to transformation of the older arc to its present-day configuration through creation of the North Fiji and Lau Basins (Fig. 6.17). This period also saw major changes in volcanism throughout the group, with initial eruption of voluminous shoshonitic volcanics in northern Viti Levu (5.5–3.0 Ma) followed by later alkali volcanism more akin to oceanic basalts.

In terms of crustal development, the geological evolution of Fiji may be viewed in four main stages: (i) an early arc stage (3512 Ma), (ii) a mature arc stage (127 Ma), (iii) an early arc rifting stage (7–3 Ma), and (iv) a late arc rifting stage (3 Ma and younger).

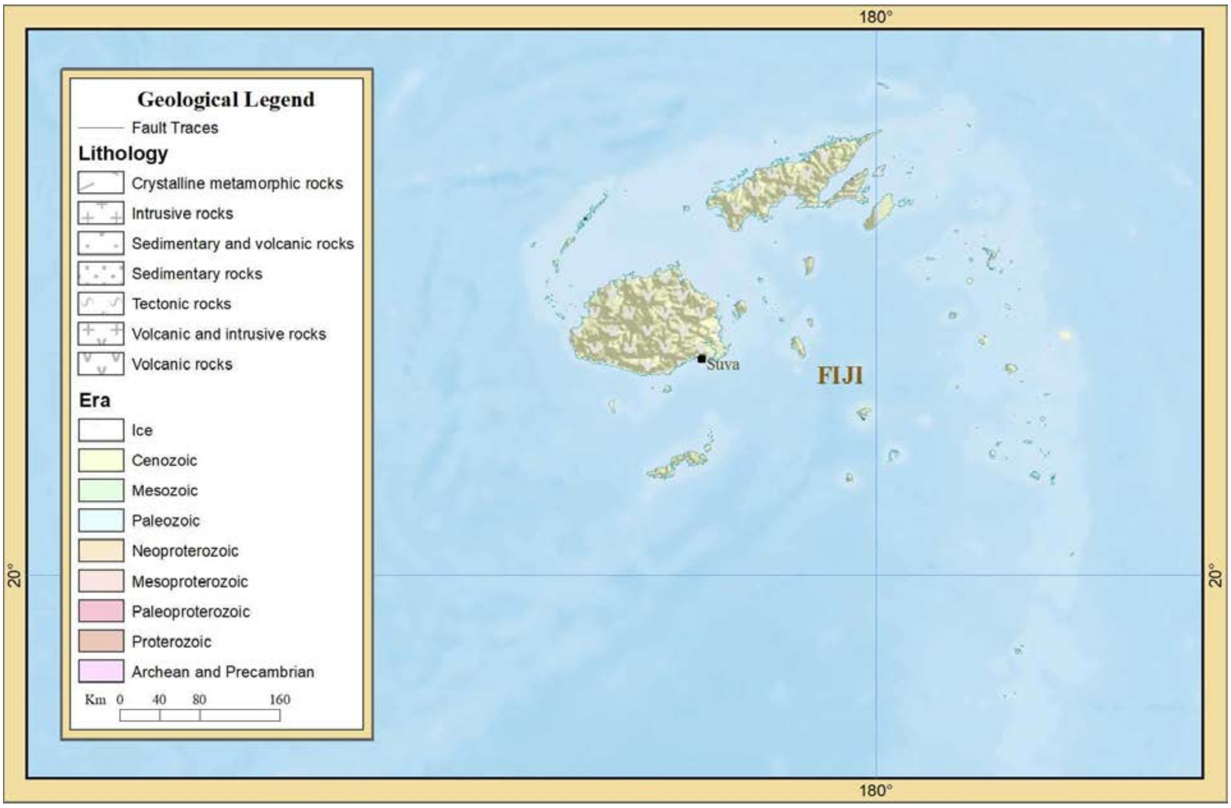


FIG. 6.16. Regional geological setting of Fiji. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

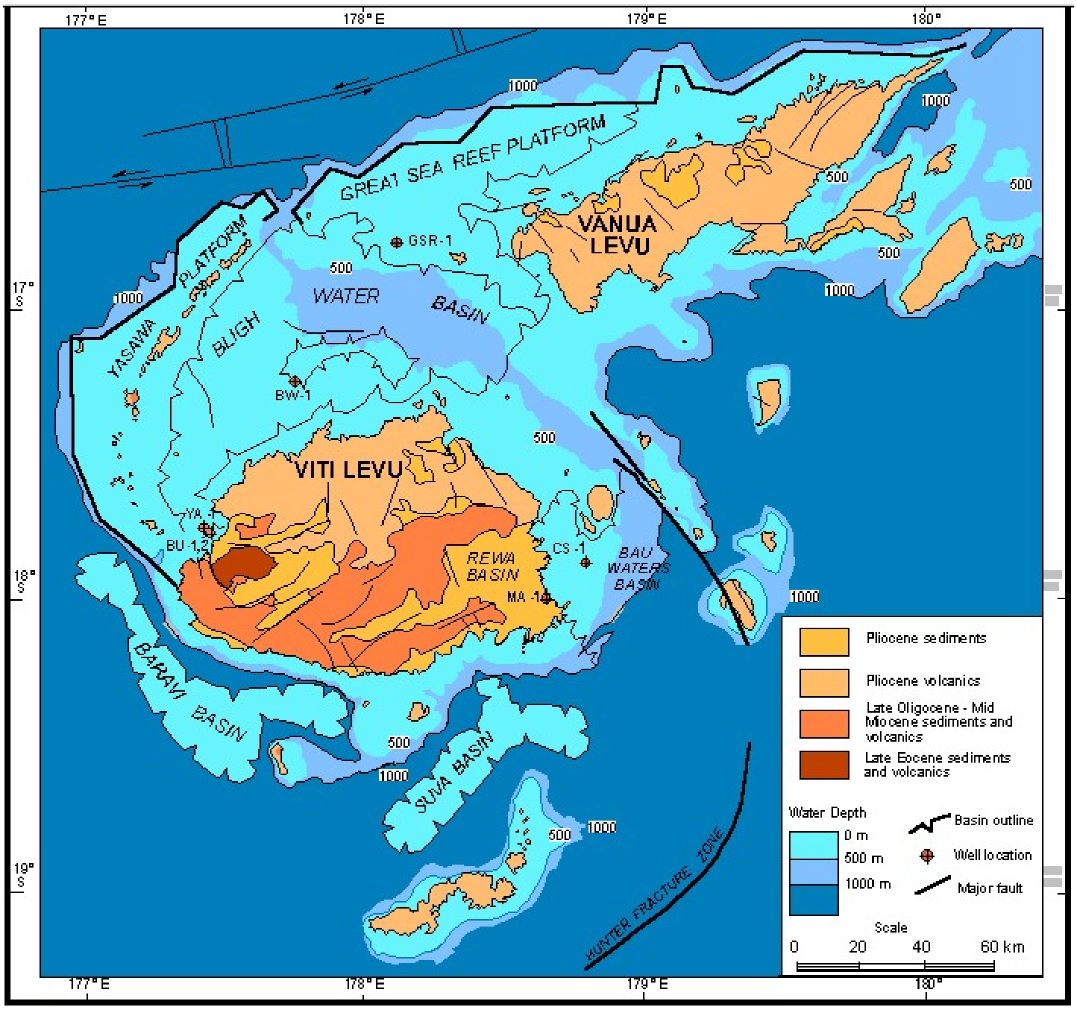


FIG. 6.17. Geology of Fiji [5.5].

These stages reflect the growth of Fiji as an island arc, its maturity and final arc break-up, with the early periods (up to 7 Ma) dominated by subduction related geology; the geochemical signature changing to a later regime more related to extension.

In the Fiji archipelago, early Tertiary rocks are found only on Viti Levu and on Mamanuca, Narokorokoyawa and Yasawa islands, where there is a succession of volcanic rocks and their sedimentary derivatives together with minor intercalations of carbonate rock. The succession ranges in age from Late Eocene to Oligocene. This stage is characterized by a geochemically primitive low potassic tholeiitic series of volcanics trending towards slightly more evolved types, including low to medium potassic calc-alkaline types within the Wainimala Group rocks exposed on the Mamanuca and Yasawa islands.

The mature stage of arc development is dominated by plutonic rocks, the Colo Plutonic Suite comprising primarily low potassic tholeiitic gabbros, tonalites and trondhjemites. The latter part of the Late Miocene was a period of intense orogenic activity for Fiji, during which the folding and faulting of the Wainimala and Tuva Group rocks occurred.

Fiji's volcanic activities have continued into recent times. Four volcanoes have recorded recent activity. The larger islands, i.e., Viti Levu and Vanua Levu, are formed of volcanic rocks, mainly of basaltic composition, while the smaller islands are primarily formed of corals.

From a metallogenic point of view, Fiji does not have potentially favourable areas for the development of uranium deposits [5.2–5.4].

6.5.3. Uranium resources

The country does not report any uranium resources. There are no favourable areas for the development of uranium deposits and therefore no potential for any discoveries [5.5].

The UDEPO database does not list any known deposits for Fiji.

6.5.4. Comments

Available information indicates that no exploration for uranium has been carried out in the past, nor is it planned in the future. Fiji has no nuclear power plants and none are planned.

References to Section 6.5

[5.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Fiji, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2009).

[5.2] GO VISIT FIJI, Geography and Geology of Fiji, http://www.govisitfiji.com/fiji (accessed 2009).

[5.3] MINISTRY OF LANDS AND MINERAL RESOURCES, Mining and Geology in Fiji, Fiji Mineral Resources Department, http://www.mrd.gov.fj/gfiji/

[5.4] FRENZEL, G., OTTEMANN, J., Eine Sulfidparagenese mit kuperhaltigen Zonarpyrit, Miner. Deposita **1** 4 (1967).

[5.5] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Fiji Islands, IAEA, Vienna (1977) 9 pp

6.6. INDONESIA

6.6.1. Geography

Indonesia consists of 17 508 islands, about 6000 of which are inhabited. These are scattered to the north and south of the Equator over about 4200 km. The five largest islands are Java, Sumatra, Kalimantan (the Indonesian part of Borneo), Irian Jaya (the Indonesian part of New Guinea) and Sulawesi. At 4884 m, Puncak Jaya on Irian Jaya is Indonesia's highest peak, and Lake Toba in Sumatra its largest lake, with an area of 1145 km^2. The country's largest rivers are in Kalimantan and include the Mahakam and Barito; such rivers provide communication and transport links between the island's river settlements.

Indonesia's location on the edges of the Pacific, Eurasian and Australian tectonic plates makes it the site of numerous volcanoes and of frequent seismicity. Indonesia has at least 150 active volcanoes, including Krakatoa and Tambora, both famous for their devastating eruptions in the 19th century. Recent disasters due to seismic activity include the 2004 tsunami, generated by an earthquake off the coast of north-western Sumatra, and the Yogyakarta earthquake of 2006.

Straddling the Equator, Indonesia has a tropical climate with two distinct monsoonal wet and dry seasons. Average annual rainfall in the lowlands varies in the range 1 780–3 175 mm, with up to 6100 mm falling in mountainous regions. Mountainous areas — particularly those on the west coast of Sumatra and in western Java, Kalimantan, Sulawesi and Irian Jaya — receive the highest rainfall. Humidity is generally high, averaging about 80%. Temperatures vary little throughout the year; the average daily temperature range of Jakarta being 26–30°C.

The services sector is the economy's largest, followed by industry and agriculture. However, agriculture employs more people than other sectors, accounting for 44.3% of the 95 million strong workforce Major industries include petroleum and natural gas, textiles and mining. Major agricultural products include palm oil, rice, tea, coffee, spices and rubber. The country has extensive mineral resources, including tin, bauxite, coal, copper, gold, nickel and silver, as well as petroleum and natural gas. Indonesia is the world's largest tin producer. Although mineral production traditionally centred on bauxite, silver and tin, Indonesia is expanding its copper, nickel, gold and coal output for export markets [6.1].

6.6.2. Geology

The geology of the extensive and varied landmasses of Indonesia is extremely complex (Fig. 6.18). The continental setting has developed under mobile belts and island arcs. The various orogenic belts of Indonesia are as follows:

(a) Malaya Orogen (the southern part of the Malaysian Tin Belt):

Although Permo-Triassic folding and granitic intrusion occurred, the major phase of plutonism and folding dates to the Late Triassic–Jurassic, during which time the tin deposits were formed. Sediments of Triassic age that are intruded by the granites are commonly carbonaceous shale; this is thought to be a favourable host for uranium mineralization.

(b) West Kalimantan Orogen:

The relationships of this orogenic belt to the Malaya Orogen are not clear. The date of granite emplacement is Jurassic and the intruded sediments are Triassic, which are locally carbonaceous and weakly radioactive. Mineralization is much more varied than in the rocks of the main Malaya Orogen, with widespread antimony, gold, iron, lead, molybdenum and zinc mineralization, all of which are, in some environments, commonly associated with uranium mineralization.

(c) Sumatra Orogen:

The oldest dated rocks are Permo-Carboniferous, but crystalline schists may be older. These and Triassic marine slate and sandstone were folded and intruded by granite no later than the Upper Jurassic. Lower Cretaceous limestone, with andesitic pyroclastics and lava, and shale, were folded and intruded by granite prior to the deposition of Eocene strata. Oligocene–Miocene volcanics were strongly folded and accompanied by a third intrusion of granites. Deformation continued into the Pleistocene, with moderate folding and thrusting. An area in south-east Kalimantan with ultrabasic rocks and chromium and iron mineralization is tentatively included within this orogenic belt, which is most characteristically developed in the highland 'backbone' of Sumatra.

(d) Sunda Orogen:

The Sunda Orogen extends down through Sumatra and Java and the eastern islands and then up through Sulawesi. The geology of the Sunda Orogen are characterized by Miocene rocks, predominantly volcanic in character, but with some Middle Miocene plutonics. Mineralization appears to be weaker in the middle part of the arc, in the Java region, and this is believed to be connected to the lack of plutonic igneous activity in this part of the orogen. However, granodiorites do crop out near the Tjikotok gold mine.

(e) The Embalock Complex:

The Embalock Complex of northern central Borneo consists of strongly folded Permo-Carboniferous to Eocene marine strata which displays light metamorphism. The Permo-Carboniferous and Triassic successions are geosynclinal and contain basic lava flows and pyroclastics.

(f) Molluccan Orogen:

The west coast islands of Sumatra are linked through Timor to the eastern portion of Sulawesi. This belt is characterized by the development of strongly folded and overthrust Late Palaeozoic, Mesozoic and Palaeogene rocks with large scale development of ultrabasic intrusions. Folding persisted locally and intermittently until the Pliocene. The sediments of Nias are potentially petroleum-bearing.

(g) Halmahera–North Irian Barat Orogen:

This is a zone of pre-Tertiary sediments with some ultrabasic and acidic intrusives. The environment is not promising for the deposition of radioactive minerals [6.2].

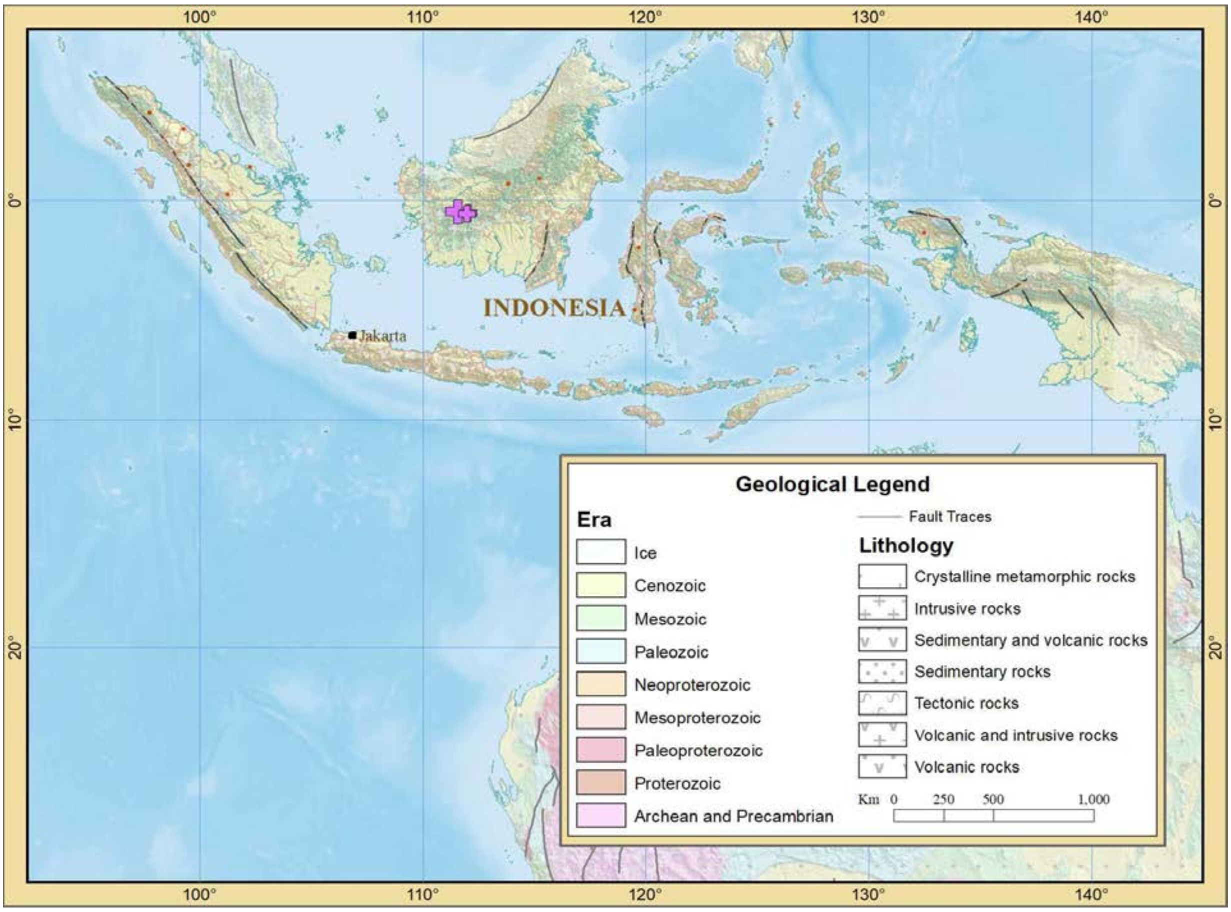


FIG. 6.18. Regional geological setting of Indonesia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.6.3. Uranium exploration

Uranium exploration conducted by the Nuclear Minerals Development Centre of the Indonesian National Atomic Energy Agency (BATAN) started in the 1960s. The first stage regional reconnaissance covered approximately 78% of the total area of 533 000 km^2 considered to be favourable for hosting uranium mineralization. Methods employed during the reconnaissance phase included integrated geochemical stream sediment, heavy mineral and radiometric surveys. Several geochemical and radiometric anomalies were found in granitic, metamorphic and sedimentary environments. Subsequently, uranium occurrences were identified in Sumatra, the Bangka Tin Belt and Sulawesi. A more detailed evaluation of these occurrences has not been made.

Efforts during the first 10 years were rather modest. This changed when France’s Commissariat à l’Energie Atomique (CEA), and later the Compagnie Générale des Matières Nucléaires (COGEMA), initiated exploration programmes in the early 1970s in Kalimantan (Borneo). Between 1976 and 1978 the Geological Survey of the then Federal Republic of West Germany carried out a regional reconnaissance survey in western Sumatra. Additional areas surveyed were northern Sumatra (Sibolga), southern Sumatra, Sulawesi (Hasamba) and eastern Indonesia (Ramsiki).

In 1987, exploration activities were conducted in the area of Sibolga (northern Sumatra), where radioactive anomalies occur in Palaeogene sediments derived from pre-Tertiary granitic terrains.

All exploration activities conducted since 1988 have been concentrated in the Kalan area of western Kalimantan, where uranium deposits have been delineated. Geologically, they are associated with volcanics, granites and metasediments. The best known are the deposits in metasediments located at Kalan, where mineralization occurs over a length of 11 km. Uranium occurs as uraninite and brannerite and is commonly associated with pyrite, arsenopyrite, magnetite, apatite and monazite in steeply dipping fractures. Average grades are reported to be in the range 0.15–0.20% U.

During 1991–1992, exploration continued in this area and was directed both at the districts surrounding Kalan and at the uranium occurrence at Kalan itself. At Kalan, exploration was concentrated in the Remaja, Rabau and Darab areas. The work included underground drilling at the Remaja exploration adit. Surface drilling was completed at Darab and at Raban. The results of the exploration were evaluated and incorporated in a pre-feasibility study for a possible uranium mining operation at Kalan. Geological and radiometric mapping were completed over 752 km^2 in the Kelawai, Kembayan and Kahayon areas. A reconnaissance survey covering about 1300 km^2 was conducted on Irian Jaya. This work consisted of heavy mineral stream sediments geochemical and radiometric surveys.

During 1993–1994, exploration, including drilling, was concentrated at several sectors of Kalan referred to as Jeronang, Kelawai Inau and Bubu. In addition, work was carried out in the Seruyan and Mentawa areas and in the districts surrounding Kalan, where similar geological conditions have been found. The follow-up work, which has been carried out in the favourable areas since 1993, included systematic geological and radiometric mapping, radon surveys, deep trenching and drilling of several hundred metres. These programmes covered relatively small areas in Tanah Merah–Dendang Arai (0.06 km^2), the Mentawa sector (0.3 km^2), and the Upper Rirang valley (0.008 km^2).

Surface mapping discovered several uranium occurrences in veinlets. The thickness of the mineralized veins ranges from some millimetres (Dendang Arai) to 1–15 cm (Tanah Merah) and 1–100 cm (Jumbang I). The veins are filled with uraninite associated with haematite, ilmenite, magnetite, molybdenite, pyrite and pyrrhotite. Several drill holes at Tanah Merah intersected 5 m of mineralization at depths of about 33, 40 and 50 m. In the Mentawa sector, the mineralization intercepted was identified as occurring as horizontal to vertical multiple lenticular zones. The radiometric surface expressions registered 300–1 500 cps on an SPP2 scintillometer.

Ten shallow non-core holes and deep trenches were excavated in the Upper Rirang valley, where boulders with high grade monazite-bearing mineralization had been discovered. The boulder type mineralization was proven to be derived from in situ sources dispersed within the 30 m wide valley.

In 1993–1994, BATAN also carried out a reconnaissance over 3000 km^2 in Irian Jaya. Exploration, including drilling, was concentrated in several sectors referred to as Jeronang, Kelawai Inau and Bubu, and aimed at increasing resources. In addition, work was undertaken in the Seruyan and Mentawa areas and in the area surrounding Kalan, where similar geological conditions prevail. In 1995 and 1996, reconnaissance mapping was completed over areas of 3 000 km^2 and 3 050 km^2, respectively. Owing to economic circumstances, the exploration budget was reduced in 1997, which resulted in no significant additional field work being undertaken.

Verification of the mineral resources outlined in the Kalan area was the only activity performed during 1997 and 1998. This study included, essentially, the re-logging of mineralized drill holes and the subsequent correlation of the radiometric values with chemical results. Only minor discrepancies affecting the specific gravity of minerals and some logging data were found but these did not warrant a revision of the previous resource estimates.

During 1998–1999, exploration activities resumed in the Tanah Merah and Mentawa sectors of the Kalan area and in the surrounding areas. These activities consisted of systematic geological and radiometric mapping and conduct of radon surveys in order to delineate mineralized zones.

Between 2000 and 2002, exploration drilling was carried out at upper Rirang (178 m), Rabau (115 m) and Tanah Merah (181 m). In 2003–2004, BATAN carried out exploration drilling in Jumbang 1 (186 m) and Jumbang 2 (227 m) sectors. In 2005, exploration activities were planned in Jumbang 3 (expected 300 m) and Mentawa (expected 300 m) sectors.

No exploration activities have been reported since this time. Figure 6.19 summarizes historical exploration data totallingUSD $18 974 140, including 67 648 metres of drilling (as well as radiometric and other surveys of 281 270 km^2 and 159 165 km^2 respectively).

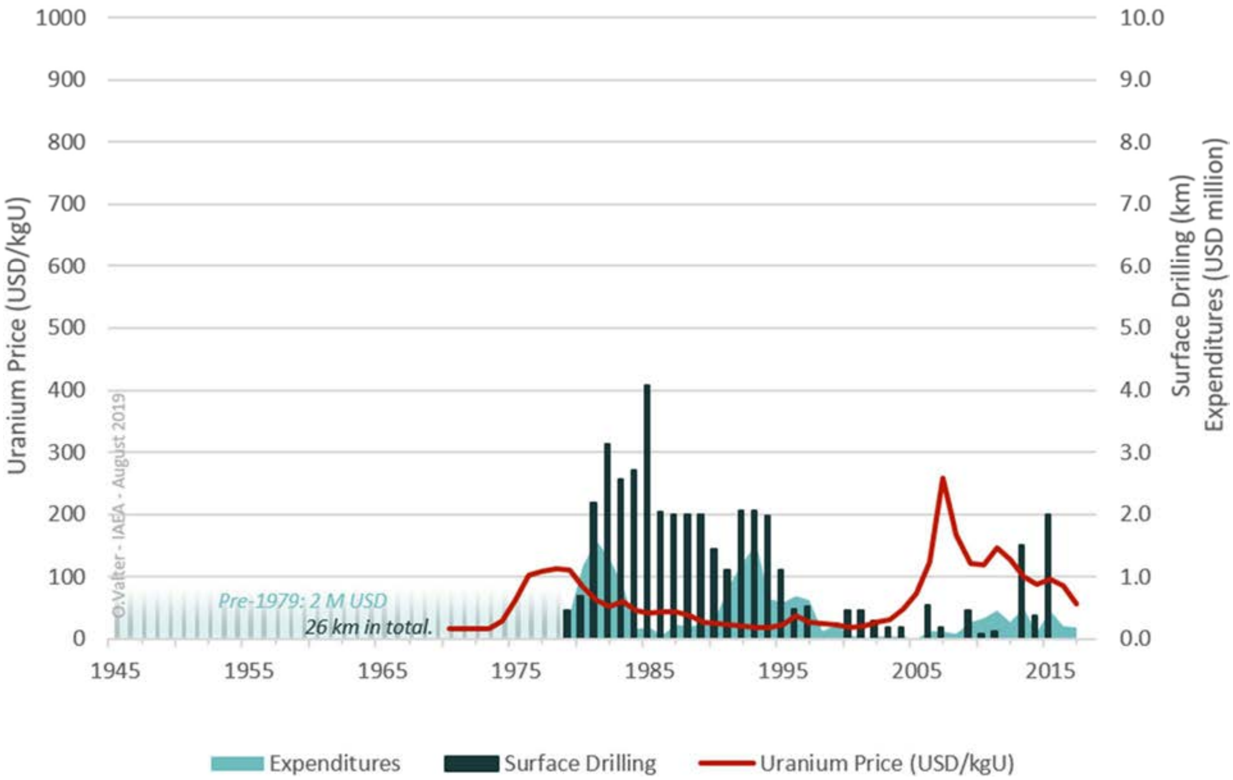


FIG. 6.19. Domestic uranium exploration data for Indonesia. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

6.6.4. Uranium resources

6.6.4.1. Identified resources

As of January 2017, reasonably assured resources totalled 7123 tU (as in situ resources, at costs <US$ 260/kgU). Of this total, 2029 tU are recoverable at costs below US $80/kgU.

Inferred resources total 2998 tU (as in situ resources, at costs <US$ 260/kgU.
These resources, associated with metamorphite-type deposits, occur in the Eko Remaja, Lembah Hitam, Lemajung and Rabau sectors of the Kalan area in western Kalimantan [6.2].

The UDEPO database lists the most significant deposits for Indonesia as Bangka Belitung, Remaja-Hitam, Lemajung, Semelangan, Rirang.

6.6.4.2. Undiscovered resources

Undiscovered resources, mainly those of the Kalan prospect, are allocated to the prognosticated resource category. The Mamuju sector has the same geological favourability as Kalan and could host additional potential. To evaluate this resource potential, a delineation drilling programme is needed. As of January 2017, prognosticated resources amount to 30 179 tU in the <US$ 260/kgU cost category.

Unconventional resources

Indonesia does not report unconventional resources.

6.6.5. Potential for new discoveries

In the Malaya Orogen, the Triassic sediments that have been intruded by Late Triassic and Jurassic granites are commonly carbonaceous shale. This region, mainly the islands of Bangka and Billiton, is thought to be favourable for the location of vein or disseminated deposits. The West Kalimantan Orogen contains Triassic sediments, locally carbonaceous, that have been intruded by Jurassic granites. Weak radioactivity has been detected and the area could be worthy of being prospected further. In the Sumatra Orogen, the oldest dated rocks are Permo-Carboniferous, but certain crystalline schists may be older. These rocks, and Triassic marine slate and sandstone, were folded and intruded by granites no younger than Upper Jurassic. Lower Cretaceous limestone, with andesitic pyroclastics and lava, and shale, were folded and intruded by granite prior to deposition of Eocene strata. Oligocene–Miocene volcanics were strongly folded and accompanied by a third episode of granite intrusion. The south-western side of Sumatra appears to be the more favourable and most of the known occurrences and anomalies have been found there. The south-western part of Java is believed to have a similar geological environment [6.3]. The potential for additional resources may be limited to these areas.

6.6.6. Uranium production

No uranium has been officially produced in Indonesia, either by the Government or by private companies. However, some uranium may have been recovered during mining tests. Indonesia has two established deposits, both in the west Kalimantan uranium district. The first, Remaja–Hitam, is a uranium vein type deposit hosted in fine-grained metamorphic rock and is thought to contain between 5000 and 10 000 tU with a grade range of 0.1–0.3% U. Also known as the Eko–Remaja prospect, this reserve is reportedly capable of providing Indonesia with a supply of yellowcake sufficient to meet the domestic needs of its planned reactors. The second deposit, Rirang–Tanah Merah, is also a vein type deposit hosted in fine-grained metamorphic rock, though it is thought to contain less than 500 tU and have a grade range of 0.3–1.0% U. While it is estimated that Indonesia could produce about 770 tU/year, the aforementioned deposits are currently believed to be dormant. Should it prove economically viable, or politically expedient, it is of the opinion of Indonesian specialists that Indonesia could probably mine sufficient uranium from its domestic reserves to provide yellowcake for its planned nuclear power reactors [6.4].

6.6.7. Comments

Indonesia has not reported any plans to produce uranium. No significant environmental issues relating to uranium exploration and resource development have been identified.

References to Section 6.6

[6.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Indonesia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2009).

[6.2] OECD NUCLEAR ENERGY AGENCY/INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand (2018).

[6.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 52

[6.4] TAYLOR, C., FELDMAN, Y., MAHAFFEY, C., MARVIN B., BOURESTON J., Indonesia, Countries of Strategic Nuclear Concern, Stockholm International Peace Research Institute (2004).

6.7. JAPAN[10]

6.7.1. Geography

Japan is located in the Pacific Ocean, close to the eastern coast of the Asian continent and separated by the Sea of Japan (Fig. 6.20). The country consists of more than 3 000 islands, the largest being Honshu (‘mainland’ Japan), Hokkaido, Kyushu and Shikoku. Japan is located in a volcanic zone (part of the so-called ‘Ring of Fire’) at the edge of the Pacific–Philippine–Eurasian Plate triple junction, and is subject to the unpredictable and complex interactions of three tectonic plates. Owing to its position along the Pacific Ocean shore, at the edge of the Pacific Plate, which is moving towards and below the Asian block, the country experiences volcanic activity and frequent seismicity. The plate movements are responsible for mountain building and this explains why about three-quarters of the country is mountainous and includes about 10% of the world’s 800 active volcanoes. The highest mountain, Mount Fuji (3776 m), has been dormant since 1707. Other signs of activity include geothermal springs, which are common. Coastal plains and intermontane basins cover about one-quarter of the country and these are major centres of population and intensive agriculture. Owing to the limited amount of arable flat land, rice paddies have historically been built on mountain terraces. Land reclamation from the sea and in river deltas has also been a major activity. Rivers are generally short and only a few are navigable. Thus, shipping along the coasts has been extensively used for the transportation of goods.

Owing to the extent of the islands in a N–S direction, the climate varies from cool to moderate temperatures in the north to subtropical conditions in the south. Distinct climatic differences are also observed as a result of elevation. Normally, four seasons are observed. In the north, snow is frequent in winter and the summers tend to be warm. The climate gradually becomes more humid and hot to the south, with correspondingly mild winters. Two major ocean currents, the warm Japan (Kuroshio) Current and the cold Okhotsk (Oyashio) Current, meet at 36° N, creating bountiful fishing grounds.

Fishing and the associated industry have been one of the traditional major sources of employment. Now, all types of modern industry, e.g., electronics and automotive engineering, have been developed. Agricultural products are still produced, but the country also imports many agricultural goods.
Japan has only very limited mineral and energy resources [7.1].

6.7.2. Geology

6.7.2.1. General

Japan’s geology is the result of tectonic plate movements that started during the Silurian and which have continued ever since. Originally, the area occupied by the present Japanese islands formed part of the eastern Eurasian Plate, a continental block stretching from Europe across the northern half of Asia. Japan was pulled eastwards by subduction of the Philippines and Pacific Plates under the more rigid Eurasian Plate (Fig. 6.21). Concurrently, it was separated from Asia by back-arc spreading. Japan’s eastwards movement was followed by the opening of the Sea of Japan during the Tertiary and, in turn, by the opening of the Strait of Korea.

---

[10] Note: This country report was drafted using information dated prior to the Fukushima nuclear accident of 11 March 2011.

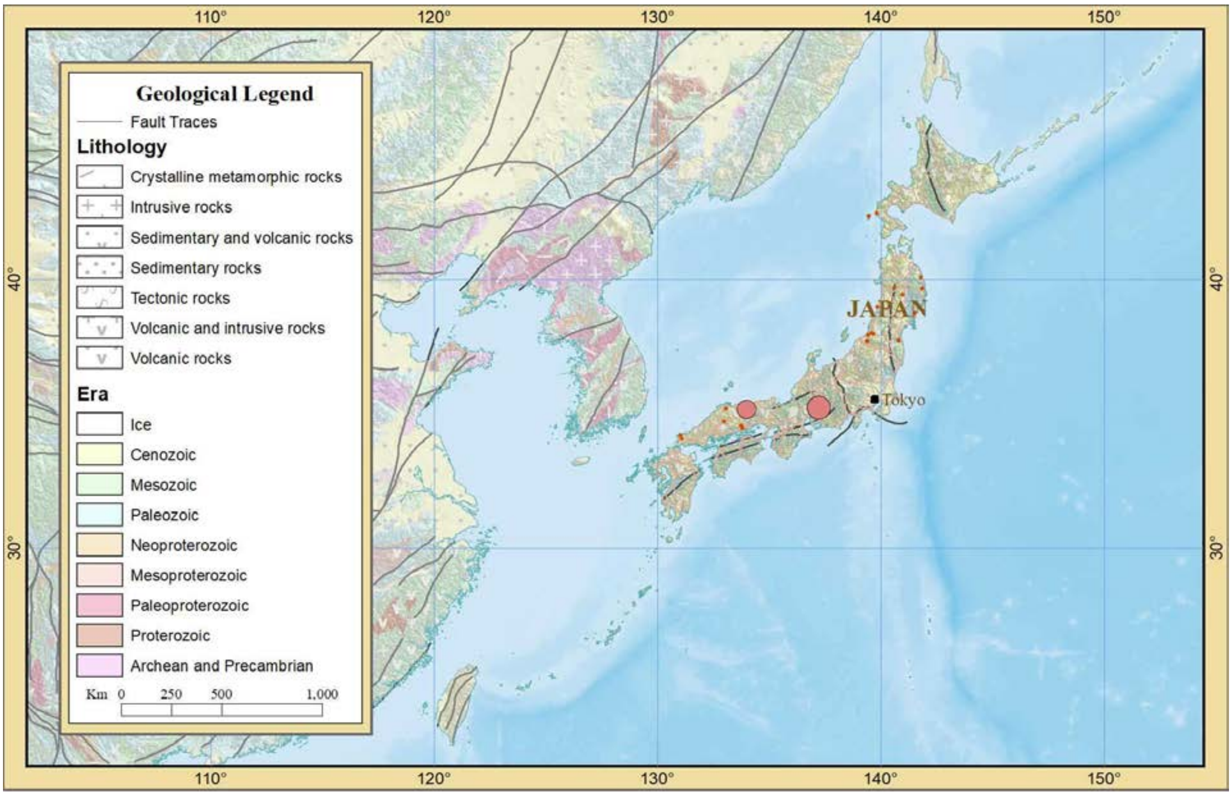


FIG. 6.20. Regional geological setting of Japan showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

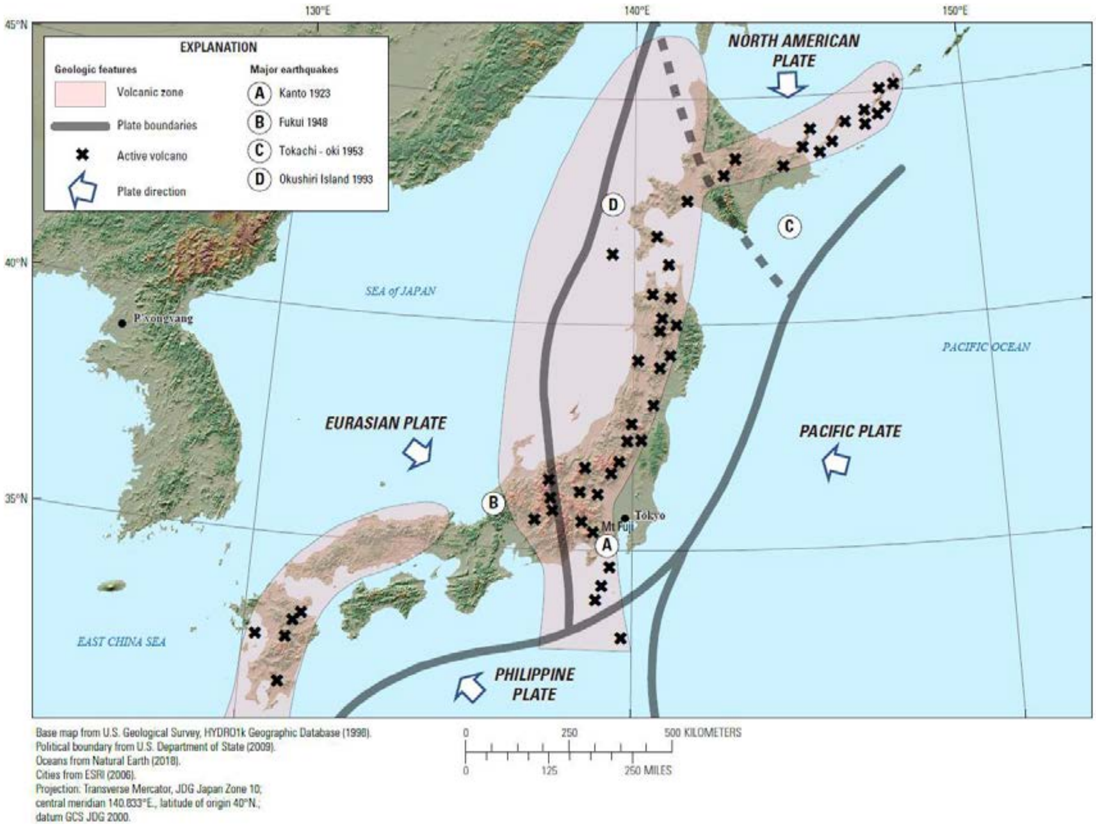


FIG. 6.21. Tectonic plate boundaries in and around Japan (courtesy of M. Mihalasky, United States Geological Survey).

The subduction tectonics includes both accretionary and large scale metamorphic events, as well as episodes of magmatism and volcanism. Thus, the geological units consist largely of accretionary wedges, metamorphic complexes and intrusions of magmatic rocks (plutonic and volcanic). Sedimentary rocks of various compositions were also deposited in various basins.

Metamorphic processes in Japanese rocks have been studied in great detail, resulting in the naming of various types of metamorphic grade, e.g., Abukuma. Owing to the complex history of tectonic processes and accretion of complexes, it is difficult to separate geological units on the basis of their age. In parts of the country, particularly in the north-east, the distribution, composition and structure of basement rocks are obscured by a thick sedimentary cover and volcanic products of Neogene age. In the south-west, the basement rocks suggest a more or less progressive pattern of development, with rock ages varying from older in the north-west to younger in the south-west. However, the complex geological history of the country is not fully understood and is the subject of much ongoing discussion [7.2, 7.3].

6.7.2.2. Geology related to uranium-bearing areas

When first initiated, uranium exploration focused on the identification of vein type deposits. Some uranium was found associated with copper, gold and tungsten mineralization, although this was not economically viable [7.4]. Investigations of pegmatitic, pneumatolytic and other hydrothermal deposits had similarly negative results. However, detailed exploration of non-marine Tertiary sediments led to the discovery of uranium at several locations. The greatest success involved uranium mineralization occurring in fluviatile conglomeratic sandstones deposited unconformably on granitic rocks. The most favourable granites are of Late Cretaceous–Early Tertiary age, while the sandstones hosting the uranium deposits are of Early–Late Miocene age [7.3].

6.7.3. Uranium exploration

The first discovery of a radioactive mineral (fergusonite, a ‘rare earth’ titanium oxide) in Japan was made in 1893. Other uranium mineralization, mostly of refractory mixed element oxides, was discovered in the 1920s. It is reported that in the areas of Ishikawa (northern Honshu), and in Naegi and Tanokami (central Honshu), columbite, monazite, xenotime and samarskite were produced.

In 1936, uraninite was first discovered and this was followed by the recognition of secondary uranium mineralization in many areas. During World War II, systematic nationwide exploration was carried out, mostly in areas hosting pegmatites. Following World War II, Japan was barred from participating in nuclear research for a period of six years [7.4]. Starting in 1955, exploration was resumed by the Geological Survey of Japan (GSJ), which focused mainly on vein-type deposits and on those areas where uranium was found in association with other metals. The first indications of the occurrence of sandstone-hosted mineralization were found in late 1955, as a result of car-borne surveys undertaken by the GSJ in the Ningyo-toge area. In subsequent years, the GSJ and the Atomic Fuel Corporation concentrated exploration on sandstone type deposits, similar to that at Ningyo-toge, and a number of deposits were found, culminating in the discovery of the Tono deposit in 1962 [7.4, 7.5].

Owing to the rugged topography, dense vegetation and thick soil cover, airborne radiometric surveys were found to be unsuitable for exploration in Japan. In contrast, car-borne surveys proved to be effective and well supported by Japan’s dense road network. More than 100 anomalies were detected by car-borne surveys, including Ningyo-toge and Tono.

In 1967, the Atomic Fuel Corporation was incorporated into the newly founded Power Reactor and Nuclear Fuel Development Corporation (PNC). Domestic uranium exploration continued until 1988, when it was terminated. PNC was reorganized into the Japan Nuclear Cycle Development Institute in October 1998. Based on a February 1998 decision taken by the Atomic Energy Commission, uranium exploration activities conducted abroad by PNC were terminated in 2000, and mining interests and technologies were transferred to the private sector. The exploration and mining interests were all in foreign locations.

Exploration data are summarized in Fig. 6.22 totalling 83 501 metres of drilling with an exploration expenditure of USD $ 417 533 000.

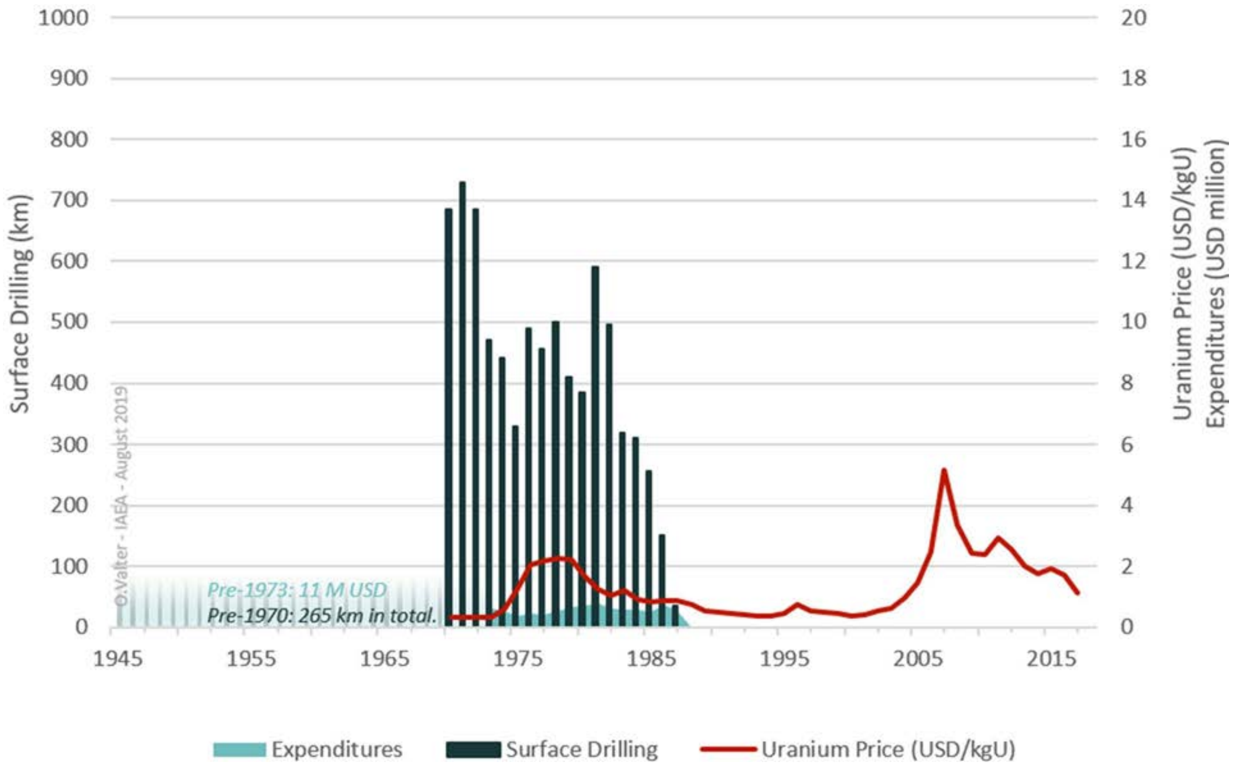


FIG. 6.22. Domestic uranium exploration data for Japan. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

In 2007 and 2008, non-domestic exploration expenditures amounted to Y 190 and Y 400 million (US $0.13 and 0.33 million), respectively. For 2009, about Y 400 million (US $0.33 million) are expected [7.6].

In 2009, in expectation of increased demand for uranium for nuclear power generation, Japan carried out exploration activities abroad, e.g., in Australia, Canada, China, Gabon, Niger, United States of America and Zimbabwe [7.6].

6.7.4. Uranium resources

Japan reports reasonably assured resources of 6600 tU recoverable at <US $130/kgU in sandstone type deposits that are mineable underground. The largest resource is located at Tono, which consists of four individual orebodies. The Tono deposit has about 4300 tU of low grade ore (0.03–0.05% U). The Ningyo-toge deposit consists of several palaeochannel type orebodies with resources totalling about 1800 tU and with grades similar to those at Tono.

The historical variation in identified resources is shown in Fig. 6.23. No resources are reported for either the inferred resource or undiscovered resource categories. No unconventional resources are reported.

UDEPO lists the Tono and Ningyo-toge deposits as dormant [7.7]. The Tono Geoscience Center was established at the Tono mine site and the former mine is being used to conduct research into deep underground environments. The goal of this research is to establish methodologies and techniques that aid the understanding of the characteristics of groundwater and rock at various depths.

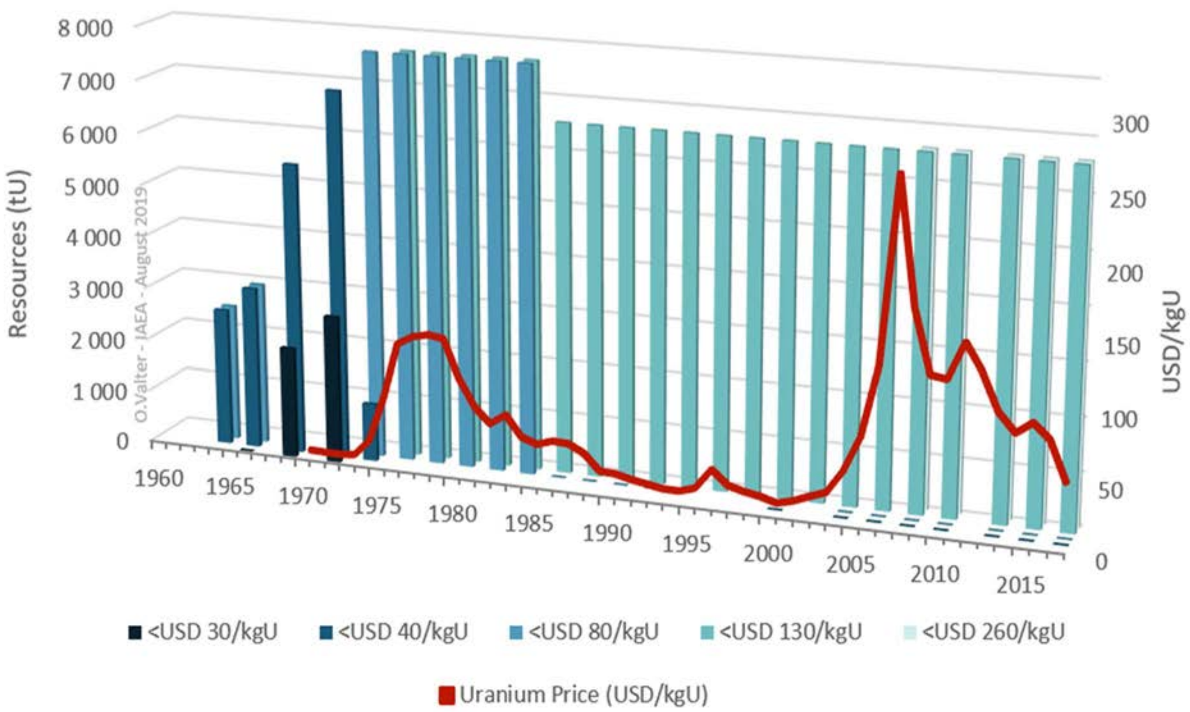


FIG. 6.23. Historical variation of recoverable reasonably assured resources within various cost categories in Japan. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

The UDEPO database lists the most significant deposits for Japan as Tono District (4 Deposits), Ningyo-Toge District (5 Deposits).

6.7.5. Potential for new discoveries

Past exploration in Japan has covered almost all accessible areas. From the beginning of systematic exploration in 1955 until its termination in 1988, an amount equivalent to almost US $20 million was spent domestically on exploration. All potential areas have been checked, therefore, the potential for new discoveries is very low.

6.7.6. Uranium production

Uranium was produced in a pilot plant at Ningyo-toge by PNC between 1969 and 1982 and between 1978 and 1987 (Fig. 6.24 for a total of 89 tU.) using a small-scale vat leach unit. Total production for both periods amounted to 84 tU. Annual production fluctuated between 1 and 10 tU [7.8]. No new production facilities are envisaged.

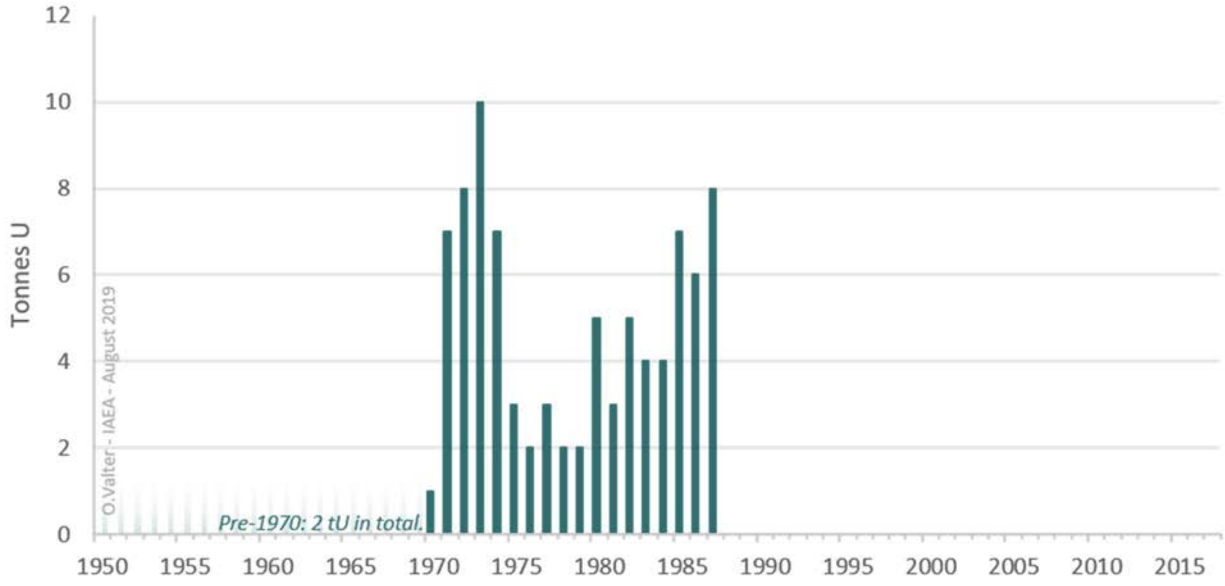


FIG. 6.24. Historical uranium production in Japan.

6.7.7. Environmental activities

No recent information on environmental activities was reported in the 2007 and 2009 editions of the Red Book. The Joint OECD/NEA–IAEA reports on environmental activities [7.9, 7.10] describe the relevant activities in a more general way. Regulations currently in force deal with mine safety regulation for all mining activities. In the Atomic Control Act, the regulations cover the decontamination of milling facilities and the proper disposal of all contaminated material. Ministerial ordinances have been enacted for safety measures [7.10].

The milling facility, operational between 1964 and 1981, was gradually dismantled between 1983 and 2001. The experimental heap leach facility for low grade ore, operational from 1979 to 1987, was reportedly under care and maintenance in 2002. A plan for the mill tailings dam, containing about 34 000 m^3 of mill tailings, precipitates and filter sands, was also under consideration in 2002. The waste rock dams, containing a total of about 432 000 m^3, are maintained and plans for their remediation were under consideration in 2002. All sites on which uranium activities have been carried out are environmentally monitored. There have been no reports of related activities since 2002.

Currently, no personnel are employed in uranium mining or milling [7.10].

6.7.8. National and local policies relating to uranium

Japanese Mining Laws and Regulations have no specific legislation for uranium exploration and exploitation. Private companies incorporated in Japan are allowed to explore and exploit uranium. However, no private companies have pursued domestic uranium exploitation.

References to Section 6.7

[7.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Japan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed July 2009).

[7.2] GEOLOGICAL SURVEY OF JAPAN, Geological map, http://www.gsj.jp/geomap/J-geology

[7.3] OKADA, S., HASHIMOTO, Y., ITOH, K., “Historical review of uranium exploration in Japan”, Uranium Deposits in Asia and the Pacific: Geology and Exploration (Proc. Tech. Mtg Jakarta, 1985), IAEA, Vienna (1988) 193–205.

[7.4] KATAYAMA, N., KUBO, K., HIRONO, S., “Genesis of uranium deposits of the Tono mine, Japan”, Formation of Uranium Ore Deposits (Proc. Int. Conf. Athens, 1974), IAEA, Vienna (1974) 437–452.

[7.5] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[7.6] OECD NUCLEAR ENERGY AGENCY/INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand (2010).
[7.7] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[7.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[7.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Activities in Uranium Mining and Milling, Joint NEA–IAEA Report, OECD, Paris (1999) 112–113.
[7.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Remediation of Uranium Production Facilities, Joint NEA–IAEA Report, OECD, Paris (2002) 233–235.

6.8. REPUBLIC OF KOREA

6.8.1. Geography

Located in eastern Asia, the Republic of Korea forms the southern half of the Korean Peninsula. It borders with the Democratic People's Republic of Korea (DPRK) and is surrounded by the Sea of Japan to the east and by the Yellow Sea to the west. More than 3000 islands belong to the country, of which the island of Cheju (Jeju) is the largest, located south of the mainland.

Around 70% of the land surface comprises mountains and uplands and 30% lowlands, of which about two-thirds is arable land.

The mountains are associated with three major ranges: (i) the Taebeck Sanmaek, entering from the DPRK and running N–S along the east coast, (ii) the Sobaek Sanmaek in the centre and south, and (iii) the Jiri Massif. The mountains on the mainland reach elevations just over 1900 m; the highest peak (1950 m) is located on Cheju.

Owing to the limited width and the mostly N–S trending mountain ranges, the longest river in the country (Nakdong River) is just 521 km long.

The Republic of Korea is separated from the DPRK by the 241 km long and 4 km wide Demilitarized Zone.

Owing to its geographical position as a peninsula extending towards Japan, the country has served, historically, over a long period of time as a bridge between the Chinese mainland and the islands of Japan.

Forests and woodlands cover around two-thirds of the mountainous areas.

The climate is temperate monsoonal, marked by four distinct seasons. The summer period is generally short and hot, with temperatures of about 25°C in Seoul; the winters are usually long and cold, with temperatures falling to about -5°C in Seoul. Most of the rain falls during the months of June–September. Generally, the amount of rain is sufficient for agriculture, although droughts occur once every eight years on average. Rice is the main agricultural product [8.1].

6.8.2. Geology

6.8.2.1. General

The oldest rocks are Archaean granites and metamorphics (gneiss, mica schist), which occur in the central mountain ranges and cover roughly 40% of the land surface (Fig. 6.25). To the west of the crystalline ranges, sediments of Palaeozoic–Triassic age were deposited in a depression covering about one-quarter of the country. These sediments contain volcanic intercalations of various ages. Orogenic events are probably of Jurassic age. The south-eastern part of the peninsula is covered by Cretaceous and Tertiary sediments cut by intrusions of Tertiary granites.

The Republic of Korea has deposits of base metals, coal, graphite and tungsten, although none are of major importance [8.2].

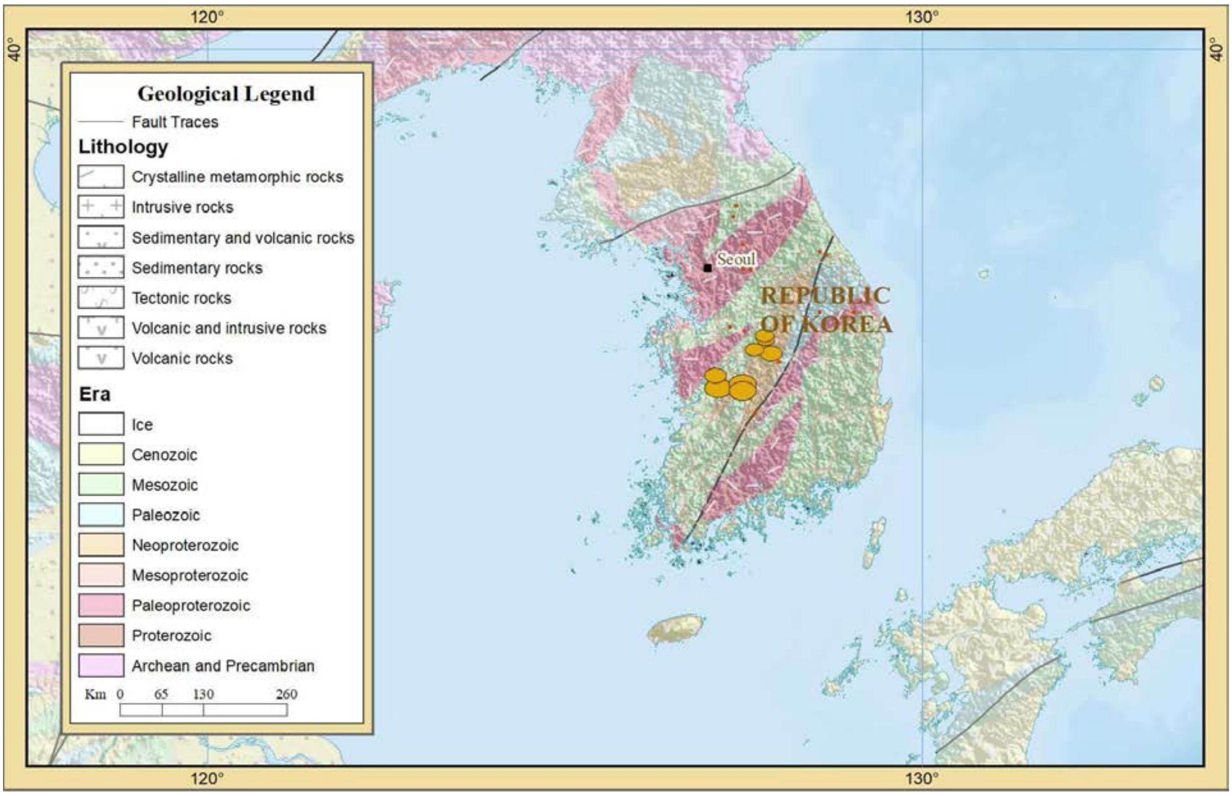


FIG. 6.25. Regional geological setting of Republic of Korea showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.8.2.2. Geology of potentially favourable uranium-bearing areas

Indications of uranium mineralization considered to be similar to the Proterozoic unconformity type have been discovered in the northern area, north-east of Seoul. The rocks exposed comprise successions of gneisses and quartzite units starting probably in the Archaean and being overlain by metasediments of probably geosynclinal origin. It is uncertain as to whether an unconformity exists separating the quartzite units. The quartzite contains uraniferous horizons, interpreted as probably being of placer origin. Boron metasomatism has been observed, which may indicate a similarity to some of the uranium deposits in the Athabasca area of Canada. At other locations, uranium has been found at the quartzite–gneiss contact.

Another type of uranium mineralization is associated with columbo-tantalite minerals and rare earth minerals in pegmatites in the central part of the country.

Small uranium occurrences occur as vein deposits, but these are of low potential. Of even less importance is the sandstone type mineralization found in Cretaceous sediments.

During the Early Palaeozoic, marine black shales were deposited in the Ogcheon System. The black shales were metamorphosed to metapelite with graphite, and contain copper, molybdenum, nickel, uranium, vanadium and zinc. The uranium grade ranges between 200 and 400 ppm [8.3].

6.8.3. Uranium exploration

Exploration started in 1955 and has been carried out intermittently since by the Geological Survey of Korea, renamed the Korea Institute of Energy and Resources. Exploration surveys mainly comprised surface radiometry, which led to discoveries of the occurrences and anomalies already described. Details are reported in Ref. [8.3].

Exploration expenditures have not been continuously reported owing to intermittent periods of activity and to a lack of information. In several instances, the expenditures recorded in the Red Book refer to foreign exploration expenditures, whereas for the country report itself, no expenditures have been provided [8.3, 8.4]. Figure 6.26 provides historical details of exploration campaigns.

6.8.3.1. Exploration expenditures

Pre-1983 expenditures were reported as US $2 565 000 and pre-2000 expenditures as US $17 886 000, which probably represent the total for 76 000 metres of drilling. No data are recorded after 1991.

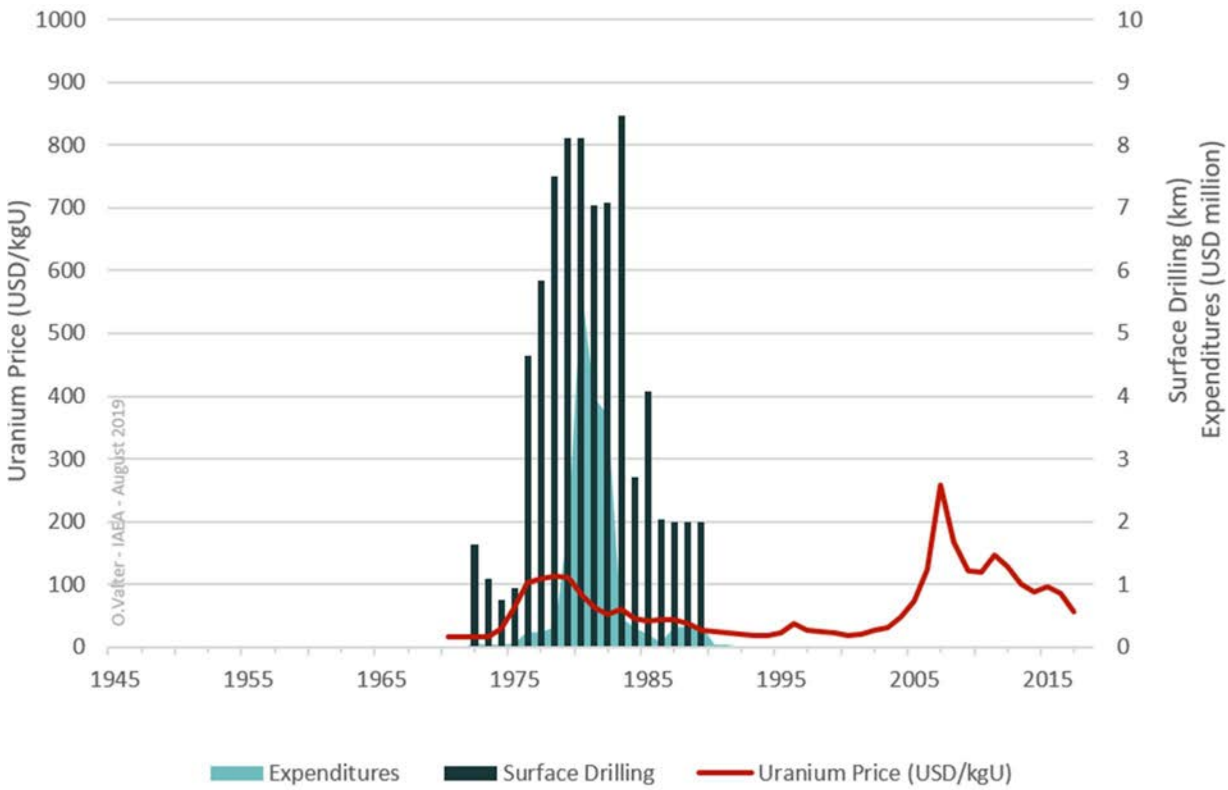


FIG. 6.26. Domestic uranium exploration data for the Republic of Korea. Comparison of exploration expenditures, drilling and uranium market price (US$ current) [8.5–8.12].

6.8.3.2. Recent developments

According to media reports in 2007, the Canadian based company, Oriental Minerals Inc., applied for mineral rights to conduct uranium exploration in the Ogcheon area. Between 2008 and 2013, Stonehenge Metals Ltd carried out exploration work on the black shales of the Ogcheon Belt (Daejon, Miwon and Gwesan Projects) [8.7].

6.8.4. Uranium resources

According to the 2018 edition of the Red Book, the Republic of Korea has no identified or undiscovered uranium resources. However, in older reports, the Republic of Korea reported for the Ogcheon black shale both reasonably assured resources recoverable at <US \$130/kgU of 11 800 tU and estimated additional resources, now inferred resources, of 3000 tU. In 2013, Stonehenge Metals Ltd published inferred resources of 27 640 t U at a grade of 280 ppm for 7 deposits located in black shales.

The UDEPO database lists the most significant deposits for the Republic of Korea as Chubu, Yokwang, Gumsan, Kolnami, Seongdang, Miwon-Isikri-Jukemuri, Gottbong (Area C), Yopyung (Area C).

6.8.5. Potential for new discoveries

Some potential exists for Proterozoic unconformity type deposits, in addition to the existing mineralization already found. The rather low level of expenditure on exploration may reflect the low level of potential. However, recent news by private companies may indicate renewed interest in some of the earlier prospects, or the adoption of a new approach with up-to-date exploration methods that were not available in previous campaigns [8.3].

6.8.6. National policies relating to uranium

The Government and utilities have a policy of securing a stable and economic supply of uranium. A one year ‘pipeline’ inventory is held by Korea Hydro and Nuclear Power Co. Ltd [8.4].

6.8.7. Comments

The Republic of Korea has not produced any uranium. No secondary sources of supply are reported. For stockpiles, it is understood that utilities hold 2000 tU of natural and 6000 tU of enriched material [8.13].

References to Section 6.8

[8.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Republic of Korea, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).

[8.2] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Republic of Korea, IAEA, Vienna (1977) 9 pp.

[8.3] KIM, J.H., “Uranium geology of the Republic of Korea”, Uranium Deposits in Asia and the Pacific: Geology and Exploration (Proc. Tech. Mtg Jakarta, 1985), IAEA, Vienna (1988) 141–154.

[8.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[8.5] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[8.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[8.7] STONEHENGE METALS LTD, ASX/Media release, Perth (Feb. 2011)

[8.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[8.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[8.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[8.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[8.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[8.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

6.9. LAO PEOPLE'S DEMOCRATIC REPUBLIC

6.9.1. Geography

Lao is a landlocked country of Southeast Asia, surrounded by Thailand to the west (The Mekong river forms a significant part of its border with Thailand), Cambodia to the south, Vietnam to the east, China and Burma to the north. The topography of the country is mainly mountainous, with the Luang Prabang Range in the northwest and the Annamite Range in the east and northeast. The country's southern part comprises vast plains in the provinces of Champasak and Savannakhét that are well suited for livestock raising ab=nd rice cultivation. Most of the province of Khammouan is mountainous. Lao has a tropical climate, with a dry season during December–April and a monsoon season during May–November. Temperatures range from 25° C in January to a maximum of 35°C in April.

Lao has shown a strong economic growth averaging more than 6% annualy in the 1988-2008 period, and being amongst the fastest in Asia, averaging more than 7% annualy for most of the last to years. However, the country's infrastructure remains underdeveloped infrastructure, especially in rural areas. Agriculture, dominated by rice cultivation in lowland areas, contributes to ~20% of GDP and 73% of total employment. Recently the economy has benefited from foreign investment in hydropower dams along the Mekong River, copper, bauxite, tin and gold mining [9.1].

6.9.2. Geology

The northern part of Lao consists of complex sandstone and limestone plateaus deeply cut by rivers. Center and southern Lao are part of the hill country west of the Annamese Cordillera [9.2, 9.3] (Fig. 6.27).

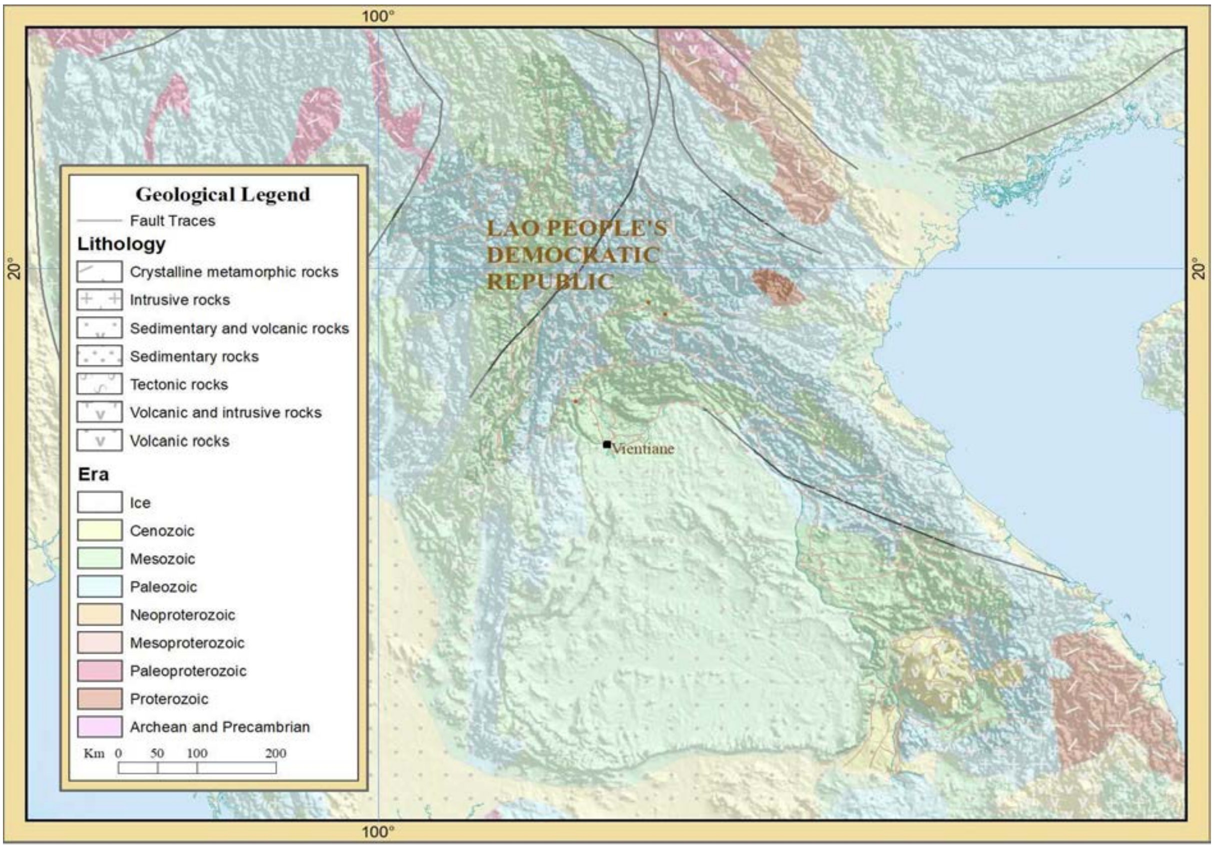


FIG. 6.27. Regional geological setting of Lao People's Democratic Republic. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The 'Chaine Annamitique' represents the last of the three orogenic pulses of the Indochina Peninsula. It extends approximately 1,100 km through Vietnam, Lao and in northeast Cambodia. Intrusive and pyroclastic extrusive formations cut and cover marine Mesozoic sediments (limestones, sandstones, siltstones). Both granite and metamorphic rocks of varying grade are present.

The southern part of Lao is predominantly of Triassic Jurassic-Cretaceous ages. In some areas the under lying carboniferous-Triassic volcanic rocks are exposed and in others quaternary basalts appear to have formed lava flows over the Triassic Jurassic-Cretaceous formations.

Further north and in the northern part of Lao, Paleozoic and Mesozoic sediments (continental and paralic sandstones and conglomerates ranging in age from Late Triassic to Cretaceous) and metamorphic rocks appear to have been intruded by or overly a paleozoic granite or granodiorite.

Some localized Precambrian schists may have been mineralized by the Paleozoic granite intrusives.

6.9.3. Uranium exploration

There has been no reported uranium exploration in Lao.

6.9.4. Uranium resources

There are no known uranium occurrences in Lao and no resources of uranium have ever been reported. The UDEPO database does not list any known deposits for Lao.

6.9.5. Potential for new discoveries

Geologically, it appears that uranium deposits might be found, principally in the Pre-Cambrian metamorphic formations but probably in quite limited quantities.

In Thailand, uranium has been observed associated to tin. This could be another potential to be investigated in Lao.

The 1977 IUREP study estimated the uranium potential of Lao to less than 1000 tonnes U.

6.9.6. Comments

There has been no past uranium production in Lao.

References to Section 6.9

[9.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Lao, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2012).

[9.2] HANSEN M.V., BOWMAN J. I U R E P NATIONAL FAVOURABILITY STUDIES N.F.S. No. 100. Democratic Kampuchea (Cambodia) (1977).

[9.3] Atlas of Mineral Resources of the ESCAP region Vol.7: Lao People's Democratic Republic. United Nations Economic and social commission for Asia and the Pacific (1990).

6.10. MALAYSIA

6.10.1. Geography

Malaysia lies in south-east Asia and is separated by the South China Sea into two similarly sized regions (Fig. 6-10.1): Peninsular Malaysia and Malaysian Borneo (i.e., northern portion of the island of Borneo).

Land borders are shared with Brunei, Indonesia and Thailand. Peninsular Malaysia, containing 40% of Malaysia's land area, extends 740 km N–S and its maximum width is 322 km. It is divided between its east and west coasts by the Titiwangsa Mountains, part of a series of mountain ranges running down the centre of the peninsula. These mountains are heavily forested. Much of the land has been eroded, creating a karst landscape. The range is the origin of some of Peninsular Malaysia's river systems. The coastal plains surrounding the peninsula reach a maximum width of 50 km.

East Malaysia, on the island of Borneo, is divided between coastal regions, hills and valleys, and a mountainous interior. The Crocker Range extends northwards from Sarawak, dividing the State of Sabah. It is the location of Mount Kinabalu (4095 m), the highest point in Malaysia. In the vicinity of these two large land areas are numerous islands, the largest of which is Banggi. The local climate is equatorial and is characterized by monsoons. The temperature is moderated by the presence of the surrounding oceans. The average annual rainfall is 2500 mm.

Malaysia is an exporter of natural resources, the most valuable exported commodity being petroleum. At one time, the country was the world's largest producer of tin, rubber and palm oil. Manufacturing has a large influence on the country's economy, although Malaysia's economic structure has been moving away from it. To diversify the economy and make it less dependent on exported goods, the Government has adopted strategies designed to increase tourism [10.1].

6.10.2. Geology

On the basis of tectono-stratigraphic terrains, Malaysia forms part of the Sibumasu block and East Malaya block. Peninsular Malaysia can be divided into three belts: west Malaysia, central Malaysia and east Malaysia. Each of these belts is characterized by its own stratigraphy, igneous suite and geological history.

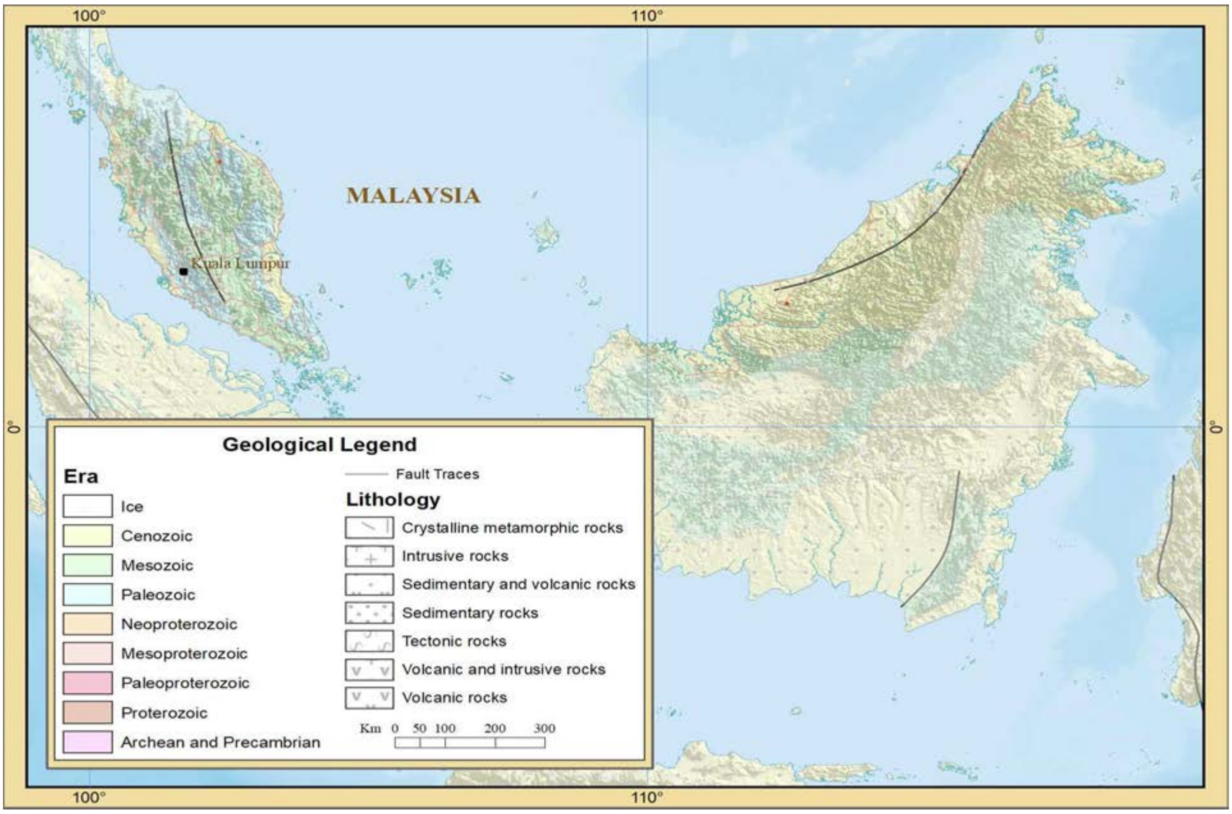


FIG. 6.28. Regional geological setting of Malaysia. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this map.

In West Malaysia, the oldest rocks exposed are Cambrian in age, consisting of about 3 000 m of predominantly sandstone–shale deposited in a shallow water and deltaic environment. These rocks are well exposed in north-west Peninsular Malaysia and are conformably overlain by a thick sequence of shallow water limestone of Ordovician–Silurian age. Both sequences are in turn, overlain by rocks of Upper Devonian–Lower Carboniferous age, which are dominated by mudstone, sandstone and thin beds of pebbly mudstone. Limestone and siliciclastics of Triassic age are best developed in north-west Peninsular Malaysia and were intruded by granite of Upper Triassic–Jurassic age.

In central Malaysia, the oldest exposed rocks are Silurian and Devonian strata of the Bentong Group. These rocks are exposed in a narrow zone, consisting of schists, amphibolites, conglomerates and other siliciclastic deposits, including some serpentinite bodies. During the Triassic period, the deposits were dominated by marine sediments and these are overlain in some areas by Jurassic–Cretaceous continental deposits. Marine Permian and Triassic rocks were deposited over the Bentong Group and cover the greater part of central Malaysia.

East Malaysia is dominated by Carboniferous and Permian clastics, carbonates and volcanics. Triassic sediments and Upper Jurassic continental rocks lie unconformably on the Carboniferous–Permian sequence.

The main intrusive body in west Malaysia is the Main Range Granite (S-type), which extends 3000 km from the southern tip of Peninsular Malaysia to northern Thailand. In central Malaysia, granitic intrusives extend from southern Thailand southwards to Johore. In east Malaysia, granites are abundant and occur as elongated N–S trending bodies.

Malaysia's mineral resources include bauxite, coal, gold, iron and tin. Malaysia was formerly the world's largest tin producer up until the 1980s, but is now only a minor tin producing nation. Tin production in 2007 totalled 2263 t [10.2].

6.10.3. Uranium exploration

6.10.3.1. Peninsular Malaysia

The first occurrences of uranium mineralization, as torbernite, were recorded in 1928 at Gunong Bakau, Pahang, and in 1931 at Sangka Dua and Sungei Chiling, Selangor. In late 1950, Anglo-Oriental Malaysia Ltd conducted uranium exploration in Ulu Selangor and Pahang. However, the results were discouraging.

In 1956, an airborne magnetometer and scintillation counter survey carried out under the Canadian Colombo Plan was undertaken over the eastern, western and southern areas, covering an area of 41 000 km².

In 1975, Agip Nuclear Australia Pty Ltd and the Geological Survey of Malaysia jointly carried out a reconnaissance uranium study of the Mesozoic Tembeling sediments in the central area, which essentially comprise sandstone and shale with interbedded tuff.

In 1977, the Geological Survey of Malaysia, with technical aid from the Canada's International Development Agency, started a systematic geochemical survey for uranium and base and precious metals in the Central Belt project in north and central Malaysia.

In 1980, an airborne magnetometer and spectrometer survey of the Central Belt area was undertaken by the Geological Survey of Malaysia under contract with Companie Générale de Géophysique.

Follow-up work on a geochemical stream sediment anomaly occurring in the Boundary Range Granite resulted in the discovery of an outcrop and some boulders registering anomalous radioactivity. Radon gas emanometry and soil sampling techniques were employed. Geochemical exploration of the Benom Igneous Complex in Pahang revealed the presence of several radiometric anomalies. No uraniferous zones were identified, although the occurrence of uranothorite and thorianite in the heavy mineral stream concentrates was noted. Geochemical anomalies have been recorded over the Senting Granite (Kelantan). Traces of uranothorite were found in the heavy mineral fraction of the stream sediments.

In 1981–1982, the Geological Survey of Malaysia undertook two follow-up uranium surveys in areas delineated by stream sediment geochemistry and by a helicopter-borne spectrometer survey. Rock, soil, water and concentrate geochemistry, radon gas emanometry and gamma ray spectrometry were used as exploration tools. A multiphase follow-up survey, involving detailed stream sediment sampling, soil sampling, radiometric mapping and radon gas emanometry was undertaken in 1983 by the Geological Survey of Malaysia over the Sok prospect, in Kelantan. Besides base and precious metal mineralization, uranium mineralization was also discovered within this prospect. The uranium mineralization is granite hosted and exists in the form of uraninite, as well as in the uranium-bearing phosphates, rhabdophane and florencite.

In 1986, uranium exploration was carried out in the Central Belt as part of a regional mineral exploration project supported by the IAEA. The area covered by airborne and geochemical surveys comprised about 40 000 km^2.

In 1987 and 1988, the regional mineral exploration project covered an area of about 1000 km^2 (1987) and 250 km^2 (1988) in the Central Belt of Peninsular Malaysia using geochemical methods (stream sediment samples, stream water samples, rock samples and heavy mineral concentrates). In addition, detailed follow-up work in an area of around 2 km^2 of the Sok area continued in 1987 under the guidance of an IAEA expert. About half of this area was covered by soil geochemistry in 1988.

In 1991–1992, the uranium exploration programme included an area in excess of 8600 km^2, covering the six States of Pahang, Perak, Selangor, Negeri Sembilan, Johorc and Kelantan. Five 'fertile' plutons were identified through geological mapping of granites, granite sampling, stream sediment geochemistry and ground scintillometry.

In 1993–1994, uranium exploration continued in Peninsular Malaysia. The programme covered an area of over 8700 km^2 and included the States of Pahang, Perak, Selangor, Negeri Sembilan, Terengganu and Kelantan. Six additional anomalous plutons were recognized. The reassessment of the reprocessed geophysical maps led to the identification of 36 radiometric anomalies, of which 32 occur in a granitic environment, three in sediments and one in volcanics. To select an appropriate exploration methodology, one anomaly was covered by an orientation survey including geochemical, radiometric and geophysical (very low frequency) methods.

In 1995–1996, car-borne radiometric surveys were carried out in parts of Pahang and Kelantan, utilizing the GR650 spectrometer system provided by the IAEA. A total of 1000 km of traverse lines was covered which resulted in the collection of about 11 500 gamma ray measurements. Fourteen areas, totalling about 100 km of traverse lines, were found to have uranium potential.

Car-borne radiometric surveys were conducted in the States of Selangor, Pahang and Negri Sembilan in 1997 and 1998, although no uranium mineralization was discovered.In 1999 and 2000, uranium exploration was conducted as part of a multielement regional geochemical survey which was implemented under the 7th Malaysia Development Programme (RMK7). The areas covered include south Pahang, north Johor and Negeri Sembilan/Melaka.

Figure 6.29 summarizes historical exploration data, totalling USD $10.487 million including 1 249 metres of drilling and 31 000 km^2 of airborne radiometric surveying (and 4924 km^2 of other airborne surveying).

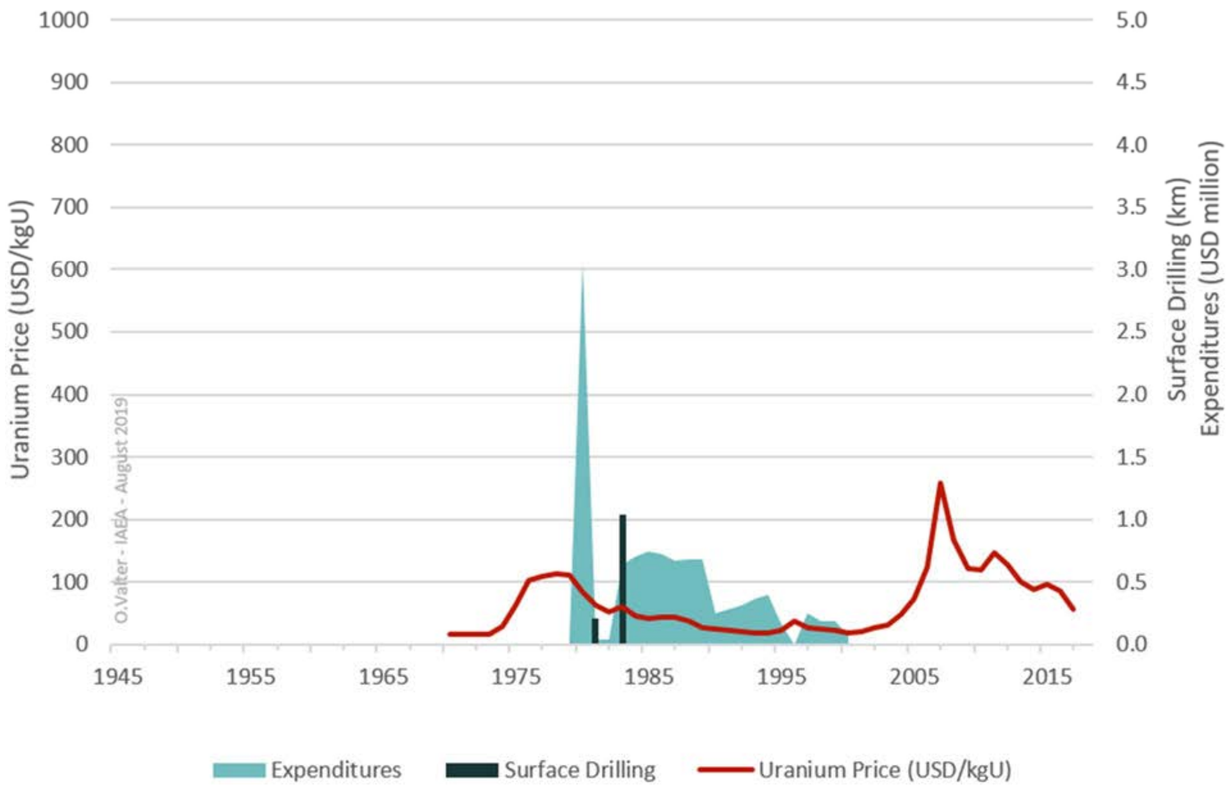


FIG. 6.29. Domestic uranium exploration data for Malaysia. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

6.10.3.2. East Malaysia (north-west Borneo (Sarawak))

The first uranium exploration work was undertaken by the Power Reactor and Nuclear Fuel Development Corporation of Japan (PNC) in April 1972. The Japanese team carried out preliminary hydrogeochemical survey work by collecting samples along part of the Kuching–Simanggang trunk road. The survey was subsequently continued by the Geological Survey of Malaysia and the trunk road between Balai Ringin and Simanggang was comprehensively sampled. Additional hydrogeochemical work was also carried out in the Kumpang area.

Geologists from Agip Nuclear made a reconnaissance survey for uranium in the western area in October 1975. Some basic geological studies were carried out and measurements taken with scintillometers along the main road.

In 1975–1981, the Geological Survey of Malaysia implemented a radioactive minerals reconnaissance survey covering an area of about 8000 km^2 in western Sarawak. An integrated approach was adopted with the collection of stream water samples, stream sediments and heavy mineral concentrates. Scintillometer readings were also taken along traverses.

No uranium exploration has been conducted in eastern Malaysia since 1984, as this area has been judged to have a low potential for hosting uranium deposits.

6.10.4 Uranium resources

No uranium resources have been discovered in Malaysia.

The UDEPO database does not list any known deposits for Malaysia.

6.10.4.1. Unconventional uranium sources

Heavy minerals associated with the tin mining industry, such as monazite, xenotime and zircon, contain small amounts of uranium which may be recovered.

6.10.5. Potential for new discoveries

No uranium resources have been reported in Malaysia. Uranium occurrences include:

- Torbernite in fissure fillings in granitic rocks in tin mineralized areas. The torbernite post-dates the tin. Localities include Kuala Kubu, Selangor and Fraser's Hill areas;
- Uranothorite in stream concentrates. Geochemical and spectrometric anomalies were delineated in the Benum and Senting granitic bodies (Central Belt Granite);
- Traces of uranium with opaline silica occur in granite from Templer Park, Selangor;
- Traces of uraninite in granite occur at the Hong Fatt mine near Kuala Lumpur, Selangor;
- A 2 m wide radioactive quartz vein occurs in granite in the Sok area. It contains uranium-bearing rhabdophane and florencite. In the same area, a radioactive shear zone, also in granite, was found mineralized with uraninite, molybdenite, pyrite, galena, allanite, magnetite and chalcopyrite;
- Geochemical and geophysical anomalies were delineated in the Boundary Range Granite (Eastern Granitoid).

Apart from these, the extensive continental Mesozoic sandstones, comprising fluvio–deltaic–estuarine sediments and the Tertiary lacustrine deposits, may have potential for hosting sandstone type uranium mineralization.

6.10.6. Comments

Malaysia has no uranium production industry. Malaysia has no plans to develop nuclear generating capacity and, consequently, has no reactor related uranium requirements. Malaysia has reported no information on national policies relating to uranium, uranium stocks or uranium prices.

References to Section 6.10

[10.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Malaysia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2012).

[10.2] ROSLAN, K., University of Kebangsaan, Malaysia, personal communication (2008).

[10.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources Production and Demand, OECD, Paris (2002).

[10.4] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

6.11. MARSHALL ISLANDS

6.11.1. Geography

The Marshall Islands is an independent state in free association with the United States. The Marshall Islands is located roughly halfway between Australia, Hawaii, south of the U.S. territory of Wake Island, east of the Federated States of Micronesia, and north of Nauru and Kiribati.

The islands and atolls form two groups: the Ralik and the Ratak. The two chains of islands are disposed roughly parallel to each another, extending southeast to northwest (Fig. 6.30), with cumulative area of roughly 180 km^2 of land mass. The country is comprised of a total of 5 isolated islands and 29 atolls.

Twenty-four of the islands and atolls are inhabited. Many atolls are unpopulated because of poor living conditions, lack of water, or nuclear contamination (US nuclear tests in the 50s and 60s).

The climate of the Marshall Islands consists of a wet season in May–November and a dry season in December–April. Many typhoons in the Pacific begin as tropical storms in the region of Marshall Islands, and intensify as they move westerly toward the Mariana Islands and the Philippines.

The islands have few natural resources. Agricultural products include melons, tomatoes, coconuts, chickens and pigs. Industry is comprised of tourism, tuna processing, production of craft items and copra. In the international shipping industry, the Marshall Islands plays an important role as a flag of convenience for commercial vessels [11.1].

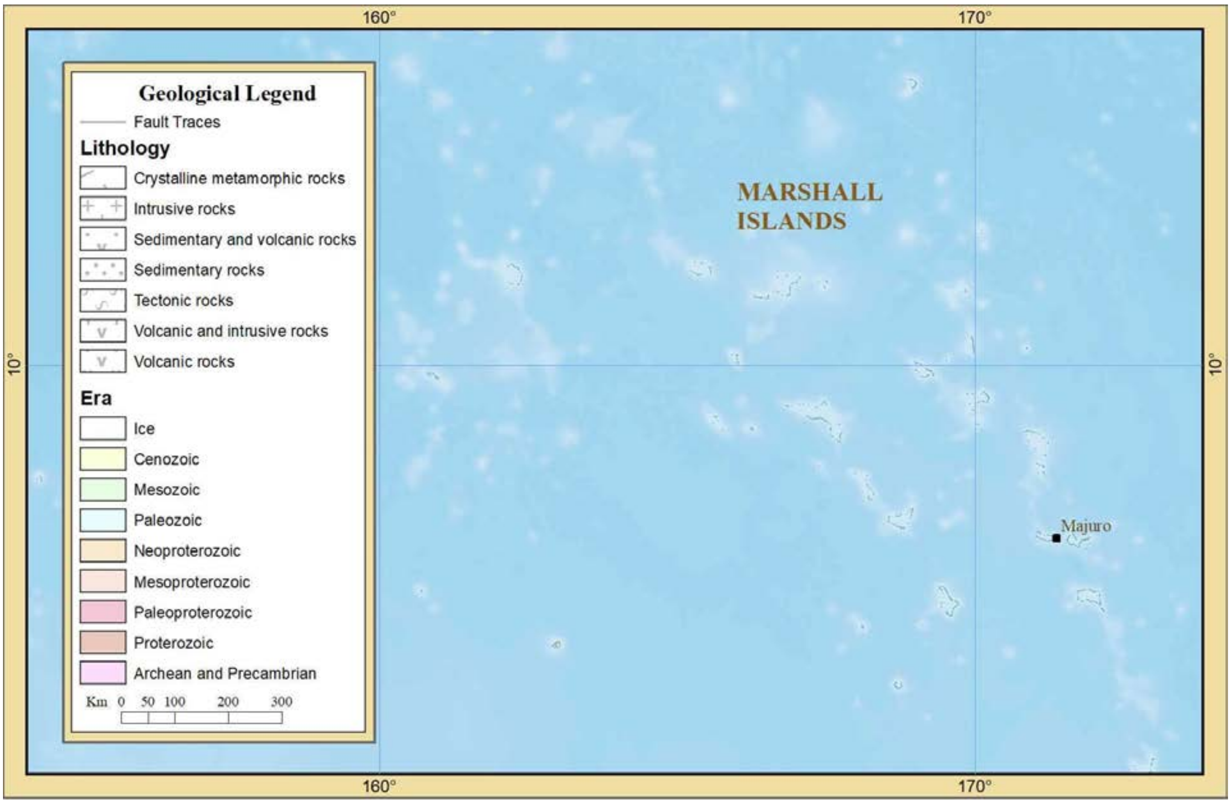


FIG. 6.30. Regional geological setting of Marshall Islands. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.11.2. Geology

The Marshall Islands consist of two "chains" of islands. These linear chains run ESE-WNW and are related to the spreading of the Pacific at the East Pacific Rise. The islands consist of volcanic rocks, mainly of basaltic composition or, where erosion has been active for longer periods, coral atolls. The basaltic formations at the base of the atoll are dated about 65 to 70 million years ago, during the Mesozoic times. They eroded and were subducted during early Eocene times, resulting in the formation of the atolls. Over the time, with the rise and fall of the ocean level, limestone and gravel deposits were formed. These go from Eocene to Oligocene, to Miocene, and to Pliocene and Pleistocene [11.2, 11.3].

6.11.3. Uranium exploration

There has been no reported uranium exploration in the Marshall Islands.

6.11.4. Uranium resources

There are no known uranium occurrences on the Marshall Islands and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for the Marshall Islands.

6.11.5. Potential for new discoveries

From a geological point of view, the Marshall Islands do not have potentially favourable areas for the development of uranium deposits. Owing to the country's size and rock types present, the potential for new discoveries is rated as nil.

6.11.6. Comments

There has been no past production in the Marshall Islands. The Marshall Islands have no nuclear power generation.

References to Section 6.11

[11.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Marshall Islands, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2018).

[11.2] JOINT STEERING GROUP ON URANIUM RESOURCES of the OECD NUCLEAR ENERGY AGENCY and the INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, World Uranium Geology and Resources Potential, (1980).

[11.3] US GEOLOGICAL SURVEY. Geology of Bikini and nearby atolls, Marshall Islands. US Geological Survey. Paper 260A. 1954.

6.12. MONGOLIA

6.12.1. Geography

Mongolia is located in northern Asia and is surrounded by China and the Russian Federation. It is mostly covered by vast semi-desert and desert plains, grassy steppe and mountains to the west and south-west. The Gobi Desert covers the south and central part of the country. The climate is continental, featuring large daily and seasonal temperature variations. Central Mongolia is a high, dissected plateau with numerous peaks in excess of 3 000 m. Dense birch and larch forests cover the high slopes above the grassed covered valleys of the Central Asian steppe. Major fish-bearing rivers flow north, into Siberia's Lake Baikal, and ultimately to the Arctic Ocean.

The lowest point is Hoh Nuur at 560 m and the highest Nayramadlin Orgil (Huyten Orgil) at 4 374 m. Natural resources include coal, copper, fluorspar, gold, iron, molybdenum, nickel, petroleum, phosphates, silver, tin, tungsten and zinc [12.1].

6.12.2. Geology

6.12.2.1. General

Located in the heart of the Central Asian Mobile Belt, in the interior portion of the Eurasian Plate, Mongolia has grown through the accretion of younger terrains and micro-plates to the ancient core in Siberia. The geology is dominated by the Altaid Orogen, an orogenic collage of subduction and accretion extending from the Ural Mountains to the Korean Peninsula. The Altaid Orogen formed between the North China Craton and the Siberian Craton.

Rocks span all ages, from Precambrian to Recent, from ancient metamorphic basement, through to carbonate platform and Mesozoic red beds, to Cenozoic basalt flows (Fig. 6.31). Mineral deposits are found throughout the region and include the Erdenet copper mine, placer gold mines, and rich phosphorite and coal deposits.

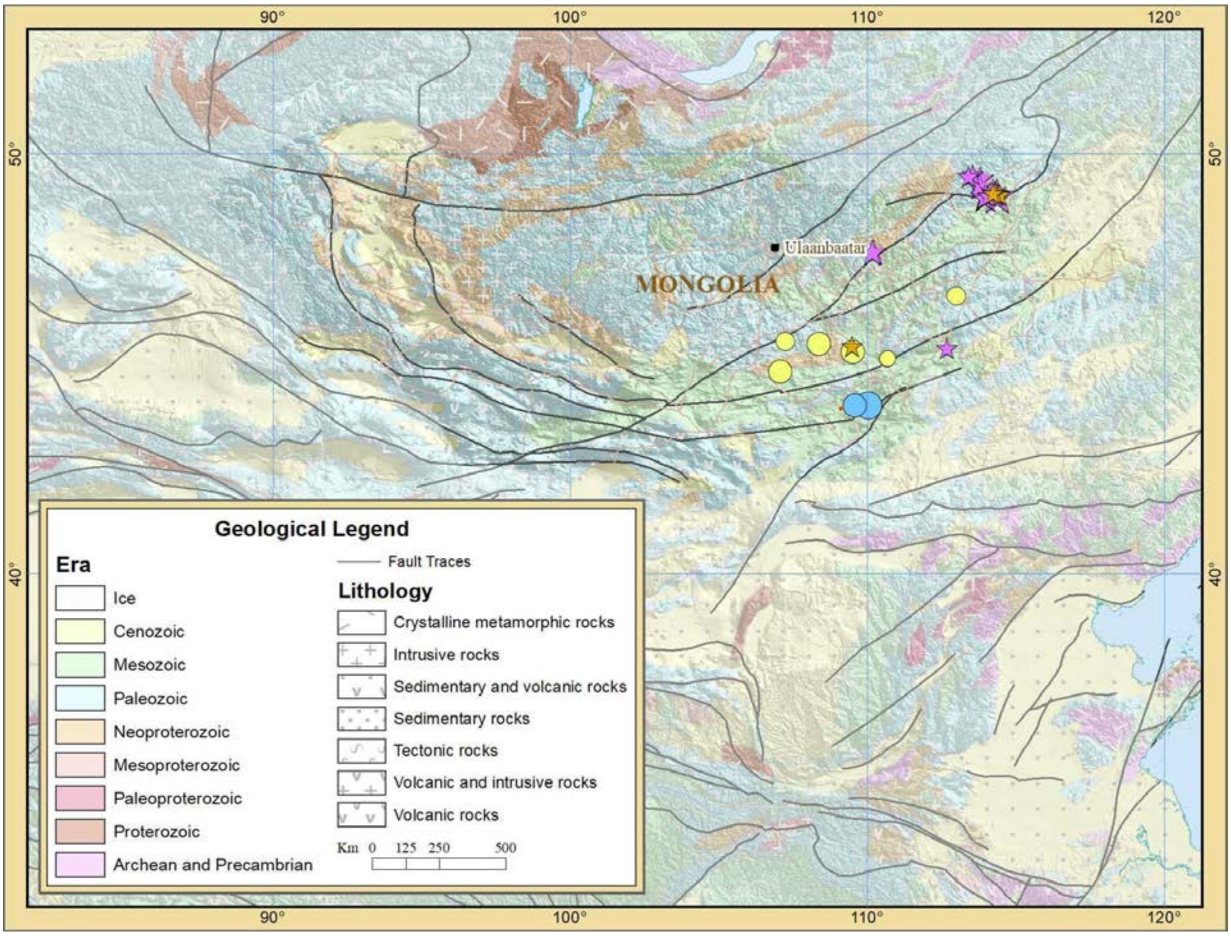


FIG. 6.31. Regional geological setting of Mongolia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Various sedimentary and volcanic terrains have been intruded by mafic and felsic plutons, ranging in age from Cambrian to Mesozoic. Palaeozoic rocks are divided into Neoproterozoic–Cambrian–Early Ordovician (Caledonian), Ordovician–Early Carboniferous (Hercynian) and Carboniferous–Permian (Indosinian). Other Palaeozoic strata are considered superimposed Palaeozoic troughs. Granitoids, also of Palaeozoic age, and related volcanic rocks are products of continental margin magmatism. Some of them are related to porphyry copper deposits.

Mesozoic volcanic rocks occur in eastern Mongolia and are related to relaxation and rifting of the continent. Mesozoic granitoids are mostly anorogenic and alkaline in nature. Rare earth element deposits are associated with some of these.

Cretaceous and younger basins unconformably overlie the Altaid rocks. Dinosaur fossils have been found in the Jurassic and Cretaceous non-marine sediments and coal deposits are mined in some of these rocks. Cenozoic non-marine sediments include placer deposits distributed in fluvial sediments. Cenozoic basalts occur locally along deep crustal fractures. Seismic activity occurs along such fractures [12.2–12.4].

6.12.2.2. *Potential uranium-bearing areas*

Uranium mineralization in Mongolia occurs as six main types according to IAEA classification: volcanic, sandstone, lignite, vein, metasomatite and phosphorite types. The two economically important deposit types are volcanic and sandstone.

Four deposits, Dornod, Gurvanbulag, Mardaingol and Nemer, all in the Dornod district in the North Choisbalsan region of north-eastern Mongolia are of tabular or vein stockwork volcanic type. Sandstone-type deposits include Haraat (Kharaat) in the Choir Basin and Nars in the Sainshand Basins, both of Cretaceous age and both in south-eastern Mongolia.

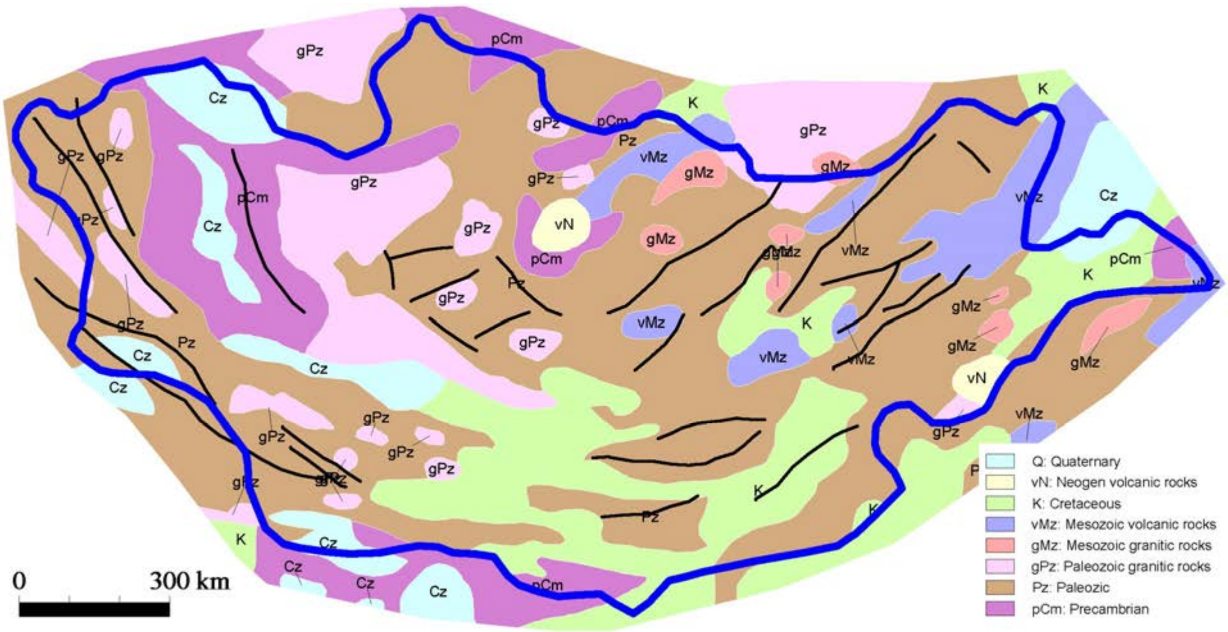


FIG. 6.32. Geology of Mongolia [12.2].

<u>Volcanic type</u>

The Dornod deposits are situated in the Dornod volcano-tectonic structure which is filled with Mesozoic volcanic flows and sediments. The uranium mineralization extends over an area of 20 km² and is concentrated in thirteen ore zones. Individual zones may contain several orebodies. All orebodies are blind and occur over a depth interval of 30-600 m. Orebodies are tabular or vein-like to stockwork in shape. The uranium mineralization consists of brannerite, coffinite and pitchblende, as well as uranium-bearing leucoxene. The average ore grade is about 0.11% U [12.5].

The Gurvanbulag deposit is associated with the same Dornod volcano-tectonic structure. Here, the structure includes two rock types. A lower, 300–400 m thick series consists of volcanic flows ranging in composition from rhyolite to andesitic basalts, interlayered with tuffaceous sediments. The upper, 300–800 m thick series includes acid effusive volcanics and their tuffaceous equivalents. The uranium mineralization, including coffinite, pitchblende and uranophane, is reportedly controlled both by lithology of the host rocks (e.g., tuffaceous ashes) and by favourable structures. It extends over a depth varying from 15–40 m to 720 m. The highest-grade mineralization is concentrated in a zone affected by low angle faulting, at the contact between the lower and upper series. Stratiform deposits are spread over an area of 3 km². These deposits also appear to be controlled by tectonic features. A total of 17 deposits of different sizes have been found. The highest-grade zone covers an area of about 1500 m² and has an average thickness of 3.5 m and an average grade of 0.17% U.

The Mardaingol and Nemer deposits are also associated with the Dornod structure. They are geologically similar to the Dornod and Gurvanbulag deposits. The Dornod, Gurvanbulag, Mardaingol and Nemar deposits were developed for underground and open pit mining in the late 1980s [12.5–12.12].

U-Pb systematics of uranium minerals and alteration minerals give ages of 153-136 Ma for the various deposits with ore formation occurring between 138-136 Ma.

Sandstone type

Late Mesozoic extensional basins are a prominent geological and topographic feature of central East Asia. The basins are interpreted as having formed in an intracontinental, back-arc tectonic setting in response to extensional faulting. These basins, which are likely fault-bounded grabens and half grabens, were filled by eroded sediments during the Jurassic and Cretaceous periods. In places, the clastic sediments are up to 1500 m thick.

Early exploration established the favourability of the sedimentary basins of the Gobi region as hosts for uranium deposits. These have been successful exploration targets. The clastic sediments and fluvial deposits were found to be suitable conduits and hosts for the formation of epigenetic uranium deposits. The depressions are surrounded by deeply weathered and dissected crystalline rocks, including granites, metamorphics and volcanics. The crystalline rocks (especially the granites) are the most likely source of the uranium that was subsequently deposited in the depression sediments.

The Haraat and Hairhan (Khairkhan) sandstone deposits occur in the upper portion of the Lower Cretaceous sediments of the Choir Basin, which overlies Proterozoic crystalline schists, gneisses and marbles which are intruded by Palaeozoic granitoids. The mineralization occurs in alternating sandstones and clays, with interbedded lignite layers. These rocks were originally geochemically reduced but are now oxidized to a depth of 25–30 m. The mineralization occurs in this oxidized environment. Common minerals include autunite, schroeckingerite and torbernite. Associated elements include cerium, germanium, lanthanum, molybdenum, rhenium, scandium, silver, ytterbium and yttrium.

The two most important sandstone deposits are Haraat in the Choir and Nars, Dulaan Uul and Zoovch Ovoo in the Sainshand Cretaceous Basins, located in south-eastern Mongolia (SE Gobi desert). Orebody shapes include tabular, lens, ribbon, peneconcordant and roll-type. The age of mineralization is 2.5 ± 0.2 Ma. Some occurrences are related to the basal channel subtype occurring in the palaeovalleys of the Chuluut Basin in Khentei Province [12.5–12.12].

Other deposit types

Lignite type occurrences are often located within deposits of Lower Cretaceous lignite and black clay. The average thickness of the uranium-bearing beds is 1–2 m, with a grade of 0.05% U.

Vein-type uranium occurrences are located within fracture and shatter zones in highly radioactive leucogranite massifs of Mesozoic age. These zones include veins and lenses with disseminated hexavalent uranium mineralization.

The metasomatite-type deposit is found at several localities in northern Mongolia and has uranium–thorium–rare earth elements and uranium–thorium associations in subalkaline and alkaline granite and syenite intrusions and in pegmatite bodies.

Phosphorite type occurrences of uraniferous fluoroapatite usually occur in Cretaceous terrigenous clastic sediments. Grades are typically up to 0.02% U [12.5–12.12].

6.12.3. Uranium exploration

Uranium exploration in Mongolia started immediately after World War II and was conducted jointly by the geological organizations of Mongolia and the former USSR.

Prior to 1966, numerous uranium occurrences were discovered in lignite deposits. Subsequently, exploration became more systematic. About 650 000 km², or 40% of the country, was investigated by airborne radiometric surveys at scales of between 1:1 000 000 and 1:25 000. A metallogenic appraisal of undiscovered uranium resource potential was completed over an area of 500 000 km^2 and more detailed geological exploration was completed at scales of between 1:200 000 and 1:50 000. Drilling, trenching and underground exploration were conducted over an area of about 50 000 km^2.

As a result of these investigations, four 'uranium-bearing provinces' were defined: Mongol-Priargun, Gobi-Tamsag, Hentei-Daur and northern Mongolia. Within these provinces, six uranium deposits were identified, as well as 100 uranium occurrences and 1400 mineral showings and radioactive anomalies.

The Mongol-Priargun Province includes the Choibalsan uranium district, as well as the Berth and Eastern Gobi, which are potential uranium districts.

The Choibalsan uranium district includes the Dornod volcano-tectonic structure. This structure is filled with more than 1000 m of Jurassic–Cretaceous volcanic rocks, ranging in composition from rhyolite to basalt, and associated sediments. The Dornod structure covers an area of about 2000 km^2 and hosts the Dornod, Gurvanbulag, Mardaingol and Nemer uranium deposits, in addition to a number of polymetallic, gold and fluorspar deposits (Fig. 6.32).

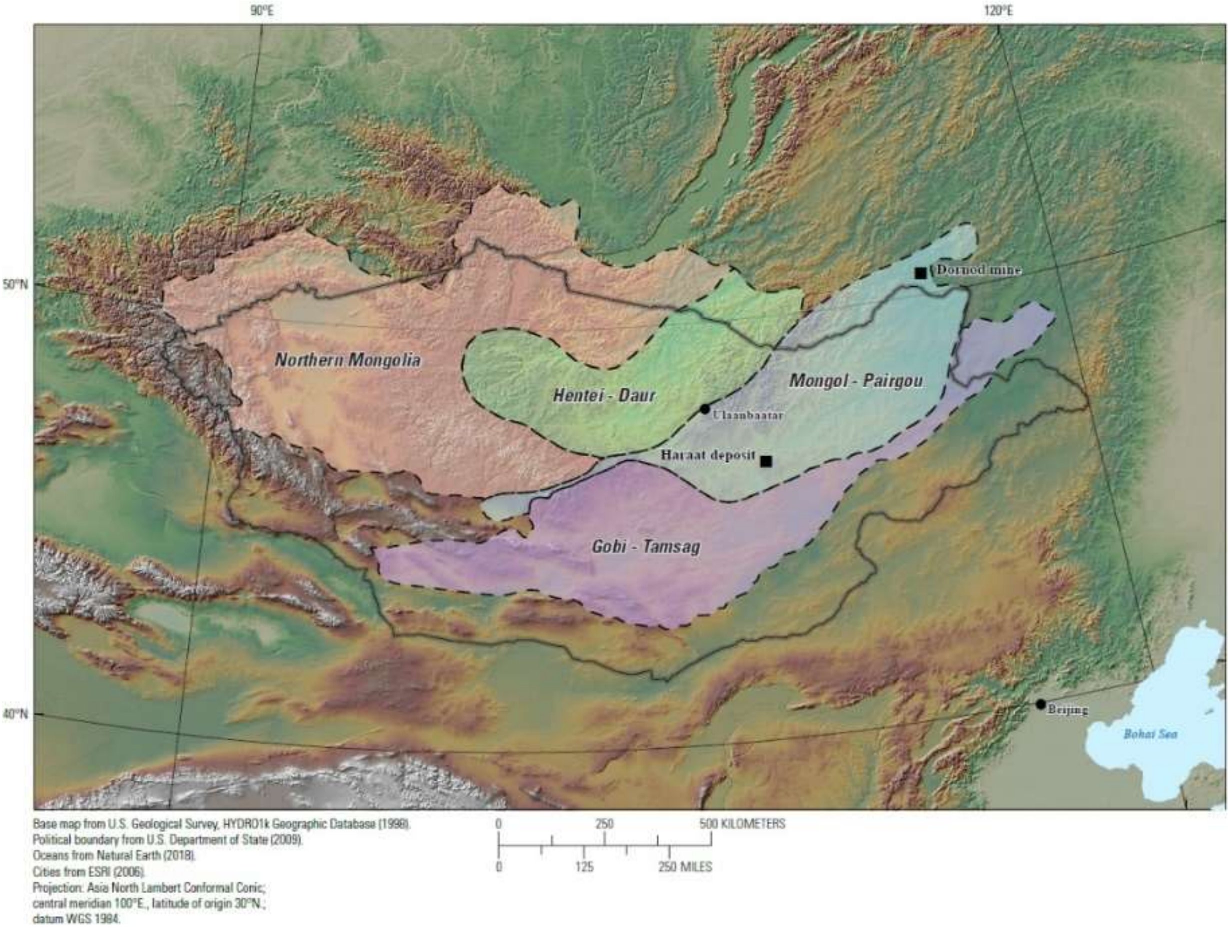


FIG. 6.32. Uranium metallogenic provinces and deposits [adapted from 12.8].

The Gobi-Tamsag Province in south-east Mongolia hosts the Nars, Dulaan Ull and Zoovch Ovoo uranium deposits, which are associated with the Sainshand sedimentary basin of Cretaceous age. In addition, numerous uranium occurrences have been found in the Tamsag, north Sainshand, Zuunbayan and other sedimentary basins.

The Haraat deposit occurs in the Eastern Gobi area in the large (150 km × 15 km) Choir sedimentary basin of Mesozoic age. In the mid-1990s, uranium exploration was conducted through the State owned Uran Company, which in 1994 entered into the Gurvan Saihan Joint Venture (GSJV) with Russian and US partners. Its objective included an investigation of the Haraat sandstone deposit, which is located within the Mongol-Priargun uranium district. Of special interest was whether the Haraat deposit could prove amenable to in situ leaching (ISL).

The Uran Company had plans to intensify uranium exploration in 1995 and to carry out approximately 40 000 m of drilling.

Exploration began in 1955 in the Choir Depression. The purpose of the drilling campaign was to extend the main known deposits. The new resource areas detailed in 1996 tended to be quite low grade, with the majority of the mineralization occurring above the water table.

The early exploration clearly established the favourability of the sedimentary basins of the Gobi region as hosts for uranium deposits. When the GSJV was formed, in January 1994, work began immediately, concentrating on the Choir Depression and specifically on the Haraat deposit. The 1994 work consisted of limited delineation drilling at Haraat in order to expand known resources and to increase confidence in the resources. The drilling campaign totalled 8430 m.

A small ISL field test was conducted in 1994 to determine the favourability of the Haraat type mineralization to ISL recovery. In the Choir Depression, more than 70% of the known mineralization of potentially economic grade occurs above the natural water table. Full groundwater saturation of the ore-bearing zone is the normal condition for ISL. However, the 1994 ISL test at Haraat included leaching from both saturated and unsaturated horizons. The test demonstrated that acid ISL was applicable to the Haraat deposits and subsequent larger scale testing was planned.

However, in 1995, Energy Fuels, the US participant in the GSJV, filed for bankruptcy. As a result, the GSJV programmes planned for the 1995 season were not implemented. Full scale work resumed in 1996.

At an IAEA Technical Meeting in June 2010, a technical specialist from Mongolia reported that ISL tests were completed in 1994 and 1996 at the Haraat deposit and that technological testing took place at the Hairhan deposit in Dundgobi Province in 1998 [12.12].

The Hairhan sandstone deposit was discovered and confirmed in the late 1990s and exploration activities continued at the Hairhan, Choir and Ulzit Depressions until it was curtailed owing to declining uranium prices.

The Dulaan Ull and the Zoovch Ovoo deposits were discovered respectively in 2007 and 2011. In 2013, ISL tests were successfully performed on the Dulaan Ull deposit.

Figure 6.33 shows the exploration expenditure history of Mongolia indicating USD $216 796 704 for 991 384 metres of drilling. No exploration or drilling expenditures were reported for 2002–2005 [12.7].

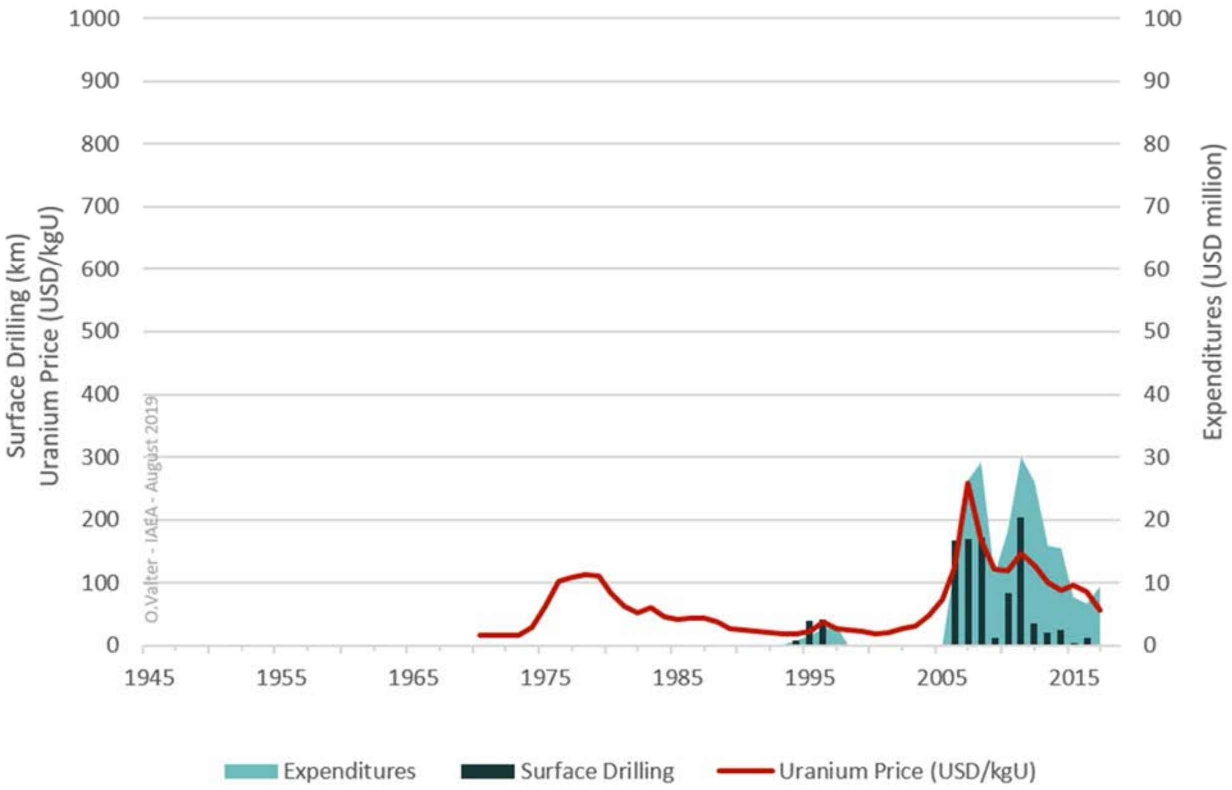


FIG. 6.33. Domestic uranium exploration data for Mongolia. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

Recent and ongoing uranium exploration and mine development activities

With the resurgence of world market uranium prices in 2003, several foreign companies increased exploration activity in Mongolia. For example, the Canadian company Denison Mines Corporation acquired several exploration licences, both for GSJV, in which it has controlling interest, and for its sole interest. Prospecting and mapping work began in 2004. In 2005, reconnaissance drilling totalling 34 000 m was conducted in five areas where previous prospecting and radiometric surveys had identified anomalies. Drilling expanded in 2006, with approximately 56 000 m completed. Exploration concentrated on those internal basins and depressions hosting Cretaceous sediments, i.e., areas considered amenable to ISL techniques.

Denison Mines' policy focused on identifying sandstone-hosted uranium deposits, especially those amenable to ISL. It succeeded in locating deposits in the Choir and Hairhan Depressions of the Haarat area and drill testing and initial recovery testing were carried out on both deposits.

East Asia Minerals, a Canadian minerals exploration company, owned eight uranium properties in 2008, including the advanced uranium projects at Inglin-Nars, Ulaan Nuur and Enger, as well as two phosphate properties.

During 2008, East Asia Minerals strengthened its Mongolian portfolio by acquiring additional uranium and phosphate licences over which it exercises 100% control. Highlights of the 2008 exploration efforts include completion of soil gas surveys on several uranium prospects and identification of two discrete anomalies of high priority on each of two project areas.

Other projects include the Baaruunbaayan uranium project operated by Solomon Resources Ltd (Solomon). Solomon conducted surface exploration and a diamond drilling programme in 2007–2008, focusing on the Cretaceous Ooshin Gobi Basin of southern and central Mongolia to follow-up on spectral anomalies detected during a Soviet era airborne survey of favourable geological environments. The project area is located immediately west of AREVA Mongol's (a subsidiary of the French company AREVA) Duulan Uul Project. Following a dispute with the Mongolian Government concerning the issue of exploration licences for the area between the Solomon and AREVA properties, Solomon's licences were to be reissued following an order by the Mongolian Supreme Court of 21 December 2009, pending an appeal.

Cogegobi, a joint venture 70% owned by AREVA, ran the Duulan Uul Project in the Gobi area from 1996–2008, when shares of Cogegobi were transferred to AREVA Mongol.

AREVA Mongol has 28 exploration licences covering an area in excess of 14 100 km^2. Its main focus of activity is centred on the Gobi Desert and, more specifically, the East Gobi Province, in the south-east of the country. This very extensive sedimentary basin contains the promising deposit of Duulan Uul (9 900 tU, 0.017 %U), a site particularly well suited to ISL mining technology. This deposit is a sandstone roll-front type. The host sandstone is described as coarse-grained with continuously distributed mineralization. ISL tests were completed in 2013. In 2011, AREVA Mongol discovered the large Zoovch Ovoo deposit with geological resources of 73 640 t U at a grade of 0.022% U. About 770 000 m of drilling was completed to 2013. A prefeasabily study was initiated for an In-situ recovery technology [12.13].

The Canada based Western Prospector Group Ltd (Western Prospector) has held the Gurvanbulag deposit as the main focus of its Saddle Hills Project since 2004. Some 9000 tU are known as a NI 43–101 inferred resource, based partly on Russian exploration conducted up to 1989. Western Prospector and its Mongolian subsidiary, Emeelt Mines, undertook a definitive feasibility study which indicated that the project was barely economic on the basis of 6900 tU of reserves averaging 0.137% U. The ownership history is complicated, but in 2009 it was taken over by Chinese interests when Western Prospector agreed to a US $25 million takeover by China's CNNC International, a subsidiary of CNNC [12.14, 12.15].

6.12.4. Uranium resources

As of 1 January 2017, reasonably assured resources and inferred resources are associated with sandstone and volcanic type deposits (Tables 6.14.–6.15) .The historic variation in resources is shown in Fig. 6.34 and Fig. 6.35 [12.16]. The UDEPO database lists the most significant deposits for Mongolia as Zoovch Ovoo, Dornod District (12 Deposits), Gurvanbulak Central Zone, Myagmar, Shinebulag, Dulaan Uul, Ulaan Nuur.

TABLE 6.14. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE (tU) [12.16]

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	26 066	26 066	26 066
Volcanic and caldera-related	23 711	23 711	23 711
Total	49 777	49 777	49 777

TABLE 6.15. INFERRED RESOURCES ACCORDING TO DEPOSIT TYPE (tU) [12.16]

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kg U
Sandstone	55 974	55 974	55 974
Volcanic and caldera-related	4051	4051	4051
Total	60 025	60 025	60 025

Prognosticated resources total to 21 000 tU in the < US$ 260/kU cost category, speculative resources 1 390 000 tU in the <US$ 260/kgU cost category.

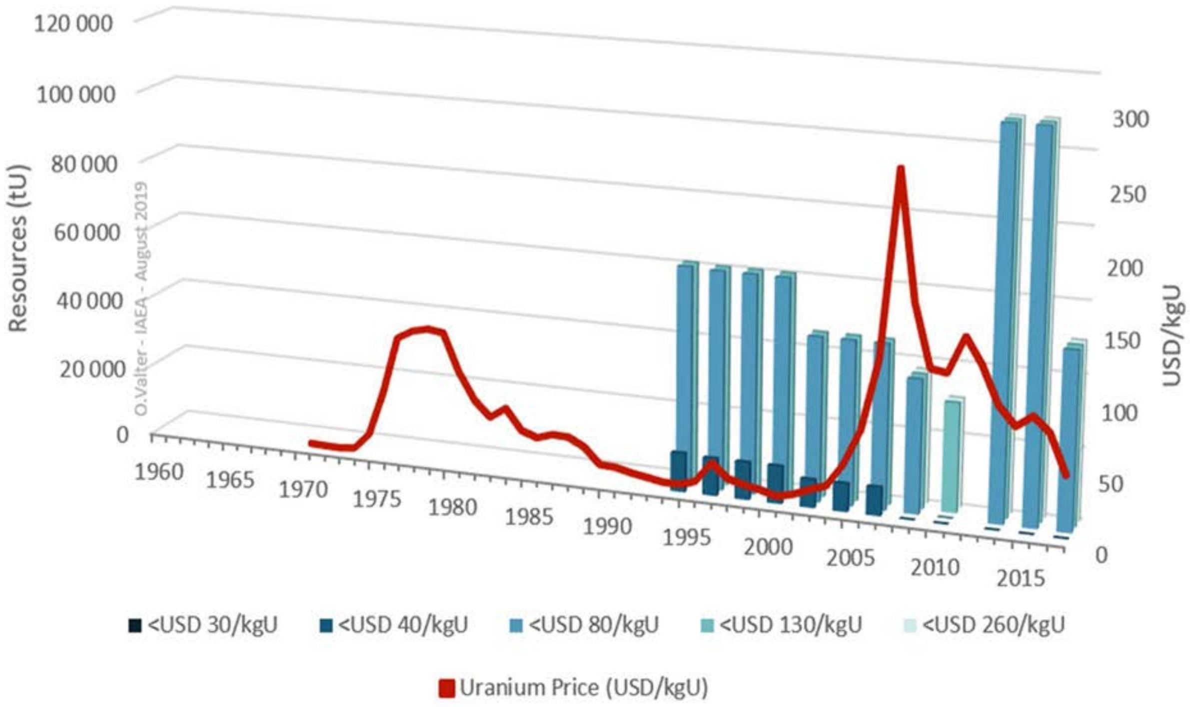


FIG. 6.34. Historical variation of recoverable reasonably assured resources within various cost categories in Mongolia. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

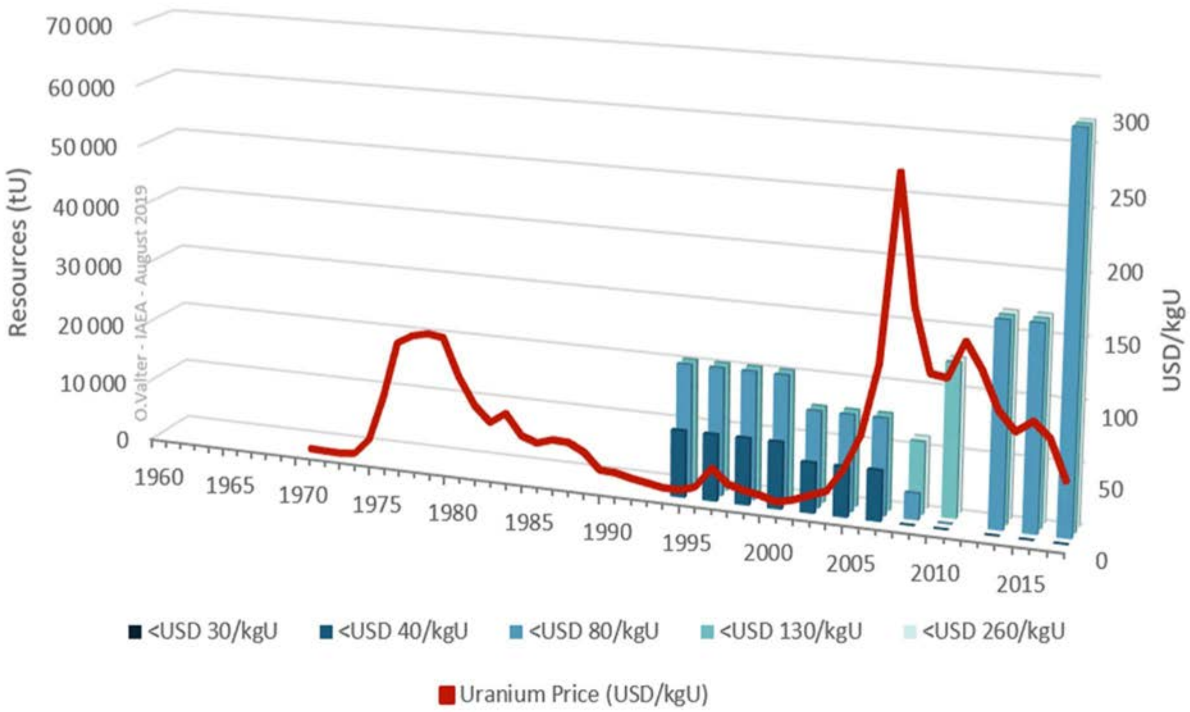


FIG. 6.35. Historical variation of recoverable inferred resources within various cost categories in Mongolia. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

6.12.5. Potential for new discoveries

On the basis of the large number of uranium occurrences in the Choir Basin, for example, it is estimated that other basins in this area, including those of Baga Nuurty, Ulaan Nuur, Alagtsav and Tavansuvaa, have the potential for hosting additional sandstone-type uranium deposits [12.7].

6.12.6. Uranium production

6.12.6.1. Historical review

Uranium production in Mongolia began with operation of the Dornod open pit mine in the Mardaingol district in 1989. Exploration was based on the known resources in the Dornod and Gurvanbulag deposits. Both open pit and underground mines were developed, with a total design capacity of 2 000 000 t ore/year. Assuming an ore grade of 0.12% U, this equates to a mining production capability of 2400 tU/year. As Mongolia has no processing facilities, the ore mined in the Mardaingol district has been transported nearly 500 km by rail for processing at the Priargunsky Mining and Processing Combine at Krasnokamensk in the Russian Federation. The mines were operated by the Erdes Mining Enterprise, a joint venture between Mongolia and the Russian Federation. Marketing was undertaken by Techsnabexport. Owing to political and economic changes, uranium production of Erdes was terminated in 1995 [12.7].

Historical cumulative uranium production between 1989 and 2017 was 535 tU, as shown in Fig. 6.36 [12.9].

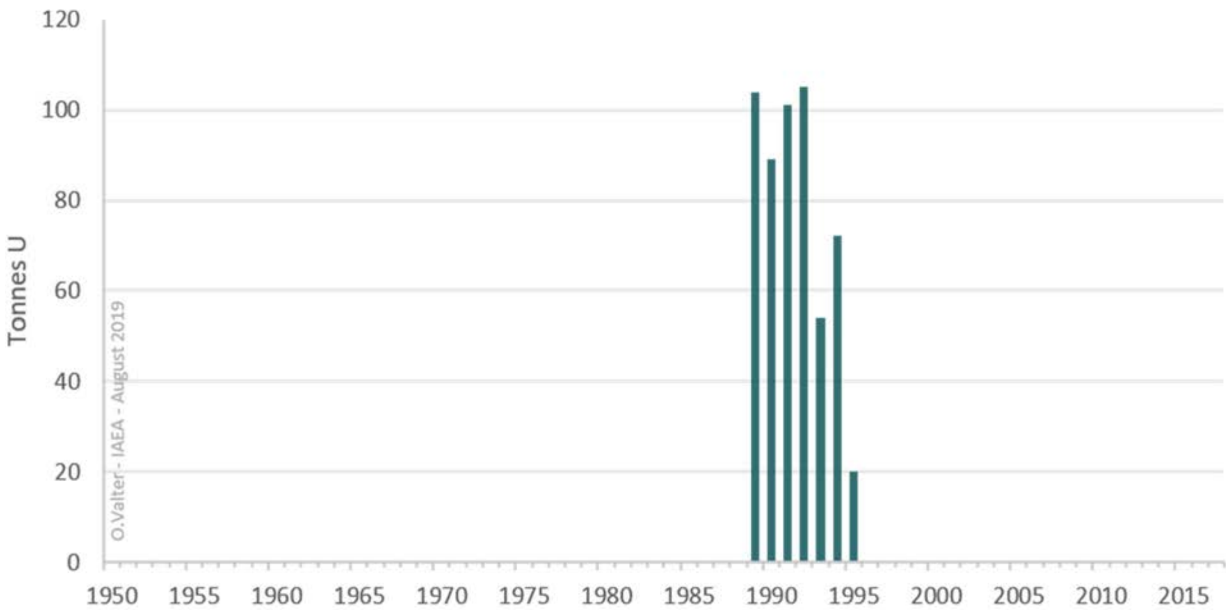


FIG. 6.36. Historical uranium production in Mongolia.

6.12.6.2. Future production centres

The Canadian uranium company, Khan Resources Inc., was in a joint venture partnership in Mongolia with a Russian Government entity (Atomredmetzoloto JSC (ARMZ)). In 2009, Khan Resources Inc. prepared a definitive feasibility study for its Dornod project, which comprises several uranium deposits and infrastructure elements. The study indicated a positive economic prospect, based on the development of underground and open pit mines producing a total of approximately 1 225 000 t/year of ore at a rate of 3500 t/d. Metallurgical recovery is 84.86–89.28%. The capital cost for mining and surface facilities is estimated at almost US $333 million, with operating costs of US $60.32/kgU (US $23.22/lb U_3O_8). The project is dormant.

Feasability studies and ISL tests were completed in 2013 and 2016 on the two AREVA Mongol Dulaan Ull and Zoovch Ovoo deposits, but no production is planned in the near future.

Reference [12.17] discusses the potential Mongolian contribution to the future uranium market in relation to the projected increase in demand from China and India in particular.

6.12.7. Environmental activities

The Priargunsky Mining and Processing Combine, on behalf of the Mongolian Government, completed an environmental review of the proposed expansion of the Dornod mine operations in mid-1995. The review concluded that the uranium mining operations, including the then proposed heap leaching operation, do not pose unusual or significant impacts on the environment and that the mine would have a positive socioeconomic impact on the working population [12.5].

6.12.8. National and local policies related to uranium

The mining sector is Mongolia's single largest industry, accounting for 55% of industrial output and more than 40% of export earnings. In 2008, the Government established a new Ministry of Mines and Energy. Mining was previously a division of the Ministry of Industry and Trade.

The Government's Nuclear Energy Agency is responsible for development of policy regarding activities relating to nuclear research and technology, radiation protection and safety, use of radiation sources and the coordination of uranium mining activity with other relevant organizations. The Nuclear Energy Agency is attached to the Prime Minister's office and is the national focal point for dealing with the IAEA. Its main functions include coordination of nuclear research activities in the country and implementation of nuclear regulatory activities.

Prior to 1996, radiation protection and safety were covered under the Law on Health Protection (1977), Radiation Safety Standards (1980) and Basic Regulation on Radiation Sanitation (1983). The Law on Radiation Protection and Safety was enacted on 21 June 2001 and amended on 2 January 2003. The Law on Nuclear-Weapon-Free-Status was enacted on 3 February 2000. Transport Regulations for Radioactive Sources was enacted in 1987.

On 16 July 2009, the Mongolian Parliament passed the Nuclear Energy Law to regulate the exploration, exploitation and development of uranium and other radioactive materials. The new law came into effect on 15 August 2009. A draft code of practice on waste management and regulation is under review.

The Nuclear Energy Law gives the Mongolian Government the right to take ownership, without compensation, of not less than 51% of the shares of a project or joint venture if the uranium mineralization was discovered by State funded exploration, and not less than 34% if State funding was not used to find the mineralization.

The State Administrative Authority has the responsibility to implement and enforce State policy on the exploration for, and development of, deposits of radioactive minerals and nuclear energy, including the power to grant, suspend or revoke any licences granted pursuant to the Nuclear Energy Law. The Nuclear Energy Law mandates that licences be obtained to conduct exploration for, and to produce, radioactive minerals.

To obtain an exploration licence, an applicant must conduct its activities in a transparent manner, possess the financial resources to support exploration and reclamation, to conduct responsible programmes and to have demonstrable mining experience. Exploration licences will only be issued to those applicants that meet the conditions set out in the Nuclear Energy Law and who agree to accept State ownership of the required percentage of shares.

The Mongolian Parliament also passed legislation regarding the re-registration of existing exploration and mining licences. Existing licence holders were required to apply to the State Administrative Authority by 15 November 2009 and to comply with all the conditions and requirements set out in the Nuclear Energy Law, including acceptance of the State's percentage share participation [12.18].

References to Section 6.12

[12.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Mongolia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed 2009).

[12.2] TAKAHASHI, Y., Introduction to Geology of Mongolia based upon GIS, GSJ Open File, 413 (2004).

[12.3] GEOSOCIETY, Geological Excursion to Central and Northern Mongolia, http://www.geosociety.org/geoventures/professionals/2004/mongolia.htm (accessed 2009).

[12.4] GEOCITIES, Outline of Geology, http://www.geocities.jp/y95480/mongeology.htm (accessed 2009).

[12.5] THE GEOLOGICAL SOCIETY OF AMERICA, Mongolia Geotrip, http://www.mongolia.cratertocirque.com/ (accessed 2009).

[12.6] AKER SOLUTIONS, Technical Report on the Definitive Feasibility Study for the Dornod Uranium Deposit, Mongolia, Prepared for Khan Resources Inc. NI 43-101, 22 April 2009.

[12.7] MIRONOV, Y.B., NAUMOV, S.S., JAMSRANDORJ, G., CHULUUN, O., "The uranium resources of Mongolia", Recent Developments in Uranium Resources and Supply, IAEA-TECDOC-823, IAEA, Vienna (1995).

[12.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[12.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[12.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[12.11] SCOTT WILSON ROSCOE POSTLE & ASSOCIATES, NI43–101 Technical Report on the Uranium Properties in Mongolia Prepared for Denison Mines Corporation (27 February 2007).

[12.12] SCOTT WILSON ROSCOE POSTLE & ASSOCIATES, Technical Report on the Preliminary Assessment of the Dornod Uranium Project, Mongolia, prepared for Khan Resources Inc., Rep. NI 43–101 (25 October 2006).

[12.13] HOCQUET, S., Zoovch Ovou and Dulaan Uul uranium deposits: Application of international reporting standards for mineral resources and ore reserves. Presented at the IAEA-UNECE meeting in Ulaanbaatar, August 2016.

[12.14] GANBAATAR, U., "Mongolian uranium deposits and in situ leaching", paper presented at IAEA Tech. Mtg on In Situ Leaching, Vienna, 2010.

[12.15] SOLOMON RESOURCES, Solomon reports decision in Mongolian court action, and Mongolian Supreme Court affirms decision in Solomon expropriation case, www.solomonresources.ca/ (accessed 2009).

[12.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[12.17] EAST ASIAN MINERALS CORPORATION, Mongolia, http://www.eaminerals.com/s/Mongolia.asp (accessed 2009).

[12.18] SACHS, R., AGVAANLUVSAN, U., Fueling the future: Mongolian uranium and nuclear power plant growth in China and India, MonAme Scientific Research Center, Ulaanbaatar, Mongolia and Stanford University, Palo Alto California (1 September 2009), http://fsi.stanford.edu/publications/fueling_the_future_mongolian_uranium_and_nuclear_power_plant_growth_in_china_and_india

6.13. MYANMAR

6.13.1. Geography

Myanmar is located in south-east Asia on the Bay of Bengal and is bordered by Bangladesh, China, India, the Lao People's Democratic Republic and Thailand. Seven states and seven districts have been established which reflect the variations in ethnic population.

Geographically, the country is divided into well marked geomorphological units: the Northern Mountains, the Western Hills, the Central Belt or Central Lowlands, the Shan Plateau and the Tenasserim strip.
The country lies in the tropical monsoonal climatic region. The highest mountains (the peaks of Hkakabo Razi (5881 m)) are a continuation of the Himalayas and are found in the far north, near the border with

China. The mountain ranges of the Angpawing Bum (Naga), Adarau Taungdan (Chin) and Ragaing Yoma (Arakan Yoma) form the western border. These are generally referred to as the Western Hills, although their elevations are high, attaining over 3800 m in the north and up to 3000 m in the central area.

The Shan Plateau, which occupies the largest area in the eastern region, is drained by the Salween River. The centre of the country is drained by the Ayeyarwady River (Irrawaddy) and its major tributaries, the Chindwin and Sittang Rivers. The Ayeyarwady is about 2200 km long and its broad, basin-like lowland is a fertile agricultural region. This area hosts the major population centres of Myanmar.

There are three major seasons: the rainy season, generally from May to October; the 'cold' season, from November to January; and the hot season, from February to April. There are variations in temperature according to geographical location and elevation.

Large parts of the country are covered by forest, where teak wood, rubber, palm trees, ironwood and other tropical hardwoods grow. Rice is the most important staple food.

In addition to the textile and food production industries, State owned or State controlled mineral extraction companies play, or have played, a major role in the economy. Among these, the production of petroleum is of major importance. Also of importance are base metals, the major deposit being the Bawdwin mines between Namtu and Lashio on the Shan Plateau. This deposit is important for copper, lead and zinc. Gemstones, mainly rubies and sapphires, are found in the Mogok area and the jade from northern Myanmar is also well known [13.1–13.3].

6.13.2. Geology

6.13.2.1. General

The oldest rocks are assigned to the Precambrian and consist of metasediments and crystalline metamorphics (Fig. 6-13.1). These occur in the Sino-Burman Range at the north-eastern corner of the country and in the Mogok Series, in the north-east centre of Myanmar. Undifferentiated metamorphics, occurring on the Shan Plateau and scattered on a N–S trending belt extending to the Gulf of Martaban, are believed to be the equivalent to the Mogok Series. The rocks of the Mogok Series are classified as Precambrian on the basis of comparison with similar rocks in India and Sri Lanka. The Mogok Series are composed of pelitic gneisses, marbles, calc-silicates and quartzites and are intruded by acid to basic magmatic rocks. Alaskites are present as the most acidic members. The Mogok Series in the Mogok area proper are famous for rubies, sapphires semi-precious stones. The geology and petrography of the Mogok Series and their equivalents are very complex and have been the subject of a number of specific studies.

During the Late Precambrian–Early Cambrian, a thick sequence of flysch type sediments was deposited (Chaung Magyi Group), followed by the Bawdwin Volcanic Formation, known for its base metal deposit. The Upper Cambrian has been dated by the presence of trilobites. During the Ordovician, clastic and carbonate sediments of both shelf and deep-water depositional environments form the Naungkangyi Group, followed by Silurian rocks, similar in composition to the older sediments. The Silurian contains a number of well developed graptolite beds. The facies appears to continue into the Devonian, where dolomite sediments are also abundant. The Carboniferous is present in elongate belts along the western edge of the Shan Plateau, continuing south to Tenasserim. The Shan Plateau, formed mainly during the Mesozoic between 285 and 65 Ma, is covered by thick calcareous sediments dated as Palaeozoic–Mesozoic or Palaeozoic–Triassic.

In contrast, large parts of the peninsula of Tenasserim are covered by undifferentiated Palaeozoic rocks, intruded by granites, which are tin-bearing in several places.

Mesozoic rocks, mainly of Triassic age, have been distinguished on the Shan Plateau. These were formerly described as Palaeozoic or undifferentiated. Sediments of both Jurassic and Cretaceous age are widespread in Myanmar. The Cretaceous occurs along a N–S belt on the Indo-Burman Range of the

Arakan Yoma, mainly as flysch type limestone. Thick Tertiary age sediments occur west of the Arakan Yoma and in the Chin Hills. Tertiary sediments are also found in the central part of the country in both the Ayeyarwady and Chindwin Basins [13.4].

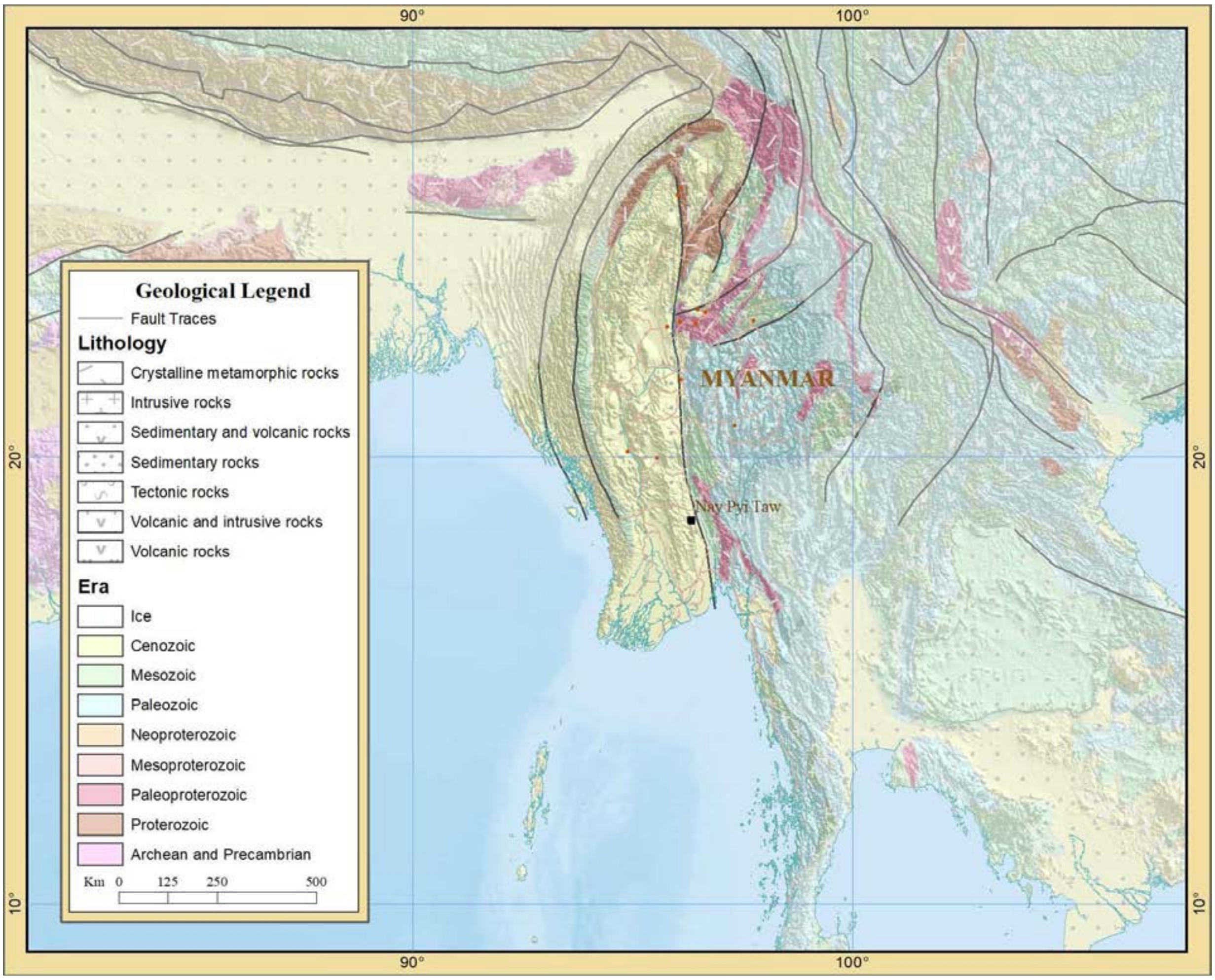


FIG. 6.36. Regional geological setting of Myanmar. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.13.2.2. Geology in relation to potentially favourable uranium-bearing areas

No uranium deposits have been described. In general, areas with granites can be regarded as favourable, although, to date, no deposit has been officially recorded. Sediments indicating continental deposition, and thus generally regarded as having favourable conditions for the formation of uranium deposits, are described in some formations.

Sediments of Upper Jurassic–Cretaceous age in the Karen State, close to the border with Thailand, contain the Kalaw Red Beds. These are regarded as possible equivalents to the Khorat Red Series in Thailand, were small uranium occurrences have been described in the Khorat Plateau. It is not known whether the Kalaw Series have been investigated for their uranium potential.

In the Middle and Upper Eocene, red bed formations are known, although no information regarding uranium potential is reported. The same applies to the 'Fossil Wood Formation' of the Pliocene–Pleistocene Irrawaddian, which may be equivalent to the Siwalik Group (see India, Nepal and Pakistan).

The Upper Miocene–Pliocene of Tenasserim contains oil shale, which is not known to contain any uranium indications.

6.13.3. Uranium exploration

Uranium minerals have been reported from the Mogok area [13.4]. Disseminated uraninite and pitchblende occur in very small quantities in alaskites and pegmatites, as well as in placers and in the tailings of gemstone mining operations in the district.

The limonitic iron orebody of Pang Pet, near Taunggyi, Shan Plateau, has an elevated uranium content ranging from a few parts per million up to 0.2% U. As remnants of rhyolite are found in the orebody, it is assumed that the limonitic iron mineralization is the result of alteration of primary haematite associated with the rhyolite. During the process of alteration, uranium was released from the rock and trapped in the limonite. This theory of formation is supported by the presence of copper.

According to the Government report [13.4], uranium deposits have been discovered in five areas in central and northern Myanmar. No further details have been reported.

6.13.4. Comments

Myanmar has no historical or current production of uranium and there is no installed or planned nuclear capacity. Myanmar has not reported to the Red Book. More information on the geology of the country and any exploration results are needed before an estimate of its potential for hosting uranium deposits can be made.

The UDEPO database does not list any known deposits for Myanmar.

References to Section 6.13

[13.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Myanmar, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2009).

[13.2] LONELY PLANET, Myanmar, http://www.lonelyplanet.com (accessed 2012).

[13.3] A Handbook on Burma, Directorate of Information, Rangoon (1968) 178 pp.

[13.4] BENDER, F., Geology of Burma, Borntraeger, Stuttgart (1983) 293 pp

6.14. NEW ZEALAND

6.14.1. Geography

New Zealand comprises a group of islands located in the South Pacific Ocean, about 1600 km south-east of Australia and separated from it by the Tasman Sea. The country consists of two major islands, North Island and South Island, separated by the Cook Strait, and smaller islands, scattered in the South Pacific Ocean.

The Cook Islands and Niue Islands, located about 3000 km north-east of New Zealand, are associated territories of New Zealand, while the islands of Tokelau are an integral part of New Zealand.

New Zealand's capital, Wellington, is located on the southern tip of the North Island. Both North and South Islands are mountainous. The North Island is dominated by volcanoes in the centre (several peaks of 2300–2800 m elevation). Auckland is the largest city and is located on the north-western peninsula. The largest lake, Lake Taupo, is located on the North Island.

The west coast of the South Island is dominated by the Southern Alps, which rises to a maximum elevation of 3754 m at Mount Cook.

The climate of the North Island is semi-tropical, while the South Island has a moderate climate [14.1].

6.14.2. Geology

The oldest rocks, considered to be Precambrian, are found in the western part of the South Island (Fig. 6.37). These comprise granite–gneisses, metamorphosed greywacke and hornfels. The Lower–Middle Palaeozoic rocks comprise arenaceous sediments, basic volcanics, pelites and carbonates. In the northern part of the South Island, low grade metamorphism has affected most of the sediments, whereas in the southern part, amphibolite grade metamorphism is frequent. Sediments of Silurian–Devonian age are intruded by granites.

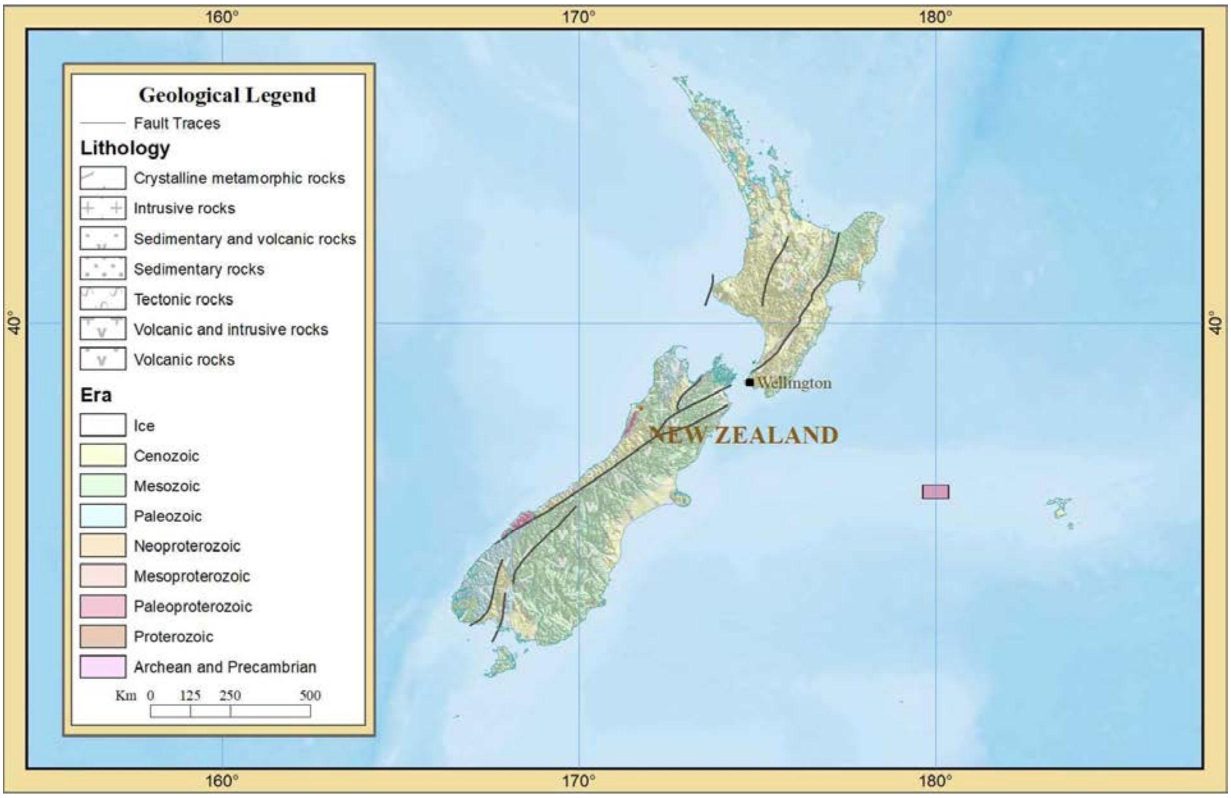


FIG. 6.37. Regional geological setting of New Zealand. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The mountain chains of both islands are built up by sequences of Carboniferous–Jurassic age, mainly of volcano-sedimentary composition. During the Cretaceous, the sedimentary trough was closed by the Rangitata Orogeny. In the coastal areas, mainly Cretaceous and younger units are deposited. The Cretaceous is well known for volcanics, continental sediments and coal measures. The latest stages are epicontinental marine sediments and basic volcanics of Tertiary age.

The South Island experienced glaciation and volcanic activity during the Quaternary. It is understood that New Zealand was part of the Gondwana continent and was separated from it by plate tectonic movements. New Zealand straddles the boundary of two slow moving tectonic plates: the Australian Plate to the west and the Pacific Plate to the east. It extends along a transitional zone between subduction to the north and a right lateral transform fault system to the south. The tectonics of New Zealand is dominated by subduction of the Pacific Plate below the North Island of the Australian Plate. This is illustrated by the deep linear Kermadec Trench lying off the east coast of the North Island. With transition to the south, the subduction occurs at an angle resulting in a right lateral strike-slip fault zone (the Alpine Fault) cutting along the axis of the South Island. Volcanism, geothermal systems and deep earthquakes predominate in the north, whereas these are lacking in the south, where shallow strike-slip earthquake motions predominate [14.1].

6.14.3. Uranium exploration

The uranium exploration campaign started by the Department of Scientific and Industrial Research in the 1940s was aimed at obtaining uranium for military purposes. However, New Zealand was not considered to be a promising candidate for exploration. No substantial anomalies were found except for black sands recovered by gold dredges on the west coast of the South Island.

In 1955, high radioactivity due to zircon in a volcanic dyke was discovered at a road cut, on the west coast of the South Island. After 1956, exploration work discovered radioactive veins and disseminations of coffinite, minor uraninite and thucolite in sediments at Buller Gorge, South Island. In addition, anomalies and limited occurrences of uranium have been found in the Porarari Valley, south of the Buller River. The west coast exploration project was terminated without success by the UK Atomic Energy Authority in August 1960 after having spent £17 775.

In 1967, CRA, an Australian company, withdrew from prospecting on the west coast after having spent A$37 000. Exploration in later years by several companies was similarly unsuccessful. In 1980, uranium was not considered to be important for the country and since the 1990s, prospection, exploration and extraction of uranium minerals is no longer permitted [14.2].

6.14.4. Uranium resources

New Zealand has neither identified nor unconventional uranium resources. On the island of Niue, which is mostly made up of coral limestone, the existence of bauxite and uranium has been reported [14.2]. This would require a relevant geological environment for which no indication was found. Thus, the existence of uranium mineralization on Niue remains very doubtful.

In 2012, a project was initiated by Chatham Rock Phosphate Ltd to mine phosphate rocks from the seabed on the Chatham Rise, east of the South Island [14.3]. Phosphate beds, at a depth of 350-500 m, would be dredged then processed onshore at a rate of 1.5 million tonnes per year for about 35 years. An average of 240 ppm uranium occurs in the phosphates representing resources of 12 250 t of uranium. In 2015 the NZ Environment Protection Authority refused permission for the project.

The Cook Islands comprise volcanic cores with surrounding coral reef and are not considered favourable for hosting uranium deposits.

The potential for new resources is very low. The country was considered in the IUREP study as having limited potential for uranium.

New Zealand has not produced uranium and there is no installed or planned nuclear generating capacity.

6.14.5. National policies relating to uranium

Under a minerals programme of 1996 and based on the Crown Mineral Act of 1991, no prospection, exploration or extraction of uranium is permitted. The ownership of uranium would remain with the Crown.

References to Section 6.14

[14.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: New Zealand,, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).

[14.2] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: New Caledonia, IAEA, Vienna (1977) 9 pp.

[14.3] CHATHAM ROCK PHOSPHATE LIMITED, Independent JORC Technical report (2012) and mineral resource estimate on the Chatham Rise project in New Zealand, 200 p. (2014).

6.15. PALAU

6.15.1. Geography

Palau is a sovereign state in free association with the United States. It sits in the western Pacific Ocean (Fig. 6.38), where it has common maritime boundaries with the Federated States of Micronesia, the Philippines, and Indonesia. The country comprises roughly 340 islands with cumulative area of 459 km2, which form the western chain of the Caroline Islands in Micronesia. The island with the highest population is Koror. Its capital Ngerulmud is situated on the nearby island of Babeldaob.

It has a tropical rainforest climate with an annual average temperature of 28°C. Rainfall is heavy throughout the year, with annual average of 3 800 mm.

Palau's economy comprises mainly of tourism, subsistence fishing and agriculture [15.1].

6.15.2. Geology

The archipelago of Palau can be subdivided into four geological areas:

- Comprising major of the land area are the islands of Ngemelachel, Ngerekebesang, Babeldaob and the western portion of Koror, which are all volcanic islands. Babeldaob Island is partly made up of old-weathered continental rocks that have been the source of some gold. The volcanic substrates consist of breccias and interbedded tuffs formed during the Eocene and Oligocene. Within this volcanic substrate there are three distinguishable geologic units which record 12 million years of arc history. The erupted material consists of basalt, andesite and dacite. Although eruption was submarine, the islands were formed by uplift;
- The southern and central islands are made up of coralline limestones, known as “Palau Limestone” which is raised coralline reef structures that formed in the warm waters of the western Pacific during the early Miocene to late Pliocene.The calcareous detritus of these ancient reefs are cemented by calcite;
- The southwestern islands are comprised of atolls and low platform islands;
- Atoll islands and reefs are situated northeast and north of Belilou.

Considerable reserves of phosphate were mined during the German and Japanese administrations of the country.

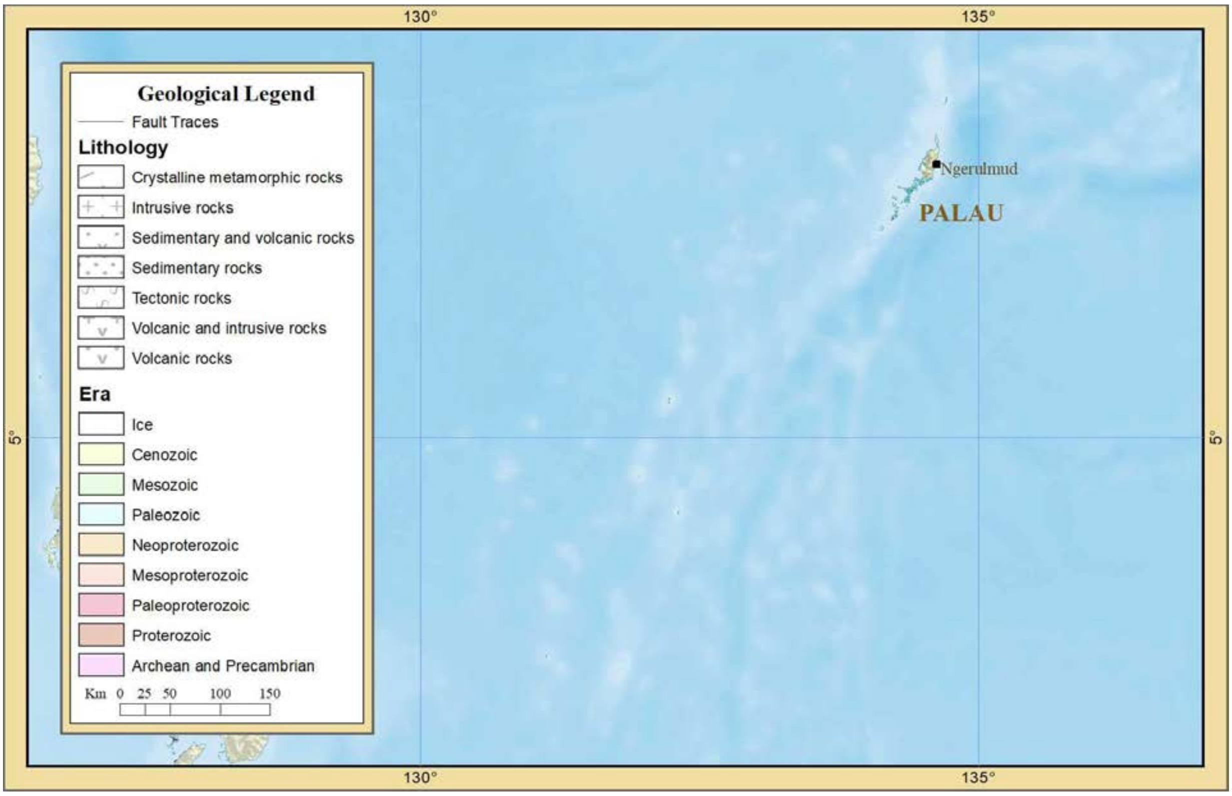


FIG. 6.38. Regional geological setting of the Palau Islands. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.15.3. Uranium exploration

There has been no reported uranium exploration on Palau.

6.15.4. Uranium resources

There are no known uranium occurrences on Palau and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for Palau.

6.15.5. Potential for new discoveries

From a geological point of view, Palau does not have potentially favourable areas for the development of uranium deposits. Owing to the country's size and rock types present, the potential for new discoveries is rated as nil.

6.15.6. Comments

There has been no past production in Palau. Palau has no nuclear power generation.

References to Section 6.15

[15.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Palau (2018) https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2018).

[15.2] NEALL V. E., TREWICK S.A., The age and origin of the Pacific islands: A geological overview.2008. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2607379/

6.16. PHILIPPINES

6.16.1. Geography

The Philippines is situated in the western Pacific Ocean and forms part of the Malay Archipelago, an island group that extends southwards to Indonesia and Malaysia. It comprises a total of 7100 islands (Fig. 6.39). Luzon (104 700 km^2) and Mindanao (94 630 km^2) are the two largest islands that anchor the archipelago in the north and south.

The Philippines archipelago can be divided into four physiographic provinces, taking into consideration inland and submarine morphology, namely: (i) Eastern Physiographic Province, (ii) Central Physiographic Province, (iii) Western Physiographic Province, and (iv) Palawan Physiographic Province (Fig. 6.40).

The Eastern Physiographic Province constitutes a belt limited to the east by the Philippines Trench and its northern extension, the East Luzon Trench, and to the west by the limits imposed by mountain ranges such as the Sierra Madre Range, Western Bicol Range, Samar Highlands and Diwata Range. This belt is divided into three subprovinces: northern Sierra Madre, Bicol and Samar-Davao.

The Central Physiographic Province is bounded on both sides by mountain ranges and comprises cordilleras, lowlands, troughs and small offshore basins. This province is subdivided into six subprovinces: Babuyan, Cagayan-Caraballo, Central Luzon, Bondoc Sarangani, Central Visayas and Cotabato.

The Western Physiographic Province consists of a series of ridges and troughs which collectively constitute the western segment of the Philippine Mobile Belt. The northern section is parallel to the Manila Trench; the southern part to the Sulu Trench. The province is divided into three subprovinces: Zambales, Antique and Zamboanga-Sulu.

The Palawan Physiographic Province comprises ranges, shelves, ridges and offshore basins forming the south-western part of the archipelago. The province is divided into four subprovinces which are parallel to each other along a NE–SW trend. The four subprovinces are: Palawan, Cuyo Shelf, Northwest Sulu Sea Basin and Cagayan de Sulu Ridge.

Located along the north-western fringes of the so-called ‘Ring of Fire’, the Philippines usually experiences frequent seismic and volcanic activities. There are about 20 active volcanoes and several inactive or dormant volcanoes. The most active is Mount Mayon, a stratovolcano in southern Luzon, which last erupted in 2009. In 1991, after lying dormant for about 600 years, Mount Pinatubo in central Luzon erupted and caused widespread damage. Lying to the east of the islands is the Philippines Trench (10 539 m), which has been the epicentre of several earthquakes. Around 20 earthquakes are registered daily, but most are very weak.

With its numerous islands, the Philippines is characterized by irregular coastlines, with several bays, gulfs and inlets. The most important is Manila Bay, with its naturally sheltered harbour. The Philippines coastline is one of the longest, totalling about 36 289 km.

The Philippines is endowed with considerable mineral resources and a major resource is geothermal energy. The country’s valuable mineral deposits include coal, cobalt, chromium, copper, gold, lead, manganese, nickel, silver and zinc. Copper has been mined extensively and is the leading mineral product. The Philippines has substantial coal deposits but limited reserves of offshore petroleum and natural gas.

The Philippines has a tropical climate, usually hot and humid. The average annual temperature is about 26°C. Annual rainfall averages about 2030 mm, with more precipitation recorded along the coastal plains than in sheltered inland valleys. There are two recognized weather conditions, a dry season and a rainy season. In the western part of the country, the rainy season occurs in May–November, when the wind blows from the south-west, and the dry season occurs in December–April, when the wind blows from the north-east. Sitting astride the typhoon belt, the Philippines is frequently visited by tropical storms, normally from June to October. About 20 storms occur every year.

6.16.2. Geology

The Philippines, in general, is characterized by diverse assemblages of igneous, sedimentary and metamorphic rocks ranging in age from pre-Jurassic to Quaternary.

6.16.2.1. Sedimentary and metamorphic rocks

The oldest rock suites that constitute the basement complex are the pre-Jurassic undifferentiated amphibolite, quartzo-feldsphathics, mica schist, phyllite and slate which are frequently associated with marble and quartzite. These rocks are well exposed in Mindoro, Romblon, Buruanga Peninsula, Cuyo Island, Busuanga Island Group, northern Palawan and Zamboanga Peninsula. Exposed on the south-eastern section of Mindoro is Jurassic arkose, subgreywacke and mudstone (Mansalay Formation). Extensively deposited are Cretaceous rocks made up of a transgressive greywacke–shale sequence, intercalated with spilites. These units are associated with tuffaceous clastics in Rizal and with limestone lenses in Catanduanes, Cebu and the Caramoan Peninsula. The metamorphosed parts vary in grade up to greenschist facies.

FIG. 6.39. Regional geological setting of Philippines. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Widely distributed are undifferentiated sequences (metasediments) composed largely of greywacke and metamorphosed shale interbedded with spilitic, basic and intermediate flows and pyroclastics. These units probably date to Cretaceous–Palaeogene. The Palaeocene–Eocene rocks consist of thick, extensive, transgressive mixed shelf and deeper marine deposits, largely wackes and shale associated with minor basal conglomerate, reef limestone and calcarenite, sometimes with dacitic and andesitic flows, pyroclastics and paralic coal measures. The exposures in southern Mindoro and Palawan are largely arkosic and quartzitic clastics. In general, the rocks are moderately folded and intruded by quartz diorite.

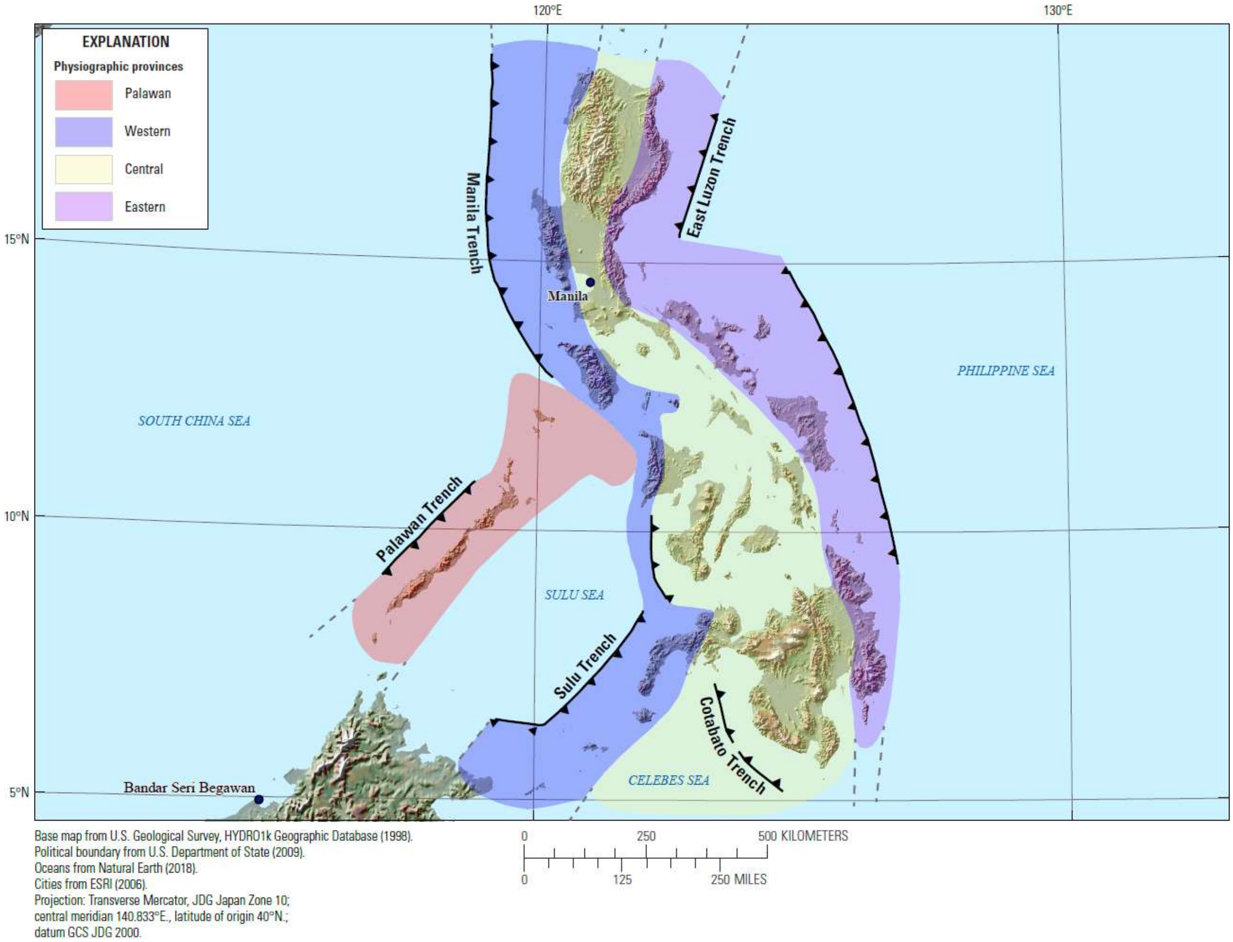


FIG. 6.40. Physiographic provinces of the Philippines [adapted from 16.1].

Oligocene rocks are represented by minor limestone, wackes and shale. These units are generally associated with keratophyre and andesite flows. Exposed extensively are thick, Oligocene–Miocene transgressive mixed shelf marine deposits consisting largely of wacke, shale and reef limestone. In some places, these units are underlain by conglomerate and are associated with coal measures and basic to intermediate lava flows and pyroclastics. In southern Mindoro and Palawan, the rocks are largely arkosic and quartzitic clastics. Generally, the rocks are well indurated, folded and locally intruded by quartz diorite.

The Upper Miocene–Pliocene sequence, consisting largely of marine clastics and locally transgressive pyroclastics and tuffaceous sedimentary rocks, are associated with calcarenite and silty limestone in Luzon, central Visayas and Mindanao, and intercalated with reef limestone and dacite and andesite flows in Zamboanga. In Palawan, the rocks are mainly arkose and arenite. The Pliocene–Pleistocene rocks are composed of marine and terrestrial sediments and include extensive reef limestone, water-borne pyroclastics and localized terrace gravel deposits. Confined to river valleys, deltaic areas and coastal plains are alluvial, fluviatile, lacustrine and beach deposits of Recent age.

6.16.2.2. Intrusive rocks

The oldest known intrusives are the pre-Jurassic (?) granite identified in western Zamboanga and the granodiorite occurring in Batangas.

The Cretaceous–Palaeogene rock units are made up of undifferentiated ultramafic and mafic plutonic rocks, essentially peridotite associated with late gabbro and/or dolerite (diabase) dykes. These rocks are generally thrust or upfaulted into Tertiary and older formations.

The Palaeogene intrusives are composed mostly of quartz diorite. Probably included in this group are the granodiorite occurring in Camarines Norte and the quartz monzonite in Palawan. The Neogene intrusives, on the other hand, are made up largely of intra-Miocene quartzdiorite and occur mostly as batholiths, stocks, laccoliths and some sills, dykes and other minor bodies. Included in this group are granodiorite and diorite porphyry facies and Late Miocene dacite.

6.16.2.3. Volcanic rocks

The volcanic deposits occupy a considerable portion of the archipelago. The Cretaceous–Palaeocene spilitic and basaltic flows constitute the oldest volcanic rocks. These rocks are usually intercalated with greywacke.

The undifferentiated volcanics (metavolcanics) are composed essentially of metamorphosed submarine flows, spilites, basalts, keratophyres and andesites. These units are dated as Cretaceous–Palaeogene and confined to structural highs and mountain ranges. The Palaeocene–Eocene volcanics are composed of minor dacite and andesite flows and dykes which are generally intercalated with or intrude Eocene clastics. The Oligocene volcanics are made up essentially of keratophyre and andesite flows, often with pyroclastics and chert of volcanic origin. The Oligocene–Miocene volcanic sequence consists mostly of submarine andesite and basalt flows that are intercalated with pyroclastics and clastic sedimentary rocks and/or reef limestone lenses. This sequence is confined largely within the axial zones of the archipelago. The Upper Miocene–Pliocene volcanics are made up principally of dacite and andesite flows and generally associated with pyroclastics.

The Pliocene–Quaternary volcanics are represented by non-active cones (generally pyroxene andesite), dacite, andesitic plugs and basaltic dykes. The volcanic plain or volcanic piedmont deposits, on the other hand, are composed mainly of pyroclastics and volcanic debris at the foot of volcanoes. The Quaternary volcanics are deposits associated with currently active volcanoes (with eruptions recorded since 1616), as exemplified by Mounts Taal, Mayon, Bulusan and Canlaon.

6.16.2.4. Structures

Tectonically, the Philippines archipelago is located along the junction of two colliding plates, the Philippine Sea Plate to the east, which is moving north-westwards and is being subducted beneath the East Luzon Trench and the Philippines Trench, and the Eurasian Plate to the west which is being subducted along the Manila Trench. The Philippines Fault, one of the country’s active faults is a major strike-slip fault that stretches for about 1200 km, extending from Luzon in the north to Mindanao in the south.

6.16.3. Uranium exploration

The search for uranium in the Philippines dates from 1953 with the joint efforts of the United States Atomic Energy Agency and the then Philippines Bureau of Mines (now Mines and Geosciences Bureau). The initial investigation covered most of the existing mines and other mineral districts known for the occurrence of valuable metallic deposits such as copper and gold, where several radiometric anomalies were identified. Over the following 25 years, exploration work consisted mainly of airborne and ground radiometric surveys conducted intermittently by the Government, mainly by the Philippines Bureau of

Mines and the then Philippines Atomic Energy Commission (now Philippine Nuclear Research Institute) as well as by private entities [16.2–16.4]. The discovery of uranium at Larap (Camarines Norte) in 1964 is the most important development to date.

A more appropriate and systematic geochemical approach was introduced in 1977 through technical assistance provided by the IAEA. Subsequent extensive regional geochemical exploration was undertaken in different parts of Luzon and Visayas, mainly by various Government agencies and spearheaded by the Philippines Atomic Energy Commission, the Philippines Bureau of Mines, the Bureau of Energy and Development and the Philippine National Oil Company. In response, the Philippines Atomic Energy Commission launched a nationwide campaign to explore for uranium, with the primary objective of assessing the country's nuclear resource potential.

The outcome of these regional surveys (covering 152 000 km^2) has delineated several anomalous areas and some of these were subsequently followed up. The Philippines Bureau of Mines, the Bureau of Energy and Development and the Philippine National Oil Company participation was, however, short lived and they ceased their exploration programme for uranium in the early 1980s owing to discouraging results. Since then, the Philippines Atomic Energy Commission has been the sole agency actively involved in the search for uranium [16.5–16.7]. However, during the past 10 years (1998–2008), exploration has generally slowed down. To date, only 50% of the country has been explored for uranium (Fig. 6.41).

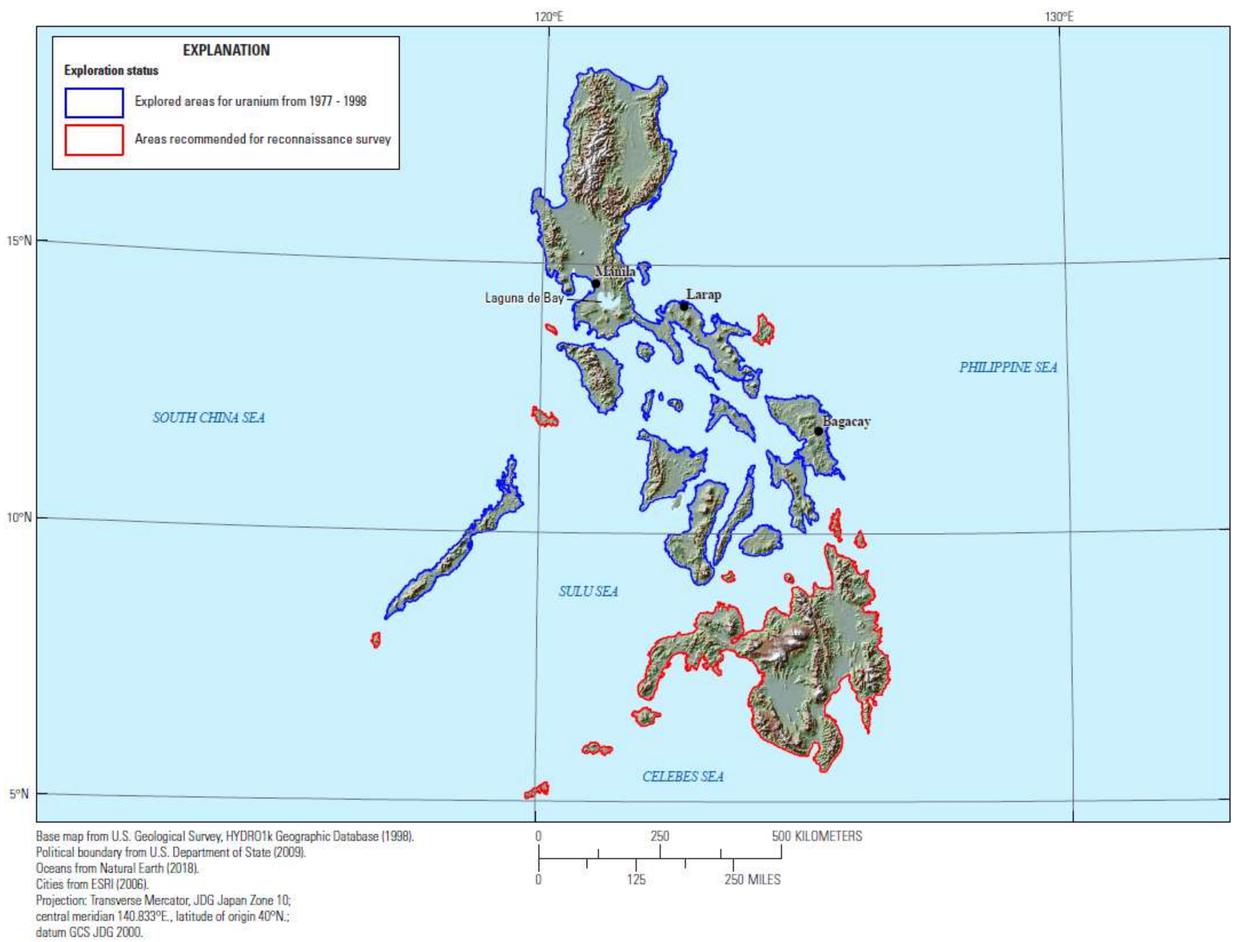


FIG. 6.41. Status of uranium exploration in the Philippines.

6.16.4. Uranium potential

The most significant development, after years of exploration, was the discovery of uranium occurrences in the Larap mining district (Camarines Norte) by Philippine Iron Mines in 1964 and the identification of radiometric anomalies in 1971 in the Bagacay copper mine, Samar, in eastern Visayas by the Sumiko Consultants Company Ltd, in partnership with the South Seas Oil and Mineral Exploration Development Company.

In Larap, uranium occurs in the form of uraninite localized within a known magnetite orebody associated with copper and molybdenum sulphides. Initial resource assessment by IAEA experts indicated a resource of 200 tU with an average grade of 0.03% U.

In the Bagacay area, radiometric analysis of rock samples from the dacite and andesite that host the main copper orebody showed a uranium content of 3–29 ppm U.

Although the results of the nationwide geochemical survey covering most of Luzon and Visayas, in general, may not have been very encouraging, several areas have, however, been identified as having minor radiometric and geochemical anomalies that could warrant further investigation. The most interesting, although relatively small in extent, is the identification of rare earth deposits in northern Palawan. The rare earths occur as alluvial beach placer deposits, consisting of radioactive resistates, mostly allanite and minor monazite.

Other areas of interest are in central Palawan and at El Nido, at the northern tip of Palawan. The former is underlain by Lower Palaeozoic rocks while the latter is associated with a granitic intrusion.

6.16.5. Comments

A considerable portion of the country remains unexplored for uranium, particularly Mindanao. It may be worthwhile continuing exploration to provide a comprehensive evaluation of the country's nuclear resource potential and thereby establish the natural baseline radioactivity level for environmental monitoring. Mindanao is among the prospective areas initially identified and would be recommended for systematic appraisal, primarily on the basis of having favourable geology and extensive metalliferous mineralization such as copper and gold, among others.

The UDEPO database lists the most significant deposit for the Philippines as Bessemer (Larap Mine).

References to Section 6.16

[16.1] BUREAU OF MINES AND GEOSCIENCES, DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES, Geology and Mineral Resources of the Philippines, 1st edn, Vol. 1, Manila (1981).

[16.2] CAMERON, J., Prospection and Evaluation of Nuclear Raw Materials: Report to the Government of the Philippines, TA Report No. 175, IAEA, Vienna (1965).

[16.3] HERNANDEZ, E.C., SANTOS, Jr., G.S., MAGSAMBOL, W.N., RAMOS, A.F., Uranium Exploration in the Philippines: An Overview, PNRI Tech. Rep., PNRI, Quezon City (1987).

[16.4] LAWRENCE, G.M., Nuclear Materials Prospection: Report to the Government of the Philippines, TA Rep. No. 1045, IAEA, Vienna (1975).

[16.5] RAMOS, A.F., SANTOS, Jr., G.S., MAGSAMBOL, W.N., REYES, R.Y., Status of Uranium Exploration in the Philippines, PNRI Tech. Rep., PNRI, Quezon City (1991).

[16.6] SANTOS, Jr., G.S., Report on the mineralogical characterization of heavy minerals from northern Palawan, Philippines, Philipp. Nucl. J. 8 27–44 (1991).

[16.7] SANTOS, Jr., G.S., et al., Reconnaissance Rare Earth Geochemical Exploration in Northern Palawan, PNRI Tech. Rep., PNRI, Quezon City (1991).

6.17. SINGAPORE

6.17.1. Geography

Singapore is a south-east Asian city State located at the southern tip of the Malay Peninsula, 137 km north of the Equator. A small island country made up of 63 islands, it is separated from Malaysia by the Straits of Johor to the north and from Indonesia's Riau Islands by the Singapore Strait to the south. Singapore has a tropical climate with no distinctive seasons, high humidity and abundant rainfall. Temperatures usually vary in the range 23–32°C. April and May are the hottest months, with the wetter monsoon season lasting from November to January.

The Singaporean economy depends heavily on exports and particularly important sectors are manufacturing and refining, which include significant electronics, petroleum refining, chemicals, mechanical engineering and biomedical sciences sectors. Tourism also forms a significant part of the economy; 10.2 million tourists visited the country in 2007. Singapore is a world leader in several economic areas. It is the world's fourth leading financial centre, the world's second biggest casino gambling market, one of the world's top three petroleum refining centres, the world's largest oil rig producer and a major ship repairer. The port is one of the five busiest ports in the world [17.1].

6.17.2. Geology

Singapore is an intensely developed urban area. Not much is known about the types of rock found on the islands essentially because its physical environment has been modified, hidden or covered during development. Igneous rocks are found in Bukit Timah, Woodlands and Pulau Ubin islands. Granite makes up the bulk of the igneous rock. Gabbro is also found in the area. Sedimentary rocks are found in the eastern part of Singapore and mainly comprise sandstones and mudstones (Fig. 6.42). Metamorphic rocks are found in the north-eastern part and also on Pulau Tekong, off the east coast [17.2].

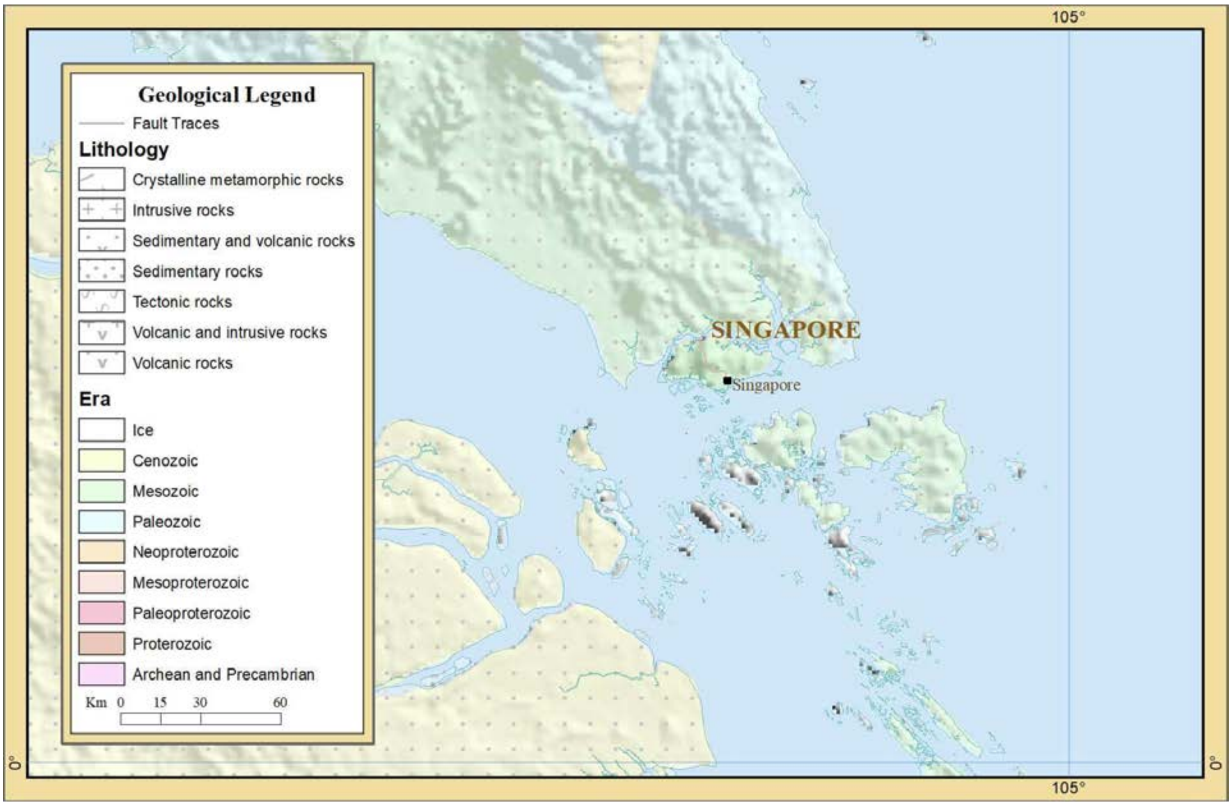


FIG. 6.42. Regional geological setting of Singapore. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.17.3. Uranium exploration

No uranium exploration activities have been reported.

6.17.4. Uranium resources

No uranium resources have been located in Singapore and there is no potential for any discoveries.

The UDEPO database does not list any known deposits for Singapore.

6.17.5. Comments

Singapore has no uranium production. Singapore has no existing nuclear facilities and no plans to develop nuclear generating capacity. Consequently, it has no reactor related uranium requirements.

References to Section 6.17

[17.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Singapore, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).
[17.2] P3 PLANNING ENGINEER, Geologic Map of Singapore and Soil, http://www.p3planningengineer.com/productivity/soil%20category_temp%20works.htm (accessed April 2013).

6.18. SOLOMON ISLANDS[11]

6.18.1. Geography

Solomon Islands are a group of islands in the Melanesian area of the southwestern Pacific, which extends in a northwest-southeast direction for almost 1500 km (Fig. 6.43). The group contains a number of low coral atolls, but the larger islands are all volcanic and rugged. The islands are arranged in two parallel chains that converge on the southernmost island, San Cristobal.

In the Solomon Islands, most of the population depends on agriculture, fishing, and forestry. The islands have significant reserves of bauxite on Rennell Island, phosphates on Bellona island, lead, zinc and nickel. Gold has been extracted on Guadalcanal island (The Gold Ridge mine was operated between 1998 and 2000 and from 2010 to 2014) [18.1].

6.18.2. Geology

The Solomon Islands have been formed along the converging Indo-Australian and Pacific plates during the Eocene period. Tectonic evolution of this region has resulted in two stages of arc development and has influenced the magmatic character of these island arc volcanoes. Very little is known of the geology of the Solomon Islands.

[11] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

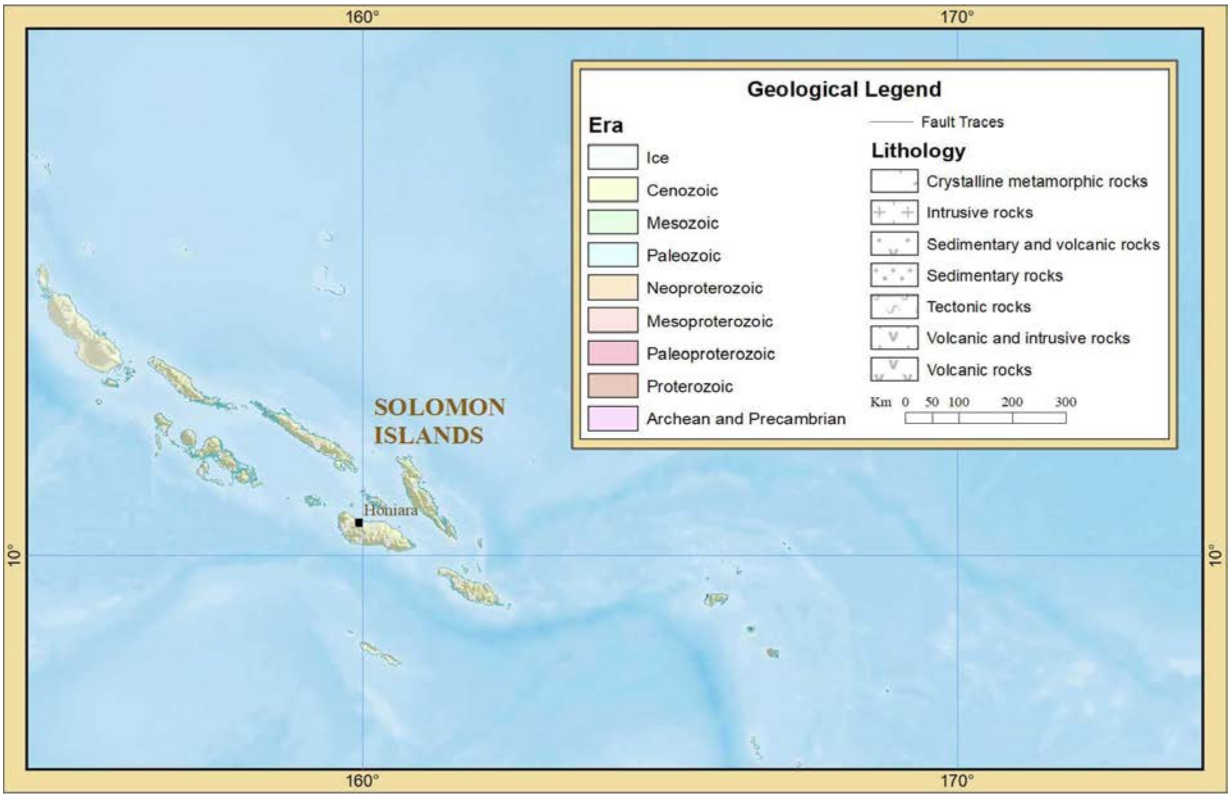


FIG. 6.43. Regional geological setting of Solomon Islands. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.18.3. Uranium exploration

There has been no reported uranium exploration in the Solomon Islands who. never reported to the Red Book.

6.18.4. Uranium resources

There are no known uranium occurrences in the Solomon Islands and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for Solomon Islands.

6.18.5. Potential for new discoveries

Volcanic islands of the Solomon Islands contain concentrations of several minerals. Uranium mineralization may also be found in this environment. In addition, a quantity of uranium is expected to be contained in the Bellona phosphate deposits (In the 70s, the Bellona deposit was estimated to contain about 10 million metric tons of phosphate rock).

The 1977 IUREP study estimated the uranium potential of the Solomon Islands to between 1,000 and 10,000 tonnes uranium (the true potential may be closer to the low end than to the high) [18.2].

References to Section 6.18

[18.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Solomon Islands, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2012).

[18.2] HANSEN M.V., BOWMAN J., IUREP NATIONAL FAVOURABILITY STUDIES N.F.S. No. 100. Democratic Kampuchea (Cambodia) (1977).

6.19. THAILAND

6.19.1. Geography

Thailand is located in south-east Asia with the Gulf of Thailand lying to the south and east, and the Strait of Malacca to the west. Thailand has borders with Cambodia, the Lao People's Democratic Republic, Malaysia and Myanmar. The topography of the country is characterized by three major units: the mountains, the central plain and the upland plateau.

The north consists of mountains reaching into Thailand from Myanmar and the Lao People's Democratic Republic. They continue in the west as an elongated ridge (Tenasserim Range) which extends southwards into Malaysia. The elevations in the north exceed 2 000 m, with the highest peak rising to 2 500 m. The mountains are incised by steep valleys, characteristic of the considerable uplift experienced by the mountain system. The climate in the mountainous areas is temperate and allows different types of plant to be cultivated. Natural resources include forests of hardwood, for which the country is renowned.

The central part is drained by the Chao Praya River system, which flows south of Bangkok and through a delta system into the Gulf of Thailand. The central area is the heart of Thailand which is often referred to as 'the rice bowl'. A distinctive feature of the central area is the system of irrigation channels providing the background for rice agriculture. The soil is very fertile.

The central part is the most densely populated part of the country, except for the large cities. The climate in the central part is tropical and marked by characteristic differences between the hot and dry season and the wet season (high rainfall and high humidity).

The north-eastern part of the country is formed by the Khorat Plateau, a hilly region, from which rivers drain into the Mekong River. Larger parts of the region are covered by lateritic soil, which, owing to its relatively high clay content, retains moisture over a long period. This favours agricultural use as the area has the longest dry period in Thailand. However, the agricultural potential is limited to a more restricted variety of crops compared with other parts of the country [19.1, 19.2].

6.19.2. Geology

The oldest rocks are found in the west and to the south, on the peninsula (Fig. 6.44). These consist of Precambrian gneiss and schist of the Yunnan–Malaya Orogen. These rocks are overlain by Cambrian, Ordovician and Silurian formations. The following succession of slate, phyllite and quartzite are of Silurian–Lower Carboniferous age. The overlying formations are of Upper Carboniferous–Permian age and comprise limestone. Triassic rocks are represented by volcanic rocks at the base, followed by shale, sandstone, limestone and, finally, shale and conglomerate.

The eastern and northern parts of the country are characterized by rocks of the Khorat Group. Mainly of non-marine composition, the Khorat Group has been divided into three major units. The lower unit consists of conglomerate, limestone, intercalations of rhyolite, shale and sandstone and has been dated as Upper Triassic–Lower Jurassic. The middle unit is mainly sandstone and siltstone. The upper unit, which is still the subject of debate, comprises a variety of sandstone, siltstone, conglomerate and limestone strata of Lower Cretaceous age. At the top of the Khorat Group, basins with saline deposits (Salt Formation) occur locally.

In southern Thailand, mainly Tertiary deposits are found, containing lignite seams. In north-east and northern Thailand, magmatic rocks of basic composition are found. Granites are also abundant. Signs of former magmatic activity are also observed in the western area. The age of these rocks ranges from Late Devonian to Early Permian. Granitic intrusions of Triassic and Cretaceous age are common in the range which extends from Myanmar (Tenasserim Range) through the western part of Thailand and into Malaysia. These granites carry deposits of tin and tungsten. Deposits of lead are being mined.

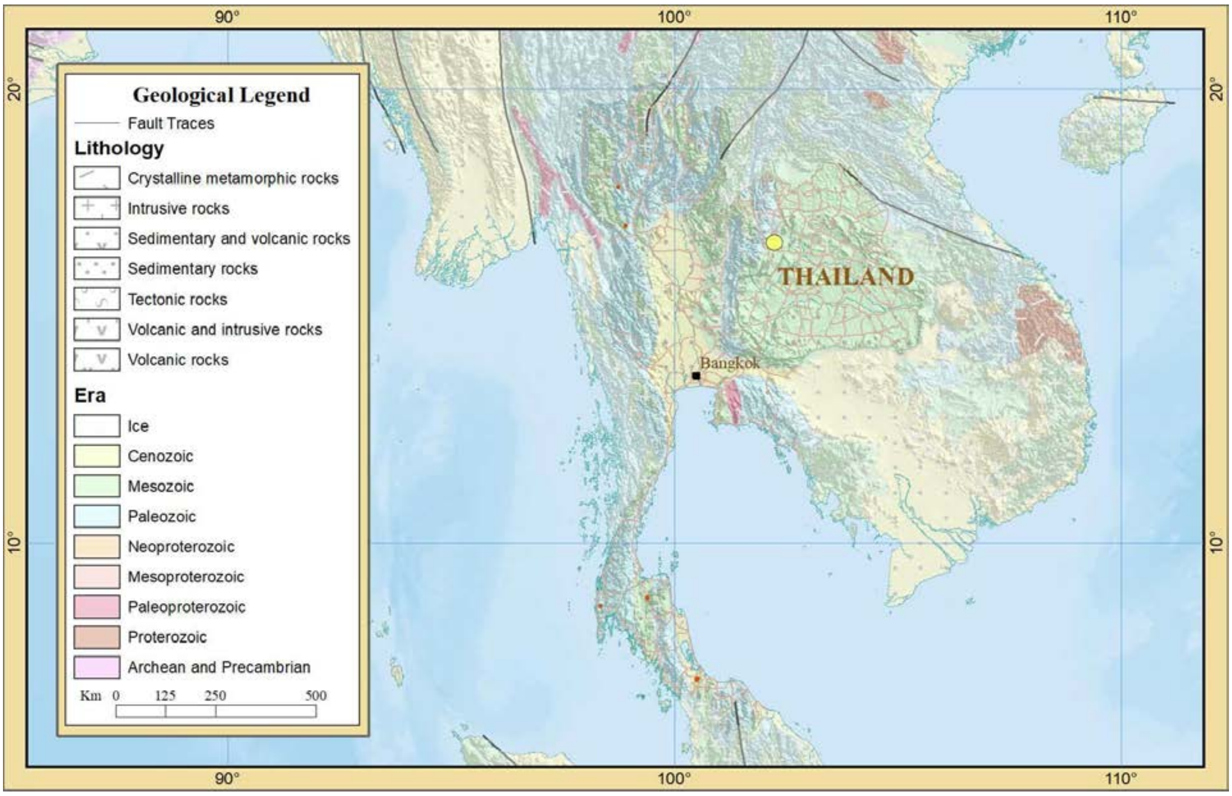


FIG. 6.44. Regional geological setting of Thailand showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

6.19.3. Potentially favourable uranium-bearing rocks

Some of the granites host radioactive minerals (pyrochlore, samarskite and others) in disseminated form or in veins. They are often associated with tin and tungsten. The non-marine sandstones of the Khorat Plateau have been the subject of uranium prospecting as they exhibit similarities to the rocks of the Colorado Plateau [19.2]. The Phu Wiang Basin in Khon Kaen Province hosts anomalous uranium values and a small copper–uranium mineralized zone was found in sandstone of Lower Jurassic age [19.3]. The deposition of the sandstone occurred in a braided channel system. Owing to the lack of roll front features or other promising parameters, the potential was regarded as limited. The lignite deposits did not record encouraging results.

Areas containing ‘high background’ granites were examined without positive results. In addition, a few anomalies and small mineralized zones were detected during exploration and mining for other commodities. The tailings of tin mining at Phuket carry monazite which includes some uranium. Extraction of uranium may require a specific technology capable of the co-extraction of thorium [19.2, 19.3].

6.19.4. Uranium exploration

The discovery of uranium anomalies in the Khorat Plateau led to systematic exploration in the early 1970s in an area of about 2 km² in the Phu Wiang Basin. The work was conducted by Thailand’s Department of Mineral Resources, with assistance provided by the US Geological Survey. Later, the IAEA conducted a bilateral programme. The Free University of Berlin also assisted the Department of Mineral Resources in the late 1970s and early 1980s, and the German Federal Institute of Geosciences and Natural Resources also carried out an investigation of sedimentary deposits in the early 1980s [19.3].

A nationwide airborne geophysical survey contracted by the Department of Mineral Resources was flown by Kenting Earth Sciences Ltd of Canada between 1985 and 1987. No exploration has been carried out since 1996. The details of work done and the results obtained are not available. However, historical expenditure details are given in Fig. 6.45 for a total of USD $11.537 million including 6150 metres of drilling.

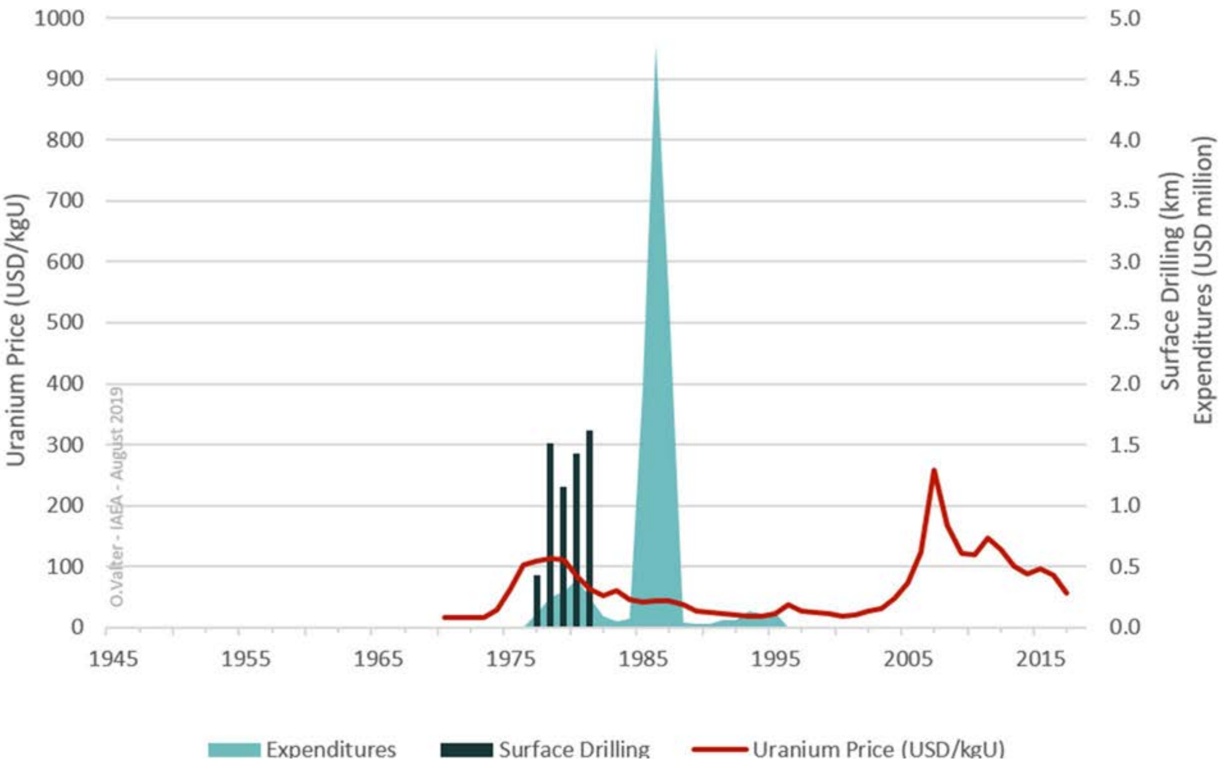


FIG. 6.45. Domestic uranium exploration data for Thailand. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

6.19.5. Uranium resources

Reports in [19.5] estimate the uranium mineralization hosted in Jurassic sandstone at Phu Wiang as a reasonably assured resource of 4.5 tU at <US $130/kgU, based on a cut-off grade of 0.01% U.
An inferred resource of 7 tU at <US $130/kgU, grading 0.02–0.25% U and based on a cut-off grade of 0.05% U, is reported for fluorite vein deposits in granites in the Doi Tao and Om Koi Districts in Chiang Mai Province, northern Thailand. Rare earth exploration activities in the Muang district of the Chiang Rai province has delineated unconventional resources of 31 800 t U and 101 800 t Th from thick weathering horizons developed on the granitic basement. Average concentrations are 22 and 72 ppm for U and Th [19.6]. Undiscovered resources are not reported.

The UDEPO database lists the most significant deposits for Thailand as Nang Lae, Lom Put, Sang Sombun, Huai Haeng, Khao Sai Daeng, Nam Rop, Bang San Tea, Phu Maung, Doi Chang, Doi Tao.

6.19.6. Potential for new discoveries

Some potential exists for sandstone hosted deposits in continental sedimentary formations, particularly in the Khorat Plateau. However, the results of exploration undertaken to date has been discouraging. Expectations were raised on the potential for vein type mineralization when uranium was found to be associated with fluorite. Results obtained so far indicate that any such potential is limited. There may be some potential in the monazite tailings resulting from tin mining. Overall potential is rated as being low. On the basis of the results achieved to date, the country's overall potential for any discovery is considered to be limited.

6.19.7. Comments

There has been no previous production and none is envisaged. There is no installed nuclear capacity and therefore there are no uranium requirements.

References to Section 6.19

[19.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Thailand, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).

[19.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[19.3] BARTHEL, F.H., "Sandstone uranium deposits in central Sumatra, Indonesia, and northern Thailand", Uranium Deposits in Asia and the Pacific: Geology and Exploration (Proc. Tech. Mtg Jakarta, 1985), IAEA, Vienna (1988) 179–191.

[19.4] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[19.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[19.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

6.20. TIMOR-LESTE[12]

6.20.1. Geography

Located in south-east Asia, the island of Timor-Leste forms part of the Malay archipelago and is the largest and easternmost of the Lesser Sunda Islands. The capital of Timor-Leste, its largest city and its main port is Dili, located on the northern coast of the country.

To the north of the mountainous island lie the Ombai Strait, Wetar Strait and the greater Banda Sea. To the south, the Timor Sea separates the island from Australia, and to the west lies the Indonesian Province of East Nusa Tenggara. The highest point is Mount Ramelau (also known as Mount Tatamailau) at 2963 m.

The local climate is tropical and generally hot and humid, characterized by distinct rainy and dry seasons. The easternmost area of Timor-Leste consists of the Paitchau Range and Iralalaro area. This area contains the last remaining tropical dry forested area within the country. It hosts a number of unique plant and animal species and is sparsely populated. The northern coast is characterized by several reef systems.

Timor-Leste is one of the world's poorest countries. The agriculture sector is moving from subsistence crops to cash crops (coffee) in an attempt to create an export oriented economy. Future hopes are linked to the development of offshore petroleum reserves [20.1].

---

[12] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition, this country has a IUREP report as the basis for updating in this publication.

6.20.2. Geology

The geology of Timor-Leste (Fig. 6.46) has long been recognized as being highly complex and many theories have been proposed to explain the island's tectonic evolution. Despite the conflict of ideas, some broad geological observations suggest a generalized model of the tectonic development of this region since the Neogene.

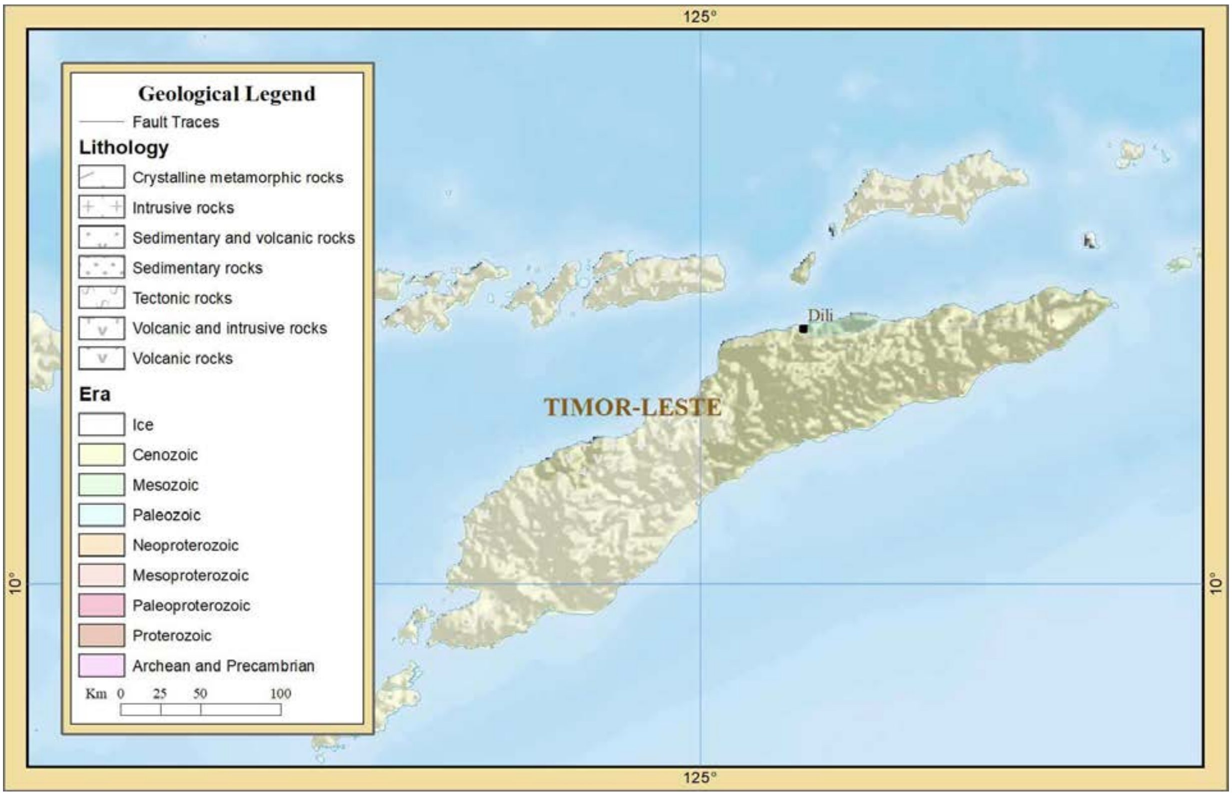


FIG. 6.46. Regional geological setting of Timor Leste. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Gravity surveys have confirmed that the Australian continental crust extends as far as the north coast of Timor-Leste. Overlying this gently deformed Australian basement are rocks derived from the distal Australian passive margin (para-autochthonous units), formed in response to the Middle–Late Jurassic break-up of eastern Gondwana and subsequent sea floor spreading. Passive margin conditions prevailed until the Neogene arc–continent collision, when rocks derived from the pre-collisional Banda fore arc (allochthonous units) were incorporated into the collision complex (Fig. 6.47). The rocks exposed include:

- Early Permian–Early Pliocene variably deformed and metamorphosed deep water sediments of the Australian passive margin (Gondwana and Kolbano Sequences);
- Late Miocene–Early Pliocene Bobonaro Scaly Clay, an olistostrome thought to be emplaced as a gravity slide in response to the southwards tilting of Timor-Leste during subduction;
- Banda Allochthon, comprising pre-Cretaceous metamorphic rocks overlain by sedimentary deposits and ophiolites of Upper Jurassic–Lower Pliocene age, all of which are derived from the pre-collisional Banda fore arc;
- Post-orogenic Upper Miocene–Recent coral reefs, alluvial terraces and turbidites, unconformably overlying all other lithotectonic units [20.2–20.6].

6.20.3. Uranium exploration

No exploration activities have been reported.

6.20.4. Uranium resources

No identified or undiscovered resources are reported and the potential for uranium discoveries is regarded as very limited. The UDEPO database does not list any known deposits for Timor-Leste.

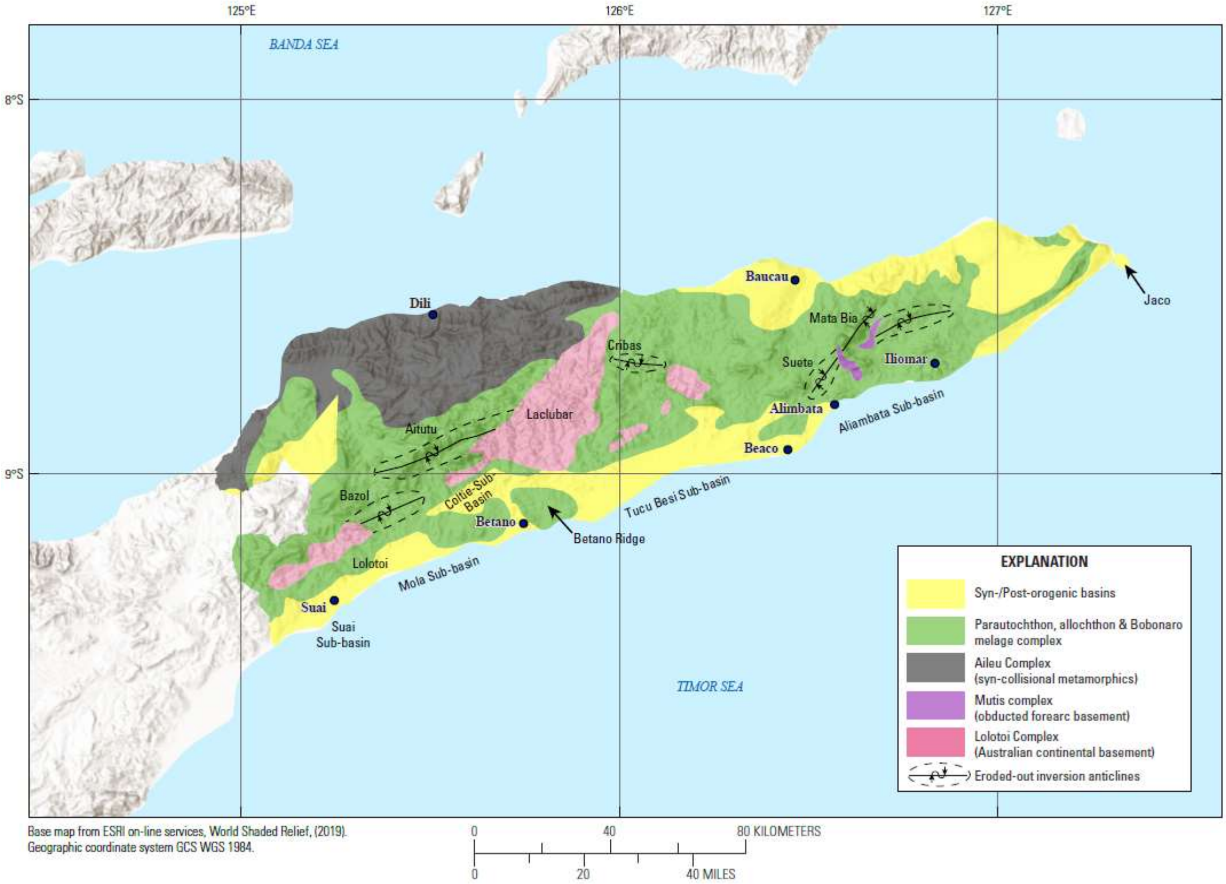


FIG. 6.47. Simplified map of geological units in Timor-Leste (adapted from Charlton [20.6]).

References to Section 6.20

[20.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: East Timor, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed June 2009).

[20.2] CHORLTON, L.B., Generalized Geology of the World, Geological Survey of Canada, Open File 5529, 2007.

[20.3] HAMSON, G., The Tectonic Evolution of East Timor and the Banda Arc, University of Melbourne (2004).

[20.4] ABBOTT, M.J., CHAMALAUN, F.H., "Banda Arc volcanics", The Geology and Tectonics of Eastern Indonesia (BARBER, A.J., WIRYOSUYONO, S., Eds), Geological Research and Development Centre Special Publication, Indonesia (1976).

[20.5] HAMILTON, W., Tectonic Map of the Indonesian Region, U.S. Department of State in Cooperation with the Geological Survey of Indonesia, Miscellaneous Investigations Series, published by the USGS as Map I-876-D (1981).

[20.6] CHARLTON, T.R., The petroleum potential of East Timor, APPEA J. 32 (2002) 351–369.

6.21. VIET NAM

6.21.1. Geography

Viet Nam occupies the eastern margin of Indochina. The country extends over 1650 km and is only 50 km wide at its narrowest point.

Geographically the country is divided into eight regions: the Northwest, Northeast and Red River Delta in the north, North Central Coast, South Central Coast and Central Highlands in the centre, and Southeast and the Mekong River Delta in the south.

The Northeast has a border with China and is a rugged continuation of the Yunnan Mountains. The Northwest, bordering the Lao People's Democratic Republic, has the highest peak in the country (3142 m). The Red River Delta is densely populated and includes the capital Hanoi. The Red River rises in China's Yunnan Province and carries significant volumes of fine-grained sediment resulting in growth of the alluvial fan in the Gulf of Tonkin. Flooding of the Red River occurs frequently and dykes are needed to protect the surrounding countryside. The water is controlled by a system of canals used for irrigation of rice fields.

The Central Highlands are characterized by the transition to rugged, forest covered mountains and plateaux. Parallel to the highlands, flat lowlands stretch from the Red River Delta in the north to the Mekong River Delta in the south. The plains have rich soil and are used for agriculture. As with the Red River Delta, the Mekong River Delta receives large amounts of alluvial sediment which results in the growth of the delta. The area is criss-crossed by canals and river branches. This area is one of the major rice growing areas of the world. The Mekong River is one of the world's largest rivers, in terms of both length and flow. Its source lies in the mountains of China and it runs through Yunnan Province, forming the boundary between Myanmar and the Lao People's Democratic Republic, and between the Lao People's Democratic Republic and Thailand before flowing through eastern Cambodia, finally entering southern Viet Nam and discharging through a delta into the South China Sea, south of Ho Chi Minh City.

The climate of the country is tropical and heavily influenced by the monsoon, and varies according to elevation and latitude. Normally, the dry season runs from November to April; the remaining months receiving the heavy rainfall of the monsoon.

Arable land accounts for approximately 20% of the total land usage and is mainly used for the cultivation of rice and vegetables. A variety of fruits are also grown. Forests and woodland cover approximately 30% of the land.

Mineral resources include base metals, bauxite, coal, chromite, ilmenite, iron, manganese, nickel and phosphate, as well as offshore petroleum and gas deposits [21.1].

6.21.2. Geology

6.21.2.1. General

The oldest rocks in Viet Nam are migmatite and orthogneiss (Fig. 6.48), which are believed to belong to the Archaean, and these are found in the north. In central Viet Nam, the Precambrian Kontum Massif comprises metamorphic rocks. Both the probable Archaean and the Kontum Massif were parts of Upper Proterozoic areas belonging to the Yangtze and the Indonesian Shield. The oldest granitic intrusions have been dated at 2300 Ma in the basement underlying southern Viet Nam.

During the Palaeozoic, the Shield areas were surrounded by troughs that were subject to several episodes of folding. Cambrian sediments are covered by thick Silurian schists and sandstone. During the Devonian and Permo-Carboniferous, limestone was the dominant rock type deposited, preferentially in central Viet Nam and in the north. Age determinations for Palaeozoic granites give a range of 360–250 Ma. Late Hercynian folding affected the rocks in the centre. During the Triassic, mainly terrigenous sediments were deposited, intercalated with volcanics. The Indosinian Orogeny, occurring during the Triassic, affected the northern area. As a result, continental basins developped in which coal deposits were formed. Continental sedimentation continued in troughs formed in the Jurassic and Cretaceous periods. Finally, during the Tertiary and Quaternary, graben and troughs were filled with sediments. Late Tertiary–Early Quaternary basaltic traps also formed plateaux in southern Viet Nam. Viet Nam forms part of the South-east Chinese Plate, which consists of Precambrian continental blocks, folded Palaeozoic ranges and Mesozoic cover rocks. In addition, parts of oceanic crust are represented [21.2–21.4].

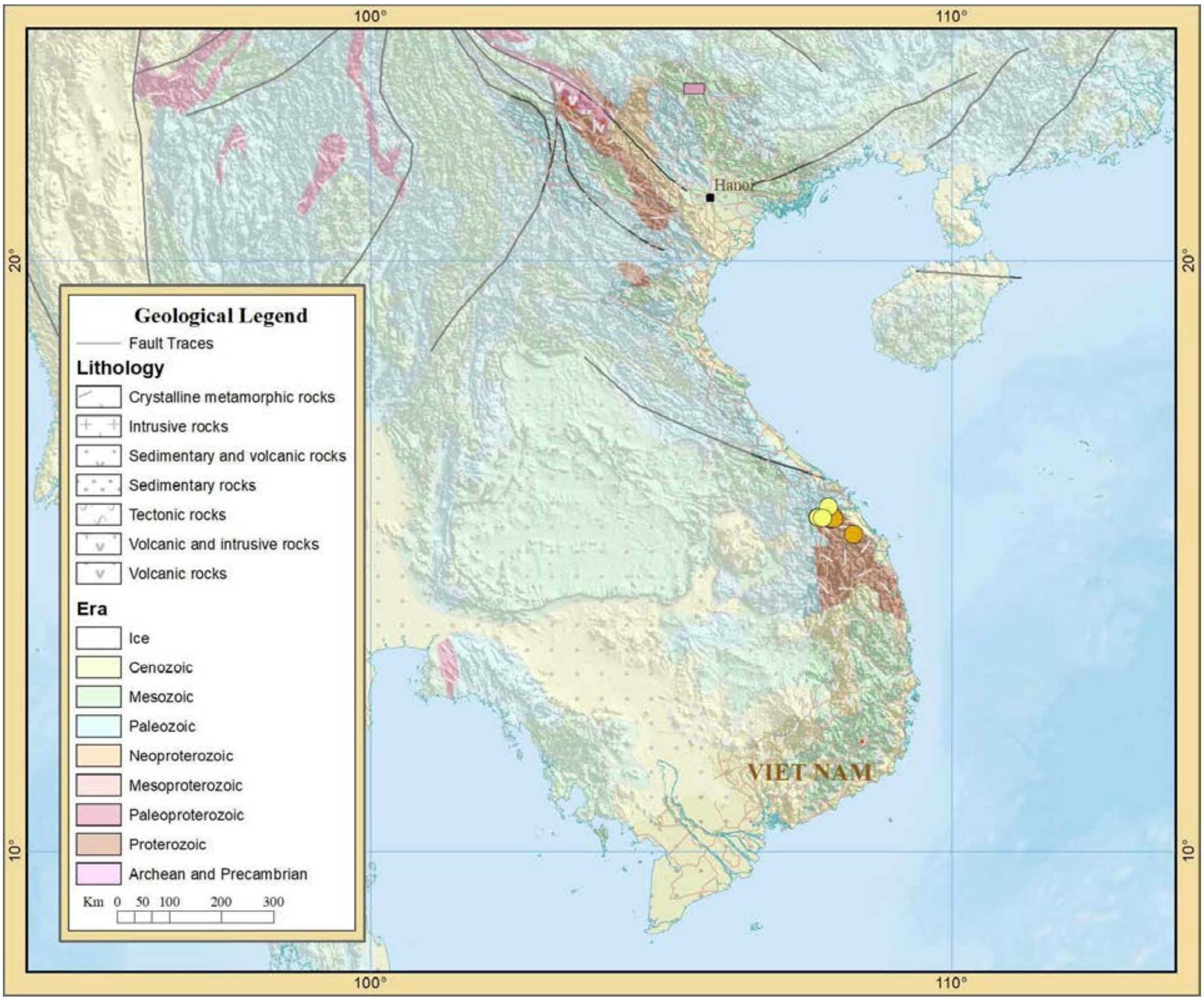


FIG. 6.48. Regional geological setting of Viet Nam showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map

.

6.21.2.2. Geology of potentially-favourable areas

Uranium anomalies found in granites during the 1950s led to the discovery of some vein occurrences. No detailed information was available as to whether the occurrences were investigated in detail. Deposits of rare earth elements at Nam Xe in Northwestern Province are known for their radioactivity, owing to the presence of thorium and uranium. Graphite deposits, for example Tien An in the Central Province, and coal deposits have elevated levels of uranium.

Pleistocene sediments of Bin Duong in Northeastern Province, unconformably overlie Cretaceous granites and Devonian limestone and contain surficial type uranium mineralization. Secondary uranium minerals have been found in lenses and pockets. The sediments also contain phosphate reserves of over 500 000 t P_2O_5. Triassic sediments of the Nong Son Basin in central Viet Nam have been investigated for uranium, with positive results [21.3, 21.4].

6.21.3. Uranium exploration

The first uranium exploration programmes started in 1955 by French geologists working for the Geological Department of Indochina. After 1978, systematic exploration covered nearly all of the territory by surface radiometry at a scale of 1:200 000. About one-third of the country was explored on the ground at a scale of 1:50 000, and about a quarter of the territory was covered at a scale of 1:25 000–1:50 000 by airborne radiometric and magnetometer surveys. This led to the discovery of a large number of promising areas in Cao Bang, Lao Cai, Yen Bai and Quang Nam Provinces. Detailed exploration (e.g., 75 800 m drilling and underground work) was conducted on what was judged to be a promising target.

Responsibilities for exploration now reside with the Department of Geology and Minerals (Geological Division for Radioactive and Rare Elements), which operated under the then Ministry of Industry (now the Ministry of Environment and Natural Resources). During 1997–2002, exploration was concentrated on evaluating the potential of the sedimentary deposits of the Nong Son Basin, Quang Nam Province (central Viet Nam). In 1997–1999, detailed exploration work in the Palua area, over an area of 2.8 km^2, included 15 196 m of drilling and 2926 m^3 of trenching and bulk sampling. In 2000–2002, the Geological Division for Radioactive and Rare Elements carried out exploration and evaluation work at Parong, covering an area of 6.8 km^2, with 1465 m of drilling and 1583 m^3 of trenching. According to Refs [21.5, 21.6], the Government decided in early 2008 to concentrate exploration activities in the Nong Son area in order to meet expected future national requirements.

Recently, activities focused on the sandstone deposits of Palua–Parong (Quang Nam Province) as well as on the mineralization found in the Nong Son Basin. Work included collection of geological, geochemical and geophysical data, and trenching and drilling (Fig. 6.49, which indicates 139 315 metres of drilling within an expenditure of USD $23 186 000). However, no figures are available for the period after 2004-2007 [21.7–21.10].

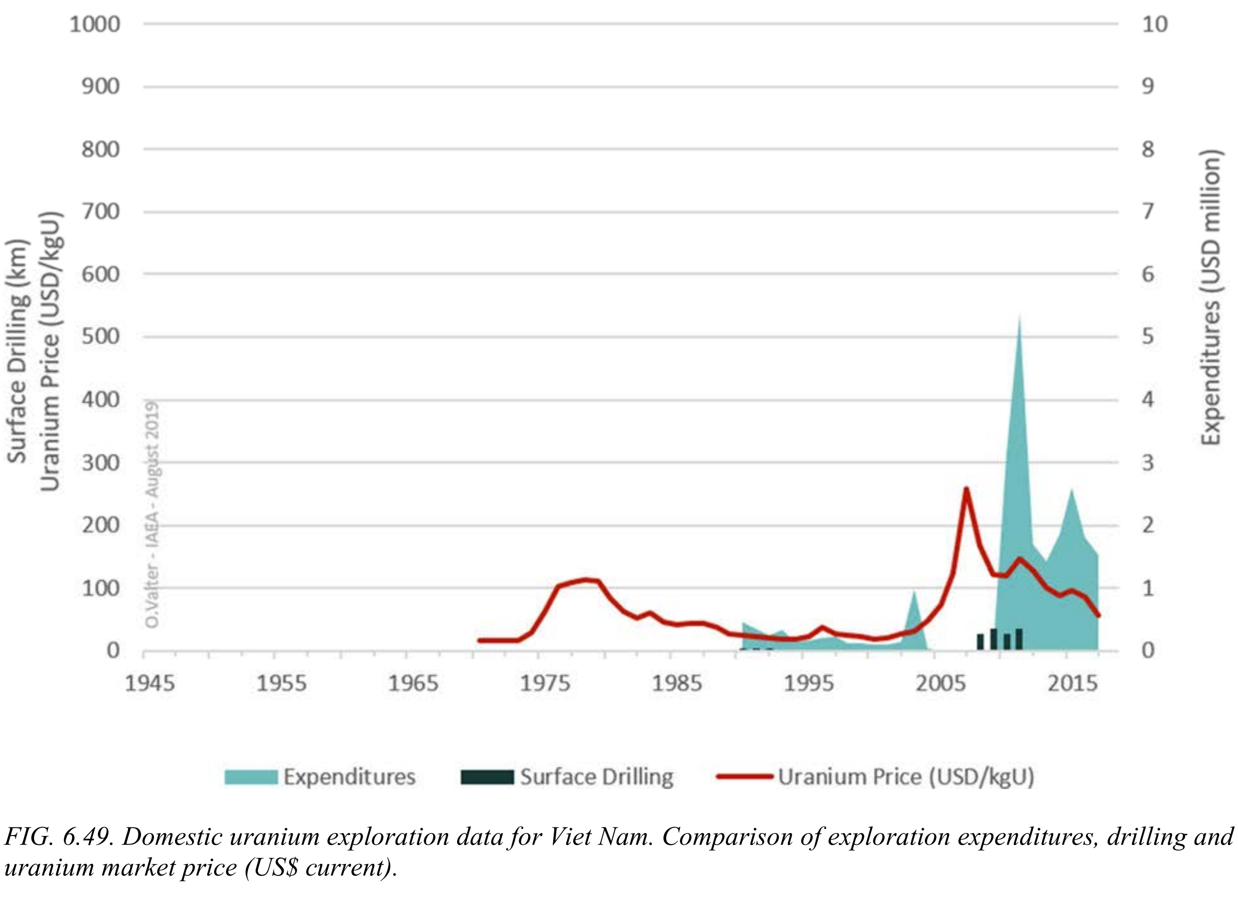


FIG. 6.49. Domestic uranium exploration data for Viet Nam. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

6.21.4. Uranium resources

As of 1 January 2017, Viet Nam reported in situ identified resources as follows [21.11, 21.12]:

a) Reasonably assured resources of 1 200 tU, recoverable at <US $260/kgU in situ, associated with sandstone type deposits, are reported;
b) Inferred resources of 4000 tU, for sandstone type deposits, recoverable at <US $260/kgU;
c) Prognosticated resources of 81 200 tU, recoverable at <US $260/kgU;
d) Speculative resources of 321 600 tU, at unassigned costs;
e) Unconventional resources include coal deposits in the Nong Son Basin, rare earth deposits in the northern provinces, a phosphate deposit at Binh Duong and a graphite deposit at Tien An.

According [21.5, 21.6], the Government goal is to develop a resource of about 7000 tU in the Nong Son Basin in two phases by 2020. The Nong Son Basin is believed to have the largest resources and is more economically attractive than deposits in other areas (with regard to lower costs of extraction and easier environmental protection owing to its remoteness from inhabited areas). The UDEPO database lists the most significant deposits for Viet Nam as Sin Quyen, Tabhing Area, Khe Hoa-Khe Cao, Palua, Parong, Nong Son, Binh Duong, An Diem, Tien An, Dong Nam Ben Ghiang.

6.21.5. Potential for new discoveries

The potential for the discovery of new deposits is moderate. For conventional deposits, the continental sedimentary basins are an attractive target for exploration. Besides those deposits already discovered, additional potential may exist in less explored areas. However, these are mostly in remote districts that are difficult to access and where exploration would be difficult owing to soil or forest cover. If necessary, the deposits of rare elements, such as the Nam deposits in the north, could be re-evaluated for their uranium and thorium potential. In addition, phosphate deposits may warrant investigation once the uranium concentrations become attractive and the technology for uranium recovery becomes economic. Uranium extraction from coal seems to be less attractive. However, the uranium grade is not known and such resources will depend on technology processing developments.

6.21.6. Environmental activities

Some monitoring of environmental impacts resulting from exploration, are carried out [21.10].

References to Section 6.21

[21.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Vietnam, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).

[21.2] NAM, T.N., The Geology of Vietnam: A Brief Summary and Problems, Geoscience Reports of Shizuoka University, Japan National Institute of Informatics, Tokyo (1995).

[21.3] KUSNIR, I., Mineral Resources of Vietnam, Acta Montanistica Slovaca 5 (2000).

[21.4] BARTHEL, F., STEINBACH, V., Überblick zur Rohstoffsituation Vietnams–Energierohstoffe, Metallrohstoffe, Industrieminerale, Steine und Erden, Z. Angew. Geol. 42 (1996).

[21.5] VIET NAM NEWS AGENCY, Local Uranium Eyed for Nuclear Plant (30 May 2008).

[21.6] WISE URANIUM PROJECTS, New Uranium Mining Projects–Asia (29 August 2008) 19–20.

[21.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[21.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).HOAI, N.V., OAI, N.V., QUYNH, P.V., "Some main types of uranium exploration in Vietnam", paper presented at IAEA Tech. Mtg on New Developments in Uranium Exploration, Resources, Production and Demand, Vienna, 1991.

[21.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[21.10] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[21.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[21.12] THAN VAN LIEN, NGUYEN TRUONG GIANG, VU VAN BICH, "Uranium exploration and resources in Vietnam", paper presented at 48th Uranium Group Mtg, Kirovograd, 2012.

CHAPTER 7. MIDDLE EAST, CENTRAL AND SOUTHERN ASIA

7.1. AFGHANISTAN

7.1.1. Geography

Afghanistan is a landlocked country in south central Asia and is bounded to the north by Turkmenistan, Uzbekistan and Tajikistan, to the NE by China, to the east and south by Pakistan, and by the Islamic Republic of Iran to the west. The country is divided, E–W, by the Hindu Kush mountain range, which rises in the east to heights of 7315 m. Except for the SW, most of the country is covered by high mountains and incised by deep valleys. Afghanistan has a continental climate, with hot summers and cold winters. Large parts of the country are dry and freshwater supplies are limited. The country is seismically active and frequently subject to minor earthquakes, mainly in the NE of the Hindu Kush mountain range.

The country's natural resources include gold, silver, copper, zinc and iron in the south-eastern part; precious and semi-precious stones such as lapis lazuli, emerald and azurite (a copper mineral) in the NE; and potentially significant petroleum and natural gas reserves in the north. The country also has coal, chromite, talc, baryte, sulphur, lead, salt and uranium occurrences.

Agricultural resources include wheat, fruits, nuts, wool, mutton and animal skins [1.1].

7.1.2. Geology

Afghanistan has a very complex and varied geology (Fig. 7.1). The ages of the rock formations date from the Archaean up to the Recent. The country also has a complex tectonic history, in part resulting from its position relative to the Himalayas. This diverse geological history has resulted in a significant mineral legacy.

The terranes, exposed in Afghanistan, include the North Afghanistan (Tajik Block), the Afghan Central blocks and the Frontal fold and thrust belts, representing the northwestern continental margin of the Indian plate. The North Tajik Block lies north of the Herat–Central Badakhshan fault system and has been part of the Asian plate since before the Permo-Triassic. The Afghan Central Blocks occur west from the Chaman Fault (a prominent linear feature thought to represent the western extreme of the modern Indian Plate). They were once part of the Gondwana but were separated prior to the separation of the Indian continent and its accretion to the southern margin of Eurasia.

The country experienced widespread marine transgressions and deposition during the Paleozoic and Mesozoic times, that continued into the Cenozoic with the uplift of the Hindu Kush mountains.

Precambrian metamorphic rocks form high regions in the center of the country and in the Hindu Kush. They are represented by phyllites, greenschists, garnet-mica-schists and anatectic gneisses. Limestone and dolomite dominate during the Paleozoic with shale, sandstone and conglomerate associated to volcanic intercalations. Cenozoic is characterized by regional folding and faulting with deposition of limestone, gypsum, conglomerate, sandstone with tuff and lava intercalations.

Historically, mining consisted mainly of gemstone production; the country hosting some of the oldest known mines in the world. Afghanistan may have produced lapis lazuli for primeval civilizations in Egypt and elsewhere. Exploration conducted during the 1960s and 1970s led to the finding of considerable metalliferous resources, including copper, iron, chromite, lead and gold, and non-metallic minerals, such as salt, talc and mica. The basement geology of the country can be likened to that of a 'jigsaw puzzle' of crustal blocks, each having a different geological history and each possessing mineral potential. This complexity was due to a series of structural events dating from the Jurassic period [1.2- 1.4].

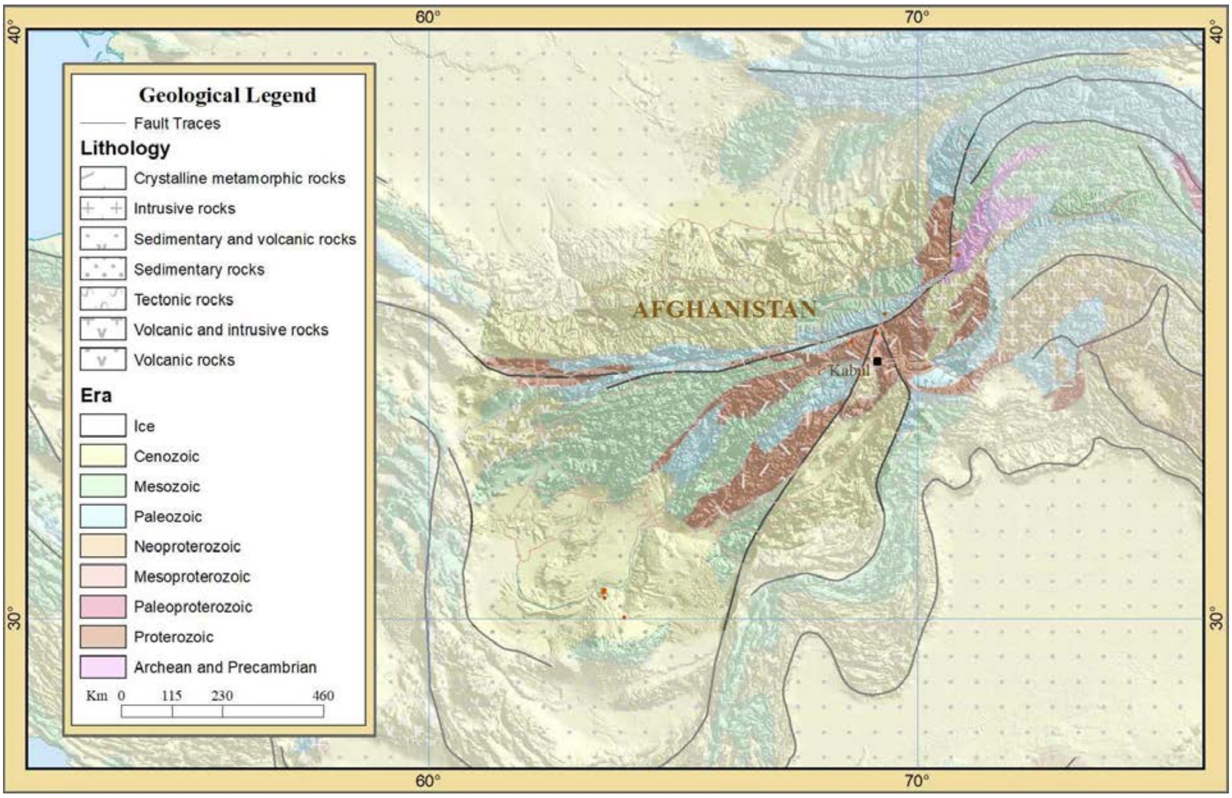


FIG. 7.1. Regional geological setting of Afghanistan. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.1.3. Uranium exploration

Very little data are available on uranium exploration in Afghanistan. The first occurrence of uranium (uraninite) in Afghanistan was reported in 1957 by the Afghan Geological Survey from a locality near the lapis lazuli mine at Sar-e-Sang in Badakhshan. Geologists working for the French CEA (Commissariat à l'Energie Atomique) with assistance from Afghan geologists conducted field work in 1959–1960 in the NE of the country in the areas where uraninite anomalies were known to exist (i.e., Surkh-e-Porsa, in Ghorband, and near Gulbahar and Marishtan in the Panjshir valley). However, no evidence of uranium mineralization was found.

Russian geologists also conducted exploration, but little information on these activities is available.

The uranium–thorium mineralization in the Khanneshin area (Helmand Province, southern Afghanistan) occurs over an area of 40 km^2 and includes a Lower Quaternary volcanic carbonatite complex, which represents the remnants of an eroded stratovolcano and comprises tuff, agglomerate and subvolcanic carbonatitic igneous rocks. The main carbonatite rock types include soevite; a baryte–ankerite–fluorite carbonatite and associated tuff; and alvikite and associated agglomerate and tuff. Leucite phonolite is also present. The rocks have high concentrations of rare earth elements, uranium, thorium, strontium, lead, fluorine, niobium and phosphorous.

The southern Khanneshin occurrence is situated on the southern edge of the volcanic complex. The mineralized body measures 300–1 500 m in length, up to 0.5 m in width and comprises an uraniferous Neogene sandstone intruded by carbonatite dykes along SW striking faults that cut radial fractures and other carbonatite dykes.

The southern area hosts four mineralized zones, one of which measures at least 300 m long and 14–58 m wide, which has been exposed by erosion to a depth of 100 m. The most porous zones of coarse-grained sandstone contain the highest uranium values, which are located along major fractures and joints. The northern Khanneshin occurrence is hosted in a sandy claystone unit which comprises a silicified zone measuring 2000 m in length and 2–25 m in width, and grading 0.006–0.015% U and 0.002–0.010% Th [1.2, 1.3]. Exploration expenditures are not available. No recent or ongoing exploration activities have been reported.

7.1.4. Uranium resources

No uranium resources are reported by Afghanistan. In 1983, IUREP reported an estimated range of 10 000–50 000 tU for speculative resources in magmatic (alkali) and sandstone geological environments [1.3]. A preliminary study of the Khanneshin carbonatite reported resources of more than 4 000 tU.

The UDEPO database lists the most significant deposit for Afghanistan as Khanneshin.

7.1.5. Potential for new discoveries

There are two main areas prospective for uranium in Afghanistan that would warrant further exploration. Arguably the more interesting is the Khanneshin carbonatite volcanic complex in Helmand Province. This comprises a Lower Quaternary domal structure with an intrusive carbonatite core 4 km in diameter. Preliminary exploration has identified zones with rare earth element enrichment and veinlets with uraninite. Although this is the only carbonatite to have been explored to date, other carbonatites are believed to exist in the area. Airborne surveys undertaken in the 1970s also identified an area in Farah Province, which recorded anomalous radioactivity. Little follow-up ground exploration has been conducted, although occurrences of uranium mineralization are reported in the area. Tertiary sandstone basins to the south could also act as mineralization traps [1.2, 1.3].

The potential for uranium resource discovery is believed to be moderate.

7.1.6. Uranium production

Afghanistan formerly produced uranium from the Khawaja Rawash Mountains, north of Kabul, following discovery of the deposits in 1983, from Koh Mir Daoud, between Herat and Shindand, and from deposits in the Khakriz area of Kandahar Province. All production was sent to the former Soviet Union. Production details are not available.

7.1.7. Comments

Currently, there is no production of uranium in Afghanistan and plans do not exist for future production. Afghanistan has no nuclear power plants and is not planning to build any. Afghanistan has never reported to the Red Book.

References to Section 7.1

[1.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Afghanistan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html

[1.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[1.3] ERIOMENKO, C.K., VIKHTER, B.Ya., CHMYRIOV, V.M., KHAMIDI KHABIBULAH, Volcanic Quaternary carbonatite complex in Afghanistan, Dokl. Akad. Nauk SSSR **223** (1975).

[1.4] AFGHANISTAN GEOLOGICAL SURVEY, Geology of Afghanistan (2017) https://www.bgs.ac.uk/AfghanistanMinerals/geology.htm.

7.2. AZERBAIJAN

7.2.1. Geography

Azerbaijan is located in the south-eastern Caucasus and Lesser Caucasus Mountains. The region of Nakhchyvan (Naxcivan) is part of Azerbaijan, although physically surrounded by neighbouring Armenia. The Caucus Mountains form the main dividing line between the two continents of Europe and Asia, along with the Urals. The northern region is occupied by the south-eastern end of the Caucasus. The centre is covered by the plains of the Kura and Aras Rivers, which flow into the Caspian Sea. In the SW, the country forms part of the Lesser Caucasus Mountains [2.1].

7.2.2. Geology

Azerbaijan forms a geological part of the Alpine folded belt (Fig. 7.2). Sedimentary deposits embracing the south-western parts of the Greater and Lesser Caucasus, including the Kura River trough and the Mid- and South Caspian Basins, consist of diverse fold systems. The geological setting of the area consists of sedimentary, volcano–sedimentary and volcanic deposits embracing almost the entire stratigraphic range from Precambrian to Holocene.

Iron, aluminum, chromite, tin, zinc, cobalt, molybdenite occur in various deposits.

FIG. 7.2. Regional geological setting of Azerbaijan. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Azerbaijan has also large deposits of oil and natural gas which are concentrated in the coastal area, continuing into the Caspian Sea (in the South Caspian Basin, Kura Trough). Most of the sedimentary sequences consist of shallow water sedimentary rocks deposited during the Late Jurassic–Early Pliocene period [2.2]. On the basis of a review of the dominantly sedimentary strata, the potential for uranium deposits is limited.

7.2.3. Comments

No uranium exploration activities have been reported. Azerbaijan has no nuclear power plant. However, discussions with neighbouring countries on jointly building a nuclear power plant have taken place [2.3]. Azerbaijan has never reported to the Red Book.

The UDEPO database does not list any known deposits for Azerbaijan.

References to Section 7.2

[2.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Azerbaijan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.
[2.2] Geologic Structure of Azerbaijan, www.azerbaijan.az/_Geography/_Geostructure/_geostructure_e.html.
[2.3] WORLD NUCLEAR ASSOCIATION, Emerging Nuclear Energy Countries (June 2019).

7.3. BANGLADESH

7.3.1. Geography

Bangladesh is located in the low lying Ganges–Brahmaputra River Delta, or Ganges Delta. The alluvium deposited by these rivers has created some of the most fertile plains in the world. Bangladesh has 58 transboundary rivers, making resolution of any water issues politically complicated and difficult to resolve. Most of Bangladesh is less than 12 m above sea level and it is believed that ~50% of the land would be flooded were the sea level to rise by a metre.

The highest point is in the Mowdok Range, where an elevation of 1052 m is reached in the Chittagong Hill Tracts in the SE of the country. A major part of the coastline comprises marshy jungle, the Sundarbans, which is the largest mangrove forest in the world. It is home to diverse flora and fauna. The country lies on the Tropic of Cancer and as a result the climate is tropical, with a mild winter lasting from October to March and a hot, humid summer lasting from March to June. The warm and humid monsoon season lasts from June to October and most of the country's rainfall occurs during these months.

Bangladesh grows very significant quantities of rice, tea and mustard. Although two thirds of the population are farmers, more than three quarters of Bangladesh's export earnings come from the garment industry [3.1].

7.3.2. Geology

The country forms part of the foreland of the Himalayan Geosyncline (Fig. 7.3). It is a vast alluvial plain with the exception of the Tertiary hill ranges in the east and NE and the Pleistocene terraces of Madhupur, Barind (North Bengal) and the Lalmai Hills. Bangladesh occupies the major part of the Bengal Basin, which lies between the Indian Foreland Shield to the west, the Shillong Plateau to the north and the Arakan-Chin Hills Geoanticline to the east. The Archaean basement of the stable shelf areas in the north and NW of the country is overlain by sedimentary rocks ranging in age from Permian to Pleistocene.

The folded miogeosynclinal Tertiary hill sedimentary rocks in the east and NE comprise sandstones, siltstones, mudstones and shales with a maximum thickness of over 15 000 m and ranging in age from Eocene to Pliocene. The Tipam and Dupi Tila Group of Tertiary sedimentary rocks are of predominantly continental nature. The facies of the Tipam sedimentary rocks is deltaic to fluviodeltaic in the south, becoming gradually more continental in the north. It is subdivided into two formations: Tipam Sandstone and Girujan Clay. The former consists mainly of sandstones, highly cross-bedded and with alteration of mudstones, shales and clays. The lower part of the formation is mostly medium- to coarse-grained sandstone, whereas the upper sequence comprises fine-grained sandstones. Intercalations of grey clays and siltstones with lignite are frequent in the middle part of the formation.

The facies of the overlying Dupi Tila Formation are fluviatile to fluviolacustrine. The lower part is composed of a series of pink and grey, cross-bedded, coarse-grained sandstones with intercalations of banded blue-grey clays. The Dupi Tila sandstones are characterized by the presence of silicified wood. The thickness of the formation varies in the range 0–300 m.

The tectonic structure of the country is relatively simple. A succession of synclines and anticlines without any major complications is the general rule. The fold axes are aligned N–S in the Chittagong Hill Tracts and in the southern Sylhet district, and align themselves in an almost E–W direction in the northern Sylhet district. In the extreme north, the sedimentary rocks mentioned form a monocline fold along the southern margin of the Shillong Plateau [3.2, 3.3].

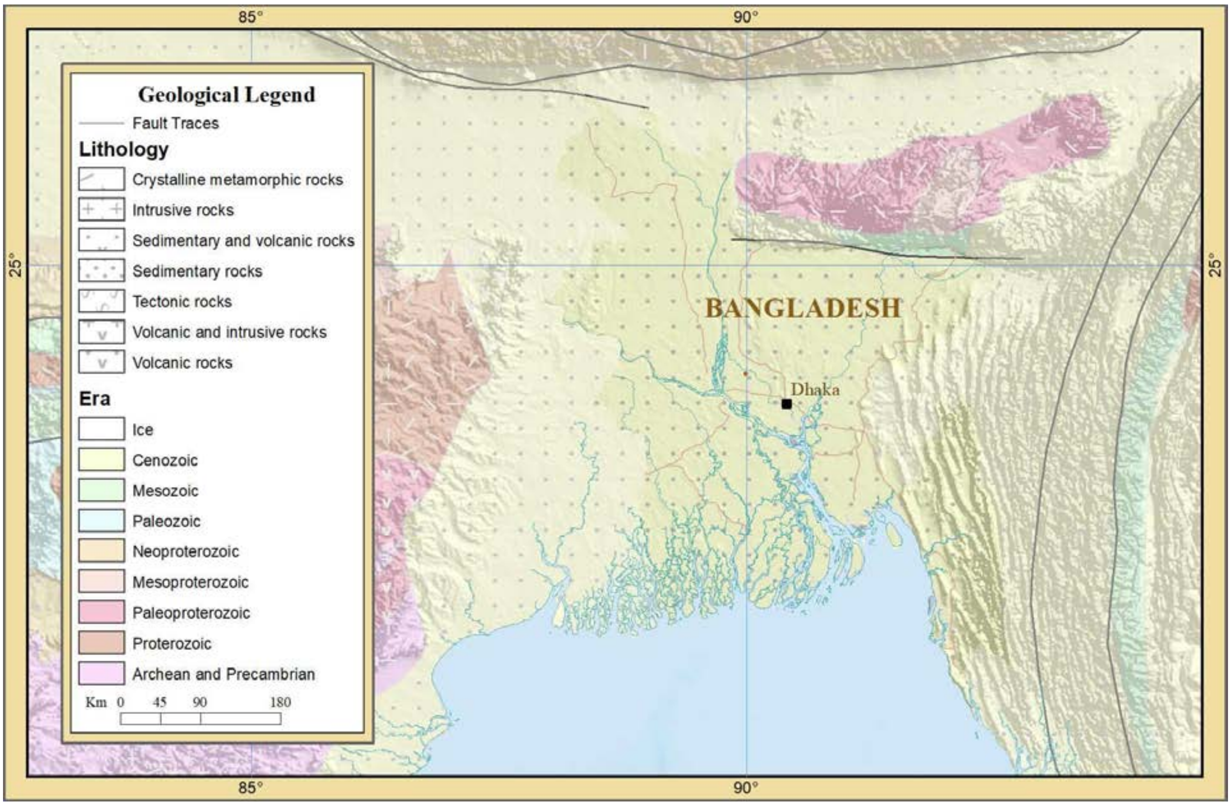


FIG. 7.3. Regional geological setting of Bangladesh. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.3.3. Uranium exploration

The Bangladesh Atomic Energy Commission (BAEC), in cooperation with the IAEA, initiated uranium exploration activities in 1976. Selected areas of the Chittagong and Sylhet districts in the western and northern parts of the country were investigated. Reconnaissance ground radiometric surveys in these areas and a limited helicopter-borne survey in the Jaldi area, Chittagong district, as well as some exploratory drilling in the Sylhet and Jaintapur areas confirmed the presence of radioactive anomalies associated with iron stained sandstones of the Miocene–Pliocene Dupmila Formation.

In 1983–1984, ground radiometric surveys in the Sylhet area continued and limited drilling was carried out to test the discovered anomalies located in the Miocene–Pliocene sandstones of the Tipam formation.

In 1985–1986, activities consisted of follow-up work in the area of the Harargaj Anticline, as well as reconnaissance surveys of other anticlinal structures in the Sylhet district. This completed the reconnaissance of the north-eastern part of the country. The results led to the discovery of 146 radiometric anomalies, of which eight were classified as high priority owing to their elevated readings (more than ten times background). The anomalies are located in fluviatile sandstones of the Middle Miocene Tipam sandstone.

BAEC suspended uranium exploration in 1988. Historical exploration data are summarized in Fig. 7.4, indicating a total expenditure of USD $453 000 including 4910 metres of drilling (as well as additionally 2000 km^2 of airborne surveys).

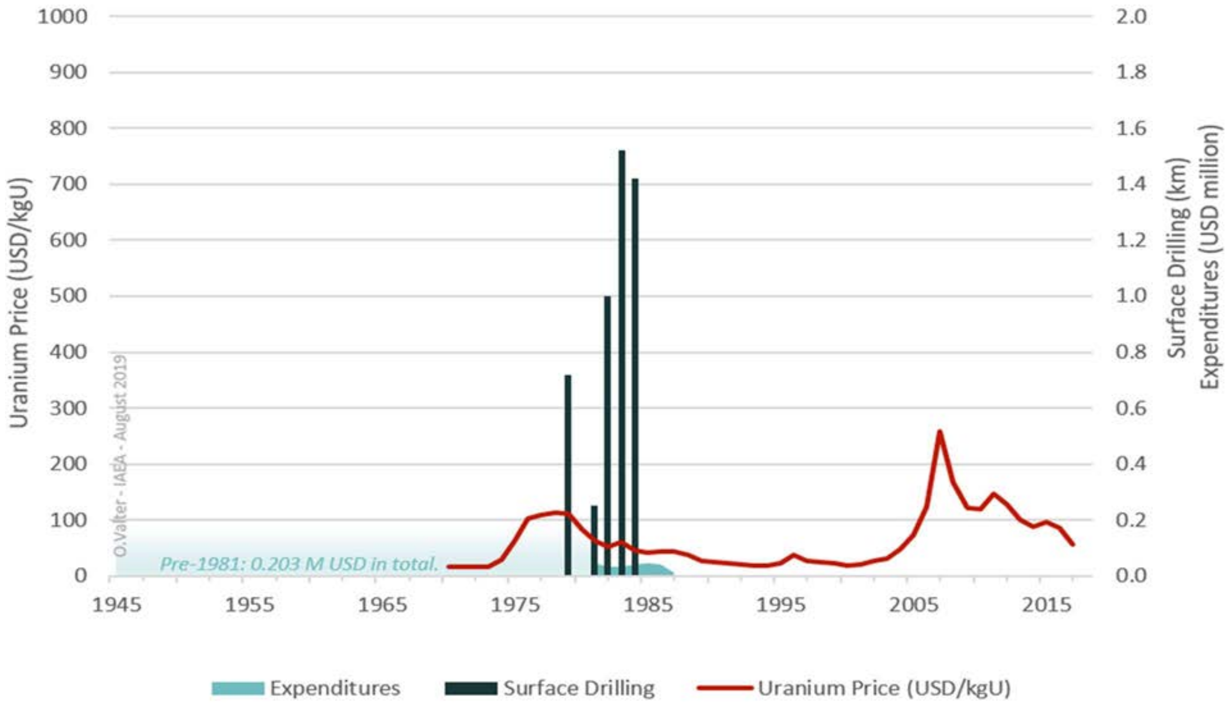


FIG. 7.4. Domestic uranium exploration data for Bangladesh. Comparison of exploration expenditures, drilling and uranium market price (US$ current) [3.4, 3.5].

7.3.4. Uranium resources

No identified resources are reported by Bangladesh. In 1983, IUREP reported an estimated range of 1–10 000 tU of speculative resources in the sandstone geological environment [3.6].

The UDEPO database does not list any known deposits for Bangladesh.

7.3.5. Potential for new discoveries

Bangladesh has no known uranium resources. However, there are geological features favourable for the formation of sandstone deposits: Bangladesh occupies the larger part of the Bengal Basin, which is partly derived from the Archaean basement rocks of Bihar and Shillong. The basin is filled with continental, fluvial and deltaic sedimentary rocks ranging in age from Permian to Pleistocene. On the basis of the exploration results obtained by BAEC and through comparison with neighbouring countries, there is potential for sandstone uranium occurrences in Permo-Triassic, Cretaceous and Tertiary sedimentary rocks [3.2, 3.3].

The potential for discovery of uranium resources is therefore rated as low to moderate.

7.3.6. Comments

There has been no historical uranium production in Bangladesh.

In 2011, an agreement with Rosatom was signed for two 1000 MWe VVER reactors to be built at Rooppur. Construction of the first unit commenced in November 2017, in July 2018 for the second unit [3.7].

References to Section 7.3

[3.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Bangladesh, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html .

[3.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, Int'l. Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[3.3] FARUQUEE, A.R., "Uranium exploration in Bangladesh", Uranium Deposits in Asia and the Pacific: Geology and Exploration (Proc. Tech. Mtg Jakarta, 1985), IAEA, Vienna (1988) 293–317.

[3.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[3.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[3.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Speculative Resources of Uranium, A Review of IUREP Estimates 1982–83, IAEA, Vienna (1983).

[3.7] WORLD NUCLEAR ASSOCIATION, Nuclear Power in Bangladesh. https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/bangladesh.aspx (2019)

7.4. BHUTAN[13]

7.4.1. Geography

Bhutan is a landlocked country of Southeast Asia, surrounded by India to the south, China to the north. The topography of Bhutan varies from alpine Himalayan mountains in the north, where some peaks are at least 7 000 m high, to plains in the south. Climate varies from tropical in the southern plains to severe winters and cool summer in the Himalaya area.

Bhutan's economy is based largely on hydropower (exportation to India), agriculture, and forestry. Natural resources include gypsum, calcium carbonate, and timber [4.1].

7.4.2. Geology

The geology of Bhutan results from the Himalayan orogenesis which took place during Eocene - Oligocene period. One can distinguish the following geostructural units:

(1) A tectonic block which is a part of the Indian Shield moved northward and was subducted under the stable Tibet massif;

[13] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

(2) A mountain boundary trust, the main Boundary fault, with a mountain mass to the north, cutting out and riding over past Himalayan orogenic detritus to the south.

Reverse metamorphism is common, illustrated by high grade metamorphism of the younger beds in contrast with low grade metamorphism of older rocks. The age of most of the exposed rocks is Precambrian (Fig. 7.5). They are primary marine metasediments of the Darjeeling gneisses and Daling Series.

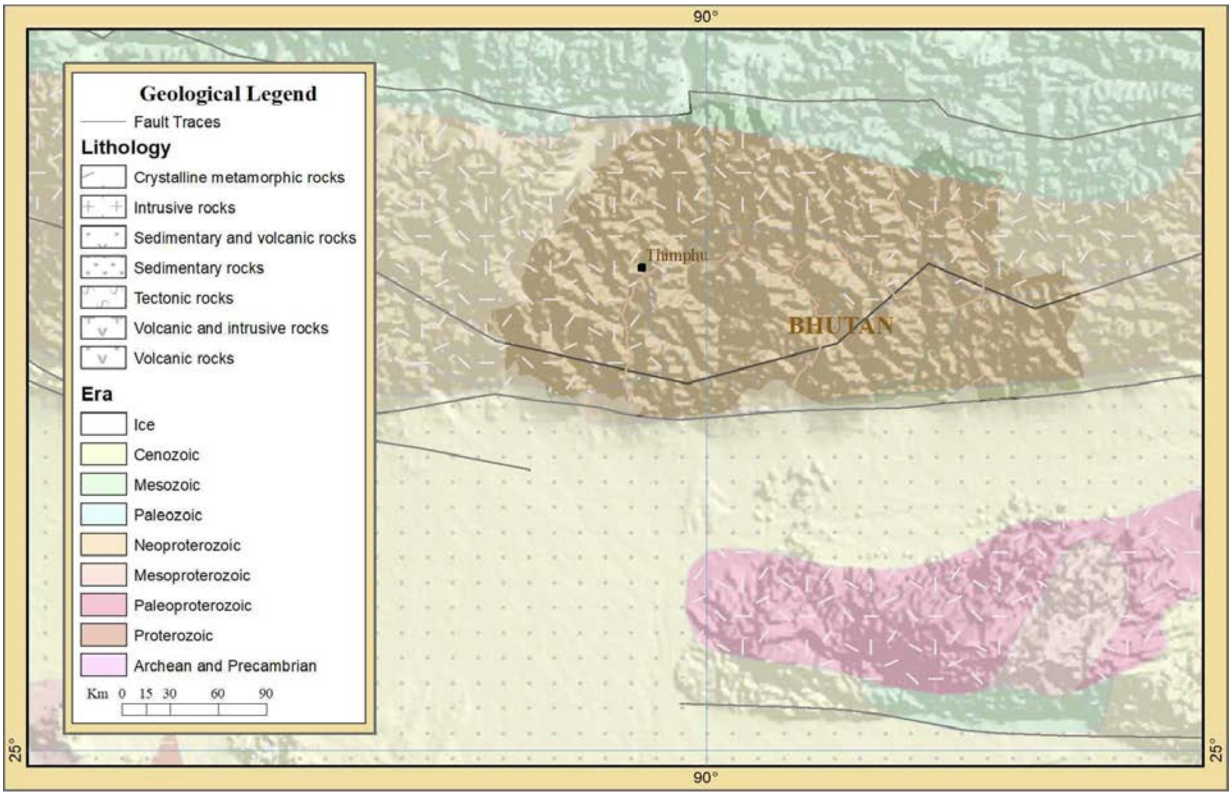


FIG. 7.5. Regional geological setting of Bhutan. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.4.3. Uranium exploration

There has been no reported uranium exploration in Bhutan. Bhutan never reported to the Red Book.

7.4.4. Uranium resources

There are no known uranium occurrences in Bhutan and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for Bhutan.

7.4.5. Potential for new discoveries

The uranium potential of Bhutan is very poor, due to mainly the tectonic pattern of the region. However, some favourable conditions for finding small uranium deposits exist. The Pleistocene Siwalik formation is a fluviatile, carbonaceous bearing sandstone. In Bhutan it is presented as a thin sequence, and in nearby Pakistan and Nepal it hosts small uranium occurrences/deposits. All the rivers draining the Himalayas have placers of uranothorium minerals. There may be disseminations of these minerals in the southern part of the Tibet Massif.. The 1977 IUREP study estimated the uranium potential of Bhutan to less than 1000 tonnes U [4.2, 4.3].

References to Section 7.4

[4.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Bhutan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[4.2] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, World Uranium Potential: An International Evaluation, OECD, Paris (1978) 170 pp.

[4.3] SIMOV S., I U R E P NATIONAL FAVOURABILITY STUDIES. IUREP N.F.S. No. 151. Bhutan (1977).

7.5. INDIA

7.5.1. Geography

India, the world's seventh largest country, lies to the north of the Equator and is bounded to the SW by the Arabian Sea, to the SE by the Bay of Bengal and to the south by the Indian Ocean.

The country can be divided into three well defined regions, namely, the Peninsula or Peninsular Shield, the Indo-Gangetic alluvial plains and the Extra-Peninsula, each having unique physical features, stratigraphy and structural characteristics. The first region occurs to the south of the plains of the Indus and Ganges River systems. The second region stretches across northern India from Assam and Bengal on the east, through Bihar and Uttar Pradesh, to the Punjab on the west. The third region comprises the Himalayan ranges and their extensions into Baluchistan (one of Pakistan's four provinces) to the west and Myanmar and Arakan to the east.

The Peninsula is a primeval plateau, long exposed to denudation and approaching peneplanation. Its mountains are of the relict type and represent the remains of harder strata which have resisted weathering. Their topographic expression may not, therefore, be directly attributable to their structure. Its rivers meander, for the most part, through comparatively level country with low gradients and these have built up broad valleys with low relief.

The Extra-Peninsula comprises folded and overthrust mountain chains which are of geologically recent origin. Its rivers are relatively young and are actively eroding their beds, carving out deep and steep sided ravines and gorges. The Indo-Gangetic plains are broad, extensive, level expanses built up of recent alluvium through which the rivers meander seawards [5.1].

7.5.2. Geology

Roughly 65% of the Indian Peninsula corresponds to Precambrian rocks (Fig. 7.6). In some areas, these rocks are comprised of Phanerozoic sedimentary assemblages and by the basalts of Deccan Plateau. Extending between the highly deformed suites of the Himalayas and the Precambrian rocks of the Indian Peninsula, the Indo-Gangetic plain covers Precambrian strata which dip northward. Because of the collision between the Indian Peninsula and the Asiatic mainland, the Precambrian rocks of the Himalayas are strongly tectonized and are detached from the southern Shield by a northerly dipping boundary thrust fault. Therefore, it is not easy to establish the continuity of Precambrian strata through this boundary thrust below the Indo-Gangetic alluvium.

The Indian Peninsula is conventionally regarded as a monolithic continental Shield comprising crystalline rocks. At a later stage, the Precambrian rocks were split into discrete sections, according to the chief orogenic trend, i.e., Satpura, Aravalli, Eastern Ghat and Dharwar.

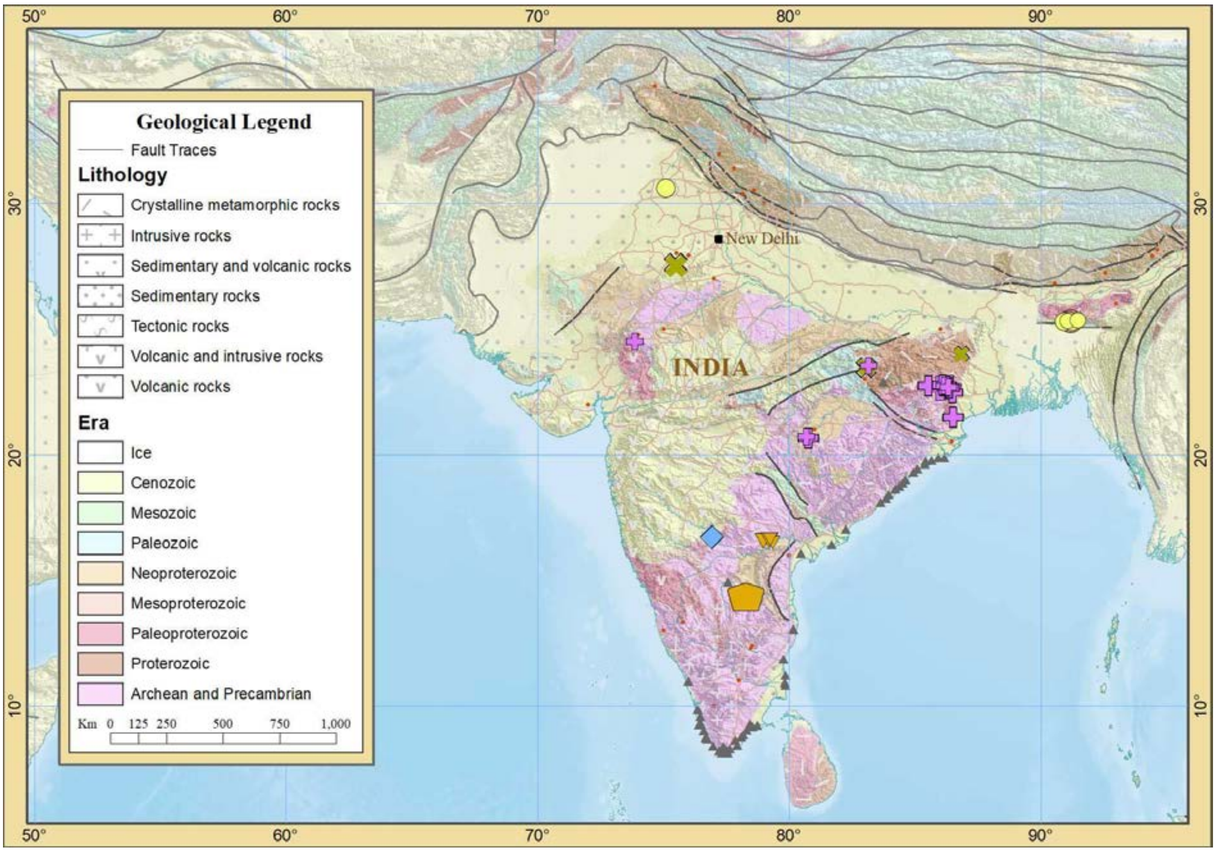


FIG. 7.6. Regional geological setting of India showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.5.2.1. Southern part of the Indian Peninsula

The southern part of the Indian Peninsula lies to the SW of the Godavari Rift and to the south of the Central India Tectonic Zone. Only a limited portion of the Eastern Ghat pertains to the north-eastern sector. The Precambrian rocks of the southern sector of the Indian Peninsula are mainly greenstones, high grade gneisses, migmatites, granulites, post-tectonic granites and primeval supracrustal rocks and cover sequences, namely the Sullavai, Pakhal, Bhima, Kaladgi, Badami, Kurnool and Cuddapah.

Two domains comprise the southern sector of the Peninsula: (i) the Southern Granulite Province, and (ii) the Dharwar Province. The latter lies to the north of the former and both are disconnected by the Palghat-Cauvery shear zone.

Corresponding to a granite–greenstone terrain, the Dharwar Province is typified by several NNW–SSE oriented belts of schistose rocks disjointed by granitic terrains. A major shear zone west of the Closepet granite divides the province into eastern and western sections. The supracrustal schistose metavolcanic rocks are mostly constituents of the Dharwar Supergroup (3000–2600 Ma), however remnants of an older supracrustal series (Sargur Group (3400 Ma)), which are older than the granitic gneisses, have been documented. The tectono-metamorphic history of the gneisses as well as that of the younger and older schist belts is unclear.

The Southern Granulite Province is comprised mostly of khondalites, mafic granulites and charnockites, and it is cut by a number of shear zones. However, the province is composed not only of granulite facies rocks, but also abundant supracrustal rocks of amphibolite facies and gneisses. Radiometric dates acquired from this province differ from 3000 to 2000 Ma, an interval covering the ages of the precursor rocks, their metamorphism into granulites and ensuing retrogression. Consequently, this province comprises the 2500 Ma Nilgiri–Madras Belt and the 550 Ma charnockites of the Trivandrum and Madurai areas. The Southern Granulite Province is often used to attempt the reconstruction of East Gondwana via a postulated Madagascar–India fit [5.2].

7.5.2.2. Central part of the Peninsula Shield

The central sector of the Peninsula Shield is largely rectangular-shaped and limited by the Narmada–Son Lineament (north), the Godavari and Mahanadi Rifts, and the Eastern Ghats. This sector is comprised mostly of Archaean–Middle Proterozoic basement complexes and Late Proterozoic–Early Palaeozoic platformal cover rocks. Most of the sector is underlain by gneisses and granites, with overlying and engulfed supracrustals of metavolcanic and metasedimentary rocks of the Bailadila, Bengpal, Sakoli, Sausar and other assemblages. In this primeval terrain, several Middle–Late Proterozoic basins were formed (e.g., Baster, Chhatisgarh, Indravati, Vindhyan) which are presently covered by unmetamorphosed sedimentary rocks. The central section has been roughly separated into three provinces: Eastern Ghats, Satpura and Bastar Provinces.

Bastar Province is the main portion of the Central Peninsula and comprises the rocks of Sakoli, Dongargarh, Bailadila, Bengpal, Amgaon and the Sukma belts. Some granitoids in Bastar Province intruded into the supracrustal rocks whilst several of them apparently comprise the basement and therefore predate the supracrustals. The oldest granitoid in Bastar Province, which yielded a Pb–Pb age of 3000 Ma, is a felsic gneiss in the Sukma area. A more recent U–Pb dating of single zircon crystals from tonalite gneiss in the basement of the Kotri Belt yielded an age of 3562 ± 2 Ma.

Satpura Province is a Proterozoic mobile belt (comprising the Betul-Chindwara, Bilaspur–Raigarh–Surguja, Sausar and Mahakoshal Belts) oriented ENE–WSW to the north of the Nandgaon, Sakoli and Amgaon supracrustals, and to the west of the Chhattisgarh Basin. In Satpura Province, the rocks have been extensively metamorphosed and deformed during the Early–Middle Proterozoic [5.2].

7.5.2.3. Eastern and north-eastern part of the Peninsula

This sector is disconnected from the other sectors of the Indian Peninsula by the Mahanadi rift graben, limiting it to the south and the west. The provinces that make up this sector are the Meghalaya, Chhotanagpur and Singhbhum–North Orissa Provinces.

The Singhbhum-North Orissa Province is typified by an Archaean continental nucleus (>3000 Ma) bordered by the Sukinda thrust in the south and by the arcuate Singhbhum thrust/shear zone in the NW and north. This Archaean basement is covered to the north by Early Proterozoic supracrustals (North Singhbhum Mobile Belt) oriented generally E–W. This belt of supracrustals is bordered by the Chhotanagpur Province, which is more developed to the north. The youngest Precambrian supracrustal sedimentary rocks in Chhotanagpur Province exist in the Kolhan Basin and exhibit a synclinal structure. Salient features of the Singhbhum–North Orissa Province consist of extensive manifestations of Early Archaean trondhjemite–tonalite gneiss as well as greenstone belts with conspicuous banded iron formations.

The Chhotanagpur Province is a ‘sea’ of complex granitoids, with ‘islands’ of granulites, metasedimentary rocks, subsidiary utramafic/mafic schists and marginal anorthosites. Chhotanagpur Belt rocks have yielded K–Ar ages of 1500–800 Ma. During at least a billion years, the terrain has underwent a sequence of tectono-thermal episodes.

The Meghalaya Province is bordered by the Dawki Lineament to the south and by alluvium from the Brahmaputra River to the north. The Precambrian rocks of the Khasi Hills, which comprise the Meghalaya Province, have been partitioned into the Khasi greenstone and porphyritic plutons, the supracrustals of the Shillong Group, non-porphyritic granitic rocks, and the gneissic complex. The Meghalaya Province represents basement reactivated terrain which has a Proterozoic tectono-thermal past and is similar to the terrain of the Chhotanagpur Province. Two Proterozoic dates have been obtained from the gneissic complex, 1700 Ma and 1150 Ma, whereas the intrusive porphyritic granite plutons have yielded ages of ~800 and ~550 Ma [5.2].

7.5.2.4. North and north-western part of the Peninsula

The north and north-western parts of the Peninsula are bordered to the south by the Narmada–Son–Tapti mega-lineament. Although the regions of northern and western India are, for expediency, regarded as one, they are in fact two sections which are disconnected from each other by a major thrust fault (Great Boundary Fault). These regions include Bundelkhand, BGC (Banded Gneiss Complex) and Aravalli–Delhi Provinces.

The Bundelkhand Province, which is roughly triangular, consists of quartzo-feldspathic gneisses, granite–granodiorite, and islands of metavolcanic and metasedimentary rocks, dolerite dykes and quartz reefs. Existing geochronological data indicate that the province was largely cratonized in the Late Archaean.

The BGC Province consists of a suite (BGC/Bhilwara Supergroup) of granulites and high grade gneisses, relics of low grade supracrustals and greenstones and synorogenic granites with a broad range of ages (3500–2000 Ma) spanning the time interval of deposition of the overlying Aravalli–Delhi Supergroup strata. A well-defined unconformity underlines the border between the BGC and the overlying supracrustal suites. A portion of the Bhilwara Supergroup apparently represents a continental rift, which subsequently formed into an ensimatic orogen.

The Aravalli-Delhi Province comprises Proterozoic supracrustal series forming the Aravalli and Delhi Supergroups. Besides, an assemblage of ultrabasic, basic and granitic intrusives and acid extrusives of varying ages likewise exist in the Province. Formation of the Aravalli rocks (mostly volcanic rocks, carbonates, and sedimentary rocks derived from granite) transpired in fault troughs in a eugeosynclinal–miogeosynclinal environment. After the development of the Aravalli Supergroup, the Delhi Basin opened near the Aravalli Province, and thick sequences of volcano-sedimentary rocks were formed therein.
Late Proterozoic assemblages of sedimentary and igneous rocks (Trans-Aravalli series) included in the Marwar Supergroup and Malani Igneous Suite, respectively, cover an extensive region to the west of the Aravalli Mountains. The Marwar and Malani rocks are undeformed, signifying that the events of the Precambrian sedimentation and magmatism in this sector of north-western India are post-tectonic [5.2].

7.5.2.5. Extra-Peninsular region

The Extra-Peninsular region, which makes up the northern edge of the Indian subcontinent, is defined by the Himalayan mountain range. The Precambrian strata of this region have been explained according to two sectors: (i) the Eastern Himalayas; (ii) the Western Himalayas. The portion of the Himalayan belt which crosses past Arunachal Pradesh, Darjeeling and Sikkim belongs to the Eastern Himalayas region, while the Western Himalayas comprises the remainder of the belt. The western and eastern sectors exhibit roughly similar geological characteristics. The general orientation of the belt in the Eastern Himalayas is E–W, whereas in the Western Himalayas is roughly NW–SE. Proterozoic rocks that have been affected by thrusting and rejuvenation throughout the Mesozoic–Cenozoic orogenesis largely comprise the Himalayan ranges.

The Himalayan ranges can be partitioned lengthwise into four parts, namely (from north to south to): (i) Tibetan (Tethyan) Himalayas; (ii) Great (central) Himalayas; (iii) Lesser (lower) Himalayas; and (iv) Sub-Himalayas (the foothills belt).

The Sub-Himalayas consists predominantly of Tertiary and Quaternary sedimentary rocks, which were sourced from the northern mountains and amassed along the Main Boundary Thrust next to the Sub-Himalayas to the north. Nappes overriding autochthonous Precambrian sedimentary assemblages largely comprise the Lesser Himalayas, which is overridden by the Great Himalayas along the Main Central Thrust. The Great Himalayas comprises predominantly high grade Precambrian metamorphites overthrust by Phanerozoic rocks, but also includes Cenozoic granites. Multiple episodes of metamorphism and deformation, migmatization, thrust–nappe tectonics and granitic emplacement have produced a convoluted tectonic unit. The Tibetan Himalayas consists of a supracrustal suite according to contentious notions of either one- or two-stage evolution of Tethys.

Although a notion of continental collision is linked to the evolution of the Himalayas, the belt exhibits other evidence of geological activity dating since Early Proterozoic to the present. In accord with the plate tectonics theory, the Indian Shield was subducted beneath the overlying Tethyan suite and a sedimentary wedge located beneath the two converging plates. The Himalayan mountain chain is considered to be a segment of the global Mesozoic–Cenozoic mobile belt which extends from the Indonesian arc in the east to the Atlas–Alpine mountain belts in the west. The northerly progressing Indo-African Plate is also believed to be subducted beneath the Eurasian Plate, forming 'trails' of ophiolite sutures. The shifting and separation of India from Eurasia occurred after the rifting of numerous continental fragments from the northern Indo-Australian border of the former Gondwana supercontinent and these tectonic processes occurred from the Silurian to the Cretaceous.

Precise categorization of the Precambrian crust at large and of the Indian Shield especially is based on a number of important aspects, namely magmatism, deformation events, metamorphism, major cycles of sedimentation occurring throughout the Precambrian period. Despite of the complexity in sorting out the history of geological evolution, the current understanding of the matter is moved forward through the build-up of new data, ground-breaking amendments in our knowledge of global geological processes and the analysis of old and recently gathered data which together have afforded a thorough depiction of this facet of Indian geology. Theories regarding the structural evolution of this area are still being developed [5.2].

7.5.2.6. Tectonics

The Indian Peninsular Shield is, tectonically, an amalgamated assortment of several Precambrian crustal blocks typified by cratons, basement reactivation, mobile belts and the like, together with overlying Proterozoic and Phanerozoic rocks which have amassed in intracratonic rifts and basins. The joints between the blocks are commonly rifts/thrusts of uncertain features. It is believed that nearly all of the evolutionary processes basically occur concurrently and successively in the individual blocks. The existing make-up of the Peninsular India Shield occurred largely throughout the Middle Proterozoic. Formation of platformal sedimentary rocks in the rifts and basins was ensued by parting of the blocks and this endured from the Middle Proterozoic to the Early Palaeozoic.

The Middle Proterozoic rocks comprise complex folded mobile belts along the borders of the cratonic blocks. These belts are related with specific major tectonic elements signifying major zones of displacement. Some of these zones of displacement are [5.2]: (i) the mega-thrusts which exhibit a general WNW–ESE orientation in Extra-Peninsular India; (ii) the E–W striking Palghat-Kaveri shear system in south India; (iii) the Singhbhum Shear Zone exhibiting a curved orientation in eastern India; (iv) the E–W striking Central Indian Shear in central India; and (v) the Phulad Lineament (suture zone) in north-western India.

7.5.3. Uranium exploration

More details on earlier activities of exploration, including major discoveries, exploration methods and areas surveyed may be found in the Red Books [5.3-5.15]. This section provides a summary of the exploration undertaken and the discoveries made and includes descriptions of favourable rock types and terrain.

Uranium exploration in India started in 1949. The initial exploration was undertaken in areas already known for uranium occurrences, such as the Singhbhum Thrust Belt (Bihar), Umra–Udaisagar Belt (Rajasthan) and the major pegmatite belts of the country. Uranium deposits and occurrences in the Umra-Udaisagar Belt and Singhbhum Thrust Belt are of the vein type.

Subsequently, on the basis of conceptual models, investigations for other types of uranium deposit were initiated in geologically favourable terrain. By the late 1970s, occurrences of uranium mineralization in quartz-pebble conglomerates and sandstones were identified in many parts of the country. Exploration in the 1980s led to the discovery of two deposit types: (i) the dolostone hosted low grade, large tonnage, stratabound uranium deposit in the Middle Proterozoic Vempalle Formation, Cuddapah Basin (Andhra Pradesh), and (ii) the fairly high grade, medium tonnage deposits, hosted by the fluviatile sandstones of the Mahadek Formation (Cretaceous) in the west Khasi Hills district (Meghalaya). The deposit hosted by dolostone is unique in the world.

Other small, moderately low grade deposits found in the course of this exploration phase are: basal quartz-pebble conglomerates at Singhbhum (Jharkhand) and Walkunji (Western Karnataka), Lower Proterozoic sheared migmatites of the Chhotanagpur gneiss complex at Jajawal (Chhattisgarh), and Lower Proterozoic amphibolites at Bodal (Chhattisgarh).

Throughout the early 1990s, a near surface deposit was found next to the unconformity contact between Proterozoic Srisailam quartzite at Lambapur in Nalgonda district (Andhra Pradesh) and the underlying basement granites. This deposit and other showings were investigated then and by 1996 several targets had been recognized based on promising exploration results and favourable geological criteria. These were then chosen for rigorous surveys and included occurrences at Aravalli in Rajasthan, in the Cretaceous sandstones in Meghalaya, the Son River valley in Uttar Pradesh and Madhya Pradesh, the Singhbhum shear zone in Orissa and Jharkhand, and the Cuddapah Basin in Andhra Pradesh.

In the Lambapur Peddagattu area, exploration drilling has established the uranium prospectivity of the north-western sector of the Cuddapah Basin. In Meghalaya, Cretaceous sandstones were recognized to be prospective for uranium mineralization. Prospecting and detailed investigations in the vicinity of the Domiasiat deposit of uranium have disclosed a number of adjoining promising areas [5.4].

Figure 7.7. summarizes trends in historical drilling campaigns across a total of 3 239 558 metres included within an exploration expenditure of USD $ 851 030 000.

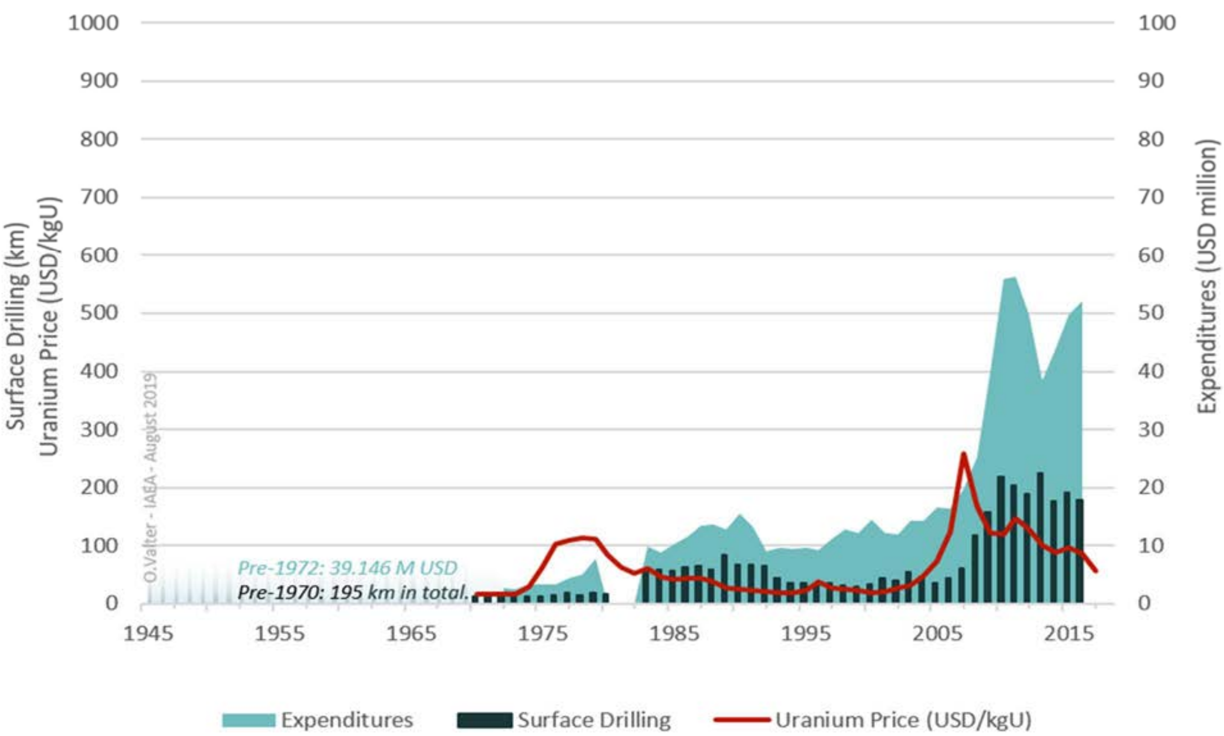


FIG. 7.7. Domestic uranium exploration data for India. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

7.5.3.1. *Recent and ongoing uranium exploration activities*

Uranium exploration is carried out by the Atomic Minerals Directorate for Exploration and Research (AMD). Following the increase of the uranium spot price in 2004, exploration activities shows the same trend (Fig. 7.7) with important drilling in several regions.

The following regions are where activities for exploration of uranium in India have been focused:

- Mesozoic–Proterozoic Delhi Basin (Rajasthan);
- Mesozoic–Neoproterozoic Kurnool and Cuddapah Basins (Andhra Pradesh);
- Neoproterozoic Bhima and Kaladgi Basins (Karnataka);
- Cretaceous sedimentary basin (Meghalaya).

7.5.3.2. *Drilling activity*

Proterozoic Delhi Basin (Rajasthan)

The Mesozoic–Proterozoic Delhi Group of metasedimentary rocks in the north-eastern sector of Rajasthan is prospective for unconformity and albitite types of uranium mineralization. This is an albitite–microclinite–pyroxenite zone that is 320 km long, also called the 'albitite line', lying between Tal in Rajasthan and Raghunathpura in Haryana. Along this zone, several surficial anomalies of uranium and uranium–thorium have been described. Uranium mineralization at Ghateshwar-Rohil is linked with albitites in relation with the mica schist and carbonaceous phyllite of the Delhi Supergroup. A fairly small low grade deposit has been recognized at Rohil. Presently, the area is being explored to prove additional resources [5.16].

Uranium mineralized intercepts have been recorded at Raghunathpura, Hurra-Ki-Dhani, Kerpura and Raghunathgarh areas along the albitite line and these could be worthy of further exploration.

Neoproterozoic Bhima Basin (Karnataka)

The Bhima Basin comprise argillaceous, calcareous and arenaceous sedimentary rocks of the Bhima Group and is cut by several major NW–SE and E–W striking faults. The exploration undertaken to this point in this area has recognized a small, medium grade deposit linked with basement granite and limestone at Gogi. Continuations of the orebody are being surveyed rigorously in areas next to the deposit. The ore is amenable to traditional alkali leaching.

Two faults zones traversing the south-eastern edge of the Bhima Basin, i.e., the Wadi and Ukinal-Kurlagere fault zones, which are geologically similar akin to the Gogi area mentioned above, are being examined by exploratory drilling for potential unconformity/vein type uranium mineralization.

Neoproterozoic Kaladgi Basin (Karnataka)

The Neoproterozoic Kaladgi Basin is evolving as a likely host for uranium mineralization related with arenites. In the Deshnur area, surface and subsurface surveys indicate the prospectivity of this area for medium grade unconformity linked uranium mineralization. At most 8300 km^2 of the basin are exposed, the remaining extensive areas of the basin being covered by trap rocks of Cretaceous age and of variable thickness.

One of the boreholes drilled in the Deshnur area yielded a grade of 0.11% U over an intersection of 63.20 m. Additional exploration is ongoing. Similar adjoining environments in the Kaladgi Basin are being investigated.

Cretaceous sedimentary basin (Meghalaya)

The resource potential of the Wahkyn deposit is further investigated by evaluation and exploratory drilling of the mineralized host Mahadek sandstone. This deposit is situated ~10 km SW of the Domiasiat deposit in the west Khasi Hills district, where a medium tonnage and medium grade deposit has been identified already. At Lostoin, a low grade, low tonnage deposit has been also been identified in the same geological environment to the west of the Wahkyn deposit.

Reconnaissance radiometric surveys have recognized important new uranium anomalies at ~30 km west of Umthongkut at Balphakram, in the Khonglah–Mawngap area in Jaintia Hills district and in the Garo Hills district, as well as in the Cretaceous Mahadek sandstones, ~20 km west of the Wahkyn deposit, near Umthongkut, west Khasi Hills district.

Other potential areas

Exploration for unconformity-related deposits of uranium has been conducted in the Indravati Basin in Chhattisgarh and in the Gwalior Basin in Madhya Pradesh. Some of the earlier identified occurrences of uranium related with quartz-pebble conglomerates in the Jajpur and Sundergarh districts of Orissa are currently being reassessed to prove their prospectivity based on the 2009 Red Book [5.17].

7.5.3.3. Future strategies

Airborne time domain electromagnetic surveys have been conducted extensively as part of India's uranium exploration programme. A proposal to conduct over 400 000 line km of airborne geophysical surveys, comprising time domain electromagnetic, magnetic and gamma ray spectrometric surveys, targeting Proterozoic basins is considered to have potential. An ambitious drilling programme totalling ~700 000 m in promising target areas of the country has been planned already to prove additional resources of uranium.

7.5.4. Uranium resources

7.5.4.1. Identified resources

As of 1 January 2017, India's known traditional resources of uranium (reasonably assured and inferred resources) are assessed to contain 207 715 tU and are hosted by carbonate (47.40%), metamorphite (28.51%), sandstone (9.79%), unconformity (8.70%), metasomatite (3.69%), granite-related (1.74%) and quartz-pebble conglomerate (0.17%) type deposits (Tables 7.1 to 7.2) [5.18].

Historical variations in identified resources up to and including this are shown in Fig. 7.8 and Fig. 7.9.

7.5.4.2.Undiscovered resources

In certain sectors of Karnataka, Rajasthan, Meghalaya, Rajasthan and Andhra Pradesh, prospective areas for resources of uranium have been established with a boosted degree of certainty. As of 1 January 2017, undiscovered resources comprise 114 480 tU in prognosticated resources and 50 880 tU in speculative resources [5.18].

TABLE 7.1. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE (tU) [5.18]

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU
Unconformity-related	n.a.[a]	n.a.	18 072
Sandstone	n.a.	n.a.	17 444
Granite-related	n.a.	n.a.	3618
Metamorphite	n.a.	n.a.	52 665
Metasomatite	n.a.	n.a.	7005
Carbonate	n.a.	n.a.	98 445
Total	n.a.	n.a.	197 249

[a] n.a.: not available.

TABLE 7.2. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [5.18]

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU
Sandstone	n.a.	n.a.	2890
Quartz-pebble conglomerate	n.a.	n.a.	352
Metamorphite	n.a.	n.a.	6558
Metasomatite	n.a.	n.a.	666
Total	n.a.	n.a.	10 466

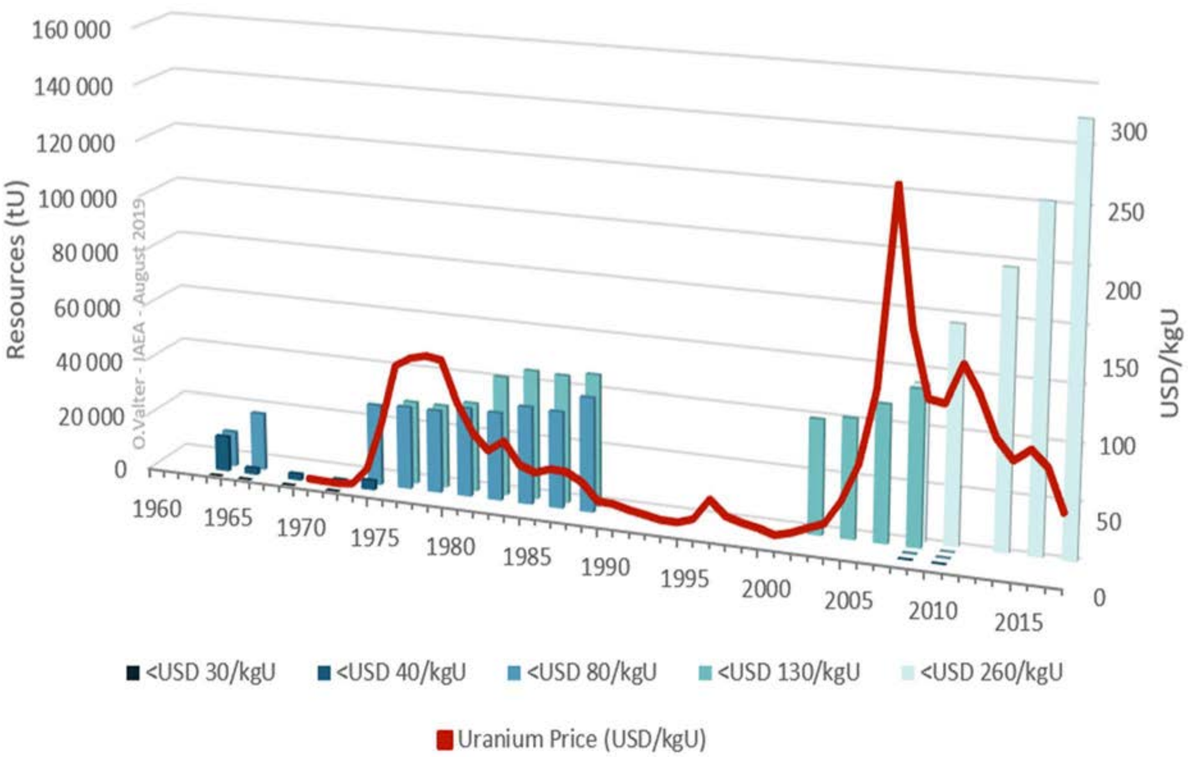


FIG. 7.8. Historical variation of reasonably assured resources within various cost categories in India. Periods where no resources are shown in any cost categories are periods where resources were not reported.

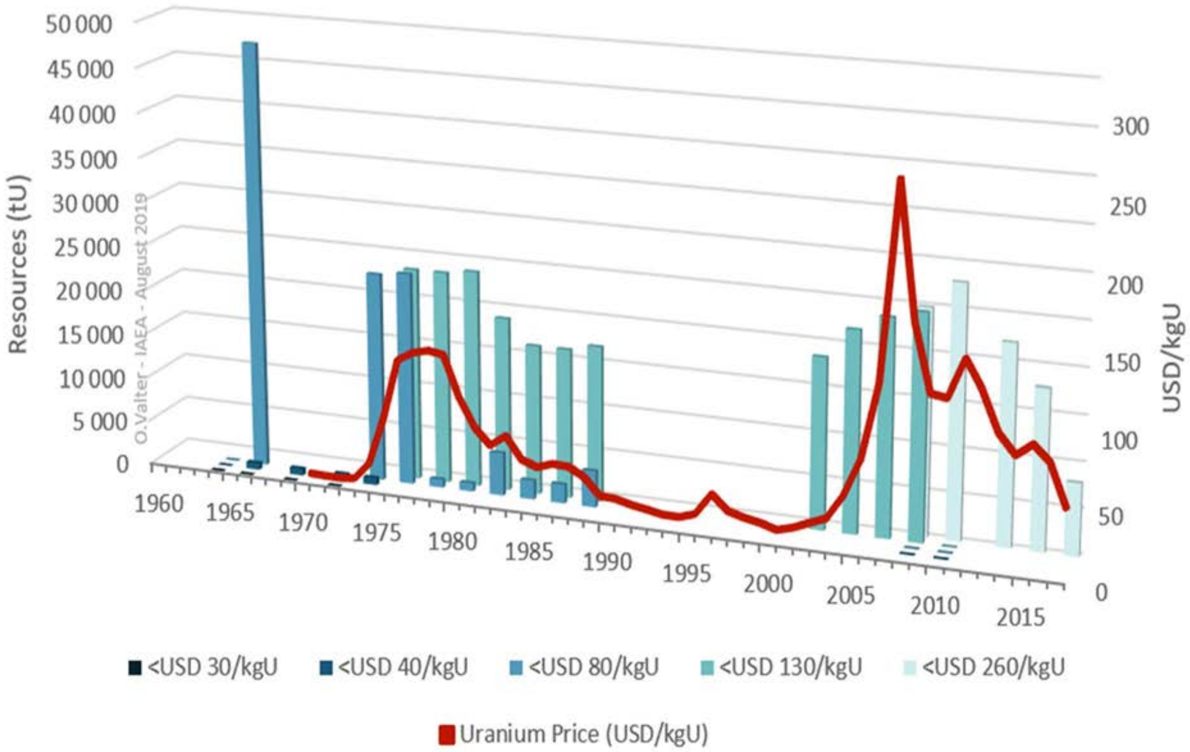


FIG. 7.9. Historical variation of inferred resources within various cost categories in India. Periods where no resources are shown in any cost categories are periods where resources were not reported.

7.5.5. Potential for new discoveries

There is moderate potential for unconformity and sandstone uranium resources to be discovered in India.

7.5.6. Uranium production

Mining and processing of uranium is carried out by Uranium Corporation of India Ltd (UCIL), a subsidiary of the Department of Atomic Energy (DAE). Details of uranium production are summarized in Tables 7.3 – 7.5 and Figs 7.10 and 7.11. No information was reported on the generation and employment of re-enriched tails or reprocessed uranium. India has produced 385 tU in 2014, 2015, 2016 and 400 t in 2017. Total historical production is 12 258 t U [5.18].

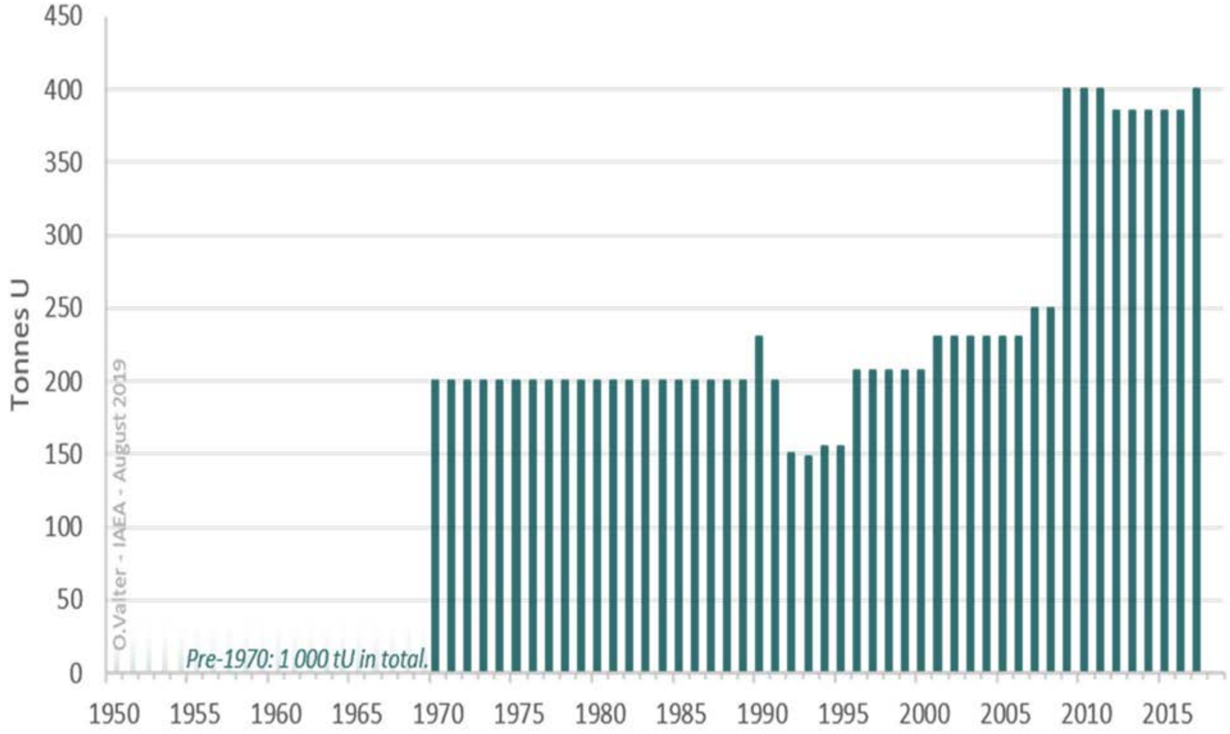


FIG. 7.10. Historical uranium production in India.

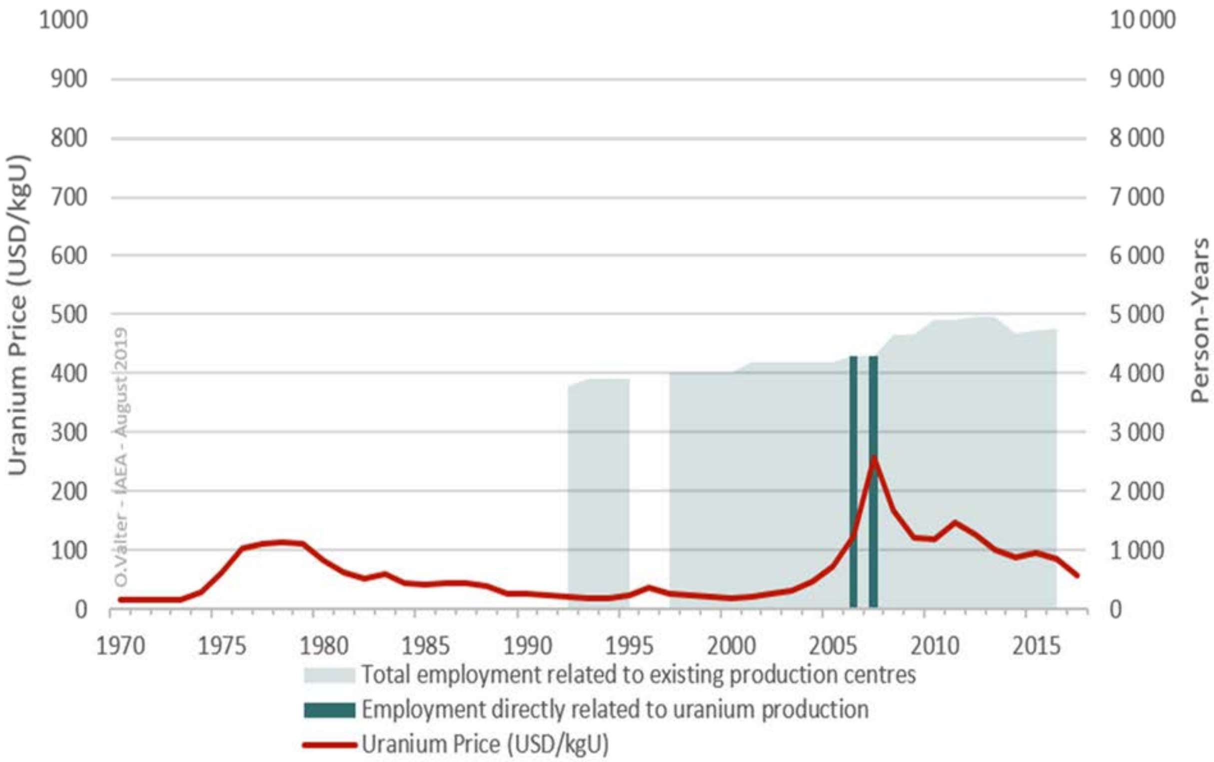


FIG. 7.11. Uranium industry employment at existing uranium production centres in India.

TABLE 7.3. URANIUM PRODUCTION DETAILS (FOR CENTRES 1–4) [5.17]

	Centre #1	Centre #2	Centre #3	Centre #4
Name	Jaduguda	Bhatin	Narwapahar	Bagjata
Status	Existing	Existing	Existing	Existing
Startup date	1967	1986	1995	2008
Source	Uranium ore	Uranium ore	Uranium ore	Uranium ore
Deposit:				
• Name	Jaduguda	Bhatin	Narwapahar	Bagjata
• Type	Vein (metamorphite)	Vein (metamorphite)	Vein (metamorphite)	Vein (metamorphite)
Mining operation:				
• Type	UG[a]	UG	UG	UG
• Size (t ore/d)	650	150	1000	500
• Average mining recovery (%)	80	75	80	80
Processing plant (acid/alkaline):	Jaduguda			
• Process	Acid			
• Type	IX[b]			
• Size (t ore/d)	2100			
• Average processing ore recovery (%)	80			
Nominal production capacity (tU/year)	175			
Plans for expansion	Undergoing expansion to treat 2500 t ore/d			
Remarks	Ore being processed at the Jaduguda plant			

[a] UG: underground mining.
[b] IX: ion extraction.

TABLE 7.4. URANIUM PRODUCTION DETAILS (FOR CENTRES 5–7) [5.17]

	Centre #5	Centre #6	Centre #7
Name	Turamdih	Banduhurang	Mohuldih
Status	Existing	Existing	Committed
Startup date	2003	2007	2011
Source	Uranium ore	Uranium ore	Uranium ore
Deposit:			
• Name	Turamdih	Banduhurang	Mohuldih
• Type	Vein (metamorphite)	Vein (metamorphite)	Vein (metamorphite)
Mining operation:			
• Type	UG[a]	OP[b]	UG
• Size (t ore/d)	750	3500	500
• Average mining recovery (%)	75	65	80
Processing plant (acid/alkaline)	Turamdih		
• Process	Acid		
• Type	IX[c]		
• Size (t ore/d)	3000		
• Average processing ore recovery (%)	80		
Nominal production capacity (tU/year)	190		
Plans for expansion	Turamdih mine (1000 t ore/d) and Turamdih plant (4500 t ore/d) are undergoing expansion		
Remarks	Ore being processed in Turamdih plant		

[a] UG: underground mining.
[b] OP: open pit mining.
[c] IX: ion exchange.

TABLE 7.5. URANIUM PRODUCTION DETAILS (FOR CENTRES 8–10) [5.17]

	Centre #8	Centre #9	Centre #10
Name	Tummalapalle	Kylleng Pyndengsohiong Mawthabah	Lambapur Peddagattu
Status	Committed	Planned	Planned
Startup date	2010	2012	2012
Source	Uranium ore	Uranium ore	Uranium ore
Deposit:			
• Name	Tummalapalle	Kylleng Pyndengsohiong Mawthabah	Lambapur Peddagattu
• Type	Carbonate	Sandstone	Unconformity
Mining operation:			
• Type	UG[a]	UG	UG
• Size (t ore/d)	3000	2000 (based on a working year of 275 d)	1000
• Average mining recovery (%)	70	75	80
Processing plant (acid/alkaline):	Tummalapalle	Kylleng Pyndengsohiong Mawthabah	Lambapur Peddagattu
• Process	Alkaline pressurized		Acid
• Type	IX[b]	IX	IX
• Size (t ore/d)	3000	2000 (based on a working year of 275 d)	1250
• Average processing ore recovery (%)	70	87	
Nominal production capacity (tU/year)	217	340	130

[a] UG: underground mining.
[b] IX: ion exchange.

References to Section 7.5

[5.1] KRISHNAN, M.S., 1982, Geology of India and Burma, CBS Publishing, New Delhi (1982).

[5.2] MINISTRY OF MINES, Geological Survey of India, http://www.portal.gsi.gov.in/portal/page?_pageid=127,687643&_dad=portal&_schema

[5.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[5.4] ATOMIC MINERALS DIRECTORATE FOR EXPLORATION AND RESEARCH, Department of Atomic Energy, Government of India, http://www.amd.gov.in/work/uranium.html

[5.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[5.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[5.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[5.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[5.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[5.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[5.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[5.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).
[5.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).
[5.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).
[5.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).
[5.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).
[5.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[5.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

7.6. IRAN, ISLAMIC REPUBLIC OF

7.6.1. Geography

The Islamic Republic of Iran (‘Iran’) lies in south-western Asia and is bordered to the north by Armenia, Azerbaijan and Turkmenistan, by Afghanistan and Pakistan to the east and by Iraq and Turkey to the west. As Iran is a littoral State bordering the Caspian Sea, Kazakhstan and the Russian Federation are also direct neighbours to the north. To the south lie the Persian Gulf and the Gulf of Oman.

The topography of Iran comprises rugged, mountainous ranges surrounding high elevation interior basins. The main mountain range is the Zagros Mountains, which consists of a series of parallel ridges interspersed with plains that bisect the country from NW to SE. Many peaks in the Zagros range exceed elevations of 3000 m and in the southern central region, there are at least five peaks exceeding 4000 m in elevation.

The centre of Iran comprises several closed basins that are collectively referred to as the Central Plateau, the average elevation of which is ~900 m. Several mountains bordering the plateau exceed 3000 m in elevation. The eastern part of the plateau is covered by two salt deserts: the Dasht-e Kavir and the Dasht-e Lut. Except for occasional oases, the salt deserts are uninhabited. Iran has only two expanses of lowland: the Khuzestan Plain in the SW and the Caspian Sea coastal plain to the north.

Iran has a variable climate. In the NW, winters are cold with heavy snowfall and sub-zero temperatures during December and January. Spring and autumn are relatively mild, while summers are dry and hot. In the south, winters are mild and the summers are very hot, with average daily temperatures in July exceeding 38°C. In general, Iran has an arid climate and most of the relatively scarce rainfall occurs in October–April. Annual precipitation averages 250 mm or less over most of the country.

Iran possesses a major proportion of the world’s proven oil reserves and an estimated 15% of its gas reserves. Estimated mineral production contributed only 0.6% of the country’s GDP in 2011. Although the petroleum industry provides the majority of the revenue, ~75% of all natural resource sector employees work in mines rather than in oil and natural gas extraction. These mines include coal, iron ore, copper, lead, zinc, chromium, baryte, salt, gypsum, molybdenum, strontium, silica, uranium and gold, the latter of which is mainly generated as a by-product of copper mining at the Sar Cheshmeh operation. The mine at Sar Cheshmeh (Kerman Province) is one of the world’s largest copper deposits. Extensive iron ore deposits exist in central Iran, near Bafq, Yazd and Kerman.

Iran has recoverable coal reserves of nearly 1.9 Bt. By mid-2008, the country produced ~1.3 Mt of coal annually. The main steel mills are located in Isfahan and Khuzestan. Iran became self-sufficient in steel in 2009. Aluminium and copper production were projected to reach 245 000 and 383 000 t, respectively, by March 2009. Cement production was 65 Mt in 2009 [6.1].

7.6.2. Geology

The oldest dated rocks in Iran are thick red and green shales of Cambrian age in the Kuh-e Dinar and in the Zagros Mountains (Fig. 7.12). The rock salt occurring with various components of the Hormuz and Ravar Series in the south and east may be coeval or even older. Old Red Sandstones are widely found in north-western, northern and eastern Iran. These are succeeded by thick, black Carboniferous limestone which was deposited when the country was covered by the Tethys Sea. Marine sedimentation continued in the Triassic period, but in two or three different facies.

During the Lower Jurassic, ~3000 m of detrital material (with intercalated coal seams) was deposited over most of Iran. This was largely metamorphosed in central Iran as a result of Middle Cretaceous diastrophism.

The resulting land surface was not covered until the Middle Cretaceous, while in the Elborz, Koppeh Dagh and Zagros, marine sedimentation continued, with breaks, throughout the Upper Jurassic and Cretaceous and extending into the Eocene and Oligocene. The Eocene deposits are mainly limestone in the Zagros region, with a tuffaceous formation containing basic lava flows (Green Series) in the Elborz, and a thick type of flysch in eastern and south-eastern Iran.

The existence of a central uranium basin in the Oligocene period is demonstrated by the occurrence of the lagoonal Lower Red Formation, which was again transgressed by the southern sea during the deposition of the oil-bearing Asmari limestone, but was re-established as a closed basin in the Upper Miocene when up to 4500 m of salty marls and clays (Upper Red Formation) were deposited, corresponding with the Fars Group of the SW.

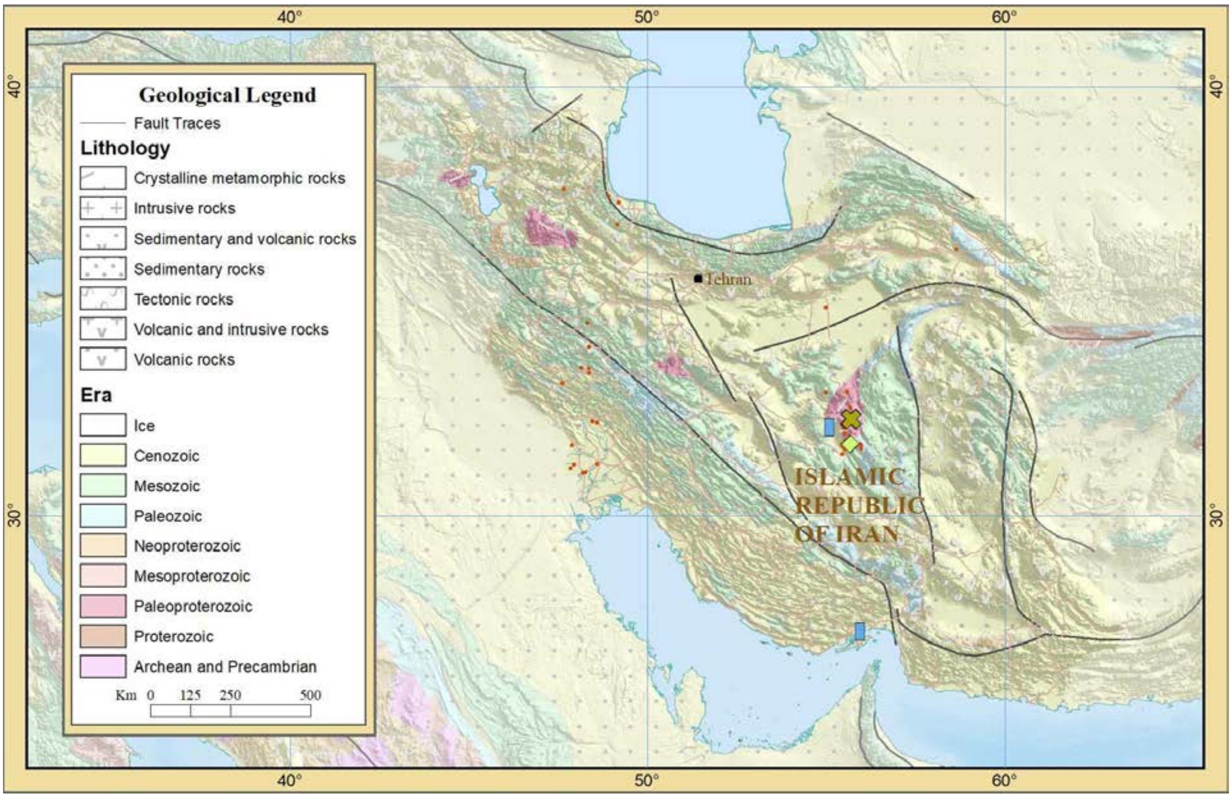


FIG. 7.12. Regional geological setting of Islamic Republic of Iran showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Irrespective of various older orogenic movements, the main structural changes to the Iranian mountain ranges occurred during the Pliocene and later, as the tilted Bakhtiari conglomerates, raised gulf beaches and active fault lines testify. Autochthonous folding is juxtaposed on thrusting. The prevailing strike is NW or west, but strong meridional components are found to the east. Fracturing has also been a factor in determining the topography.

An additional element was introduced by Pliocene–Pleistocene volcanism in Azerbaijan (Kuhha-ye Sabalan, Kuh-e Sahand), Elborz (Mount Demavend), Kerman (Kuh-e Hazaram, Kuh-e Laleh Zar) and Baluchistan (Kuh-e Taftan, Kuh-e Bazman). Salt domes of different ages are also widespread in the Persian Gulf area and in central Iran.

Iran is governed by two major systems of folding. The Elborz system commencing west of the Caucasus and Turkey passes through north-western Iran and forms the Elborz Mountains, continues south to the Caspian Sea, and then follows an easterly trend continuing into Afghanistan. The second or Zagros system begins NW of Azerbaijan and trends SW, passing through Kurdistan, Lorestan and Bakhtiari. It continues along the Persian Gulf and on into India where it forms the Himalayas.

The Elborz folds are asymmetric and the geological formations are predominantly Upper Tertiary in age. These formations attain considerable thicknesses of 2000–3000 m. On the eastern side, there are numerous faults perpendicular to the direction of folding. Faulting is also in evidence in the Caspian region.

The Zagros folding is not intense in the west and is reasonably symmetrical, forming anticlines and synclines in strata of Pliocene age. Following the movement to the NE, folding becomes more intense and a faulted thrust zone appears, forming mountains of greater elevation, up to 4000 m at Bakhtiari, where Cretaceous rocks occur.

In the central plateau, strata of Precambrian, Palaeozoic, Mesozoic and Early Tertiary age occur, these latter being little folded and of limited thickness. Precambrian outcrops cover a limited area and there is little evidence of igneous activity or metamorphism [6.2].

7.6.3. Uranium exploration

Radioactive minerals were first detected in 1935 in the Anarak mining region and the search for uranium began in 1959 with the examination of mines and dumps for anomalous radioactivity. In 1961, a preliminary survey was made of the intrusive bodies in the west, NW and NE of the country. In 1970–1971, France's Commissariat à l'Energie Atomique (CEA) and the Geological Survey of Iran examined several sedimentary formations in Anarak, Khorassan, central Iran and Azarbaijan regions in order to assess the potential for uranium mineralization in these areas.

Up to the end of 1978, the significant nuclear power programme embarked on by Iran stimulated domestic exploration. A private operator company, Uriran, was created and sponsored by the Atomic Energy Organization of Iran (AEOI). Airborne survey contracts were made with several companies to survey 656 000 km² of the country. The favourable regions investigated by these methods included the Bafq-Robateh Posht e Badam region (Khoshumi, Narigan, Saghand), Hudian and Maksan in the SE and Guvarchin, Mianeh and Dechan in Azerbaijan Province. In addition to the airborne geophysics survey area, occurrences of uranium at Kelardasht, Meskani and Talmesi and the salt plugs in southern Iran were investigated as well.

The AEOI evaluated the uraniferous potential in some selected areas. Follow-up of roughly one-sixth of the area subjected to the airborne surveys resulted in the identification of some small deposits. New concepts and methodologies of exploration for uranium were introduced during 1998–1999 in support of recognition of sandstone-hosted and polymetallic deposits of uranium.

In 1998–2000, the AEOI continued exploration for uranium in central Iran (Sechahun, Khoshumi and Narigan) and in NW Iran. Ground magnetic and radiometric surveys, geological mapping, trenching, drilling and logging as well as geochemical surveys were undertaken in prospective Precambrian formations in central Iran and in Tertiary rock units (volcanic rocks, intrusives and sedimentary rocks) in north-western Iran. Ground follow-up of airborne anomalies and evaluation of Mesozoic–Cenozoic sedimentary units were the activities employed to collect those data requested by the specialist groups involved in data integration and metallogenic evaluation.

Systematic exploration research such as compiling and integrating geodata, metallogenic prognosis and prediction of potential areas were regarded the chief methods for the evaluation of sedimentary sequences of Mesozoic–Cenozoic age, the Pan-African metallogenic structural zones and the Alpine polymetallic uraniferous igneous systems.

More recently, exploration efforts have led to the identification of sedimentary basins in central and north-western Iran with potential for sandstone-hosted mineralization. These efforts have been mainly directed at:

- Assessment of resources of uranium in the Bafq-Posht-e-Badam metallogenic zone, which hosts the Sechahun, Zarigan and Saghand occurrences;
- Within this zone, exploration potential comprises hydrothermal vein and metasomatic deposits related with Upper Precambrian metasomatic and magmatic complexes;
- Assessment of the potential of intermontane basins in central Iran for sandstone-hosted mineralization;
- Assessment of resources of uranium in polymetallic hydrothermal deposits found in Azarbaijan Province and in late Alpine basins in the same region;
- Exploration for uranium in coal-bearing basins in north-western and central Iran;
- Exploration in the Great Kavir Basin and within its catchment area.

In addition to the projects that are still under evaluation, exploration has commenced in new areas in the Razavi Khorasan, south Khorasan, Sistan-va-Baluchstan and Kerman Provinces in the SE and east of the country.

Regional structural studies continued in 2008–2009 to cover nearly the whole eastern part of Iran. Detailed exploration works [6.3-6.10] were conducted in the following areas:

- *Saghand orefield*: Areas near the Saghand 1 and Saghand 2 deposits are in different phases of exploration. Trenching and drilling have been conducted. Mineralization in this area is of the hydrothermal and metasomatite types and caused by an alkaline granite intrusion into volcanic rocks;
- *Markesheh–Ravar exploration area*: Sedimentary complexes of Lower Triassic–Upper Jurassic age contain uranium mineralization related with copper and silver mineralization in a coal-bearing arkosic sandstone. A combined geological and geophysical investigation is being undertaken, besides exploratory drilling and logging;
- *Narigan exploration area*: This area hosts hydrothermal type uranium mineralization and various anomalies;
- *Koshumi exploration area*: Metasomatite type mineralization is the predominant type;
- *Gachin salt plug (Bandar Abbas)*: Exploration has been conducted in order to find new resources of uranium and to develop known ones;
- *Lut and Jazmurian regions*: These depression zones could have potential for sedimentary basins hosting uranium mineralization [6.2].

Figure 7.13 summarises historical exploration data, including 345 259 metres of drilling within an exploration expenditure of USD $ 367 377 000.

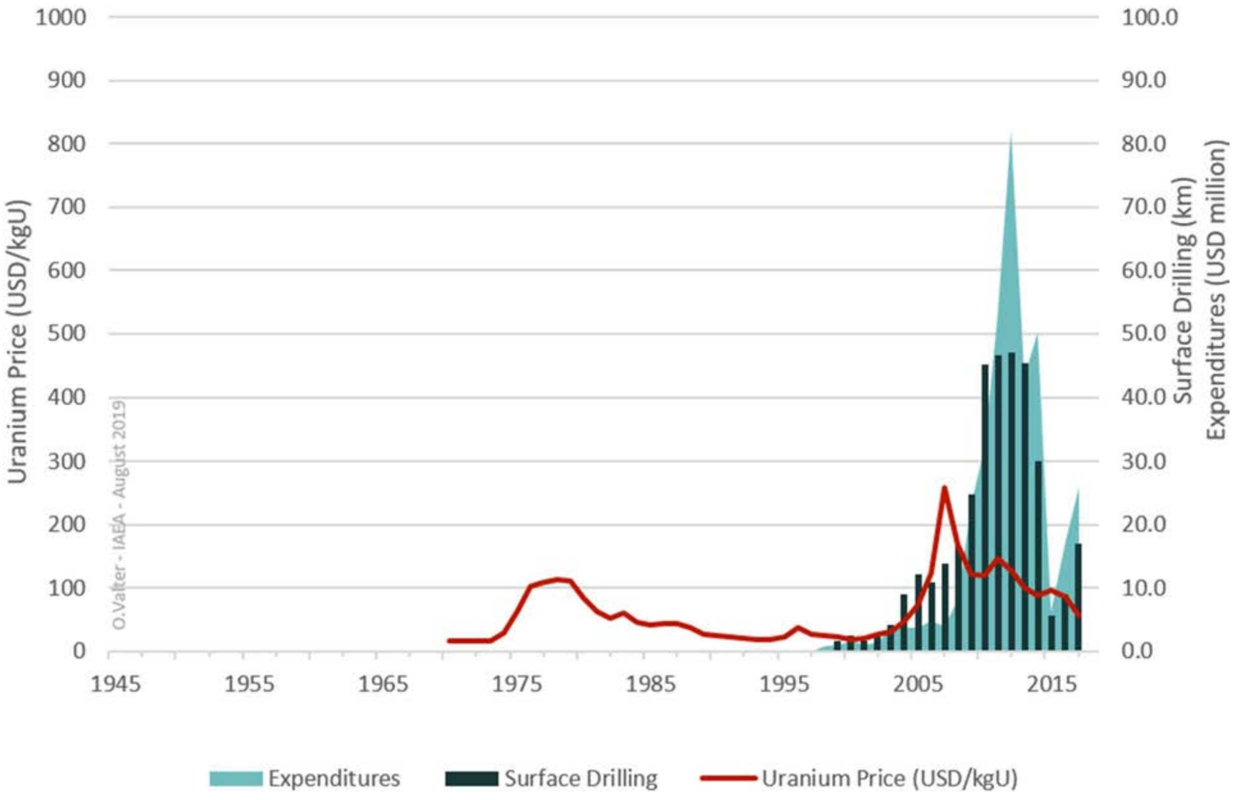


FIG. 7.13. Domestic uranium exploration data for Iran. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

7.6.4. Uranium resources

7.6.4.1. Identified resources

As of 1 January 2017, reasonably assured resources total 1407 tU in the <US$ 130/kgU cost category, associated to granite-related (653 tU), metamorphite (136 tU) and metasomatite (618 tU) deposits [6.11].

Inferred resources total 6750 tU in the <US$ 130/kgU cost category, associated to granite-related (479 tU), metamorphite (25 tU), volcanic-related (128 tU) and metasomatite (6118 tU) deposits [6.11].

The UDEPO database lists the most significant deposits for the Islamic Republic of Iran as Saghand 1 and 2, Khoshoumi 1, Bandar Abbas, Gachin, Narigan 1.

7.6.4.2. Undiscovered resources

Undiscovered resources include prognosticated (12 450 tU) and speculative (33 200 tU) resources and these are assigned to the following deposits and prospects [6.11]:

- Kerman-Sistan trend, with volcanic-related, metasomatic and granite-related mineralisation;;
- Naiin-Jandagh trend, with granite-related and volcanic-related mineralisation;
- Birjand-Kashmar trend, with granite-related, sedimentary and volcanic-related mineralisation;
- Hamedan-Marand trend, with granite-related, sedimentary, intrusive and volcanic-related mineralisation.

Historical variations in resources are shown in Figs 7.14 and 7.15.

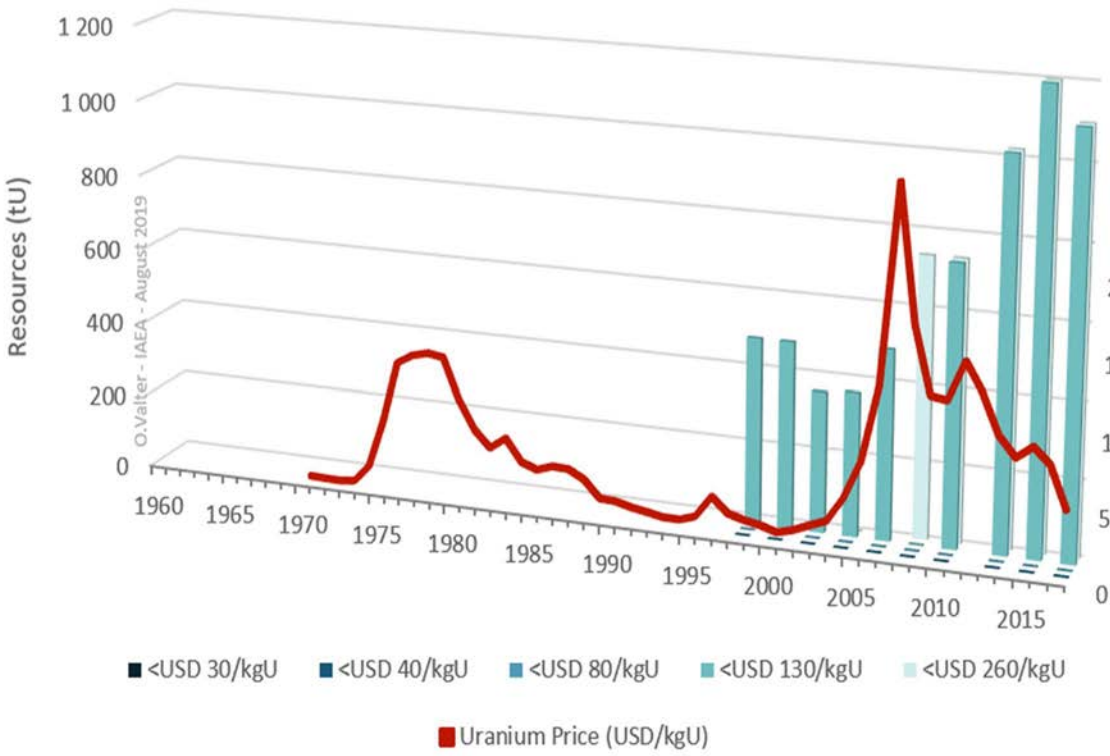


FIG. 7.14. Historical variation of recoverable reasonable assured resources within various cost categories in Iran. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

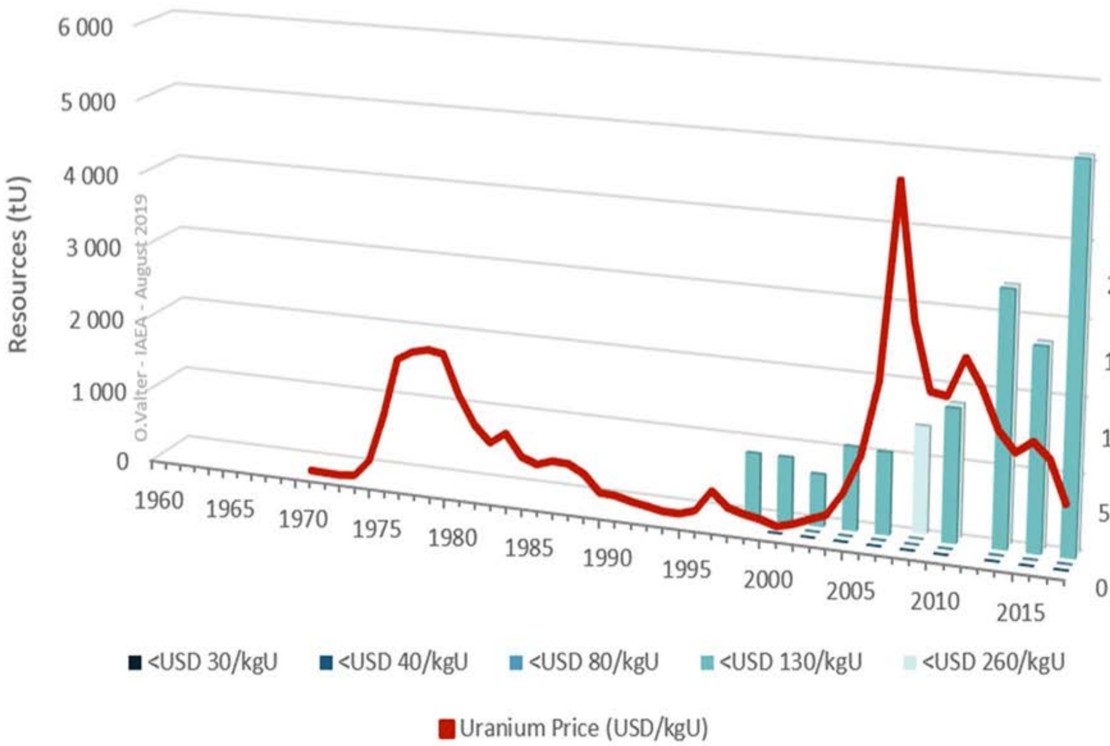


FIG. 7.15. Historical variation of recoverable inferred resources within various cost categories in Iran. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

7.6.5. Potential for new discoveries

The greatest potential for uranium deposits in Iran appears to be in the continental sedimentary rocks. The Lower Cambrian Lalun sandstone contains several minor occurrences and the Lower Jurassic Shemshak Formation, which contains coal beds and organic debris, also hosts several low grade occurrences.

The Middle Jurassic Hodjek Formation in central Iran contains several very favourable host lithologies. Discoveries of mineralization in the Oligocene–Miocene sedimentary rocks of the Jaz-Murian Depression, in southern Iran, show that this area, which is bounded to the north by granites, rhyolites and tuffs, has good potential.

Other areas potentially favourable for sandstone deposits include the Neogene basins in the north of the country, which contain conglomerates with some sandstones and mudstones and are surrounded by metamorphic and igneous rocks that could be a source of uranium. In south-western Iran, Pliocene continental beds of the Fars Group could be worthy of investigation. The source rocks here are similar to those in the north, but the presence of carbonaceous matter in the beds, which are up to 5000 m thick, has not been reported.

Vein deposits and disseminated deposits in metamorphic rocks may be found in the central tectonic zone in and near granitic bodies. In the western part of this belt, granitic rocks, which may be described as ‘fertile’, and rhyolites and tuffs have been reported which have abnormally high levels of uranium and thorium.

The closed interior drainage basins have a climate that is favourable for the formation of calcrete deposits which may be uranium- and/or vanadium-bearing.

Phosphatic beds, some of which are slightly uraniferous, have been found in Devonian and Upper Cretaceous marine formations. In this case, it is envisaged that the phosphate could yield uranium as a by-product of phosphoric acid production [6.2].

7.6.6. Uranium production

Uranium is obtained from the Gachin salt plug, which is extracted by open pit mining and has been treated in the Bandar Abbas uranium production plant since 2006 (Fig. 7.16) for an estimated total of 106 tU. The annual production capacity of the plant is 21 tU. A second production plant, near Ardakan (Saghand underground mine), with annual production capacity of 50 tU, is being built.

In 2017, most of the mining activities were at Gachin mine. An underground mine was developed at Saghand in the central desert region of Yazd province over 1999-2003. Production from the metasomatite ore started in 2017 [6.11]. Uranium production was estimated to be 20 t in 2017.

FIG. 7.16. Uranium production in the Islamic Republic of Iran.

References to Section 7.6

[6.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Iran, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[6.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[6.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[6.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[6.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[6.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[6.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[6.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[6.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[6.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).

[6.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

7.7. IRAQ

7.7.1. Geography

Iraq is situated in western Asia and encompasses most of the north-western section of the Zagros Mountains, the eastern part of the Syrian Desert and the northern part of the Arabian Desert. Iraq borders the Syrian Arab Republic to the NW, Turkey to the north, the Islamic Republic of Iran to the east, Jordan to the SW, and Kuwait and Saudi Arabia to the south. Iraq has a narrow section of coastline just 58 km long on the northern tip of the Persian Gulf. Two major rivers, the Tigris and the Euphrates, flow through Iraq in a NW–SE direction. These rivers provide the country with significant agricultural potential, which contrasts with the steppe and desert landscape characterizing most of western Asia.

Northern Iraq is mostly mountainous, the highest point, Cheekah Dar, being 3611 m in elevation.

The local climate is mostly semi-arid, with mild to cool winters and dry, hot summers. Most of the country has a hot arid climate with subtropical influence. Average summer temperatures exceed 40°C for much of the country; winter temperatures frequently exceed 21°C. Precipitation is typically low; most places receive less than 250 mm annually, with maximum rainfall occurring during the winter months. Rainfall during the summer months is extremely rare, except in the far north of the country.

With its 143.1 billion barrels of proven oil reserves, Iraq ranks second only to Saudi Arabia in the size of its oil resources [7.1].

7.7.2. Geology

Iraq is near the centre of the so-called ‘fertile crescent’, an area characterized by topographically low relief, which extends from central part of the Syrian Arab Republic to the Arabian Gulf (Fig. 7.17). This NW–SE trending area contains the youngest sedimentary rocks in Iraq and is flanked by a plateau to the west and SW, and by a series of ridges and depressions that grade into the mountainous areas in the NE.

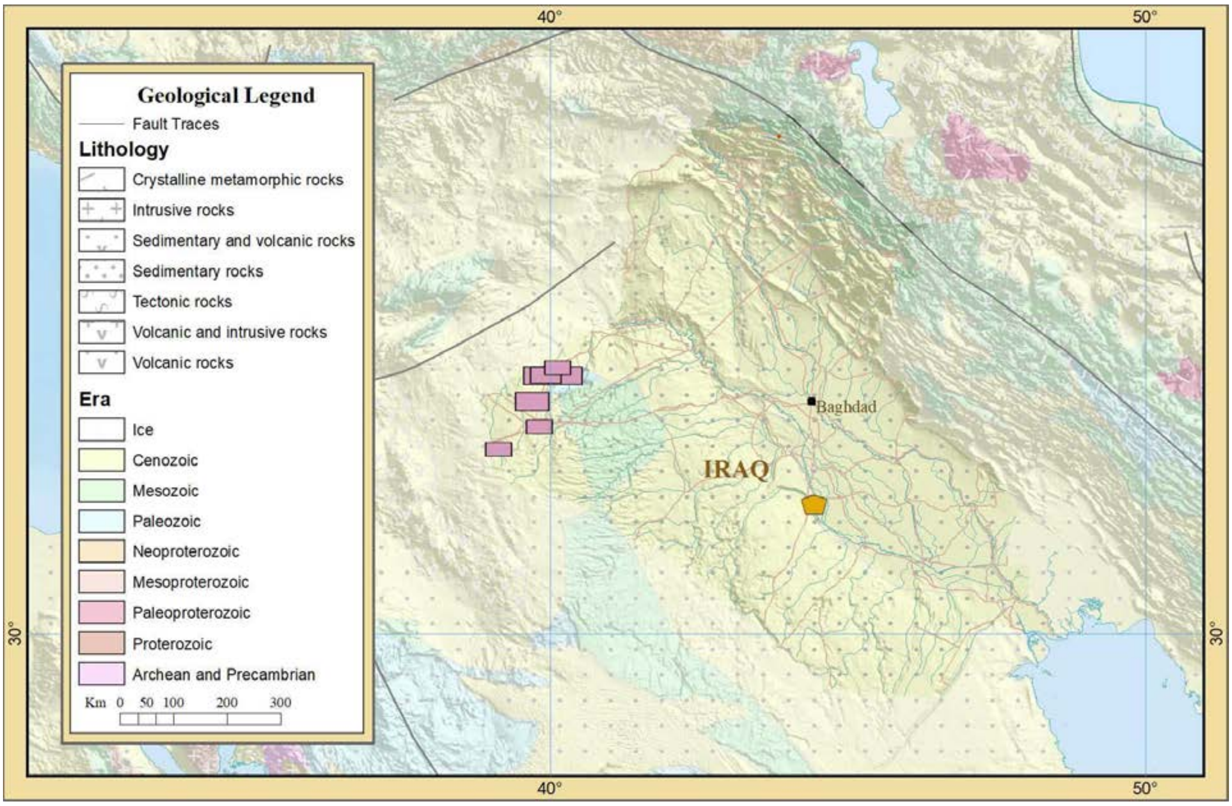


FIG. 7.17. Regional geological setting of Iraq showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The geology of Iraq reflects its morphology whereby the youngest sedimentary rocks, Neogene and Quaternary in age, lie within the central depression while the flanks expose older strata of Palaeogene–Palaeozoic age.

The area to the SW of the Euphrates River is characterized by NE dipping strata. In western Iraq, near the settlement of Rutba, the strata dip to the west away from the axis of a major ENE–WSW trending anticlinorium in which rocks as old as Permian crop out.

The Jezira area in NW Iraq is dominated by a massive uplift. Middle Miocene deposits, exposed in the core of this uplift, are flanked to the east, north and west by Upper Miocene clastics. To the south, erosion by the Euphrates River has exposed Oligocene and Lower Miocene carbonates along tight anticlinal structures controlled by east–west faults.

The foothills NE of the Mesopotamian depression comprise narrow anticlines. Upper Miocene–Pleistocene molasse sedimentary rocks and Middle Miocene evaporites are exposed in their cores. Some higher anticlines within the Sinjar and Qara Chanq areas have exposures of Palaeogene and, locally, Upper Cretaceous formations.

The mountainous region to the NE of Kirkuk is characterized by harmonic folding, with Cretaceous or older rocks exposed in the cores of the folds. Palaeogene and Neogene rocks form the adjacent synclines. In northern Iraq, along the Turkish border, Palaeozoic–Cretaceous rocks crop out.

Along the border with the Islamic Republic of Iran, there are thrust sheets of sedimentary and igneous rocks which were formed in the neo-Tethyan oceanic domain. The lowest of these comprise cherts and volcanic rocks, intruded by large basic and ultrabasic plutons [7.2].

7.7.3. Uranium exploration

Iraq has never supplied information for inclusion in the Red Book and very little information is available on uranium exploration in the country.

Reports on uranium exploration in Iraq cover wide areas, including field checking of all surface anomalies identified by radiometric airborne survey. Some localities have received more attention than others, such as the Al-Qaim area and Abu Skhair. Exploration work has also been conducted in Taqtaqana, Shithatha and Hit areas.

In 1974, an airborne spectrometric survey revealed a consistent and semi-continuous belt of radioactive anomalies along the Euphrates River basin but concentrated mostly along the southern and western sides of the basin. These radioactive anomalies were attributed to uranium mineralization and coincide with surface expressions of two geological features, namely, the exposures of the Euphrates Formation and the Euphrates Fault Zone.

Geological investigations have shown that the upper parts of the Euphrates Formation are characterized by generally higher than background uranium concentrations (>10 ppm) and by the presence of thin horizons recording higher levels of radioactivity where uranium concentrations reach 300 ppm. These radioactive horizons were encountered in most of the exposures and near surface sections of the Euphrates Formation, from Al-Qaim in the NW to Nassirriya in the SE.

The uranium concentrations in these horizons are generally in the range 10–300 ppm (averaging 70–80 ppm U). The host rocks are mostly dolostones varying in colour from greyish-white to pale brown and yellow. These strata are hard, occasionally fossiliferous and clayey, and commonly contain organic or bituminous matter. The thickness of the uranium-bearing horizons averages 30 cm and the seams persist and show regional extension along the western side of the Euphrates River. No definite uranium minerals have been identified, but it is believed that uranium occurs in dolomite crystals in unidentified form.

Secondary (epigenetic) uranium deposits are developed in certain localities, such as at Al-Qaim and Abu Skhair. The uranium is oxidized and leached from the underlying syngenetic uranium-bearing horizons and redeposited near the erosional contact of the Euphrates Formation with the overlying units.

Unusual uranium mineralization, developed by the end of the Early Miocene, occurs in the carbonates of the Euphrates Formation. Tectonism reactivated some of the old fault systems along the Euphrates River, which allowed uranium-bearing solutions to percolate upwards, together with bitumen and H_2S. The shallow intertidal parts are enriched with uranium, which was precipitated in the interstices, below the sediment–water interface, under reducing conditions. Epigenetic mobilization of uranium resulted in the formation of new deposits.

The Abu Skhair area was subjected to systematic exploration in order to evaluate the uranium mineralization discovered in the Hor Al-Jebssa area, close to the settlement of Al-Zejrey. The uranium deposits of Abu Skhair consist of a non-uniform grey to dark grey marly limestone layer of variable thickness (0.2–4.7 m) rich in organic materials and broken fossil shells. According to the conclusion of this study, the uranium of the Abu Skhair deposit originated from a specific limestone layer within the Euphrates Formation (Lower–Middle Miocene), which contains roughly70–80 ppm U and is considered the source rock for the uranium mineralization in the area.

Uranium is also found in marine sedimentary phosphorites (Late Cretaceous–Early Tertiary) in variable concentrations up to 100 ppm U [7.3].

7.7.4. Uranium resources

No uranium resources have been reported by Iraq.

The UDEPO database lists the most significant deposits for Iraq as Swab, Dwaima, Marbat, Akashat, H 3, Ethna, Hirri, Abou Skhair.

7.7.5. Potential for new discoveries

Iraq possesses world class reserves of phosphate with the four largest deposits totalling 5.75 Bt (representing 9% of global reserves) and giving Iraq the second largest phosphate reserves in the world, after Morocco. Four phosphate deposits, Akashat, H3, Ethna and Swab, are the most promising discoveries. The two largest, Akashat and Swab, are estimated to have reserves of 1.7 and 3.5 Bt of phosphate, respectively. The phosphate rock deposits of western Iraq contain uranium levels in the range 30–50 ppm [7.4]. At an average grade of 40 ppm U, the uranium resources contained in 7 phosphorite deposits are estimated in the order of 350 000 t. [7.5]

The country is predominantly covered by clastic calcareous and evaporitic sequences and the potential source rocks are already known. On the basis of its unfavourable geology, the potential for the discovery of conventional uranium deposit types is considered to be very limited.

7.7.6. Uranium production

The Akashat mine, located 420 km west of Baghdad, close to the border with the Syrian Arab Republic, is a phosphate mine associated with the Al-Qaim site. In January 1976, Iraq contracted a Belgian company to construct a chemical fertilizer complex at Al-Qaim. By the second half of 1982, phosphate ore from the Akashat mine was being processed. In 1982, Iraq ordered the construction of a uranium extraction facility at the Al-Qaim site, which was commissioned at the end of 1984. The unit was designed to produce 54 tU/year (as $UO_4.2H_2O$), assuming continuous production of phosphoric acid at 150 m^3/h and a uranium content of 75 ppm in the phosphate.

The uranium extraction facility at the Al-Qaim complex never attained maximum production. Through January 1991, total production at the site was 170 t of uranium peroxide containing 110 tU. The relatively low output, combined with phosphate ore that yielded only 40 ppm uranium as opposed to 75 ppm, was due to technical problems in the phosphoric acid unit. The production facility was destroyed in 1991 during the Gulf War.

The Abu Skhair uranium mine was located 25 km SW of Najar. Production began in September 1988 and ended at the end of 1990 when the mine was flooded. Uranium ore (150 ppm) was associated with marly limestone [7.6].

7.7.7. Comments

No facilities nor plans to develop nuclear generating capacity exist in Iraq. Therefore, it has no reactor related uranium needs.

References to Section 7.7

[7.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Iraq, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[7.2] SAAD, Z.J., GOLL, J.C. (Eds.), Geology of Iraq, Geological Society, Brno (2006).

[7.3] AL-BASSAM, K.S., MAHDI M.A., AL-DELAIMI, M.R., Contribution to the origin of the syngenetic uranium enrichment in the early Miocene carbonates of the Euphrates Formation, Iraq, Iraqi Bull. Geol. Min. **2** 2 (2006).

[7.4] BLAIR, D., US finds 'world-class' phosphate in Iraq, Financial Times (7 September 2011).

[7.5] AL-BASSAM, K.S., Development of the Phosphate Industry in Iraq: Resources, Requirements and Challenges. Iraqui Bulletin of Geology and Mining, Special Issue, No 7, Baghdad (2017).

[7.6] ALBRIGHT, D., HINDERSTEIN, C., Is the activity at Al Qaim related to nuclear efforts?, http://isis-online.org (10 September 2002).

7.8. ISRAEL

7.8.1. Geography

Israel consists of the Mediterranean coastal plain (narrow in the north, broader in the south), part of the Golan Heights, the central hills (Upper Galilee, Lower Galilee, Judean Hills), the Jordan Rift Valley, and the Negev in the south. The country extends N–S over a length of 424 km and its width ranges from 15 km to 114 km.

The highest point is Mount Meron (1208 m). The Dead Sea, 408 m below sea level, is the lowest point on earth. Israel's lowlands contain fertile soil, although irrigation is required in many areas. The Negev, with the exception of the north, is virtually a desert. However, with irrigation some of the land is arable. Much of the irrigation water is taken from the Jordan River, which rises in the Golan Heights and in Lebanon and flows for 320 km before discharging into the Dead Sea. The Dead Sea is highly saline owing to the high evaporation rate. The largest freshwater body is Lake Tiberias, also known as the Sea of Galilee.

The climate is mainly Mediterranean, particularly in proximity to the sea. Large parts of the country, especially in the south and centre and in the Negev, have an arid climate. In winter, snow falls on the highest mountains [8.1, 8.2].

7.8.2. Geology

7.8.2.1. General

The geology of the country is dominated by sedimentary rocks of Mesozoic and Tertiary age (Fig. 7.18). In contrast, along the coastal plain and in the Jordan Rift Valley, alluvial sediments of Quaternary age cover older rocks. In the Mesozoic, the Tethys Sea covered what is now Israel and during this period limestone and dolomite were the main strata deposited, with intercalations of chert and marl commonplace. In the southern area, shale deposition denotes an increase in water depth. At the time, the Tethys Sea was characterized by episodes of transgression and regression.

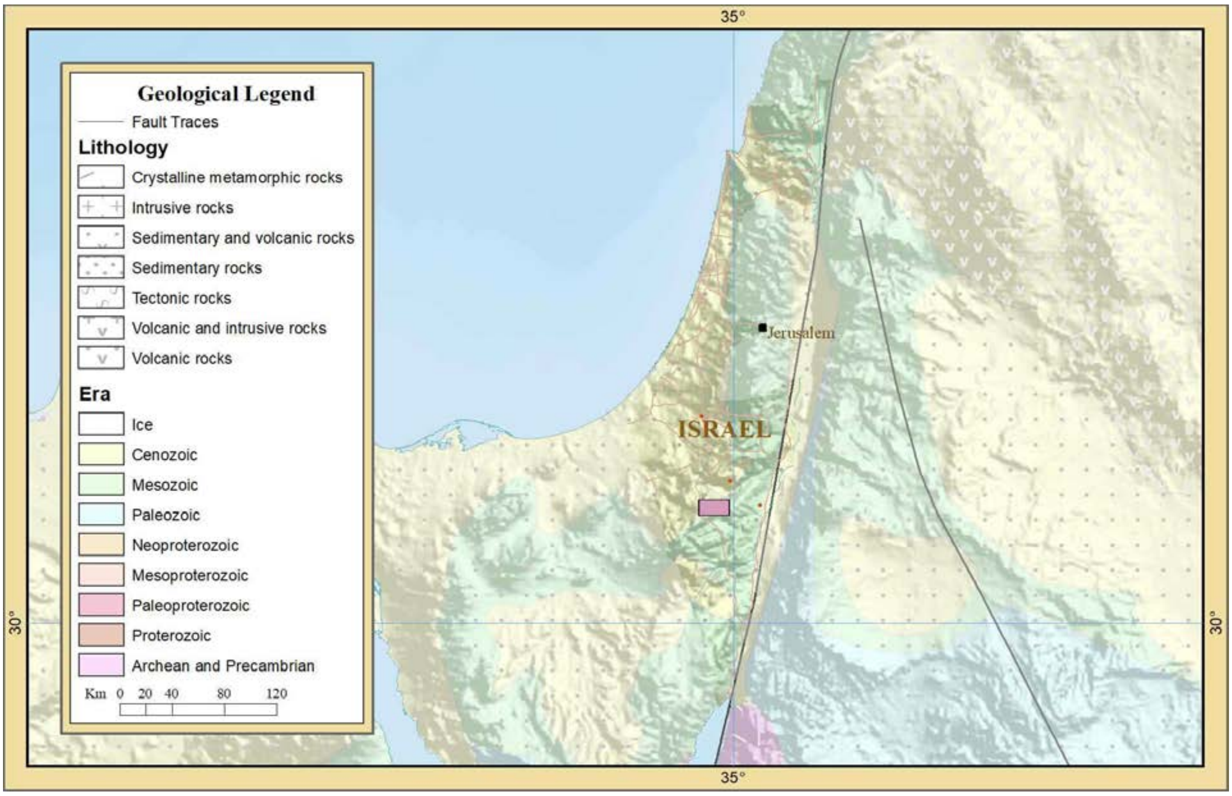


FIG. 7.18. Regional geological setting of Israel showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

During the Jurassic period, the break-up of the Africa and Arabia Plates started along the Red Sea. The break-up continued further north, forming the Dead Sea Basin which was subsequently filled with Miocene and Pleistocene sedimentary rocks. The continuation of the depression is found in the Jordan Rift Valley (the Jordan Graben).

As a result of tectonically active margins, Miocene volcanism of mainly basaltic composition is characteristic of the entire area. Saline brines developed in the Dead Sea Depression, forming evaporite deposits. Many parts of the Dead Sea Basin and of the Negev are covered with the mostly reddish to light brown coloured Nubian Sandstone which has resulted from the denudation of the Arabian Shield. Its deposition probably started in the Upper Jurassic and continued into the Upper Cretaceous.

In addition to the Nubian Sandstone, the Tethys Sea covered large parts of both present-day North Africa and the Middle East. During the Upper Cretaceous, marine phosphorite/phosphate was deposited in basins no deeper than 300 m. These conditions prevailed over an area extending from NW Africa (Morocco) through Tunisia, Egypt, Israel and Jordan and in to the Syrian Arab Republic. The resulting deposits in the Negev have been investigated in at least twenty locations. The phosphorite/phosphate horizons overlie, and are interbedded with, chert and chalk sequences. The overlying rocks consist of marl of Maastrichtian age which also hosts oil shale in some areas [8.2].

7.8.2.2. Geology relevant to uranium mineralization

Individual deposits of uranium have not been reported by Israel. However, as in many other countries, the phosphorite/phosphate deposits are uraniferous. The total resources of phosphorite/phosphate are reported in several publications, although no official national report is available.
According to the US Geological Survey Mineral Commodity Summaries, the phosphate rock reserves in Israel have been estimated at 180 Mt [8.3]. The proven reserves of phosphate have been reported at 220 Mt

[8.2]. At average grades in the range 100–170 ppm U, the contained uranium resource would amount to ~25 000 tU. Another publication reported that the total uranium contained in Israel's low grade phosphate rocks is estimated at 30 000–60 000 tU. However, only that portion of mined phosphate used for the production of phosphoric acid could be regarded as a potential source of by-product uranium. Phosphate production in Israel is estimated at ~3 Mt annually. If uranium were extracted at all the phosphoric acid plants operating in the country, then less than 100 tU/year would be recovered [8.4, 8.5].

7.8.3. Uranium exploration

No official reports are available, although it is expected that national organizations have conducted exploration for conventional uranium deposits. Reference [8.2] reports the involvement of staff members of the Geological Survey in overseas training in exploration, uranium geology and evaluation of low grade deposits. Exploration has been undertaken for phosphorite/phosphate deposits which are known to have low grade uranium contents.

7.8.4. Uranium resources

While no official resource estimates are available, estimates have been made of uranium resources contained in phosphorite/phosphate deposits. The total uranium contained in these deposits is estimated to be 25 000–60 000 tU. Neither specific resource categories nor cost classes are given.

The UDEPO database lists the most significant deposit for Israel as Negev Desert District.

7.8.5. Potential for new discoveries

It was assumed in Ref. [8.2] that potential may exist for new discoveries and that the speculative resource potential is assessed as 10 000–50 000 tU. This assumption is made on the basis of favourable economic conditions for both the phosphate industry and the uranium industry. This suggests limited potential for locating conventional uranium deposits.

7.8.6. Comments

Israel's uranium requirements are unknown and the country has reportedly imported uranium and obtained natural uranium supplies on the world market from a number of sources. Starting in the mid-1970s, Israel imported 600 t of yellowcake from South Africa. Israel has also devised a method of extracting uranium from the phosphate deposits in the Negev Desert. Active mining of phosphate deposits takes place near Beersheba. No official production reports are available. Reference [8.2] notes that were the phosphoric acid plants to operate at full capacity, then an annual production of roughly 90–100 tU could be feasible. Israel has never reported to the Red Book.

References to Section 7.8

[8.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Israel, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[8.2] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Israel, IAEA, Vienna (1977) 9 pp.

[8.3] US GEOLOGICAL SURVEY, Mineral Commodity Summaries, Phosphate Rock (2009), http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2009-phosp.pdf

[8.4] WISCONSIN PROJECT ON NUCLEAR ARMS CONTROL, Israel: Uranium processing and enrichment, The Risk Report **2** 4 (1996).

[8.5] WORLD NUCLEAR ASSOCIATION, Emerging Nuclear Energy Countries (2009), http://www.world-nuclear.org/info/inf102.html

7.9. JORDAN

7.9.1. Geography

Jordan is situated in western Asia, lying on the east bank of the Jordan River. The country is bounded by Saudi Arabia to the east and SE, Iraq to the NE, the Syrian Arab Republic to the north and the West Bank and Israel to the west, sharing control of the Dead Sea with the latter.

Over half of Jordan is covered by the Arabian Desert. It comprises an arid plateau in the east, irrigated by oases and seasonal precipitation, and a highland area in the west comprising arable land and Mediterranean evergreen forests.

The country has a Mediterranean climate, that is, semi-dry in summer with average temperatures around 30–35°C and relatively cold in winter, averaging ~13°C.

With the notable exception of phosphates, Jordan has limited natural resources. The principal hindrances to Jordan's economy are regional instability, a complete reliance on oil imports for energy and scarce water supplies.

In addition to phosphates, Jordan has significant deposits of oil shale and uranium; these potential sources of indigenous energy have been the focus of renewed interest in recent years. Phosphate mines in the south have made Jordan one of the major producers and exporters of this mineral in the world. Potassium, salt, natural gas and dimension stone are the other significant natural resources mined [9.1].

7.9.2. Geology

Jordan can be split into five regions, base on its underlying geology (Fig. 7.19):

(a) Limestone with flint in interior deserts and the highlands;
(b) Sandstone hills in the Jordan rift margins and Wadi Rum area;
(c) Primeval basement rocks north of Aqaba;
(d) Basalt desert in the NE;
(e) The Jordan Rift Valley, which forms Jordan's western borders.

7.9.2.1. Sandstone country

Sandstones are exposed along the rift borders and in the Wadi Rum desert. The sandstones are mainly of Palaeozoic (Precambrian–Silurian) and the ages range from 570 to 408 Ma. Some younger Lower Cretaceous sandstones date to 140–100 Ma. Three principal types of sandstone exist in Jordan, each imparting its own characteristic desert scenery:

(a) Hard, red sandstones (Cambrian) forming cliffs;
(b) White sandstones (Ordovician) forming domes;
(c) Soft, pink and white sandstones (Lower Cretaceous) forming gentle slopes.

These clastic sedimentary rocks were deposited as sand and mud in diverse marine and fluvial settings. Fluvial sandstones are the most typical and comprise thick cross-bedded units.

7.9.2.2. Basement country

Jordan's oldest rocks (Precambrian and dated to 570 Ma) comprise the mountains to the north of Aqaba. These consist mainly of granites, which are transected by sheets of dykes, which form the distinctive dark stripes seen throughout the hillsides. Intense fluvial erosion of the Aqaba granites has created widespread alluvial fans which mantle the lower hill slopes and fill the wadis.

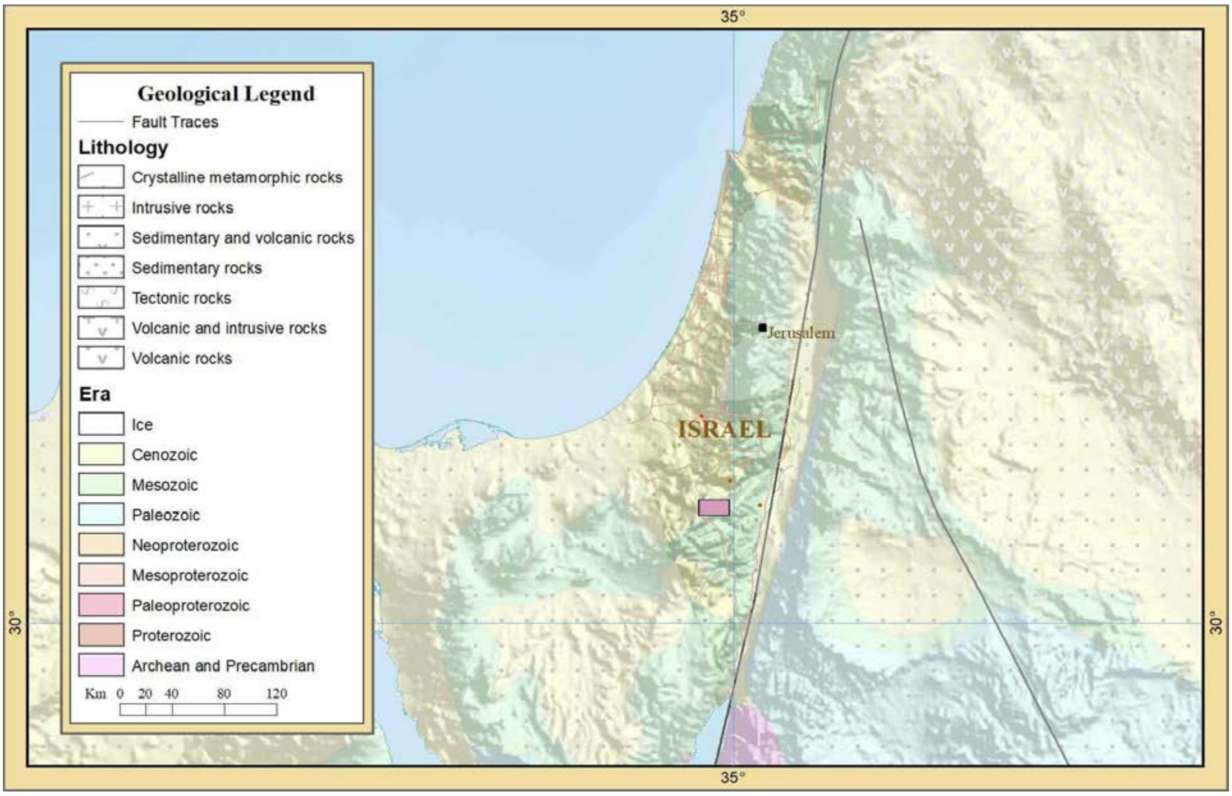


FIG. 7.19. Regional geological setting of Jordan showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.9.2.3. Basalt desert

The basalts of northern Jordan were generated by volcanic activity which occurred between 25 and 1 Ma. The weathering of these basalts in the extreme temperatures of the desert climate (hot days and cold nights) has produced the widespread and distinctive boulder fields. Silt filled depressions between low basalt hills are typical.

7.9.2.4. Jordan Rift Valley

The single most vital structural feature in the country is the Jordan Rift Valley, which traverses the entire length of the country and forms its western boundary with Israel. The Jordan Rift Valley is an extension of the Red Sea and the East African Rift Valley. Its existence is due to a deep seated, linear, strike-slip (or transcurrent) fault which denotes the frontier between the African and Arabian Plates. Movement occurred largely throughout the Middle Miocene and Pliocene–Recent phases. The structure is a left lateral strike-slip fault system with an offset of 105 km. This strike-slip motion has also resulted in the development of interchanging compressional folds and extensional grabens along its length.

The country's youngest rocks exist in the Jordan Rift Valley. These are characteristically soft mudstones and siltstones deposited in the broad lakes which once occupied these sites.

7.9.3. Mineral exploration

Jordan is an important producer and exporter of phosphates. Production for 2005 totalled 6.2 Mt. Reserves are assessed to be 1300 Mt. Two extremely large open cast mines operate in the interior desert (Al Hasa and Ash Shidiya) [9.2].

7.9.4. Uranium exploration [9.3–9.6]

An airborne radiometric survey in 1980 covering the entire country outlined radiometric anomalies in Ordovician sandstones. On the basis of this, the Natural Resources Authority of the Ministry of Energy and Mineral Resources, with the backing of the IAEA, conducted a study on the uranium potential of Jordan. This resulted in the selection of an area of 6000 km² covering both Precambrian basement and Cambrian sedimentary strata as a target for a multi-year exploration programme.

Ground based radiometric surveys of anomalies recognized in the airborne survey had been accomplished by 1988. The Precambrian basement and Ordovician sandstone target areas were investigated during 1988–1990 using geological, geochemical and radiometric mapping surveys. The results of this work led to the definition of two uranium–thorium anomalies.

A regional geochemical sampling campaign collecting stream sediments and some rock samples was accomplished during 1990–1992 over the basement complex area. Geological and radiometric follow-up was undertaken in areas within the basement complex and in Precambrian sandstones.

A methodical survey and assessment of the enrichment of uranium in the phosphate deposits of Jordan was also carried out to evaluate the uranium's environmental impact. The average content of uranium in four phosphate deposits in southern and central Jordan was 50–140 ppm U. Base on these results, the non-traditional or by-product resources of Jordan is assessed to be 100 000 tU.

During 1994–1996, annual expenditures for uranium exploration incurred by the Government rose from US $10 000 to US $100 000. Twenty-six drill holes totalling 250 m were drilled in 1995. The assessment of airborne gamma anomalies conducted since 1995 led to the recognition of a zone linked to non-phosphatic formations. The results of ground radon (track-etch) measurements and gamma surveys revealed a number of areas with surficial uranium occurrences related with Palaeocene and Pleistocene sedimentary rocks in various sections of the country. In these areas, uranium concentrations of 100–500 ppm exist over a thickness of ~1.5 m. The mineralization consists either of minute dispersed grains within the sedimentary rocks or as yellowish secondary uranium minerals filling small pockets and fractures in the sedimentary rocks.

Reconnaissance and exploration studies during the 1990s indicated deposits of surficial uranium scattered in several parts of the country. In central Jordan, exploration, which included excavating 1700 trenches and drilling over 2000 boreholes, was conducted and indicated the presence of uranium mineralization as tiny grains dispersed within fine calcareous sedimentary rocks of Pleistocene age and as yellowish coatings of carnotite and as other uranium minerals coating fractures in shattered Maastrichtian–Palaeocene marl or chalk. In three areas in central Jordan, the outcomes of channel sampling recorded concentrations of uranium in the range 140–2200 ppm over an average thickness of ~1.3 m, with an average thickness of overburden of ~0.5 m.

The reconnaissance studies also identified three other areas with anomalous uranium concentrations which are also considered to have potential for hosting uranium deposits, namely: Wadi Sahb Alabiadh, Al-Bahiyyah and Mafraq.

The JAEC (Jordan Atomic Energy Commission) has been created in 2007, in agreement with the ratified Nuclear Energy Law (Law No. 42 of 2007) and its Amendments of 2008. It is the authorized body mandated to promote and implement the programme for nuclear power of Jordan. The exploration, extraction and mining of all nuclear materials, comprising uranium, thorium, vanadium and zirconium, are nowadays within the mandate of the JAEC.

The JAEC signed in September 2008 an exploration contract with AREVA and established the JFMUC (Jordanian French Uranium Mining Company), a joint venture that will conduct every activity for exploration heading to a feasibility analysis of fostering resources in central Jordan. A thorough exploration programme is being undertaken over 1400 km² of central Jordan and, in anticipation of positive results, JFMUC hopes to develop a mine. In June 2012 JFUMC announced identified resources over 20 000 tU. In October 2012 JAEC terminated the JFUMC joint venture mining licence.

The JAEC reached an agreement with Rio Tinto at the end of 2008 and a Memorandum of Understanding was signed in January 2009 allowing Rio Tinto to conduct reconnaissance and prospecting work in Rewashid, Wadi Sahb Alabiadh and north of Wadi Al-Bahiyyah. Reconnaissance activities have begun and if these are successful the programme will continue into an exploration phase and, ultimately, a mine development phase through a joint venture with JAEC. In 2014, the state-owned Jordan Uranium Mining Co (JUMCO) announced that it would build a 300-400 tU/yr uranium mill in the central region, about 80 km south of Amman, where resources of 30,900 tU at an average grade of 0.011%U have been delineated [9.6].

In 2017, JAEC signed an agreement with Saudi Arabia's King Abdullah City for Atomic and Renewable Energy (K.A.CARE), covering uranium exploration and mining in central Jordan.

Activities for exploration by Jordanian workers in cooperation with the Chinese company SinoU are also being undertaken in Wadi Al-Bahiyyah and Mafraq.

Exploration expenditure in Jordan in the period 1973–2010 amounted US $12.2 million [9.3].

7.9.5. Uranium resources

In June 2012, JFMUC reported that it had identified reserves in excess of 20 000 tU over an area of 72 km². It reportedly intended to carry out a feasibility study to investigate the potential to develop an open pit mine.

A further 22 000 tU of reserves has been reported at Hasa and Qatrana, 80 km south of Amman, following work undertaken in 2010–2011 by Jordan Energy Resources Inc. This resource is hosted in the Qatrana phosphorites, where grades of 0.015–0.017% U would be in addition to vanadium. Reserves of ~52 Mt of phosphate are reported, but none of these resources is considered to be JORC (Joint Ore Reserves Committee) compliant. As of late 2012, Jordan Energy Resources was tendering for bids from major mining companies to develop seven blocks covering the deposit.

Some uranium mineralization is also reported at Rewashid in the far NE of the country, near the border with Iraq.

A total of ~70 000 tU are related with phosphate deposits of Upper Cretaceous and Eocene age and these, therefore, belong in the by-product category (Table 7.6).

TABLE 7.6. UNCONVENTIONAL OR BY-PRODUCT (IN SITU) RESOURCES [9.5]

Deposit	Grade (ppm U)	Uranium (tU)
Ruseifa	100	10 350
Al Hassa	60–80	13 300
El Abiad	60–80	16 700
El Shidia	35–50	83 020
Total		123 370

A feasibility study for extraction of uranium from phosphoric acid was conducted in 1982 by the engineering company LURGI for the Jordan Fertilizer Industry Company, which was subsequently acquired by the Jordan Phosphate Mines Company. An extraction process that was assessed was initially determined are reasonably viable, but because of the drop in uranium prices, that process became unprofitable and building of the extraction plant was delayed. The feasibility analyses that were continued in 1989 by using a micro-pilot plant have been concluded in 1990, and became the foundation for groundwork of a project paper for a pilot plant for extraction of uranium from phosphoric acid [9.6].

As of 1 January 2017, identified conventional resources, recoverable at costs <US$ 130/kgU, total 6900 tU as reasonably assured resources in the Central Jordan area, and 55 200 tU as inferred ressources in the Central Jordan area (26 500 tU) and in the Hasa-Qatrana area (28 700 tU). These resources are associated to surficial type deposits [9.6].

Speculative conventional resources total to 50 000 tU, in the <US$ 260/kgU cost category.

Unconventional uranium resources, associated to phosphate deposits, amount about 100 000 tU.

The UDEPO database lists the most significant deposits for Jordan as Al Shedeye–Eshidiya, Siwaqa, Al Hassa–Al Qatrana, Al Abiad–Al Wady, Khan Azzabib, Attarat–Wadi Maghar, Al Ruseifa.

7.9.6. Environmental considerations

To evaluate the impact of uranium-bearing phosphate deposits on the environment, a methodical study and investigation of the concentrations of uranium in Jordanian phosphates is being undertaken. The El Shidia phosphate deposits, which contain the largest phosphate reserve in Jordan, are typified by fairly low uranium content (varying in the range 35–50 ppm). This was considered to be very favourable, from an environmental standpoint, with regard to raw phosphates, derived phosphoric acid and phosphatic compounds and derived fertilizer products.

7.9.7. Comments

Jordan does not currently produce uranium commercially.

References to Section 7.9

[9.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Jordan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[9.2] ANDREWS, I.J., Geology and geography of Jordan (1996), http://www.andrewsi.freeserve.co.uk/jordan-geology.htm

[9.3] XOUBI, N., "Recent developments of uranium exploration in Jordan", paper presented at IAEA Tech. Mtg on Uranium Exploration and Mining Methods, Amman, 2008.

[9.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).

[9.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[9.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

7.10. KAZAKHSTAN

7.10.1. Geography

With a surface of 2 724 900 km^2, Kazakhstan is the largest of the former Soviet republics, excluding the Russian Federation. It is located in central Asia, NW of China and occupies a small portion west of the Ural (Zhayyq) River in easternmost Europe. A landlocked country, it comprises a vast flat steppe extending from the Volga River in the west to the Altai Mountains in the east and from the plains of western Siberia in the north to the oases and deserts of central Asia in the south. Kazakhstan borders the inland Aral Sea and the Caspian Sea.

The climate is arid to semi-arid continental with cold winters and hot summers. Natural hazards include earthquakes in the south and mudslides near Almaty.

Kazakhstan possesses abundant fossil fuel reserves (i.e., petroleum, natural gas, coal) and major deposits of uranium, copper and zinc. Additional natural resources include iron ore, manganese, chromium, nickel, cobalt, molybdenum, lead, bauxite and gold. It also has a large agricultural sector that includes livestock and grain production [10.1].

7.10.2. Geology

Major uranium occurrences and deposits are known from nine regions in Kazakhstan (Fig. 7.20). Six of these regions contain uranium deposits with notable resources and mining potential: Kokshetau (Kokchetav) in northern Kazakhstan; Pricaspian in SW Kazakhstan; the Chu-Sarysu Basin in south central Kazakhstan; the Syr-Darya Basin in south Kazakhstan; Pribalkhash or the Kendyktas–Chuily–Betpak Dala region in SE Kazakhstan and the Ily Basin, also in SE Kazakhstan. Three regions of more reduced profitable interest are the Turgai–Priiyrtysh region in the north and the Zhalanshiksky and Granitnoye regions in central Kazakhstan [10.2].

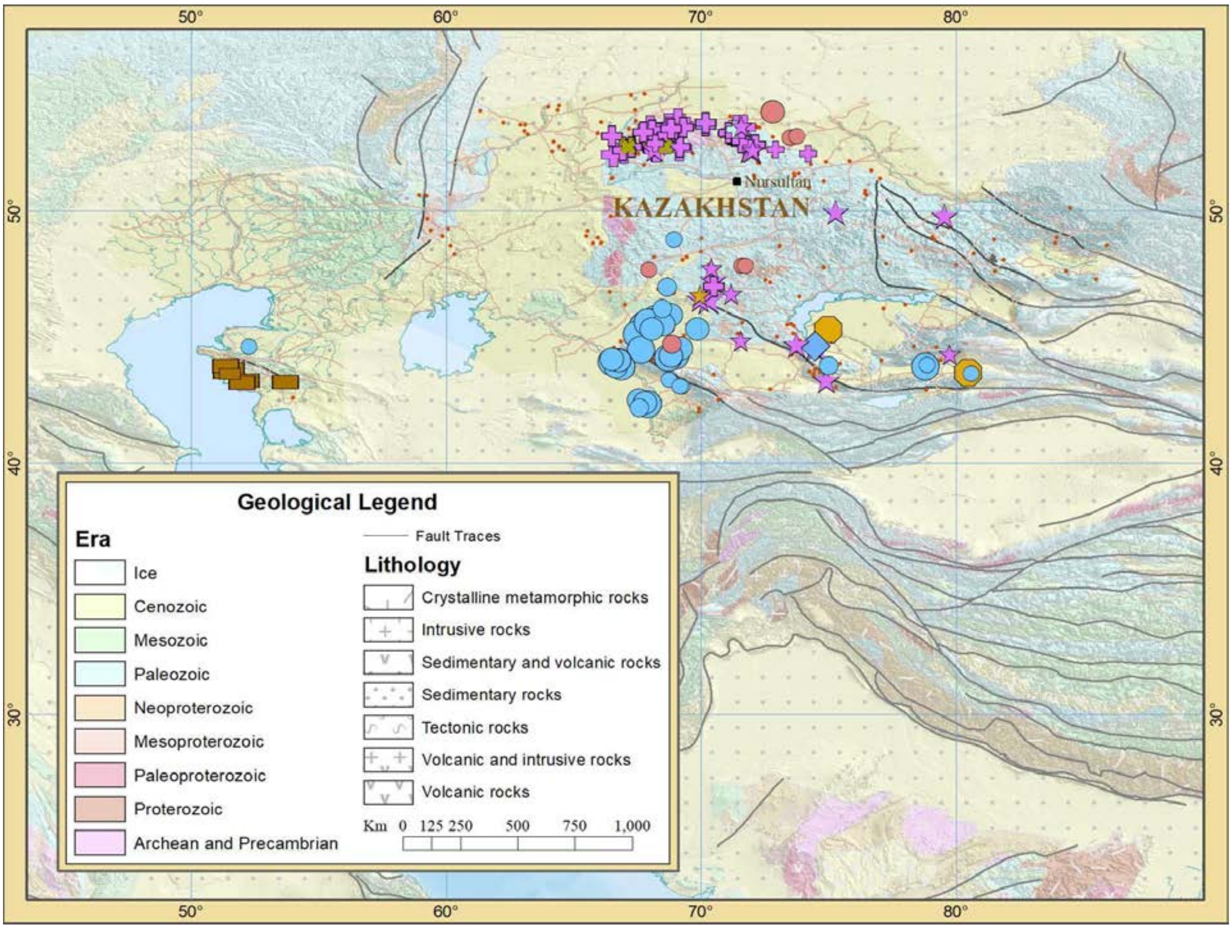


FIG. 7.20. Regional geological setting of Kazakhstan showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Uranium deposit types in Kazakhstan include sandstone, vein stockwork, volcanic stockwork, lignite/coal and a distinctive kind of organic phosphorite type (i.e., phosphatized fossil fish bone hosted in clay). Most of the deposits belong to the sandstone and vein stockwork types [10.3].

7.10.2.1. Kokshetau uranium region

Around 40 deposits of uranium have been mapped and several major occurrences have been recognized in the Kokshetau uranium region. The majority of these, representing eight orefields, occur in crystalline rocks, with one hosted in sedimentary terrain. Some sporadic deposits/occurrences are recognized in the north-western and south-western region of Kokshetau.

There are two major types of uranium deposit in the Kokshetau region: vein stockwork and sandstone. The vein stockwork type predominates and comprise structurally controlled mineralization that is somewhat monometallic and somewhat polymetallic. The sandstone type occurs in palaeovalleys incised into Upper Jurassic sedimentary rocks and which are described as basal channel, tabular sandstone type deposits. The latter are limited to the north-eastern margin of the massif.

The main features of vein stockwork deposits of the region of Kokshetau include two pre-uranium emplacement episodes in the host rocks: one involves alkali metasomatism, which includes albitization with haematitization, and the other involves beresitization (i.e., quartz–sericite–ankerite–pyrite alteration), which extends from the mineralized structures up to 100 m into wall rocks. In some deposits, syn-uranium beresitization related with hydromicazation and chloritization is formed locally. Late- to post-uranium phase carbonatization (chiefly dolomitization) telescoped the pre-existing alteration facies by up to 100 m from the mineralized structures. Beresitization and albitization of variable intensities exist in the majority of the deposits [10.2].

There are three marked mineralization assemblages in the vein stockwork deposits: (i) uranium–apatite (e.g., Vostok, Zaozernoye and Tastykolskoye deposits), (ii) uranium–molybdenum (e.g., Ishimskoye, Grachevskoye, Balkashinskoye and several Bayskoye deposits), and (iii) uranium–albite mineralization (e.g., Kamyshevoye, Shokpak and Kosachinoye).

Deposits vary in size from a few hundred tonnes to 95 000 tU and grades are in the range 0.05–0.18% U. The deposits occur at variable depths, from near surface to depths of at least 1000 m [10.2]. Mineralization is primarily structurally-controlled and the resulting orebodies are highly variable in size and shape.

7.10.2.2. Eastern Kokshetau region

Several basal channel type sandstone deposits occur in the eastern Kokshetau Massif, close to the boundary of the Priirtysh Basin. This includes the Kiziltuk, Selentinsk, and Semizbay deposits where mineralization exists in palaeovalleys filled with Upper Jurassic–Lower Cretaceous fluvial and alluvial sediments which are covered by roughly 100 m of Cretaceous and younger sediments [10.2].

The Semizbay deposit has been described in detail by Dahlkamp [10.2]. At the Semizbay deposit, the chief uranium minerals are ‘sooty’ pitchblende, pitchblende and coffinite, which occur with related elements, including selenium, germanium and significant concentrations of scandium. The uranium mineralization is disseminated and typically held in the matrix of the sandy facies. The age of 120–110 Ma obtained by isotopic dating of the pitchblende is regarded as the main ore forming stage. Semizbay consists in several orebodies distributed over a channel section that measures 15 km in length and 500 m in width. Within this sector the orebodies occur intermittently in two horizons, which are separated by an argillaceous horizon measuring 10–15 m in thickness. The upper horizon, 30–35 m in thickness, hosts ore in basal grey sand lenses. The lower horizon, measuring 15–20 m in thickness, hosts a number of superimposed orebodies in grey sand beds.

The morphology of the mineralization is variable and may consist of discontinuous, subhorizontal, elongated lenses or stratiform ribbons or tabular and pocket-like or roll-like bodies. The thicknesses of the orebodies vary from tens of centimetres up to 7.5 m (average 2.1 m), and vary from ~500 m to 5 km in length and typically 20–80 m wide or up to 200 m in width. Mineralization occurs at depths of 50–150 m and grades are very erratic, varying from several tens of parts per million to 0.5% U, and locally up to 8% U. The average grade is roughly 0.05–0.07% U.

Significant recognition and ore controlling criteria of the basal sandstone type in the Semizbay orebodies include: palaeovalleys predominantly cut into leucocratic granitic basement with interchanging permeable and roughly impermeable fluvial beds in palaeovalleys; valley fill blanketed by impermeable clay; intraformational hiatuses; reductants in the form of carbonaceous matter and sulphides; carbonaceous, reduced sandy facies host rocks; and evidence of arid climate episodes that permitted the release and transport of uranium into valley sediments. Favourable alteration features include early oxidation of valley fill indicated by oxidation zones in basal channel facies succeeded by later reduction of alluvial sediments indicated by bleaching related with obliteration of organic matter and evidence of ore associated sulphidization and post-ore carbonatization (i.e., presence of calcite).

7.10.2.3. Pricaspian (Mangyshlak) uranium region, west Kazakhstan

The Pricaspian uranium region is located east of the Aktau town (previously Shevchenko) on the Mangyshlak Peninsula on the north-eastern coast of the Caspian Sea in western Kazakhstan. There are two orefields in this region: (i) the Karagiin orefield, which comprises the partially mined Sadyrnyn, Tomak, Taybagar, Tasmurun–Ashisai and Melovoye deposits; and (ii) the Karynzharyk orefield which contains three subeconomic occurrences and is located ~80 km to the SE of the Karagiin field.

In this region, the ore deposits comprise uraniferous mineralization related with fossil fish bones held in pyritic clays. These are a unique type of organic phosphorous deposit documented only close to the northern Caspian Sea in western Kazakhstan and in the Ergeninsky region, in the Kalmyk Autonomous Republic in the Russian Federation [10.2].

Ore grades average 0.04–0.06% U and while this grade is low, the bone detritus is readily removed from the matrix and can yield a concentrate with uranium contents two to three times higher and a phosphate content of ~30% P_2O_5. Additionally, scandium and rare earth elements have been recovered.

The lithostratigraphic profile of the Karagiin orefield consists of Cretaceous–Neogene marine sedimentary rocks resting on a basement of folded Permo-Triassic and Jurassic sedimentary rocks. Mineralization occurs in the Karagiin Member of the Lower Oligocene–Lower Miocene Maikop Formation, which is over 800 m thick.

The mineralized Karagiin Member is partitioned into three units: (i) an upper unit measuring 80 m in thickness and consisting of greenish-grey clay with dispersed pyrite concretions and intercalated mud beds; (ii) the middle (or fish) unit, measuring 40–150 m in thickness, comprising dark clay with beds enriched in pyrite and melnicovite concretions, fish scales and fish bones; and (iii) a lower unit, measuring 90 m in thickness, of greenish-grey, partly carbonate clay with rare ‘mud eater’ and shell fossils.

Minable uranium mineralization is confined to the middle (fish) unit of the Karagiin Member. The uraniferous beds vary in thickness between 0.1 and 11 m and measure laterally up to 18 km long and several kilometres wide. Mineralization occurs at the surface (Tasmurun, Sadyrnyn) down to a depth of 240 m (Taybagar). The phosphate exists as a rock component and in fossil fish bones, and the uranium, rare earth elements and scandium are genetically included into the phosphatized fish bone detritus. The genesis of the deposits is generally accepted to be a diagenetic concentration of uranium and other metals by sorption onto phosphate or phosphatized fish bone detritus with seawater as the source of the ore-bearing elements. The great stock of fish bone debris is ascribed to a striking build-up in hydrogen sulphide in seawater leading to an appalling effect on the population of fish.

7.10.2.4. Chu-Sarysu Basin, south central Kazakhstan

The Chu-Sarysu Basin is situated in south central Kazakhstan and measures up to 250 km in width, extending for at least 600 km from the foothills of the Tien Shan Mountains to the SE and south to the flats of the Aral Sea depression to the NW. The Chu-Sarysu Basin is bordered to the SW by the NW–SE oriented Karatau mountain range, which disconnects the Chu-Sarysu Basin from the south-westerly located Syr-Darya Basin. These basins are believed to be initially comprised of a single basin before the periodic uplift of the Karatau range split it into two. The split occurred after the uranium deposits were formed.

Yazikov [10.4] describes a total record of 973 000 tU for the basin. Most deposits occur in two districts in the basin: the Kenze–Budenovskaya district in the central western part, the Uvanas–Kanzhugan district in the central southern part. Mineralization is controlled by dynamic redox fronts in arenaceous strata, mainly as the roll front sandstone type and less commonly as the tabular sandstone type.

The Chu-Sarysu Basin contains Cretaceous–Quaternary strata up to 2000 m thick, comprising mostly continental and minor shallow marine sedimentary rocks, which are split by a major unconformity into two stratigraphic–structural units. Quaternary–Neogene sedimentary rocks up to several hundreds of metres thick comprise the upper unit, whereas Upper Cretaceous–Eocene, mostly unconsolidated lacustrine, deltaic, fluvial and alluvial sediments comprise the lower, uranium-bearing unit that is at most 500 m thick. Throughout the closing phase of the Eocene, the region was flooded and shallow marine, grey-green, argillaceous sedimentary rocks roughly 150 m thick were deposit. Later orogenic activity, which was the most intense throughout the Oligocene, brought about uplift of basement blocks like the Tien Shan Mountains situated to the south of the basin. Related erosion resulted in the deposition of pink coloured continental facies of the upper unit on the Palaeogene unconformity. It was in this time that the basin became artesian [10.2].

The marine Upper Eocene clays comprise the upper confining unit whereas the Palaeozoic, locally Jurassic, rocks comprise the basal regional confining unit for hydraulic systems in the Cretaceous–Eocene stratigraphic–structural units of the Chu-Sarysu Basin.

Uranium is held in six continental stratigraphic formations, 20–150 m thick, of Late Cretaceous and Palaeogene (Uvanas–Kanzhugan zone) age. Three of these are Palaeogene uraniferous formations hosted by Palaeocene and Lower–Middle Eocene sedimentary rocks of mostly medium- to fine-grained weakly carbonaceous sands parted by continuous argillaceous beds. In comparison, the three mineralized formations in the Turonian–Maastrichtian strata comprise a number of 10–40 m thick horizons that begin with a basal gravel bed up to 10 m thick grading upwards into irregularly sized, mainly coarse-grained sands which are overlain and interbedded with discontinuous argillaceous and silty lenses.

Regional faults strike mostly NW–SE and, to a lesser extent, N–S and E–W. Synsedimentary, pre- to syn-Oligocene faulting produced major dislocations in the lower unit of the basin and the Proterozoic–Palaeozoic basement is block-faulted.

In the lower stratigraphic–structural unit of the Chu-Sarysu Basin, a regional oxidation zone is a conspicuous alteration feature. A hydrodynamic system of oxygenated groundwater, which initiated in the Late Oligocene but still active at present, migrated north-westwards, downdip of the regional trend of aquifers, and a number of multilevel redox fronts, up to 300 km long, were recognized within the aquifers of six superjacent lithostratigraphic units. Permeable grey arenaceous horizons that were reduced by diagenetic processes were subsequently oxidized and are now commonly ‘speckled’ in appearance.

Additionally, owing to the erratic permeabilities of the aquifers, the redox fronts advanced at different rates. For example, oxidation fronts in the Upper Cretaceous sedimentary rocks of the Kenze-Budenovskaya zone advanced for up to 500 km. In contrast, oxidation fronts in the Palaeogene sedimentary rocks of the Uvanas–Kanzhugan zone advanced for about 350 km from the recharge area in the Tien Shan Mountains. The most progressed redox front, which is 10–18 km in advance of that in the

Mynkuduk aquifers, exists in the Inkuduk Formation, which is the most permeable in the Chu-Sarysu Basin.

Uranium ore in the Chu-Sarysu Basin is mainly monometallic although, locally, some areas contain rhenium and/or selenium in sufficiently high enough grades to warrant mining. Coffinite, pitchblende, and sooty pitchblende are the main uranium minerals. Related minerals/elements comprise sphalerite, pyrite, marcasite, pyrolusite, hydrogoethite, goethite, radiobaryte, siderite and calcite, which exist in reduced concentrations, and minor to trace amounts of arsenic, germanium, molybdenum, vanadium, selenium, rhenium, yttrium and rare earth elements. As in other sandstone roll front type deposits, selenium, vanadium and arsenic commonly exist in oxidized sands at the rear of a roll whereas molybdenum exists in the reduced part at the front [10.5]. Rhenium is distributed throughout the orebody and extends into the non-uraniferous grey facies. The mineralization has a dispersed nature; the uranium phases being finely disseminated in the silty-clayey matrix of arenites, filling microfissures and cavities in rock fragments, coating sand grains and forming pseudomorphs of vegetal remnants.

Uranium exists in more than nine arenaceous horizons at depths ranging from 80 m to at least 500 m along almost continuously mineralized zones extending up to several hundreds of kilometres in length, following sinuous redox fronts, individual parts of which are subjectively termed as deposits. Deposits comprise several individual orebodies disconnected by barren or weakly mineralized ground. In situ ore has grades in the range <0.01–0.4% U and locally higher, while average deposit grades vary from 0.02 to 0.07% U.

Deposit genesis

An early diagenetic reduction of Upper Cretaceous and Palaeogene sedimentary rocks of the lower stratigraphic–structural unit of the artesian basin was succeeded by an Oligocene–Miocene oxidation event (overprint) which constitutes the regional oxidation tongue. The inflow of oxygenated waters was caused by the uplift of the Tien Shan Mountains and sustained subsidence of the axial part of the Turan Plate. Oxygenated waters carried uranium and other metals to the site of deposition where reducing conditions at the redox front were made available by water dissolved reductants, which had developed by bacterial and thermo-oxidative obliteration of plant matter. The restraint of aquifers by footwall and hanging wall aquicludes permitted the development of roll type orebodies. Owing to the regional nature of the oxidation front as well as the plainness of the host rock lithology, laterally widespread orebodies of simple crescent shapes developed. The ore forming processes commenced throughout Oligocene but remobilization processes are still ongoing, as indicated by younger ages of mineralization at the head of the rolls relative to the rear sections of rolls, tails and tabular ore.

7.10.2.5. Syr-Darya Basin, south Kazakhstan

The Syr-Darya Basin is in southern Kazakhstan, bordered to the NE by the NW–SE oriented Big Karatau range and to the south by the Tien Shan Mountains/Chatkal-Kuramin range at the borders with Kyrgyzstan and Uzbekistan. The Karatau range disconnects the Syr-Darya Basin from the Chu-Sarysu Basin with which it was initially joined.

In the Syr-Darya Basin, deposits of uranium are of the roll front sandstone type where mineralization in the host arenites is controlled by dynamic redox fronts. Mineralization consists of either a uranium–selenium or uranium–vanadium–(selenium) assemblage. Average grades are in the range 0.03–0.08% U [10.2].

The deposits occur in three districts: (i) Karamurun, (ii) Karaktau and (iii) Kyzylkol–Chayan. Uranium was first found at North Karamurun, Irkol and Zarechnoye in 1972, 1976 and 1977, respectively. Additional findings were accomplished in the 1980s and profitable exploitation by in situ leaching (ISL) methods commenced in 1985 at North Karamurun, next by production at South Karamurun.

Regional geology of the Syr-Darya Basin

The artesian Syr-Darya Basin is bordered to the NE by the NW–SE oriented Big Karatau Uplift, a mountain range consisting of crystalline schists of Proterozoic–Ordovician age which are overlain unconformably by Carboniferous and Devonian sandstone and limestone. The southern boundary is the Chatkal-Kuramin Uplift, which is comprised of Proterozoic and Palaeozoic crystalline schists, limestone, granites and felsic to mafic volcanic rocks. The south-western limit of the basin is indicated by the Central Kyzylkum Uplift, which disconnects the Syr-Darya Basin from the SW situated Kyzylkum uranium region and the Amu-Darya Basin in Uzbekistan.

The Syr-Darya Basin is a complex depression occupied mostly by continental (including pyroclastic) and minor marine sedimentary rocks which have a thickness of up to 3000 m. An upper stratigraphic–structural unit of Neogene–Quaternary sedimentary rocks unconformably overlies a lower stratigraphic–structural unit of Upper Cretaceous–Palaeogene sedimentary rocks which measure roughly 500 m in thickness.

The Mesozoic–Cenozoic strata dip and thicken away from the Karatau Uplift in a south-westerly trend for roughly 50–80 km. More to the SW, the strata warp upwards with reduction in thickness of the Neogene sedimentary rocks. Pre-Neogene synsedimentary vertical faults triggered dislocations of at least 250 m, related with increasing thickness of the sedimentary series in the basin's western sector. Regional faults strike NE–SW and NW–SE.

The Paleozoic series of Carboniferous dolomite and limestone units, as well as Devonian continental sedimentary rocks, overlies unconformably Proterozoic–Ordovician crystalline schists. Igneous rocks comprise Upper Palaeozoic dacite–andesite sheets, felsic intrusives and granitoids. The basement is block faulted with major dislocations. Locally downthrusted grabens are occupied by Jurassic–Lower Cretaceous terrestrial sedimentary rocks, and basement relief exceeds 300 m.

Deposits of uranium are confined to the artesian lower stratigraphic–structural unit where they are hosted in Upper Cretaceous–Eocene strata. Host rocks comprise sand and gravel–sand beds with high permeabilities and with generally low amounts of carbonaceous matter but which can be at most 5% in the uranium deposits. Argillaceous aquicludes part of the permeable arenaceous horizons. An Upper Eocene clay horizon forms the upper regional restraint whereas Palaeozoic and Early–Middle Mesozoic rocks along the pre-Cretaceous unconformity represent the lower limit for all hydraulic systems in the lower stratigraphic–structural unit.

Typical alteration characteristics include multilevel regional oxidation tongues in Cenomanian–Eocene aquifers in the basin's eastern and western halves with delineation of three redox fronts. The westernmost redox front, which is disposed sinuously in a roughly N–S direction, is held by Upper Cretaceous sedimentary rocks and controls the Irkol deposit. Roughly 30–50 km to the east of this front, another curved N–S trending redox front exists in Upper Cretaceous strata, extending northwards from the Tien Shan Mountains for at least 350 km, and controls the deposits of the Karatau district ~140 km to the south and those of the Karamurun district to the north. The third redox front is situated in the eastern Syr-Darya Basin, ~120 km east of the aforementioned redox front; it controls deposits of the Kyzylkol–Chayan district.

The alteration characteristics of the redox fronts and uranium deposits are alike those of the Chu-Sarysu Basin. The ore grades of the deposits average 0.05–0.08% U, whereas those of individual orebodies are in the range 0.01–0.6% U. Several deposits contain appreciable levels of vanadium and/or selenium as well as other trace elements such as rhenium and germanium. The ore exists at depths of 100–700 m and may comprise stacked ore zones. The largest deposits exist in Upper Cretaceous strata.

Regional geochronology, probable sources of uranium, ore controls, recognition criteria and metallogenic points of view are basically the same as those of the Chu-Sarysu Basin although probable sources of uranium may also be seen in the Chatkal–Kuramin uranium region at the borders with Kyrgyzstan and Uzbekistan.

7.10.2.6. Pribalkhash (Lake Balkhash)/Kendyktas–Chuily–Betpak Dala region, SE Kazakhstan

In SE Kazakhstan, the Pribalkhash uranium region extends from the Kyrgyzstan boundary in the Kirgizian to the area west of Lake Balkhash and more northwards and north-westwards into the Betpak Dala (Hunger Steppe). Deposits cluster mainly in the northern Betpak Dala and the central Chuily area. Moreover, there are few small deposits such as Karatal in the Shuisky area and Kurday in the southern Kendyktas. The north-western portion surrounds the Granitnoye orefield, a small sedimentary basin with a few basal channel sandstone type deposits such as Kopalysay. Majority of the deposits in this region are related with volcanic rocks and comprise structurally-controlled stockwork mineralization.

The first deposit to be discovered was Kurday, in 1951. Mining commenced in 1953 and endured until 1990. Throughout those years, Stepgeology conducted exploration while Kyrgyz Mining Combine, subsequently renamed Yuzhpolymetal Production Enterprise, based in Bishkek, operated the mining. Roughly 15–20 deposits of uranium have been exploited, most of them small. Gross total production is in order of ~10 000 tU. Ore was processed in a mill at Kara Balta (Kyrgyzstan), some 60 km west of Bishkek, which had a token capacity of 1.5 Mt/year of ore and an assessed production capacity of 3600 tU/year [10.2].

Regional geological setting of mineralization

The Pribalkhash uranium region lies within the Chuily–Kendyktas Uplift, a section of the Ural–Mongolian fold belt of Caledonian age. The basement is formed by Precambrian schist and gneiss and Late Silurian–Early Devonian continental mafic to felsic volcanic rocks. Devonian felsic volcanic rocks and granites were emplaced throughout the Caledonian Orogeny. Most deposits of uranium are situated within the boundary of this Devonian igneous belt. The crystalline rocks are overlain by Mesozoic–Cenozoic sedimentary rocks. The continental Silurian–Devonian volcanic suite comprise folded interchanging layers of andesite and rhyolite intercalated with clastic and pyroclastic rocks. Intruded into this assemblage in a linear NW–SE trending belt are Caledonian subvolcanic stocks of rhyolitic composition and small hypabyssal batholiths of granite. The belt is a graben and horst structure measuring up to several hundreds of kilometres in width and controlled by NW–SE striking, deep-seated lineaments with NW–SE trending first order structures of large horizontal and vertical dislocations in the pre-Caledonian basement. These structures are characterized by wide zones of brecciation and/or penetrative jointing and fracturing, tens to hundreds of metres in width, and by subvolcanic intrusions and dyke belts in the overlying volcanic assemblage. Later fault systems of erratic trends inflicted further deformation on the magmatic belt.

The main types of alteration related with structurally controlled deposits of uranium comprise argillization, beresitization and propylitization. These took place throughout the Upper Devonian–Lower Carboniferous and altered the diverse deformed lithologies within uranium hosting regional fault zones and exist also along the margins of Devonian granitic massifs. The alteration facies are scattered in a concentric zoning that surrounds the uranium deposits, grading inward from propylitization at the edge to beresitization and, lastly, to argillization. Sodic metasomatism of the country rocks is evident in some deposits, e.g., at Dzhusandalinskoye.

Mineralization of volcanic type is polymetallic, comprising a uranium–molybdenum assemblage. Pitchblende and, at places, coffinite are the main uranium minerals and related minerals include pyrite, marcasite, molybdenite, jordisite and other minor sulphides. Gangue minerals comprise fluorite, carbonates, sericite and quartz.

Structurally-controlled orebodies are of highly erratic configuration with respect to both size and grade, the latter varying from 0.03% to at most 10% U or more (e.g., Dzhideli). The orebodies comprise a complex system of interconnected stockworks, lenses and/or veins in which ore exists in dispersed, streaky and, more seldom, massive forms. The majority of the deposits that were already mined had initial reserves varying from 1000 to 2000 tU with the exception of Botaburum, which contained some 10 000 tU [10.2]. Felsic effusive sheets, pyroclastics and volcanic dykes and necks made up of quartz porphyry, felsite, rhyolite, breccia and tuff are the main host rocks but not at Kurday, where the ore is held by granodiorite porphyry and is also in contact with a steeply dipping felsite body.

The principal phase of structurally-controlled uranium mineralization in the Pribalkhash region is dated at 370–350 Ma, with additional episodes of uranium introduction or redistribution yielding ages of 330–310 and 285–265 Ma. An early phase of uranium mineralization dated at 484–450 Ma has been recognized in some deposits [10.6].

Recognition criteria of the major volcanic type deposits in the Pribalkhash region comprise a large volcanic belt consisting mostly of felsic facies of Caledonian age controlled by deep penetrating regional faults. The deposits of uranium are basically related with felsic–rhyolitic volcanic rocks. Structures are important to deposit genesis and include regional faults linked with widespread cataclastic zones along which the location of orebodies is controlled by at least one of the following features: intersection of transverse fractures with dykes; junctures of faults along the axial orientation over basement highs; volcanic necks and granite porphyry dykes in annular fault zones and contacts of volcanic lithofacies; and axial faults that follow steeply dipping contacts between volcanic rocks and hypabyssal granite, and sudden variations in the dip of facies contacts intersected by a fault [10.2].

7.10.2.7. Ily region, SE Kazakhstan

The uranium region of Ily in south-eastern Kazakhstan extends along the Ily River from Lake Balkhash to the Chinese boundary and stretches into NW China. The Ily region covers two basins: to the north a western section of the Balkhash Basin called Nizhne-Ily Sub-basin and to the south the adjoining Ily Basin.

Resources of uranium are held in three major deposits, the sandstone type Suluchekinskoye deposit and the lignite type Koldzhat and Nizhne-Ilyskoye deposits. All of there were developed but never exploited. Moreover, several small sandstone type deposits, such as Aktau and Kalkan, exist in the region.

Nizhne-Ily Sub-basin

The Nizhne-Ily Sub-basin developed from block faulting along N–S and NW–SE oriented deep faults. In this basin, grabens are downfaulted into Palaeozoic rocks and are occupied by Jurassic sedimentary rocks, as well as a 125–260 m thick unit of Lower–Middle Jurassic lignite-bearing facies at depths of 100–500 m. Upper Tertiary and Quaternary sedimentary rocks of at most several hundred metres thickness overlie the pre-Tertiary rocks. The grabens are remnants of Mesozoic intermontane depressions set within a large central Asian orogenic belt. Tectonic rejuvenation in pre-Oligocene produced sub-longitudinal faults, which presently delimit the geometry of the grabens. Uplifted blocks were intensely eroded and only thin relics of Jurassic strata remain.

The Nizhne-Ilyskoye lignite–uranium deposit was found in 1973 and explored in 1978–1980. In situ resources total 60 000 tU at a grade of 0.1% U. Mining has been delayed, despite the deposit being developed, owing to unfavourable economic conditions [10.2].

Conspicuous regional alteration features in Jurassic rocks comprise reduction and oxidation processes evidenced by grey, pink and yellow coloured facies. Mineralization is polymetallic, consisting primarily of uranium–molybdenum with associated trace concentrations of other elements. Uranium minerals comprise sooty pitchblende and pitchblende (representing ~80%) and coffinite, which represents ~20%. More exotic uranium minerals present include studtite, uranium selenide, fourmarierite, mourite and ianthinite. A large proportion of the uranium is adsorbed by carbonaceous matter present in limonitized lignite. The chief molybdenum minerals are jordisite, ilsemannite and, less frequently, molybdite and molydenite. Related minerals include mainly pyrite, marcasite, ferroselite and subordinate to rare occurrences of native lead and selenium, tennantite, sphalerite, skutterudite, realgar, radiobaryte, orpiment, galena and arsenolite. Several trace elements exist in the deposit and from these two elemental groups are recognized: (i) uranium ore zones that contain cadmium, silver, cobalt, gallinium, germanium, molybdenum, nickel, rhenium, tellurium and zinc, and (ii) limonitized lignite which contains beryllium, copper, lead, scandium, selenium, vanadium, yttrium, zirconium and rare earth elements [10.2]. Most of the uranium ore is restricted to lignite. In comparison, carbonaceous clays contain low uranium and no uranium is detected at the border of the oxidation zones with grey sandstone.

Ily Basin

The Ily Basin is an E–W elongated depression, measuring up to 100 km in width, stretching from the west of Almaty eastwards to the border with China and into Xinjiang in NW China where the basin has its greatest extension. The basin is filled with Mesozoic–Cenozoic sedimentary rocks overlying a Palaeozoic basement. The basin fill comprises continental clastic sedimentary rocks divided into a Lower–Middle Jurassic suite subjacent to Cretaceous–Tertiary sequence. Both units comprise lignite seams. Lignite-bearing Jurassic sedimentary rocks exist in the Kazakh sector of the basin over a distance of 30 km downdip and 30 km along regional strike. The lignite-bearing series is exposed in the southern section of the basin, dipping 5–7°N and extending to depths beyond 1500 m in the basin's axial zone.

Several uranium deposits/occurrences of sandstone type and of lignite type (e.g., Koldzhat) are documented, including the large Suluchekinskoye deposit and a number of smaller deposits such as Malai-Sary, Aktau and Kalkan. The Koldzhat deposit is located ~300 km east of Almaty and extends from the Chinese boundary in the SE towards the NW. It is regarded a uranium–molybdenum–lignite deposit. Coal was found in 1957. After two years, two uraniferous coal seams were intercepted by drilling. Underground exploration to depths of 600 m was conducted during 1969–1978. At Koldzhat, in situ resources total 37 000 tU with average of ~0.1% U.

Uranium mineralization at Koldzhat comprise coffinite, sooty pitchblende and pitchblende, and molybdenum minerals present include molybdenite, jordisite and ilsemannite. Related iron sulphides include marcasite and pyrite. The mineralization has a dispersed form and exists in differently shaped orebodies within lignite-bearing clastic sedimentary rocks of Jurassic age. Uranium is enriched in lignite seams and in sand–conglomerate beds whereas the molybdenum concentration is limited to uranium orebodies in lignite [10.7]. The evolution of the Ily Basin and the formation of the Koldzhat deposit are postulated to be akin, respectively, to that of the Nizhne-Ily Sub-basin and of the Nizhne Ilyskoye uranium–molybdenum deposit.

Of the uranium resources at Koldzhat, lignite hosts 58.5% and sandstone 41.5% [10.7]. The orebodies have lenticular, tabular and roll morphology. The roll type is characteristic sandstone-hosted ore whereas lenticular and tabular types of ore exist especially in lignite. Orebodies typically measure 0.5–14.5 km in length, 20–2000 m in width and roughly 2 m in thickness. The uranium level is erratic but varies from 0.05 to >0.1% U [10.7].

The Suluchekinskoye deposit is situated 5 km north of the Ily River in the NE of the Ily Basin, near the boundary with China and roughly 200 km NE of Almaty. The deposit was found in 1978 and contains 33 000 tU with grades of 0.07–0.13% U [10.7]. The roll front type sandstone deposit was developed for an ISL operation but the project has not reached production stage.

Orebodies comprising the Suluchekinskoye deposit exist in the East Kalkanskaya anticline, which comprises Middle Cretaceous–Neogene sedimentary rocks. The host rocks are fine- and medium-grained feldspathic sandstones with some interbedded gravel, silt and clay lenses comprising the 60–120 m thick Middle Cretaceous–Lower Palaeogene Ily Formation. These underlie the mottled or pink sandstone and green-grey clay of the Eocene Aktau Formation which in turn underlies silty and limy clays. Neogene sedimentary rocks comprise the topmost layer as well as the 50–330 m thick Ily suite and the 60–90 m thick Pavlodar clay suite. The former is made up of clay, sand and silt. Palaeozoic tuff and tuffaceous sandstone constitute the basement and are exposed west and NE of the deposit.

Alteration comprises epigenetic reducing processes with pervasive pyritization of the host rocks. Later, an oxidation tongue infiltrated the Ily Formation from the east. Roll front type orebodies exist at the redox front and exhibit a zonal distribution of elements. Rhenium infiltrates furthest into reduced ground and then a uranium–rhenium zone. Selenium mineralization constitutes the rear of a roll in oxidized ground. Grades of ore vary in the range 0.07–0.13% U, 1–24 ppm (average 1–2 ppm) Re and 10–30 ppm Se, although the selenium level can increase to at least 100 ppm in limonitized intervals [10.2, 10.7]. Uranium exists mainly as pitchblende and minor coffinite. Selenium occurs as ferriselite and as native selenium.

Orebodies are distributed over an area 24 km in length, in an E–W orientation, and 150–8000 m in width, with depths ranging up to 700 m. Separate orebodies measure 2–6 km in length, 150–2000 m in width and 2–3 m in thickness. Ore genesis is ascribed to strata infiltrational processes that occurred throughout Late Oligocene–Miocene, although ore formation was seemingly hindered and confounded by the introduction of abyssal reducing solutions, which infiltrated the aquifers along deep faults.

7.10.2.8. Zhalanshiksky region, central Kazakhstan

Two sandstone type uranium occurrences are identified in this region, Lunnoye (in Torgae) and Lazarevskoye. The uranium mineralization is hosted by Palaeogene argillaceous sand and siltstone containing disseminated vegetal debris which exists as lenses measuring up to several hundred metres in length. Mineralized strata have at most 0.4% U and are 'sandwiched' between clay beds. Organic carbon varies between 10 and 27% and coffinite and pitchblende exist in relation with organic matter in high grade ore [10.7].

7.10.2.9. Turgai-Priiyrtish region, northern Kazakhstan

A number of uranium occurrences are recognized in the Turgai-Priiyrtish region in northern Kazakhstan, in the southern extension of the Transural region (Russian Federation). These occurrences tend to fit in the same basal channel sandstone type deposits like those in the Transural region. Documented occurrences are Aurtav, Torfj Anoye, Pjatigorsk, Koitass, Sensharskoye and Tobolskoye [10.2].

7.10.3. Uranium exploration

Exploration for uranium in Kazakhstan began in 1948, when the country formed part of the former Soviet Union. Historical activities can be split into discrete phases, on the basis of target areas and with the concepts of exploration applied.

Throughout the first phase, which continued past 1957, regional airborne and ground radiometric surveys were conducted over parts of the country not covered by young unconsolidated sediments [10.3]. Those surveys led to the finding of many deposits of uranium in what subsequently turned out to be the uranium districts of Pricaspian, Kokshetau and Pribalkhash. The first findings were made SW of Lake Balkhash in volcanic rocks of the Caledonian Kendyktas (or Pribalkhash) region where the Kurday deposit was discovered in 1951. This was succeeded by the finding of the Botaburum and Kyzylsay (Kyzyltas) deposits in 1953 and 1957, respectively.

Exploration in the Caledonian Kokshetau Massif, northern Kazakhstan, by Stepnoi Expedition led to the findings of deposits of the vein stockwork type at Shatskoye, Balkashinskoye and Kubasadyrskoye in 1953 as well as at Zaozernoye, Tastykol, Ishimskoye and Manybayskoye in 1954–1955. These were succeeded by discoveries of at least 50 deposits, which included the large Vostok (1964) and Grachevskoye (1967) deposits [10.2].

The finding of uraniferous fossil fish bones in Tertiary sedimentary rocks (e.g., Melovoye deposit) close to Aktau (formerly Shevchenko), on the north-eastern shore of the Caspian Sea in 1954, ascertained the Pricaspian uranium region.

Exploration by Stepnoi Expedition throughout 1954–1962 for deposits of surficial and sandstone types in Mesozoic–Cenozoic sedimentary rocks at the southern boundary of the West Siberian Platform led to the discoveries of several uranium occurrences, such as Koitass and Pjatigorsk (Jurassic–Cretaceous clastic sedimentary rocks), Torfj Anoye (Oligocene lignite), and Aurtav (Quaternary clays). However, none of these deposits were considered to be economically viable.

Uraniferous coal deposits were discovered during 1957–1968 in the Ily Basin but were uneconomic. Likewise, the sandstone type deposits of Uvanas and Zhalpak were found during 1957–1968 in the Chu-Sarysu Basin as well as the volcanic Djidely deposit in the Pribalkhash region.

During the early 1970s, a reassessment of historical data resulted in a resumed exploration effort which led to the finding, in 1973, of the Semizbay deposit of sandstone type within the inner border of the Kokshetau Massif, and other similar deposits in western Siberia such as Dalmatovskoye in the Transurals (i.e., Russian Federation).

Throughout 1970 and 1971, ISL tests were effectively accomplished at the Uvanas deposit in the Chu-Sarysu Basin. Since then, exploration was largely focussed on Mesozoic and Cenozoic sedimentary basins with potential for ISL amenable deposits [10.8]. Therefore, the principal accomplishments of exploration over the past three decades are findings of major deposits of uranium related with Cretaceous and Palaeocene sedimentary rocks of the Chu-Sarysu and Syr-Darya Basins, which have considerably enhanced the resource base of Kazakhstan [10.8].

Exploration of deposits of the sandstone type was undertaken in 2005–2008 at northern Kharassan in the Syr-Darya uranium province and at Buddenovskoye, Mynkuduk, Inkai and Moinkum in the Chu-Sarysu uranium province. A geological and economic re-assessment of vein type deposits was undertaken in 2007–2008 in the northern Kazakhstan uranium province. The Akbastau JSC will commence exploration in 2009–2010 at sites numbers 1, 3 and 4 of the Buddenovskoye deposit, with pilot ISL production planned at all these sites. The Zarechnoye JSC will start exploration of the South Zarechnoye deposit in 2009. The Volkovgeology JSC is preparing to recommence in 2010 geological exploration of deposits of the sandstone type in fresh prospective zones within the uranium provinces of Chu-Sarysu and the Syr-Darya. Details of exploration and development expenditures and drilling campaigns are provided in Fig. 7.21, including 11 858 521 metres of drilling within a total expenditure of USD $667 195 000 [10.8–10.17].

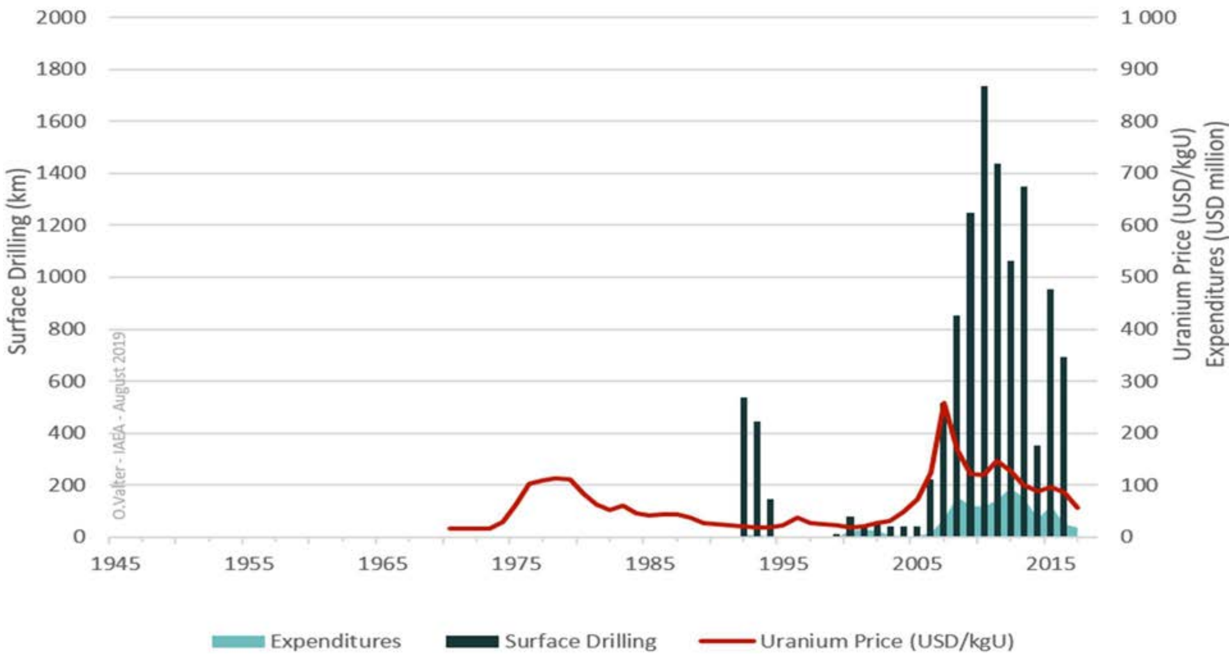


FIG. 7.21. Domestic uranium exploration data for Kazakhstan. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

7.10.4. Uranium resources

7.10.4.1. Identified resources

Identified in situ resources of uranium, as of 1 January 2017, total 1 031 331 tU (recoverable at <US $260/kgU), comprising 718 284 tU that are amenable to ISL mining [10.17]. Details of traditional resources are summarized in Tables 7.7 – 7.8. Historical variation in identified resources is shown in Fig.7.22 and Fig. 7.23.

TABLE 7.7. REASONABLY ASSURED CONVENTIONAL RESOURCES BY DEPOSIT TYPE (tU) [10.17]

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	256 031	338 131	351 481	351 481
Metasomatite	0	4179	61 097	75 471
Phosphate	0	0	29 184	38 455
Lignite-coal	0	0	29 433	29 433
Total	256 031	342 310	471 195	494 840

TABLE 7.8. INFERRED CONVENTIONAL RESOURCES BY DEPOSIT TYPE (tU) [10.17]

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	284 474	371 855	394 617	394 617
Metasomatite	0	4896	80 226	126 814
Phosphate	0	0	0	4857
Lignite-coal	0	0	10 203	10 203
Total	284 474	376 751	485 046	536 491

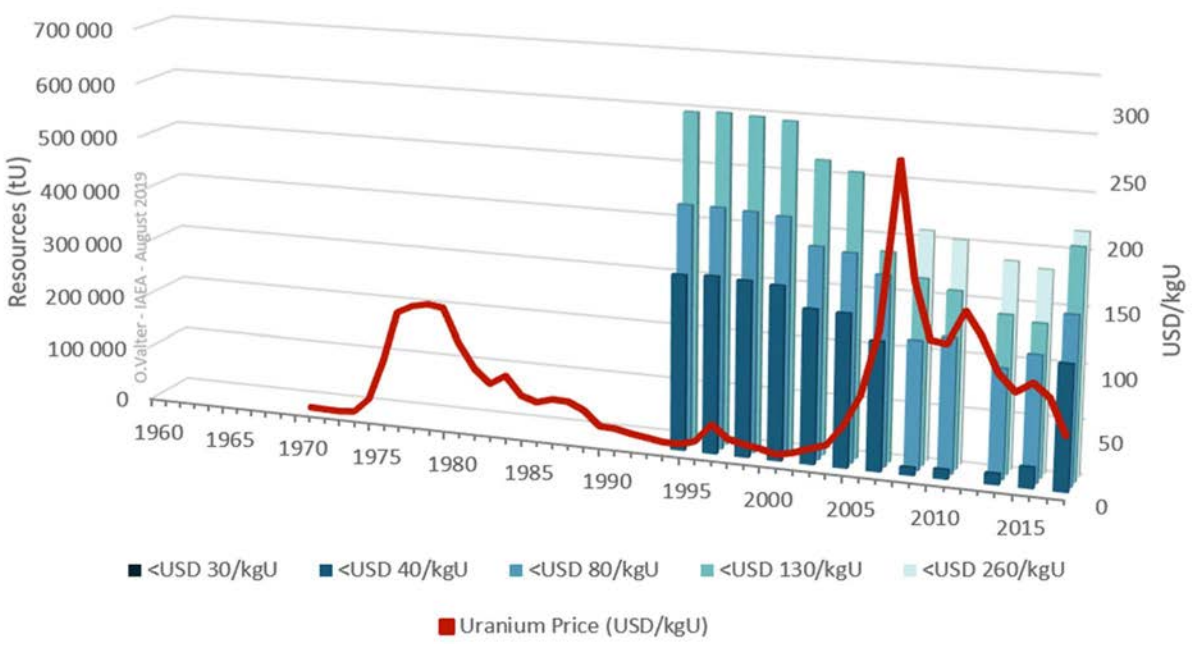


FIG. 7.22. Historical variation of recoverable reasonable assured resources within various cost categories in Kazakhstan. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

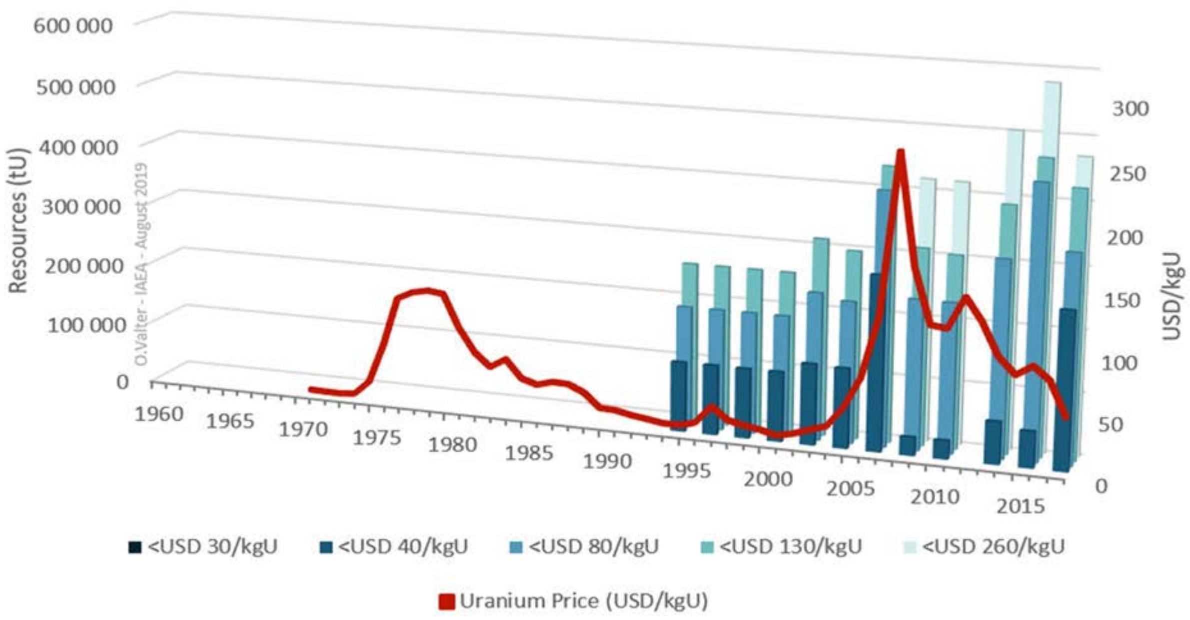


FIG. 7.23. Historical variation of inferred resources within various cost categories in Kazakhstan. Periods where no resources are shown in any cost categories are periods where resources were not reported.

The UDEPO database lists the most significant deposits for Kazakhstan as Inkai 1-2-3, Mynkuduk East, Budennovskoye 2 (Karatau), Kosachinoye (10 deposits), Budennovskoye 1-3-4 (Akbastau).

7.10.4.2. Undiscovered conventional resources

There are 230 583 tU of prognosticated resources, of which 229 053 tU relate to sandstone deposits and 2000 tU to metasomatite deposits.
Out of 300 000 tU of speculative resources, 270 000 tU are sandstone type deposits and 30 000 tU are unconformity type deposits.

7.10.4.3. Unconventional resources

There are no estimates of Kazakhstan's unconventional resources.

7.10.5. Potential for new discoveries

Kazakhstan has several highly prospective Mesozoic and Cenozoic sedimentary basins containing sandstone-hosted uranium deposits which are currently being exploited, primarily by ISL methods. Additional resources within these basins are likely to be delineated in the future as exploration in the country continues to be strongly focused on these types of deposit. Additionally, some potential remains for lignite–coal type deposits within these basins. Less potential exists for new discoveries of vein type deposits in the Kokshetau region or for volcanic-related deposits in the Kendyktas–Chuily–Betpak Dala / Pribalkhash (Lake Balkhash) region. Potential additional resources may be found from a relatively unique diversity of organic phosphorite type deposit (i.e., clay-hosted phosphatized fossil fish bone) in the Pricaspian (Mangyshlak) region.

7.10.6. Uranium production

Traditional mining for uranium began in the Pribalkhash region in 1953. Operations by underground mining generated uranium until 1990. The ore was transported to the Kara Balta mill in Kyrgyzstan. In the Kokshetau region, exploitation started with the Manybayskoye open pit operation in 1957, succeeded by several underground mines that ran up to 1995. Following a brief shutdown, these operations were revived for a short period (1997–1998) before again being closed. A mill for the region ran at Stepnogorsk in 1958-1995. In the Pricaspian region, open pit mining was operated during 1959–1993 and output was processed at the Aktau mill, which commenced operation in 1959 and ceased in 1993 [10.2].

In 1977, ISL operations commenced on a commercial basis at Uvanas in the Chu-Sarysu Basin, succeeded in 1988 by Mynkuduk and Kanzhugan after a number of years of testing. Then, ISL production was authorized at Moynkum 1 and, in 2001, at Moynkum 2 and 3, and at Inkai and Akdala. In the Syr-Darya Basin, ISL operations began at the North Karamurun deposit in 1985, succeeded by production at South Karamurun [10.2].

In 2007 and 2008, uranium output amounted to 15 145 tU, which was produced from 15 deposits: Akdala, Buddenovskoye, Inkai, Irkol, Kanzhugan, Moinkum, Mynkuduk, North Karamurun, South Karamurun, Uvanas, Vostok, Zarechnoye and Zvezdnoye. All deposits are being mined by ISL, except Zvezdnoye and Vostok, where underground methods of mining are employed [10.15].

As of 1 January 2009, the total capacity of Kazakhstan's uranium production centres was 12 000 tU/year, with an intended annual growth in production capacity to 19 000–28 000 tU by 2015 [10.15]. Production of uranium at the ISL mines is conducted with sulphuric acid to generate pregnant uraniferous solutions, further treatment of which is according to ion exchange sorption–elution know-hows with precipitation of uranyl salts and/or further processing to yield natural uranium concentrate. Details of historic production data and production centre data are summarized in Table 7.9 and Fig. 7.24 for a total of 219 432 tU. This is comprised of 212 115 tU, 6 424 tU, 668 tU with *in situ* leach (ISL), underground and open pit mining techniques respectively.

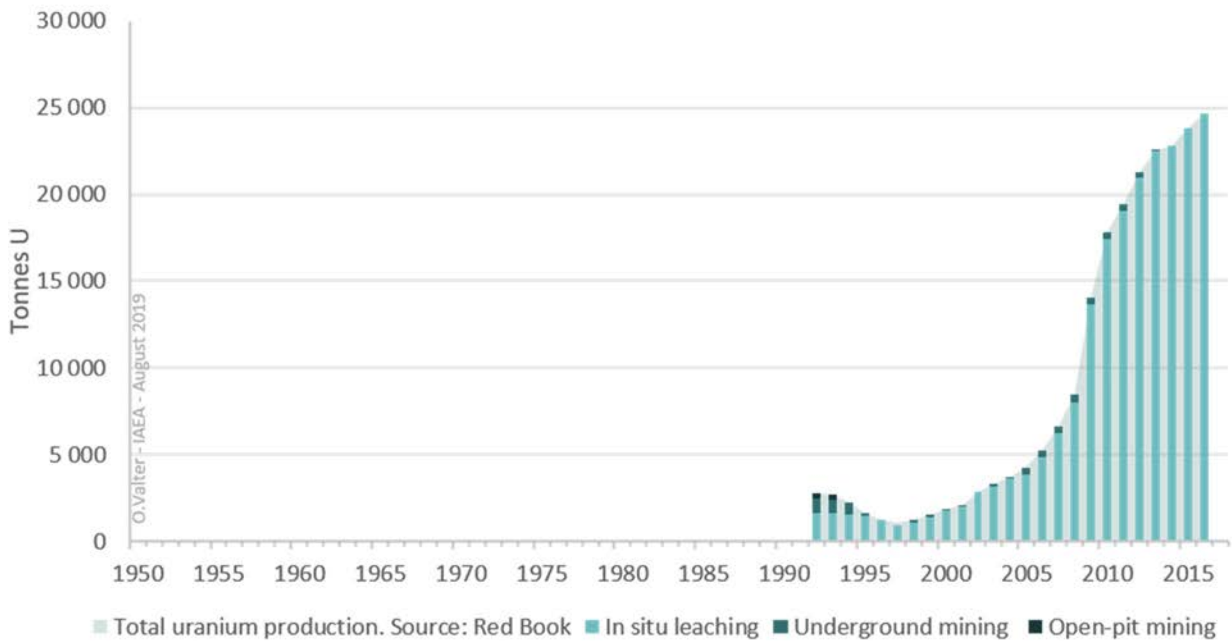


FIG. 7.24. Historical uranium production in Kazakhstan.

TABLE 7.9. URANIUM PRODUCTION CENTRE TECHNICAL DETAILS [10.15]

Production centre	Taukentskiy	Stepnoye	Mining Group 6	Betpak–Dala	Katko	Inkai
Startup date	1982	1978	1985	2004	1996	1996
Deposit	Kanzhugan, Moinkum (1, 3)	Mynkuduk, Uvanas	Karamurun (North and South)	Adkala Inkai (4)	Moinkum (1, 2, 3)	Inkai (1, 2, 3)
Deposit type	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Reserves (tU)	36 211	24 286	28 414	38 230	52 353	159 600
Grade (%U)	0.046	0.032	0.081	0.048	0.074	0.047
Mining operation	ISL	ISL	ISL	ISL	ISL	ISL
Mining recovery (%)	87	90	91	90	85	80
Process type	IX[a], SX[b]	IX	IX	IX	IX	IX
ISL(kl/h)	2700	2800	1900	2000	2800	560
UG[c] (ore t/d)	0	0	0	0	0	0
Process recovery (%)	98.9	98.7	98.7	98.7	98.7	98.5
Production capacity (tU/year)	1200	1300	1300	2000	3000	1000

Production centre	Mining Chemical Complex	Zarechnoye	Karatau	Ken-Dala	Appak	Kyzylkum
Startup date	1958	2001	2006	2005	2005	2005
Deposit	Vostok, Zvezdnoye	Zarechnoye	Buddenovskoye (2)	Mynkuduk (central)	Mynkuduk (west)	North Kharassan (1)
Deposit type	Vein stockwork (metamorphite)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Reserves (tU)	10 464	18 694	16 929	46 919	24 845	34 352
Grade (%U)	0.167	0.050	0.094	0.032	0.032	0.108
Mining operation	UG	ISL	ISL	ISL	ISL	ISL
Mining recovery (%)	90	94	85	90	90	90
Process type	SX, AL[d]	IX	IX	IX	IX	IX
ISL(kl/h)	0	500	500	700	150	150
UG[c] (ore t/d)	1000	0	0	0	0	0
Process recovery (%)	90	98.5	98	98.7	98.9	98.5
Production capacity (tU/year)	500	500	1000	1000	500	1000

Production centre	Baiken-U	Akbastau	Semizbai-U	NAC Kazatomprom
Startup date	2009	2006	2006	2010

North Kharassan (2)	Buddenovskoye (1, 3, 4)	Semiznai Irkol	Zhalpak
Sandstone	Sandstone	Sandstone	Sandstone
24 824	25 100	46 251	14 525
0.108	0.094	0.050	0.035
ISL	ISL	ISL	ISL
90	85	87	90
IX	IX	IX	IX
n.a.[e]	n.a.	600	n.a.
0	0	0	0
98.5	98.9	98.5	n.a.
2000	3000	750	

[a] IX: ion exchange.
[b] SX: solvent extraction.
[c] UG: underground mining.
[d] AL: acid leaching.
[e] n.a.: not available.

7.10.7. Environmental activities and sociocultural issues

In the context of ecological policy in Kazakhstan, several actions to enhance environmental protection and promote the careful use of natural resources have recently been executed. A variety of environmental protection undertakings concerning firms and organizations within the corporate management field are being achieved in accord with statute, by-laws and governing documents. Legal acts controlling deleterious effects on the environment have been developed, comprising conditions for recording emission and pollutant discharges. A substantial decline in emission and pollutant discharges in the past few years has been accomplished at major enterprises as the result of implementation of activities for environmental protection. Generation and utilization waste volumes are also being reduced.

As a consequence of the generation and profitable operations of uranium facilities, about 266 600 t of waste were utilized and neutralized in 2008, representing an increase of 2400 t over that for 2007. About 707 800 t were reassigned to third party firms and disposed of in specialized stowage and dumping facilities, 5.3% more than in 2007 [10.15]. Wells for examining radionuclide passage in groundwater were set up to monitor any discharges from tailing ponds at the Ulba Metallurgical Plant and Stepnogorskiy Mining and Chemical Complex. No instances of radionuclide passage beyond the tailing impoundments were documented. In the interest of the careful use of natural resources, initiatives to minimize water utilization were considered by increasing retrieval and reprocessing throughout the restitution of disturbed soils.

Another organization for recovering land after ISL mining was established as component of the Kazatomprom Mining Company LLP and a long term, incremental programme of reclamation of exhausted blocks at ISL sites was developed. The first phase (2007–2010) concerns the restitution of exhausted blocks of the Uvanas deposit, which has been mined since 1978. During the last couple of years, 98 blocks of the Uvanas deposit (comprising a total area of 261 ha) have been reclaimed. A total of 2205 wells have been removed, 6 ponds recovered and 11 385 t of polluted soil taken away and disposed of. In 2007 and 2008, Uranlikvidrudnik RSE resumed recovery operation in areas with closed uranium mines, as well as with the closure of mines. At the close of 2009, the recovered area of 261 ha will be reassigned to the State for use as fallow. During 2009, additional 84 blocks of the Uvanas deposit, 10 ponds and 1810 wells will be recovered [10.15]. In 2010, restitution work will start at the Kanzhugan

deposit, which began operation in 1982, and in 2012, similar work will start at the Karamurun deposit, which began operation in 1985.
A great deal of work has been spent at several uranium facilities to prepare for the establishment of an environmental management system and authorization of production processes in compliance with ISO 14001 requirements. As of January 2009, 15 enterprises conducted an environmental audit and have been given ISO 14001 international certification. Government expenditure amounted to KZT 1227.082 million, including KZT 17.233 million for radiation control of formerly rehabilitated facilities (US \$1 ≈ 270 KZT (Kazakhstan Tenge)) [10.15].

Every contract for exploration and mining of uranium offered by the Government demands monetary commitments for the development of local sociocultural enhancements. Every subsoil user is compelled to fund the formation, expansion, protection and promotion of the regional social infrastructure, comprising facilities for health care of personnel and local citizens as well as education, recreation, sport and other activities, in accord with the policy of the JSC NAC Kazatomprom and by treaty with local authorities. Annual provisions per operator totalled US \$30 000–100 000 (throughout the exploration phase) and up to 15% of yearly operating expenditures (US \$50 000–350 000 per year) throughout the mining phase [10.15]. At the close of 2004, Demeu–Kazatomprom LLP was created. It oversees sociocultural issues related to production of uranium in Kazakhstan.

7.10.8. Employment in the uranium industry

Total personnel in companies that produce uranium in Kazakhstan swelled from 6941employees in 2006 to 7940 in 2008. Owing to the formation of new uranium production centres and the development of existing ones, Kazakhstan persisted to bear the lack of qualified employees in 2007 and 2008. Training was carried out in two educational centres to groom qualified staff from among Kazakh nationals: the Regional Geotechnology Training Centre and the Kazakhstan Nuclear University.

7.10.9. National policies relating to uranium

The Decree of the Government of Kazakhstan authorized in 23 January 2004 the Programme for Development of the Uranium Industry in Kazakhstan from 2004 to 2015. This programme prioritizes the advancement of the uranium industry as amongst of the country's 'high tech' industries as well as expansion of export and access into such product markets in an endeavour to grow the country's export potential.

On the basis of prevailing resources of uranium, the foremost strategic mission of the programme was to realize a yearly production capacity of 15 000 tU by 2015, which was reached and exceeded. The programme further aims at firming Kazakhstan's status as the chief producer of fuel pellets for nuclear reactors in previous Soviet Union countries, thereby achieving entry to the world market of nuclear fuel, keeping and growing world market statuses for products of uranium together with conversion services, expanding nuclear fuel production capacity and taking part in the world market for products containing uranium derived from Kazakhstan's raw materials and executing an action plan to promote the environmental security of facilities for the nuclear fuel cycle.

Kazatomprom was appointed as the national operator for the import and export of uranium and its compounds, nuclear fuel, special equipment and technologies, and related materials. Capitalizing on a theoretical foresight of the global energy supply grown in 2005, Kazatomprom has been following a scheme of making a transnational, vertically integrated company that participates in all phases of the nuclear fuel cycle (barring reprocessing of irradiated fuel and nuclear waste disposal).

References to Section 7.10

[10.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Kazakhstan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.
[10.2] DAHLKAMP, F.J., Uranium Deposits of the World: Asia, Springer, Berlin (2009) 493 pp.

[10.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).
[10.4] YAZIKOV, V.G., “Uranium raw material base of the Republic of Kazakhstan and prospects of using in situ leach mining for its development”, T1-TC-975, paper presented at IAEA Tech. Mtg on In Situ Leach Uranium Mining, Almaty, 1996.
[10.5] ADAMS, S.S., CRAMER, R.T., “Data-process-criteria model for roll-type uranium deposits”, Geological Environments of Sandstone-type Uranium Deposits, IAEA-TECDOC-328, IAEA, Vienna (1985) 383–399.
[10.6] PETROV, N.N., et al., Uranium Deposits of Kazakhstan (endogenous), “Gylym”, Almaty (2000) 523 pp.
[10.7] PETROV, N.N., et al., Uranium Deposits of Kazakhstan (exogenous), “Gylym”, Almaty (1995) 264 pp.
[10.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).
[10.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).
[10.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).
[10.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).
[10.25] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).
[10.13] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.
[10.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[10.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[10.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).
[10.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

7.11. KUWAIT

7.11.1. Geography

Kuwait is bordered by Iraq, Saudi Arabia and the Persian Gulf. It is a constitutional monarchy. Amongst the Persian Gulf Arab countries, it has the oldest directly elected parliament.

The country is mostly covered by the flat, sandy Arabian Desert. It has an arid climate, with intensely hot summers and cool winters. Rainfall varies from 75 to 150 millimetres a year.

It is a small, rich, rather open economy-based on petroleum (with self-reported crude oil reserves of about ~104 billion barrels, or 10% of world reserves), natural gas and fish [11.1].

7.11.2. Geology

Kuwait is located on the Interior Stable Platform of the Arabian Shield (Fig. 7.25). It is west of the Persian Gulf synclinorium. Geological features consist of marine sediments of Cretaceous and Tertiary age. Outcrops of bedrock are rare. Most of the surface is covered by sand, salt marsh, playa and alluvium. Other than oil, no mineral deposits are known in Kuwait.

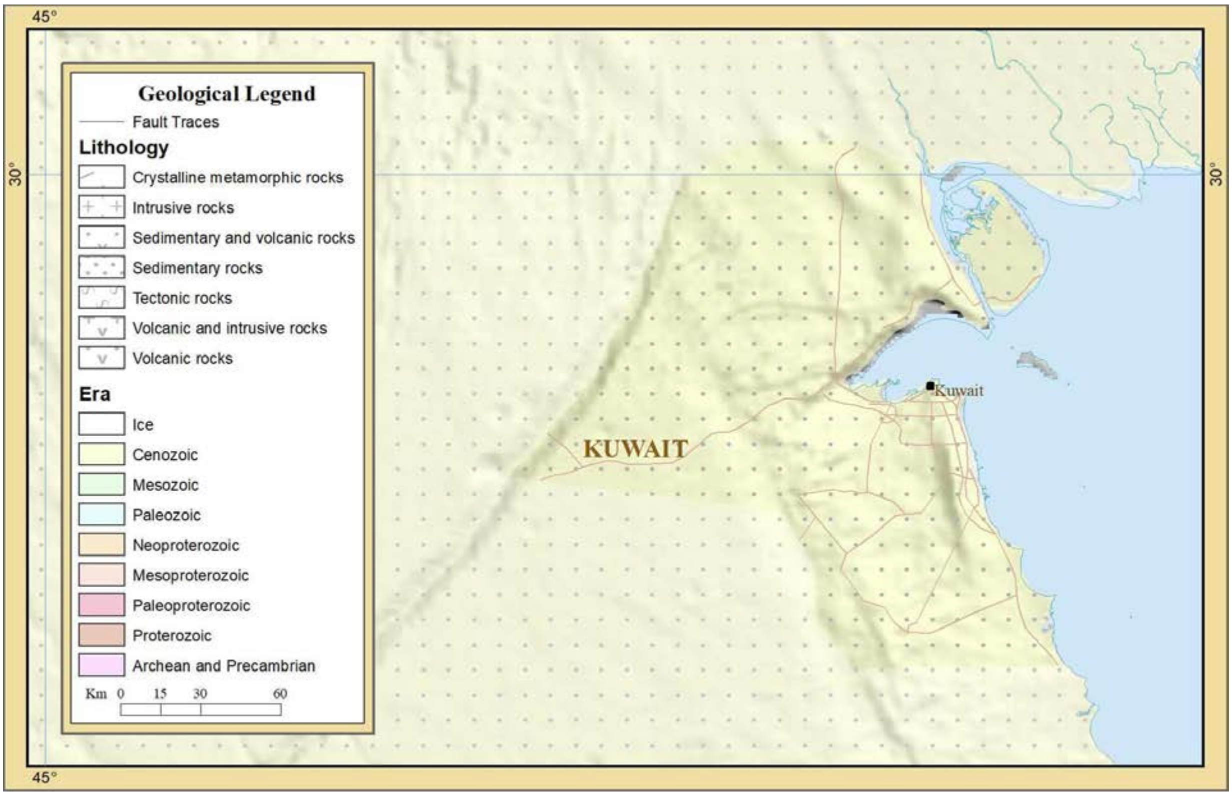


FIG. 7.25. Regional geological setting of Kuwait. A general global geological legend is shown although not all geological units necessarily occur on this particular map

7.11.3. Uranium exploration

There has been no reported uranium exploration in Kuwait.

7.11.4. Uranium resources

There are no known uranium occurrences in Kuwait and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for Kuwait.

7.11.5. Potential for new discoveries

From a geological point of view, Kuwait does not have potentially favourable areas for the development of uranium deposits. Owing to the country's size and rock types present, the potential for new discoveries is rated as negligible [11.2].

7.11.6. Comments

There has been no past uranium production in Kuwait.

References to Section 7.11

[11.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Kuwait, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[11.2] BOWMAN J., I U R E P NATIONAL FAVOURABILITY STUDIES. IUREP N.F.S. No. 126. Kuwait (1977).

7.12. KYRGYZSTAN

7.12.1. Geography

Kyrgyzstan is a landlocked country in central Asia and has borders with Kazakhstan, China, Tajikistan and Uzbekistan. The Tien Shan Mountains cover over 80% of the country, with the remainder made up of valleys and basins.

Issyk-Kul Lake in the north-eastern Tien Shan is the largest lake in Kyrgyzstan and the second largest mountain lake in the world after Titicaca. The highest peaks are in the Kakshaal Too range, which constitutes the Chinese border. At an elevation of 7439 m, Jengish Chokusu is the highest point.

The principal river is the Kara Darya, which flows west through the Fergana Valley into Uzbekistan, where it meets the Naryn, another major Kyrgyz river. The confluence forms the Syr-Darya, which originally flowed into the Aral Sea.

The climate varies according to the region and altitude. The south-western Fergana Valley is subtropical and extremely hot in summer, with temperatures attaining 40°C. The northern foothills are temperate and the Tien Shan climate varies from dry continental to polar, according to elevation. In the coldest areas, temperatures are sub-zero for ~40 days in winter, and even some desert areas experience constant snowfall in this period.

Kyrgyzstan has significant metalliferous deposits, including gold and rare earth metals. Owing to the country's mountainous terrain, less than 10% of the land is cultivated and this is concentrated in the northern lowlands and along the edges of the Fergana Valley [12.1].

7.12.2. Geology

The geology of is dominated by the complex sequences that comprise the Tien Shan mountain belt (Fig. 7.26). The mountains form an arc running through the country from west to east, with sub-parallel ranges separated by intermontane basins and valleys.

A large part of the country is located in the Tien Shan folded area, the geosynclinal development of which was completed at the end of the Palaeozoic (200 Ma). The stage of relatively quiescent platform development in the Neogene (30–20 Ma) was interspersed by episodes of violent tectonism, which continue to the present-day and which have determined the topography of the country. Two areas are distinguished, the Caledonian (Ordovician–Silurian) folded system of North Tien Shan dating from 400 Ma and the Hercynian system of the Middle and South Tien Shan dating from 300 Ma, which are divided by zones of deep faults. These zones are frequently the major source of earthquakes.

Intermontane areas have thick accumulations of Mesozoic and Cenozoic continental sedimentary rocks. The structure of the Northern Tien Shan (Caledonian) also comprises Lower Palaeozoic folded complexes overlying a primeval basement dated at 500 Ma. The Hercynian system comprises, for the most part, continental sedimentary and volcanogenic complexes. Caledonian granitoid magmatism is a common feature and gneiss and granitoid comprise the basement of Palaeozoic rocks.

The country has major deposits of gold, uranium and rare earth metals, as well as deposits of copper, mercury and bismuth. It also has minor deposits of coal, oil and natural gas. In the Northern Tien Shan, deposits of commercial significance include complex ore deposits associated with Late Palaeozoic magnetism, as well as gold and pyrite deposits.

In Middle Tien Shan, a sedimentary iron ore basin has been discovered with reserves of ~10 Bt. In addition, molybdenum and vanadium mineralization and other complex ores have also been discovered.

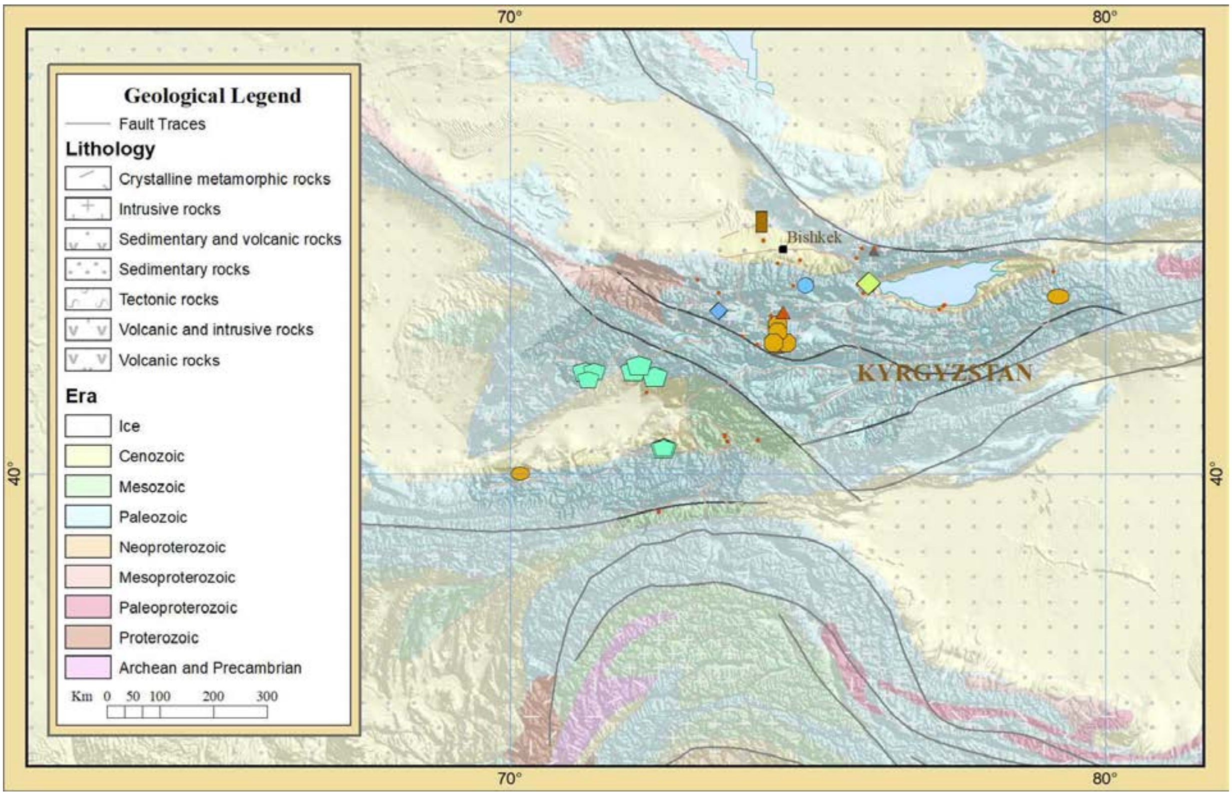


FIG. 7.26. Regional geological setting of Kyrgyzstan showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

In Southern Tien Shan, mercury, antimony and tin have been identified. Promising occurrences of gold and bauxite have also been reported. In the Fergana basin, oil and gas are extracted from Cretaceous and Palaeogene deposits [12.2].

7.12.3. Uranium exploration

Uranium mineralization in Kyrgyzstan was initially found in the 19th century in the Fergana Valley in the country's north-western section. This area was chosen for rigorous exploration of uranium by the former Soviet Union after World War II. The Mailuu-Suu deposit in the Fergana Valley was found in 1943. Thorough exploration led to findings of the Shakaptar and Mailuu-Suu deposits in 1946. These deposits exist in Palaeogene bituminous limestones. Total resources in these deposits were less than 1000 tU and ore grades did not exceed 0.01% U. Majority of the recognized resources of the former Soviet Union at the close of the 1940s, which totalled ~700 tU, were situated in the Fergana Valley in Kyrgyzstan, Tajikistan and Uzbekistan.

Three small medium-size deposits of uraniferous coal were also found in the Min-Kush Basin (Tien Shan area of central Kyrgyzstan) in the 1940s: Kashka-Su, Tuyuk-Su and Tura-Kavak. A fourth uraniferous coal deposit, Dzhilskoye, was found close to the southern shore of Lake Issyk-Kul [12.3].

7.12.4. Recent and ongoing uranium exploration and mine development activities

The Australian company Monaro Mining NL has eight exploration licences in Kyrgyzstan, all of which have potential for uranium. These projects comprise Gavasai, Hodjaakan, Sogul, Sumsar, Naryn, Djurasay, Utor and Aramsu. Several of these projects also include precious and base metals. Several other companies, such as Canada's Uranium One, are likely keenly exploring for uranium. Nimrodel Resources Ltd (Australia) has leases in the Mailuu-Suu area.

Monaro signed in January 2008 a Memorandum of Understanding with Chinese resources group Sinosteel to assume exploration of Sinotsteel's Kyrgyz projects, under which it could finally own up to 60% of two new uranium mines. Monaro reported at the end of 2009 that it had traded a 75% interest in its Kyrgyz project to Gate Bridge Co. Ltd, which is based in Hong Kong and is owned by a consortium of Chinese investors. Monaro will keep a 25% free carried interest until such time as Gate Bridge undertakes a pre-feasibility study on any of the licence areas.

Raisama Ltd, also based in Australia, has a 75% interest in the Kashkasu project, west of the former uranium mines, which records uranium mineralization extending over a strike length of 2.6 km. China's Hebei Mining has a 10.94% interest in Raisama.

A number of the licences have locally defined resources. However, these do not comply with JORC or NI 43-101 standards and substantial additional work is required before JORC compliant resource statements can be made.

On 9 January 2008, Nimrodel Resources announced that its wholly-owned Kyrgyz subsidiary, Linia Prava Uranium Ltd, has been issued licences to allow for the reprocessing and extraction of uranium and other metals from 23 tailings deposits in the Mailuu-Suu district of central Kyrgyzstan. On 23 October 2008, Nimrodel Resources issued a statement noting that the economic conditions and uranium price prevailing at that time prevented it from continuing with the re-processing of the Mailuu-Suu tailings [12.4].

Canada Azarga Uranium, through its 70% subsidiary UrAsia has the uranium and rare earths Kyzyl Ompul project, 125 km east of Bishkek. The main deposit is Kok Moinok, a hydrothermal deposit discovered in 1953 and containing 2900 tU of inferred resources (NI 43-101). Additional resources are associated to the Tash Bulak and Backe placer deposits. [12.5].

US IMC Invest Inc owns several deposits including the Kamushanovskoye deposit located about 70 km northeast of Kara Balta on the Kazakh border. At Kamushanovskoye uranium is adsorbed onto peat. IMC Invest Inc project would include a satellite ISL alkaline plant, the loaded resin being processed at the Kara Balta mill (starting in 2009, a total of 2300 tU would be produced over ten years). Measured and indicated resources are about 2500 tU (JORC compliant). It is also exploring the Jetym black shale deposits several hundred kilometres southeast of Kara Balta, with 48 700 tU in 'prognostic resources' [12.5].

In 2011, China's Hebai Mining purchaised from Raisama Ltd the major interest in the Kashkasu project,, with uranium mineralisation spread over 2.6 km strike length.

In 2012, Central Asia Mining Co had a licence to process the Kara Balta tailings for uranium and molybdenum. JSC Kentor has an exploration licence for uranium and other minerals at Bashkol [12.5]. Australia Monaro Mining NL had uranium exploration licences at Aramsu, Utor, Naryn, Sumsar, Sogul, Djurasay, Hodjaakan, and Gavasai. The company was liquidated in 2016. A number of other companies including ARMZ's Uranium One and Nimrodel, which has leases in the Mailuu-Suu area, have been actively exploring for uranium. [12.5].

7.12.5. Uranium resources

There are at present no economically viable resources of uranium in Kyrgyzstan. Mbendi reports on its web site that uranium production could be possible with the development of proven reserves in the Sarydzhaz River Basin and in the Kyzyl-Ompulsky placer fields. Sarydzhaz hosts an estimated 7000 tU averaging 0.019% U, and Kyzyl-Ompulsky hosts 2650 tU averaging 0.027% U [12.6]. Large black shale and lignite-coal formations with geological uranium resources are also present.

The UDEPO database lists the most significant deposits for Kyrgyzstan as Jetym District, Tash Bulak, Sarydjaz, Backe, Tyuya-Muyum, Mailuu-Suu, Turakavak (Min-Kush), Kok Moinok, Maylisay.

7.12.6. Potential for new discoveries

Kyrgyzstan's uranium geology is similar to that of Kazakhstan, with the Chu-Sarysu and Syr Daria uranium districts in south Kazakhstan totalling over one million tonnes of uranium resources , which represents a significant proportion of the known recoverable resources in the region. Sedimentary rocks in the Fergana Valley could potentially host significant uranium deposits in the form of roll front type mineralization.

7.12.7. Uranium production

Mining of uranium in Kyrgyzstan was carried out in four areas: (i) Mailuu-Suu, (ii) Tura-Kavak (also known as Min-Kush), (iii) Dzhilskoye (also known as Kadju-Say), and (iv) Shekaftar (Fig. 7.27). The ore was treated at local hydrometallurgical leaching facilities sited in each of these areas.

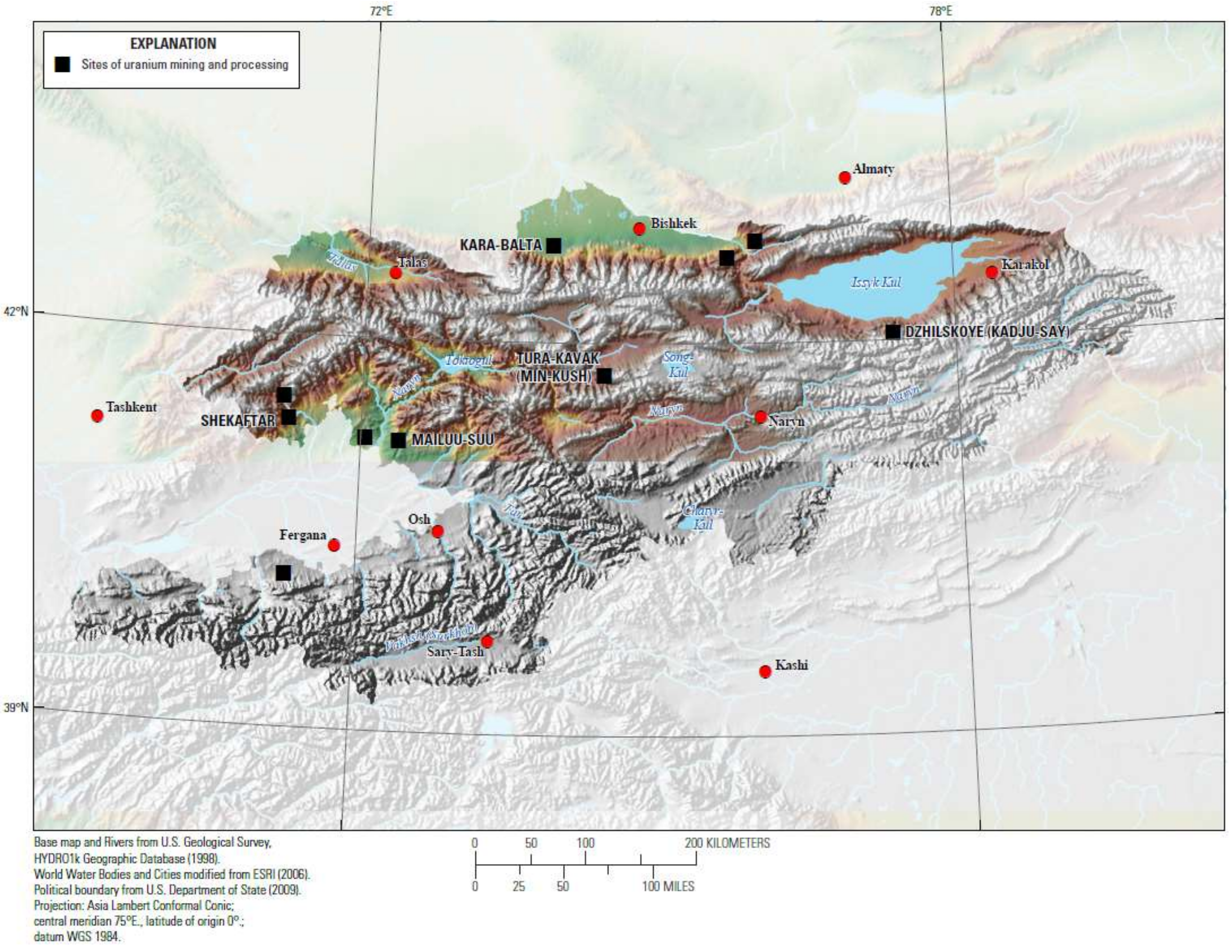


FIG. 7.27. Sites of selected uranium mining and processing in Kyrgyzstan [12.7].

Mining at Mailuu-Suu took place during 1946–1968. Six underground shafts provided access to the ore, which was then treated at two local plants. Twenty-three tailings ponds linked with the Mailuu-Suu mining and processing complex and cover an area of 10 km^2 and comprise 1.96 million m^3. Moreover, there are 13 waste rock piles derived from the mining operation at Mailuu-Suu comprising a total volume of 1 million m^3.

A dedicated production facility was built in 1948 to treat the uranium-bearing coal of the Dzhilskoye deposit. The coals were burned initially at a proximate power plant. A hydrometallurgical treatment was then applied to retrieve uranium from the generated ash. In 1956, the mine and treatment facility at

Dzhilskoye were shut due to excessive expenses of production. A similar treatment was applied to process the uraniferous coals at Tura-Kavak. The tailings ponds built for these two operations contain ~1.4 million m^3 of waste material — 1 million m^3 at Tura-Kavak and 0.4 million m^3 at Dzhilskoye.

Bulk ore, ore concentrates and leach products from operations of uranium production in Kyrgyzstan were exported for final treatment to the Leninabad Mining Chemical Association (former Combine 6) mill in Tajikistan, which was constructed in 1946.

Milling of uranium in Kyrgyzstan started in 1955, when the Kara Balta mill was constructed. The mill, located ~100 km west of the capital Bishkek, had a yearly capacity of 1.5 Mt of ore or ~2500 tU and was originally ran by Yuzhpolymetal Mining and Metallurgical Combine. Its successor, Kara Balta Ore Processing Combine, was later operated by the Kyrgyzstan Ore Refining Combine. The Kara Balta mill processed ore from Kyrgyzstan, Kazakhstan and the Russian Federation. Traditional operations for milling were stopped in 1989 when mining was ended in south-eastern Kazakhstan. The Kara Balta mill has, since 1994, treated yellow cake slurries from ISL operations in southern Kazakhstan. The slurries have 40–45% U and generate ~400 tU/year. A section of the Kara Balta milling circuit has been re-organized to treat other minerals, as well as gold ore, until processing of uranium ore can be continued.

The Government accepted in March 2007 a bid from a Russian resources investment group, Renova, for its 72% stake in the company, which steered to a contract in October 2008 with the Eurasian Development Bank to finance US $150 million to develop the mill and manage 50 years' accumulation of plant tailings. Kara Balta contracted with Zarechnoye JV and Kazatomprom for toll milling. The mill restarted production in August 2007 and by 2009 had grown annual production from ~800 tU to 2574 tU, exceeding historic output levels for the first time. This production is all recorded as being Kazakh [12.3, 12.4, 12.7].

7.12.8. Environmental activities

Very large tonnages of waste rock and uranium residues have accumulated near mining and processing sites. Fig. 7-12.1 shows the location of the sites associated with the uranium industry (mines and processing sites).

According to an approximate assessment by Kyrgyzstan's Ministry of Emergency Situations, there are, within the country, 35 tailings dumps and 25 sites used for waste rock. Of these, 30 tailings dumps comprise residues from uranium production. The total volume of residues is estimated at 254 million m^3.

From March 1999, pursuant to Government Decree No. 161, the uranium tailings dumps and other waste rock piles comprising radionuclides of the uranium and thorium series are administered by a special section that forms part of the Ministry of Emergency Situations. This section is accountable for the institution of investigation and monitoring services at the sites where the previous facilities were located, as well as for the upkeep of protective fences and supervision of the remediation programme.

To institute the remediation priorities, data from a number of international reports were analysed. The results indicate that the chief element of accumulated risk, which has been considered, upsets the geotechnical stability of the tailings and waste piles in mountainous areas, which may possibly have a substantial impact on the engineered features of the tailings dumps and the immediate environment. Based on such criteria, the Min-Kush and Mailuu-Suu sites are regarded as first priority for remediation [12.6].

References to Section 7.12

[12.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Kyrgyzstan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[12.2] EDNES, Geology of Kyrgyzstan, www.ednes.org/telesol/cis/Kyrgyz.html

[12.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[12.4] WORLD NUCLEAR ASSOCIATION, Uranium in Central Asia (May 2011).

[12.5] MBENDI, Uranium and thorium mining in Kyrgyzstan, http://www.mbendi.com/indy/ming/urnm/as/kg/p0005.html.

[12.6] WORLD NUCLEAR ASSOCIATION, Uranium in Kyrgyzstan (2011).
[12.7] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Proposals for Uranium Production Legacy Sites in Central Asia: An International Approach, Proc. IAEA Tech. Mtg, IAEA, Vienna (2010).

7.13. LEBANON

7.13.1. Geography

Lebanon is located in Western Asia. It is bounded to the west by the Mediterranean Sea, to the south by Israel, and to the east and north by Syria. The country is partitioned into four discrete physiographic regions: the Anti-Lebanon mountains, the Beqaa valley which is a segment of the Great Rift Valley system, the Lebanon mountain which summits at 3 088 metres in Qurnat as Sawda' in North Lebanon, and the coastal plain.

Lebanon has a moderate Mediterranean climate, but there are sharp local contrasts as a result-of the varied relief. On the coast, the summers are hot and although rainless, rather humid. Winters are very mild at low levels and rainfall is moderate, with the main rains occurring between November and March. The average annual precipitation is 760 to 1 000 mm on the coast, rising to over 1 500 mm in the mountains. The Beqaa valley is drier and receives 380 to 650 mm in precipitation.

Lebanon is a developing economy. Its private sector adds to 75% of cumulative demand and a huge banking sector that supports this demand. Its industrial areas comprise agriculture (produce comprises lemons, oranges, peaches, and apples), metal products, chemicals, and transport equipment [13.1].

7.13.2. Geology

Geologically, Lebanon is young because the oldest terrains in the country are of Jurassic age (Fig. 7.28).

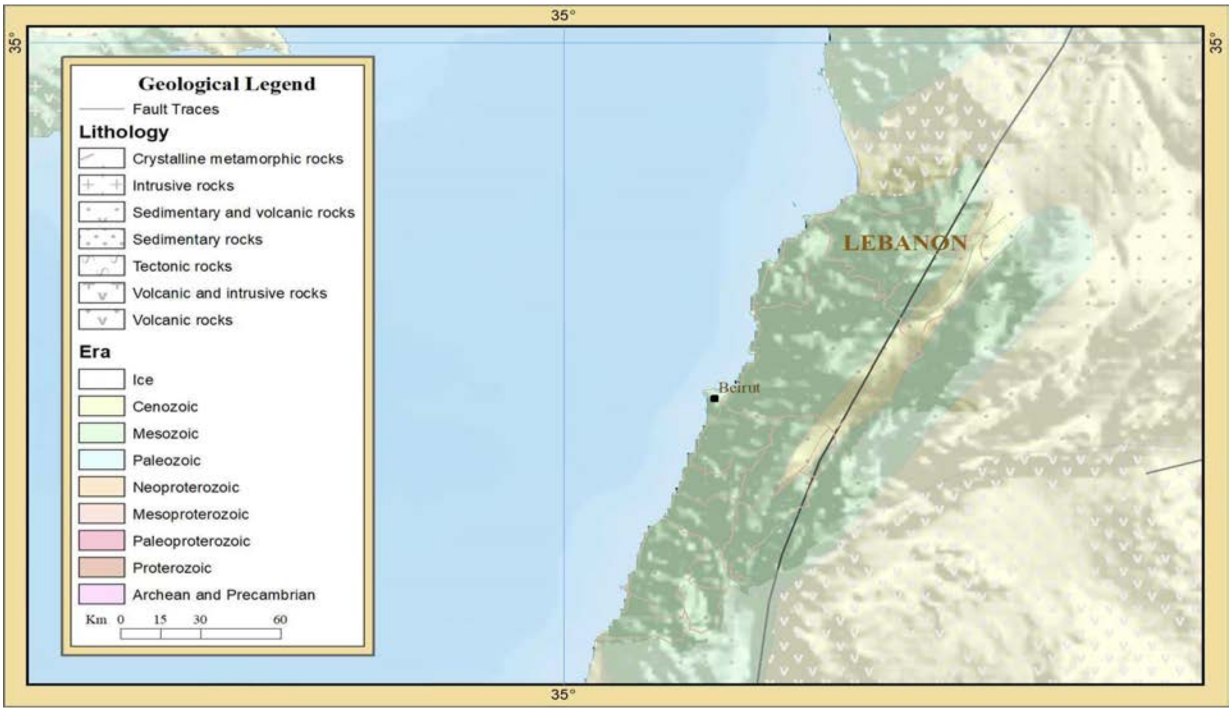


FIG. 7.28. Regional geological setting of Lebanon. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Jurassic dolomites and grey limestone, 1500 m - 1600 m thick, constitute the core of the Lebanon and the Anti-Lebanon, The Cretaceous in the Lebanon and Anti-Lebanon begins with a red or white, non-fossil quartz sandstone which connects, up with the Fubian sandstones. It is composed of three successive groups of layers; sandstone and argillaceous sandstone, limestones and limestone marls, and chalk marls, justifying a division into Lower, Middle and Upper Cretaceous. The more recent terrains have undergone two volcanic periods: the first beginning in Jurassic to Aptien and the second beginning in Miocene, both with formations of basalt. The country is intersected by numerous faults, mainly the two that surround the valley of the Beqaa, but also including a number of small transverse faults.

7.13.3. Uranium exploration

There has been no reported uranium exploration in Lebanon.

7.13.4. Uranium resources

There are no known uranium occurrences in Lebanon and no resources of uranium have been reported.

The UDEPO database does not list any known deposits for Lebanon.

7.13.5. Potential for new discoveries

From a geological point of view, the country has poor likelihood of existence of nuclear minerals. That is due to the recent geological age of the terrain and the basic nature of igneous extrusions, Lebanon offers little possibility for minerals of any type. Owing to the country's size and rock types present, the potential for uranium discoveries is rated as nil [13.2].

7.13.6. Comments

There has been no past uranium production in Lebanon. Lebanon has no plan to produce nuclear energy.

References to Section 7.13

[13.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Lebanon, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[13.2] I U R E P NATIONAL FAVOURABILITY STUDIES. IUREP N.F.S. No. 102. (1977).

7.14. MALDIVES[14]

7.14.1. Geography

Maldives is an island nation located in the Indian Ocean (Fig. 7.29) and comprises a group of 26 atolls lying ~700 km SW of Sri Lanka, in the Laccadive Sea. The 26 atolls encompass a territory numbering 1192 islets, of which 200 are inhabited. Maldives is recorded as being the country with the world's lowest elevation, with a maximum natural ground elevation of only 2.3 m and an average elevation of only 1.5 m. In areas where construction exists this has been increased to several metres.

The mixed economy of Maldives is based on the principal activities of tourism, fishing and shipping [14.1].

[14] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

7.14.2. Geology

The islands initially formed on a foundation of lagoonal sediments between 5500 and 4500 years BP, when the reef surface was as much as 2.5 m below the current sea level. The islands accumulated rapidly during the subsequent 1500 years, effectively reaching their current dimensions by 4000 years BP. Since then, the raised circumperipheral ridge has been subject to seasonal and longer-term shoreline changes and the outer reef has grown upwards, reducing the energy window and confining the islands [14.2].

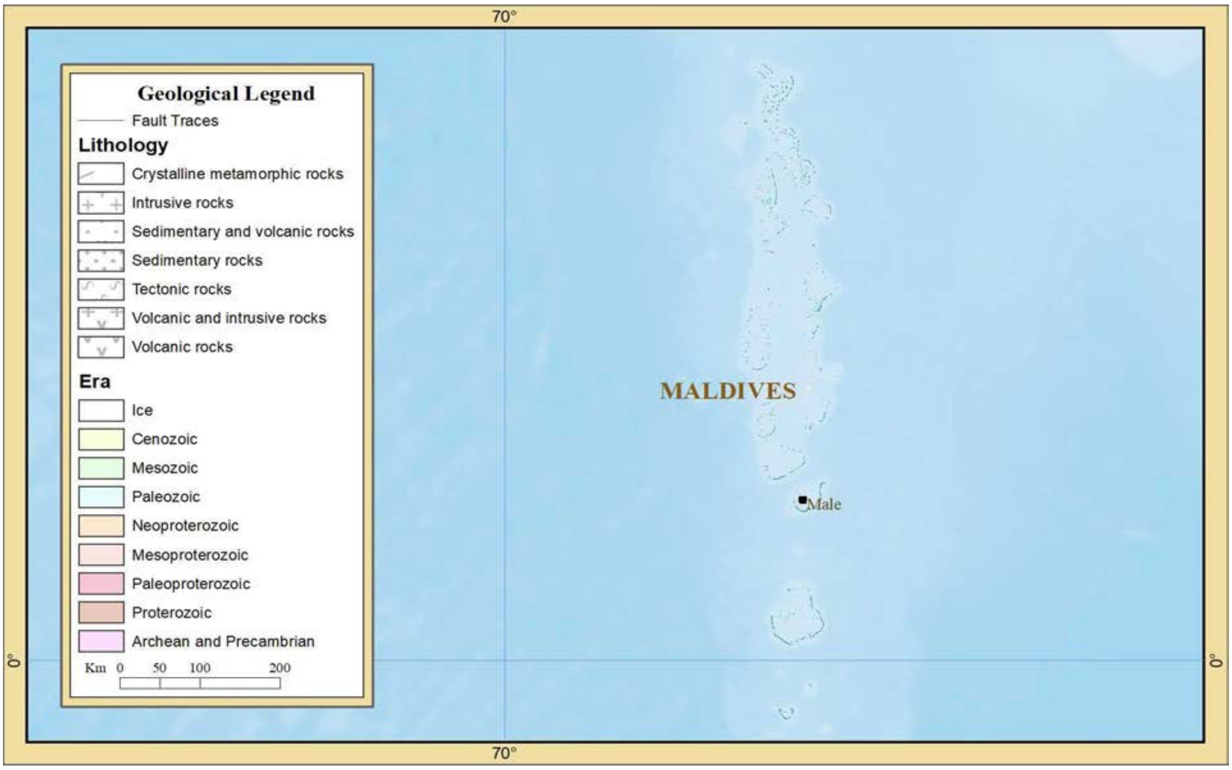


FIG. 7.29. Regional geological setting of Maldives. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.14.3. Uranium resources

No identified or undiscovered resources are reported. The UDEPO database does not list any known deposits for Maldives.

7.14.4. Comments

The potential for uranium discoveries is regarded as nil. No information is available on uranium exploration in Maldives. There has been no past production in Maldives and the country has no nuclear power generation.

References to Section 7.14

[14.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Maldives, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html .

[14.2] KENCH, P.S., New model of reef-island evolution: Maldives, Indian Ocean, Geology (February 2005), Geological Society of America, Boulder (2005) 145–148.

7.15. NEPAL

7.15.1. Geography

Nepal is a landlocked southern Asian country located in the Himalayas and bordered to the north by China and to the south, east and west by India. The country is ~ 800 km long and ~200 km wide.

Nepal is commonly divided into three physiographic areas: Terai, Hill and Mountain regions. These belts run E–W and are intersected by Nepal's major N–S flowing river systems.

The southern lowland plains or Terai that border India are part of the northern rim of the Indo-Gangetic Plain. This region has a subtropical to tropical climate. The outermost range of foothills, known as the Siwalik or Churia Range and attaining elevations of 700–1000 m, marks the limit of the Gangetic Plain.

The Hill region varies in elevation in the range 800–4000 m and this is reflected in the progression from subtropical climates below 1200 m to alpine climates above 3600 m. The Mahabharat Range, at 1500–3000 m, marks the southern limit of this region, with subtropical river valleys and hills alternating to the north of this range. Population density is high in the valleys.

The Mountain region, situated in the Great Himalayan Range, comprises the northern part of Nepal and possesses the highest elevations in the world, including, at 8848 m, Mount Everest, which lies on the border with China. Seven of the world's 8000 m high peaks are in Nepal or on its border with China: Lhotse, Makalu, Cho Oyu, Kanchenjunga, Dhaulagiri, Annapurna and Manaslu.

Nepal is one of the least developed countries in the world. Agriculture is the mainstay of the economy, providing a livelihood for three quarters of the population and accounting for roughly one third of GDP. Industrial activity mainly involves the processing of agricultural products, including pulses, jute, sugarcane, tobacco and grain. Although the steep mountain terrain makes exploitation difficult, mineral surveys have found small deposits of limestone, magnesite, zinc, copper, iron, mica, lead and cobalt. Nepal has considerable scope for exploiting its potential in hydropower, with an estimated 42 000 MW of feasible capacity [15.1].

7.15.2. Geology

Nepal occupies the central part of the Himalayan arc (Fig. 7.30). As with other parts of the Himalayas, Nepal can be also subdivided, from south to north, into five major tectonic zones, namely: (i) Gangetic Plain, (ii) Sub-Himalayan (Siwalik) Zone, (iii) Lesser Himalayan Zone, (iv) Higher Himalayan Zone, and (v) Tibetan–Tethys Himalayan Zone [15.2].

Just like the contact 'knot' that splits the Indian Plate from the Tibetan (Eurasian) Plate, which is the Indo-Tsangpo Suture Zone, thrust faults split the above-mentioned tectonic zones from each other. The Gangetic Plain is from the Sub-Himalayan (Siwalik) Zone by the Main Frontal Thrust, the southernmost fault. The Sub-Himalayan (Siwalik) Zone is split from the Lesser Himalayan Zone by the Main Boundary Thrust. The Higher Himalayan Zone and the Lesser Himalayan Zone are split by the Main Central Thrust. The Higher Himalayan Zone is split from the overlying fossiliferous sequence of the Tibetan–Tethys Himalayan Zone by the South Tibetan Detachment System.

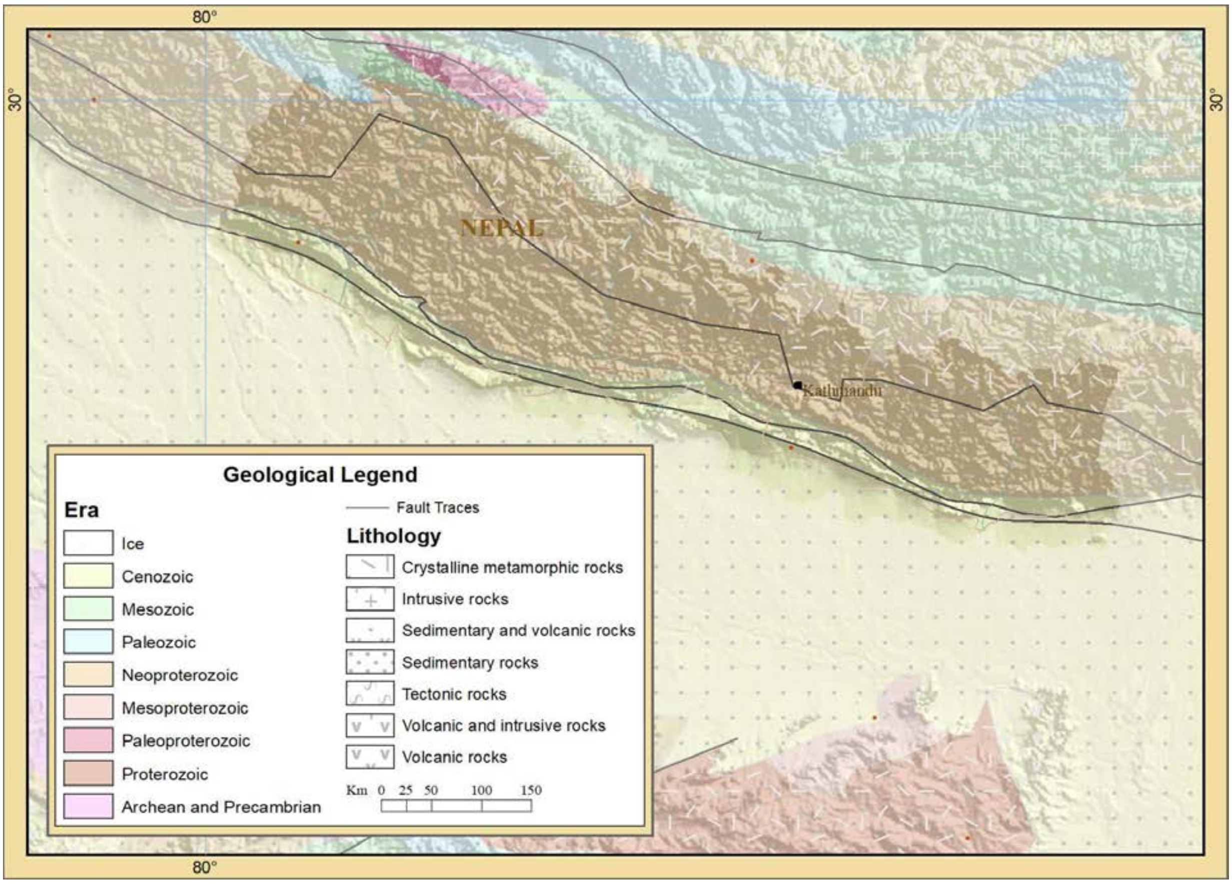


FIG. 7.30. Regional geological setting of Nepal. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.15.2.1. Gangetic Plain

The Gangetic Plain, also known as the Terai Zone, is the Nepalese part of the Gangetic Plain that extends from the Sub-Himalayan (Siwalik) Zone in the north to the Indian Shield in the south. The Gangetic Plain does not exceed 200 m in elevation and possesses thick (~1500 m) accumulations of alluvial sediments, which comprise mainly clay, silt, gravel and boulders. The width of Terai Zone ranges between 10 and 50 km, and comprises an almost continuous E–W oriented belt. The Terai Zone is a foreland basin, the sediments originate from the peaks in the northern sector. To the north, this zone is split from the Sub-Himalayan (Siwalik) Zone by the Main Frontal Thrust, which is an active thrust system. At some places along the Main Frontal Thrust, the Siwalik rocks are found to overlie the recent sediments of the Terai.

Northern Terai Zone

The Northern Terai Zone is adjacent to the foothills of the Siwalik Zone and continues southwards to a full extent of 12 km. This zone mainly comprises boulders, cobbles, pebbles and sand sourced from the rocks of the Siwalik and Lesser Himalayan Zones. The boulders, cobbles and pebbles are typically sandstones and lithologies derived from the proximate northern locality.

Middle Terai Zone

The Middle Terai Zone is a constricted strip, roughly10–12 km in width, situated between the Southern Terai Zone and the Northern Terai Zone. It is typified by pebbly and brown–grey unconsolidated sandy sediments with a scarce clay partings. The clay is chiefly dark grey and intercalated with brown sand layers. The medium- to coarse-grained sandy layers possess favourable groundwater reservoir properties.

Southern Terai Zone

Southern Terai Zone is the southernmost portion of the Terai and extends beyond the Nepal–India border into India. In this zone, the main sediments are clay, silt and sand, which are generally finer sediments than those in the Middle Terai Zone. The sediments become finer and exhibit change of facies in the extreme south, next to border with the Indian Plains.

7.15.2.2. Sub-Himalayan (Siwalik) Zone

The Sub-Himalayan Zone, also known as the Siwalik Zone, is bordered to the north by the Main Boundary Thrust and to the south by the Main Frontal Thrust. It is essentially made up fluvial deposits of Neogene age (23–1.6 Ma) and extends along the Himalayas, comprising the southernmost hill range which measures 8–50 km in width.

Rocks of the Lesser Himalayan are thrust southwards, over the Siwalik strata, along the Main Boundary Thrust. The dip of the Siwalik strata generally has a northwards orientation with variable angles and its general strike is E–W. The Siwalik Zone has several E–W striking thrusts. Fossils of plants, fish, reptiles and mammals have been documented in the Siwalik strata.

The threefold categorization of the Siwalik sequence in the western Indian Himalayas and the Potwar region of Pakistan can be used for the corresponding Siwalik strata in Nepal. Based on the threefold classification, the Siwalik can be categorized as: (i) Lower Siwalik, (ii) Middle Siwalik and (iii) Upper Siwalik.

Lower Siwalik

The Lower Siwalik consists of unevenly laminated beds of fine-grained greenish sandstone and siltstone with mudstone. The interchanging mudstone beds are thickly bedded and are multi-coloured brown, purple and red.

Middle Siwalik

The Middle Siwalik comprises medium- to coarse-grained ‘salt-and-pepper’ sandstones intercalated with mudstone. The absence of multi-coloured sandstone and mudstone is distinct from the Lower Siwalik. Pebbly sandstone beds are also present in the upper section of the Middle Siwalik. The thicknesses of the sandstone beds in the Middle Siwalik vary from 1 to 45 m.

Upper Siwalik

The Upper Siwalik comprises boulder beds and conglomerate together with subordinate silt and sand beds. The mudstone beds of the Upper Siwalik are massive and unevenly bedded and have many invertebrate fossils, comprising gastropods and brachiopods. The upper section of this series comprises conglomerate beds with commonly rounded to subangular cobbles and boulders of Lesser Himalayan strata.

7.15.2.3. Lesser Himalayan Zone

The Lesser Himalayan Zone is delimited by the Main Boundary Thrust to the south and by the Main Central Thrust to the north. The rocks of the Lesser Himalayan Zone have been moved southwards in several thrusts. Throughout the Himalayas, two types of sequence – allochthonous and autochthonous – can generally be recognized in the Lesser Himalayan Zone. Both sequences of the Lesser Himalayas contain non-fossiliferous, metasedimentary and sedimentary rocks such as quartzite, schist, phyllite, slate, dolomite and limestone, varying in age from Precambrian to Eocene. Some granitic intrusions also exist in the Lesser Himalayan Zone. The Lesser Himalayan Zone in Nepal varies, from east to west, as regards rock type, age, structure and occurrence of igneous rock intrusions.

Eastern Nepal is typified by extensive thrust sheets (allochthonous) of high grade metamorphic rocks (schist and gneiss) which have moved towards the south. Widespread outcrops of low grade metamorphic rocks (autochthonous) can be observed beneath this sequence, as a consequence of erosion. In central Nepal, a large thrust sheet called the Kathmandu Nappe (allochthonous) occupies a wide area in the Kathmandu region. The area west of Kathmandu, between the Bheri and Budhi Gandaki Rivers, is generally covered by autochthonous sequences and so the proportion of transported high grade metamorphic rocks (allochthonous) is very low. However, high grade metamorphic rocks resurface and underlie much of the terrain west of the Bheri River and up to the western border of Nepal.

7.15.2.4. Higher Himalayan Zone

The Higher Himalayan Zone largely comprises extensive sequences of strongly metamorphosed rocks. It comprises the rocks below the highly fossiliferous Tibetan–Tethys Zone and lying north of the Main Central Thrust. The Higher Himalayan Zone is split from the Tibetan–Tethys Zone by a normal fault system called the South Tibetan Detachment System. It comprises ~10 km thick sequence of strongly metamorphosed coarse-grained rocks. It occupies the full length of the Himalayas but its width varies. The kyanite–sillimanite gneisses, marbles and schists of the Higher Himalayan Zone comprise the basement of the Tibetan–Tethys Zone. Granites intruded the upper portion of the unit.

7.15.2.5. Tibetan–Tethys Zone

The Tibetan–Tethys Zone is located in the northern sector of Nepal. The fossiliferous rocks of the Tibetan–Tethys Zone are well developed in the Dolpa, Manang and Mustang areas of the country. In the eastern sector, the outcrop of the Tibetan–Tethys Zone is nearly non-existent and exists only at the top of Mount Everest. Several of the other major Himalayan peaks, such as Dhaulagiri, Annapurna and Manaslu are made up of Tibetan–Tethys Zone strata comprising sedimentary rocks, such as sandstone, limestone and shale of Cambrian–Eocene age [15.2]. The geological map shown in Fig. 7.31 shows the main rocks.

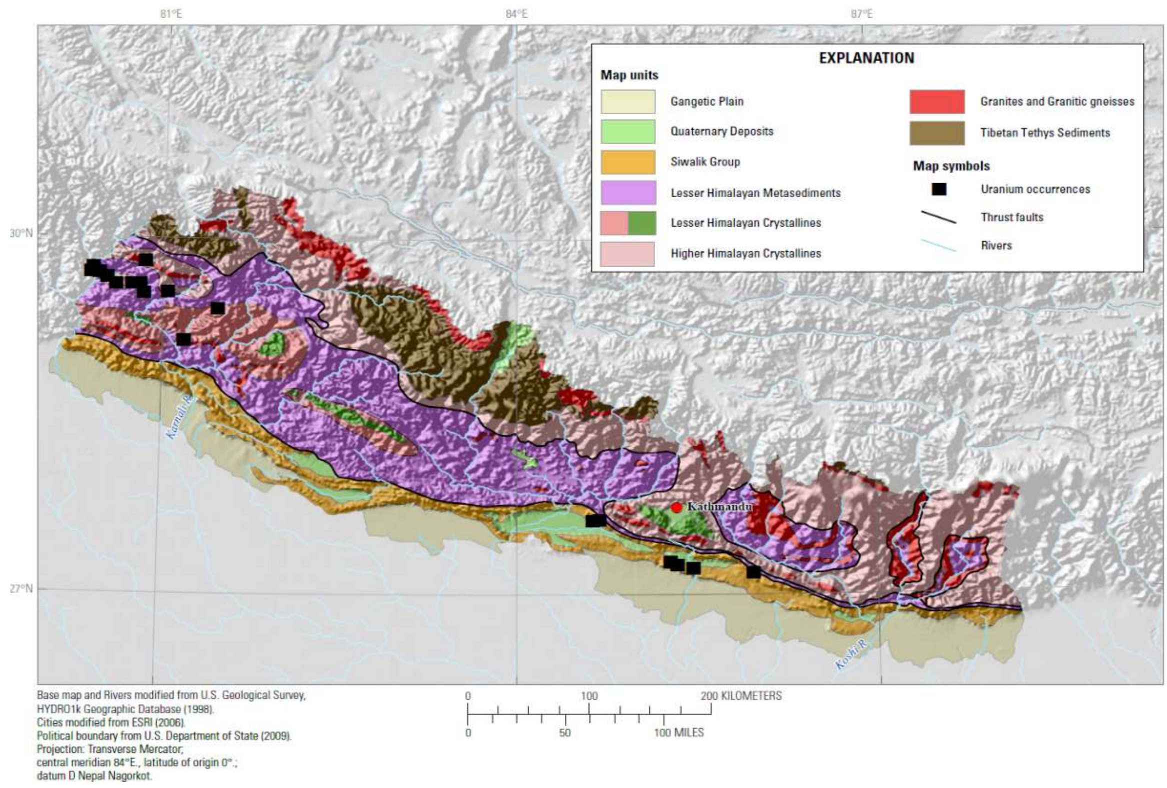


FIG. 7.31. Geological map of Nepal.

7.15.3. Uranium exploration

Since 1972, the Department of Mines and Geology has been continuously engaged in the exploration for mineral resources in Nepal. In this context, the Department of Mines and Geology has conducted ground radiometric surveys in some parts of the country in the search for uranium mineralization, using Geiger-Müller counters, scintillation counters and gamma ray spectrometers.

A preliminary ground radiometric survey was initiated in 1972 in parts of the Palung and Ipa granites in the Makawanpur and Lalitpur districts. Systematic ground exploration, using scintillation counters, commenced in 1981 and targeted uranium mineralization in the sedimentary rocks of the Siwalik range.

In 1981–1987, radiometric surveys were conducted over an area of ~8000 km² of the Siwalik range. In 1982, radiometric surveys were carried out in Thumki-Jagat and Kakani-Panchmane areas, north of Kathmandu. Roughly 100 anomalies were identified during these preliminary surveys.

Based on the above works, follow-up ground radiometric surveys covering an area of ~1200 km² were carried out between the Kamala and Narayani Rivers in 1988–1990. Mineralization was detected in the Tinbhangale area, in the Makawanpur district, where a uranium grade of up to 0.13% U was recorded.

In 1992–1994, preliminary and follow-up ground radiometric exploration campaigns were carried out in selected areas of Baitadi, Bajhang and Darchula districts. Exploration covering ~150 km² was conducted between the Mahakali River and the Jamari Gad area of Baitadi and Darchula districts. A uranium content of up to 0.92% U was observed in bedrock and float in some parts of the area.

In total, 24 uranium showings and occurrences have been identified in Nepal, mainly associated with sandstones, granites and quartzites [15.3, 15.4].

7.15.4. Uranium resources

Nepal has no known uranium resources. Possible resources of ~35 tU occur at Tinbhangale, in the Siwalik region.

The UDEPO database does not list any known deposits for Nepal.

7.15.5. Potential for new discoveries

Some exploration activities have been carried out in Nepal. However, limited uranium potential exists in areas associated with sandstone, vein, metasomatite and phosphate types of mineralization.

7.15.5.1. Uranium potential in sandstones

The Siwalik Group of strata was deposited during the Middle Miocene–Lower Pleistocene and comprises shale, claystone, mudstone, sandstone and conglomerates of mainly fluviatile origin. Plants, as well as invertebrate and vertebrate fossils, and coalified plant remains (fossil wood, lignite layers) are common. These characteristics (coarse-grained sandstones which may have high permeability and which are characterized by the presence of reductants) are favourable for the formation of sandstone type uranium mineralization.

Small and irregular occurrences of uranium mineralization have been discovered in the upper parts of the Middle Siwalik and the basal part of the Upper Siwalik formations in central Nepal. The Palung, a two mica peraluminous granite complex located to the north of the mineralized areas may have represented a major uranium source for these deposits. The uranium is associated with coal material in gritty to pebbly arkosic sandstone. The mineralized sections are 1–5 m thick and 500 m long in the Tinbhangale area. Uranium contents of 10–1308 ppm have been measured on chip/channel samples.

7.15.5.2. Uranium potential of the Banku quartzite

Uraninite and autunite mineralization have been discovered in the Banku quartzite in west Nepal, cropping out over 1500 m with a thickness in the range 1.5–8 m. Surface radiometry has recorded local total counts of 3500–10 000 cps (GAD 6 scintillometer). Outcrop sample analyses have recorded uranium contents of 137–9213 ppm. Owing to the regional extension of the radioactive anomalies, this area is considered prospective for the discovery of vein type uranium mineralization [15.5].

7.15.5.3. Uranium potential related to sodic metasomatism

Uranium mineralization persisting for several hundred metres was discovered above the Main Central Thrust during a field trip undertaken in 1982 by a team of French geologists along the Chhuling Khola. Laboratory studies revealed that the mineralization comprises brannerite disseminated in an albitized rock. These features are typical of uranium deposits associated with sodic metasomatism and may be indicative of significant uranium resources [15.6].

7.15.5.4. Uranium potential in phosphates

An important phosphate occurrence of Middle Proterozoic age has been identified in the Baitadi carbonate formation in the Lesser Himalayan Zone of east Nepal. The phosphatic horizon is confined in the stromatolitic massive cherty dolomite member. It extends laterally over more than 25 km and its thickness varies from a few metres up to 18 m. The P_2O_5 content varies in the range 10–32 wt%.

7.15.6. Comments

Nepal has no uranium production industry.

References to Section 7.15

[15.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Nepal, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html .

[15.2] DAHAL R.K., Geology of Nepal, published on personal home page www.ranjan.net.np (2006).

[15.3] DEPARTMENT OF MINES AND GEOLOGY, Mineral Resources of Nepal, DMG, Lainchour, Kathmandu (2011).

[15.4] HIFZUR RAHMAN, Present Status of Uranium Prospects and Occurrences in Nepal, Internal Report, Department of Mines and Geology, Lainchour, Kathmandu (2010).

[15.5] KAPHLE, K.P., Geochemistry of the Dadeldhura granite and its mineral potential, Nepal Geol. Soc. **7** (1991) 21–38.

[15.6] MARUEJOL, P., Métasomatose alcaline et minéralisations uranifères: les albitites du gisement de Lagoa Real (Bahia, Brésil) et exemples de Xihuashan (SE Chine), Zheltorechensk (Ukraine) et Chhuling Khola (Népal), Centre de recherches sur la géologie de l’uranium, Nancy (1988) 428 pp.

7.16. OMAN

7.16.1. Geography

Oman is a country of the Middle East, bounded by the Arabian Sea, the Gulf of Oman, the Persian Gulf, between east of Saudi Arabia, the United Arab Emirates (UAE) and Yemen. Oman also comprises two exclaves, the peninsula of Musandam, on the Strait of Hormuz, and Madha inside the UAE territory.

The country is covered mostly by a desert plain, with mountain ranges along the north (Al Hajar Mountains) and southeast coasts (Dhofar of Qara Mountains). It has a desert climate, hot and humid along the coast, dry in the interior

The country is deeply reliant on resources of oil and gas, which can produce 70–85% of government revenue. Natural resources include petroleum, natural gas, copper, chromium [16.1]

7.16.2. Geology

Oman is situated at the southeast part of the Arabian plate (Fig. 7.32), which is being driven sluggishly northward, as the Red Sea extends. The collision between the Arabian and the Eurasian plates resulted in the Hajar Mountains. Throughout the Cretaceous period, Oman was situated next to a subduction zone. The obducted assemblage of ultramafic to mafic rocks constitutes the Semail Ophiolite complex, which is endowed locally in copper and chromite.

The Oman Mountains are a part of the Zagros mobile belt, which form a link between the Alpine and the Himalayan structures. Marine formations, constitutes the Oman Mountains and are of Paleozoic, Mesozoic and Cenozoic age. Volcanics of Tertiary age characterize the Arabian homocline. The Oman Mountains foreland is characterized by gently deformed west dipping Mesozoic rocks.

The country's interior plains are underlain by young sedimentary rocks, gravels, dune sands and salt flats. These are underlain a thick sequence of sedimentary rocks that host the country's resources of oil and gas [16.2, 16.3].

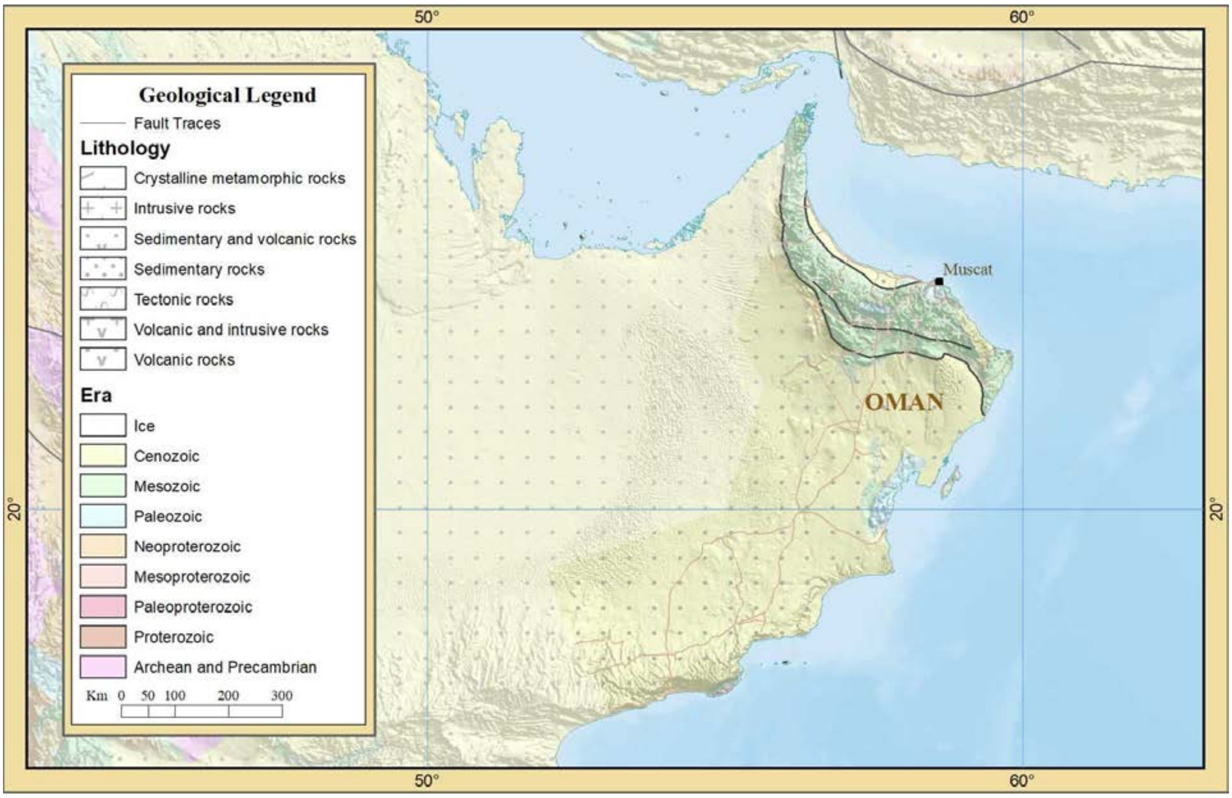


FIG. 7.32. Regional geological setting of Oman. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.16.3. Uranium exploration

There has been no reported uranium exploration in Oman. Oman never reported to the Red Book.

Oman and Russian Rosatom signed in 2009 a statement of intent for collaboration in the field of nuclear power, including among others, the exploration and mining for uranium. The Oman Department of Earth Sciences started in 2013 a project with the objective of uranium research in the Dhofar region of southern Oman.

The Proterozoic basement of the Dhofar region of Oman is a likely source and trap for uranium and related minerals. Reconnaissance surveys conducted throughout the late 1970s imply the likelihood of uranium occurrence in this region. An assemblage of accumulated hydrocarbons, carbon-rich shales, and evaporites represents a possible geochemical trap for enrichment of uranium. The objective of this proposal was to use comprehensive geochemical and geophysical surveys to map the Proterozoic basement in order to define the potential location for a possible resource. No results of this possible exploration project are available.

7.16.4. Uranium resources

There are no known uranium occurrences in Oman and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for Oman.

7.16.5. Potential for new discoveries

The potential for uranium deposits in Oman seems very limited. No continental sedimentary formations are reported. The potential for primary type deposits seems very low. Deposits may be found in calcareous calcrete formations of Tertiary age which is deposited in the Empty Quarter region. However, few lenses of calcrete are found in the south of the country.

The 1977 IUREP study estimated the uranium potential of Oman to less than 1000 tonnes U [16.2].

References to Section 7.16

[16.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Oman, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[16.2] BOWMAN J., I U R E P NATIONAL FAVOURABILITY STUDIES. IUREP N.F.S. No. 124. Oman (1977).

[16.3] NARASIMMAN SUNDARA, Uranium and associated minerals in the Sultanate of Oman-Geophysical and geochemical exploration, Muscat (2016) https://www.researchgate.net/project/Uranium-and-associated-minerals-in-the-Sultanate-of-Oman-Geophysical-and-geochemical-exploration

7.17. PAKISTAN

7.17.1. Geography

Pakistan has land borders with Afghanistan, China, India, the Islamic Republic of Iran and borders the Indian Ocean. The country is divided into the Northern Highlands, Punjab and Sindh Provinces of the Indus River Plain and the Balochistan Plateau (Fig. 7.33).

The Northern Highlands consist of parts of the Hindu Kush, the Karakorum (K2 or Mount Godwin Austen), which, at an elevation of 8611 m, is second highest peak in the world. The north-western tip of the Himalayas is marked by the 8126 m peak of Nanga Parbat. The terrain is very rugged and in most parts access is extremely difficult. A road connection between Pakistan and China (Friendship Highway) follows the valleys of Gilgit and Hunza and crosses the Karakorum (Kundjirab Pass).

The western part of the Northern Highlands belongs to the Frontier Province. A road connection from Islamabad and Rawalpindi through Peshawar to Afghanistan passes the Khyber Pass, which has been traversed since antiquity. The mountainous area known as the Sulaiman Range extends along the western part of the country, forming the border with Afghanistan. Its southern continuation is found in the ranges of Balochistan.

The Indus Plain extends south of the Northern Highlands and forms almost half of the country, occupying the eastern part. Beginning at the Salt Range, south of Islamabad/Rawalpindi, the Indus Plain continues south through Punjab and Sindh Provinces, discharging into the Arabian Sea south of Karachi, the industrial centre of the country.

The Indus River has a length of ~3200 km and, together with its tributaries, forms the backbone for water supply to the population centres and for agriculture. The Indus Plain has been inhabited for ~5000 years. The largest dam on the Indus River is at Tarbela, ~75 km NW of the capital. The dam has two functions: electricity generation and flood prevention.

The area of Balochistan covers the eastern part of the Iranian Plateau and extends from the border with the Islamic Republic of Iran up to the Sulaiman Range. Being a dry, mountainous region, the density of population is very low. Large expanses are desert.

The climate of the country varies according to geographic position and elevation. In general, four seasons are observed: (i) a cool and dry winter from December to February, (ii) a hot, dry season from March to May, (iii) a rainy monsoon season in the SW from June to September, and (iv) a more moderate rainy season from October to November. In Punjab, the winters tend to be cold. The summer period can be very hot and reports of temperatures rising to more than 50°C have been recorded in June for Multan.

Roughly one quarter of the country is arable land, which is supported by an extensive system of irrigation. Cotton, wheat, rice and a number of other grains are grown, together with various vegetables and fruits. Energy resources include oil and gas. Chromite and rock salt are some of the important mineral resources exploited [17.1–17.3].

7.17.2. Geology

7.17.2.1. General

The country has a complicated geological history, which relates to the movements of tectonic plates. A more comprehensive description is provided in Ref. [17.4].

The eastern and southern parts of the country, mainly Sindh and Punjab, belong to the Indian Plate, which formed part of Gondwana. The provinces in the east and NW, Balochistan and Frontier Provinces, are mainly located at the edge of the Iranian Plateau, which belongs to the Eurasian Plate. The mountainous regions are mainly the result of uplift due to tectonic movement. The most prominent example of this is the mountain ranges in the north being uplifted by the movement of the Indian Plate towards the rigid Asian Block.

As a result of plate tectonics, Pakistan features several thrust zones with subductions and intrusions of basic material, believed to be of mantle origin.

The oldest rocks have been found in the Nanga Parbat Massif, south of the Main Mantle Thrust Zone, which have been dated at 2.5–1.85 Ma. The rocks are highly metamorphosed and exhibit frequent instances of granitization. In Azad Kashmir and Hazara, Proterozoic rocks related to the Main Central Thrust Zone have been mapped. West of the Indus River, granitic intrusions dated at ~500 Ma have been found.

In summary, the geological development in this part consists of an Early Proterozoic orogenic event succeeded by intrusions of granite. In the Himalayas, one orogeny has been dated to Late Proterozoic–Early Cambrian and is associated with magmatic rocks. Another orogeny has been compared with the

Pan-African event and dated to ~460 Ma, and this has produced granitic rocks and extensive metamorphism.

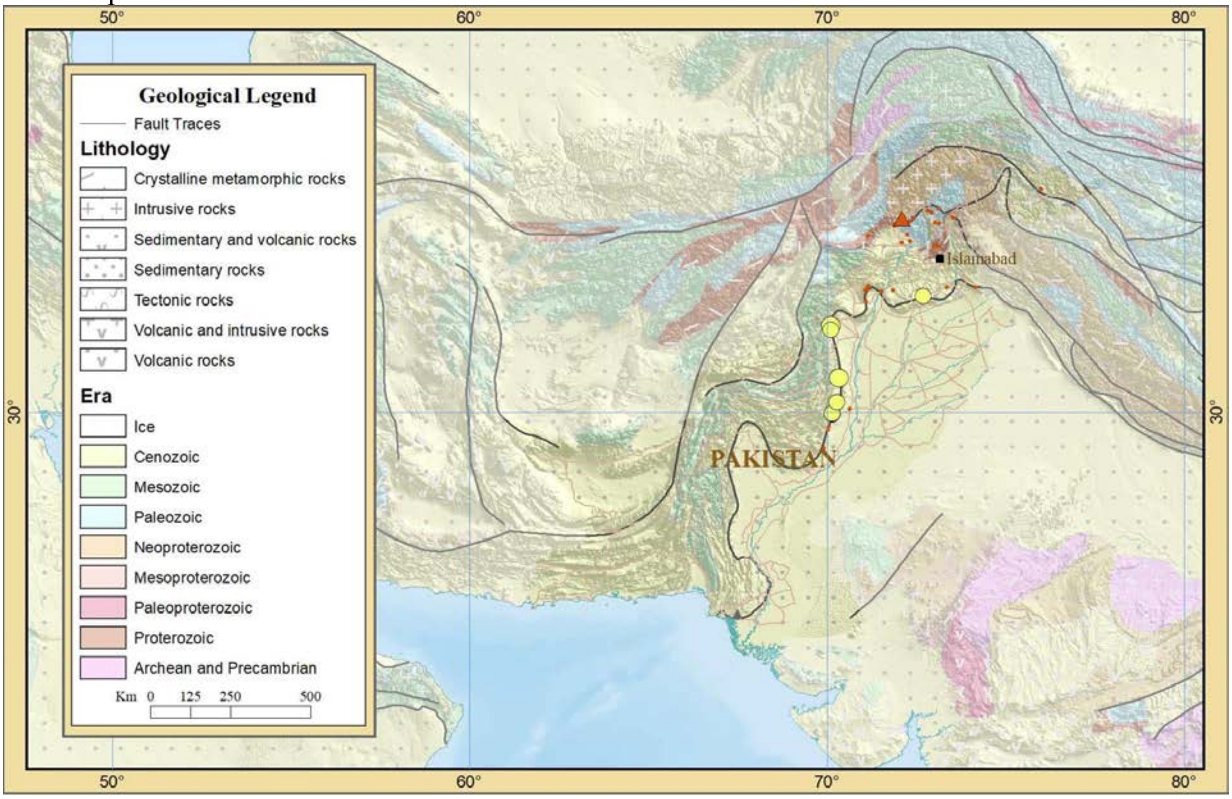


FIG. 7.33. Regional geological setting of Pakistan showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Three major orogenic episodes occurred during the Cretaceous and Tertiary periods as the result of mountain building, e.g., in the Himalayas and in the Karakorum. The third episode, in the Lower–Middle Miocene, was probably the most severe. In the area south of the Karakorum, the well known Kohistan Island Arc Complex was developed.

In the Peshawar region, extensive alkaline igneous activity has been dated at 40 Ma and emplacement of several intrusions of carbonatites at 30 Ma.

In the Main Mantle Thrust Zone, post-Hercynian events have been reported. In particular, subduction processes of Late Cretaceous age resulted in ophiolitic magmatism.

Sedimentary rocks were deposited at various periods. The sedimentary processes are not uniform in the various sedimentary basins of the country. Continuous sedimentation from the Precambrian to the Upper Palaeozoic has not been found in all of them.

During the Mesozoic, sedimentary basins were developed in the Sulaiman Range, the Kohat-Potwar Salt Range and in the West Pakistan Fold Belt. Mixtures of marine and terrestrial sedimentation occur, frequently interbedded with volcanic rocks. Overthrusting and nappe formation result from tectonic movements.

During the Cenozoic, the closure of the Tethys Sea was recorded, manifested by a variety of sedimentation processes, depending on the region. In the Indus Basin, a change from Palaeogene marine sequences towards terrestrial formations in the Neogene has been found. In Balochistan, mostly marine flysch type sedimentary rocks occur [17.4].

7.17.2.2. Geology favourable for the formation of uranium deposits

In the foredeep of the mountain ranges, during the Middle Miocene–Lower Pleistocene, a 4500–5000 m thick sedimentary unit of Siwalik strata, or their equivalent, was deposited. This unit consists of clastics derived from the erosion of the hinterland and is made up of sands, conglomerates and clays, which are typical for flood plain sediments of river systems [17.1, 17.2].

The Siwaliks and their equivalents extend over large areas, from Rawalpindi in the north through the Potwar Plateau and Sulaiman Range to Quetta in the south. Equivalents are found at the coast of the Makran/Arabian Sea and in the Kithar Range of Sindh, NE of Karachi [17.2]. The Siwalik sandstones have been investigated for their uranium potential.

In 1959, exploration by carborne survey discovered anomalies in Middle Siwalik sandstones near Dera Ghazi Khan in an asymmetric syncline on the eastern flanks of the Sulaiman Range. Subsequently, at Baghal Chur, uranium mineralization was found which justified mine development.

Anomalies have been found in other areas covered by Siwalik strata and development has been reported for the mineralization occurring at Qabul Khel (Bannu Basin) in North-West Frontier Province [17.5].

The mineralization at Baghal Chur is hosted in 2000–2500 m thick Middle Siwalik strata and restricted to the so-called Baghal Chur sand (70–80 m thick). The Baghal Chur sand is light grey and medium- to fine-grained and enclosed by clays above and below [17.6].

In northern Pakistan, several granitic intrusions and carbonatites located south of the Main Mantle Thrust Zone have exhibited a variety of uranium showings, some in pegmatites and others in clayey material (areas around Tarbela, Mansehra and Malakand). Migmatites at several locations also show varying degrees of uranium enrichment [17.4]. However, to date, none of the above mentioned anomalies are of any economic importance. Precambrian graphitic metapelites in the Kagan valley and near Muzaffarabad in Azad Kashmir have exhibited higher levels of radioactivity associated with disequilibrium due to leaching of pyrite [17.4].
Calcrete type mineralization has been found in the Thar Desert, although details are unavailable [17.7].

7.17.3. Uranium exploration

Exploration for uranium started in the 1950s and has been extensive. Detailed figures on expenditures and drilling campaigns are not available. However, it is reported that drilling at Baghal Chur amounted to several thousand metres [17.6].

The IAEA and the United Nations Development Programme carried out exploration in the Baghal Chur area in the 1970s which included the drilling of 1029 holes totalling 43 000 m [17.1].

It is not reported to what extent other anomalies have been investigated. It can be assumed, however, that at least ground radioactivity surveys have been carried out. Exploration in the area surrounding Baghal Chur (over 50 anomalies or groups of anomalies) was extensive in the 1970s although it has been stated that the area was not totally explored in the campaigns conducted in this period [17.1].

In the second half of the 1990s, exploration continued in areas of the Siwalik sandstone in Kashmir, the Potwar Plateau, Bannu Basin and the Sulaiman Range. Under the guidance of an IAEA supported programme (platform survey), a prospective area in the Potwar Plateau was reduced, first to 2000 km^2, and later to 400 km^2 [17.8].

In the Bannu Basin, in situ leaching (ISL) methods have been applied using ammonium bicarbonate and hydrogen peroxide to recover uranium.

In the 1999 Red Book [17.9], it is reported that exploration was successful in discovering an uraniferous horizon in the Kamlial Formation of the Salt Range. The finding of a uranium-bearing vein system in the granitic rocks of the Maraghzar area in the Swat district has also been reported [17.9].

In July 2017 CNNC signed a framework agreement with PAEC for technical cooperation in the exploration and development of uranium resources [17.10].

7.17.4. Uranium resources

Pakistan has not provided the official reports required for the evaluation of resources for the Red Book, neither for identified resources nor for undiscovered or unconventional resources.

In an evaluation in 1976, the resources at Baghal Chur were estimated at ~180 tU, based on a cut-off grade of 0.08% U. The UDEPO database lists Baghal Chur as having less than 500 tU with a grade range of 0.05–0.1% U [17.5]. The deposit, however, is now depleted.

In UDEPO, the deposit at Qabul Khel, in North-West Frontier Province, was reported to be under development. Resources at Qabul Khel are estimated by UDEPO as being between 500 and 1000 tU with a grade range of 0.03–0.05% U.

Studies were also undertaken to investigate the recovery of uranium from carbonatites such as the Sellai Patti intrusion which are estimated to contain a few thousand tonnes of uranium at average grades of 0.02% U. The studies have shown that the uranium content can be upgraded by a factor of 150 [17.8].

The UDEPO database lists the most significant deposits for Pakistan as Shanawah, Sellai Patti, Taunsa, Kalar Kahar, Rakhi Munh, Qabul-Khel, Nangar Nai (Nangana), Baghal Chur.

7.17.5. Potential for new discoveries

Exploration for deposits occurring in continental to lacustrine or fluvial sandstones has shown that uranium mineralization occurs in the Siwalik sandstones and their equivalents. At present, it is not known whether generally favourable sandstones have been explored to the required level. Thus, it remains an open question as to whether exploration would again be worthwhile for Siwalik type mineralization. Examples found so far indicate that the Siwaliks seem to be limited in potential, with any mineralization being of restricted tonnage and of relatively low grade. However, ISL methods have been developed and have proven economic in the recovery uranium, even from small and low grade deposits [17.11].

As exploration has shown anomalies to be present in graphitic metapelites, further investigation may be worthwhile to determine to what extent leaching has occurred and what model of possible enrichment of uranium may be applied.

The anomalies in calcrete in the Thar Desert could also be of interest in view of the recent success recorded on the calcrete type mineralization at Langer Heinrich in Namibia.

7.17.6. Uranium production

Uranium production started at Baghal Chur in 1978 using a pilot plant with a yearly capacity of 30 tU [17.10]. Official production figures, however, are not available. It was reported that production started in 1971, with 30 tU/year produced between 1971 and 1991. In 1992, production was estimated at 23 tU annually up to the present day. Other unofficial information assumes an annual production of 40–45 tU from three ISL operations [17.12]. From 2008 to 2017, production is estimated to be approximately 45 t U/year (Fig. 7.34) for a total of 1576 tU [17.13].

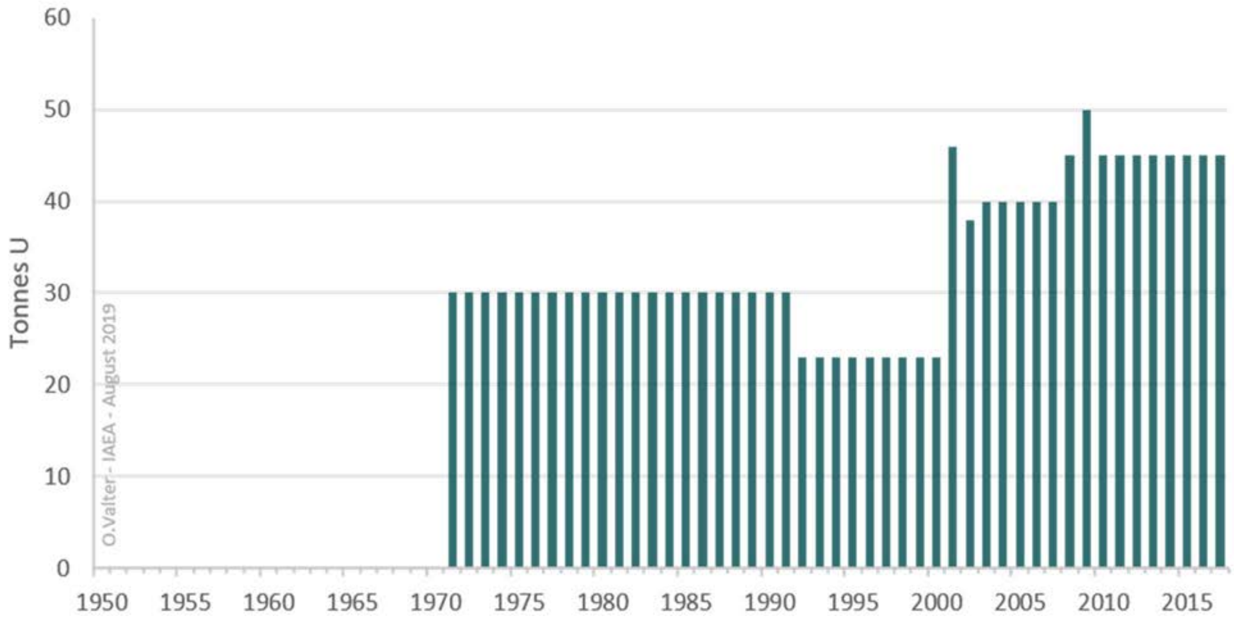


FIG. 7.34. Historical uranium production in Pakistan.

References to Section 7.17

[17.1] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Pakistan, IAEA, Vienna (1976) 17 pp.

[17.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[17.3] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Pakistan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[17.4] BENDER, F.K., RAZA, H.A., Geology of Pakistan, Borntraeger, Stuttgart (1995) 41 pp.

[17.5] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[17.6] MOGHAL, M.Y., "Uranium in Siwalik sandstones, Sulaiman Range, Pakistan", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 383–403.

[17.7] TAUCHID, M., "Uranium resources potential for Asia and the Pacific", Uranium Deposits in Asia and the Pacific: Geology and Exploration (Proc. Tech. Mtg Jakarta, 1985), IAEA, Vienna (1988) 21–38.

[17.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[17.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[17.10] WORLD NUCLEAR ASSOCIATION, Country Reports Pakistan (2019).

[17.11] BASHAM, I.R., RICE, C.M., "Uranium mineralization in Siwalik sandstones from Pakistan", Formation of Uranium Ore Deposits (Proc. Int. Symp. Athens, 1974), IAEA, Vienna (1974) 405–418.

[17.12] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[17.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

7.18. QATAR

7.18.1. Geography

Qatar occupies the small Qatar Peninsula on the northeastern coast of the Arabian Peninsula. It has land boundary only with Saudi Arabia, to the south. The remainder of the country is bounded by the Persian Gulf. It is disconnected from the proximate island country of Bahrain by a segment of the Persian Gulf.

Most of the country is comprised of a low, barren plain, overlaid with sand, although a low chain of mountains follow the west coast.

Qatar has mild winters and very hot, humid summers. Rainfall is only 75 to 100 mm a year.

The cornerstones of the country's economy are petroleum and natural gas. As of 2012, it had proven oil reserves of 15 billion barrels. It has the third largest proven natural gas reserve in the world. It is the second-largest exporter of natural gas in the world [18.1].

7.18.2. Geology

Outcrops are limited. Alluvium, either dunes or salt flats, covers most of the country. Qatar is on the west flank of the Persian Gulf synclinorium. In the sub-surface this basin has a thick Tertiary section. Qatar itself is on the stable Interior Platform. This feature received some Mesozoic and Cenozoic marine sedimentation (Fig. 7.35).

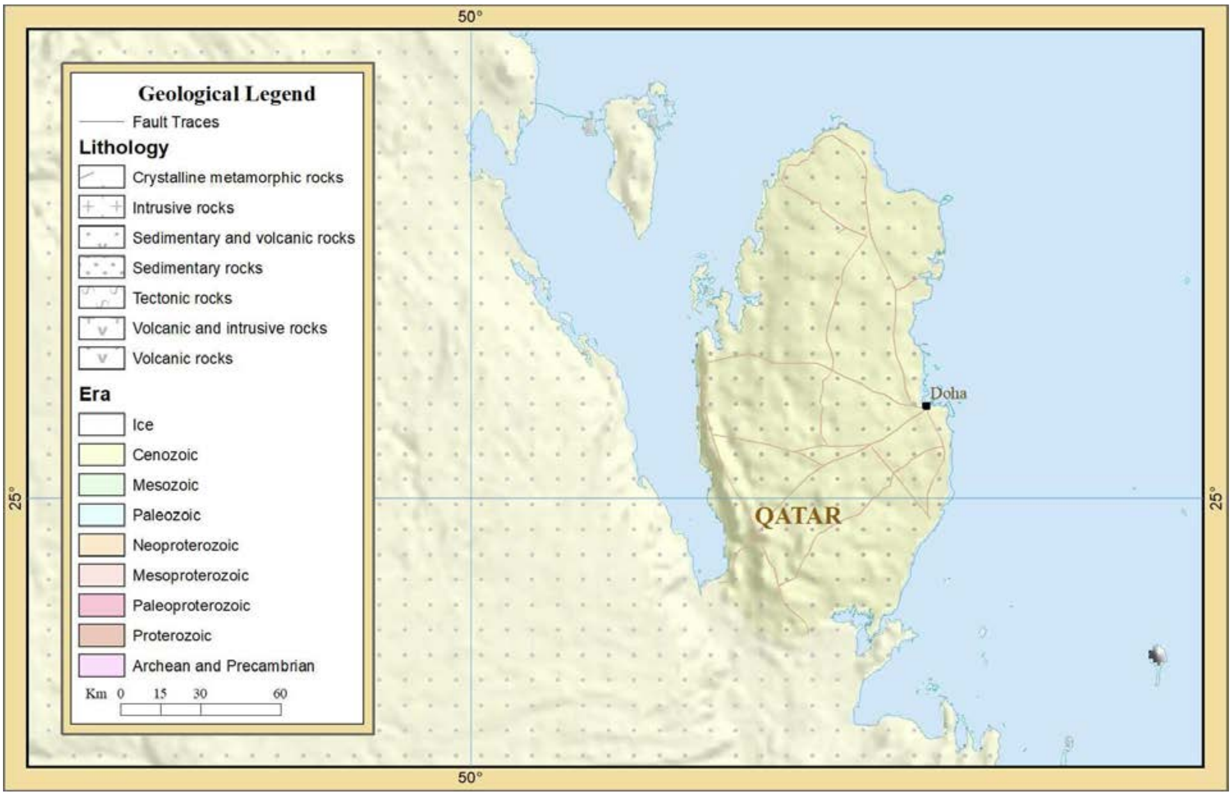


FIG. 7.35. Regional geological setting of Qatar. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.18.3. Uranium exploration

There has been no reported uranium exploration in Qatar.

7.18.4. Uranium resources

There are no known uranium occurrences in Qatar and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for Qatar.

7.18.5. Potential for new discoveries

From a geological point of view, Qatar does not have potentially favourable areas for the development of uranium deposits. Owing to the country's size and rock types present, the potential for new discoveries is rated as nil [18.2].

7.18.6. Comments

There has been no past uranium production in Qatar.

References to Section 7.18

[18.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Qatar, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[18.2] BOWMAN J., I U R E P NATIONAL FAVOURABILITY STUDIES (1977). IUREP N.F.S. No. 123.

7.19. SAUDI ARABIA

7.19.1. Geography [19.1]

Saudi Arabia, a kingdom of south-west Asia, is bounded to the north by Jordan and Iraq, to the northeast by Kuwait, to the east by the United Arab Emirates, Bahrain and Qatar, to the southeast by Oman, and to the south by Yemen. The Gulf of Aqaba disconnects it from Egypt and Israel.

The country's geography is dominantly characterized by the Arabian Desert and its related semi-desert, numerous highlands and mountain ranges, and shrub land. A few lakes exist in the country but no perennial rivers; however, there several wadis (streambed, gully, or valley in northern Africa and southwest Asia that is usually dry except during the rainy season) exist. The chief topographical mark is the central plateau which mounts sharply from the Red Sea and drops slowly into the Nejd region and toward the Persian Gulf. A narrow coastal plain, known as the Tihamah, exists on the Red Sea coast; a striking escarpment goes parallel to it. The highest point in the country, the 3,133 m Mount Sawda, is situated in the southwest mountainous province of Asir.

Except its province of Asir, the country has a desert climate; very high temperatures during the day, dropping sharply at night. Average temperature in summer is ~45 °C. Winter temperatures seldom fall to less than 0 °C. Climate in spring and autumn is temperate, with average temperatures of ~30 °C and extremely low annual rainfall. In contrast, the Asir region is affected by the Indian Ocean monsoons, often during October–March with 300 mm average rainfall or 60% of annual precipitation.

The country's economy is based on petroleum. Around 75% of budget revenues and ~90% of export incomes are derived from the oil industry. The country has ~260 billion barrels of oil reserves, accounting for about one-fifth of the proven total petroleum reserves in the world. Besides petroleum and gas, the country has in the region of Mahd adh Dhahab a small gold mining area, it has other mineral industries (phosphate, sulphur, lead, tungsten, manganese, zinc, copper, iron, silver) as well as agricultural (particularly in the SW) based on livestock and dates.

7.19.2. Geology [19.2, 19.3]

The Arabian Shield of igneous and metamorphic rocks protrudes eastward from the Hejaz into Najd as a bulge curving round from the Gulf of Aqaba to a point less than 200 km west of Riyadh and then receding toward the southern Red Sea (Fig. 7.36). The shield contains many extinct volcanoes surrounded by lava beds. Sloping eastward are the platform sediments in which rich oil fields are found. The shield gives symmetry to Saudi Arabia's geography, as many escarpments and sand deserts follow its contour.

The Arabian Shield acted as a cratonic stable block since Late Precambrian time. It outcrops from under sands; sand comprises most of the western third of the country. Marine platform deposits occupy much of the north whereas geosynclinal marine accumulations of over 6 100 m occupy narrow troughs paralleling the Persian Gulf and Red Sea. Pleistocene to Recent volcanic flows and cinder cones are superimposed upon the older rocks. The physiographic character of the country has been determined by recent rifting and tilting of the western portion of the peninsula acting as a discreet block. The Red Sea coast has been tilted up so that the west coast is a high plateau 1 500 m above the Red Sea, and approaching 3 000 m in places. This plateau slopes East to the Persian Gulf but even there scarps front the Gulf.

The Cambrian to Pleistocene platform, and minor geosynclinal, deposits are, except for some of the Permian and Triassic strata, marine. The nonmarine beds are nearly all thin, and alternate with marine beds. No carbonaceous material is reported in the sandstones, and no carbonaceous shales are described in the succession. Recently. However, radioactive anomalies were obtained from the Wajid Sandstone of Lower Permian and older age. The map of Africa shows some areas of Nubian sandstone, but no additional information is given concerning them.

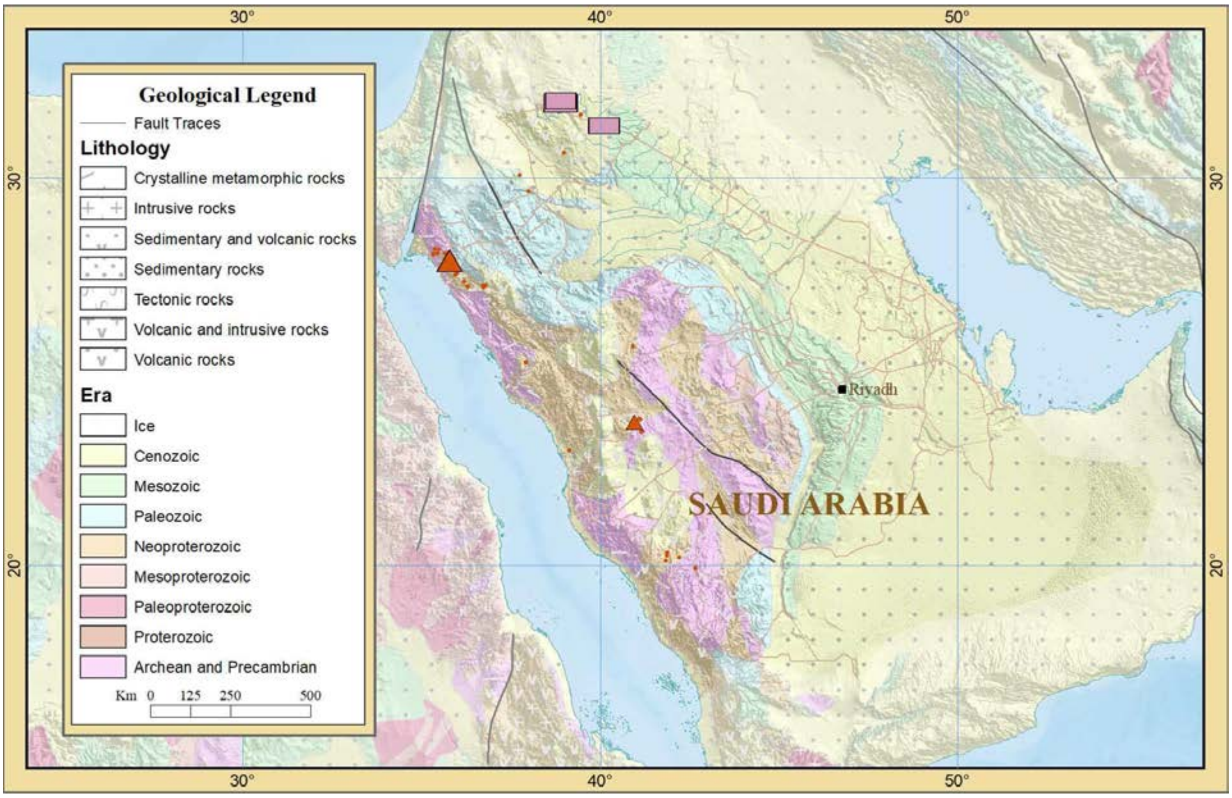


FIG. 7.36. Regional geological setting of Saudi Arabia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

It shows also extensive areas of Neogene continental deposits, but this is not in accord with other accounts. It is possible that continental sediments of the upper part of the Miocene-Pliocene Fars Group may extend southwards from the Tigris-Euphrates Basin into north-eastern Saudi Arabia, and these beds may be favourable for uranium.

Quartz-pebble conglomerate uranium deposits and Proterozoic unconformity-related deposits are unknown in Saudi Arabia, nor does there seem any possibility that they will be found, in view of the Late Proterozoic age of the Arabian Shield. No sandstone deposits have been reported, and the environment in general does not seem favourable for such deposits. No vein deposits are known, but the geology of the shield area is to a degree favourable.

7.19.3. Uranium exploration [19.3]

Mapping of Saudi Arabia was undertaken by the geologists of the Arabian American Oil Company, in post-war years, in collaboration with the U.S. Geological Survey. Reconnaissance geographical and geological maps of the whole of Saudi Arabia were published in 1963 at a scale of 1: 2 000 000.

The next step was detailed evaluation of mineral prospects. Some 42 000 km^2 (about 7 % of the Precambrian shield) of air-borne geophysical survey (magnetometric and radiometric) was accomplished by a firm of geophysical consultants in 1961-1962.

In the 1950s and early 1960s, technical assistance in uranium exploration was received from US and French sources. Two contract aerial surveys (1962) were made over part of the Precambrian shield on the western side of the peninsula. An IAEA field expert assisted the Government in its investigations of nuclear raw materials from June 1963 to June 1964.

A substantial number of anomalies were found and most of them checked by the IAEA, expert. Later, in 1965-66, Huntings Geology and Geophysics Ltd were contracted to fly a major regional radiometric and magnetometer survey over a 300 000 km^2 area. No information has been made available on the results of the 1965-1966 and 1974 aerial surveys and evaluations by Hunting Geology and Geophysics Ltd.

From 1976 to 1985, MINATOME (French uranium exploration company) was contracted by the Government of Saudi Arabia for consultancy work on uranium exploration and follow-up of an airborne spectrometer survey over the granitic formations of the Hijaz and Asir areas, and the sandstones formations fringing the Arabian Shield in the Tabuk, Najd, Wajid and Quasim areas. Works included study of previously available data (geology, geophysics, geochemistry), selection of favourable areas for uranium mineralization, field works (geology, radiometric survey, geochemistry, geological drilling). No significant results were obtained during these exploration works [19.4]

Limited information is available on the present status of uranium exploration in Saudi Arabia. The Saudi Geological Survey (SGS) and the China National Nuclear Corporation (CNNC) signed in March and August 2017 agreements to cooperate in uranium exploration. According to CNNC, it would explore, over the next two years, nine areas that are prospective for uranium resources in Saudi Arabia. The SGS has begun exploration in the Hail region of the Al Hail Province (north of Saudi Arabia) in cooperation with the K.A.CARE (King Abdullah City for Atomic and Renewable Energy) and the CNNC. In 2017, K.A. CARE signed an agreement with Jordan JAEC covering uranium exploration and mining in central Jordan.

7.19.4. Uranium resources

The radioactive anomalies checked by the IAEA expert were found during the 1962 aerial surveys which only covered 7 percent of the Pre-Cambrian Shield area. The expert examined 40 anomalies on the ground and classified them into two groups:

Group I: Eleven anomalies of possible economic importance;
Group II: Twenty-nine anomalies found to be of no direct economic importance.

Within Group I, two anomalies warranted more detailed work: the Jebel Said anomaly in the Central Shield area at Aqiq Urn ad Damar and the Al Ghrayyat anomaly in the Wadi Sawawin area about 70 miles from the Jordan border.

The UDEPO database lists the most significant deposits for Saudi Arabia as Umm Wu'Al, Al Jalamid, Ghurayyah, Al Khabra, Jabal Sayid.

7.19.4.1. Radioactive anomalies of Jebel Said area

The Jebel Said anomalies were discovered in 1956 on the ground before air survey work commenced. The discovery was made during the period of inflated uranium prices, and the possible economic importance of the deposit was realized. A programme of diamond-drilling was put initiated. Three holes were drilled with a combined footage of 293 m.

The preliminary follow-up work was undertaken by the Australian Mineral Development Laboratories who reported, among other minerals, calcium, rare-earth niobite and pyrochlore. Interest in the prospect as a possible source of niobium revived.

The anomalies occur as a zone of north dipping- pegmatite, and pegmatised and altered granite to the north of a red or pink un-metamorphosed alkalic to per-alkalic granite containing accessory fluorite, riebeckite, and aegirine. Extensive kaolinisation of the feldspars has occurred. The Jebel Said granite is light grey in color and coarse-grained with quartz constituting about 60 percent of its mass.

The mineralized structure consists of a north-dipping zone of reddish and altered rocks consisting largely of pegmatite and pegmatised granite.
The twenty samples assayed by the U.S. Geological Survey gave an average grade of 0.048 % U. The deposit was estimated to contain between 660 and 1100 tU. UDEPO indicates resources of 2630 t U at a grade of 0.0130% in what is considered an intrusive peralkaline complex [19.5].

7.19.4.2. Radioactive anomalies of Al Ghrayyat

The Wadi Sawawin area is one where many ferruginous bands of interest as potential iron deposits, were reported.

The radioactive area is within a intrusive peralkaline granite which is traversed by pegmatites. A proved reserve of 12.5 million tons of ore, at a grade of 0.28 - 0.30% Nb_2O_5, is present, but the uranium content is very low.

In 2006 Tertiary Minerals PLC considered the recovery uranium as a by-product of tantalum-niobium mining. Uranium inferred resources were estimated about 45 700 tU at an average grade of 0.012 % U. (Tertiary Minerals PLC April 19, 2006).

7.19.4.3. Other Areas

Some occurrences in other areas are reported such as at Hulayfah where veins of dark coloured amorphous material show radioactivity up to 20 times the background level.

No resources of uranium have ever been reported to the Red Book. In 1977, IUREP estimated the speculative uranium potential of Saudi Arabia between 10 000 and 50 000 tU. The chief atomic energy officer of K.A.CARE, Maher al Odan, announced at an electricity forum in Riyadh on October 11, 2017 that preliminary investigations have assessed Saudi Arabia’s potential of ~60,000 tU (Reuters Oct. 30, 2017).

7.19.5. Potential for new discoveries

In the present state of knowledge, the Arabian Shield seems to offer the best potential. Vein deposits may be found in or near granite bodies. Pegmatitic deposits may be discovered. Niobium deposits with recoverable uranium may be found in alkalic granite intrusions or in carbonatites.

Radioactive anomalies have been reported in the Wajid Sandstone, and some of the Triassic beds may contain uranium, but in both formations the sandstone beds are, for the most part, thin.
Nubian sandstone is indicated in the southern part of Saudi Arabia and could be favourable for sandstone type uranium deposits. Sandstone deposits may also be found in northern Saudi Arabia, where continental beds of Pliocene age may be present, and perhaps further south.
In the desert, uraniferous calcrete deposits may be present.

In the northern Saudi Arabia, uraniferous phosphorite deposits are present. The phosphate deposits are organic sediments of Mesozoic age, overlying Paleozoic sediments. Saudi Arabia has 750 Mt of known phosphate reserves. At the Al Jalamid, Al Khabra and Umm Wu'Al phosphorite deposits, uranium grades are between 50 and 150 ppm U, giving geological resources in the order of 250 000 t U [19.6].

7.19.6. Comments

There has been no past uranium production in Saudi Arabia.

References to Section 7.19

[19.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Saudi Arabia, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[19.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[19.3] CAMERON J., I U R E P NATIONAL FAVOURABILITY STUDIES (1977). IUREP N.F.S. No. 90.

[19.4] PAUCARD A., et al. La mine et les mineurs de l'uranium français.Tome IV / Volume II pp 441-446. AREVA 2008.

[19.5] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), IAEA-TECDOC-1843, 2016 Edition (2018).

[19.6] TULSIDAS H., Phosphate resources and production. (2013). https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/documents/uranium/tm-pre-feasibility-2013/12.Tulsidas(2013)_Phosphate_Resources_&_Production.pdf

7.20. SRI LANKA

7.20.1. Geography

Sri Lanka is an island country in the northern Indian Ocean, lying off the southern coast of India. Sri Lanka has maritime borders with India to the NW, across the Gulf of Mannar and Palk Strait, and with Maldives to the SW.

The country consists mostly of flat coastal plains, with mountains rising only in the southern central part of the island. The highest point is Pidurutalagala, which has an elevation of 2524 m. The climate of Sri Lanka is tropical and the warm climate is moderated by ocean winds and high precipitation. The mean temperature ranges from ~17°C in the Central Highlands to a maximum of ~33°C in low lying areas.

The rainfall pattern in the country is influenced by monsoon winds from the Indian Ocean and Bay of Bengal. The wet zone and some of the windward slopes of the Central Highlands receive rain regularly, but the leeward slopes to the east and NE record little rainfall.

The country is well known for tea, coffee, gemstones, coconut, rubber and cinnamon production and export. The island is rich in minerals. The existence of petroleum in the Gulf of Mannar has been confirmed [20.1].

7.20.2. Geology

The geology of Sri Lanka is dominated by the presence of high grade metamorphic rocks in a Precambrian terrain (Fig. 7.37). These rocks form three major litho-tectonic units: (i) the Highland Complex, (ii) the Vijayan Complex, and (iii) the Wanni Complex.

The Highland Complex is the largest unit and forms the backbone of the Precambrian rocks of Sri Lanka. Included in this unit are the supracrustal rocks of the Highland Series and the South-western Group, together with a variety of igneous intrusions of predominantly granitoid composition that occur as banded gneisses. The rocks comprising the Highland Complex are mainly granulite facies metamorphites, predominantly varieties of granulites, including charnockites, garnet–sillimanite–graphite schists, quartzites, marbles and calc-gneisses. Widespread charnockite formation has been observed within this unit. These rocks are dated at ~550 Ma.

The Vijayan Complex, lying to the east of the Highland Complex, consists of biotite–hornblende gneisses and scattered bands of metasedimentary rocks and charnockitic gneiss. Among the other prominent geological features of the Vijayan Complex are the small plutons of granites and acid charnockites near the east coast and the NW trending suite of dolerite dykes at Kallodai. The granitoid gneisses of the Vijayan Complex have been described as having compositions ranging from tonalite to leucogranite. The Vijayan Complex is mostly of amphibolite facies grade.

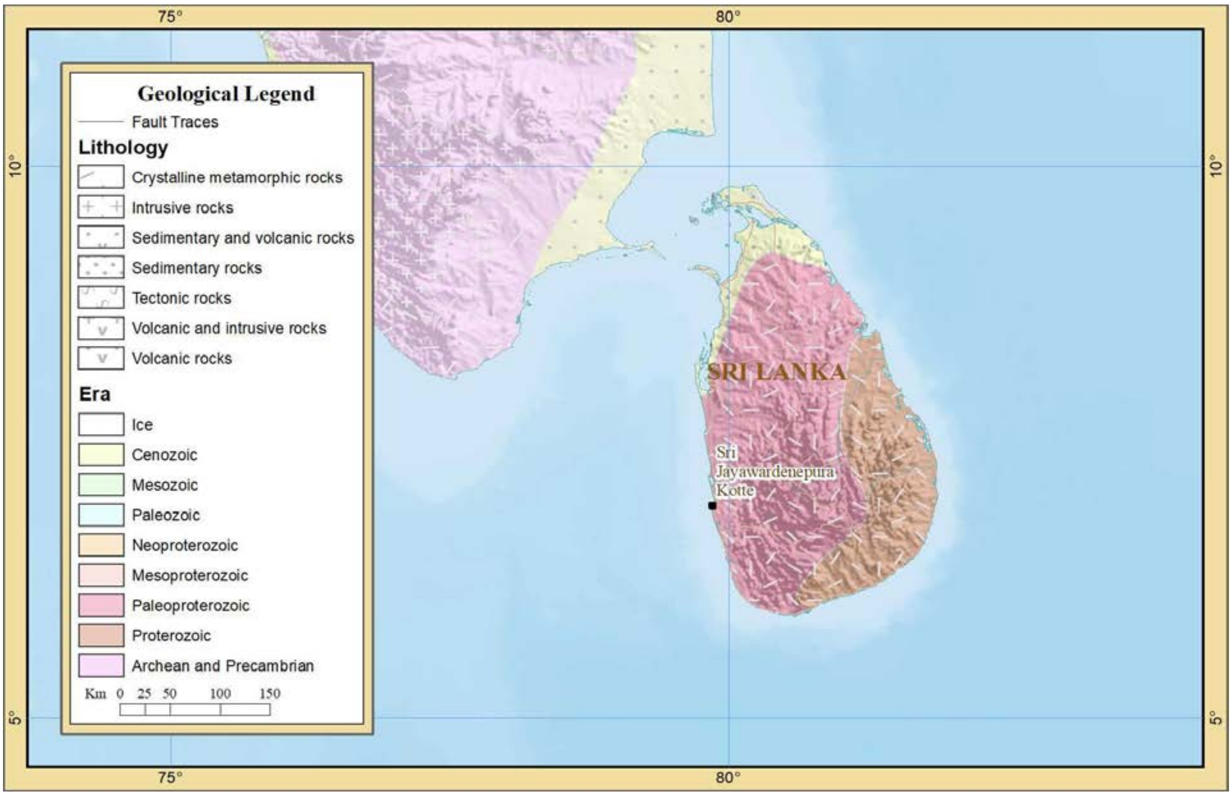


FIG. 7.37. Regional geological setting of Sri Lanka. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Wanni Complex consists of a suite of granitoid gneisses, charnockitic gneisses and granites, along with a variety of amphibolite to granulite facies rocks, such as metasedimentary rocks of predominantly pelitic to semi-pelitic composition. Studies of detrital zircons from metapelites have shown the Wanni

Complex to be younger than the Highland Complex, even though the boundary between these two litho-tectonic units remains poorly defined.

Jurassic sedimentary rocks are present in very small areas near the western coast and Miocene limestones underlie the north-western part of the country and extend south in a relatively narrow belt along the west coast.

The geological history of the island results in an extensive tracts of metamorphic rocks, but also minor exposures of volcanic and sedimentary rocks. The metamorphic rocks are rich in mineral deposits, including iron ore, zinc, manganese, molybdenum, nickel, cobalt, arsenic, tungsten, tellurium and gold. There are numerous precious gems found on the island, including ruby, sapphire, topaz and spinel [20.2].

7.20.3. Uranium exploration

Interest in exploration for radioactive minerals in Sri Lanka began in 1903 when thorianite was discovered in the gem gravels of the Ratnapura district. This resulted in the search for other radioactive minerals. During 1903–1909, 9 t of uranothorianite, containing up to 32% U, were recovered from stream gravels. The most common radioactive mineral is monazite, which occurs in seasonal beach deposits predominantly on the SW coast. From 1918 until the mid-1970s, the beach sand deposits were exploited until coast conservation regulations forced a stoppage to operations. During this period nearly 100 t of monazite was sold.

The first systematic exploration programme for radioactive minerals began in 1958 with an airborne magnetic and radiometric survey carried out under a Canada–Ceylon technical assistance programme. This survey covered a third of the island and identified nearly 250 anomalous areas, most of which coincided with monazite-bearing beach sands. In 1961, ground follow-up work was carried out with IAEA cooperation. A total of 1066 samples were collected over an area of 3505 km², confined mainly to the southern half of the island. Sampling density varied in the range 2–5/km².

In 1979, a first phase geochemical stream sediment programme covering the whole island (65 000 km²) was initiated with IAEA assistance. A total of 1750 samples were collected from 874 locations at a density varying from one sample per 27–278 km². A number of anomalous areas in the eastern half and the north-eastern sector of the island were scheduled for follow-up work as part of the second phase of the programme.

The second phase project area covered an area of nearly 10 000 km² and was investigated in 1982 at a sampling density of one sample per 2–5 km². This work led to the further selection of nine areas covering 7800 km², which were assessed on a priority basis in 1983 and 1984. The high priority targets were Kantaiei, Polonnaruwa, Kala Oya and Naha Oya, which were geochemically sampled at a sampling density of up to one sample per km². The outcome of this programme was the selection of the Kala Oya and Naha Oya as being areas that merited further work. Both areas are mainly underlain by metasedimentary rocks of the Proterozoic Vijayan Series and intruded by granites, some of alkaline composition.

In 1985, exploration activities were limited to laboratory studies of samples previously collected in the Kala Oya (25 km²) and Naha Oya (40 km²) areas [20.3]. No activities have been reported to the Red Book since 1988. Historical exploration data are summarized in Table 7.10.

7.20.4. Uranium resources

Sri Lanka has no known uranium resources.

The UDEPO database does not list any known deposits for Sri Lanka.

7.20.5. Potential for new discoveries

Limited exploration has been carried out in Sri Lanka and any geologically favourable areas for uranium mineralization remain unidentified. However, there are two areas which possess limited uranium potential, both of which straddle or lie close to major lithostratigraphic boundaries in the west and the east:

(a) The western boundary especially represents a Proterozoic–Tertiary unconformity. The Tertiary sedimentary rocks are continental grey arkosic sandstones that contain organic matter. The area covers almost 1100 km². The results from eighteen panned concentrate samples from the first phase of exploration gave concentrations of 36–80 ppm U;

(b) In the east, the boundary mainly defines the two major lithologies of the island. The proposed area, which is 1270 km² in extent, lies to the east of, and in close proximity to, this boundary. The host rocks belonging to the Vijayan complex consist of biotite–hornblende gneiss, migmatites, granites and augen gneiss. Within this complex, uranium may be related to pegmatites. A significant feature of the area is a fracture pattern seen clearly on Landsat imagery. These fractures could possibly provide a setting for secondary uranium mineralization. The uranium contents of the panned concentrates from the first phase of exploration averaged 31 ppm U.

7.20.6. Comments

Sri Lanka has no uranium production or nuclear generating capacity.

TABLE 7.10. EXPLORATION DATA [20.3–20.14]

	Aerial radiometric surveys (km²)	Geochemical surveys (km²)	Expenditures (US $1000)
Pre-1977	30 000	n.a.[a]	5000[b]
1977			
1978			
1979		60 000	8000
1980			
1981		3200	12 000
1982			
1983		800	5000
1984		600	2000
1985			675
Total	30 000	64 600	32 675

[a] n.a.: not available.
[b] Cost of airborne survey not included.

References to Section 7.20

[20.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Sri Lanka, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[20.2] DISSANAYAKE, C.B., CHANDRAJITH, R., Sri Lanka–Madagascar Gondwana linkage: Evidence for a Pan-African mineral belt, J. Geol. **107** (1999) 223–235.

[20.3] OECD EUROPEAN NUCLEAR ENERGY AGENCY, World Uranium and Thorium Resources, OECD, Paris (1965).
[20.4] OECD EUROPEAN NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources: Revised Estimates, OECD, Paris (1967).
[20.5] OECD EUROPEAN NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium: Production and Short Term Demand, OECD, Paris (1969).
[20.6] OECD EUROPEAN NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1970).
[20.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1973).
[20.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1976).
[20.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).
[20.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).
[20.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).
[20.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).
[20.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).
[20.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

7.21. SYRIAN ARAB REPUBLIC

7.21.1. Geography

The Syrian Arab Republic (‘Syria’) is located in the Middle East and borders Turkey to the north, Iraq to the east, Jordan to the south and Israel and Lebanon to the west. It also borders the eastern margin of the Mediterranean Sea. The country consists, primarily, of a semi-arid and desert plateau, a narrow coastal plain and mountains in the west. The highest point is Mount Hermon, which has an elevation of 2814 m. The summer (June–August) is mostly hot and dry and the winter (December–February) is typically mild and rainy along the coast, although snow is recorded occasionally. Natural resources include petroleum, phosphates, chromium, manganese, asphalt, iron ore, salt, marble and gypsum [21.1].

7.21.2. Geology

7.21.2.1. General

The tectonic setting of the country, within the Arabian Plate, shows it is surrounded by active plate boundaries. The western boundary is marked by the left-lateral Dead Sea Fault System. The Dead Sea Fault marks the boundary between the Arabian Plate to the east and the Levantine (east Mediterranean) sub-plate to the west. The Bitlis Suture, which lies to the north of the country, represents the collision zone of the Arabian and Eurasian Plates. Two major structural features of the country are the Palmyrides fold and thrust belt and the Euphrates Fault System to the east. It has been conjectured that these structures may be evidence of reactivation along zones of weakness in the Arabian Plate that have persisted since the Proterozoic.

Tectonism is concentrated in four major zones which are separated by less deformed areas. These include a fold and thrust belt, a plate boundary transform fault, inverted basins and an extensive aborted rift. The country’s topography indicates the physiographic provinces that exhibit prominent relief.

Extending ~400 km NE from the Lebanese border into central Syria are the Palmyrides, Syria’s largest topographic feature. The Palmyrides have been extensively studied by the Cornell Syria Project [21.2].

The low level topography of the second major tectonic zone, the Euphrates Fault System, belies its complex structure, one which hosts the country's largest petroleum reserves. The Euphrates Fault System extends across Syria from the border with Iraq in the SE to the border with Turkey in the NW. The south-eastern area, the Euphrates Graben, is the most intensely deformed part and most reminiscent of a classic steep-sided graben. The Abd el Aziz and Sinjar structures are both topographically prominent uplifts in NE Syria and these denote the location of the third major tectonic zone. The fourth major tectonic zone is the Dead Sea Fault System, an active transform plate boundary located in western Syria [21.3].

As regards lithologies, with the minor exceptions of crystalline rocks associated with the northerly trending transform Dead Sea Fault System, which extends along the western coast of Syria, and Neogene–Recent volcanic flows, the geology is dominated by a thick (>6 km) sequence of marine clastic, shale and carbonate rocks overlying the Arabian Shield (Fig. 7.38).

After cratonic accretion of the Arabian–Nubian Shield had taken place in the Proterozoic, Syria formed part of the northern passive margin of Gondwana, bordering the Tethys Sea for most of the Phanerozoic. Gentle, early Palaeozoic subsidence of this eastwards facing margin led to the regional accumulation of a thick sequence of Phanerozoic sedimentary rocks. The lithology reflects the shift from predominantly Palaeozoic deposition of clastics to the formation of Mesozoic and Cenozoic carbonates. Numerous widespread unconformities representing long lived hiatuses and erosion occur throughout the section, particularly during the Devonian and Late Jurassic.

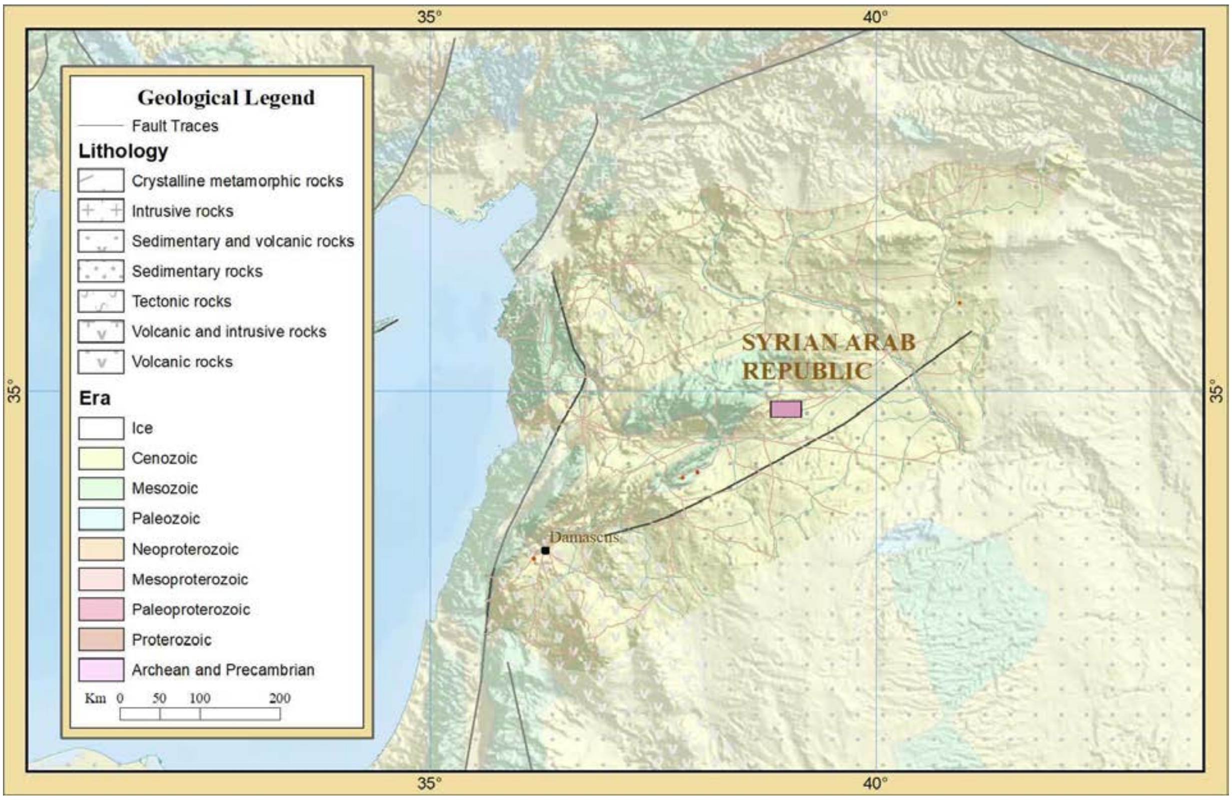


FIG. 7.38. Regional geological setting of Syrian Arab Republic showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

As a result, with the few exceptions of minor crystalline rocks, the geology of Syria is comprised of a thick sequence of dominantly marine sandstones interspersed with various carbonate rocks developed during the Cambrian–Miocene. These overlie the crystalline Precambrian basement, which in Syria is generally deep (>6 km) and has only once been penetrated by drilling. Exceptions include two relatively small areas of the Baer-Basset ophiolite assemblage of basic volcanic rocks, layered gabbros and related sedimentary rocks cropping out along the north-western coast. The Tethyan nappe, consisting of the ophiolite assemblage, was thrust onto the northern border of the Arabian Shield during the Maastrichtian. The only other igneous rocks are the Neogene–Quaternary age basaltic flows in south-western Syria and the much less extensive Neogene basalt flows in north-eastern Syria, as well as a few isolated flows cropping out along a trend from Homs to Aleppo [21.2, 21.3].

7.21.2.2. Potential favourable uranium-bearing areas

Phosphorite deposits occur in the general area of the oasis town of Palmyra in the central part of the country. The Eastern Group mines A and B and the Khneifiss deposits are located in the Ghadir el Hamel region, some 50–80 km SW of Palmyra; the Al Haeri (Maberi) area, ~100 km SE of Palmyra; and the Wadi al Rakheime area to the NW of Palmyra, respectively.

The phosphorite beds are intercalated within a relatively flat lying sequence, 30–150 m in thickness and composed of fine-grained, argillaceous limestone, marl and chert. The phosphorite beds are 1–20 m thick and exhibit abrupt lateral changes in thickness [21.4].

7.21.3. Uranium exploration

An airborne gamma ray survey was carried out over Syria during 1987 as part of an IAEA–United Nations Development Programme project [21.5]. Roughly 11 000 line km of data were recorded along parallel lines over three adjoining rectangular areas:

(a) Syrian Desert (7189 line km at a 4 km line spacing);
(b) Ar-Rassafeh Badyieh (2240 line km at a 4 km line spacing);
(c) Northern Palmyrides (1600 line km at a 3 km line spacing).

The main purpose of the survey was to further uranium exploration but the survey did not indicate the presence of any strong anomalies. The highest values of gamma ray activity, found in the central southern Palmyrides, correspond to phosphate outcrops. These phosphate deposits have been exploited for many years at Khneifiss and at Al-Sharquieh, located 65 km and 45 km SW of Palmyra, respectively.

The study area is significant, owing to the occurrence of phosphate outcrops of Cretaceous age, the main source of any uranium, and the presence of favourable geological structures for the formation of uranium traps. This area was not covered by the earlier airborne survey and consequently gamma ray spectrometry was used on rock samples taken from outcrops of different geological units to determine their uranium potential.

In the early 1990s, the Atomic Energy Commission initiated a feasibility report to assess the prospects for uranium recovery from phosphoric acid. Exploration expenditures incurred during the early 1990s are summarized in Table 7.11.

TABLE 7.11. EXPLORATION EXPENDITURES (US$) [21.5]

Year	1990	1991	1992	1993 (expected)
Government expenditures	89 000	179 000	83 000	94 000

7.21.4. Uranium resources

No conventional uranium resources have been discovered in Syria.

Unconventional resources in Upper Cretaceous phosphates are estimated to amount to 45 000 tU in the deposits associated with the Khneifiss and Eastern Group mines A and B, according to the 1993 Red Book [21.5]. An additional 15 000 tU were estimated for the Lower Palaeogene phosphate deposits in the Syrian Desert (Table 7.12) [21.5].

In Ref. [21.6], Dahlkamp included resource estimates reported by three other sources:

(a) De Voto and Stevens (1979) [21.7] estimated a total amount of recoverable phosphate product at 405 Mt with an average grade of 130 ppm U;
(b) Krauss et al. (1984) [21.8] estimated resources of 431 Mt at grades of 27.5–29.6% P_2O_5 for the open pit mining areas at Khneifiss and Eastern Group mines A and B;
(c) Pool (1993) [21.9] calculated from these figures potentially recoverable resources of some 40 500 tU.

The UDEPO database [21.10] lists the deposits in the Palmyra district as being dormant (April 2010).

In conclusion, there is potential for expanding the phosphate-hosted resources described above. However, there is no potential for conventional uranium resources owing to the unfavourable marine sedimentary rocks and carbonate rocks and basalt flows that comprise the near surface geology of Syria.

TABLE 7.12. UNCONVENTIONAL URANIUM RESOURCES (IN SITU) [21.5]

Deposit	Location	Type	Resource (tU)	Grade (ppm U)
Upper Cretaceous	Khneifiss, Charquieh	Phosphate	35 000	30–140
	Awabed	Phosphate	10 000	40–60
Lower Palaeogene phosphate	Syrian Desert	Phosphate	15 000	30–40

The UDEPO database lists the most significant deposits for the Syrian Arab Republic as Khneifiss, Syrian Desert, Awabed.

7.21.5. Uranium production

Syria has attempted to extract uranium from phosphate rock with two major projects: the 1986 phosphate extraction facility located near Homs and the 2001 tri-superphosphate extraction facility located near Palmyra. The 1986 project was intended to recover uranium from the phosphoric acid that was produced at the plant in Homs. The Homs plant produced the phosphoric acid from phosphate rock extracted at Charkia and Kneifiss. The grades of the deposits vary in the range 60–100 ppm U. The project between the IAEA and the Atomic Energy Commission was cancelled despite the fact that the technology worked, as the world market price of uranium prevailing at the time would not justify the programme. Financial constraints also delayed the 2001 project [21.5, 21.11, 21.12].

References to Section 7.21

[21.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Syria, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.
[21.2] BREW, G.E., Tectonic Evolution of Syria, Cornell Syria Project, Cornell University (2001), http://atlas.geo.cornell.edu/people/brew/gbthesis5.html
[21.3] ASFAHANI, J., AL-HENT, R., AISSA, M., Geological and hydrogeological conditions for forming uranium occurrences in the Froqlos–Jabal Abou Rabah Region, Palmyrides, Syria, Expl. Min. Geol. **19** (2010) 1–12.
[21.4] INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project, IUREP, National Favourability Studies: Syria, IAEA, Vienna (1977) 13 pp.

[21.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).
[21.6] DAHLKAMP, F.J., Uranium Deposits of the World: Asia, Springer, Berlin (2009) 493 pp.
[21.7] DE VOTO, R.H., STEVENS, D.N. (Eds), Uraniferous Phosphate Resources and Technology and Economics of Uranium Recovery from Phosphate Resources, USA and Free World, US Department of Energy Rep. GJBX 110, Earth Sciences Inc., Golden, CO (1979).
[21.8] KRAUSS, U.H., SAAM, H.G., SCHMIDT, H.W., International Strategic Minerals Inventory Summary Report — Phosphate, USGS Circ. 930-C, US Geological Survey, Reston, VA (1984).
[21.9] POOL, T.C., "Uranium resources for long-term, large-scale nuclear power requirements", paper presented at Nuclear Energy Workshop, Oak Ridge National Laboratory, 1993.
[21.10] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[21.11] GLOBALSECURITY, Syria's Nuclear Program, http://www.globalsecurity.org/wmd/library/report/2007/syria_nuke.html.
[21.12] FIELDS, J., Syria, Stockholm International Peace Research Institute (SIPRI), http://www09.sipri.org/research/disarmament/nuclear/researchissues/past_projects/issues_of_concern/syria/syria_def aultwww.nps.edu/Academics/centers/ccc/publications/OnlineJournal/2009/Dec/steinhauslerDec09.html.

7.22. TAJIKISTAN

7.22.1. Geography

Tajikistan is a mountainous landlocked country in central Asia. It borders Afghanistan to the south, Uzbekistan to the west, Kyrgyzstan to the north and China to the east.

The mountains of the Pamir Range cover over 90% of the country and over 50% of the country lies at an elevation of over 3000 m. The only major areas of lower lying land are in the north (part of the Fergana Valley), and in the southern Kofarnihon River and Vakhsh River valleys, which join to form the Amu-Darya River. The capital, Dushanbe, is located on the southern slopes above the Kofarnihon valley.

The primary sources of income in Tajikistan are aluminium production, cotton growing and remittances from migrant workers. Tajikistan's rivers, such as the Vakhsh and the Panj, have significant hydropower potential and the Government has focused on attracting investment for hydroelectric projects to generate electricity for internal consumption and for export [22.1].

7.22.2. Geology

Tajikistan's territory is extremely diverse, with many rock types and geological epochs represented (Fig. 7.39). Quaternary, Neogene and Palaeogene strata crop out in the SW and north of the country. Cambrian, Ordovician, Carboniferous, Permian, Jurassic and Cretaceous strata and intrusive rocks dominate in central Tajikistan. Upper Cambrian, Carboniferous, Permian, Triassic and Jurassic strata dominate in the Pamir Mountains, along with intrusive rocks.

Tajikistan is rich in mineral resources, with coal, oil, gas, mercury, molybdenum, antimony, tin, gold, silver, phosphate, salt, talc, asbestos, fluorspar, marble, gypsum, clay and gemstones [22.2].

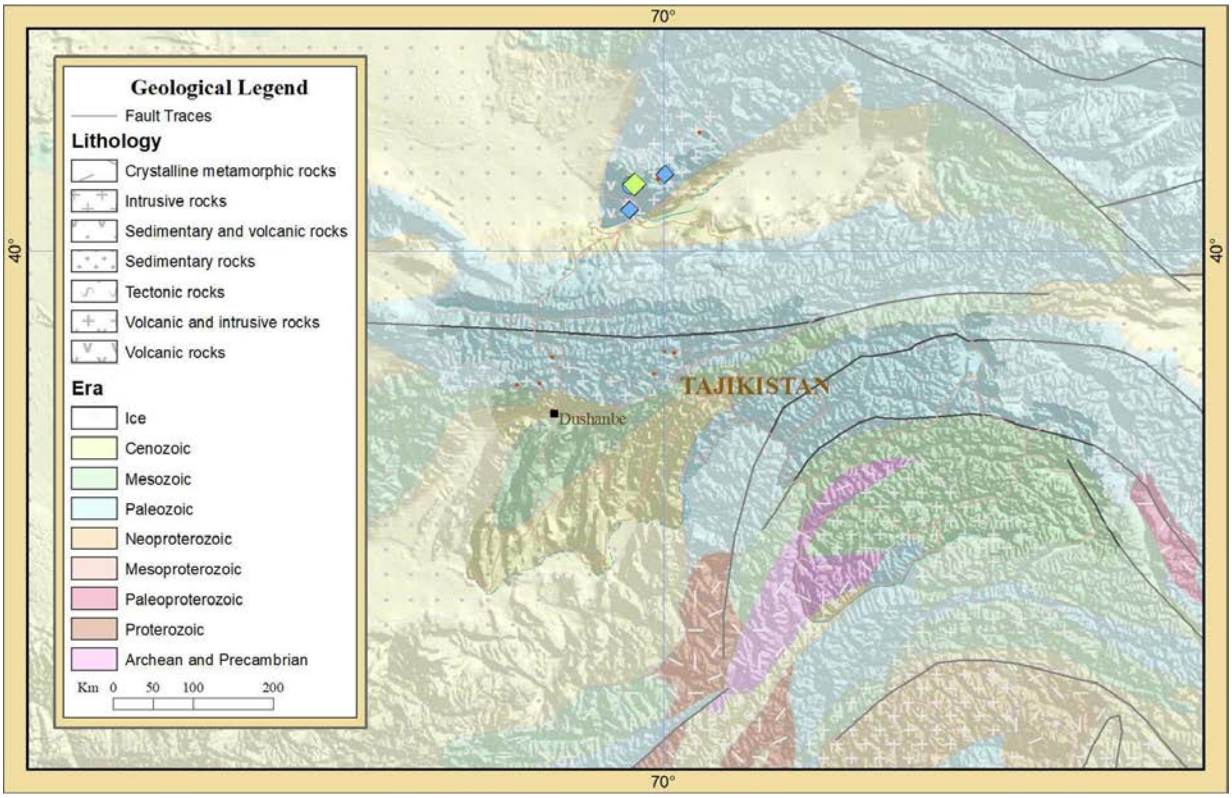


FIG. 7.39. Regional geological setting of Tajikistan showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.22.3. Uranium exploration

Initial details of uranium occurrences in Tajikistan come from the 1920s, when uranium was found in the Kuramin range west of the Tien Shan Mountains [22.3]. The Taboshary deposit, which was discovered in 1925, is located ~40 km north of Khodzent (formerly Leninabad) and was initially exploited for radium, which was extracted at a plant in Taboshary, commencing in 1934. Uranium mineralization at Taboshary exists as veins in a granitic host rock. The average ore grade was 0.06% U and secondary uranium minerals comprised most of the mineralization [22.3].

The Adrasman deposit, situated ~70 km NE of Khodzent, was found in 1934 and was initially mined in 1945 for bismuth and copper. Subsequently, uranium was found at Adrasman in 1940. The geology of the Adrasman deposit is similar to that at Taboshary [22.3].

Uranium mineralization has also been documented in the Karetegin and Gissar ranges of the southern Tien Shan. These occurrences are related with Palaeozoic complexes and comprise [22.3]:

(a) Pitchblende mineralization in Permian volcanic rocks at Mumin, Rafikon, Paridan and Khanaka;
(b) Pitchblende in granite at Moscovskoye and Yakhob;
(c) Pitchblende–brannerite–fluorapatite in granite at Farkak and Lugur;
(d) Pitchblende–fluorapatite in Middle Palaeozoic carbonates at Vaidara; and
(e) Bitumen–pitchblende and fluorapatite–bitumen–pitchblende in metasedimentary rocks at Kamaroy and Karategin.

7.22.4. Uranium resources

Tajikistan has not conveyed any information on minable resources of uranium.

The UDEPO database lists the most significant deposits for Tajikistan as Taboshar, Adrasman, Keektal, Uigur Mine.

7.22.5. Potential for new discoveries

Tajikistan has significant mineral resources awaiting development, including a large number of occurrences of rare metals, rare earth elements and uranium. Several countries have expressed interest in participating in the development of Tajikistan's uranium resources. The Russian Federation was considering assisting Tajikistan to develop its uranium resources, as well as assisting in geological prospecting, with the aim of involvement in the subsequent extraction and possible processing of uranium. China's Guangdong Corporation has also expressed an interest in participation in projects to develop uranium deposits. The Government of Tajikistan has agreed to allow Indian companies to explore for uranium mineralization.

It is believed that uranium reserves in the northern parts of Tajikistan were depleted in the 1950s and that any new uranium mining would likely take place in the south of the country [22.2].

7.22.6. Uranium production

The original uranium production centre in the former Soviet Union was constructed close to Khodzent (Leninabad) in 1943. This production centre, which treated uranium ore up to the early 1990s, was first known as Combine No. 6 and subsequently as the Leninabad Mining–Chemical Combine (Fig. 7.40). Production throughout the early functioning years of this mill was based on ore mined domestically (at Adrasman and Taboshary) as well as ore derived from the Mailuu-Suu deposit in Kyrgyzstan and from the Tuya-Muyun and Uigur deposits. Uranium concentrate from the former German Democratic Republic, the former Bulgaria, Poland and Czechoslovakia was also transported to the Leninabad mill for treatment between 1945 and 1950 [22.3].

Underground mining for uranium started at Taboshary in 1943 and it was the earliest deposit of uranium mined in the erstwhile Soviet Union during World War II. Production from the Taboshary deposit, which is now depleted, totalled 500 tU. Underground mining at Adrasman began in 1946 and lasted until the 1950s. Production at Adrasman, which has also been depleted by mining, totalled 103 tU at an average grade of 0.053% U [22.3].

Uranium has also been mined at Chauly (4500 tU) and at Kattasay and Alatanga (4500 tU). Total uranium production from the Karamazarsky district in Tajikistan amounted to ~20 000 tU [22.4].

7.22.7. Environmental activities

Mining and milling of uranium was a major industry in most of the central Asian countries of the Soviet Union and it has left a heritage of radioactive residues.

Mining of most of the uranium deposits in Kyrgyzstan, Tajikistan and Uzbekistan was stopped after the dissolution of the Soviet Union. These countries have the same problem with regard to the safe administration and remediation of several sites impacted by the operation of facilities for mining and milling of uranium. Following the independence gained by these countries, the concerns of decommissioning and restructuring the mines and other uranium facilities arose.

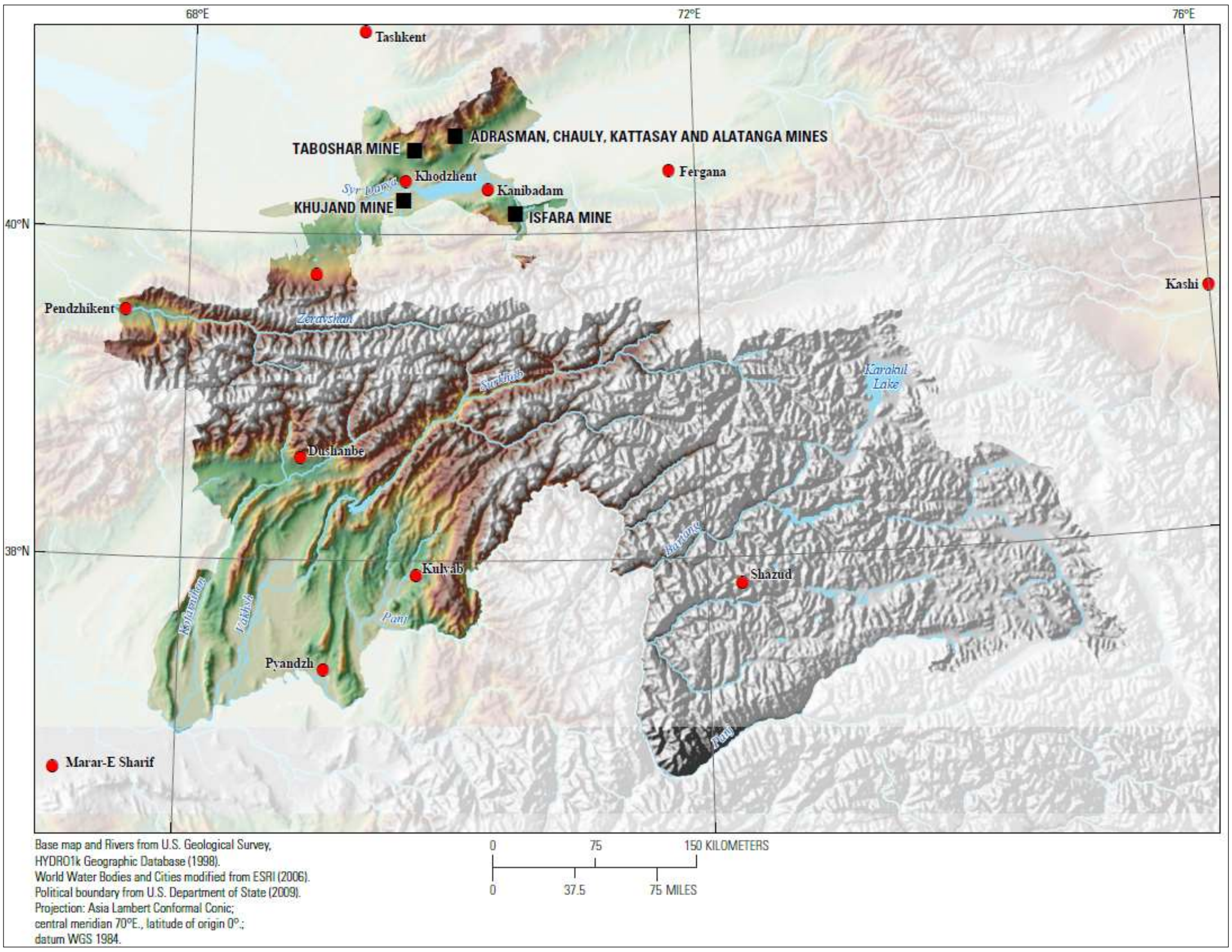


FIG. 7.40. Former uranium industry sites in northern Tajikistan [22.4].

Consequently, the IAEA and several international organizations (e.g., European Commission, United Nations Development Programme, Organization for Security and Co-operation in Europe) embarked on an initiative to develop a mutual perception of the risks presented by these sites with the objective of protecting their populaces and the environment.

One of the main aims of this initiative was to develop a publication (Assessment and Proposals for Uranium Production Legacy Sites in Central Asia: An International Approach) that provides a technical baseline for achieving a mutual appreciation of regional and site specific concerns [22.4]. This publication should serve as a basis for recognizing, ranking and organizing the essential actions needed to render these sites secure for the populace and the environment around them.

7.22.8. National policies relating to uranium

Until recently (2008), Tajikistan's Law on Natural Resources prohibited foreign companies from implementing any projects related to uranium resources. In addition, the Programme on Developing Geological Industry, which covered the period up to 2015, did not include any plans for uranium exploration or for the development of uranium mines.

Several developments in 2008 demonstrated a change of policy in relation to conducting uranium exploration in Tajikistan. In early 2008, the Government announced its intention, with respect to exploration for uranium resources, to change existing legislation and to provide improved access to relevant information on natural resources with the aim of attracting direct foreign investment. In 2008, the prohibition on foreign involvement in the uranium industry was revoked [22.5].

References to Section 7.22

[22.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Tajikistan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[22.2] UNITED STATES GEOLOGICAL SURVEY, Area Reports: Countries of the Baltic, the Caucasus, the Central Asia, and the Eurasia Regions, Minerals Yearbook, Vol. 3, USGS, Reston, VA (2008).

[22.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[22.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Proposals for Uranium Production Legacy Sites in Central Asia: An International Approach, Proc. IAEA Tech. Mtg, IAEA, Vienna (2010).

[22.5] KASSENOVA, T., Uranium production and nuclear energy in Central Asia: Assessment of security challenges and risks, China and Eurasia Forum Quarterly **8** 2 (2010) 221–241.

7.23. TURKMENISTAN

7.23.1. Geography

Turkmenistan borders the Islamic Republic of Iran, Afghanistan, Uzbekistan and Kazakhstan. Turkmenistan's average elevation is 100–220 m above sea level. Its highest point is Mount Ayrybaba (3137 m) which lies in the Kugitang Range of the Pamir-Alay Mountains in the east. The lowest point is the Transcaspian Depression (100 m below sea level). Almost 80% of the country lies within the Turon Depression, which slopes S–N and E–W.

Turkmenistan's mountains include a 600 km long extension of the northern reaches of the Kopetdag Range, which it shares with the Islamic Republic of Iran. The Kopetdag Range is characterized by arid foothills, mountain plateaus and steep ravines. The Krasnovodsk and Üstirt plateaus are the most prominent topographical features of north-western Turkmenistan. Another prominent topographical feature is the Garagum Desert, which occupies an area of ~350 000 km². Winds create desert 'mountains' 2–20 m high and up to several kilometres in length. Extensive marshy salt flats, formed by capillary action in the soil, exist in many depressions, including the Kara Shor, which occupies an area of 1500 km² in the NW of the country. The Sundukly Desert, west of the Amu-Darya, is the most southerly limit of the Qizilqum Desert, most of which lies in Uzbekistan to the NE.

Turkmenistan has a subtropical desert climate that is continental. Summers are long (May–September), hot and dry, and winters are generally mild and dry, although occasionally cold and wet in the north. Most rainfall occurs between January and May. Precipitation is low throughout the country, with annual averages ranging from 300 mm in the Kopetdag to 80 mm in the NW.

Turkmenistan has substantial reserves of oil and gas. It also has deposits of sulphur, iodine, celestine, salt, potassium and magnesium salts, bentonite clays, limestone, gypsum, lignite, basalt and dolomite [23.1].

7.23.2. Geology

Most of Turkmenistan is located within the Turan plate where thick sedimentary formations accumulated from late Paleozoic to Cenozoic. It is bounded in the NE by the Altaids-Uralides-Ust Yurds domains, part of the Kazakh plate and in the SW by the Iranian plate. The Skyto-Turanian fault and the Paleotethys suture delineate respectively the northern and southern boundaries of the Turan plate (Fig. 7.41) [23.2].

The basement of the plate is composed of NW-SE parallel magmatic arcs and forearc accrecionary wedges developed during late Paleozoic to Triasic times. Then, extensional basins formed in the basement between Jurassic and Paleogene. Extensive thick Neogene to Quaternary sedimentary formations covers more than 75% of the country surface [23.2].

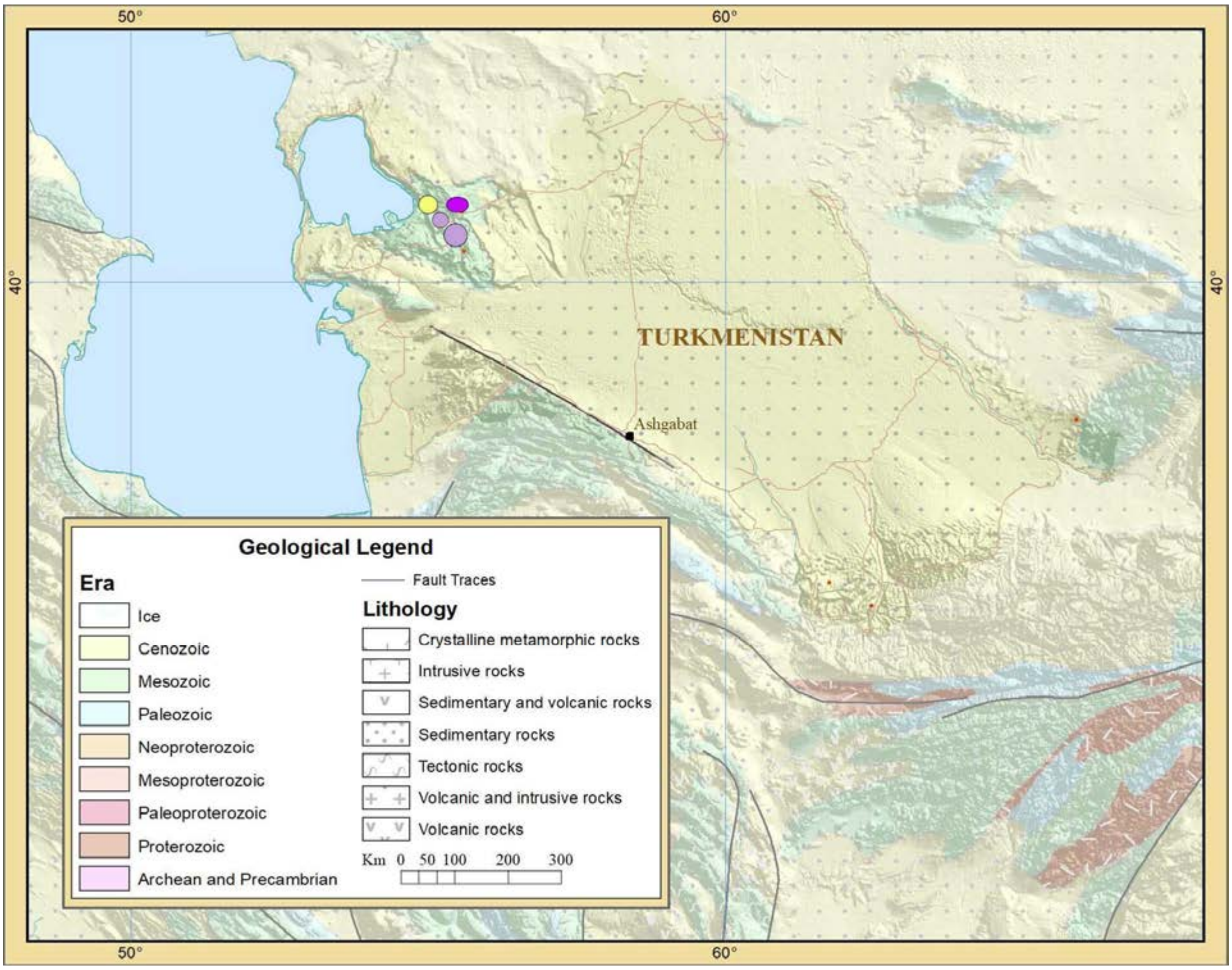


FIG. 7.41. Regional geological setting of Turkmenistan showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Precambrian to Triassic rocks are only exposed in the small Kizylkaya structure, Western Karakum Desert, near the Caspian Sea. The domal structure (also called the Taukyr Dome), is an anticline outcropping for 17 km in a regional NW-SE direction and 5 km wide. Steeply dipping Permian and Triassic formations form the core of the anticline [23.2].

The lithostratigraphic succession of the Taurkyr region comprises Precambrian schists and amphibolites, Silurian carbonates, Devonian volcano-sedimentary schists, Carboniferous basal volcanics (basalts to rhyolites – Unit C1), black shales (Unit C2), sandstone (Unit C3) and carbonates (Unit C4). These older formations are unconformably covered by Permian mudstone, siltstone, sandstone, conglomerate and tuff. The Permian lithologies, up to 2500 m thick, contain most of the uranium mineralization [23.2].

7.23.3. Uranium exploration

Exploration for uranium in Turkmenistan commenced in the 1940s and was mostly conducted by Uzbek geologists who found the Cernoye deposit, which was subsequently mined over the period 1952–1967 [23.3].

The Cernoye deposit is characterized by a radiometric anomaly occurring along an E–W striking fault. The deposit, 20–40 m wide, extends to a depth of more than 245 m and has a horizontal continuation of 200 m along the fault. Uranium mineralization, chiefly coffinite related with copper and molybdenum sulphides, is localized in oxidized conglomerates and coarse sandstones, with countless pebbles of acid volcanic rocks (rhyolites, ignimbrites), which are likely the uranium source. Resources were in the order of 7000 t U for a grade of 0.45% [23.3].

The Novodgony deposit is situated at the north-western edge of the Permian horst of Touarkir. The anomalous area measures 2 km in length, 200 m in width and extends to a depth of 300 m. Uranium mineralization is related with the reduced facies intercalated with oxidized layers, which exists in a thick succession of conglomerates. Uranium (urano-vanadates) is related with silver, lead, zinc and molybdenum. Resources have been assessed at 2000–2500 tU at an average grade of 0.03% U. The deposit could also contain 10 000–15 000 t of molybdenum as jordisite [23.3, 23.4].

Uranium mineralization is also documented at Amanboulak over a span of 1.6 km. These occurrences are related with the contact between argillites and sandstones of Permian age [23.3].

The Bailik site is situated in Carboniferous formations located NE of the Permian dome of Touarkir. Uranium mineralization, related with metamorphosed pelites and black shales, is situated directly below the unconformity with Jurassic conglomerates, at depths of 130–180 m. The uranium, chiefly coffinite, is related with cobalt, nickel and vanadium. Uranium mineralization has also been encountered along a NW–SE trend, in a zone 400 m wide and over 5 km long. The uranium potential is estimated to be in excess of 5000 tU, but of low grade [23.3, 23.4].

7.23.4. Uranium resources

No economically viable uranium resources have been reported in the country.

The UDEPO database lists the most significant deposits for Turkmenistan as Sernoye, Bailik, Novogodny, Amanbulak.

7.23.5. Potential for new discoveries

Known occurrences of uranium in Turkmenistan are situated in the country's north-western sector, are related with the Touarkir dome on the western margin of the Karakum Desert. These occurrences are related with Permian formations (Amanboulak, Novogodny, Cernoye), and with Carboniferous black shales (Bailik) [23.3]. However, available information is insufficient to estimate potential uranium resources.

7.23.6. Uranium production

Found in 1952 by Uzbek geologists, the Cernoye deposit was mined over during 1952–1967 by both underground and open pit methods. Following enrichment by radiometric ore sorting conducted on-site, concentrates of ore were transported to the Mungishlak plant in Kazakhstan for yellow cake generation. From the Cernoye deposit, total production has been estimated at around 5 000–7 000 tU at an average grade of 0.4–0.5% U, with grades locally varying in the range 0.1–20% U.

Uranium was also mined at Amanboulak (average grade of 0.1% U over a maximum thickness of 13 m) in the 1950s, at the same time as exploitation of the Cernoye deposit.

References to Section 7.23

[23.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Turkmenistan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html .

[23.2] GHASSEMI M.R., GARZANTI E., Geology and geomorphology of Turkmenistan: A review, Geopersia 9, (20190 pp 125-140

[23.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[23.4] DAHLKAMP, F.J., Uranium Deposits of the World: Asia, Springer, Berlin (2009) 493 pp.

7.24. UNITED ARAB EMIRATES

7.24.1. Geography

The United Arab Emirates (UAE) is a federation of seven emirates. The country is located on the Arabian Peninsula and includes several islands. The UAE is bordered to the north by the Arabian Gulf, to the east by the Gulf of Oman and Sultanate of Oman, and to the south and west by Saudi Arabia. It lies between latitudes 22–26.5° N and longitudes 51–56.5° E (Fig. 7.42).

The UAE has some 700 km of coastline, including 100 km bordering the Gulf of Oman. Along the Arabian Gulf coast lie offshore islands, coral reefs and salt marshes, whereas the inland region is characterized by stretches of gravel plain and barren desert. To the east lie the Hajar Mountains, which extend to the north into the Musandam peninsula on the Arabian Gulf. The western interior of the federation, most of which is Abu Dhabi territory, consists mainly of desert interspersed with oases. One of the largest oases is Al Liwa, beyond which is lies the Rub al-Khali desert, or Empty Quarter.

The UAE lies in the arid tropical zone that extends across Asia and North Africa. Climate is strongly influenced by the proximity of both the Arabian Gulf and the Gulf of Oman. The climate is characterized by high temperatures in summer (an average maximum of 45°C in July) combined with high humidity along the coast. There are noticeable variations in climate between the coastal regions, the deserts of the interior and the mountainous areas. In November–March, daytime temperatures average 26°C.

Average rainfall is low, usually less than 65 mm annually, more than half of which falls in December and January [24.1].

7.24.2. Geology

The geology of the UAE is well known because of the extensive oil and gas exploration programmes that have been conducted.

Geologically, the UAE is situated on a corner of the Arabian Platform, a body of continental rock that has stayed rather stable from the Cambrian period. From a geological viewpoint, the Arabian Platform comprises not just present-day 'Arabia' but also the shallow Arabian Gulf (which is not a real ocean basin) and the rocks of the coastal Zagros Mountains in the Islamic Republic of Iran. For most of its history, the Arabian Platform has been a component of the bigger Afro-Arabian continent, and the two have wrought as a unit in reaction to plate tectonic motions.

About 25 Ma, with the early opening of the Red Sea, Arabia started to split from the African Plate. Movement of the Afro-Arabian Plate throughout the Palaeozoic twice triggered Arabia to pass near to the South Pole (in the Ordovician and Carboniferous periods), during which time the UAE may have been glaciated. From the close of the Palaeozoic, however, the UAE has stayed in tropical or subtropical latitudes. Regardless of its tectonic history, the area seems to have stayed tectonically quite stable.

Over time, sediments amassed on the coast and continental shelf that later was to turn out to be the UAE. Limited pre-Permian outcrops in the UAE reveal fine-grained, shallow water terrigenous sediments (silts and shales). These were likely fairly thin overall and possibly mostly removed by intermittent erosion and emergence. Subsequently, in the tropical Mesozoic seas, thick successions of carbonate rocks (dolomites and limestones) were formed. The Late Permian and Mesozoic seas of the UAE were part of the Tethys Sea that opened up north of Arabia throughout this period, splitting the Afro-Arabian continent from the Eurasian continent. This palaeo-ocean extended westwards to the present-day Mediterranean countries and eastwards to the Himalayas.

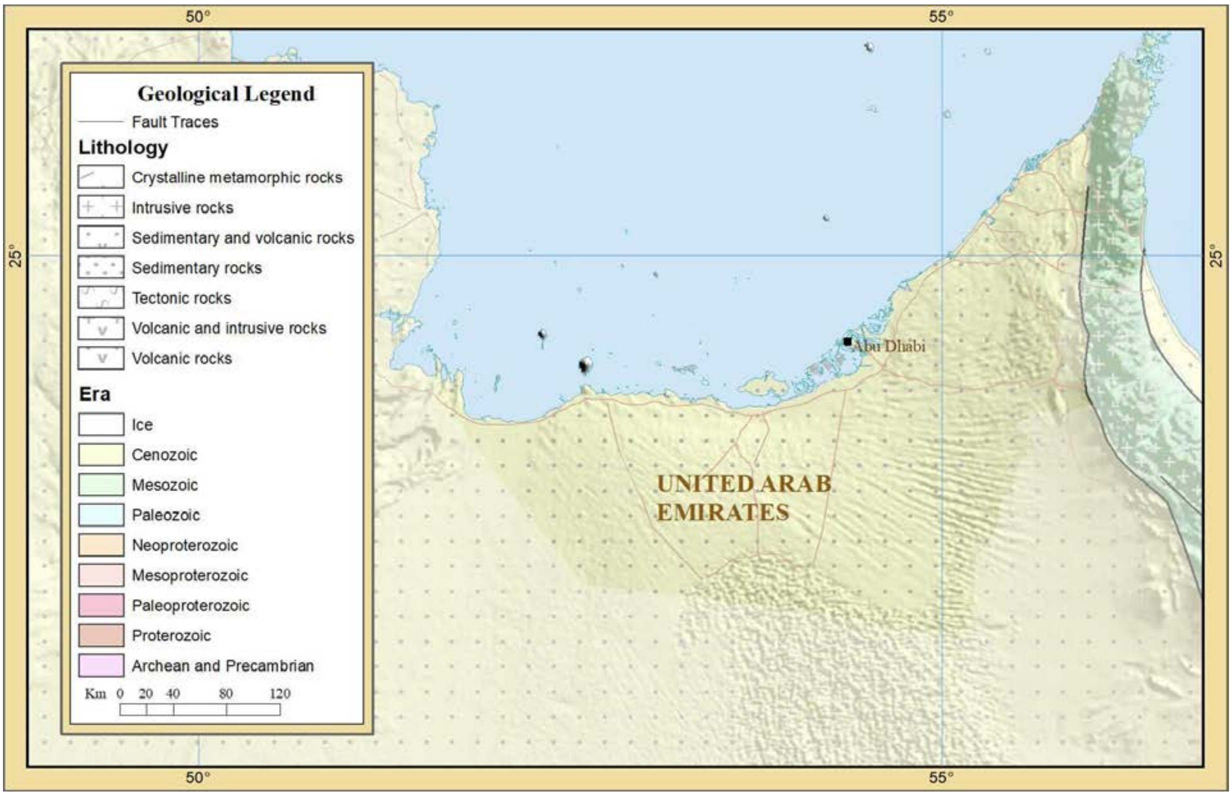


FIG. 7.42. Regional geological setting of United Arab Emirates. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Fossiliferous Jurassic–Late Cretaceous (210–85 Ma) dolomites and limestones are the strata in which the UAE's copious oil reserves typically exist. Some of these rocks represent depositional environments very much similar to the present-day Arabian Gulf shores, although they are now buried at depths of some 2400–7000 m. The lower portion of the Mesozoic succession comprises sabkha deposits symbolic of limited ocean circulation.

Aside from the rocks of the Hajar Mountains, there is not much outcrop of any kind all over eastern Arabia, and most of what is recognized in detail of the geological history of the Arabian Platform in this area is derived from seismic and drilling information. Two persistent regional structural features observed by petroleum geologists are: (1) a major trough running through western Abu Dhabi and into the Empty Quarter, and (2) a parallel and adjacent major ridge running NE–SW through the Qatar peninsula. Subsurface structures may be very gentle, but gradients of about 2% can be enough to allow migration and entrapment of petroleum.

The land arose above sea level several times during its Early Mesozoic and Tertiary depositional history, but only in the form of low-lying topography, similar to the present-day. These periods, when the sea did not inundate the land, are supported by sporadic hiatus in the sedimentary record (developed by mud and sand being deposited on the seabed) and by sedimentary features signifying surface erosion, such as the formation of palaeo-soils.

From the Middle Cretaceous (100 Ma), local topographic highs (and major structural traps for petroleum) have been formed by salt domes originating from thick Cambrian salt deposits that underlie many areas of the southern Arabian Gulf at depths of at least 6000 m. These salt domes are responsible for the present-day topography of coastal hills and for creating several of the UAE's offshore islands.

Earth motions driven by plate tectonics caused the floor of the deep ocean, then lying to the NE, to be pushed over the margin of the Arabian Platform and its cover of shallow water sedimentary rocks. This process formed a structure of massive superposed sheets (nappes) of various rock types that now seem to have been ‘shuffled’ on a grand scale. This process formed the Hajar Mountains which comprise one of the most widespread outcrop of oceanic crust in the world. Their present height and rugged topography are products of repeated uplift and erosion due to regional forces starting at the close of the Oligocene (25 Ma) and enduring up to the present-day. Geologically recent events such as Pleistocene glaciation and its related effects on climate and sea level have also left their imprint on the present-day geology of the UAE.

The UAE’s proven oil reserves have been estimated to represent ~10% of the world’s total reserves and its natural gas reserves represent ~3% of the world total (as of 2010).

The mineral industry is generally restricted to construction materials, although some mineral exploration has been undertaken and minor exploitation of chromite is noted. One source also mentions modest deposits of iron, copper and uranium. However, no uranium deposits or resources are noted in IAEA records or in other commentaries on the resources of the UAE [24.2–24.5].

7.24.3. Uranium explorarion

There has been no reported uranium exploration in the United Arab Emirates.

The UDEPO database does not list any known deposits for the United Arab Emirates.

References to Section 7.24

[24.1] UAE INTERACT, Physical Features, Climatic Conditions, Population, http://www.uaeinteract.com/uaeint_main/yearbook/yr_country/002country03.asp .

[24.2] UAE INTERACT, Natural UAE, http://www.uaeinteract.com/nature/geology/geo01.asp.

[24.3] FUELNER, G., Geological Overview, The Emirates — A Natural History, The Environment Agency, Abu Dhabi (2005) 41–63.

[24.4] COUNTRIES QUEST, Natural Resources, Land and Resources, http://www.countriesquest.com/middle_east/united_arab_emirates/land_and_resources/natural_resources.html.

[24.5] SHIHAB, M., “Economic development in the UAE”, United Arab Emirates — A New Perspective (ABED, I.A., HELLYER, P., Eds), Trident Press Ltd, London (2001) 249–259.

7.25. UZBEKISTAN

7.25.1. Geography

Uzbekistan is a landlocked country in central Asia. The country shares borders with Kazakhstan to the west and to the north, Kyrgyzstan and Tajikistan to the east, and Afghanistan and Turkmenistan to the south. The topography of Uzbekistan is diverse, ranging from the flat, desert terrain that comprises almost 80% of the country, to mountains in the east which attain elevations of ~4500 m. The south-eastern portion of Uzbekistan is characterized by the foothills of the Tien Shan Mountains, which attain greater elevations in neighbouring Kyrgyzstan and Tajikistan and form a natural border between central Asia and China. The Kyzylkum Desert, which extends into southern Kazakhstan, dominates the northern lowland parts of Uzbekistan.

The most fertile region is the Fergana Valley, which covers an area of ~21 440 km² directly east of the Kyzylkum Desert and which is rimmed by mountain ranges to the north, south and east. The western end of the Fergana Valley is defined by the course of the Syr-Darya River, which runs across the NE of the country, from southern Kazakhstan and into the Kyzylkum.

The two largest rivers feeding Uzbekistan are the Amu-Darya and the Syr-Darya, which rise in the mountains of Tajikistan and Kyrgyzstan, respectively. Both rivers form the two main river basins of central Asia and are used primarily for irrigation; several canals having been built to increase the amount of arable land in the Fergana Valley and elsewhere to the west. Uzbekistan is a dry country. Less than 10% of its territory is intensively cultivated irrigated land in river valleys and oases; the rest is largely desert (Kyzylkum) and mountains.

The highest point in Uzbekistan is the Khazret Sultan (4643 m) in the southern part of the Gissar Range in Surkhandarya Province. The climate is continental, with minor precipitation the norm (100–200 mm annually). The average daytime summer temperature is ~40°C, in contrast to the average winter temperature of around -23°C.

Uzbekistan's economy relies mainly on commodity production, including cotton, gold, uranium, potassium salts and natural gas [25.1].

7.25.2. Geology

Uzbekistan is located in the intrastream area of the Amu-Darya and Syr-Darya Rivers and within the structures of the Tien Shan Mountains and the Turan Plate. Geosynclinal development of the territory was completed by the end of the Palaeozoic, which was succeeded by a relatively quiescent stage of platform conditions. Subsequent intense tectonic movements, which still persist, formed the alpine relief displayed in the east of the country (Fig. 7.43).

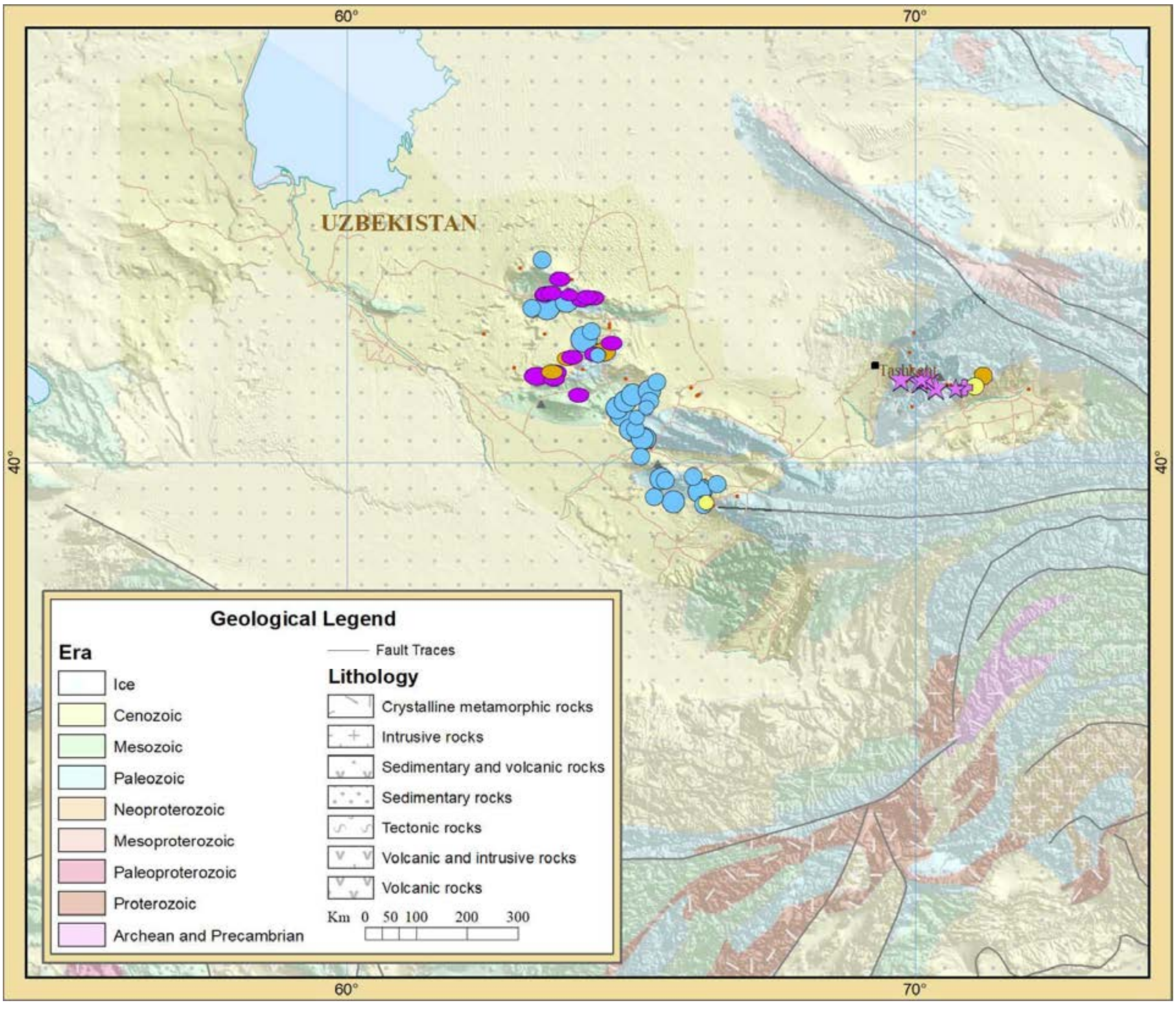


FIG. 7.43. Regional geological setting of Uzbekistan showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Tien Shan Mountains are composed of Devonian and Carboniferous red and carbonate strata distorted into linear folds of north-eastern strike and magmatic formations (mainly granites). The lithologies of the folded complexes of the median massifs comprise Carboniferous and Permian volcanogenic rocks, Devonian limestone and numerous intrusions of granodiorite.

The structure of the Fergana intermontane basin comprises Mesozoic and Cenozoic platform formations (sandy, clayey and locally coal-bearing). Many areas in the mountain areas of Uzbekistan are renowned for their seismicity. The Turan Plate comprises several plateaus bounded by deep faults. The basement is composed of Precambrian crystalline schist and the overlying sedimentary cover is, for the most part, composed of terrigenous, carbonaceous and salt-bearing deposits (Carboniferous). In the overlying troughs of the southern Tien Shan occur Carboniferous volcano–sedimentary and flysch–molasse deposits with granitoid intrusions.

The basement of the plate is composed of NW-SE parallel magmatic arcs and forearc accrecionary wedges developed during late Paleozoic to Triasic times. Then, extensional basins formed in the basement between Jurassic and Paleogene. Extensive thick Neogene to Quaternary sedimentary formations covers more than 75% of the country surface [23.2].

Uzbekistan is rich in a variety of minerals. Bismuth deposits are associated with Tien Shan magmatic formations, porphyry copper deposits are associated with diorite, complex polymetallic ore deposits are associated with carbonate rocks and gold deposits are associated with formations of volcanic origin. Gold and uranium deposits also occur in the Precambrian rocks of the Kyzylkum Desert. Oil is extracted in the Fergana Valley. Deposits of tungsten, coal, potassium salts, salt, sulphur, graphite, clays and semi-precious stones are also found in Uzbekistan [25.2, 25.3].

7.25.3. Uranium exploration

Uranium exploration in Uzbekistan predates the mid-1940s commencement of mining of the small vein deposits (Uiguz Sai, Shakaptaz and others) in the Fergana Valley in eastern Uzbekistan. Exploration, comprising airborne geophysical surveys, ground radiometry and underground work undertaken throughout the early 1950s across the far-flung Kyzylkum Desert in central Uzbekistan resulted in the finding of uranium in the Uchkuduk area. The preliminary finding was confirmed by drilling. This led to the development of the first open pit mine at Uchkuduk, which commenced operation in 1961.

After development of a model for uranium deposits held in unconsolidated oxidized Mesozoic–Cenozoic sedimentary rocks, core drilling and a variety of geophysical downhole logging methods come to be the main tools of exploration applied in investigating the sedimentary environment.

On the basis of knowledge gained about the deposit characteristics and the use of advanced drilling methods, vast areas were explored in the Karakata Depression, which is situated in the Bukinai area, and along the southern margin of the Zirabulak–Ziaetdin Mountains. This resulted in the finding of signficant sandstone-hosted deposits of uranium, comprising Ketmenchi, Lavlakan, Sugraly, Yuzhny Bukinai, Sabyrsai and Severny Bukinai. Moreover, in 1961, prospecting for deposits of uranium in metamorphic schists in the Altyntau and Auminzaatau areas commenced. This led to the finding of the Koscheka and Rudnoye deposits of uranium–vanadium–molybdenum.

Development of the ISL (in situ leaching) method for retrieval of uranium from sandstone deposits in the early 1970s paved the way for the re-evaluation of formerly disregarded deposits, comprising Ketmenchi and Lavlakan, and to an expansion of efforts for exploration aimed at the sedimentary environments of the Kyzylkum Desert.

Exploration was focussed on the south-eastern sector of the Zirabulak–Ziaetdin Mountains and on the north-western Nuratau Mountains. The findings made in these areas comprise the Severny Maizak and Shark deposits (Zirabulak–Ziaetdin Mountains) and the Yuzhny Kanimekh, Severny Kanimekh and Alendy deposits (Nuratau Mountains). Identification of the polymetallic nature of the sandstone uranium deposits paved the way for the finding of scandium, rhenium, molybdenum and selenium as probable by-products during ISL treatment.

From 1994, the NMMC (Navoi Mining and Metallurgical Complex) has financed all activities for exploration of uranium in the country. Exploration for uranium is the accountability of two organizations. Exploration at and in the vicinity of each deposit is the accountability of the geological departments of the producing companies. The exploration for new deposits is conducted by Kyzyltepageologia (the State geological company). Yet, from the early 1990s, exploration drilling has been focused on the delineation and development of known deposits and the exploration for expansions in these deposits. Kyzyltepageologia also conducts prospection and exploration work in new areas.

Kyzyltepageologia developed in 1995–1996 the known resources of the Tokhumbet, Kendyktyube, Alendy and Severny Kanimekh deposits. Moreover, evaluations of undiscovered resources were made in the Fergana, Bukhara-Khiva and Kyzylkum Provinces. Kyzyltepageologia appraised, in 1997–2000, the existing resources (reasonably assured resources and estimated additional resources (EAR-I)) of the Ulus, Tokhumbet, Severny Kanimekh and Kendiktyube deposits. Part of the resources in these deposits was then transferred to NMMC for development. Neverttheless Kyzyltepageologia continued to delineate the margins of these three deposits.

Delineation drilling was carried out in 2002 on the Kendyktyube and Tokhumbet deposits. Some of the resources was moved to Mining Division No. 5 for economic development. Exploration and resource assessment of the extensions of the Shark and Sabursai deposits was resumed. Exploration and resource assessment of the Yangy site of the Tutly deposit was starting.

Kyzyltepageologia carried out exploration and appraisal work in 2003–2004 on the Tokhumbet and Kendyktyube deposits, on the Senoman ingress, which is regarded as a small deposit situated on the south-western fringes of the Sugraly deposit, and on both the eastern and western fringes of the Ketmenchi deposit. It also explored the southern and northern areas of the central Kyzylkum. Historical exploration data, carried out after 1993. Historical uranium exploration trends are shown in Fig. 7.44 for a total of 7 072 700 metres of drilling within an expenditure of USD $269 715 000. This can be regarded as a minimum because data from 2010 is not reported [25.4-25.7].

All major resources of Uzbekistan are located in the central Kyzylkum area, which correspond to a belt measuring 125 km in width and over ~400 km in extent from Nurabad in the SE to Uchkuduk in the NW. The deposits are found in four districts: Nurabad or Zirabulak–Ziaetdinsky, Zafarabad or West Nuratinsky, Zarafshan or Auminza-Beltausky, and Uchkuduk or Bukantausky. Uzbekistan’s uranium resources are either black shale (breccia complex) type or sandstone type deposits.

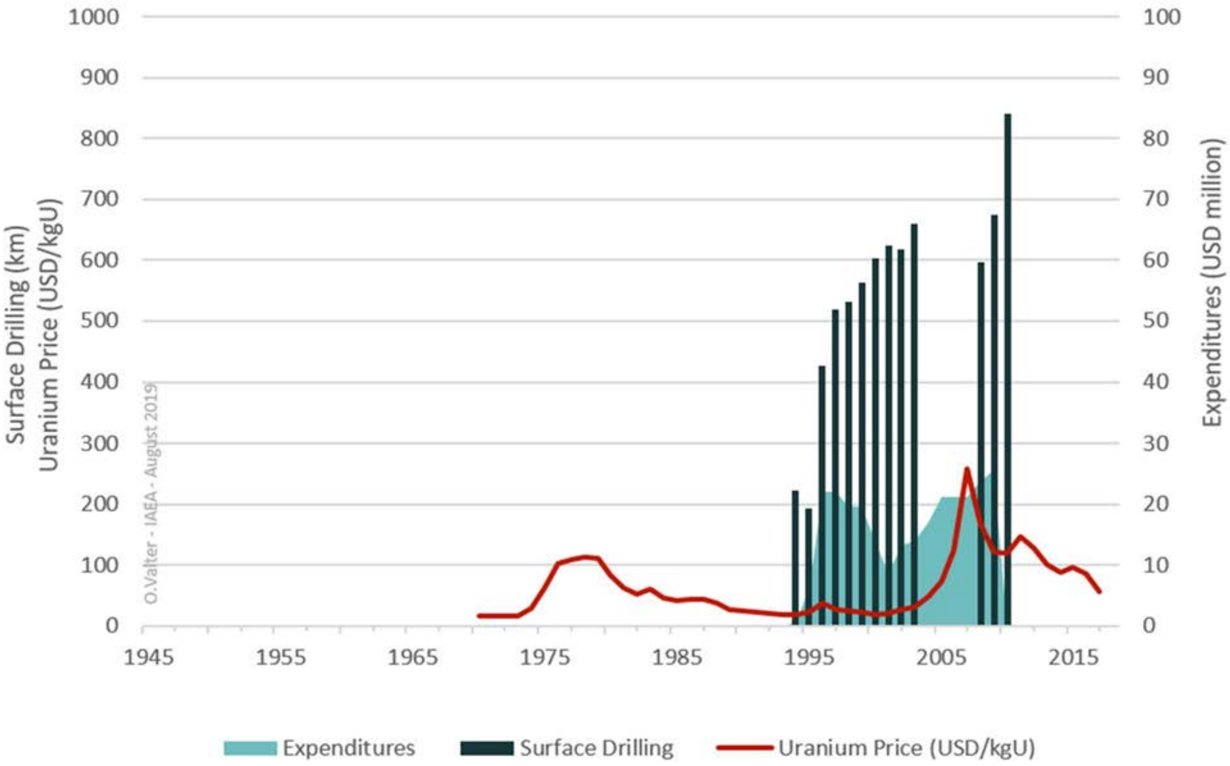


FIG. 7.44. Uranium exploration data for Uzbekistan. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

7.25.4. Uranium resources

The variation in historic identified convetional resources is shown in 7.45 and 7.46.

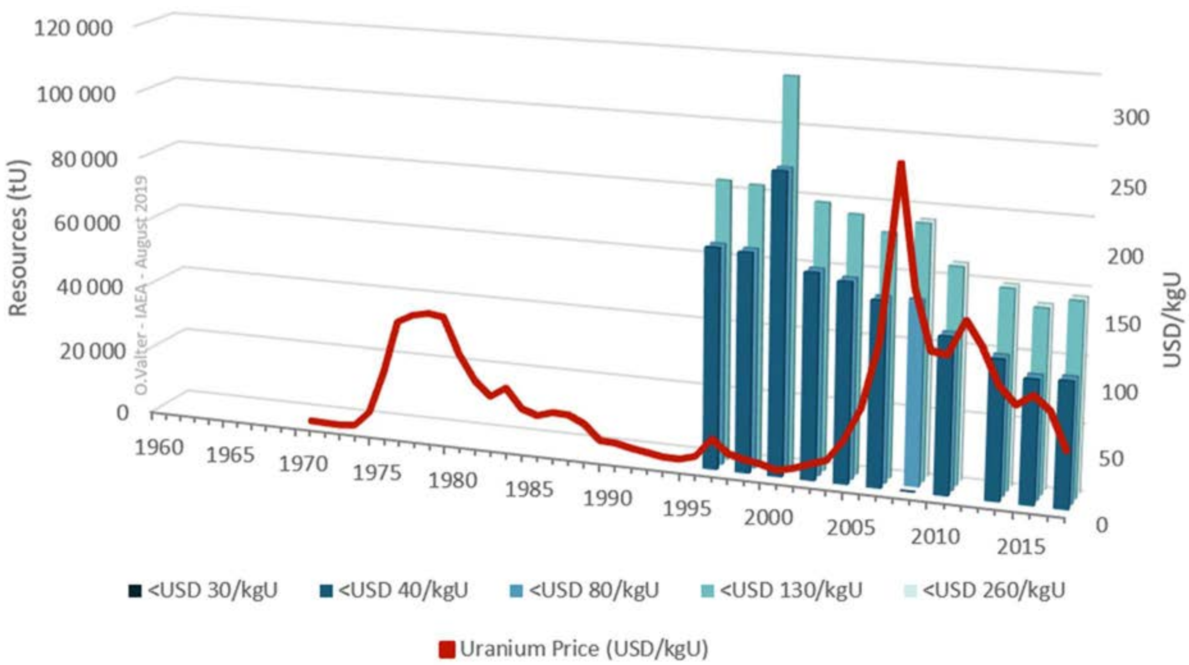


FIG. 7.45. Historical variation of recoverable reasonably assured resources within various cost categories in Uzbekistan. Periods where no resources are shown in any cost categories are periods where resources were not reported , either by the Member State or as a secretariat estimate.

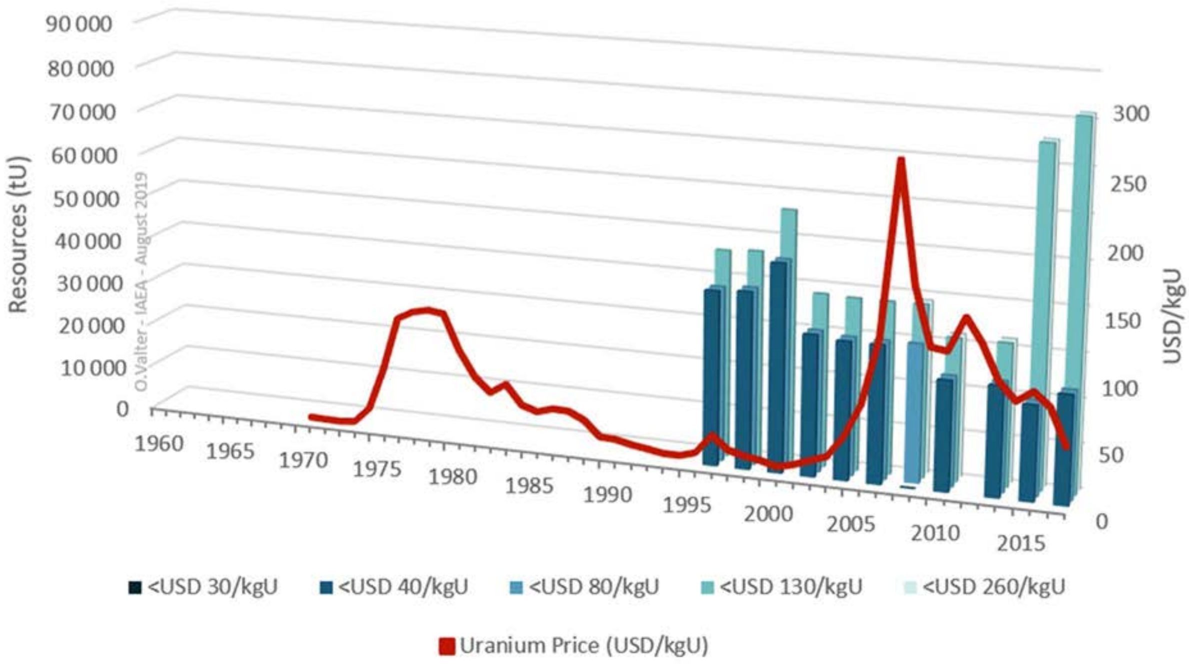


FIG. 7.46. Historical variation of recoverable inferred resources within various cost categories in Uzbekistan. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

Tectonically deformed and metamorphosed Precambrian–Lower Palaeozoic siliceous and black carbonaceous schists host the black shale (breccia complex) type deposits. Mineralization is comprised of uranium–vanadium–phosphate ores, which an average grade in the range of 0.06–0.132% U, associated with Mo (up to 0.024%), V (0.1–0.8%), Y (68 g/t) and Au (0.1–0.2 g/t). The deposits extends at depths of 20–450 m. There are seven deposits of the black shale type, most of which could be exploited by open pit mining and then by heap leaching [25.8].

The sandstone type deposits can be found in Mesozoic–Cenozoic depressions occupied by up to 1000 m thick Cretaceous, Palaeogene and Neogene clastic sedimentary rocks. The uranium is enriched as roll fronts (oxidation–reduction zones) in sandstone and in gravel units. The mineralization comprises sooty pitchblende and pitchblende with minor coffinite. Average ore grades are in the range 0.026–0.18% U. Associated elements are represented by lanthanides, scandium, rhenium, molybdenum, vanadium and selenium in potentially economic concentrations. However, except for vanadium, these commodities are rarely recovered on an economic basis. The depth of the orebodies varies in the range 50–610 m. Twenty-five uranium deposits of this type are documented, several of which are amenable to ISL extraction methods.

As of 1 January 2017, identified resources (reasonably assured and inferred), associated with sandstone and black shales hosted deposits, recoverable at costs of <US $130/kgU totalled 139 150 tU (Tables 7.13 and 7.14) [25.9].

Undiscovered resources (prognosticated) as of 1 January 2017 amounted to 24 800 tU.

TABLE 7.13. REASONABLY ASSURED RESOURCES (tU) [25.9]

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU
Sandstone	37 370	37 370	57 610
Total	37 370	37 370	57 610

TABLE 7.14. INFERRED RESOURCES (tU) [25.9]

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU
Sandstone	24 320	24 320	48 640
Black shales	0	0	32 900
Total	24 320	24 320	81 540

The UDEPO database lists the most significant deposits for Uzbekistan as Uchkuduk, Sugraly, Bukinay South, Sabyrsai, Yuzhny Bukinai, Kendyktjube, Bukinay North, Kenimekh, Severny Kanimekh.

7.25.5. Potential for new discoveries

Although the country has been extensively explored, moderate potential may exist for the discovery of additional uranium resources.

7.25.6. Uranium production

Uranium production in Uzbekistan began in the mid-1940s at a number of small volcanic vein deposits in the Fergana Valley and in the Kazamazar uranium district. The mines are already inactive because the deposits are exhausted. The ore was treated at the Leninabad (Khodzent) uranium production centre in Tajikistan.

NMMC forms part of the State holding company Kyzylkumredmetzoloto and carries out every mining of uranium in the country. Prior to 1992, all uranium mined and milled in Uzbekistan was transported to the Russian Federation. From 1992, all domestic production of uranium has been exported by Nukem Inc to the USA and to other countries.

Throughout the former Soviet era, Uzbekistan supplied a large part of the uranium extracted to the Soviet military–industrial complex. Annual production peaked at 3800 tU in the mid-1980s. Five ‘company towns’ were built to support activities for the production of uranium: Navoi, Nurabad, Zafarabad, Zarafshan and Uchkuduk. These five towns had an aggregate population of ~500 000.

NMMC started to operate at the end of the 1950s and focused on uranium and gold in central Kyzylkum. Initial mining of uranium was underground (until 1990) succeeded by open pit (until 1994). From 1994, NMMC has been generating uranium using ISL techniques only.
The Northern Mining District, 300 km north of Navoi, was founded in 1961 to mine uranium at Uchkuduk by both open pit and underground mining, with the ore processed at a central plant in Navoi. From 1965, ISL extraction has been undertaken at both Uchkuduk and Kendyktyube. The Sugraly deposit was mined underground from 1977 and subsequently exploited by ISL up to 1994, when it was closed. The Sugraly deposit is thick and geologically complex (high carbonate content) and required specialist mining techniques.

Central Mining District No. 5 at Zafarabad, near Navoi, was established in 1971 and became a component of NMMC in 1993. This operation exploits the Bukinai group of uranium deposits using ISL; the mines comprise Severny Bukinai, Yuzhny Bukinai, Beshkak, Istiklol, Kukhnur, Lavlakan and Tokhumbet.

The Southern Mining District at Nurabad, Samarkand Province, was established in 1964 to exploit the Sabirsay uranium deposit of uranium by underground mining, which lasted up to 1983 when ISL was introduced and which remains to be the main mining method. Ownership of the Sabirsay deposit was moved from Tajikistan to NMMC around 1994. Other mines are Ulus, Shark and Ketmenchi (using ISL since 1978).

In 2008, NMMC started mining the major new Severny Kanimekh deposit, NW of Navoi. Severny Kanimekh ore occurs at depths of 260–600 m with 77% of uranium reserves hosted at depths of between 400 and 500 m. NMMC has also began constructing a pilot plant for ISL at the Yarkuduk and Alendy deposits and has commenced operation of the Aulbek ISL mine in central Kyzylkum, as well as at the Meilysai and Tutlinskaya deposits [25.10].

Uranium production was 2385 t in 2015, 2405 t in 2016 and 2404 t in 2017. Total production from 1991 to 2017 is 56 734 t U [25.10]. Total production via open pit, underground, in situ and heap leaching is 1325 tU, 600 tU, 44 559 tU and 780 tU respectively.

Details of historic production data and production centre data are summarized in Fig. 7.47.

FIG. 7.47. Historical uranium production in Uzbekistan.

7.25.7. Future production centres

The Uzbek–Chinese joint venture Uz-China Uran plans to start the mining of black shale (breccia complex) type deposits in the Navoi region by early 2013. Actions will be coordinated to develop technologies for extracting both uranium and vanadium while developing black shale uranium deposits by late 2011 (Table 7.15) [25.11–25.13].

TABLE 7.15. URANIUM PRODUCTION CENTRE TECHNICAL INFORMATION [25.9]
(As of 1 January 2011)

	Centre #1	Centre #2	Centre #3
Name of production centre	Northern Mining Division	Southern Mining Division	Mining Division #5
Production centre classification	Existing	Existing	Existing
Operational status	Operating	Operating	Operating
Startup date	1964	1966	1968
Deposit:			
• Names	Kendyktyube, Sugraly, Uchkuduk, Meilysai	Sabyrsaj, Ketmenchi, Jarkuduk, Yogdu	Shimoliy Bukinai, Janubiy Bukinai, Beshkak, Lavlakan, Istiklol, Kokhnur, Janubiy Sugraly
• Type	Sandstone	Sandstone	Sandstone
Mining/milling operation:			
• Type	ISL[a]	ISL	ISL
• Average recovery (%)	70	70	70
• Annual production (tU)	800	800	2100
Hydrometallurgical plant (Navoi):			
• Average process recovery (%)		99.5	
• Nominal capacity (tU/year)		2350	

[a] ISL: in situ leaching.

7.25.8. Environmental activities and sociocultural issues

At least 30 years' of uranium activities by NMMC have affected the natural environment in Uzbekistan. This comprises the areas impacted by the traditional mining and treatment of uranium ores, and by the running of ISL facilities. Aside from the areas immediately impacted by these activities, surface stocks consisting of an assessed 2.42 million m^3 of sub-profitable uranium-bearing material exist. The grade of this material is assessed to be 0.002–0.005% U. This is besides the 60 Mt of tailings situated close to Navoi Hydrometallurgical Plant No. 1 and groundwater affected by ISL mining. The total area affected by ISL mining is estimated at 13 km^2.

To fully appraise the coverage of any pollution and develop a programme for retrieval and restitution, NMMC is collaborating with Uzbekistan's chief specialists in the field, as well as with regional experts and global establishments. The outcomes of the radiation monitoring of NMMC's uranium mining and treatment activities show that the average effective equivalent radiation dose of the critical population group living in these regions is less than 1 mSv/year compared to the total contributions of all factors of radiation hazard. The overall environmental policy of NMMC with regard to its production activities for uranium is:

(a) To cater for the ecological safety of every NMMC project using the most ecologically appropriate and the cleanest ISL mining technique;
(b) To shut down the mining and treatment projects that are economically and environmentally unsound;
(c) To separate and appropriately dispose of all amassed radioactive wastes;
(d) To retrieve land distraught by the enterprise's uranium activities.

To achieve these intentions, NMMC has been cultivating and undertaking a step-by-step programme for appraising and, where needed, reducing the environmental effects of at least 30 years' of production operations for uranium. Instances of these activities are given in the following sections.

7.25.8.1. Weak acid leaching

From the time it started using ISL extraction in 1963, NMMC has undertaken research, as well as pilot studies, geared towards reducing its deleterious effects on groundwater. After efficacious accomplishment of pilot studies, NMMC executed what it calls 'weak acid leaching', which has the benefit of producing less pollution of the aquifer. Moreover, weak acid leaching is roughly 17–20% cheaper than strong acid leaching. Weak acid leaching has low recovery ratio compared to strong acid leaching, although that shortcoming is more than counterbalanced by its cost and environmental benefits. About 50% of uranium production in Uzbekistan now derives from weak acid leaching.

7.25.8.2. Tailings impoundment

Treatment of uranium ore at NMMC's hydrometallurgical plant during 1964–1994 spawned a mill tailings impoundment covering an area of 600 ha and containing around 60 Mt of tailings. A system of wells has been fixed to observe and check probable groundwater pollution from the tailings impoundment. Retrieved waters are reverted to the plant for use in treatment.

When treatment of traditional uranium ore ended in 1994, NMMC started shielding the tailings impoundment with inert tailings produced from the treatment of gold ore. Roughly 100 ha or 17% of the uranium tailings impoundment area had been shielded with a 0.5–1.0 m layer of inert tailings by the end of 2000. Radon exhalation above the shielded portion of the tailings impoundment has been reduced tenfold and the generation of radioactive dust has been ended in the shielded area. NMMC anticipates to have the while uranium tailings impoundment shielded by 2012.

7.25.8.3. Low grade stockpiles

Throughout underground mining at Uchkuduk, low grade stockpiles with a volume of 1.4 million m³ and occupying an area of 237 000 m² were produced. The stockpiles are situated in enclosed areas indicated with radiation hazard signs. Drains have been set up to check rainwater runoff from the stockpiles. Because of a lack of funding, NMMC has no direct proposals to bury or treat the stockpiles.

7.25.8.4. Waste water treatment

No wastewater with radionuclides is produced throughout NMMC's ISL operations. Based on NMMC studies, residual solutions in aquifers where 'hard' or concentrated acid leaching has been used go through self-remediation to conditions prior to mining after a period of 10–15 years. Weak acid leaching does not considerably alter the constituents of the production aquifer waters.

7.25.8.5. Restoration of exhausted ISL sites

Recovery of exhausted ISL mine sites is undertaken based on national environmental laws. Specific importance is given to cleaning up surface spills of production solutions with sulphuric acid salts and radionuclides. Site restitution comprises gathering and disposing of polluted soil in specifically organised sites. After the site restitution is accomplished, the land is reverted to the owner. From 1994, NMMC has reverted 25 087 ha of recovered lands to landowners, comprising at least 1000 ha of past ISL sites.

7.25.9. National policies relating to uranium

Uranium generation is presently owned and regulated by the State. Private entities, comprising foreign and domestic individuals and companies, are not presently operational in exploration and production for uranium. Uzbekistan states that it keeps no stockpiles of uranium, all production being exported. Information on prices of uranium has not been conveyed [25.9].

References to Section 7.25

[25.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Uzbekistan, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html.

[25.2] STATE COMMITTEE OF THE REPUBLIC OF UZBEKISTAN FOR GEOLOGY AND MINERAL RESOURCES, Mineral Resources of Uzbekistan — New Opportunities for Japanese Investors, http://www.jp-ca.org/navoiforum/materials/no.3/1geologiya.pdf .

[25.3] COMMISSION FOR THE GEOLOGICAL MAPS OF THE MIDDLE EAST (CGMME), Geology of Uzbekistan, http://www.cgmme.com/Article.aspx?CId=Uzbekistan&Txt=1.

[25.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[25.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[25.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[25.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[25.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[25.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[25.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).

[25.11] WORLD NUCLEAR ASSOCIATION, Uranium in Central Asia, http://www.world-nuclear.org/info/inf118_centralasiauranium.html.

[25.12] WORLD NUCLEAR NEWS, Uranium production startup in Uzbekistan, http:wnn.world-nuclear-news.org .

[25.13] TREND, Uzbek–Chinese JV to begin field development, http://en.trend.az/capital/energy/1941387.html.

7.26. YEMEN

7.26.1. Geography

In 1990, the Yemen Arab Republic (West) and the People's Democratic Republic Yemen (South) united to form the Republic of Yemen.

Yemen is located at the southern end of the Arabian Peninsula, and is bordered by Saudi Arabia to the north, the Red Sea to the west, the Gulf of Aden and Arabian Sea to the south, and Oman to the east-northeast. Yemen's territory includes more than 200 islands, the largest of these is Socotra.

Yemen can be divided geographically into four main regions: the coastal plains in the west (flat and arid), the western highlands, the central highlands (high plateau over 2 000 m in elevation), and the Rub al Khali desert in the east. The Rub' al Khali desert, "the Empty Quarter desert" is the largest contiguous sand desert in the world, encompassing most of the southern third of the Arabian Peninsula.

Climate is mostly desertic, hot and humid along the west coast, temperate and affected by seasonal monsoon in the western mountains, extraordinarily hot and dry in the eastern deserts.

Prior to the civil war that began in 2014, Yemen was highly dependent on oil and gas resources for revenue. Principal agricultural commodities produced Yemen include grain, vegetables, fruits, fish, livestock, and poultry.

7.26.2. Geology

Yemen composes part of the Arabian Shield within the larger framework of the Arabian-Nubian Shield (Fig. 7.48).

The basement rocks of Yemen, which represent the southern extension of the Arabian Shield, are of Paleoproterozoic to Neoproterozoic age. Precambrian basement rocks in Yemen comprise metasediments, gneiss and migmatite belts produced in arc tectonic environments intruded by post tectonic granites and granodiorites. These are now located throughout western Yemen from the northwest (Sa'dah−Al Jawf) and southwest areas (Marib-Al-Bayda), in addition to small outcrops in south of Tai'zz and west of al Mukalla.

The oldest rocks of Yemen's sedimentary structures go back to early Proterozoic. Such rocks are represented by Ghaba'er and Gunab groups which have sandstones and limestones. Sedimentary rocks in Yemen comprise Paleozoic, Mesozoic and Cenozoic sediments he formation of the Red Sea's basin was associated with the process of regional uplifting of the western areas of Yemen, through volcanic activities from late Cretaceous to recent time.

Calcareous duricrust is common in the Empty Quarter. It occurs in streaks of a few centimeters to 7 meters of thickness. These beds are Quaternary in age.

Yemen has identified metal resources which include gold, lead, nickel and copper. Fossil fuels are present of petroleum, as well as small deposits of coal.

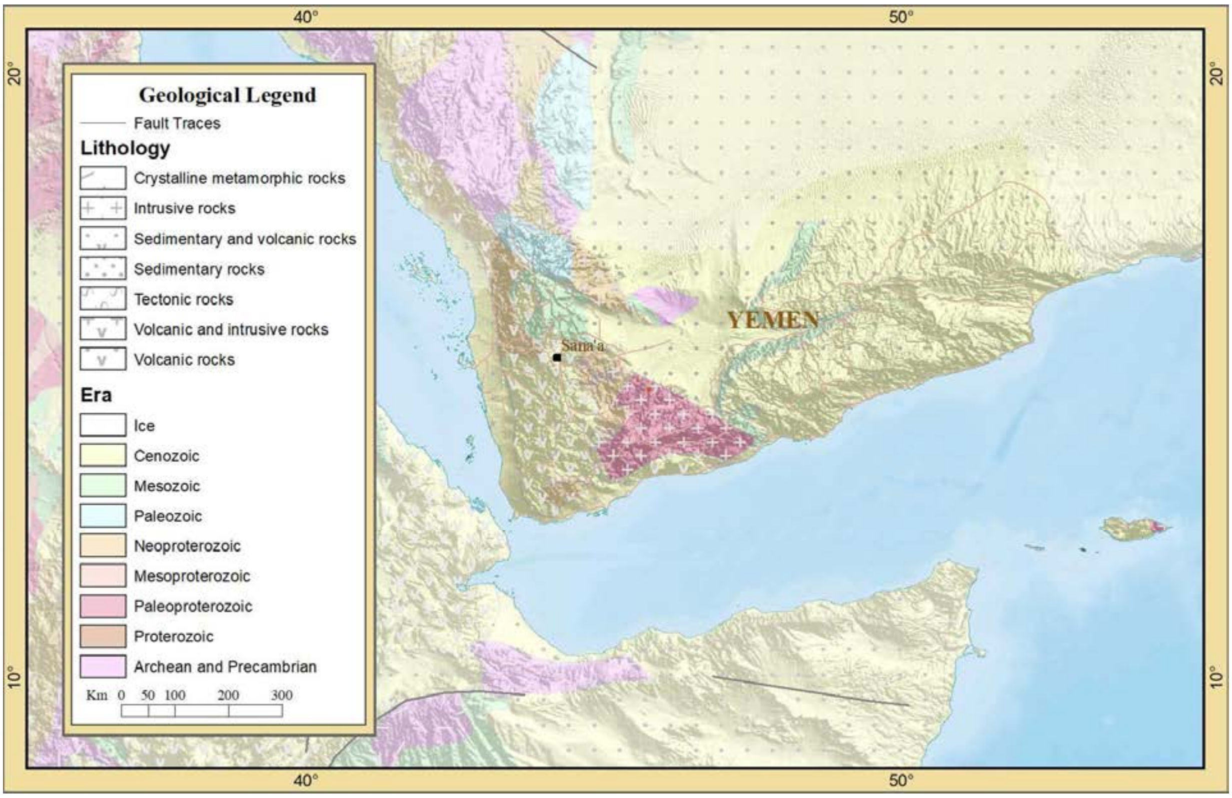


FIG. 7.48. Regional geological setting of Yemen. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

7.26.3. Uranium exploration

Little information is available about any uranium exploration activities in the Republic of Yemen. About 80% of the country is covered by government radiometric surveys from 1975-78.R Radometric surveying by Geosurvey Limited and Robertson Group during 1984-85 is reported in [26.1]. Exploration for radioactive minerals in the North and Southwestern part of Yemen at Suda'a and Taiz, was undertaken by Total Minerals. Radioactive minerals are concentrated in the ironic curst of the Alwajidah sandstones and pegmatite veins. In 1999, the Yemeni Geological Survey and Mineral Resources Board (GSMRB) followed up radioactive anomalies related to granite and pegmatitic veins, including in the regions of Juban City and south part of Nawah Village with support from the Malaysian Government [26.2].

7.26.4. Uranium resources

There are no known uranium occurrences in the Republic of Yemen and no resources of uranium have ever been reported.

The UDEPO database does not list any known deposits for Yemen.

7.26.5. Potential for new discoveries

Uranium may be found as primary type deposits of the shield. Vein deposits may be found in or near granite bodies.

Conglomerate formations similar to those in South Africa may be found in the shield Precambrian rocks. Sandstone uranium type deposits could exist associated to sedimentary formations of the Ghaba'er and Gunab groups.

Calcrete deposits could potentially be found in the duricrust in the Empty Quarter desert.

In 1977, IUREP [26.3, 26.4] estimated the speculative potential of Yemen as minor to moderate, between 1000 and 10 000 tU. This evaluation has not changed.

References to Section 7.26

[26.1] ABDULRAHMAN ABDUL-HADI • WEDAD AL-QADHI, ENAYAT EL-ZEEN. Determination of uranium, thorium and potassium contents of rock samples in Yemen. Journal of Radioanalytical and Nuclear Chemistry (2011) 290, 261–26.

[26.2] WEDAD ALI ABDURABU, AHMAD TERMIZI RAMLI, MUNEER AZIZ SALEH, ARIEN HERYANSYAH, ANEES ALNHARY AND SHADI FADHL. Terrestrial gamma dose rate, radioactivity and radiological hazards in the rocks of an elevated radiation background in Juban District, Ad Dali' Governorate, Yemen. Journal of Radiological Protection, Volume 36, Number 1 (2016).

[26.3] BOWMAN J., CAMERON J., I U R E P NATIONAL FAVOURABILITY STUDIES Yemen Arab Republic (1977) IUREP N.F.S. No. 116.

[26.4] CAMERON J., I U R E P NATIONAL FAVOURABILITY STUDIES People's Democratic Republic of Yemen (1977) IUREP N.F.S. No. 106.

CHAPTER 8. NORTH, CENTRAL AND SOUTH AMERICA

8.1. ARGENTINA

8.1.1. Geography

Argentina, South America's second largest country (after Brazil), has a strategic location with respect to the sea lanes traversing the South Pacific Ocean (Drake Passage, Beagle Channel, Strait of Magellan) and the South Atlantic Ocean. The climate is varied, ranging from tundra in the far south to tropical in the north. The topography is likewise diverse, with the rich plains of the Pampas covering the northern half of the country, the rolling to flat plateau of Patagonia to the south, and the Andes extending along the western boundary with Chile.

The Andes are the world's longest continental mountain range, a continuous chain of high land which runs along the western coast of South America. The range is at least 7000 km long, 200 km–700 km wide (the widest part occurring between a latitude of 18–20° S) and has an average height of ~4000 m. At least one half, or 3600 km, of this range extends along the western boundary of Argentina.

The Andes range encompasses Argentina, Bolivia, Chile, Colombia, Ecuador, Peru and Venezuela. The Andes range is the highest mountain range outside of Asia. Aconcagua, the highest peak, rising to 6962 m, is the tallest mountain in the Western Hemisphere. Aconcagua is located in the north-western part of Argentina, in Mendoza Province. Also located in Argentina is Laguna del Carbon in Santa Cruz Province, which at -105 m is the Western Hemisphere's lowest point.

The climate is mostly temperate; arid in the SE and sub-Antarctic in SW. The country has abundant natural resources, including copper, iron ore, lead, manganese, silver, tin, zinc, petroleum and uranium [1.1]. Argentina was the 12th largest silver producer in the world in 2009 [1.2].

8.1.2. Geology

8.1.2.1. General

The Andes range is a Mesozoic–Tertiary orogenic belt of mountains along the so-called 'Pacific Ring of Fire', a zone of volcanic activity and orogeny that encompasses the Pacific rim of the Americas as well as the Asia–Pacific region. The Andes are the result of plate tectonic processes and were created as the result of subduction of oceanic crust beneath the South American Plate. The main cause of the uplift of the Andes is due to the compression of the western rim of the South American Plate resulting from the subduction, from the west, of the Nazca and the Antarctic Plates. To the east, the Andes are bounded by several sedimentary basins, such as the Orinoco, Amazon, Madre de Dios and Gran Chaco Basins, which separate the Andes from the ancient cratons of eastern South America. In the south, the Andes shares an extensive boundary with the former Patagonian terrain.

Along its length, the Andes range is split into several ranges and separated by intermediate depressions. Two of the more prominent ranges are the Cordillera Oriental and the Cordillera Occidental.

The South American landmass consists of a craton, which was created throughout the Brazilian orogenesis in the Late Precambrian and is mostly covered with unfolded younger sediments. There are intrusives of various ages in both the craton and in its cover. Along the Atlantic, the craton breaks off abruptly and this feature, together with its 'jigsaw' fit with the west coast of Africa, contributed to theories of continental drift and plate tectonics. Along the Pacific coast, the craton is bounded by the Cordilleras, an orogenic fold belt which runs north–south. This belt was mainly created throughout Late Mesozoic and Tertiary times by the relative westwards movement of the continent which resulted in underthrusting of the Nazca and Antarctic Plates from the west. Volcanism has been widespread throughout the Cordillera and continues in certain areas. An orogenic belt separates the Precambrian Patagonia Massif from the Rio de la Plata Massif to the north, suggesting that the former was part of the old, greater Antarctic continent. A geological map of Argentina is presented in Fig. 8.1.

FIG. 8.1. Regional geological setting of Argentina showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The South American craton proper is made up of five massifs joined by a series of fold belts. A sixth, the Patagonia Massif, occupies a somewhat different geological position and may be part of the old Antarctic continent. The Patagonia Massif is very poorly exposed. It is probably mainly of Proterozoic age and consists of metamorphic and plutonic, mainly granitic rocks, and has an extensive cover of Palaeozoic rocks.

Though younger sediments are well distributed throughout the continent, three areas of thicker and more continuous sedimentation can be distinguished. One of these is the Paraná Basin, in southern Brazil, Uruguay, Paraguay and northern Argentina.

Permian sediments are widespread throughout the Paraná Basin and usually consist of sandstones, shales and limestones deposited under continental or lagoonal conditions. Coal deposits are relatively common.

The majority of the rocks exposed in the Cordilleras of South America are of Mesozoic and Tertiary age and the main orogenic events took place at this time. Remnants of older rocks and events are present.

In the NW part of Argentina, the Sierras Pampeanas fold belt and the NW striking Palaeozoic orogeny represent more complicated geology. Precambrian rocks occur throughout the Andes and these, together with the Palaeozoic rocks, consist of both marine and continental sediments. Granitic intrusives and rhyolitic volcanics are also present. Geosynclines formed throughout the Mesozoic and Cenozoic are found in Chile and westernmost Argentina.

In general, Lower Palaeozoic sediments are better represented in the southern part of the Cordilleras, mainly by marine shales, sandstones and quartzites. The Mesozoic in the south is not metamorphosed [1.2, 1.3].

8.1.2.2. Potentially favourable uranium-bearing areas

Virtually all known Argentine uranium resources are contained within sedimentary rocks in continental or transitional facies from the Permian, Cretaceous and Tertiary periods.

Situated in the NW of the country, the northern sub-Andean region is characterized by the presence of Cretaceous and Tertiary sediments distributed discordantly across Palaeozoic formations. Recent reports on exploration in this area, particularly associated with silver and other metals, are available, although there has been insufficient work done to allow compilation of a uranium resource.

The Pampas Mountain region contains three distinct uranium districts: Cosquin, Los Gigantes and Comechingones. Tertiary continental sediments run north–south between crystalline basement mountain ranges of the Sierra Grande and the Sierra Chica in Córdoba Province, 50 km NW of the city of Córdoba.

The pre-Cordillera region in La Rioja Province, NW of Córdoba, includes the districts known as Guandoacol and Los Colorados. The most important deposit discovered here has been the Urcal deposit, which is hosted in brecciated calcareous conglomerates as peneconcordant lenses. The main Los Colorados deposit occurs as lenticular bodies, hosted in carboniferous sandstones and pelites.

In the Sierra Pintada region, the uranium occurrences in the south of Mendoza Province form the San Rafael district. Palaeozoic, Mesozoic and Cenozoic strata are the host rocks, of which the most important sandstone deposit hosts are the Permian and Permo-Triassic sequences. Uranium occurrences follow various sedimentary models in sandstones and conglomerates, and occur as accumulations in peribatholithic schists, veins and stockworks and calcretes.

In Chubut Province, in Patagonia, uranium occurrences found in Cretaceous sediments were noted as being of little economic importance in 1980. Several occurrences noted by the Comisión National de Energía Atomica (CNEA) in the Cretaceous of Chubut have been the targets of foreign mining exploration companies in recent years [1.4–1.7].

8.1.3. Uranium exploration

8.1.3.1. Historical review of work undertaken and expenditures

The first uranium surveys in Argentina began in 1948 with the assistance of various State entities. From 1950, exploration was pursued more actively by the former Dirección Nacional de Energía Atomica. In 1956, all activities were grouped under the CNEA.

In the late 1960s, it was estimated that 400 000 km² of Argentina could be highly prospective for the presence of uranium deposits on the basis of the geology of the country and the information available on numerous uranium deposits and occurrences.

By the end of 1969, at least 20 000 km² of the areas referred to above had been covered by airborne prospection. Follow-up airborne prospecting of a more detailed character conducted across 5500 km² on a 250 m grid led to the discovery of the Sierra Pintada district in San Rafael (Mendoza Province). The discovered deposits are associated with Permian sandstones, the thickness of the mineralized formation varying in the range 2–12 m, with grades averaging 0.08–0.13% U.

Regular airborne prospection continued and a new uranium-bearing district, Sierra de Pichinan, was discovered in the Chubut Province, 30 km NW of Los Adobes. Various uranium bodies were identified in sub-horizontal sandstones and conglomerates of Cretaceous age. Also throughout the 1960s, the La Estela and Schlagintweit vein deposits were discovered by ground exploration in granitic terrain. The resources were later mined in the production centres of La Estela and Los Gigantes, respectively.

Airborne surveys also resulted in the finding of the Dr. Baulies deposit in the Sierra Pintada district in the Mendoza Province. Mineralization in the Los Gigantes district consisted of uranium accumulations in the Sierra Los Gigantes granite. The best known deposit is Schlagintweit, which had initial resources of 1700 tU. The Dr. Baulies deposit was associated with lenticular bodies in Permian sandstones. Initial resources were estimated to be of the order of 12 300 tU at 0.09% U.

In the 1970s, follow-up exploration at and around earlier found occurrences of uranium in Patagonia resulted in the finding of two additional sandstone deposits: Cerro Solo and Cerro Condor. An airborne survey conducted in 1978 in Patagonia assisted in the finding of the small Laguna Colorado deposit which is hosted in a volcanic environment.

In 1986, ground work following up airborne survey anomalies identified the Las Termas vein deposit in the Catamarca Province. In the late 1980s, CNEA initiated a programme to evaluate favourable geological units.

The Cerro Solo uranium–molybdenum deposit in Patagonia was the target of exploration activities in the 1990s. Cerro Solo is a sandstone hosted uranium–molybdenum deposit lying at a depth of 50–120 m. The estimated resources are 9230 tU (reasonably assured plus inferred resources [1.8]) at 0.2% U. A pre-feasibility study was followed by preliminary testing of the host palaeochannel structure, based on the results of 56 000 m of drilling. The final feasibility study on Cerro Solo was completed in 2001 and the deposit was offered for public auction. However, Local Law 5001/03 prohibits open pit mining in the province, thereby preventing development of the deposit.

Regional assessment of the overall potential of the country for uranium continued through 2000 and areas of interest were selected for more detailed study. The reinterpretation of old CNEA data and more recent Geological Survey of Argentina data supported continued exploration and geological mapping. An IAEA technical cooperation project was approved to support these activities.

Areas and host environments selected for more detailed study included: Las Termas vein deposit; assessment of host rocks (sandstones) for potential use of in situ leach technology; exploration of targets identified through airborne surveys in Patagonia (sandstone and volcanic); favourability studies in granitic environments (vein type) and metallogenic studies in the Sierra Pintada and Cerro Solo deposit areas.

A reassessment project, including evaluation drilling, laboratory scale testing of treatment methods, resource evaluation, and survey of environmental conditions at the Sierra Pintada production centre was approved in the 1990s and accelerated in 2000.

The 2005 Red Book [1.9] reports that car-borne gamma ray survey instrumentation was put into operation as recommended under an IAEA technical cooperation project [1.10]. Figure 1.2 indicates the location and nature of the uranium deposits in Argentina.

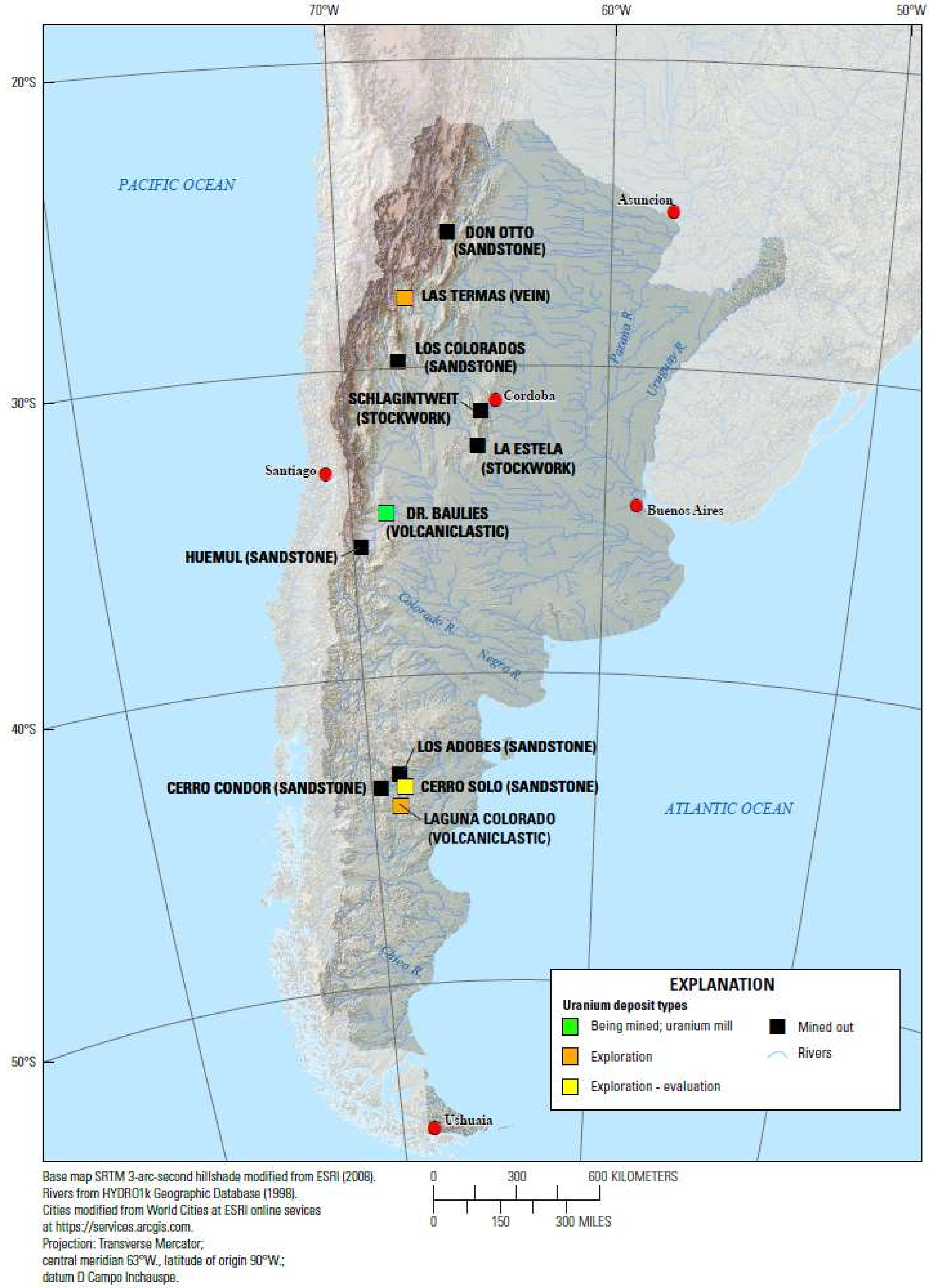


FIG. 8.2. Uranium deposits of Argentina.

As shown in Fig. 8.3, industry (non-government) was involved in exploration and drilling throughout 2004–2005, when uranium exploration activity was increasing worldwide. No industry drilling has been reported since 2005. Total exploration expenditure was USD $132 163 663, including 605 492 metres of drilling.

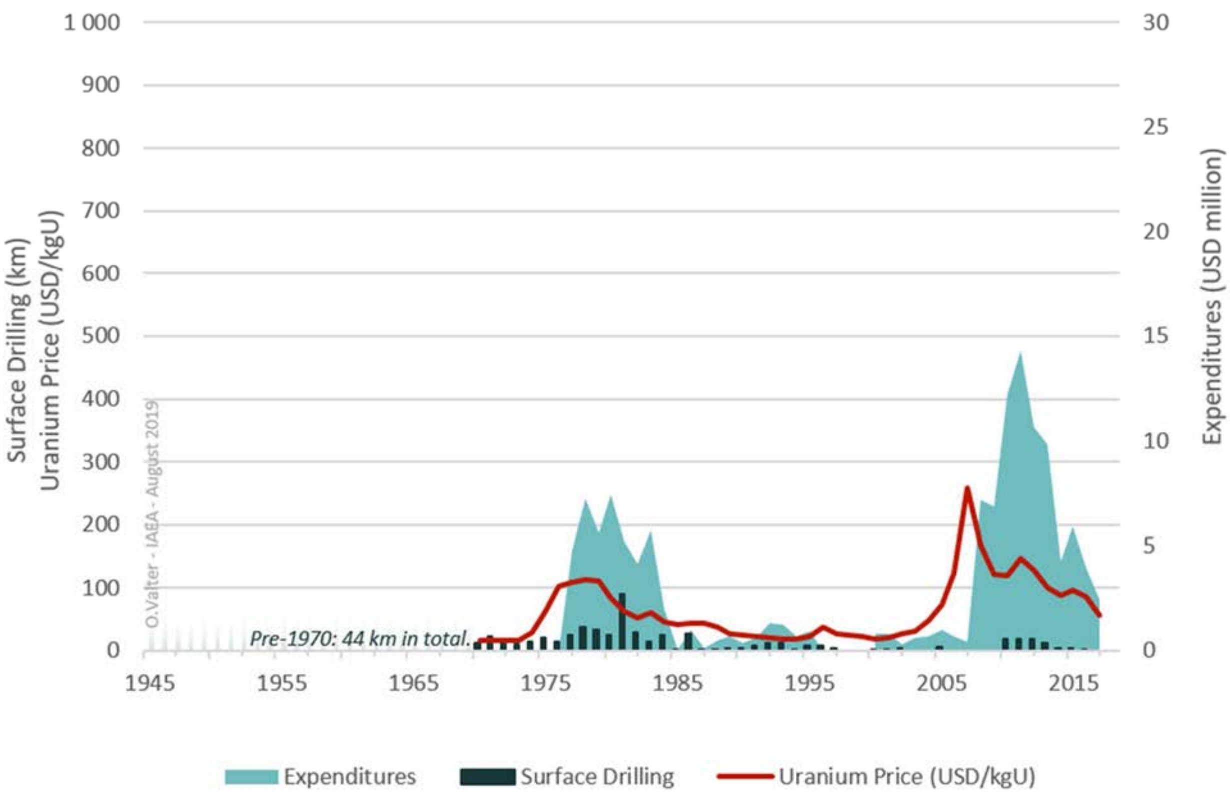


FIG. 8.3. Domestic uranium exploration data for Argentina. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

8.1.3.2. Recent and ongoing uranium exploration and mine development activities

The U3O8 Corporation announced the acquisition of Mega Uranium Ltd's South American uranium properties on 8 April 2010. With the Laguna Salada project, one of three major projects in Argentina, the company aimed to increase NI-43-101 compliant resources in the short term. Laguna Salada hosts uranium mineralization within three metres of the surface in unconsolidated sandy gravel. In 2011, U3O8 Corp. discovered 2 deposits in the Laguna Salada area, Chubut province, and provided a preliminary economic assessment in 2016. The U-V deposits, Guanaco and Lago Secco, correspond to surficial lacustrine-playa deposits with resources of 3427 and 500 t U respectively at grades of 150-550 ppm. [1.11, 1.12].

Calypso Uranium Corporation publicized on 4 August 2009 that it obtained provincial consent for the exploration phase of the Huemul project at Malargüe, in Mendoza Province. According to Calypso Uranium, the Malargüe deposit has the potential to produce uranium again [1.13].

AREVA NC has investigated its options concerning resources of uranium in southern Argentina and has cooperated with different proprietors, which include Urex Energy Corporation, to support a potential central processing facility. The lowest mineable uranium reserve needed to support such a processing facility was assessed at 8462 tU (22 million pounds of U_3O_8). The idea was that the mining of several satellite orebodies of uranium, controlled by various proprietors, would make available uranium ore feedstock to the central milling facility. Urex Energy has conducted uranium exploration in the Chubut Province, next to CNEA's Cerro Solo uranium deposit.

In 2007, CNEA and the Salta Provincial Government (both through subsidiary entities) moved to a deal to reactivate the Don Otto uranium mine in the Salta Province. This mine was being explored and evaluated to assess the economic feasibility of reopening it. The Don Otto mine is located near to the western margin of the Salta Basin, where sandstone hosted uranium deposits occur in the Yacoraite Formation. The reopening of the Don Otto mine was to be formally started in August 2007 with the aim of producing 30 tU/year, but the project never started. Globe Metals and Mining was formerly working in this area. [1.14]

Following unsuccessful efforts to auction the Cerro Solo deposit, CNEA, in late 2004, announced plans to clarify its strategy for restarting work at the deposit in southern Chubut Province. Between 2001 and 2004, there was also a change in the Provincial Government whereby the new administration designated the vicinity surrounding Cerro Solo an exclusion zone with respect to a law that forbids open pit mining there. Possible strategies involved creating a collaboration with a private company, starting a new auction for the project or formulating another alternative.

Opposition to new mining ventures or plans to reactivate mining was expressed in other parts of the country throughout 2007–2009. Protests were held against exploration for uranium in a UNESCO World Heritage area, Quebrada de Humahuaca (Jujuy Province). Protests counter to mining projects for uranium in the west of Catamarca Province took place on 6 November 2007. CNEA suspended exploration for uranium that was under way in Catamarca Province owing to budgetary constraints.

A proposal in June 2004 to reactivate the Rafael mining–milling complex (Sierra Pintada mine) was submitted to provincial and national licensing authorities. The environmental impact assessment was prepared and studies established that past operations had not adversely impacted the quality of water in the area. Mendoza Province authorities disallowed the proposed project and demanded remediation be conducted prior to restart of production. Local Law 7722 was adopted, which bans the use of sulphuric acid in operations for mining and this further confounded plans to restart activities for mining [1.8, 1.15–1.24].

From 2010 to 2019, successful exploration was carried out on several areas.

Ur America Ltd has focused its efforts on developing its properties in the San Jorge Basin, Province of Chubut. They surround known high grade deposits and historical mines such as the Cerro Solo deposit. Three deposits were discovered, Graben, Plateau West and Plateau East with total resources of 7350 t U at a grade of 265 ppm. The Cretaceous host rock (Los Adobes Formation) is comprised of fluviatile to lacustrine siltstones, sandstones and conglomerates [1.25].

In 2007, Blue Sky Uranium started exploration on the Amarillo Grande Project, Rio Negro Province. The Ivana deposit was discovered in 2016 with resources of 8625 t U at a grade of 207 ppm U [1.25]. The project is located at the SE border of the Neuquen Basin filled with Mesozoic and Cenozoic sedimentary and volcanic deposits. The formations present at the Ivana deposit are continental epiclastic and pyroclastic rocks of the Oligocene-early Miocene Chichinales Formation that were deposited unconformably over the rocks of the North Patagonian Massif. The lower member of the Chichinales Fm, host to the Ivana U-V mineralization, is cross-bedded medium- to coarse-grained sandstone with silicified logs and plants-wood debris [1.26].

8.1.4. Uranium resources

Reasonably assured resources and inferred resources, as of 1 January 2017, are recorded in Tables 8.1 and 8.2. Historical variations in these are shown in Figs 8.4 and 8.5 [1.27].

Prognosticated conventional resources were reported as 1400 tU at <US $130/kgU. These resources exist in the La Volanta deposit in the Cerro Solo area, Chubut Province.

TABLE 8.1. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE (tU) [1.27]

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	2 890	4600	4600
Volcanic-related	2240	4000	4000
Surficial	0	2420	2420
Total	5130	11 020	11 020

TABLE 8.2. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [1.27]

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	2200	11 360	12 410
Volcanic-related	1 800	6 170	6 170
Surficial	0	1 460	1 460
Total	4000	18 990	20 040

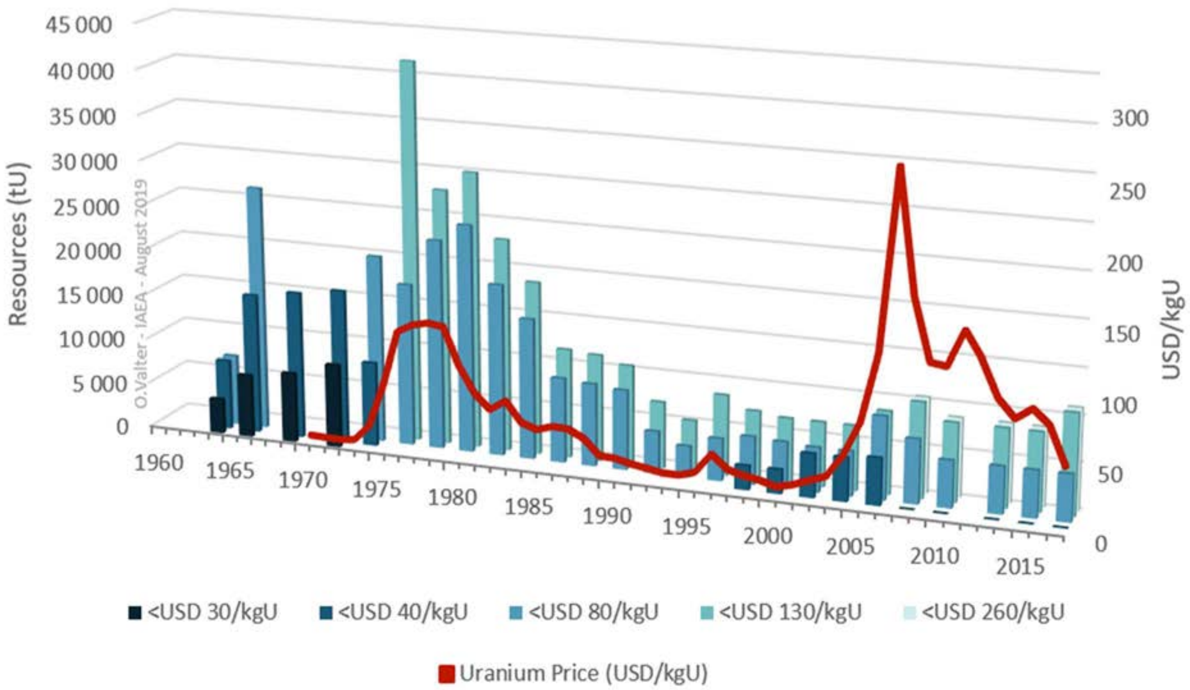


FIG. 8.4. Historical variation of recoverable reasonably assured resources within various cost categories in Argentina. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

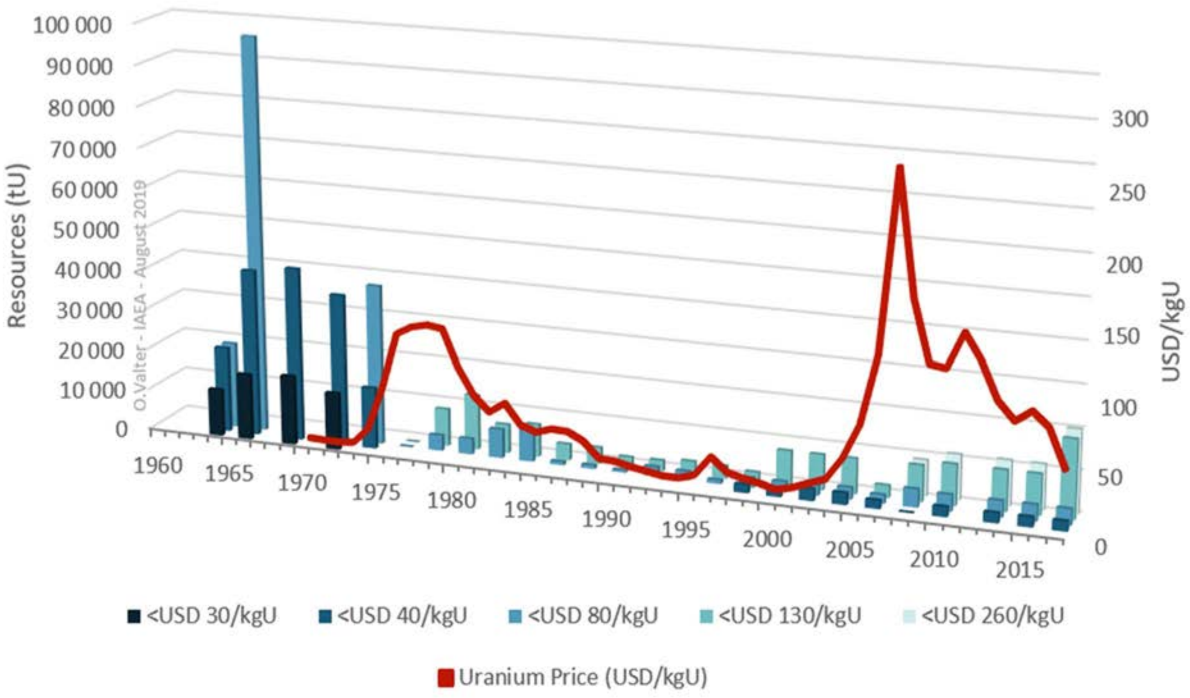


FIG. 8.5. Historical variation of recoverable inferred resources within various cost categories in Argentina. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

The UDEPO database lists the most significant deposits for Argentina as Cerro Solo, Ivana, Tigre I, Graben, La Terraza, Guanaco, Rodolfo, Terraza North, Plateau West, Alipan, Franca, Laguna Sirven.

8.1.5. Potential for new discoveries

There are extensive regions of Argentina where only limited exploration has been undertaken. Considering the extent of the potentially favourable areas and the number of occurrences discovered in earlier exploration programmes, there remains significant potential for new discoveries to be made.

As already mentioned, uranium occurrences have been identified or exploration or mining activities have been carried out in favourable geological environments in seven provinces.

CNEA reported 2000 uranium occurrences in Argentina that are of interest and which remain to be explored. This total includes five occurrences in Chubut Province and one each in Catamarca and Santa Cruz Provinces where no activities have been carried out. The total potential resource for these seven sites is reportedly ~6200 tU [1.7].

8.1.6. Uranium production

Argentina started production of uranium concentrates in 1952. Chronologically, its activities consisted of the following steps:

(a) 1952: Pilot plant in Córdoba, heap leaching, percolation and mechanical agitation;
(b) 1954: Experimental plant at Malargüe (Mendoza Province);
(c) 1963: New plant at Malargüe, mechanical agitation and solvent extraction (80 t ore/d.;
(d) 1963: New plant at Don Otto (Salta Province), heap leaching, 'calcio' pre-concentration (100 t ore/d). Pre-concentrates (2–3% U) were produced at Malargüe and Don Otto and further refined to yellow cake at the Córdoba plant;

(e) 1970: Expansion and application of ion exchange at the Don Otto plant (200 t ore/d);
(f) 1977: New plant at Pichinan (Chubut Province), heap leaching, ion exchange (200 t ore/d);
(g) 1978: Expansion of Malargue, application of ion exchange, solvent exchange (200 t ore/d);
(h) 1979: New plant at San Rafael (Mendoza Province), heap leaching, ion exchange (500 t ore/d).

All of the abovementioned plants processed uraniferous minerals from deposits of the sedimentary sandstone type and all were operated by CNEA.

In 1982, the Los Gigantes production centre (Córdoba Province) went into operation. It had a capacity of 1600 t ore/d of low grade (300 ppm U) ore using the heap leaching and ion exchange processes. The plant was operated by a private company [1.4, 1.13].

Up to the end of 2008, 2839 tU in concentrate was produced by open pit mining. Of this total, 1097 tU was processed at a conventional mill by heap leaching, including treatment of mine water and restoration of the environment. Details of historic production data are summarized in Fig. 8.6 for a total of 2463 tU.

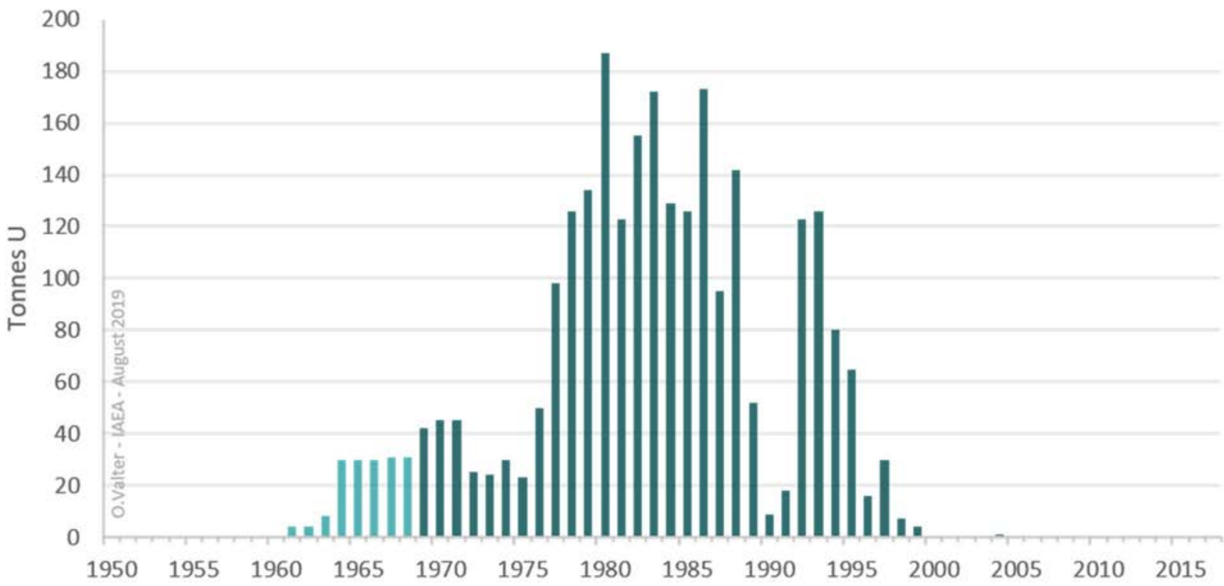


FIG. 8.6. Historical uranium production in Argentina (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

Cumulative national production to 1997 from open pit and at a conventional mill by heap leaching at seven mines was 2643 tU from sandstone deposits including treatment of mine water and restoration of the environment [1.9, 1.13,1.24].

8.1.7. Environmental activities

The European Union project entitled Innovative Strategies for the Preservation of Water Quality in the Mining Areas of Latin America conducted hydrogeochemical investigations to establish baseline values preceding mining operations of the Cerro Solo uranium–molybdenum deposit.

In 2009, an ongoing project to apprise the Sierra Pintada feasibility study emphasized improving surface and subsurface monitoring of water and conducting investigations on management of mining waste and mill tailings as short term objectives.

The World Bank was considering a grant to remediate past mines and production plants for uranium [1.13].

8.1.8. Employment in the uranium industry

In 2002–2005, the uranium production industry hired 60 persons, and in recent years (2006–2008) the number of persons employed in the uranium production industry had risen to 133. This number was expected to increase to 140 by 2009. By way of comparison, in 1989, employment stood at 700, which then decreased each year.

References to Section 8.1

[1.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Argentina, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2010).

[1.2] THE SILVER INSTITUTE, Silver Production, http://www.silverinstitute.org/production.php (2011).

[1.3] ALDEN, A., Generalized Geologic Map of Argentina, http://geology.about.com/library/bl/maps/blargentinamap.htm

[1.4] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[1.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Production and Short Term Demand, OECD, Paris (1969).

[1.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[1.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[1.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[1.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[1.10] PARRA, F.J., RUMIZ, M.L., CNEA paper presented at IAEA Regional Training Course on Uranium Geology and Exploration, Poços de Caldas, 2009.

[1.11] U3O8 CORP., Preliminary Economic Assessment of the Laguna Salada Uranium- Vanadium Deposit, Chubut Province, Argentina. Report prepared by Tenova Mining and Minerals (Australia) Pty Ltd (2014) 322 p.

[1.12] U3O8 CORPORATION, News Release (8 April 2010), http://www.u308corp.com

[1.13] CALYPSO URANIUM CORPORATION, http://www.calypsouranium.com (2009).

[1.14] GLOBE URANIUM LTD, http://www.globeuranium.com.au (12 June 2007).

[1.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources,6Production and Demand, OECD, Paris (1988).

[1.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[1.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[1.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[1.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[1.20] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[1.21] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[1.22] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[1.23] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[1.24] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[1.25] URAMERICA LTD., An Overview of UrAmerica Ltd: Central Plateau Project in the San Jorge Basin, Chubut Province, Argentina (2013) 11 p.

[1.26] BLUE SKY URANIUM CORP., NI 43-101 Technical Report. Initial Mineral Resources Estimate for the Ivana Uranium-Vanadium Deposit, Rio Negro Province, Argentina (2018) 120 p.

[1.27] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

8.2. BELIZE

8.2.1. Geography

Belize is located in Central America and has land borders with Guatemala and Mexico and a maritime border with the Caribbean Sea. It is the only country in Central America that does not have a coastline on the North Pacific Ocean.

The climate is tropical, being very hot and humid. The dry season lasts from February to May; the rainy season from May to November. The terrain is mostly flat with a swampy coastal plain. However, there are mountains in the central and southern areas. A number of mineral occurrences are known, but none have been found in economic quantities. These minerals include dolomite, baryte, bauxite, tin and gold [2.1].

8.2.2. Geology

Belize is located near the junction of the North American and Caribbean Plates, which are sections of the Earth's crust that have moved past each other throughout the last 80 million years. Eastwards drift of the Caribbean Plate has resulted in the dominantly structurally controlled, major features of Belize, i.e., the Maya Mountains, offshore atolls surrounded by deep water and the location of a coral barrier reef.

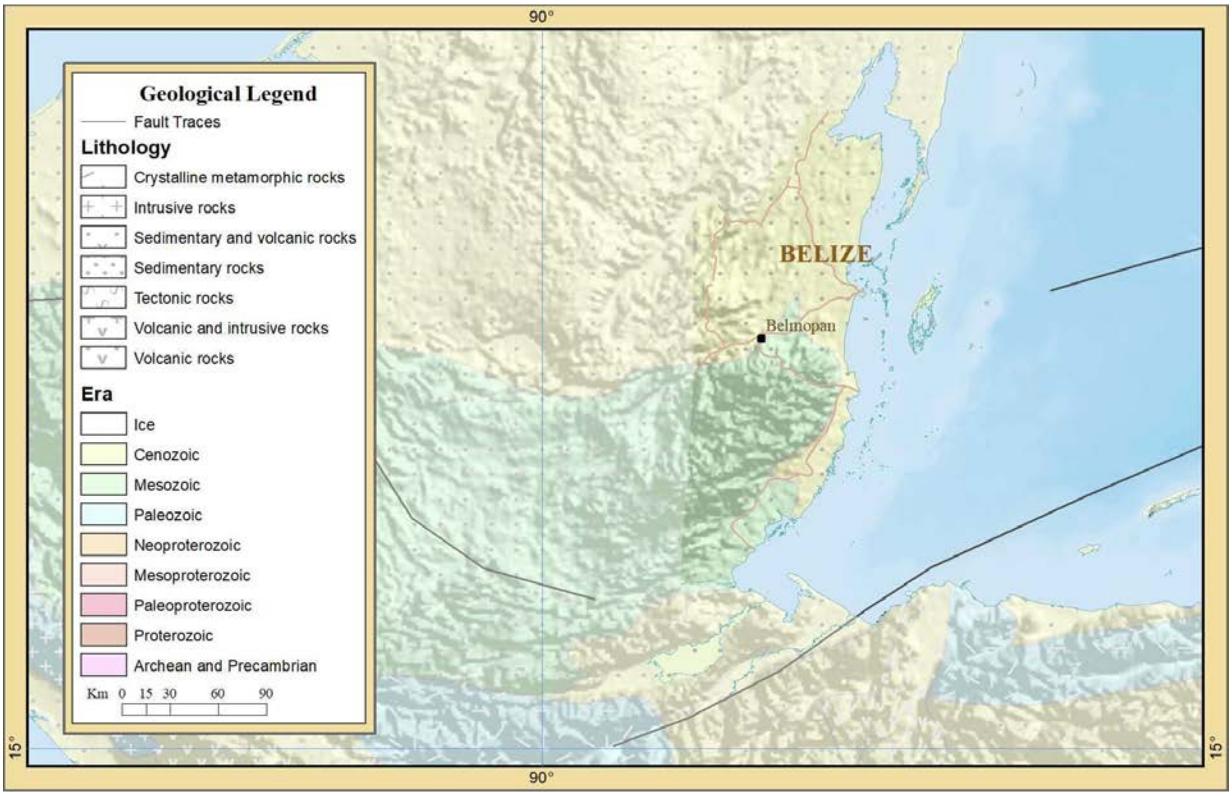


FIG. 8.7. Regional geological setting of Belize. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Maya Mountains represent the high, rugged core of Belize, and consist of igneous, metamorphic and sedimentary rocks that are 320–125 Ma in age (Fig. 8.7). The surrounding flat plains are underlain by Cretaceous and Tertiary rocks (65–1.6 Ma), principally limestones, which indicate that Belize was covered by a warm, shallow sea throughout this period. The Quaternary (Pleistocene) rocks and modern sediments along the coast represent the youngest cycle of deposition in Belize and mainly comprise shallow water, limy sediments.

A number of major faults cross the highlands, although most of Belize sits outside the tectonically active zone that underlies most of Central America. Throughout the Cretaceous period, what is now the western portion of the Maya Mountains existed above sea level, producing the oldest land surface in Central America, the Mountain Pine Ridge plateau. The hilly areas neighbouring the Maya Mountains comprise Cretaceous limestone. These regions are typified by karst topography that is characterized by several underground streams, caverns and sinkholes.

Much of the northern half of Belize sits on a tectonically stable region, the Yucatán Platform. Even though generally flat, this portion of the country also has some karst terrain and hilly areas, like along the western boundary with Guatemala and in the region covering south of Belize City to Dangriga. Alluvial deposits overlie the mostly level topography of the coastal plains. There are no known occurrences of uranium in Belize [2.2, 2.3].

8.2.3. Uranium exploration

No reports on uranium exploration have been made. Belize has not submitted any reports to the Red Book.

8.2.4. Uranium resources

No uranium resources have been reported in Belize.

The UDEPO database does not list any known deposits for Belize.

8.2.5. Potential for new discoveries

On the basis of the rock types reported, there is low potential for locating uranium deposits in Belize. The igneous and metamorphic rocks making up the core of the Maya Mountains would be the only area that would warrant further work.

References to Section 8.2

[2.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Belize, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed July 2010).

[2.2] MAZZULLO, S.J., Late Pliocene to Holocene platform evolution in northern Belize, and comparison with coeval deposits in southern Belize and the Bahamas, Sedimentology **53** (2006) 1015–1047.

[2.3] MERILL, T. (Ed.), Belize: A Country Study, US Library of Congress, US Government Printing Office, Washington, DC (1992).

8.3. BOLIVIA

Bolivia is a landlocked country located in central western South America. The western part of the country is dominated by two ranges of the Andes: the Cordillera Occidental on the western flank of the high plateau (Altiplano) and the Cordillera Real (or Oriental) on the eastern flank. The northern Andes average 5486 m in elevation with the highest point being the Illimani (6458 m) near-by La Paz. The Altiplano ranges in elevation from 3658 to 4267 m and is ~129 km wide. It forms the largest basin of inland drainage in South America and contains the renowned Lake Titicaca which straddles the border with Peru.

The eastern tropical lowlands or pampas (Oriente) comprise roughly two thirds of the country, with rainforest predominating in the northern portion. An intermediate zone of valleys and basins lies between the eastern Andes and the Oriente. The lowlands of Bolivia have a humid tropical climate.

Metals are Bolivia's most important mineral resources and include tin, zinc, tungsten, antimony, silver, iron, lead and gold. Other resources include natural gas, oil, timber and hydropower [3.1].

8.3.1. Geology

8.3.1.1. General

The geology of Bolivia is determined by two main features: the Precambrian Shield in the east and the younger orogenic system of the Andes in the west (Fig. 8.8). These comprise rocks ranging in age from Proterozoic to Pleistocene.

The Bolivian Precambrian appears to be the south-western margin of the Central Brazilian Shield and is found mainly in eastern Bolivia, although two minor occurrences are described from western Bolivia, south of Tarija and SW of La Paz.

The epeirogenic uplift of the eastern Andes occurred in Neogene times and developed two basins: one in the Andean foreland, the other in the Altiplano. The Andean foreland basin is filled with oxidized molasse type sediments, 3000–4000 m thick, derived from the Andean block and which are stratigraphically further subdivided.

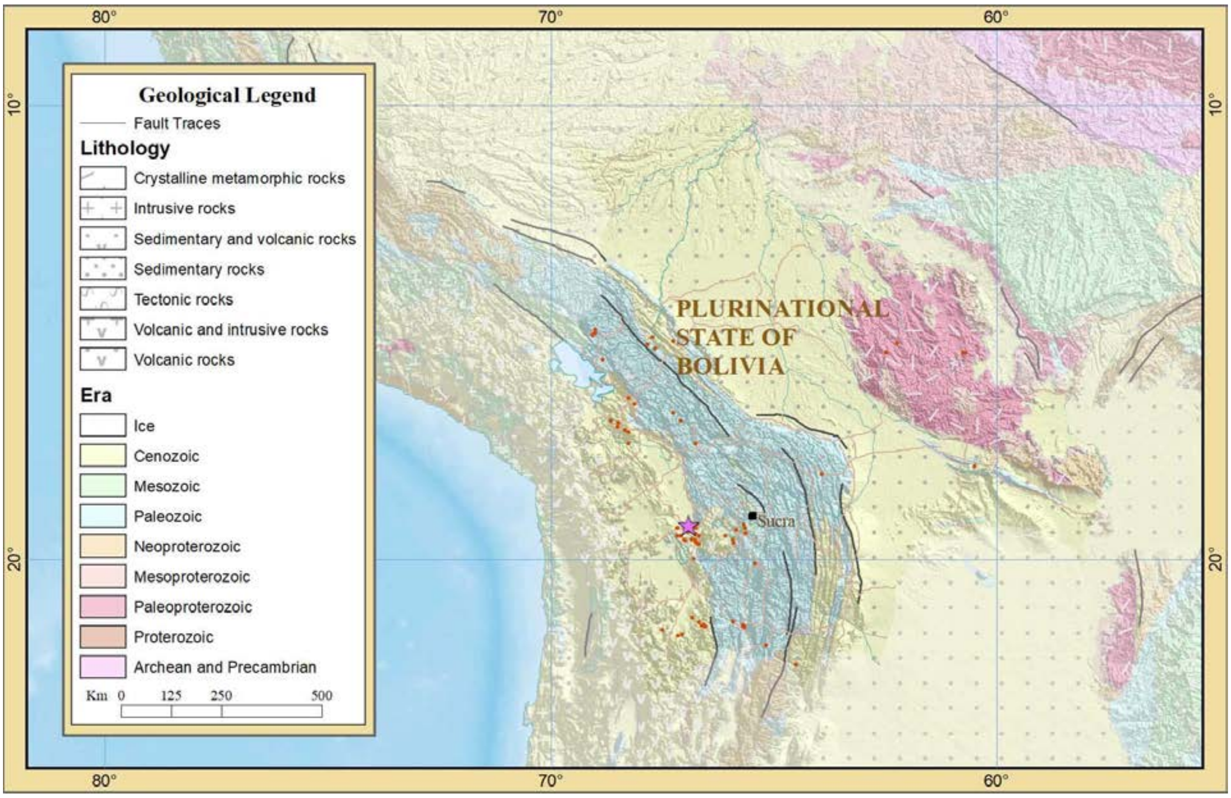


FIG. 8.8. Regional geological setting of Bolivia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The eastern basin occupying the Altiplano area is the type locality for a refined Tertiary stratigraphy consisting of ten different units that lithologically comprise clastic and chemical sediments interbedded with acid to intermediate volcanics. Apparently, the stratigraphic equivalent to the Perez Formation is in the eastern Cordillera: the Los Frailes formation consists of acid–intermediate volcanics, which in the Cotaje area are known to host uranium mineralization. Quaternary deposits cover extensive areas of the

Cordilleras, the Altiplano and the eastern plains and include glacial deposits, fluvial gravels, volcanics, lacustrine sediments and saline deposits.

Much of the country has not been mapped in detail. A high ranking official in Bolivia's mining industry stated in early 2009 that "Bolivia's geological map covers just 25 per cent of its territory" [3.2].

8.3.1.2. Potentially favourable uranium-bearing areas

Along with 20 other countries, Bolivia was one of the countries selected by the International Uranium Resources Evaluation Project (IUREP) for the conduct of an orientation phase. These were countries with a relatively unknown, but promising resource position.

Although Bolivia does not have identified resources of uranium, a large number of occurrences are known, several of which were noted in IUREP reports (1980 and 1985) as being potentially economically viable deposits [3.3, 3.4].

There are no known occurrences of quartz pebble conglomerates or of Proterozoic unconformity related uranium mineralization. Bolivia does, however, have large areas underlain by the Precambrian rock of the Guaporé Shield, including schists, gneisses, migmatites and granites. These rocks, which crop out in the eastern part of the country, are probably of Archaean or Lower Proterozoic age.

Disseminated deposits in igneous and metamorphic rocks

Radioactive anomalies have been found at several locations in the Cordillera de Los Frailes area, which consist of a series of sheets of volcanic material such as rhyolites, lavas, tuffs and other types of Tertiary pyroclastic rocks. The mineralization occurs in fractures or is disseminated in the host rock. The uranium is in the form of pitchblende, torbernite, coffinite and autunite and is associated with iron, manganese, arsenic and molybdenum minerals together with smoky quartz and baryte and is related to a nearby dacitic intrusive. Surface leaching and re-precipitation appear to have played a part in the formation of these occurrences. The grade is around 0.09% U_3O_8.

Locations where granitic intrusives, ranging in age from Triassic to Recent, intersect Precambrian metamorphic or Lower Palaeozoic sediments (mainly dark marine shales and sandstones) are of particular interest. The Bolivian Andes, for instance, could be investigated for mineralization, especially if it can be shown that the granites are of the 'fertile' type.

Vein occurrences are found in the central Cordillera. In the northern part of the Cordillera, several vein occurences have been found containing pitchblende and autunite associated with copper and iron mineralization. The most important finds appear to be the Charazani anomalies and the Urania mine, a former producer of tin and tungsten, located 70 km SE of La Paz. More details are available in the IUREP reports for 1980 and 1985 [3.3, 3.4].

Sandstone deposits

In the Altiplano, many radioactive anomalies have been detected within the Tertiary succession. This basin is filled with continental sediments and volcanics. The rocks are folded and covered by extensive lava flows and ignimbrites.

In the northern sector of the Altiplano, between Peru and latitude 18° S, a high frequency of radiometric anomalies was recorded around Chacarilla and Corocoro. This area contains sedimentary copper deposits of the red bed type. Uraniferous occurrences are linked to palaeochannels where the presence of organic matter played an important role in the precipitation of the uranium.

There are also anomalies in the southern sector, associated with copper and with organic material. The most important anomalies in this area occur at the Kollpani copper mine and at Ague de Castillo.

Other types of deposit in the central part of the Cordillera Oriental

Radioactive anomalies associated with phosphates, organic matter and sulphides have been detected in the Tapacari zone, hosted in Ordovician black shales [3.3–3.5].

8.3.2. Uranium exploration

8.3.2.1. Historical review

In 1953–1955, the Government of Bolivia, in cooperation with the US Atomic Energy Commission, conducted radiometric surveys in 70 metalliferous mining districts, as well as undertaking airborne traverses across the Brazilian Shield. Uranium mineralization was discovered at several mines, including the Siglo XX tin mine.

In 1963, the National Department of Geology, supported by the United Nations Development Programme, conducted an aerial survey across 15 000 km² of the Cordillera de los Frailes and this resulted in the identification of radiometric anomalies.

In 1974, the Bolivian Nuclear Energy Commission (COBOEN) signed a production sharing contract with AGIP of Italy to explore 50 000 km² within the main area of Tertiary red beds. COBOEN was assisted in its work by the IAEA and by France's Commissariat à l'Energie Atomique (CEA).

In the period 1970–1982, COBOEN conducted exploration which was partly supported by the IAEA (1979–1981). In 1970, uranium mineralization was discovered at Cotaje, Cordillera de los Frailes. Subsequently, exploration activities were concentrated on the Cordillera de los Frailes and within the Eastern Cordillera.

Other occurrences were found, including Tholapalca I-III, Los Diques, La Calera and Torko in the Cordillera de los Frailes, and at Yauricoya, Tollojchi, Cohuila and Cerro Sapo in the Eastern Cordillera. Mine development at Cotaje included carrying out heap leach tests (at a pilot plant) on ~12 000 t of mineralized material. COBOEN terminated its active work in 1982.

AGIP, under a production sharing contract with COBOEN, explored four areas in Tarija, Lipez, Corocoro and San Jose de Chiquitos, covering an area totalling 48 778 km². Methods used included airborne and ground radiometrics, geological mapping and drilling. Owing to unfavourable results, the contract was terminated in late 1978.

A geological and multielement geochemical project known as the Precambrian Project was carried out jointly by the Geological Survey of Bolivia (GEOBOL) and the British Geological Survey. The project covered ~220 000 km², corresponding to nearly the entire surface exposure of the Precambrian Brazilian Shield, and included the determination of uranium in several sample media.

An IUREP Orientation Phase Mission was carried out in 1982.

In June 1983, COBOEN was dissolved and the raw material activities were divided between GEOBOL, responsible for activities from uranium exploration through to evaluation, and Bolivia's Research Institute of Mining and Metallurgy, which is responsible for mining and metallurgical activities with respect to uranium. No activities took place between 1983 and 2009.

8.3.2.2. Expenditures

Between 1974 and 1978, AGIP spent US $8 400 000 on exploration and the Government spent US $967 788 in 1977–1982. These expenditures covered airborne radiometric and other surveys as well as surface drilling programmes.

8.3.2.3. Drilling effort

AGIP drilled 18 026 m (113 holes) between 1974 and 1978, while the Government drilled another 2674 m (57 holes) in 1977–1982. The costs of these drilling programmes are included in the total exploration expenditures already noted and are not detailed separately.

Including the planned exploration for 1979, a total area of 49 600 km² was surveyed by airborne spectrometry and 40 000 km² by other methods. In addition, 22 600 m of drilling was completed. Exploration costs between 1972 and 1979 exceeded US $11 million (including US $2.5 million planned for 1979).

Drilling in the Los Frailes sector up to January 1979 indicated an estimated 50 tU resource at an average grade of 0.08% U, as reported in the 1983 Red Book [3.6, 3.7].

8.3.2.4. Recent and ongoing uranium exploration and mine development activities

The Government has confirmed plans to restart uranium exploration at the Cotaje mine in Potosí Department, according to an EFE news agency report in May 2009. The article noted that Bolivia is currently not producing or exporting uranium.

The Government is considering restarting a mine at Cotaje to produce uranium by 2010 if uranium reserves are confirmed. The Government is reportedly not directly involved in the project at the Cotaje deposit.

The IAEA announced, on 27 March 2009, its intention to collaborate with Bolivia in the exploration for, and exploitation of, uranium deposits. Uranium deposits exist in Bolivia; however, the information has been classified by the Government as ‘reserved’.

In the meantime, the National Service of Geology and Mining recognized 11 sites with uranium mineralization in the Cotaje district, between the towns of Huari in Oruro and Sevaruyo in the border area between both departments and the Mulato River in Potosí. However, technical reports indicate that these deposits of uranium are not extensive, but are rather minor discrete concentrations of mineralization. The resources are unknown owing to absence of investment in the quantification work. The Servicio Nacional de Geología y Técnico de Minas, part of Bolivia’s Ministry of Mines and Metallurgy, announced plans to begin work in Oruro in May 2009 [3.8–3.10].

8.3.3. Uranium resources

In the 1985 Red Book [3.7], there were no entries in the reasonably assured resource and estimated additional resource categories. However, ~50 uranium occurrences are reported as having been discovered in the geological–topographical environments of the Precambrian Shield, the Eastern Cordillera and the Altiplano, where a number of deposit types may occur. These include unconformity-related deposits, disseminated magmatic, pegmatitic and contact deposits in igneous and metamorphic rocks (related to both Precambrian and Palaeozoic intrusives and veins associated with Ni, Co, W and Sn mineralization) and sandstone hosted deposits.

Speculative resources, as reported in the 1983 Red Book [3.6], were estimated, according to host strata, as: Precambrian rocks (80 000 tU), Palaeozoic rocks (15 000 tU), Mesozoic rocks (7500 tU) and Tertiary rocks (5000 tU). The distribution of these speculative resources by deposit type is shown in Table 8.3.

TABLE 8.3. SPECULATIVE RESOURCES BY DEPOSIT TYPE (tU) [3.6]

Deposit	Speculative resource (tU)
Unconformity related	0–50 000
Disseminated (magmatite)	0–30 000
Vein (metamorphite)	50–10 000
Sandstone	0–15 000
Others (Tertiary acid volcanics)	50–15 000
Total	100–120 000

As of 1 January 2017, Bolivia reports 1 718 tU of speculative conventional resources [3.11].

The UDEPO database lists the most significant deposit for Bolivia as Cotaje.

8.3.4. Potential for new discoveries

The areas underlain by the Precambrian rocks of the Guaporé Massif could be investigated to ascertain their potential for hosting quartz pebble conglomerate type deposits and possibly for deposits of the unconformity-related type.

The Cretaceous and Tertiary red beds along the sub-Andean zone, as well as Palaeozoic strata and those close to the Precambrian Shield in eastern Bolivia, are also favourable targets. The Lower and Middle Palaeozoic continental sediments are probably lower priority targets.

The large expanse covered by the Tertiary volcanic sheets in the Cordillera de Los Frailes is the most prospective for mineralization of the disseminated type. In addition to this area, there are many other localities in the Bolivian Andes where granitic intrusives, ranging in age from Triassic to Recent, intersect Precambrian metamorphic and Lower Palaeozoic dark marine shales and sandstones.
Areas of Bolivia that are prospective for the existence of sandstone-hosted uranium deposits comprise the Tertiary continental sediments of the Altiplano, which are associated with extensive lava flows and ignimbrites. Other areas of particular interest are those with known occurrences and radioactive anomalies and where the sediments are intruded by granitic stocks or associated with rhyolites, such as the western margin of the Alta Meseta de Los Frailes.

The occurrences of Carboniferous, Permian and Cretaceous red beds preserved within the Palaeozoic rocks along the eastern Altiplano and in the Cordillera Oriental (extending from the border with Peru to Argentina) are also attractive targets [3.5].

8.3.5. Uranium production

News reports in 2009 mentioned that heap leach tests had been conducted in 1974 on 12 000 t of mineralized material from the volcanic-type deposit at the Cotaje mine.

In 2009, the Government announced that the Potosí authorities' would consider restarting operations at the Cotaje mine in 2009–2010 if sufficient resources were confirmed [3.12].

8.3.6. National policies related to uranium

COBOEN (now ABEN) was established in 1969 to control the exploration for radioactive mineralization and its exploitation, treatment and marketing. Foreign agencies are allowed to operate in Bolivia by agreement with COBOEN. In 1983, COBOEN was dissolved and its responsibilities were divided between the GEOBOL and the Research Institute of Mining and Metallurgy.

References to Section 8.3

[3.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Bolivia, Washington, DC (accessed Jul. 2008). https://www.cia.gov/library/publications/the-world-factbook/index.html.

[3.2] Geological map of Bolivia, http://www.geology.com (accessed July 2010).

[3.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[3.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, IUREP Orientation Phase Mission Report: Bolivia, IAEA, Vienna (1985) 29 pp.

[3.5] UNIVERSITY OF CALIFORNIA, Salar de Uyuni, UCLA Geology Field Trip to Bolivia September 2003, UCLA, http://www2.ess.ucla.edu/~bolivia/sidebar_salar.html

[3.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[3.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[3.8] STRATFOR GLOBAL INTELLIGENCE, Bolivia: Government Confirms Plans to Restart Uranium Exploration, http://www.stratfor.com/situation-report/bolivia-government-confirms-plans-restart-uranium-exploration/ (accessed 28 May 2009).

[3.9] EFE-LA PAZ, Bolivia confirms plans to explore for uranium, EFE-La Paz (16 August 2009 www.larepublica.pe/28-05-2009/gobierno-de-bolivia-confirma-proyecto-para-buscar-uranio.

[3.10] WANG GUANQUN, UN offers aid for Bolivia to exploit uranium, Xinhua (27 March 2009), http://news.xinhuanet.com/english/2009-03/28/content_11088015.htm.

[3.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[3.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (2009).

8.4. BRAZIL

8.4.1. Geography

Brazil occupies almost half the South American continent and has 7490 km of Atlantic coastline. To the north, Brazil shares borders with French Guiana, Suriname, Guyana, Venezuela and Colombia and to the west and south with Peru, Bolivia, Paraguay, Argentina and Uruguay. The dominant geographical feature of the country is the Amazon Basin. The Amazon River and its more than 200 tributaries drain ~60% of the country. The basin comprises a vast tropical rainforest, whereas the remainder of Brazil is made up predominantly of highlands. The Central Highlands, which extend into the Amazon Basin, occupy nearly all of the southern area and include major mountain chains. The Guiana Highlands fringe the northern Amazon Basin and extend into Venezuela, Guyana, Suriname and French Guiana. Lowland areas other than the Amazon Basin are found in western Mato Grosso and along the Atlantic coast, extending from French Guiana to Uruguay.

The topography is relatively low lying, much of the country being below 500 m in elevation, and reflects its ancient geological basement and absence of recent tectonism. The Guyana Shield area has mountains which include the highest elevation in Brazil — Pico do Nevlina (3014 m).

Relatively high temperatures and humidity combined with heavy rainfall are characteristic of northern, central and coastal Brazil. Moderate temperatures, humidity and rainfall prevail in the southern uplands. The interior of NE Brazil is subject to variable rainfall, with floods and droughts equally common.

Brazil is extensively endowed with mineral resources. Large iron and manganese reserves are important sources of industrial raw materials and export earnings. Deposits of nickel, tin, chromite, bauxite, beryllium, copper, lead, tungsten, zinc, gold, uranium and other minerals are exploited. In 2011, Brazil was the largest producer of liquid fuels in South America [4.1].

8.4.2. Geology

8.4.2.1. General

Brazil is totally enclosed within the South American Platform, the basement of which has had a very complex geological evolution that originated in the Archaean period (Fig. 8.9). Its consolidation was complete by the beginning of the Palaeozoic period.

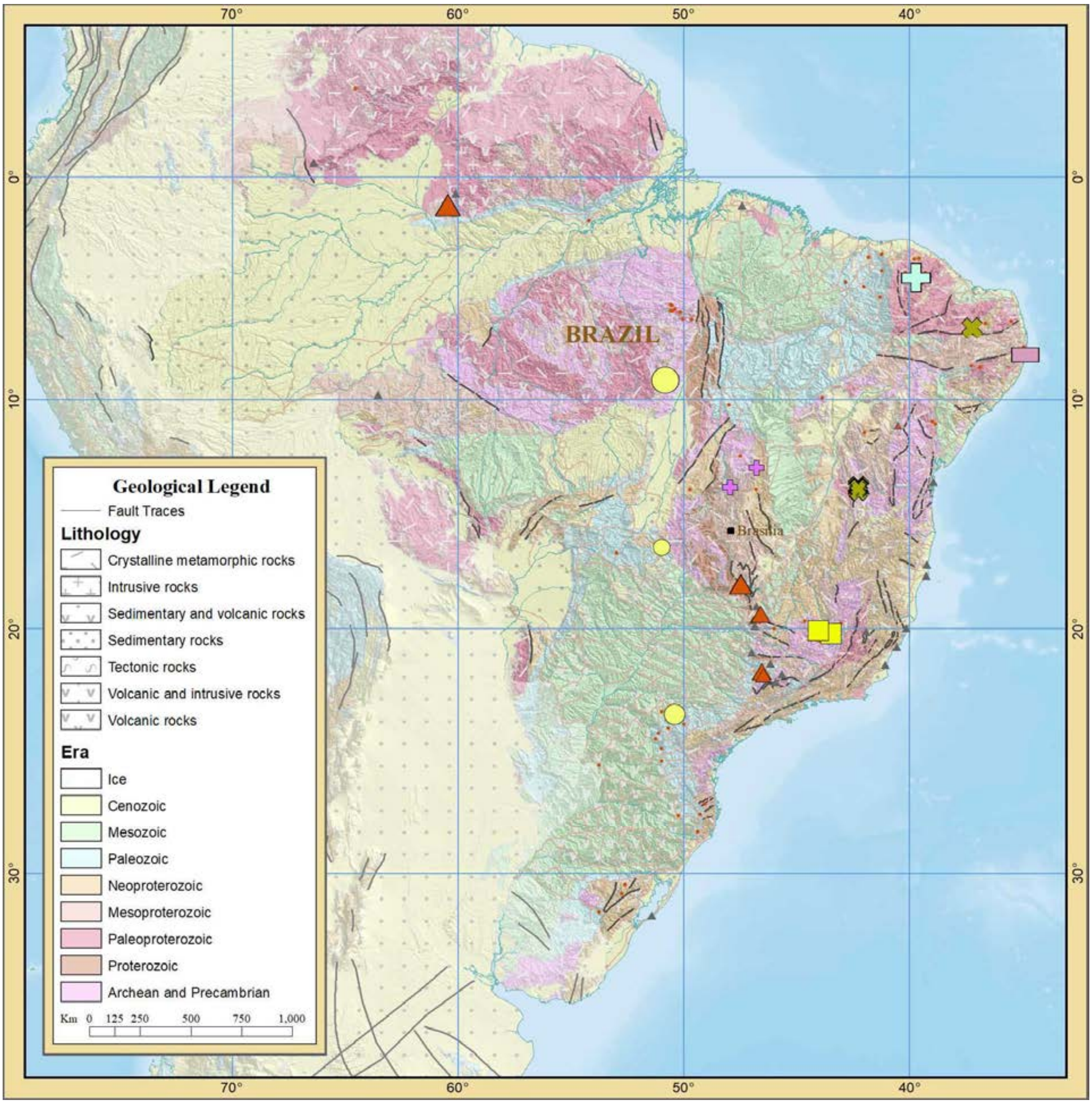


FIG. 8.9. Regional geological setting of Brazil showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The basement of the South American Platform is essentially structured on metamorphic rocks of amphibolite to granulite facies of Archaean age and associated with Proterozoic units that are often represented by folded strips of greenschist facies and sedimentary and volcanic cover (seldom metamorphosed), as well as several granitoids.

The basement is widely exposed in the major Shield areas, separated from each other by Phanerozoic cover, whose limits extend into neighbouring countries. Prominent amongst these are the Guyana, Central Brazil and Atlantic Shields. These Shields are exposed in more than 50% of the country.

The Guyana Shield extends to the north of the Amazon Basin and is made up of crystalline Precambrian rocks. The Central Brazil Shield, or Guaporé, extends into the interior of Brazil and south of that basin, whereas the Atlantic Shield is exposed in the eastern portion, reaching the Atlantic coast.

In stable conditions, throughout the Ordovician–Silurian, sedimentary and volcanic cover developed and filled three extensive basins: Amazonas, Paraíba and Paraná. Several other smaller basins, including coastal basins, are also exposed.

The Brazilian Plateau, encompassing a large area in the central part of the country, is formed by eroded crystalline rocks and sedimentary basins.
In the north of the country, below the Guyana Plateau, are recent river valleys, fluvial terraces and low plateaux of Tertiary sediments. These are known as the plains and Amazon lowlands.

The Pantanal plain in Mato Grosso do Sul is formed of Quaternary rocks, whereas the plains and coastal lowlands to the east and south of the country are formed of strata of Tertiary and Quaternary age [4.2, 4.3].

8.4.2.2. Potentially favourable uranium-bearing areas

Uranium deposits and occurrences in Brazil are localized in several diverse and widely scattered geological settings.

Unconformity-related type

This is the only major type of uranium deposit that has not yet been discovered in South America. Brazil has the most favourable geological environment, in the Guyana Shield, for the discovery of this type deposit.

Sandstone and other sedimentary types

Three major sedimentary basins, the Amazon, Paraná and Piaui Maranhão, contain the bulk of the Palaeozoic sedimentary sequences in Brazil. Each of them is large, generally shallow and partially covered in some instances by Mesozoic and Tertiary strata.

Prospecting has been carried out to varying degrees in all three basins, but to date, appreciable reserves have only been identified in the Paraná Basin (the Figueira deposit). The Amorinopolis deposit is also located in the Paraná Basin; its host rock is arkosic sandstone. Considerable drilling has been undertaken in the Piaui Maranhão Basin but the results have been disappointing.

There are several small Mesozoic basins along the east and NE coast which are mainly filled with Cretaceous sediments. Prospecting campaigns of varying degrees of intensity have been carried out in all of these basins, revealing several areas of potential interest.

These small basins were deposited in fluvial environments, relatively close to potential source rocks. No mineable deposits have been identified.

Igneous and metasomatic type

A large proportion of the known uranium resources in South America is contained in the phosphorous–uraniferous Itataia deposit in the Jaguaribeana Fold Belt, Ceara State, north-eastern Brazil. A large lens of carbonate rock, at least 10 km in length, includes graphite-marbles and calc-silicate rocks with uranium-bearing collophane (microcrystalline apatite) and is intercalated with Precambrian paragneiss strata. The marbles and the gneisses are highly folded and cut by several granites and granitic pegmatites. The Itataia orebodies are located in one of the regional compressional release faults as massive lens shaped and vein-like structures of variable size and morphology but which are concordant with the surrounding marbles.

Disseminated mineralization occurs elsewhere in the Serido geosyncline and hosted in granite and pegmatoid granite where it is restricted to facies containing microcline and quartz as characteristic minerals, with subordinate plagioclase and biotite. The granitic and pegmatoid masses almost always occur on or near the anticlinal axes and exhibit synorogenic genetic relationships. Uranium and thorium occur in roughly the same concentrations (400 ppm) in the granites.

The Espinharas deposit, in Paraíba State, is hosted in Precambrian strata. The mineralization occurs in feldspathic dykes which have been subjected to sodium metasomatism. The primary minerals have undergone complete alteration. Uranium grades average 0.07%.

Uranium enrichment, probably epigenetic, has also been found in the schists of the Serido Group. This mineralization, which occurs at the contact between the schist and the granite, is best developed where fracturing is intense.

North of the Poços de Caldas Plateau, apatite at Araxa has long been a source of phosphate and some uranium has been recovered.

The potential for additional uranium deposits of this type is high. Others include the Tunas Group, which extends from Sao Paulo through Paraná to Santa Catarina and consists of quartz syenite, syenodiorite and related rocks considered favourable for uranium.

Granitization occurred in Brazil from Precambrian to Late Tertiary times. Disseminated deposits related to granites are known in the Serido area. Mineralization similar to that related to the Hercynian granites of Europe could occur in other areas in Brazil. The similarity between some of the mineralization in the Serido district and that at Rössing in Namibia is also encouraging. Geologists from the Comissão Nacional de Energia Nuclear have correlated the belt with the Damara system of SW Africa. There is potential for the occurrence of disseminated uranium in the pegmatite province in NE Brazil and in pegmatites found in east central Brazil.

There are no known Proterozoic unconformity-related deposits in Brazil but with the extensive occurrence of Proterozoic sediments and metasediments conditions could exist that would be favourable for the development of this type of deposit.

Quartz-pebble conglomerate type

Uranium is known to occur in conglomerates in the Quadrilatero Ferrifero area in the vicinity of Belo Horizonte, Minas Gerais, in the Onca do Pitangui area ~100 km west of Belo Horizonte and in Serra de Jacobina, in Bahía.

In the Quadrilatero Ferrifero, the Rio das Velhas Series, which consists mainly of phyllites and schists of Archaean age, is unconformably overlain by the Minas Series. This latter series is divided by disconformities into four groups. These include the Tamandua Group (quartzites and dolomites), the Caraca Group (quartzites and phyllites whose basal part is the Moeda Formation), the Itabira Group (which contains extensive iron and manganese deposits) and the Piracicabab Group (quartzites, dolomites and phyllites). The uraniferous meta-conglomerates are contained in the Moeda Formation which is comprised mainly of quartzites of varied grain size interlayered with conglomerate lenses and phyllites.

Mineralized lenses made up of well-rounded quartz pebbles occur in restricted areas of the Moeda Formation, coinciding with its widest sections. These have a maximum thickness of 1.5 m and no lateral continuity. Detrital uraninite and pitchblende, together with torbernite and metatorbernite, have been identified in association with pyrite, which usually makes up 5–20% of the rock. Gold and other minerals occur with the uranium in the conglomerate.

These conglomerates were likely deposited in a fluvial environment and the source of the sediments of the Moeda Formation was granites that were intruded into the Rio das Velhas Series throughout a metamorphic event dated at around 2800 Ma. The Minas Series is overlain by the Itabira Group which contains the oldest Precambrian red beds in this area.

Occurrences in the Onca do Pitangui area are in conglomerates similar to, and probably contemporaneous with, those of the Moeda Formation. They occur at the border of the São Francisco Craton, an extensive area which is the most stable of the Brazilian central region. These conglomerates are, however, stratigraphically located in the upper to middle part of the sedimentary unit and no basal conglomerates have been discovered. The thorium and titanium concentrations are higher here than in the Moeda Formation.

The Gandarela and the Serra Des Gaviotas deposits are also of the quartz-pebble conglomerate type.

Vein type

The Serido region, in north-eastern Brazil is potentially favourable for hosting vein type deposits.

Other rock types

Elevated levels of uranium have been measured in Palaeozoic black shales in the Piaui Basin [4.4].

8.4.3. Uranium exploration

8.4.3.1. Historical review

Methodical prospection for radioactive minerals started in 1952 and was undertaken by the Brazilian National Research Council. Brazil also entered in a joint programme with the US Geological Survey and sponsored by the US Atomic Energy Commission. This programme resulted in numerous discoveries, the most notable of which was the discovery of pyrochlore at Araxa, north of Poços de Caldas, and of uranium in the Serra de Jacobina in central Bahía.

In 1962–1966, a new exploration campaign was undertaken with the cooperation of France's Commissariat à l'Energie Atomique. The work was concentrated in the Maranhão and Paraná areas and on the alkaline intrusions of the Poços de Caldas, where mineable deposits were discovered.

In 1966–1970, exploration work was conducted by the Comissão Nacional de Energia Nuclear and a systematic evaluation of the entire country began.

Work primarily focused on the Palaeozoic and Mesozoic sedimentary basins. However, some reconnaissance work carried out in the Precambrian strata led to the selection of large areas suitable for airborne geophysical surveys. In 1970–1978, there was a significant increase in the number of airborne gamma ray surveys flown across the Precambrian basement. By 1977, airborne radiometric surveys had covered ~750 000 km² of the country.

Between 1970 and 1975, the main reserves at Poços de Caldas and at Figueira were outlined. In 1974, Empresas Nucleares Brasileiras S.A. (Nuclebrás) was established by the Government and assumed responsibility for exploration, mining and milling of uranium.

In 1975, Germany and Brazil entered into an agreement with Canada to undertake geophysical exploration across a large area. In the same year, the discovery of deposits was announced at Amorinopolis (sandstone) and at Campos Belos (vein) in Goias.

The anomaly which became the Itataia deposit was discovered by a Nuclebrás geologist in July 1977. Drilling started in the area in July 1977 and by 1979, eight orebodies had been found.

In 1979, exploration in Roraima generated considerable interest but details were not published. Geophysical reconnaissance detected uranium and thorium anomalies near the borders with Venezuela and Suriname.

There was no exploration reported between 1991 and the late 1990s. As of 1994, all uranium activities were the responsibility of Indústrias Nucleares do Brasil (INB). In 1995–1996, INB completed the feasibility study for the Lagoa Real site. INB carried out an airborne survey in November 1999 covering the major areas of the Rio Cristalino region, which concluded with the identification of 240 anomalies.

Limited exploration was carried out from 2000 onwards, with no exploration reported in 2005–2008 [4.4–4.6].

Work done

Over the years, exploration work included large scale airborne radiometric and other car-borne and geochemical surveys, as well as surface drilling. Despite this, much of the country remains unexplored.

8.4.3.2. Expenditure

Expenditures on uranium exploration in Brazil in the period 1969–1978 amounted to US $121.3 million. In the period 1979–1984, an additional US $52 million was spent (Table 8.4).

8.4.3.3. Drilling effort

From 1969 through 1983, at least 800 500 m of surface drilling were completed. A total of at least 3200 holes were drilled.

In 2004, the Government spent US $1.4 million on exploration and drilled 40 holes totalling 8000 m. The 2004 drilling programme was conducted at Lagoa Real in order to better define the thickness and continuity of the Cachoeira and Engenho deposits, since old boreholes were widely spaced. The results confirmed the continuity and the grade of the orebodies.

Expected expenditures for 2007 were US $1 million, which included drilling costs for ~100 holes (5000 m). Completion of this work, planned for 2007, did not materialize. For 2009, 1000 m of drilling was planned at a projected cost of BRL 10.2 million.

Exploration and development expenditures and drilling are displayed on Fig. 8.10 for a total of 702 630 metres of drilling included within an expenditure of US$ 191 917 000.

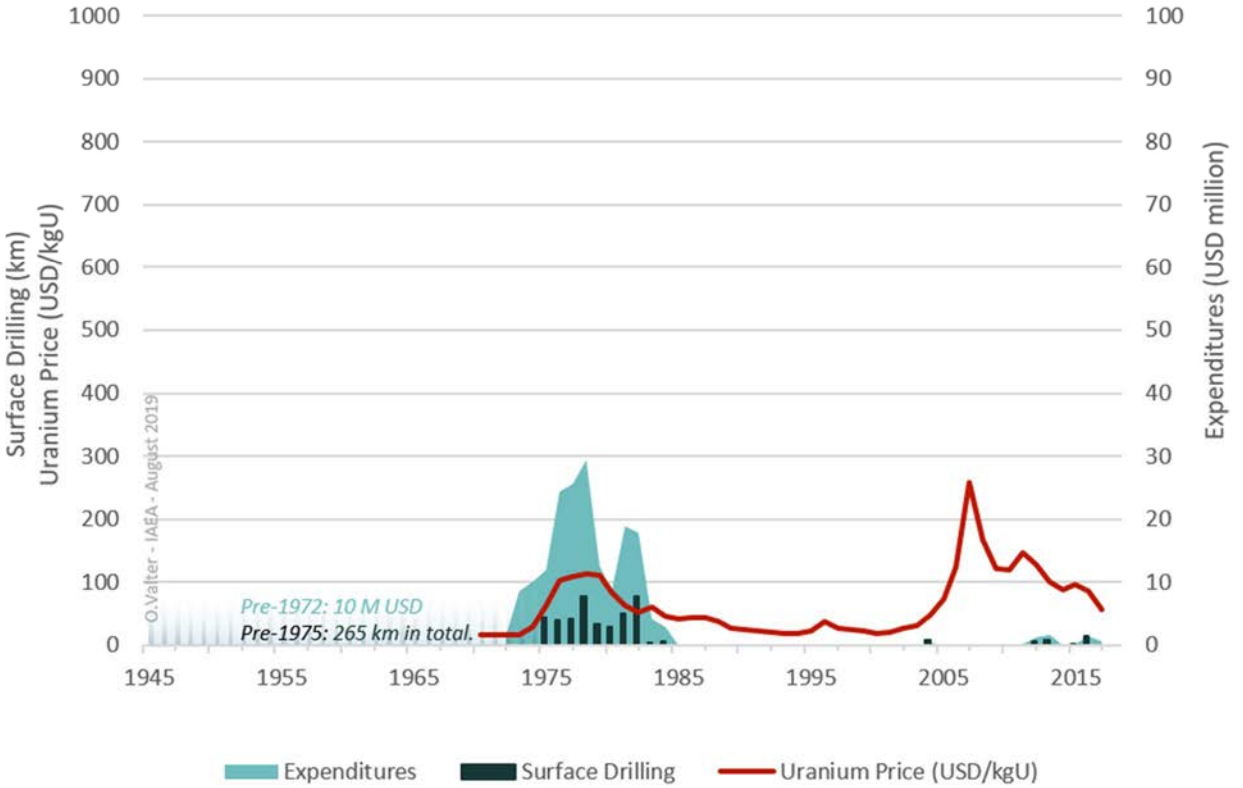


FIG. 8.10. Domestic uranium exploration data for Brazil. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

8.4.3.4. Recent and ongoing uranium exploration and mine development activities

Drilling and other activities for development in the Lagoa Real Province were planned for 2009 in order to verify the size of the Engenho and Cachoeira deposits.

Geological mapping of additional targets in Bahía State was scheduled to begin by the close of 2009, and in the Rio Cristalino area, in Pará State, trenching and processing tests were also planned for that year.

In July 2009, the Brazilian fertilizer company Grupo Galvani announced that it was to sign a 25-year contract with INB to develop a uranium and phosphate mine. The contract is worth US $420 millions and mining would occur at Itataia, near Santa Quitéria, in Ceará State. The mine would increase Brazil's uranium concentrate production fourfold and its phosphate output by 10%. The new production centre will begin to be operational in 2012 and will have a starting annual output of 180 000 t of phosphate and 1200 t of uranium concentrate. Galvani will be responsible for marketing the phosphates, while the uranium mining and usage will be a prerogative of the State. With this undertaking, it will be the first time that INB has worked in partnership with the private sector. Production is now planned for 2014–2015 with Galvani extracting uranium from phosphates on behalf of INB. INB has stated that when production eventually reaches the planned 1600 t/year of concentrate, Brazil will be able to fulfil its domestic requirements for new nuclear plants.

According to a report in The Latin American Herald, a memorandum of cooperation on the peaceful use of nuclear energy was signed by the Russian Federation and Brazil in order to pave the way for production of radioisotopes and training of nuclear energy experts [4.7–4.9].

Discovery costs and resources are provided in Tables 8.4–8.7.

TABLE 8.4. DISCOVERY COSTS
(As of 1 January 2009)

RAR[a] (tU)	Inferred resources (tU)	RAR and inferred resources (tU)	Production (tU)	Exploration expenditures (US $million)	Discovery cost (US$/kgU)
157 700	121 000	278 700	2068	186 577	0.67

[a] RAR: reasonably assured resources.

8.4.4. Uranium resources

8.4.4.1. Identified resources

As of 1 January 2017, identified in-situ resources in Brazil totalled 382 300 tU (Tables 8.5 and 8.6) [4.10]. Historical variation in reasonably assured resources and inferred resources are shown in Figs 8.11 and 8.12 respectively.

TABLE 8.5. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE [4.10]
(As of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Granite-related	25 400	50 800	50 880	50 880
Metasomatite	82 300	82 300	82 300	82 300
Plutonic,peralkaline complex	500	500	500	500
Phosphate	76 100	76 100	76 100	76 100
Total	184 300	209 700	209 700	209 700

TABLE 8.6. INFERRED RESOURCES BY DEPOSIT TYPE [4.10]
(As of 1 January 2017)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Granite-related	0	0	67 700	67 700
Metasomatite	0	5000	5000	5000
Plutonic, peralkaline complex	0	26 400	26 400	26 400
Sandstone	0	13 000	13 000	13 000
Quartz-pebble conglomerate	0	15 000	15 000	15 000
Phosphate	0	44 600	44 600	44 600
Total	0	104 900	172 600	172 600

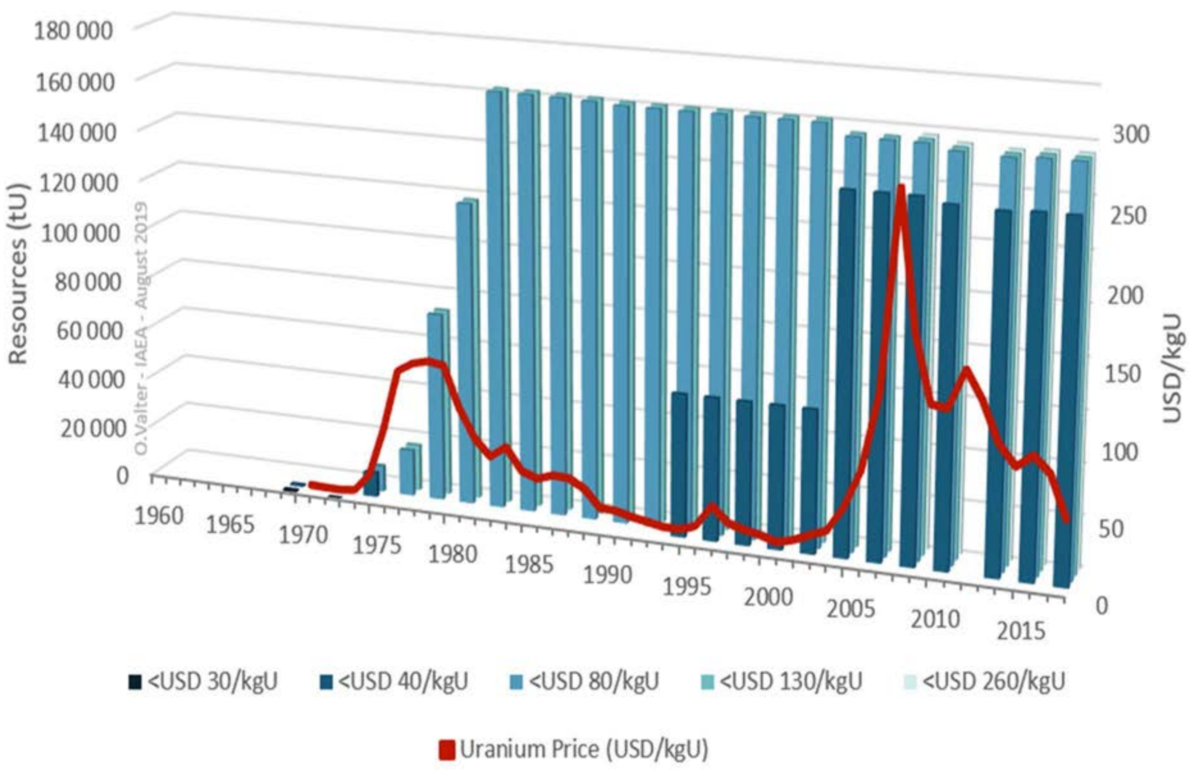


FIG. 8.11. Historical variation of recoverable reasonably assured resources within various cost categories in Brazil. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

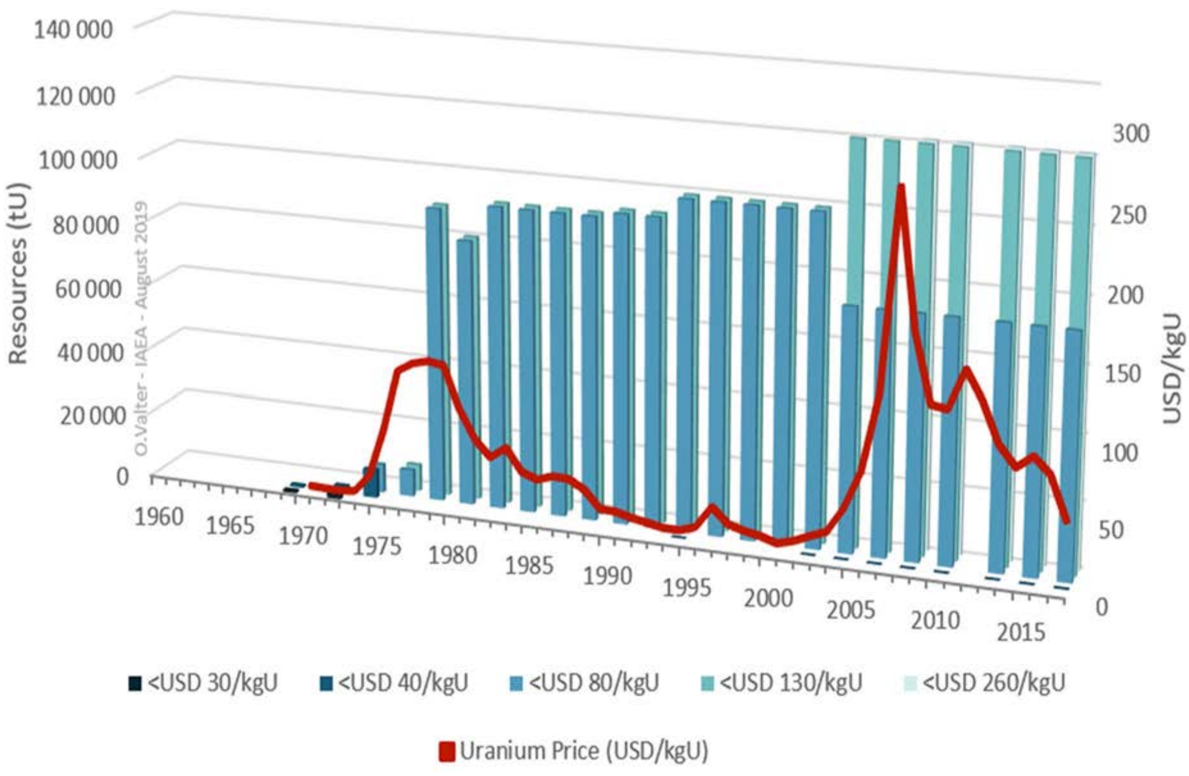


FIG. 8.12. Historical variation of inferred resources within various cost categories in Brazil.Periods where no resources are shown in any cost categories are periods where resources are not reported.

The UDEPO database lists the most significant deposits for Brazil as Pitinga, Rio Cristallino, Itataia-Santa Quiteria District, Catalao, Salobo, Igarape Bahia-Alemao, Olinda, Engenho.

8.4.4.2. Undiscovered resources

Prognosticated resources in the cost ranges of <US $80/kgU and <US $260/kgU are reported at 300 000 tU. These in situ resources are yet to be identified through activities for exploration developed on the prospective area of Rio Cristalino (south of Pará State) together with new resources at the Pitinga site (see Section 4.4.3.).

Speculative resources are reported as 500 000 tU at unassigned cost.

8.4.4.3. Unconventional resources

Itataia is considered a conventional resource, although the uranium will be extracted as a by-product of phosphate production.

The Pitinga deposit (Amazonas State) produces tantalite–columbite concentrates and uranium as a by-product. It is feasible to retrieve the associated uranium as a concentrate product. Cost categories are assigned according to the process stage of the plant at which the uranium is recovered. Details were reported in the 2005 Red Book [4.5], although no update was given in either the 2007 or 2009 Red Books [4.6, 4.11].

A total resource of 13 000 tU associated with carbonatites was reported in the 2006 publication Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective [4.12]. Another 2000 tU has been reported as unconventional non-ferrous ores. These resources, which total 15 000 tU, are associated with the Araxa deposit, north of the Poços de Caldas Plateau. Reference [4.12] also reports that monazite deposits are currently being exploited in Brazil.

Total uranium resources hosted in phosphates are reported at 88 900 tU at <US $260/kgU. The 2009 Red Book [4.10] includes this resource as conventional. In Ref. [4.12], Itataia is also included as a conventional resource.

8.4.5. Potential for new discoveries

Brazil has favourable geology for the occurrence of nearly every known type of uranium deposit. The probability for the discovery of new resources is considered to be high to very high.

8.4.5.1. Unconformity types

The alkalic complex in Rio de Janeiro and São Paulo States consists of a variety of rock types. This area deserves much more detailed study, though the high degree of weathering and the vegetative cover will make exploration difficult.

Proterozoic rocks in Brazil are widely distributed. Conglomerates are largely developed around the São Francisco Craton and the possibility of finding economic uranium deposits in these Precambrian conglomerates appears promising. Further work on the Moeda Formation conglomerate is needed. The geology of the Cavalcante Tocantine mining district, 200 km north of Brasilia, may also contain rocks favourable for hosting this type of mineralization.

Other areas of interest include: the unconformity between the Minas Series and the overlying Itacolomi Series in the Quadrilatero Ferrifero, though the latter is predominantly marine; the unconformity between the Upper Precambrian Serido Group and the Lower Precambrian Caico Group in the Serido geogyncline; and the pre-Roraima unconformity in the north of the country which could potentially be a good target for this type of deposit.

8.4.5.2. Vein type

Granitic intrusions have been emplaced from the Precambrian to Late Tertiary periods in Brazil. These would appear to offer good potential for the discovery of vein type deposits, in addition to those already discovered in the Serido region.

8.4.5.3. Intrusive and metasomatite types

The potential for additional uranium deposits of the disseminated type exists in several areas of Brazil:

(a) Around the Itataia deposit where several anomalies have been identified;
(b) In addition to the alkali complexes already mentioned, promising localities exist in the alkali belt of the Tunas Group, which extends from São Paulo through Paraná to Santa Catarina. These must be considered favourable, along with the Itataia and Ipanema alkali complexes which are recognized for their similarity to the Rössing deposit in Namibia, which are among the world's largest deposits;
(c) In the Serido district, where the similarities between some of its mineralization and that at Rössing are particularly encouraging for the potential of this district, as are the similarities between the mineralization here and that related to Hercynian granites in Europe (i.e., France).

8.4.5.4. Sandstone type

The Paraná Basin, in spite of its extensive basaltic cover, is thought to have the highest potential for further exploration for sandstone hosted type deposits. The area around Figueira has been likened to the Arlit region in Niger.

In addition to the area around Figueira, which contains known sandstone type deposits, the sub-basin of Cerro Partico in Rio Grande could be worthy of study as it contains potential host rocks considered to be the equivalent of the Rio Bonito Formation. Other areas of interest within the Paraná Basin are the Klabin coal area and the area to the NE of Cuiaba in Mato Grosso.

8.4.5.5. Other potential sedimentary targets

Little prospecting has been undertaken in the Amazon Basin. The Tertiary Alto do Chão sandstone is known to exhibit above background radioactivity.

The Piaui Maranhão Basin contains continental Carboniferous and Permian sediments but no deposits have yet been identified.

Many of the Mesozoic basins in the east and NE of the country contain arkosic sandstones which have been deposited in fluvial environments in relatively close proximity to potential source rocks. Uranium occurrences have been noted in several areas but no mineable deposits have been identified to date.

8.4.5.6. Other types of deposits

The potential of the Palaeozoic black shales in the Piaui Basin could perhaps merit further evaluation.

<u>Poços de Caldas (Minas Gerais), volcanic type</u>

Located in the alkaline complex of Poços de Caldas, the complex was formed by an Upper Cretaceous alkaline intrusion emplaced within Precambrian gneissic rocks. The main alkaline lithological types are foyaite, tinguaite and phonolite. The mineralization occurs either in irregular veins filling breccias and fractures in tinguaites or in pyroclastic rocks. This mineralization is either primary (hydrothermal) or secondary (related to weathering and leaching processes and associated with a vertical oxidation–reduction front). There are appreciable resources of molybdenum and zirconium present.

The Poços de Caldas uranium deposit was discovered in 1966 and mining commenced in 1981–1982 [4.6, 4.11–4.14].

8.4.6. Uranium production

Uranium production at Poços de Caldas started in 1981–1982 and stopped at the facility in 1997. The Poços de Caldas facility was utilized to recover rare earth compounds from treatment of monazite until 2006. By 2009, the facility was finally shut down for economic reasons. The Caetité unit (Lagoa Real) commenced production in 2000. The Caetité unit is presently the sole production facility for uranium in Brazil that is operational [4.4, 4.5, 4.8]. Historical uranium production totalling 4 121 tU is summarized in Fig. 8.13, and production centre details are given in Table 8.7.

Historical uranium production up to 2017 in Brazil is 4121 t U. No production was recorded in 2017.

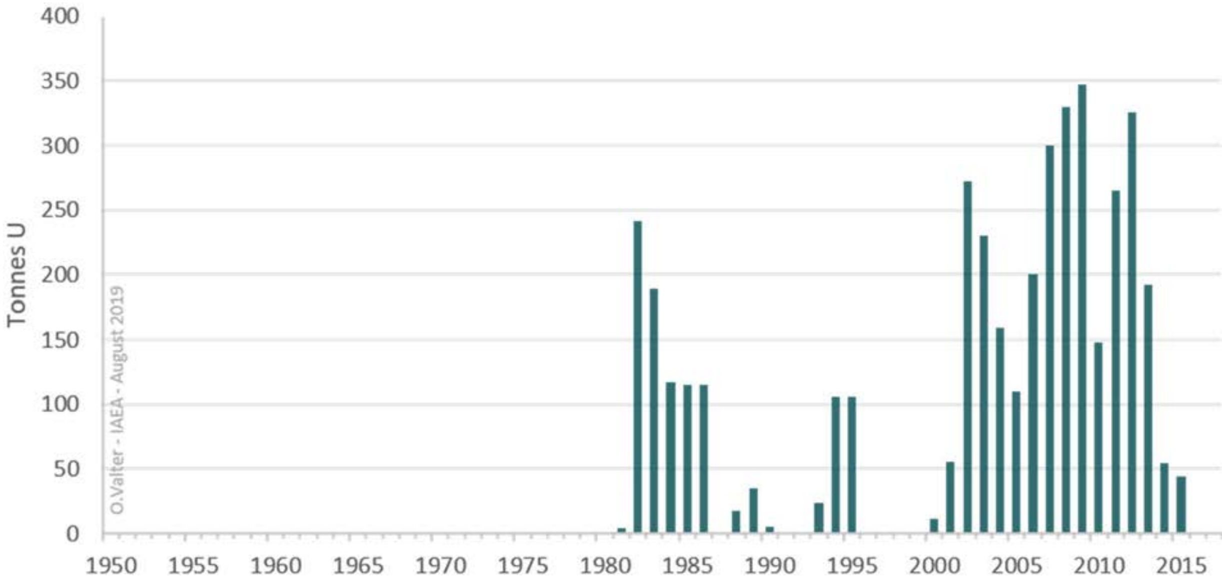


FIG. 8.13. Historical uranium production in Brazil.

TABLE 8.7. URANIUM PRODUCTION CENTRE TECHNICAL DETAILS [4.6, 4.11]

Name of production centre	Poços de Caldas [4.7]	Caetité (Lagoa Real) [4.12]	Itataia [4.12]
Production centre classification	Closed (1997)	Existing (2009)	Committed
Startup date	1981	2000	2012
Source of ore:			
• Deposit name	Cercado mine	Cachoeira	Santa Quitéria
• Deposit type	Per-alkaline complex	Metasomatite	Metamorphic/phosphorite
• Reserves (tU)		12 700	76 100
• Grade (%U_3O_8)		0.3	0.08

Name of production centre	Poços de Caldas [4.7]	Caetité (Lagoa Real) [4.12]	Itataia [4.12]
Mining operation:			
• Type	OP[a]	OP	OP
• Size (t ore/d)	2500	1000	64 000
• Average mining recovery (%)	80	90	90
Processing plant:			
• Type	SX[b]2500	HL[c]/SX	
• Size (t ore/d)	90	80	
• Average process recovery (%)			
Nominal production capacity (tU/year)	425	340	1000
Plans for expansion		Yes	Yes
Remarks	Closed 1997	Startup of open pit Engenho deposit (2010). Transition to underground mining in 2010.	Co-product with phosphoric acid.

[a] OP: open pit mining.
[b] SX: solvent extraction.
[c] HL: heap leaching.

8.4.6.1. Lagoa Real district (Caetité, Bahía)

Caetité, in Bahía State, was discovered as the result of regional airborne geophysical surveys flown between 1976 and 1977, which led to the localization of 13 mineralized bodies. The Lagoa Real district is located in the central southern part of Bahía, on the southern part of the San Francisco Craton. Operations began in 2000.

8.4.6.2. Itataia (Ceará)

Itataia was discovered during the conduct of a car-borne radiometric survey in 1975. The deposit is located in the uranium–phosphate district of the central part of Ceará State. This district straddles two tectonic units known as the Jaguaribean Fold Belt and the Santa Quitéria Massif. Regional rocks are Precambrian paragneisses in addition to a large carbonate lens at least 10 km in length. Both the gneisses and the carbonates are cut by several granitic and pegmatitic apophyses in addition to a small granite cupola. These intrusives have been affected extensively by deuteric processes. Two types of mineralization have been recognized. The first consists of uniform masses of collophane and the second of collophane and stockwork mineralization in marbles and episyenites, as well as impregnations in the gneisses. Uranium occurs in cryptocrystalline hydroxy apatite, which is also the phosphate ore. The rock has been referred to as collophanite. The uranium is evenly distributed, but no discrete uranium mineral species has been found. For more details on Itataia, reference should be made to the 1981 Red Book [4.15] and Dahlkamp [4.16].

8.4.7. Environmental activities

Stopping the Poços de Caldas operation in 1997 led to a close of the development of a low grade ore deposit, one which generated extensive quantities of waste rock. Closure, remediation and restitution were still on going in 2017. Studies were being undertaken to characterize the hydrochemical and geochemical features of the environmental impacts of the waste rock and the tailings dam, and to institute measures for mitigation as needed. An important aspect of the decommissioning plan for Poços de Caldas is to treat and prevent acid drainage.

An environmental impact assessment for the Lagoa Real production centre was accomplished and became a component of the operational blueprint for the mine–mill complex.

8.4.8. Employment in the uranium industry

Red Book reports show that employment in the industry peaked in 1988–1990, when 520–560 persons were employed. Employment directly related to uranium production dropped almost every year after that until it stabilized at 340 in 2004–2008. It was expected to remain the same in 2009.

8.4.9. Installed and planned nuclear capacity

The Angra site is located at the Central Nuclear Almirante Álvaro Alberto on the Itaorna beach in Angra dos Reis, Rio de Janeiro. It consists of two pressurized water reactors. Angra I, with a net output of 657 MW(e), was first connected to the power grid in 1985, and Angra II, with a net output of 1350 MW(e), was connected in 2000. Work on a third reactor, Angra III, with a projected output of 1350 MW(e), began in 1984 but was halted in 1986.

In March 2009, the State nuclear energy company, Eletronuclear, announced that it had received environmental approval to resume construction of the country's third nuclear power plant. Eletronuclear's Angra III will have an installed capacity of ~1400 MW(e). Recommencement of the work is expected to start in 2009 with a view to entry into service in late 2014. First concrete for Angra III was poured in June 2010. Eletrobras suspended the construction in 2016 following a corruption probe. At present, construction of Angra 3 is still suspended. The unit is about 70% completed [4.17].

The Government is planning to construct four additional 1000 MW(e) nuclear power plants by 2030. The first of these four facilities will be built before 2019; five years after the projected completion date for Angra III. This will be sited between the north-eastern cities of Salvador and Recife. The remaining three units will be located in the SE [4.5].

8.4.10. Uranium requirements

Brazil's current uranium requirement is ~450 tU/year, comprising around 150 tU/year for the Angra I nuclear power plant and ~300 tU/year for Angra II.

The long term electrical energy supply scheme comprises the building of four additional 1000 MW(e) nuclear power plants by 2030. Therefore, an increase in uranium requirements is expected in 2015 when the high case scenario predicts demand to rise to 750 tU annually. Throughout the period 2020–2030, the expected annual uranium requirement will be 750–1750 tU.

8.4.11. National and local policies related to uranium

In 1974, Nuclebrás was instituted by the Government and made responsible for the exploration, mining and milling of uranium. As a result, foreign agencies may undertake exploration only after a bilateral agreement with the Government has been signed.

Currently, the uranium industry of Brazil is 100% Government owned through INB.

INB is formulating to grow its uranium production so as to continue to address domestic uranium requirements. Aside from expanding the Caetité Lagoa Real operation, INB's focus is on the Santa

Quitéria project in Ceará State. The licensing of the Santa Quitéria project is divided into a non-nuclear component including production of phosphate, which had a building permit granted in 2005, and the nuclear component, which is under discussion between INB and the federal regulatory body, the Institute of the Environment and Renewable Natural Resources (Ministry of Environment) and the Comissão Nacional de Energia Nuclear (Ministry of Science and Technology).

Brazil has plentiful known reserves, but it has never undertaken to exploit them extensively because the resource is considered strategic and its exploitation is controlled by the State. More exploration will depend entirely on development of the country's nuclear power programme.

References to Section 8.4

[4.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Brazil, Washington, DC https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2008).

[4.2] UNITED STATES GEOLOGICAL SURVEY, Geologic map of Brazil,http://geology.about.com/od/othernationgeomaps/ss/South-America-Geologic-Maps_3.htm

[4.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[4.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[4.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[4.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[4.7] EFE NEWS AGENCY, Russia, Brazil to cooperate on nuclear power (23 July 2009), http://www.laht.com/article.asp?ArticleId=339701&CategoryId=14090

[4.8] ASSOCIATED PRESS, Brazil nuclear reactor gets environmental licence (5 March 2009).

[4.9] NUCLEAR BUSINESS (22 July 2009).

[4.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[4.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[4.12] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[4.13] McNEIL, M., Brazil's Uranium/Thorium Deposits: Geology, Reserves, Potential, M. Freeman Publications, San Francisco (1979).

[4.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[4.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[4.16] DAHLKAMP, F.J., Uranium Deposits of the World – USA and Latin America - Brazil, pp. 451-480. (2010).

[4.17] WORLD NUCLEAR ASSOCIATION, Nuclear Power in Brazil (2018).

8.5. CANADA

8.5.1. Geography

Canada constitutes the northern part of the North American continent and through its numerous islands extends into the Arctic Archipelago to the north. It has a land area of 9 984 670 km^2 and extends between roughly 42° N and 83° N, and 53° W and 141° W.

The St. Lawrence Seaway is the principal waterway, extending from the Gulf of St. Lawrence to Lake Superior and carrying deep-sea vessels. Physiographically, the country can be divided into two units: (i) Shield regions, occupying the main part of the mainland, and (ii) Borderlands, including the mountainous belts of the Cordilleran region in the west and the Appalachian region along the east coast, together with the extensive plains lying between these mountainous regions and the Shield. At an elevation of 5959 m, Mount Logan, which is located in the Coastal Mountains west of Whitehorse in Yukon, is the highest peak in Canada and the second highest in North America.

A third of the country is covered by tundra and has permanently frozen ground. There are as many as two million freshwater lakes located within five major drainage basins, covering 7.6% of the country's total area.

Climatically, Canada can be divided into several zones ranging from moderate in the south to Arctic in the north and exhibiting conditions from continental to marine. The climate does not, for the most part, permit year-round exploration of any one type of deposit and the bulk of exploration, with the exception of drilling and certain geophysical surveys, must be undertaken throughout the relatively short summer (May–September or even shorter).

Most of the inhabited areas are accessible by road, railway, waterway or commercial airline. The areas along the western, eastern and, at certain times of year, northern coasts are accessible by sea. The remaining parts of Canada can be reached by charter aircraft, or for some places in winter, by winter roads.

Canada is a federation comprising ten provinces and three territories. In turn, these may be grouped into four main regions: Western Canada, Central Canada, Atlantic Canada and Northern Canada.

The Federal Government directly administers the Northwest Territories, Yukon and Nunavut, but is restricted to specific functions in relation to the provinces. While minerals in Canada are controlled by the provinces, uranium is unique in that, while the ownership rights associated with the resources are vested in the province, control is vested in the Federal Government which regulates uranium production and export.

A revised policy was announced by the Federal Government in 1987 which, while placing no limitation on foreign participation throughout exploration, limited non-resident ownership of new producing uranium mines to 49% but also allowed for exemptions to this policy to exceed 49% ownership. The foreign interest must be held through a company incorporated in the country.

In Canada, surface rights and mineral rights were both held with the purchase of land until the early 1900s, depending on the jurisdiction. Since then, mineral rights have been owned by the Federal Government and cannot be purchased, but only leased, by individuals or companies. As a result, the mineral rights on more than 90% of Canada's surface area are currently owned by governments. Where mineral rights are privately owned, they can be sold independently of surface rights, such that surface and mineral rights on the same property can be held by different owners.

As determined by the Canadian Constitution, the regulation of mining activities on publicly owned mineral leases falls under provincial/territorial government jurisdiction. Thus, there is separate mining rights legislation for each of the thirteen Canadian jurisdictions except for Nunavut (the northern and eastern portions of the former Northwest Territories that became a separate territory on 1 April 1999).

For the time being, Nunavut mining and exploration activities will continue to be regulated by the Department of Indian Affairs and Northern Development office based in the Northwest Territories. However, in a land claims settlement, the mineral rights of ~10% of Nunavut have been allocated to the Inuit community. These lands comprise large blocks that are scattered throughout Nunavut. The Inuit community establishes the rules and regulations in those blocks that are not under Federal Government jurisdiction [5.1–5.3].

8.5.2. Geology

8.5.2.1. General

Canadian Shield

The Precambrian Shield covers ~5.56 million km^2 (44.5% of Canadian territory) and consists of broad, monotonous sub-horizontal terrain, a typical product of peneplanation where local relief ranges from 60 to 150 m across most of the area. The greatest elevation of the Shield reaches more than 1525 m in the Davis and Labrador Highlands. All of the area has been glaciated by continental ice sheets. The shield covered by water exceeds 25% in some areas, consisting of lakes, ponds and swamps. The swamps are commonly peat-bearing.

Geologically, the central part of Canada contains the Precambrian rocks of the Canadian Shield, the outcropping part of the North American Craton. The several structural provinces comprising the Shield are composed of rocks laid down throughout the different Precambrian eras and rocks, mainly crystalline, which were produced or affected by the orogenies occurring near the close of the Archaean eon and those of the Proterozoic eras. These are the Superior, Slave, Bear, Churchill, Nain, Grenville and Southern Provinces. The North American Craton is bordered by three geosynclines composed mainly of Phanerozoic and Late Precambrian rocks. These have been deformed at various times and at present constitute the Appalachian, Innutian and Cordilleran Orogens. Between the Canadian Shield and the orogens are the St. Lawrence, Arctic and Interior Platforms, which are parts of the Craton that subsided slightly in the past and which are now covered by thin veneers of Phanerozoic sedimentary rock. In the central part of the Canadian Shield, and underlying most of Hudson Bay, is the Hudson Platform. Bordering the oceans are the continental shelves [5.2].

Subdivisions of the Canadian Shield

Geological structures and evidence of orogenies show that the Canadian Shield is composed of different parts that were once probably as distinct physiographically as the Cordilleran Region and Interior Plains are now. The ancient boundaries are still geologically evident and in places are physiographically distinct. Accordingly, some geological boundaries transect terrain that forms a single physiographic unit. Four types of terrain in the Shield are relatively easy to distinguish as physiographic units and coincide with specific geological characteristics:

(i) Plains, formed on areas of unmetamorphosed sub-horizontal rocks, such as the sandstone and conglomerate terrains of the Thelon, Athabasca and Cobalt Plains, or the terrain of the flat lying gabbro sills of the Nipigon Plain;
(ii) Hills composed of low grade metamorphic rocks, generally tilted or gently folded sediments or sills, such as the Bathurst, East Arm, Penokean and Labrador Hills;
(iii) Mountains composed of particularly resistant massive rocks, such as the anorthosites of the Mealy Mountains which stand above the surrounding terrain;
(iv) Highlands formed of broad uplifted areas of deeply incised massive crystalline rocks, such as the Labrador Highlands or the glacier capped Davis Highlands.

Other units are distinguished by less obvious characteristics, and in some places the boundaries are arbitrarily drawn to divide uniform but unwieldy units. Subdivisions of the Shield are designated as the Kazan, Davis, Hudson, James and Laurentian Regions.

Various Precambrian orogenies, each followed by a profound erosional interval, provide the framework for a natural time–stratigraphic classification of the sedimentary, volcanic and intrusive rocks. The earliest is the Archaean eon relating to the Kenoran Orogeny (2480 Ma), followed, in turn, by the Proterozoic eon, with the earliest era being the Aphebian and the Hudsonian Orogeny (1735 Ma), with the dates related to the mean K–Ar mica age. This is, in turn, followed by the Helikian era, which is divided into the Palaeohelikian and Neohelikian sub-eras associated with the Elsonian Orogeny (1370 Ma) and

Grenvillian Orogeny (955 Ma), respectively. These are postdated by Hadrynian, the youngest of the Precambrian eras.

Arctic Archipelago:

The Canadian Arctic Archipelago extends from Resolution Island (61° N) to the northern tip of Ellesmere Island (83° N), ~800 km from the North Pole. The region extends from the northern edge of the continent to beyond north-western Greenland.

The Arctic Islands Region, including the sea surface, totals ~2.0 million km^2, of which land covers 1.3 million km^2 (~13% of the total terrestrial surface of Canada). Much of the region consists of the Arctic Lowlands, which, with the exception of the Arctic Uplands, form a mountainous chain extending along the eastern margin of Baffin Island, further to the north on eastern Devon and Ellesmere Islands. The region is formed of flat to sub-horizontal Palaeozoic and Late Proterozoic sedimentary rocks, lying between the Shield and the Innuitian Region.

The Borderlands:

The Borderlands, which contain a great variety of physiographic provinces, are divided into easily recognized subdivisions, many with long established names. These include the Innuitian Region, Arctic Coastal Plain and Arctic Lowlands to the north, the Interior Plains and the Cordilleran Region of western Canada, and the St. Lawrence Lowlands and Appalachian Region to the east.

Innuitian Region:

This is a region of varied topography which is, on average, more rugged than that of the surrounding provinces and which is developed from the thick assemblages of deformed sedimentary rocks and minor intrusions. The region is roughly triangular in shape, covers an area of ~544 000 km^2 and forms part of the outer ring of the Borderlands, between the Shield and the Arctic.

Arctic Coastal Plain and Continental Shelf:

The Arctic Coastal Plain includes the coastal terrain along the shores of the Arctic Ocean from Meighen Island to Alaska. It borders and lies seawards of the Innuitian Region, Arctic Lowlands, Interior Plains and Cordilleran Region.

Arctic Lowlands:

The Arctic Lowlands are formed on flat to sub-horizontal Palaeozoic and Late Proterozoic sedimentary rocks, lying between the Shield and the Innuitian Region.

Interior Plains:

The Interior Plains are underlain by Phanerozoic sedimentary rocks, the sub-horizontal later Proterozoic, Palaeozoic, Mesozoic and Tertiary strata, occupying the region between the Shield in the east and the mountains of the Cordilleran Region to the west. They make up the north-western part of the North American Craton, the stable interior region of the continent, and they join with the St. Lawrence Lowlands of eastern Canada through the United States of America and are separated from the Arctic Lowlands by the Amundsen Gulf. The southern part is semi-arid grassland, the central part is tree covered and the northern part is tundra.

Cordilleran Region:

The Cordillera in Canada (1.62 million km^2) makes up part of the Circum-Pacific Orogenic Belt. It comprises an 800 km wide zone of mountains and plateau, trenches, valleys and fjords in British Columbia, western Alberta and Yukon.

It is divided longitudinally into three extensive belts: (i) the Eastern System, (ii) the Interior System and (iii) the Western System. Each system has its own characteristic geology and likewise its own physiography. The Eastern System is composed almost entirely of folded sedimentary strata. The region generally received miogeosynclinal and exogeosynclinal sediments that underwent surficial or decollement deformation with little or no metamorphism, volcanism or plutonism throughout the orogenic phases.

The Western System consists of that part of the geosyncline that received eugeosynclinal and epieugeosynclinal assemblages. In the Western System, the largest unit, the Coast Mountains, is composed mainly of plutonic rocks, whereas other parts comprise a mixture of folded volcanic and sedimentary strata intruded by scattered intrusions of massive igneous rocks. The eugeosynclinal belt was at times dominated by north-westerly elongate troughs separated by geanticlines; the latter were repeatedly the site of regional metamorphism, granitic emplacement and intense deformation. Ultramafic rocks are spatially restricted to the eugeosynclinal belt and temporally associated with basaltic volcanic rocks. Late Tertiary and Pleistocene clastic sediments occur along the Pacific Continental Shelf and along parts of the Coastal Plain.

The Interior System comprises folded sedimentary and volcanic strata and massive metamorphic rocks, all intruded by large or small bodies of igneous rocks, with local areas of flat lying volcanic strata. The eastern margin consists of the elongate Omineca Crystalline Belt, including extensive areas of metamorphic rocks that form the core zone of an Alpine type orogen, the marginal zone of which is the Eastern Cordilleran Orogen. To the west is the Columbian Zwischengebirge, between the Omineca Crystalline Belt and the Coast Plutonic Complex, which is structurally homogeneous although dominated by an elongate NW trending geanticlinal belt of disconnected horsts and by two broad transverse arches.

The three principal systems are further divided into areas and subdivided into mountains, ranges, plateaux, hills, valleys, trenches, basins, plains, etc.

The Cordilleran Orogen of Canada is a feature of great geological variety and complexity that developed throughout the evolution of the Cordilleran Geosyncline which has continued from the mid-Proterozoic to the Recent. Currently, the region is tectonically quiescent relative to other parts of the Circum-Pacific Orogenic Belt [5.3].

St. Lawrence Lowlands:

The St. Lawrence Lowlands border the Shield to the SE, extending from the west end of Lake Huron and the head of Lake Erie north-easterly to the Strait of Bell Isle. The province is underlain by unfolded Palaeozoic strata with a maximum thickness of ~3650 m, and the western and central lowlands comprise plain-like areas [5.2].

Appalachian Region:

The Appalachian Region in Canada is a northern extension of the Appalachians of the USA, extending as far north as Newfoundland. It comprises a glacial region divided into a large number of physiographic units. The physiography is dominated by a well-developed peneplain, probably of Cretaceous age, which is generally highest in the NW and which slopes gently south-eastwards to the ocean. The highest peak is Mont Jacques-Cartier, at an elevation of 1268 m. The various subdivisions of the region are formed by the differential erosion of ‘soft’ and ‘hard’ rocks to form lowlands, highlands and uplands. The Appalachian Region is bounded by the Atlantic Continental Shelf. The protolith of the Appalachian

Orogen was an orthogeosyncline characterized by great mobility and by relatively thick eugeosynclinal Lower and Middle Palaeozoic sedimentary and volcanic deposits. The north-western part is locally miogeosynclinal. The Appalachian Orogen is divided into two parts: (i) a fold belt produced by the Ordovician Taconian Orogeny and the Devonian Acadian Orogeny, and (ii) an epieugeosyncline of Late Palaeozoic strata, part of which was mildly deformed by the Maritime Disturbance.

8.5.2.2. Uranium geology

The geology described here is exclusively limited to that which is directly related to the different types of uranium occurrences and which is thought to have some bearing on the location of economic uranium deposits. The locations of the uranium production centres are shown in Fig. 8.14 and the geological provinces in Fig. 8.15. Current uranium production is derived exclusively from the unconformity-related deposit type.

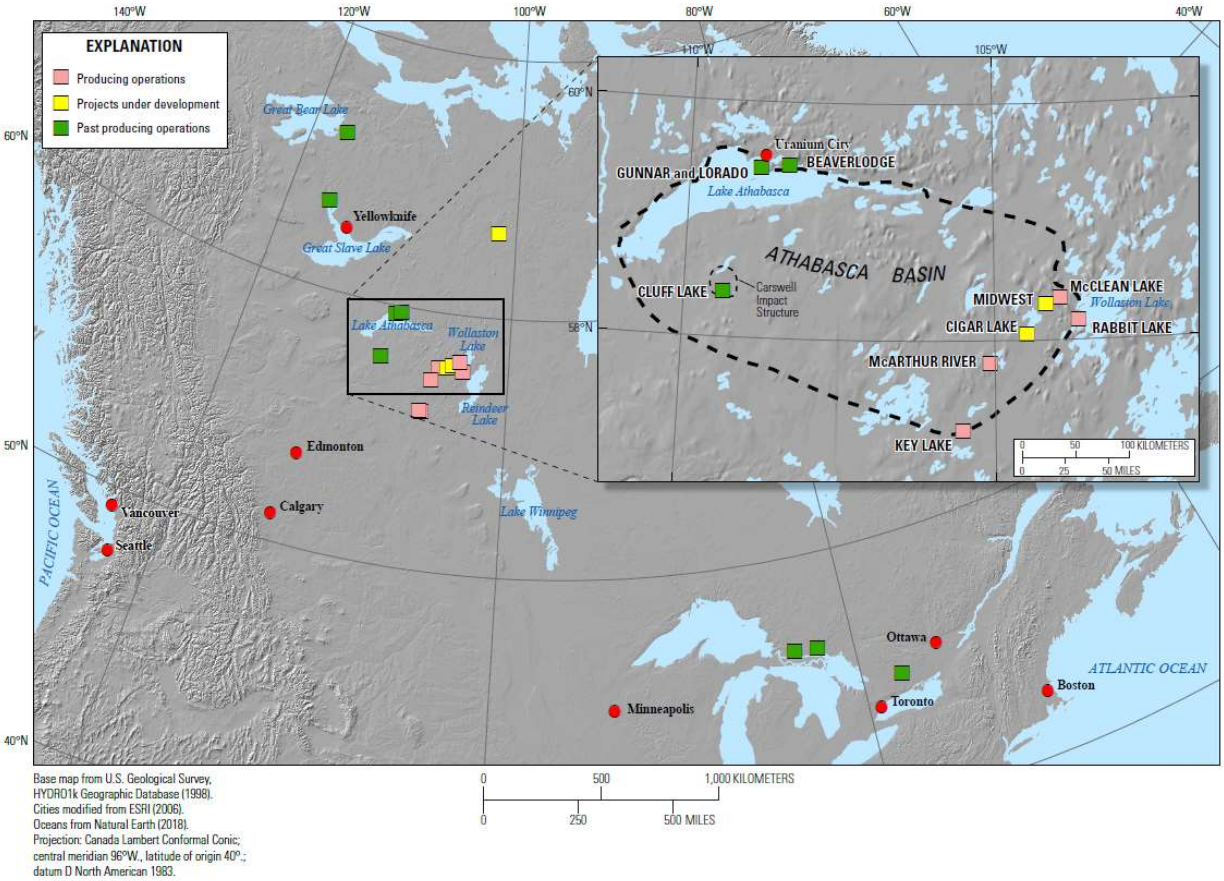


FIG. 8.14. Uranium producing areas (source: Uranium and Radioactive Waste Division, Natural Resources Canada). Producing operations: (1) Rabbit Lake, (2) Key Lake, (3) McClean Lake, (4) McArthur River, (6) Cigar Lake. Projects under development: (5) Midwest, (7) Kiggavik. Past producing operations: (8) Cluff Lake, (9) Port Radium, (10) Agnew Lake, (11) Madawaska and others (Bancroft), (12) Rayrock (Marian River, (13) Beaverlodge and others, (14) Quirke/Panel/Denison/Stanleigh and others (Elliot Lake), (15) Gunnar, Lorado and others.

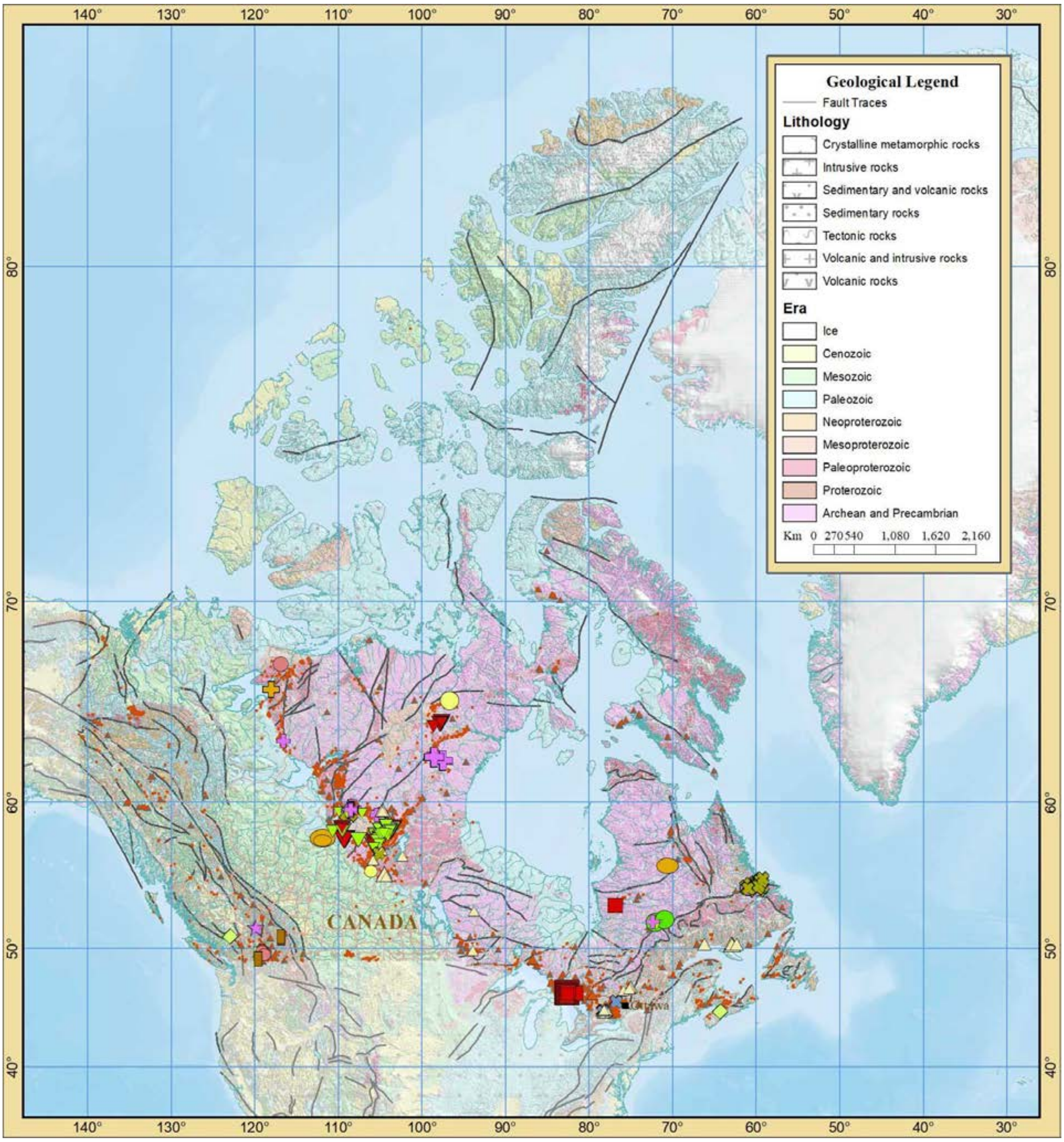


FIG. 8.15. Regional geological setting of Canada showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Proterozoic unconformity-related deposits

In the Athabasca Basin, Saskatchewan, pods, veins and semi-massive replacements of uraninite (as pitchblende) are located close to unconformities between Late Palaeozoic to Mesoproterozoic conglomeratic sandstone basins and metamorphosed basement rocks. The thin, sub-horizontal and apparently unmetamorphosed but pervasively altered, mainly fluvial strata include red to pale tan quartzose conglomerate, sandstone and mudstone. Beneath the basal unconformity, red haematitic and bleached clay altered regolith grades through chloritic altered rocks down to fresh basement rocks. The highly metamorphosed interleaved Archaean to Palaeoproterozoic granitoids and supracrustal basement rocks include graphitic metapelites that preferentially hosts reactivated shear zones and numerous deposits. There is a wide variety of deposit morphology, size and composition, ranging from monometallic and generally basement-hosted veins to polymetallic lenses located just above or straddling the unconformity, which have variable Ni, Co, As and Pb levels and traces of Au, Pt, Cu and rare earth elements [5.4].

The unconformity deposits of the Athabasca Basin represent the largest concentration of high grade uranium resources in the world and constitute the sole source of Canada's primary uranium. The most spectacular grades and tonnages are those of Cigar Lake (east and west zones combined comprise 875 000 t of ore grading ~15% U and containing 131 400 tU) and McArthur River (1 017 000 t of ore grading ~22.28% U and containing 192 085 tU). The average grade of some 30 unconformity deposits in the Athabasca Basin, including these two exceptionally high grade examples, is 1.97% U.

Economic deposits include those located at Rabbit Lake, Cluff Lake, Key Lake, Cigar Lake and McArthur River, all located in Saskatchewan. Other, currently subeconomic, deposits have also been discovered. The Rabbit Lake, Key Lake, Cigar Lake and McArthur River deposits occur at the unconformity within underlying rocks of the Wollaston Lake Fold Belt. This fold belt forms part of the Churchill Structural Province of the Canadian Shield. It consists of Palaeoproterozoic metasediments, initially deposited in a shelf environment across a crystalline Archaean basement, which were highly deformed by the Hudsonian Orogeny. These rocks were altered by prolonged weathering prior to the deposition of the Mesoproterozoic Athabasca Group, which consists of fluviatile sandstones and pebble conglomerates, resulting in the development of a regolith. The sub-Athabasca basement rocks hosting the mineralization include garnet-, cordierite- and graphite-bearing quartz–feldspar–biotite gneisses (metapelites), metaquartzites (Key Lake, Cigar Lake, McArthur River) and calc-silicates (Rabbit Lake). The main ore minerals are uraninite and pitchblende, usually of a colloform nature, and the ore contains little or no thorium. Nickel sulphides are very common at Key Lake and can constitute 45% of the ore. The Athabasca sandstone overlies the deposits and is, in some instances, mineralized. Faulting, shearing and brecciation are significant features of these deposits, with post-ore formation and structural reactivation of post-sandstone faults rooted in basement graphitic rocks. The deposits vary in length from ~500 m to 1500 m, in width from l0 m to at least l00 m and in thickness from a few metres to 120 m.

Quartz-pebble conglomerates

A substantial portion of Canada's historical economic uranium resource was discovered in quartz-pebble conglomerates in basal Palaeoproterozoic rocks of the Elliot Lake and Agnew Lake areas, Ontario. The Huronian clastic sediments lie within a 320 km long and 80 km wide fold belt. These sediments overlie Archaean volcanics and sediments and the Algoman granite. The Murray Fault, a high angle reverse fault, runs the length of the fold belt and may have been an important Huronian hinge line or the edge of an ancient continental shelf. The Huronian sediments were deposited in regressive marine cycles with each subsequent cycle more transgressive onto the provenance area, which is mainly a granitic terrain. This provenance area may also have been the source of the uranium–thorium minerals found in the deposits. The uranium deposits are hosted in pyritic quartz pebble conglomerates, which were developed under a variety of depositional conditions. The individual gravel 'sheets' hosting the deposits are composed of intercalated quartzite and conglomerate beds of lenticular shape which exhibit cut and fill relationships. The uranium minerals occur in the conglomerate and their concentrations generally show a direct correlation with the coarseness and compaction of the detritus and the pyrite content. In all cases, the economic uranium deposits lie within 150 m of the pre-Huronian basement. The main ore minerals are brannerite and uraninite. Monazite forms 5% of the ore mined and uranothorianite together with uranothorite occur in limited quantities. Many other heavy minerals are found in the conglomerate beds, including allanite, xenotime, garnet, spinel and chromite. Radioactive hydrocarbon and gummite also occur. The Th:U ratios vary within the deposits in the range 0.2–3.0. The pebbles are of quartz and chert and the matrix minerals are quartz, feldspar and sericite. Pyrite is an important constituent and may constitute 5–20% of the conglomerate by weight. These deposits are considered to be primarily syngenetic placers with reducing conditions at the site of deposition, which explains the preservation of detrital uranium minerals.

Vein deposits

Pitchblende deposits in the Beaverlodge area, Northwest Territories, occur in the subsidiary structures of major faults transecting a wide variety of wallrock types, including granite, migmatite, paragneiss, and metavolcanic and metasedimentary rocks. Mylonites are also important host rocks. The largest deposits, except Gunnar, are hosted in mafic rocks, particularly meta-argillite, amphibolite, chlorite–epidote rock and the chlorite schists of the basement complex (Tanzin Group), which is of Archaean or Palaeoproterozoic age. Minor deposits also occur in the Martin Formation, a dominantly clastic red bed sequence of arkose, siltstone and conglomerate, with some basaltic flows of Early Mesoproterozoic age, which unconformably overlies the basement. In most deposits, the mineralogy is simple, consisting of pitchblende with lesser amounts of pyrite, chalcopyrite and galena. Geological environments exhibiting features similar to those described above also occur elsewhere in the Wollaston Lake and Tanzin–Nonacho Fold Belts and in the East Arm.

Gunnar, in the same area, is a pipe-like deposit within metasomatized granites.

The uranium deposits at Port Radium occupy steeply north dipping, NE trending fractures which transect Late Palaeoproterozoic or Early Mesoproterozoic metasedimentary and volcanic strata. The volcanic rocks are believed to be the extrusive equivalent of the Great Bear Batholith, which possesses anomalous uranium values. The deposits occur in a range of forms from high grade veins to low grade stockworks. The veins are composed mainly of quartz, carbonate minerals and haematite, along with pitchblende, chalcopyrite, sulpharsenides of cobalt and nickel, native silver and bismuth, pyrite, argentite, galena and chlorite. The small Rayrock mine consists of fracture controlled pitchblende in a quartz vein stockwork cutting gneissic granodiorite. This is the most significant of several pitchblende, copper, nickel and cobalt 'showings' in 'giant' quartz veins in this area.

Disseminated deposits in igneous and metamorphic rocks

This type of deposit was historically economic in the Bancroft area of Ontario, which lies within the Grenville Province in which the regionally metamorphosed rocks, which include paragneiss, amphibolite and marble, were affected by the Grenville Orogeny. The area is permeated by dykes, lenses and diffuse zones of pegmatitic granite and syenite within which the uranium orebodies lie. The main ore minerals are uraninite, uranothorite and uranothorianite. The Rexspar deposit in British Colombia occurs in Late Palaeozoic trachytic tuffs, breccias and flows. The radioactive zones contain fine grained uraninite together with biotite, sericite, pyrite and, locally, fluorite. Regional metamorphism is at the greenschist facies grade. Uranium and niobium mineralization occur in carbonatites near Lake Nipissing, Ontario, and at Oka and in the Lake St. John area, both in Quebec. Uranium occurs in pegmatite bodies and in the pegmatoid phases of granites throughout the Canadian Shield. Other occurrences worthy of note include the pegmatites of the Mount Laurier area (Quebec) and in Palmerston Township (Ontario). Uranium also occurs in the Johan Beetz area on the north shore of the Gulf of St. Lawrence (Quebec). At this locality, the uranium is disseminated in granite, which hosts small pods of pegmatite, and several deposits (Double S, Middle Zone, TJ, Drucourt Zone, Doran…) were delineated. Environments favourable for these types of deposit can be found in the Churchill, Superior, Grenville and Nain Structural Provinces and also in parts of the Cordilleran Orogen.

Volcanic-related and other types of deposit

The Kiggavik uranium deposits occur in close spatial proximity to the unconformity at the base of the Proterozoic Thelon Basin, Nunavut. Gabbro dyke-related uranium mineralization has been discovered at the Matoush locality in the Proterozoic Otish sandstone basin, Quebec. Felsic volcanic associated mineralization and shear-related uranium deposits have been discovered in the Central Mineral Belt of Labrador. The Michelin deposit occurs in felsic metavolcanics of the Ailik Group and the Kitts deposit is related to epigenetic shear-hosted uranium mineralization in granites.

Sandstone deposits and surficial deposits

Syngenetic stratabound uranium accumulations are known to occur in the Palaeoproterozoic Amer Group metasediments, Nunavut (Amer Lake deposit).

Otherwise, there are no known economic sandstone-hosted uranium deposits in Canada. Environments regarded as favourable for the location of such deposits are found in the Tertiary basins of the Cordilleran Orogen and in Mesozoic and Tertiary sediments in the Interior Platform, the Arctic Platform, the Appalachian Orogen and the Innuitian Orogen.

Areas favourable for supergene uranium deposits exist in British Columbia, where small surficial deposits some located within peat-bogs have been discovered (Mallow Creek, North Wow Flat, Prairie Flats…). It is assumed that the geological and climatic conditions are the main factors controlling the formation of these deposits. A study of geological environments that may contain fossil calcretes could lead to the identification of uranium resources [5.2–5.4].

8.5.3. Uranium exploration

8.5.3.1. Historical review [5.5–5.25]

Exploration for uranium in Canada started in 1942, with activity initially focused at Great Bear Lake in the Northwest Territories, where pitchblende ore had been mined from the 1930s and used as a source of radium. Exploration quickly extended to other regions of Canada, causing the development of mines in the Bancroft and Elliot Lake regions of Ontario and in northern Saskatchewan throughout the 1950s. In 1942, exploration for and mining of all radioactive materials by private individuals was prohibited in the Northwest Territories and several other provinces. Instead, exploration was conducted by a Federal Crown company, Eldorado Nuclear Ltd, and by the Geological Survey of Canada. The ban on private prospecting was lifted in 1947 and various incentives were offered by the Federal Government to encourage exploration. By 1956, more than 10 000 radioactive occurrences had been discovered, many of which proved to be viable deposits.

Exploration for uranium virtually ceased in the late 1950s and was not revived until the mid-1960s. By 1969, exploration had returned to near record levels, but this resurgence was short-lived and exploration again declined in response to a growing oversupply and depressed prices in the world uranium market. Throughout this period, both domestic and foreign companies were actively engaged in exploration in Canada. Exploration returned in the late 1960s to northern Saskatchewan where large high grade deposits were found in the Athabasca Basin, which were subsequently developed. Saskatchewan is nowadays the only producer of uranium in Canada.

Exploration activities resumed in 1973 as consumers moved to acquire long term uranium supplies, which led, in turn, to projected supply shortfalls. Discovery of the Rabbit Lake and Key Lake deposits in the Athabasca Basin resulted from this resurgence in exploration. Exploration levels expanded throughout 1974 and 1975, and by 1976 it was estimated that some 200 companies were spending a total of US \$45 million annually on exploration. Though exploration was conducted in virtually all provinces and territories, most of the activity was concentrated in Saskatchewan, followed by Quebec, Ontario, British Columbia and the Northwest Territories. Activity reached a peak in 1979 and 1980, with expenditures totalling US \$111.9 million and US \$111.6 million, respectively. In 1975, the Geological Survey of Canada embarked on a 10-year, CAD 30 million uranium reconnaissance programme intended to identify and delineate all areas in Canada which may be favourable for the occurrence of uranium deposits.

In 1979 and 1980, uranium exploration continued at a high level, mainly in Saskatchewan where activities focused on unconformity-type deposits. Expenditures amounted to \$CDN 129.5 million and \$CDN 128 million respectively. More than 50% was spent in Saskatchewan, and over 20% in the Northwest Territories. 483 300 m and 503 300 m of surface drilling were completed in 1979 and 1980, with more than 60% of which in Saskatchewan, Drilling activity was also reported in British Columbia, Newfoundland, Nova Scotia, Northwest Territories, Ontario and Quebec.

In early 1980, exploration activity was curtailed in British Columbia, due to a Government moratorium on uranium exploration and mining.

Exploration activities declined in 1981 and 1982. Expenditures were reported at $CDN 71 million in 1982, surface drilling decreased to 247 000 m. Over 80% of the expenditure and drilling activity took place in Northwest Territories and Saskatchewan. Main results during that period included the discovery of the Peter River deposit at Cluff Lake, the confirmation of Eagle point resources estimation, favorable results at Dawn Lake, all of them in Saskatchewan.

In March 1983, COGEMA Canada Ltd announced the discovery of Cigar lake deposit. The deposit was estimated to contain 110 000 tU at an average grade of 12 %U, with 40 000 tU at 4 %U of additional resources in the western extension of the deposit.

In 1984 total expenditures were reported at $CDN 35 million. 198 000 m of surface and development drilling were completed mainly in Saskatchewan and Northern Territories.

In 1986, Eldorado resources Ltd announced successful exploration drilling at Eagle point, where resources were reported to exceed 50 000 tU.

In 1987, exploration expenditures lightly increased to $CDN 357 million. Activity focused on properties with known mineralization. In 1988, expenditures rose to $CDN 59 million due to underground exploration activities at Cigar Lake and Midwest projects.

In 1989, Minatco Ltd announced the discovery of shallow-depth mineralization on its Wolly project (near the McClean Lake project).

During the 1989/1990 field season, the Geological Survey of Canada conducted exploration activities near great bear Lake in Northwest territories, looking for deposits similar in style to Olympic Dam in Australia.

In May 1990, Cameco announced the discovery of the P2 North deposit at McArthur River. Resources were estimated to amount to over 77 000 tU, grading 3% U on average.

In 1992, exploration activities continued in Saskatchewan and Northwest Territories, with geochemical and geophysical surveys, and drilling on extensions of known mineralized structures. In the Athabasca Basin, drilling led to the discovery of mineralization associated with the the Collins Bay granitic dome. In the Thelon Basin, Northwest Territories, exploration activities continued on the Kiggavik trend Grassroot exploration were conducted in Alberta and in the Great Bear area.

As in previous years, exploration activities from 1993 to 2002 concentrated in areas where Proterozoic unconformity deposits could potentially occur, in the Athabasca and Thelon basins. Limited activities were also conducted in Labrador and Quebec. Most of the expenditures were associated with underground exploration at Cigar Lake, Eagle Point and McArthur River.

In 2003-2004, significant increase of the uranium spot price created a surge in exploration in new areas within Alberta, Labrador, Manitoba, newfoundland, Ontario, Quebec and Yukon. A significant discovery was made at the Millenium deposit. Encouraging drilling results were also reported at Shea Creek in the western Athabasca Basin.

In 2006, total exploration and development expenditures amounted to $CDN 476 million and exploration and development drilling to 275 600 m.

During 2007 and 2008, exploration efforts continued to focus on areas favourable for the occurrence of deposits associated with Proterozoic unconformities in the Athabasca Basin of Saskatchewan, and to a lesser extent, similar geologic settings in the Thelon and Hornby Bay Basins of Nunavut and the Northwest Territories. Uranium exploration remained very active in the Otish Mountains of Quebec where Strateco Resources Inc. applied for a licence to conduct underground exploration on the Matoush deposit. Exploration activity in the Central Mineral Belt of Labrador, where Aurora Energy Resources Inc. was proposing to develop the Michelin and Jacques Lake deposits, was reduced after April 2008 when the regional aboriginal government imposed a three-year moratorium on uranium mining. New uranium discoveries were made in the Athabasca Basin, including Centennial (UEM Inc.), Shea Creek (AREVA Resources Canada Inc.), Wheeler River (Denison Mines Inc.), Midwest A (AREVA Resources Canada Inc.) and Roughrider (Hathor Exploration Ltd.).

Figure 8.5.3 summarises uranium exploration activities totalling 10 687 125 metres of drilling within an expenditure of USD $8 268 325 000 (which also includes 1 830 500 km^2 of airborne radiometric surveys and 1 662 000 km^2 of geochemical surveys).

8.5.3.2. Recent and ongoing uranium exploration and mine development activities

Throughout 2009 and 2010, endeavours for exploration sustained to concentrate on areas prospective for deposits related with Proterozoic unconformities in the Athabasca Basin in Saskatchewan and, to a reduced level, similar geological settings in the Northwest Territories and in the Thelon Basin, Nunavut. Exploration for uranium was also undertaken in the Otish Basin in Quebec, where Strateco Resources Inc. applied for an authority to undertake subsurface and underground exploration on the Matoush deposit. However, in 2013, the Government of Quebec announced a moratorium on uranium exploration and mining. Since, the project is on care and maintenance with little hope of restarting in the near future.

Extremely minor activity was undertaken in other areas of Canada in 2009 and 2010.

Surface drilling, geochemical and geophysical surveys remained to be the tools used to recognize new occurrences uranium, outline extensions of existing zones and re-evaluates deposits which were last investigated in the 1970s and 1980s.

Expenditures for domestic exploration of uranium were CAD 355 million in 2010, down 5.1% from expenses for uranium exploration of CAD 374 million in 2009. Exploration and development drilling for uranium made 373 900 m in 2010, in contrast with 447 900 m made in 2009. At least 70% of the integrated exploration and development drilling in 2010 was made in Saskatchewan.

Total expenditures for exploration and development of uranium in Canada amounted to CAD 605 million in 2010. Not more than one third of the total expenditures for exploration in 2010 can be ascribed to advanced subsurface exploration, deposit evaluation activities, and expenditures for care and maintenance of projects pending approval for production [5.26].

Surface drilling conducted on the Triple R deposit in 2013 and 2014 (Fission Uranium) outlined a significant resource, making Triple R the third largest uranium deposit in the Athabasca Basin.

Despite overall declining expenditures, Canada maintained higher exploration expenditures than other countries and in 2016 this accounted for 45% of the world total. This led to new uranium discoveries in the Athabasca Basin, including Phoenix/Gryphon (Denison Mines Inc.), Arrow (Next-Gen Energy Corp.) and Fox Lake (Cameco Corp.), (see Fig. 8.16) [5.26].

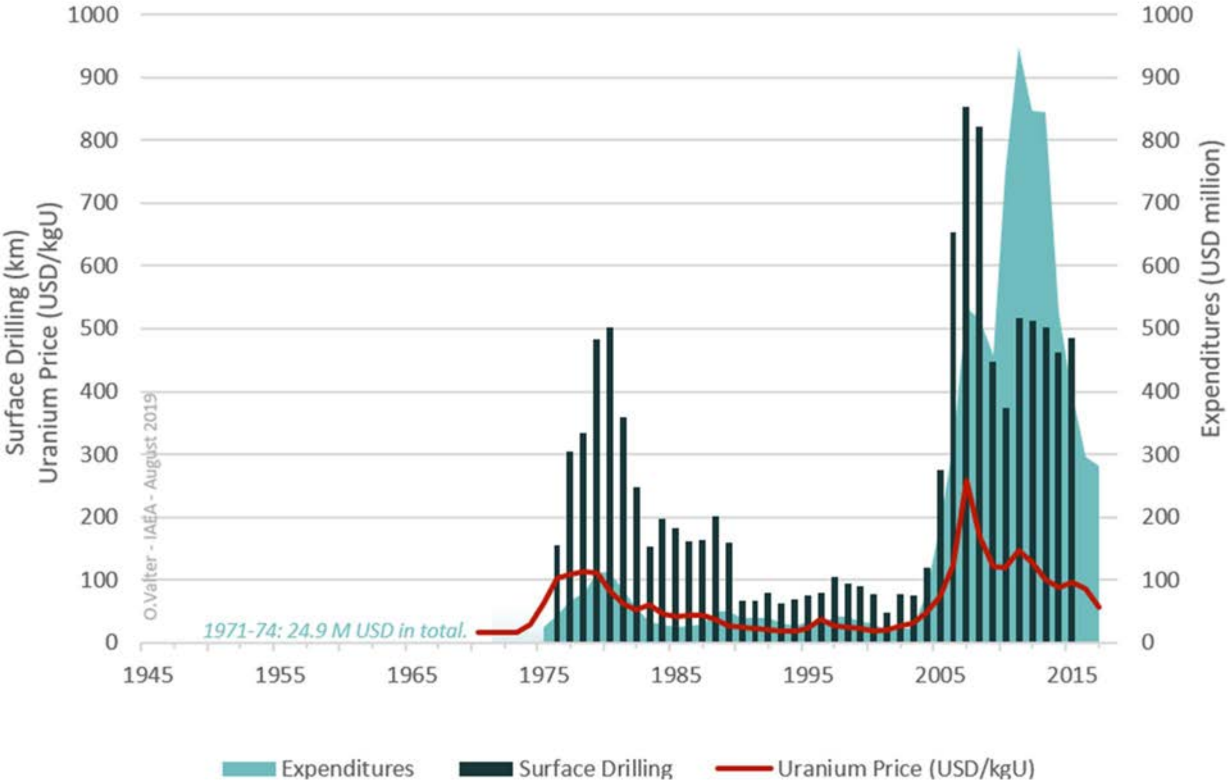


FIG. 8.16. Domestic uranium exploration data. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

8.5.4. Uranium resources

Canada's total identified conventional uranium resources at a cost of <US $80/kgU were 416 800 tU as of 1 January 2011, a 7% decrease from the estimate of 447 400 tU in 2009. As of 1 January 2011, Canada's total identified uranium resources recoverable at a cost of <US $130/kgU were 468 600 tU, a 3.5% decrease from the estimate of 485 600 tU in 2009. These reductions are mainly the result of reclassification of resources into higher cost categories as costs of mining increased. The uranium mining companies re-evaluate yearly most of Canada's uranium resources. Tables 8.8 – 8.11 provide details of the various categories of resource.

Most of Canada's identified conventional uranium resources exist in deposits of Proterozoic age in the Basin of Nunavut and in the Athabasca Basin of Saskatchewan. Mineralization in these deposits is hosted close to the unconformity as either monometallic or polymetallic mineral assemblages, with pitchblende in the former deposits and uranium–nickel–cobalt assemblages in the latter deposits. The average grade ranges from 1% up to 16% U. None of the uranium resources mentioned or quantified herein are a co-product or by-product of any other minerals of economic significance.

As of 1 January 2017, Canada's total identified conventional uranium resources at a cost of <US $260/kgU were 846 367 tU. Total identified uranium resources recoverable at a cost of <US $80/kgU were 310 390 tU (Tables 8.8 to 8.11) [5.26].

Historical variations in reasonable assured resources and inferred resources are shown in Figs 8.17 and 8.18 respectively.

8.5.4.1. Identified resources

TABLE 8.8. REASONABLY ASSURED RESOURCES (tU)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Unconformity-related	255 930	275 190	403 680	543 003
Quartz-pebble conglomerate				5255
Metasomatite			0	38 626
Sandstone			6000	6000
Total	255 930	275 190	409 680	592 884

TABLE 8.9. INFERRED RESOURCES (tU)

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Unconformity-related	7 560	35 200	98 678	205 775
Quartz-pebble conglomerate				18 947
Metasomatite				16 520
Sandstone			6044	12 241
Total	7560	35 200	104 722	253 483

TABLE 8.10. PROGNOSTICATED CONVENTIONAL RESOURCES (tU)

Cost ranges		
<US $80/kgU	<US $130/kgU	<US $260/kgU
50 000	150 000	150 000

TABLE 8.11. SPECULATIVE CONVENTIONAL RESOURCES (tU)

Cost ranges		
<US $80/kgU	<US $130/kgU	Unassigned
700 000	700 000	0

The UDEPO database lists the most significant deposits for Canada as McArthur River, Denison Mine, Cigar Lake, Arrow, Eagle Point, Triple R, Banana Lake, Deilmann, Quirke, Michelin, Stanleigh.

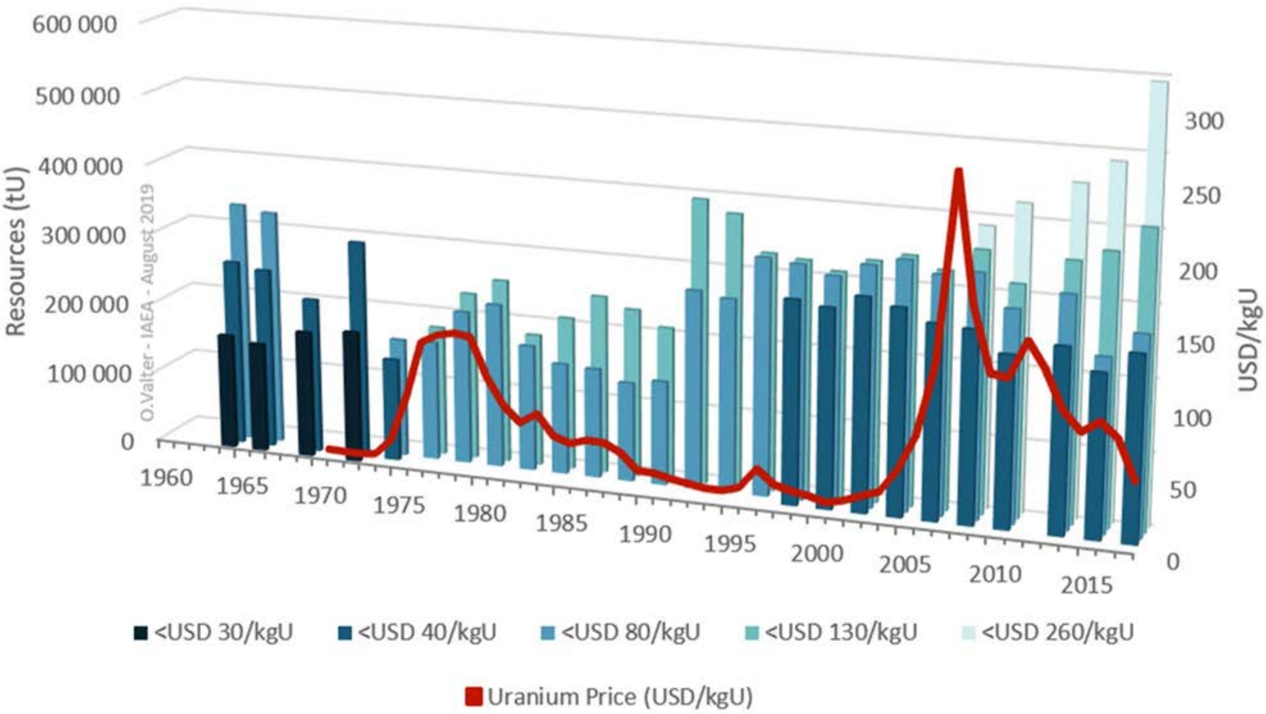


FIG. 8.17. Historical variation of recoverable reasonably assured resources within various cost categories in Canada. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

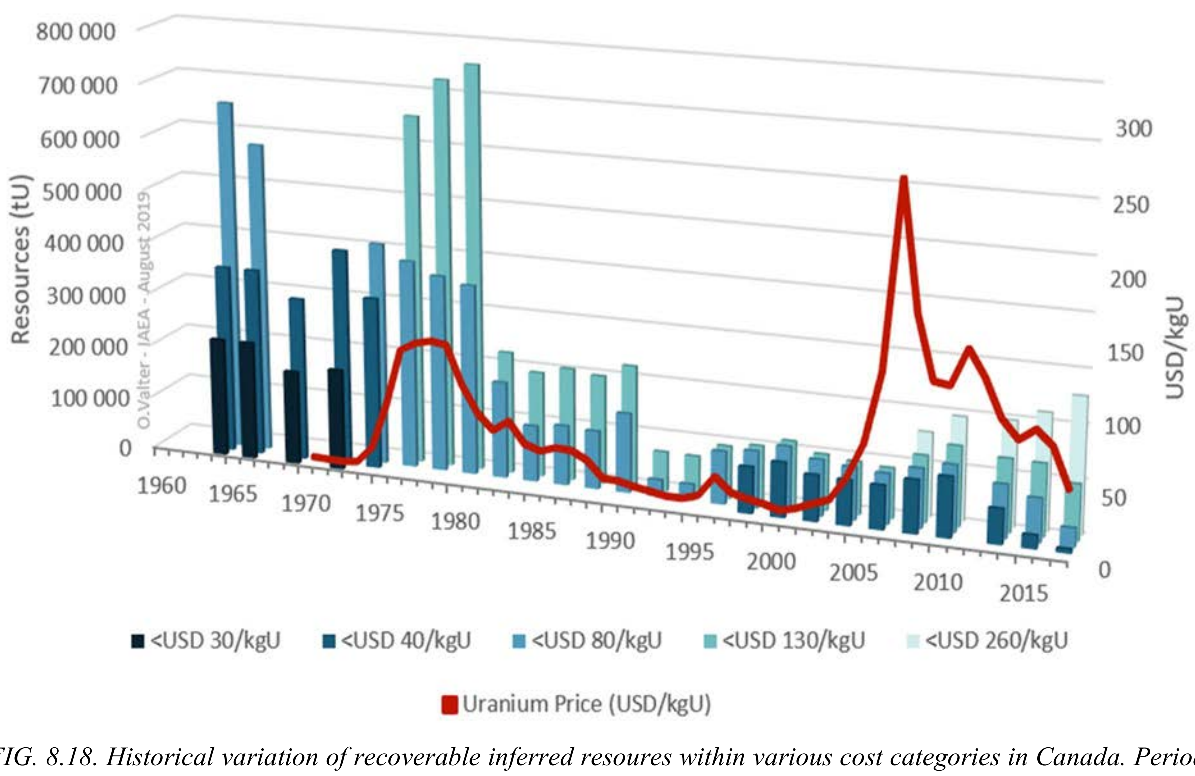


FIG. 8.18. Historical variation of recoverable inferred resoures within various cost categories in Canada. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

8.5.5. Uranium production

8.5.5.1. Historical review

The uranium industry of Canada started in the Northwest Territories with the finding of the Port Radium pitchblende deposits in 1930. Exploited for radium throughout the period 1933–1940, these deposits were reopened in 1942 in reply to the uranium need by the United Kingdom and the USA for their defence programmes. A prohibition on exploration and development by private firms was repealed in 1947, and by the late 1950s ~20 production centres for uranium had begun in the Northwest Territories, Saskatchewan and Ontario. By 1959, 23 mines with 19 treatment plants were in operation in five districts. Of these 19 plants, ~11 in the Elliot Lake area were operated by Rio Algom Ltd and Denison Mines Ltd. Two other plants were located in the Northwest Territories, three near Bancroft in SE Ontario, and three in northern Saskatchewan. Production was highest in 1959 at 12 200 tU. No additional defence contracts were authorized after 1959 and production started to drop. In spite of Government stockpiling programmes, output dropped swiftly to 3025 tU by 1966, by which time just four producers were left.

Although the first commercial sales to electric utilities were authorized in 1966, it was not until the mid-1970s when demand and prices had grown adequately to encourage growths in activity for exploration and mine development. With the industry definitely re-instituted by the late 1970s, a number of additional facilities were under development in Ontario and Saskatchewan. Yearly output increased gradually during the 1980s, as Canada's focus for production of uranium moved progressively to Saskatchewan. The last Ontario uranium mine that left shut down in mid-1996. Fig. 8.19 provides national historical production details for the period 1945–2017 of 509 975 tU, comprising 179 288 tU and 56 245 tU underground and open pit mining respectively.

The Rabbit Lake deposit, in northern Saskatchewan, was discovered in 1968 and was brought into production as an open-pit in 1975. The mill then processed ore from the Collins Bay A, B and D open pits, then from the underground Eagle Point deposit which was put in care and maintenance in 2016. Also in 1975, deposits at Cluff Lake and Key Lake were found on the west and south of the Athabasca Basin, and production started in 1980 and 1983, respectively.

Throughout the 1990s, Cameco's Key Lake was the largest uranium mine in the world, supplying 15% of global production in 1997 from the Deilmann and Gaertner open pits.The other uranium production center in operation in the late 1990s was at Cluff Lake, where several deposits were mined (open pits and undergrounds). Owned and operated by COGEMA Resources Inc. (now Orano), Cluff Lake ceased production in 2002.

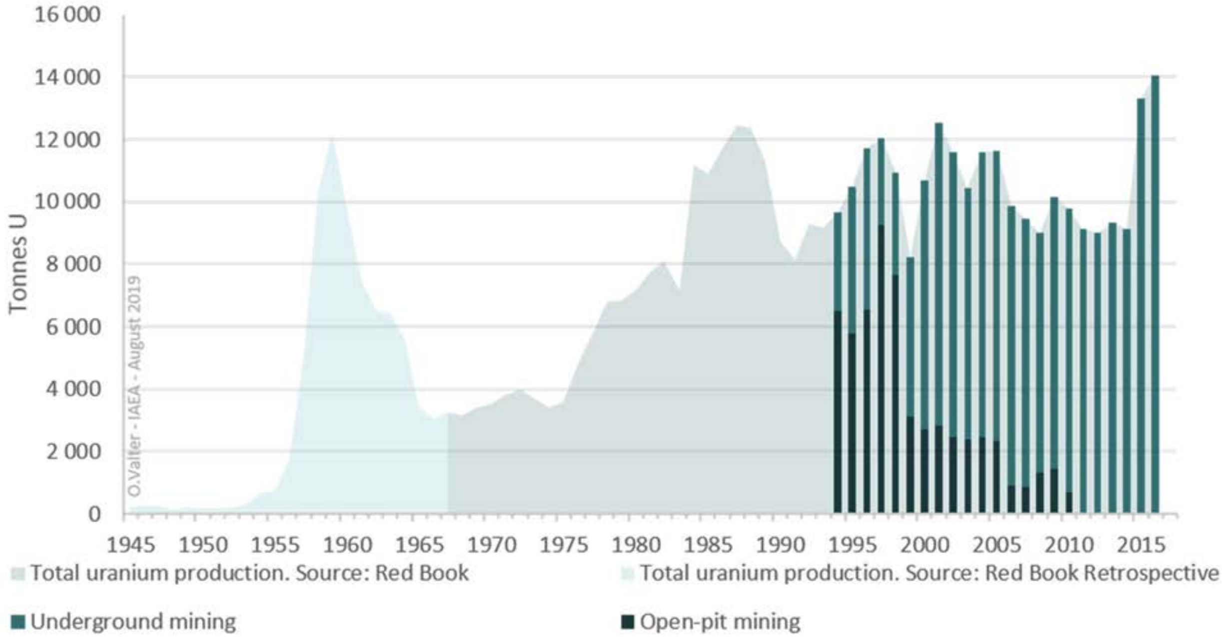


FIG. 8.19. Historical uranium production in Canada (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

The McClean Lake mine and mill, NE of the Athabasca Basin, commenced operation in mid-1999. Initially, mining was conducted from four open pits (Sue A, B, C and E) now depleted. The mill and other infrastructures are used to treat ore from Cigar Lake since 2014.

The McArthur River mine, operated by Cameco, has extensive reserves of very high grade ore and opened its underground mine at the end of 1999. Remote control raise boring methods are used for mining, some 600 m underground. Ore is trucked to the Key Lake mill, 80 km to the south [5.5, 5.6]. Due to low prices and oversupplies, Cameco stopped production at McArthur River in 2017.

8.5.5.2. Mined deposits and future projects

From the time the last Elliot Lake production facility shut down in 1996, all active uranium production centres are now found in northern Saskatchewan (Fig. 8.17). Present Canadian production of uranium continues to be lower than full production capacity. Production in 2010 was 9786 tU, slightly lower than the 2009 production of 10 174 tU, which was mainly because of the exhaustion of the ore stockpile at the McClean Lake mill. Production of uranium in Canada was anticipated to drop to 8600 tU in 2011, 2012 and 2013, though it will grow substantially in 2014 as production starts in the Cigar Lake mine [5.5].

Canada uranium production was 9134 t in 2014, 13 325 t in 2015, 14 039 in 2016 and 13 130 in 2017. Cigar Lake is the only producing deposit in 2018.

Total historical production to 2017 is 509 975 t U.

8.5.5.3. Status of production capability

Cameco Corporation operates the McArthur River mine, which is a joint venture between Cameco (70%) and Orano (30%). Here, the largest high grade uranium mine in the world, production was 7273 tU and 7594 tU in 2009 and 2010, respectively. High grade ore is extracted by raise bore mining behind a freeze curtain constructed to restrict inflow of groundwater. After that, slurry with high grade ore is generated by facilities for underground crushing, grinding and mixing. Then, the slurry is driven to the surface and filled into specifically fabricated vessels that are transported 80 km to Key Lake, where all McArthur River ore is milled.

Cameco also operates the Key Lake mill, which is also a joint venture between Cameco (83%) and Orano (17%). Even though mining at Key Lake ceased in 1997, the mill continued its status as the largest uranium production centre in the world by generating 7339 tU and 7654 tU in 2009 and 2010, respectively. These figures correspond to slurry of high grade McArthur River ore mixed with stockpiled, mineralized Key Lake special waste rock to generate a feed for the mill with grade of ~3-4% U.

Orano operates the McClean Lake production centre, which is a joint venture between Orano (70%), Denison Mines Inc. (22.5%) and OURD (Canada) Co. Ltd, subsidiary of the Overseas Uranium Resources Development Corporation of Japan (7.5%). Mining by open pit was accomplished in 2008 and ore with 2500 tU was stockpiled to supply mill feed. Production in 2009 and 2010 totalled 1388 tU and 657 tU, respectively, and was obtained from treating the higher grade ore from the stockpile. The leftover lower grade ore in the stockpile was uneconomic to treat and thus the mill was put on care and maintenance in July 2010. Production restarted in 2014 as high grade ore from Cigar Lake becomes available for treatment. Adjustments to the mill to expand annual capacity to 4615 tU and to treat ore from the Cigar Lake mine have been accomplished.

The environmental assessment of a plan to mine the small Caribou deposit was finished in April 2010. AREVA has chosen, however, to delay mining the deposit until economic conditions recuperate.
Cameco fully owns and operates the Rabbit Lake production centre, which generated 1447 tU and 1463 tU in 2009 and 2010, respectively from the Eagle Point deposit. Exploratory drilling in the Eagle Point mine throughout the preceding several years has outlined new assured resources, prolonging the life of the mine to at least 2017. Cameco has signified that it aims to undertake in 2012 underground exploratory drilling at the Eagle Point mine to asses an orebody that was found throughout the most recent phase of surface drilling.

With recoverable resources of 121 400 tU with average grade of ~14% U (as of 1 January 2017), Cigar Lake is the second largest high grade deposit of uranium in the world. Cameco operates the mine, which is a joint venture among Cameco (50.025%), Orano (37.1%), Idemitsu (7.875%) and TEPCO (5%). Production was 5124 t in 2015, 7863 t in 2016 and 8165 t in 2017. Ore from this mine is transported to the McClean Lake mill for treatment.

Development of the Cigar Lake mine started on 1 January 2005, and was initially anticipated to be finished in 2007. Throughout October 2006, development was halted due to a major uncontrolled inflow of groundwater which resulted in the mine being flooded. Cameco carried out work to block the rupture. However, while dewatering the mine in 2008, a second groundwater inflow happened and operations were stopped. The second rupture was blocked and dewatering of the mine was fulfilled in February 2010. [5.5]. Production started in 2014.

8.5.5.4. Ownership structure of the uranium industry

Orano and Cameco Corporation operate the existing uranium production centres in Canada. Cameco is the proprietor and operator of the Rabbit Lake production centre, which comprises the Eagle Point mine as well as the Rabbit Lake mill. Cameco likewise operates the McArthur River mine as well as the Key Lake mill, which are joint ventures with Orano. Orano is the main proprietor and operator of the McLean Lake production centre in which OURD (Canada) Ltd and Denison Mines Inc. have smaller ventures [5.5].

8.5.5.5. Future projects

There are a number of other projects for exploration in the Athabasca Basin with recognized substantial high grade mineralization of uranium that may develop into plans for new mines. The Denison Gryphon and Phoenix deposits in the East part of the basin and the Triple R and Arrow deposits in the western area of the basin.

There is the likelihood, too, of mines being developed in provinces other than Saskatchewan. A plan by AREVA to develop the Sissons and Kiggavik deposits in Nunavut was going through an environmental assessment as well as a feasibility study. In 2016, the Canadian government agreed with the Nunavut Impact Review Board recommendation, and stated that Orano (then AREVA Resources) could resubmit when it had a proposed start date [5.27].

Strateco Resources Inc. has submitted an application for a permit to undertake subsurface and underground exploration at the Matoush deposit in Quebec. Development of the deposit was postponed in 2013 when the Government of Quebec announced a moratorium on uranium exploration and mining. Since, the project is on care and maintenance.

There is likewise a plan to develop the Jacques Lake and Michelin deposits in Labrador. This plan is presently on hold when a 3-year suspension that was ratified by the Nunavut Assembly in 2008 [5.5].

8.5.6. Environmental activities and sociocultural issues

8.5.6.1. Environmental impact assessments

Both the Federal Government and the Saskatchewan Provincial Government have extensive environmental review processes that must, under law, be completed before any major industrial development judged to have potential environmental impacts is undertaken within their respective territories. Prior historical experience has shown that the environmental assessment and permitting processes for uranium projects in Canada are complex and may take a considerable amount of time to complete. For example, the process of permitting several of Canada's projects still active in 2013 began as early as the late 1980s with the submission of proposals for preparing environmental impact assessments for the Dominique Janine, Midwest joint venture and McClean Lake projects. The process included a lengthy public review which began in August 1991 with appointment of The Joint Federal/Provincial Panel on Proposed Uranium Mining Developments in Northern Saskatchewan (Canada-Saskatchewan) ('the Panel'). By late 1997, the Panel had completed its review of the six new uranium facilities, including mines (Cigar Lake, McArthur River, Dominique Janine Extension/Cluff Lake and Midwest mines) and mills (JEB mill, McClean Lake project) and related tailings disposal sites (JEB Tailings Management Facility) planned in northern Saskatchewan. In completing its six-year review, the Panel made various recommendations regarding the projects. Only after this did the various regulatory bodies take decisions regarding authorization of the various projects. While the regulatory bodies were not bound by the recommendations made by the Panel, they did take them into consideration in issuing the licences and conditions for operation [5.25].

The environmental assessment of the Midwest project started on 2 March 2006. The Midwest project is a joint venture between Orano (69.16%), Denison Mines Inc. (25.17%) and OURD (Canada) Co. Ltd. (5.67%). The plan is to mine by open pit the Midwest deposit (13 300 tU at an average grade of 4.68% U) and to ship the ore to McClean Lake for milling.

AREVA (now Orano) publicized in 2008 its choice to delay development of the project because of the existing low price for uranium. In spite of this, AREVA is continuing with the process of environmental assessment. If the project is given regulatory authorization, and if the money matters of the project gets better, it will need two years to develop the mine and another two years to mine the ore. Milling of the Midwest ore is anticipated to last 5–7 years. In 2018, the project is dormant.

AREVA publicized on 3 December 2007 its choice to carry on with an economic feasibility study and to start the regulatory procedure to acquire authorization for the development of the Kiggavik–Sissons project in Nunavut. The deposits have an assessed 44 000 tU with average grade of 0.47% U. An environmental assessment of the project was presented to the Nunavut Impact Review Board as an element of the Canadian Nuclear Safety Commission (CNSC) permitting procedure. In 2015, the Nunavut Impact Review Board declined to approve the project due to the indefinite start date, but invited resubmission when Orano (then AREVA Resources) could provide a more definite timescale.

The environmental assessment of the Matoush exploration project started in November 2008. The plan, submitted by Strateco Resources Inc., is to undertake subsurface and underground exploration on the Matoush deposit, which is situated in the Otish Mountains in Quebec. It has known resources of 6500 tU with average grade of 0.42% U. The environmental impact assessment was presented for regulatory appraisal in November 2009 and a decision was anticipated in 2011. Development of the deposit was postponed in 2013 when the Government of Quebec announced a moratorium on uranium mining.

Cameco submitted in August 2009 a plan to the CNSC to develop the Millennium deposit, which is situated 35 km north of Key Lake at depth below 600m. The planned subsurface mine would generate 150 000–200 000 t of ore yearly for six to seven years. Ore and related waste materials, other than clean waste rock, would be shipped to the Key Lake mill along a new 21 km access road. Cameco is, aside from an environmental assessment, carrying out an economic feasibility study of the project. The project is dormant in 2018 due to low uranium prices.

A plan to prolong the lifespan and grow the yearly production capacity of the Key Lake milling operation by 33% (from 7200 tU/year to 9600 tU/year) was presented to the CNSC in May 2010. The plan comprised growing the storage capacity of the Deilmann Tailings Management Facility and making adjustments to the mill to enable processing of a broader range of ore and waste rock from other deposits. AREVA submitted in February 2010 a plan to ship slurry of uranium ore from the McArthur River mine to the McClean Lake mill for treatment. The main goal of this project, which went through an environmental assessment, was to enhance the mill's high grade circuit in expectation of the subsequent feed of similar high grade ore from Cigar Lake [5.5].

8.5.6.2. Effluent management

Treatment of water and minor engineering works remained to be the major activities conducted at the sites of the terminated Elliot Lake area uranium mine and mill throughout 2009 and 2010. The quality of water in the Serpent River watershed has recovered from the time of closing and mothballing of the mines and presently fulfils the drinking water standards of Ontario [5.5].

8.5.6.3. Site rehabilitation

Operations for mining and milling in the Cluff Lake mine, situated in the western Athabasca Basin of Saskatchewan, stopped in May 2002. A 2-year mothballing programme was started in 2004, after a 5-year thorough environmental assessment study. Mothballing was basically accomplished by 2006 and AREVA remains to carry out site restitution activities, such as planting of at least 800 000 tree seedlings. A supplementary monitoring programme is ready to substantiate that the aims of the mothballing plan are achieved.

The Federal Government and the Provincial Government of Saskatchewan publicized on 2 April 2007 financial support for the first phase of the rehabilitation and restoration sites of uranium mining (mainly the Lorado and Gunnar mines) that operated in northern Saskatchewan since the late 1950s to the early 1960s. The private sector firms that operated these facilities are already non-existent. When the sites were shut, there was no regulatory structure in place to properly contain and process the waste and this has led to environmental impacts on local soils and lakes. The projects to mothball the Lorado and Gunnar sites are presently going through environmental assessments.

At Elliot Lake, the principal uranium mining centre in Canada for at least 40 years, uranium mining firms have pledged in excess of CAD 75 million to mothball all mines, mills and waste management areas. These firms remain to pledge around CAD 2 million yearly for processing and monitoring activities [5.5].

8.5.7. Employment in the uranium industry

Total direct employment in uranium industry of Canada was 1379 in 2009 and 1305 in 2010. Total employment, comprising head office and contract personnel, was 2205 in 2009 and 2399 in 2010 [5.5].

References to Section 8.5

[5.1] SCHERTZER, W.M., “Freshwater lakes”, The Surface Climates of Canada, McGill-Queen’s University Press, Montreal and Kingston (1997).

[5.2] GEOLOGICAL SURVEY OF CANADA, Geology and Economic Minerals of Canada, Part A, (DOUGLAS, R.J.W., Ed.), Dept. of Energy, Mines and Resources, Ottawa (1968).

[5.3] GEOLOGICAL SURVEY OF CANADA, Geology and Economic Minerals of Canada, Part B, (DOUGLAS, R.J.W., Ed.), Dept. of Energy, Mines and Resources, Ottawa (1968).

[5.4] JEFFERSON, C.W., et al., “Unconformity associated uranium deposits of the Athabasca Basin, Saskatchewan and Alberta”, Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods (GOODFELLOW, W.D., Ed.), Geological Association of Canada, St. Johns, NL (2007).

[5.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).

[5.6] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[5.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1976).

[5.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1977).

[5.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[5.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[5.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

[5.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[5.13] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[5.14] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

[5.15] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[5.16] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[5.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1995: Resources, Production and Demand, OECD, Paris (1996).

[5.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[5.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[5.20] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2001: Resources, Production and Demand, OECD, Paris (2002).

[5.21] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[5.22] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).

[5.23] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[5.24] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[5.25] UNDERHILL, D.H., “Stakeholder involvement in the Canadian review process for uranium production projects in northern Saskatchewan”, Stakeholder Participation in Radiological Decision Making: Processes and Implications (Proc. Third Villigen Workshop, 2003), OECD, Paris (2004) 19–22.

[5.26] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[5.27] WORLD NUCLEAR NEWS, www.world-nuclear-news.org/UF-Areva-disappointed-with-Kiggavik-decision-0408167.html, (2016)

8.6. CHILE

8.6.1. Geography

Chile is located in southern South America and has a Pacific coastline of 6435 km in length. It occupies a strategic location with respect to the sea lanes between the Pacific Ocean (Strait of Magellan, Beagle Channel and Drake Passage) and Atlantic Ocean. Chile also comprises Isla Sala y Gomez and Easter Island (Isla de Pascua) in the south-eastern Pacific Ocean.

The mainland topography comprises low coastal mountains, a fertile central valley and the rugged Andes in the east. A high plateau, the Altiplano, is shared with Peru, Bolivia and Argentina. Its western margin borders the Pacific Ocean and its eastern boundary lies within the Andes. Its width rarely exceeds 200 km and the topography rises from sea level to almost 7000 m. To the south of latitude 42°, the Andes are exposed along the coast, where they form rugged fjord-like terrain.

Severe earthquakes, active volcanism and tsunamis pose continual risks. The north is characterized by the Atacama Desert, one of the driest areas on earth. The climate is Mediterranean in the central region and cool and damp in the south of the country. Copper, timber, iron ore, nitrates, precious metals, molybdenum and hydropower are natural resources. Chile is a leading copper producer. The highest point in Chile is Nevado Ojos del Salado at an elevation of 6880 m [6.1].

8.6.2. Geology

8.6.2.1. General

Chile is mainly a product of the Andean and preceding orogenies and was created by the long lived convergent boundary along South America's western coast. The geological evolution of Chile has resulted from the effects of the eastwards subduction of the Pacific Ocean floor beneath the South American continent. This subduction has generated the Andes, which is a chain of mountains whose primary uplift dates back to a Miocene event but whose emergence continues to the present-day, as exemplified by the major seismic activity recorded in the region. In 2010, an earthquake of magnitude 8.8 was recorded just off the coast, ~300 km SW of Santiago. The Late Proterozoic–Late Palaeozoic evolution was punctuated by terrain accretion and westwards arc migration and this sequence of events can be described as a collisional history.

Around 80–90% of Chile is comprised of volcanic rocks (Fig. 8.20) related to the subduction zone. Owing to its economic importance, the geology of the mining areas in northern Chile has always received much more attention and is thus far better known than that of the expanses of southern Chile, where very much less mineral wealth has been found [6.1].

FIG. 8.20. Regional geological setting of Chile showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.6.3. Uranium exploration

8.6.3.1. Historical review and work done

Activities for exploration of uranium in Chile began in the early 1950s. Geological mapping, geochemical drainage surveys, ground and airborne radiometry were carried out. These led to the recognition of 3800 geochemical and radiometric anomalies, the identification of 120 sectors of interest and the finding of 80 uranium occurrences. Preliminary exploration took place at 12 sites and resources of uranium as a by-product of copper and phosphate mining were evaluated.

Throughout the 1970s and into the 1980s, various surveys and studies were concentrated in the mining districts:

(a) Throughout 1970–1974, the Nuclear Energy Board (JEN) of Spain and Chile completed a survey of the Tambillos mining district;
(b) The Centro de Estudios Nucleares del Ejército (CENE), JEN and the Comisión Chilena de Energía Nuclear (CCHEN) conducted metallurgical studies at the Chuquicamata copper mine;
(c) CCHEN and the Corporación Nacional del Cobre (Codelco) carried out uranium recovery testing at the company's copper mines. In 1979–1982, Essex Mineral Co. conducted geological exploration and radiometry in the area between Arica and Quillagua;
(d) In 1980–1984, Pudahuel Mining Co. and CCHEN conducted exploration using boreholes drilled at the Sagasca sandstone-hosted copper–uranium deposit at Tarapaca. Technical and economic evaluation of the Huinquintipa sandstone-hosted copper deposit was also undertaken;
(e) The IAEA and the United Nations Development Programme carried out regional prospecting across an area of 150 000 km² between 1976 and 1990, as well as providing training on uranium exploration. Productora (Estacion Romero), which is associated with a hydrothermal metasomatic alteration zone in the north, was the location of the first uranium mineralization identified in Chile.

Since 1984, CCHEN focused primarily on geological research related to uranium. Key phases in uranium exploration in Chile are summarized in Refs [6.2, 6.3]. These are as follows:

(a) In 1986–1987, the Production Promotion Corporation and CCHEN conducted exploration and technical and economic evaluation of the Bahía Inglesa phosphorite deposit (Atacama);
(b) In 1990–1999, CCHEN conducted a geological and metallogenic survey of uranium, mainly in the north of the country. It established the National Uranium Potential Evaluation Project and, together with the National Mining Company (ENAMI), conducted an investigation of rare earth elements related with radioactive minerals in the Coquimbo and Atacama regions, with the Diego de Almagro anomaly no. 2 given the priority;
(c) An initial geological study of uranium and rare earth element mineralization at the Cerro Carmen site, situated in Atacama III Region, was conducted under a Specific Co-operation Agreement in 2000–2002;
(d) Geophysical surveys at the Cerro Carmen site and regional exploration for uranium and rare earth elements continued until the cooperation agreement between ENAMI and CCHEN was terminated in about 2003;
(e) Work on the database of projects continued throughout 2004 and paid consultative services were provided to the mining industry from 2004 through 2006 [6.2–6.3].

8.6.3.2. Recent and ongoing uranium exploration and mine development activities

Since October 2007, Lefroy Resources, an Australian company, has been involved in exploration for uranium across a large area (30 000 ha) in Chile and Peru. An area of particular interest is the Tarapaca region, where the projects lie close to major infrastructure. No further details or more recent information is available on these projects.

Polar Star Mining Corporation, a porphyry copper mining company, reports through a wholly owned subsidiary, Minera Celeste, that its property included at least six collapse breccia pipes hosting uranium, copper, molybdenum and other mineralization. The property, known as the Los Azules project, lies ~800 km north of Santiago. The breccias are most likely to be hosted in igneous rocks and therefore are not similar to the collapse breccia type environments where economic deposits have been identified, such as those in the United States of America.

In July 2008, U3O8 Corporation, a Canadian company, conducted exploration related to anomalous radiometric readings from soil and sediment samples in an area near Concepción. U3O8 Corporation has seven exploration prospects identified primarily on review of the literature and by modelling, identifying those prospects which showed indications of matching either the Massif Central model or the sandstone Shirley Basin Wyoming model. One area of interest lies in southern Chile, which is underlain by Upper Triassic continental sedimentary rocks (shales, sandstones and conglomerates), that are unconformable with the granitoid rocks of the exposed coastal batholith. No recent update on progress is available.

By year-end 2008, Codelco, the State-owned copper company, reported that it would be operating with Chile's Nuclear Energy Commission to establish the viability of extricating uranium from its northern Radomiro Tomic and Chuquicamata mines.

In June 2009, Southern Hemisphere Mining Ltd announced that it had acquired two prospects from two Australian exploration companies (Pan American Mining and South America Mining) that include gold, base metals, uranium and iron. No further details are available [6.4–6.8].

8.6.3.3. Expenditures

Figure 8.21 lists the exploration expenditures of Government entities for the period 1975–2017, for a total of USD $10 million, including 5510 metres of drilling and radiometric and other surveys.

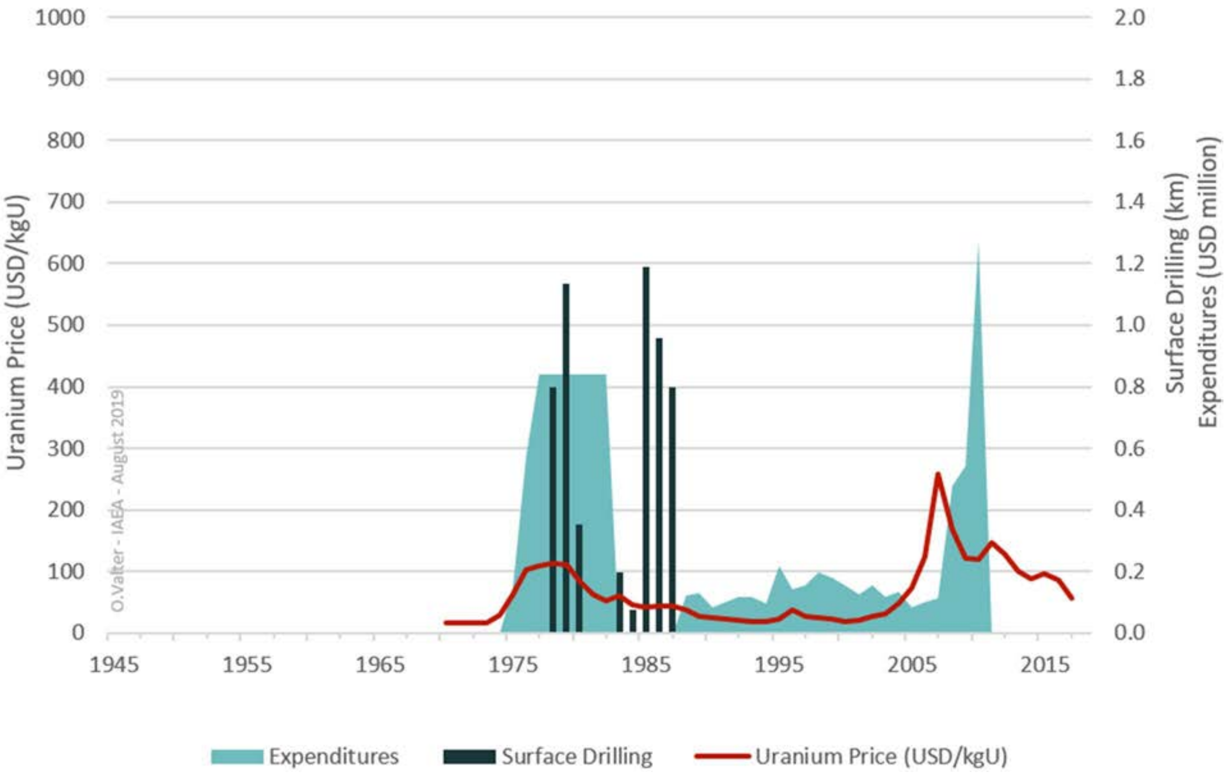


FIG. 8.21. Domestic uranium exploration data. Comparison of exploration expenditures, drilling and uranium market price (US$ current). For 2000–2003, expenses comprise wages and salaries, operating expenses incurred by ENAMI and CCHEN, and CCHEN's administration expenses.

8.6.4. Uranium resources

As of 1 January 2017, Chile reports known conventional resources totalling 1448 tU, comprising 561 tU of reasonably assured resources and 887 tU of inferred resources, in the <US$ 260/kgU cost category (Tables 8.12 and 8.13).

The UDEPO database lists the most significant deposits for Chile as Chuquicamata, Radomiro Tomic, Sierra Gorda, Cerro Carmen, Carizal Alto, Bahia Inglesia, Mejillones, Chuqui Sur, El Algorrobo.

TABLE 8.12. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE (tU) [6.8]

Deposit type	< US$ 260/kgU
Volcanic related	540
Surficial	21
Total	561

TABLE 8.13. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [6.8]

Deposit type	< US$ 260/kgU
Volcanic related	75
Metasomatite	782
Surficial	30
Total	887

8.6.4.1. Undiscovered resources

Undiscovered conventional resources (prognosticated resources and speculative resources) are assessed to total 4684 tU. Most of this resource (4060 tU) is anticipated to reside in the Upper Cretaceous metasomatite type occurrences. Among this group, the bulk of the resource, totalling 2900 tU, is allotted to the Diego de Almagro occurrence [6.9].

8.6.4.2. Unconventional resources

Chile reported total reasonably assured unconventional or by-product resources of 1169 tU. Most of these resources are related with the Chuquicamata copper deposit and with the Mejillones and Bahía Inglesa deposits of uraniferous phosphate. Uranium could theoretically be retrieved as a by-product from both types of deposit. However, owing to the very low content of uranium, of the order of 8–10 ppm (or 0.0008–0.001% U), costs of production are expected to be at least US $130/kgU [6.9].

In addition to the reasonably assured resources, Chile reported 5458 tU of prognosticated and speculative unconventional resources.

8.6.5. Potential for new discoveries

In 1979, IUREP recognized that vein and/or disseminated deposits related to igneous intrusions could occur in Chile. Favourable geological environments are being investigated, but as of 2010 no significant deposits had been delineated [6.2, 6.10].

Chile has no recorded uranium production.

8.6.6. National policies related to uranium

As stipulated in Law 16.319, CCHEN has the directive to counsel the Government in all issues concerning the peaceful use of nuclear energy. It is likewise in charge of developing, proposing and executing the national proposals for research, development, utilization and control of all aspects of energy.

Pursuant to Law 18.248 of 14 October 1983, the Mining Code permits free claims to uranium, as an enticement to private sector prospecting and exploration for natural radioactive minerals. The law likewise provides CCHEN the first preference to buy. However, due to the market conditions existing throughout 1980–2004, there was no private sector involvement in exploration. In the last two years, both national and foreign firms have indicated an interest in developing businesses for uranium exploration and production in the country. Thus, in order to fulfil its directive under the law, CCHEN, as a State agency, is developing basic geological information on potential national resources of radioactive minerals in place of the private sector.

Supreme Decree No. 302 of 21 December 1994 authorized the National Nuclear Development Plan, comprising goals related to prospecting and exploration for materials of nuclear interest. This directive has been realized by way of geological surveys [6.9].

References to Section 8.6

[6.1] BRINEY, A., Geography and maps of Chile (March 2010), http://geography.about.com/od/atlas/a/chile.htm

[6.2] ARANCIBIA NANJARI, M., "Uranium exploration in Chile", paper presented at IAEA Regional Training Course on Uranium Geology and Exploration, Poços de Caldas, 2009.

[6.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

[6.4] LEFROY RESOURCES LTD, News release (15 January 2010), http://www.lefroyresources.com.au

[6.5] POLAR STAR MINING CORPORATION, News release (21 January 2010), http://www.polarstarmining.com

[6.6] U3O8 CORPORATION, News releases (2008–2009), http://www.U3O8corp.com

[6.7] SOUTHERN HEMISPHERE MINING LTD, News release (June 2009).

[6.8] WISE URANIUM, New Uranium Projects: Central/South America – Chile (September 2008), http://www.wise-uranium.org/upsam.html#CL

[6.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[6.10] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

8.7. COLOMBIA

8.7.1. Geography

Colombia occupies the north-western portion of the South American continent, adjoining the Isthmus of Panama. The Pacific Ocean lies to the west and the Caribbean Sea to the NE. The western two fifths of the country contain most of the population.

The rugged ridges of the Serania de Baudo lie along the Pacific coast and have an elevation up to 4877 m. To the east lie the three Andean ranges: (i) the Cordillera Occidental, (ii) the Cordillera Central and (iii) the Cordillera Oriental, which rise to more than 5790 m. The Cordillera Occidental is the lowest and the least populated of the three ranges. In the north, on the Guajira Peninsula, is the Sierra Nevada de Santa Marta, which is separated from the Andean chains and rises above 5790 m. Lowlands and rainforest comprise the eastern three fifths of Colombia. Other lowland areas lie along the Pacific and Caribbean coasts and between the Andean cordilleras, in the lower stretches of the valleys of the Magdalena and Cauca rivers.

Most of the country is hot and there is little seasonal temperature variation. Rainfall is heavy, generally from June to September, and especially along the western coast and the south-eastern lowlands.

Colombia is rich in natural resources and its main exports include petroleum, coal, gold, coffee and other agricultural produce [7.1].

8.7.2. Geology

8.7.2.1. General

Large areas of Colombia have not yet been mapped (Fig. 8.22). This is particularly true of the Precambrian rocks of the Guyana Shield in the eastern part of the interior zone [7.2]. In addition, the ages of many of the metamorphic and intrusive rocks are unknown, which severely hampers investigation of deposit types on the basis of restricted ages.

Colombia is located within the South American plate, at the contact with the Caribbean and the Nazca plates. Scattered outcrops of metamorphic rocks are relics of Precambrian formations in the eastern Llanos. During the Paleozoic, the ocean invaded the area exposed in the Andean zone with volcanic eruptions in the western part of the country. During the Triassic, the sea that occupied the Andean zone separated into two arms after the surge of the Cordillera Central. Thick layers of sedimentary rocks were deposited during the Jurassic, which ended with developed igneous activity. During the Cretaceous, the sea to the east of the Cordillera Central extended in the south to the Putumayo region, while subterranean volcanic activity continued to the west of the Cordillera Central. During Cenozoic the seas withdrew from most of Colombia's territory, and very large granite intrusions formed along the Cordillera Occidental. Formation of the three cordilleras started 12 million years ago. The Cordillera Occidental and the Cordillera Central form the western and eastern sides of a large crystalline arch which extends from the Caribbean lowlands to the southern border of Ecuador. The Cordillera Oriental is composed of folded stratified rocks overlying a crystalline core.

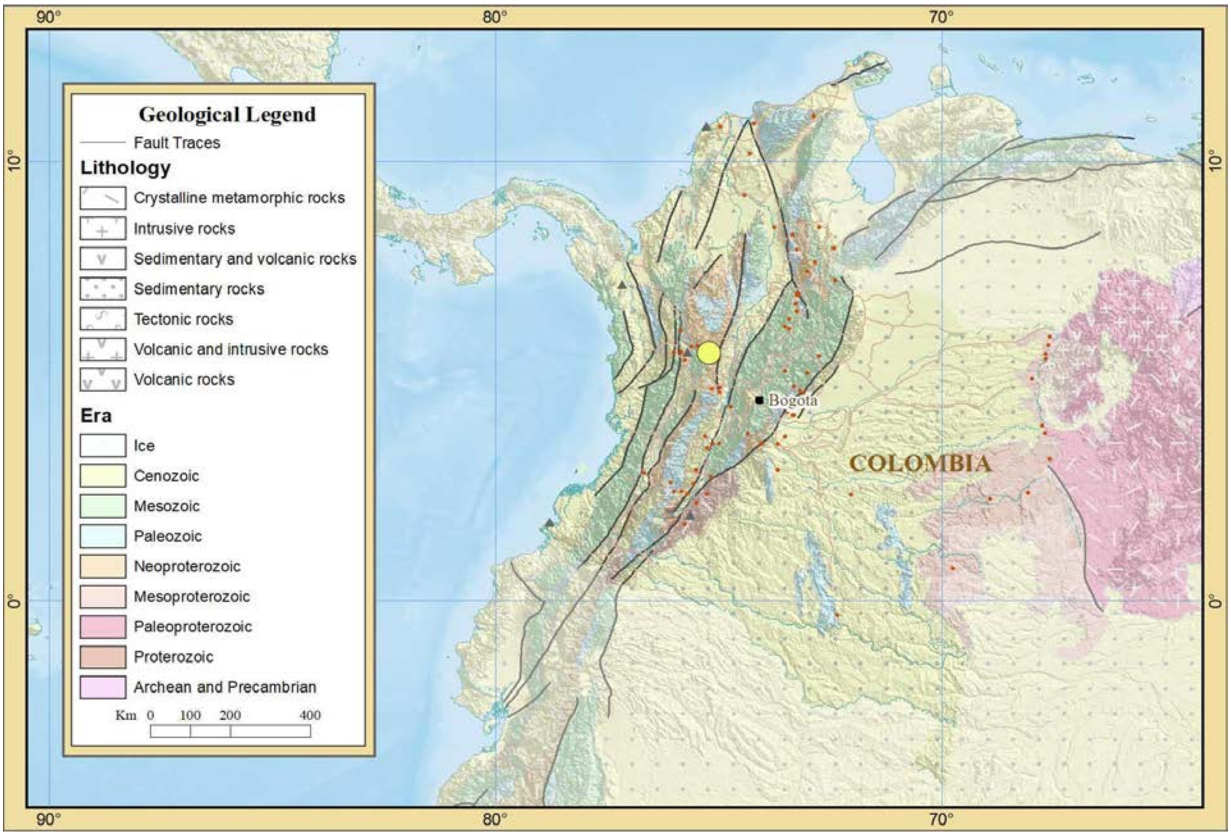


FIG. 8.22. Regional geological setting and uranium mineralisation of Colombia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.7.2.2. Potentially favourable uranium-bearing areas

Little data have been published on uranium occurrences in Colombia. Numerous unpublished reports on uranium occurrences and radiometric surveys in Colombia are catalogued in two libraries in Bogota. These reports are available for re-evaluation by companies in relation to recent geological mapping.

There are no occurrences of the quartz-pebble conglomerate type of mineralization in Colombia. Precambrian outcrops are usually described as comprising high grade metamorphic rocks. The best area in which to search for deposits of this type would possibly be the Guyana Shield.

There are no known occurrences of the Proterozoic unconformity-related deposit type, although areas within the interior zone may have some potential for this type of deposit. The interior zone is divided into basins in the west and the Guyana Shield in the east. The basins are, in general, underlain by shallow shelf deposits, both continental and marine, of Cretaceous and Tertiary age. These lap onto the Guyana Platform of Precambrian gneisses. Other Precambrian areas, such as the Garzon Massif and the metamorphic terrain of the Cordillera Central, may also have some potential for deposits of this type.

Uranium is found in pegmatite dykes in an extensive pegmatite belt in the northern part of the Santander Massif. There are additional areas in the Cordillera Central and in the Guyana region of the interior zone which may also have some potential.

Uraniferous vein deposits occur in the La Baja and Vetas districts of the California gold–silver area of the Santander Massif. Several deposits are reported to contain ore grade material. The La Baja area appears to host the most promising resources of this type. Other areas in the Santander and Garzon Massifs may also be worthy of investigation.

As regards the potential for sandstone type deposits in Colombia, Palaeozoic rocks hold relatively little potential, with the possible exception of Devonian and Carboniferous continental to shallow marine sediments that crop out in the central and southern parts of the Cordillera Oriental, in particular in the Quetame Massif.

Several radiometric anomalies have been identified in black shales in the Cordillera Oriental, around Guadelupe, Villeta and Caqeza.

The 1985 Red Book includes a list of areas identified as having uranium potential, along with a map showing locations [7.3].

8.7.3. Uranium exploration

8.7.3.1. Historical review

There had never been any exploration undertaken particularly for uranium in Colombia up until 1962. Only some sporadic data existed from some very preliminary studies. The Institute for Nuclear Affairs (Instituto de Asuntos Nucleares (IAN)) started, after 1962, to have an interest and conducted field studies. The result of this phase led to the discovery of some anomalies at sites such as San Celestino and Contratacion (Santander Department), Berlin (Caldas Department) and Zapatota, California, Santa Elena (Norte de Santander Department).

The United Nations provided assistance to IAN in the exploration of three areas of the country throughout a three-year period (ongoing in 1979). Despite the limited work undertaken, at least 1300 radioactive anomalies were recorded in the early years of exploration.

The work indicated that the ranking given to Colombia on the basis of speculative resources reported by the NEA–IAEA Steering Group on Uranium Resources in the IUREP report [7.4] may have been too low. The wide range reported in the IUREP Orientation Phase Mission Report: Colombia [7.2], based on favourable geology, is of the order of 20 000–200 000 tU, occurring as disseminated and vein deposits, and as sandstone and other sedimentary type deposits.

In 1976, a contract was signed with the French company Minatome for exploration, development and possible exploitation of an extensive area of central Colombia. The Spanish company ENUSA contracted to explore part of NE Colombia. These contracts involved annual investments in excess of US $1 million throughout the exploration phase. Japanese specialists also undertook surveys of parts of Colombia, particularly the eastern Andes. In addition, companies from the former West Germany and Italy are reported to have carried out surveys with IAN. A detailed history of early (pre-1980) uranium exploration and development, including maps, is included in Ref. [7.2]. IAN presented in 1981 a report on a regional programme for evaluation of uranium-bearing areas which identified 450 anomalies. However, no solid evaluation proposal was formulated to ascertain specific deposits. Ten uranium-bearing geological formations, comprising ~90% (1 024 312 km^2) of the country, were explained in this report.

In 1978–1981, the French company Minatome investigated in the Caldas Province, the southernmost 5 km of a 12 km north-south trending syncline by trenches, adits and widely spaced diamond drill holes. Using a simple cross-sectional area method, Minatome estimated that the area investigated (Berlin deposit) had a resource potential of 12.9 million tonnes at a grade of 0.11% U corresponding to resources of 14 190 tU.

8.7.3.2. Work done

A wide range of exploration techniques were used by various companies involved in exploration with IAN. A detailed history of activities up to about 1982 is found in the IUREP reports [7.2, 7.4].

8.7.3.3. Drilling effort

Pre-1979, there was no surface drilling reported. From 1980 through 1983, a total of 14 905 m (81 drill holes) was reported as having been drilled (Fig. 8.23) [7.5].

8.7.4. Recent and ongoing uranium exploration and mine development activities

Not until 2005 did the Colombian Institute of Geology and Mining (INGEOMINAS) begin reporting applications for mining concessions in the country. The Colombian mining registry listed, as of March 2007, nine mining concessions in the name of two holders. The concessions covered included areas in which previous studies discovered either favourable geological formations or actual uranium mineralization. Concession applicants have been concentrating on focusing and confirming the information detailed in studies which had been undertaken in the past by enterprises and by the State.

A strategic alliance formed in 2008 between Sprott Resources and Lara Exploration Ltd includes a portfolio of exploration projects for phosphate rock in Colombia and Brazil, as well as a uranium exploration project in Colombia (no details are available).

By 2009, the main uranium company exploring in Colombia was the Canadian company Mega Uranium. However, on 8 April 2010, another Canadian company, U3O8 Corporation, announced it had completed the acquisition of Mega Uranium's South American uranium properties, including those located in Colombia. Concessions of interest include:

(a) Four exploration concessions in the Zapatoca–Contratacion uranium district in the Cordillera Oriental of Santander Province: Betulia 1, Betulia 2, Simatoca and Galan. The four tenements, totalling 74 km^2, have potential for sediment-hosted uranium mineralization within Triassic–Jurassic continental clastic sediments of the Giron Formation. In late 2006 to early 2007, a programme of reconnaissance geological mapping, rock–stream sediment sampling and ground radiometric surveys was undertaken on the Betulia 1 concession. Of several anomalies investigated, the most favourable results corresponded to intersections of 1.2 m at a grade of 0.05% U and 0.9 m at a grade of 0.07% U;

(b) The Berlin deposit, in Caldas Province, comprises a 1–3 m thick, concordant layer of uranium mineralization within Lower Cretaceous carbonaceous and phosphatic shales in a north–south trending syncline. In 1978–1981, Minatome investigated the southernmost 5 km of the 12 km syncline by means of 20 trenches, 4 adits and 11 widely spaced diamond drill holes (total 2136 m). Using a simple cross-sectional area method, Minatome estimated that the area investigated had a resource potential of 12.9 million tonnes at a grade of 0.11% U (equating to 14 190 tU);

(c) Three areas of the Central Cordillera, Murillo (87 km^2), Quinchia (13 km^2) and Saldana (11 828 km^2), are under a farm-in agreement with AngloGold. These areas were chosen following a detailed review of the multielement analysis of 4870 rock and stream sediment samples collected by AngloGold in its comprehensive geochemical survey of the Central Cordillera;

(d) Four concession applications covering 78 km^2 in the Chaparral area of the Central Cordillera in Tolima Province. The applications cover ground in which Minatome radiometric surveys and trenching in 1976–1981 delineated three separate, 1–1.5 m thick, concordant layers of 'Berlin style' uranium mineralization within Lower Cretaceous carbonaceous/phosphatic shales. The mineralized zones have not been investigated by drilling;

(e) Two concession applications covering 40 km^2 of ground in the Abejorral area of the Central Cordillera in Antioquia Province. In 1976–1981, Minatome discovered Berlin style uranium mineralization in the Lower Cretaceous black shales of the area.

One of three principal projects U3O8 Corp. is focusing on the Berlin project. Trenching and drilling will aim to verify the grade and width of mineralization in the 1981 historical resource estimate, which also indicated significant levels of vanadium, molybdenum and phosphate. In 2012, a NI-43-101 estimate indicate resources of 8240 t U at a grade of 0.0933% with additional P, V, Y, Mo, Ni, Ag, Re and Nd [7.6].

Other companies have shown interest in Colombia for uranium exploration. On its web site, UrAmerica Ltd, a private British company, reported in November 2008 that it was awaiting Government approval for exploration permits covering 60 000 ha in Santander Province, where uranium has been identified by previous Government studies. The Santander Province property is underlain by the Jurassic Giron Formation and may have potential for hosting sandstone type uranium mineralization. The prospective uranium areas are included in the Jurassic–Cretaceous sequence. However, in a recent executive summary that includes projects in Argentina and Paraguay, no reference to active projects in Colombia is made.

Blue Sky Uranium Corp., a Canadian company, is also noted in the World Information Service on Energy (WISE Uranium Project) for having interests in uranium projects in Colombia, although no current projects are shown on the Blue Sky web site [7.7–7.14].

8.7.4.1. Expenditures

Figure 8.23 summarizes uranium exploration expenditures incurred up to 1989 for a total of USD $33.377 million, including 16 005 metres of drilling. The 2007 Red Book reported that the principal uranium exploration company in Colombia was the Canadian company Lerida Bay Ltd [7.5]. Lerida became part of Mega Uranium Ltd, which was subsequently acquired by Canada's U3O8 Corporation in early 2010.

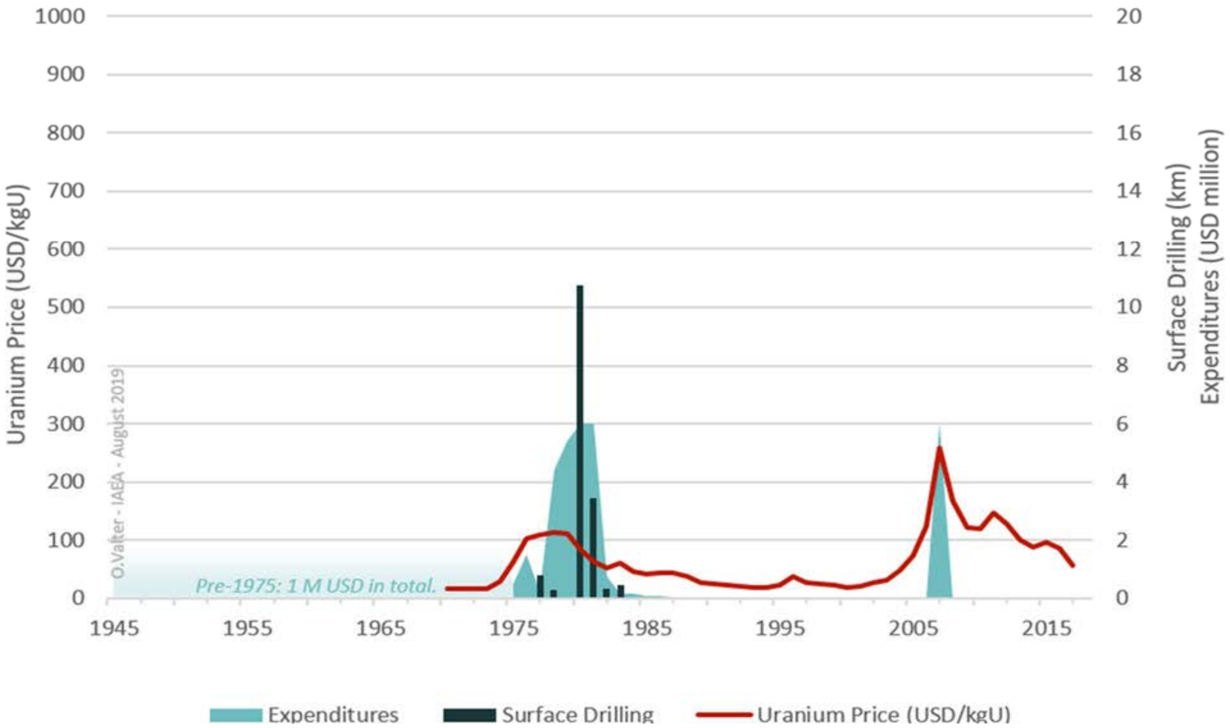


FIG. 8.23. Domestic uranium exploration data for Columbia. Comparison of exploration expenditures, drilling and uranium market price (US$ current). Includes activities carried out throughout the period 1976–1982 by foreign companies. This corresponds to ~65 drill holes totalling 13 275 m and US $22 000 000 in exploration expenditures.

8.7.5. Uranium resources

It is assessed that in situ resources exist in Colombia and estimates of 11 000 tU of prognosticated and 217 000 tU of speculative resources have been made.

There are no officially reported secondary or unconventional resources. The IUREP mission reported 40 000–60 000 tU hosted in Cretaceous phosphates with recovery dependent on development of the phosphate industry.

UDEPO lists the Berlin deposit as having an estimated resource range of 5000–10 000 tU hosted in tabular sandstones [7.14].

The UDEPO database lists the most significant deposits for Colombia as Boyaca, Huila, Berlin, Norte de Santander, Santander, La Bara – Vetas.

8.7.6. Potential for new discoveries

Little is known about the quartz-pebble conglomerates in the Guyana Shield where there could be some potential.

The Santander and Garzon Massifs contain the best potential for new discoveries of disseminated and vein-type mineralization.

The greatest potential for sandstone-hosted deposits occurs in Mesozoic sediments, such as those of the Triassic red beds in the central sector of the Cordillera Central.

The IUREP mission report of 1980 encouraged exploration into the region shared with Venezuela known as La Orinoquia or Llanos Orientales. This extensive area has the potential for quartz pebble conglomerate, Proterozoic unconformity and sandstone type deposits [7.2].

On the basis of known and inferred geology and on the number of known occurrences, Colombia appears to have a moderate likelihood for finding additional uranium resources. It should be noted that climatic conditions, access and relatively limited geological knowledge make realization of their potential a difficult task, in particular in the east of the country [7.2].

8.7.7. Uranium production

There is no reported uranium production for Colombia. The IUREP mission report [7.2] summarizes some early reports which described production of 1500–2000 tU in 1961 from the California region. It appears there was some confusion between reporting related to uranium and that relating to uranium ore. In 1962, an IAEA preliminary assistance mission reported that some mining had been carried out by a private company yielding 2000 t of uranium-bearing ore on which some metallurgical testing was done in Germany and the former Czechoslovakia with the objective of installing ore concentration and treatment facilities. The mined ore was reportedly stockpiled. This is the most plausible explanation for the reports [7.2–7.6, 7.15].

8.7.8. National policies related to uranium

Since its creation in 1959, IAN has been responsible for promoting exploration for, and potential exploitation of, radioactive ores in Colombia. Uranium exploration activities in Colombia can only be carried out in association with IAN and Government participation must be equal to that of the associated party. The Government allows foreign companies operating in Colombia to export their share of uranium without any restrictions [7.2].

References to Section 8.7

[7.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Colombia, Washington, DC (accessed April 2010), https://www.cia.gov/library/publications/the-world-factbook/index.html

[7.2] CAMERON, J., MEUNIER, A.R., TAUCHID, M., International Uranium Resources Evaluation Project (IUREP) Orientation Phase Mission Report: Colombia, February–March 1980, IAEA, Vienna (1980) 181 pp.

[7.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[7.4] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[7.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

[7.6] U3O8 CORP., Berlin project, Columbia. NI-43-101 Report prepared by Coffey Mining (2012) 201 p.

[7.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, International Uranium Resources Evaluation Project (IUREP), Orientation Phase Mission Summary Report: Colombia, OECD, Paris (1984) 26 pp.

[7.8] URAMERICA, Colombia, http://www.uramerica.co.uk/pages/en/280/colombia (accessed June 2009).

[7.9] WISE URANIUM PROJECT, New Uranium Mining Projects — South/Central America, Colombia, http://www.wise-uranium.org/upsam.html#CO (accessed 24 April 2010).

[7.10] BLUE SKY URANIUM, Blue Sky Uranium Corporation, http://www.blueskyuranium.com/s/Home.asp (accessed 24 April 2010).

[7.11] MEGA URANIUM, South America Properties, http://www.megauranium.com/main/?colombia (accessed August 2009).

[7.12] LARA EXPLORATION, Lara and Sprott Complete Asset Swap and Private Placement (accessed 5 January 2010), http://www.laraexploration.com/i/pdf/NR-2010-01-05-Sprott-Alliance-PP.pdf

[7.13] U3O8 CORPORATION, U3O8 Corp. Completes Acquisition of Mega Uranium's South American Assets (8 April 2010), http://www.u3o8corp.com/docs/Press_Releases/2010/April8.pdf

[7.14] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

[7.15] INTERNATIONAL ATOMIC ENERGY AGENCY International Uranium Resources Evaluation Project (IUREP), National Favourability Studies: Colombia, IAEA, Vienna (1977) 19 pp.

8.8. COSTA RICA

8.8.1. Geography

Costa Rica is a Central American nation which, like its neighbours, has coastlines bordering both the Pacific Ocean and the Caribbean Sea. At its narrowest point, only 119 km separates the Caribbean Sea from the Pacific Ocean and even at its widest point, Costa Rica is only 280 km in width.

Situated between 8° and 11° north of the Equator, Costa Rica lies completely within the tropics. However, elevation and extremes of relief add variations to the tropical climate. In fact, the country asserts at least a dozen discrete climatic zones.

Costa Rica can be divided into four geographical areas: (i) the tropical lowlands on the Pacific and Caribbean coasts, (ii) the North Central plains, (iii) the Central Valley, and (iv) the North-west Peninsula. The lowland area covers much of the northern part of the country and is dissected by rivers flowing down from the highlands. These plains extend from the north to the Caribbean coast. Dense tropical rainforests and beaches line both the Caribbean and Pacific coasts. The Pacific coast has a varied topography, with mountainous peninsulas and scattered narrow beaches, whereas the Caribbean coast is generally flat. Most of the cities in Costa Rica, and the bulk of the population, are located in the highland Central Valley, which is overlooked by two intermittently active volcanoes. These form part of the Cordillera Central, one of four mountain ranges running NW–SE.

The major difference in elevation between the mountain peaks in the centre of the country and the lowlands near the coast is one reason for the radically diverse ecosystems and wildlife found in the different areas of Costa Rica. The country used to be known principally as a producer of bananas and coffee. Even though coffee, bananas, pineapple, sugar, lumber, wood products and beef are still important exports, electronics, pharmaceuticals, financial outsourcing, software development and ecotourism have in recent times become major pillars supporting Costa Rica's economy [8.1, 8.2].

8.8.2. Geology

The geology of Costa Rica (Fig. 8.24) is dominated by plate tectonic activities. The volcanic arc of Costa Rica, where the volcano Mount Arenal is located, is a chain of mountains resulting from the subduction of the Cocos Plate under the Caribbean Plate. Costa Rica is part of the Central American isthmus, which connects the North and South American continents. Volcanoes are mostly confined to a NW–SE trending strip in the northern part of the country because the Cocos Plate subducts at a very steep angle there and because the Cocos Ridge disrupts normal subduction to the SE.

Costa Rica has one of the youngest land masses in the Americas — only three million years old — for the volatile region has only recently been thrust from beneath the sea.

Costa Rica lies at the heart of one of the most active volcanic regions on earth and is home to seven of the isthmus' 42 active volcanoes (part of the Pacific Ring of Fire), plus 60 dormant or extinct ones.

The most famous volcano, Mount Arenal, has been almost continuously active since the 1968 eruption, extruding basaltic/andesitic lava flows, and experiencing Strombolian and occasionally Vulcanian explosions from the summit craters, with pyroclastic flows generated from the collapsing fronts of the lava flows.

Much of the country is covered by surficial, volcanic and shallow intrusive rocks and ocean floor peridotite and basalt. Sedimentary rocks are primarily deep water Cretaceous–Quaternary limestone, sandstone, shale and turbidites, and Eocene–Quaternary sedimentary rocks grading from volcaniclastic breccia to sandstone, including some marine carbonate rocks. The rock types present are not generally favourable to hosting uranium mineralization and hence the uranium potential is very low [8.3–8.8].

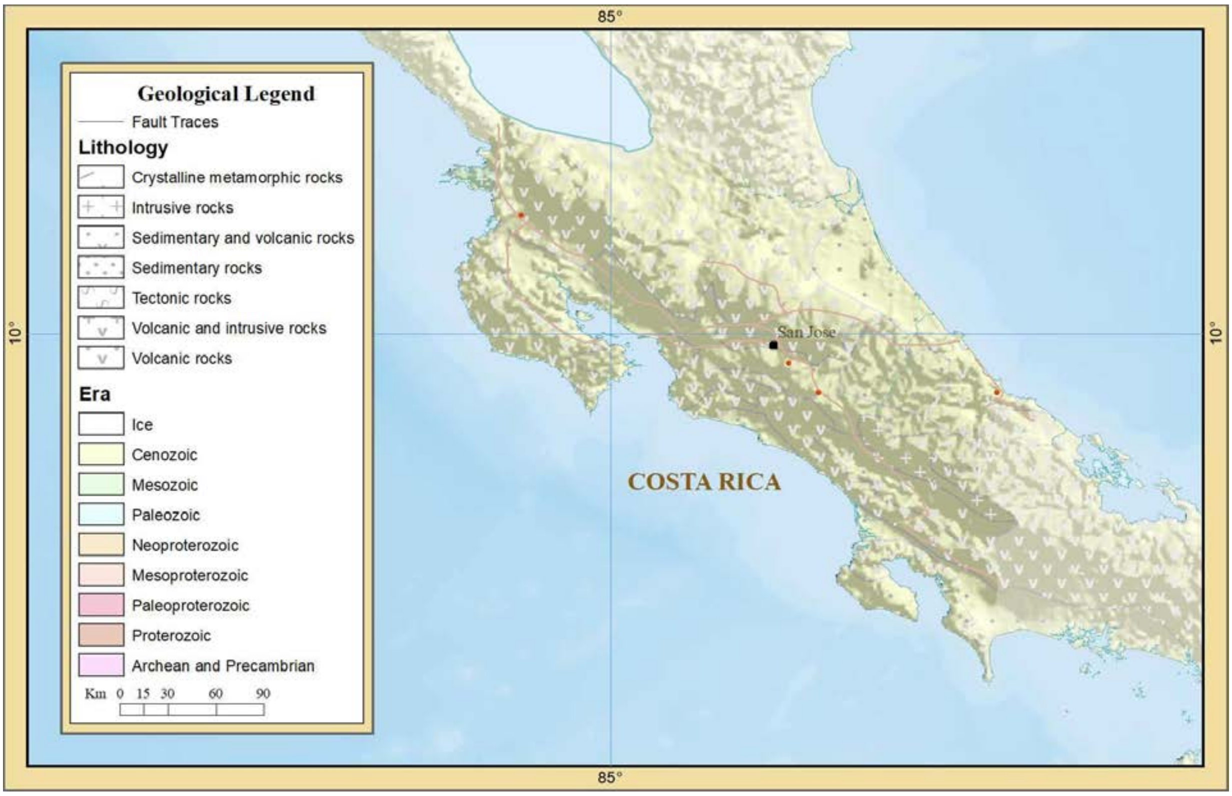


FIG. 8.24. Regional geological setting and uranium mineralisation of Costa Rica. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.8.3. Uranium exploration

8.8.3.1. Historical review

Uranium exploration was initiated in Costa Rica in 1980 by the Costa Rica Development Corporation (CODESA) and supported by the IAEA with the objective of selecting favourable areas for a systematic exploration programme. Work continued on a limited scale until 1983. The original area investigated throughout 1980 and 1981 covered portions of northern Costa Rica.

At the end of 1984, a Technical Cooperation project was initiated with support from the United Nations Financing System for Science and Technology, a subsidiary of CODESA, Mineral Nacional S.A. and the IAEA. The coordination of the project was the responsibility of the Atomic Energy Commission of Costa Rica. The objective was to explore an area of 6000 km² in the Cordillera de Guanacaste, Tilaran and the Monte del Aguacate, which is underlain by Tertiary–Quaternary acid volcanics. Methods used were car-borne radiometrics and multielement reconnaissance geochemistry.

The project was terminated in 1986 as the results indicated that the uranium potential of Costa Rica is very limited [8.8].

8.8.3.2. Expenditures

A total of US $361 000 was spent on uranium exploration from 1980 through 1989 according to Costa Rica's report for the 1989 Red Book [8.8]. Costa Rica reported no surface drilling for 1980–1989 [8.8].

8.8.4. Uranium resources

No uranium resources have been reported.

The UDEPO database does not list any known deposits for Costa Rica.

8.8.5. Potential for new discoveries

The results of exploration efforts made in the 1980s indicate that the uranium potential of Costa Rica is very limited.

References to Section 8.8

[8.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Costa Rica, Washington, DC https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2008).

[8.2] INFOCOSTARICA, Geography, http://www.infocostarica.com/nature/geography.html (accessed July 2010).

[8.3] CENTRAL AMERICA, Geology of Costa Rica, http://www.centralamerica.com/cr/moon/moland.htm (accessed July 2010).

[8.4] PORTLAND STATE UNIVERSITY, Geological Map of Costa Rica, http://pumice.pdx.edu/CostaRica/big_geol_map.pdf (accessed July 2010).

[8.5] BALL, J., Arenal volcano, Costa Rica, http://geology.com/volcanoes/arenal/ (accessed July 2010).

[8.6] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[8.7] ENGEL, J., Landforms, geology, and natural disasters of Costa Rica, (16 May 2001), http://jrscience.wcp.muohio.edu/fieldcourses01/MarineEcologyArticles/Final-LandformsGeologyand.html

[8.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1990).

8.9. CUBA

8.9.1. Geography

Cuba is one of the largest of the Antilles group of islands that are situated within the Caribbean Sea. In overall dimensions, Cuba is 1250 km long and around 190–230 km wide. Topography consists mostly of flat to rolling plains, with rugged hills and mountains in the SE. From the lowest point on the coast of the Caribbean Sea, elevations rise to a high point at Pico Turquino (2005 m). The climate is tropical, but regulated by trade winds. The dry season is typically the November–April period and the rainy season spans the months of May–October. Natural resources include chromium, cobalt, copper, iron ore, nickel, salt, silica, timber and petroleum [9.1].

8.9.2. Geology

Cuba is located almost entirely on the North American Plate and only the east–west trending south-eastern coast of the island is located along the northern strike-slip fault boundary with the Caribbean Plate. Almost 70% of the island is covered by limestone (Fig. 8.25) and there are numerous remarkable limestone towers and caves developed. Cuba's location close to the Equator with a humid, warm climate accounts for the widespread development of karst terrain throughout the island.

FIG. 8.25. Regional geological setting of Cuba. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The western portion of the island is dominated by limestone of Jurassic–Cretaceous age. The central part also records Cretaceous volcanics and the Mabujina amphibolite complex at the top of the Escambray inverted metamorphic complex. At the eastern end of the island, Cretaceous volcanics and fore-arc or foreland sediments are structurally intercalated with ophiolites. The Palaeogene strata of the Sierra Maestra arc crop out in the very SE of the country.

As regards the potential for uranium-bearing areas, with the possible exception of those areas where granitic intrusives are to be found, the widespread rock types found in Cuba are not favourable for hosting uranium deposits [9.2–9.5].

8.9.3. Uranium exploration

8.9.3.1. Historical review

The Centre for Studies Applied to Nuclear Development at the Ministry of Science, Technology and Environment started, in 1985, exploration for uranium in Cuba. This activity was strongly linked to the building of two nuclear reactors at Juragua in Cienfuegos. Owing to budgetary constraints, exploration activities were scaled back in 1990 [9.6].

8.9.3.2. Work done

Work completed by the mid-1980s included the review and evaluation of available geological information, surface investigation of anomalies recognized in an earlier airborne radiometric survey across the country, limited drilling in NW Cuba, application of track-etch and charcoal radon detectors and favourability studies of 70% of the country. Owing to financial constraints, exploration for uranium was scaled back in 1990 and only limited field work was conducted in the 1990s (Fig. 8.26) totalling USD $ 972 000. Despite this, office-based favourability studies continued [9.6].

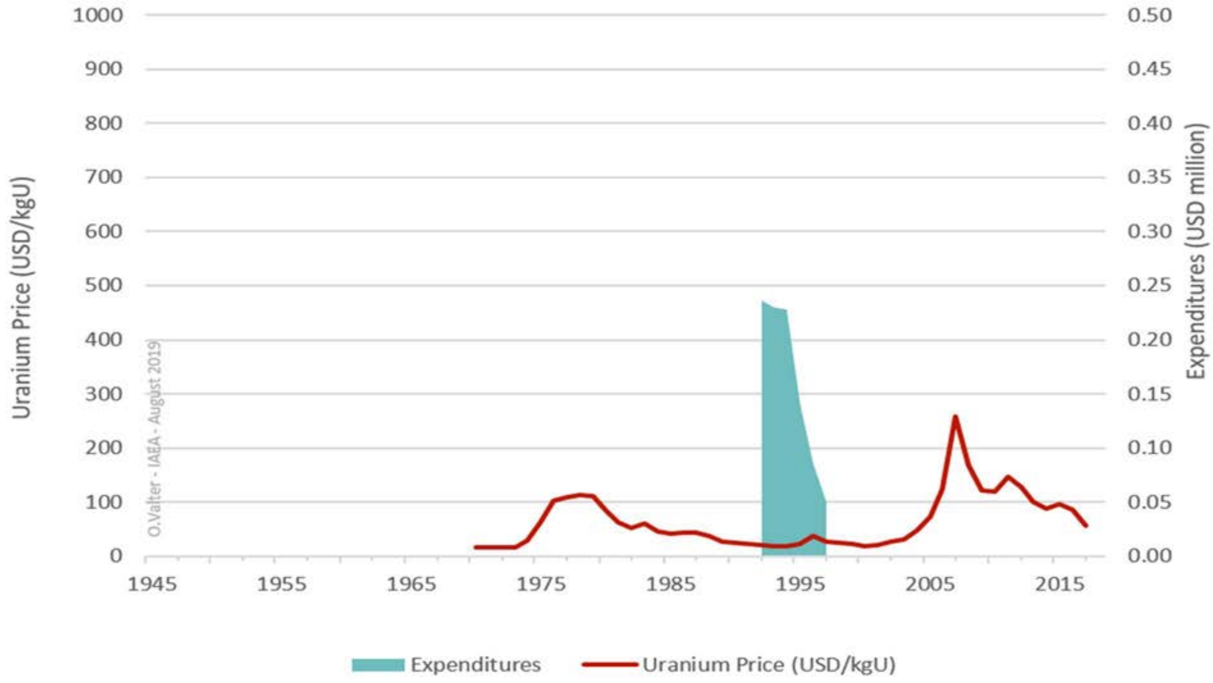


FIG. 8.26. Domestic uranium exploration data for Cuba. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

8.9.4. Uranium resources

Cuba has not reported any uranium resources. The UDEPO database does not list any known deposits for Cuba.

8.9.5. Potential for new discoveries

With more than 70% of the country covered by limestone, discovery of significant uranium deposits is unlikely. Uranium mineralization could, however, be present in association with granitic intrusives.

The 1997 Red Book [9.6] reported one uranium occurrence with surficial values up to 3500 ppm U. This anomaly is related to the contact between Upper Cretaceous limestones and a granitic intrusive in the Escambray region [9.7]. As this geological setting is widespread, it may warrant further exploration.

References to Section 8.9

[9.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Cuba, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed 2009).

[9.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[9.3] KERR, A.C., ITURRALDE-VINENT, M.A., SAUNDERS, A.D., BABBS, T.L., TARNEY, J., A new plate tectonic model of the Caribbean: Implications from a geochemical reconnaissance of Cuban Mesozoic volcanic rocks, Geol. Soc. Am. **111** 11 (1999) 1581–1599.

[9.4] OLDHAM, T., Geology of Cuba (2003), http://www.showcaves.com/english/cu/Geology.html

[9.5] GEOLOGICA ACTA, Geological maps of Cuba,

[9.6] http://www.geologica-acta.com:8080/geoacta/MostrarArticlesAGHAC.do?article=aghv3301

[9.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1997: Resources, Production and Demand, OECD, Paris (1998).

[9.8] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

8.10. DOMINICAN REPUBLIC

8.10.1. Geography

The Dominican Republic lies within the Caribbean region. It occupies the eastern two thirds of the island of Hispaniola, the western part being Haiti. It is a mountainous country and many of the highest peaks in the region are found here. The mountains are separated by valleys which have the same general NW–SE trend. From north to south, the mountain ranges and valleys comprise the:

(a) Cordillera Septentrional;
(b) Cibao Valley, which is the largest and the most important valley in the country;
(c) Cordillera Central is the island's most rugged and imposing feature. The highest mountains of the Caribbean are in this range. Pico Duarte has an elevation of 3098 m, with others above 3000 m;
(d) San Juan Valley and the Plain of Azua have elevations in the range 0–600 m;
(e) Sierra de Neiba has Mount Neiba (2279 m), the highest mountain in the range;
(f) Hoya de Enriquillo (or Neiba Valley) is of low altitude (on average only 50 m, with some points actually below sea level) and with an extensive salt lake (Enriquillo Lake);
(g) Sierra de Bahoruco is a southern mountain group, the geology of which is quite distinct from the rest of the island;
(h) Llano Costero del Caribe (Caribbean Coastal Plain) is a large prairie east of Santo Domingo.

Several smaller islands and cays also form part of the country's territory, the largest islands being Saona, Beata and Catalina.

The country is tropical, with annual mean temperature of 25°C. Regional mean temperatures range from 18°C in the centre of the Cordillera Central to as high as 27°C in more arid regions. The rainy season for the northern coast lasts from November to January. For the rest of the country, the rainy season lasts from May to November. The average annual rainfall is 1346 mm, with extremes of 2500 mm or more in the mountainous NE. The Dominican Republic is occasionally damaged by tropical storms and hurricanes.

The economy of the Dominican Republic is primarily dependent on agriculture, trade and services, especially tourism. Mining is limited to the extraction of nickel (Bonao mine). Production of gold and silver was suspended in 1999 and production of bauxite, traditionally the principal mining product, ceased in 1992. Deposits of copper and platinum are known to exist [10.1].

8.10.2. Geology

The island of Hispaniola can be considered part of a mature island arc formed in an intra-oceanic setting. It lies on the boundary region separating the Caribbean Plate to the south from the North America Plate to the north. This plate boundary is dominated by left-lateral strike-slip motion and compression, and accommodates an annual slip movement of ~20 mm, with the Caribbean Plate moving eastwards with respect to the North America Plate. The island is composed of Cretaceous–Early Eocene igneous, metamorphic and sedimentary substrates which form the basement for Late Tertiary sedimentary basins (Fig. 8.27).

The basement of Hispaniola is made up of several fault-bounded blocks, or geological terrains. The geological history of adjacent terrains is often quite distinct. Basement rock south of the Cordillera Central formed as part of a Cretaceous Caribbean oceanic plateau. Basement rock forming the Cordillera Central are associated with Cretaceous–Eocene volcanic arcs. Rocks underlying the Cordillera Septentrional are additionally associated with a Cretaceous–Eocene fore-arc. The island remains tectonically active, with a severe earthquake (magnitude 7.0) occurring on 3 January 2010 (Haitian earthquake) and smaller earthquakes occurring quite frequently [10.2, 10.3].

FIG. 8.27. Regional geological setting of Dominican Republic. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.10.3. Uranium exploration

No information is available on uranium exploration in the Dominican Republic. An exploration programme for radioactive minerals, including training of the personnel that would have been in charge of its implementation, was being considered in the early 1980s.

8.10.4. Uranium resources

No identified or undiscovered resources are reported.

The UDEPO database does not list any known deposits for the Dominican Republic.

8.10.5. Potential for new discoveries

The likelihood of finding deposits of uranium in the Dominican Republic appears to be very limited. There has not been any domestic uranium production.

References to Section 8.10

[10.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Dominican Republic, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).

[10.2] KLAUS, J.S., McNEILL, D.F., BUDD, A.F., LOPEZ PEREZ, R.A., "Geology of the Dominican Republic", paper presented at a workshop on Paleoecology and Sedimentology of Ancient Coral Reefs in the Dominican Republic, Santo Domingo, 2006, http://eusmilia.geology.uiowa.edu/drworkshop/Guidebook-eng2.pdf

[10.3] NEHM, R.H., BUDD, A.F. (Eds), Evolutionary Stasis and Change in the Dominican Republic Neogene, Topics in Geobiology, vol. 30, Springer, Berlin (2008) 318 pp.

8.11. ECUADOR

8.11.1. Geography

Ecuador lies on the Equator in north-western South America. It has borders with Peru and Colombia and has a coastline bordering the Pacific Ocean. The Galapagos Islands, which lie 1000 km to the west are also part of Ecuador. The coastline and the coastal plain of Ecuador, referred to simply as ‘La Costa’, includes marshland, mangrove swamps, creeks, estuaries and long stretches of beach. The Andes traverse the country and there are extensive areas of cloud forest. The country records some of the world’s highest active volcanoes, of which Mount Cotopaxi, at 5897 m, is the highest.

The eastern slopes of the Andes stretch down towards the Amazon Basin, the world’s largest rainforest. This part of the country is known as El Oriente, an area which constitutes ~30% of the country. The discovery of oil in El Oriente in the 1970s led to the building of new roads and the opening of huge tracts of virgin forest. Rivers flowing down from the Andes and through tribal lands eventually link up with the Amazon River which flows for 3200 km through Brazil before discharging into the Atlantic Ocean.The climate is tropical along the coastal plains, becoming cooler inland at higher elevations in the central highlands, and tropical in the Amazonian rolling jungle lowlands to the east. The highest point in Ecuador is Mount Chimborazo (6267 m), which is a dormant stratovolcano.

The economy of Ecuador is based mostly on exports of oil, shrimp, gold, bananas and other primary agricultural products and supplemented by the repatriation of money from nearly a million Ecuadorian immigrants employed abroad. In 2002, oil accounted for roughly one third of public sector revenue and 40% of export earnings. Mining has not traditionally been an important part of Ecuador’s economy [11.1].

8.11.2. Geology

8.11.2.1. General

Many of Ecuador’s rocks formed within the past few million years as a result of the subduction of the Nazca Plate beneath the South American Plate. This collision generated the Andes, which forms the 6500 km long western fringe of South America. Movement of the plates continues, making Ecuador very seismically active and susceptible to earthquakes and volcanic eruptions.

Mesozoic volcanic and Mesozoic–Cenozoic intrusives form the Cordillera Occidental. The central Andes are made up of Cretaceous–Tertiary volcanics, with undifferentiated Precambrian basement along the eastern border of the Cordillera. Mainly Tertiary sedimentary rocks cover the coastal plains and the eastern portion of the country in the upper Amazon Basin (Fig. 8.28).

Lying off the Pacific coast, the Galapagos Islands were created from the solidified lava issuing from erupting undersea volcanoes associated with a mantle plume. The rock types erupted are tholeiite, alkaline basalt, icelandite (minor) and minor quartz trachyte. The Galapagos are arid, volcanic outcrops.

Ecuador is located along the spine of the Andean Cordillera and is divided into three geomorphological and geological provinces: the Costa, the Sierra and the Oriente.

The Costa is an accreted region extending along the Pacific margin and comprises Upper Cretaceous–Cenozoic fore-arc sedimentary basins. The basement rocks are Lower Cretaceous marine basalts and basaltic andesites.

The Sierra is a young, active mountain belt formed by at least two orogenic events: the Cordillera Occidental to the west being of Palaeozoic age and the Cordillera Real to the east being of Late Mesozoic–Cenozoic age. The Cordillera Occidental contains remnants of a Cretaceous island arc overlain by Lower Tertiary volcanic and volcaniclastic rocks. A series of Tertiary intrusions are found along the western flank of this cordillera. Active volcanoes of Pliocene–Pleistocene age occur along the western and eastern flanks of both the Cordillera Occidental and the Cordillera Real.

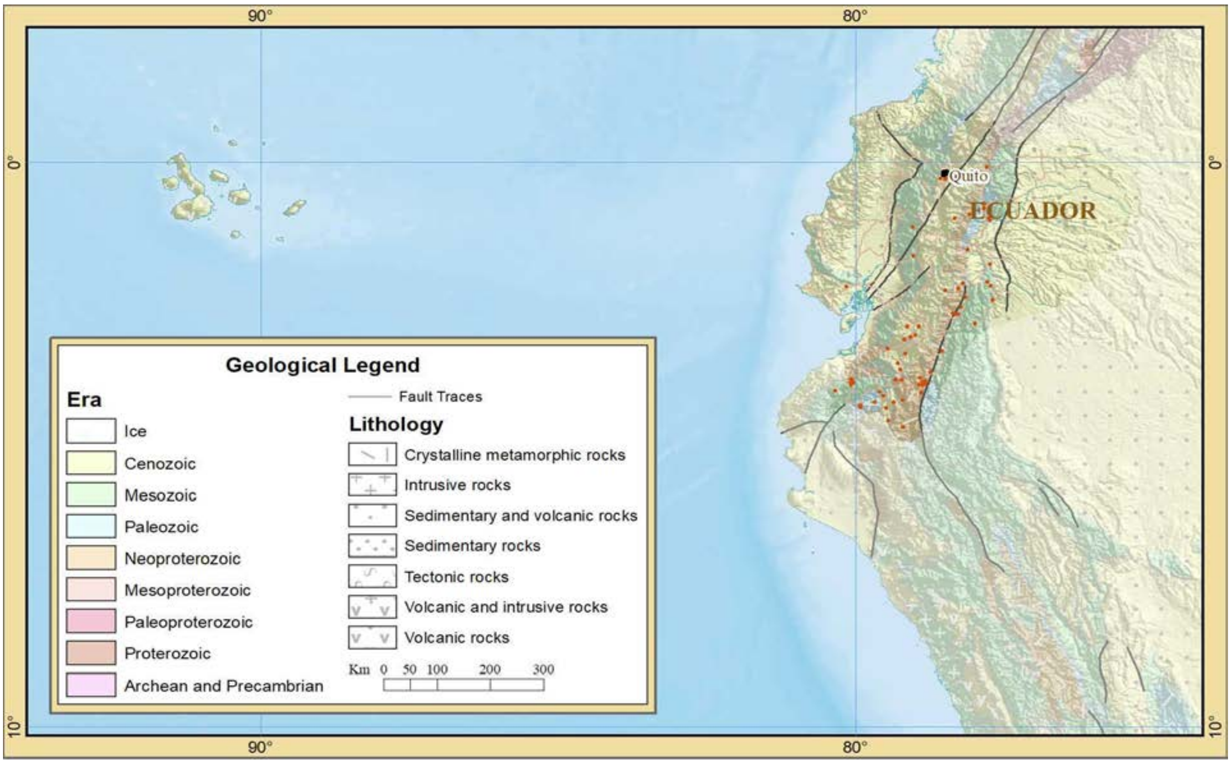


FIG. 8.28. Regional geological setting and uranium mineralisation of Ecuador. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Inter-Andean Valley separates the Cordillera Occidental from the Cordillera Real. The Cordillera Real is composed of metamorphic rocks and composite calc-alkaline batholiths of Triassic–Tertiary age. The Oriente consists of a series of Cretaceous back-arc sedimentary basins occurring as flat lying sequences in the Amazon Basin. This region is almost completely covered by vegetation. Volcanic rocks of Jurassic–Tertiary age occur along the western margins of the Oriente. Tertiary rocks cap all the Cretaceous structures.

There is potential in Ecuador for the discovery of a variety of mineral resources. These include volcanogenic massive sulphide, base metal, porphyry copper, epithermal and mesothermal gold, as well as skarn base metal and gold deposits [11.2].

8.11.2.2. Potential favourable uranium-bearing areas

The most favourable host rocks for uranium deposits are considered to be the igneous intrusions occurring along the Andes, for vein and disseminated type mineralization, and the red beds in the eastern portion of the country for sandstone type deposits. Reference [11.3] notes the presence of anomalies and lists the potential types of uranium deposit in Ecuador as follows:

(a) Sandstone type in the Jurassic Puyango Formation or in the Cretaceous Macuma Formation;
(b) Breccia pipe type associated with the Tarqui Formation;
(c) Phosphorites in the Tena Formation;
(d) Calcareous deposits associated with sub-Andean basins (Cutucu).

No details of the anomalies were provided [11.3].

8.11.3. Uranium exploration

8.11.3.1. Historical review

The Government of Ecuador initiated uranium exploration in 1964, mainly through the National Polytechnic Institute, and since 1979 through the Ecuadorean Atomic Energy Commission (CEEA).

Throughout 1964–1965, a French company carried out a limited airborne radiometric survey and discovered 49 anomalies. This was followed in 1966 and 1967 by an IAEA supported car-borne scintillometer survey which covered 3097 km. A variety of radiometric and geochemical surveys were completed between 1967 and 1979, but no significant anomalies were located.

In January 1980, CEEA initiated a systematic car-borne spectrometric survey of the entire country. By 1981, 12 000 km had been covered and 116 anomalies identified in igneous, metamorphic and sedimentary strata. One anomaly, R-89, which is located in Cretaceous sediments, was of particular interest. A regional geochemical exploration and radiometric survey exceeding 3000 km² in the sub-Andean Basin was also undertaken.

In 1982, a CEEA–IAEA–United Nations Development Programme project began exploration of 24 000 km² in the eastern sub-Andean Basin (Macas, Zamora and La Bonita areas) in the Cordillera Occidental and the Cordillera Real, and in the south-western part of the country. Methods used included radiometric surveys and stream sediment geochemistry. This project continued through 1984. Its results included the discovery of numerous radiometric and geochemical anomalies, the most significant being those in the Puyango area, in SW Ecuador, an area which is underlain by Cretaceous phosphatic sediments. The CEEA continued field work in the Puyango district to select areas for a follow-up drilling programme. It is not known whether this drilling programme was completed [11.4].

8.11.3.2. Work done

Many surveys were conducted, often across limited areas. These included car-borne radiometric, geological, geochemical, emanometric and magnetic surveys. The costs of these surveys are summarized in Section 8.11.3.3.

8.11.3.3. Expenditures

Pre-1979 expenditures on surveys covering 9300 km² totalled US $208 000. From 1979 through 1984, a total of US $1 855 550 was spent and 43 300 km² were surveyed.

Ecuador reported plans to spend US $200 000 on a 4000 km² survey as well as 500 m of drilling (5 holes) in 1985. Confirmation that this drilling was undertaken and any results that were forthcoming are not available [11.4].

8.11.3.4. Recent and ongoing uranium exploration and mine development activities

Spirit Exploration Inc. (Spirit) is an exploration/mining company and through its 99% owned subsidiary, ECUADORGOLDCORP S.A., it acquired and evaluated mineral (gold, silver, copper) concessions in Ecuador. In April 2008, Spirit announced its involvement in a number of projects in Ecuador, including the evaluation of uranium projects.

In January 2008, Bolivar Mining Corporation announced that it was evaluating several carnotite and uraninite uranium deposits in Ecuador, Argentina and Peru. No more recent information has been made available.

In March 2009, the Associated Press reported an announcement by the IAEA that it would assist Ecuador explore for uranium and survey the potential of developing nuclear energy for peaceful purposes. The

IAEA had added Ecuador in a project for regional exploration of uranium as the country pursues energy security through the development of alternative energy sources [11.5, 11.6].

8.11.4. Uranium resources

No uranium resources are reported and UDEPO lists no deposits [11.7].

The UDEPO database does not list any known deposits for Ecuador.

8.11.5. Potential for new discoveries

IUREP's regional summary included Ecuador as a country with limited uranium potential, but acknowledged there is the possibility of locating uranium deposits, particularly of the vein or disseminated type, in association with igneous intrusive outcrops along the Cordillera Real [11.6]. The Zamora granite in the SE of the country was cited as one area of possible interest.

According to a presentation made at a Regional Training Course at Poços de Caldas in 2009, occurrences or anomalies are known in several parts of the country [11.3]. Occurrences are known in sedimentary formations in the eastern part of Ecuador, which range in age from Devonian to Cretaceous.

In the Puyango area, the Cretaceous Napo Formation may contain mineable deposits of uraniferous phosphorites, from which uranium could be extracted as a by-product.

Calcareous deposits may be found associated within Tertiary volcanogenic sedimentary basins in the south of Ecuador, especially in the Cuenca Basin [11.8].

8.11.6. National policies related to uranium

There are no policies directly relating to uranium. Publication of a new mining mandate was adopted by Ecuador's Constituent Assembly on 18 April 2008. The mandate invoked an immediate 180 day suspension of activities on virtually all mining concessions in Ecuador pending a new mining law being drafted and adopted. Since then, regulations have been published in the Official Gazette [11.9].

References to Section 8.11

[11.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Ecuador, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2009).
[11.2] DYNASTY METALS & MINING, Ecuador Geologic Overview, http://www.dynastymining.com/ecuador/geo.php
[11.3] DUQUE, P., DIAZ, X., "A brief review of U exploration in Ecuador", paper presented at IAEA Regional Training Course on Uranium Geology and Exploration, Poços de Caldas, 2009.
[11.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).
[11.5] ASSOCIATED PRESS, IAEA to help Ecuador develop nuclear energy (25 March 2009).
[11.6] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.
[11.7] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).
[11.8] BOLIVAR MINING CORPORATION, Bolivar Mining Corp. Operations Update (10 January 2008).
[11.9] ECUADOR MINING NEWS, Ecuador lifts the Mining Ban, Uncertainty Persists (November 2009), http://ecuadorminingnews.com/news.php?id=124

8.12. EL SALVADOR

8.12.1. Geography

El Salvador is Central America's smallest country and the only one without a coastline adjoining the Caribbean Sea. The country lies between Honduras and Guatemala and has a coastline adjoining the North Pacific Ocean. The climate is tropical, especially on the coast, with a rainy season (May–October) and a dry season (November–April). The uplands are temperate. The terrain consists mostly of mountains with a narrow coastal belt and a central plateau. Topography is varied and the highest point, Cerro El Pital, attains an elevation of 2730 m. Natural resources include geothermal power, hydropower and arable farming.

El Salvador has a long history of seismicity in the form of destructive earthquakes and volcanic eruptions. The capital, San Salvador, was devastated in 1756 and again in 1854, and it endured extensive damage in the 1919, 1982 and 1986 earthquakes. The country has at least 20 volcanoes, but only two, Izalco and San Miguel, have been active in recent years. Violent eruptions are rare.

El Salvador lacks significant mineral resources, although it has small amounts of gold and silver, as well as limestone and gypsum. Its fertile valleys and coastal plain, however, remain its principal natural resource, providing rich soil in which to grow substantial crops for export and subsistence [12.1, 12.2].

8.12.2. Geology

Along with Mexico and the rest of Central America, El Salvador is one of the most seismically active regions on Earth. It lies on top of three large tectonic plates, the motion of which is responsible for the area's seismicity and resultant volcanic activity (Fig. 8.29).

Most of the Caribbean Basin and Central America rest on the fairly stable Caribbean Plate. However, the Pacific Ocean floor is being carried NE by the underlying movement of the Cocos Plate. Ocean floor material is dense and is subducted below the land mass, producing the deep Middle America Trench located off the coast of El Salvador. The subduction of the Cocos Plate causes the frequency of earthquakes close to the coast. As the rocks comprising the ocean floor are forced down, they undergo melting and the molten material rises through zones of weakness in the surface rock, generating volcanoes.

North of El Salvador, Mexico and most of Guatemala are situated on the westwards moving North American Plate that abuts the northern boundary of the immobile Caribbean Plate in southern Guatemala. The motion of these two plates generates a fault, comparable to the San Andreas in California, which runs the length of the valley of the Rio Motagua in Guatemala. Movement along this fault is the source of earthquakes in the north of the country [12.3].

Less than 5% of El Salvador is mapped as granitic intrusive or sedimentary rocks of Mesozoic age. The country is covered by a variety of volcanic material, occurring as lava domes, thick tuffs, mountains (massifs), lava flows and alluvium along the Pacific coastal plain and along inland rivers.

None of the rock types present are favourable for hosting uranium mineralization with the possible exception of the sparse granitic intrusive and sedimentary rocks.

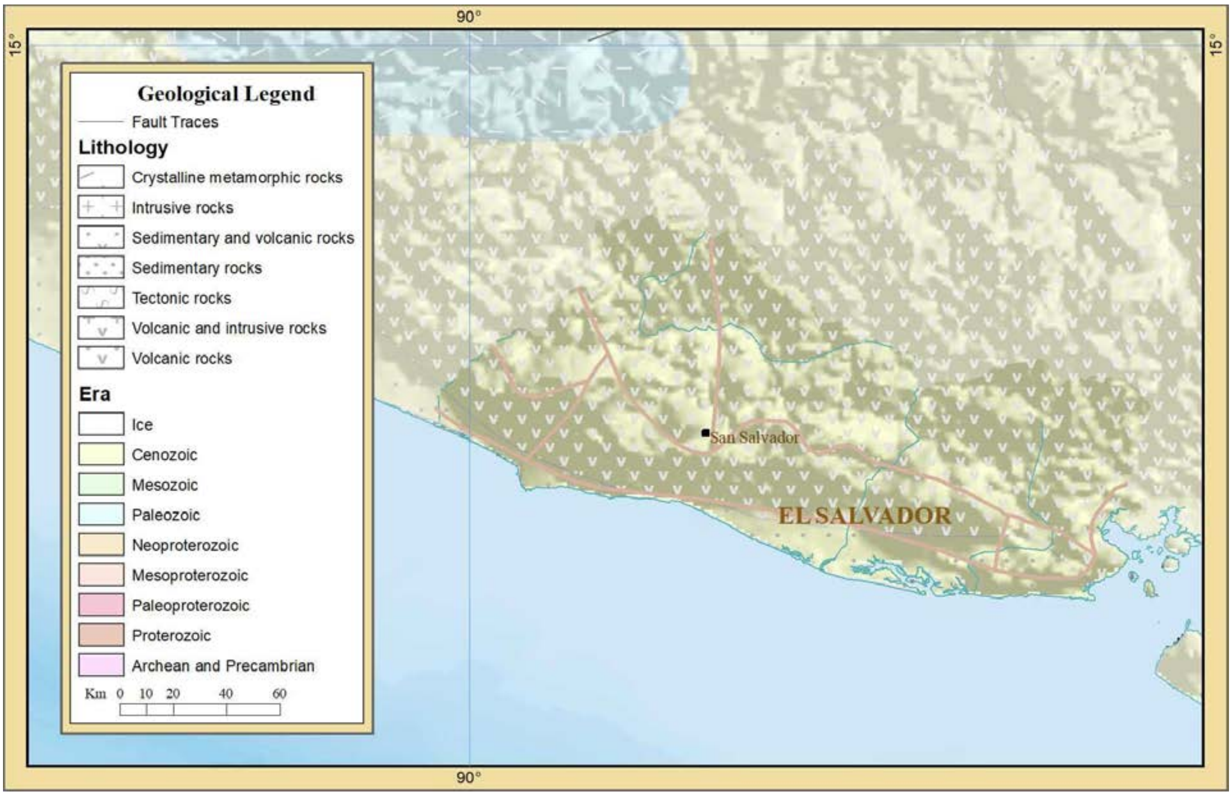


FIG. 8.29. Regional geological setting of El Salvador. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.12.3. Uranium exploration

El Salvador has reported that 8000 km² (more than one third the total area) has been explored using scintillometers. The survey was conducted between 1969 and 1970 as part of a United Nations Development Programme mineral survey. No anomalous areas or uranium occurrences were detected throughout this survey. There are no more recent reports of exploration activities. No exploration expenditures have been reported.

8.12.4. Uranium resources

There are no uranium resources reported by El Salvador or UDEPO [12.4]. The UDEPO database does not list any known deposits for El Salvador.

8.12.5. Potential for new discoveries

On the basis of a review of the rock types found in El Salvador, there is very low potential for any discoveries.

References to Section 8.12

[12.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: El Salvador, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2010).

[12.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[12.3] MARKET RESEARCH, El Salvador: Geology, http://www.country-data.com/cgi-bin/query/r-4220.html (November 1988).

[12.4] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, 2009 Edition, IAEA-TECDOC-1629, IAEA, Vienna (2009).

8.13. GUATEMALA

8.13.1. Geography

Guatemala is located in Central America, lying between El Salvador and Honduras to the south and Mexico and Belize to the north. It also has coastlines on the North Pacific Ocean to the west and the Gulf of Honduras (Caribbean Sea) to the east. The terrain is mostly mountainous, with narrow coastal plains and a rolling limestone plateau. Elevations vary up to 4211 m (Volcan Tajumulco) in the west.

The climate is tropical: hot and humid in the lowlands and cooler in highlands. Natural resources include chicle, fish, hydropower, nickel, petroleum and rare woods [13.1].

8.13.2. Geology

The geological history of Guatemala is poorly described. Existing studies indicate a dynamic and complex geology. The geological terrains that comprise Guatemala are best considered in the context of the complex evolution of plate boundaries between the Cocos, Caribbean and Pacific Plates (Fig. 8.30). Guatemala is typified by active volcanoes, transform faulting, extensive karst topography, northern lowlands and rugged terrain in the Central Cordillera. Many of these features are the product of an active history of subduction, related arc volcanism, plate collision, very high grade metamorphism and deep ocean basin or shallow shelf deposition within the general plate tectonic evolution of the Caribbean region.

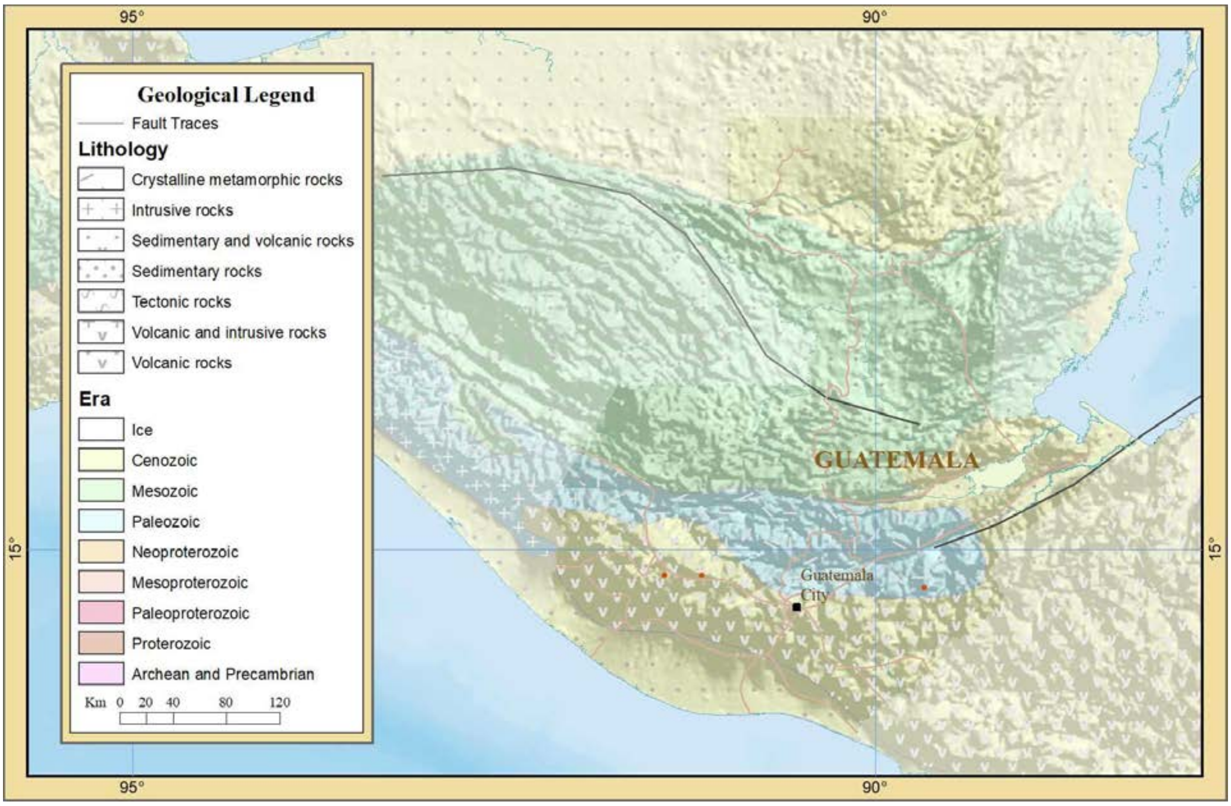


FIG. 8.30. Regional geological setting and uranium mineralisation of Guatemala. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Guatemala is located near the centre of an area of active plate convergence and transform plate motion. The Middle American Trench runs along its SW coast, formed by the Cocos Plate being subducted beneath the North American and Caribbean Plates. The plate boundary between the North American and

Caribbean Plates cuts Guatemala's central region. Present-day plate interactions can account for many of the geological and geomorphological features found in Guatemala. However, regional variations in Guatemalan geology are mostly ascribed to earlier phases of tectonic and volcanic evolution.

The country is split into two major tectonic blocks: the Chortís and Maya Blocks. These blocks intersect on the present-day Motagua Valley fault zone. The Maya Block makes up the southernmost part of the North American Plate and underlies northern Guatemala. The southern Chortís Block represents the northern part of the Caribbean Plate.

The oldest rocks of the Maya Block comprise metamorphic and igneous cratonic basement rocks, overlain unconformably by Upper Palaeozoic metasedimentary rocks. Radiometric dating of these rocks indicates intense deformation and metamorphism throughout the Devonian period. Mesozoic sedimentary rocks overly the Palaeozoic strata and comprise a thick series of interchanging red beds, marine limestones and evaporites, which indicate a long lived and interchanging terrestrial and marine depositional regime operating along the Yucatán Peninsula. Northern Guatemala's karst topography is the result of extensive carbonate deposition. Regional deformation of the Palaeozoic and Mesozoic rocks happened throughout a collisional orogeny in the Devonian period. The intense deformation and metamorphism resulted in the uplift of the southern portion of the Maya Block. The present-day mountain range in central Guatemala was formed by folding and thrusting of this area. Tertiary rocks are mostly marine volcanic and clastic, signifying a period of active volcanism, tectonic activity and high erosion rates.

South of the Motagua Valley, the Chortís Block's tectonic history is complex. Generally, this block is acknowledged as being derived elsewhere and subsequently tectonically moved to its present position. Studies of Mesozoic stratigraphy and basement rocks of the Chortís Block propose strong relationship with south-western Mexico. This relationship is regarded by many authors as indicating an eastern translation of the block to its present position south of the Maya Block. This event happened by the close of the Mesozoic and was coeval with extensive and intermittent magmatic and tectonic activity.

The Late Cretaceous Chortís Block displays brittle deformation and regional uplift characteristics, linked likely to regional uplift to the north throughout the formation of the Laramide Cordillera of Mexico. The present-day subduction zone and transform margin result from plate interactions between the Caribbean Plate and the North American Plate, respectively. In the first instance, oblique convergence with the Cocos Plate has generated Quaternary development of an Andean type volcanic front along the Pacific margin of Guatemala. In the second case, left-lateral transform motion between the Caribbean and North American Plates has produced strike-slip movement along the Motagua–Polochíc fault zone [13.2].

8.13.3. Uranium exploration

The Direccion General de Energia Nuclear continued uranium exploration through 1986. On the basis of the results of these investigations, the following anomalous areas were selected for follow-up:

(a) Chanmagua, comprising an area of 90 km² with outcrops of arkosic sediments of the Tertiary Subinal Formation;
(b) Santa Anita, an area underlain by Tertiary volcanics;
(c) Llano de Cozote Sur-Echimal, comprising an area of 40 km² underlain by volcanic and acid intrusives;
(d) Huiten–San Vicente Buenabay.

The plan for 1987 was to continue the radiometric exploration of 1000 km² and complete a follow-up assessment of the anomalous areas listed above [13.3].

8.13.3.1. Work done

Activities included ground radiometrics across an area of 2600 km² and geochemical analysis of samples taken throughout earlier base metal exploration projects (1969–1970, 1976, 1979–1981).

8.13.3.2. *Exploration expenditures*

In 1984, Guatemala spent US $580 000 on exploration. No expenditures were reported in 1985. In 1986, Guatemala spent US $30 200 on exploration; the plan for 1987 was to allocate US $37 300.

8.13.3.3. *Drilling effort*

According to the 1987 Red Book [13.3], the above efforts did not include surface drilling.

A 2006 press release by a Canadian company planning exploration activities in Guatemala mentions that a mining technical mission from Taiwan, China completed programmes that culminated in the drilling of five diamond drill holes in 1987–1991. Several occurrences were reportedly located. Location of the drill holes is not known, although it is thought to be related to follow-up on anomalies identified in sediments investigated in the early 1980s [13.4].

8.13.3.4. *Recent and ongoing uranium exploration and mine development activities*

There has been some interest shown in uranium prospection and/or exploration throughout the past few years, although no reports on current (2009) projects have been located. In 2006, a news release notes interest in sedimentary-hosted occurrences potentially similar to the Blizzard deposit in British Columbia and the Honeymoon deposit in Australia, and their possible amenability to in situ recovery [13.5].

8.13.4. Uranium resources

No identified or undiscovered resources are reported. No uranium has been found in Guatemala, although exploration to date has been limited.

The UDEPO database does not list any known deposits for Guatemala.

References to Section 8.13

[13.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Guatemala, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed 2009).

[13.2] STANFORD UNIVERSITY, Field Guide to Guatemalan Geology, Stanford Alpine Project 2004–2005, https://pangea.stanford.edu/groups/SAP/previous_expeditions/Guatemala/SAP_Guatemala_guidebook.pdf

[13.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1988).

[13.4] PATHFINDER RESOURCES, SANTOY RESOURCES, Uranium syndicate commences exploration program in Guatemala (17 February 2006), http://www.marketwire.com/press-release/Pathfinder-Resources-Ltd-Gold-Ore-Resources-Ltd-Santoy-Resources-Ltd-Uranium-Syndicate-TSX-VENTURE-PHR-580671.htm

[13.5] INFORPRESS CENTROAMERICANA, Canadian firms begin uranium explorations in Guatemala (3 March 2006), http://www.inforpressca.com

8.14. GUYANA

8.14.1. Geography

Guyana is situated in the NE of South America and shares borders with Brazil, Suriname and Venezuela. It has a coastline which borders on to the North Atlantic Ocean. The Roraima Basin straddles northern Brazil, Venezuela and Guyana.

The country comprises three main geographical zones: (i) the coastal plain, (ii) the white sand belt, and (iii) the interior highlands. The largest of Guyana's three geographical regions is the interior highlands, a series of plateaux, flat topped mountains and savannahs that extend from the white sand belt to the country's southern borders. The Pacaraima Mountains dominate the western part of the interior highlands. In this region are to be found some of the oldest sedimentary rocks in the Western Hemisphere. Mount Roraima, on the border with Venezuela, forms part of the Pacaraima Mountains and, at 2762 m, is Guyana's highest peak. To the south lie the Kaieteur Plateau, a broad, rocky area ~600 m in elevation, the 1000 m high Kanuku Mountains and the low elevation Acarai Mountains situated on the southern border with Brazil. Much of the interior highlands consist of grassland. The largest expanse of grassland, the Rupununi Savanna, covers ~15 000 km^2 of southern Guyana. This savanna also extends far into Venezuela and Brazil. The savanna is split into northern and southern regions by the Kanuku Mountains.

The main economic activities in Guyana are agriculture (rice and sugar), bauxite, gold, timber and shrimp fishing. The sugar industry, which accounts for 28% of all export earnings, is largely run by the Guyana Sugar Corporation, which employs more people than any other industry [14.1–14.3].

8.14.2. Geology

Guyana comprises two main geological provinces, Northern and Southern, separated by the Takutu graben (Fig. 8.31). Northern Guyana is underlain by metamorphic fold belt terrains (Barama-Mazaruni Group) dated at 2000 Ma and composed of pelites, sandstones, greywackes, conglomerates with spilite-keratophyres intercalations. The Group is laterally passing in the NE to the strongly metamorphic Bartica Complex (amphibole-garnet gneisses) and in the south, mafic volcanic rocks with abundant pyroclastics become dominant. The Mazaruni Formation passes laterally to the sedimentary facies (orthoquartzites) of the Murawa Formation which is in turn covered by a thick metavolcanics unit (andesites to ignimbrites), the Iwokrama Formation. The various formations are intruded around 1900-1800 Ma by several granitic batholiths (Trans-Amazonian Orogeny). Granites and metamorphites are unconformably overlain by the Roraima Formation a continental sedimentary episodes of mid-Proterozoic age.

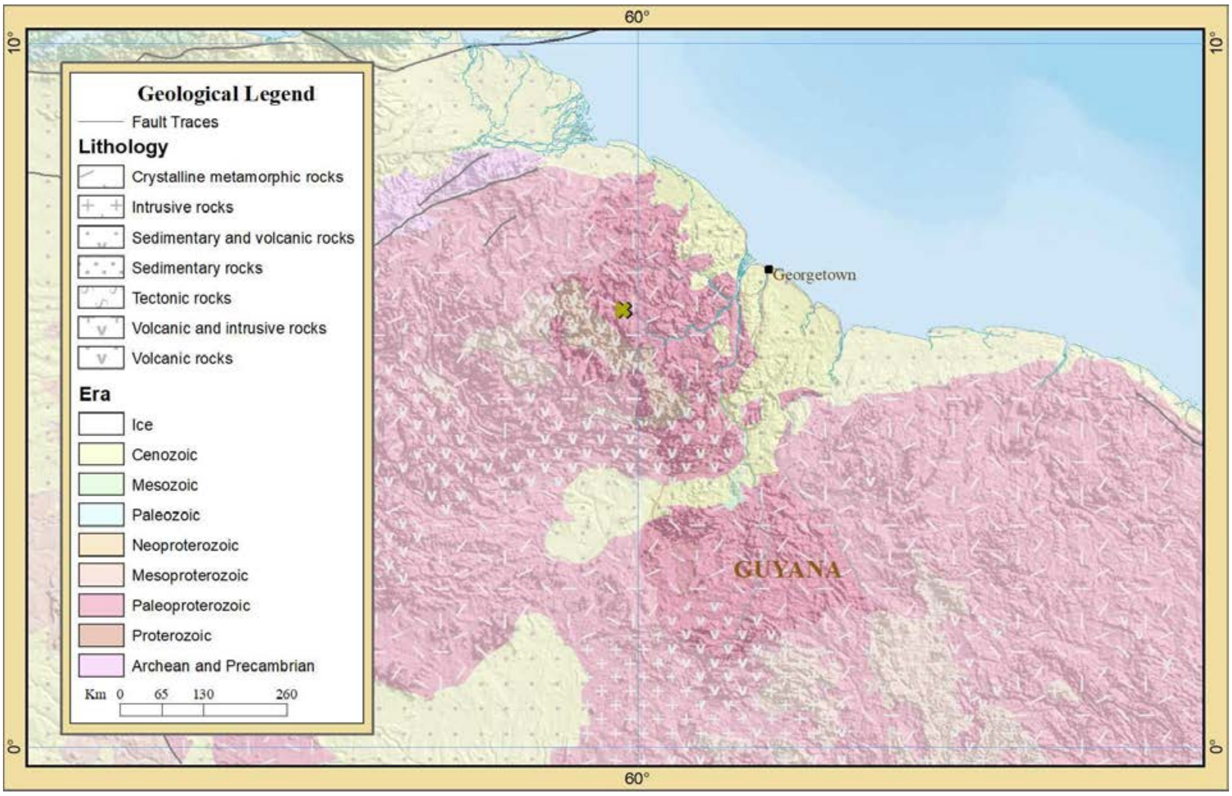


FIG. 8.31. Regional geological setting of Guyana showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Roraima Supergroup consists of a thick succession of about 2800 meters of siliciclastic, pyroclastic and volcaniclastic rocks. The Supergroup is part of the Pakaraima Sedimentary Block, forming a continuous area of sedimentary rocks and covering 73000 km^2 of the Guiana Shield in Venezuela, Brazil and Guyana. Deposition of the supergroup is comprised between 1950-1780 Ma. Several formations have been defined but only those of the basal Arai Formation representing braided fluvial environments are economically important since gold and diamonds were mined. Quartz sandstone, pebbly sandstones and conglomerates are the dominant facies with subordinate siltstone and mudstone. Intercalations of dolerite sills and of volcanoclastites are common [14.4]. Southern Guyana is largely underlain by mid-Proterozoic granitic rocks, with inliers of an older granulitic terrain and a later metasedimentary series. Later, continental volcanics probably correlate with those of the earlier of the continental formations in the north. The north and south are partly separated by a large rift valley filled with 4000–7000 m of Mesozoic–Lower Tertiary basin sediments and basic lavas, the Takutu graben. A thick Tertiary–Quaternary alluvial formation covers much of the north and centre of the country [14.5].

8.14.3. Uranium exploration

8.14.3.1. Historical review

Prior to 1969, exploration for uranium in Guyana was limited to a few traverses carried out with a hand-held scintillometer. Prospection for uranium deposits concentrated at first (1941–1958) on pegmatites in both the north and the south, undertaken by the local geological survey, the United Kingdom Atomic Energy Authority and, occasionally, by private prospectors. Small quantities of euxenite, torbernite, uranothorite and betafite were identified (minor anomalies). Exploration in the north was unsuccessful despite locating some anomalies in acid tuffaceous rocks.

In 1969–1970, four exploration companies were active. The Canadian company Denison Mines flew an airborne radiometric survey along the edge of the Roraima Formation and carried out ground traverses in the Siparuni, Kurupung, Merume and adjacent areas, along the base of the Roraima scarp. Six diamond drill holes were drilled in the area, with no success reported. Asarco briefly examined the Makari and Pacaraima Mountains.

Another Canadian company, Cominco, flew an airborne survey across the Muruwa Formation and discovered radioactive laterite boulders in the area. Some field work, including a small drilling programme, was carried out. Uranerzbergbau of Germany undertook a reconnaissance survey of the Makari Mountains, a Roraima Formation outlier, but without success. These projects covered ~24 000 km² by airborne radiometric survey and 620 km² by other surveys. A total of ten holes (3000 m) were drilled by Denison (6 holes) and Cominco (4 holes).

In 1979, the Compagnie Générale des Matières Nucléaires (COGEMA) signed an exploration agreement with the Government of Guyana to undertake a preliminary survey for uranium throughout a three-year period. During this survey, COGEMA had access to an area covering 156 000 km² in the north and south Rupunumi Savannas, and in the Pakaraima and Makari Mountains (Roraima Formation).

COGEMA employed a number of exploration techniques, including airborne radiometric surveys employing a line spacing of ~10 km, with closer spaced lines (1 km) flown across anomalous zones, ground radiometrics, geological mapping, water, stream sediment and soil geochemistry. The main target area in early 1981 was the Pacaraima Mountains, which are underlain by the Roraima basement unconformity.

Later that year, work started in the Kurupung area, where significant radiometric anomalies were discovered overlying the Kurupung batholiths. Exploration was intensified in the area and included close spaced radiometric grids, pitting and trenching, which lead to the discovery of uranium mineralization of unknown mineralogical composition. In the latter part of 1982, percussion and core drilling commenced in the Kurupung area and continued through November 1984, when COGEMA terminated its activities. No other private or State company has actively explored for uranium since that time [14.5].

8.14.3.2. *Work done*

A total of 24 000 km² was covered by radiometric surveys from 1979 through 1984. Other surveys covered a total of 52 270 km². Surface drilling of 255 holes, totalling 37 310 m, was completed in the same period. No exploration expenditures were reported for this period.

Investigations currently being carried out (2009–2010) by U3O8 Corporation, a Canadian company, are primarily seeking basement hosted uranium and unconformity-related deposits.

8.14.3.3. *Recent and ongoing uranium exploration and mine development activities*

U3O8 Corp. undertook its Guyana exploration programme on the basis of its geological similarities with the Athabasca Basin in Saskatchewan. In August–December 2009, the company began a 6000 m diamond drilling programme as part of the Kurupung Batholith project. The drilling programme continued into 2010. Reconnaissance drilling aimed to identify additional mineralized areas in order to demonstrate the size potential of the Kurupung project and to add to the existing NI 43-101 resources.

U3O8 Corp. reports that geologically similar albitite-hosted deposits elsewhere in the world typically contain resources in the 19 000-50 000 tU (50-130 million pounds U_3O_8) range. At an average grade of 0.085% U, characteristic of albitite hosted deposits in the world, uranium in the Kurupung extends from ~10 m below surface to depths of over 220 m, the maximum vertical depth to which U3O8 Corp. has drilled to date. Mineralization is still open at depth. Uranium in the Kurupung Batholith is situated in a coherent network of shear zones and faults comparable to structural systems that contain the large albitite-hosted deposits in the world. While U3O8 Corp. discussed the possibility of the Kurupung deposits being albitite-related, evidence presented in the NI-43-101 technical review supports the interpretation that these deposits are of the unconformity type [14.6]. For UDEPO, the deposits are classified as Na-metasomatite granite-derived deposits.

U3O8 Corp. also reported its use of advanced targeting techniques in the Kurupung district. The main geophysical targeting tools are very low frequency electromagnetics (VLF-EM) and magnetics, while radiometric surveying, whose signatures are easily masked by water, vegetation, humus and soil, is used as a secondary exploration tool.

The batholith comprises uniformly magnetic areas that are split by ‘corridors’ of low magnetism. All uranium-bearing structures drilled to date by U3O8 Corp. occur within these weakly magnetic corridors. Measurements on drill core from these areas indicate that the magnetism of the granite drops abruptly in the faults that host uranium. U3O8 Corp. is employing the magnetic data to outline where demagnetized faults are situated within the batholith, as corridors of potential uranium mineralization for scout drilling. The choice of targets uses a model which assumes that only portions of the weakly magnetized faults may host uranium.

VLF-EM surveys conducted in the field across areas that have been drilled by U3O8 Corp. indicate that uranium-bearing ‘shoots’ are situated in areas where faintly conductive zones coincide, or overlap with, demagnetized fault zones obvious in the magnetic data. Points where conductive zones intersect the magnetite-scarce faults are targets for scout drilling.

Besides the work on basement hosted uranium in the Kurupung area, the company’s exploration for unconformity-type deposits in the Roraima Basin persists to advance on two fronts:

(i) U3O8 Corp. keeps on with the analysis of some 10 000 m of core drilled earlier through the Roraima succession throughout exploration for gold in the mid-1990s. Recognition of certain clay minerals as a way to define alteration zoning, akin to pathfinder alteration linked to deposits of uranium in the Athabasca Basin, was judged by U3O8 Corp. to be key to establishing the feasibility of uranium targets in the Roraima. Besides, a portable analyser (a hand-held X-ray fluorescence device) was to be employed on the core for a first pass analysis for pathfinder elements (metal zoning) characteristically linked with unconformity-related deposits in the Athabasca Basin;

(ii) Ground follow-up of radiometric anomalies outlined by U3O8 Corp. from its 2008 airborne geophysics programme. Priority is being given to radiometric anomalies that coincide with areas where old basement faults are crossed by younger, cross-cutting faults in the Roraima Basin. Efforts for exploration concentrate on mapping the widespread clay alteration evident in the field and on rock chip geochemistry along fault zones to identify potential drill targets [14.7–14.9].

In 2010, two other companies reported exploration activities in Guyana [14.10, 14.11]. Epsilon Energy Ltd, an Australian company, recently acquired prospects in the West Omai area. Current activities include verifying or continuing previous work in trench mapping and sampling and a geochemical orientation survey is under way. Epsilon Energy planned to start a drilling campaign at the end of April 2010.

Argus, a Canadian company, is targeting a low grade, large tonnage deposit (the Kaituma East and Kaituma West uranium/gold projects), modelled on the alaskite Rössing and Rössing South deposits in Namibia. The Kaituma project is situated in NW Guyana. Soil sampling has been conducted and drilling is planned for 2010. No historic drilling has been done on the property [14.12].

The Government of Guyana reports that the Islamic Republic of Iran is providing a US $1.5 million grant to boost Guyana's health care system and assist to map mineral resources under a recently signed agreement. It is understood that Iranian scientists will help recognize uranium deposits using up-to-date technology, changing the current prospecting system [14.7].

8.14.4. Uranium resources

No identified or undiscovered resources have been officially reported. No resources have been reported in the Red Book.

Identified resources are reported in a NI 43-101 Technical Review of the Aricheng North and Aricheng South uranium deposits in western Guyana, which was prepared for U3O8 Corp. and Prometheus Resources (Guyana) Inc., details of which are as follows:

(a) Total Aricheng North and Aricheng South (using 0.042% U cut-off and 1.1% U high grade cap);
(b) Indicated resource: 2 676 523 t of ore grading 0.085% U (2240 tU);
(c) Inferred resource: 645 169 t of ore grading 0.076% U (515 tU);
(d) With resources defined at Aricheng West and C total resources are 6189 t U at an average grade of 0.075%.

All resources are reported as being in place [14.6]. A peculiar characteristic of the Kurupung mineralization is the abundance of zirconium which can reach several percent in the samples The Aricheng deposits are classified as being of the unconformity type in the Red Book, but as Na-metasomatite granite-derived deposits in UDEPO.

The UDEPO database lists the most significant deposits for Guyana as Aricheng West, Aricheng South, Aricheng C, Aricheng North.

8.14.5. Potential for new discoveries

IUREP's regional summary considered Guyana, Suriname and possibly French Guiana as having some potential for quartz-pebble conglomerate and Proterozoic unconformity-related deposits. Recent work by U3O8 Corp. indicates potential for the occurrence of unconformity type deposits in Guyana.

No uranium production has been reported. There is no installed nuclear capacity and there are no plans for installation of nuclear generating capacity [14.2].

8.14.6. National policies related to uranium

The investment policy of the Government of Guyana makes provision for investment by the private sector and the State and/or private sector in collaboration with international companies, as stated in the investment code. In order for an international company to explore for, and exploit, uranium in Guyana, an agreement with terms acceptable to both parties (Government and private sector company) has to be signed and a local company formed and incorporated in Guyana [14.4].

References to Section 8.14

[14.1] GOVERNMENT OF GUYANA, National Population Trends: Size, Growth and Distribution, Report on 2002 Census (17 April 2010), http://www.statisticsguyana.gov.gy/pubs/Chapter1_National_Population_Trends.pdf

[14.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[14.3] LIBRARY OF CONGRESS, Country Study: Guyana, http://lcweb2.loc.gov/frd/cs/gytoc.html

[14.4] REIS, N.J., NADEAU, S., FRAGA, L.M., BETIOLLO, L.M., LINS FARACO, M.T., REECE J., LACHMAN, D., AULT R., Stratigraphy of the Roraima Supergroup along the Brazil-Guyana border in the Guiana shield, Northern Amazonian Craton – Results of the Brazil-Guyana Geology and Geodiversity Mapping Project. Brazilian Journal of Geology, 47(1), p. 43-57 (2017)

[14.5] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1979).

[14.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[14.7] ALEXANDER, R.B., BREEDE, K., U3O8 Corp. NI 43-101 Technical Report on the Aricheng South and Aricheng North uranium deposits, http://www.u3o8corp.com (14 January 2009).

[14.8] U3O8 CORPORATION, U3O8 Corp. completes acquisition of Mega Uranium's South American assets, http://www.www.u3o8corp.com (8 April 2010).

[14.9] U3O8 CORPORATION, A new uranium deposit, http://www.www.u3o8corp.com (January 2009).

[14.10] THE POST STANDARD, Iran assists Guyana with uranium prospection (27 January 2010).

[14.11] EPSILON ENERGY, Guyana Exploration Update (15 March 2010), http://www.epsilonenergy.com.au/_content/documents/640.pdf

[14.12] ARGUS METALS CORPORATION, Kaituma gold-uranium project drilling to begin in March (25 February 2010), http://www.argusmetalscorp.com/s/NewsReleases.asp?ReportID=386597&_Type=News-Releases&_Title=Kaituma-Gold-Uranium-Project-Drilling-To-Begin-In-March

8.15. HAITI

8.15.1. Geography

Haiti occupies the western part of the island of Hispaniola, which it shares with the Dominican Republic in the Greater Antilles archipelago. The northern region consists of the Massif du Nord and the Plaine du Nord. The Massif du Nord is an extension of the Cordillera Central in the Dominican Republic. The lowlands of the Plaine du Nord lie along the northern border with the Dominican Republic, between the Massif du Nord and the Atlantic Ocean. The central region consists of two plains and two sets of mountain ranges.

The southern region consists of the Plaine du Cul-de-Sac and the mountainous southern peninsula (also known as the Tiburon Peninsula). The Plaine du Cul-de-Sac is a natural depression which incorporates saline lakes. The Chaîne de la Selle mountain range, an extension of the southern mountain chain of the Dominican Republic (the Sierra de Baoruco), extends from the Massif de la Selle in the east to the Massif de la Hotte in the west. This mountain range incorporates Pic la Selle, which, at 2680 m, is the highest point in Haiti. Haiti has a small mining industry, bauxite, copper, calcium carbonate, gold and marble being the most extensively mined commodities [15.1].

8.15.2. Geology

The geology of Haiti is still imperfectly understood and large tracts of the island have never been examined in detail. On a plate tectonic level, the island of Hispaniola can be considered part of a mature island arc formed in an intra-oceanic setting. It lies on the boundary region separating the Caribbean Plate, which lies to the south, from the North American Plate, which lies to the north. This plate boundary is dominated by a left-lateral strike-slip motion and compression and accommodates annual movement (slip) of ~20 mm, with the Caribbean Plate moving eastwards with respect to the North American Plate. The island is composed of Cretaceous–Early Eocene igneous, metamorphic and sedimentary strata that form the basement for Late Tertiary sedimentary basins.

Northern Haiti is underlain by NW trending terrain comprising Early Cretaceous–Middle Eocene igneous, metamorphic and sedimentary rocks (Fig. 8.32), which has been interpreted as a fore-arc environment. This is followed to the SW by a narrow band of Late Cretaceous–Early Eocene sedimentary and minor volcanic rocks, which has been interpreted as a back-arc basin. To the south lies the major sequence that comprises roughly 50% of the country and consists of Late Cretaceous–Eocene igneous and sedimentary rocks interpreted as island arc related. In the far south, Late Cretaceous igneous rocks are present, interpreted as part of the uplifted Caribbean oceanic plateau.

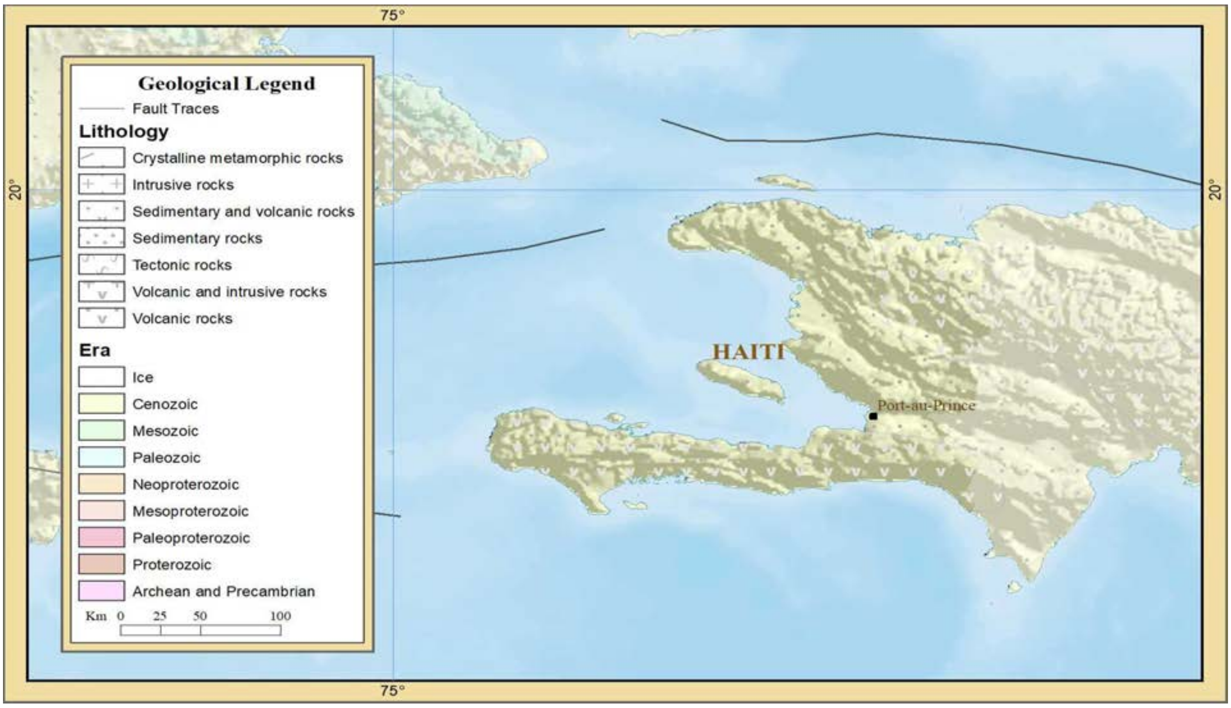


FIG. 8.32. Regional geological setting of Haiti. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Haitian earthquake (magnitude 7.0) occurring on 13 January 2010 was centred ~16 km west of the capital of Port Au Prince and located on the major Enriquillo–Plantain Garden Fault, which runs roughly east–west through Haiti. In this case, the Caribbean Plate south of the fault line was sliding eastwards and the smaller Gonave Platelet north of the fault was sliding westwards.

On a more detailed level, the schists that have been observed in some parts of the island may be earlier than the Cretaceous, but the oldest rocks in which fossils have yet been found belong to the Cretaceous system and the geological sequence is very similar to that observed in Jamaica. Excluding those schists of doubtful age, the series begins with sandstones and conglomerates that contain pebbles of syenite, granite, diorite, etc., which are overlain by marls, clays and limestones containing Hippurites. There then follows a series of sandstones, clays and limestones with occasional seams of lignite, evidently of shallow water origin. These are considered to be Eocene (and by some earlier writers as Miocene) and they are succeeded by chalky beds which were laid down in a deeper sea and which probably correspond with the Montpelier beds of Jamaica (Oligocene). Finally, there are limestones and marls composed largely of corals and molluscs, which are probably of very Late Tertiary or post-Tertiary age. However, until the island has been more thoroughly mapped, the correlation of the various Tertiary and post-Tertiary deposits remains uncertain. Extensive eruptions of basalt of post-Pliocene age have also been reported [15.2, 15.3].

8.15.3. Uranium exploration

No official information is available on uranium exploration in Haiti.

8.15.4. Uranium resources

The UDEPO database does not list any known deposits for Haiti.

8.15.5. Potential for new discoveries

To date, only very limited uranium exploration has been undertaken and no uranium mineralization has been found.

References to Section 8.15

[15.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Haiti, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).

[15.2] 1911 CLASSIC ENCYCLOPEDIA, Haiti (27 October 2006), http://www.1911encyclopedia.org/Haiti

[15.3] ITURRALDE-VINENT, M.A., "Geological reconnaissance of Haiti: Preliminary conclusions", paper presented at University of Texas meeting on Caribbean Plate Tectonics (IGCP Project 433), Austin, 2001.

8.16. HONDURAS

8.16.1. Geography

Honduras is situated in Central America. It has land borders with Guatemala, El Salvador and Nicaragua and maritime borders with the Caribbean Sea and the North Pacific Ocean.The terrain is mostly mountainous in the interior combined with narrow coastal plains. The climate is subtropical in the lowlands and temperate in the mountains. Elevations attain 2870 m at Cerro. Natural resources include antimony, coal, copper, fish, gold, iron ore, hydropower, lead, silver, timber and zinc, [16.1].

8.16.2. Geology

Honduras is positioned on the Chortís Block, near the junction of three tectonic plates, the North American, Cocos and Caribbean Plates. The plate tectonic and geological histories of Honduras are not well known. The exact location of the southern boundary of the Chortís Block in Nicaragua, where continental rocks end and oceanic rocks begin, has not been determined. Plate movements continue, creating faulting throughout Honduras and pulling the country apart along an east–west axis. Rainwater circulating through faulted regions has created numerous geothermal systems.

The rocks of Honduras were deposited in rapidly changing environments and the resulting stratigraphy is as complex as the structures that modify it (Fig. 8.33). Precise geological dating is difficult because of the absence of identifiable fossils and the rapid changes in rock types across short geographic distances. However, three distinct age groups are described: (i) a basement complex of Palaeozoic low grade metamorphic rocks of ~245 Ma, (ii) an overlying section of Mesozoic limestones and red beds that is estimated to be around 200–100 Ma, and (iii) a thick upper sequence of volcanic rocks derived from two distinct episodes of volcanism.

The Matagalpa Formation, a series of early Tertiary interbedded lava flows, pyroclastic flows, debris flows and interbedded sediments, dates to roughly 60–40 Ma. The Padre Miguel Group, the result of the second episode of volcanism, is a thick sequence of ignimbrite similar to the Bandelier Tuff and is found throughout the southern half of Honduras. It has been dated to 20–15 Ma [16.2].

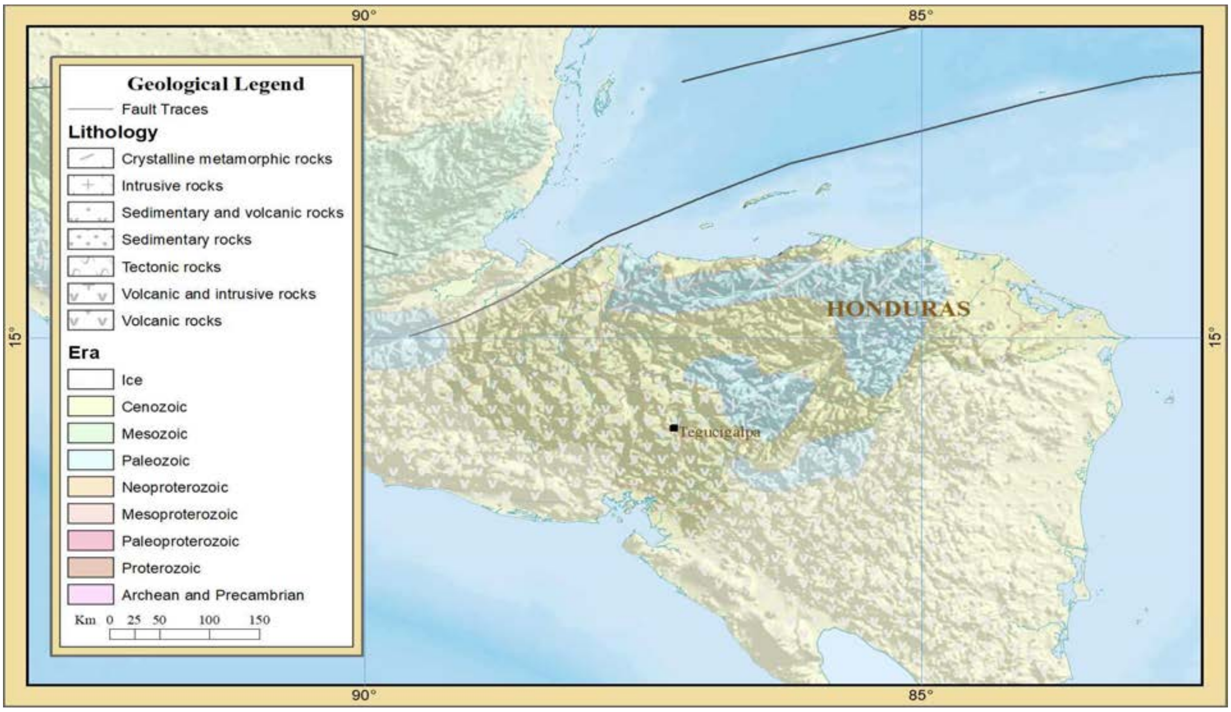


FIG. 8.33. Regional geological setting of Honduras. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.16.3. Uranium exploration

No uranium exploration activities have been reported.

8.16.4. Uranium resources

The UDEPO database does not list any known deposits for Honduras.

8.16.5. Potential for new discoveries

On the basis of the rock types reported, the complex tectonics and the limited information available, the potential for locating uranium deposits in Honduras is considered to be low. Possible exceptions include the Mesozoic red beds and other Palaeozoic rocks of low metamorphic grade.

References to Section 8.16

[16.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Honduras, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2010).

[16.2] EPPLER, D.B., Geology of Honduran Geothermal Sites, Caribbean Basin Proyecto, Los Alamos Science (Fall 1986) 86–89, http://www.fas.org/sgp/othergov/doe/lanl/pubs/00326883.pdf

8.17. JAMAICA

8.17.1. Geography

Jamaica is the third largest island in the Caribbean. The country can be divided into three topographic regions: (i) the eastern mountains, which includes the Blue Mountains, (ii) the central valleys and plateaux, and (iii) the coastal plains. Most major towns and cities are located on the coast.
Jamaica's climate is tropical, with hot and humid weather, although higher inland regions have a more temperate climate. The average annual rainfall is 1960 mm. Temperatures are relatively constant throughout the year, averaging 25–30°C in the lowlands and 15–22°C at higher elevations. Some regions on the south coast, such as the Liguanea Plain and the Pedro Plain, are located in relatively dry rain shadow areas. Jamaica lies in the hurricane belt of the Atlantic Ocean; as a result, the island periodically experiences significant storms.

Jamaica is a mixed economy with State enterprises as well as private sector businesses. Major sectors of the Jamaican economy include agriculture (sugar, bananas, coffee, rum and yams), mining (bauxite), manufacturing, tourism (the largest foreign exchange earner), and financial and insurance services [17.1, 17.2].

8.17.2. Geology

Jamaica is located on the Caribbean Plate to the south of the boundary with the North American Plate. Jamaica, together with the other islands of the Antilles, evolved from an arc of ancient volcanoes. Throughout periods of submersion, thick sequences of limestone were deposited over the old igneous and metamorphic rocks (Fig. 8.34).

The highest area comprises the Blue Mountains. These eastern mountains are formed by a central ridge of metamorphic rock running NW–SE from which many long spurs extend to the north and the south. For at least 3 km, the crest of the ridge exceeds an elevation of 1800 m, the highest point attained being Blue Mountain Peak at an elevation of 2256 m. The Blue Mountains rise to these elevations from the coastal plain within a distance of ~16 km, which represents one of the steepest general gradients in the world. In this part of the country, the old metamorphic rock reveals itself through the surrounding limestone. To the north of the Blue Mountains lies the strongly tilted limestone plateau forming the John Crow Mountains. This range rises to elevations of at least 1000 m. To the west, in the central part of the country, are two rolling plateaux: the Dry Harbour Mountains to the north and the Manchester Plateau to the south. Between the two, the land is rugged and here, also, the limestone strata are broken by the older rocks. Streams that rise in the region flow outwards and disappear into the limestone strata.

The limestone plateau covers two thirds of the country, and consequently karstic landforms dominate the island. To the west of the mountains is the rugged terrain of the Cockpit Country, one of the world's most dramatic examples of karst topography. The age of the limestone ranges from Palaeocene to Middle Miocene (54–14 Ma) and can be divided into two principal stratigraphic units: the Yellow Limestone Group and the White Limestone Supergroup in which nearly all the caverns are formed.

The Cockpit Country is pockmarked with steep sided hollows, as much as 120 m deep in places, which are separated by conical hills and ridges. Where the ridges between sinkholes in the plateau area have dissolved, flat bottomed basins or valleys have been formed that are filled with terra rossa soils, which are some of the most agriculturally productive on the island. The largest basin is the Vale of Clarendon, which is roughly 80 km long and 32 km wide [17.3].

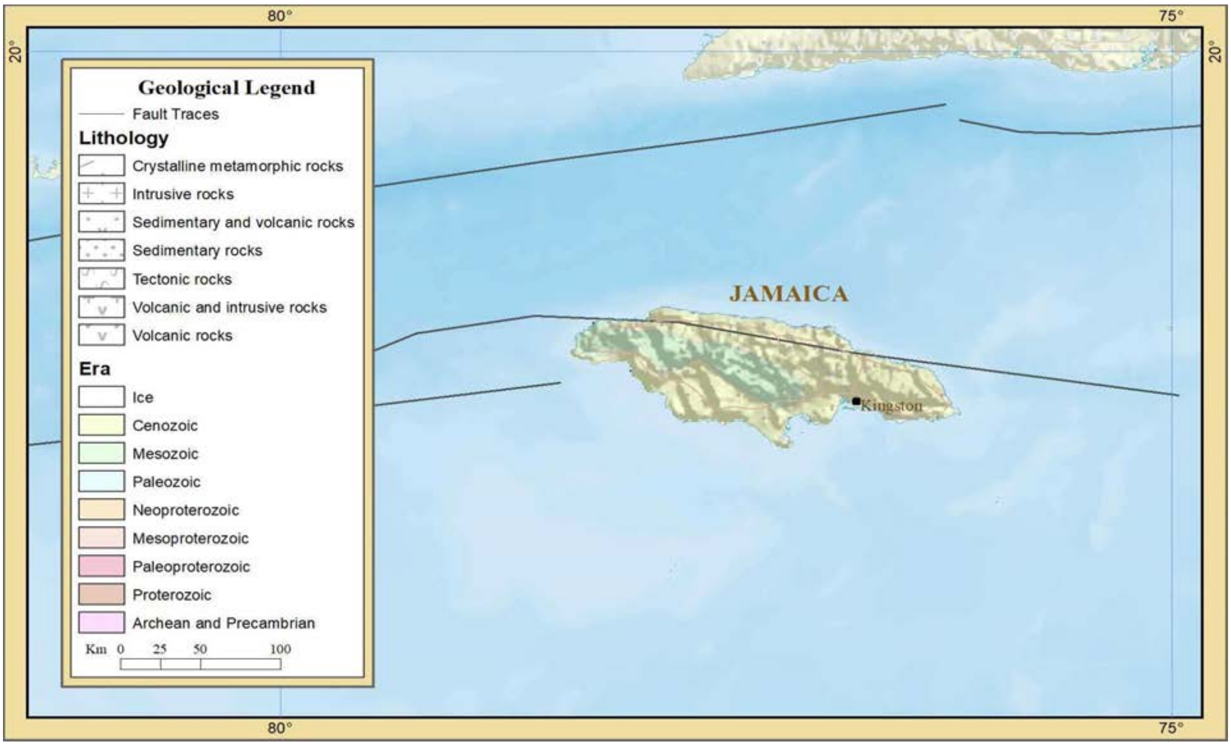


FIG. 8.34. Regional geological setting of Jamaica. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.17.3. Uranium exploration

Throughout the early 1980s, very preliminary and small-scale studies were carried out using a scintillation detector and a four-channel gamma spectrometer, which were attached to a vehicle. This programme also included airborne surveys, particularly helicopter-borne surveys, and the use of chemical and fluorescence analysis of samples. No drilling has been undertaken. The work was carried out by the University of the West Indies and a State-owned company. The total expenditure, of which the Government met around half the costs, was of the order of US $50 000.

No exploration activities have recently been reported [17.4].

8.17.4. Uranium resources

No identified resources have been reported.

The UDEPO database does not list any known deposits for Jamaica.

8.17.5. Potential for new discoveries

There is potential for the occurrence of uranium mineralization in the Mesozoic and Tertiary sandstones of Jamaica. However, the predominantly limestone terrain is not conducive to the formation of uranium deposits.

References to Section 8.17

[17.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Jamaica, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed October 2009).
[17.2] LIBRARY OF CONGRESS, Country Profile: Caribbean Islands, http://countrystudies.us/caribbean-islands/20.htm
[17.3] GEOLOGICAL SURVEY, The Mineral Resources of Jamaica, Geol. Surv. Bull. No. 8, Kingston (1981).
[17.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1983).

8.18. MEXICO

8.18.1. Geography

Mexico is a generally mountainous country located in the south-western part of the North American continent. With an area in excess of 1.96 million km^2, Mexico ranks as the 15th largest country in the world.

Mexico's chief structural features are the Sierra Madre Occidental, the country's most extensive mountain system, which is an extension of the Rocky Mountains from northern North America and which runs parallel to the Pacific coast, and the Sierra Madre Oriental, which runs parallel to the Gulf coast. Between these ranges lies the large arid Meseta Central, consisting of highlands and basins. Another prominent structural feature is the Trans-Mexico Volcanic Belt in central Mexico, known as the Sierra Nevada, along which seismic activity is frequent.

Much of the Mexico's central and northern territories are located at high altitudes and the highest elevations are to be found in the Trans-Mexico Volcanic Belt: Pico de Orizaba (5700 m), Popocatépetl (5462 m), Iztaccíhuatl (5286 m) and the Nevado de Toluca (4577 m). In spite of the seismicity, valleys in this area contain a large percentage of the country's population, including Toluca, Mexico City and Puebla. A fourth mountain range, the Sierra Madre del Sur, runs from Michoacán to Oaxaca. Most of Mexico's major rivers are in the south. Deserts occupy much of the north-western and north central regions. Lowland areas are found along the Pacific coast, Gulf coast and Yucatan Peninsula.

Although at least half of Mexico is arid, both tropical and temperate climates are also represented, depending on elevation, winds and ocean currents. The rainy season extends from late May through October or November throughout most of the country, but rainfall is quite irregular and variable.

Mexico is exceptionally rich in minerals. In 2010, it was the world's second largest producer of silver, fluorspar and bismuth and the third largest producer of strontium, the fourth largest producer of wollastonite and diatomite, the fifth largest producer of lead, the sixth largest producer of oil, cadmium, molybdenum and zinc, the eleventh largest producer of gold and the twelfth largest producer of copper [18.1, 18.2].

8.18.2. Geology

Mexico extends at least 3000 km from NW to SE and has a highly varied and complex geology. Many areas have not been mapped and are little known, in part owing to very difficult access.

The geology of Mexico has been profoundly shaped by the presence and interaction of the Pacific, Rivera and Cocos Plates and the truncated end of the East Pacific Rise all interacting along the western margin of the North American Plate. In addition, the major left-lateral fault between the North American Plate and the Caribbean Plate cuts east–west across the far south of the country. These major tectonic elements are responsible for the complex structural geology, as well as for the evolution and the variety of many of the rock types that occur in the country.

The active nature of the continental margin along the Pacific resulted in the uplift and associated vigorous erosion of the western and southern parts of the country, thereby creating large areas of exposure of metamorphic and plutonic strata from the deeper levels of the upper crust (Fig. 8.34). In contrast, the continental margin along the Gulf of Mexico has generally been considered to be a gradually emergent passive margin over which sedimentation took place throughout the Cenozoic. Although there are exceptions to this broad generalization, the principal morphotectonic provinces recognized in mainland Mexico reflect this broad framework [18.3–18.5].

Reference [18.4] provides a comprehensive overview of the geology as well as an extensive reference list of geological work carried out throughout the country and to other sources of information.

Mexico's landmass may be divided into several major morphotectonic provinces: (i) Baja California Peninsula, (ii) Sonoran Basin and Range Province, (iii) Sierra Madre Occidental, (iv) Sierra Madre Oriental, (v) Gulf Coastal Plain Foreland and Yucatan, (vi) Trans-Mexico Neovolcanic Belt, (vii) Sierra Madre del Sur, and (viii) Sierra de Chiapas. A brief description of each geological province follows based on that published by de Cserna [18.4, 18.5].

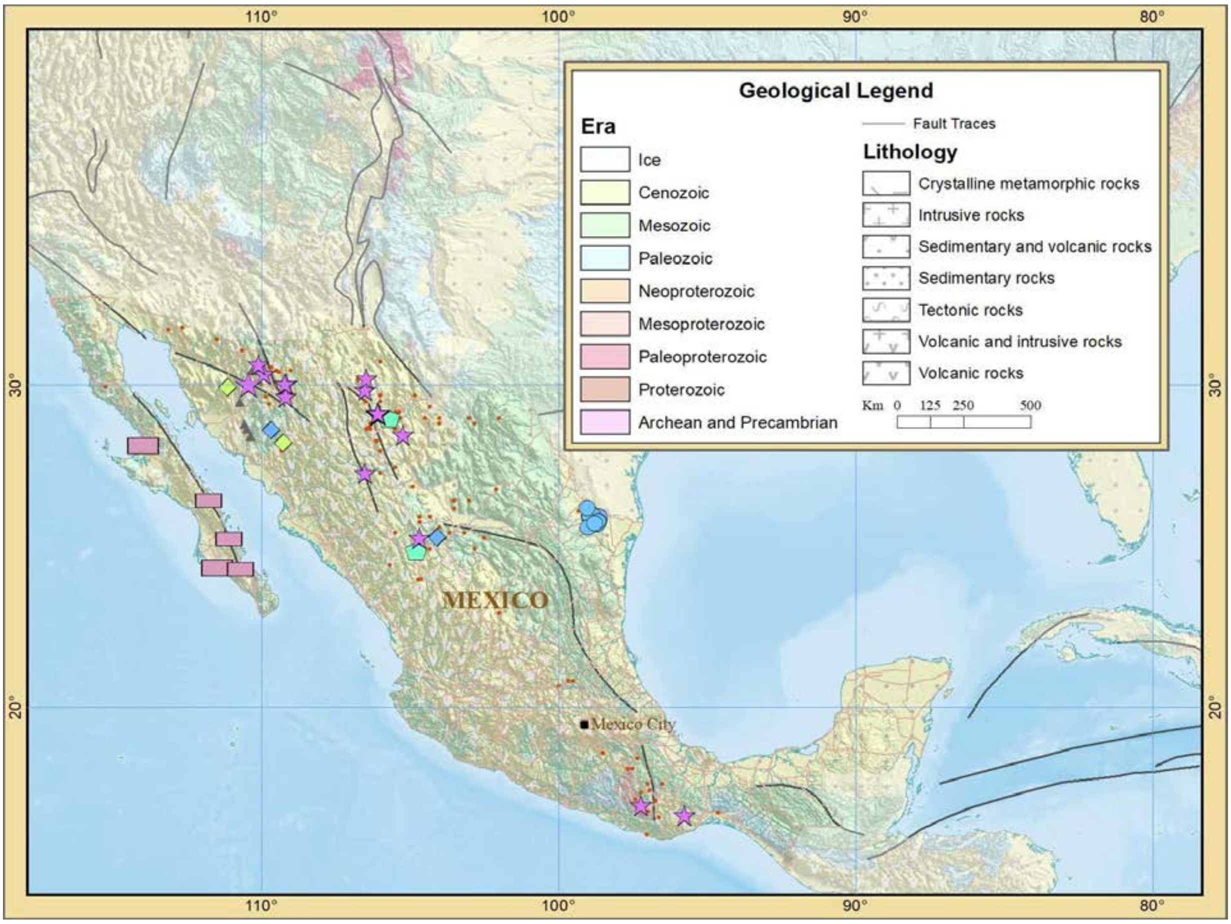


FIG. 8.34. Regional geological setting of Mexico showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.18.2.1. Baja California Peninsula

Baja California Peninsula, the westernmost tectonic province of Mexico, extends 1300 km SSE from the border with the United States of America to Cape San Lucas in the south. The Baja California Peninsula is bordered on the east by a complex structural depression whose floor lies below sea level and deepens towards the SE. The Peninsula is divisible from north to south into three morphotectonic subprovinces: (i) the Peninsula Ranges, (ii) the central region, and (iii) the Southern Cape region:

(i) *The Peninsula Ranges*: The poorly exposed eastern half of the Peninsula Ranges consists of the oldest rocks on the Peninsula and comprises weakly metamorphosed sandstone, shale, limestone and basic volcanics. Fossils date the sediments from Precambrian to Triassic. The next sequence of younger rocks on the western Peninsula comprises several thousand metres of metasedimentary and metavolcanic rocks of Middle Cretaceous age which are intruded by numerous plutons. Of these, 387 have been mapped in the Peninsula Ranges with 250 identified as 118 tonalites and quartz diorites, 87 granodiorites and 34 gabbro and diorite. Of the remaining 11, 5 are granites and 6 are adamellites. The total area of plutonic rock exposure is ~40% of the surface area of Baja California Norte. A post-batholithic marine sedimentary sequence of Late Cretaceous–Early Tertiary age forms a narrow belt along the west coast;

(ii) *The central region*: This consists of a near horizontal dissected volcanic plateau, the Sierra de La Giganta, flanked on the west by younger Tertiary sediments and Pliocene–Quaternary volcanics. A wide variety of other rock types ranging from sediments to volcanics occur in the area, most of which are metamorphosed and deformed;

(iii) *The Southern Cape region*: This consists of granitic and metamorphic terrain and includes a large granitic massif which attains an elevation of just over 2000 m. The massif is flanked by metamorphic rocks and covered by a thin sequence of Miocene volcanics and Pliocene marine sedimentary rocks.

The dominant geological structures of the region are many N–NW trending high angle faults, some extending 15–20 km in length.

Large volumes of marine phosphorites occur in Tertiary uplifted sediments on the west coast of southern Baja California.

8.18.2.2. Sonoran Basin and Range Province

The Sonoran Basin and Range Province extends from the Arizona-Sonora segment of the international boundary to latitude 21° N. It extends from the Gulf of California in the west to the volcanic plateaux of the Sierra Madre Occidental. Between the international boundary and latitude 28° N, the region is characterized by NNW trending mountain ranges separated by valleys which increase in width westwards. To the west this forms a large desert region, the Altar Desert, which has moving sand dunes that emphasize the inselberg aspect of many of the mountain ranges. West of longitude 110° W, the region is very similar to the Basin and Range province of the USA.

South-east of Guaymas, the Range Province forms a narrow coastal plain on the Gulf of California. The oldest exposed rocks in Mexico occur in this morphogenic province and consist of quartz-muscovite schists, quartzite and quartzo-feldspathic gneisses intruded by calc-alkaline plutons dated at 1750 Ma. Various Precambrian rocks believed to form the basement occur widely throughout the province. Outcrops occur in widely spaced mountain blocks, making the interpretation of the regional geology difficult. Various strata of Late Precambrian–Palaeozoic age are found overlying the basement rocks. Upper Triassic continental and locally coal-bearing clastic deposits are primarily confined to the Sonoran Province. Various rocks types, including sediments and volcanics of Jurassic–Cretaceous age, are also distributed throughout the province.

Numerous granitic plutons are emplaced throughout the province and range in age from Late Cretaceous to Tertiary, with a tendency for the age to become younger from west to east. Deep fracturing of the northern part of the province throughout the Miocene and Pliocene reflects the Basin and Range tectonics of south-western North America. In Sonora, this resulted in block mountains oriented NNW and adjacent valleys controlled by high angle faults. In the western area, volcanic features are apparently related to faulting originating from the tectonic framework that resulted from the opening of the Gulf of California.

8.18.2.3. Sierra Madre Occidental

The geology of the Sierra Madre Occidental is very poorly known owing to difficult access caused primarily by the very rugged terrain. Only one railway and one highway cross the range. The Sierra Madre Occidental is a linear volcanic plateau elongated in a NNW direction along a distance of ~1200 km and varying in width in the range 200–300 km. The elevation averages 2000 m but attains a maximum height of 3348 m. The Sierra Madre Occidental is a broad anticlinal uplift with a gently dipping eastern flank and a more steeply dipping western flank.

The geology of the region is defined by a lower volcanic complex formed by batholithic intrusive and associated extrusive rocks whose ages are in the 100–45 Ma range, and an upper volcanic supergroup, formed mostly by ignimbrites, caldera complexes and small volumes of mafic lavas, with ages of 34–27 Ma. The extrusive rocks of the lower volcanic complex rest unconformably on deeply eroded terrain comprising Precambrian, Palaeozoic and Mesozoic metamorphic and plutonic rocks, as well as remnants of some sedimentary strata. The dominant rock is andesite with some intercalated rhyolitic ignimbrites. Water-borne pyroclastic material, as well as agglomerates and tuffs, are found at many places in the 1000–1400 m thick sequence. The plutonic rocks frequently intrude the lower volcanic complex. This sequence is characterized by intense alteration and the presence of mineral deposits, in contrast to the overlying upper volcanic supergroup.

The upper volcanic supergroup unconformably overlies the lower volcanic complex and consists primarily of rhyolitic and rhyodacitic ignimbrites. Some mafic lava flows occur near the top of the ignimbrite sequence, which is roughly 600–800 m thick. Numerous rhyolitic domes and calderas have been identified in this sequence [18.4]. However, significant uranium occurrences are not known.

8.18.2.4. Sierra Madre Oriental

The Sierra Madre Oriental extends south from the international border to roughly latitude 20° N. The western boundary is transitional to the main Sierra Madre Occidental and in the east it extends to the western margin of the low lying Mexican portion of the Gulf Coastal Plain. The region is formed by a complex folded thrust sequence of Mesozoic carbonates with some interbedded shale, overlain by flysch, in which locally post-tectonic granitoid stocks are emplaced.

The province is elongated in a NNW direction and extends to ~1500 km with a width varying from 200 km in Chihuahua to 400–500 km further south.

The major structures of this province are folds that have been modified by thrusting and later normal faults. These structures are formed principally in Lower Cretaceous carbonate and Upper Cretaceous flysch, although Upper Jurassic sandstone, shale and some carbonates of the lower parts of the deformed sequence are occasionally exposed. At isolated locations, exposure of both Palaeozoic and Precambrian strata occur.

Reference [18.5] notes that a tectonic model of the Sierra Madre Oriental, including large scale thrusts, is comparable to those of the southern Rocky Mountains of Canada or the Jura Mountains in Switzerland. The period of folding and faulting was followed by the emplacement of granitic, monzonitic and granodioritic stocks towards the end of the Eocene. These intrusives are widely distributed in the western two thirds of the Sierra Madre Oriental, whereas very few occur in the eastern frontal belt. The intrusives produced some important skarn mineralization and set the stage for hydrothermal activity and mineral deposition. The products of the Miocene volcanic activity of the Sierra Madre Occidental covered some of the western parts of this province. Widespread block faulting of Basin and Range tectonics accompanied the Pliocene uplifting of the entire province, as well as of the Sierra Madre Occidental.

8.18.2.5. Gulf Coastal Plain Foreland and Yucatan

The Gulf Coastal Plain Foreland and Yucatan morphotectonic province is adjacent to the eastern edge of the Sierra Madre Oriental, barely flanks the eastern termination of the Trans-Mexico neo-volcanic belt, lies to the east of the Sierra Madre del Sur and NNE of the Sierra de Chiapas. This region represents the breakdown of the foreland in the Late Cretaceous–Early Tertiary, ENE directed folding and thrusting north of the Tuxtlas volcanic massif, and the burial and build-up of the present coastal plain by the products of erosion from the western, south-western and southern fold and thrust belt. In the north, the Rio Grande River supplied a considerable amount of clastic material. The coastal plain between the Rio Grande in the north and the Laguna del Carmen in the SE may be divided into four palaeoembayments corresponding to the four principal depositional sites of the major rivers.

The Upper Eocene–Miocene, and at places even Pliocene and Pleistocene, sequence comprises sandstone and shale with some conglomerate and limestone. Most of these deposits are undisturbed, or are deformed by compaction, faulting and folding produced as drag along faults. However, in the northern parts of the Isthmus of Tehuantepec, numerous salt domes (the salt being of Middle Jurassic age) are emplaced in the Tertiary sequence, producing doming and associated faulting. The stratigraphy of the province is reasonably well known through oil and gas exploration. The basement for the Eocene and younger, primarily clastic sequence consists of deformed Mesozoic–Palaeocene sediments, which is in turn underlain by Palaeozoic metamorphics that are, in places, overlain by Permian flysch.

The Tertiary sequence varies in maximum thickness from 10 000 m in the Rio Grande embayment to 2000–5000 m in most other areas of the Gulf Coastal Plain. Another feature of the Gulf Coastal Plain is the presence of alkalic strata dated at 28–7 Ma in the Sierra de San Carlos and in the southern parts of the Sierra de Tamaluipas, as well as numerous basaltic volcanic rocks occurring as flows, volcanic necks and dykes. The alkalic volcanics have been alikened to the Trans-Pecos Magmatic Province of Texas, which is considered by some to be the source of uranium in the south Texas sandstone-hosted deposits [18.6].

Yucatan is considered to be a stable platform with near surface strata consisting of Neogene and Palaeogene marine deposits. The deposits consist of marls and limestones of Miocene–Oligocene age with a combined thickness of ~2000 m, as well as underlying 1200 m of Upper Cretaceous interbedded limestone, dolomite and anhydrite.

8.18.2.6. Trans-Mexico Neovolcanic Belt

This province extends across Mexico from the Pacific coast to near the Gulf coast, roughly between latitudes 19° and 20° N. It is ~900 km long and up to 100 km wide. Morphologically, it is a broad, west sloping volcanic plateau, formed by polygenetic stratovolcanoes, monogenetic volcanoes and cinder cones, caldera complexes and explosion craters or maaren, with associated lava flows and pyroclastic deposits. Six of the stratovolcanoes constitute the highest peaks in the country.

The belt is thought to have developed in the central part throughout Late Miocene–Early Pliocene with the eruption of calc-alkaline andesite and dacite, with some small areas of rhyodacites and rhyolites. Magma generation was intimately related to the subduction process of the Rivera and Cocos Plates. The monogenetic volcano fields, which occupy large areas within this province, are formed by basalts (chemically basaltic andesites) and are interpreted as having originated from the mantle throughout subduction and without having incurred much contamination.

8.18.2.7. Sierra Madre del Sur

Were it not for the Trans-Mexico Neovolcanic Belt forming throughout the Pliocene–Quaternary, the Sierra Madre del Sur would comprise those strata that underlie Mexico north of latitude 19° N. It is located along and bounded by the Pacific Ocean in south-western Mexico. The morphology of this region has been governed by subduction processes along the Middle America Trench since the end of the Miocene, which has resulted in the truncation of the continent along the southern coast of Mexico. This uplift is recorded by the presence of onshore marine Cenozoic strata, the generation of magma and the occurrence of suitable tectonic conditions needed to form a natural dam across Mexico: the Trans-Mexico Neovolcanic Belt.

With the exception of a narrow coastal plain extending along the Pacific, the entire province is maturely dissected. The most prominent topographic feature is the segmented coastal cordillera, generally referred to as the Sierra Madre del Sur, which extends ESE from Bahía de Banderas for a distance of 900 km. Most of the highest elevations along this cordillera lie between 2600 and 3000 m, although the highest peak is 4342 m. The area of the Puebla–Oaxaca upland has a very complex geology, which, is poorly understood. The oldest rocks are Precambrian granulites including quartzo-feldspathic gneiss, charnockite, paragneiss, marble and meta-anorthosite, among others. There is also a wide variety of Palaeozoic strata, many of them metamorphosed schists and gneisses. The area west of longitude 102° W is described as largely unknown, except for parts of Colima. Younger rocks include sedimentary sequences, as well as Upper Cretaceous and older granitic stocks that are widely distributed in the province. Early Tertiary deposition consists of continental clastics that are preserved in fault-controlled basins, while Middle Tertiary volcanic activity of andesitic composition is practically confined to the north central part of Oaxaca.

8.18.2.8. Sierra de Chiapas Province

The morphotectonic province extends from the Gulf Coastal Plain in the east to the Pacific Ocean and in the west, as far as southern Mexico. Bordering the Pacific is a coastal plain built by rivers flowing from the Chiapas Massif, which has an average elevation of 1500 m. Mesozoic deposits are adjacent to the coastal cordillera in the NE and form the NW elongated and fault-controlled Central Depression of Chiapas, as well as NE lying Chiapas Highlands. North and NE of the Chiapas Highlands is the Sierra de Chiapas proper, formed by a series of elongated mountain ranges and parallel valleys. The Chiapas Massif consists of the oldest strata found in this province and is a pre-Permian Palaeozoic, probably Devonian, batholith emplaced in Upper Precambrian metamorphic rocks. The Sierra de Chiapas is apparently separated from the Sierra Madre del Sur to the north by a transcurrent fault or shear zone marked by intense modern day seismic activity. The NE flank of the Chiapas Massif is overlain to the SE by 2700 m of black slates and ferruginous sandstones of either Carboniferous or Lower Permian age. The oldest Mesozoic rocks in Chiapas are continental red beds that are equivalent to, or underlie, Upper Jurassic and basal Cretaceous marine deposits. There is also a 12 000 m thick sequence of Palaeocene–Lower Miocene strata of shale, sandstone and limestone. Other strata in the area include a few granitic stocks of Late Triassic–Early Jurassic age, as well as Quaternary volcanics of andesitic composition. The area includes several recently active volcanoes and registers intense seismic activity [18.4–18.6].

8.18.3. Uranium exploration

Uranium exploration in Mexico began in 1957 and continued up to cessation in May 1983, with all work undertaken by governmental organizations. The areas explored, in order of importance, are in the States of Coahuila, Zacatecas, Chihuahua, Nuevo León, Queretaro, Puebla and Tamaulipas. Exploration included ground and airborne prospecting by geological and radiometric methods in addition to surface sampling, drilling and mining. Airborne and ground-based geochemical, emanometric and magnetometric techniques have also been used to a lesser extent.

Prior to 1970, exploration was conducted by the Mexican Nuclear Energy Commission, which, in 1971, became the National Nuclear Energy Institute. Following a major reorganization in 1979, the National Nuclear Energy Institute was split into the following organizations: the Atomic Energy Agency, whose activities were coordinated by Uranio Mexicano (URAMEX), which is in charge of all activities concerning the nuclear fuel cycle; the Mexican National Commission for Nuclear Safety and Safeguards and the National Nuclear Research Institute.

In February 1995, URAMEX was dissolved and its responsibilities transferred to the Mineral Resources Board (Consejo de Recursos Minerales) and to the Mining Development Commission (Comisión de Fomento Minero). Both organizations report to the Ministry of Energy, Mines and State-Owned Industry.

Through 1980, a total area of 260 000 km^2 were explored by airborne radiometric surveys at line spacings of 0.8–1.0 km. In addition, 35 000 line-km of car-borne surveys were undertaken.

By 1981, drilling totalled 1 243 170 m (including 200 000 m planned for 1981) at a cost of US $18.569 million [18.7]. In 1981, 1982 and 1983, drilling campaigns of 150 640 m, 136 330 m and 49 555 m, respectively, were conducted. The costs for the drilling campaigns completed in 1981, 1982 and 1983 are not available. A total of 14 643 holes were drilled through 1983. Holes were logged using electrical and gamma ray methods.

Throughout the period 1981–1983, URAMEX continued the exploration and evaluation of 19 prospects located in the States of Chihuahua (4), Durango (5), Zacatecas (2), San Luis Potosi (1), Nuevo León (3), Sonora (2) and Oaxaca (2). The geological environments of the prospects explored include: acid volcanics (La Gloria, La Mesa, Majalca, Cerros Colorados, La Perla, Montosa, Teresa, Lajoy and El Refugio), Tertiary sandstones (La Diana, Santa Fe and Dos Estados), contacts between acid to intermediate intrusives and volcanics (Granaditas and El Picacho), pre-Jurassic gneiss and schist and Jurassic shale (San Juan Mixture and Tayata).

Fifteen properties where drilled in 1981–1983 [18.8].

8.18.4. Uranium resources

The principal deposits or districts and their recoverable resources are in Chihuahua, Nuevo León, Sonora, Oaxaca and Durango (Fig. 8.35, Table 8.14).

The UDEPO database lists the most significant deposits for Mexico as Santo Domingo, San Hilario, UF 1, San Juan De La Costa, Tembabiche, El Boleo, La Sierrita, Buenavista, Los Amoles District.

TABLE 8.14. URANIUM DEPOSITS [18.8-18.10]

Deposit	Location	Type	Resource (tU)	Grade (%U)	Remarks
El Nopal	Chihuahua	Volcanic (breccia pipe)	306	0.25	Disseminations and veins in rhyolite and tuffs
Margaritas-Puerto III	Chihuahua	Volcanic at limestone contact	2542	0.10	Disseminations and veins in rhyolite and tuffs
Los Amoles	Sonora	Veins in fractured silicified andesite	403 (reserves), 485 (additional resources)	0.16	Occurs in roof pendant of intrusive body
Las Preciosa	Durango	Volcanic (breccia and intrusive)	368	0.05	
Santa Catarina Tayata	Oaxaca	Volcanic (tuff and conglomerate)	<424	0.04–0.08	
La Coma	Nuevo León	Sandstone (roll front)	1114	0.2	
Buenavista (La Sierrita(?))	Nuevo León	Sandstone (roll front)	1200	0.2	
El Chapote	Nuevo León	Sandstone (roll front)	672	0.07	

8.18.4.1. Chihuahua

The Peña Blanca district, in Chihuahua State, is part of the Sierra del Cuervo and consists of a sequence of Cenozoic acid volcanics, Cretaceous limestones and basal conglomerates. The main portion of the uranium mineralization is generally related to both hydrothermal and supergene processes and occurs as breccia pipe fillings, fracture fillings and disseminations and in tabular orebodies in rhyolitic tuffs. The mineral association includes primary and secondary uranium and molybdenum minerals. Total recoverable resources in the RAR and EAR-1 categories at costs of <US $130/kgU reported in [18.8] amount to ~3220 tU.

The La Sierrita district is situated in the State of Nuevo León, close to the border with Tamaulipas State. Geologically, the area is underlain by Oligocene–Miocene tuffaceous sediments of the Burgos Basin. Uranium mineralization, grading 0.05–0.12% U, includes coffinite and uraninite occurring in a roll front redox interface in carbonaceous sandstones of Oligocene age. Within this district, there are 8 deposits with combined uranium resources of up to 850 tU. These deposits include, in order of size, La Coma, Buenavista, La Diana and El Chapote, as well as Peñoles, La Presita, Dos Estados and Las Trancas.

Mexico's three defined roll front type sandstone deposits (La Coma, Buenavista and El Chapote) are of Oligocene age and occur within the fluvial wedge of the Gulf Coastal Plain. The deposits are not described in detail in the published record, although the host is identified as fine- to coarse-grained sands of the Frio Formation. In addition to the above resources hosted in rhyolitic volcanics, uranium occurrences have also been found in Upper Cretaceous limestones in the areas of Domitila, Jales, Lotes, Valle de Aldama, Adargas and Lamentos.

Roughly 90% of these resources, with a grade of ~0.085% U, are located in five deposits: Margaritas, Puerto III, Nopal I, Nopal III and Laguna de Cuervos. The remainder occur in 10 small lower grade (0.019% U) deposits: Puertos I, II, IV, V, VIII, Laguna del Diablo, Cerva Amarilla, Peñon Blanco, Nopal II and La Gloria.

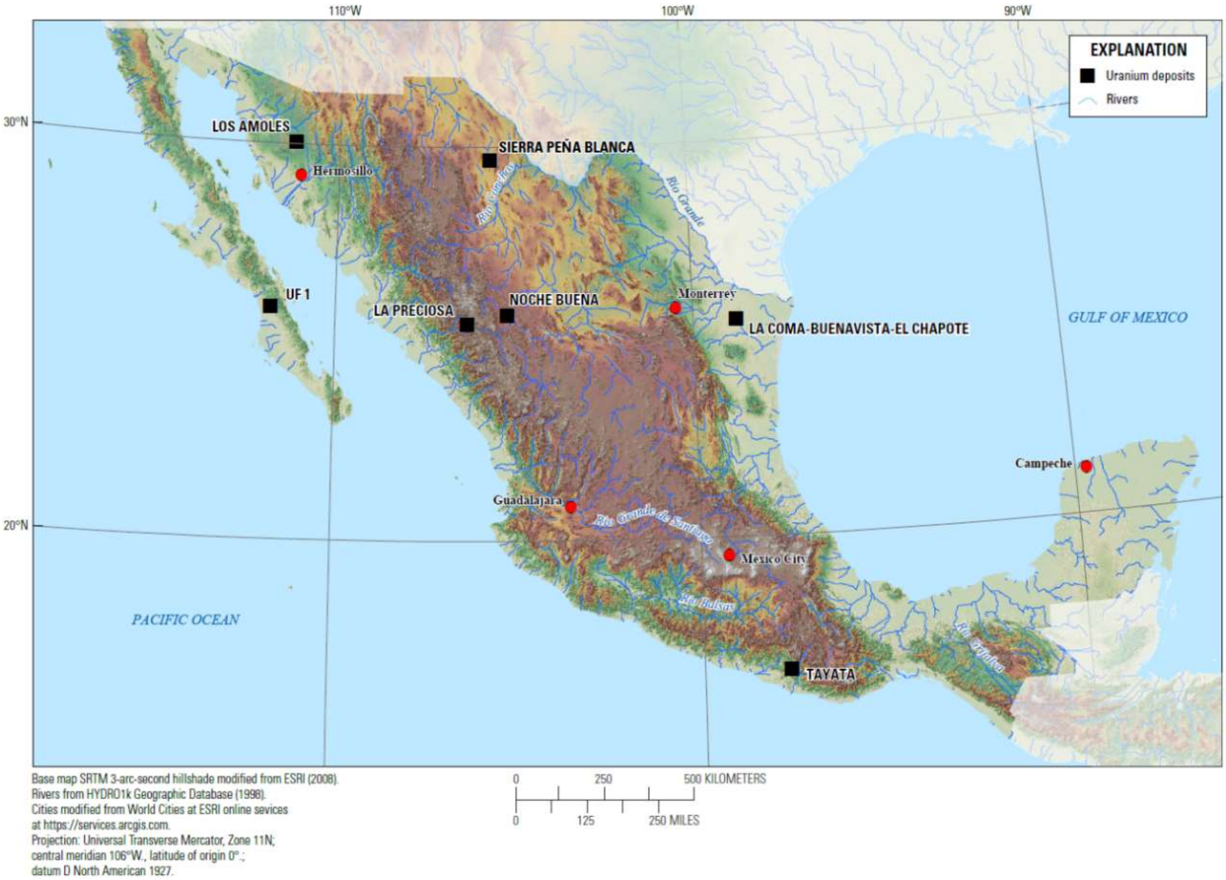


FIG. 8.35. Uranium deposits of Mexico [modified from 18.10].

8.18.4.2. Nuevo León

The Frio Formation is of the same age and is equivalent to the Oligocene Catahoula Formation and occurs to the north in the south Texas uranium province. The Catahoula Formation is a highly tuffaceous fluvial unit that was deposited in a marginal marine environment and serves as the principal host for uranium deposits in south Texas. In addition, the Mexican deposits are of a similar size and uranium grade as the south Texas deposits. The development of in situ leach production in south Texas has primarily taken place since the discovery of the Mexican deposits and much has been learned about this geological environment since work on the Mexican deposits was suspended.

8.18.4.3. Sonora

Los Amoles is the most important uranium deposit in Sonora State. The deposit consists of three orebodies: Amoles, Amoles II and Martin. The mineralization comprises primary and secondary uranium minerals and is associated with argentiferous galena and baryte which occur in fractures in altered trachyandesite that overlies a Mesozoic granite. The estimated uranium resources in [18.8] totals ~1050 tU RAR and EAR-I, recoverable at less than US $130/kgU. In addition, there appears to be a high potential for discovery of additional deposits, which would merit future exploration in the area surrounding the Los Amoles II and Martin deposits.

Additional uranium deposits in the Sonora State are Noche Buena, San Antonio de las Huertas, Granaditas, Santa Rosalia, Picacho, Yecora, Huasabas, Moctezuma and Los Caballos. Their total resources (RAR plus EAR-1 recoverable at <US $130/kgU) are estimated at 850 tU, hosted in the following geological settings:

(a) *Noche Buena*: Secondary uranium minerals associated with Ag, Pb and Zn minerals as fracture fillings in altered granite of Mesozoic age;
(b) *San Antonio de las Huertas*: Secondary uranium minerals associated with Ag, Pb, Zn and Cu minerals as fracture fillings in Jurassic sediments intruded by an acid to intermediate Cenozoic intrusive;
(c) *Granaditas–Santa Rosalla–Picache*: Uranium mineralization in acid to intermediate volcanics of Cenozoic age;
(d) *Yecora*: Uranium mineralization associated with W and Mo minerals in a brecciated granite of Mesozoic age. Although the known resources are small, the potential of this area is estimated by URAMEX to be around 500 tU;
(e) *Huasabas, Moctezuma and Los Caballes*: Secondary uranium mineralization in fractures in Cenozoic acid to intermediate volcanics as well as at the contacts of lava flows.

8.18.4.4. Oaxaca

The Tayata and San Juan Mixtepex deposits, located in the western part of Oaxaca State, were discovered sometime around 1980. The deposits are located in the Tlaxiaco Basin and host total resources (RAR), as reported in [18.6] in the US $80–130/kgU cost category, of ~470 tU [18.8]. Uranium mineralization is related to a structurally complex area underlain by conglomerates and tuffs of Cenozoic age in fault contact with Cretaceous limestone and silicified sandstone and schist of Jurassic age, occurring in fault contact with pre-Jurassic gneisses. It is reported that Tayata contains ~85% of the total resources of the area.

8.18.4.5. Durango

La Preciosa, El Mezquite, Coneto-Buenavista and Sierra de Coneto, all located in Durango State, are deposits and prospects with RAR and EAR-1 resources reported in the [18.8] as 840 tU in the US $80–130/kgU cost category and occurring in a variety of geological environments.

La Preciosa is the largest but lowest grade deposit in Durango, accounting for ~50% of the resources of in the State. The uranium mineralization is associated with a brecciated intrusive contact between Lower Cretaceous sediments and granitic rocks.

El Mezquite contains roughly tabular disseminated and fracture filling mineralization in a tuffaceous bed of probable Middle Tertiary age. The Coneto-Buenavista occurrence is hosted in a vein structure in a Cretaceous limestone host. Uranium minerals are associated with fluorite. The Sierra de Coneto deposit contains a number of other uranium occurrences in Cenozoic acid volcanics.

According to the 1999 Red Book [18.3], estimates of uranium resources were last prepared in 1982. Feasibility reports had been prepared for the Amoles and Peña Blanca deposits [18.8].

Known uranium resources total 2400 tU, which are recoverable in the US \$80–130/kgU cost category. New undiscovered resources comprise 12 700 tU, of which 2700 tU are designated as EAR-II and 10 000 tU are speculative resources (Table 8.15) [18.8].

TABLE 8.15. REPORTED UNDISCOVERED CONVENTIONAL RESOURCES (tU)

Category	<US \$130/kgU	Cost range unassigned
Prognosticated	3000	
Speculative resources		10 000

8.18.5. Identified resources

As of 1 January 2017, reasonably assured resources (RAR) and inferred resources (in-situ) totalled to 2540 tU and 4 264 tU respectively, in the <US\$ 260/kgU cost category [18.9]. Resources are associated to sandstone-type deposits (RAR: 852 tU, IR: 4 264 tU) and volcanic related deposits (RAR: 1598 tU). The historical variation in identified resources is shown in Fig. 8.36 and Fig. 8.37.

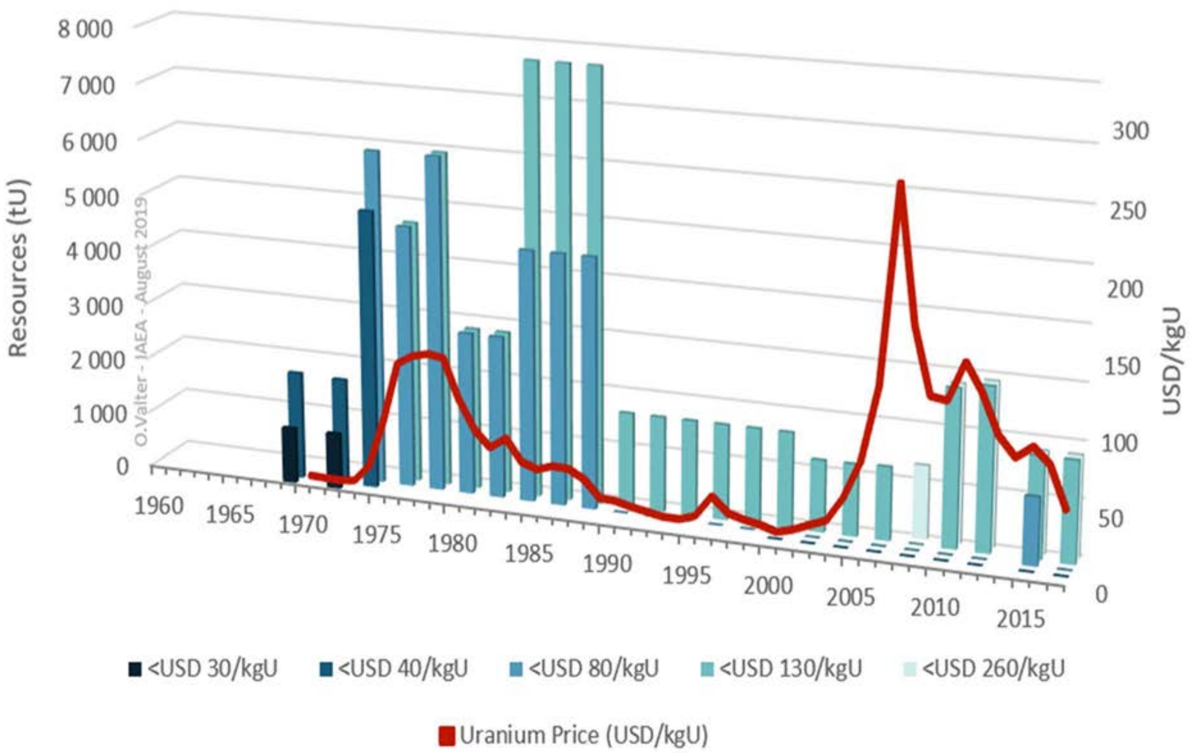


FIG. 8.36. Historical variation of recoverable reasonable assured resources within various cost categories in Mexico. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

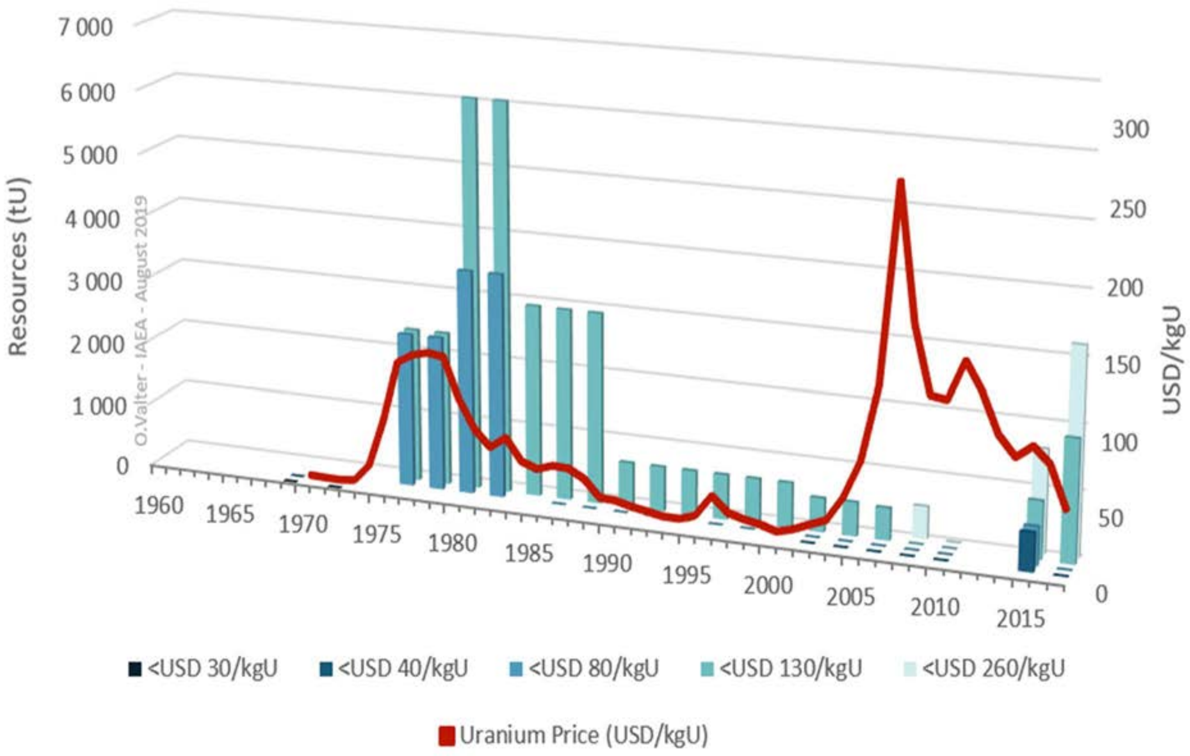


FIG. 8.37. Historical variation of recoverable inferred resources within various cost categories in Mexico. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

8.18.6. Unconventional resources

Unconventional uranium resources in marine phosphates are reported for Baja California, totalling 150 000 tU. In addition, 1000 tU of unconventional resources related with hydrothermal non-ferrous mineralization in La Preciosa (Durango), Noche Buena (Sonora) and Tayata (Oaxaca) are reported. This resource was previously classified as a conventional resource (Table 8.16).

TABLE 8.16. REPORTED UNCONVENTIONAL RESOURCES

Deposit	State	Type	Resource (tU)	Grade (ppm U)	Source
San Juan de la Costa	Baja California	Phosphorite	6000	90–150	1999 Red Book
Santo Domingo	Baja California	Phosphorite	145 000	90–150	1999 Red Book
Tayata Noche Buena La Preciosa	Oaxaca Sonora Durango	Non-ferrous mineralization	Total 1000	n.a.[a]	1986 Red Book

[a] n.a.: not available.

8.18.7. Potential for new discoveries

The 1980 IUREP report [18.11] provides a description of uranium potential. Since 1980, very little uranium exploration has been conducted in Mexico. Therefore, except for the major advances in the use of in situ leach technology for the extraction uranium from roll front type sandstone deposits made since 1980, which may be applied to exploit the La Coma, Buenavista and El Chapote deposits, little else has changed.

IUREP reports that there are several areas that appear promising for the discovery of sandstone, vein and disseminated deposits. However, only limited exploration has been undertaken.

Large areas of Mexico are covered by volcanic rocks and many of these are of acidic composition. The Oligocene–Pliocene acid volcanics of the Sierra Madre Oriental are considered to be obvious targets. Volcanics of this type occur in the States of Chihuahua, Sonora, Durango, San Luis Potosi, Nayarit, Zacatecas, Queretaro and Hidalgo, with isolated outcrops in Baja California and Coahuila. Volcanics of the same age and composition also crop out in the Sierra Madre del Sur in the States of Guerrero and Oaxaca. Mesozoic acid volcanics occur as isolated outcrops in the States of Sonora, Sinaloa, Jayarit, Durango, Coahuila, Zacatecas, Michoacan and Guerrero. There are also many outcrops of these rocks in the States of Veracruz, Puebla, Oaxaca, Chiapas and Baja California. Palaeozoic acid volcanics occur along the Pacific Coastal Plain.

No occurrences of uranium are known in pegmatites, migmatites or metamorphic rocks in general. The potential for deposits in rocks of this type, plus granites, exists in the Sonoran Desert and Plains, the Sierra de la Baja California, the Sierra Madre del Sur, the Oaxaca Valley and the Sierra de Chiapas. In general, these areas contain Palaeozoic or older metamorphics which have, in places, been intruded by Mesozoic or Tertiary granodiorites, granites, quartz monzonites and syenites.

The potential for vein uranium deposits occurs in many parts of Mexico, especially in areas hosting acid igneous intrusives, including Baja California, the Sonoran Desert and Plains, the Sierra Madre del Sur and the Oaxaca Valley, and in those areas where acid volcanics occur, as detailed above.

In addition to the Gulf Coastal Plain, there are several additional areas with potential for uranium deposits in sandstones. In the north-western part of Baja California, Lower Cretaceous tuffs are overlain by Palaeozoic and Eocene marginal marine and fluvial sediments and throughout the Peninsula there are Cretaceous–Pleistocene sediments interbedded with volcaniclastics. The Parras and La Popa Basins of southern Coahuila and western Nuevo León in the Sierra Madre Oriental contain terrigenous sediments of Late Cretaceous and Palaeocene age, the Difunta Group being of particular interest. Similar Upper Cretaceous deltaic sediments are also found in the Sabinas and Ojinaga Basins of eastern Coahuila and north-eastern Chihuahua, respectively, also within the Sierra Madre Oriental.

In the Maseta Central, the Late Triassic Nazas Formation was deposited in a lacustrine environment consisting of red to purple mudstones, siltstones and sandstones interbedded with andesitic to rhyolitic tuffs, flows and ignimbrites. In northern Zacatecas and adjacent Durango, the formation overlies highly folded and faulted schists, metavolcanics and metasediments of possible Palaeozoic age.

In the Sierra Madre del Sur, in the basin of the Balsas River and in the Oaxaca Valley, Tertiary continental beds are frequently interbedded with andesitic to rhyolitic volcanics. The Eocene–Oligocene Balsas Formation is a very attractive target in this area. Also in the Oaxaca Valley, the Middle Jurassic consists of continental conglomerate, sandstone, shale, siltstone and coal.

There exists the possibility of finding calcrete deposits in northern Mexico where surficial, unconsolidated fluvial sediments occur in the restricted basins of arid regions. There is also some potential for finding uranium deposits in petroliferous limestones in the Sierra Madre Oriental and the Gulf of Mexico Coastal Plain.

In summary, the potential for additional uranium resources in Mexico is moderate to high [18.11].

8.18.8. Uranium production

Mexico's Mining Development Commission operated an experimental uranium recovery plant (Planta de Beneficio de Uranio) at Villa Aldama, Chihuahua, in 1969–1971. The facility used alkaline leaching and had a capacity of 80 t ore/d. The operation recovered molybdenum and a total of 49 tU of by-product uranium from ores mined at the Domitilia (Peña Blanca), Sierra de Gomez and other occurrences, all in Chihuahua State. Tailings from the operation were disposed of at Peña Blanca. The plant has been decommissioned.

8.18.9. National policies related to uranium

Government policy accords the State exclusive rights regarding activities related to nuclear matters, including uranium mining. Uranium exploration in Mexico ceased in May 1983 and URAMEX, the organization accountable for this activity, was disbanded in 1985. Some of URAMEX's accountabilities were assumed by the Mineral Resources Board (Consejo de Recursos Minerales). Under the Mexican Law on Mining (Art.5, II) exploration for, and exploitation of, radioactive minerals are controlled activities. This type of mineral is incorporated in the National Mining Reserve Zone System [18.3].

References to Section 8.18

[18.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Mexico, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed May 2009).

[18.2] LIBRARY OF CONGRESS, FEDERAL RESEARCH DIVISION, Country Profile: Mexico July 2008, http://lcweb2.loc.gov/frd/cs/profiles/Mexico.pdf

[18.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).

[18.4] DE CSERNA, Z., "An outline of the geology of Mexico", The Geology of North America: An Overview, Geological Society of America, Boulder (1989).

[18.5] DE CSERNA, Z., "Geotectonic framework of Mexican and Central American mineral deposits", Pacific Rim Congress 90 (Proc. Int. Conf. 1990, Gold Coast), vol. II, Australasian Institute of Mining and Metallurgy (1990).

[18.6] ADAMS, S.S., SMITH, R.B, Natural Uranium Resource Evaluation: Geology and Recognition Criteria for Sandstone Uranium Deposits in Mixed Fluvial-shallow Marine Sedimentary Sequences, South Texas, Final Rep. No. GJBX-4(81), US Department of Energy, Grand Junction (1981), http://www.osti.gov/bridge/servlets/purl/6554832-WNmUUO/6554832.pdf

[18.7] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[18.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[18.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[18.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1993).

[18.11] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

8.19. NICARAGUA

8.19.1. Geography

Nicaragua is Central America's largest country and has borders with Costa Rica to the south and Honduras to the north. The terrain includes wide-ranging Atlantic coastal plains rising to central interior mountains and a narrow Pacific coastal plain punctuated by volcanoes. The highest peak, Mogoton, rises to an elevation of 2438 m and Nicaragua has the distinction of hosting, Lago de Nicaragua – Central America's largest freshwater body. A major part of the Caribbean lowlands and eastern highlands is uninhabited and consists mostly of tropical rainforest, swamps and jungle. Natural resources include fish, timber, copper, gold, lead, silver, tungsten and zinc [19.1].

8.19.2. Geology

8.19.2.1. General

The interaction of the Cocos, Nazca and Caribbean Plates between the North and South American Plates produces the complicated structural geology seen not only in Nicaragua, but also in the rest of Central America. Several geotectonic events are superimposed upon one another, commencing probably in the Jurassic (certainly since the Cretaceous), including rifting in connection with the separation of Laurasia and Gondwana, the recent convergence in a NW–WNW direction between the South and North American Plates, and the subduction of the Pacific Plate under the North and South American Plates. The triangular Cocos Plate is bordered in the west by the East Pacific rise against the Pacific Plate, towards the south against the Nazca Plate by the Galapagos rift and in the NE against the Caribbean and North American Plates by the Central American subduction zone along the Middle America Trench.

A belt of volcanoes (part of the so-called 'Ring of Fire') extends along a length of ~1100 km from Mexico to Costa Rica and separated by a distance of ~200 km from the Middle America Trench. The volcanic front is formed by the subduction of the Cocos Plate beneath the Caribbean Plate. Volcanic activity in Central America dates from the Pliocene–Quaternary. The magmatic arc consists mainly of basaltic to andesitic volcanic rocks (predominantly pyroclastics with subordinate lava sheets). Many of the volcanoes are classified as active. Seismicity is frequent in Nicaragua and there are occasional volcanic eruptions.

The geology of Nicaragua roughly coincides with four major physiographic provinces (Fig. 8.38): (i) the Pacific Coastal Province, (ii) the Nicaragua Depression, (iii) the Interior Highlands, and (iv) the Atlantic Coastal Plain.

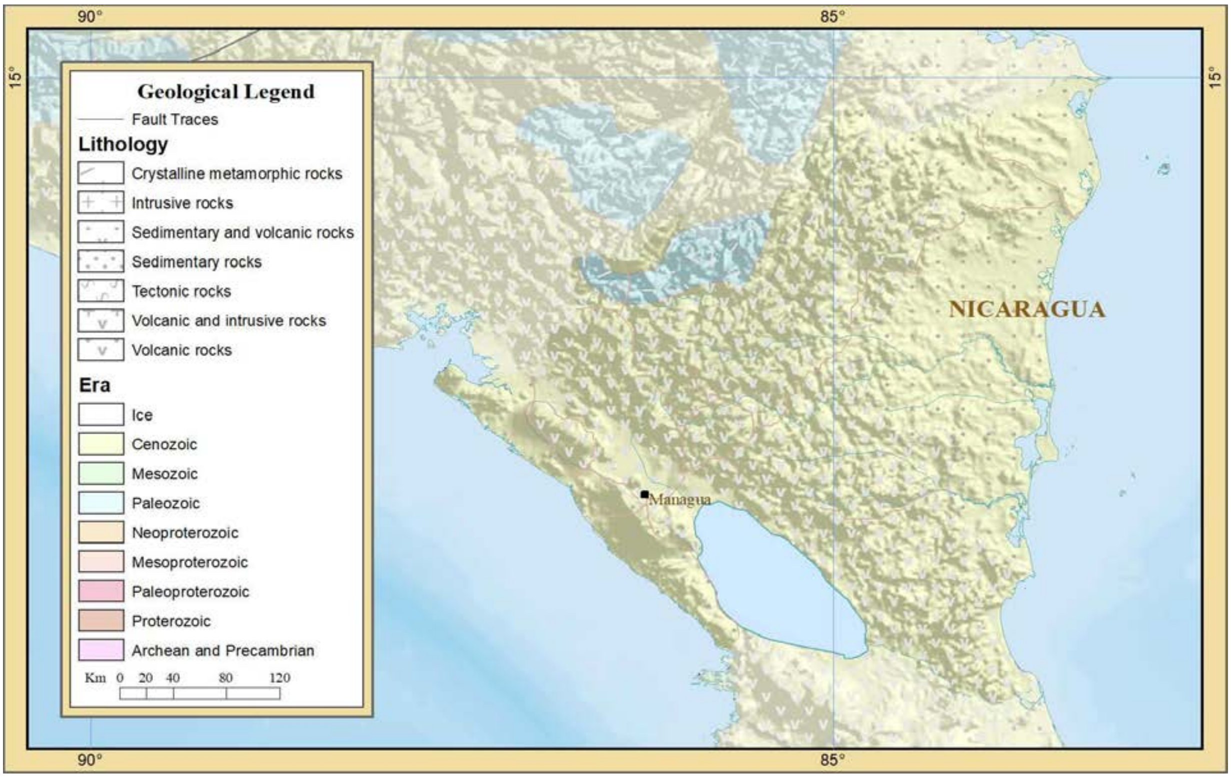


FIG. 8.38. Regional geological setting of Nicaragua. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Pacific Coastal Province is composed of Quaternary and Late Tertiary volcaniclastic deposits and marine sediments. It also includes a Cretaceous–Tertiary marine sedimentary sequence.

The Nicaragua Depression, some 30 km from the Pacific coast, is up to 80 km wide and extends the entire length of the country, parallel to the coast. It is underlain by unconsolidated pyroclastic deposits, ash flow tuffs and mud flow deposits, of Quaternary age. The depression is the site of Quaternary volcanoes that are currently active.

The Interior Highlands are composed largely of Tertiary volcanics of Middle and Upper Miocene age. In this region, copper mineralization is associated with granite intrusives which reportedly contain alaskites. Beneath the limestones, near the city of Siuna in the north central area, is a sequence of Jurassic continental red beds known as the Todos Santos Formation.

The oldest rocks in Nicaragua are in the Northern Highlands, near the border with Honduras. These strata are believed to be older than Lower Cretaceous, probably Palaeozoic, and are intruded by Mesozoic plutons of granite–diorite composition. Mica schists and phyllites predominate.

The Atlantic Coastal Plain consists of Quaternary volcanic-related sediments which are occasionally interbedded with basalt flows [19.2, 19.3].

8.19.2.2. Potentially favourable uranium-bearing areas

With the exception of the Northern Highlands metamorphics, for which there is little information, the country is dominated by basaltic to andesitic volcanism associated with the volcanic front, with some tectonic basins and coastal plains comprised of sediments eroded from the volcanic highlands. These volcanic and associated sedimentary environments are considered to be unfavourable for hosting significant uranium deposits.

8.19.3. Uranium exploration

On behalf of the Government of Nicaragua, the US Atomic Energy Commission conducted a reconnaissance exploration programme for uranium in March 1953. Operating and abandoned mines, as well as prospects, formation contacts, dykes and sills en route to these mines were tested by scintillometer. The reconnaissance included investigation of two mineralized areas exposed in ‘windows’ within the volcanic belt. However, the programme did not include the schists and granitic intrusions in the north-eastern part of the country. No anomalous radioactivity was detected.

No exploration expenditures have been reported.

The IUREP mission [19.2] noted that exploration of any favourable formations has been hindered by volcanic ash cover in western Nicaragua and by dense vegetation cover in the east. Little geological work has been undertaken on either the Palaeozoic metamorphic rocks or the Todos Santos Formation of the Northern Highlands. These could possibly have some potential for discovery of uranium, as might the alaskites occurring near Siuna [19.3, 19.4].

8.19.4. Uranium resources

There are no uranium resources in Nicaragua. The UDEPO database does not list any known deposits for Nicaragua.

8.19.5. Potential for new discoveries

The IUREP mission estimated the potential uranium resources in Nicaragua at less than 1000 tU [19.2]. These resources would likely be associated with the Palaeozoic metamorphic strata of the Northern Highlands or possibly the alaskites near Siuna [19.4].

References to Section 8.19

[19.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Nicaragua, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed 2009).

[19.2] INTERNATIONAL ATOMIC ENERGY AGENCY International Uranium Resources Evaluation Project (IUREP), National Favourability Studies: Nicaragua, IAEA, Vienna (1977).

[19.3] MARSHALL, J.S., "The geomorphology and physiographic provinces of Central America", Central America: Geology, Resources, Hazards (BUNDSCHUH, J., ALVARADO, G.E., Eds), 2 vols, Balkema, Leiden (2007), http://www.csupomona.edu/~marshall/jsm.pubs/Marshall.07.pdf

[19.4] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

8.20. PANAMA

8.20.1. Geography

Panama is situated in Central America and has maritime borders with the Pacific Ocean to the south and the Caribbean Sea to the north. Panama has land borders with Costa Rica to the NW and with Colombia to the SE. It extends ~420 km from east to west.

The main element of the country's topography is the central spine of hills and mountains that constitutes the continental divide. However, the divide does not constitute the mountain chains of North America and it is just close to the Colombian border here highlands associated with the Andean system of South America exist. Volcán Barú, with elevation of 3475 m, is the country's highest point.

The economy of Panama is based chiefly on a well-developed services sector, including the Panama Canal, which contributes nearly 80% of GDP. The country's industry includes manufacturing of aircraft spare parts, cement, drinks, adhesives and textiles. Leading exports for Panama are bananas, shrimp, sugar, coffee and textiles [20.1].

8.20.2. Geology

The present position of Central America, to the NW of Costa Rica, is interpreted as being the result of a 1000 km left-lateral translation of the southern part of the Cordilleran orogenic belt. Costa Rica and Panama were both subject to additional left-lateral translation, which is estimated to represent a movement of ~600 km from their current positions.

Panama's geology is very recent (Fig. 8.39), dating to the Pliocene, around 3 Ma, and relates to the collision occurring between the Pacific and Caribbean Plates. This collision led to the formation of volcanoes, some of which grew to large islands as recent as 15 Ma, and pushed up the sea floor, eventually forcing some areas above sea level. Over time, the area between the newly formed islands was filled in and thereby formed the Isthmus of Panama. Its formation is one of the most important geological events to have occurred in the past 60 million years, as it separated two oceans, altered ocean currents and, consequently, changed the climate [20.2].

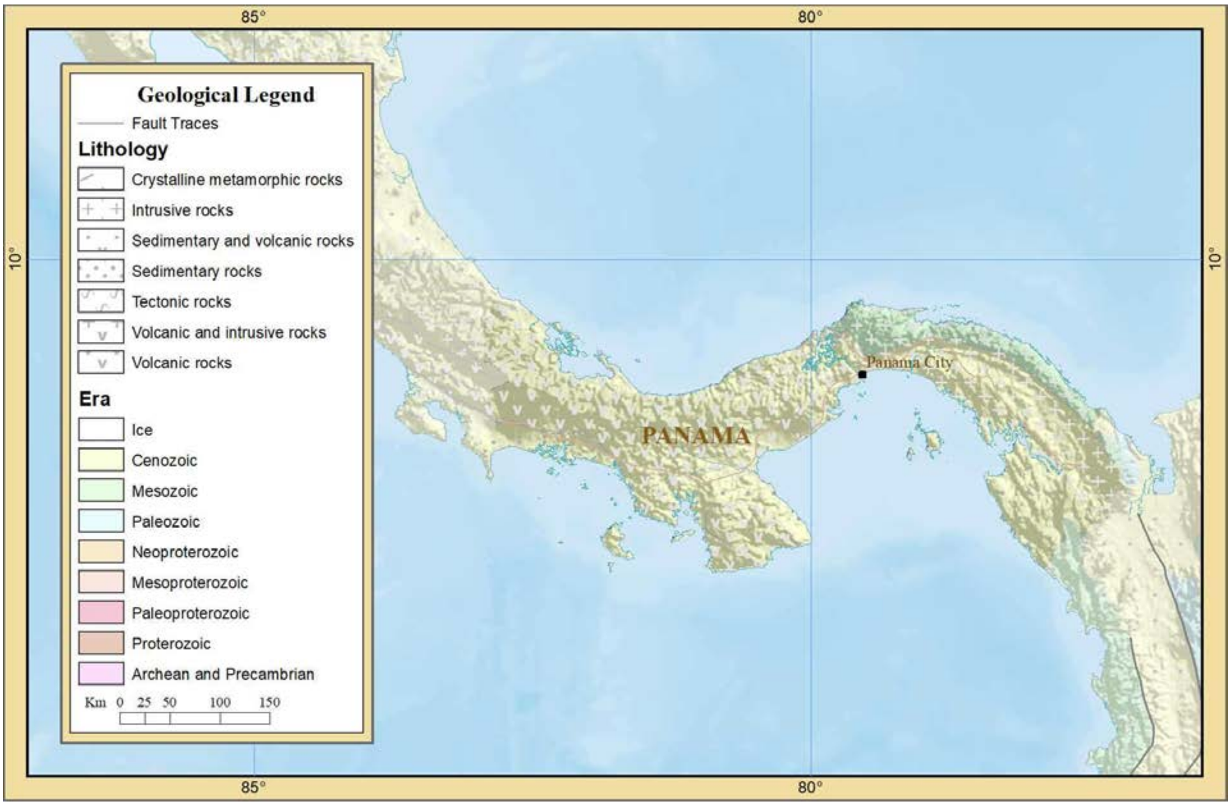


FIG. 8.39. Regional geological setting of Panama. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.20.3. Uranium exploration

In the 1983 Red Book [20.3], Panama reported that no systematic evaluation of its geological potential for radioactive minerals had been conducted. In 1967, ~20% of Panama was surveyed by airborne scintillometer as part of a general airborne survey for the central region of Panama. However, there was no ground follow-up.

Another 20% of Panama (15 400 km²) was covered by a geochemical survey throughout which at least 7000 stream sediment samples were taken. Unfortunately, these samples had not been assayed for uranium.

The Directorate of Mineral Resources, part of the Ministry of Commerce and Industry, developed a plan in the early 1980s to determine which areas in Panama were geologically favourable for hosting uranium and to initiate basic prospecting activities under the Panamanian Code of Mineral Resources.

An area of ~6000 km² was surveyed in 1984 with IAEA support. Of these 6000 km², an area totalling 760 km² located in the provinces of Veraguas, Herrera and Los Santos was selected for more detailed follow-up work.

There is no record of expenditures and no surface drilling was reported [20.3].

8.20.4. Uranium resources

There are no known occurrences of uranium in Panama.

The UDEPO database does not list any known deposits for Panama.

8.20.5. Potential for new discoveries

The volcanics and related intrusives, including recent ones, are related to tectonic collisions between plates and are generally not considered as a potential host rock favourable for uranium deposits.

Any potential targets for finding uranium mineralization are likely [20.3] to be hosted in a volcanic environment similar to those in Mexico, Peru and Bolivia, where some acidic rock types may occur, and also in granitic intrusives.

Insufficient information is known about the red beds, which could have limited potential [20.3].

8.20.6. Comments

There has been no uranium production and there are no nuclear power plants or plans to introduce nuclear energy in Panama.

References to Section 8.20

[20.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Panama, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed July 2010).

[20.2] NASA EARTH OBSERVATORY, Panama: Isthmus that Changed the World (31 December 2003), http://earthobservatory.nasa.gov/IOTD/view.php?id=4073

[20.3] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

8.21. PARAGUAY

8.21.1. Geography

Paraguay is a landlocked country located in central South America. The population is concentrated in the south of the country. The climate is subtropical to temperate, with abundant rainfall in the eastern region, turning into semi-arid in the far west. Wooded hills and grassy plains exist to the east of the Paraguay River. The Gran Chaco region west of the Paraguay River comprises largely low marshy plains close to the river, and thorny scrub and dry forest elsewhere. Cerro Pero (also known as Cerro Tres Kandu), with an elevation of 842 m, is the highest point. Natural resources include hydropower (intersection of Paraguay and Paraná Rivers), timber, iron ore, manganese and limestone [21.1].

8.21.2. Geology

8.21.2.1. General

Little is known of the geology of Paraguay. A large part of the area is covered by Quaternary deposits, which completely conceal the basement strata (Fig. 8.40). The hills and plateaux appear to be composed chiefly of the same sandstone series (Jurassic–Cretaceous) which in the Brazilian province of Rio Grande do Sul contains seams of coal, with plant fossils similar to those of the Karharbari series of India (Permian or Upper Carboniferous). It is also probable that the Palaeozoic rocks of Matto Grosso, Brazil, extend into the northern part of the country [21.2].

8.21.2.2. Potentially favourable uranium-bearing areas

The 1980 IUREP report considered that there is potential for finding uranium in sandstones in the Paraguay and Uruguay portions of the Paraná Basin [21.3].

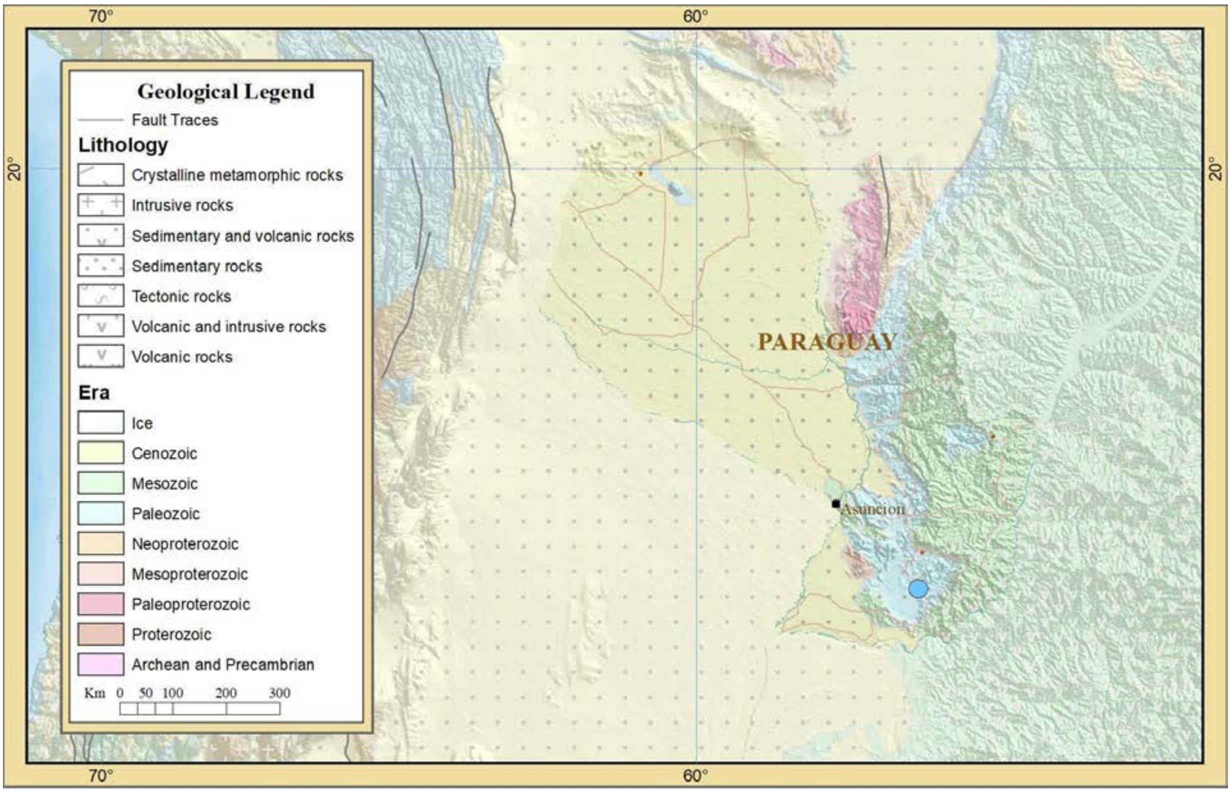


FIG. 8.40. Regional geological setting and uranium mineralisation of Paraguay. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.21.3. Uranium exploration

8.21.3.1. Historical review and work done

In 1976, the Government of Paraguay granted the Anschutz Corporation an exploration/exploitation licence in the eastern region of Paraguay. Subsequently, Anschutz formed a joint venture with the Korea Electric Power Corporation and Taiwan Power Company to investigate the area, which covers ~160 000 km². Airborne radiometric and magnetic surveys were undertaken throughout the entire concession, with follow-up airborne surveys of specific areas. Reconnaissance and detailed ground traverses using integrated geological, geochemical and geophysical techniques were also carried out. At least 120 000 m of rotary drilling were completed in selected areas underlain by Permo-Carboniferous sediments in the western part of the Paraná Basin (Table 8.17). The results indicated widespread very low grade uranium mineralization at depths of 95–150 m.

In 1978, the Government embarked on a six-month programme for exploration covering the whole country in order to assess the favourability for hosting radioactive raw materials. Exploration activities supported by the IAEA were carried out jointly by the Institute de Ciencias Basicas de la Universidad Nacional de Asuncion and the Direccion de Industrias Militares. Satellite imagery, photo interpretation, car-borne reconnaissance, and field and laboratory geochemical techniques were used, with an emphasis on training national personnel in exploration strategies and management. Three metallogenetic targets were selected as having good potential: (i) uraniferous calcretes, (ii) Palaeozoic continental sandstones, and (iii) orthomagmatic differentiations, which included the Cerro Cora alkaline complex where uranium mineralization was found to be related to the mineral pyrochlore.

In 1981, Teton Exploration Drilling Company, a US company, was granted an exploration/exploitation concession in the Chaco region (west of the Paraguay River). Subsequently, Teton completed an interpretation of Landsat images as well as undertaking ground reconnaissance, geological, geochemical and geophysical traverses. Both the joint venture and Teton terminated their exploration programmes in 1982 [21.4].

8.21.3.2. Recent and ongoing uranium exploration and mine development activities

Throughout the past several years, uranium prospection and exploration were planned or initiated by several companies in Paraguay and particularly in the Parana Basin. Crescent Resources Corporation filed an NI 43-101 for its Coronel Oviedo uranium project in March 2008, after contracting with Compania Paraguaya de Mineria S.A. for 20 000 m of drilling on the project to follow up in two significant areas where historical drilling intercepted significant uranium values in 21 of 65 closely spaced (less than 15 m) diamond drill holes. [21.5]

The Oviedo property is a large property covering at least 504 000 ha in central Paraguay that was subject to extensive uranium exploration in 1976–1983. Activity was centred on a large belt of Permo-Carboniferous continental sandstones on the western flank of the Paraná Basin.

8.21.3.3. Expenditures and drilling effort

In neighbouring Brazil, these same sandstones contain numerous uranium occurrences, including the Figueira deposit. Most of the uranium occurrences in this environment are roll-front type and similar to those currently being exploited by low cost in situ leach methods in the western United States of America. There is no mention of activities on the Oviedo property since the filing of the NI 43-101 Technical Report on 25 January 2008. The NI 43-101 Technical Report gives drilling results for Crescent Resources' programme. In 2011, due to the lack of compliances with requirements in the mining law of Paraguay, the concession expired. Subsequently, the Oviedo concession was granted to Piedra Rica Mining SA and Rio Bravo SA, and then, the same year, Uranium Mining Corp. (UEC) acquired Piedra Mining SA. UEC completed 91 drill holes in 2012. A 21 km long redox roll front was defined with potential resources in the order of 5000-10 000 t U at a grade of 0.01-0.05% in Permian-Carboniferous sandstones [21.6].

Cue Resources Ltd filed an updated NI 43-101 Technical Report for the Yuty project for uranium in south-eastern Paraguay, including a significant increase to a historical resource estimate. As announced in April 2009, the mineral resource estimate and classification conforms to the reporting requirements of NI 43-101. The indicated resource is 9 million t at a grade of 0.036% eU (containing 3190 tU) and the inferred resource is 1.1 million t at a grade of 0.042% eU (containing 462 tU) [21.7]. The study was carried out internally by Cue Resources, with the assistance of American BRS, Wyoming and Adams Consulting updating a previous independent resource estimate by Scott Wilson RPA of Canada from 2008.

TABLE 8.17. DRILLING EFFORT AND EXPLORATION EXPENDITURES [21.4]

Year	Aerial radiometric surveys area covered (km²)	Other surveys (km²)	Surface drilling		Total exploration expenditures (US$)
			(m)	(holes)	
Pre-1979	160 000[a]	20 000[b]	10 500	70	2 870 000
1979	-	-	19 000	130	4 140 000
1980	60 000[b]	10 000[c]	33 000	225	7 250 000
1981	-	-	40 000	265	6 750 000
1982	-	-	21 000	140	4 500 000
1983	-	-	-	-	850 000
Total	220 000	30 000	123 500	830	26 360 000

[a] 5 km line spacing.
[b] 3 km line spacing.
[c] 1 km line spacing.

The report also reviews results of metallurgical and physical property testing, indicating that the deposit may be amenable to extraction by in situ leach technology. A column leach test has a demonstrated recovery of 86% of the contained uranium from cores taken from the Yuty project. In addition, Cue Resources reports that laboratory testing on drill core has shown permeability and porosity values within the range of existing commercial in situ recovery operations. The depth to mineralization lies in the range 60–150 m and averages ~100 m.

Cameco Corporation entered into a joint venture drilling agreement with Cue Resources in 2007 and 2009 with regard to the drilling of 234 holes. The joint venture was terminated by mutual agreement early in 2009.

A new NI-43-101 mineral resources estimate was filed in 2011 indicating resources of 4286 t U (measured-indicated-inferred) at an average grade of 0.044 % [21.8]. In 2018, the project is dormant.

Since there are no in situ recovery projects operating in Paraguay, Cue Resources anticipates participation with the various Government agencies to assist in the development of environmental regulations to international standards.

Two additional companies that have examined or held concessions in Paraguay in 2007 were the Australian company Wildhorse Energy Ltd and Yellow Cat Uranium Plc of the United Kingdom (Caazapá and Amamba projects). Yellow Cat acquired Picomayo Minerales, a Paraguayan exploration company. Both companies showed interest in areas previously investigated by Anschutz in eastern Paraguay. The projects were located near the western side of the Paraná Basin in south-eastern Paraguay, in environments similar to that of the Figueira sandstone deposit in Brazil. The 2007 activity reports/news releases are the most recent to have been issued [21.5–21.8].

8.21.4. Uranium resources

As of 1 January 2017, Reasonably assured resources (RAR) and inferred resources (in-situ) totalled to 3429 tU and 857 tU respectively, in the <US$ 260/kgU cost category.
Resources are associated to sandstone-type deposits.

The UDEPO database lists the most significant deposit for Paraguay as Yuti.

8.21.5. Potential for new discoveries

As already noted, there was renewed interest as of 2007 in the potential of south-eastern Paraguay, which is coincident with the western portion of the Paraná Basin. There is potential here for roll front sandstone type deposits which may be amenable to in situ recovery.

8.21.6. National and local policies related to uranium

Cue Resources owned a 100% interest in its property, as of 11 September 2008, through its wholly owned subsidiary Transandes Paraguay S.A. The latter obtained, on 10 September 2008, a grant from the Government for rights to explore and exploit in the Yuty project for uranium.

A title to concessions is held through a Concession Contract, with the State of Paraguay granting mining rights for a minimum period of 20 years.

Wildhorse Energy reported in August 2007 that Paraguay had recently passed a mining law similar to laws in force in the USA and Australia. No details have been given [21.9].

References to Section 8.21

[21.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Paraguay, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2010).

[21.2] ENCYCLOPEDIA BRITANNICA CLASSIC 1911 EDITION, Paraguay, http://www.1911encyclopedia.org/Paraguay (accessed April 2010).

[21.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[21.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[21.5] CRESCENT RESOURCES, Crescent Resources signs drilling contract for Oviedo Uranium Project, Paraguay (28 June 2007), http://www.crescentresourcescorp.com/i/pdf/news/NR20070628.pdf

[21.6] URANIUM ENERGY CORPORATION, Coronel Oviedo Uranium project. Technical Report, Exploration Potential (2012) 122 p.

[21.7] CUE RESOURCES, Cue Resources Files NI 43-101 Technical Report on SEDAR (29 May 2009).

[21.8] WILDHORSE ENERGY, Caazapá Prospect, Paraguay, Initial Drilling Defines Regional Uranium Anomaly, http://www.wildhorse.com.au/en/search (23 April 2008).

[21.9] WILDHORSE ENERGY, Wildhorse Energy Granted Extensive Uranium Concessions in South America (28 August 2007).

8.22. PERU

8.22.1. Geography

Peru is situated in the northwestern part of South America. It shares land borders with Chile, Bolivia, Brazil, Colombia and Ecuador and in the west has a maritime border with the Pacific Ocean. The country is divided geographically into several regions: the Costa region, which comprises dry, flat coastal plains; the western Andean foothills, which are widest in the north and much narrower in the south; the Sierra region, which consists of three Andean mountain ranges superimposed on a high plateau; and the Andes, which are 96 km wide at the Ecuador border and nearly 322 km wide around Lake Titicaca.

Around 60% of Peru comprises the lightly populated Silva (or Montana), which extends along the eastern Andes and is characterized by tropical rainforests. Lake Titicaca marks part of the Peru–Bolivia border and covers an area of 8288 km². Peru is prone to seismic activity and related phenomena.
Peruvian economic performance is mainly linked to exports, of which the main ones are copper, gold, zinc, textiles, chemicals, pharmaceuticals, manufactures, machinery and fish meal [22.1].

8.22.2. Geology

Much of Peru formed as a result of the subduction of the Nazca Plate beneath the South American Plate. The collision of these tectonic plates forced up the Andean cordillera which forms the 6500 km long western fringe of South America. Tectonism continues, making Peru constantly vulnerable to earthquakes.

The geology of Peru starts more than two billions years ago with Proterozoic rocks deformed during the Grenville orogeny and Paleozoic and Mesozoic volcanic and sedimentary rocks present in numerous basins. The Andes Mountains formed during Cenozoic times.

In the Eastern Cordillera, Proterozoic magmatism is represented by ultramafic, mafic and felsic rocks. The basement of Central Andean includes gneissic and granulitic rocks of the Arequipa Massif, the oldest metamorphic rocks (circa 2000 Ma) of Peru. The geology of Peru was also greatly affected by the Grenville orogeny (1150-1000 Ma).

During Paleozoic times, Peru was on the western margin of the Gondwana continent. Ordovician and Devonian sandstones of the Eastern Cordillera contain zircon grains formed to the east in Brazil during the Braziliano Orogeny. Sandstones of the Altiplano and the Coastal Cordillera are probably originating from the Arequipa Massif. Plutonic and volcanic rocks in the Inner Arc domain include metagabbros-metagranites of the San Gaban Complex and the alkali basalts of the Permian Mitu Group. formed during magmatism pulses in back-arc basins. Granitoid intrusions, nepheline syenite, syntectonic granites and calc-alkaline volcanism appeared during the Hercynian Orogeny (350-290 Ma). Basins were formed along the Pacific coast during the subduction with an important volcanic activity which produced the two km thick Yamayo Group and the overlying one to six km thick volcanic and volcaniclastic Yura Group.

The Andean Orogeny started in the Upper Triasic. In the early Cretaceous, the 1600 km long Coastal Batholith formed in an ensialic marginal basin.

Mesozoic volcanic and Mesozoic–Cenozoic intrusives form the western Cordillera. The central Andes are made up primarily of Cretaceous–Tertiary volcanics. Mainly Tertiary and Quaternary sedimentary rocks cover the eastern portion of the country, including the upper Amazon Basin in the NE, and are also found in some areas along the coast (Fig. 8.41).

With few exceptions, the major ore systems known from Peru are associated with arc related igneous rocks. Metallogenic zoning is characteristic of continental margin activity where early episodes are dominated by copper–gold mineralization close to the subduction trench, progressing to lead–zinc and then tin–tungsten mineralization systems further inside the continental margin [22.2].

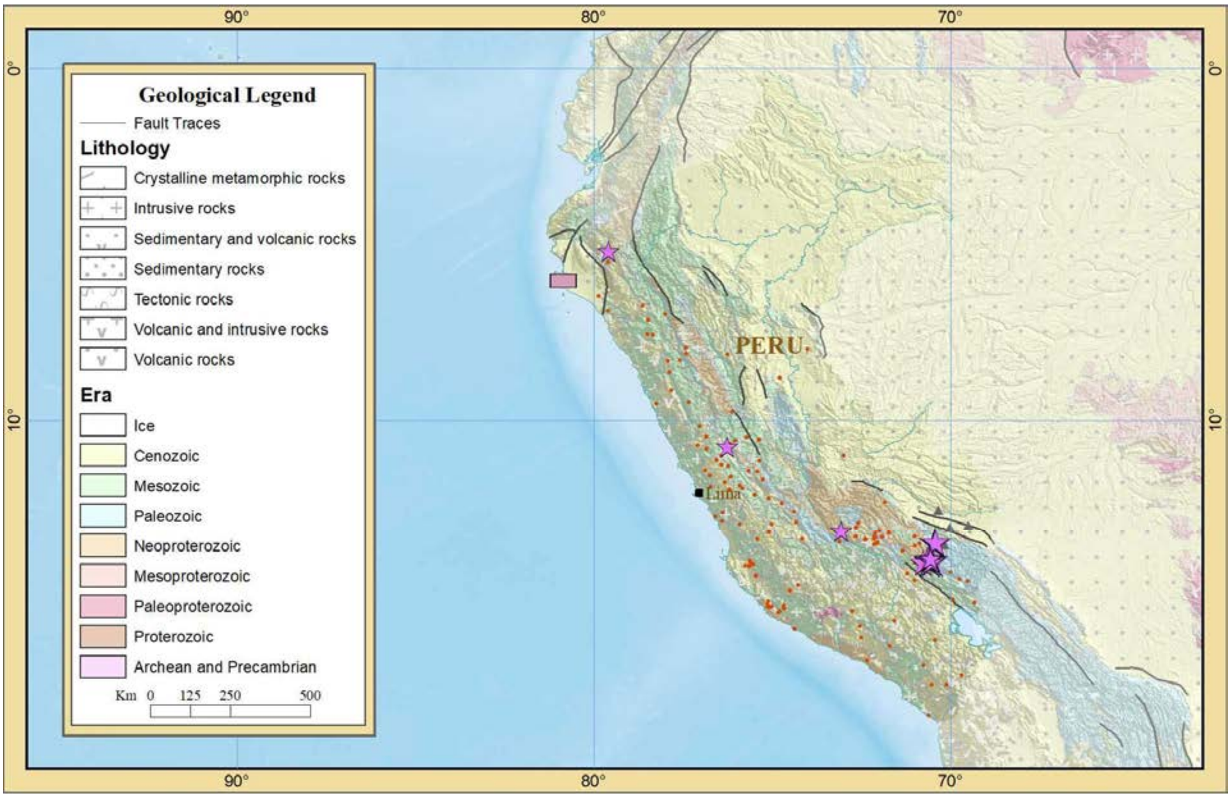


FIG. 8.14. Regional geological setting and uranium mineralisation of Peru showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.22.3. Potentially favourable uranium-bearing-areas

The most significant uranium deposits are in the uraniferous district of Macusani (Puno Department) in south-eastern Peru. The mineralization is hosted in acid volcanic rocks of Miocene–Pliocene age, which fill the Macusani tectonic depression that overlies Palaeozoic strata. The lapilli tuff of the volcanic Quenamari Formation is the host rock. The mineralogy comprises pitchblende, gummite, autunite and meta-autunite which occupy sub-horizontal to sub-vertical fractures with impregnations on both sides of fractures.

Known uranium occurrences in the Macusani area, as identified by IUREP, are associated with Pliocene Quenamari Formation tuffs, ignimbrites and interbedded sediments in a NW–SE trending graben. Macusani Yellowcake Inc., one of several companies recently exploring in the Macusani area, describes the geology of four of its target areas as being Late Tertiary tuffs, ignimbrites and associated sediments that are preserved in a NW trending graben. Uranium in the form of pitchblende, uranophane, gummite and meta-autunite occur predominantly in a fluviolacustrine sediment between two pyroclastic units. The thickness of the sedimentary unit varies from less than 1 m to at least 5 m.

Other uranium minerals are indicated by IUREP (1984) to be hosted in acidic volcanic rocks of rhyolitic composition that cover large areas of the Macusani Plateau in horizontal formations from the surface to a depth of ~100 m, but these appear to be lenticular or confined to fracture zones. Several volcanic centres in the centre of the Macusani district are believed to be the source of the uranium and these were active throughout the Miocene period (24–20 Ma).

In addition to the Macusani uraniferous district, other areas of the country are regarded to be favourable for hosting resources of uranium. These include the central Andes, Junín and Cerro de Pasco regions and in the coastal Piura Department in northern Peru. Detailed geology is not well known in some areas owing to difficulties in gaining access.

Reference [22.3] describes the presence of uranium in phosphates at Bayover. This project is located in the Sechura Desert, in the Piura region, where 12 layers of phosphates have been identified in two areas. These Bayover phosphates are of marine origin and consist predominantly of phosphorite. The uranium is associated mainly with apatite and the source is thought to be the western Cordillera [22.4–22.6].

8.22.3.1. Historical review

In 1953, a joint programme of exploration by the US Atomic Energy Commission (USAEC) and the Junta de Control de Energia Atomica del Peru (JCEA) was organized. The first four years included examination of museum specimens and mill concentrates. As a result of this, three mines appeared sufficiently promising to warrant further investigation. All were later rejected as uneconomic sources of uranium.

Radiometric prospecting in the Macusani district discovered at least 40 uraniferous areas, the most significant ones being Cerro Calvario, Cerro Concharrumio, Chilcuno VI, Chapi and Pinocho. Of all these areas, Chapi is the most significant, and it has been subjected detailed radiometry, emanometry, trench and gallery work, as well as diamond drilling. The mineralization is located in sub-vertical fractures distributed in structural lineaments roughly 20–30 m in thickness and 15–150 m in width. The grades fluctuate in the range 0.03–0.75% U, with average grade of 0.1% U. On the basis of results of exploration achieved so far and taking account of both the emanometry and geological information, a minimum potential of 10 000 tU has been allotted to the Chapi site and 30 000 tU to the whole uraniferous district of Macusani [22.4, 22.5].

8.22.3.2. *Work done*

Technical assistance was received from the USAEC in 1965, from the French Commissariat à l'énergie atomique in 1959 and 1968, and from the Atomic Energy Commission of the then Federal Republic of West Germany in 1967.

Throughout 1971 and 1972, radiometric airborne surveys of limited scale were conducted under the technical guidance of the IAEA.

In 1975, the Instituto Peruano de Energia Nuclear (IPEN) with the support of the Government and with assistance from the United Nations Development Programme and the IAEA started work on medium and long term prospecting for radioactive materials. The first step was to develop a preliminary analysis of the geological favourability of Peru for hosting uranium deposits and this phase quantified 750 000 km² as being favourable for prospecting [22.4, 22.5].

8.22.3.3. *Expenditures*

Annual exploration expenditures are reported for the period 1974–1983 in Ref. [22.7].

All Government sponsored uranium activities stopped in 1992 as Peru initiated privatization of all mineral exploration and development activities, including those pertinent to uranium (Fig. 8.42) [22.8–22.11]. These total USD $3.947 million including 1 625 metres of drilling.

8.22.3.4. *Drilling effort*

No drilling has been reported in the Red Book since 1987 [22.9]. Several companies recently working in the Macusani district have reported undertaking diamond and rotary drilling. For example, Solex Resources Corporation reports that 20 000 m of drilling on Macusani targets took place in 2007–2008 (370 holes) and follow-up drilling was conducted in 2009 [22.12].

8.22.3.5. *Recent and ongoing uranium exploration and mine development activities*

IPEN ceased exploration after a change in Government policy that aimed to promote private investment. IPEN instead began, in 2005, focusing on providing support and addressing the requirements of exploration companies. Investors interested in uranium exploration are encouraged by IPEN to use the information it previously compiled.

A Toronto based mining company, Vena Resources, was one of the first to announce the beginning of a data confirmation campaign using data provided by IPEN on the Puno area. Vena Resources signed a binding agreement with Cameco Corporation to create a jointly owned company (Minergia S.A.C.) to explore and develop Vena Resources' uranium assets in Peru, for which it remains the operator. There are no details about uranium projects under investigation and the company is only involved in base metal projects.

Strathmore Resources made an announcement in 1998 that uranium mineralization from the Macusani project in Peru was, at the request of a major uranium enterprise, being transported to North America for ultimate metallurgical testing. There is no current information available [22.13].

Lefroy Resources Ltd, in a quarterly activity report for the period ending 30 June 2009, reported that its Macusani project is located ~200 km north of Puno in south-eastern Peru. The project was originally acquired by King Energy Pty Ltd to cover 17 uranium anomalies identified from an airborne radiometric survey undertaken by IPEN. King Energy assessed 7 of the 17 anomalies with negative results. Lefroy assessed 9 of the remaining 10 anomalies in June 2009 with the remaining anomaly inaccessible owing to mountainous terrain. Lefroy concluded that the anomalies are spurious and may have resulted from inappropriate treatment of the original airborne data. No further work is warranted and Lefroy's tenements will be relinquished.

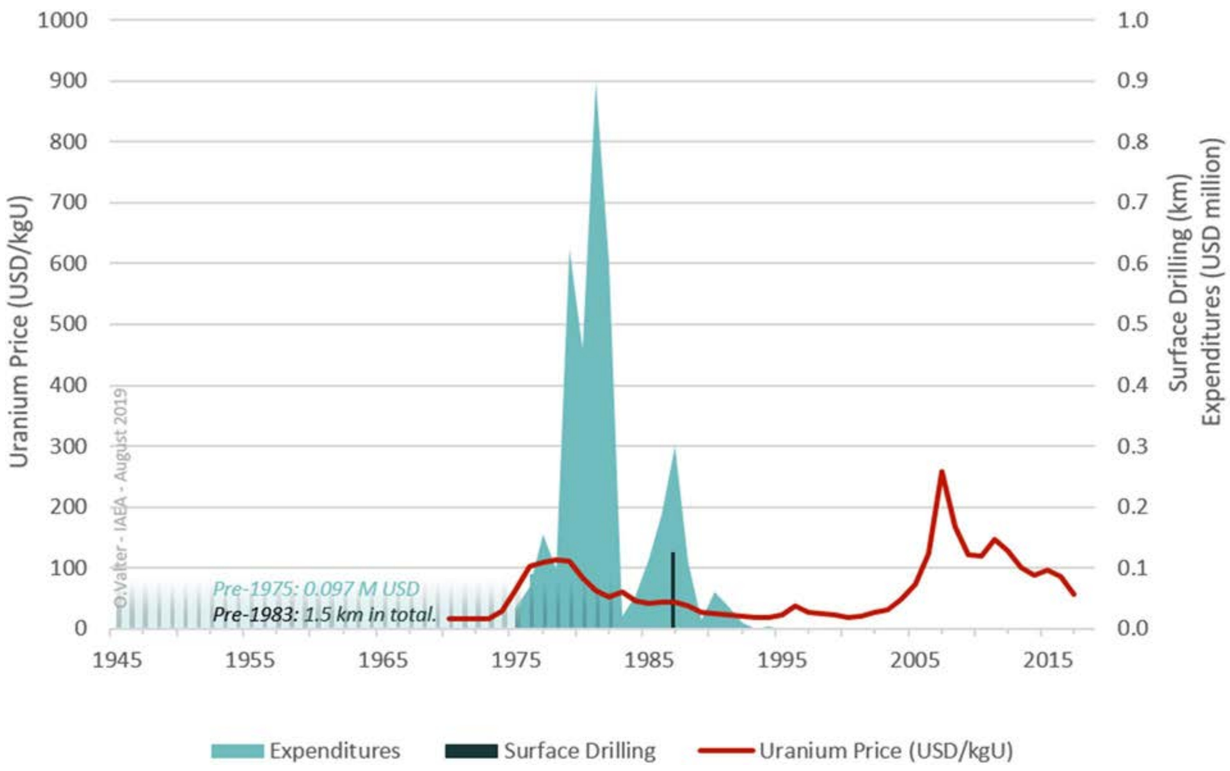


FIG. 8.42. Domestic uranium exploration data for Peru. Comparison of exploration expenditures, drilling and uranium market price (US$ current). Pre-1983 includes 21 900 km2 covered by airborne surveys and 168 700 km2 covered by geochemical, reconnaissance and other radiometric survey.

Solex Resources Corporation acquired Eldorado Gold Corporation in January 2010 and completed NI 43-101 reports on the Pilunani project and one other project in 2008. No recent announcements regarding any activities have been reported. As already mentioned, nearly 20 000 m of drilling on Macusani targets was carried out in 2007–2008 (370 drill holes). Several near surface low grade ignimbrite deposits were located and some follow-up drilling and leaching tests were conducted in 2009.

Fission Energy's web site describes its Macusani property in south-eastern Peru. Fission holds the rights to 9 claim blocks encompassing 51 km² and surface rights across some of the areas with known uranium mineralization. Within the area, IPEN carried out exploration in the 1970s and this continued through the 1980s and early 1990s. The stratigraphy is dominated by the sub-horizontal Pliocene Quenamari Formation, which is mainly composed of ignimbrite layers. Uranium anomalies occur on plateaux that are composed of the Upper Yapamayo member of the Quenamari Formation. Sampling to date has shown that the most significant uranium anomalies appear to be restricted to this stratum. Mineralization within the area is dominated by very high grade autunite veins associated with fault planes, which act as sites of enrichment, together with weaker disseminated mineralization (i.e., vein stockwork). The significant fault planes can vary in thickness up to 2 m thick and multiple uranium enriched fault planes occur in shear zones up to 150 m across.

Macusani Yellowcake Inc. is an exploration company working in the Puno district. It has concessions covering 240 km² in the Macusani, Munani, Langunillas and Rio Blanco areas. Exploration is currently focused on four targets hosted by acidic tuffs with pyroclasts ranging in size from sub-macroscopic up to 60 mm. The main mineral constituents of the tuff are quartz and orthoclase and plagioclase feldspars in a groundmass of amorphous glass. A crude stratification is evident in some outcrops owing to the presence of larger and smaller pyroclasts in addition to differential weathering. The tuff is interpreted as having a sub-horizontal dip [22.5, 22.6, 22.12–22.16].

In 2012, Macusani Yellowcake merged with Southern Andes to become the dominant land holder on the Macusani Plateau, then acquires Minergia in 2014. The same year, a preliminary economic assessment was released. The company changed its name to Plateau Uranium in 2015, then to Plateau Energy Metals in March 2018. Uranium resources scattered in several deposits are as follows: 20 367 t (measured and indicated) at 210 ppm U and 27 759 t (inferred) at 213 ppm U for a total of 48 126 t U [22.17]. In addition, large lithium resources have been highlighted (Falchani deposit) associated to the uranium deposits, but also within formations devoid of any uranium mineralization.

8.22.4. Uranium resources

The identified resources in Peru are chiefly located in the Macusani area in the Department of Puno (Tables 8.18 and 8.19).

In a 2010 NI 43-101 report on Colibri 2 and 3 deposits, which are controlled by Macusani Yellowcake, indicated resources of 770 tU at a grade of 0.19% U are reported, as well as inferred resources of 5580 tU at a grade of 0.15% U. Reference [22.18] provides further details on the NI 43-101 report, including cut-off grades.

TABLE 8.18. REASONABLY ASSURED CONVENTIONAL RESOURCES BY DEPOSIT TYPE (tU) [22.19]

Deposit type	<US $40/kgU	<US $80/kgU	<US $130/kgU	<US $260/kgU
Volcanic-related	0	19 970	19 970	19 970
Total	0	19 970	19 970	19 970

TABLE 8.19. INFERRED CONVENTIONAL RESOURCES BY DEPOSIT TYPE [22.19]

Deposit type	<US $40/kgU	<US $80/kgU	<US $130 US$/kgU	<US $260/kgU
Volcanic and caldera-related	0	27 739	27 739	27 739
Total	0	27 739	27 739	27 739

2014 uranium resources of 48 126 t are located within the Colibri 2 and 3 — Tupuramani project, the Kihitian project (Quebrada Blanca, Pinochio and Chilcuno Chico deposits) and the Triumfador project (Calvario 1, Calvario 2–3, Calvario Real and Puncopata deposits) [22.17].

The UDEPO database lists the most significant deposits for Peru as Chilcuno Chico, Bayovar, Tantamaco, Colibri 2–3, Quebradra Blanca, Isivilla, Corachapi, Macusani, Tupuramani, Punco Pata.

8.22.4.1. Undiscovered resources

Undiscovered conventional resources are assessed to total 26 350 tU, of which 6610 tU are hosted in the Chapi deposit area and are categorized as prognosticated resources and 19 740 tU are categorized as

speculative resources. These estimates give due consideration to the distribution of the Tertiary volcanic host rock in the Chapi deposit area, and with reference to the distribution of the volcanic host rock in the uraniferous district of Macusani (1000 km²).
Prognosticated conventional resources are reported at 6610 tU in the cost category <US $260/kgU and speculative conventional resources are reported at 19 740 tU in the cost category <US $130/kgU [23.16].

8.22.4.2. Unconventional resources

The uranium in phosphate rocks, with average content of 90 ppm U, plus that hosted in polymetallic deposits (Ag, Cu, Ni, Pb, W, Zn) is assessed to amount to 21 600 tU (Table 8.20) [22.19].

TABLE 8.20. URANIUM RESOURCES IN PHOSPHATES (tU) [22.19]

Location	Resource (tU)
Bayovar	16 000
Other locations (39)	5600
Total	21 600

8.22.4.3. Proximity of resources to deposits

Reference [22.3] summarizes Peru's uranium potential as totalling 51 493 t U_3O_8 (estimated on the basis of two projects, 16 prospects and 53 anomalies) primarily in the Bayovar, Cerro de Pasco, Vilcabamba and Macusani areas.

The largest portion of the total is associated with Miocene and Pliocene formations (total of probable plus inferred of 42 760 tU). The Macusani projects, including Macusani East, Macusani West, Macusani South areas were reported at over US $5 million. Most of this outlay was spent by Solex Resources Corp. [22.5, 22.12].

8.22.5. Potential for new discoveries

Other than the ongoing work being carried out in the Macusani district, other potentially favourable host environments have not been investigated. IPEN, through its promotional activities, is working to highlight new areas of interest, such as the central Andes and the coastal areas for phosphate deposits, such as that at Bayovar.

Chemical sampling, physical laboratory testing and core drilling have been conducted at Bayovar. Chemical analysis results demonstrate that the uranium content (60 ppm U) in these phosphates is below the average for world phosphate deposits.

8.22.6. Comments

Peru has never generated uranium and reportedly has no intentions to do so. It has no demand for uranium nor does it have any proposal to develop capacity for nuclear generation [22.16].

8.22.7. National and local policies related to uranium

Activities for mining under the accountability of the State, pursuant to the Law for the Promotion of Investment in the Mining Sector, have been the focus of a privatization process as element of a programme to ensure the firmness and guarantee of long-term investments, including uranium. In the last few years, focus on exploration for uranium has rejuvenated, allowing many foreign private firms to restart exploration in the zone where IPEN undertook its prospecting and exploration work and using technical information made available by IPEN [22.20].

The State, in boosting investment in mining for uranium in the country, is revaluating new areas to explore for uranium and thereby enhance the uranium potential of the country. The Technical Office of the National Authority is in charge for policy and regulatory matters [22.21].

References to Section 8.22

[22.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Peru, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed October 2012).

[22.2] KARAKOUZIAN, M., CANDIA, M.A., WYMAN, R.V., WATKINS, M.D., HUDYMA, N., Geology of Lima, Peru, Environ. Eng. Geosci. **3** 1, American Geological Institute (1997) 55–88.

[22.3] JACINTO VALENCIA HERRERA, "Study of the presence of uranium in phosphates of Bayover", paper presented at IAEA Regional Training Course on Uranium Geology and Exploration, Poços de Caldas, 2009.

[22.4] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[22.5] MACUSANI YELLOWCAKE, http://macyel.com/properties (March 2010).

[22.6] MACUSANI YELLOWCAKE, http://macyel.com/properties/geology.cfm (March 2010).

[22.7] OECD NUCLEAR ENERGY AGENCY, Forty Years of Uranium Resources, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.

[22.8] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1986).

[22.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1989).

[22.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1991: Resources, Production and Demand, OECD, Paris (1992).

[22.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 1993: Resources, Production and Demand, OECD, Paris (1994).

[22.12] SOLEX, http://www.homelanduranium.com (accessed January 2010).

[22.13] WISE URANIUM, New uranium deposits, Central/South America,

[22.14] http://www.wise-uranium.org/upsam.html#PE

[22.15] LEFROY RESOURCES LTD, Quarterly activity report for the period ended 30 June 2009.

[22.16] CHARIOT RESOURCES, Peru geology,

[22.17] http://www.chariotresources.com/perugeology.php (accessed 21 April 2010).

[22.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).

[22.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).

[22.20] MACUSANI YELLOWCAKE INC., Macusani Yellowcake Project, Macusani, Peru. Preliminary Economic Assesment (2014) 352 p.

[22.21] MACUSANI YELLOWCAKE, NI 43-101 Macusani Yellowcake for Colibri 2 and 3, updated report (September 2010).

8.23. SURINAME[15]

8.23.1. Geography

Suriname is located in north-eastern South America and has a coastline bordering the North Atlantic Ocean and land borders with French Guiana, Brazil and Guyana. The climate is tropical and moderated by trade winds. The lowest point is an unnamed location on the coastal plain at -2 m; the Juliana Top, with elevation of 1230 m, is the highest point. The topography comprises mostly rolling hills and narrow

[15] This country is not an IAEA Member State. However its geology, mineralisation and resources — even if relatively unprospective — are relevant to the geology, uranium mineralisation and resource supply/demand relationships of adjacent or nearby Member States. In addition this country has a IUREP report as the basis for updating in this publication.

coastal plains with swamps. Natural resources include timber, fish, shrimp, hydropower, bauxite, kaolin, gold and small amounts of copper, iron ore, nickel and platinum [23.1].

8.23.2. Geology

8.23.2.1. General

Archaean crystalline rocks dominate the geology of Suriname (Fig. 8.43). Two important features are the main NE–SW tectonic structure, which is inherited by later Mesozoic and Tertiary tectonic movements, and the Permo-Triassic dyke systems.

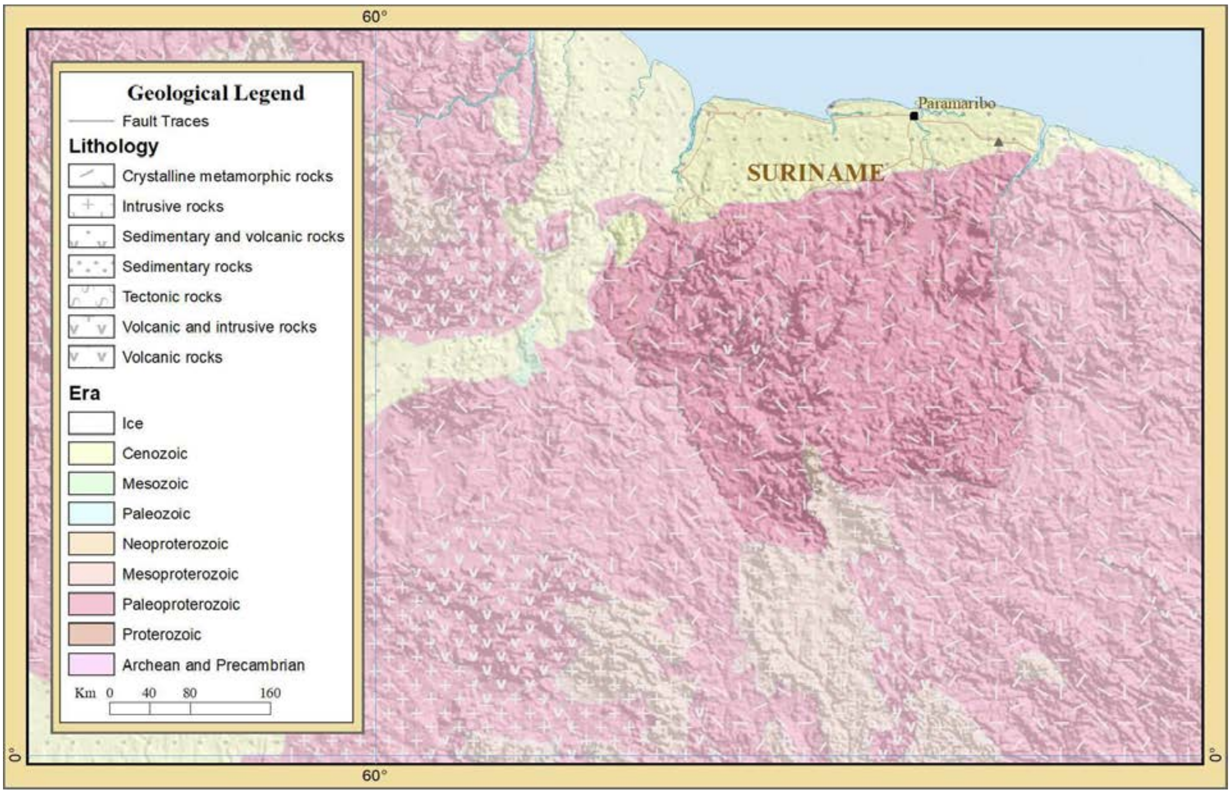


FIG. 8.43. Regional geological setting of Suriname. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The Shield covers more than 80% of the country and forms part of the Guiana Shield, which stretches between the Orinoco and Amazon Rivers and includes eastern Venezuela, Guyana, Suriname, French Guiana and northern Brazil. The crystalline basement is formed principally of igneous (granites and acid volcanic rocks) and metamorphic rocks. Small, scattered bodies of gabbro and ultramafitite are also described. The Precambrian basement was largely formed during the final phase of the Trans-Amazonian Orogeny Cycle, about 1900 Ma ago. The coastal plain, which stretches along the northern fringe of the Shield area, is exclusively sedimentary.

Post Transamazonian events include the unconformably deposition of tabular sandstones with intercalated acid volcanics forming an inselberg (the Tafelberg) in central Suriname and representing remnants of a large eroded platform, part of the Roraima formation. They reach a thickness of around 700 m and their age is estimated at 1700-1650 Ma.

Dolerite dykes occur in many places in Suriname and often dip under the sediments of the coastal plain. The oldest series (1600 Ma) of these dykes are found in the western part of Suriname. The general trend is NE–SW, which coincides with the Jurassic rift faults trend (reactivation). The second series of dolerite dykes (pigeonite dolerite dated at 227 Ma) have a general trend of NW–SE and are found in eastern Suriname. They mark the onset of continental break-up.

The hinterland of Suriname was largely quiescent after the intrusion of the pigeonite dolerites, with no further orogenic events occurring. The Shield area has been flattened by erosion [23.2, 23.3].

8.23.2.2. Potentially favourable uranium-bearing areas

Some potential for quartz-pebble conglomerate and Proterozoic unconformity-related deposits is associated with the Shield area [23.2].

8.23.3. Uranium exploration

8.23.3.1. Historical review

Interest in exploration for radioactive minerals began in 1949 when the occurrence of the uranium mineral euxenite was reported in neighbouring Guyana. This discovery was made in the Kanuku Mountains in the Guiana Shield, which continue into Suriname and known as the Bakhuys Mountains. However, a planned systematic study of this horst-like structure of Proterozoic rocks was never carried out. Only occasional samples taken from outcrops, heavy mineral concentrates and drill cores were analysed for radioactivity in the laboratory.

An airborne radiometric survey was conducted by the Government in 1971. A total of 9023 line-km was flown across an area of 5000 km², composed of metaquartzites with intra-formational conglomerates, largely intruded by volcanic and sub-volcanic rocks, all of Proterozoic age. This survey identified some point source anomalies and slightly anomalous zones. Throughout 1972–1973, the airborne survey was followed up by ground-based fieldwork, including scintillometer surveys, soil sampling and trenching. Laboratory results did not verify the radiometric results and further work ceased.

After publication of the geological map of Suriname in 1976, exploration for radioactive minerals continued in 1977 using a complete set of detection instruments. A shortage of field geologists resulted in operations being discontinued in 1979.

As noted in the 1982 Red Book [23.4], the exploration programme initiated in 1977 was still scheduled to be carried out. The fieldwork was to be a combination of detailed geology, geochemistry and scintillometry undertaken in selected areas.

8.23.3.2. Recent and ongoing uranium exploration and mine development

A 2006 report by the US Geological Survey for French Guiana, Guyana and Suriname mentions no uranium exploration or other activities being undertaken in Suriname [23.5].

8.23.4. Uranium resources

No known uranium reserves or resources are reported as of 1982, although exploration was just beginning. According to the Suriname country report included in the 1982 Red Book, the Geological and Mining Service of Suriname prepared a report which described the geology of six zones favourable for uranium exploration and proposed models for mineralization in igneous and metamorphic environments [23.4].

There are no deposits listed in UDEPO. The UDEPO database does not list any known deposits for Suriname.

8.23.5. Potential for new discoveries

There is some potential for quartz-pebble conglomerate and Proterozoic unconformity-related deposits in the relatively unexplored Shield area.

8.23.6. National policies related to uranium

The Government promotes the participation of foreign and private companies in exploration activities. Any such agreement would be based on a service contract with a State company holding a concession for radioactive minerals. The terms of the service contract would be negotiated. None were reported in the 1982 Red Book [23.4].

References to Section 8.23

[23.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Suriname, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed August 2010).

[23.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[23.3] STAATSOLIE, http://www.staatsolie.com/company.html (accessed 2009).

[23.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1982).

[23.5] SZCZESNIAK, P.A., US Geological Survey Minerals Yearbook 2001, The Minerals Industry of Suriname, http://www.minerals.usgs.gov/minerals/pubs/country/2001/nsmyb01.pdf

8.24. UNITED STATES OF AMERICA

8.24.1. Geography

The United States of America are situated mostly in central North America, where their forty-eight contiguous states and Washington, D.C., the capital district, lie between the Pacific and Atlantic Oceans, bordered by Canada to the north and Mexico to the south. The State of Alaska lies in the NW of the continent, bordering Canada to the east and with the Russian Federation lying to the west across the Bering Strait. The State of Hawaii is an archipelago in the Pacific Ocean. The country also possesses several territories in the Pacific (the Northern Mariana Islands, Guam and American Samoa) and Caribbean (the United States Virgin Islands and Puerto Rico).

The geography of the USA varies across a very large area. Within the continental USA, eight distinct physiographic divisions exist, though each is composed of several smaller physiographic subdivisions. These major divisions are:

(a) The Laurentian Upland, which is that part of the Canadian Shield which extends into the northern Great Lakes area of the USA;
(b) The Atlantic Plain, the coastal regions of the eastern and southern parts of which include the continental shelf, the Atlantic Coast and the Gulf Coast;
(c) The Appalachian Highlands, lying on the eastern side of the USA, include the Appalachian Mountains, the Watchung Mountains, the Adirondacks and New England province;
(d) The Interior Plains, which form part of the interior continental USA, include much of what is referred to as the Great Plains;
(e) The Interior Highlands form part of the interior continental USA;
(f) The Rocky Mountain System (the Rocky Mountains), at the western edge of the Great Plains, extends north–south across the country, reaching elevations greater than 4300 m in Colorado;

(g) The Intermontane Plateaux, also divided into the Columbia Plateau, the Colorado Plateau and the Basin and Range Province, is a system of plateaux, basins, ranges and gorges lying between the Rocky and Pacific Mountain Systems;
(h) The Pacific Mountain System, the coastal mountain ranges and features along the western coast of the USA.

Southern Alaska is a region of high, rugged, heavily glaciated mountain ranges. The interior of the State consists of broad valleys and generally low lying mountains situated between the Alaska Range to the south and the Brooks Range to the north. At an elevation of 6194 m, Mount McKinley is the tallest peak in the country.

Hawaii consists of a series of mountain islands which are of volcanic and coral origin.

The continental USA, with its large size and geographic variety, includes most climate types. To the east of the 100th meridian, the climate ranges from humid continental in the north to humid subtropical in the south. The southern tip of Florida is tropical, as is Hawaii. The Great Plains west of the 100th meridian are semi-arid. Much of the western mountains are alpine. The climate is arid in the Great Basin, desert in the SW, Mediterranean in coastal California, and oceanic in coastal Oregon, Washington and southern Alaska. Most of Alaska is subarctic or polar. Extreme weather is not uncommon; the States bordering the Gulf of Mexico are prone to hurricanes, and most of the world's tornadoes occur within the country, mainly in the Midwest.

While its economy has reached a post-industrial level of development and its service sector constitutes 67.8% of GDP, the USA remains the premier industrial power. The leading business field by gross business receipts is the wholesale and retail trade; by net income it is manufacturing. Chemical products are the leading manufacturing field. The USA is the third largest producer of oil in the world, as well as its largest importer. It is the world's number one producer of electrical and nuclear energy, as well as liquid natural gas, sulphur, phosphates and salt. It is also an important producer of industrial, base and precious metals. While agriculture accounts for just less than 1% of GDP, the USA is the world's top producer of corn and soybeans [24.1].

8.24.2. Geology

A detailed description of the geology and uranium potential can be found in the 1980 US Department of Energy (DOE) report, an assessment report on uranium in the United States of America and the associated National Uranium Resource Evaluation (NURE) Program [24.2].

The geological provinces, or regions, with a known uranium endowment are (Fig. 8.44): (i) Colorado Plateau, (ii) Wyoming Basins, (iii) Coastal Plain (south Texas portion), (iv) Northern Rockies, (v) Southern Rockies, (vi) Great Plains, (vii) Basin and Range, (viii) Pacific Coast, (ix) Central Lowlands, (x) Appalachian Highlands, (xi) Columbia Plateaux, (xii) Southern Canadian Shield, and (xiii) Alaska. There are no known uranium resources, or potential resources, in the volcanic Hawaii islands.

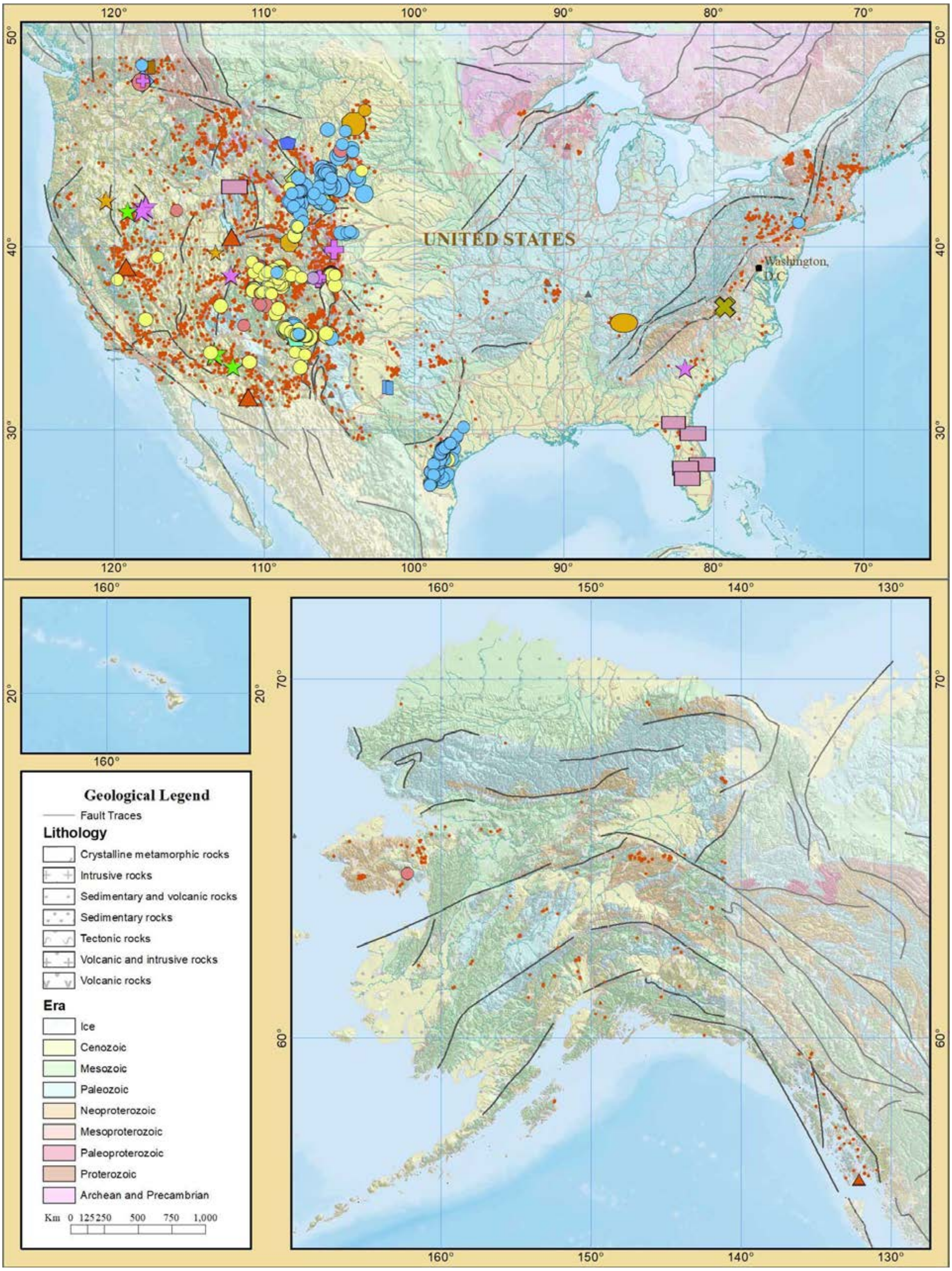


FIG. 8.44. Regional geological setting and uranium mineralisation of the United States of America. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

8.24.3. Uranium exploration

The Government, from 1947 through 1958, adopted both a Federal and a private sector uranium exploration and production industry to obtain uranium for military uses as well as for peaceful atomic energy applications. From 1958 through 1970, the Government continued its support of private sector exploration and production. This effort led to widespread exploration by prospectors throughout the western USA, and the successful identification of thousands of uranium occurrences. The number of additional deposits being brought into production by private industry by late 1957 had grown amply to sustain anticipated needs, and Federal subsidies for exploration programmes were stopped.

The Government did, however, continue to support research in uranium geology and exploration. For example, it initiated the National Uranium Resource Evaluation programme (NURE) [24.2]. The NURE programme was conducted by the US Department of Energy (USDOE) from 1974 to the early 1980s in order "to make a comprehensive assessment of the uranium resources of the U.S." The programme prepared estimates of the total uranium resources for 13 resource assessment regions that comprised distinctive geological provinces. The analysis was done by evaluating 135 complete and 45 partial 2-degree National Topographic Map Series quadrangles of the 621 that cover the complete USA. These quadrangles contained all known uranium deposits as well as the then known geological environments favourable for uranium deposits. The comprehensive systematic national evaluation was undertaken at the then current cost of roughly US \$320 million (equivalent to ~US \$890 million in 2012 currency) according to a retired USDOE and NURE programme staff member.

This major programme provided the first published comprehensive estimate of existing potential undiscovered US resources, listed according to deposit type and other characteristics. The estimated reserves and potential resources were derived from an extensive database of information derived from private company and Government drilling, logging, resource estimation and related studies, and developed by the USDOE and dating from the initiation of US uranium exploration programmes in the 1940s.

The major investigations were as follows:

(a) At least 1.6 km line spacing aerial radiometric surveys to measure values of uranium, thorium and potassium covering 5.4 million km^2;
(b) Several hundred thousand hydrogeochemical samples of surface waters, stream sediments and groundwater covering 4.7 million km^2 were collected to determine variations in uranium and other selected elements as guides for uranium exploration;
(c) A total of 115 800 m of drilling from 255 drill holes sited in selected areas where surface information alone was inadequate to determine the extent and character of favourable geological environments;
(d) Geological investigations to provide a better understanding of the known uranium environment and to identify new areas that were favourable for uranium deposits.

Other investigations included:

(a) Geochemical studies to provide a better understanding of uranium movement;
(b) Application of remote sensing techniques for the identification of favourable areas;
(c) Development of new and improved borehole logging systems;
(d) Improvement of radon and helium detection methods for use in exploration;
(e) Investigation of new methodologies for uranium resource estimation;
(f) Development of improved mining and milling technology.

This work was supplemented by 540 person-years of geological field work, as well as drilling and logging in 18 project areas. The result was perhaps the most complete national uranium resource evaluation completed in any country. It includes an estimate of the then current uranium reserve base, as well as an appraisal of the undiscovered uranium resource endowment for the USA. Owing to the fall of the uranium market price throughout the 1980s and the persistent low prices throughout the 1990s and early 2000s, the resources and personnel available to the NURE programme were drastically cut. As a result, there have been no comprehensive estimates of undiscovered resources made in the USA since the NURE programme, and the NURE estimates remain the best available information. In addition, because of the limited personnel and resources available, some of the other information generated by the NURE programme has not been significantly updated and remains the best available for the USA. This was paralleled by the very low level of exploration and supporting research conducted throughout this period by both private industry and Government entities. The United States completed part of their re-evaluation of undiscovered resources in 2015.

The radiometric drill hole logs and supporting geological and engineering information provided to the USDOE by companies comprising the domestic uranium industry were the prime source of information used to estimate NURE uranium reserves and resources. Since 1980, the USDOE and the Energy Information Administration have updated the associated estimated production costs, deleted production and added new discoveries. However, the NURE database remains the primary database and benchmark for uranium deposits, resources and geological knowledge for the USA. Following the closure of the NURE programme, all exploration and production activities in the USA have been conducted by private entities (non-Government).

Uranium exploration in the USA [24.3-24.12] grew during the 1970s in reaction to increasing uranium prices and the anticipated huge requirement for uranium to fuel a growing number of nuclear reactors being constructed or proposed for generation of electricity. The highest point in yearly surface drilling (exploration and development) was attained in 1978, when 14 700 km of borehole drilling were accomplished and expenses amounted to US $374.5 million. Beginning in the late 1960s and accelerating through the 1970s, many US oil companies diversified into uranium exploration and production. The rapid growth of exploration in the 1970s can be directly correlated to the entry of these well-funded oil companies into the uranium sector. Their wholesale exodus from the uranium industry was a major reason for the precipitous decline in US exploration beginning in the early 1980s.

Surface drilling throughout 1966–1982 amounted to ~116 400 km and expenditures totalled roughly US $2121 million. In response to falling uranium market prices, exploration activities decreased rapidly between 1981 and 1984, before the downward trend started to level off, reaching a low of US $0.35 million in 2002, when Government statistics indicate that there was only one person involved in uranium exploration in the USA. Expenditures increased slightly in 1997–1998 in response to the 1996 increase in the spot market price of uranium. This increase was short lived and exploration quickly returned to pre-1996 levels. The unprecedented run-up in the spot market price that began in 2002 reach a peak of US $354/kgU on 25 June 2007, before erratically falling back to US $115/kgU by late November 2009, and since then has fluctuated in the US $115–130/kgU range. The high uranium prices rekindled interest in exploration in the USA, resulting in at least US $50 million being spent in 2007 and 2008 before falling to US $24.2 million in 2009.

Both domestic and foreign companies have been actively involved in exploration in the USA, with increased foreign participation in the industry beginning in the 1970s. Uranium exploration in the USA has primarily been directed towards the discovery of sandstone-type deposits of uranium in districts such as the Uravan Mineral Belt and Grants Mineral Belt of Utah, Colorado and New Mexico, the Texas Gulf Coastal Plain and the Wyoming Basins. Vein and other deposits that are structurally-controlled were exploration targets in the Front Range of Colorado, in Utah and in north-eastern Washington State. Many relatively high grade deposits related with collapse breccia pipe deposits were discovered in northern Arizona and were mined in the 1970s through the early 1990s [24.13].

Experimental in situ leach (ISL) pilot tests were carried out in the 1960s in the Shirley Basin and Powder River Basin in Wyoming. The first commercial ISL operation began production in 1964 (577 tU were produced by ISL at the Shirley Basin mine in 1964–1970). Mining companies in the USA considered ISL operations as one of the most viable types of commercial project in the USA in the depressed uranium market that characterized the 1980s and 1990s. Therefore, as low uranium market prices persisted, exploration emphasis was concentrated almost entirely on sandstone deposits that were potentially amenable to ISL extraction. Most of the exploration activity up until the period following the post-2002 uranium market price increase was focused on the Wyoming Basins and south Texas, both of which had hosted ISL production centres. While New Mexico also has significant ISL amenable resources, public opposition to uranium mining has delayed development of its potential.

Figure 8.45 (encapsulating USD $ 4 545 768 000 domestic expenditure including 169 212 metres of drilling) and summarizes historical exploration activities.

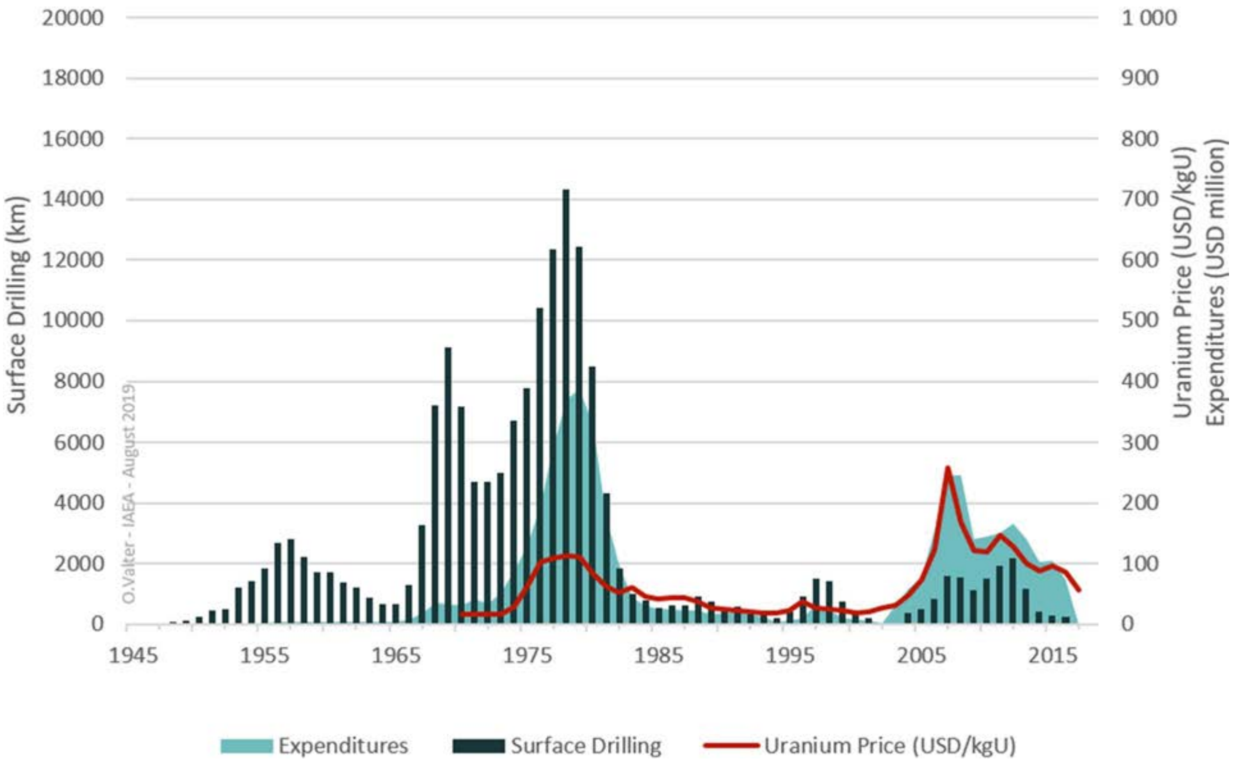


FIG. 8.45. Domestic uranium exploration data for the United States of America. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

The marked increase in the uranium market price after 2003 generated a commensurate increase in exploration. This led to enhanced exploration for all the types of uranium deposit previously recorded in the USA. This exploration comprised the full spectrum of activities, including drilling to expand known deposits through exploration in previously untested areas. Much effort was directed into the re-evaluation of both previously known deposits and those with incomplete exploration results from programmes that were abruptly curtailed when the uranium market prices fell throughout the early 1980s. Exploration was conducted for deposit types that had not been sought in years, including volcanic targets in, for example, the McDermitt Caldera, Nevada and in Oregon, as well as deposits to be mined conventionally such as in the Gas Hills, Wyoming and the Grants Mineral Belt, New Mexico. Exploration for breccia pipe targets was also resumed in northern Arizona.

Greatly expanded exploration was accompanied by a large increase in the availability of reliable uranium projects and resource information resulting from the development of technical reporting under the Committee for Mineral Reserves International Reporting Standards and related regimes such as the JORC Code (Australian Joint Ore Reserves Committee) and NI 43-101 (Canadian National Instrument 43-101) and similar national reporting schemes implemented since about 1990 [24.14].

While exploration and development activities moderated with the relatively low recent uranium market price activities, several projects are scheduled for reactivation as they have almost completed the lengthy permitting process and are only awaiting an upturn in uranium market prices.

In 1980, 23 US companies were involved in exploration projects outside the USA. They were exploring in Australia, Canada, Africa, Europe, and Central and South America (Fig. 8.46).

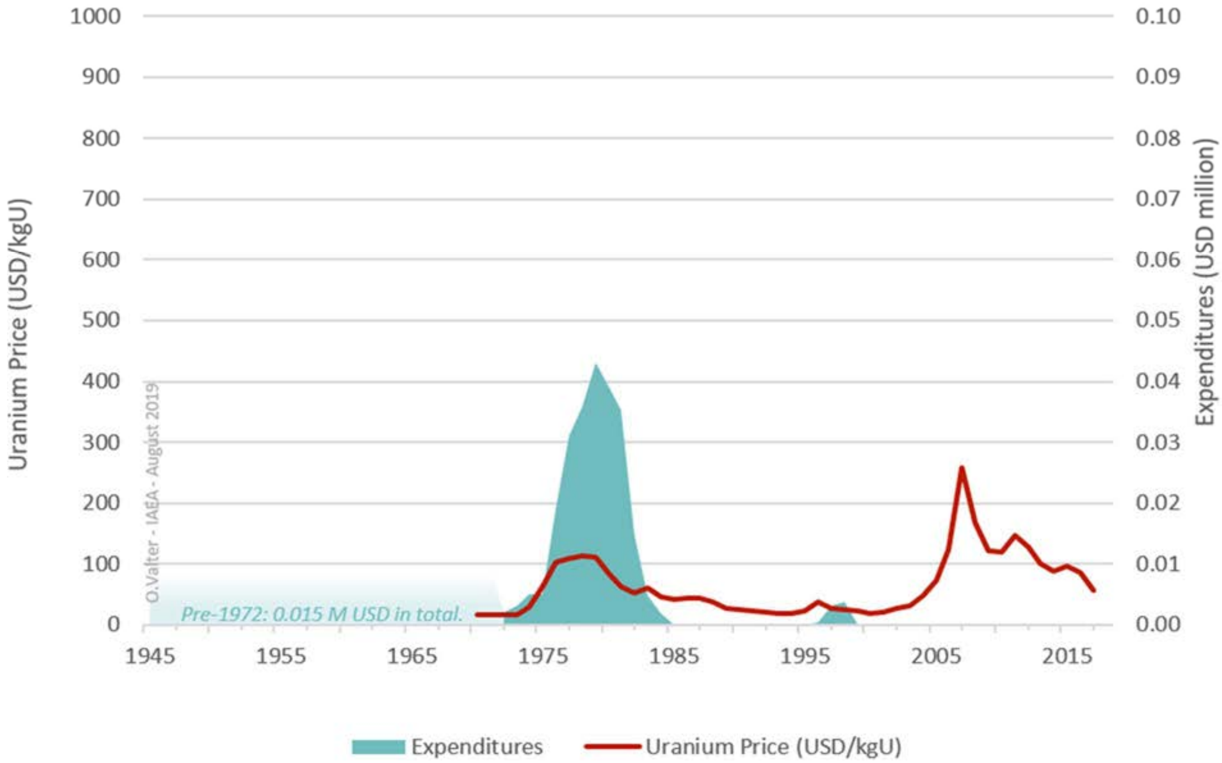


FIG. 8.46. Non-domestic uranium exploration data for the United States of America. Comparison of exploration expenditures and uranium market price (US$ current).

8.24.4. Uranium resources [24.15, 24.16]

Historical variations in identified conventional resources are shown in Fig. 8.47 and Fig. 8.48. Known conventional resources in the USA increased in the period 1965–1979. In 1965, uranium resources hosted in conventional deposits, in the <US $26/kgU cost category, amounted to 520 000 tU (reasonably assured resources and possible additional resources), and these resources were hosted in comparatively few large deposits and numerous small deposits. The largest deposits contained at least 90% of the reserve and were relatively shallow; ~50% of the resources were in deposits less than 100 m deep and mineable by open pit methods. Although conventional uranium deposits occurred in a wide variety of rocks and in many types of deposit, ~95% were in coarse clastic sediments as irregularly shaped but generally tabular disseminated deposits. In addition to the conventional deposits, resources of uranium exist in phosphate and copper deposits.

In 1973, reasonably assured resources in the <US $26/kgU cost category were estimated to be 259 000 tU [24.17]. Estimated additional resources of 231 000 tU were assessed by extrapolation of information on reasonably assured resources to areas having demonstrably favourable geology.

Throughout 1975 and 1976, 135 000 tU were added to reasonably assured resources recoverable at less than US $80/kgU, resulting in a total of 523 000 tU as of 1 January 1977 [24.18]. Estimated additional resources increased throughout this period from 812 000 to 838 000 tU [24.4].

Throughout the 1980 NURE assessment programme, an undiscovered resource estimation methodology was developed, which provides mean values and distributions characterizing the reliability of the estimates at various confidence levels. This methodology was applied to prospective areas within the USA [24.2]. The estimation procedure was standardized and documented to minimize personal bias and to facilitate review and revision as new data became available. The resource estimates as of 1 January 1983 [24.19] were made utilizing the large amount of data acquired under the NURE programme, which continued from 1974 through 1981. The data were made available by private companies and also included data accumulated since the late 1940s.

In January 2009, the USA updated its reasonably assured resource estimates. Differences from the 2003 estimates were due to a revised examination of major properties, using primarily published reassessments of current resources, recently evaluated properties and mine depletion. For the <US $80/kgU cost category, this resulted in a decrease from 102 000 tU in 2003 to 39 064 tU in 2009.

Estimates of prognosticated (EAR-II) and speculative resources have been brought forward without modification from 1994 to 2009. For the 2011 edition of the Red Book [24.20], the USA did not report these resource categories and will not report them until new resource estimates are completed or supporting documentation is found.

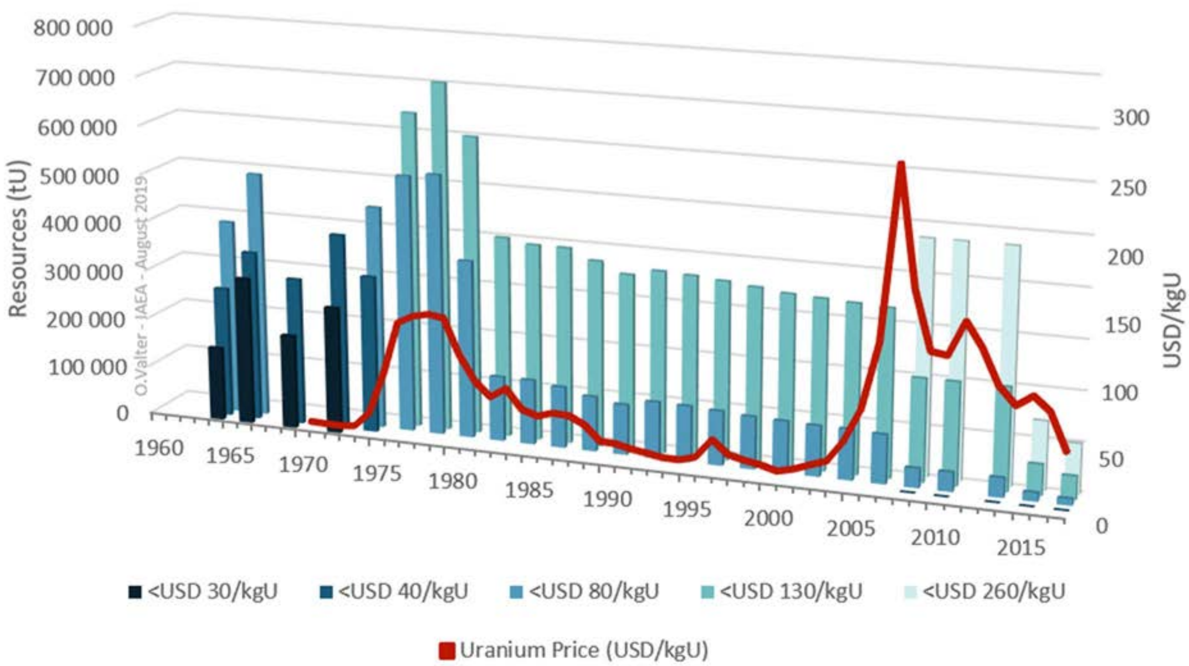


FIG. 8.47. Historical variation of recoverable reasonably assured resources within various cost categories in the United States of America. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

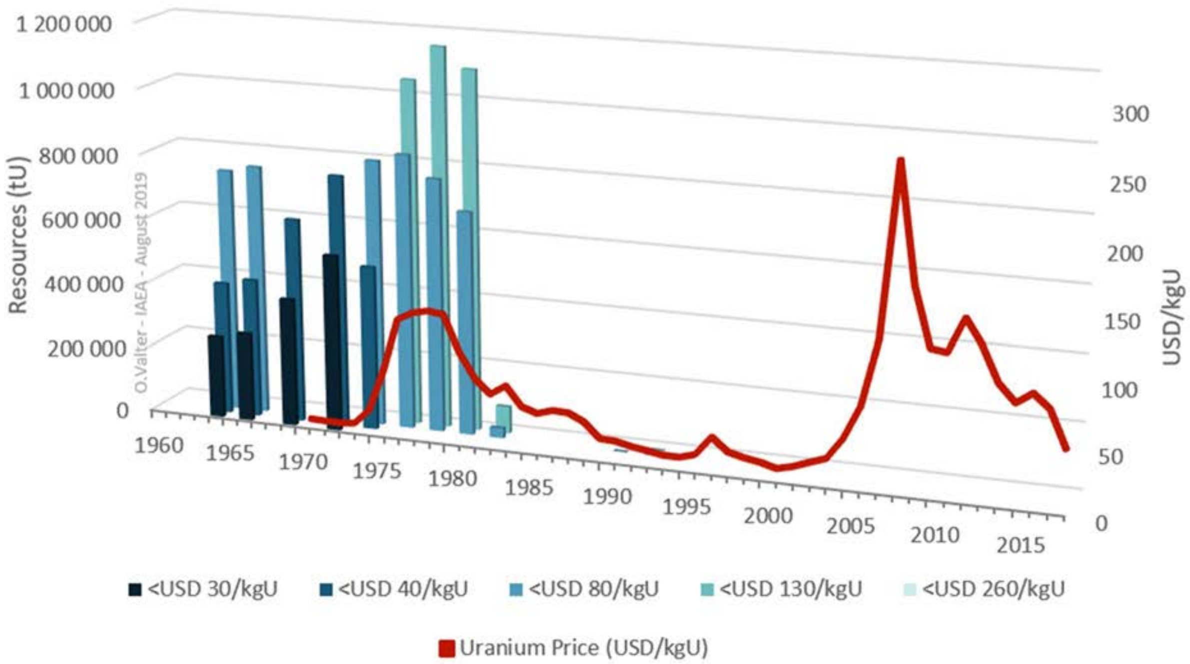


FIG. 8.48. Historical variation of recoverable inferred resources within various cost categories in the United States of America. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State or as a secretariat estimate.

Tables 8.21–8.27 provide details of the various categories of resources.

TABLE 8.21. HISTORICAL DISTRIBUTION BY REGION AND FORWARD COST CATEGORY (US$/lb U_3O_8) OF URANIUM RESERVES AND POTENTIAL RESOURCES (1000 tU) [24.21]
(As of 1 October 1980)

Region	Reserves			Potential resources								
				Probable			Possible			Speculative		
	Cost categories (US$/lb$U_3O_8$)											
	30	50	100	30	50	100	30	50	100	30	50	100
Colorado Plateau	273	366	417	253	422	599	123	255	421	4	7	14
Wyoming Basins	139	235	314	89	209	370	35	72	102	3	7	15
Coastal Plain	33	42	47	173	213	253	39	47	56	4	5	7
Northern Rockies	15	20	20	13	20	32	11	15	19	48	70	97
Southern Rockies	19	25	25	68	83	94	29	39	47	26	34	40
Great Plains	8	11	14	17	36	54	14	29	46	47	87	134
Basin and Range	7	20	24	58	104	188	16	37	82	18	32	42
Pacific Coast	1	2	2	6	9	12				2	3	3
Central Lowlands	0	0	0							23	36	62
Appalachian Highlands	0	0	0							61	81	98
Columbia Plateaux	0	0	0							3	8	16
Southern Canadian Shield	0	0	0							0.2	0.2	0.3
Alaska	0	0	0	2	2	2				0.1	0.2	0.3
Total	495	721	863	679	1098	1604	267	494	773	239	370	529

TABLE 8.22. HISTORICAL DISTRIBUTION OF <US \$100/lb U_3O_8 POTENTIAL RESOURCES BY TYPE OF HOST ROCK (1000 tU) [24.21]
(As of 1 October 1980)

Host Rock	Probable		Possible		Speculative	
	Resource (tU)	Host (%)	Resource (tU)	Host (%)	Resource (tU)	Host (%)
Sandstone	1400	87	690.6	89	361.7	67
Conglomerate	43.8	5	12.3	2	19.2	4
Granitic and	81.5	3	20.0	3	122.3	23
metamorphic rocks	43.1	3	26.9	4	19.2	4
Volcanic rocks	16.2	1	16.9	2	10.8	2
Limestone	15.4	1	6.2	<1	3.1	<1
Lignite						
Total	1600	100	772.9	100	536.3	100

TABLE 8.23. DISTRIBUTION OF URANIUM RESERVES (<US \$50/lb U_3O_8) [24.22]
(As of 1 January 1998)

Region	Number of properties	Grade (%U)	Resource (tU)
Colorado Plateau	345	0.134	164 600
Wyoming Basins	125	0.062	140 400
Colorado and Southern Rockies	12	0.088	13 800
Northern Rockies	8	0.055	10 000
West. Gulf	52	0.051	10 000
N. & C. Basin and Range	8	0.055	1500
Others	30	0.082	17 700
Total	580	0.088	358 000

Host rock	Number of properties	Grade (%U)	Resource (tU)
Sedimentary:			
• Clastic	505	0.089	323 800
• Coal/lignite	18	0.305	3100
• Chemical	10	0.106	800
Metasedimentary	W	W	W
Igneous:			
• Intrusive	5	0.045	4600
• Extrusive	W	W	W
Others	38	0.075	23 500
Total	580	0.088	358 000

W: withheld

TABLE 8.24. FORWARD COST RESERVES[a] ACCORDING TO STATE (tU) [24.11]
(As of 1 January 2009)

State	<US $50/lb U_3O_8		<US $100/lb U_3O_8	
	Grade (%U)	Resource (tU)	Grade (%U)	Resource (tU)
Wyoming	0.064	84 600	0.047	171 500
New Mexico	0.119	68 800	0.089	150 000
Arizona, Colorado, Utah	0.123	24 200	0.071	76 200
Texas	0.075	10 400	0.053	15 400
Other[b]	0.076	19 200	0.069	59 200
Total	0.083	207 200	0.063	472 300

[a] Uranium reserves recoverable as a by-product of phosphate or copper mining are excluded.
[b] Includes Alaska, California, Idaho, Montana, Nebraska, Nevada, North Dakota, Oregon, South Dakota, Virginia and Washington.

TABLE 8.25. REASONABLY ASSURED RESOURCES (tU) [24.11]
(As of 1 January 2009)

Deposit type	<US$ 40/kgU	<US$ 80/kgU	<US$ 130/kgU	< US$ 260/kgU
Sandstone	0	39 064	191 953	401 149
Other[a]	0	0	15 482	70 907
Total	0	39 064	207 435	472 056

[a] Includes intrusive, volcanic and caldera related, and collapse breccias pipe deposits.

TABLE 8.26. PROGNOSTICATED RESOURCES (tU)
(As of 1 January 2009)

<US $80/kgU	<US $130/kgU	<US $260/kgU
839 000	1 273 000	1 273 000

TABLE 8.27. SPECULATIVE RESOURCES (tU)
(As of 1 January 2009)

<US $80/kgU	<US $130/kgU	Unassigned
858 000	858 000	482 000

As of 1 January 2017, reasonably assured resources (in-situ) reported by the USA amount to 138 204 tU in the <US$ 260/kgU cost category (8.25.9). All the reported resources are associated to sandstone-type deposits [24.23].

The USA do not report inferred resources.

The UDEPO database lists the most significant deposits for the United States of America as Northern Great Plains, Chattanooga Shale Formation, Phosphoria Formation, East Florida District.

8.24.5. Uranium production

Mining for uranium in the USA started in 1871. From 1871 to 1905, two types of uranium ore were produced in small volumes for the world market: pitchblende and carnotite ores from Colorado.

Pitchblende was first identified in the USA in 1871 at mines in Gilpin County, near Denver, Colorado. The mines had been worked for gold since about 1859 and at the Wood Mine in the Quartz Hill, pitchblende of high grade was dumped as waste since it contained no gold. In 1872, 3 t of ore were produced and production continued at the mine until 1884. Carnotite type uranium ores were discovered on the Colorado Plateau in 1881.

Under the Atomic Energy Act of 1946, drawn up to sustain the uranium requirements of the Government, the Atomic Energy Commission (AEC), from 1947 to 1970, adopted a domestic uranium industry, mainly in the western States, by way of incentive programmes for exploration, development and production. To ensure that the uranium ore supply would be adequate to meet future requirements, the AEC implemented in April 1948 a procurement programme for domestic uranium ore intended to kindle a civil industry based on domestic mining. Pursuant to the Atomic Energy Acts of 1946 and 1954, the AEC also negotiated procurement contracts for uranium concentrate with ensured prices for source materials provided within definite times. Contracts were prepared to enable milling companies that constructed and operated mills the prospect to amortize plant costs throughout their procurement contract periods [24.13, 24.24]

The AEC, as the only purchasing agent of the Government, provided the only domestic uranium market. Several of the mills were shut down immediately after finishing deliveries programmed under their uranium contracts, even though many mills remained to generate concentrate for the commercial market after satisfying their AEC commitments. The Atomic Energy Act of 1954 legalized the private proprietorship of nuclear reactors for commercial generation of electrical power. Domestic ore reserves and milling capacity were, by late 1957, adequate to sustain the anticipated needs of the Government's. The AECs procurement programmes were decreased in range in 1958, and, in order to nurture use of atomic energy for peaceful purposes, domestic producers of ore and concentrate were permitted to vend uranium to private domestic customers.

The uranium procurement programme of the Government concluded in 1970 and in 1971 the industry became a private sector, commercial enterprise with no additional Government purchases.

Seven ISL plants with combined annual capacity of 14 539 tU were, at the end of 2010, operating or operational in Nebraska, Texas, Utah and Wyoming. Two ISL operations, Christensen Ranch in Wyoming and La Palangana in Texas, commenced production in 2010. In 2010, four underground mines and four ISL operations produced uranium [24.20].

Total cumulative uranium production in the USA amounted to 366 867 tU throughout the period 1947–2010. Eight plants for the recovery of uranium from phosphoric acid were built (six in Florida, two in Louisiana) and these operated throughout the period 1975–1999. Roughly 17 150 tU were recovered from phosphate ores.

In 2018, uranium production was 564 t originating from 7 mills: White Mesa (hard rock operation), and Crow Butte, Smith Ranch-Highland, Willow Creek, Lost Creek, Nichols Ranch, Lance (Ross) (ISL operations). Total historical uranium production in the US to 2018 is 376 171 t.

Historical uranium production totalling 376 171 tU is summarized in Fig. 8.49, and production centre details are given in Table 8.28.

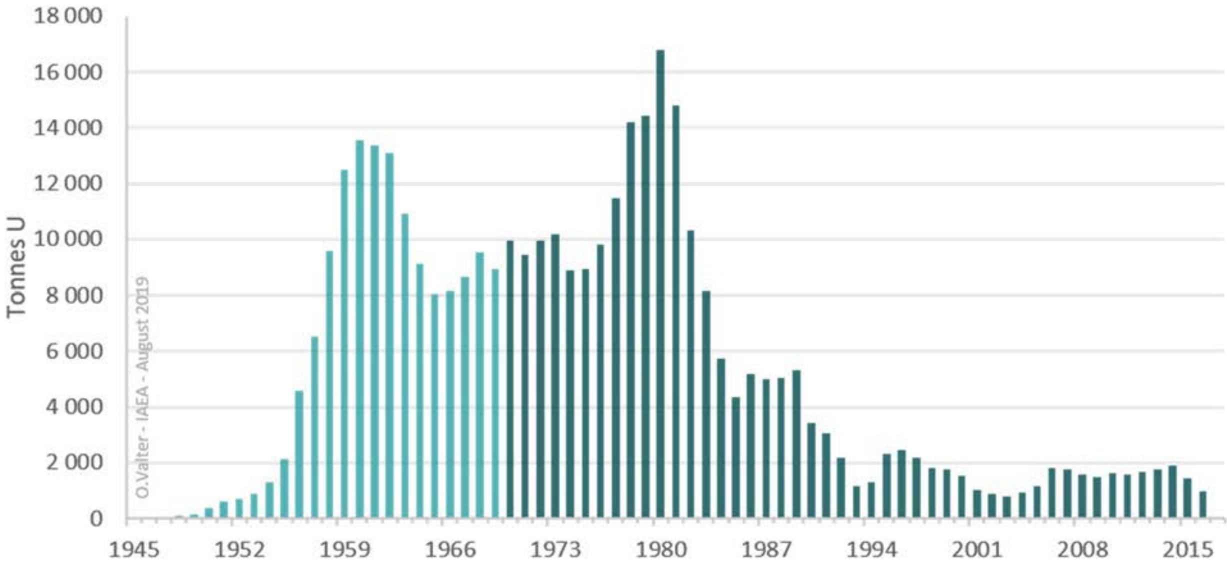


FIG. 8.49. Historical uranium production in United States of America (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

TABLE 8.28. URANIUM PRODUCTION CENTRE TECHNICAL INFORMATION (OPERATING CENTRES 1–6)
(As of 1 January 2011)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6
Name of production centre	Crow Butte	Smith Ranch, Highland	White Mesa[a]	Alta Mesa	Christensen Ranch	La Palangana
Start-up date	1991	1988	1968	2005	Initially 1978 at Irrigaray	2010
Source of ore:						
• Deposit name	Crow Butte	Smith Ranch Highland	Various	Alta Mesa	Christensen	Various
• Deposit type	North Trend Sandstone	Sandstone	Sandstone, collapse breccia pipe	Sandstone	Sandstone	Sandstone
Mining operation:						
• Type	ISL[b]	ISL	UG[c]	ISL	ISL	ISL
• Average recovery (%)	n.a.[d]	n.a.	n.a.	n.a.	n.a.	n.a.
Processing plant:						
• Acid/alkaline	Alkaline	Alkaline	Acid	Alkaline	Alkaline	Alkaline
• Type	IX[e]	IX	SX[f]	IX	IX	IX
• Size (t/d)			1538			
• Nominal capacity (tU/year)	385	2116	n.a.	385	385	385

[a] White Mesa includes both uranium and vanadium recovery circuits.
[b] ISL: in situ leaching.
[c] UG: underground mining.
[d] n.a.: not available.
[e] IX: ion exchange.
[f] SX: solvent exchange

8.24.5.1. *Future production centres*

At the end of 2010, three uranium mills were on standby status (combined capacity of 3255 t/d of ore) and one was under development.

Three ISL operations, with a combined capacity of 962 tU, were on standby or permitted and licensed. Eight additional ISL projects were under development.

A number uranium companies are in pre-licensing negotiations with State and Federal regulatory agencies for both conventional and ISL mining in Colorado, New Mexico, Texas, Utah and Wyoming. Existing and additional ISL operations are to be most probably the largest contributors to expanded production in the near term [24.20].

8.24.6. Environmental activities

In the USA, an increasing understanding of the degree and seriousness of damages that had accrued in the natural environment as a result of ineffective regulatory oversight in former mining operations, including the governing of mine discharges, hazardous waste disposal and un-reclaimed mining sites led to the passage, in the 1970s, of several US Federal and State laws designed to protect air, water and land resources. Environmental effects that can be traced to extraction and beneficiation of uranium can comprise the direct disruptions of the natural surface environment, the presence of radionuclides in the waste products from mines and mills, enhanced surface water runoff from mined areas, erosion by wind and water, and pollution of neighbouring groundwater reservoirs.

Expenditures for environmental management subsequent to closure comprise mainly of reclamation and monitoring expenses. For uranium mills, these expenses cover mill decontamination and demolition, long term stabilization of tailings and remediation of groundwater. For mines, the reclamation expenses incurred include partial backfilling of pits, stabilization of waste-rock piles, re-contouring the disturbed land surface and revegetation. Monitoring is a post-closure expense for both mines and mills.

In the USA, the total cost for surface clean-up of 22 erstwhile uranium ore processing sites specified as Title I sites under the Uranium Mill Tailings Remedial Action Project was reported to be US $1.476 billion. Excluded in this total is the expense for clean-up of groundwater at the Title I sites, which the USDOE assessed in 1995 would include an additional US $147 million over the expense for surface clean-up, with completion of the clean-up work for groundwater expected for 2014. Surface clean-up of the Title II sites is ongoing, and at the end of 1999, the total estimate of expenses for work already accomplished at these sites was roughly US $600 million. Also in 1999, it was estimated that the costs of surface clean-up completed at 22 major uranium mining sites in the USA was roughly US $300 million. The expenses incurred to date under the OSM abandoned mines programme for surface clean-up of abandoned uranium mine properties which is managed by several States have not been laid out.

8.24.7. National policies related to uranium

"The U.S. allows supply and procurement of uranium production to be driven by market forces with resultant sales and purchases conducted solely in the private sector by firms involved in the uranium mining and nuclear power industries".

References to Section 8.24

[24.1] UNITED STATED GEOLOGICAL SURVEY, Physiographic Regions of the 48 United States, http://tapestry.usgs.gov/physiogr/physio.html (accessed August 2012).

[24.2] UNITED STATES DEPARTMENT OF ENERGY, An Assessment Report on Uranium in the United States of America, Rep. GJO-111, USDOE, Grand Junction, CO (1980).

[24.3] VIRGINIA ENERGY RESOURCES, http://www.virginiaenergyresources.com/s/Home.asp

[24.4] UNITED STATES DEPARTMENT OF ENERGY, Statistical Data of the Uranium Industry 1982, Rep. GJO-100, USDOE, Grand Junction, CO (1982).
[24.5] AYLOR, J.G. Jr., "Coles Hill, Chatham, Virginia uranium deposit, Paleozoic faulting, and mineralization by fluids derived from the adjacent Triassic basin", 41 1 Geol. Soc. Am. (2009) 48.
[24.6] BAWIEC, W.J. (Ed.), Geology, Geochemistry, Geophysics, Mineral Occurrences and Mineral Resource Assessment for the Commonwealth of Puerto Rico: US Geological Survey Open-File Report 98-038 (1999), http://pubs.usgs.gov/of/1998/of98-038/
[24.7] OECD NUCLEAR ENERGY AGENCY, Forty years of Uranium, Production and Demand in Perspective: The Red Book Retrospective, OECD, Paris (2006) 280 pp.
[24.8] INTERNATIONAL ATOMIC ENERGY AGENCY, World Distribution of Uranium Deposits (UDEPO), with Uranium Deposit Classification, IAEA-TECDOC-1629, Vienna (2009).
[24.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004) .
[24.10] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2005: Resources, Production and Demand, OECD, Paris (2006).
[24.11] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2009: Resources, Production and Demand, OECD, Paris (2010).
[24.12] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).
[24.13] HAHNE, F.J. Early uranium mining in the United States, World Nuclear Association, http.//wwwworld-nuclear.org/reference/usumin.html (Sept. 1989)
[24.14] ENERGY VENTURES, JORC resources (July 2011), http://web.archive.org/web/20150304220505/http://energyventures.com.au/component/filecabinet/?task=download&fid=510
[24.15] SMITH, L.L., Estimating U.S. Uranium Reserves, J. Met. 50 12 (1998) 41–43.
[24.16] UNITED STATES ENERGY INFORMATION ADMINISTRATION, U.S. Uranium Reserves Estimates, http://www.eia.gov/cneaf/nuclear/page/reserves/ures.html (accessed 2012).
[24.17] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1973: Resources, Production and Demand, OECD, Paris (1973).
[24.18] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1977: Resources, Production and Demand, OECD, Paris (1977).
[24.19] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1983: Resources, Production and Demand, OECD, Paris (1983).
[24.20] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand, OECD, Paris (2012).
[24.21] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1981: Resources, Production and Demand, OECD, Paris (1981).
[24.22] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 1999: Resources, Production and Demand, OECD, Paris (2000).
[24.23] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2018: Resources, Production and Demand, OECD, Paris (2018).
[24.24] JONES, J.Q., Uranium Production, in Proceedings Uranium Industry Seminar, Oct. 21, 1981, Grand Junction, CO, GJO-108 81, USDOE (1981).

8.25. URUGUAY

8.25.1. Geography

Uruguay is situated between Argentina to the west and Brazil to the north and east. It also has a maritime border with the South Atlantic Ocean. The topography comprises mostly rolling plains and low hills, with a fertile coastal lowland. The climate is warm temperate and freezing temperatures are almost unknown. The highest point is Cerro Catedral at an elevation of 514 m. Most of the low-lying topography (covering three quarters of the country) is grassland, which is ideal for cattle and sheep ranching.

The economy of Uruguay is characterized by an export oriented agricultural economy (cattle, wool and dairy products). Natural resources include minor mineral production (feldspar, gold, gypsum) and hydropower [25.1, 25.2].

8.25.2. Geology

The geology of Uruguay consists of a Proterozoic basement covered by younger sediments and flood basalts (Fig. 8.50). At least 40% of Uruguay's surface area is an extension of the Brazilian Shield. The basement is divided into two cratonic areas, namely, the Piedra Alta and the Nico Perez. Rocks of Proterozoic age are present in the Piedra Alta terrain and Archaean ages have been determined for some Nico Perez lithologies.

These basement rocks have been mapped up to 100 km inland along the southern and south-eastern portions of the country, although they are obscured by Cenozoic sands along much of the coastline. To the north and west, exposures are dominated by Mesozoic volcanics, and Palaeozoic sediments crop out in the NE of the country, near the border with Brazil.

Some areas are known in detail through copper, gold and diamond exploration. The Isla Cristalina Belt is located 450 km from Montevideo in northern Uruguay and hosts the San Gregorio gold mine at Minas de Corrales. The belt is composed of granites and greenstones which range in metamorphic grade from greenschist to amphibolite facies.

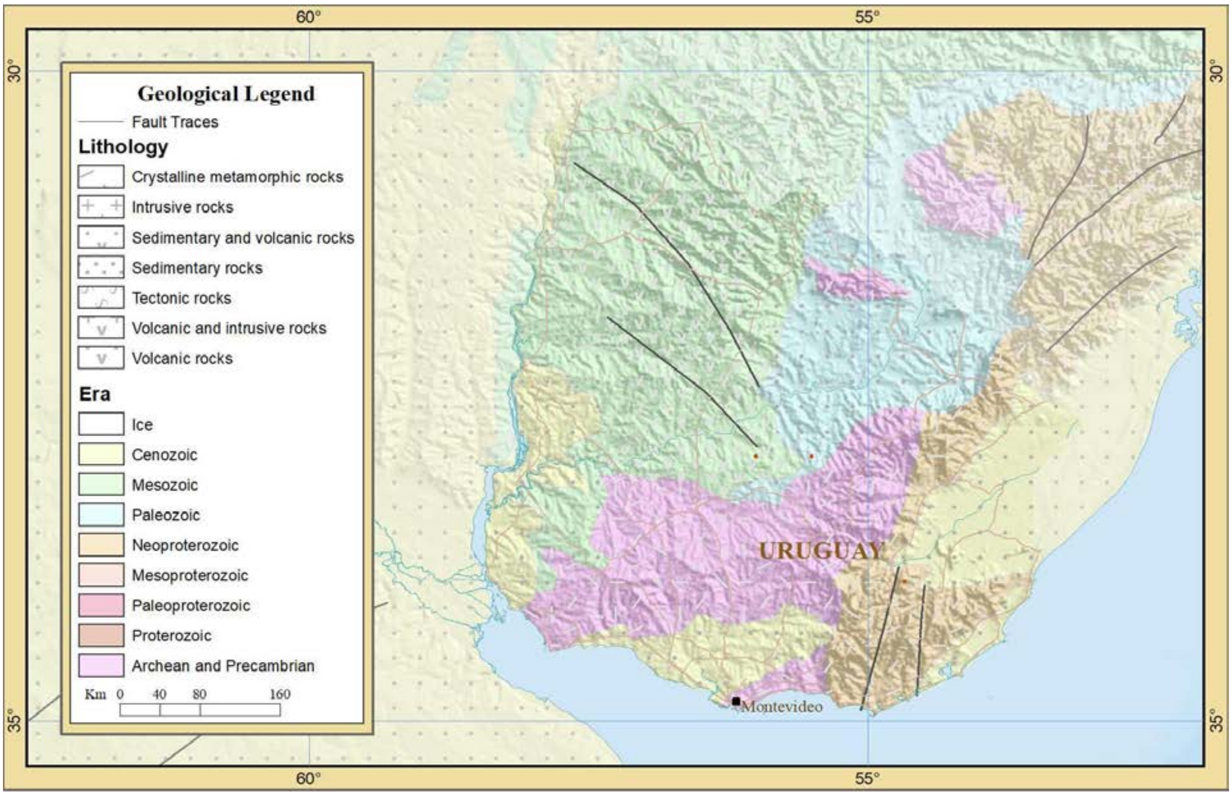


FIG. 8.50. Regional geological setting and uranium mineralisation of Uruguay. For the general uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

The southern end of the NNE trending Dom Feliciano fold and thrust belt is located 95 km east of Montevideo. The fold and thrust belt is exposed for at least 250 km along strike and for 40–50 km in an east–west direction. It comprises structurally deformed Proterozoic metasediments, greenstones and granitoids which are bound on the east and west by two major NNE trending shear zones.

The Laguna Merin Basin is located along the eastern coast of Uruguay. This basin is Cretaceous in age and overlies basement rocks of the Dom Feliciano Belt. It is filled with clastic material and volcanic rocks which are associated with continental break-up and the opening of the South Atlantic Ocean. The Lascano copper–gold project is located in the Laguna Merin Basin.

The La Florida and Arroyo Grande Belts, which comprise Proterozoic metavolcanic and metasedimentary rocks interspersed through a granitic terrain, occupy the south-western third of the country (part of the Piedra Alta terrain). These rocks are exposed for 240 km from the western side of the Dom Feliciano Belt and extend almost to the western border of Uruguay, and up to 175 km north of Montevideo, where they are covered by younger Palaeozoic and Mesozoic sediments and flood basalts [25.2–25.4]. Lower Devonian sedimentary rocks are present in the central part of Uruguay as a narrow east-west to northeast oriented belt. The upper part of this sequence is composed of sandstones. The large Parana basin, present in the north of Uruguay, accumulated siliciclastic, chemical and volcaniclastic sediments between the Ordovician and Late Cretaceous (450-65 Ma). During the Late Paleozoic the territory of Uruguay was affected by the Karoo Glaciation that covered large parts of the Gondwana continent.

Volcanic materials from the Paraná continental flood basalt province form a major lithological unit extending into Argentina and Brazil and underlies more than half of Uruguay. The volcanic rocks erupted in the Cretaceous during the opening of the South Atlantic ocean. Most of the volcanic material correspond to basalt, but rhyolites are also present. Syenite and granitoid intrusions are associated to the volcanism.

8.25.3. Potentially favourable uranium-bearing areas

The most prospective areas in Uruguay include the Permo-Carboniferous sedimentary sequences of the Parana Basin in the NE, the Lower Devonian sedimentary sequence in the central part of the country and the basement rocks. Reference [25.5] provides more details on this.

8.25.4. Uranium exploration

8.25.4.1. Historical review

Prospecting for uranium using car-borne radiometric surveys began in Uruguay in the 1950s and has been carried out by State owned organizations. Throughout 1968–1969, various anomalies in the Permo-Carboniferous sedimentary formations of the Department of Cerro Largo were investigated. Limited drilling revealed a limonitic, fine-grained sandstone bed containing an average of 700 ppm U. Informal estimates indicated the resource of ~2000 tU.

On the basis of a review of results of a series of car-borne radiometric surveys undertaken in 1971–1975 by the Uruguayan Atomic Energy Agency, an IAEA expert recommended airborne prospection of areas bordering Permo-Carboniferous and Devonian basins.

In 1977, airborne prospection began across a wide area of Uruguay with the aim of defining zones for detailed exploration. Throughout a 3-year period, an area of 24 435 km² was covered and 37 900 line-km flown on a 500 m × 500 m grid. The areas flown were in the Departments of Cerro Largo, Tucuarembo, Durazno, Treinta y Tres, Lavallejo, Rocha, Maldonado and Florida. Some detailed follow-up work was performed in the Cerro Largo and Las Canas districts, consisting of mapping, geochemical sampling, radiometric and emanometric surveys and limited a drilling campaign.

In April 1981, a nationwide mineral exploration project was started under the framework of a contract between the Government and the French Bureau de Recherches Géologiques et Minières (BRGM). The methods applied included radiometrics, geochemistry, geophysics and drilling. The first phase of this project was completed in August 1983. Favourable areas were defined and occurrences of uranium mineralization detected.

A second phase of this project, which ended in early 1985, included a drilling programme to test the Permo-Carboniferous sedimentary basin in NE Uruguay. Personnel from the National Directorate of

Mining and Geology (DINAMIGE), which is Government funded, provided geological support for the drilling programme. In addition, prospects in the crystalline basement of Upper Proterozoic age were evaluated by DINAMIGE. This work continued in 1986.

In 1987 and 1988, assessment focused on four large areas covering 1200 km². The investigations included radiometrics, rock geochemistry, electrical geophysical methods and detailed geological mapping, as well as some trenching, pitting and tunnelling. This work resulted in an improved definition of three prospects and further evaluation was planned.

An area of some 70 000 km² is reserved for uranium exploration by DINAMIGE [25.6].

8.25.4.2. Expenditures and drilling effort

Figure 8.51. summarizes historical exploration data for a total of USD $239 800 including 4 939 metres of drilling.

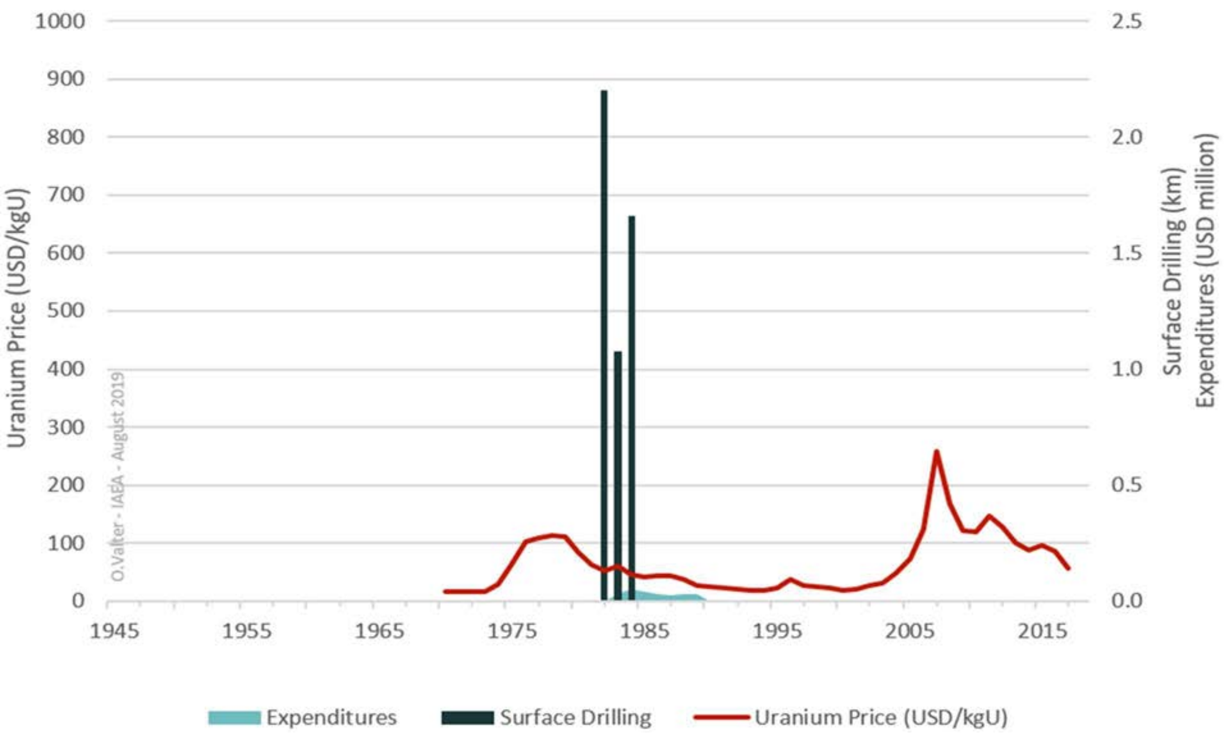


FIG. 8.51. Domestic uranium exploration data for Uruguay. Comparison of exploration expenditures, drilling and uranium market price (US$ current)

8.25.4.3. Recent and ongoing uranium exploration and mine development activities

DINAMIGE reported in 2007 that it was considering launching a bidding process with respect to uranium exploration. DINAMIGE was not prepared for the high degree of interest shown by several firms in exploring in Uruguay and was at the time taking into consideration starting a bidding process in areas of interest. The official parties had until mid-September 2007 to present plans. Uruguayan mining law ascertains that minerals with energy purposes are to be given special treatment and the State retains exclusive rights to mining. As such, bidding processes are required for third-party exploratory studies. The outcome of these events is not known [25.7].

8.25.5. Uranium resources

There are no resources reported and no deposits listed by UDEPO.

The UDEPO database does not list any known deposits for Uruguay.

8.25.6. Potential for new discoveries

Under the classification of 'countries with limited potential', IUREP has reported the possibility of uranium mineralization occurring in Permo-Carboniferous sandstones in the Paraguay and Uruguay portions of the Paraná Basin [25.2]. References [25.2, 25.5] provide more details on Uruguay's potential.

8.25.7. National policies related to uranium

In May 2007, the Government announced it would invite potential investors and mining enterprises to conduct further uranium exploration. It is unclear whether this transpired [25.8].

References to Section 8.25

[25.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Uruguay, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (2009).

[25.2] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[25.3] ALDEN, A., Generalized Geologic Map of Uruguay, http://geology.about.com/library/bl/maps/bluruguaymap.htm

[25.4] URUGUAY MINERALS, Geology, http://www.uruguayminerals.com/explorations/introduction/geology/ (2007).

[25.5] ADMINISTRACIÓN NACIONAL DE COMBUSTIBLES, ALCOHOLES Y PORTLAND (ANCAP), paper presented at IAEA Regional Training Course on Uranium Geology and Exploration, Poços de Caldas, 2009.

[25.6] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand 1990, OECD, Paris (1990).

[25.7] BUSINESS NEWS AMERICAS, Uruguay considers launching bid for uranium exploration (30 July 2007).

[25.8] FINANCIAL TIMES, Uruguay to invite companies for uranium exploration (14 May 2007).

8.26. VENEZUELA

8.26.1. Geography

Venezuela is located in the northern part of South America. It borders the Caribbean Sea and has land borders with Guyana, Brazil and Colombia. The country also includes at least 70 islands. The majority of the population lives along the north coast.

The Venezuelan Mountains are represented by two distinct and separate mountain systems: the Andes system to the west and the Montañoso system to the north and east. An arc of northern mountains with peaks rising to elevations of 4877 m extends from the border with Colombia to the Atlantic Ocean. Within this group of mountains are several ranges, including two coastal ranges and the Eastern Highlands. Lake Maracaibo and the Gulf of Venezuela are encompassed by the nearly level Maracaibo Lowlands, while the region between the northern mountains and the Orinoco River contain the Orinoco Lowlands. Extensive salt flats occur along the Atlantic coast in eastern Venezuela.

Venezuela has some of the largest oil and gas reserves in the world and consistently ranks among the world's top ten crude oil producers. The country has non-conventional oil deposits (extra heavy crude oil, bitumen and tar sands) roughly equal to the world's reserves of conventional oil. Other natural resources include iron ore, gold, bauxite, hydropower and diamonds [26.1, 26.2].

8.26.2. Geology

8.26.2.1. General

Venezuela is divided geologically as well as topographically into three large regions, which are, from SE to NW: (i) Guyana Province, (ii) Llanos Province, and (iii) the Venezuelan Mountains and Maracaibo Basin.

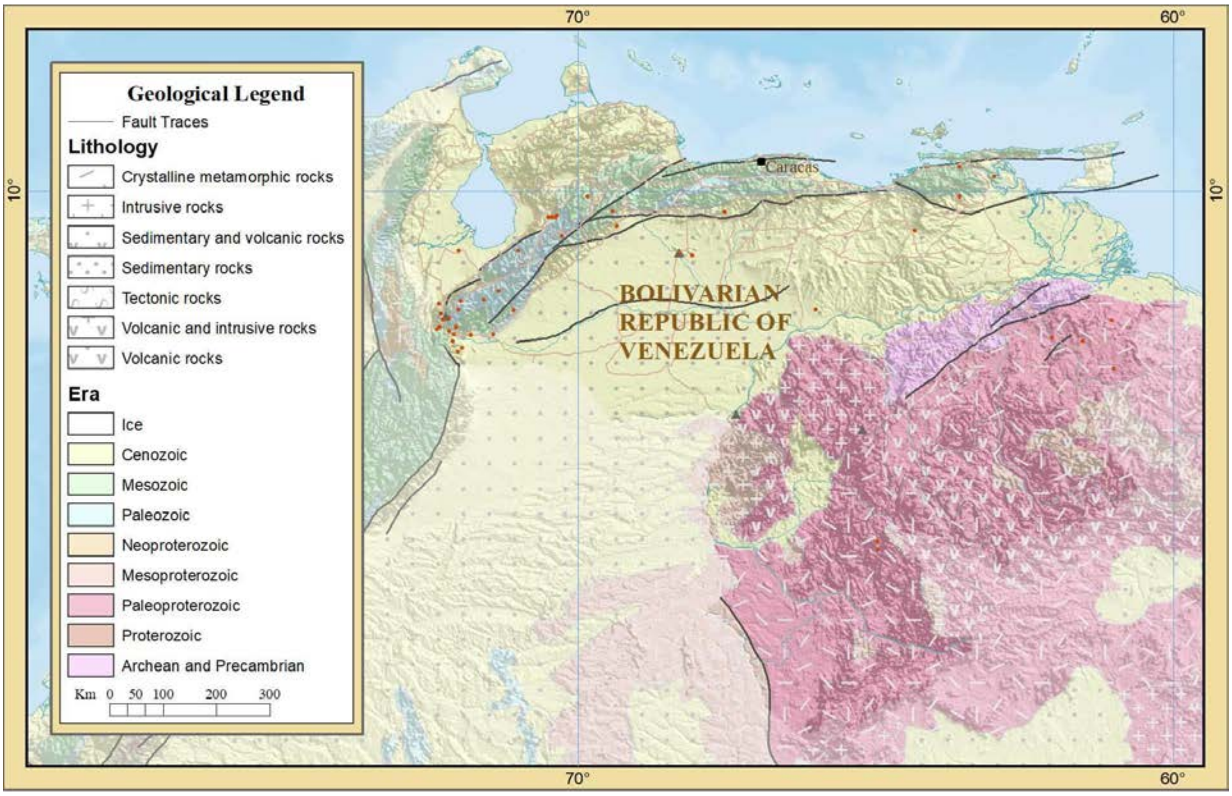


FIG. 8.51. Regional geological setting and uranium mineralisation of Venezuela. For the general uranium deposit and uranium occurrence legend see Fig. 2.1b. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Precambrian rocks of the Guyana Shield cover south-eastern Venezuela (Fig. 8.51). It is an extremely rugged and inaccessible region consisting of ~425 000 km² at elevations of 300–3000 m. The entire area is covered by equatorial forest except for the high Roraima plateaux. The Roraima Province near the centre of the Guyana Shield consists of high plateaux and various outliers of continental sandstone and conglomerate of Middle and Upper Proterozoic age.

The northern part of the Brazilian Shield crops out in Venezuela in Bolívar State and in the territories of Delta Amacuro and Amazonas. Three general groups of rocks are recognized, granites, gneisses and schists of the Archaean basement complex, as well as two overlying younger series of sandstones, quartzites, shales, tuffs and mafic intrusions. The two series are separated by a major unconformity.

All of the overlying Lower Proterozoic rocks are moderately folded and metamorphosed and are intruded by granitic bodies.

The Llanos, a large lowland area situated between the Venezuelan Andes to the north and the Guyana Shield to the south, is very flat and covers an area of ~260 000 km² at an average elevation of ~150 m. Very extensive oil exploration has defined the existence of two deep basins separated by the NW–SE trending El Baul Saddle structure.

The basins are filled with Mesozoic and thick Cenozoic sediments. Relatively small oilfields have been found in the Barinas-Apure Basin to the west, in contrast to the Eastern Venezuela Basin which hosts the largest oilfields in Venezuela. Much of the basinal area is covered by thick Quaternary sediments deposited by the Apure and Orinoco Rivers.

There are no outcrops in this very large flat province, except in the NE where Upper Tertiary sediments are exposed. Also, a few Palaeozoic plutonic and volcanic outcrops of the El Baul saddle are exposed between the two basins.

The Venezuelan Mountains are represented by two distinct and separate systems: the Andes system to the west and the Montañoso system to the north and east.

The Merida Andes are ~425 km long, 80 km wide and up to almost 5000 m in elevation. The mountain ranges are extremely steep and rise abruptly from the adjoining flatlands. They cover a surface area of ~34 000 km². There is a metamorphic crystalline core with considerable granitization and minor volcanic activity terminating at the end of Permian time. Thick Palaeozoic and Mesozoic sedimentary rocks form the bulk of the mountains, with minor remnants of early Tertiary rocks. The main structural features are horsts and grabens associated with the normal fault pattern in which three directions predominate, a longitudinal direction which trends roughly NE and the two others which cut it at an angle of roughly 30°. Despite the Venezuelan Andes systems having a long tectonic history extending from the Palaeozoic to the Cenozoic, the present structural framework was formed throughout the Tertiary. The actual uplift of the Andes began after the Eocene, and movement persisted into the Pliocene when the mountains assumed their present form.

The Sierra de Perija is 250 km long and up to 3600 m in elevation, rising steeply from the intermontane basins. The crest of the mountains forms the border between Colombia and Venezuela. The surface area of the Sierra de Perija is ~7500 km². Owing to the steep terrain and the dense undergrowth, the geology of this area has not been mapped in detail. The core of the steep mountains is composed of Precambrian and Palaeozoic metamorphic strata and this core is covered mainly by Pennsylvanian, Permian and Mesozoic sedimentary rocks [26.3].

8.26.2.2. Potentially favourable uranium-bearing areas

There are no known uranium deposits in Venezuela. The Precambrian rocks have been little studied but are considered to have high potential for hosting uranium mineralization, especially Proterozoic unconformity-related deposits underlying the Roraima Series. As in the Northern Territory of Australia, many of the rocks that underlie the unconformity are Lower Proterozoic metasediments and metavolcanics, generally greenschists, which have been moderately folded and faulted. Some of the metasediments are carbonaceous and many are pyritic. These are intruded over extensive areas by younger granite or overlie an older gneissic basement. More than half of the surface underlying the Roraima Series probably consists of granite and gneisses, therefore resembling the general geological situation in northern Saskatchewan, Canada.

The unconformity has been above sea level since the Tertiary period. The base of the Roraima Series is rarely exposed and is frequently obscured by a large talus pile accumulated from cliff-falls of Roraima rocks. The zone of unconformity is believed to have had a tectonic history similar to that of the sub-Kombolgie in northern Australia.

The Guyana Shield may also contain economic deposits of uranium in quartz-pebble conglomerates. In addition, there appears to be a more limited potential for sandstone, disseminated and vein uranium deposits in the Andean areas. Details have been provided in the 1985 IUREP Orientation phase mission in Venezuela [26.4].

The potential for roll front sandstone deposits in the El Baul granite area and a proposed depositional model showing roll front and tabular orebodies in the Los Andes area, south of Maracaibo, which have similarities to those in Kazakhstan [26.4–26.6].

8.26.3. Uranium exploration

8.26.3.1. Historical review

According to IUREP, investigations for radioactive materials have been undertaken at various times throughout the period 1939–1979 [26.5]. In 1951, the Ministry of Mines and Hydrocarbons invited US Geological Survey geologists to participate in a three-month reconnaissance project consisting of a bibliographic compilation, examination and evaluation of radiometric logs from 140 oil wells, as well as a radiometric survey. Consequently, prospects were recognized in phosphatic shales (La Luna Formation, Tachira, Merida and Trujillo), low grade placer deposits (Bolívar State) and in carnotite- and copper-bearing sandstones of the La Quinta Formation (Tachira, stratigraphic equivalent of the Giron group of Colombia).

Subsequently, geologists from the Ministry of Mines and Hydrocarbons and contractors carried out car-borne radiometric and geochemical surveys and large scale airborne radiometric surveys. Hunting Geology and Geophysics Limited and Aeroservice Corporation surveyed Bolívar State and part of Zulia State on the western border in 1960–1962. Total airborne radiometric coverage amounted to 288 500 km², which equates to ~32% of the country. Since 1951, radioactive minerals have been reported at Rio Candelaria and Santa Catalina.

An extensive uranium exploration project comprising car-borne radiometric and geochemical surveys was carried out by the National Nuclear Industry Board and the Ministry of Energy and Mines. Exploration continued in 1979 under the Directorate of Geology and Geophysics, part of the Ministry of Energy and Mines.

In 1981, uranium related activities decreased and were limited to the uranium assessment by IUREP and the conclusion of an agreement between the Institute of Geochemistry of the Central University of Venezuela and CADAFE, the Government utility company, for a geochemical research programme investigating the behaviour of uranium in a tropical environment.

Though a total of 990 600 km² was covered by airborne and other surveys, a large part of the interior remained unsurveyed. A track etch survey was undertaken in 1983–1984 over the El Baul (Cojedes) occurrence, where uranium–thorium mineralization is associated with the younger fine-grained facies of a granite. In addition, ground follow-up of the radiometric anomalies in the Amazonas Territory was carried out. In the late 1980s, detailed exploration was undertaken on the Chiguara prospect (Merida), as well as on the anomalies detected by airborne radiometrics in the Amazonas Territory. The assessment of phosphates around Jaji (Merida) was planned. Information on the results of these investigations and on current exploration activities in Venezuela is not available [26.4, 26.5].

8.26.3.2. Work done and results achieved

IUREP's Orientation Phase Mission reported anomalies in the following locations (States):

(a) Andean region: Tachira, Merida and Trujillo;
(b) Guyana Shield: Bolívar and Amazonas Territory;
(c) Llanos Province: Cojedes, Anzoategui, Monegas and Sucre.

8.26.3.3. Recent uranium exploration activities

References [26.5–26.7] describe recent exploration activities and the deposit types and models currently being studied.

The Islamic Republic of Iran has been assisting Venezuela in exploring for uranium deposits and initial evaluations suggested resources are significant, according to a Government statement made on 25 September 2009 [26.8]. Specifically, it has been assisting Venezuela with geophysical survey flights and geochemical analysis of the deposits and those evaluations reportedly indicate the existence of uranium in western parts of the country and in Santa Elena de Uairén, in south-eastern Bolívar State. No further information is available.

A cooperation agreement for the use of nuclear energy for peaceful purposes between Venezuela and the Russian Federation was passed by the National Assembly and published in the Official Gazette No. 368.817 dated 4 May 2009. Details of the agreement provide for the exploration and development of uranium and thorium deposits and their use for peaceful purposes [26.9]. The agreement also includes the development of nuclear infrastructure, the safety of nuclear facilities and radioactive sources, and industrial production of components and materials to be used in nuclear reactors, among others.

8.26.4. Uranium resources

8.26.4.1. Inferred resources

There are no known uranium deposits in Venezuela. There were reports of a deposit discovered in 1967 in basement strata in eastern Venezuela, near the border with Brazil. Preliminary assays were stated to be roughly 0.3–0.5% U_3O_8. No other data are available.

8.26.4.2. Undiscovered resources

In the 1986 Red Book [26.9], Venezuela reported speculative (in situ) resources totalling 163 000 tU distributed among the following deposit types: quartz-pebble conglomerate, unconformity-related, disseminated, vein, sandstone and surficial (Table 8.29).

In addition, unconventional resources from Cretaceous phosphates are estimated at 42 000 tU.

The IUREP mission estimated speculative resources of between 2000 and 42 000 tU, including 2000–6000 tU recoverable as a by-product from the processing of the Navay Formation phosphates [26.4]. Of the total, 25 000 tU were hosted in the Guyana Shield.

The UDEPO database lists the most significant deposits for Venezuela as Navay Zone, Monte Fresco.

TABLE 8.29. SPECULATIVE (IN SITU) RESOURCES (tU)

Deposit type	Resource (tU)
Quartz-pebble conglomerate	10 000
Unconformity-related	140 000
Disseminated magmatic, pegmatitic and contact deposits in igneous and metamorphic rocks	5 000
Vein	2 000
Sandstone	3 000
Surficial	3 000

8.26.5. Potential for new discoveries

IUREP's 1980 report [26.3] stated that, from the standpoint of potential, Precambrian strata are perhaps of most interest, although there is a possibility of finding all types of deposit in Venezuela with the exception of calcrete.

The most interesting formation, as regards uranium potential, is the Roraima Series, or the sub-Roraima unconformity. This continental series consists of fluvial sandstones with minor conglomerates near the base and is similar to the Athabasca and Kombolgie sandstones of Canada and Australia, respectively. The Roraima Series may merit exploration for sandstone type deposits if reducing environments can be shown to be present within the rocks.

IUREP has suggested that a first priority for any exploration programme would be to investigate the potential for unconformity-related type deposits, as these may occur below the Roraima sandstone. The second priority should be exploration for hydrothermal vein type deposits in igneous and metamorphic rocks. The third priority should be directed at stockwork and breccia pipe deposits in the volcanic rocks of Cuchivero Province, which cover an area of ~15 000 km^2.

The IUREP mission reported that deposits in the Guyana Shield would likely be relatively small, as most of the host rocks are mantle-derived rather than of the sialic crust origin. The 1985 IUREP report gives more detail and recommendations for exploration methods in different areas [26.4].

Radioactive minerals have been found in detrital black sand beds in the basal part of the Roraima Series at Peraitepuy. In 1980, IUREP reported that this suspected radioactivity may be due to thorium.

One of the anomalies detected by a radiometric survey of the Amazonas Territory is the Cerro Impacto. Groundwork, including geophysical and geochemical investigations, as well as a limited drilling programme, supported by laboratory work, resulted in the recognition of a carbonatite complex with associated thorium, zirconium, niobium and rare earth element mineralization.

8.26.6. National and local policies related to uranium

In 1980, IUREP reported that, at least theoretically, the States of the Venezuelan Union own mineral deposits located within their borders, but in practice the Federal Ministry of Mines and Hydrocarbons controls all mineral resource development. At the time, concessions were generally available to any person or company, both national and foreign. The 1986 Red Book states that the entire national territory is reserved for the State for uranium exploration and production, which is represented in this field by CONADIN and the Ministry of Energy and Mines [26.9].

References to Section 8.26

[26.1] CENTRAL INTELLIGENCE AGENCY, The World Factbook: Venezuela, Washington, DC, https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed April 2010).

[26.2] LIBRARY OF CONGRESS, FEDERAL RESEARCH DIVISION, Country Profile: Venezuela March 2005, http://lcweb2.loc.gov/frd/cs/profiles/Venezuela.pdf (2005).

[26.3] OECD NUCLEAR ENERGY AGENCY–INTERNATIONAL ATOMIC ENERGY AGENCY JOINT STEERING GROUP ON URANIUM RESOURCES, World Uranium: Geology and Resource Potential, Report on Phase 1, International Uranium Resources Evaluation Project (IUREP), Miller Freeman Publications, San Francisco (1980) 524 pp.

[26.4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, International Uranium Resources Evaluation Project (IUREP) Orientation Phase Mission, Summary Report: Venezuela, OECD, Paris (1985).

[26.5] THEIS, R., Rusia colaborará con Venezuela para la explotación de uranio Caracas, El Universel (8 May 2009), http://www.eluniversal.com/2009/05/08/pol_art_rusia-colaborara-con_1378541.html

[26.6] RIVAS, I., DAVILA, L., "Uranium Geology in Venezuela", paper presented at IAEA Regional Training Course on Uranium Geology and Exploration, Poços de Caldas, 2009.

[26.7] PASQUALI, J., SIFONTES R., Exploración de Uranio en Venezuela, Universidad Central de Venezuela, Instituto de Ciencias de la Tierra, Caracas (2007).

[26.8] BOSTON GLOBE, Iran assists Venezuela with search for uranium deposits (25 September 2009).

[26.9] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand 1986, OECD, Paris (1986).

Appendix I

IUREP (INTERNATIONAL URANIUM RESOURCES EVALUATION PROJECT)

The objective of the International Uranium Resources Evaluation Project (IUREP) was to review the state of knowledge pertinent to the existence of uranium resources, to review and evaluate the potential for discovery of additional resources and to suggest new exploration activities which might be carried out in promising new areas in collaboration with the concerned countries. 176 Countries were proposed to be assessed for the 'World Outside the Centrally-planned economies Area' (WOCA), as well as Eastern Europe (collectively Romania, Hungary, Bulgaria, Czechoslovakia, Poland and the German Democratic Republic) the USSR and China.

Phase I of IUREP studies, undertaken from November 1976 to June 1978, consisted of conducting initial bibliographic information studies and national favourability studies. Information on the following was collected by approximately 30 consultant experts:

- General geography, including the area, population, climate, terrain, communications, means of access to different areas and, when available, a brief summary of the laws which would be pertinent to an exploration programme;
- Geology in relation to potentially favourable uranium bearing areas;
- Past exploration;
- Uranium occurrences, resources and past production;
- Present status of exploration;
- Potential for new discoveries.

At the end of Phase I of IUREP (June 1978), a report by the Joint Steering Group on Uranium Resources of the OECD Nuclear Energy Agency and the IAEA compiled data on 165 countries and was released in December 1978. The information was published, with minor updates to the identified resources, geology and production, as World Uranium: Geology and Resource Potential, Report on Phase I of the International Uranium Resources Evaluation Project, Miller Freeman Publications, San Francisco (1980).

135 individual reports are available in INIS: http://inis.iaea.org/search/default.aspx. A significant number of reports, particularly for African countries, cannot be found, but summarised information for most of these can be found in an anonymous unpublished IAEA report, Speculative Resources of Uranium: A Review of IUREP Estimates 1982-83, was completed in 1983. Several countries have no data, such as Botswana, Lesotho, Malawi, Namibia and South Africa, many of which are now known to have significant potential for uranium resources.

FAVOURABILITY STUDIES

Afghanistan	NFS 4, J. Cameron, Dec. 1976
Algeria[#]	NFS 18, P. Barretto, July 1977
Angola[#]	NFS 156, P. Barretto, Dec. 1977.
Antigua	NFS 75, USERDA, Aug. 1977
Argentina	NFS 38, USERDA, Aug. 1977
Australia	NFS 67, Australian Atomic Energy Commission, Aug. 1977
Austria	NFS 96, F. Barthel, Oct. 1977
Bahamas	NFS 73, USERDA, Aug. 1977
Bahrain	NFS 125, J. Bowman, Nov. 1977
Bangladesh	NFS 160, S. Simov, Jan. 1978
Barbados	NFS 61, USERDA, Aug. 1977
Belgium	NFS 162, GEC, Dec. 1977
Belize (Former British Honduras)	NFS 39, USERDA, Aug. 1977
Bermuda	NFS 51, USERDA, Aug. 1977
Bhutan	NFS 151, S. Simov, Dec. 1977
Bolivia	NFS 40, USERDA, Aug. 1977
Brazil	NFS 17, Unknown*, June 1977
Brunei	NFS 166, M.V. Hansen, Feb. 1978
Burkina Faso (Former Upper Volta)	NFS 33, P. Baretto, July 1977

Burma	NFS 101, S. Simov, Oct. 1977
Cabo Verde	NFS 31, P. Baretto, July 1977
Cameroon#	NFS 3, Unknown*, Dec. 1976
Canada	NFS 88, V. Ruzicka, Aug. 1977
Cayman Islands	NFS 113, M.V. Hansen, Nov. 1977
Central African Republic#	NFS 9, J. Cameron, May 1977
Chad	NFS 159, Unknown*, 1977
Chad#	NFS 208, P. Barretto, Mar. 1978
Chile	NFS 41, USERDA, Aug. 1977
China	NFS 99, M.V. Hansen, Oct. 1977
Colombia	NFS 82, USERDA, Aug. 1977
Comoros Islands	NFS141, M.V. Hansen, Dec. 1977
Congo (The Congo)#	NFS165, S. Simov, Feb. 1978
Congo, Democratic Republic# (formerly Zaire)	NFS 119, Unknown*, Nov. 1977
Cook Islands	NFS110, M.V. Hansen, Nov. 1977
Costa Rica	NFS 74, USERDA, Aug. 1977
Cuba	NFS 48, USERDA, Aug 1977
Cyprus	NFS 11, J. Cameron, Nov. 1977
Dahomey (Benin)	NFS 27, P. Baretto, July 1977
Democratic Kampuchea (Cambodia)	NFS 100, M.V. Hansen, J. Bowman, Oct. 1977
Denmark (Greenland)	NFS 130, Federal Institute for Geosciences and Natural Resources, Nov. 1977
Djibouti	NFS 87, M.V. Hansen, Sept. 1977
Dominica	NFS 52, USERDA, Aug. 1977
Dominican Republic	NFS 54, USDERDA, Aug. 1977
Ecuador	NFS 81, USERDA, Aug. 1977
Egypt#	NFS 1, J. Cameron, Dec. 1976
El Salvador	NFS 42, IJSERM, Aug. 1977
Ethiopia#	NFS 37, M. V. Hansen, Aug. 1977
Falkland Islands**	NFS 161, USERDA, Jan. 1978
Fiji Islands	NFS 146, M.V. Hansen, 1977
Finland	NFS 129, Federal Institute for Geosciences and Natural Resources, Nov. 1977
France	NFS 92, CEA France, Sept. 1977
French Guiana	NFS 59, USERDA, Aug. 1977
French Polynesia	NFS 135, M.V. Hansen, Dec. 1977
Gabon#	NFS 91, S. Simov, Sep. 1977
Gambia	NFS 32, P. Baretto, July 1977
Ghana#	NFS 13, P. Barretto, June 1977
Germany, Federal Republic	NFS 93, F. Barthel, Oct. 1977
Gilbert and Ellice Islands	NFS 114, M.V. Hansen, Nov. 1977
Greece	NFS 104, CEA France, Oct. 1977
Grenada	NFS 53, USERDA, Aug. 1977
Guinea#	NFS 36, P. Barretto, Aug. 1977
Guinea-Bissou#	NFS 29, Barretto, July 1977
Guadeloupe	NFS 77, USERDA, Aug. 1977
Guatemala	NFS 43, USERDA, Aug. 1977
Guyana	NFS 60, Unknown*, Aug. 1977
Guinea	NFS 36 P. Baretto, Aug. 1977
Guinea-Bissau	NFS 29, P. Baretto, July 1977
Haïti	HFS 71, USERDA, Aug. 1977
Honduras	NFS 44, USERDA, Aug. 1977
Hong Kong	NFS 112, M.V. Hansen Nov. 1977
India	NFS 64, J. Cameron, Aug. 1977
Indonesia	NFS 97, J. Cameron, Oct. 1977
Iran	NFS 138, Unknown*, Dec. 1977
Iraq	NFS 127, J. Cameron, Oct. 1977
Ireland	NFS 103, CEA France, Oct. 1977
Israel	NFS 139, J. Cameron, Dec. 1977
Ivory Coast# (Côte d'Ivoire)	NFS 35, P. Barretto, Aug. 1977

Italy	NFS 94, F.Pantanetti, Oct. 1977
Jamaica	NFS 78, USERDA, Aug. 1977
Jordan	NFS 49, J. Cameron, Aug. 1977
Kenya	NFS19, M.V. Hansen, July 1977
Korea, Republic of	NFS 154, M.V. Hansen, Dec. 1977
Kuwait	NFS 126, J. Bowman, Nov. 1977
Laos	NFS 109, M.V. Hans, J. Bowman, Nov. 1977
Lebanon	NFS 102 J. Cameron, Oct. 1977
Liberia	NFS 34, P. Baretto, July 1977
Libya#	NFS 8, J. Cameron, May 1977
Luxembourg	NFS 163, GEC, Dec. 1977
Madagascar#	NFS 10, J. Cameron, May 1977
Malaysia	NFS 152, M.V. Hansen, J. Bowman, Dec. 1977
Maldives	NFS 128, M.V. Hansen, Nov. 1977
Mali#	NFS 15, P. Barretto, July 1977
Martinique	NFS 80, USERDA, Aug. 1977
Mauritania	NFS 34, P. Baretto, July 1977
Mauritius	NFS 144, M.V. Hansen, Dec. 1977
Mexico	NFS 20, J. Cameron, July 1977
Mongolia	NFS 150, M.V. Hansen, Dec. 1977
Morocco#	NFS 14, P. Barretto, June 1977
Mozambique#	NFS 155, P. Barretto, Dec. 1977
Nauru	NFS 142, M.V. Hansen, 1977
Nepal	NFS 158, S. Simov, Dec. 1977
Netherlands	NFS 164, Unknown*, Jan. 1978
Netherlands Antilles	NFS 79, USERDA, Aug. 1977
New Caledonia	NFS 149, M.V. Hansen, Dec. 1977
New Hebrides	NFS 147, M.V. Hansen, Dec. 1977
New Zealand	NFS 66, Australian Atomic Energy Commission, Aug. 1977
Nicaragua	NFS 45, USERDA, Aug. 1977
Niger#	NFS 11, J. Cameron, May 1977
Nigeria#	NFS 89, S. Simov, Oct. 1977
Niue	NFS 140, M.V. Hansen, Dec. 1977
Norfolk and Lord Howe Islands	NFS 65, Australian Atomic Energy Commission, Aug. 1977
Norway	NFS 133, Federal Institute for Geosciences and Natural Resources, Nov. 1977
Oman	NFS 124, J. Bowman, Nov. 1977
Pakistan	NFS 5, J. Cameron, Dec. 1976
Panama	NFS 58, USERDA, Aug. 1977
Papua New Guinea	NFS 68, Australian Atomic Energy Commission, Aug. 1977
Paraguay	NFS 44, USERDA, Aug. 1977
Peru	NFS 57, USERDA, Aug. 1977
Philippines	NFS 6, J. Cameron, Dec. 1976
Portugal	NFS 85, CEA France, Oct. 1977
Portugese Timor	NFS 143, M.V. Hansen, Dec. 1977
Puerto Rico	NFS 55, USERDA, Aug. 1977
Qatar	NFS 123, J. Bowman, Aug.1977
Saudi Arabia	NFS 90, J. Cameron, Sept. 1977
Singapore	NFS 134, M.V. Hansen, Dec. 1977
Senegal	NFS 16, P. Baretto, June 1977
Sierra Leone	NFS 30, P. Baretto, July 1977
Sikkim	NFS 115, S. Simov, Nov. 1977
Solomon Islands	NFS 136, M.V. Hansen, Dec. 1977
Somalia#	NFS 2, J. Cameron, Dec. 1976
Spain	NFS 107, NA, 1977
Sri Lanka	NFS 105, J. Cameron, Oct. 1977
St. Christopher, Nevis and Anguilla	NFS 63, USERDA, Aug. 1977
St. Lucia	NFS 62, USERDA, Aug. 1977
St. Vincent	NFS 47, USERDA, Aug. 1977
Sudan#	NFS 98, M. V. Hansen, Oct. 1977

Surinam	NFS 56, USERDA, Aug. 1977
Sweden	NFS 132, Federal Institute for Geosciences and Natural Resources, Nov. 1977
Switzerland	NFS 131, P. Gilleron, F. Barthel
Syria	NFS 121, J. Cameron, Oct.1977
Taiwan	NFS 148, M.V. Hansen, Dec. 1977
Tanzania	NFS 153, M.V. Hansen, Dec. 1977
Thailand	NFS 50, J. Cameron, Aug. 1977
Togo#	NFS 28, P. Barretto, July 1977
Trinidad and Tobago	NFS 72, USERDA, Aug. 1977
Tunisia	NFS 77, P. Baretto, June 1977
Turkey	NFS 84, J. Cameron, Aug 1977
Uganda#	NFS 157, S. Simov, Dec. 1977
United Arab Emirates	NFS 122, J. Bowman, J. Cameron, Oct. 1977
United Kingdom	NFS 108, Unknown*, Oct. 1977
United States of America	NFS 83, USERDA, Aug. 1977
Uruguay	NFS 69, USERDA, Aug. 1977
Venezuela	NFS 70, USERDA, Aug. 1977
Vietnam	NFS 117, J. Bowman, J. Cameron, Oct. 1977
Virgin Islands	NFS 76, USERDA, Aug. 1977
Western Samoa	NFS 145, M.V. Hansen, Dec. 1977
Yemen Arab Republic	NFS 116, J. Bowman, Nov. 1977
Yemen, People's Democratic Republic	NFS 106, J. Bowman, J. Cameron, Oct. 1977
Yugoslavia	NFS 95, F. Barthel, Oct. 1977
Zambia#	NFS 7, J. Cameron, May 1977

* Publisher/author was not specified
** A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).
# No National Favourability Study was located for this country. Details are taken from the 1983 unpublished IAEA report Speculative Resources of Uranium: A Review of IUREP Estimates 1982-83.

Phase I was followed in some countries (20) by a further assessment of the potential for the discovery of additional uranium resources. Such work was accomplished through field missions to the country (Oriented Phase Mission) and included:

- Development of a better understanding of the uranium potential of the country;
- Delineation of areas favourable for the discovery of uranium;
- Recommendations on the best methods for evaluating the favourable areas;
- Estimated costs of the evaluation of these areas.

Summary reports were published in 1982–1985 by the OECD/NEA–IAEA for the 20 countries where field missions were conducted.

IUREP ORIENTATION PHASE MISSION: SUMMARY REPORTS

Austria (1981)
Bolivia (1985)
Burundi (1985)
Cameroon (1985)
Colombia (1984)
Finland (1982)
Ghana (1985)
Madagascar (1985)
Morocco (1985)
Norway (1983)
Peru (1984)
Portugal (1985)
Rwanda (1985)
Somalia (1985)

Sudan (1984)
Thailand (1985)
Turkey (1985)
Uganda (1985)
Venezuela (1985)
Zambia (1985)

IUREP ORIENTATION PHASE MISSION REPORTS

Bolivia	Muller-Kahle, E., Leroy, J. (1982)
Burundi	Gehrisch, W., Chaigne, M. (1983)
Colombia	Cameron J., Meunier S.R. (1980)
Cameroon	de Trey, M., Leney, G.W. (1983)
Ghana	Guelpa, J.P., Vogel, W. (1982)
Madagascar	Meyer, J.H., Brinck, J.W. (1981)
Morocco	Aniel, B., Hetland, D.L., Glasson, P.J. (1983)
Peru	Hetland, D.L., Michie, U.McL. (1981)
Rwanda	Gehrisch, W., Chaigne, M. (1983)
Somalia	Levich, R.A., Muller-Kahle, E. (1983)
Sudan	Kneupper, G., Scivetti, N. (1984)
Thailand	Inazumi, S., Meyer, J.H. (1981)
Turkey	Ziehr, A., Komura, A.(1985)
Uganda	de Trey, M., Levich, R.A. (1977)
Venezuela	Hetland, D.L., Obellianne, J.-M. (1981)

The IUREP study provided insights into possible ranges of speculative uranium resources that could be exploited at costs less than \$130/kg U (with dollar values at the time of assessment, and stated as US \$50/pound of uranium, generally consider to be low to medium cost resources). A summary of the results is shown in Table 1 and Fig. 1 from Cameron, 1982 An International View of Nuclear Raw Materials (Uranium) in Resources for the 21st Century. Proceedings of the Intenernational Centenial Symposium of the Unites States Geological Survey. Professional Paper 119.

TABLE 1. IUREP SPECULATIVE URANIUM RESOURCES OF 185 COUNTRIES BY GEOGRAPHIC REGION

Continent	Number of countries	Speculative resources (Mt U)
Africa	51	1.3 - 4.0
North America	3	2.1 - 3.6
South and Central America	41	0.7 - 1.9
Asia and Far East[a]	41	0.2 - 1.0
Australia and Oceania	18	2.0 - 3.0
Western Europe	22[b]	0.3 - 1.3
Total (WOCA)	176	6.6 - 14.8
Eastern Europe[c]	7	0.3 - 1.3
USSR[d]	1	2.0 - 4.0
China	1	1.0 - 2.0
Total (non-WOCA)	9[b]	3.3 - 7.3

[a] Excluding China and the eastern part of USSR;
[b] variously reported as 23 (Western Europe) and 8 (non-WOCA) respectively in various IUREP sources, presumably due to one unspecified Western European country being considered as part of Eastern Europe or vice versa (likely Albania);
[c] Including Romania, Bulgaria, Hungary, Czechoslovakia, German Democratic Republic and Poland;
[d] Consisting of Russia, Georgia, Uzbekistan, Kazakhstan, Ukraine, Belarus, Azerbaijan, Lithuania, Moldova, Latvia, Kyrgyzstan, Armenia, Tajikistan, Estonia, Turkmenistan).

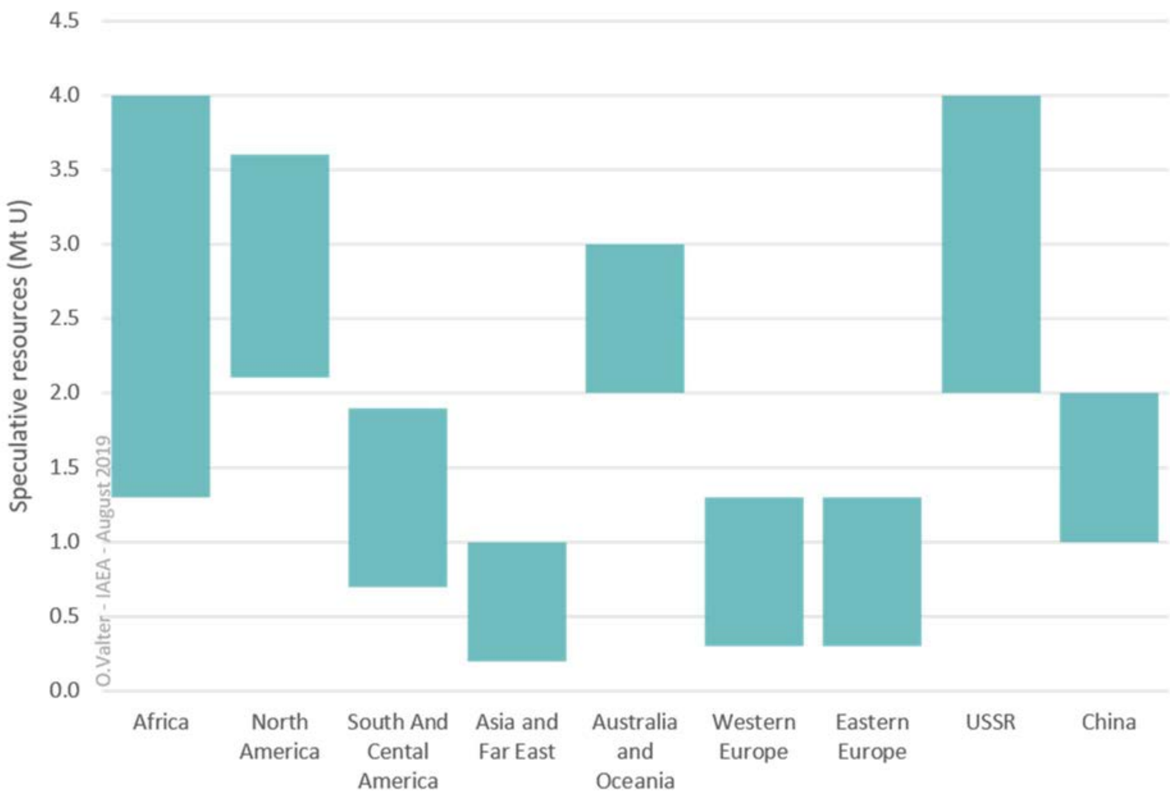


FIG. 1. Ranges of regional IUREP estimates based upon regions.

The 1983 unpublished IAEA report Speculative Resources of Uranium: A Review of IUREP Estimates 1982-83 provided brief revisions of some countries from 'Western Europe', 'Australia and Oceania', 'Africa' and 'Asia and Far East' regions including additional information regarding the confidence of the upper and lower estimates and well as the most likely quartile in which the most confident estimate would be considered to occur (Fig. 2).

.

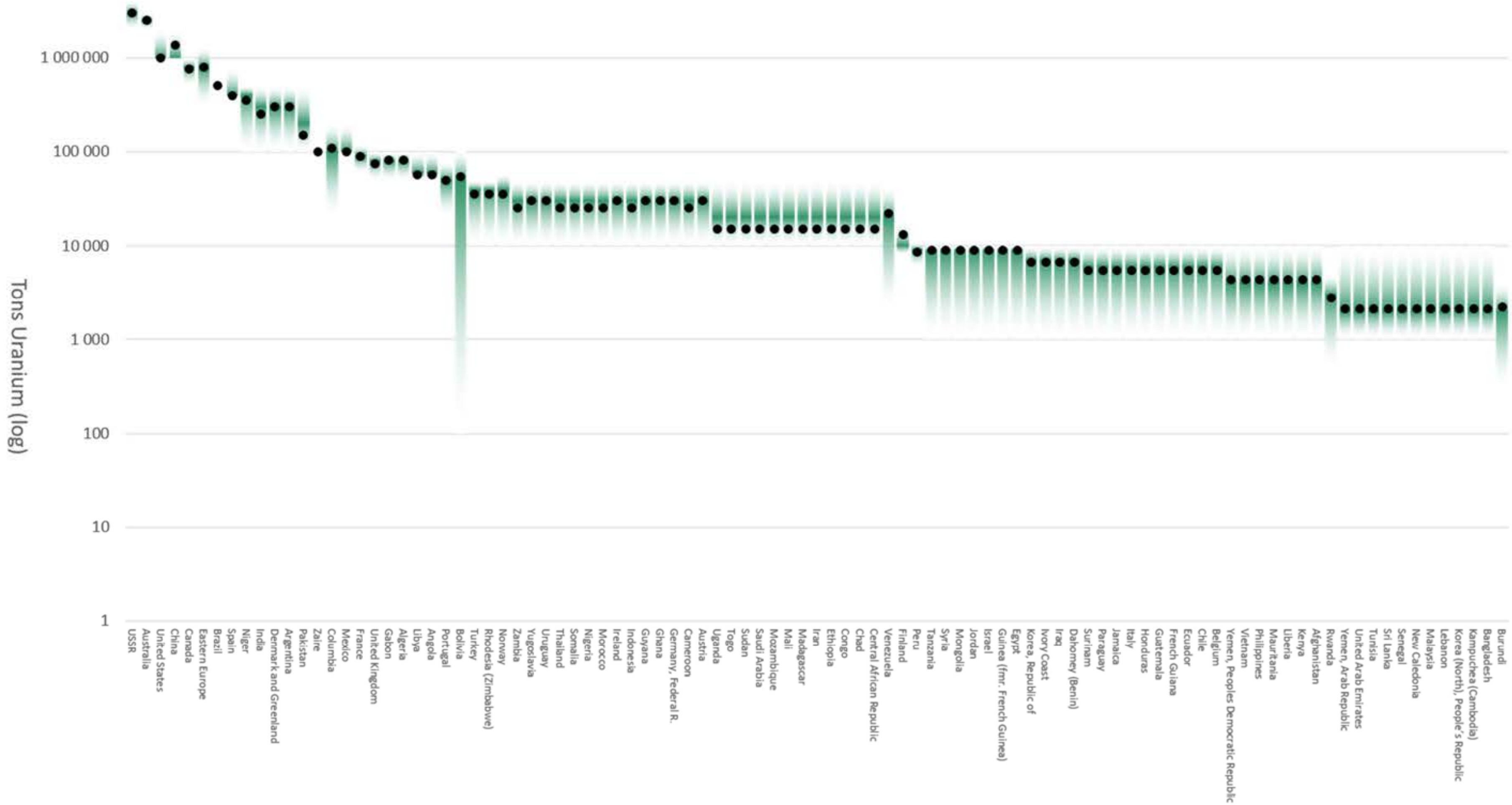


FIG. 2. Range of proposed IUREP speculative resources, showing the most likely value (block dots). Where the most likely quartile is not given, the most likely value is take as the median of the range. In some cases, only a minimum or maximum speculative resource is stated and so the range is displayed as percentage of the absolute value above or below the value. Only countries with 5000 tU or greater are shown.

By assuming that the most likely value between the range is valid, it can be shown that at the time of the IUREP project was completed, the global potential for speculative uranium deposits was dominated by Soviet Union (and associated countries), Australia and North America (Fig. 3 and Fig. 4).

FIG. 3. The most likely speculative regional uranium resource value, with main constituent countries shown.

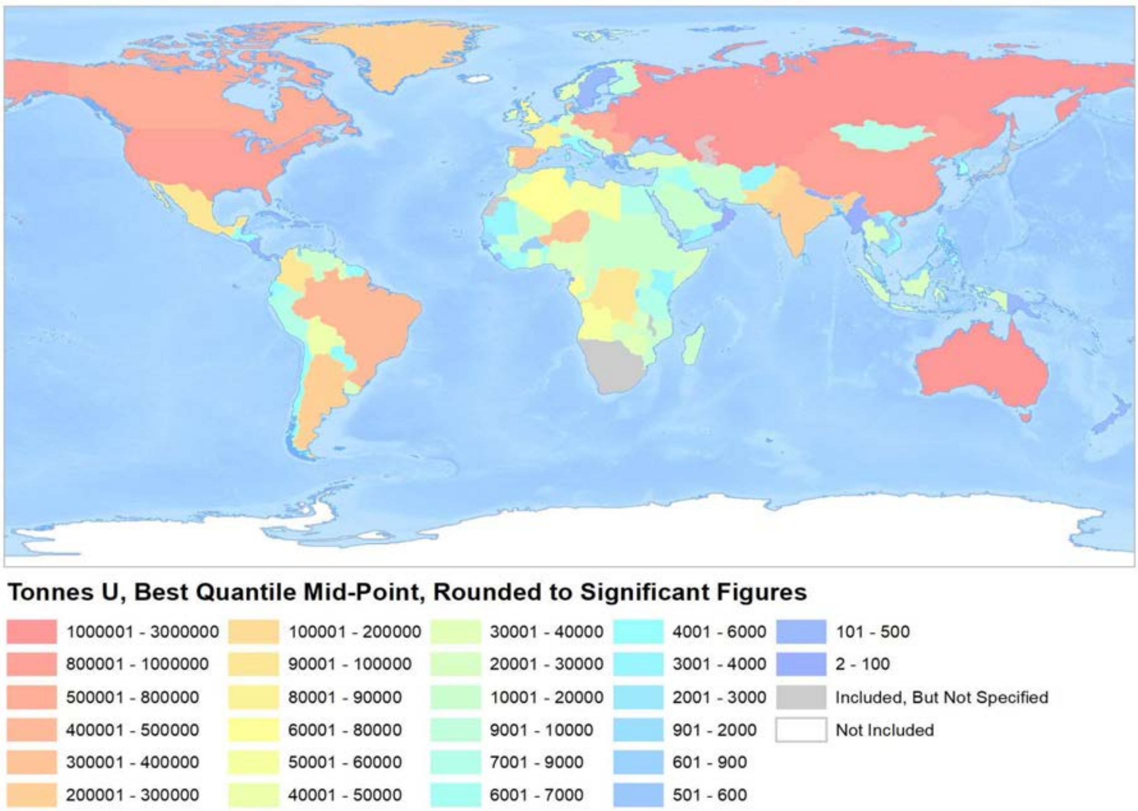


FIG. 4. Distribution of IUREP speculative resources.Areas area generalised from borders during the period of the project ca. early 1980s..

At a global level, the IUREP study assigned the speculative resources to 6 different deposit types:

- Quartz pebble conglomerate deposits;
- Proterozoic unconformity-related deposits;
- Disseminated magmatic, pegmatite and contact deposits in igneous and metamorphic rocks;
- Vein deposits;
- Sandstone deposits;
- Other types of deposits.

At the country report level, attempts were made to classify the speculative resources into 10 deposit types by further subdividing 'other types' into placer, calcrete, surficial and phosphates. Subsequent deposit classification schemes are more detailed (Appendix III), and so a direct mapping is not possible. Most speculative resources in the IUREP study were not classified into deposit types (Fig. 5), but a broad conclusion that they were predicted to be dominated by vein and sandstone deposits can be made (Fig. 6).

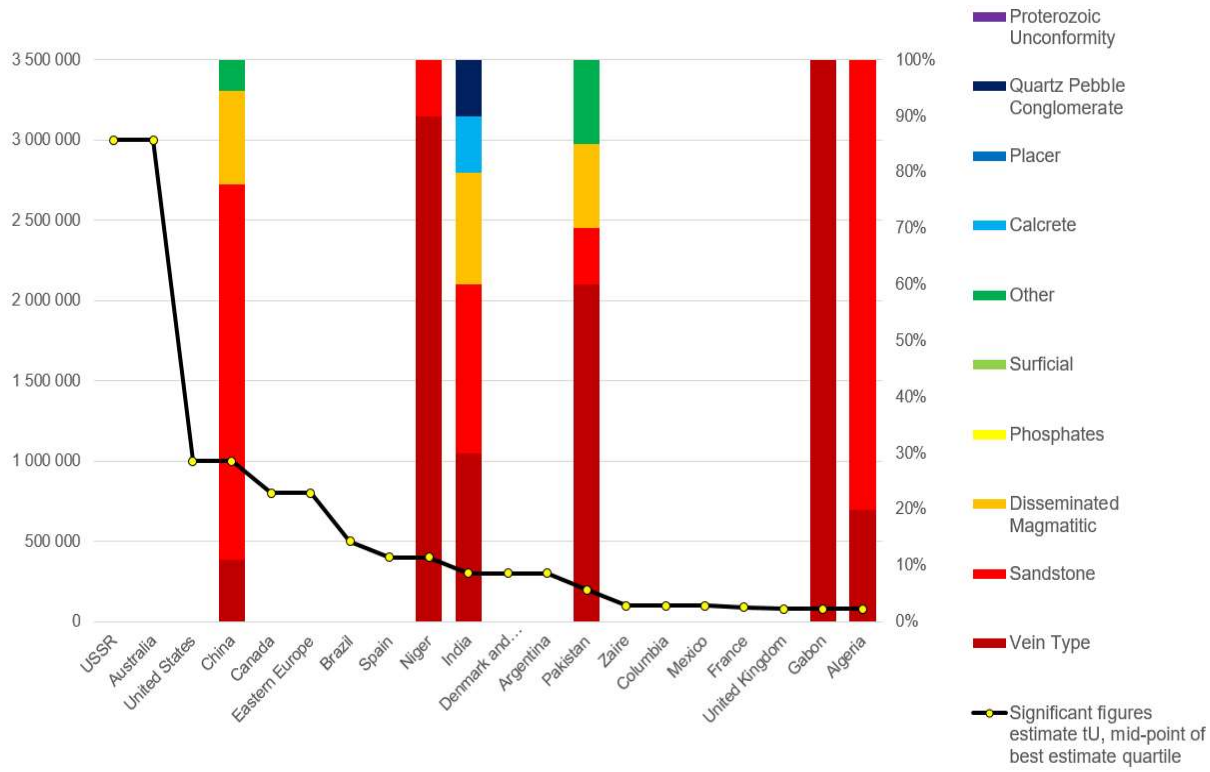


FIG. 5. The top 20 countries (by total estimated speculative resources according to the IUREP project), categorised by the proportions of predicted deposit type.

It is important to note that the IUREP study did not originally provide information for predicted deposit types for Canada, Australia and the non-WOCA countries in the country reports. Accordingly, while the importance of sandstone and vein mineralisation is clear, the potential for substantial resources associated with a new type of deposit at that time, haematite breccia complex (more commonly known in copper research as iron oxide copper gold [+/-uranium] deposits), was not considered (Appendix II). Moreover Proterozoic unconformity deposits were initially significantly underestimated globally. While not included in the primary IUREP summary, a synchronous study by Taylor and Cameron (Uranium Deposits of the Future, 1980 IAEA STI/PUB/555, pp 743-750) separately reassessed the potential of Proterozoic unconformity deposits as a previously underestimated component of speculative uranium resources (included in Table 2). Thus, with increasing knowledge of these deposit types in the Athabasca Basin of Canada and the Pine Creek area of northern Australia during the early 1980's, a more confident assessment could be made indicating that Proterozoic unconformity related deposits were predicted to be a substantial part of post-IUREP future uranium resources could be made. This has proven to be correct, and demonstrates both the limitations of the original estimates, as well as the opportunities for better estimates with increasing geological understanding of the settings of global uranium mineralisation.

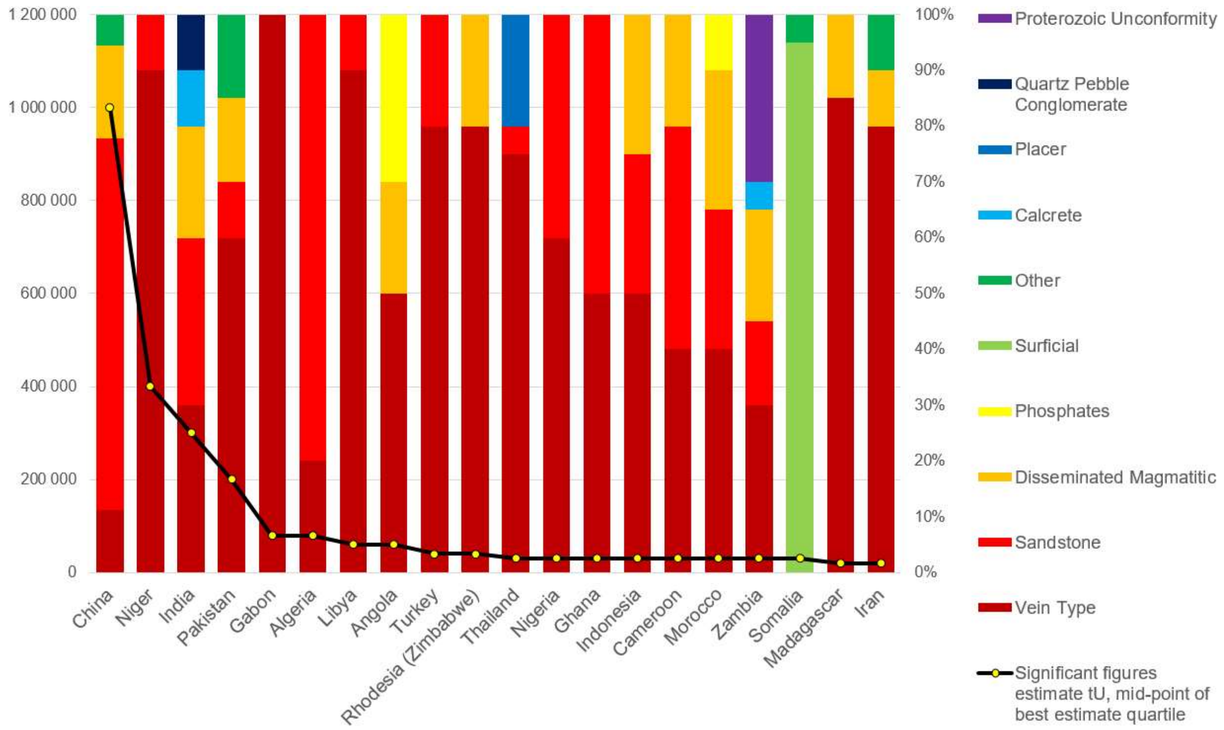


FIG. 6. The top 20 countries (by estimated speculative resources according to the IUREP project) where categorised by the relative proportions of predicted deposit type. For comparison, the most likely total absolute speculative resources (in tU) are also shown. Note that the top 3 countries shown in Fig. 5 (USSR, United Stated of America, and Australia) are not shown because their resources were not subdivided into deposit types in the IUREP study

Taylor and Cameron (Small Veins: A Big Future, in IAEA STI/PUB/600 Vein-Type and Similar Uranium Deposits in Rocks Younger than Proterozoic, 1982) expanded upon this unconformity-related assessment. They categorised multiple deposit types for all continental regions, presumably including all countries (Table 2).

TABLE 2. DISTRIBUTION OF SPECULATIVE URANIUM RESOURCES BY DEPOSIT TYPE (KT U). FROM TAYLOR AND CAMERON (1980 and 1982)

Continent	Conglomerate	Proterozoic unconformity-related	Disseminated	Vein	Sandstone	Other	Total
Africa	311 - 648	171 - 635	130 - 524	66 - 250	450 - 1455	152 - 480	1280 - 3992
North America	250 - 500	600 - 1200	168 - 295	136 - 230	877 - 1345	19 - 30	2050 - 3600
South, Central America	106 - 239	222 - 475	103 - 291	77 - 241	159 - 559	22 - 50	689 - 1855
Asia	20 - 100	15 - 75	48 -250	31 - 158	92 - 362	9 - 56	215 - 1001
Australia and Oceania	10 - 15	1500 - 2250	181 - 275	61 - 110	152 - 240	100 - 150	2004 - 3040
Western Europe	2 - 10	2 - 10	141 - 580	94 - 262	110 - 439		349 - 1301
Total (WOCA)	699 - 1512	2510 - 4645	771 - 2215	465 - 1241	1740 - 4400	305 - 766	6587 - 14789
USSR, China, Eastern Europe	350 - 748	1255 - 2290	386 - 1092	232 - 612	919 - 2170	153 - 378	3295 - 7290

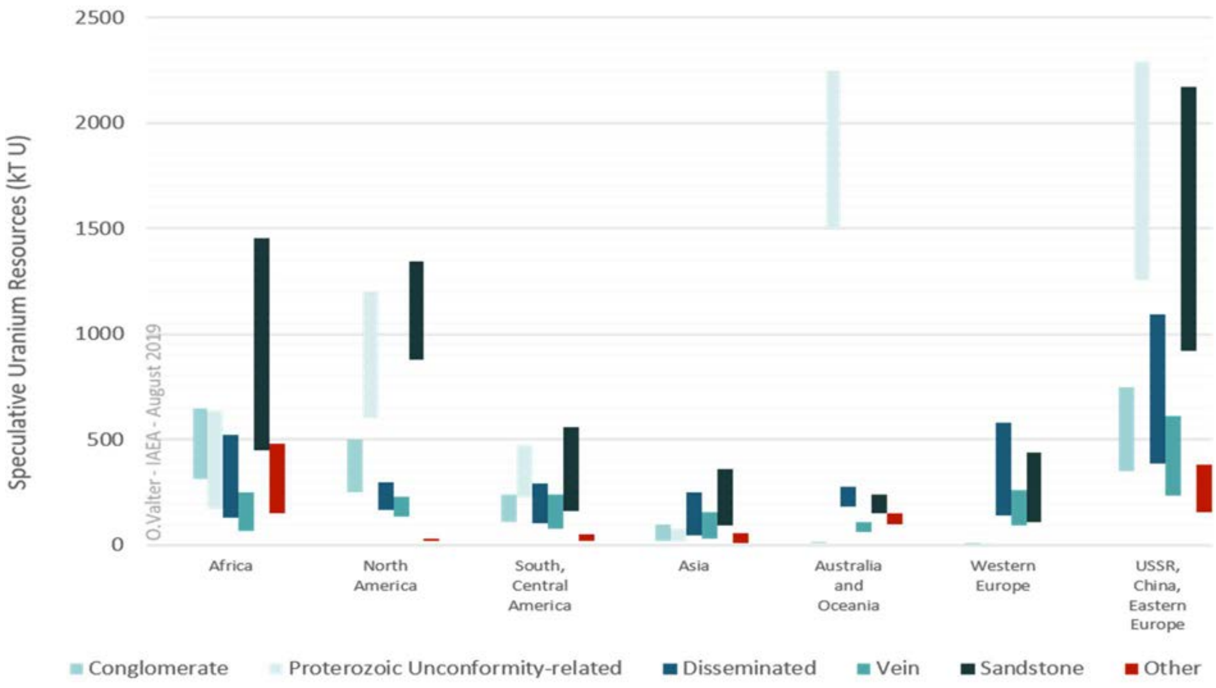


FIG 7. Ranges of speculative resources by deposit type.

Further refinement by De Vergie (Some Aspects of Long-Term Availability of Uranium, IAEA STIPUB 627, 1983) was undertaken for the purposes of utilising the IUREP data in sensitivity modelling of potential production. Table 3 shows the subdivision of the deposit types used for this modelling. The differences between different evaluations can be compared between Table 2 and Table 3.

TABLE 3. REVISED IUREP RESOURCES BY DEPOSIT TYPE FROM DE VERGIE (1983) AND TAYLOR & CAMERON (1982) EXCLUDING FORMER SOVIET UNION, CHINA AND EASTER EUROPE.

Deposit type	Speculative resources (Mt U)[a]	Speculative resources (Mt U)[b]
Proterozoic unconformity related	1.399 - 2.400	2.510 - 4.645 -
Quartz-pebble conglomerate	0.736 - 1.490	0.699 - 1.512
Sandstone	1.8825 - 4.515	1.840 - 4.400
Disseminated magmatic	0.7495 - 2.2045	0.771 - 2.215
Vein	0.700 - 1.737.5	0.465 - 1.241
Alkalic rock	0.103 - 0.220	
Calcrete	0.361 - 0.9375	
Phosphate	0.0265 - 0.0605	
Carbonatite	0.0625 - 0.1575	
Monazite placer	0.0065 - 0.0325	
Volcanic	0.137 - 0.260	
Phosphatic limestone	0.009 - 0.045	
Undefined	0.046 - 0.410	0.305 - 0.766[C]
Total	6.2185 - 14.470	6.587 - 14.789[d]

[a] INTERNATIONAL ATOMIC ENERGY AGENCY, Some Aspects of Long-Term Availability of Uranium, Nuclear Power Experience, Proceedings of an International Conference,.1980. IAEA-STI -PUB 627, IAEA, Vienna (1982).

[b.] INTERNATIONAL ATOMIC ENERGY AGENCY, Small Veins: A Big Future? Uranium in the Pine Creek Geosyncline, Sydney, 4-8 June 1979. , Proceedings.. IAEA-STI -PUB 555, IAEA, Vienna (1982).

[c.] described as 'other' in Taylor and Cameron, 1982 and likely includes other Alkalic rocks, calcrete, phosphate, carbonatite, monazite placer, volcanic, phosphatic limestone and undefined from De Vergie, 1983, the latter of which have an aggragated range of 0.7515–2.123 Mt U.

[d.] Rounded to 6.6–14.8 Mt U in most IUREP summaries.

Appendix II

GLOSSARY OF DEFINITIONS AND TERMINOLOGY

Units

Metric units are used in all tabulations and statements. Resources and production quantities are expressed in terms of tonnes (t) contained uranium (U) rather than uranium oxide (U_3O_8).

1 short ton U_3O_8	= 0.769 tU
1% U_3O_8	= 0.848% U
US \$1.0/lb U_3O_8	= US \$2.6/kgU
1 tonne	= 1 metric ton

II–1. RESOURCE TERMINOLOGY

Resource estimates are divided into separate categories reflecting different levels of confidence in the quantities reported. The resources are further separated into categories based on the cost of production.

II–1.1. Definitions of resource categories

Uranium resources are broadly classified as either conventional or unconventional. Conventional resources are those that have an established history of production where uranium is a primary product, co-product or an important by-product (e.g., from the mining of copper and gold). Very low grade resources or those from which uranium is only recoverable as a minor by-product are considered unconventional resources.

Conventional resources are further divided, according to different confidence levels of occurrence, into four categories. The correlation between these resource categories and those used in selected national resource classification systems is shown in Fig. II–1.

Reasonably assured resources: Uranium that occurs in known mineral deposits of delineated size, grade and configuration such that the quantities, which could be recovered within the given production cost ranges with currently proven mining and processing technology, can be specified. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. Reasonably assured resources have a high assurance of existence. Unless otherwise noted, reasonably assured resources are expressed in terms of quantities of uranium recoverable from mineable ore (see recoverable resources).

Inferred resources: Uranium, in addition to reasonably assured resources, that is inferred to occur based on direct geological evidence, in extensions of well explored deposits, or in deposits in which geological continuity has been established but where specific data, including measurements of the deposits and knowledge of the deposit's characteristics, are considered to be inadequate to classify the resource as reasonably assured. Estimates of tonnage, grade and cost of further delineation and recovery are based on such sampling as is available and on knowledge of the deposit characteristics as determined in the best known parts of the deposit or in similar deposits. Less reliance can be placed on the estimates in this category than on those for reasonably assured resources. Unless otherwise noted, inferred resources are expressed in terms of quantities of uranium recoverable from mineable ore (see recoverable resources).

The terms illustrated are not strictly comparable as the criteria used in the various systems are not identical. 'Grey zones' in correlation are therefore unavoidable, particularly as the resources become less assured. Nonetheless, the chart presents a reasonable approximation of the comparability of terms.

Prognosticated resources: Uranium, in addition to inferred resources, that is expected to occur in deposits for which the evidence is mainly indirect and which are believed to exist in well defined geological trends or areas of mineralization with known deposits. Estimates of tonnage, grade and cost of discovery, delineation and recovery are based primarily on knowledge of deposit characteristics in known deposits within the respective trends or areas and on such sampling, geological, geophysical or geochemical evidence as may be available. Less reliance can be placed on the estimates in this category than on those for inferred resources. Prognosticated resources are normally expressed in terms of uranium contained in mineable ore, that is, in situ quantities.

Speculative resources: Uranium, in addition to prognosticated resources, that is thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The location of deposits envisaged in this category could generally be specified only as being somewhere within a given region or geological trend. As the term implies, the existence and size of such resources are speculative. Speculative resources are normally expressed in terms of uranium contained in mineable ore, that is, in situ quantities.

	Identified resources			Undiscovered resources		
NEA/IAEA	Reasonably assured		Inferred	Prognosticated	Speculative	
Australia	Demonstrated		Inferred	Undiscovered		
	Measured	Indicated				
Canada (Natural Resources Canada)	Measured	Indicated	Inferred	Prognosticated	Speculative	
United States of America (Dept of Energy)	Reasonably assured		Estimated additional		Speculative	
Russian Federation, Kazakhstan, Ukraine, Uzbekistan	A + B	C 1	C2	P1	P2	P3
UNFC[1]	G1 + G2		G3	G4	G4	

[1] United Nations Framework Classification correlation with NEA/IAEA and national classification systems is still under consideration.

FIG. II–1. Approximate correlation of terms used in major resources classification systems.

II–1.1.1. Cost categories

The cost categories, in United States dollars (US $), used in this report are defined as: <US $40/kgU, <US $80/kgU, <US $130/kgU and <US $260/kgU. All resource categories are defined in terms of costs of uranium recovered at the ore processing plant. It should be noted that it is not intended that the cost categories should follow fluctuations in market conditions.

Conversion of costs from other currencies into US $ is done using an average exchange rate for the month of June in that year except for the projected costs for the year of the report, which uses the exchange rate of 1 January 2009.

When estimating the cost of production for assigning resources within these cost categories, account has been taken of the following costs:

- The direct costs of mining, transporting and processing the uranium ore;
- The costs of associated environmental and waste management during and after mining;
- The costs of maintaining non-operating production units, where applicable;
- In the case of ongoing projects, those capital costs that remain non-amortized;
- The capital cost of providing new production units where applicable, including the cost of financing;
- Indirect costs, such as office overheads, taxes and royalties, where applicable;

— Future exploration and development costs wherever required for further ore delineation to the stage where it is ready to be mined;
— Sunk costs are not normally taken into consideration.

II–1.1.2. Relationship between resource categories

Figure II–2 illustrates the inter-relationship between the different resource categories. The horizontal axis expresses the level of assurance about the actual existence of a given tonnage based on varying degrees of geological knowledge, while the vertical axis expresses the economic feasibility of exploitation by division into cost categories.

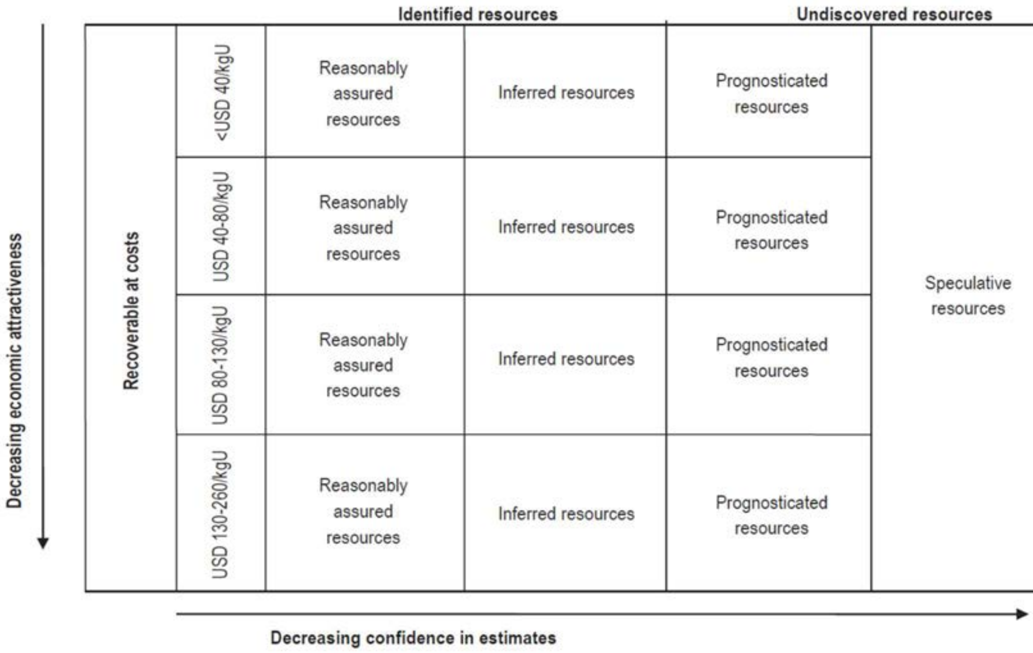


FIG. II–2. OECD/NEA–IAEA classification scheme for uranium deposit types.

II–1.1.3. Recoverable resources

Reasonably assured resource and inferred resource estimates are expressed in terms of recoverable tonnes of uranium (i.e., quantities of uranium recoverable from mineable ore) as opposed to quantities contained in mineable ore, or quantities in situ (i.e., not taking into account mining and milling losses). Therefore, both expected mining and ore processing losses have been deducted in most cases. If a country reports its resources as in situ and the country does not provide a recovery factor, the Secretariat assigns a recovery factor to those resources based on geology and projected mining and processing methods to determine recoverable resources. The recovery factors that have been applied are shown in Table II–1.

TABLE II–1. RECOVERY FACTORS FOR VARIOUS MINING AND MILLING METHODS

Mining and milling method	Overall recovery factor (%)
Open pit mining with conventional milling	80
Underground mining with conventional milling	75
In situ leach (acid)	75
In situ leach (alkaline)	70
Heap leaching	70
In-place leaching (block leaching/stope leaching)	75
Co-product or by-product	65
Unspecified method	75

II–1.2. Secondary sources of uranium terminology

Mixed oxide fuel: MOX is the acronym used for a fuel for nuclear power plants that consists of a mixture of uranium oxide and plutonium oxide. Current practice is to use a mixture of depleted uranium oxide and plutonium oxide.

Depleted uranium: Uranium where the U-235 assay is below the naturally occurring 0.7110%. Natural uranium is a mixture of three isotopes, uranium-238 (99.2836%), uranium-235 (0.7110%), and uranium-234 (0.0054%). Depleted uranium is a by-product of the enrichment process, whereby enriched uranium is produced from initial natural uranium feed material.

II–1.3. Production terminology[1]

II–1.3.1. Production centres

A production centre, as referred to in this report, is a production unit consisting of one or more ore processing plants, one or more associated mines and uranium resources that are tributary to these facilities. For the purpose of describing production centres, they have been divided into four classes, as follows:

- *Existing* production centres are those that currently exist in operational condition and include those plants which are closed down but which could be readily brought back into operation;
- *Committed* production centres are those that are either under construction or are firmly committed for construction;
- *Planned* production centres are those for which feasibility studies are either completed or under way, but for which construction commitments have not yet been made. This class also includes those plants that are closed and which would require substantial expenditures to bring them back into operation;
- *Prospective* production centres are those that could be supported by tributary reasonably assured and inferred resources, i.e., ‘identified resources’, but for which construction plans have not yet been made.

II–1.3.1.1. Production capacity and capability

Production capacity: Denotes the nominal level of output, based on the design of the plant and facilities over an extended period, under normal commercial operating practices.

Production capability: Refers to an estimate of the level of production that could be practically and realistically achieved under favourable circumstances from the plant and facilities at any of the types of production centre described above, given the nature of the resources tributary to them. Projections of production capability are supported only by reasonably assured resources and/or inferred resources. The projection is presented based on those resources recoverable at costs <US $130/kgU.

Production: Denotes the amount of uranium output, in tonnes of uranium contained in concentrate, from an ore processing plant or production centre (with milling losses deducted).

II–1.3.1.2. Mining and milling

In situ leaching: The extraction of uranium from sandstone using chemical solutions and the recovery of uranium at the surface. In situ leach extraction is conducted by injecting a suitable uranium dissolving leach solution (acid or alkaline) into the ore zone below the water table thereby oxidizing, complexing and mobilizing the uranium, then recovering the pregnant solutions through production wells, and finally, pumping the uranium bearing solution to the surface for further processing. This process is sometimes referred to as in situ recovery.

Heap leaching: Heaps of ore are formed over a collecting system underlain by an impervious membrane. Dilute sulphuric acid solutions are distributed over the top surface of the ore. As the solutions seep down through the heap, they dissolve a significant (50–75%) amount of the uranium in the ore. The uranium is recovered from the heap leach product liquor by ion exchange or solvent extraction.

In-place leaching: This involves leaching of broken ore without removing it from an underground mine. This is also sometimes referred to as stope leaching or block leaching.

Co-product: Uranium is a co-product when it is one of two commodities that must be produced to make a mine economic. Both commodities influence output, for example, uranium and copper are co-produced at Olympic Dam in Australia. Co-product uranium is produced using either open pit or underground mining methods.

By-product: Uranium is considered a by-product when it is a secondary or additional product. By-product uranium can be produced in association with a main product or with co-products, for example, uranium recovered from the Phalabora copper mining operations in South Africa. By-product uranium is produced using either the open pit or underground mining methods.

Uranium from phosphate rocks: Uranium has been recovered as a by-product of phosphoric acid production. Uranium is separated from phosphoric acid by a solvent extraction process. The most frequently used reagent is a synergetic mixture of tri-moctyl phosphine oxide and di-2-ethylhexyl phosphoric acid.

Ion exchange: Reversible exchange of ions contained in a host material for different ions in solution without destruction of the host material or disturbance of electrical neutrality. The process is accomplished by diffusion and occurs typically in crystals possessing one or two dimensional channels where ions are weakly bonded. It also occurs in resins consisting of three-dimensional hydrocarbon networks to which are attached many ionizable groups. This method is used to recover uranium from leaching solutions.

Solvent extraction: A method of separation in which a generally aqueous solution is mixed with an immiscible solvent to transfer one or more components into the solvent. This method is used to recover uranium from leaching solutions.

II–1.4. Demand terminology

Reactor related requirements: Refers to natural uranium acquisitions *and not necessarily* to consumption during a calendar year.

II–1.5. Environmental terminology[16]

Close-out: In the context of uranium mill tailings impoundment, the operational, regulatory and administrative actions required to place a tailings impoundment into long term conditions such that little or no future surveillance and maintenance are required.

Decommissioning: Actions taken at the end of the operating life of a uranium mill or other uranium facility in retiring it from service with adequate regard for the health and safety of workers and members of the public and for protection of the environment. The time period to achieve decommissioning may range from a few years to several hundred.

Decontamination: The removal or reduction of radioactive or toxic chemical contamination using physical, chemical or biological processes.
Dismantling: The disassembly and removal of any structure, system or component during decommissioning. Dismantling may be performed immediately after permanent retirement of a mine or mill facility or it may be deferred.

Environmental restoration: Cleanup and restoration, according to predefined criteria, of sites contaminated with radioactive and/or hazardous substances arising from past uranium production activities.

Environmental impact statement: A set of documents recording the results of an evaluation of the physical, ecological, cultural and socioeconomic effects of a planned installation, facility or technology.

Groundwater restoration: The process of returning affected groundwater to acceptable quality and quantity levels for future use.

Reclamation: The process of restoring a site to predefined conditions, which allows new uses.

---

[18] These definitions are based on those published in Environmental Remediation of Uranium Production Facilities, OECD, Paris (2002).

Restricted release (or use): A designation, by the regulatory body of a country, that restricts the release or use of equipment, buildings, materials or the site because of its potential radiological or other hazards.

Tailings: The remaining portion of a metal bearing ore consisting of finely ground rock and process liquids after some or all of the metal, such as uranium, has been extracted.

Tailings impoundment: A structure in which the tailings are deposited to prevent their release into the environment.
Unrestricted release (or use): A designation, by the regulatory body of a country, that enables the release or use of equipment, buildings, materials or the site without any restriction.

II–1.6. Geological terminology

Uranium occurrence: A naturally occurring, anomalous concentration of uranium.

Uranium deposit: A mass of naturally occurring mineral from which uranium could be exploited at present or in the future.

Geological types of uranium deposit: Uranium resources can be assigned on the basis of their geological setting to the following categories of uranium ore deposit types (listed according to their approximate economic significance). This classification of the geological types of uranium deposit was developed by the IAEA in 1988–1989 and updated for use in the Red Book. It has since been updated with minor renaming (e.g. Vein Type is now Granited-related Type). The 3 Sub-types within '12. Other Deposits' Type, now being considered discrete Types and '13. Rock types with elevated uranium content' is now restricted to Black Shales. This classification is only used in Appendices in this publication.

1. Sandstone deposits;
2. Unconformity related deposits;
3. Haematite breccia complex deposits;
4. Quartz pebble conglomerate deposits;
5. Vein deposits;
6. Intrusive deposits;
7. Volcanic and caldera related deposits;
8. Metasomatite deposits;
9. Surficial deposits;
10. Collapse breccia pipe deposits;
11. Phosphorite deposits;
12. Other types of deposit;
13. Rock types with elevated uranium contents.

1. *Sandstone deposits*: Sandstone hosted uranium deposits occur in medium to coarse grained sandstones deposited in a continental fluvial or marginal marine sedimentary environment. Uranium is precipitated under reducing conditions by the presence of a variety of reducing agents within the sandstone, for example, carbonaceous material, sulphides (pyrite), hydrocarbons and ferro-magnesium minerals (chlorite). Sandstone uranium deposits can be divided into four main sub-types:

- *Roll front deposits*: The mineralized zones are convex down the hydrological gradient. They display diffuse boundaries with reduced sandstone on the down-gradient side and sharp contacts with oxidized sandstone on the up-gradient side. The mineralized zones are elongate and sinuous, approximately parallel to the strike and perpendicular to the direction of deposition and groundwater flow. Resources can range from a few hundred tonnes to several thousands of tonnes of uranium, at grades averaging 0.05–0.25% U. Examples are Moynkum, Inkay and Mynkuduk (Kazakhstan); Crow Butte and Smith Ranch (USA) and Bukinay, Sugraly and Uchkuduk (Uzbekistan);
- *Tabular deposits*: Tabular deposits consist of uranium matrix impregnations that form irregularly shaped lenticular masses within reduced sediments. The mineralized zones are largely oriented parallel to the depositional trend. Individual deposits can contain from several hundreds of tonnes up to 150 000 tU at average grades of 0.05–0.5% U and occasionally up to 1% U. Examples of deposits include Westmoreland (Australia), Nuhetting (China), Hamr-Stráz (Czech Republic), Akouta, Arlit, Imouraren (Niger) and Colorado Plateau (USA);
- *Basal channel deposits*: Palaeodrainage systems consist of channels several hundred metres wide that are filled with thick permeable alluvial–fluvial sediments. Here, the uranium is predominantly associated with detrital plant debris in orebodies that display, in plan view, an elongated lens or ribbon-like configuration

and, in cross-section, a lenticular or, more rarely, roll shape. Individual deposits can range from several hundreds to 20 000 tU, at grades of 0.01–3% U. Examples are the deposits of Dalmatovskoye (Transural Region), Malinovskoye (west Siberia), Khiagdinskoye (Vitim district) in the Russian Federation and Beverley in Australia;

— *Tectonic/lithological deposits*: This type of deposit occurs in sandstone related to a permeable zone. Uranium is precipitated in open zones related to tectonic extension. Individual deposits contain from a few hundred tonnes up to 5000 tU at average grades of 0.1–0.5% U. Examples include the deposits of Mas Laveyre (France) and Mikouloungou (Gabon).

2. Unconformity related deposits: Unconformity related deposits are associated with, and occur immediately below and above, an unconformable contact that separates a crystalline basement intensively altered from overlying clastic sediments of either Proterozoic or Phanerozoic age.
The unconformity related deposits include the following sub-types:

— Unconformity contact:
  - Fracture-bound deposits occur in metasediments immediately below the unconformity. Mineralization is monometallic and of medium grade. Examples include Rabbit Lake and Dominique Peter in the Athabasca Basin, Canada;
  - Clay-bound deposits occur associated with clay at the base of the sedimentary cover directly above the unconformity. Mineralization is commonly polymetallic and of high to very high grade. An example is Cigar Lake in the Athabasca Basin, Canada;

— Sub-unconformity post-metamorphic deposits: These deposits are structure- and/or stratabound in metasediments below the unconformity on which clastic sediments rest. These deposits can have large resources, at low to medium grade. Examples are Jabiluka and Ranger in Australia.

3. Haematite breccia complex deposits: Deposits of this group occur in haematite-rich breccias and contain uranium in association with copper, gold, silver and rare earths. The main representative of this type of deposit is Olympic Dam in South Australia. Significant deposits and prospects for this type occur in the same region, including Prominent Hill, Wirrda Well, Acropolis and Oak Dam, as well as some younger breccia hosted deposits in the Mount Painter area.

4. Quartz pebble conglomerate deposits: Detrital uranium oxide ores are found in quartz pebble conglomerates deposited as basal units in fluvial to lacustrine braided stream systems older than 2.3–2.4 Ga. The conglomerate matrix is pyritiferous, and gold and other oxide and sulphide detrital minerals are often present in minor amounts. Examples include deposits found in the Witwatersrand Basin in South Africa, where uranium is mined as a by-product of gold. Uranium deposits of this type were mined in the Blind River/Elliot Lake area of Canada.

5. Vein deposits: In vein deposits, the major part of the mineralization fills fractures of highly variable thickness, but which have generally important extensions along strike. The veins consist mainly of gangue material (e.g., carbonates, quartz) and ore mineralization, mainly pitchblende. Typical examples range from the thick and massive pitchblende veins of Pribram (Czech Republic), Schlema-Alberoda (Germany) and Shinkolobwe (Democratic Republic of Congo), to the stockworks and episyenite columns of Bernardan (France) and Gunnar (Canada), to the narrow fissures in granite or metamorphic rocks, also filled with pitchblende, at Mina Fe (Spain) and Singhbhum (India).

6. Intrusive deposits: Deposits included in this type are those associated with intrusive or anatectic rocks of differing chemical compositions (alaskite, granite, monzonite, peralkaline syenite, carbonatite and pegmatite). Examples include the Rössing and Husab deposits (Namibia), the uranium occurrences in the porphyry copper deposits at Bingham Canyon and Twin Butte (USA), the Ilimaussaq deposit (Greenland (Denmark)), Phalabora (South Africa), as well as the deposits in the Bancroft area (Canada).

7. Volcanic and caldera related deposits: Uranium deposits of this type are located within and nearby volcanic caldera filled by mafic to felsic volcanic complexes and intercalated clastic sediments. Mineralization is largely controlled by structures (minor stratabound), occurs at several stratigraphic levels in the volcanic and sedimentary units, and extends into the basement where it is found in fractured granite and in metamorphites. Uranium minerals are commonly associated with molybdenum, other sulphides, violet fluorite and quartz. The most significant commercial deposits are located within the Streltsovsk caldera in the Russian Federation. Other examples are known in China, Mongolia (Dornod deposit), Canada (Michelin deposit) and Mexico (Nopal deposit).

8. Metasomatite deposits: Deposits of this type are confined to the areas of tectono-magmatic activity of the Precambrian shield and are related to near-fault alkali metasomatites and developed on different basement rocks:

granites, migmatites, gneisses and ferruginous quartzites with production of albitites, aegirinites, alkali-amphibolic and carbonaceous-ferruginous rocks. Ore lenses and stocks range from a few metres to tens of metres thick and several hundred metres in length. The vertical extent of ore mineralization can be up to 1.5 km. Ores are uraninite-brannerite by composition and the deposits are of average grade. The reserves are usually medium scale to large. Examples include Michurinskoye, Vatutinskoye, Severinskoye, Zheltorechenskoye and Pervomayskoye deposits (Ukraine), Lagoa Real, Itataia and Espinharas (Brazil), the Valhalla deposit (Australia) and deposits of the Arjeplog region in the north of Sweden.

9. Surficial deposits: Surficial uranium deposits are broadly defined as young (Tertiary to Recent) near surface uranium concentrations in sediments and soils. The largest of the surficial uranium deposits are in calcrete (calcium and magnesium carbonates), and these have been found in Australia (Yeelirrie deposit), Namibia (Langer Heinrich deposit) and Somalia. These calcrete hosted deposits are associated with deeply weathered uraniferous granites. They can also occur in valley fill sediments along Tertiary drainage channels and in playa lake sediments (e.g., Lake Maitland, Australia). Surficial deposits can also occur in peat bogs and soils.

10. Collapse breccia pipe deposits: Deposits in this group occur in circular vertical pipes filled with down dropped fragments. The uranium is concentrated as primary uranium ore, generally uraninite, in the permeable breccia matrix, and in the arcuate, ring fracture zone surrounding the pipe. Type examples are the deposits in the Arizona strip north of the Grand Canyon and those immediately south of the Grand Canyon in the USA.

11. Phosphorite deposits: Phosphorite deposits consist of marine phosphorite of continental shelf origin containing synsedimentary stratiform, disseminated uranium in fine-grained apatite. Phosphorite deposits constitute large uranium resources, but at a very low grade. Uranium can be recovered as a by-product of phosphate production. Examples include New Wales Florida (pebble phosphate) and Uncle Sam (USA), Gantour (Morocco) and Al-Abiad (Jordan). Other types of phosphorite deposit consist of organic phosphate, including argillaceous marine sediments enriched in fish remains that are uraniferous (Melovoe deposit, Kazakhstan).

12. Other deposits:

— *Metamorphic deposits*: In metamorphic uranium deposits, the uranium concentration directly results from metamorphic processes. The temperature and pressure conditions and age of the uranium deposition have to be similar to those of the metamorphism of the enclosing rocks. Examples include the Forstau deposit (Austria) and Mary Kathleen (Australia);
— *Limestone deposits*: This includes uranium mineralization in the Jurassic Todilto Limestone in the Grants district (USA). Uraninite occurs in intraformational folds and fractures as introduced mineralization;
— *Uranium coal deposits*: Elevated uranium contents occur in lignite/coal, and in clay and sandstone immediately adjacent to lignite. Examples are found in the Serres Basin (Greece), North Dakota and South Dakota (USA), Koldjat and Nizhne Iliyskoe (Kazakhstan) and Freital (Germany). Uranium grades are very low and average less than 50 ppm U.

13. Rock types with elevated uranium contents: Elevated uranium contents have been observed in different rock types, such as pegmatite, granite and black shale. In the past, no economic deposits have been mined commercially in these types of rock. Their grades are very low and it is unlikely that they will become economic in the foreseeable future:

— *Rare metal pegmatites*: These pegmatites contain lithium, niobium, tantalum and tin mineralization. They have variable uranium, thorium and rare earth element contents. Examples include the Greenbushes and Wodgina pegmatites (Western Australia). The Greenbushes pegmatites commonly have 6–20 ppm U and 3–25 ppm Th;
— *Granites*: A small proportion of unmineralized granitic rocks have elevated uranium contents. These ‘high heat producing’ granites are potassium feldspar rich. Roughly 1% of the total number of granitic rocks analysed in Australia have uranium contents exceeding 50 ppm;
— *Black shale*: Black shale related uranium mineralization consists of organic rich marine shale or coal rich pyritic shale, containing synsedimentary disseminated uranium adsorbed onto organic material. Examples include the uraniferous alum shale in Sweden and Estonia, the Chatanooga shale (USA), the Chanziping deposit (China) and the Gera-Ronneburg deposit (Germany).

Annex

SUPPLEMENTARY FILE

WORLD DISTRIBUTION OF URANIUM DEPOSIT TYPES[17]

The supplementary file for this publication can be found on the publication's individual web page at www.iaea.org/publications.

1. Intrusive
2. Granite-related
3. Polymetallic iron oxide breccia complex
4. Volcanic-related
5. Metasomatite
6. Metamorphite
7. Proterozoic unconformity-related
8. Collapse breccia pipe
9. Sandstone
10. Paleeo quartz-pebble conglomerate
11. Surficial
12. Lignite-coal
13. Carbonate
14. Phosphate
15. Black shal

[17] Modified from INTERNATIONAL ATOMIC ENERGY, World Distribution of Uranium Deposits map, Second Edition. IAEA-STIPUB1800., IAEA, Vienna (2018).

CONTRIBUTORS TO DRAFTING AND REVIEW

Aranha, M.	International Atomic Energy Agency
Barthel, F.	Germany
Benbow, R.J.	International Atomic Energy Agency
Blaise, J.R.	International Atomic Energy Agency
Boitsov, A.	Russian federation
Bruneton, P.	France
Carranza, E.J.M.	Philippines
Chaki, A.	India
Fairclough, M.	International Atomic Energy Agency
Hanly, A.	International Atomic Energy Agency
Irvine, J.	Australia
Katona, L.	Australia
Marlatt, J.	Canada
McMurray, J.	United States of America
Mihalasky, F.	United States of America
Mihalasky, M.	United States of America
Potot-Tarmann, M.	International Atomic Energy Agency
Pylypenko, O.	International Atomic Energy Agency
Slezak, J.	International Atomic Energy Agency
Tulsidas, H.	International Atomic Energy Agency
Underhill, D.	United States of America
Valter, O.	International Atomic Energy Agency
Vance, R.	Canada
Van Kalleveen, A.	International Atomic Energy Agency
Warthan, K.	United States of America
Wallis, J.	United States of America

Consultants Meetings

Vienna, Austria: 21–23 November 2007; 3–7 November 2008;
12–13 November 2009; 27–30 August 2012; 23-27 September 2019

IAEA
International Atomic Energy Agency

No. 26

ORDERING LOCALLY

IAEA priced publications may be purchased from the sources listed below or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

NORTH AMERICA

Bernan / Rowman & Littlefield

15250 NBN Way, Blue Ridge Summit, PA 17214, USA
Telephone: +1 800 462 6420 • Fax: +1 800 338 4550
Email: orders@rowman.com • Web site: www.rowman.com/bernan

REST OF WORLD

Please contact your preferred local supplier, or our lead distributor:

Eurospan Group

Gray's Inn House
127 Clerkenwell Road
London EC1R 5DB
United Kingdom

Trade orders and enquiries:

Telephone: +44 (0)176 760 4972 • Fax: +44 (0)176 760 1640
Email: eurospan@turpin-distribution.com

Individual orders:

www.eurospanbookstore.com/iaea

For further information:

Telephone: +44 (0)207 240 0856 • Fax: +44 (0)207 379 0609
Email: info@eurospangroup.com • Web site: www.eurospangroup.com

Orders for both priced and unpriced publications may be addressed directly to:

Marketing and Sales Unit
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530 • Fax: +43 1 26007 22529
Email: sales.publications@iaea.org • Web site: www.iaea.org/publications

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA

20-01735E