Uranium

I –Summary of worldwide U deposits by deposit characteristics and classification

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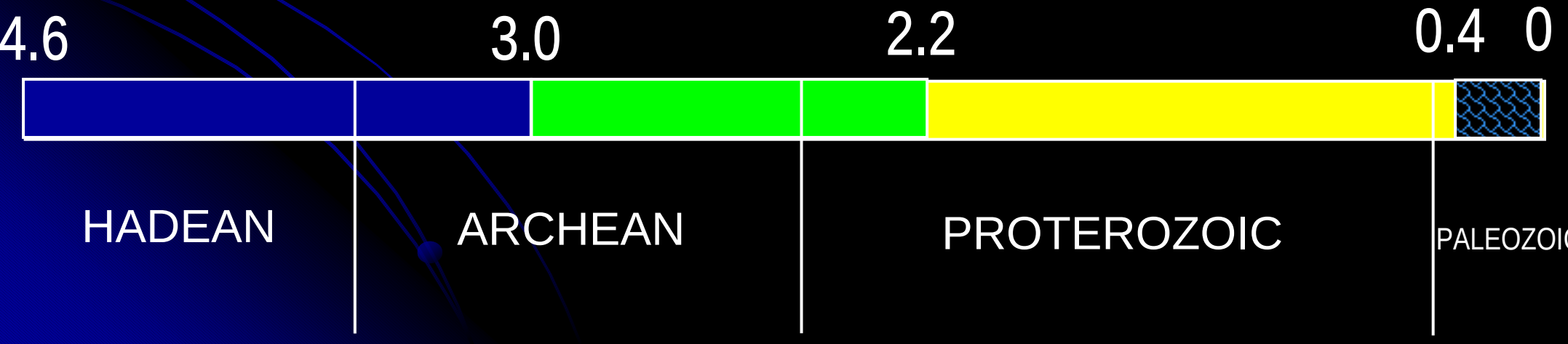
EVOLUTION Of U-GEOCHEMISTRY DURING EARTH HISTORY

4 major periods :

1 : 4.6 – 3.0 Ga
2 : 3.0 – 2.2 Ga
3 : 2.2 – 0.4 Ga
4 : 0.4 - present



EVOLUTION Of U-GEOCHEMISTRY DURING EARTH HISTORY

1

4.6-3.0 Ga : HADEAN - PALEOARCHEAN

- thin mafic crust
- basalts & TTG melts
- moderate magmatic U enrichments (few ppm)
- No or weak subduction processes
- anoxic atmosphere

NO URANIUM DEPOSITS

EVOLUTION Of U-GEOCHEMISTRY DURING EARTH HISTORY

2

3.0-2.2 Ga : ARCHEAN & Upper PALEOPROTEROZOIC

Start of subduction : recycling of U-Th-K-rich crust material

stronger magmatic enrichment : first K-U-Th granites

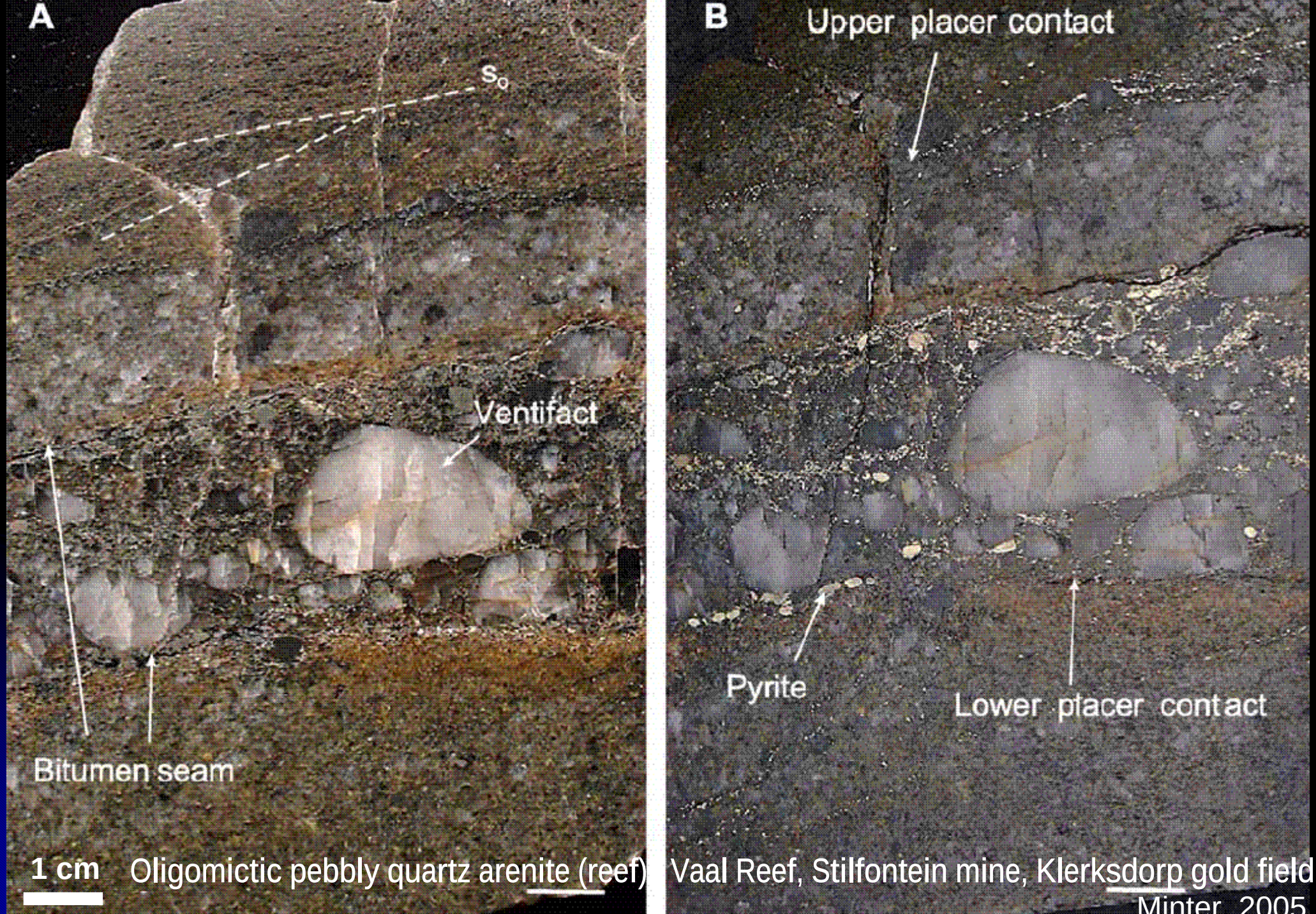
large intracratonic basins

anoxic atmosphere => U(IV) only

PLACER TYPE U DEPOSITS

first type of U deposit on the earth

conglomerates with detrital uraninite: Witwatersrand, Eliott Lake ...


A
S_o
Ventifact
Bitumen seam
1 cm
Oligomictic pebbly quartz arenite (reef)
B
Upper placer contact
Pyrite
Lower placer contact
Vaal Reef, Stilfontein mine, Klerksdorp gold field
Minter, 2005

EVOLUTION Of U-GEOCHEMISTRY DURING EARTH HISTORY

3

2.2-0.4 Ga

high pO2 , uranyle ion $[UO2]^{2+}$ -> in solution

U rich precursor organic rich shelf sediments; phosphorites ...

First chemical deposit (redox control) :

Oklo (Gabon) at 2.O Ga

Then, unconformity related deposits in oxidized continental sandstones and other deposits ...

EVOLUTION Of U-GEOCHEMISTRY DURING EARTH HISTORY

3a

2.2-1.8 Ga

Oxydation of U accumulated as detrital uraninite

Huge production of organic matter ➔
Carbon-rich shelf sediments (shungite) ; phosphorites …

Strong U enrichment of post 2.2Ga epicontinental platform sediments

Genesis of large U provinces : Wollaston belt (Athabasca)

EVOLUTION Of U-GEOCHEMISTRY DURING EARTH HISTORY

4

0.4Ga-present

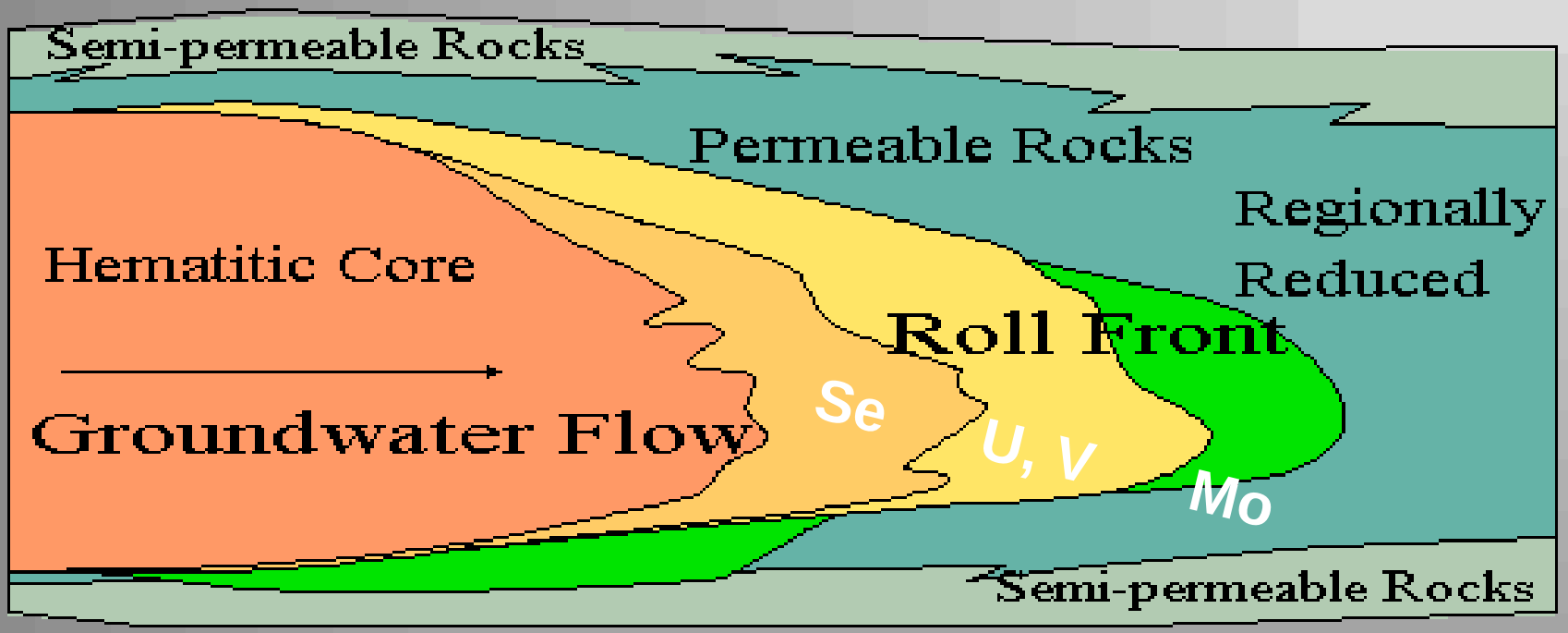
Devonian → land plant apparition

➔ reduced terrestrial clastic sediments

⇒ **U trapping in porous - organic matter bearing continental sandstones**

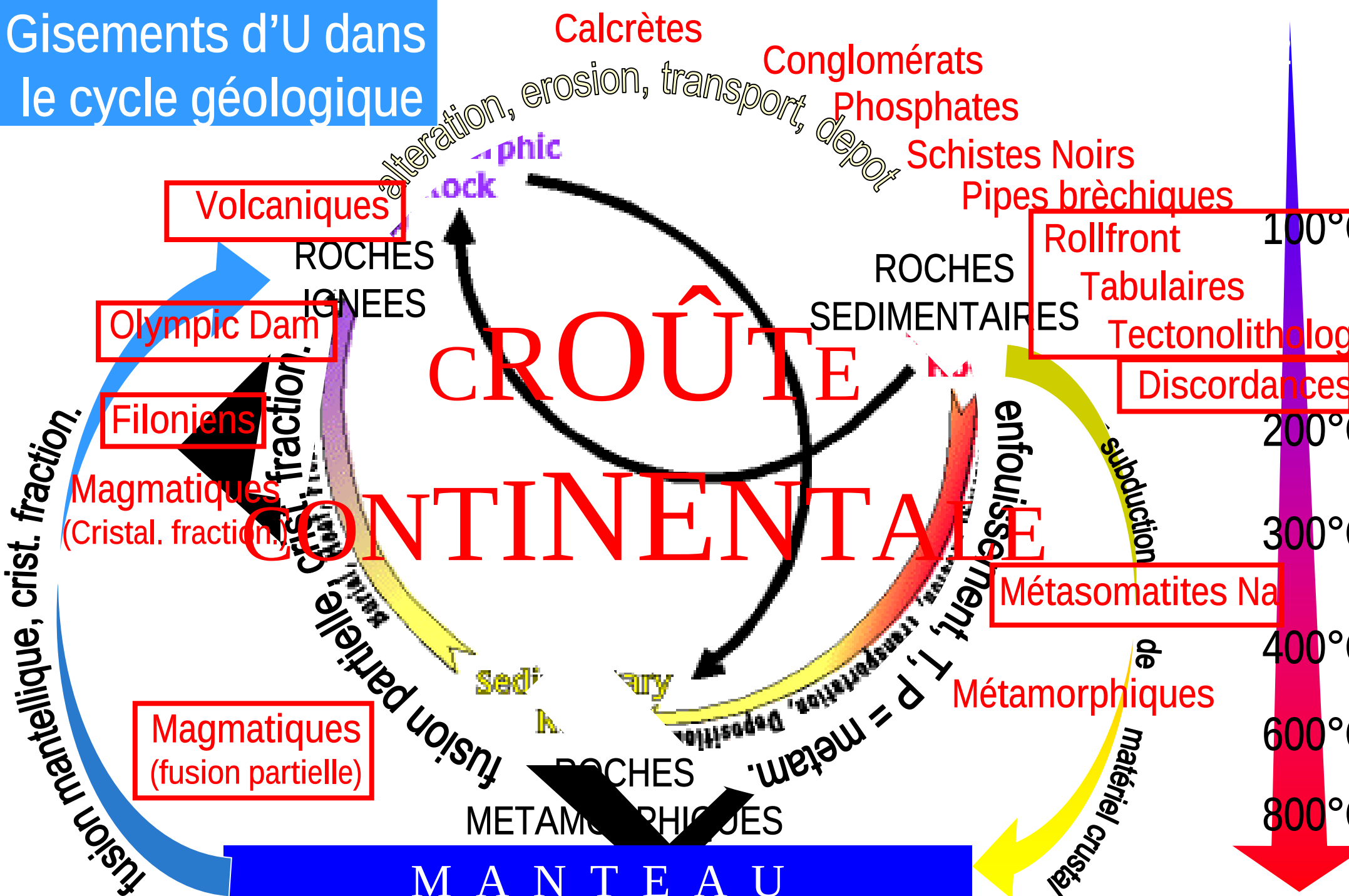
<u>Roll front deposits</u>

CONCEPTUAL MODEL OF URANIUM ROLL FRONT DEPOSIT (After Devoto, 1978)



Hematitic Core	Alteration Envelop	Ore-Stage Uranium	Ore-Stage Pyrite	Reduced Sandstone
Hematite Magnetite	Siderite Sulfur-β Ferroselite Goethite	Uraninite Pyrite FeS Selenium Ilsemannite	Molybdenite Pyrite Jordisite Calcite	Pyrite Jordisite Calcite

Gisements d'U dans le cycle géologique



Main types of world uranium deposit

Total 858 deposits 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***

U deposit classification (Dalkamp, 1993)

1. Deposits related to Proterozoic unconformities

1.1 deposits localized in the basement

(Eagle Point, Millenium, Rabbit Lake, Dominique Peter, Kiggavik, Jabiluka, Ranger, Kintyre)

1.2 deposits localized at the unconformity

1.2.1 complexe type polymetallic (Cigar Lake, Midwest, Dawn Lake, Key Lake, McClean, Sue A-B, Jeb)

1.2.2 simple type monometallic (McArthur pod 2, Sue C)

1.3 deposits localed in the sandstone (BJ, Westmoreland, Indice L))

U deposit classification (Dalkamp, 1993)

2. Deposits enclosed in sandstone

2.1 tabular deposits

2.1.1 with organic matter (Arlit, Coutras, Grants)

2.1.2 with vanadium (Plateau du Colorado, ceinture Uravan)

2.1.3 basal chanel type (Monument Valley, Ningyo-Toge)

2.2 roll type deposits (Wyoming, Kazakhstan, Ouzbékistan)

2.2.1 continental bassin (Wyoming, Beverley, Kazakhstan)

2.2.2 proximal marine, with sulfides (sud Texas, Crow Butte)

2.3 tectono-lithologic deposits (Oklo, Lodève)

3. Deposits related to quartz pebble conglomerates

3.1 type Au + (U) (Witwatersrand)

3.2 type Elliot Lake U + (Au)

U deposit classification (Dalkamp, 1993)

4. Vein type deposits

4.1 associated with granites

4.1.1 intragranitic (Limousin)

4.1.1.1 in the granites

4.1.1.2 in the épisyénites

4.1.2 perigranitic

4.1.2.1 monometallic (type Bohème)

4.1.2.2 polymetallic (type Jachymov)

4.1.2.3 contact metamorphism (type Ibérien)

4.2 deposits not related to granites (Schwartzwalder)

5. Deposits ralated to breccia complexes

with hematite (Olympic Dam)

U deposit classification (Dalkamp, 1993)

6. Intrusive-magmatic deposits

6.1 Alaskite (Rossing)

6.2 Granite-monzonite (Bingham)

6.3 Carbonatite (Palabora)

6.4 Peralcaline syenite (Illimaussaq)

6.5 Pegmatite (Bancroft)

7. Volcanic deposits

7.1 Stratiform deposits

7.1.1 intracaldera (McDermitt, Aurora, Dornot)

7.1.2 outside a caldera (Pena Blanca, Margaritas, Macusani)

7.2 Intracaldeira deposits related to structures (Streltsovska)

U deposit classification (Dalkamp, 1993)

8. Deposits related to phosphates

8.1 in marine phosphates (Maroc, Tunisie, USA)

8.2 in igneous phosphates (Kola)

8.3 in continental phosphates (Bakouma)

9. Deposits filling breccia pipes

collapse breccia pipes (Arizona Strip)

10. Surficial deposits

10.1 calcretes

10.1.1 fluviatil type : filling of valleys (Langer Heinrich, Yeelirrie, Henkries), flood plains, deltaic (Salar Grande, Napperby), colluvial

10 1.2 lacustrine type and playa : controled by topography, by drainage

10.1 3 pedogenetic type : authigenic, allogenic

10.2 Basal type (Blizzard, Saint Pierre du Cantal)

Dalkamp (1993)…..

11. Metasomatic deposits

11.1 deposits in metasomatosed granites (Lagoa Real, Ross Adam, Espinharas)

11.2 deposits in metasomatosed sediments (Krivoi Rog)

12. Métamorphic deposits

12.1 synmetamorphic (Forstau)

12.2 hosted by metamorphic rocks

12.2.1 vein (Shinkolobwe)

12.2.2 in pyroxenites with uranothorianite (Madagascar)

12.2.3 in "molasses" (north Kazakhstan)

12.2.4 Elkon type, with brannerite (Aldan)

Dalkamp (1993).....

13. Deposits associated with brown coal and coal

- *13.1 stratiform deposits (Williston Basin)*
- *13.2 deposits in fractures and joints (Williston Basin)*

14. Deposits in black shales

- *14.1 sapro-pelitic type with bitumen (Chattanooga)*
- *14.2 humique type (Ranstad)*
- *14.3 related to shungites (lac Onega)*

15. Other deposits types

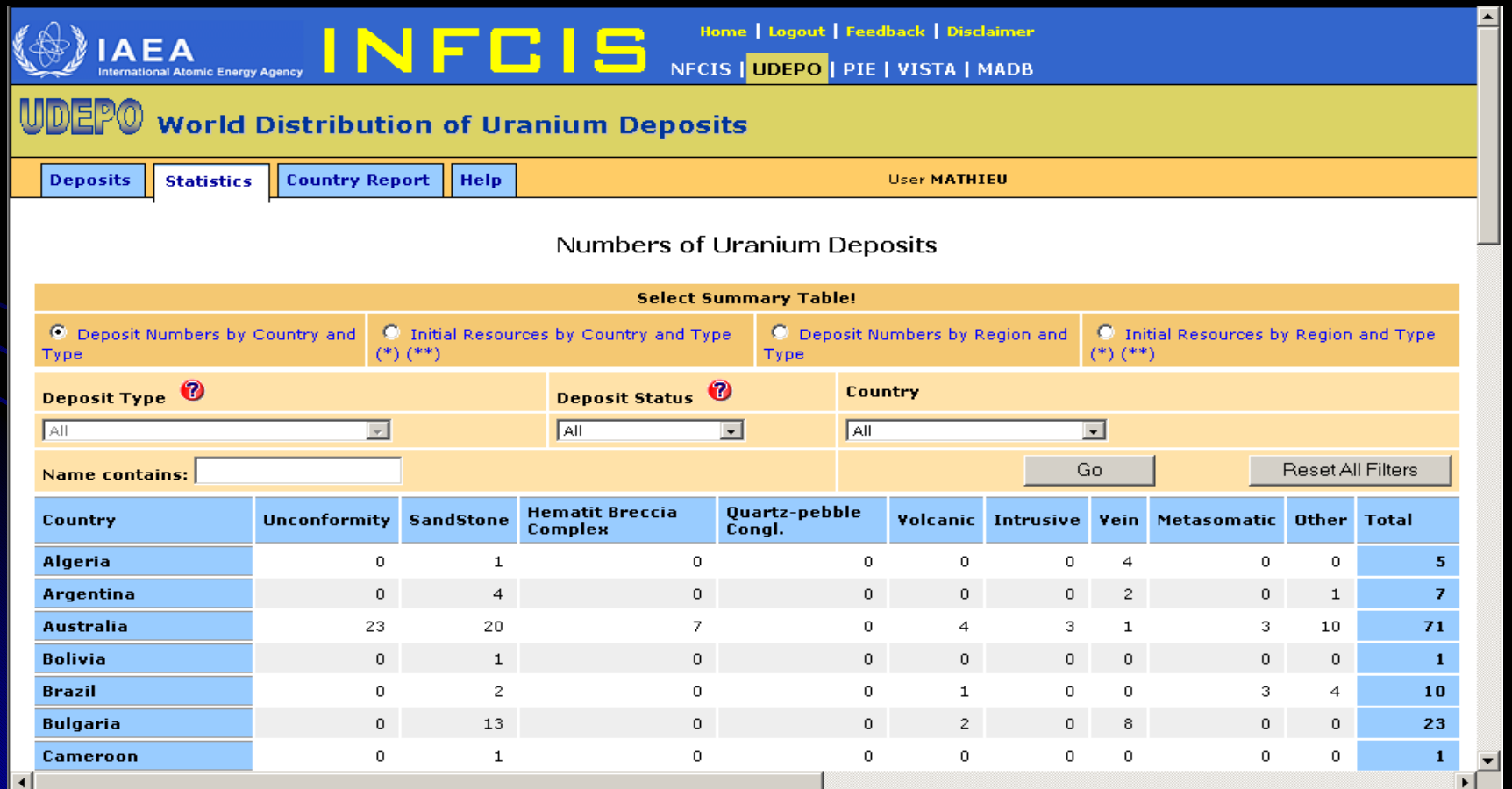
- *15.1 in karsts (Chine)*
- *15.2 in limestones (Todilto)*
- *15.3 in peat*

Carte Mondiale des Gisements U

582 gisements de taille >500 tU, 48 pays

UDEPO database (IAEA, 2003-2006)

- (UDEPO) ***http://www-nfcis.iaea.org***
- ***858 Uranium*** deposits (> 500 t, > 300 ppm), 51 countries
- > 300 « new deposits » mainly from USSR and China



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UDEPO World Distribution of Uranium Deposits

Deposits | Statistics | Country Report | Help — User MATHIEU

Numbers of Uranium Deposits

Select Summary Table!

(•) Deposit Numbers by Country and Type | ( ) Initial Resources by Country and Type (*) (**) | ( ) Deposit Numbers by Region and Type | ( ) Initial Resources by Region and Type (*) (**)

Deposit Type: All | Deposit Status: All | Country: All

Name contains: | Go | Reset All Filters

Country	Unconformity	SandStone	Hematit Breccia Complex	Quartz-pebble Congl.	Volcanic	Intrusive	Vein	Metasomatic	Other	Total
Algeria	0	1	0	0	0	0	4	0	0	5
Argentina	0	4	0	0	0	0	2	0	1	7
Australia	23	20	7	0	4	3	1	3	10	71
Bolivia	0	1	0	0	0	0	0	0	0	1
Brazil	0	2	0	0	1	0	0	3	4	10
Bulgaria	0	13	0	0	2	0	8	0	0	23
Cameroon	0	1	0	0	0	0	0	0	0	1

The various types of uranium deposits

- **1 – Diagenetic (Unconformity related)**

  Occur in the vicinity of a stratigraphic unconformity between a sedimentary cover and basement

  - **1a – post 2.2 Ga and pre-Devonian:** the cover consists of oxidized continental fluviatil, eolian to marginal marine, highly mature, oxidized, siliclastic sediments able to generate highly saline hot diagenetic brines, the basement comprises U-rich & graphite-rich metamorphosed epicontinental sediments & highly potassic calcalkaline granites. The faults controlling the deposits are rooted in graphitic schists (Athabasca, Kombolgie).
  - **1b – intrabasinal:** the redox barrier controlling the deposit is located in the upper part of the sandstone below oil generating shales (ex.: Oklo, Gabon).
  - **1c – post-Silurian:** the cover consists of reduced and oxidized continental to marine sediments able to generate moderately saline & hot diagenetic brines and reduced fluids, the basement comprises highly potassic calcalkaline granites (South French Massif Central).

- **2 – Volcanic diatreme (Breccia complexes)**

  Breccia complex resulting from magma boling, fluid unmixing with hydraulic fracturing, tectonic faulting, chemical corrosion, and gravity collapse. Much of the brecciation occurred in near surface eruptive environment of a crater complex. The main mineralisation is Cu and Au ± Ag, REE … associated with abundant magnetite and hematite (ex. Olympic Dam, South Australia)

The various types of uranium deposits

- **3 – sandstone related:**

Occur in continental fluvial or marginal marine siliclcatic sediments interbedded with impermeable shale/mudstone units. U precipitated under reducing conditions caused by a variety of reducing agents : carbonaceous material (detrital plant debris, amorphous humate, marine algae), sulphides (pyrite, H2S), migrated hydrocarbons (oil or gas), Fe-Ti oxides, interbedded basic volcanics.

- **3a - rollfront**

Deposits form arcuate bodies crosscutting sandstone bedding, with a strong zonation of the redox and of metal distribution (Se, U-V, Mo) (ex. Powder River Basin, Wyoming)

- **3b – tabular**

Deposits form elongated bodies conformable to the sandstone bedding (ex. : Grants Mineral Belt, San Juan Bassin, Colorado Plateau, NW New Mexico)

- **3c - tectono/lithologic**

Deposits form complex bodies partly controlled by tectonic structures (Akouta, Niger)

- **3d – paleovalley**

Deposits located in colluvium between a U-rich granitic basement and a basalt cover (ex.: Vitim, Transbaïkalia, Russia).

The various types of uranium deposits

- 4 – Magmatic
  - 4a – related to partial melting: ex.: Rössing (Namibia)
    Quartzofeldspathic sediments or volcanics enriched in uranium are submitted to low degree of partial melting. Uranium-rich resulting melts are emplaced as felsic dykes (alaskites) in graphite and marble bearing metasediments.
  - 4b – related to fractional cristallisation
    Extreme fractional cristallisation of peralkaline felsic magmas, undersaturated in silica (Ilimausacq) or oversaturated (Bokan Mountain) led to the formation of residual melts and fluids extremely enriched in U, Th, Zr, REE … which genrally crystallize as refractory minerals.

The various types of uranium deposits

- 5 – Related to metasomatism
  - 5a – Alkali metasomatism (Lagoa Real, Brazil; Krivoi Rog, Ukrainia)

    The most significant deposits of this category occur as disseminated uraninite associated with regional scale albitisation of granitic (Lagoa Real) or various metamorphic rocks (Krivoi Rog) with strong quartz dissolution,generally followed par Ca-metasomatism
  - 5b –Granulitic domain metasomatism (Tranomaro, Madagascar)

    F, U, Th, REE –rich fluids and melts mainly deriving from the dehydration of micas produce the metasomatism of dolomitic marble levels altered to scapolitite ans diopsidites mineralized in uranothorianite.

The various types of uranium deposits

- **6 – Related to volcanism** (Streltsovka, Russia)
  The most typical deposit of this category are related to uranium veins and dissemination mobilized in geothermal systems associated with acid volcanics (peralkaline to high-K calc-alkaline) in large caldera structures.
- **7 – Veins**
  - **7a – intra and perigranitic** (Limousin, France)
    Uranium deposited by geothermal systems developed in or around leucogranite bodies (peraluminous or high-K calcalkaline) well after granite crystallization, as discontinuous veins or episyenite bodies.
  - **7b – intrametamorphic** (Schwartzwalder, USA)
    Uranium veins developed in metamorphic formations without any relation with metamorphism or granite intrusions.

The various types of uranium deposits

- 8 - Surficial (calcrètes) (Yeleeree, Western Australia)
  Surficial U deposits are young (Tertiary to recent) near-surface U concentrations (as carnotite) in fine-grained surficial sand and clay (sediments or soils) resulting from evapo-transpiration of U-rich waters deriving from U-rich granites or volcanics. Cementing minerals include calcite, gypsum, dolomite, ferric oxide, halite.

- 9 – Quartz pebble conglomerates (Witwatersrand, S. Africa)
  Detrital accumulation of uraninite together with pyrite and gold in oligomictic conglomerate (paleoplacer) under anoxic atmospheric conditions (pre 2.2 Ba).

- 10 – Phosphates (Morocoo)
  U deposited with phosphates (in the structure of collophane and interstitial) and organic matter in upwelling zones of a continental platform.

The various types of uranium deposits

- 11 – Black shales (Alum shales, Sweden)

  Uranium precipitated with fine grained clayey sediments extremely rich in organic matter deposited in conditions of extremely low rate of sedimentation (very low clastic minerals supply)

- 12 – Breccia pipes (karsts) (Colorado)

  Uranium deposited as a cement of breccias resulting from karstic dissolution of marbles and collapse of the upper layers.

- 13 - Related to metamorphism (Mistamisk, Québec)

  Uranium deposited in veins by metamorphic fluids, in epicontinental sedimentary formations containing evaporites and black shales in the upper sequences and basal silicoclastic sediments and/or metavolcanic sequences. Same T, P, age as the metamorphic event.

WORLD MAIN URANIUM DISTRICTS