Acknowledgments:

From sources to deposits: Recent advances about the unconformity-related U deposits

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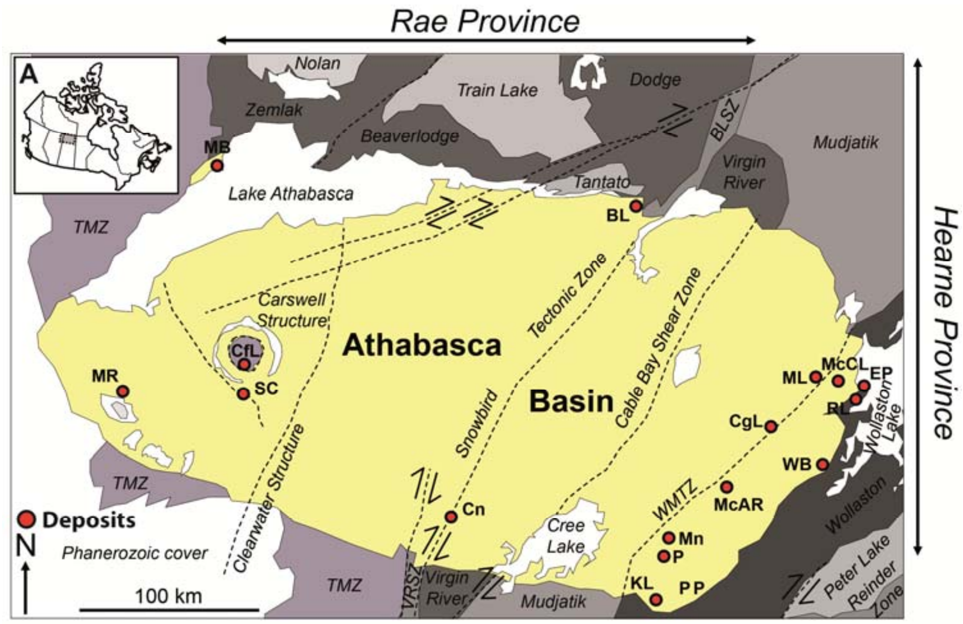
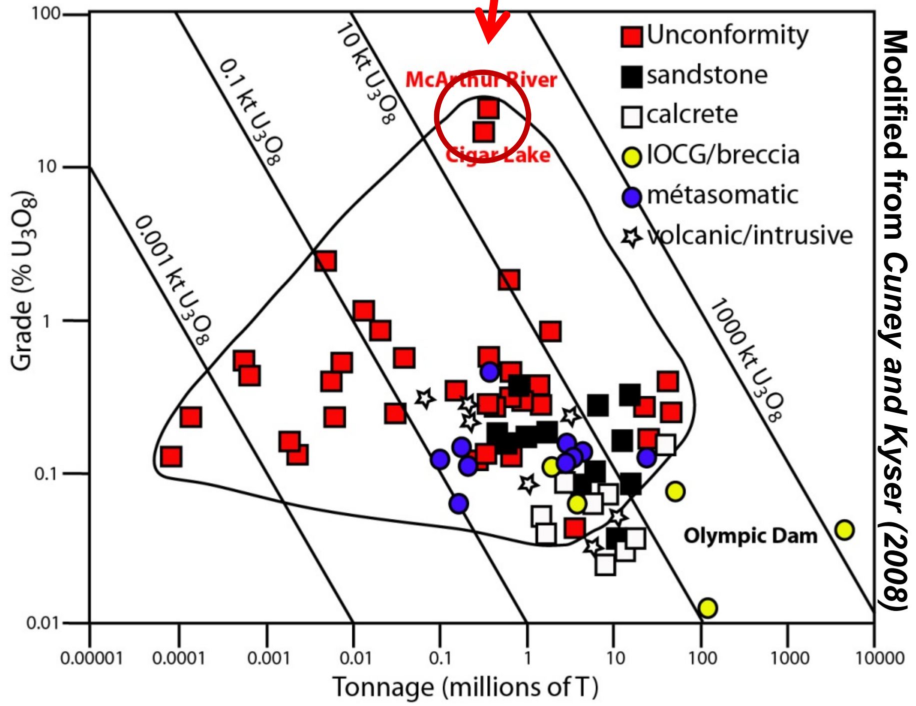
URAM 2014, Vienna, Austria

The unconformity-related U deposits

Athabasca Basin – Canada



200 kT U @ 20%



> 30 deposits

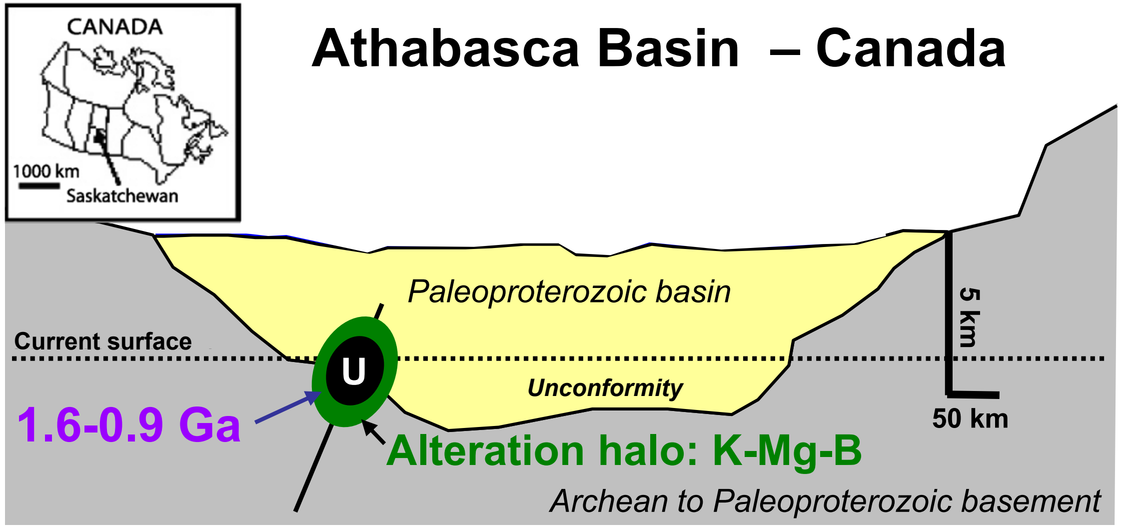
600 000 T U @ 2% U

33% of world resources

Exceptionnal high-grades

Good tonnages

The unconformity-related U deposits



Cluff Lake mine

Uranium oxide

$[U]_{crust}$ ~ 1.7 ppm

$[U]_{unconformity\text{-}related}$ ~ 20%

× 10^5

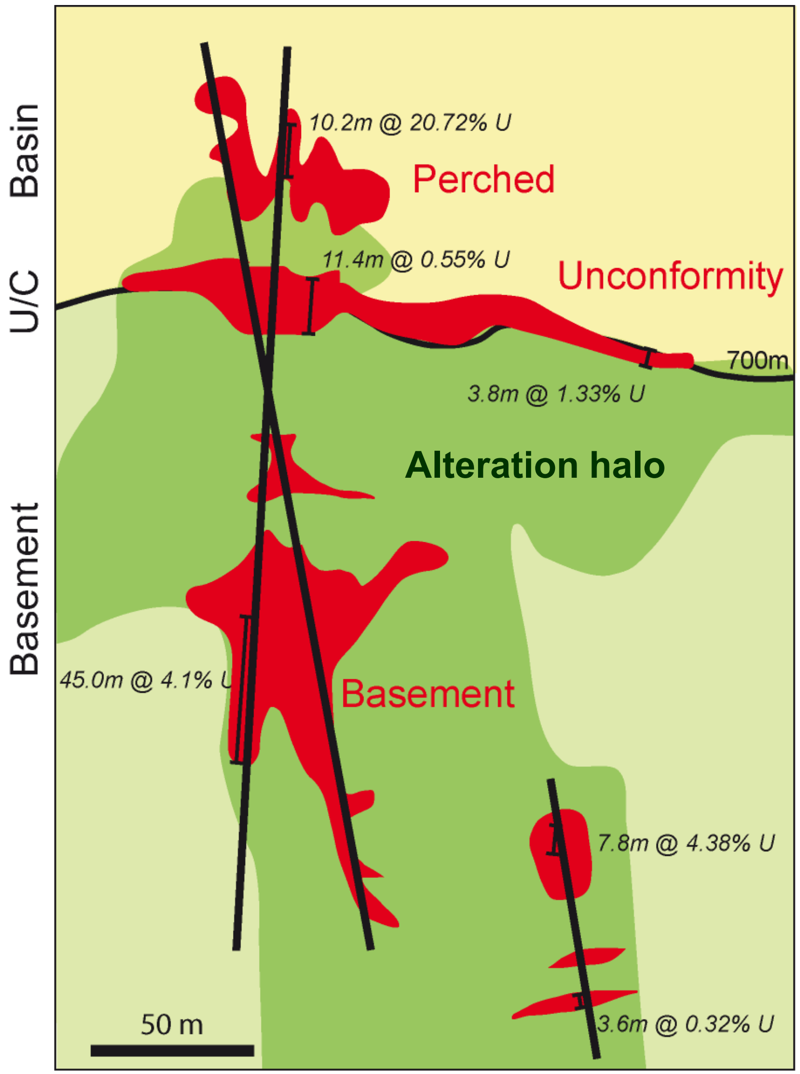
How to reach these extreme grades?

Geochemical cycle of Uranium: Sources – Transport - Deposition

Current knowledges

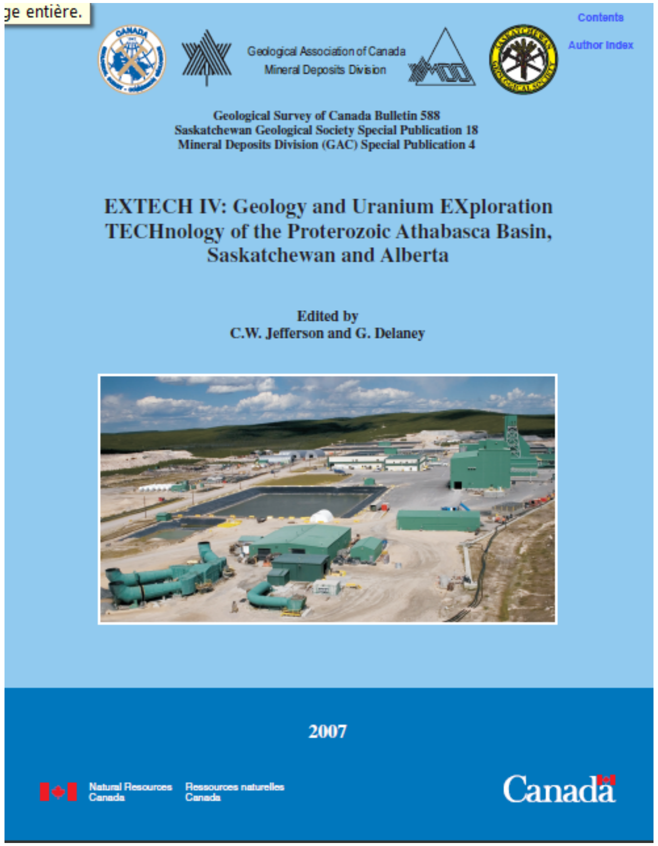
- Hydrothermal deposits (< 250°C)
- U-Pb ages: 1.6-0.9 Ga + late remobilizations
- 3 locations
- Structure-related, graphite
- Strong K-Mg-B alteration : illite-chlorites-dravite/Mg-foitite (Mg Tour)-hydrothermal quartz
- Mineralizing fluids: Na-Ca-rich brines (25-35 wt% eq. NaCl)

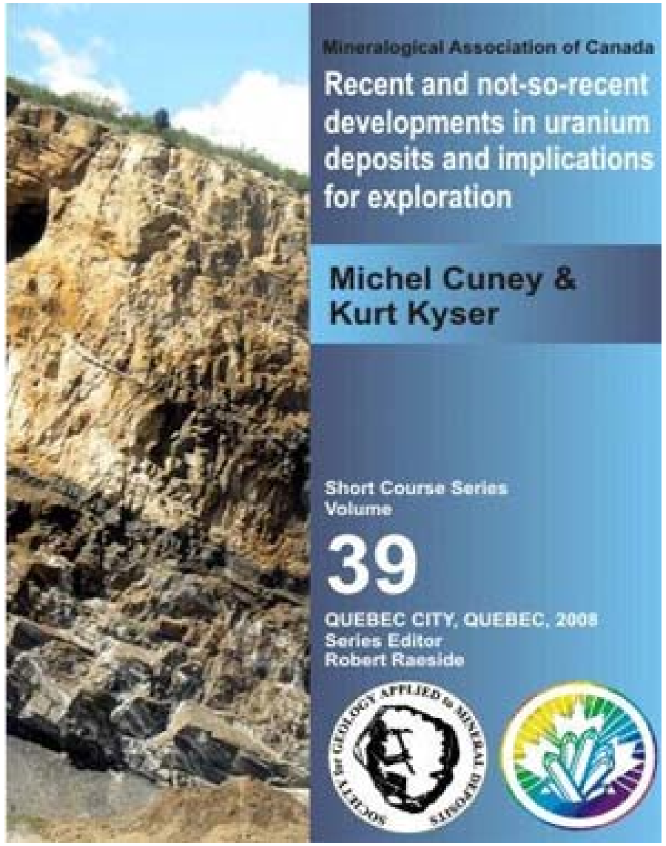
Precious witnesses of extremely efficient and large-scale fluid flows at the basin / basement interface



Kiana deposit (Shea Creek)
AREVA - UEX

These deposits : well-studied and a lot known about them





However still relevant scientific/geological questions

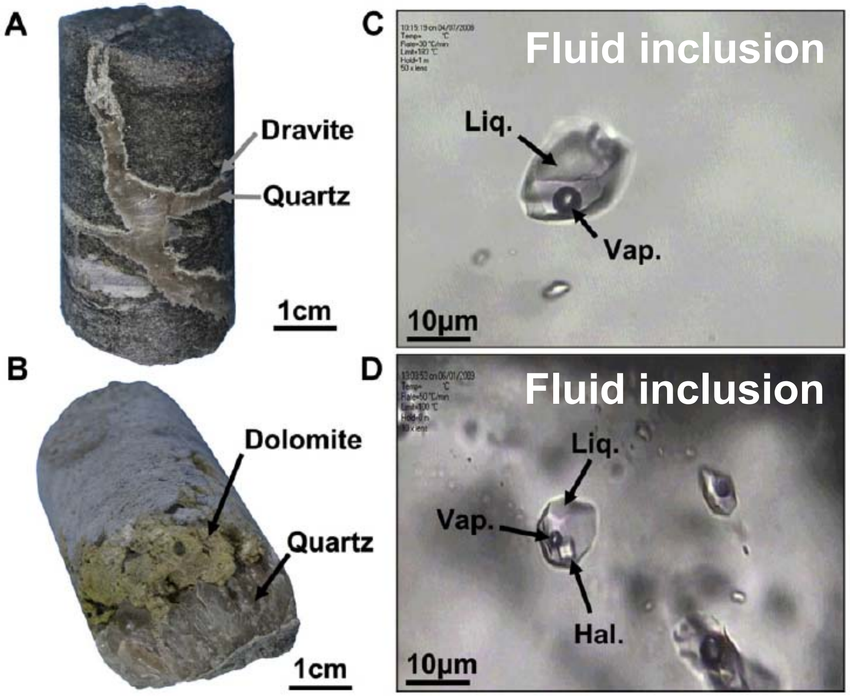
Can we provide new insights about:

- the origin of the brines?
- the source of U and other metals?
- the percolation conditions within the basement rocks?
- the chemical modifications at the origin of the formation of mineralizing brines?
- the conditions for the transport and deposition of uranium?

For the brines, where to find these new information?

1. Fluid inclusions = aliquot of the mineralizing brines

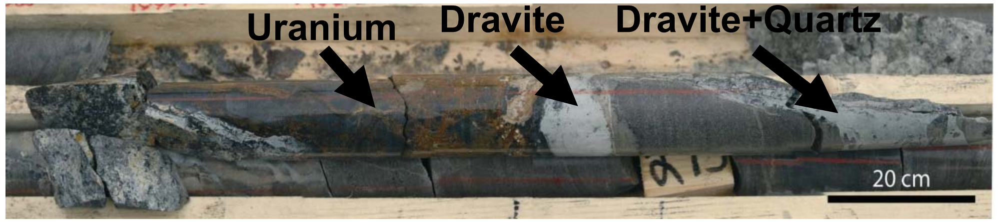
Ex: quartz and dolomite veins

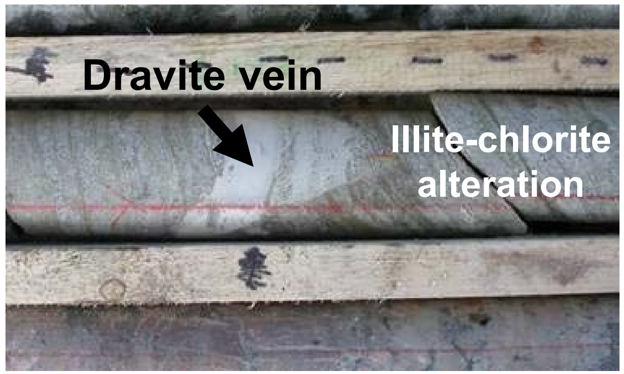


P-Patch and Millennium deposits (East Athabasca)

2. Hydrothermal minerals contemporaneous of UO_2

Ex: dravite/ Mg foitite (Mg-tourmaline)



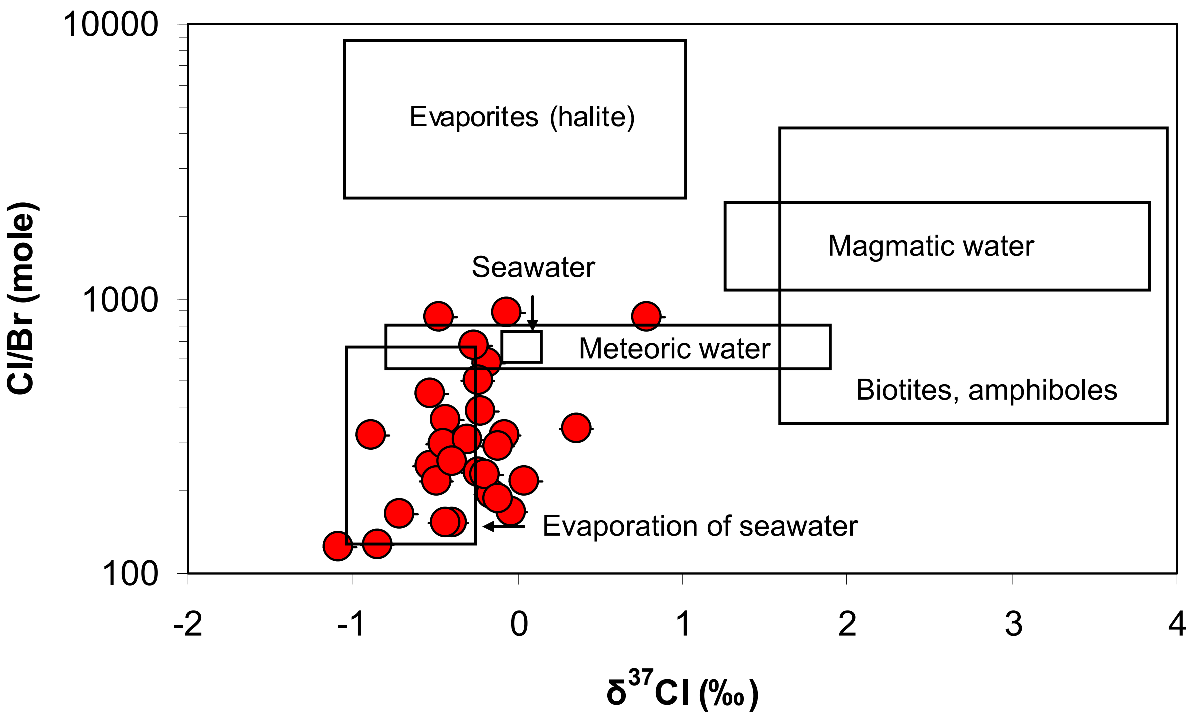


P-Patch deposit (East Athabasca)

I: Origin of the brines

Technique: Crush-leach of quartz / dolomite veins

Na-Ca-brines: 6 mol/l chlorine



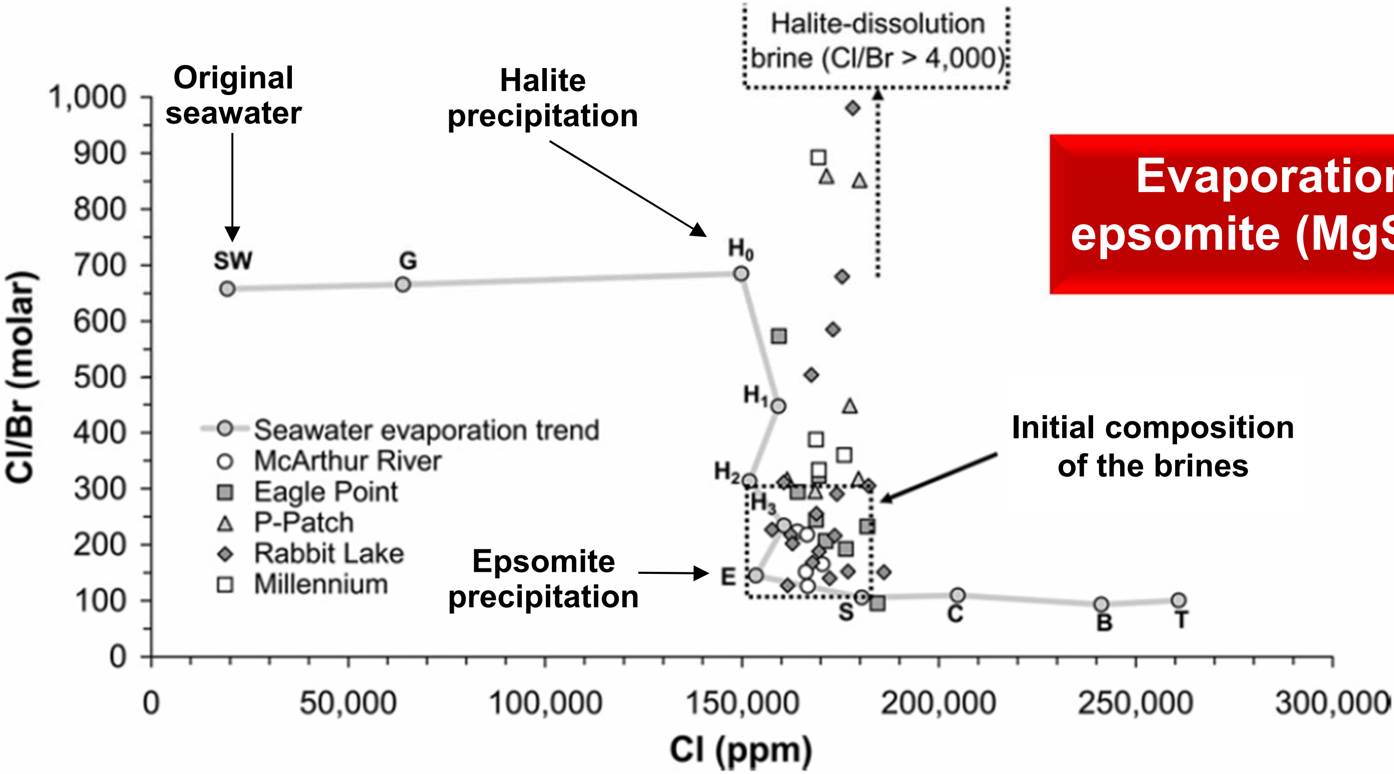
Cl was concentrated in the brines by the subaerial evaporation of seawater

Richard et al. (2011), *Geochimica and Cosmochimica Acta,* 75, 2792-2810

I: Origin of the brines

Technique: Crush-leach of quartz / dolomite veins

Na-Ca-brines: 6 mol/l chlorine



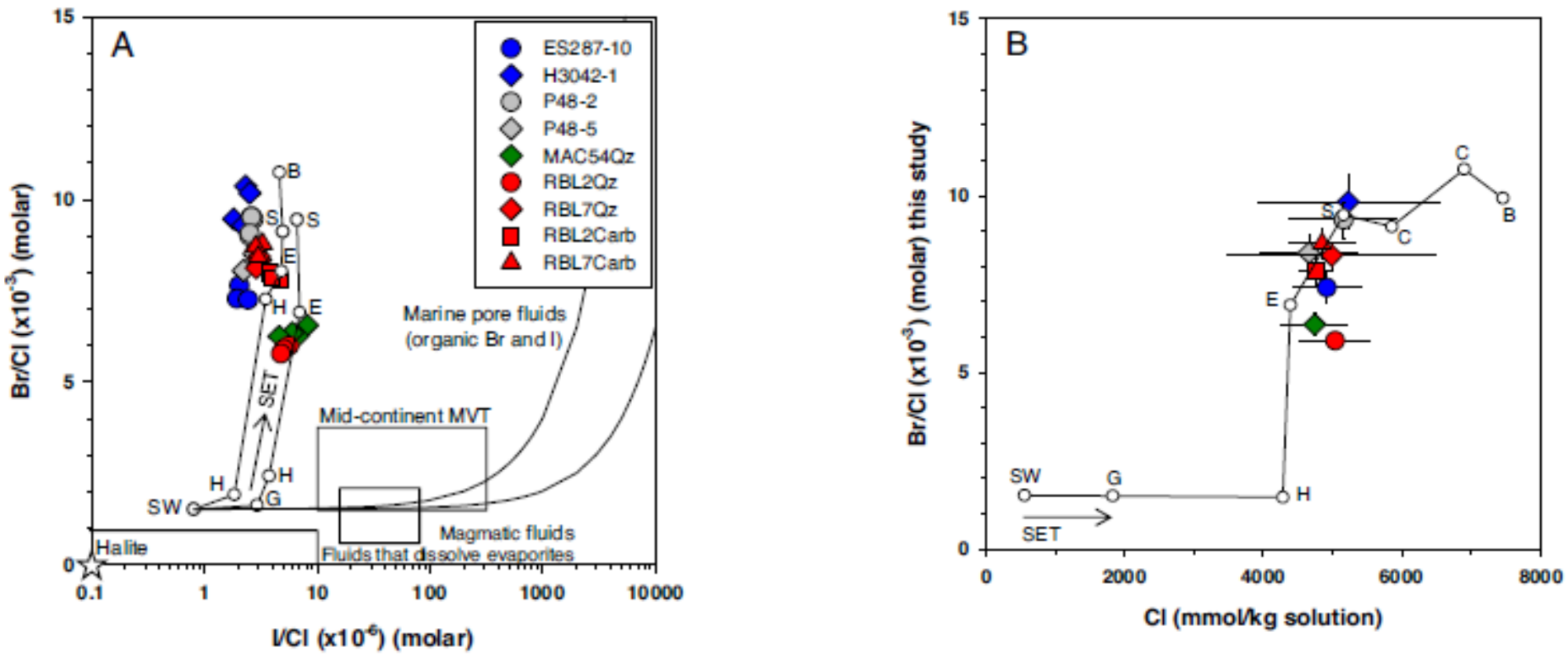
Evaporation of seawater up to epsomite ($MgSO_4$, 7 H_2O) saturation

Richard et al. (2011), *Geochimica and Cosmochimica Acta,* 75, 2792-2810

I: Origin of the brines

Technique: Halogens + noble gases of quartz / dolomite veins

Na-Ca-brines: 6 mol/l chlorine



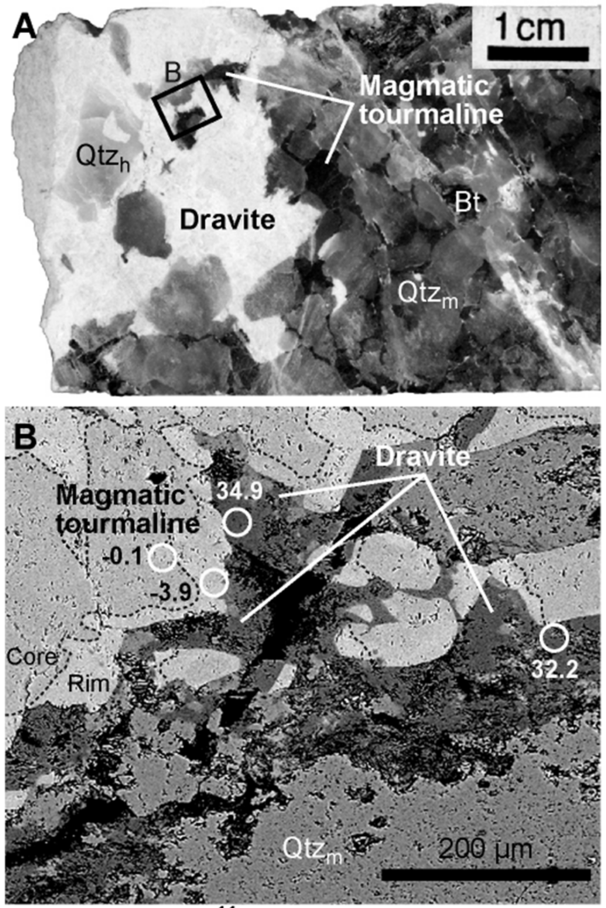
Richard et al. (2014) , *Precambrian Research,* 247, 110-125

Evaporation of seawater up to epsomite ($MgSO_4$, 7 H_2O) saturation

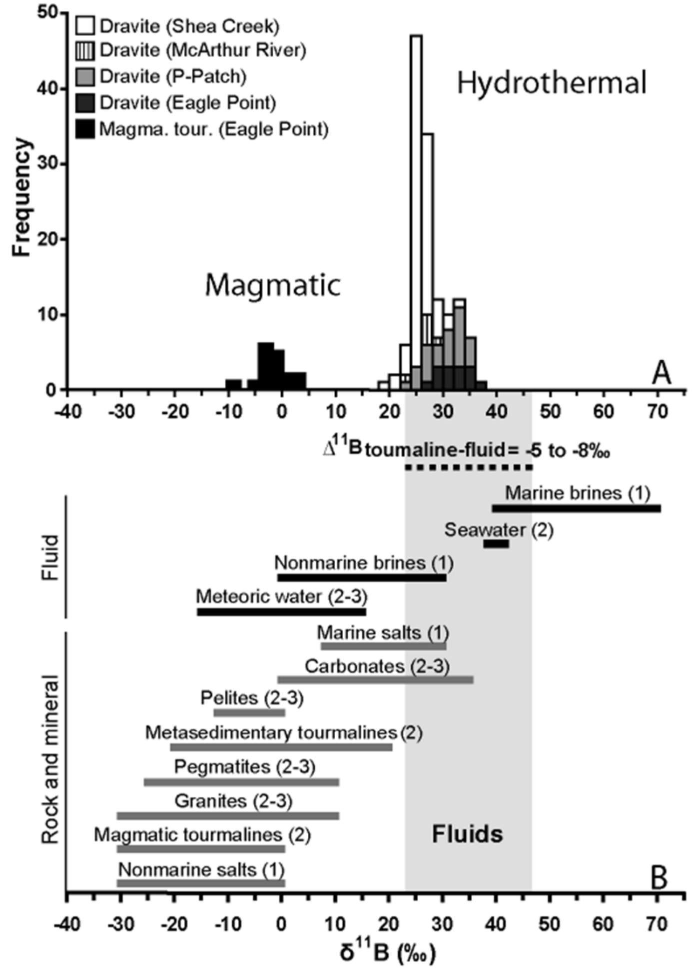
I: Origin of the brines

Technique: δ^{11}B of dravite (Mg tourmaline) by SIMS

Mercadier et al. (2012) , *Geology,* 40, 231-234

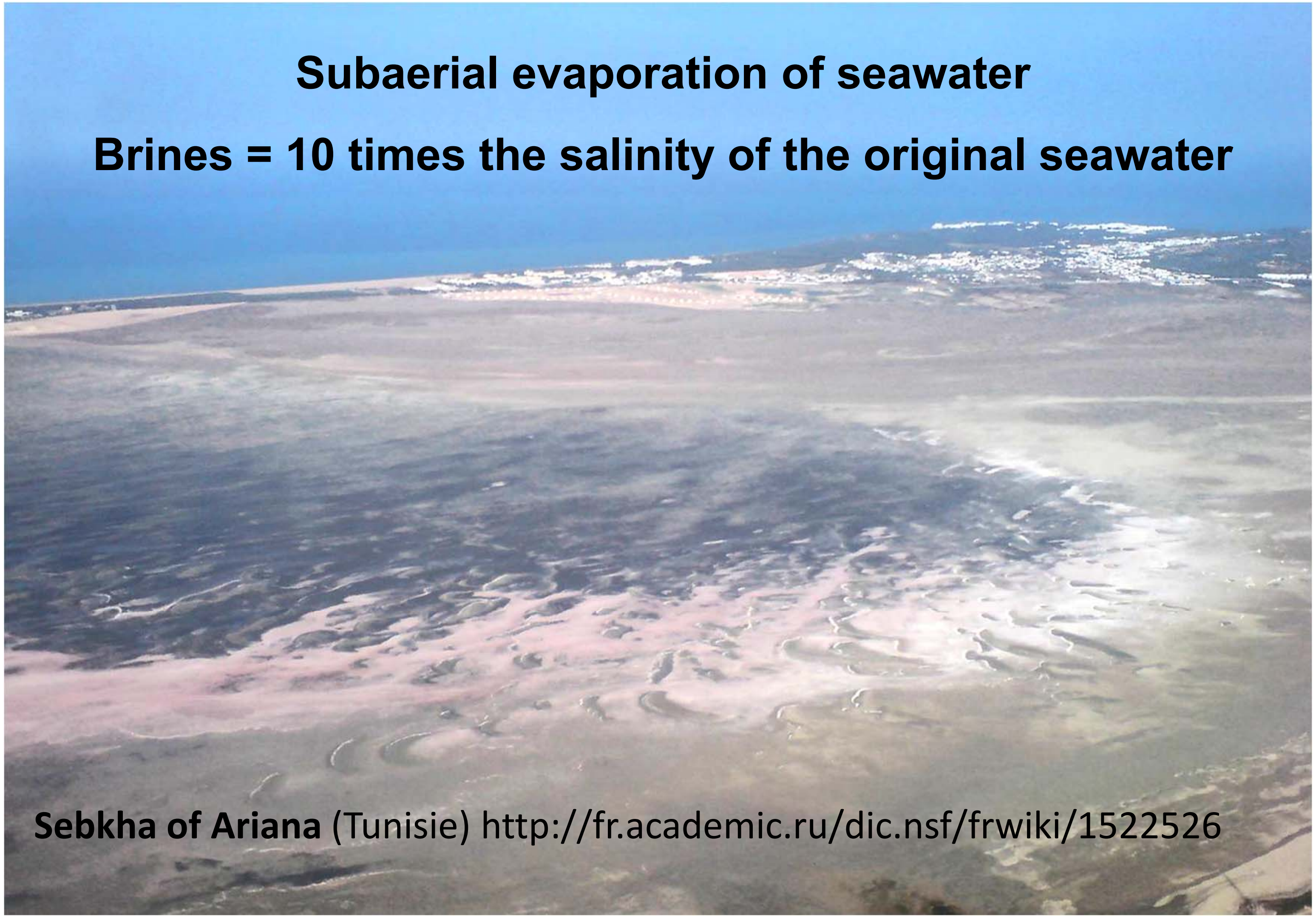


○: δ^{11}B (‰) of tourmaline



B has an isotopic signature typical of brines from evaporation of seawater
Majority of B + Mg in deposits from brines

I: Origin of the brines

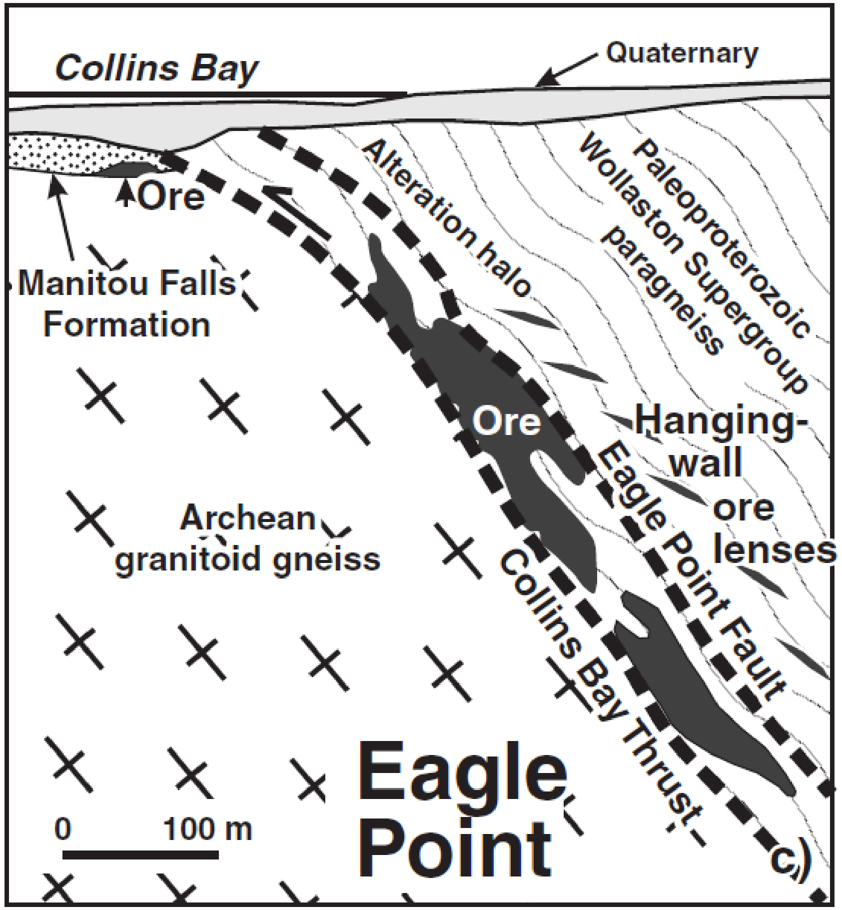


Sebkha of Ariana (Tunisie) http://fr.academic.ru/dic.nsf/frwiki/1522526

II: brine percolation in the basement and alteration

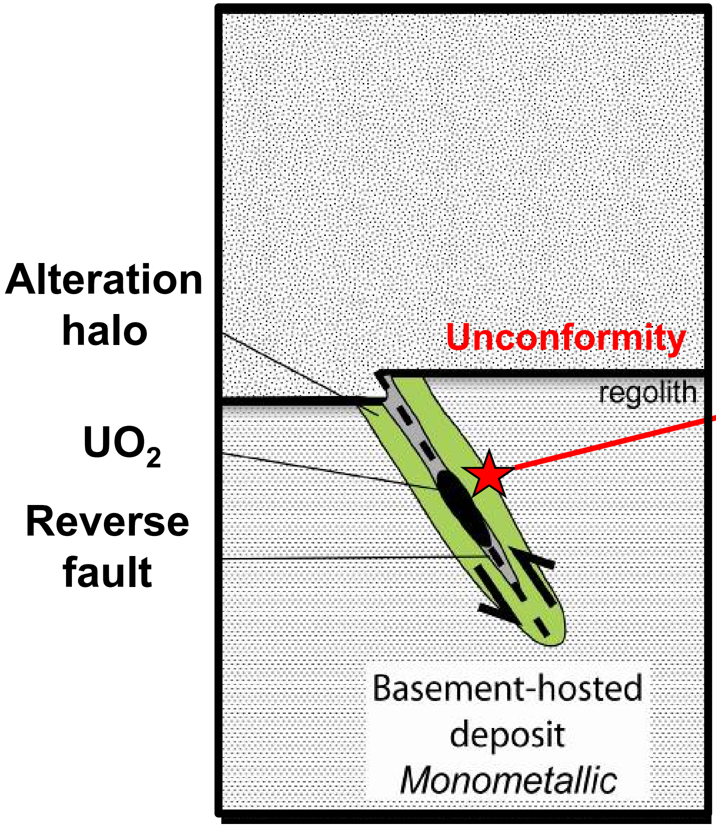
Unconformity

Basement

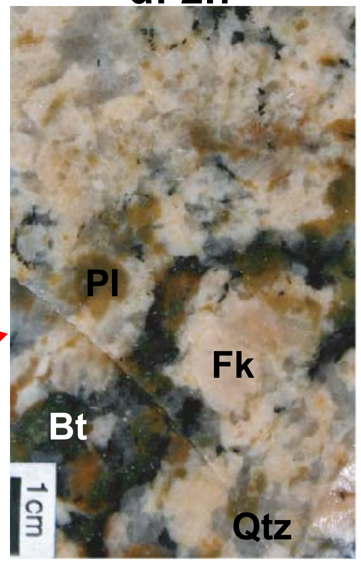


Jefferson et al. (2007)

II: brine percolation in the basement and alteration



d: 2.7



Fresh pegmatite

d: 1.7

Altered pegmatite

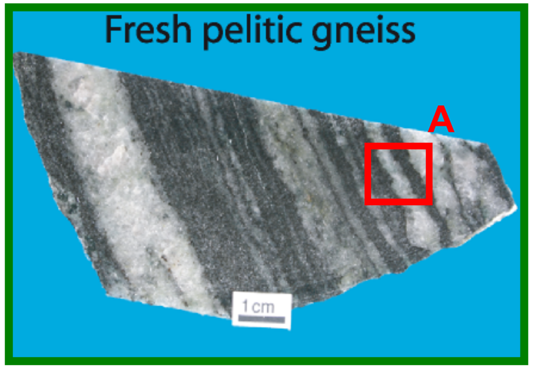
0.5 – 2 % MgO
< 2% K_2O
< 30 ppm B

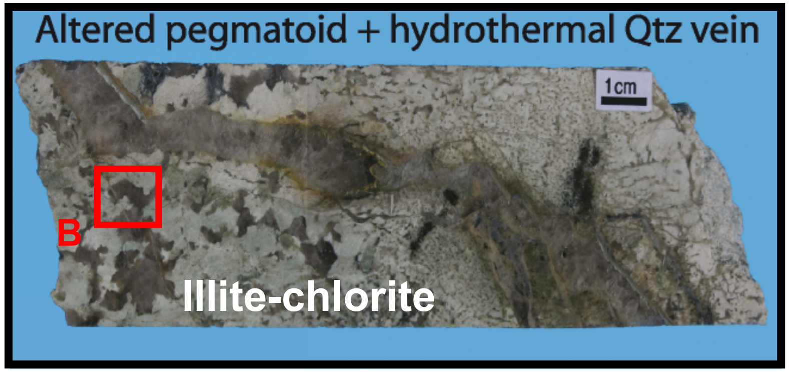
Up to 7% MgO
Sup. 5%K_2O
Up to % B

How the brines percolated in the basement and developed the alteration and mineralization?

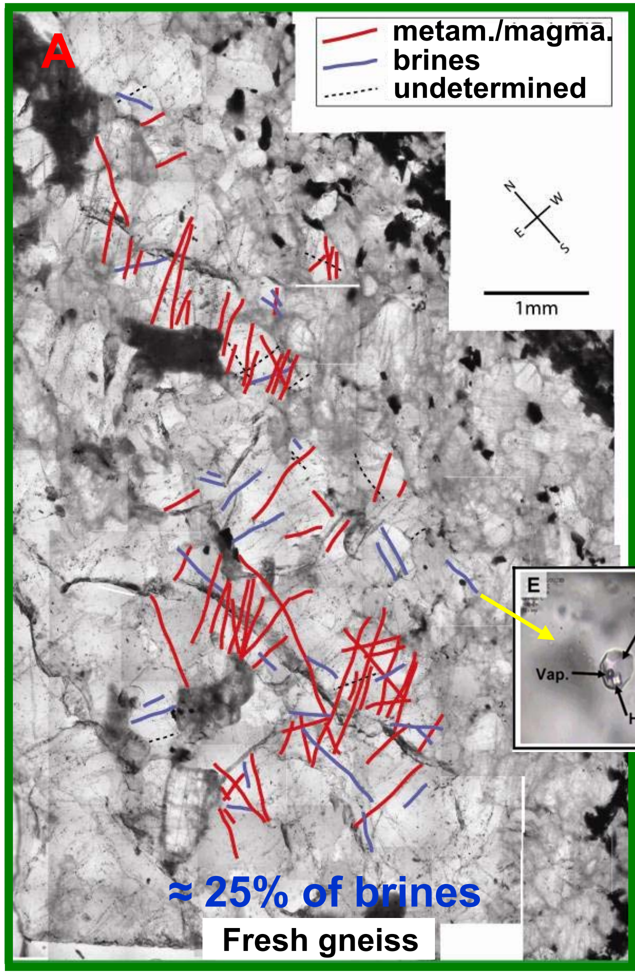
II: brine percolation in the basement

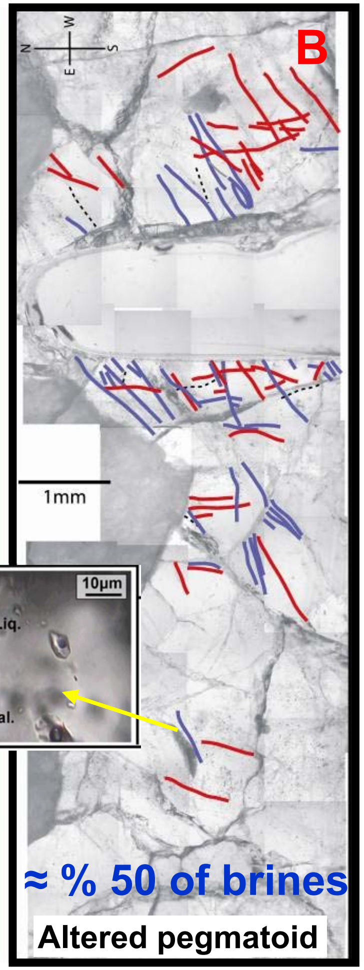
Technique: Fluid Inclusion Plane (FIP) nature and orientation in basement rocks





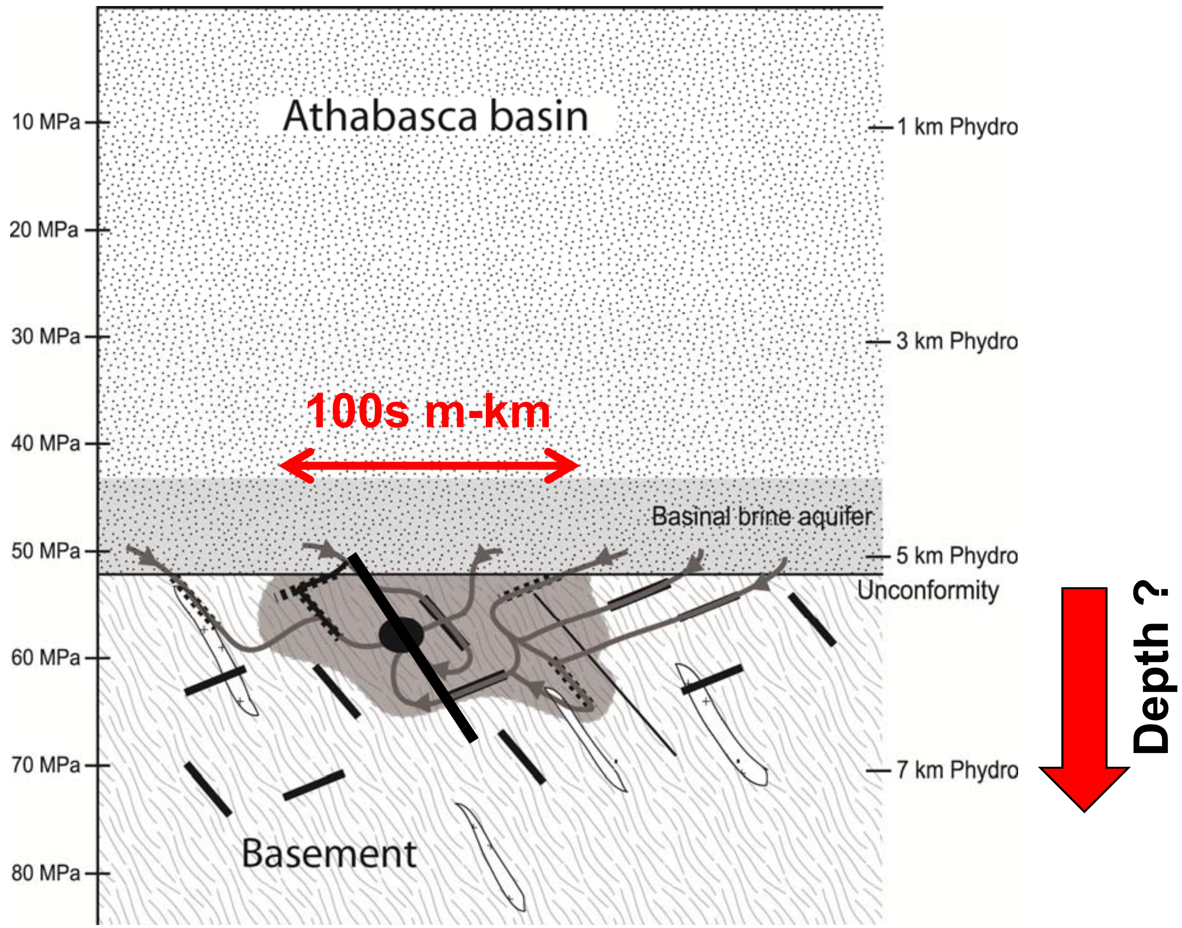
Basement rocks from P-Patch deposit





Mercadier et al. (2010) , *Lithos,* 115, 121-136

II: brine percolation in the basement



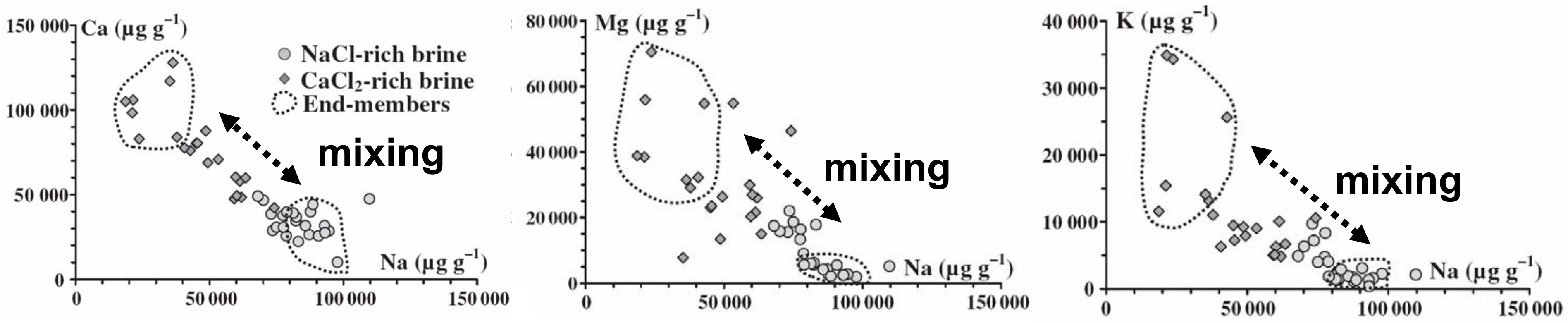
Extensive brine percolation in the basement (400 m) via dense µfracturation networks during tectonic reactivation

III: brine modification via brine/basement interactions

Technique: LA-ICP-MS on individual fluid inclusion from hydrothermal quartz veins

Brine/basement rock interactions : major chemical and isotopic changes of the initial brines

2 brines: Cl-Na-Ca-Mg-K (NaCl-rich) and Cl-Ca-Mg-Na-K ($CaCl_2$-rich) brines



Richard et al. (2010) , *Terra Nova,* 22, 303-308

Anti-correlation Na vs Ca-Mg-K-Sr-Ba

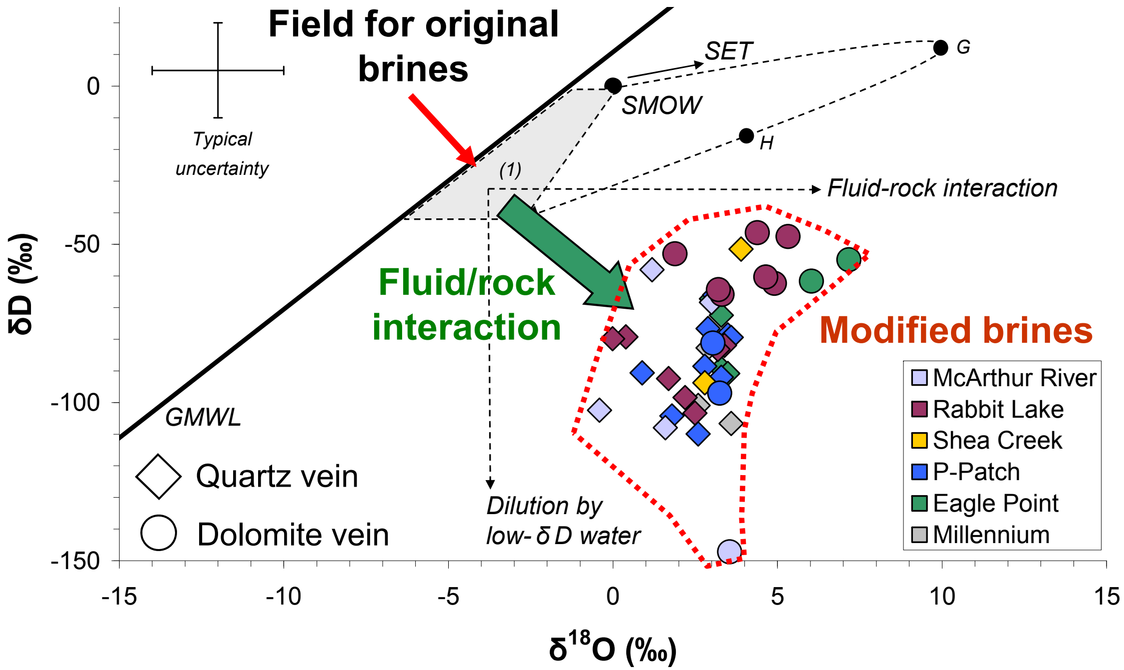
NaCl-rich: Mg + K depleted vs evaporated seawater : alteration halo

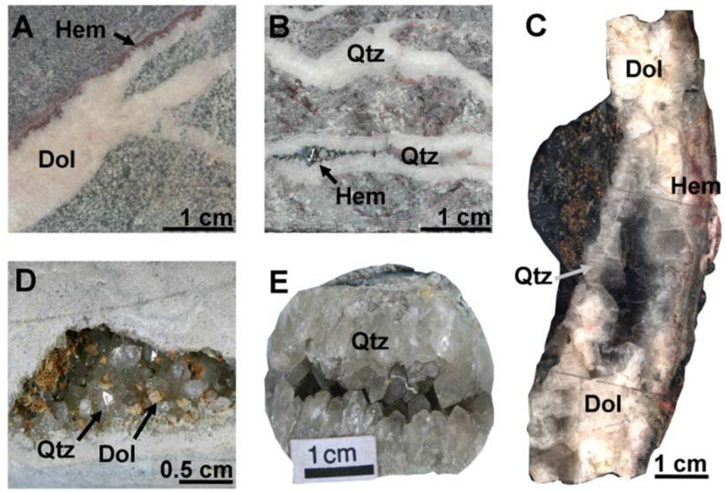
Ca enrichment: albitization?

III: brine modification via brine/basement interactions

Technique: O and H isotope on quartz and dolomite veins

T_{fluid}: 150 ± 30°C (µthermometry)





Quartz – dolomite veins

Richard et al. (2013), *Geochimica and Cosmochimica Acta, 113, 38-59*

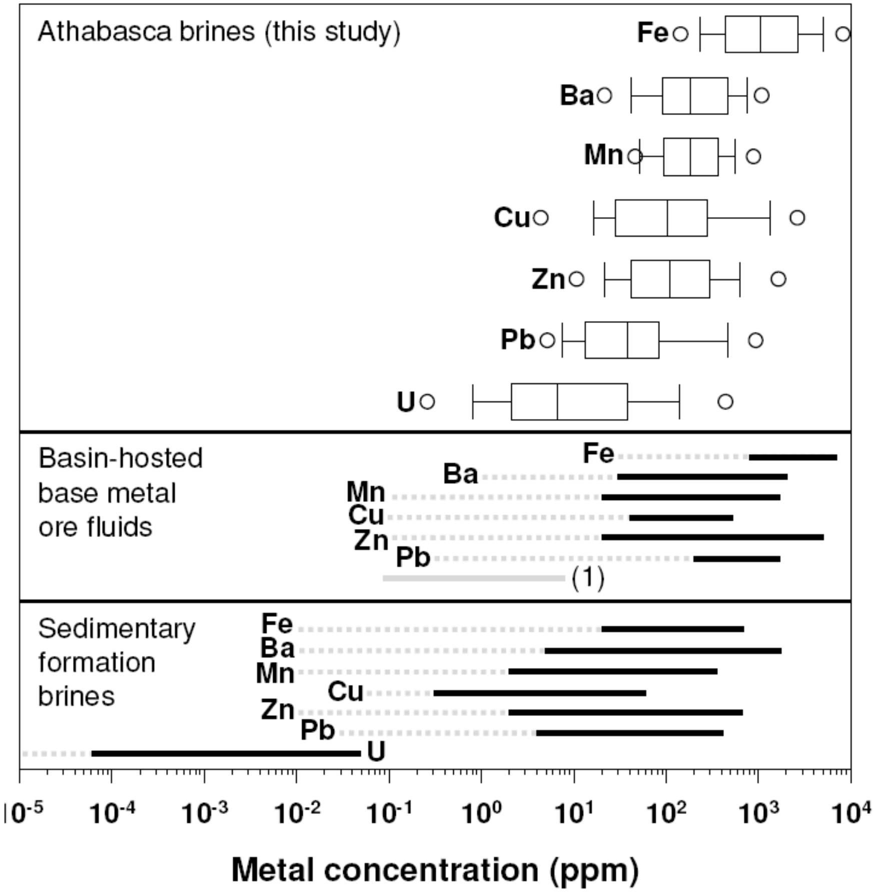
$\delta^{18}O > 0$ ‰ : protracted fluid/basement rock interaction at low fluid-rock ratio

δD ↘ : low δD water (radiolyse – bitumen synthesis)

III: brine modification via brine/basement interactions

Technique: LA-ICP-MS on individual fluid inclusion from hydrothermal quartz veins

Metal uptake in the modified brines: Pb, Mn, Zn, Fe, Cu, U, Li, Sr



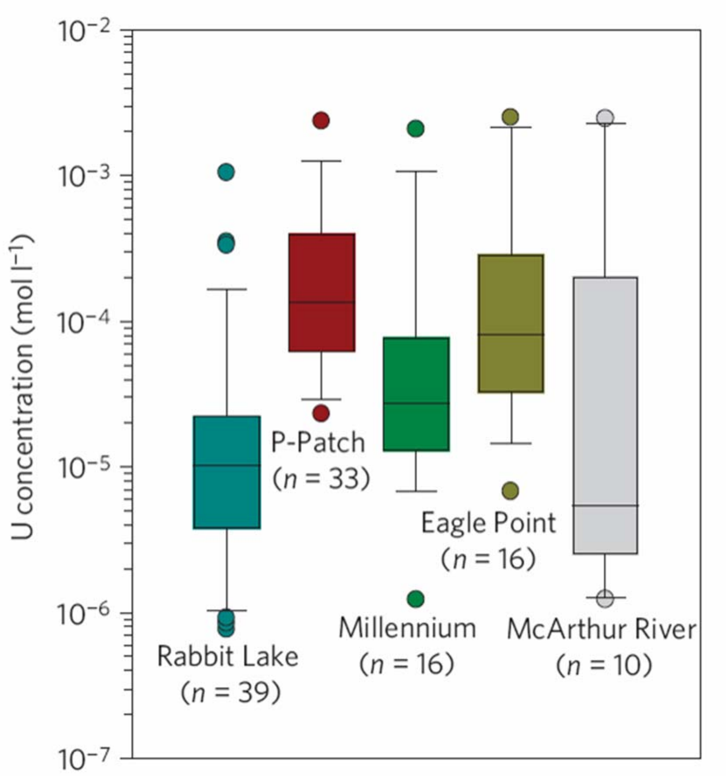
Strong metal enrichment compared to classical basinal brines and evaporated seawater

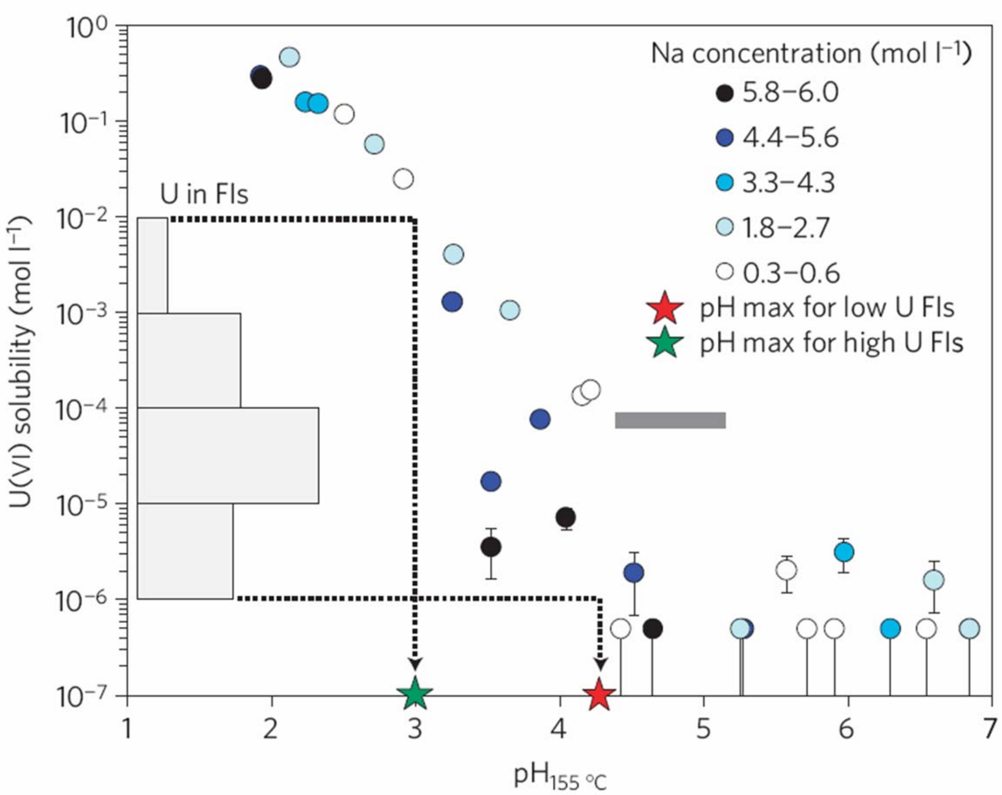
Correlation for the metals and similarity for deposits with basement metal source

Copper belt, MVT, Zn-Pb…

IV: Transport and deposition of U

Techniques: LA-ICP-MS on individual fluid inclusion + experimental work on U solubility in Na-Cl mixture analoguous to ore forming brines



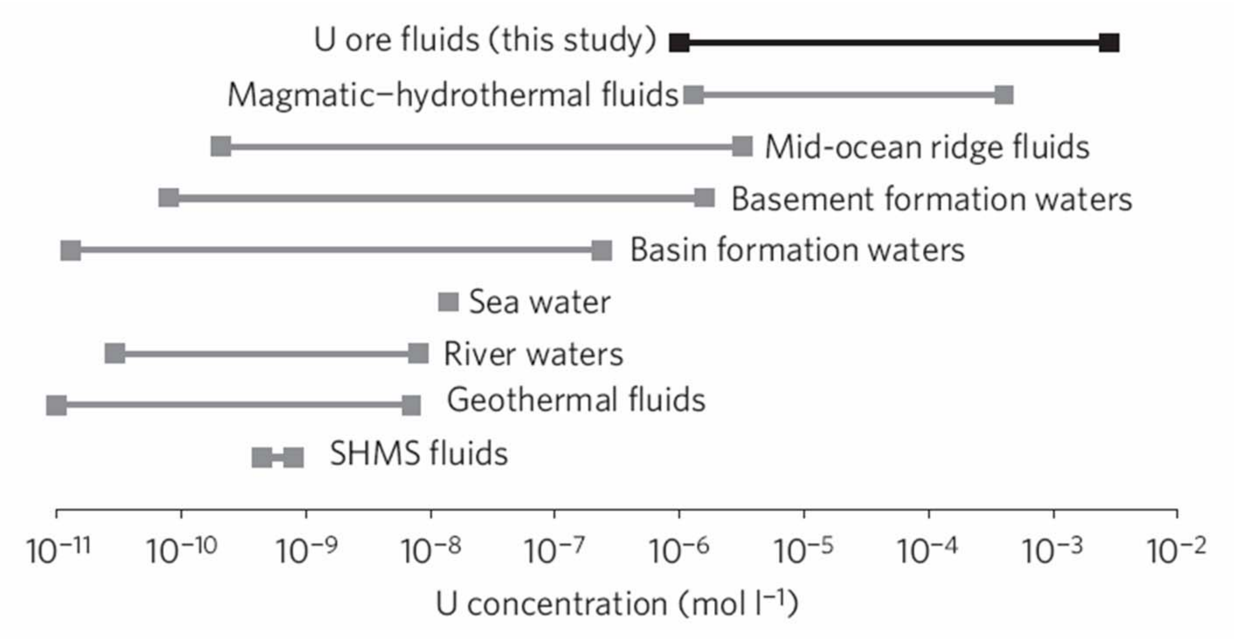


[U] in individual FI: 0.1 to 500 ppm

pH of ore forming brines: 2.5 - 4.5

Richard et al. (2012) , *Nature Geoscience, 5, 142-146*

IV: Transport and deposition of U



Richard et al. (2012) , *Nature Geoscience, 5, 142-146*

Mineralizing brines from Athabasca = U richest crustal fluids thanks to:

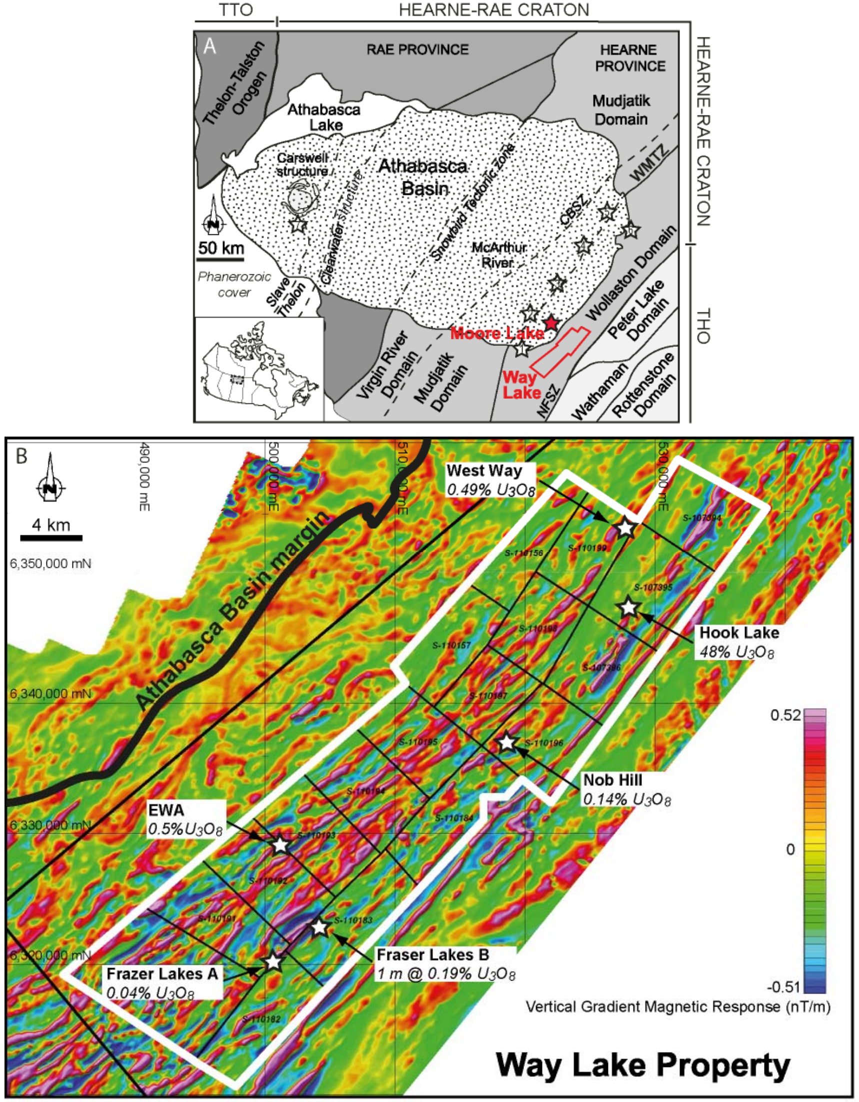
-oxidizing, acidic (pH: 2.5-4.5) and Cl-rich (6 mol/l) nature

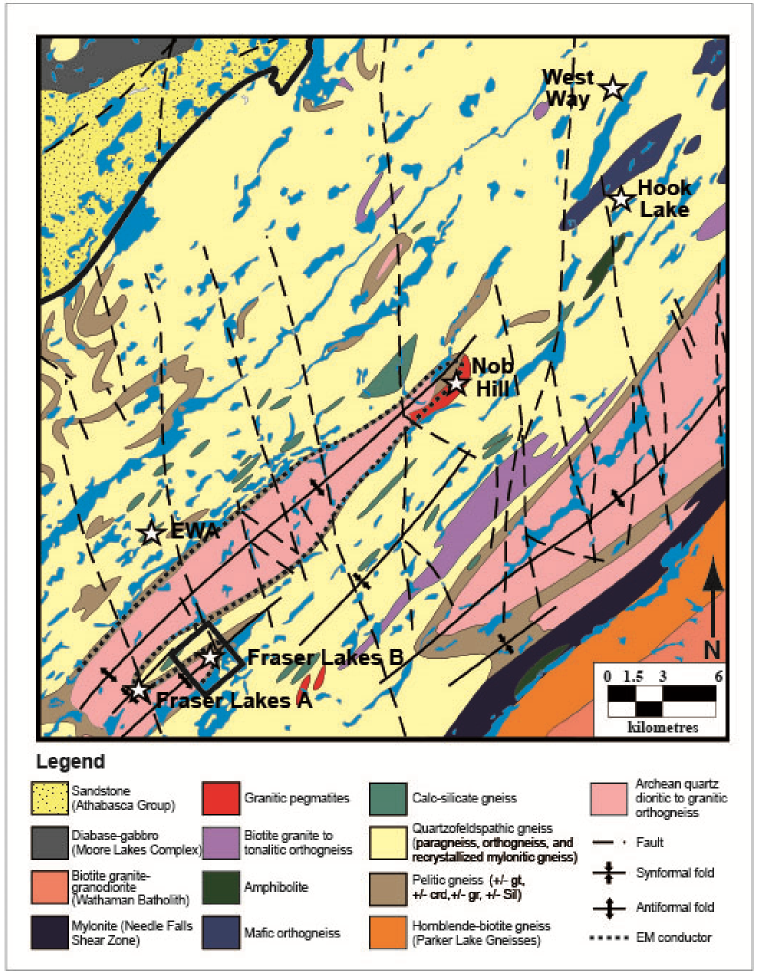
- U availability in the environment

High [U] : formation in a short period of time (0.1-1 Myr) as other world-class deposits of Pb-Zn and Au (Simmons et al., 2006; Wilkinson et al., 2009)

V: Source(s) of uranium ?

Basin vs. Basement, still in discussion

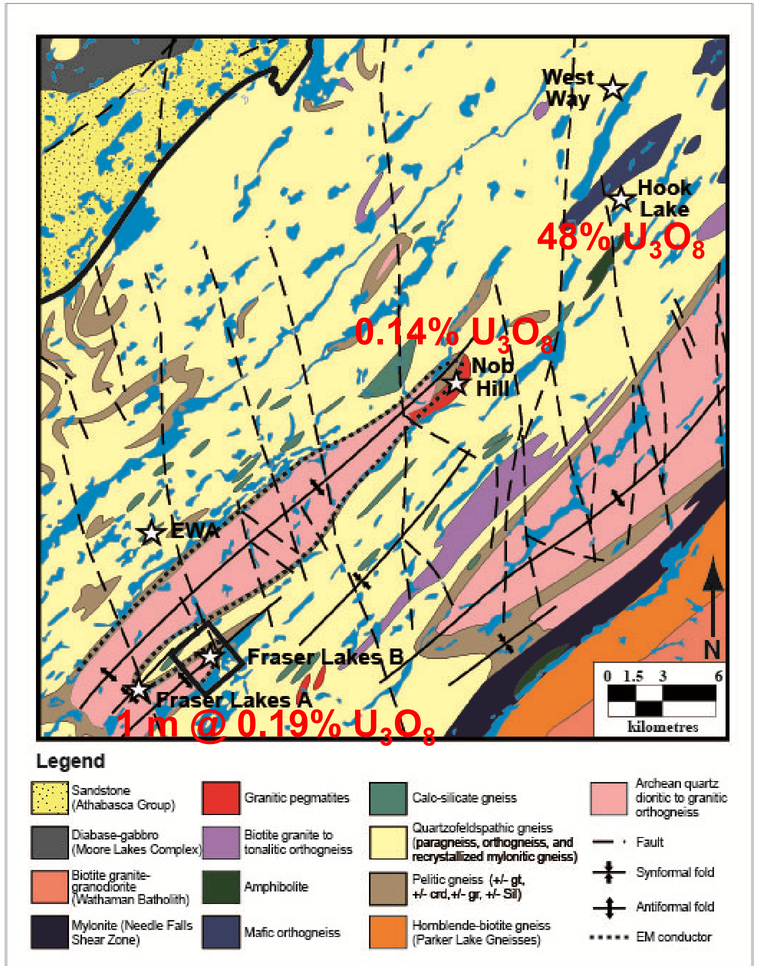


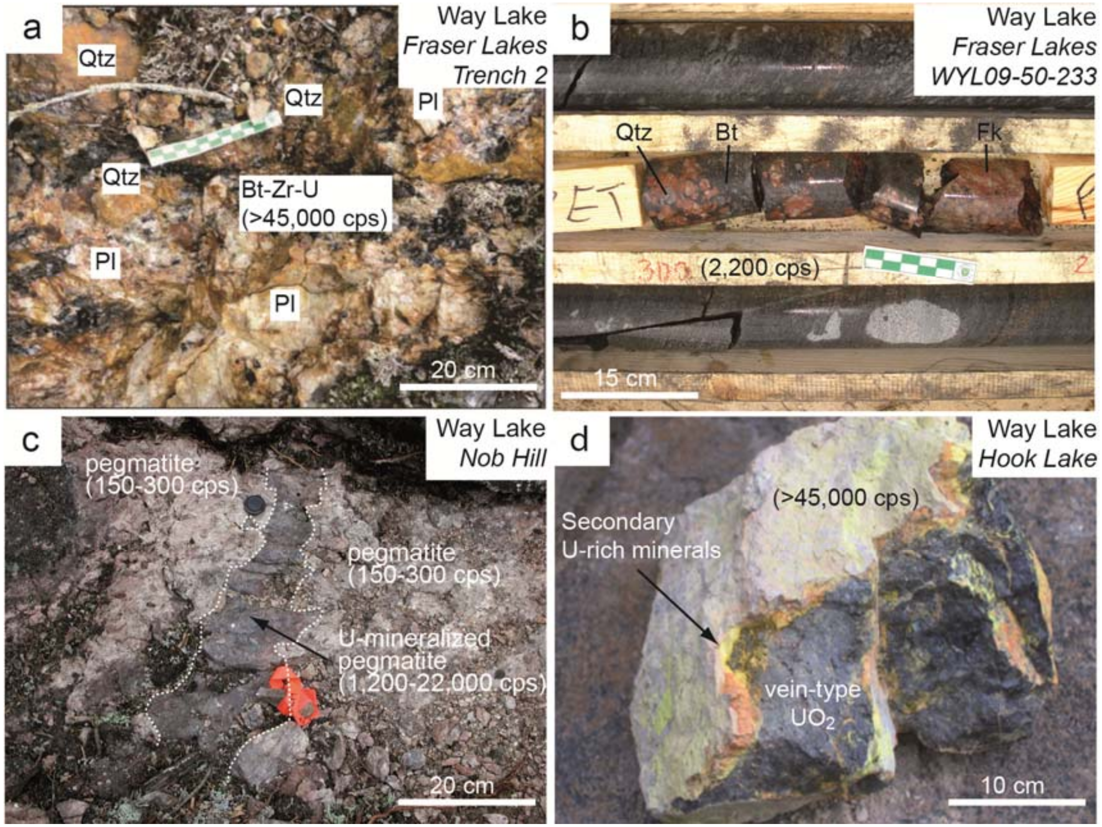


Mercadier et al. (2013) , *Economic Geology, 108, 913-933*

V: Source(s) of uranium ?

U occurrences in the basement

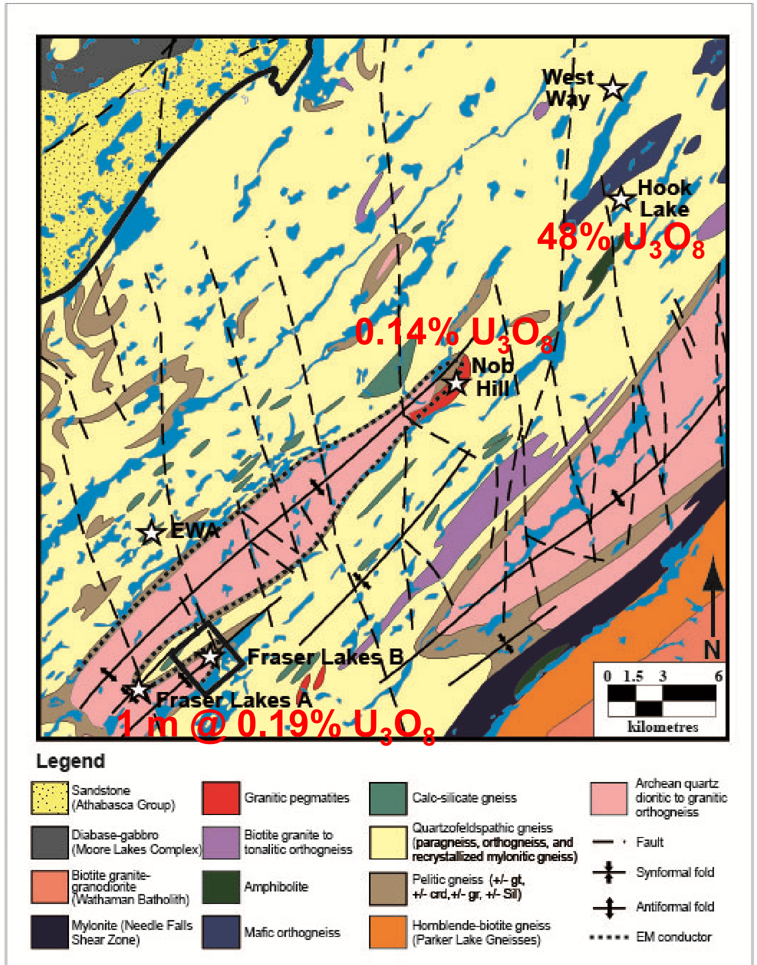


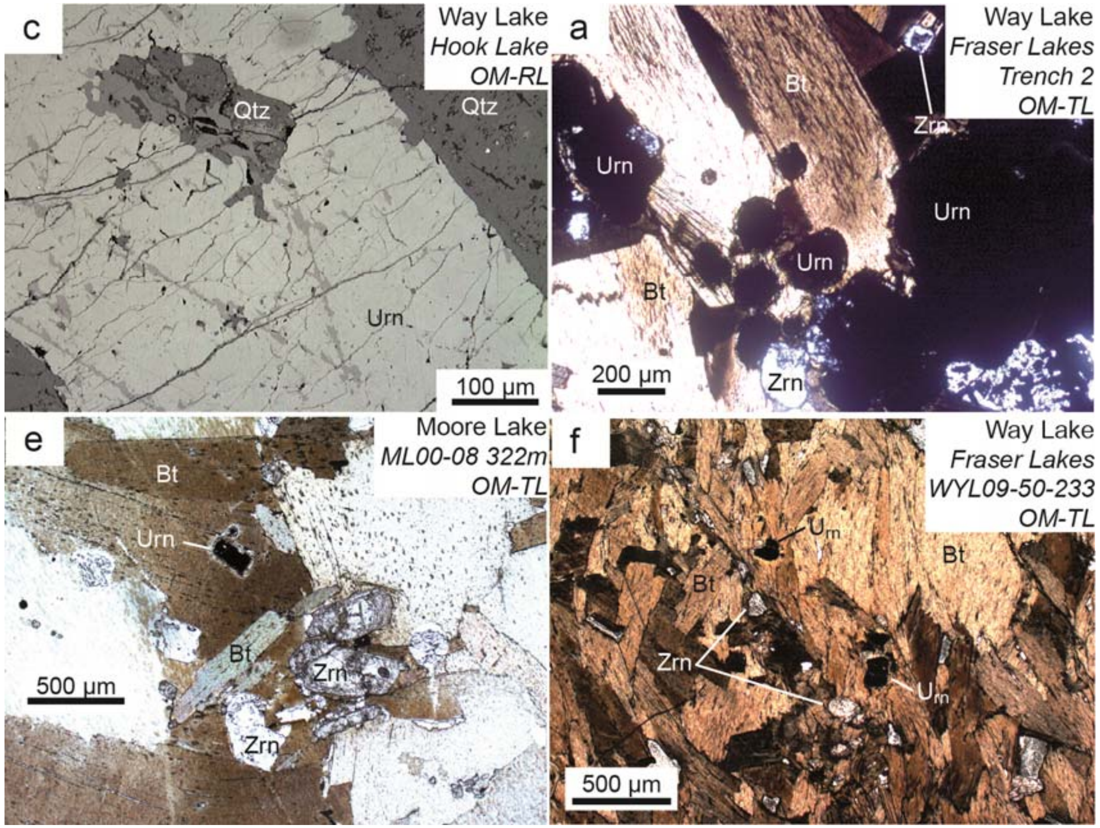


Mercadier et al. (2013) , *Economic Geology, 108, 913-933*

V: Source(s) of uranium ?

U occurrences in the basement





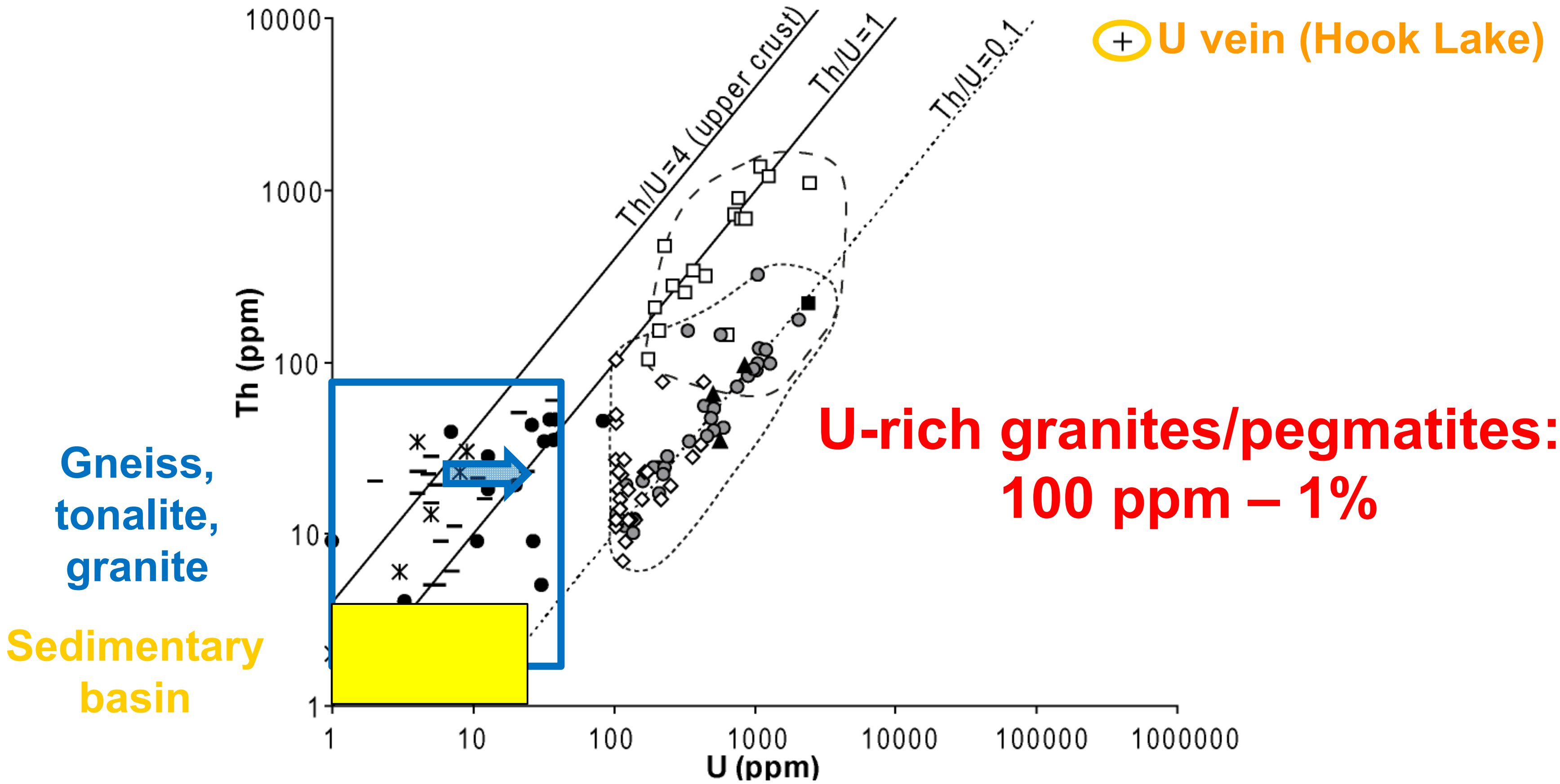
Age: 1805-1750 Ma = Hudsonian

ante Athabasca Basin

Mercadier et al. (2013) , *Economic Geology, 108, 913-933*

V: Source(s) of uranium ?

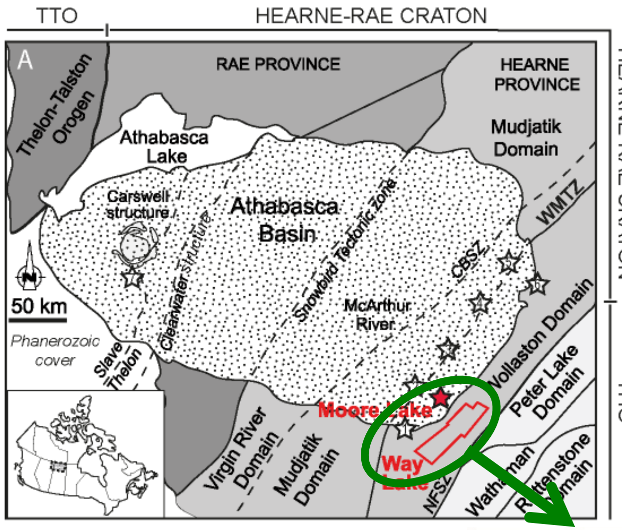
U occurrences in the basement



Mercadier et al. (2013) , *Economic Geology, 108, 913-933*

V: Source(s) of uranium ?

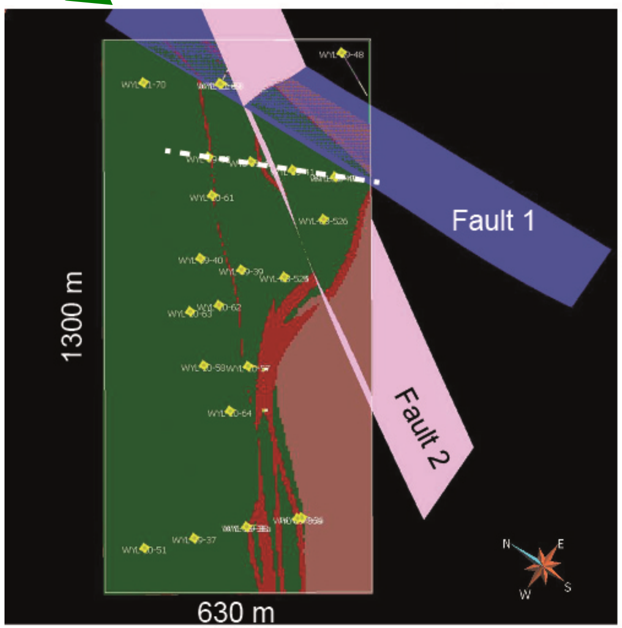
U-rich granites/pegmatites:
An important lithology of the basement (7%)

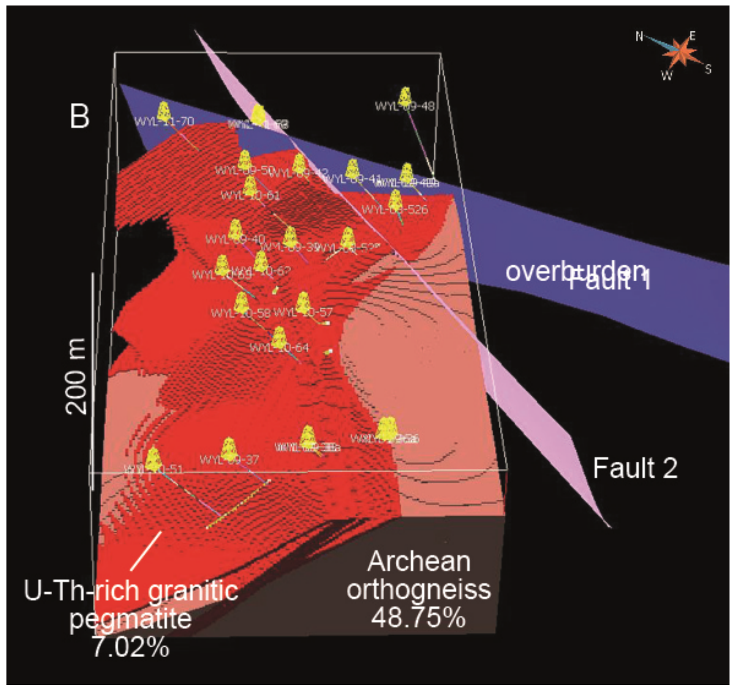


3D modelization of the basement

Gocad software

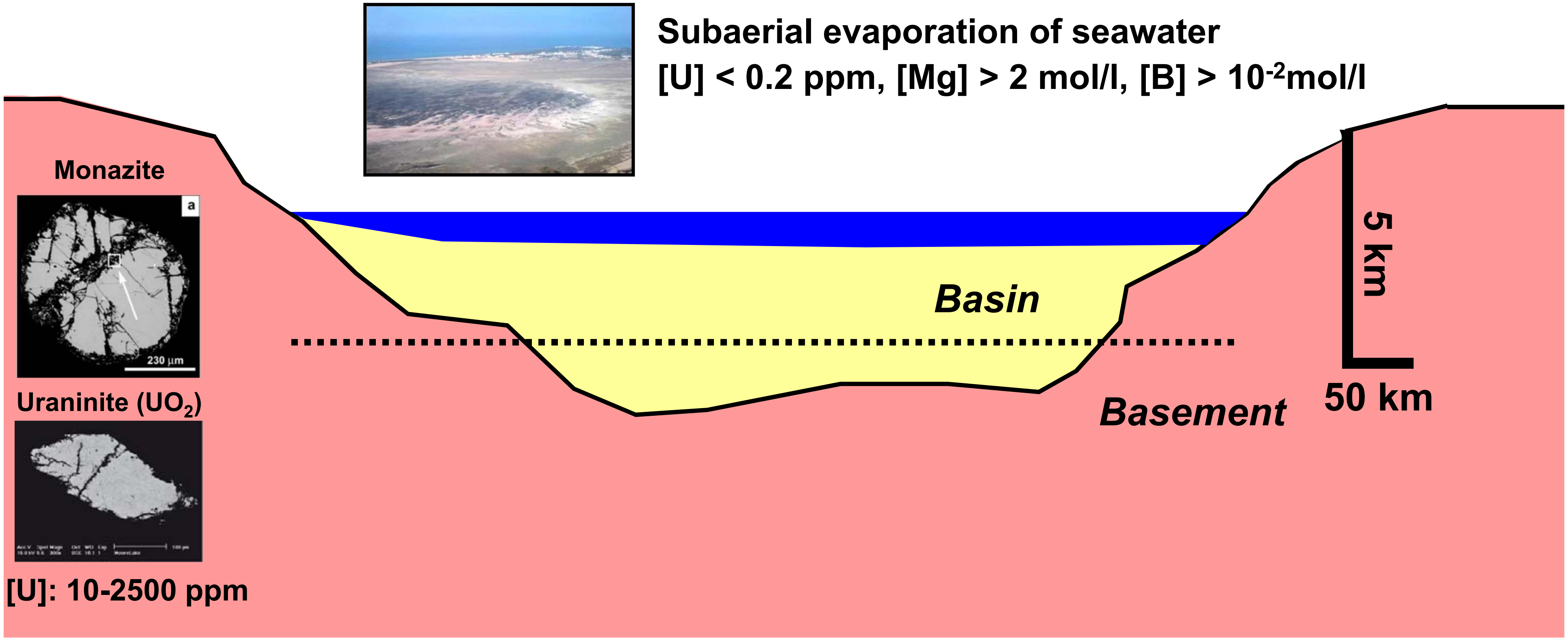
Mercadier et al. (2013) , *Economic Geology, 108, 913-933*





A new model for unconformity-related U deposits

Brine factory

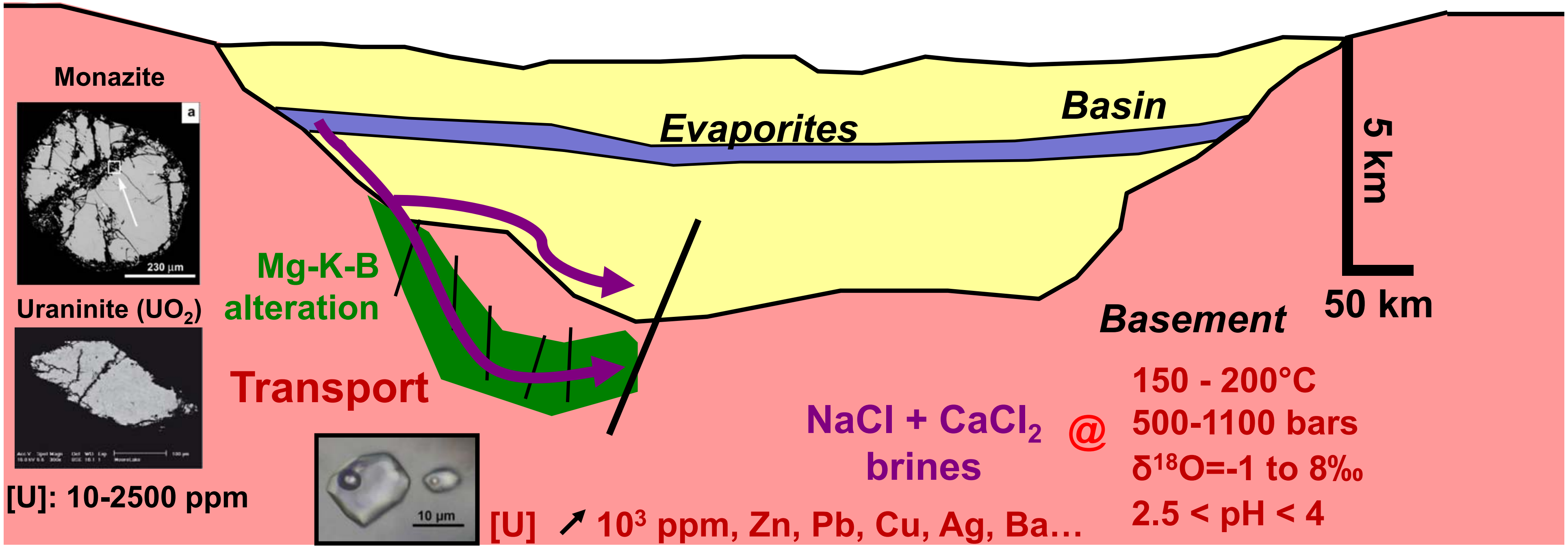


U Source

A new model for unconformity-related U deposits

Brine percolation in the basement thanks to µfractures + faults during tectonic reactivation

Chemical + isotopic modifications of the original brines to 2 end-members

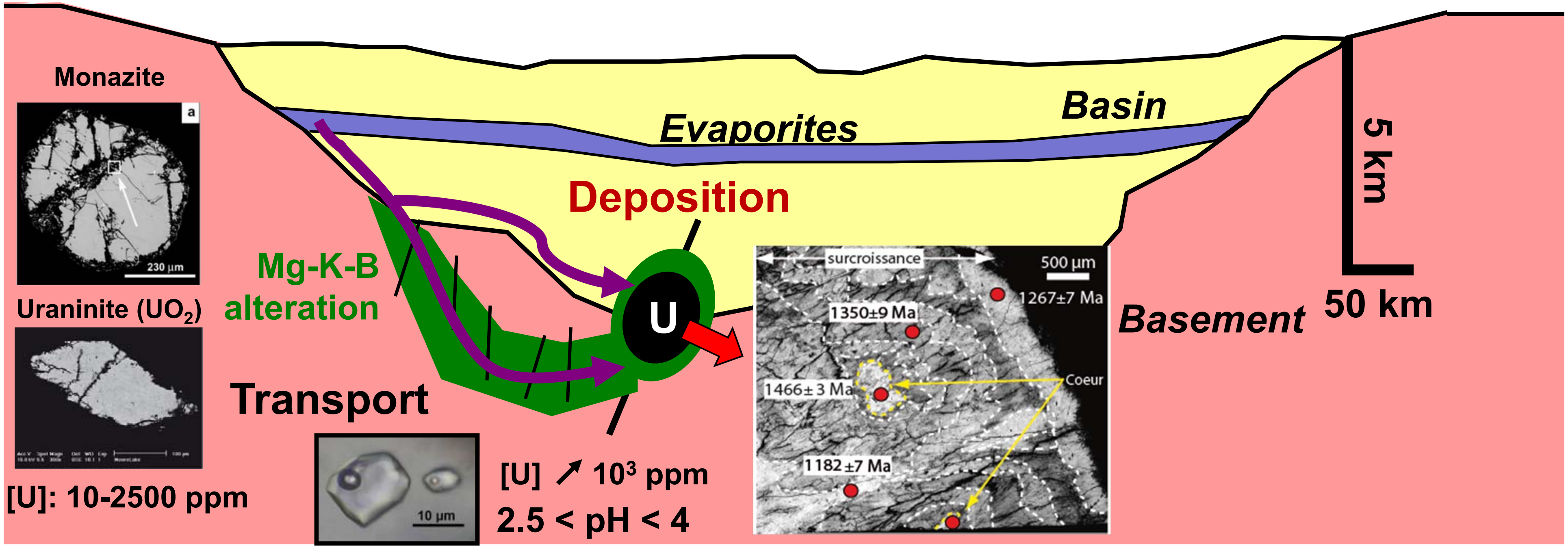


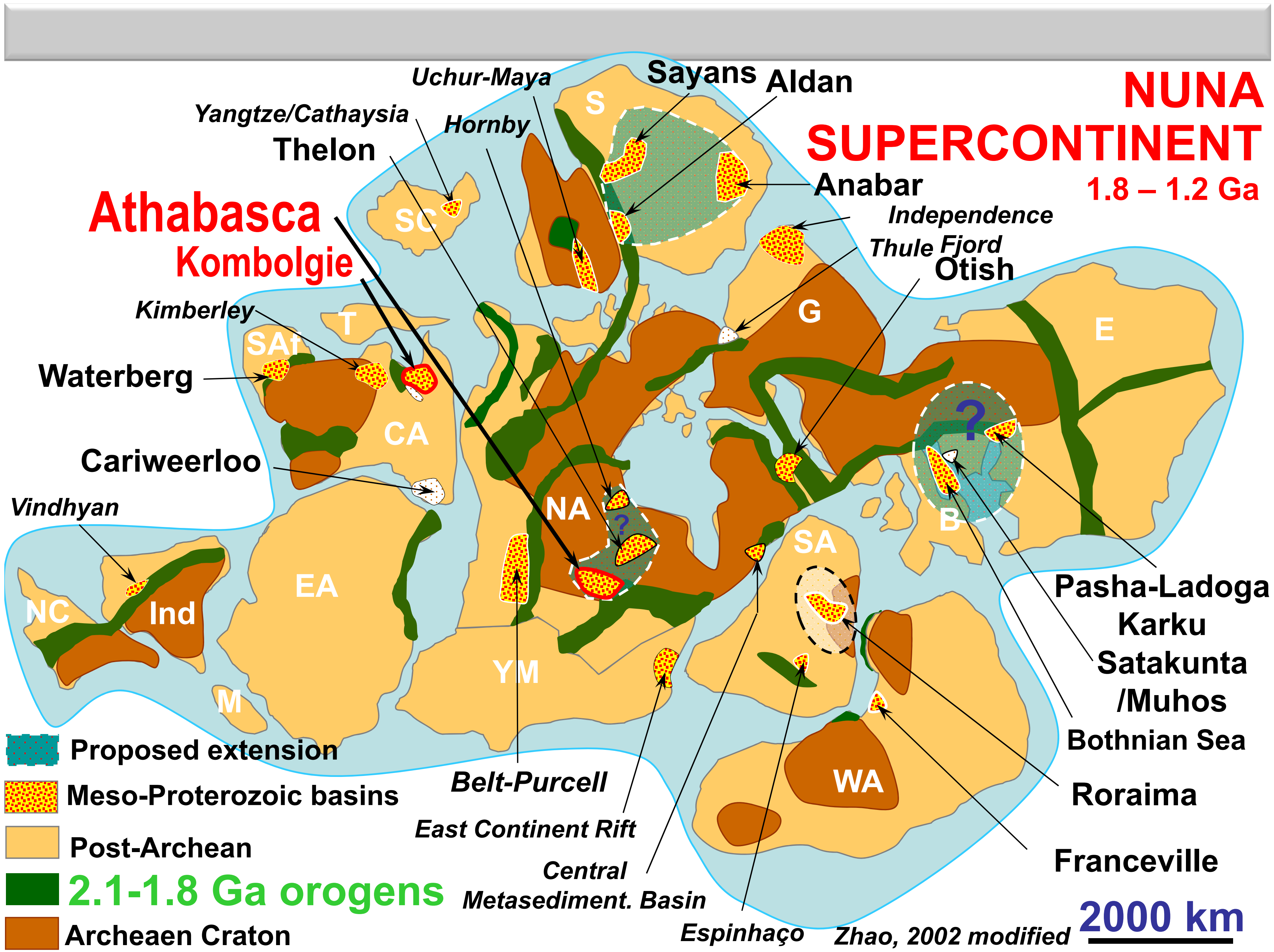
metal uptake

Dissolution/alteration of accessory minerals + silicates due to low pH, oxydation and Cl availability

A new model for unconformity-related U deposits

U deposition: Brine mixing?
Gas-brine mixing?
Brine-mineral?





NUNA
SUPERCONTINENT
1.8 – 1.2 Ga
Athabasca
Kombolgie
Uchur-Maya
Yangtze/Cathaysia
Hornby
Thelon
Sayans
Aldan
Anabar
Independence
Thule Fjord
Otish
Kimberley
Waterberg
Cariweerloo
Vindhyan
S
SC
T
SAf
CA
G
E
NA
SA
B
EA
NC
Ind
M
YM
WA
?
Pasha-Ladoga
Karku
Satakunta
/Muhos
Bothnian Sea
Roraima
Franceville
Belt-Purcell
East Continent Rift
Central
Metasediment. Basin
Espinhaço
Zhao, 2002 modified
2000 km
Proposed extension
Meso-Proterozoic basins
Post-Archean
2.1-1.8 Ga orogens
Archeaen Craton

SESSION 6. Uranium symposium - in honour of Michel Cuney

This symposium welcomes papers dealing with uranium metallogeny and geochemistry. This session will illustrate the extreme diversity of uranium deposits and contributions could cover a large scale of geological environments (igneous, hydrothermal, sedimentary or superficial) and geological processes. Presentations of non-conventional deposits are welcomed. This session will be in honour of Michel Cuney who spent his entire scientific career to decipher the uranium geological cycle.