Felsic magmatism and uranium deposits

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Uraninite (St Sylvestre two micas granite)

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METAL FRACTIONATION
FROM ULTRABASIC ROCKS TO GRANITES

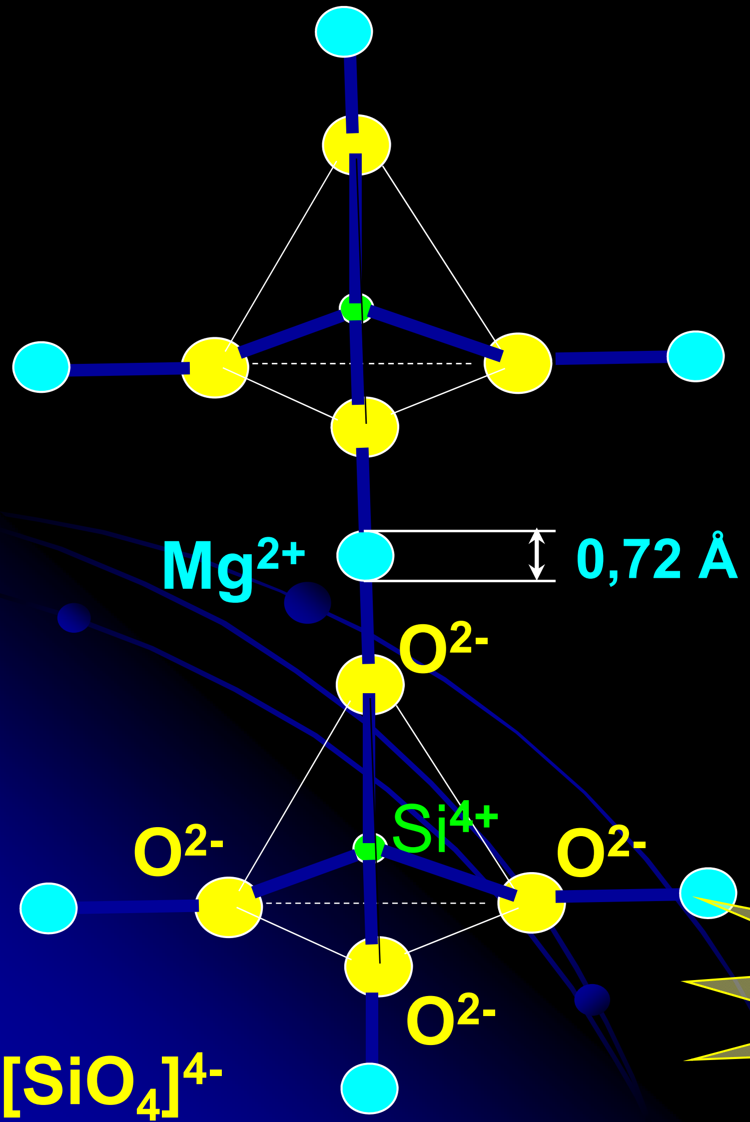
ppm	Ultrabasic		Basic		Intermediate		Granites	X
U	0.021	→	0.75	→	2.4	→	3.3	x 160
Th	0.060	→	3.5	→	7.8	→	17.5	

Earth average Th/U = 4

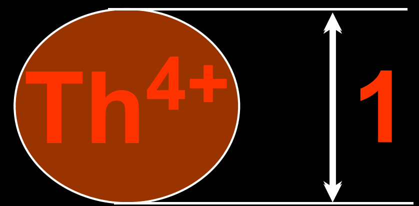
INCOMPATIBLE BEHAVIOR

WHAT IS AN INCOMPATIBLE ELEMENT ?

OLIVINE > ← MANTLE = SILICATES



Mg^{2+} low charge
small ionic radius] **≡ Ni^{2+} = 0.69**



1 Å (coordinance 8)

Th^{4+} high charge
large ionic radius

INCOMPATIBLE **with the silicate network**

U INCOMPATIBLE BEHAVIOUR

→ several major geochemical, geophysical and metallogenic consequences:

(i) U continuously transferred from the mantle to the Earth crust, & within the continental crust towards its upper part together with Th, K, …

(ii) radiogenic heat production is maximized in the upper crust → radiogenic heat flux production may delineate radioelement enriched crustal blocks,

(iii) the most felsic melts tend to be the most enriched in U,

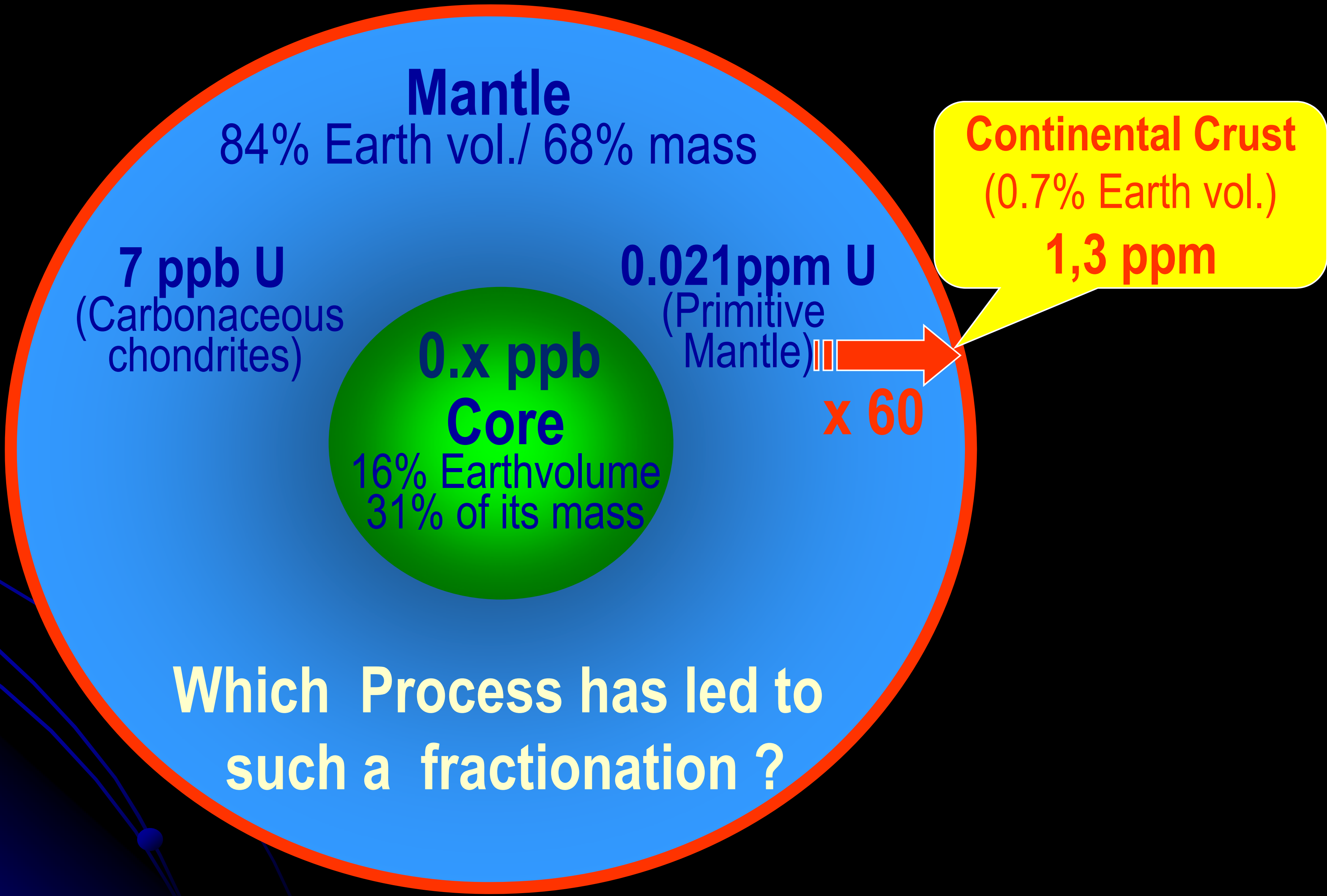
(iv) granites & rhyolites = primary U sources for the formation of most U deposits

Despite the strongly incompatible behavior of U, deposits dominantly resulting from magmatic processes are rare.

Average granite (U= 3-4 ppm), U mainly in zircon, apatite, monazite, titanite, … from which U cannot be leached by most geological fluids.

Some specific granites have higher U contents permitting crystallization of other accessory minerals from which U can be more or less easily leached for the formation of U deposits → "fertile granites" of Moreau [1966]

U continuously transferred from the mantle to the Earth crust



Fondamental fractionation processes in magmas

Partial melting

Fractional crystallisation

Sediment subduction and mantle metasomatism

Mixing with crustal material

Melt/fluid fractionation

Magma aluminous indices to classify magmatic rocks

Al/(Na+K+2Ca) = A/CNK in cations

= ASI **A**luminium **S**aturation **I**ndex

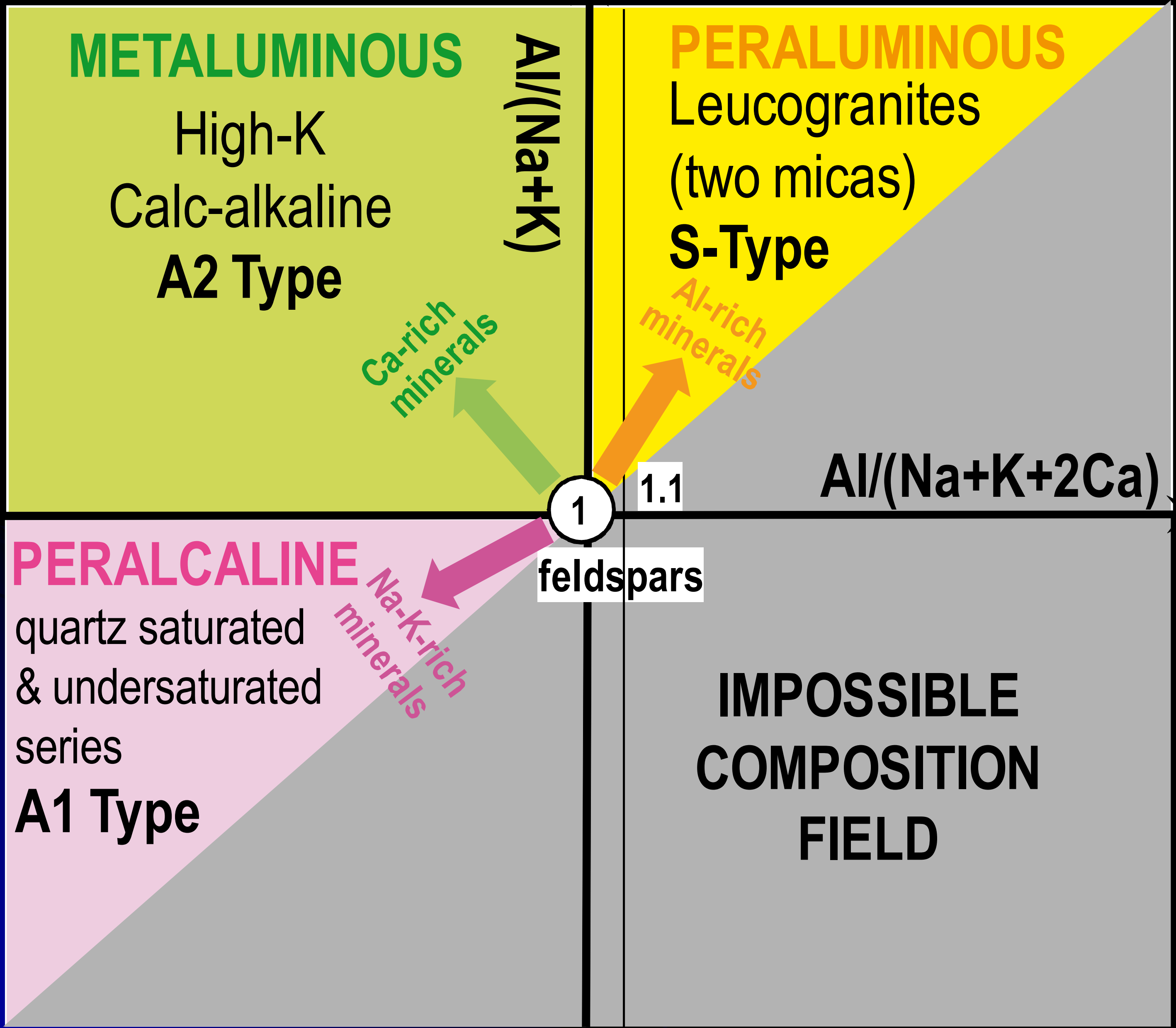
Al/(Na+K) ou (Na+K) Al = AGPAICITY

why ?

= INDEX OF MAGMA POLYMERISATION

U-rich magma classification using aluminous indices

some specific granites have higher U contents



Al/(Na+K) = 1 &
Al/(Na+K+2Ca) = 1
when
Al-Na-K-Ca in feldspars only

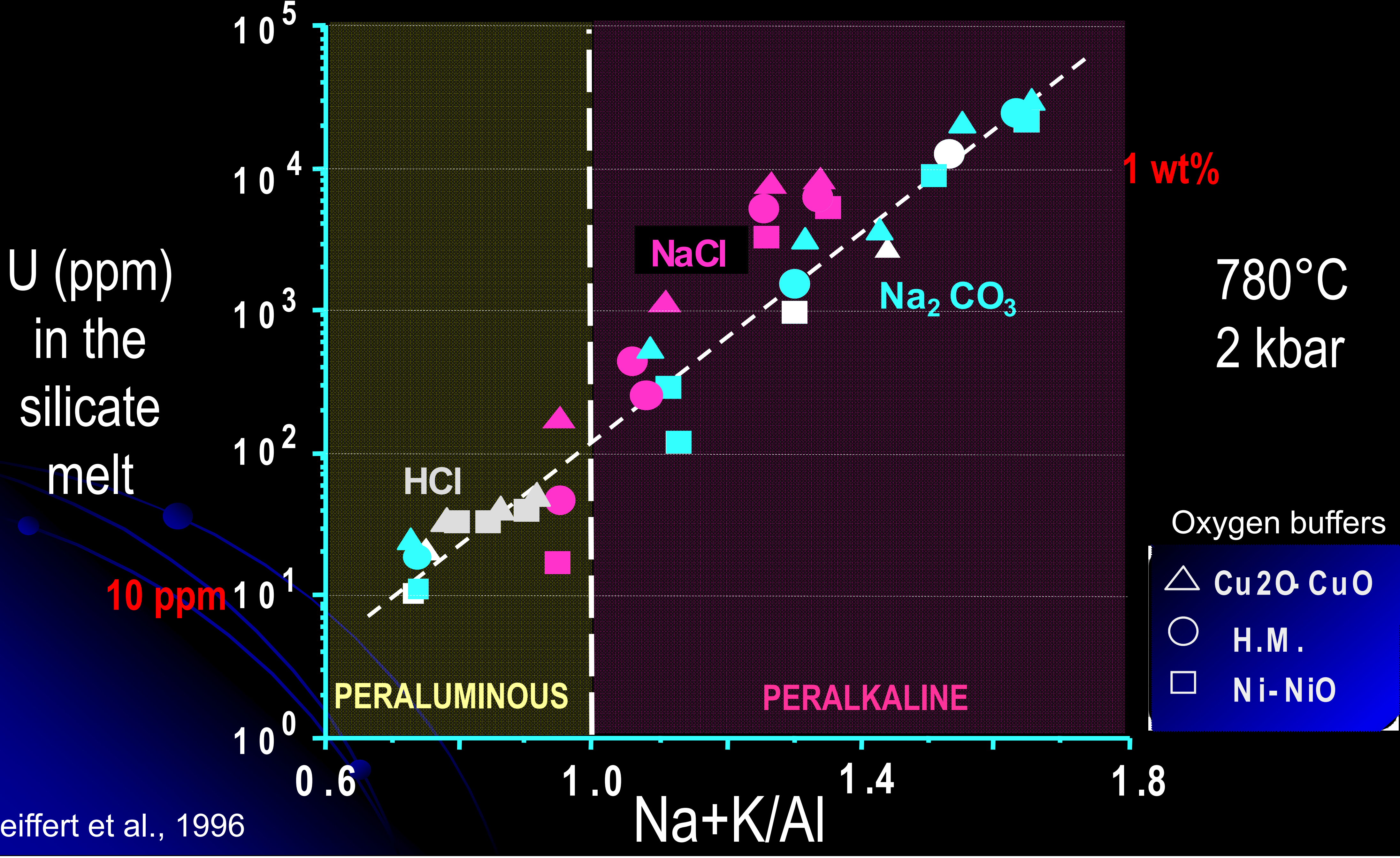
Al/(Na+K+2Ca) > 1
➔ peraluminous

Al/(Na+K+2Ca) < 1
& Al/(Na+K) < 1
➔ peralkaline

Al/(Na+K+2Ca) >1
& Al/(Na+K) > 1
➔ calc-alkaline

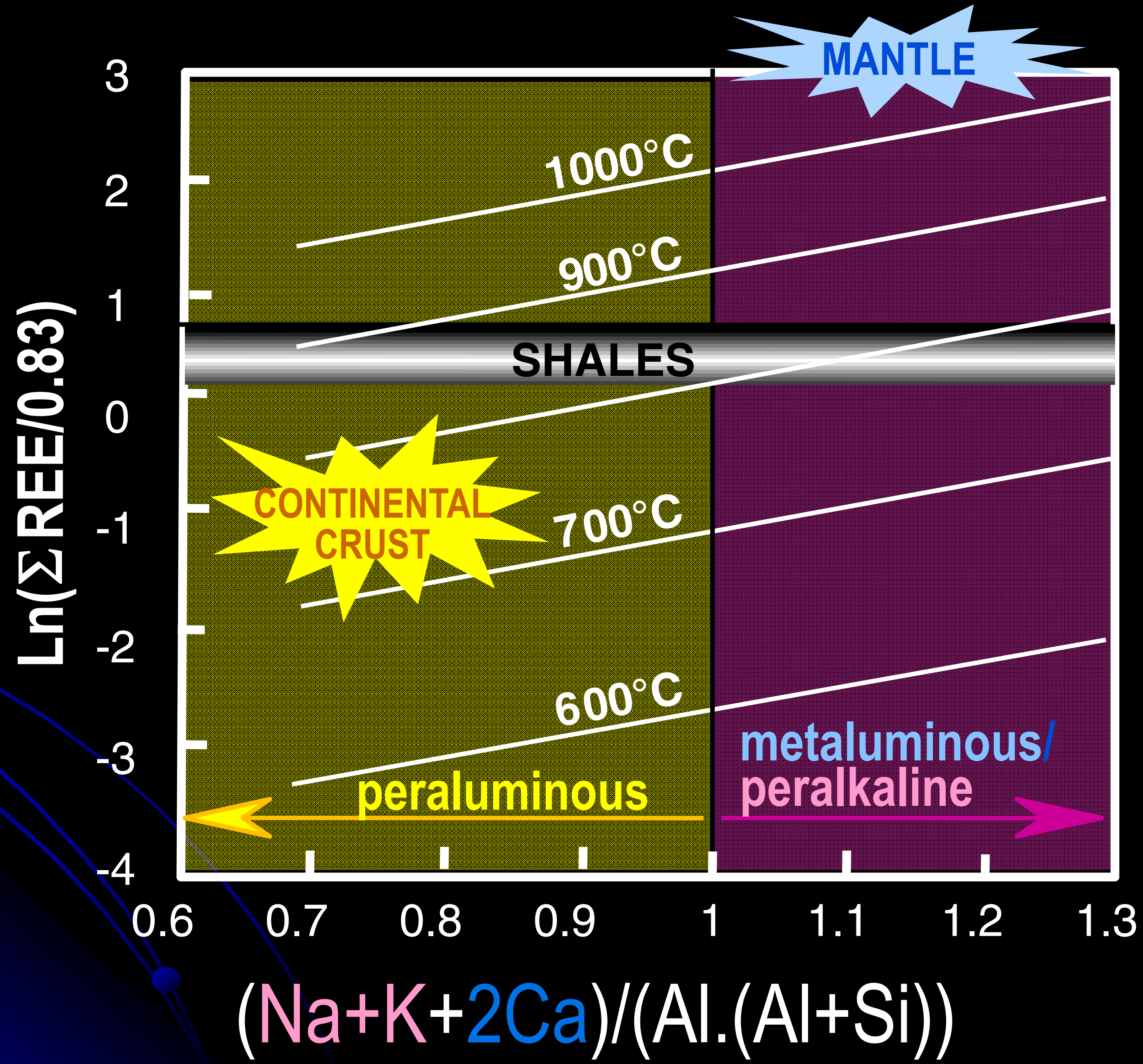
Why using aluminous indices for magma classification ?

UO_2 SOLUBILITY IN GRANITIC MELTS



Peiffert et al., 1996

MONAZITE SOLUBILITY IN SILICATE MELTS



from Montel, 1986

THREE TYPES OF U – RICH ACIDIC MAGMAS

- **PERALKALINE MAGMAS**
  - **Na+K > Al**
  - Riebeckite, Aegyrine, Avfedsonite
  - betafite, thorite, complex U,Th,REE,Zr minerals
  - **Strongly enriched in U, Th, REE, Zr, …**
- **METALUMINOUS HIGH-K CALC-ALKALINE MAGMAS**
  - **Al < Na+K+2Ca**
  - Amphibole, Pyroxene, biotite
  - Allanite, U-thorite, titanite, ± Th-rich uraninite, magnetite
  - **Enriched in U, Th, REE**
- **PERALUMINOUS FELSIC MAGMAS**
  - **Al > Na+K+2Ca**
  - Al-biotite, Muscovite, ± sill, andalusite, garnet, topaz, tourmaline
  - Low-Th uraninite, monazite, ilmenite
  - **Enriched in U, poor in Th, REE, Zr …**

PERALKALINE MAGMAS

Na + K > 1 + high T → highly depolymerized

▼

Very high solubility of accessory minerals

▼

very high U, Th, Zr, REE, Nb, Ta, ... contents
continuously enriched in the residual melts

Volcanic rocks :
U in the glassy matrix

▼

Very good U-source

▼

Ex : - Streltsov (Russia)
- McDermitt (USA)

Granites/Syenites : crystalliz. of a complex mineral paragenesis : zircon, U-Th-Zr silicophosphates, Nb-Ta oxydes, ...

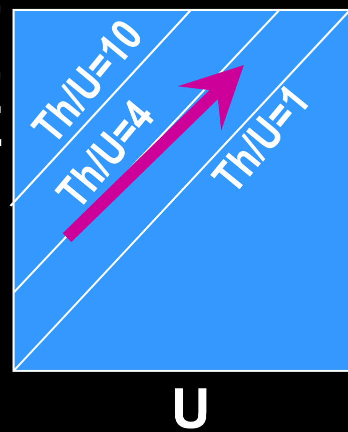
▼

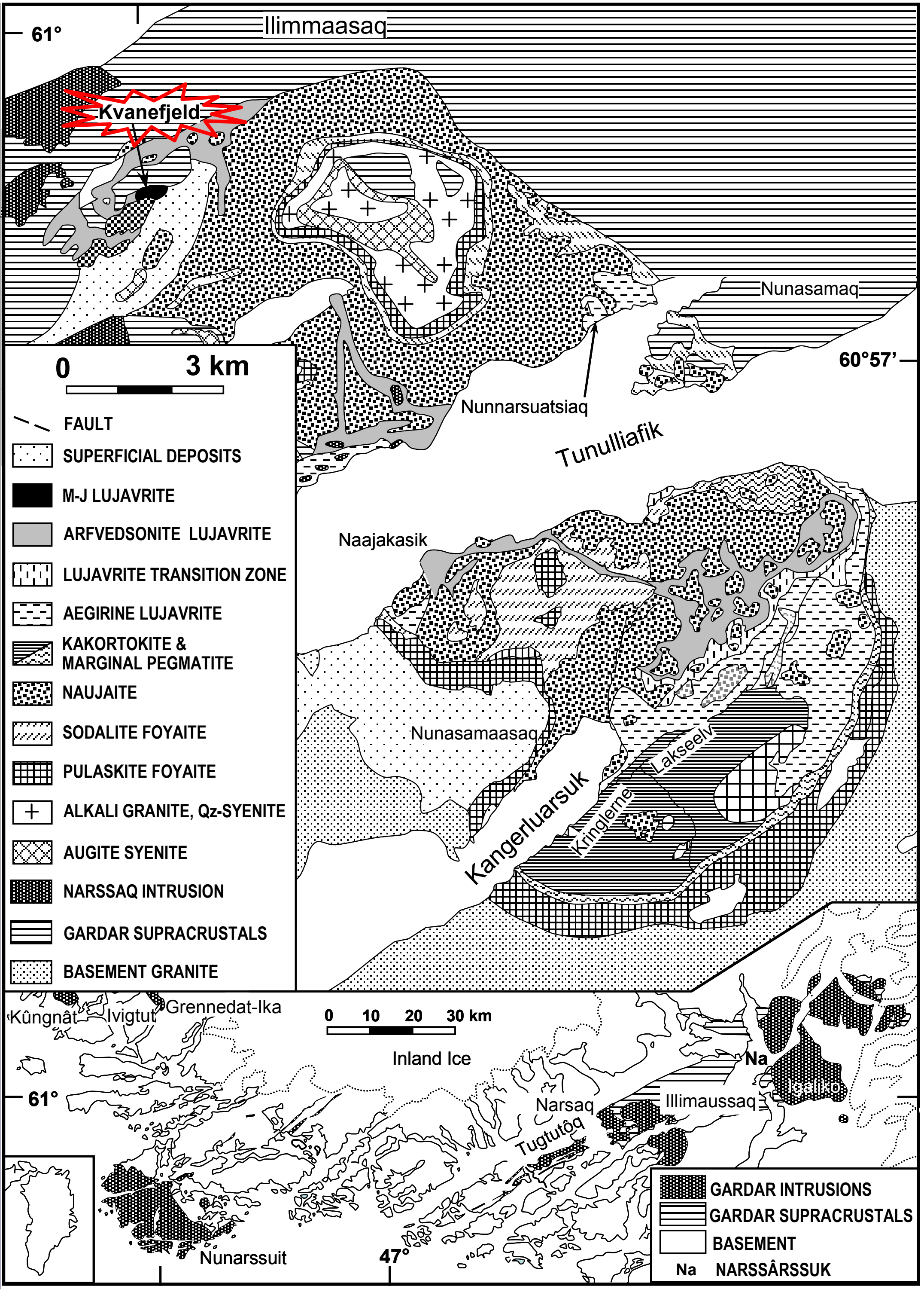
U in refractory sites

▼

Bad U source / high extraction cost

Ex. : - Ilimaussaq, Groenland (syenites)
- Bokan Mountain Alaska (granites)





PERALKALINE MAGMAS

Ilimausacq (Greenland)

peralkaline complexe

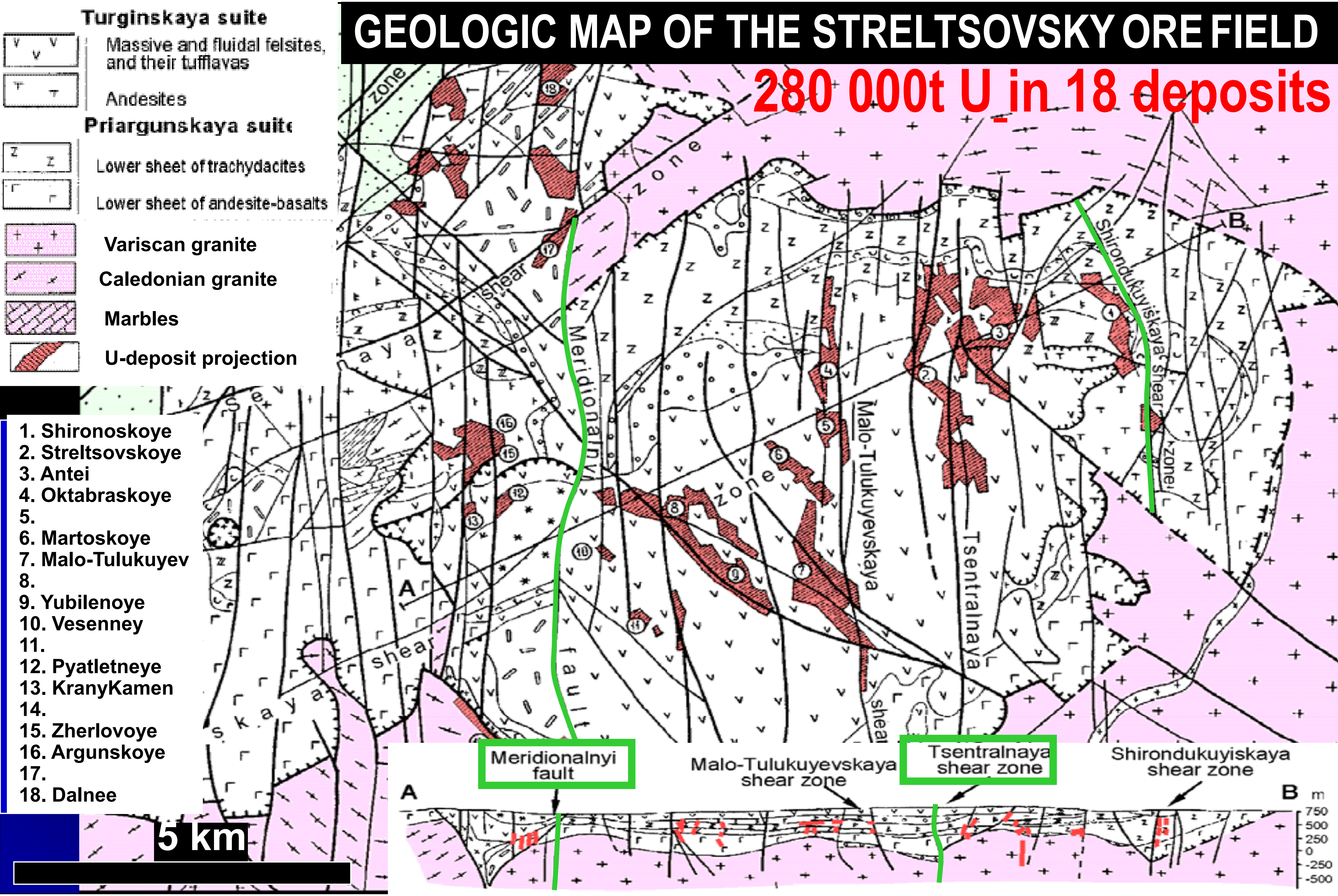
U mineralization
in the most fractionated part
where fluid oversaturation occured

➔ simultaneous enrichment in :
U, Th, Zr, REE, Nb, Ta, F …
U in **steenstrupine** :
Silicophosphate of U, Th, Zr, REE, Nb, Ta

220,000 t U @ 250 ppm

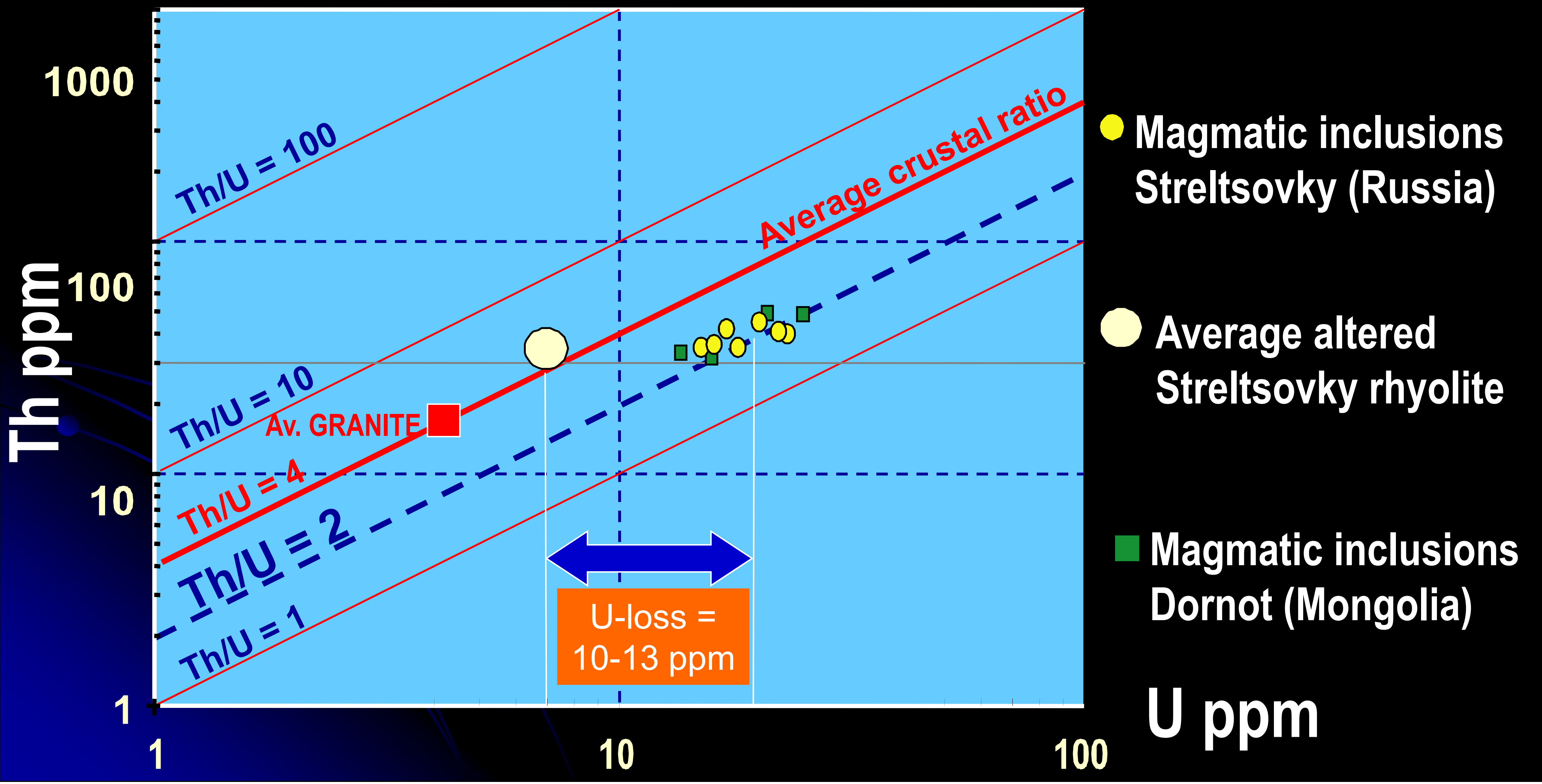
GEOLOGIC MAP OF THE STRELTSOVSKY ORE FIELD

280 000t U in 18 deposits

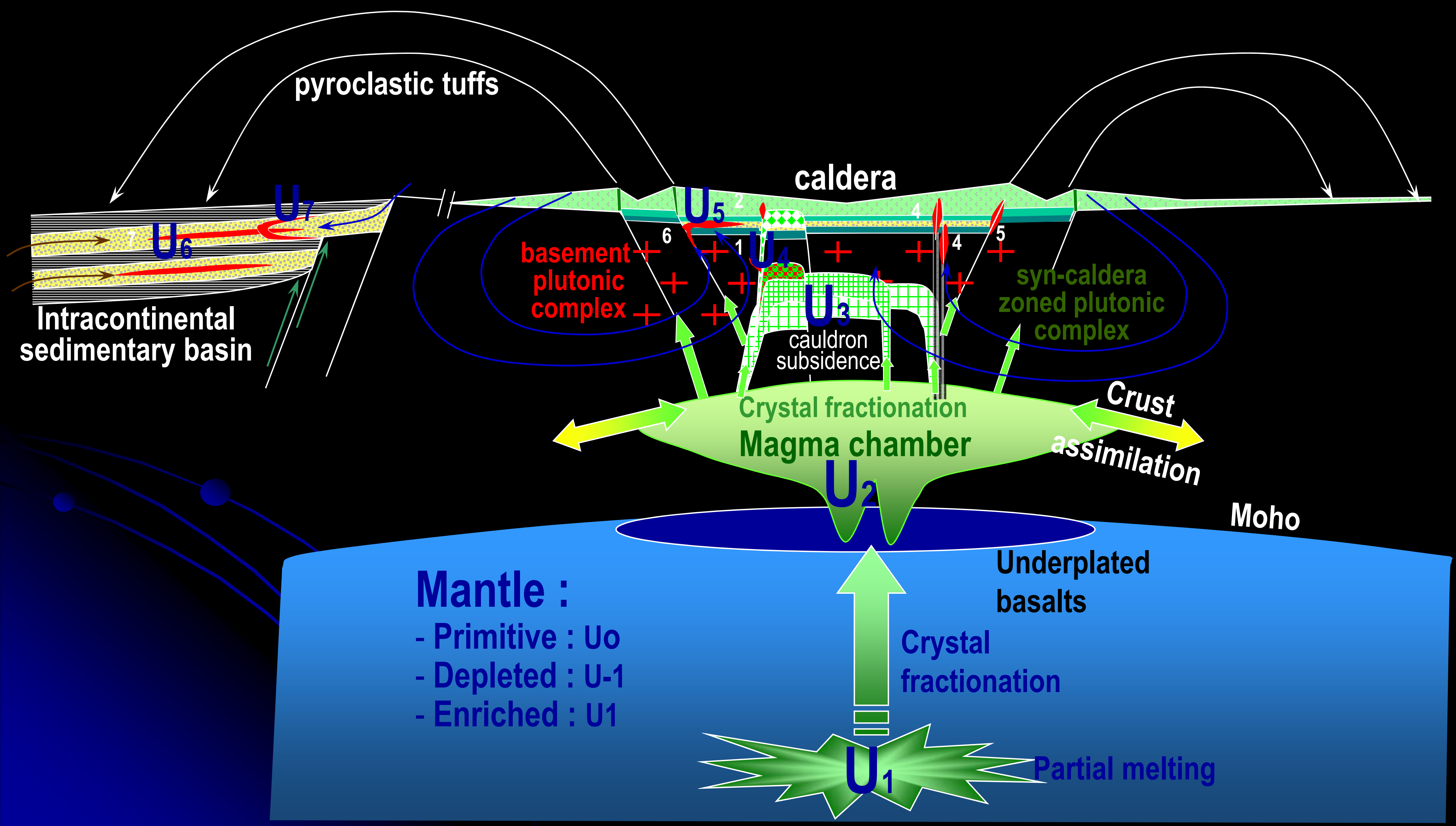


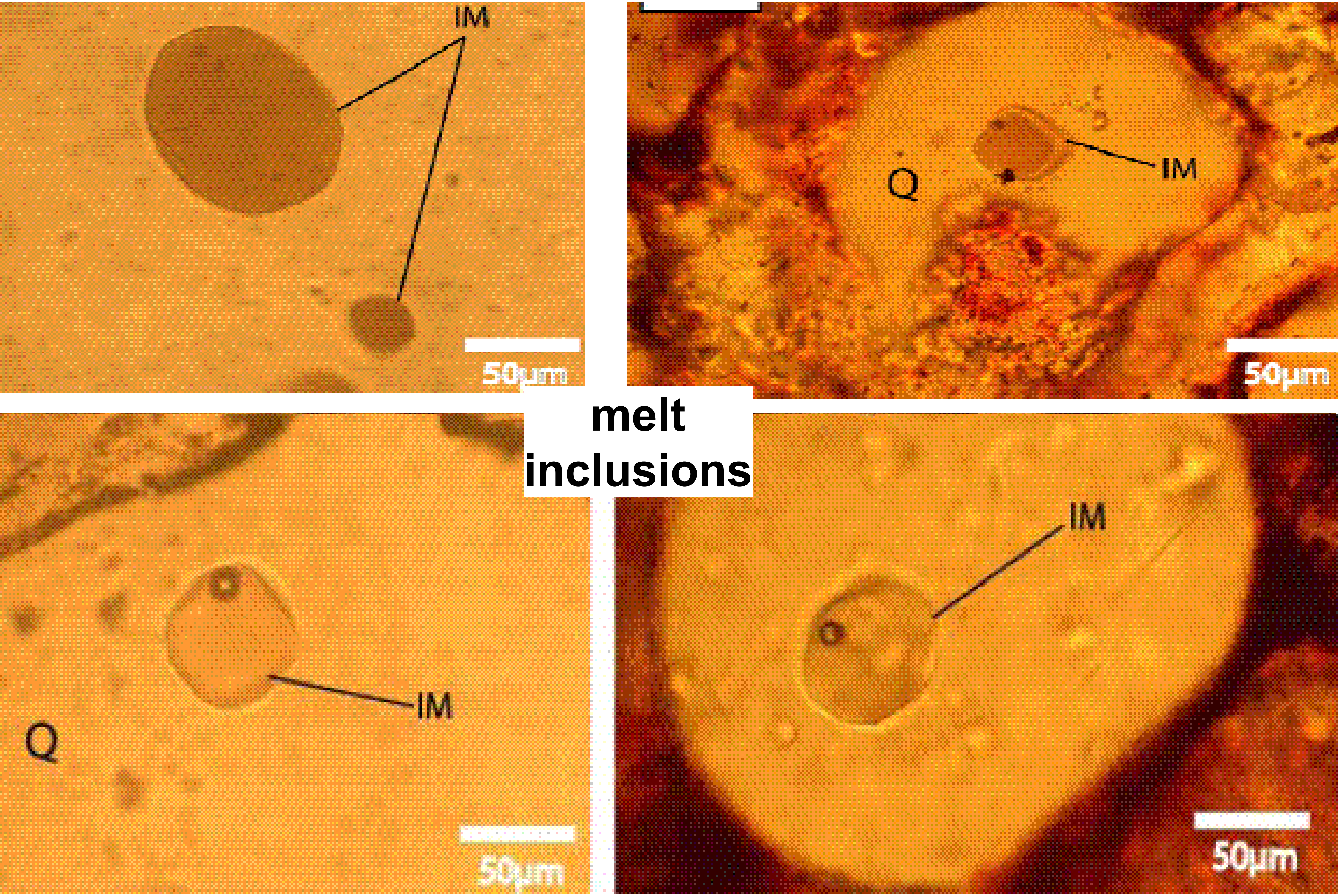
U loss evaluation from U-contents of melt inclusions (acidic volcanics compared to altered rhyolites)

STRELTSOV caldera

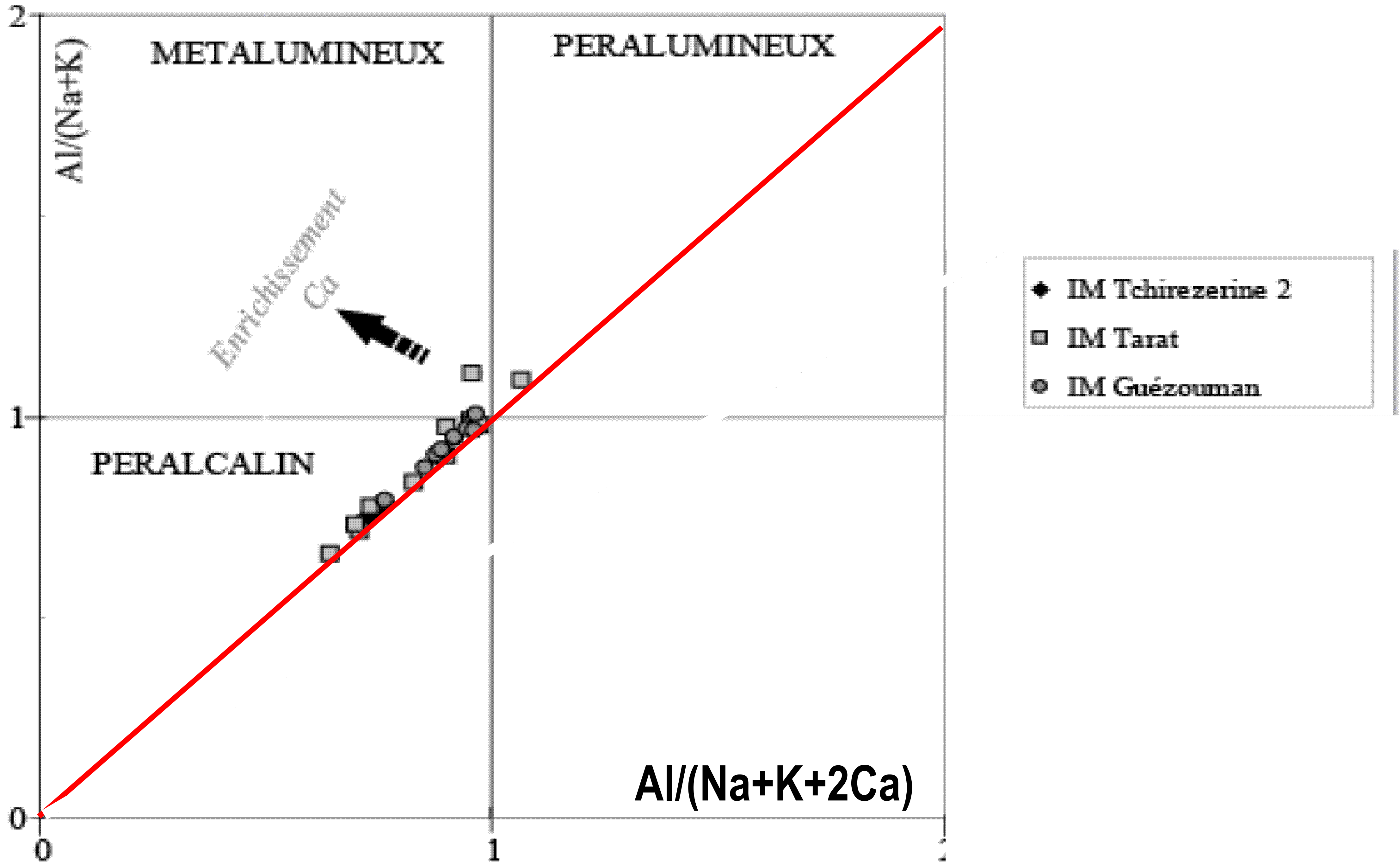


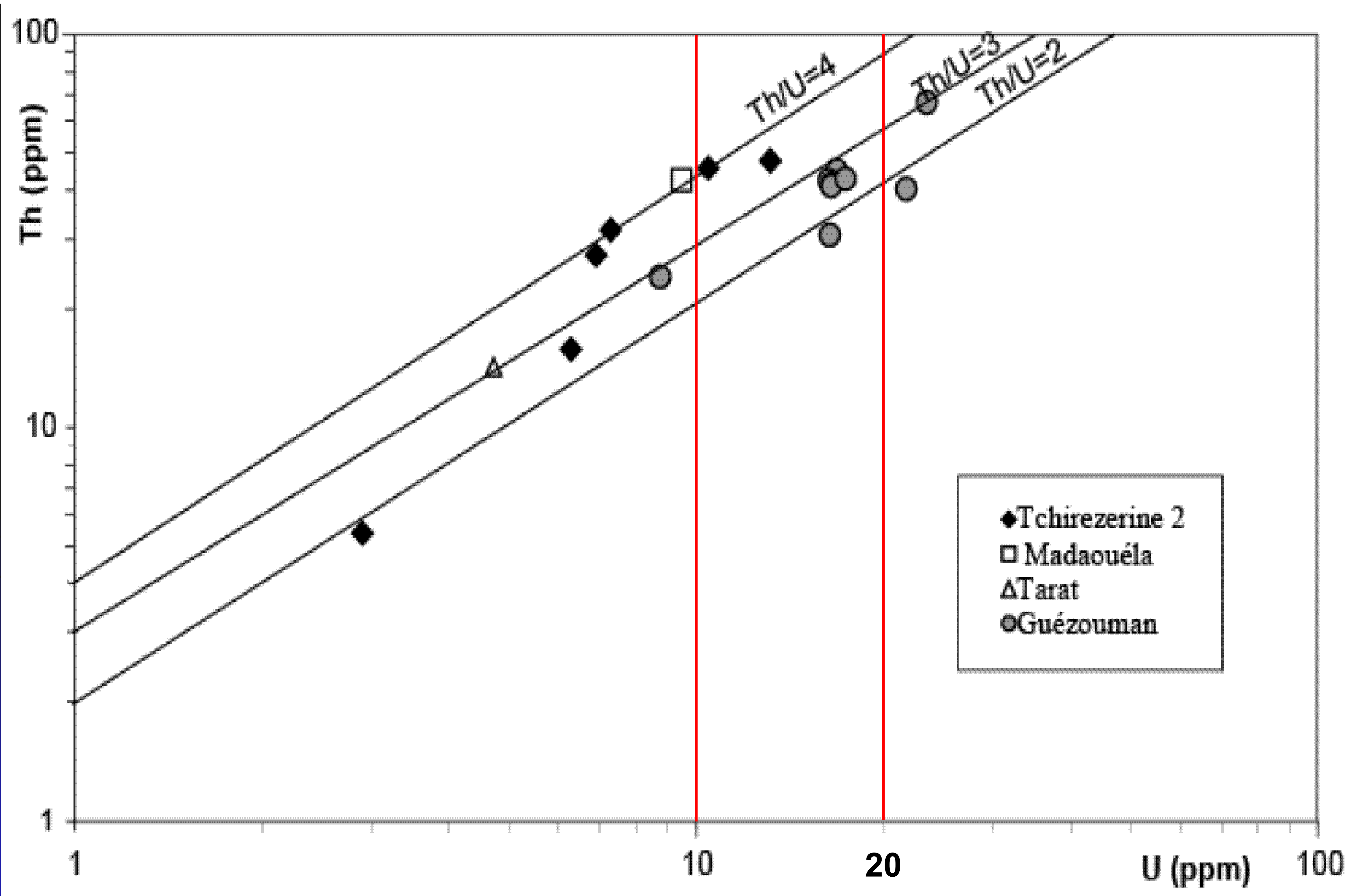
Conceptual model for U deposits related to peralkaline magmatism




IM
50µm
Q
IM
50µm
melt
inclusions
Q
IM
50µm
IM
50µm

Melt inclusion geochemistry from sandstone





100
10
1
Th (ppm)
Th/U=4
Th/U=3
Th/U=2
Tchirezerine 2
Madaouéla
Tarat
Guézouman
1
10
20
U (ppm)
100

PERALUMINOUS MAGMAS

Highly polymerized : A/CNK > 1 + low T

Accessory minerals low solubility

low Th, Zr, REE,... contents
continuously depleted in the residual melts

Early crystallization of monazite and zircon :
With limited amount of U

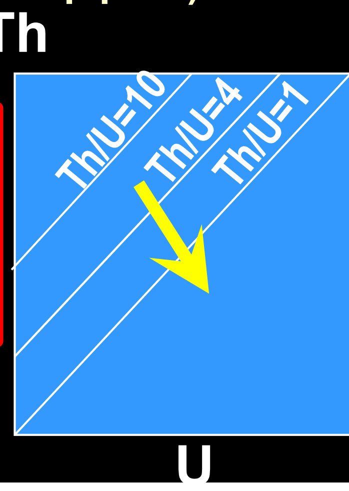
U enriched in residual silicate melts (up to some tens of ppm)

Volcanic rocks: RARE
FERTILE U-SOURCE

Ex. : - Macusani (Peru)

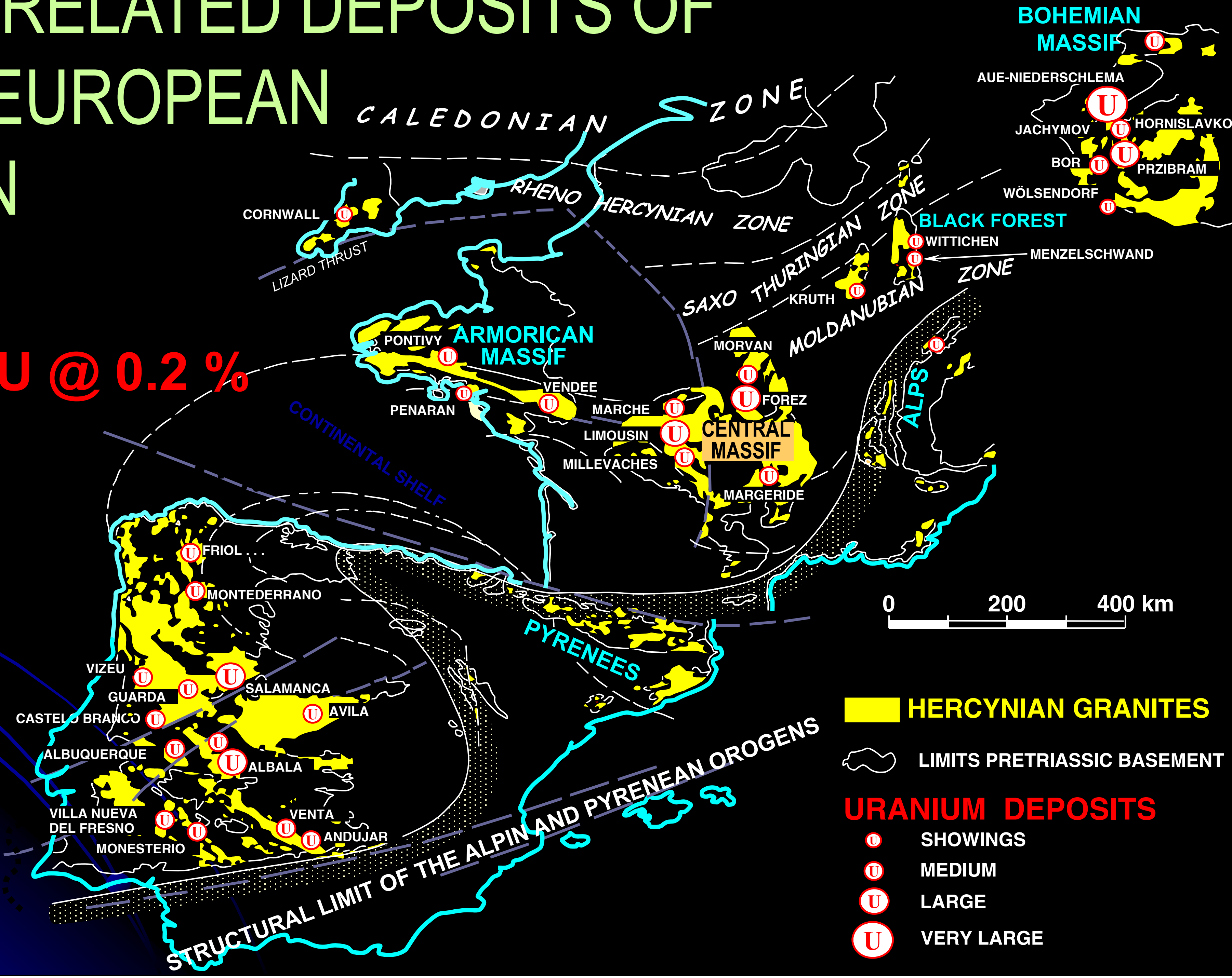
Granites: U >> as low-Th URANINITE
► FERTILE U-SOURCE

Ex. : - St Sylvestre (Limousin)
- Erzgebirge (Germany)



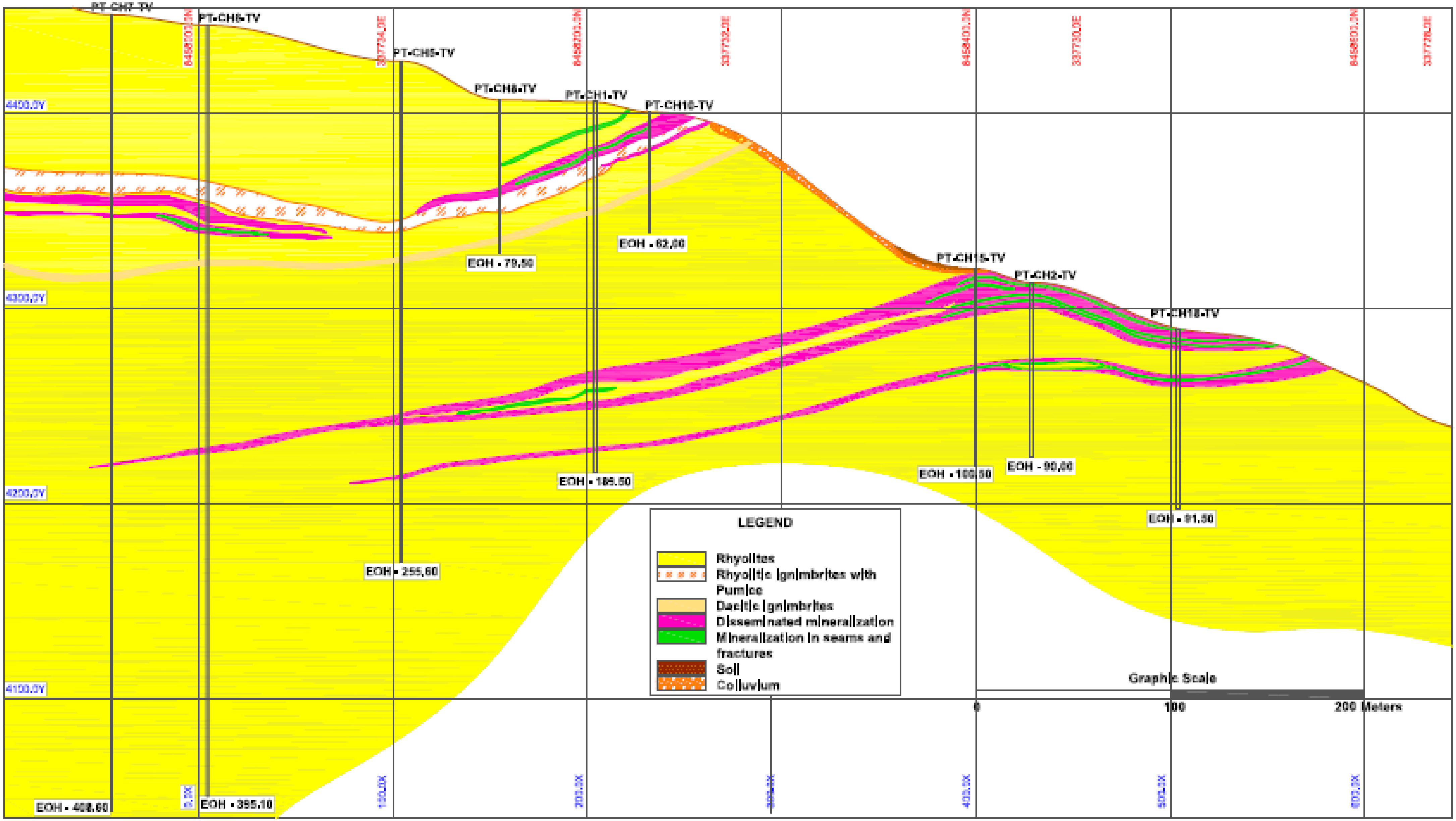
GRANITE RELATED DEPOSITS OF THE MID-EUROPEAN VARISCAN BELT

> 300,000 t U @ 0.2 %



MACUSANI YELLOW CAKE

"KIHITIAN CONCESSION", CHILCUNO-CHICO PROJECT
N-S PROFILE, LOOKING WEST
DRILL HOLES; PT-CH7-TV, PT-CH6-TV, PT-CH5-TV, PT-CH8-TV, PT-CH1-TV, PT-CH10-TV, PT-CH15-TV, PT-CH2-TV, PT-CH18-TV




30,000 t U @ 0.02
CUSANI YELLOW CAKE

HIGH-K CALC-ALKALINE MAGMAS

Intermediate : A/CNK ~ 1 + moderately high T

Accessory minerals intermediate solubility

high U, Th, Zr, REE, Nb, Ta, ...

constant or decreasing in the residual melts

High Ca-contents

Monazite not stable

REE in Ca-minerals :

- amphibole, allanite, titanite

Volcanic rocks

Variable fertility

According to glass/accessory mineral ratio

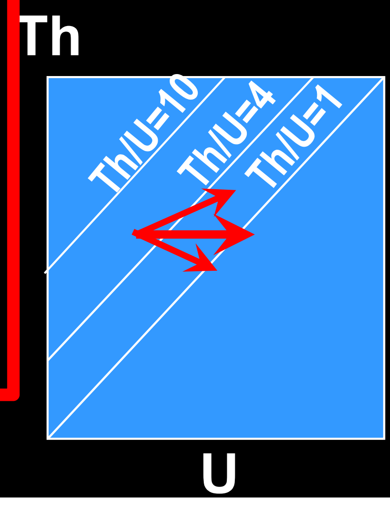
Ex.: Ben Lomond (Australia)

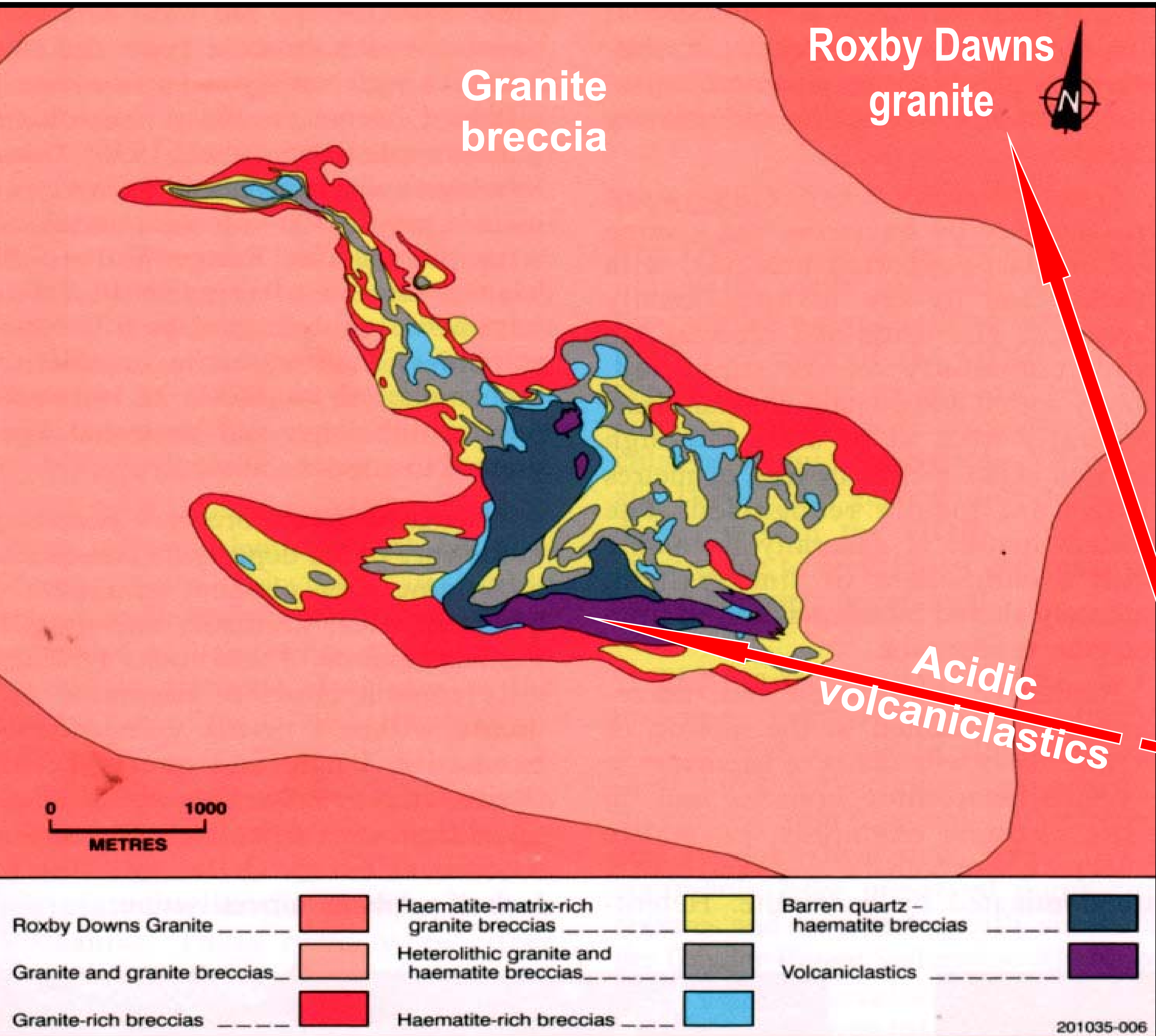
Granites

Th>U ▶ Allanite+ U-thorite ▶ **BARREN if not metamict**

U>Th ▶ **± uraninite** **± fertile**

Ex.: Hotagen (Sweden)





Geologic Map of the Olympic Dam Iron Oxide Cu-Au +U (REE) (IOCG) deposit

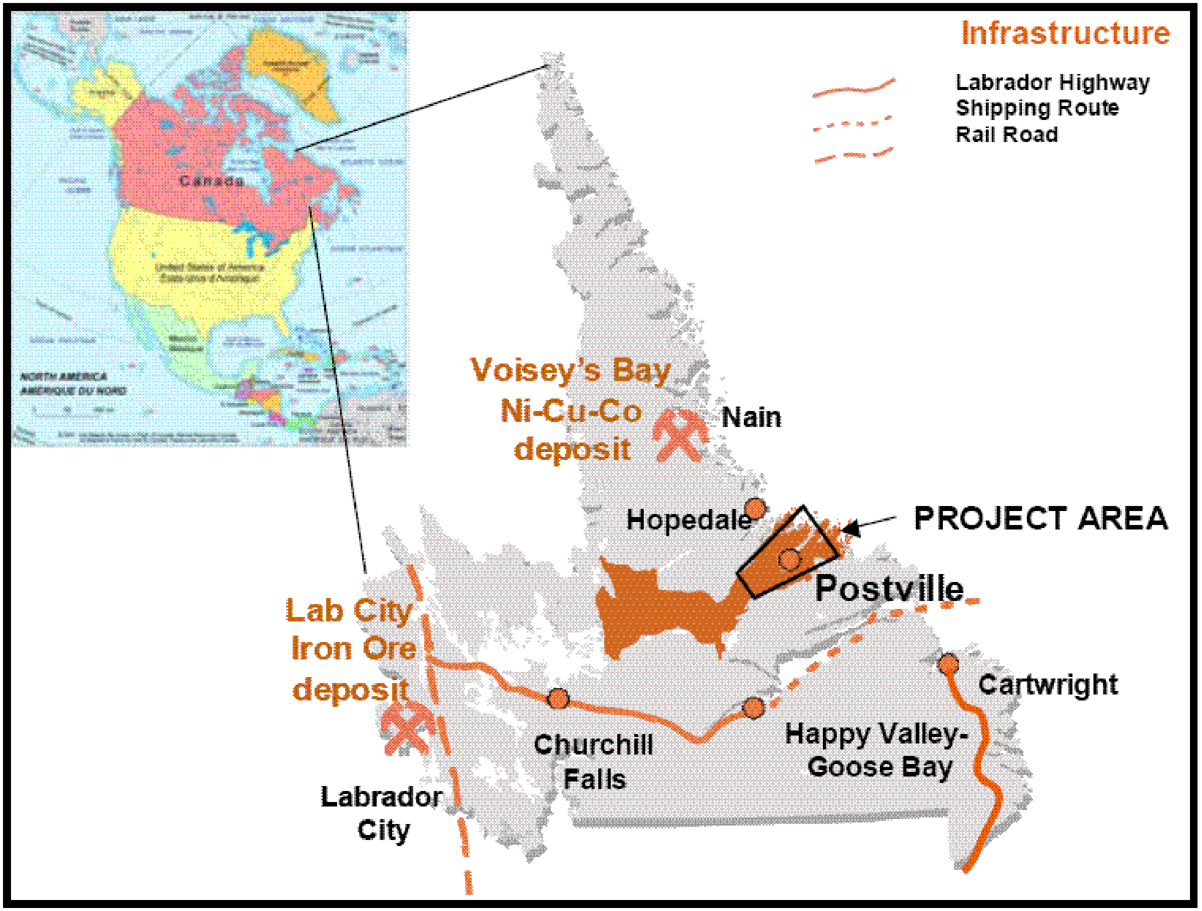
2.100 Mt U

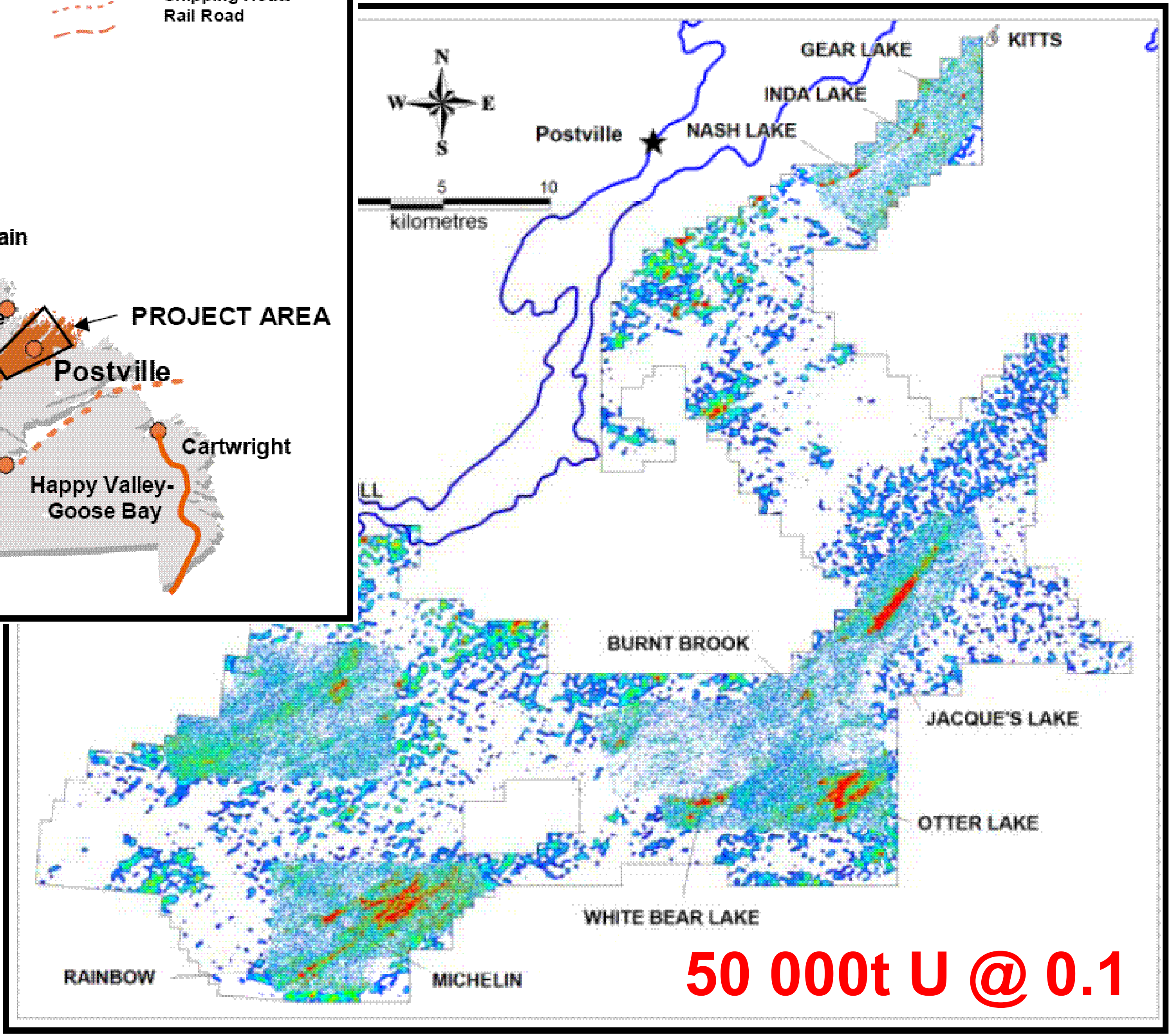
2 U-rich sources

high-K calc-alkaline magmas

MICHELIN U DEPOSIT

Property Location Map





Associated with **high-K calc-alkaline metavolcanic gneisses** of the Aillik Group

U mineralization associated with hematization + albitization

ANATECTIC PEGMATOIDS

Partial melting of U rich metasediments and/or metavolcanics

Low A/CNK : ~ 1.1 + low T

▼

Accessory minerals intermediate solubility

▼

high U **and/or** **Th** **and/or** **Zr** **and/or** **REE** **and/or** **Nb, Ta, ...**

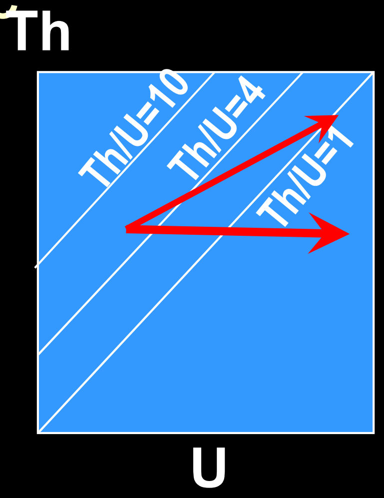
depending of the nature of the source

constant or decreasing in the residual melts

▼

Uraninite ± Monazite ± Allanite ± Uranothorite

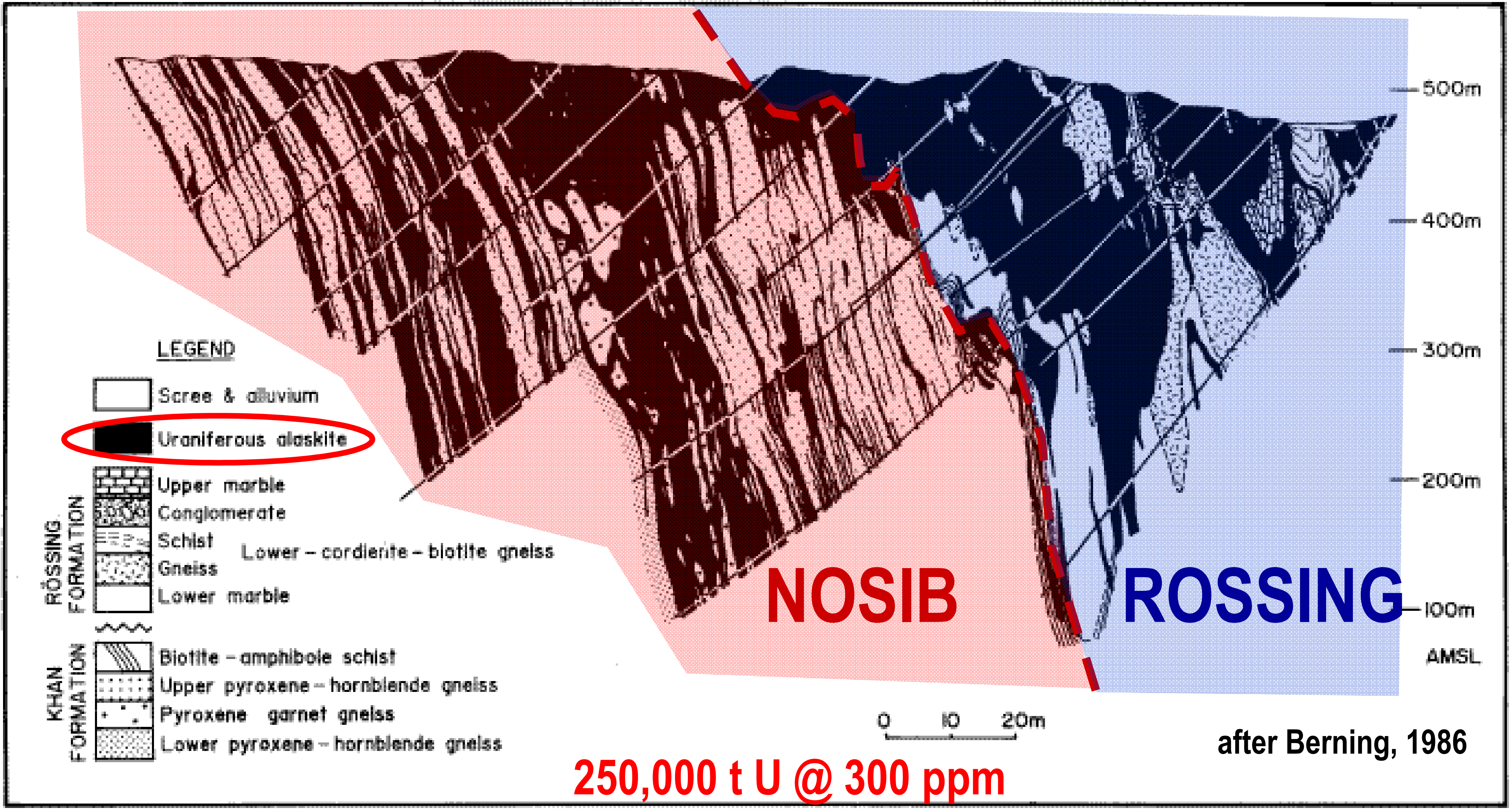
± Zircon ± Nb-Ta minerals ± …



Ex.: Rössing (Namibia)

ANATECTIC PEGMATOIDS

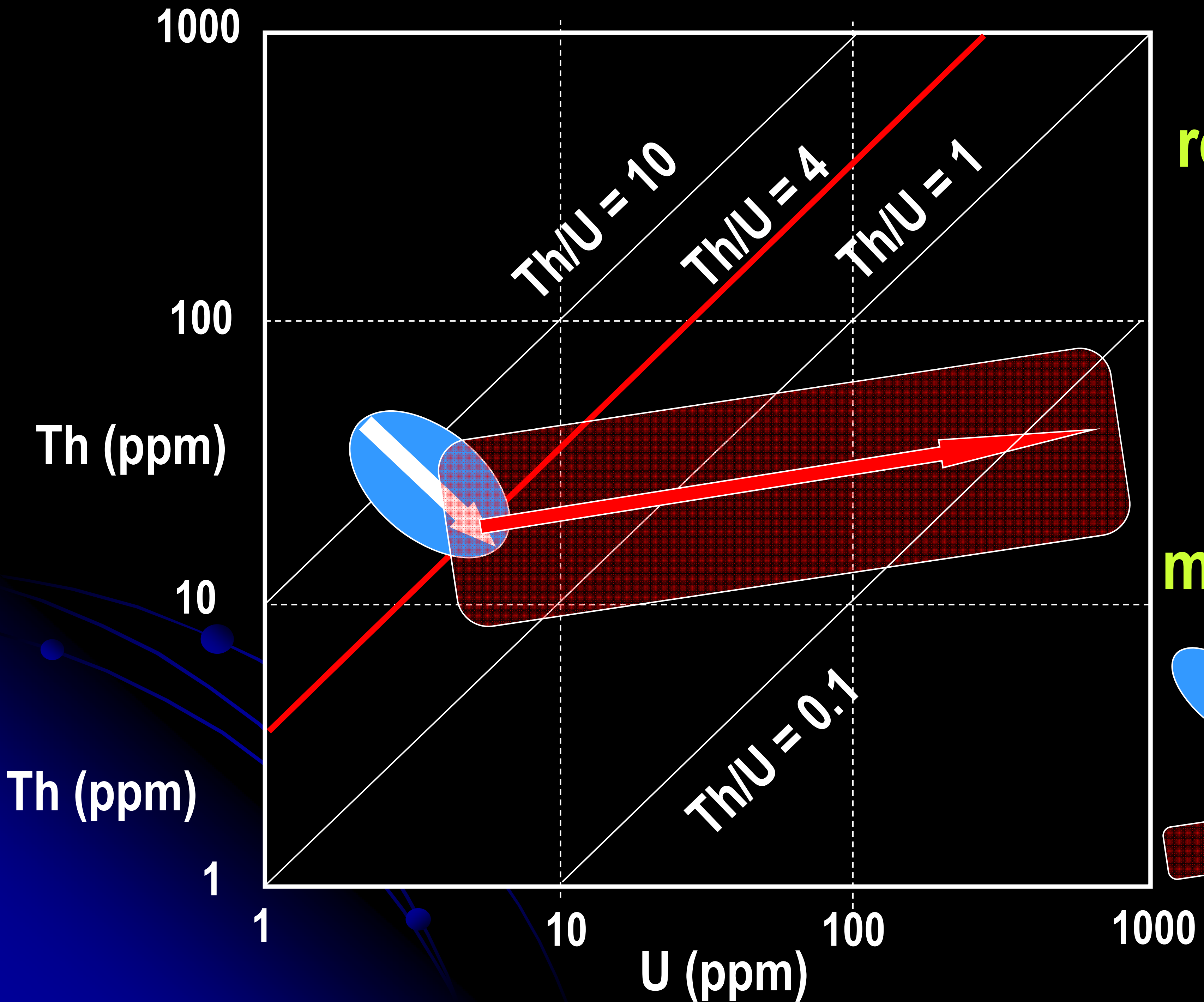
Cross-section of the Rossing alaskite body geology & boreholes (drill section zero)



after Berning, 1986

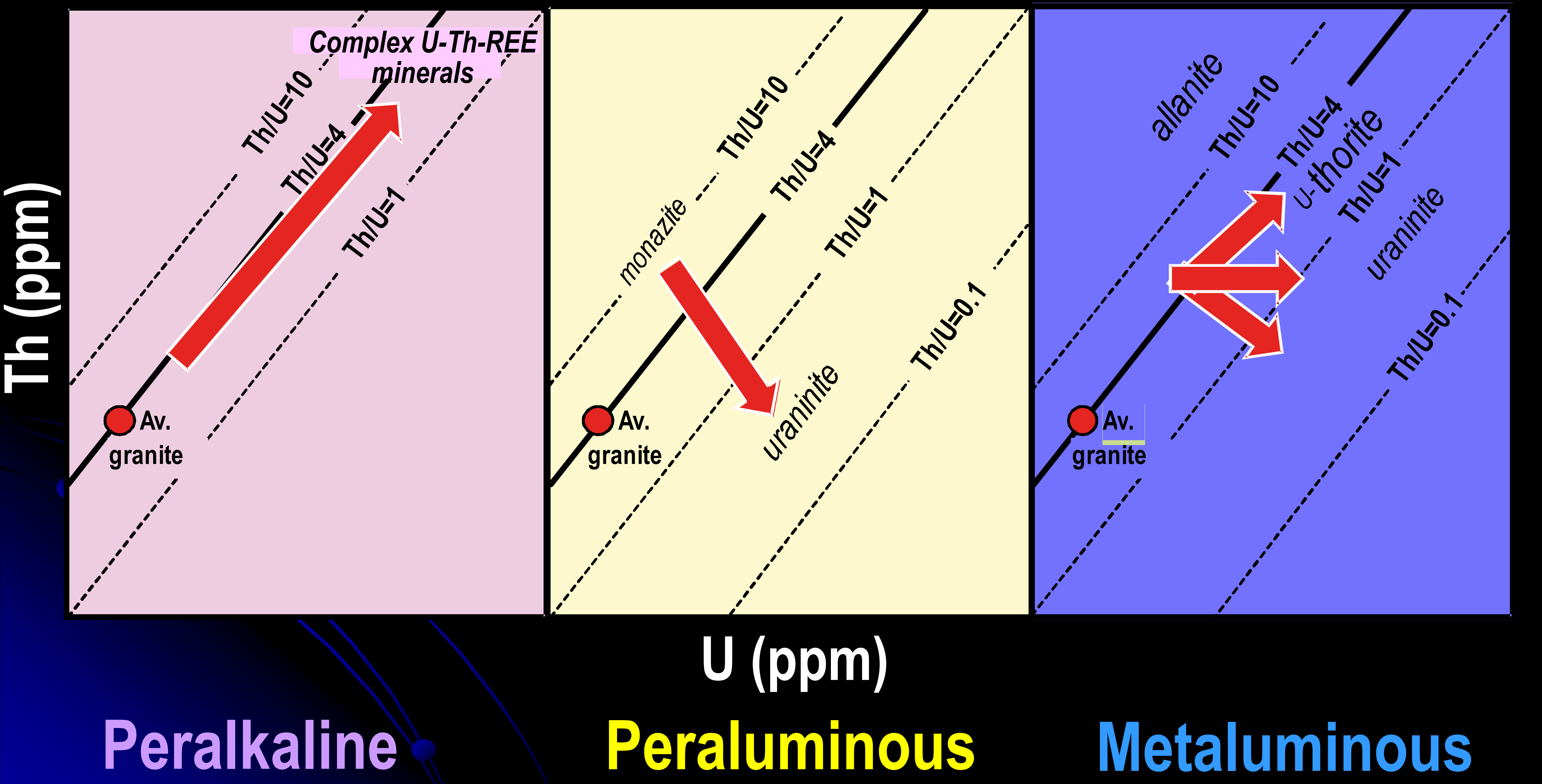
250,000 t U @ 300 ppm

U-Th relationships in the Rossing Alaskites & metsediments



Cuney, 1981

U - Th FRACTIONATION IN THE 3 TYPES OF U – RICH ACIDIC MAGMAS



CONCLUSIONS

Three types of U-rich felsic magmas identified:

- Peralkaline (fractionated A1-type)
  - Weakly fertile granites (U in highly refractory phases)
    - Examples: Ilimausacq (Groenland), Bokan Montain (Alaska)
  - Highly fertile volcanics if high glass/crystal ratio
    - Example: Streltsovka (Russia), Dornot (Mongolia)
- Metaluminous high-K calc-alkaline (A2-type)
  - Fertile granites if uraninite-rich or metamict accessories for vein & sedimentary deposits
  - Fertiles volcanics if large glass/crystal ratio
    - Examples : Source for Olympic Dam deposit
- Peraluminous felsic : + Anatectic pegmatoids
  - Uraninite bearing granites
    - Very fertile for vein type deposits & sec. dep. in sedimentary basins
    - Example: Variscan belt (Europe), Yenshanian belt (China), …
  - Peraluminous volcanics :
    - Fertile for vein type deposits, rare
    - Example : Macusani (Peru)