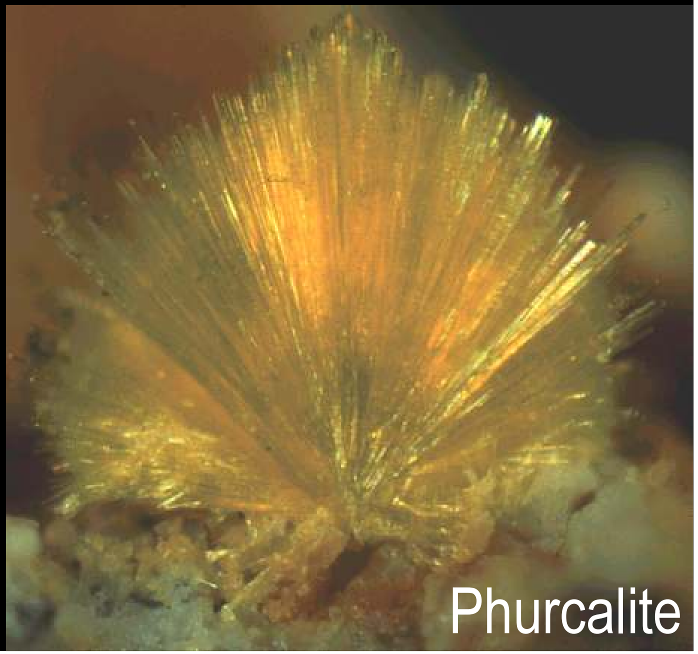
Training and education in uranium geology and exploration

Michel CUNEY

NANCY UNIVERSITE - UMR G2R – CREGU – CNRS
54 506, Vandoeuvre les NANCY
FRANCE



Phurcalite

URAM 2009 – IAEA – VIENNA – June 25th 2009

History of training & education in uranium geology & exploration

Evolution of the scientific research in U metallogenesis and training closely follows the evolution of exploration budgets :

➔ themselves being a direct consequence of the metal price on the market

1970's : Strong increase of exploration, consequence of the 1973 oil crisis,

end of 1980's to early 2000's sudies and training related to U metallogenesis almost stopped in most countries

> 1990 : opening of the Soviet block countries,

➔ huge research effort developed by USSR since 1945 became accessible :

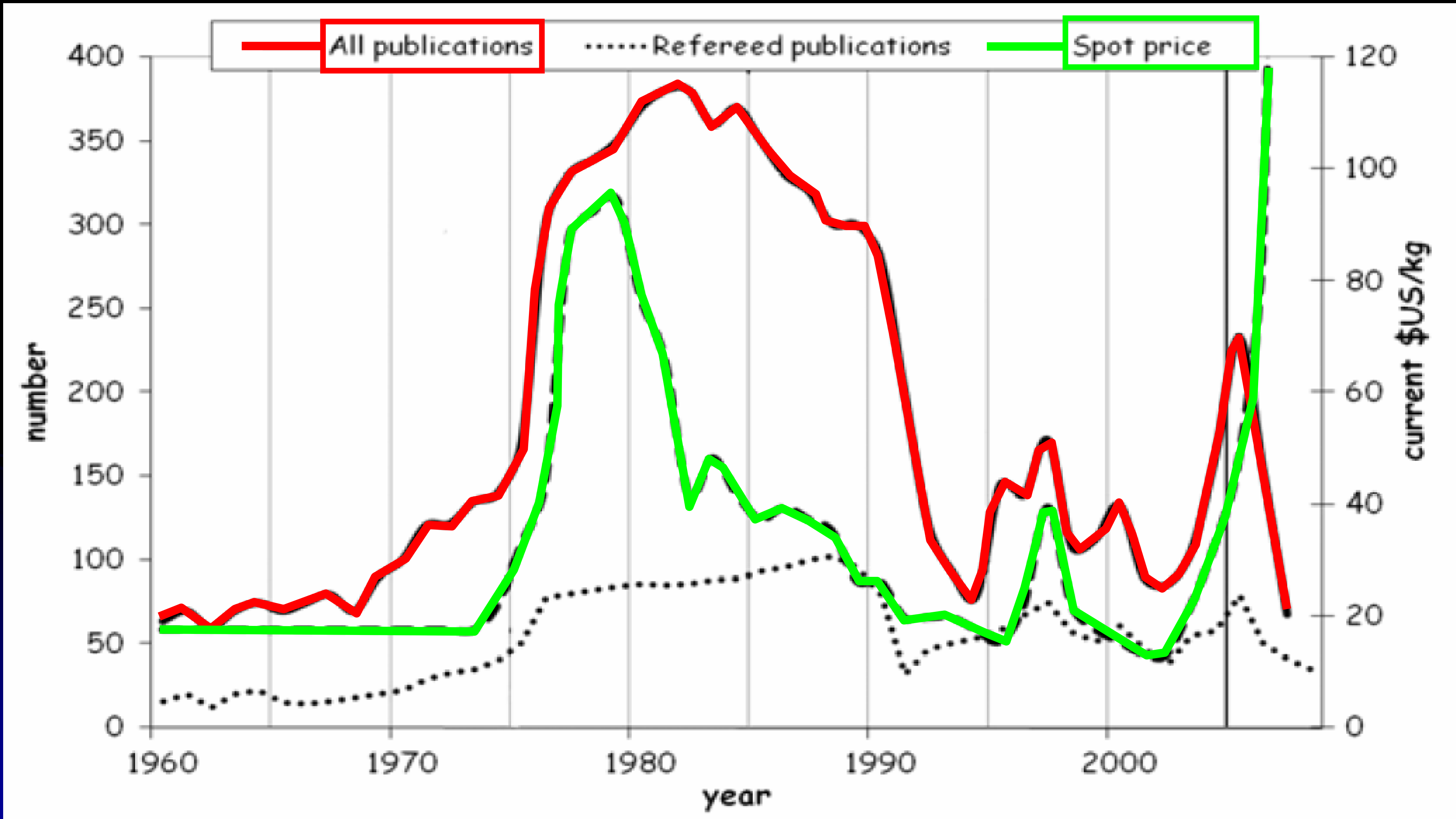
→ USSR had mined almost half of the U produced in 1990,

→ partly from deposits not known to have large resources in the W. countries

→ several hundreds of deposits have been added to the IAEA data base

> 2008 : the number of publications on U deposits will become exponential in relation with the explosion of exploration budgets, research in the universities project development in large companies and junior companies following the strong increase of the U prices on the spot market.

Development of R & D studies with the evolution of U spot price



From Kyser and Cuney 2008

History of training & education in uranium geology & exploration

As a result of the weak exploration & research efforts during the last 20 years:

→ skilled professionals in the field of U geology and exploration have tremendously decreased

→U explor. companies have faced a severe lack of experienced geologists

→ Retired U geologists have massively returned to work in the junior companies and as consultants

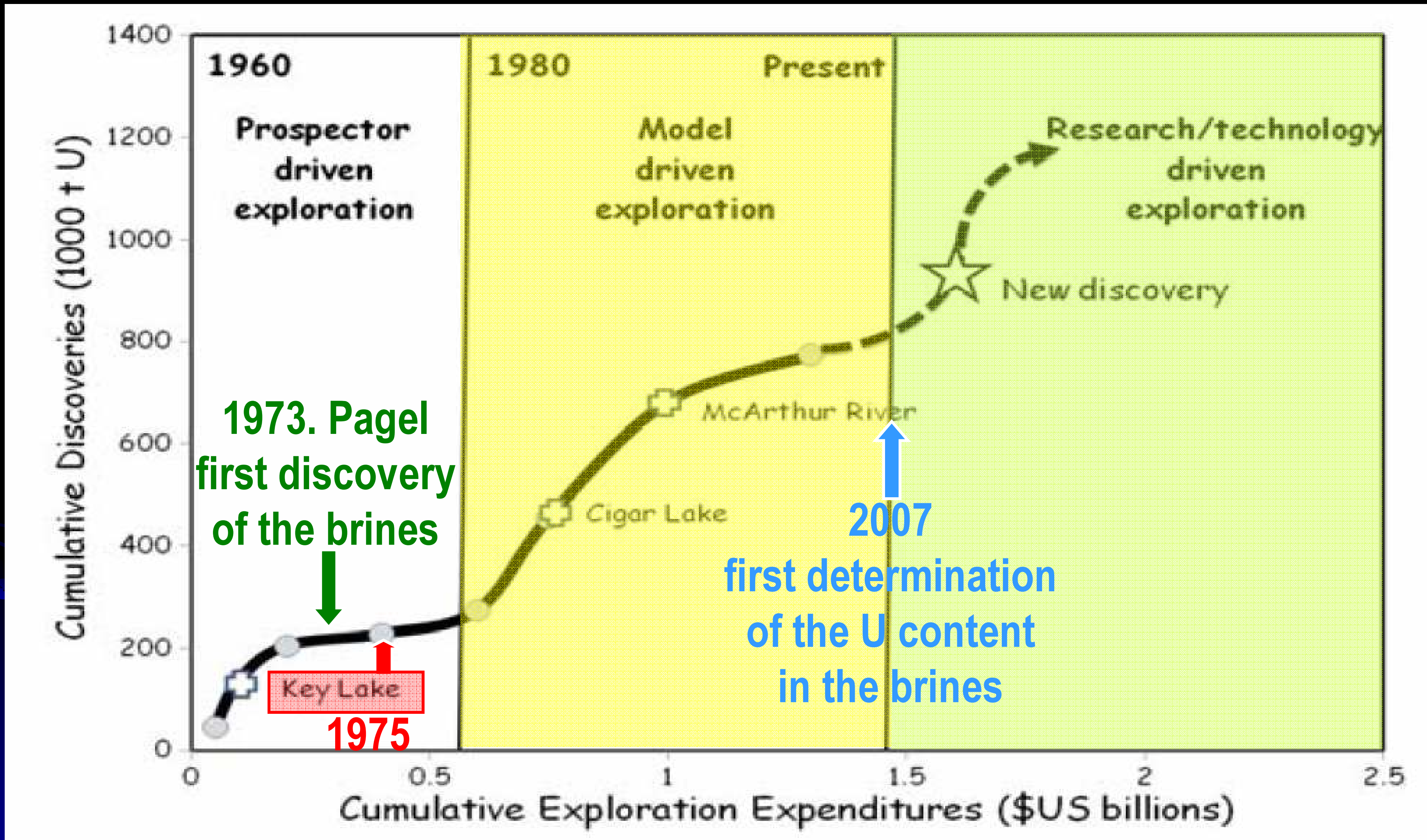
→ Training programs are developed worldwide, but needs are tremendous

→ Presently, the best training are made for radioprotection because of the strong existing regulations.

→ A considerable effort has to be made for developing the education in the physical & geochemical properties of U, very specific to this element, and for the understanding of the multiple geologic models of U-deposits

→Such knowledge is required to develop efficient exploration programs and to prevent spending large investments for hopeless targets as illustrated by many case studies.

Increasing R & D and training are required to sustain exploration



The Key Lake discovery demonstrated that the “unconformity model” can explain the ATHABASCA uranium deposits

From Marlatt 2006

Major lines of education & training in U geology & exploration

1 – **Uranium has specific properties** mainly due to its radioactivity and redox compared to other metals which have major implications :

→ in exploration
→ in safety issues

2 – **U deposits occur in extremely diverse geologic settings** all around the geological cycle → needs of a comprehensive education in geology

3 – **The knowledge of the ways to evaluate the quality of the U sources** to estimate area favourabilty for U exploration is outmost Importance,
the knowledge of traps is of second order priority, and then the vectors

4 – **The uranium hosting phases are very diverse** : the knowledge of their nature is critical for the economics of the ore processing

5 – **geophysical techniques Increasingly sophisticated** will be needed for the discovery of deeper and deeper deposits

6 – **Development of integrated GIS based exploration techniques**

Major lines of education & training in U geology & exploration

1a – Uranium has specific physical properties especially its radioactivity, compared to other metals which have major implications :

- ➔ in exploration :
  - → Gamma scintillometers, spectrometers
  - → Heat flow/heat production ➔ U provinces
  - → Age determinations :
    - U-Pb isotopic Concordia diagrams
    - U-Pb chemical ages (1% PbO = 100 Ma)
    - U decay series (> 1Ma)
    - Spontaneous fission (U-Xe & U-Kr ages / fission tracks)
  - → Equilibrium vs disequilibrium
  - → Metamictization of U minerals
  - → Destruction rims/pleochroic haloes/coloration of minerals
  - → ^{4}He, Radon emanations
  - → Radiolysis of water ➔ secondary oxidation, H_2 emission
- ➔ in safety issues : will not be developed here

Major lines of education & training in U geology & exploration

2a - Uranium has specific chemical properties :

- ➔ **U is highly mobile in the oxidized state as uranyl complexes**
- ➔ **U has an extremely low solubility in reduced conditions**

  (more than 10 orders of magnitude for crystallized phases)

  equivalent to the solubility of ThO_2

➔ redox is the major control on U-mobilization & deposition

for most U deposits (except calcretes, quartz pebble conglomerates, …)

➔ Strong relation with organic matter from very low to high T

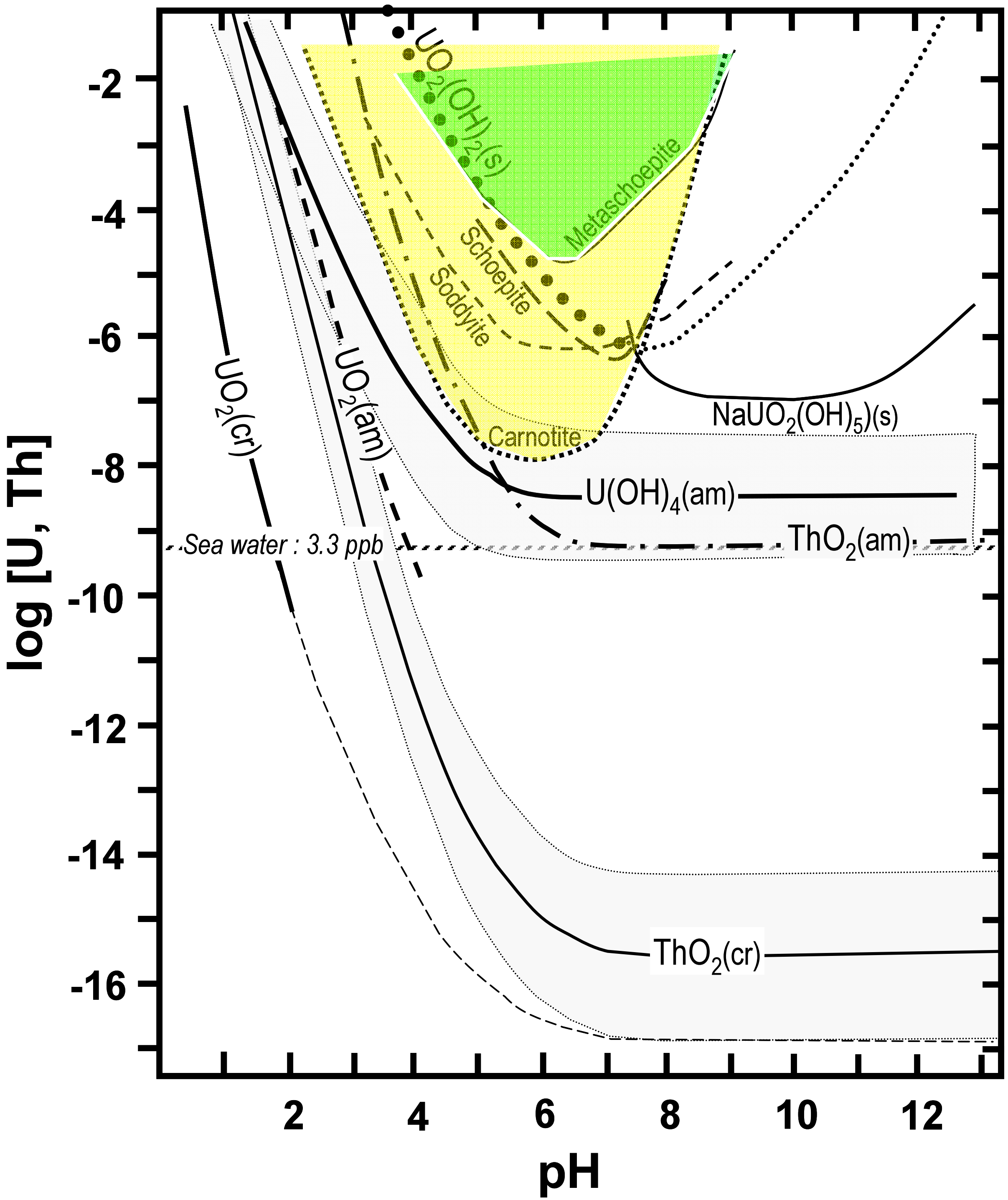
- ➔ Uranyl ions form more than 40 complexes with variable pH

  and ligands concentrations

Uranium and thorium solubility at 20°C

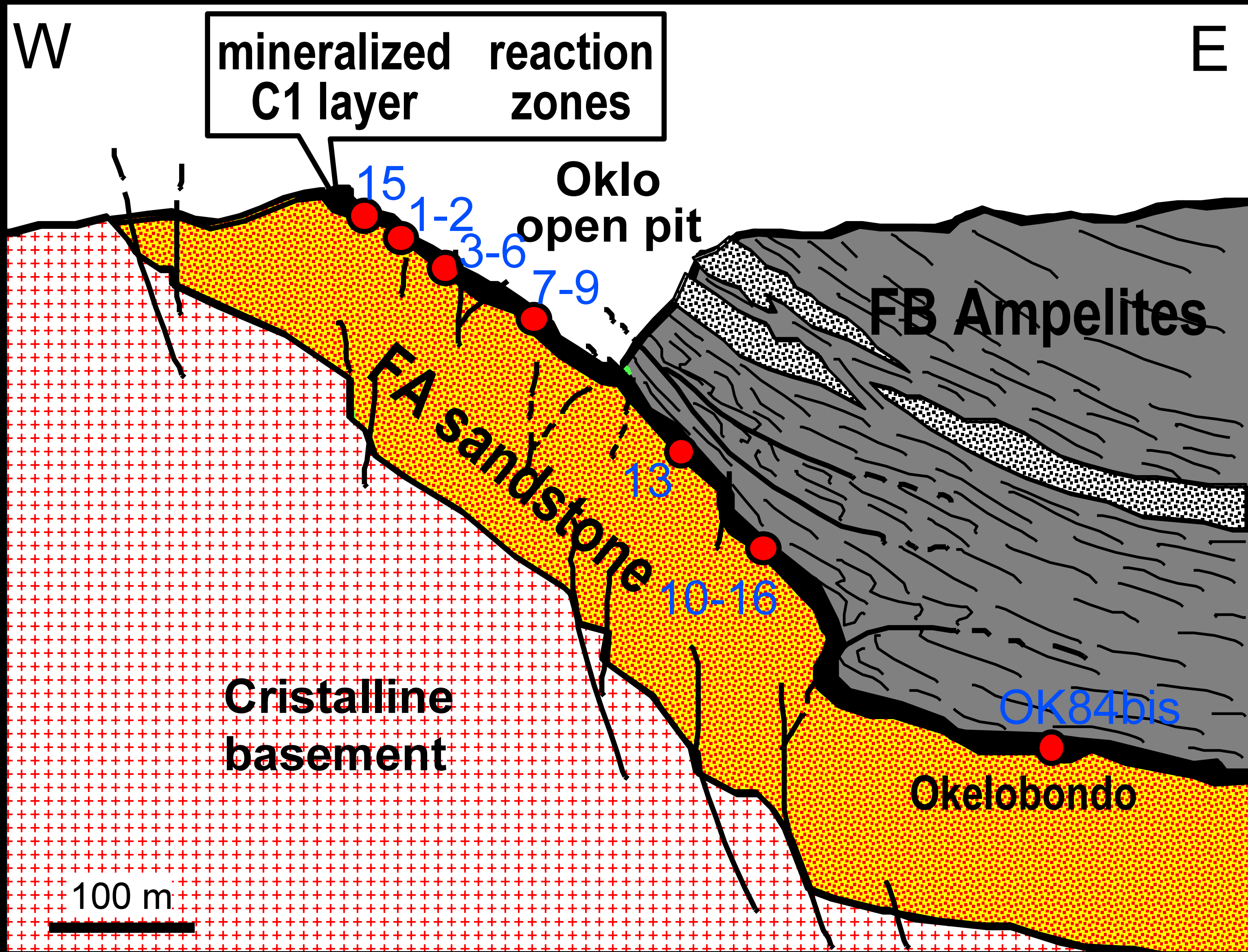
UO_2, ThO_2 / UO_2^{2+}

Carnotite/metaschoepite

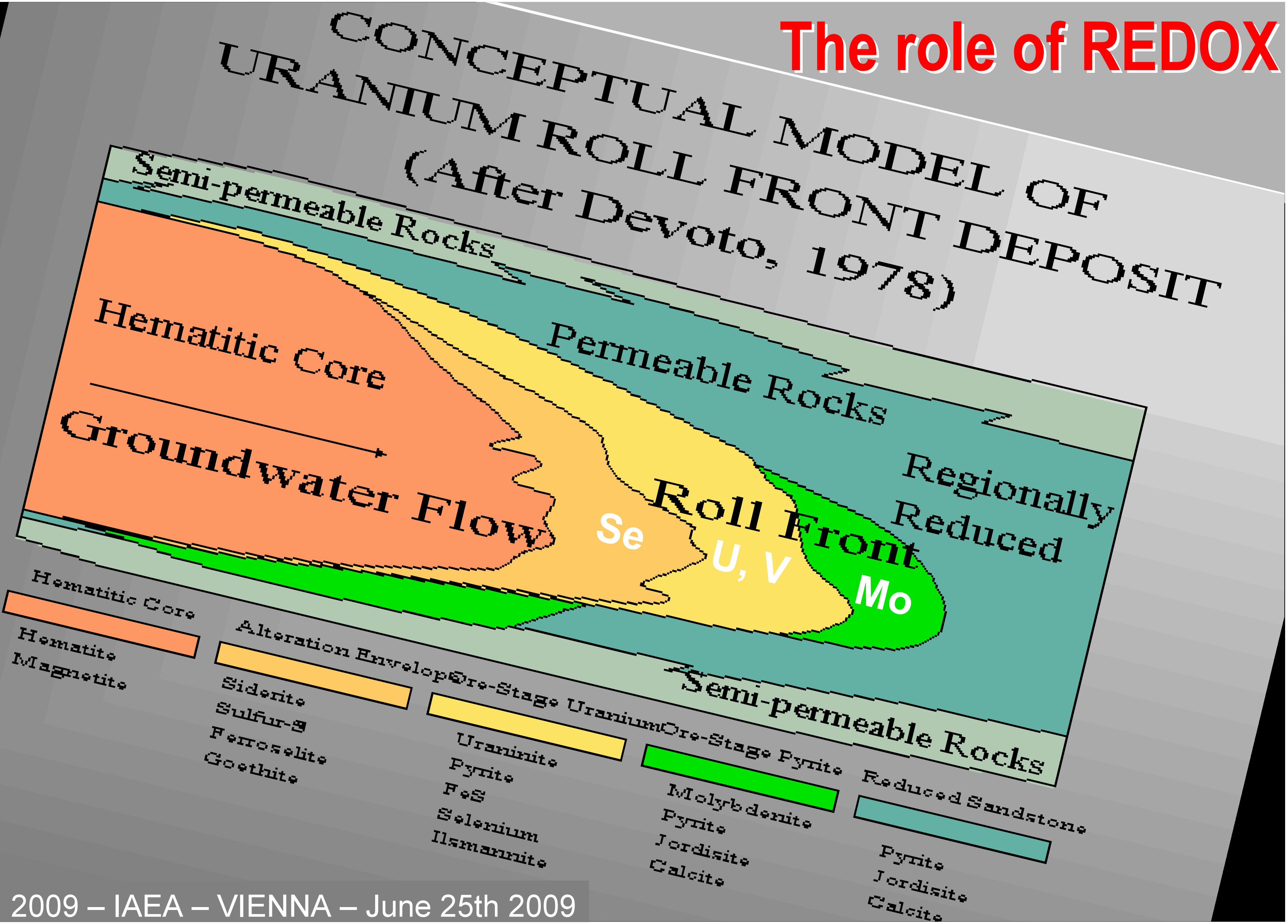


Oklo Deposits & Natural Nuclear Reactors, Gabon

First deposit on the Earth controlled by redox Reactions at 2 Ga



The role of REDOX



Major lines of education & training in U geology & exploration

2 – U deposits occur in extremely diverse geologic settings all around the geological cycle

→ needs of a comprehensive education in all fields of geology, except may be in ultrabasic magmatism !

IAEA classification of uranium deposit types

*Total > 1,200 deposits (**UDEPO data base**) ranked into > 9 types:*

1) Unconformity-related (47) : *Mac Arthur, Cigar Lake, Ranger, Jabiluka*
2) Sandstones (346) : *Arlit, **Akouta, Mynkuduk, Colorado plateau***
3) Hematite breccia complexes (7) : *Olympic Dam*
4) Quartz-pebble conglomerates (27) : ***Witwatersrand basin, Elliot Lake***
5) Veins (53) : ***Singhbhum, Pribam,** Bernardan,*
6) Intrusive (21) : *Rössing*
7) Volcanic and caldera-related (174) : *Streltsovsk, **Dornot, Xiangshan, McDermitt***
8) Metasomatites (24) : : ***Michurinskoye, Lagoa Real, Arjeplog***
9) Others (159)

- ***surficial*** : ***Yeelirie, Langer Heinrich***
- ***collapse breccia pipes (11)*** : ***Grand Canyon-Arizona Strip***
- ***phosphorites (17)*** : ***Gantour, Al-Abiad, Uncle Sam, Melovoe***
- ***metamorphic (10)*** : ***Forstau, Mary Kathleen,***
- ***limestones (?)*** : ***Grants***
- ***coal (8)*** : ***Serres, Dakota, Nizhne, Freital***
- ***black shales*** : ***Chatanooga, Chanziping, Randstadt, Padma***
- ***unknown***

Weaknesses of the IAEA classification

Mainly based on the nature of the host rock lithology :

- easy to apply,
- BUT may lead to strong misunderstanding of the nature of the exploration targets
- because do not take into account the ore forming processes

Exemple : type 6

- INTRUSIVE TYPE : disseminated mineralization in intrusive rocks

in fact regroups 2 very different types of mineralization :

- U deposits related to partial melting (ex. Rössing)
- U deposits related to fractional crystallization (ex. Ilimaussaq)

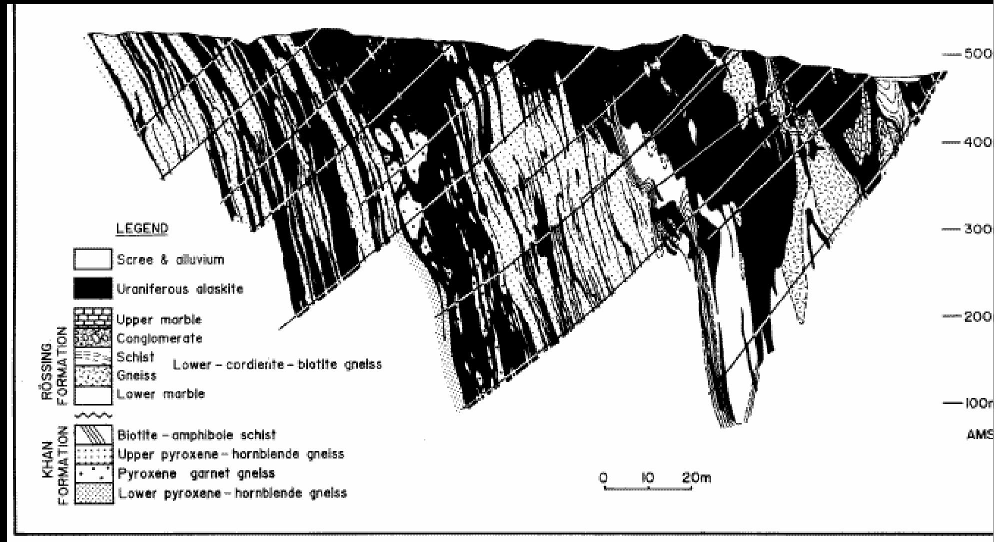
U deposits related to partial melting :

→ Always occurs in high-grade migmatitic domains with limited partial melting

→ Do not originate from a deeper granitic body, but rather merging of granitic dikes to form small granitic lenticular bodies.

→ Uraninite main ore mineral

Cross section of the Rössing deposit



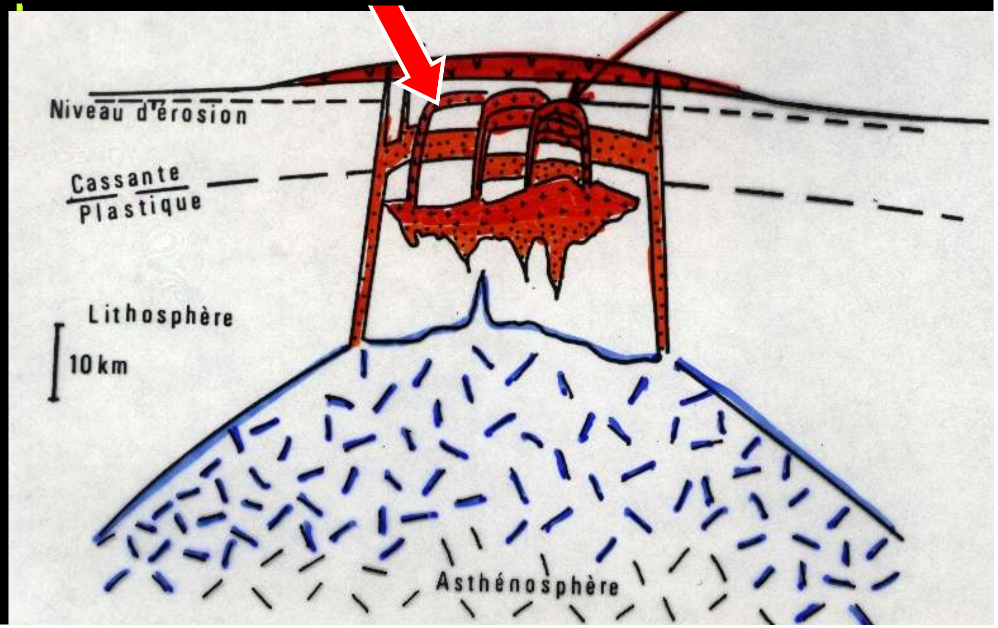
U depos. related to crystal fractionation :

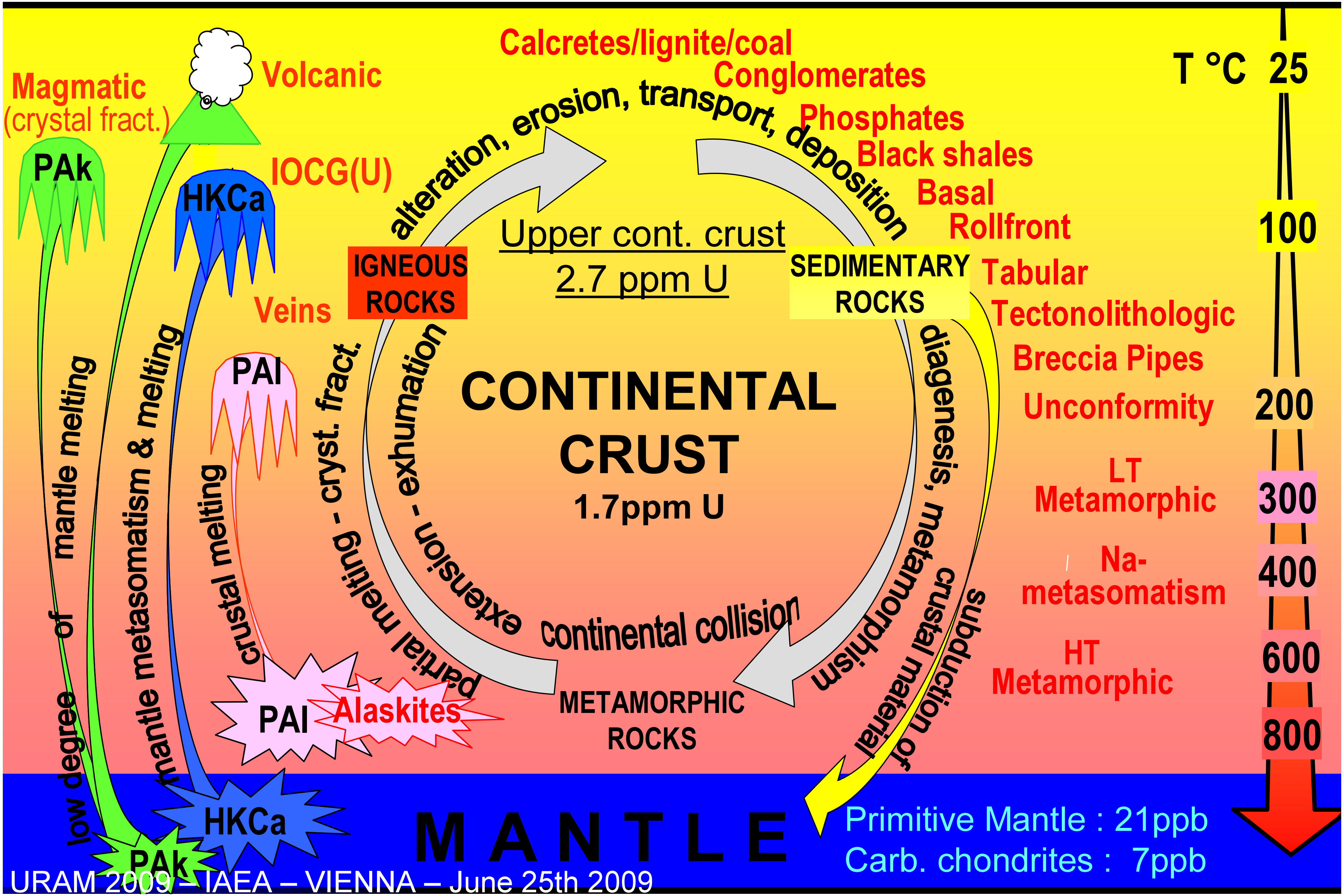
Located in the apical & most differentiated part of the peralkaline plutonic complexes

→ High structural level

→ Complex and highly refractory U ore minerals

Cross section of a peralkaline syst.




Calcretes/lignite/coal
Conglomerates
Phosphates
Black shales
Basal
Rollfront
Tabular
Tectonolithologic
Breccia Pipes
Unconformity
LT Metamorphic
Na-metasomatism
HT Metamorphic
T °C
25
100
200
300
400
600
800
Magmatic (crystal fract.)
Volcanic
IOCG(U)
Veins
PAk
HKCa
PAl
Alaskites
alteration, erosion, transport, deposition
Upper cont. crust
2.7 ppm U
IGNEOUS ROCKS
SEDIMENTARY ROCKS
METAMORPHIC ROCKS
CONTINENTAL CRUST
1.7ppm U
partial melting - cryst. fract.
extension - exhumation
continental collision
diagenesis, metamorphism
crustal material
subduction of
low degree of mantle melting
mantle metasomatism & melting
crustal melting
MANTLE
Primitive Mantle : 21ppb
Carb. chondrites : 7ppb

A GENETIC CLASSIFICATION OF U-DEPOSITS

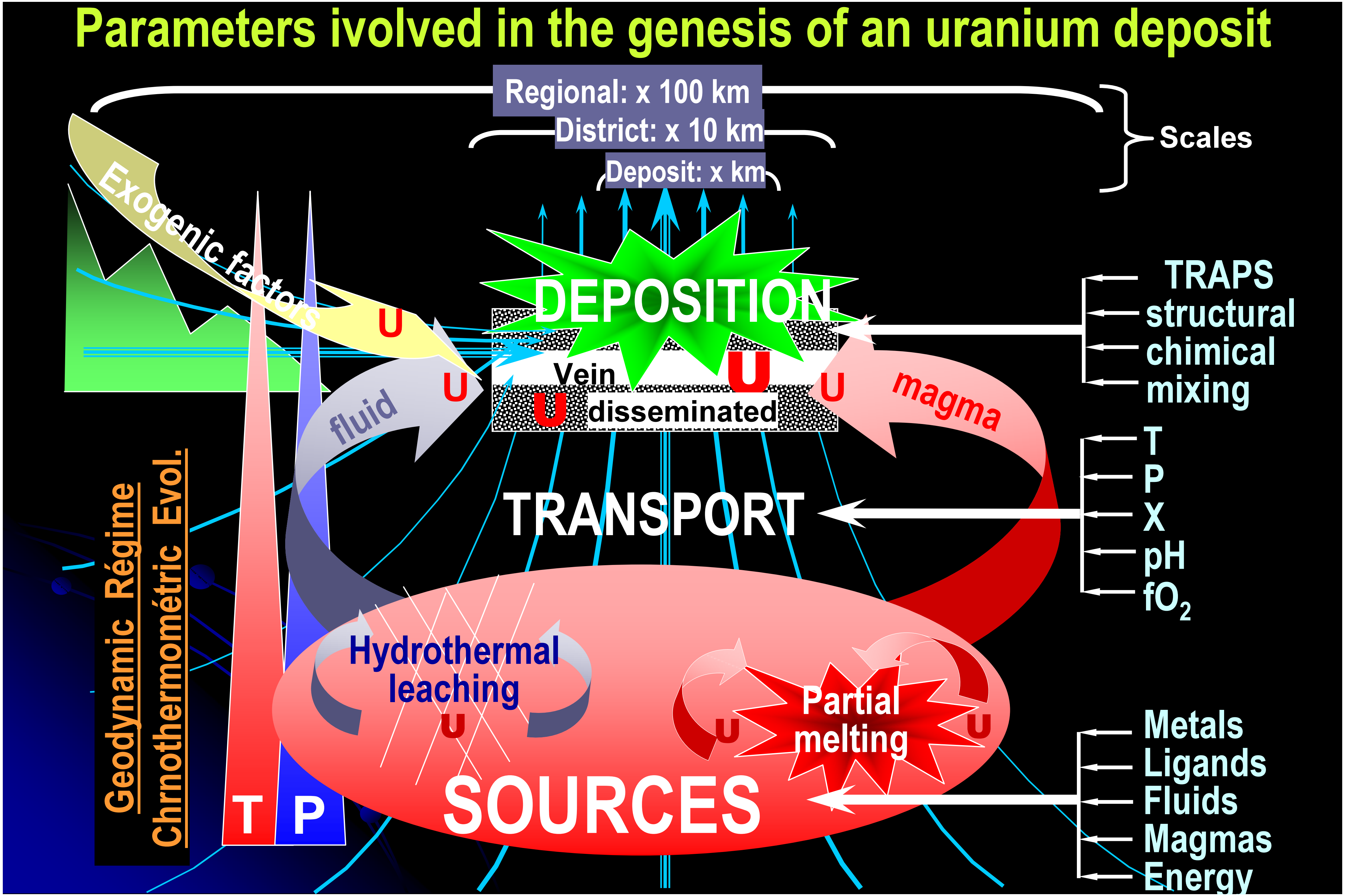
- 1 – **Fractional crystallization**: Ilimausacq, Bokan Mountain
- 2 – **Partial melting**: Rössing
- **3 – Hydrothermal high level post-orogenic** :
  - 3A – Volcanic - hydrothermal (Streltsovska)
  - 3B – Granitic - hydrothermal (French Variscan, Erzgebirge)
- 4 – **Diagenetic hydrothermal systems**:
  - 4C: Intraformational redox control
    - 4C1: Tabular: Grants Mineral Belt, Bevereley Hills
    - 4C2: Tectonolithologic: Akouta, Niger
    - 4C3 : Karsts (beccia pipes): Colorado
  - 4A: Basin/basement redox control (unconformity related)
  - 4B: Interformational redox control (Oklo, Gabon)
- **5 - Hydrothermal metamorphic**: Shinkolobwe, Mistamisk
- 6 – **Hydrothermal metasomatic:**
  - 6A – Alkali-metasomatism : Lagoa Real, Krivoi Rog
  - 6B – Skarns :Mary Katheleen - Tranomaro (Madagascar)
- 7 – **Syn-sedimentary**:
  - 7A: Mechanical sorting: Qz pebble conglomerates: Witwatersrand, Elliot Lake
  - 7B: Redox trapping: black shales, Alum shales Sweden (marine & continental)
  - 7C: Crystal-chemical/redox trapping: phosphates : Maroc
- **8 - Intraformational meteoric fluid infiltration**
  - 8A: Sealed paleovalleys: Vitim (Transbaikalia)
  - 8B: Roll fronts: Powder River Basin (Wyoming)
- 9 –- **Weathering & evapotranspiration**: calcretes: Yeleerie
- 10 – Other **types** : breccia complex (Olympic Dam)

Major lines of education & training in U geology & exploration

3 – The knowledge of the ways to evaluate the quality of the U sources to estimate area favourabilty for U exploration is outmost Importance, (large volumes ➔ strategic exploration)

the knowledge of traps is also very cruxial after the source, (generally more localized)

and then the vectors which may particularly complex and rarely easy to evidence


Parameters ivolved in the genesis of an uranium deposit
Regional: x 100 km
District: x 10 km
Deposit: x km
Scales
Exogenic factors
U
fluid
U
DEPOSITION
Vein
disseminated
U
U
U
magma
TRAPS
structural
chemical
mixing
TRANSPORT
T
P
X
pH
fO2
Geodynamic Régime
Chrnothermométric Evol.
T
P
Hydrothermal
leaching
U
Partial
melting
U
U
SOURCES
Metals
Ligands
Fluids
Magmas
Energy

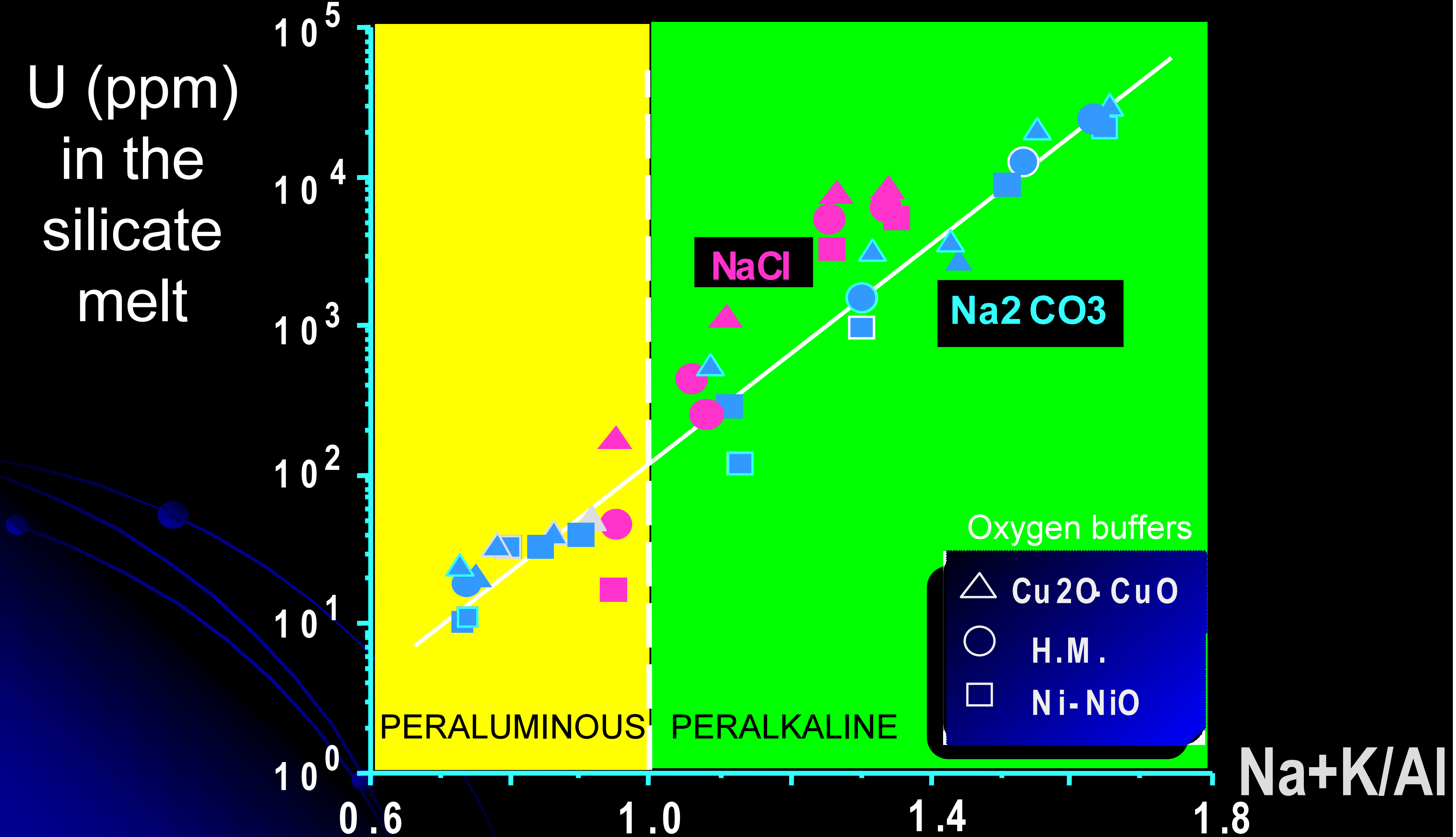
THE URANIUM SOURCES

➔ **Acidic magmatic rocks are the most enriched in U, but enrichment depends of :**

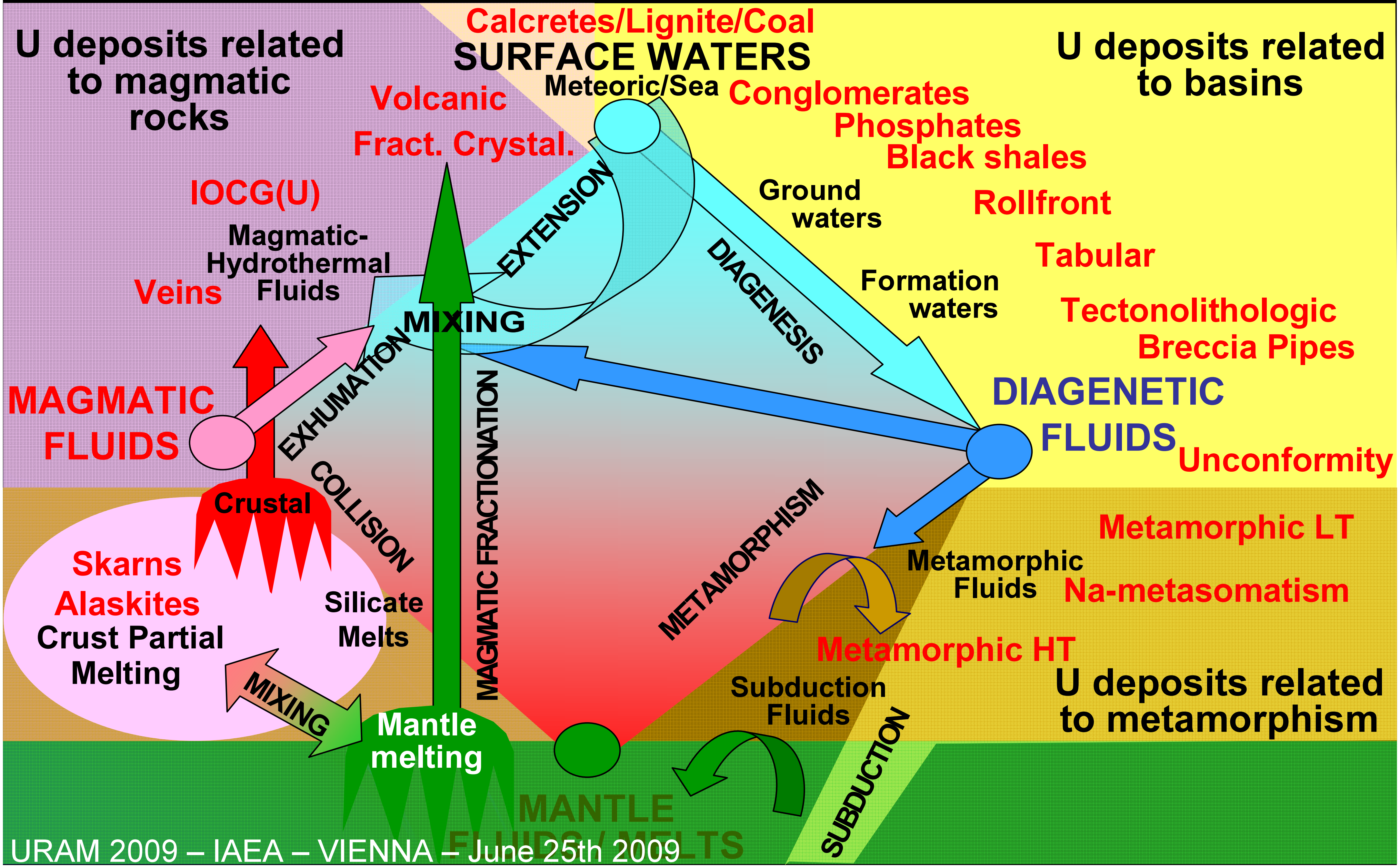
- The rate of partial melting of the mantle and continental crust
- The variations related to the degree of enrichment of the protolith
  - primitive mantle / enriched mantle / depleted mantle
  - average crust / U-enriched crust (U-rich acidic rocks, U trapped in reduced sediments)
- The degree of crystal fractionation …

➔ **Epicontinental platform sediments (major period : Lower Paleoproterozoic)**

UO_2 SOLUBILITY IN GRANITIC MELTS



THE IMPORTANCE & COMPLEXITY OF MINERALIZING FLUIDS



Major lines of education & training in U geology & exploration

4 – The uranium hosting phases are very diverse :

the knowledge of theirnature is critical for the economics of the ore processing :

Easily soluble : U oxides, coffinite, hexavalent U minerals

Moderately soluble : brannerite, nyngyoite, collophane

Refractory : U-Ti-Nb-Ta phases, zircon and zirconolsilicates …. typical of peralkaline plutonic complexes

CONCLUSIONS AND PERSPECTIVES

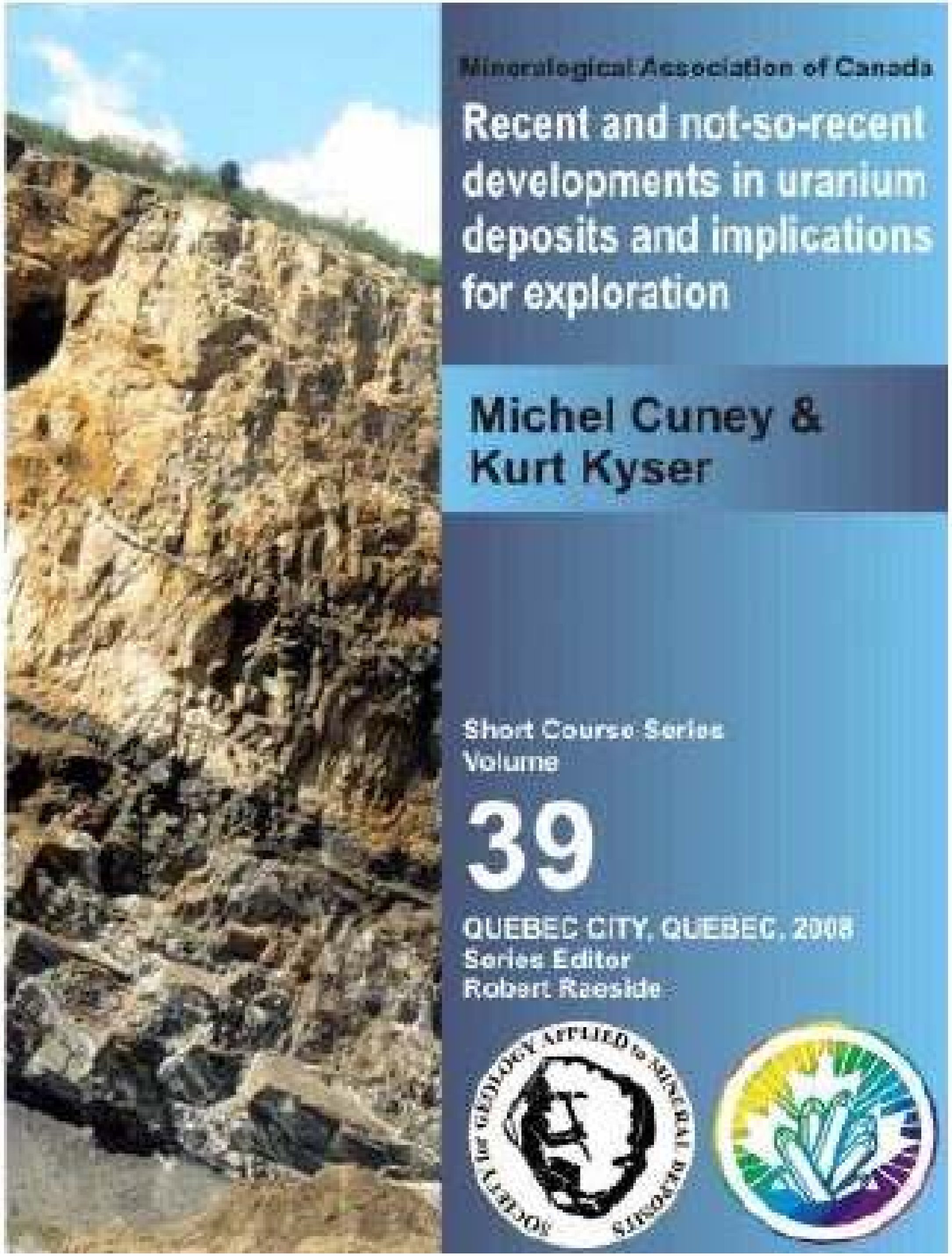
→Most training programs were stopped in most countries from about 1985 to 2005

→ Considerable needs in education and training in uranium geology and exploration after about 20 years of very weak exploration and mining activities, except in a few places.

→ Organization of International exchange of geologic information and mineral collections illustrating the major world deposit types is need to homogenize the description of uranium deposits :

→ ex. what is an episyenite ?

→ to what mineralogical – geochemical changes correspond Na-metasomatic alteration related to U deposits ?



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By Michel Cuney and Kurt Kyser

office@mineralogicalassociation.ca

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