Undiscovered Resource Modelling: Towards Applying A Systematic Approach To Uranium

Martin Fairclough[1] and Laz Katona[2]

[1]IAEA , [2]Geological Survey of South Australia

With contributions from the Geological Survey of South Australia

URAM 2014

IAEA
International Atomic Energy Agency

Or

How much Uranium is left and where might it be found?

Martin Fairclough[1] and Laz Katona[2]

[1]IAEA , [2]Geological Survey of South Australia

With contributions from Bernd Michaelsen, Geological Survey of South Australia

URAM 2014

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Uranium Resource Modelling

“Why do we want to model undiscovered uranium resources?”

If you can’t quantify, you can’t plan for it

Uranium Resource Modelling

“Why don’t we want to model undiscovered uranium resources?”

“lies, damn lies...............and (geo)statistics”

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Uranium Resource Modelling

“Aren’t imaginary numbers just geofantasy?”

(But) we use geostatistics everyday to interpolate and extrapolate? (kriging, co-kriging, conditional simulation, gridding of geophysical and geochemical data, best fit curves, regression analysis for geochemical data etc)

Uranium Resource Modelling

But isn’t large scale modelling of unknown resources “fringe geoscience”?

Not at all

1) used routinely in other commodities including base metals, precious metals, hydrocarbons etc
2) geologists do it in their heads everyday (target generation, area selection, begging for money from the board) – we just don’t put a number on it

Uranium Resource Modelling

<u>If you can quantify, you can't plan for it</u>

Uranium Resource Modelling

But why do we want to plan for it?

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Uranium Resource Modelling

But why do we want to plan for it?

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Uranium Resource Modelling

Why do we want to plan for it?

Purely from a supply-demand perspective:

1) Current supplies (at mid-range demand scenario) only enough until 2035*
2) Not all uranium will be brought into production
3) Long lead in times (particularly) for U mines
4) Projections to 2060 (beyond IR)e.g IAEA Techdoc)

*likely to increase due to reactor shut down/stockpiling

Uranium Resource Modelling

Why do we want to plan for it?

From a socio-economic perspective:

1) Need for financial analysis
2) Need for comparison with other land uses
3) Need for comparison with other tracts of land
4) Need for consideration of economic/environmental consequences of possible development
5) Security of supply!!!

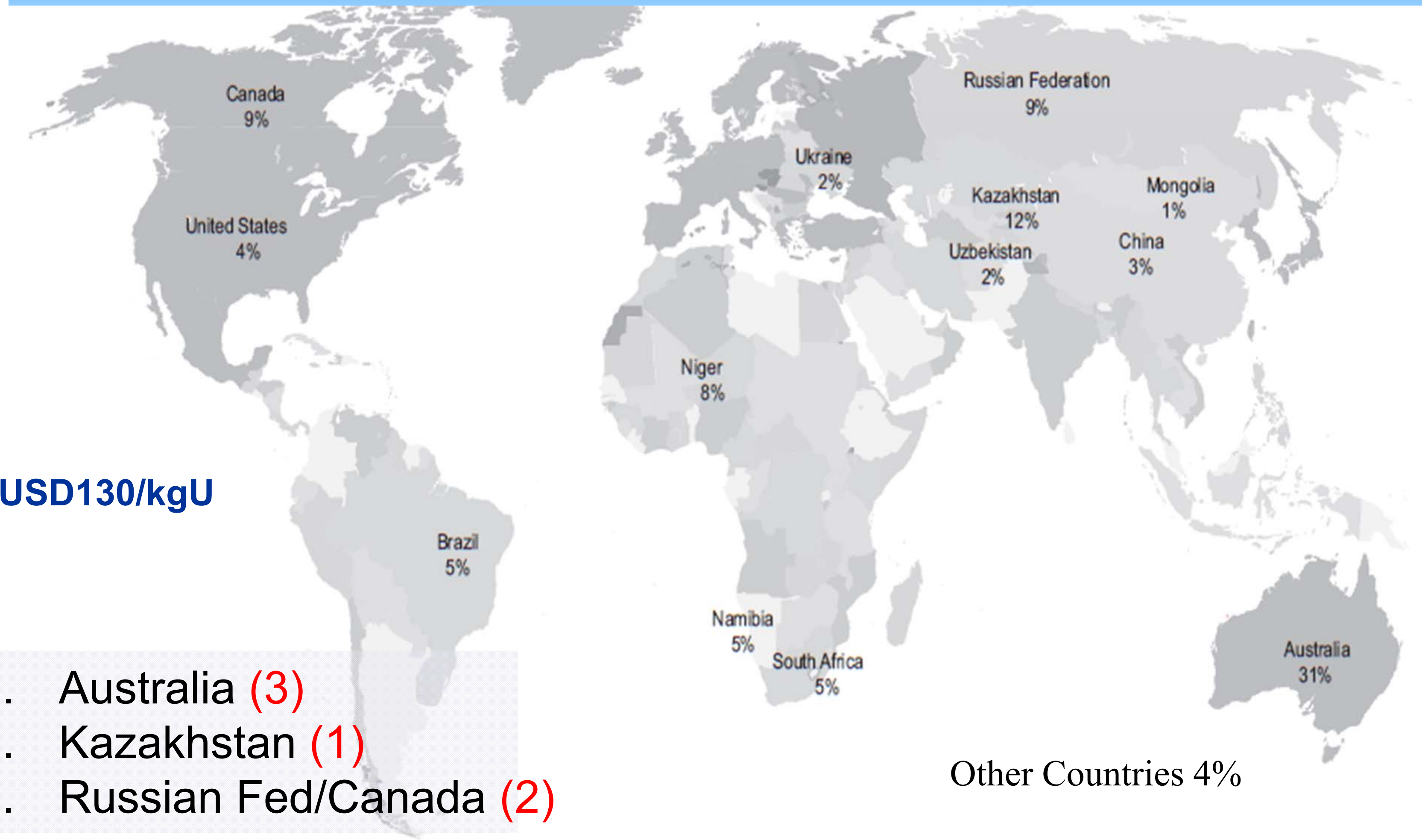
Uranium Resource Modelling

Lets look at a few of these factors

- Security of supply

Uranium Resource Modelling

13 countries represent approx. 96% of total world U resources

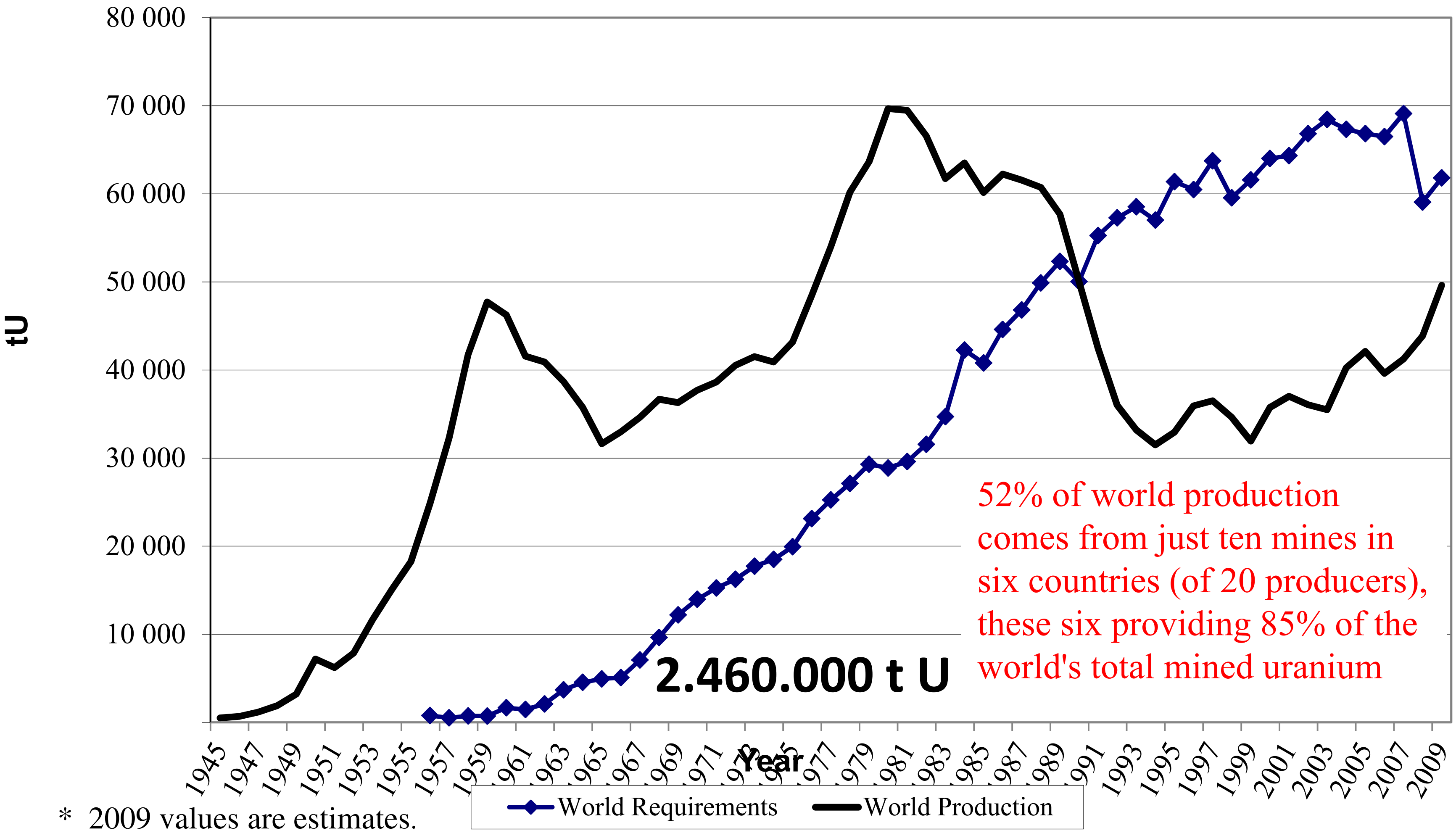


<USD130/kgU

1. Australia (3)
2. Kazakhstan (1)
3. Russian Fed/Canada (2)

Other Countries 4%

Uranium Resource Modelling



2.460.000 t U

52% of world production comes from just ten mines in six countries (of 20 producers), these six providing 85% of the world's total mined uranium

* 2009 values are estimates.

Uranium Resource Modelling

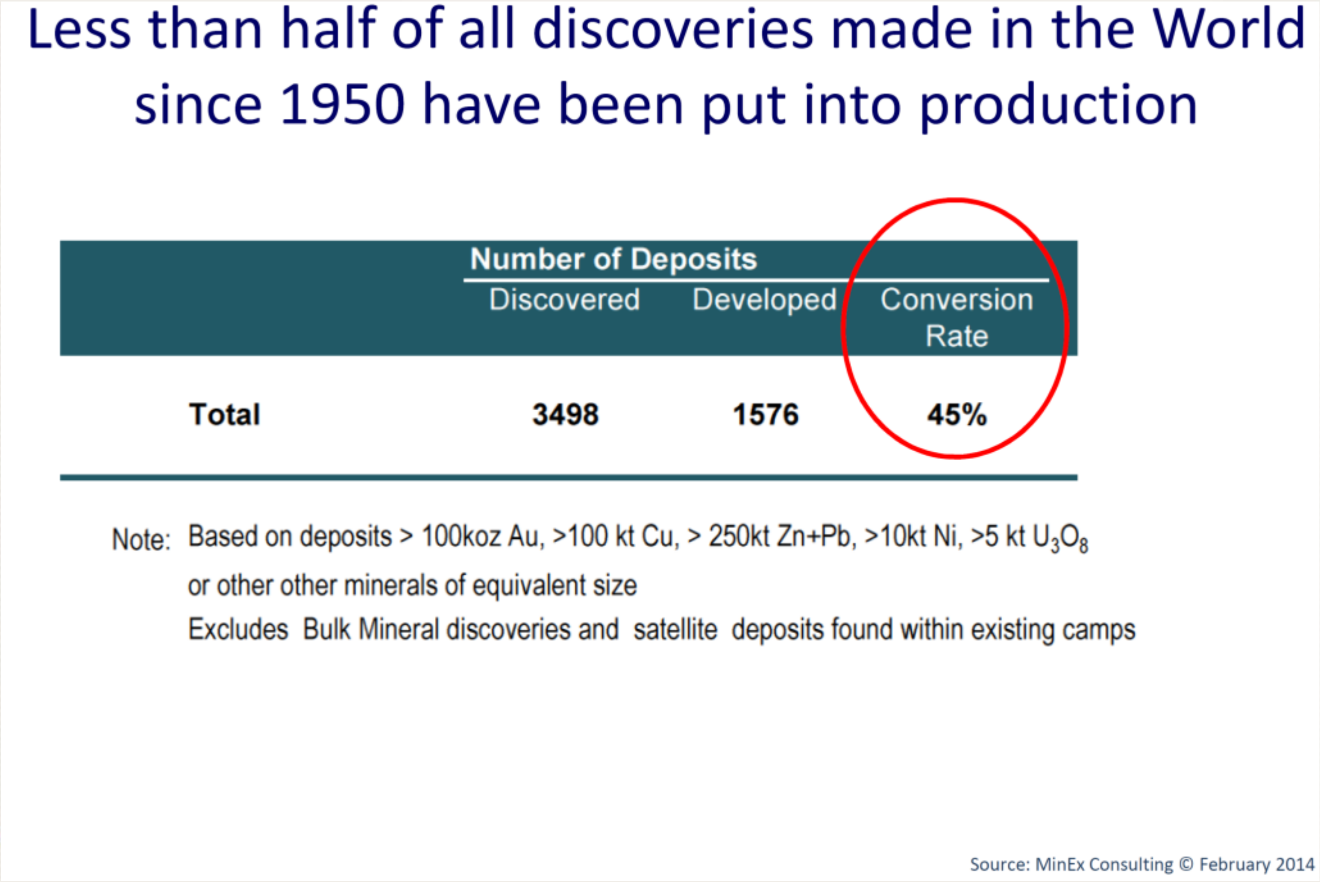
Lets look at a few of these factors

Not all uranium will be brought into production

Uranium Resource Modelling

Lets look at a few of these factors

Not all uranium will be brought into production



Less than half of all discoveries made in the World since 1950 have been put into production

	Number of Deposits		
	Discovered	Developed	Conversion Rate
Total	**3498**	**1576**	**45%**

Note: Based on deposits > 100koz Au, >100 kt Cu, > 250kt Zn+Pb, >10kt Ni, >5 kt U_3O_8 or other other minerals of equivalent size

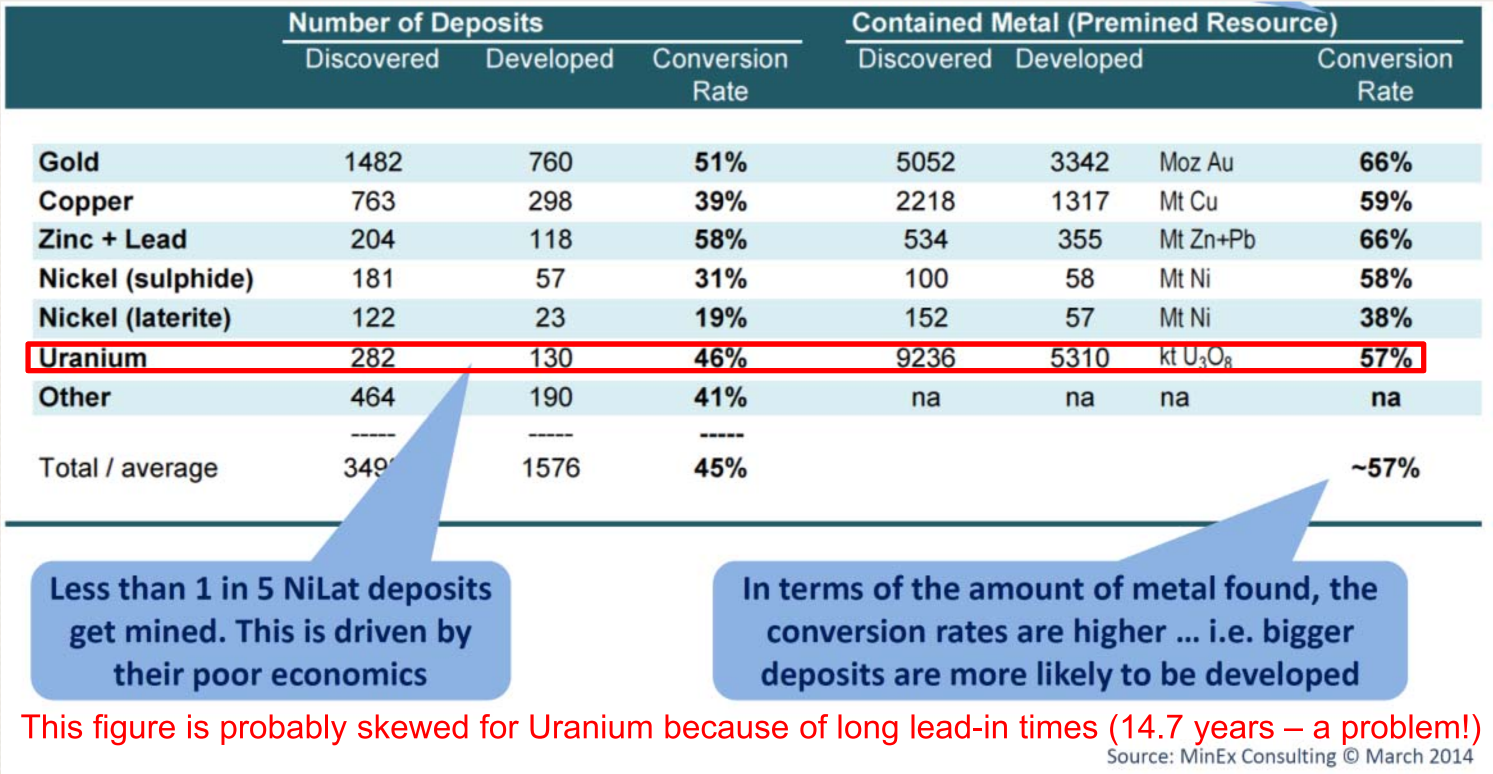
Excludes Bulk Mineral discoveries and satellite deposits found within existing camps

Source: MinEx Consulting © February 2014

Uranium Resource Modelling

Lets look at a few of these factors

Not all uranium will be brought into production



	Number of Deposits			Contained Metal (Premined Resource)			
	Discovered	Developed	Conversion Rate	Discovered	Developed		Conversion Rate
Gold	1482	760	**51%**	5052	3342	Moz Au	**66%**
Copper	763	298	**39%**	2218	1317	Mt Cu	**59%**
Zinc + Lead	204	118	**58%**	534	355	Mt Zn+Pb	**66%**
Nickel (sulphide)	181	57	**31%**	100	58	Mt Ni	**58%**
Nickel (laterite)	122	23	**19%**	152	57	Mt Ni	**38%**
Uranium	282	130	**46%**	9236	5310	kt U_3O_8	**57%**
Other	464	190	**41%**	na	na	na	**na**
	-----	-----	-----				
Total / average	349	1576	**45%**				**~57%**

Less than 1 in 5 NiLat deposits get mined. This is driven by their poor economics

In terms of the amount of metal found, the conversion rates are higher … i.e. bigger deposits are more likely to be developed

This figure is probably skewed for Uranium because of long lead-in times (14.7 years – a problem!)

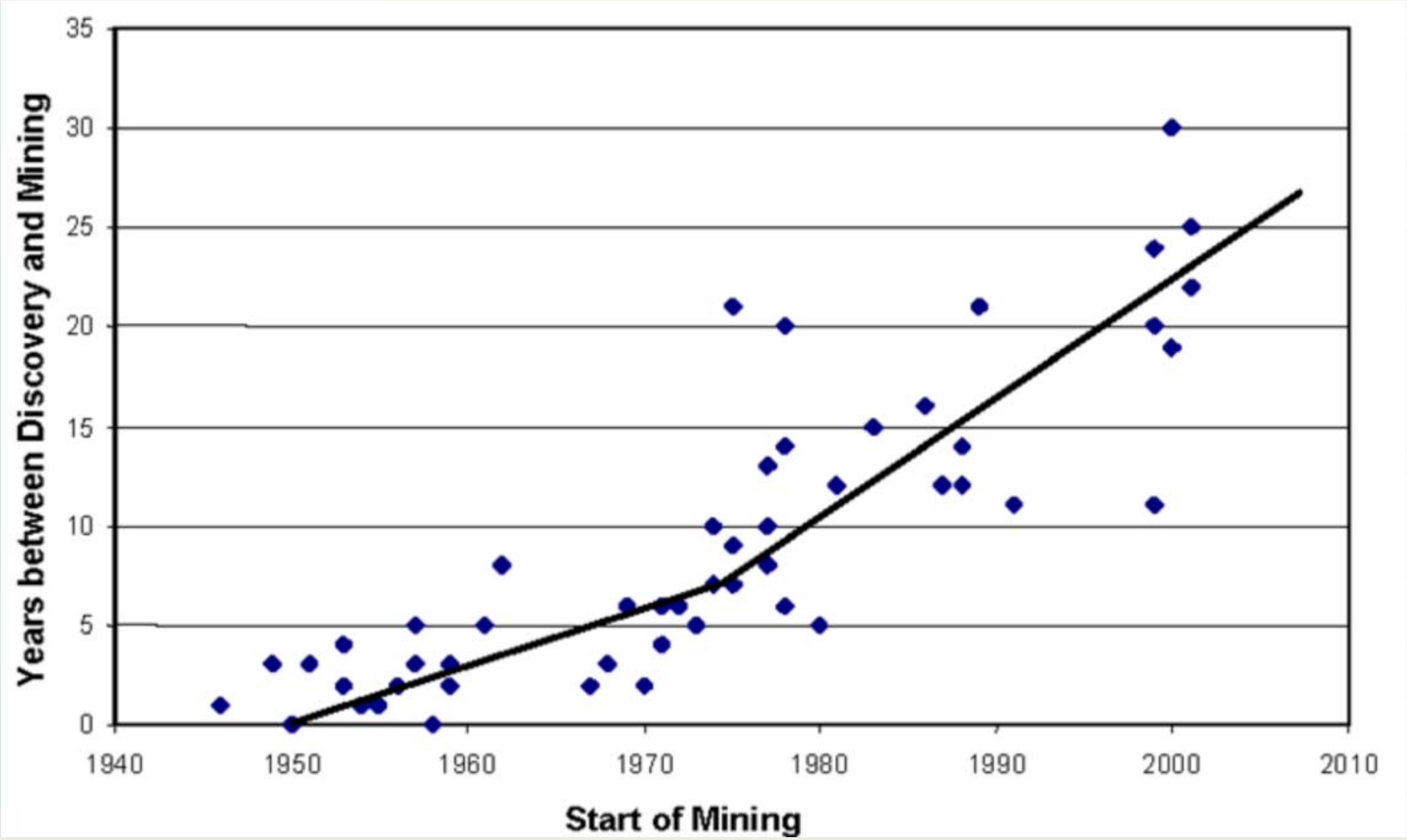
Source: MinEx Consulting © March 2014

Uranium Resource Modelling

Lets look at a few of these factors

Long lead-in times (15-20 years getting longer)

Vance, 2005



Uranium Resource Modelling

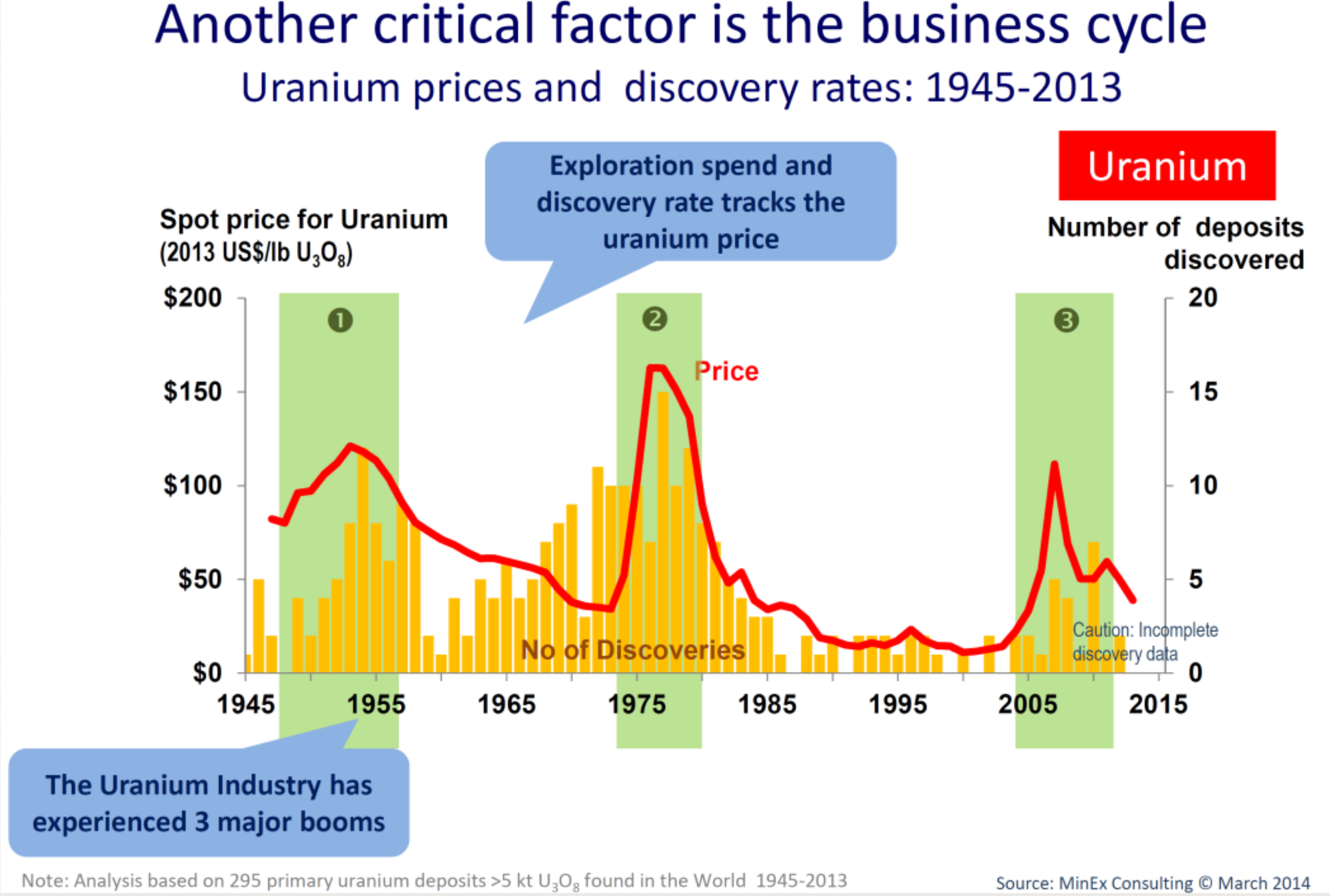
Lets look at a few of these factors

Long lead-in times average >14 years for Uranium

Partly related to timing and cycles, and partly related to uranium-specific development constraints.

Discoveries found in 1 boom are often delayed until the next boom.

And the delays are getting longer….



Another critical factor is the business cycle

Uranium prices and discovery rates: 1945-2013

Uranium

Exploration spend and discovery rate tracks the uranium price

The Uranium Industry has experienced 3 major booms

Note: Analysis based on 295 primary uranium deposits >5 kt U_3O_8 found in the World 1945-2013

Source: MinEx Consulting © March 2014

Uranium Resource Modelling

Projections of supply-demand out to 2060

………..necessarily significantly rely either on Unconventional Resources or on resources yet to be found - or both (due to depletion of identified resources)

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Uranium Resource Modelling

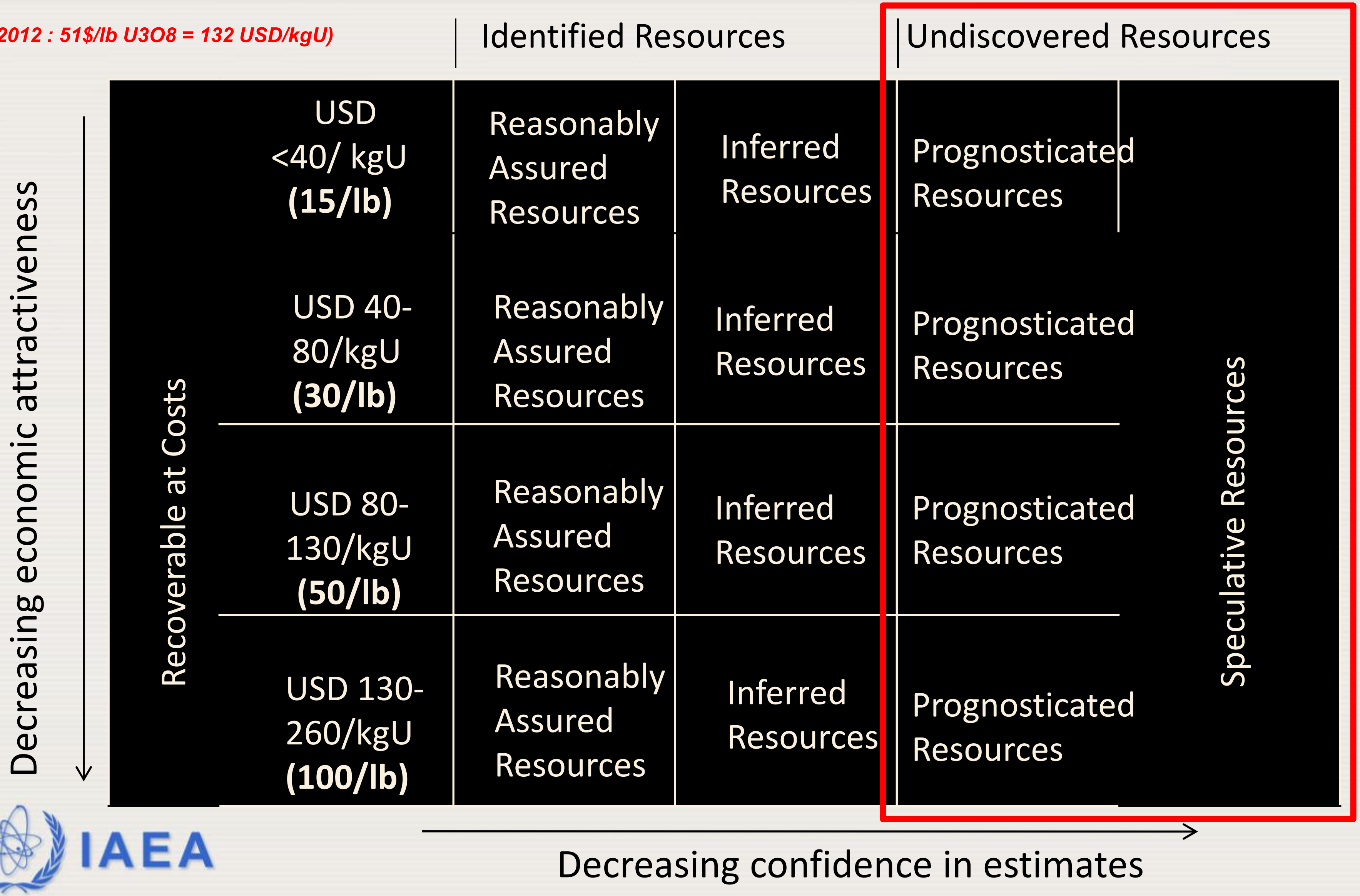
Projections of supply-demand out to 2060

………..necessarily significantly rely either on Unconventional Resources or on resources yet to be found - or both (due to depletion of identified resources)

…….but long lead-in times mean we have to assess these now!!

Uranium Resource Modelling

(June 2012 : 51$/lb U3O8 = 132 USD/kgU)



Decreasing economic attractiveness

		Identified Resources		Undiscovered Resources	
Recoverable at Costs	USD <40/ kgU **(15/lb)**	Reasonably Assured Resources	Inferred Resources	Prognosticated Resources	Speculative Resources
	USD 40-80/kgU **(30/lb)**	Reasonably Assured Resources	Inferred Resources	Prognosticated Resources	
	USD 80-130/kgU **(50/lb)**	Reasonably Assured Resources	Inferred Resources	Prognosticated Resources	
	USD 130-260/kgU **(100/lb)**	Reasonably Assured Resources	Inferred Resources	Prognosticated Resources	

Decreasing confidence in estimates

Uranium Resource Modelling

Modified from Tilton & Lagos 2007

Reserves

Resources (IR + Undiscovered Resources)

Resource Base (“The World”)

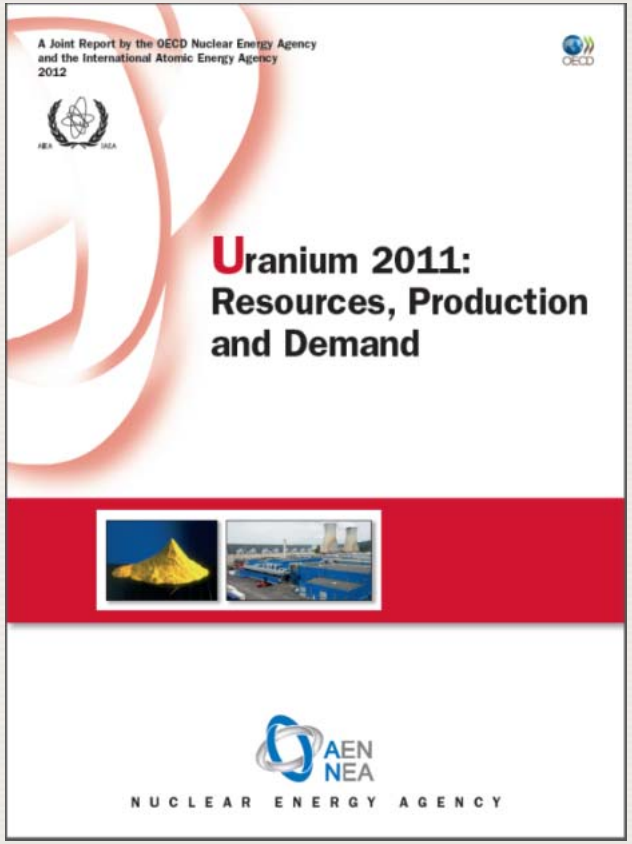
Decreasing economic attractiveness

Decreasing confidence in estimates

Uranium Resource Modelling

2009 Resources

- At least 7 100 000 tU Conventional identified resources recoverable at for all cost categories
- Plus as yet undiscovered deposits 10400000 tU
- However for the countries that do report to Red Book, most do not report Undiscovered Resources
- And for those that do, we do not know how the numbers were made



A Joint Report by the OECD Nuclear Energy Agency
and the International Atomic Energy Agency
2012

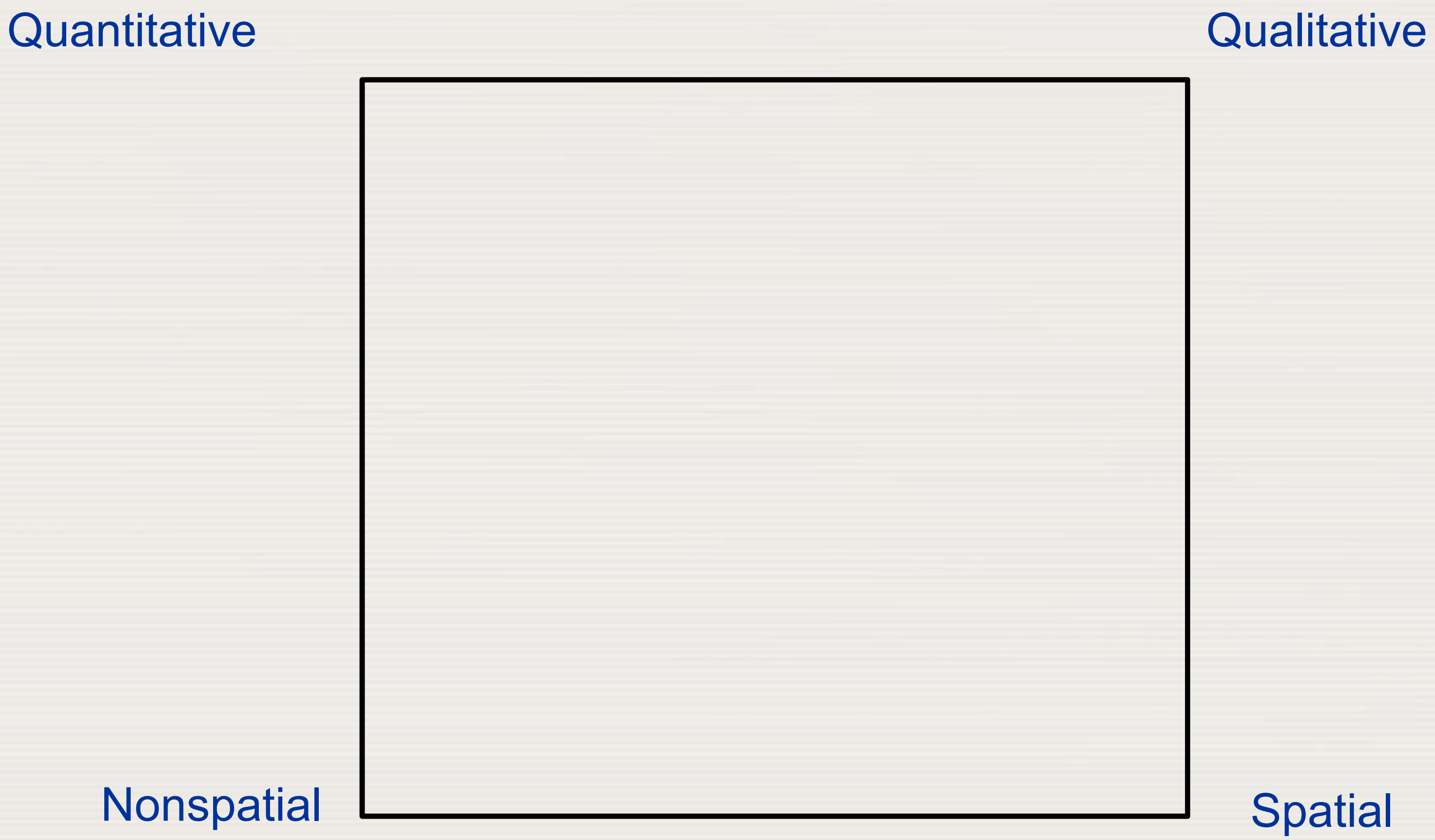
Uranium 2011:
Resources, Production
and Demand

AEN
NEA
NUCLEAR ENERGY AGENCY

Uranium Resource Modelling

So how do we assess undiscovered resources?

Uranium Resource Modelling



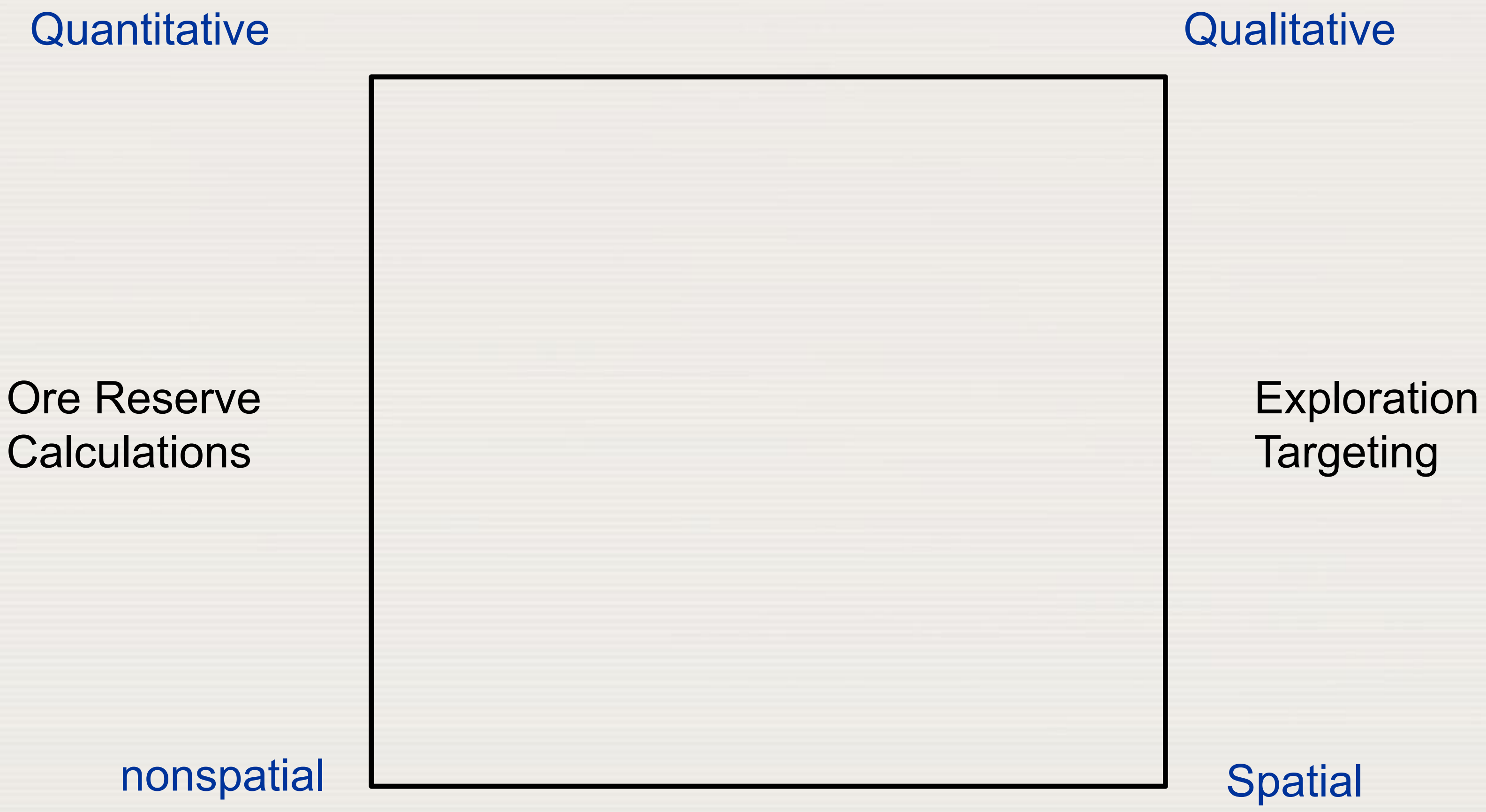
Quantitative

Qualitative

Nonspatial

Spatial

Uranium Resource Modelling



Quantitative

Qualitative

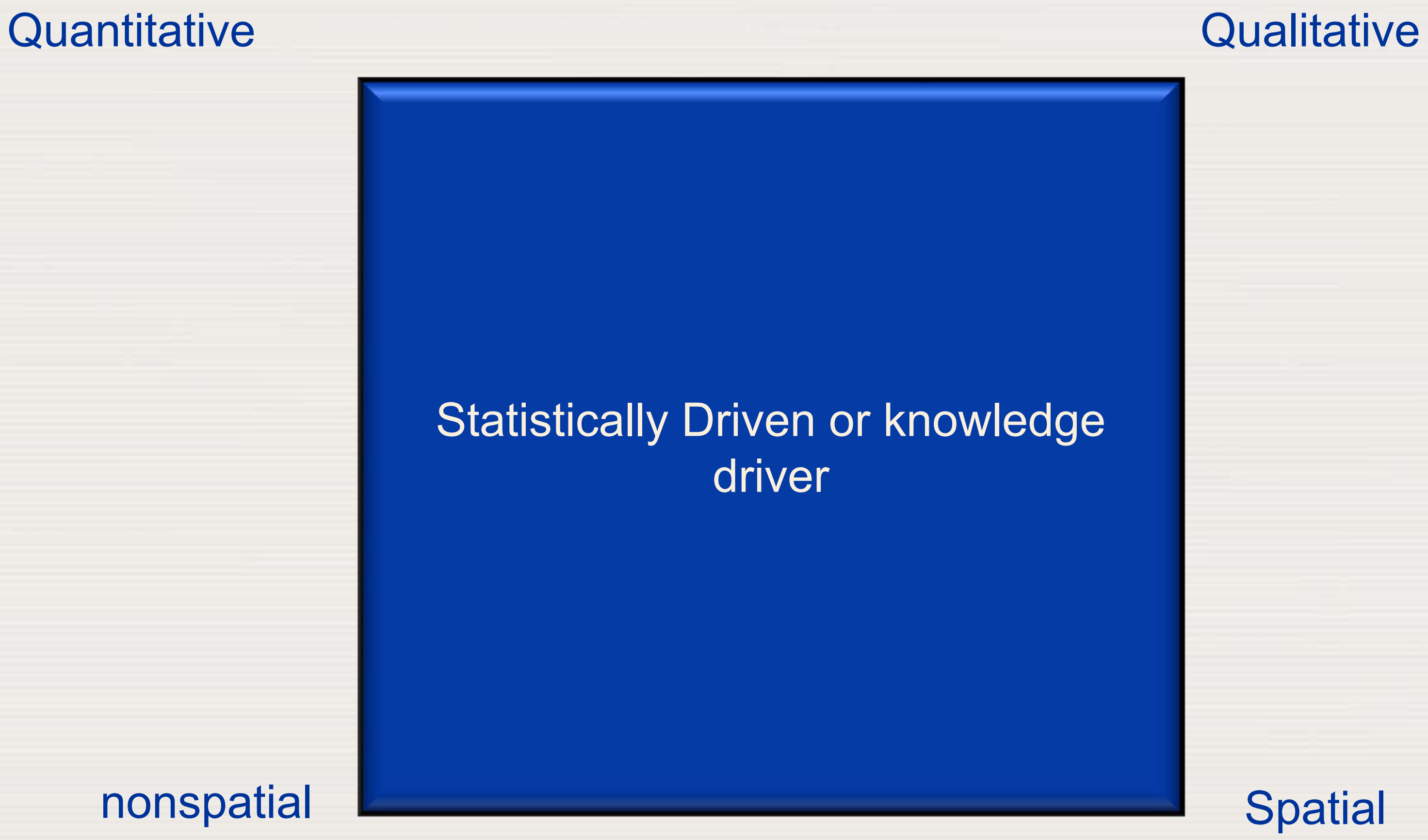
Ore Reserve
Calculations

Exploration
Targeting

nonspatial

Spatial

Uranium Resource Modelling



Quantitative

Qualitative

Statistically Driven or knowledge driver

nonspatial

Spatial

Uranium Resource Modelling

Mineral Potential Modelling is common in other commodities – but not common in Uranium.

So there is a need to transfer expert knowledge from other commodities such as copper, gold, nickel

Uranium Resource Modelling

Large Scale Quantitative Assessments

Rarely publicly exist for uranium, but several early attempts:

1) Quantitative – **NURE** (National Uranium Resources Evaluation) 1974-1982 for USA ca 3-4 Mt . Being revisited now by USGS.

2) Semi-quantitative – **IUREP** (International Uranium resources Evaluation Project), 1976-1978. IAEA+OECD. 185 countries ranked low->high prospectivity, and subjectively assigned broad tonnage ranges. Total 6.6-14.8 Mt U. Partially being revisited for Red Book Country Retrospectives

Uranium Resource Modelling

A possible modern process….

Uranium Resource Modelling

Three-part Resource Assessments

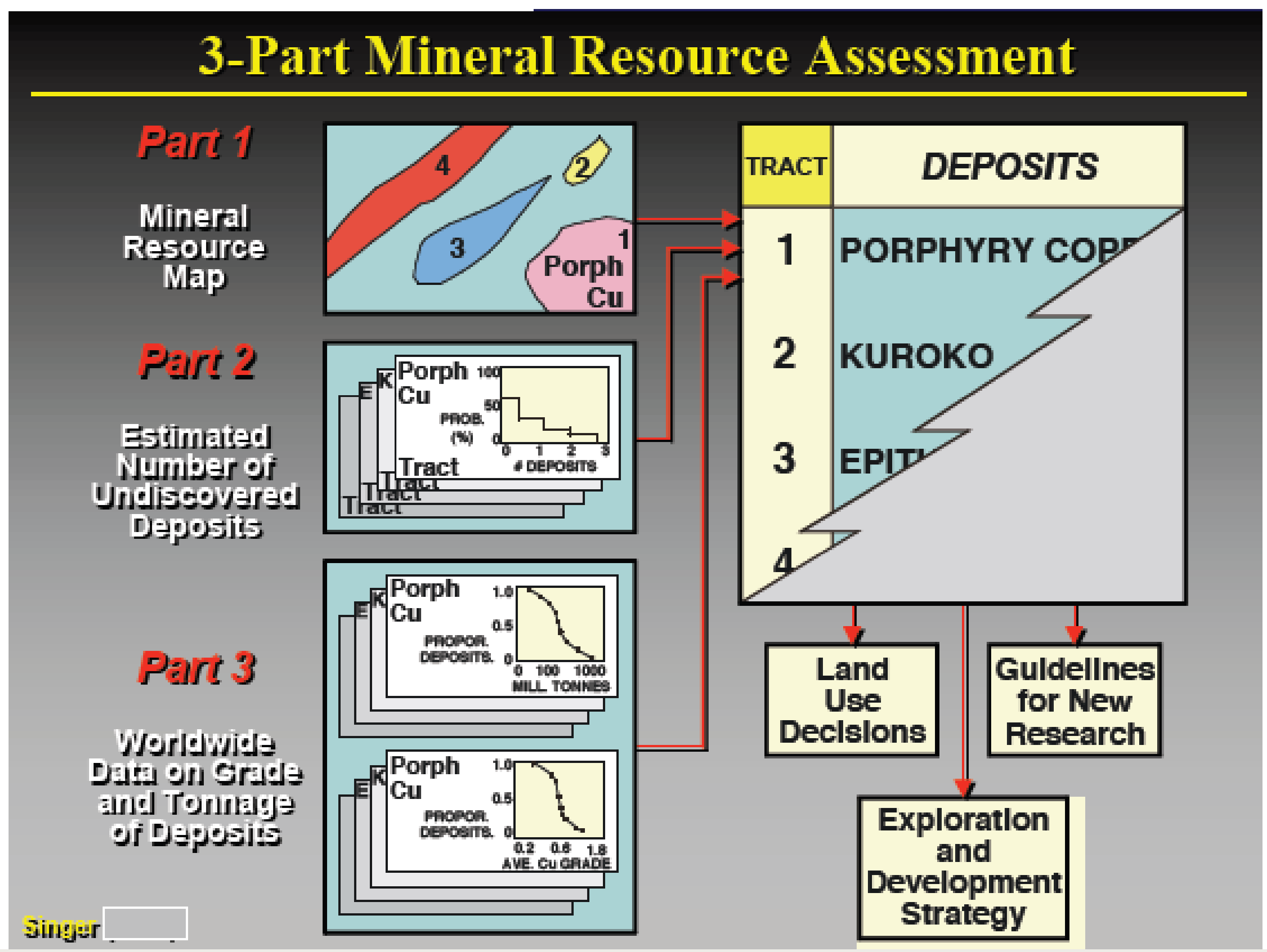
- General locations of undiscovered deposits are delineated from a deposit type's geologic setting – permissive tracts within metallogenic provinces

- Frequency distributions of tonnages and grades of well-explored deposits serve as models of grades and tonnages of undiscovered deposits

- Number of undiscovered deposits are estimated probabilistically by type

(and then we can do economic filtering!)

Uranium Resource Modelling



3-Part Mineral Resource Assessment

Part 1

Mineral Resource Map

Part 2

Estimated Number of Undiscovered Deposits

Part 3

Worldwide Data on Grade and Tonnage of Deposits

TRACT	DEPOSITS
1	PORPHYRY COPP
2	KUROKO
3	EPIT
4	

Land Use Decisions

Guidelines for New Research

Exploration and Development Strategy

Singer

Uranium Mineral Potential Modelling

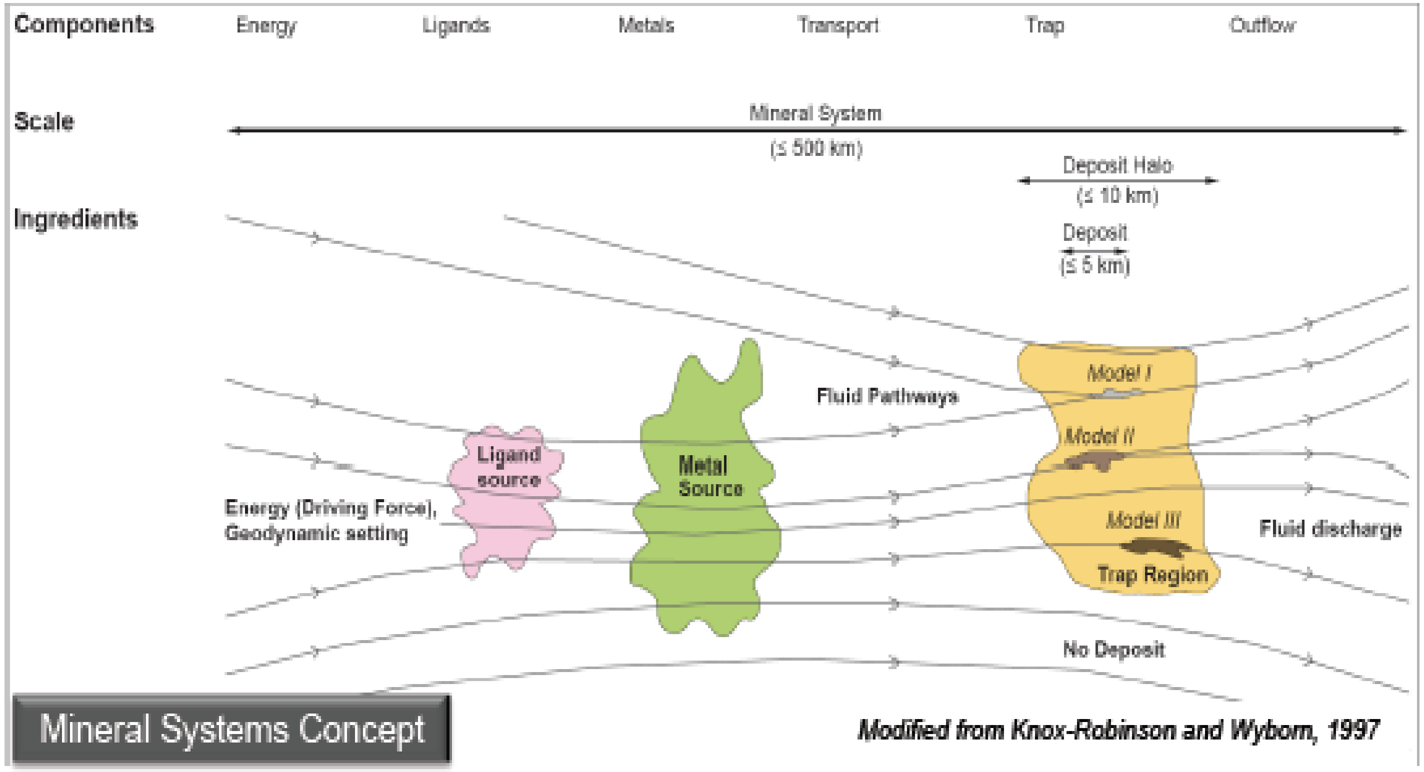
Part 1

- General locations of undiscovered deposits are delineated from a deposit type's geologic setting

1) Deposit model (genetic is best)
2) Key ingredients (knowledge of processes)
3) Identify mappable criteria (proxies – the data components)
4) Identify the large datasets that show where are the permission tracts
5) Optionally smaller-scale mineral potential mapping

Uranium Mineral Potential Modelling

Knowledge components (Kreuzer et al, 2010)

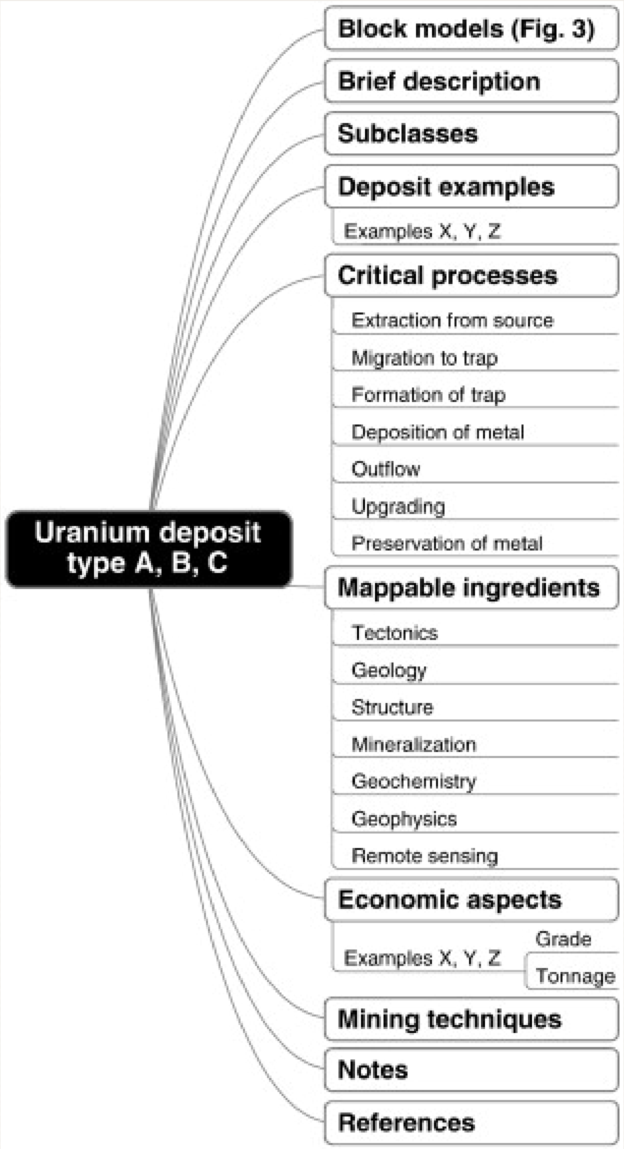


Modified from Knox-Robinson and Wyborn, 1997

- → Focuses on the critical processes that must occur to form a mineral deposit
- → Mineral deposit formation is precluded where a particular system lacks (an) essential component(s)
- → Mineral deposits are focal points of much larger systems of energy and mass flux
- → Requires identification of genetic processes and their mappable criteria at all scales of the system
- → Is not restricted to a particular geological setting / deposit type / conceptual exploration model
- → Can be linked to concepts of probability that allow for more meaningful and robust relative ranking

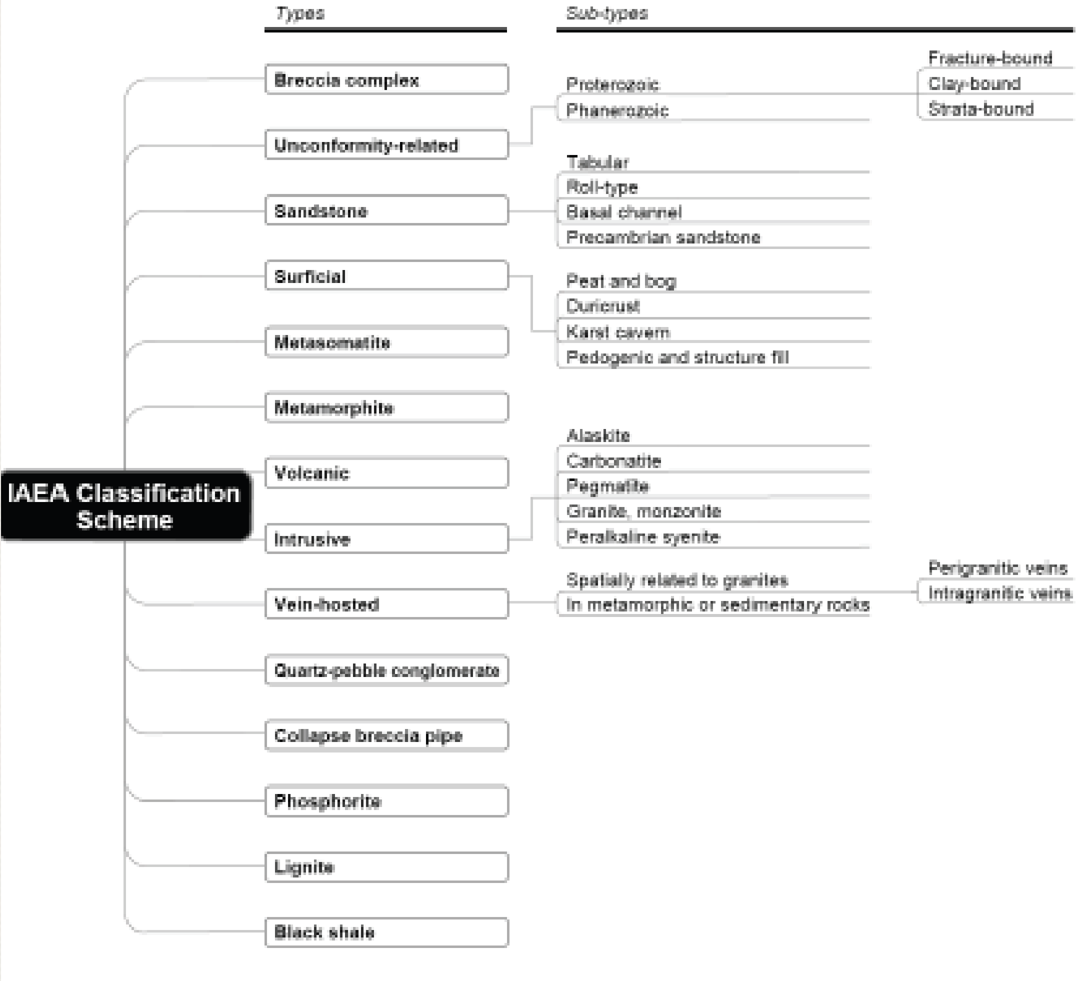
Uranium Mineral Potential Modelling

Data components (Kreuzer et al, 2010)



Uranium Mineral Potential Modelling

Deposit models (Kreu
et al 2010)



IAEA Classification Scheme

Types / *Sub-types*

- **Breccia complex**
- **Unconformity-related**
  - Proterozoic
    - Fracture-bound
    - Clay-bound
    - Strata-bound
  - Phanerozoic
- **Sandstone**
  - Tabular
  - Roll-type
  - Basal channel
  - Precambrian sandstone
- **Surficial**
  - Peat and bog
  - Duricrust
  - Karst cavern
  - Pedogenic and structure fill
- **Metasomatite**
- **Metamorphite**
- **Volcanic**
- **Intrusive**
  - Alaskite
  - Carbonatite
  - Pegmatite
  - Granite, monzonite
  - Peralkaline syenite
- **Vein-hosted**
  - Spatially related to granites
    - Perigranitic veins
    - Intragranitic veins
  - In metamorphic or sedimentary rocks
- **Quartz-pebble conglomerate**
- **Collapse breccia pipe**
- **Phosphorite**
- **Lignite**
- **Black shale**

14 principal U deposit types

22 sub-types

→ Published U deposit classification schemes are invaluable for communication of scientific concepts, reference and learning

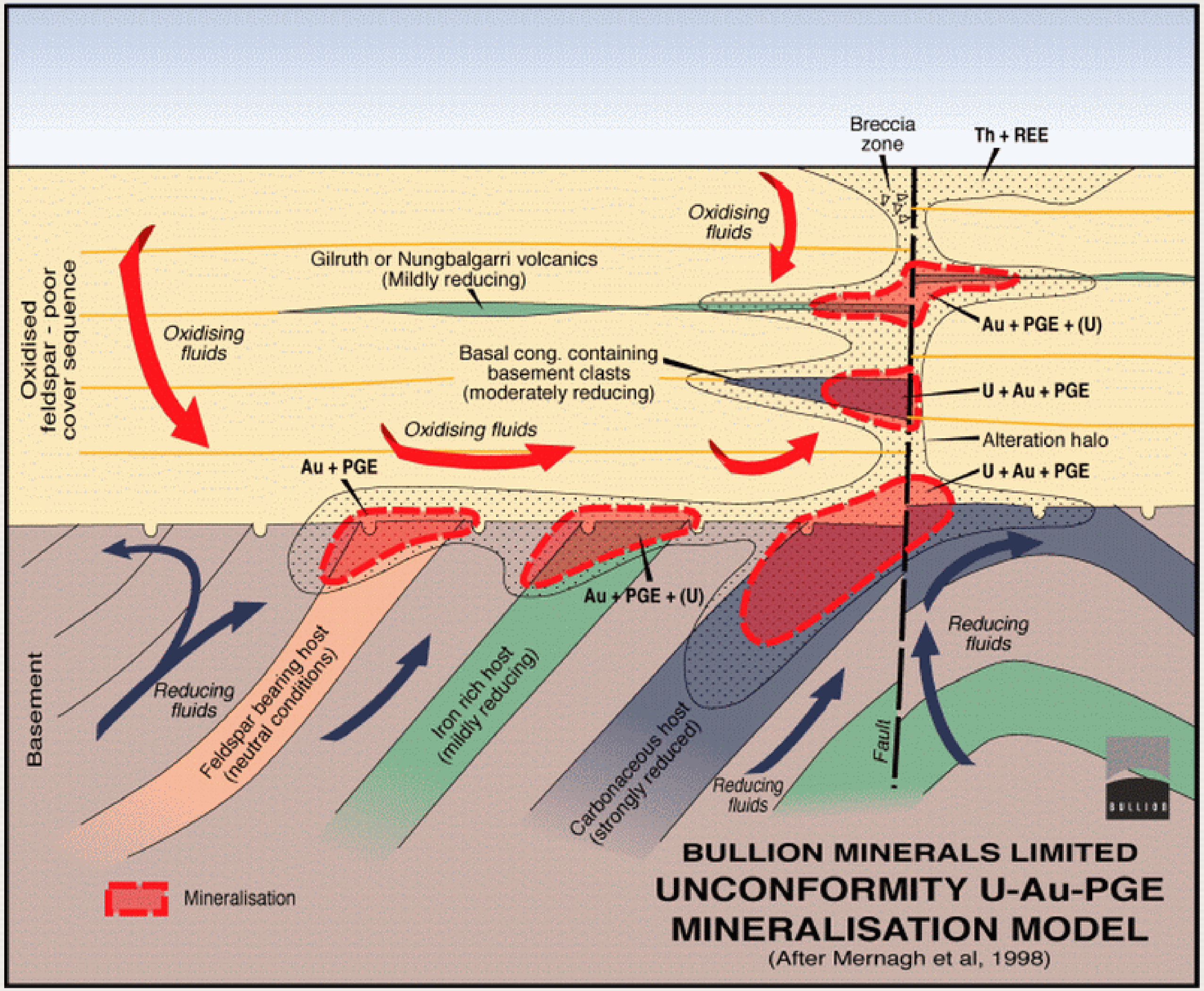
→ But they comprise a large number of U deposit types and sub-types, which translates into a large number of geological variables

→ Working with too many variables is impractical for continent-wide prospectivity analysis because of potential introduction of bias and reduction of efficiency

→ Many geological variables are only evident at the deposit-scale, whereas at larger scales many types of U deposits illustrate fundamental similarities in terms of source, transport and depositional processes

Uranium Mineral Potential Modelling

Key Ingredients
(Kreuzer et al 2010)

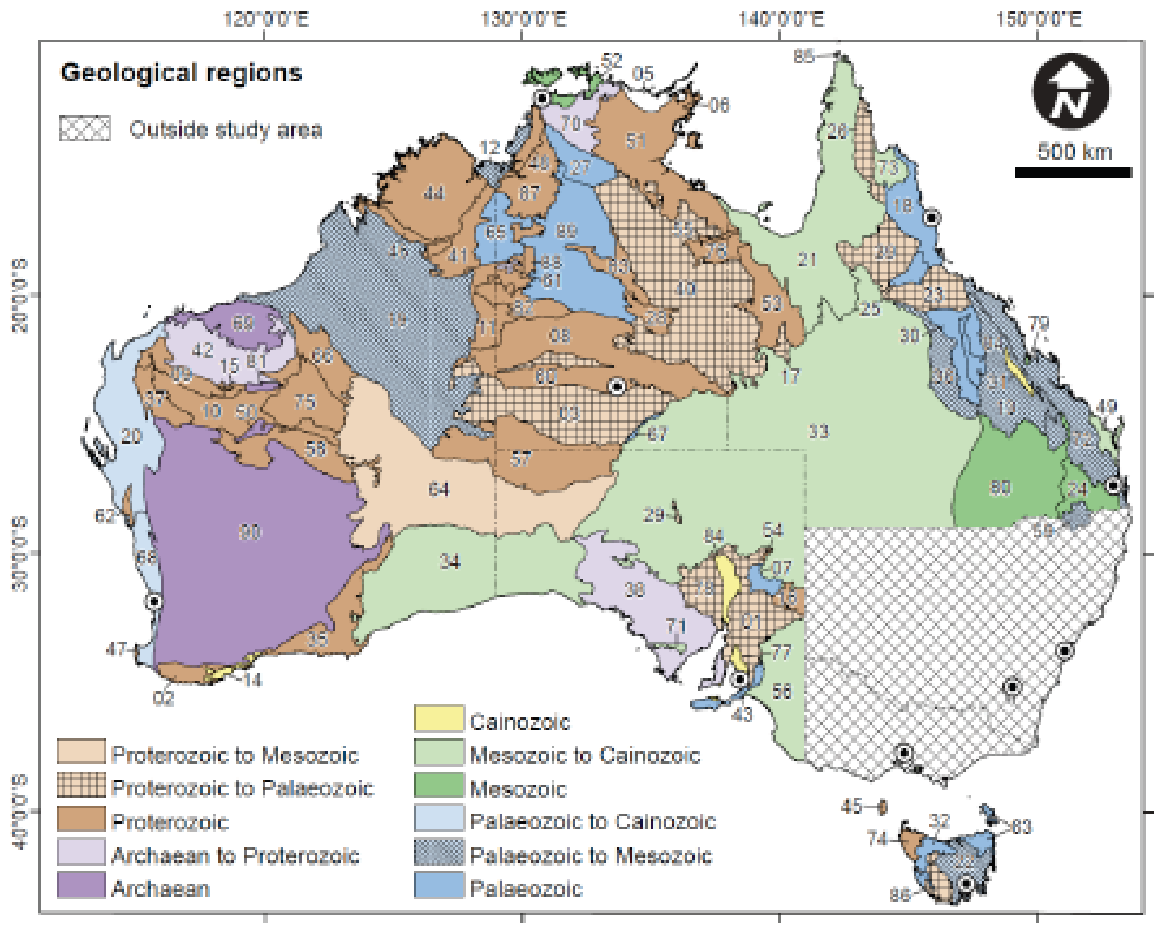


BULLION MINERALS LIMITED
UNCONFORMITY U-Au-PGE MINERALISATION MODEL
(After Mernagh et al, 1998)

Uranium Mineral Potential Modelling

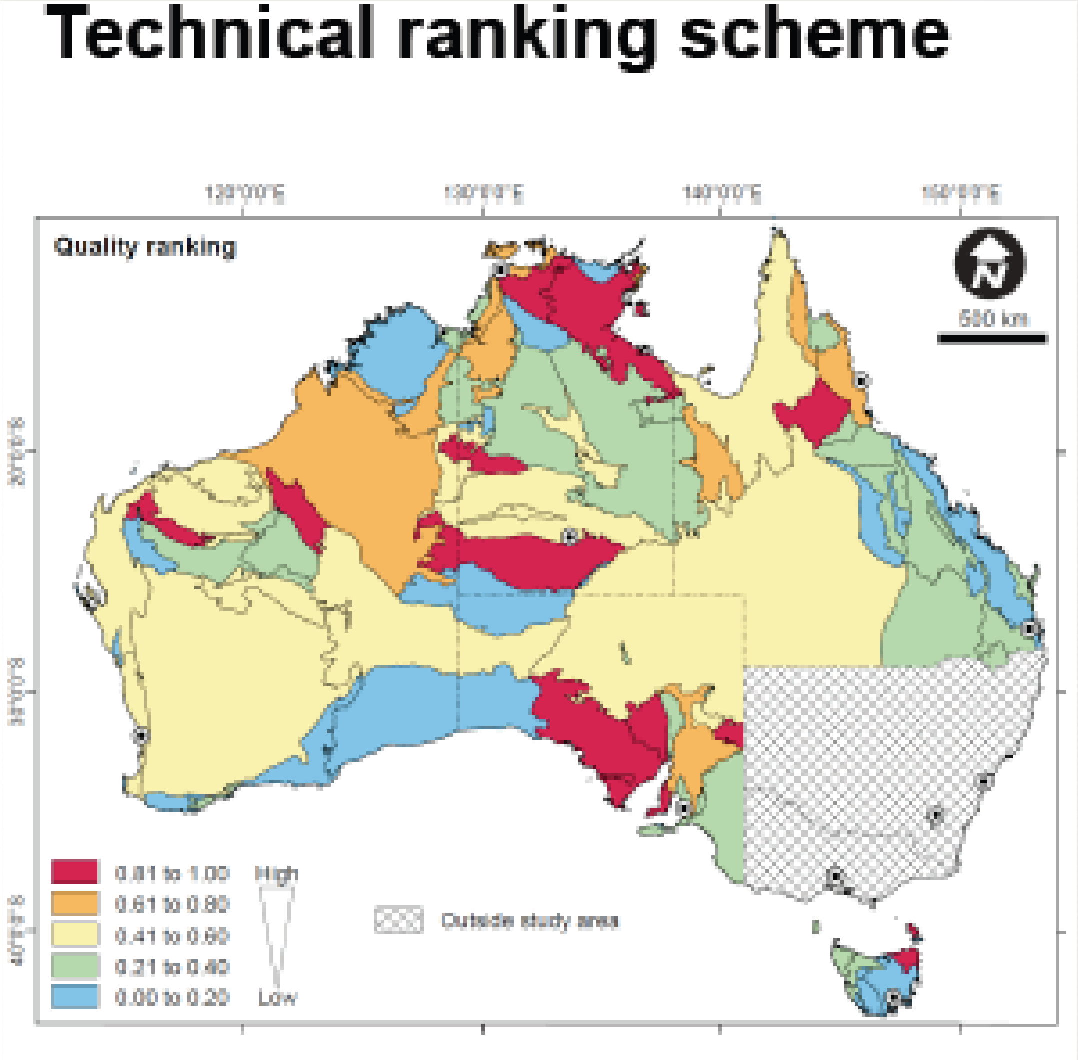
Datsets criteria (Kreuzer et al 2010)

Geological regions = assessment units



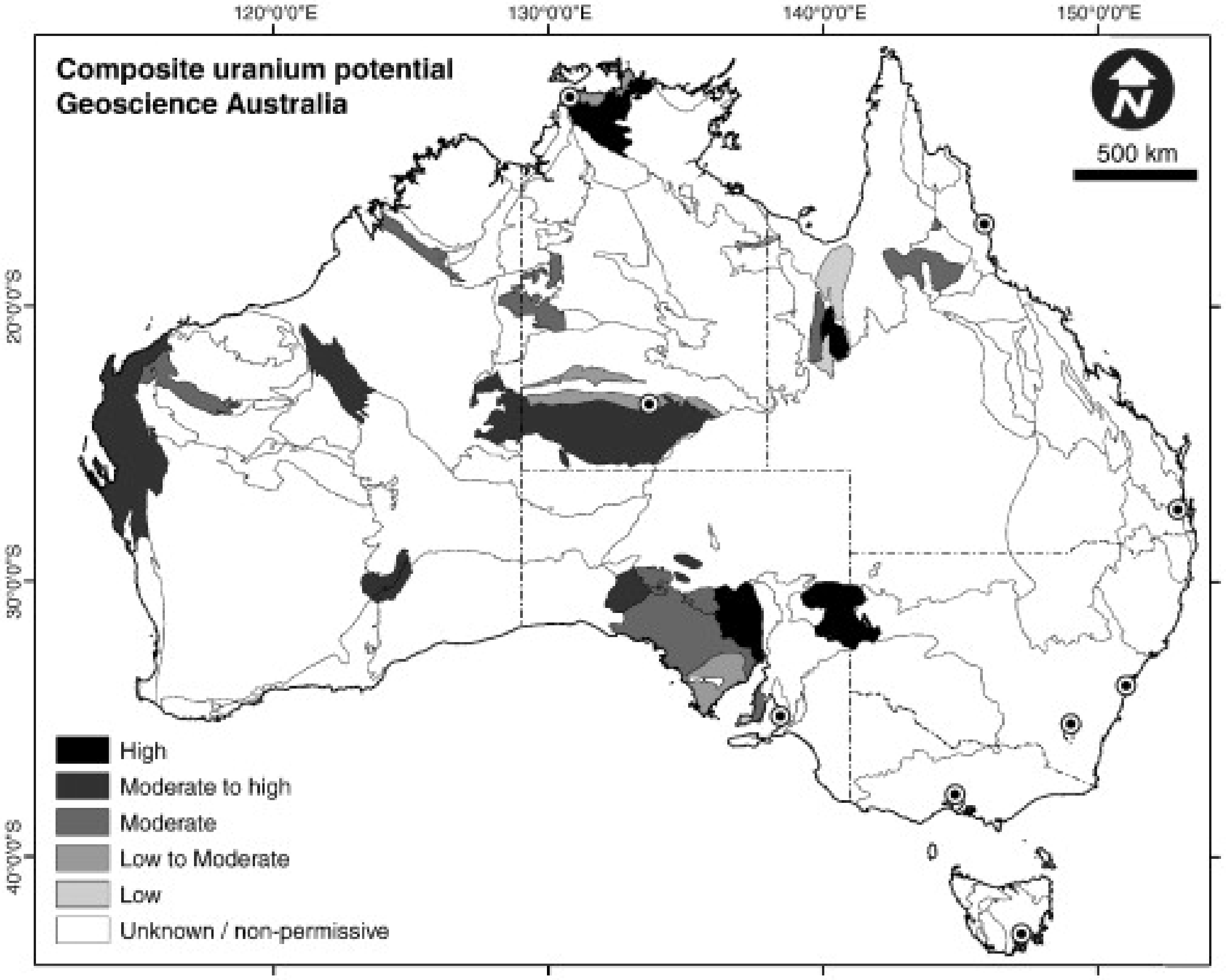
Uranium Mineral Potential Modelling

Permissive tracts (Kreuzer et al 2010)



Uranium Mineral Potential Modelling

Area selection based upon ranking of potential (cf small scale target generation)

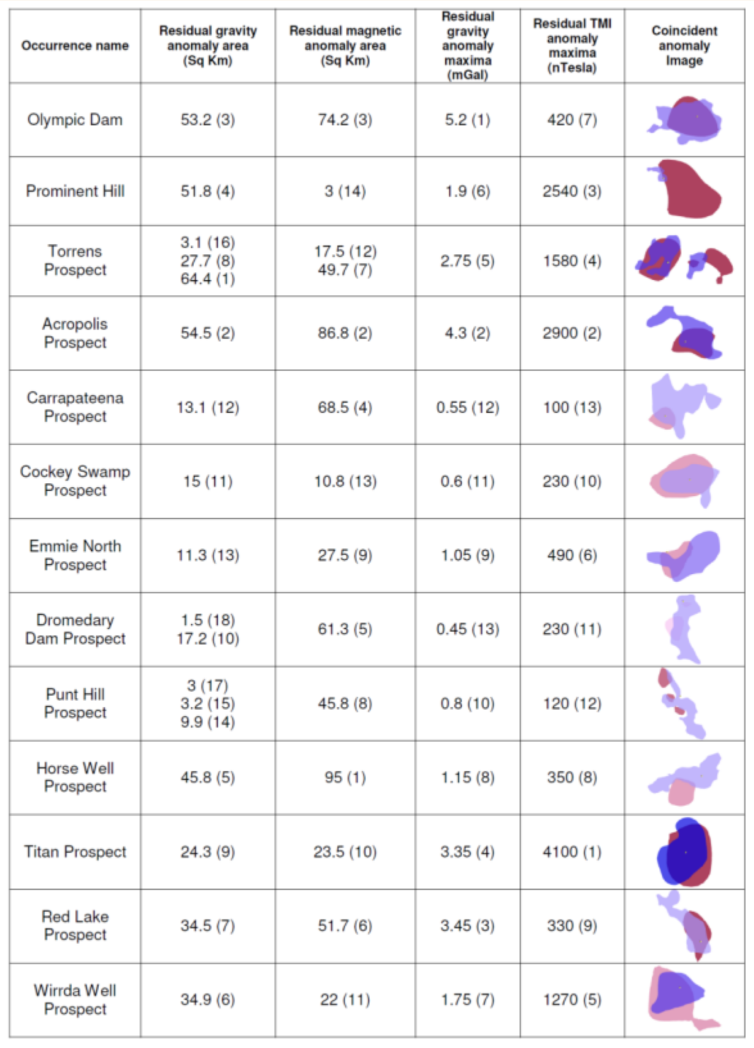


Uranium Mineral Potential Modelling

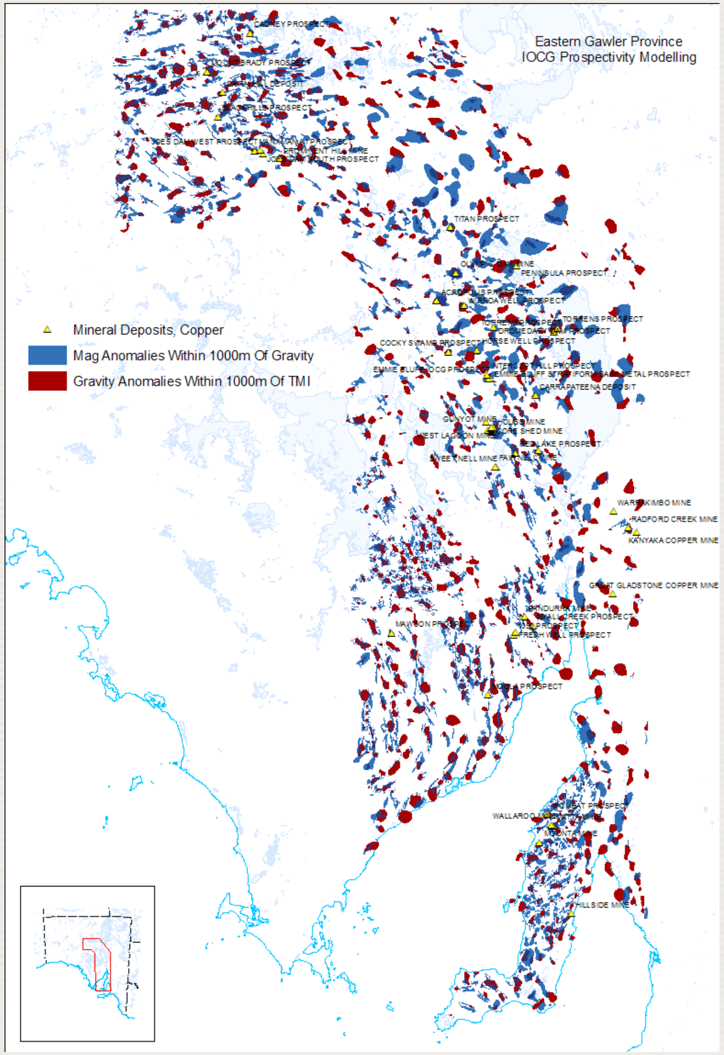
Similar techniques are uses in traditional smaller-scale mineral potential/prospectivity mapping. Some examples from South Australia

Uranium Mineral Potential Modelling

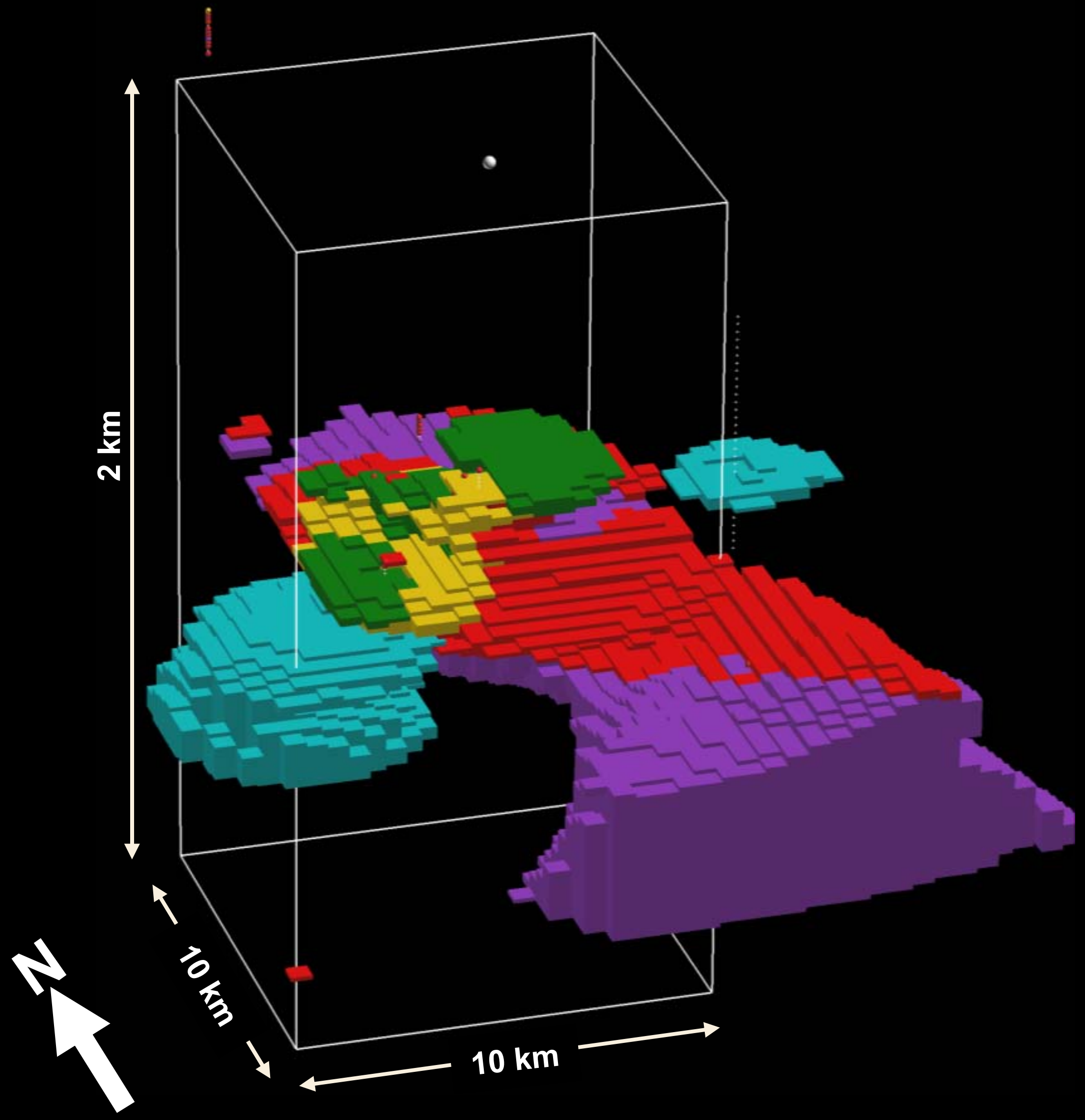
An example of IOCGU modelling of mappable criteria – SA (mag-hem distribution)



Occurrence name	Residual gravity anomaly area (Sq Km)	Residual magnetic anomaly area (Sq Km)	Residual gravity anomaly maxima (mGal)	Residual TMI anomaly maxima (nTesla)	Coincident anomaly Image
Olympic Dam	53.2 (3)	74.2 (3)	5.2 (1)	420 (7)	
Prominent Hill	51.8 (4)	3 (14)	1.9 (6)	2540 (3)	
Torrens Prospect	3.1 (16) 27.7 (8) 64.4 (1)	17.5 (12) 49.7 (7)	2.75 (5)	1580 (4)	
Acropolis Prospect	54.5 (2)	86.8 (2)	4.3 (2)	2900 (2)	
Carrapateena Prospect	13.1 (12)	68.5 (4)	0.55 (12)	100 (13)	
Cockey Swamp Prospect	15 (11)	10.8 (13)	0.6 (11)	230 (10)	
Emmie North Prospect	11.3 (13)	27.5 (9)	1.05 (9)	490 (6)	
Dromedary Dam Prospect	1.5 (18) 17.2 (10)	61.3 (5)	0.45 (13)	230 (11)	
Punt Hill Prospect	3 (17) 3.2 (15) 9.9 (14)	45.8 (8)	0.8 (10)	120 (12)	
Horse Well Prospect	45.8 (5)	95 (1)	1.15 (8)	350 (8)	
Titan Prospect	24.3 (9)	23.5 (10)	3.35 (4)	4100 (1)	
Red Lake Prospect	34.5 (7)	51.7 (6)	3.45 (3)	330 (9)	
Wirrda Well Prospect	34.9 (6)	22 (11)	1.75 (7)	1270 (5)	



3D Mineral Mapping of IOCGU deposits



- 🟥 Hematite
- ⬜ Magnetite
- 🟫 Hematite – Magnetite
- 🟦 Albite
- 🟪 K-Feldspar
- 🟥 Sericite
- 🟨 Sericite – Chlorite
- 🟩 Chlorite

500 m x 500 m x 10 m cell size

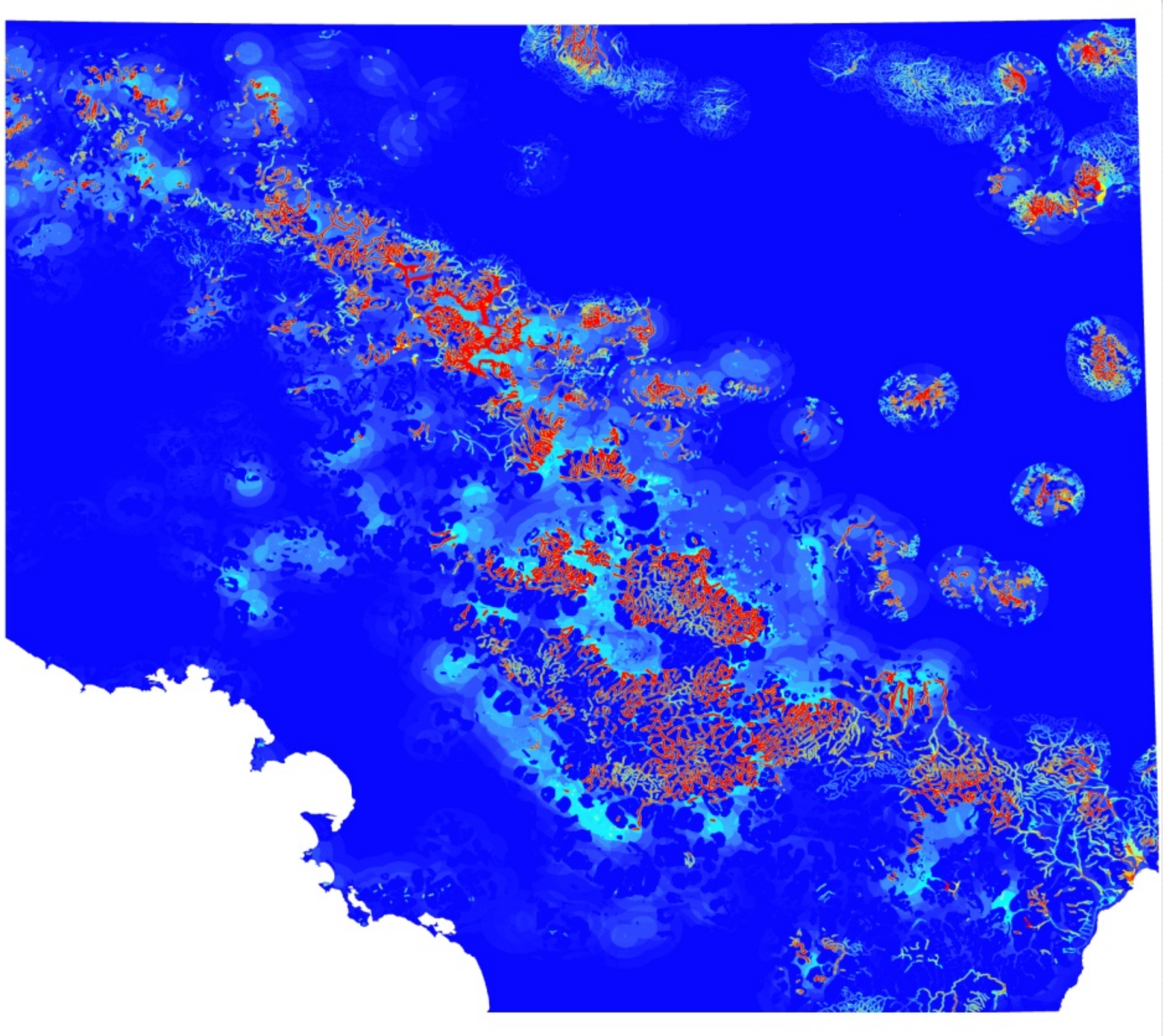
10x vertical exaggeration

Alteration Voxet

Uranium Mineral Potential Modelling

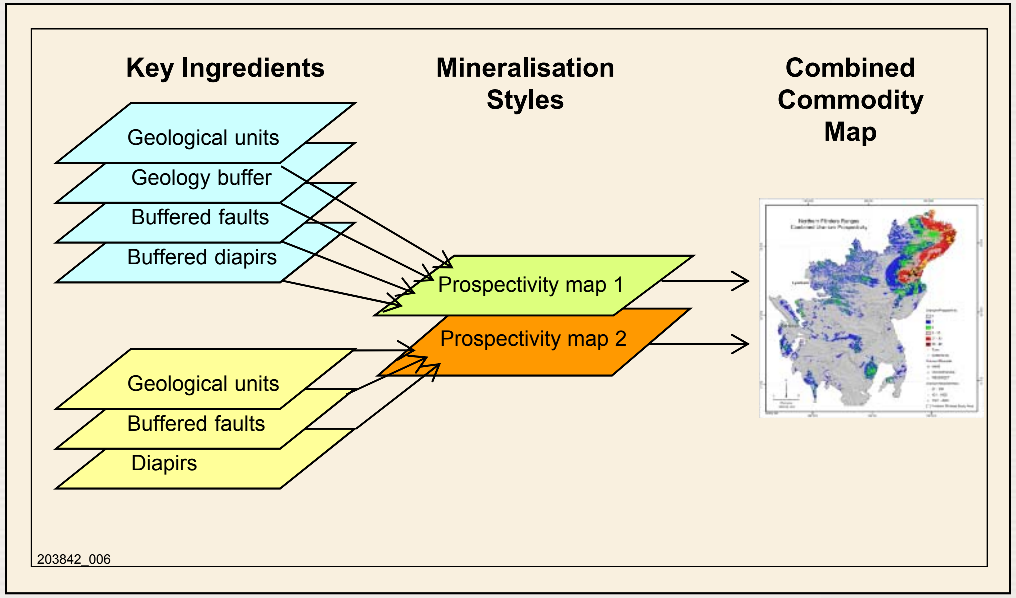
Calcrete hosted

Uranium potential



Uranium Mineral Potential Modelling

- An evolution of approaches…
- Mineral Potential Review
- Assessment of Key ingredients (Mineral Systems approach)
- Mappable Criteria
- **Knowledge Driven GIS**
  - **Rank and combine predictor variables**
  - **Produce prospectivity maps**
  - **Visual assessment and revision**



Key Ingredients

Geological units
Geology buffer
Buffered faults
Buffered diapirs

Geological units
Buffered faults
Diapirs

Mineralisation Styles

Prospectivity map 1
Prospectivity map 2

Combined Commodity Map

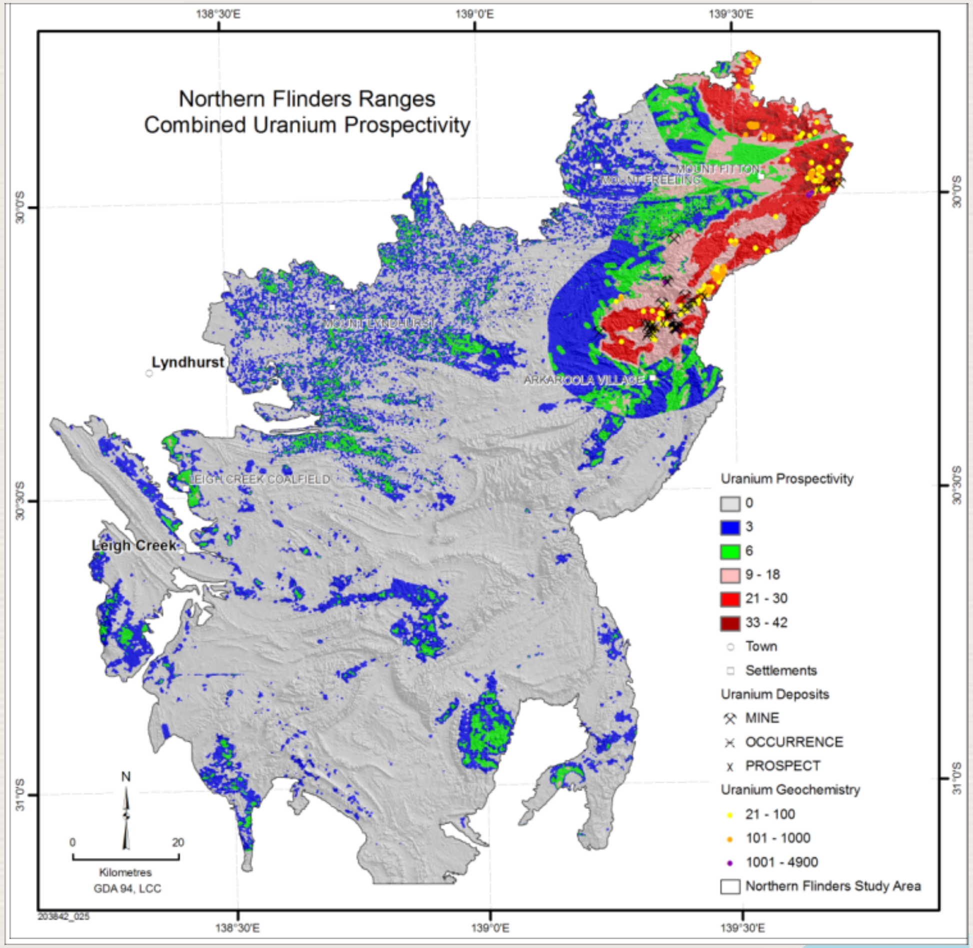
203842_006

Overlay of GIS layers producing prospectivity maps

Uranium Mineral Potential Modelling

Combined U prospectivity (SA)

- An evolution of approaches…
- Mineral Potential Review
- Assessment of Key ingredients (Mineral Systems approach)
- Mappable Criteria
- **Knowledge-driven GIS**
  - **Northern Flinders Ranges Case Study**
  - **Mineralisation Styles:**
  - **Hydrothermal Breccia/vein/skarn**
  - **Granite Sourced (elevated U)**
  - **Granite Sourced (High U)**
  - **Radiometric U**
  - **Combined Prospectivity**



Uranium Resource Modelling

In 1996, IAEA publication of the « Guidebook » to accompany the uranium deposits map

582 deposits listed from 48 countries

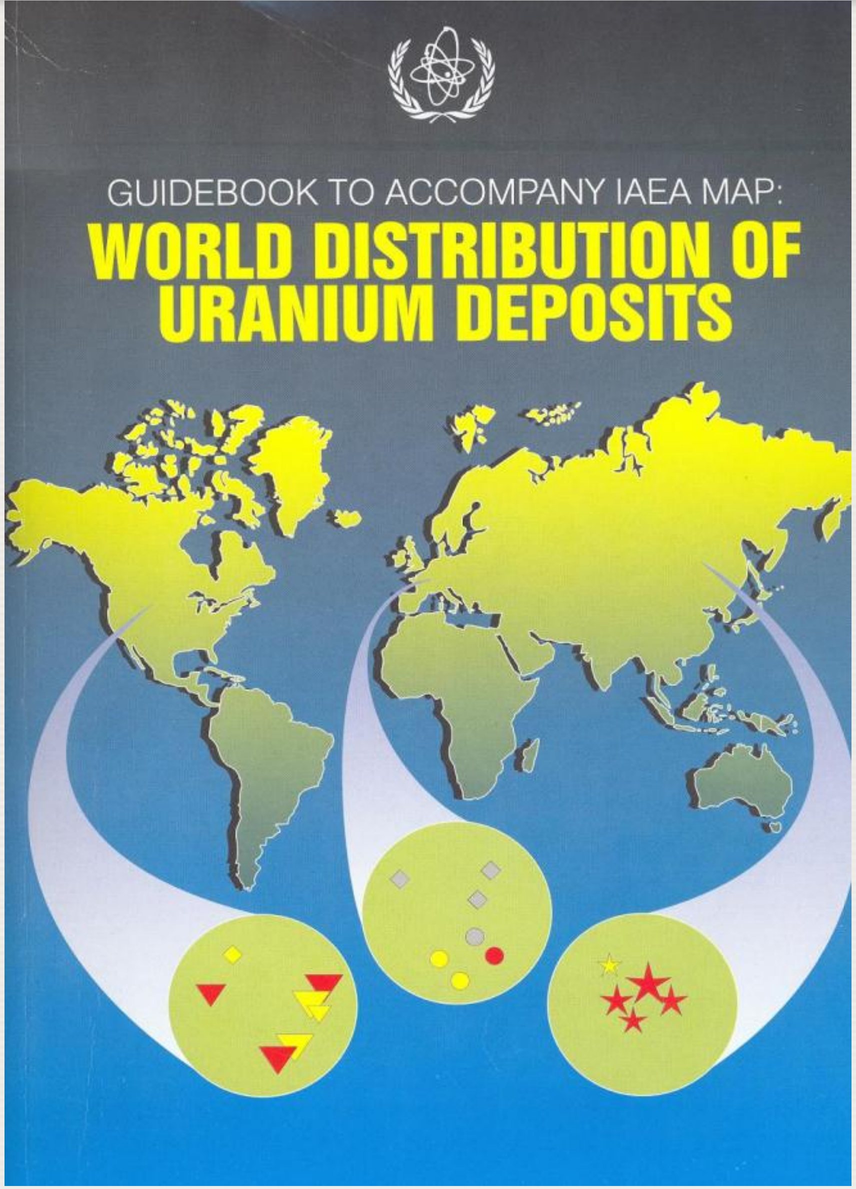
≥ 500 t U, ≥ 300 ppm

14 parameters recorded

15 deposit types

Creation of the UDEPO Database (Uranium DEPOsits)

IAEA


GUIDEBOOK TO ACCOMPANY IAEA MAP:

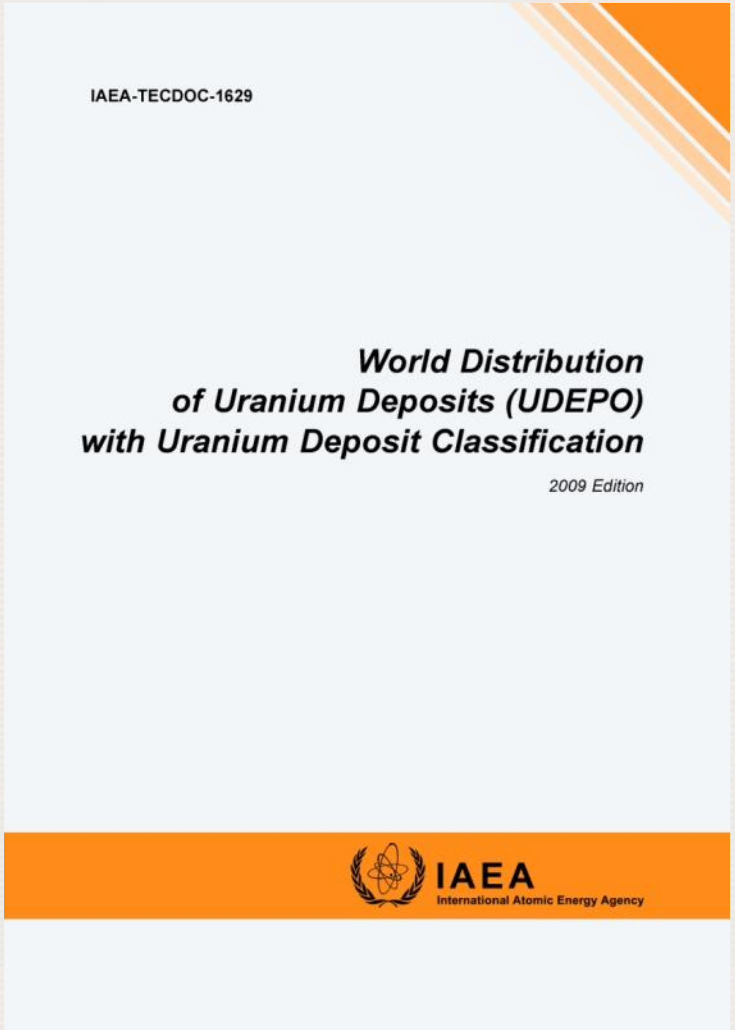
WORLD DISTRIBUTION OF URANIUM DEPOSITS

Uranium Resource Modelling

In 1995, publication by the IAEA of a geological map
« World distribution of uranium deposits »
with the geographical distribution of ***582*** *deposits located in* ***48*** *countries.*

Uranium Resource Modelling

Now we have new-improved UDEPO with >1500 deposits

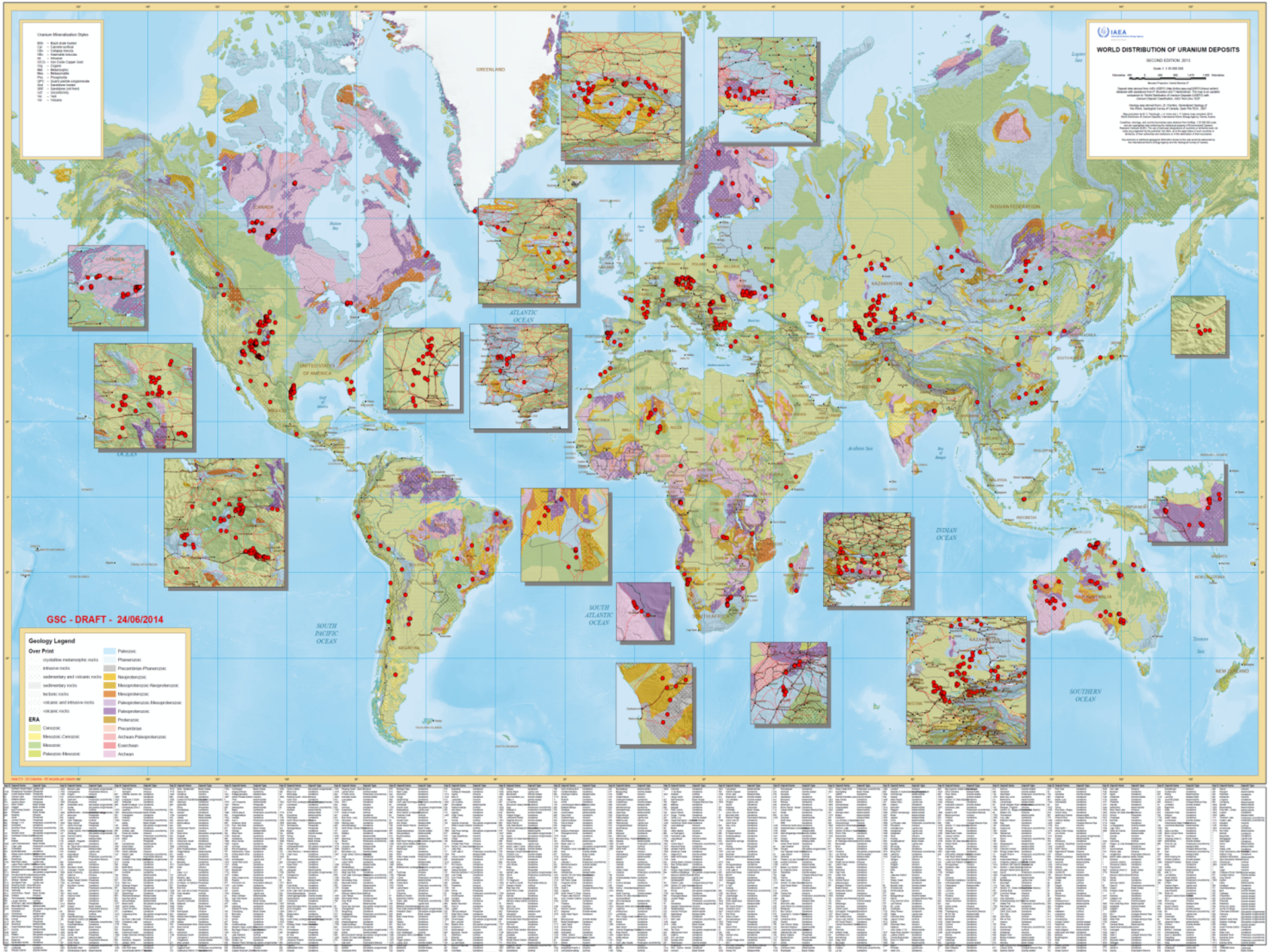


IAEA-TECDOC-1629

World Distribution of Uranium Deposits (UDEPO) with Uranium Deposit Classification

2009 Edition

IAEA
International Atomic Energy Agency



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WORLD DISTRIBUTION OF URANIUM DEPOSITS

SECOND EDITION: 2013

Geology was derived from L.B. Chorlton, Generalized Geology of the World, Geological Survey of Canada, Open File 5529, 2007

Uranium Mineralisation Styles

BSh – Black shale hosted
Cal – Calcrete surficial
CBx – Collapse breccia
HBx – Haematite breccias
Int – Intrusive
IOCG – Iron Oxide Copper Gold
Org – Organic
Met – Metamorphic
Mso – Metasomatite
Pho – Phosphorite
QPC – Quartz pebble conglomerate
Snd – Sandstone hosted
SRF – Sandstone (roll front)
Unf – Unconformity
Vei – Vein
Vol – Volcanic

GSC - DRAFT - 24/06/2014

Geology Legend

Over Print

crystalline metamorphic rocks
intrusive rocks
sedimentary and volcanic rocks
sedimentary rocks
tectonic rocks
volcanic and intrusive rocks
volcanic rocks

ERA

Cenozoic
Mesozoic-Cenozoic
Mesozoic
Paleozoic-Mesozoic
Paleozoic
Phanerozoic
Precambrian-Phanerozoic
Neoproterozoic
Mesoproterozoic-Neoproterozoic
Mesoproterozoic
Paleoproterozoic-Mesoproterozoic
Paleoproterozoic
Proterozoic
Precambrian
Archean-Paleoproterozoic
Eoarchean
Archean

23 Columns - 65 records per column

Uranium Resource Modelling

Three-part Resource Assessments

- General locations of undiscovered deposits are delineated from a deposit type's geologic setting
- Frequency distributions of tonnages and grades of well-explored deposits serve as models of grades and tonnages of undiscovered deposits
- Number of undiscovered deposits are estimated probabilistically by type

Uranium Resource Modelling

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- Number of undiscovered deposits are estimated probabilistically by type

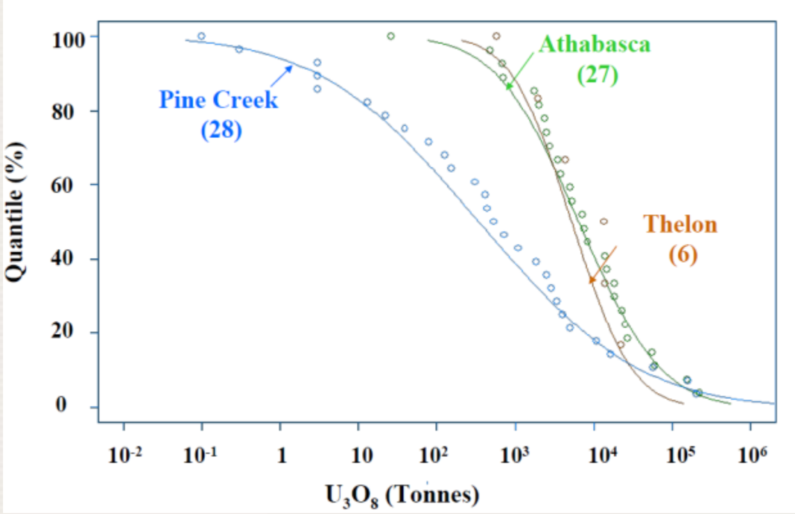
IAEA

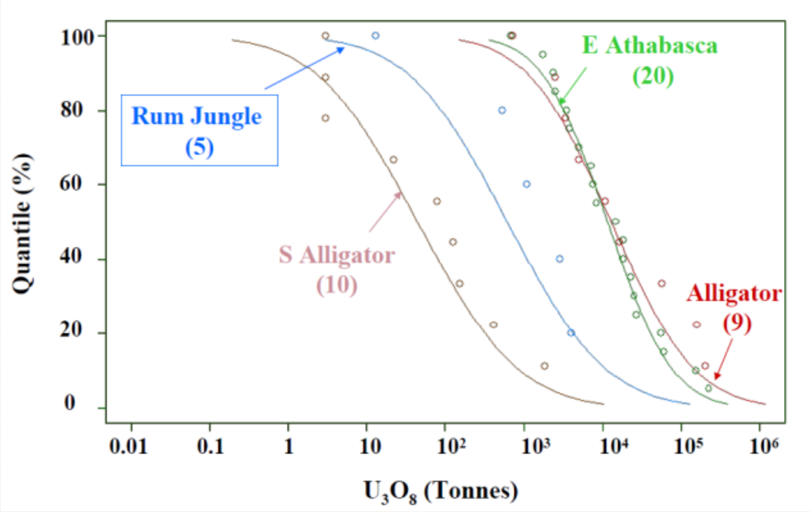
Uranium Resource Modelling

Three-part Resource Assessments

Verified Grade-tonnage cumulative frequency curves are uncommon for U (but can be generated from UDEPO)

- But need to be generated for each deposit type and region - and need to be statistically valid and internally consistent

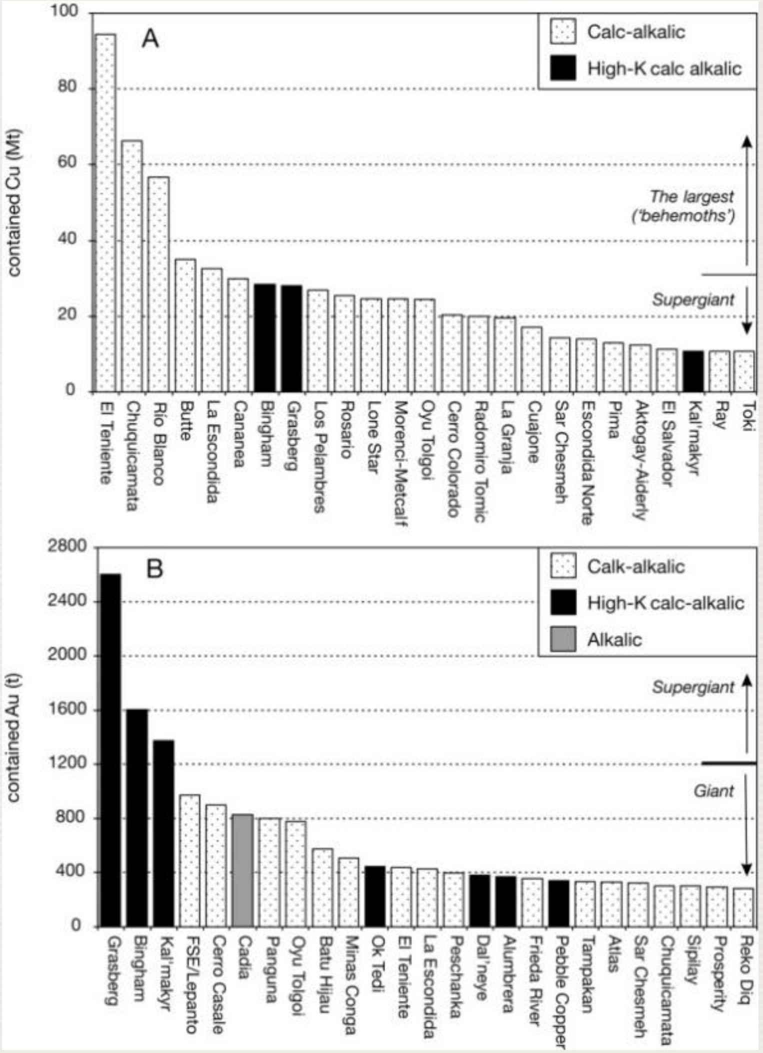




Jaireth et al, 2008, AESC

Uranium Resource Modelling

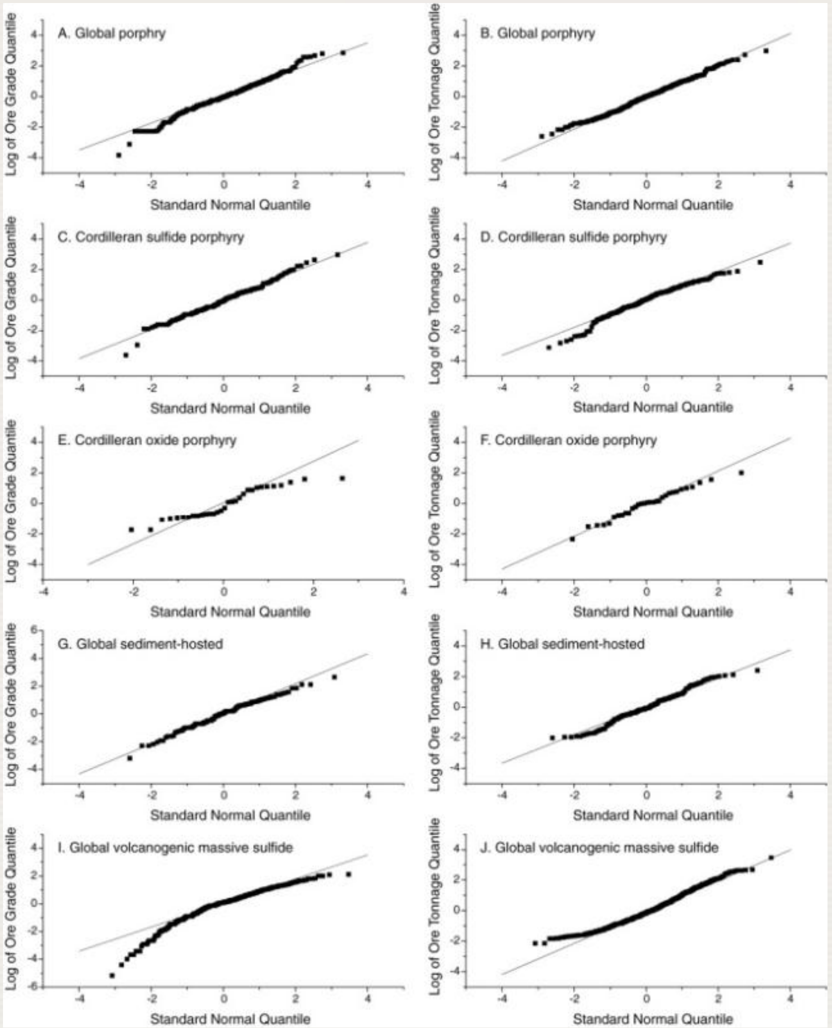
Exist for porphyry copper



A. The 25 largest porphyry deposits, identified by magma series. A. Giant copper deposits. Data listed in Table 1⇑. B. Giant gold deposits. Data listed in Table 2⇑. D. R Cooke &P. Hollings. Giant Porphyry Deposits: Characteristics, Distribution, and Tectonic Controls. Economic Geology Augustv. 100 no. 5 p. 801-818.

Uranium Resource Modelling

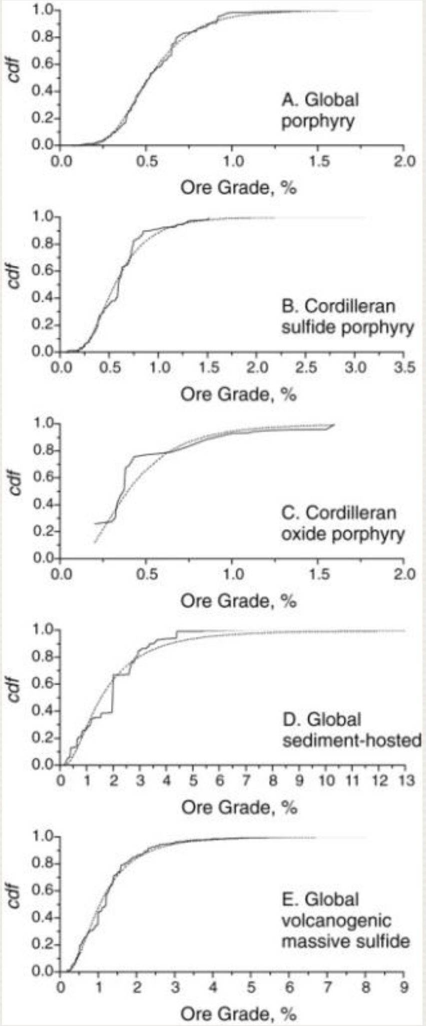
Exist for porphyry copper



Log ore grade and log ore tonnage quantile-quantile (Q-Q) plots by ore type. Q-Q plots compare the ranked empirical data against the standard normal quantiles and can be used as a visual test of the normality of a dataset (see Walpole et al., 1998, for more details). If the plotted data appear linear in relationship to a line drawn through the first and third quartiles, then strong evidence exists for the normal distribution. Because the data are transformed logarithmically, then the appearance of the linear relationship is evidence for the lognormal distribution. Inspection of the plots indicate that most of the datasets exhibit evidence of lognormality. Important deviations include the appearance of skewness in the VMS plots and thin tails in the Cordilleran oxide porphyry ore-grade plot.. M. D. Gerst. Revisiting the Cumulative Grade-Tonnage Relationship for Major Copper Ore Types. Economic Geology May vol. 103 no. 3 615-628

Uranium Resource Modelling

Exist for porphyry copper



Observed (solid lines) and predicted (dashed lines) cumulative distribution functions (*cdf*). Similar to the Q-Q plots shown in Figure 1⇑, Figure 3 can be used as a graphic aid to assess the appropriateness of the log-normal distribution assumption. The method to create Figure 3, and its use in calculating the Lilliefors' test statistic in Table 3⇑, is discussed in the Appendix. The curves shown for the global VMS data are those with the outliers removed. M. D. Gerst. Revisiting the Cumulative Grade-Tonnage Relationship for Major Copper Ore Types. Economic Geology May vol. 103 no. 3 615-628.

Uranium Resource Modelling

Three-part Resource Assessments

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IAEA

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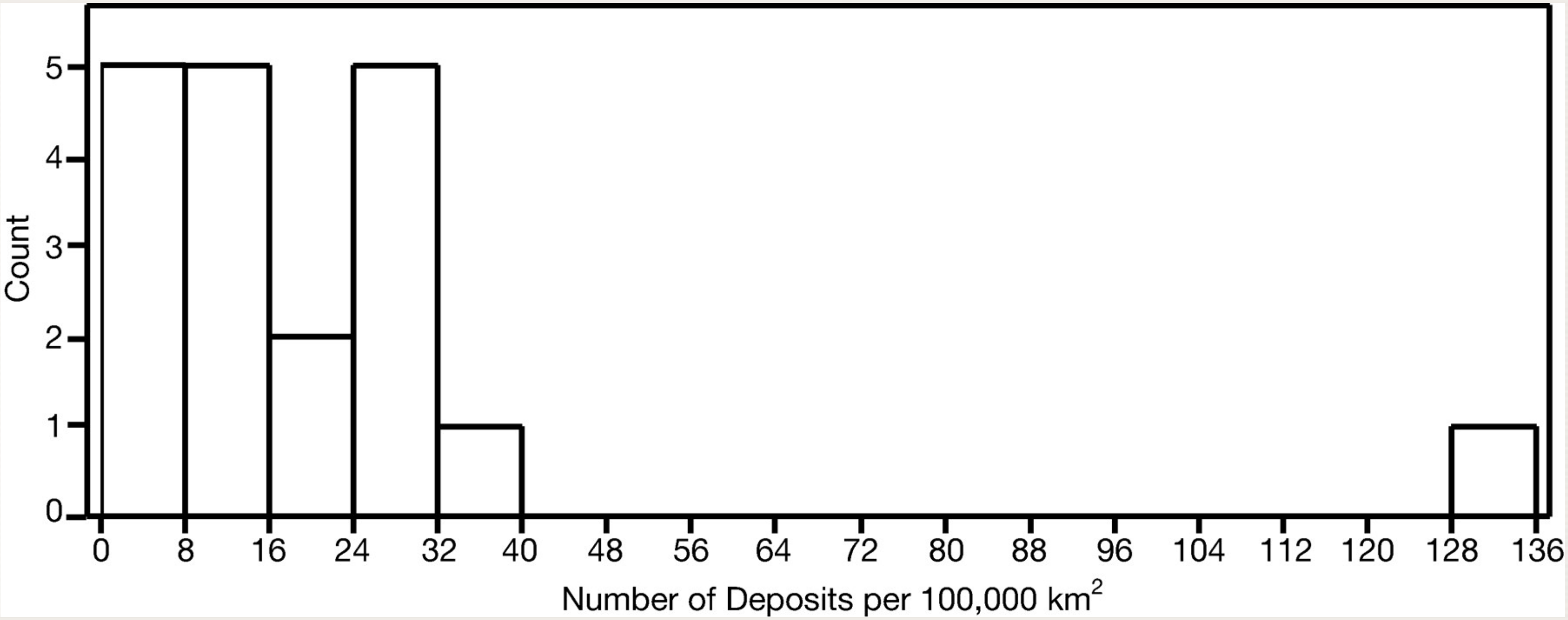
Uranium Resource Modelling

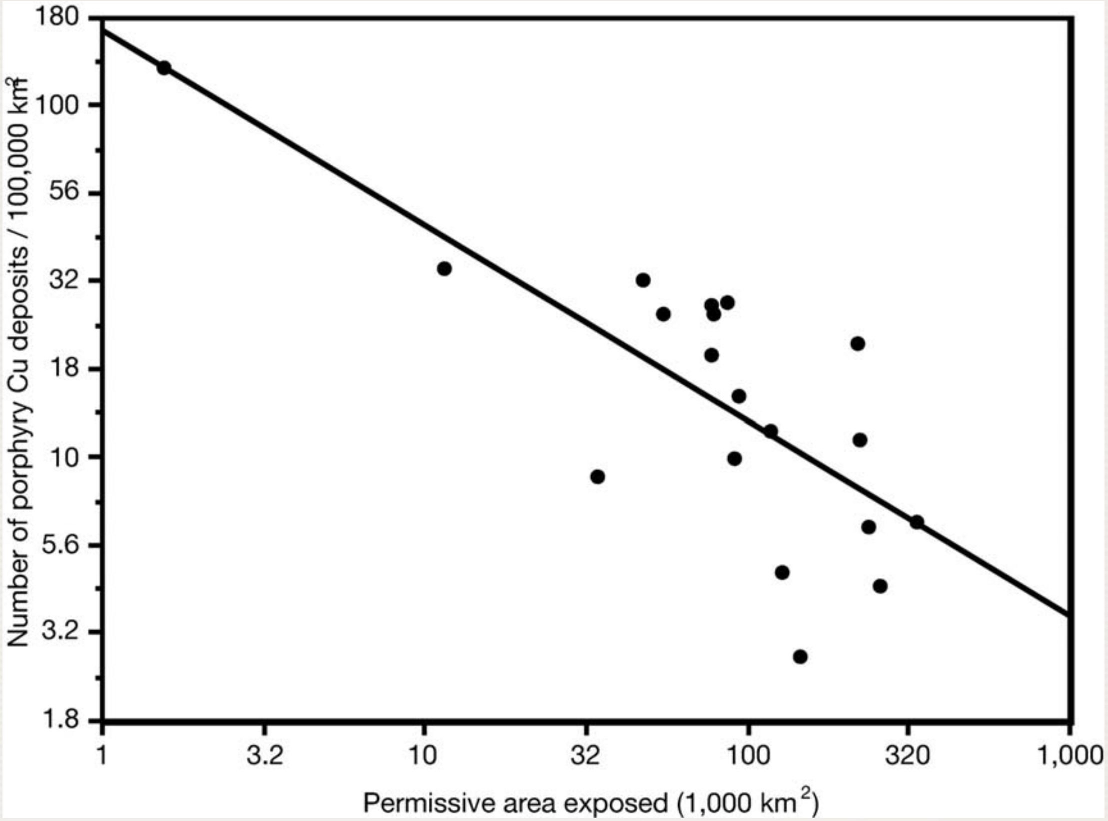
Exist for porphyry copper



Histogram of porphyry copper deposit densities per 100,000 km^2. Singer & V. I. Berger. Porphyry Copper Deposit Density. Economic Geology May 2005 v. 100 no. 3 p. 491-514.

Uranium Resource Modelling

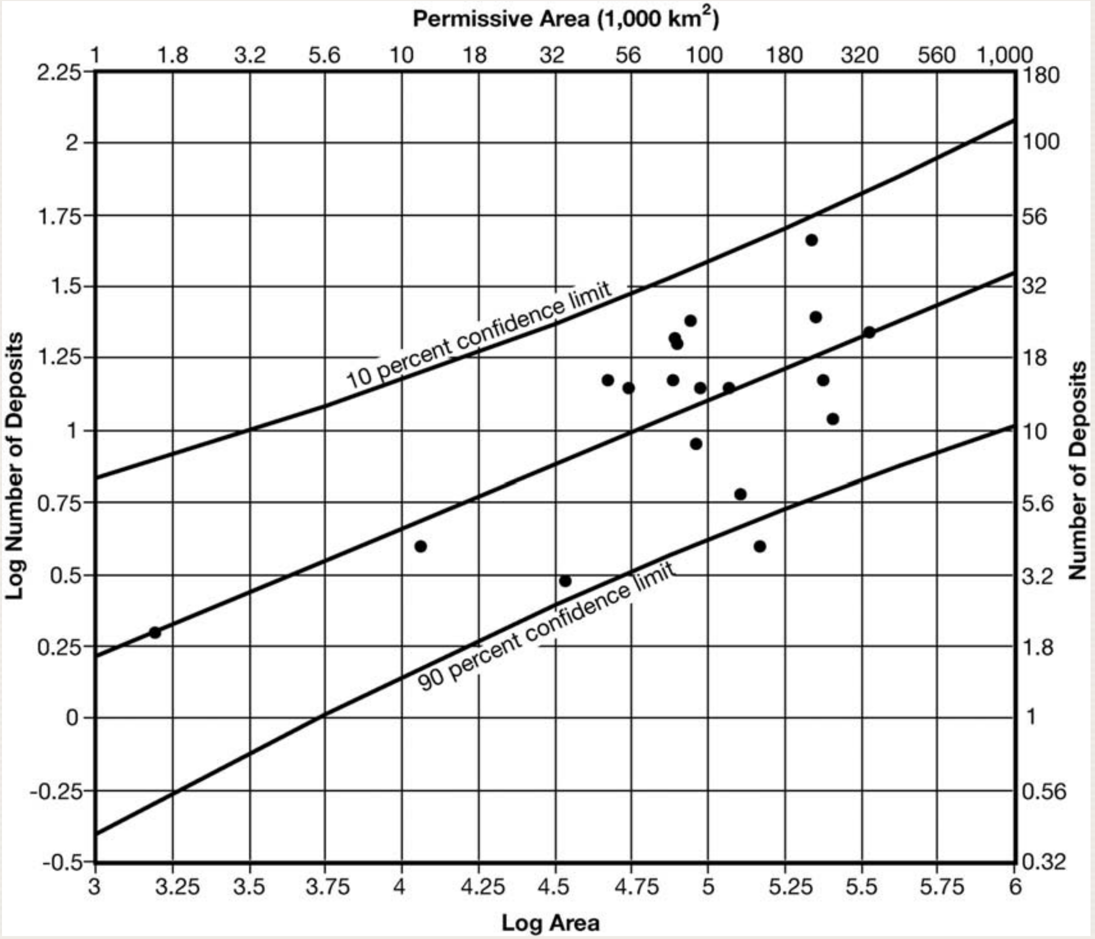
Exist for porphyry copper



Porphyry copper control area exposed vs. density of deposits. Singer & V. I. Berger. Porphyry Copper Deposit Density. Economic Geology May 2005 v. 100 no. 3 p. 491-514.

Uranium Resource Modelling

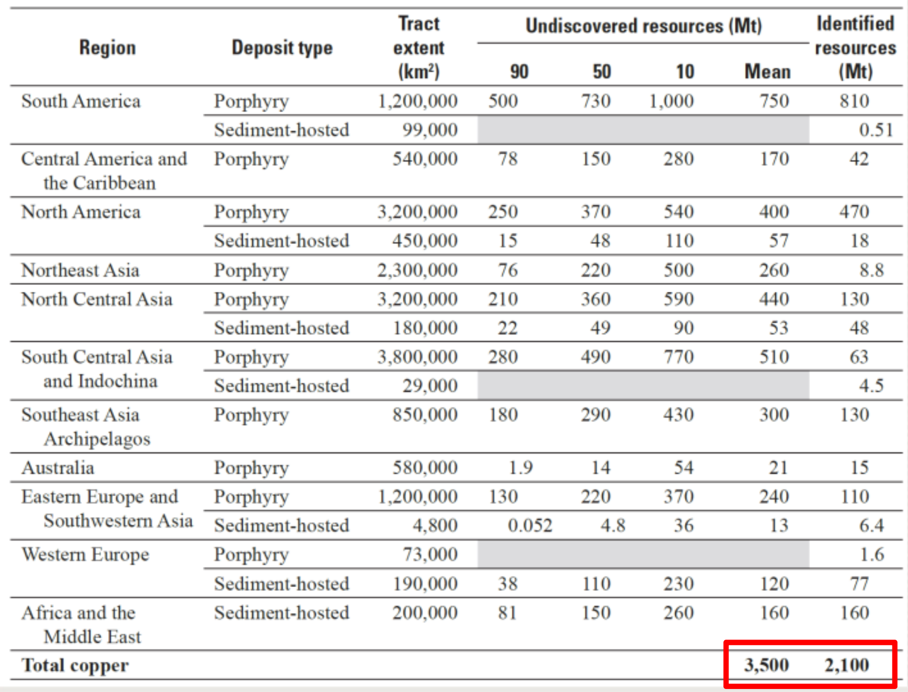
Exist for porphyry copper



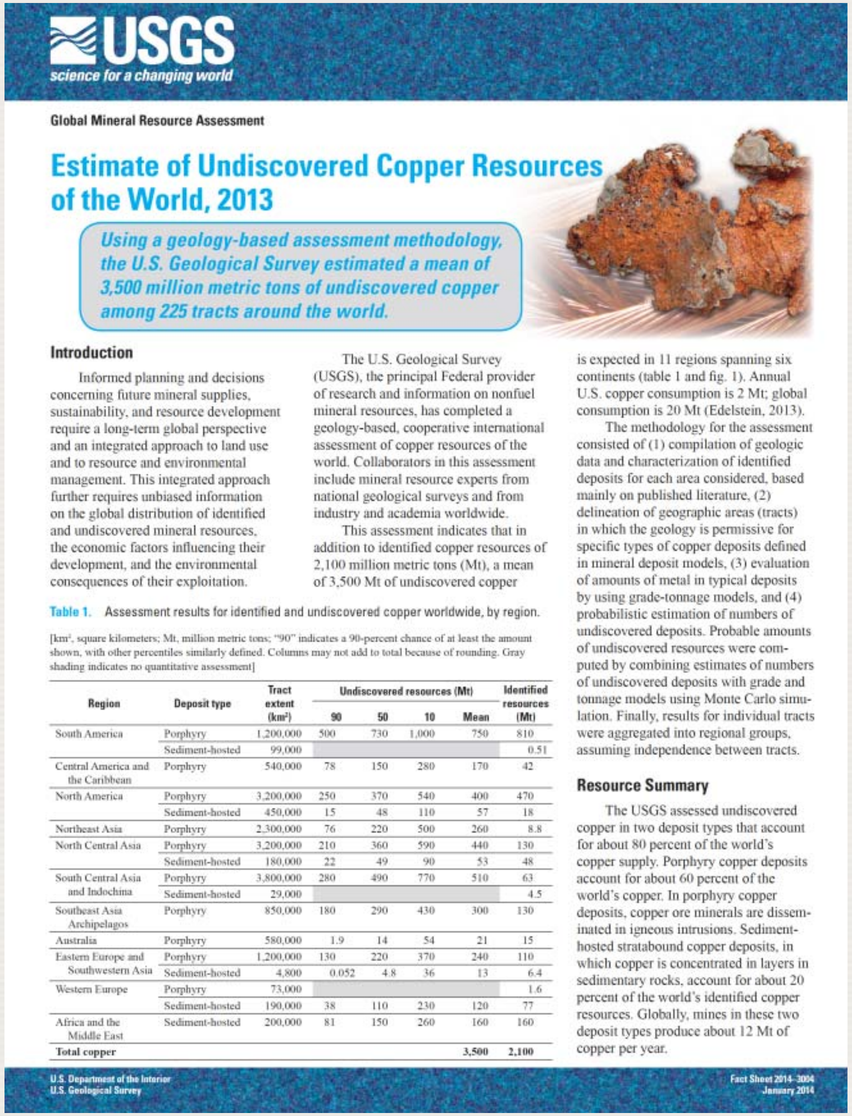
Porphyry copper control area exposed vs. number of deposits with 90 and 10 percent confidence limits for number of deposits. Singer & V. I. Berger. Porphyry Copper Deposit Density. Economic Geology May 2005 v. 100 no. 3 p. 491-514.

Uranium Mineral Potential Modelling

The end (update result)



Region	Deposit type	Tract extent (km²)	Undiscovered resources (Mt)				Identified resources (Mt)
			90	50	10	Mean	
South America	Porphyry	1,200,000	500	730	1,000	750	810
	Sediment-hosted	99,000					0.51
Central America and the Caribbean	Porphyry	540,000	78	150	280	170	42
North America	Porphyry	3,200,000	250	370	540	400	470
	Sediment-hosted	450,000	15	48	110	57	18
Northeast Asia	Porphyry	2,300,000	76	220	500	260	8.8
North Central Asia	Porphyry	3,200,000	210	360	590	440	130
	Sediment-hosted	180,000	22	49	90	53	48
South Central Asia and Indochina	Porphyry	3,800,000	280	490	770	510	63
	Sediment-hosted	29,000					4.5
Southeast Asia Archipelagos	Porphyry	850,000	180	290	430	300	130
Australia	Porphyry	580,000	1.9	14	54	21	15
Eastern Europe and Southwestern Asia	Porphyry	1,200,000	130	220	370	240	110
	Sediment-hosted	4,800	0.052	4.8	36	13	6.4
Western Europe	Porphyry	73,000					1.6
	Sediment-hosted	190,000	38	110	230	120	77
Africa and the Middle East	Sediment-hosted	200,000	81	150	260	160	160
Total copper						**3,500**	**2,100**



USGS
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Global Mineral Resource Assessment

Estimate of Undiscovered Copper Resources of the World, 2013

Using a geology-based assessment methodology, the U.S. Geological Survey estimated a mean of 3,500 million metric tons of undiscovered copper among 225 tracts around the world.

Introduction

Informed planning and decisions concerning future mineral supplies, sustainability, and resource development require a long-term global perspective and an integrated approach to land use and to resource and environmental management. This integrated approach further requires unbiased information on the global distribution of identified and undiscovered mineral resources, the economic factors influencing their development, and the environmental consequences of their exploitation.

The U.S. Geological Survey (USGS), the principal Federal provider of research and information on nonfuel mineral resources, has completed a geology-based, cooperative international assessment of copper resources of the world. Collaborators in this assessment include mineral resource experts from national geological surveys and from industry and academia worldwide.

This assessment indicates that in addition to identified copper resources of 2,100 million metric tons (Mt), a mean of 3,500 Mt of undiscovered copper is expected in 11 regions spanning six continents (table 1 and fig. 1). Annual U.S. copper consumption is 2 Mt; global consumption is 20 Mt (Edelstein, 2013).

The methodology for the assessment consisted of (1) compilation of geologic data and characterization of identified deposits for each area considered, based mainly on published literature, (2) delineation of geographic areas (tracts) in which the geology is permissive for specific types of copper deposits defined in mineral deposit models, (3) evaluation of amounts of metal in typical deposits by using grade-tonnage models, and (4) probabilistic estimation of numbers of undiscovered deposits. Probable amounts of undiscovered resources were computed by combining estimates of numbers of undiscovered deposits with grade and tonnage models using Monte Carlo simulation. Finally, results for individual tracts were aggregated into regional groups, assuming independence between tracts.

Table 1. Assessment results for identified and undiscovered copper worldwide, by region.

[km², square kilometers; Mt, million metric tons; "90" indicates a 90-percent chance of at least the amount shown, with other percentiles similarly defined. Columns may not add to total because of rounding. Gray shading indicates no quantitative assessment]

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The USGS assessed undiscovered copper in two deposit types that account for about 80 percent of the world's copper supply. Porphyry copper deposits account for about 60 percent of the world's copper. In porphyry copper deposits, copper ore minerals are disseminated in igneous intrusions. Sediment-hosted stratabound copper deposits, in which copper is concentrated in layers in sedimentary rocks, account for about 20 percent of the world's identified copper resources. Globally, mines in these two deposit types produce about 12 Mt of copper per year.

U.S. Department of the Interior
U.S. Geological Survey

Fact Sheet 2014–3004
January 2014

Uranium Mineral Potential Modelling

The end (update result)

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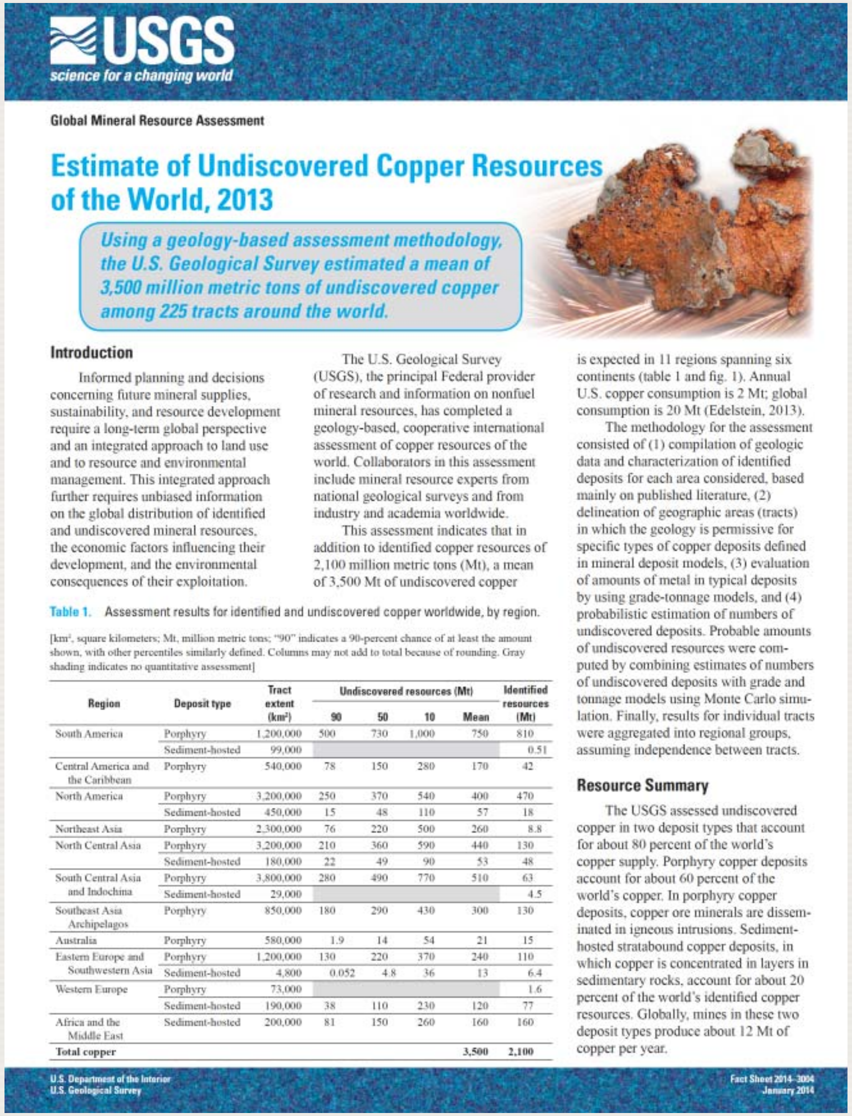
This is what we want for Uranium



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