The role and character of fluids in rare-metal deposits: insights from Thor Lake, NWT.

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References

Much of the data presented in this talk comes from the thesis work of Yonggang Feng and Justin Hoyle:

Feng, Y., 2014, Hydrothermal Geochemistry and Mineralizing Processes in the T Zone, Thor Lake Rare-element Deposit, Northwest Territories. PhD Thesis, University of Windsor. 341 p.

Hoyle, J., 2017, Rare-Earth Elements in the Nechalacho Deposit, NWT: Hydrothermal Controls on Mineralogy and Fractionation, MSc Thesis, University of Windsor. 91 p.

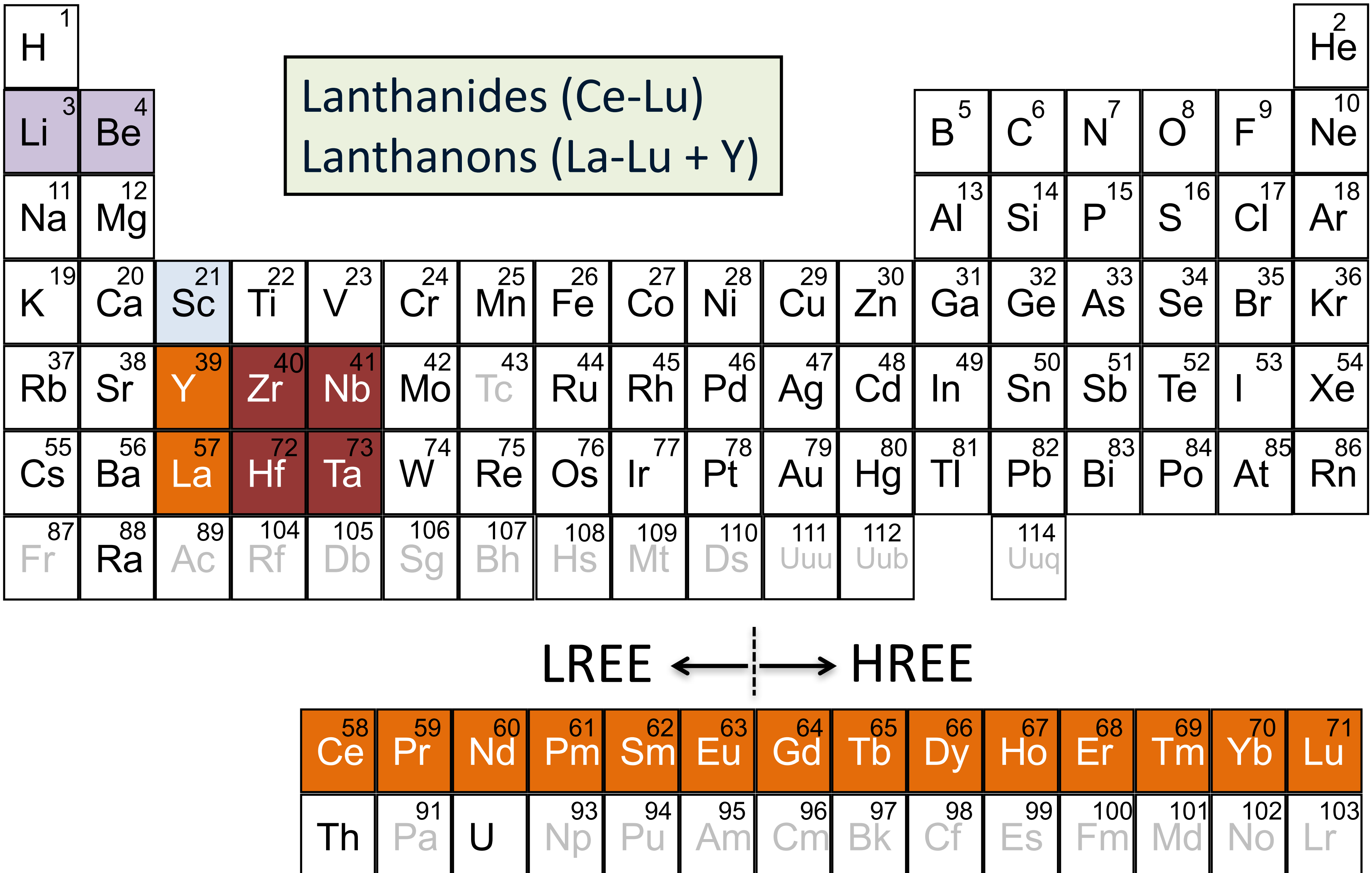
Partly published as:

Feng, Y., Samson, I.M., 2015, Replacement Processes involving high field strength elements in the T Zone, Thor Lake rare-metal deposit, Northwest Territories. Canadian Mineralogist. v.53, p.31-60.

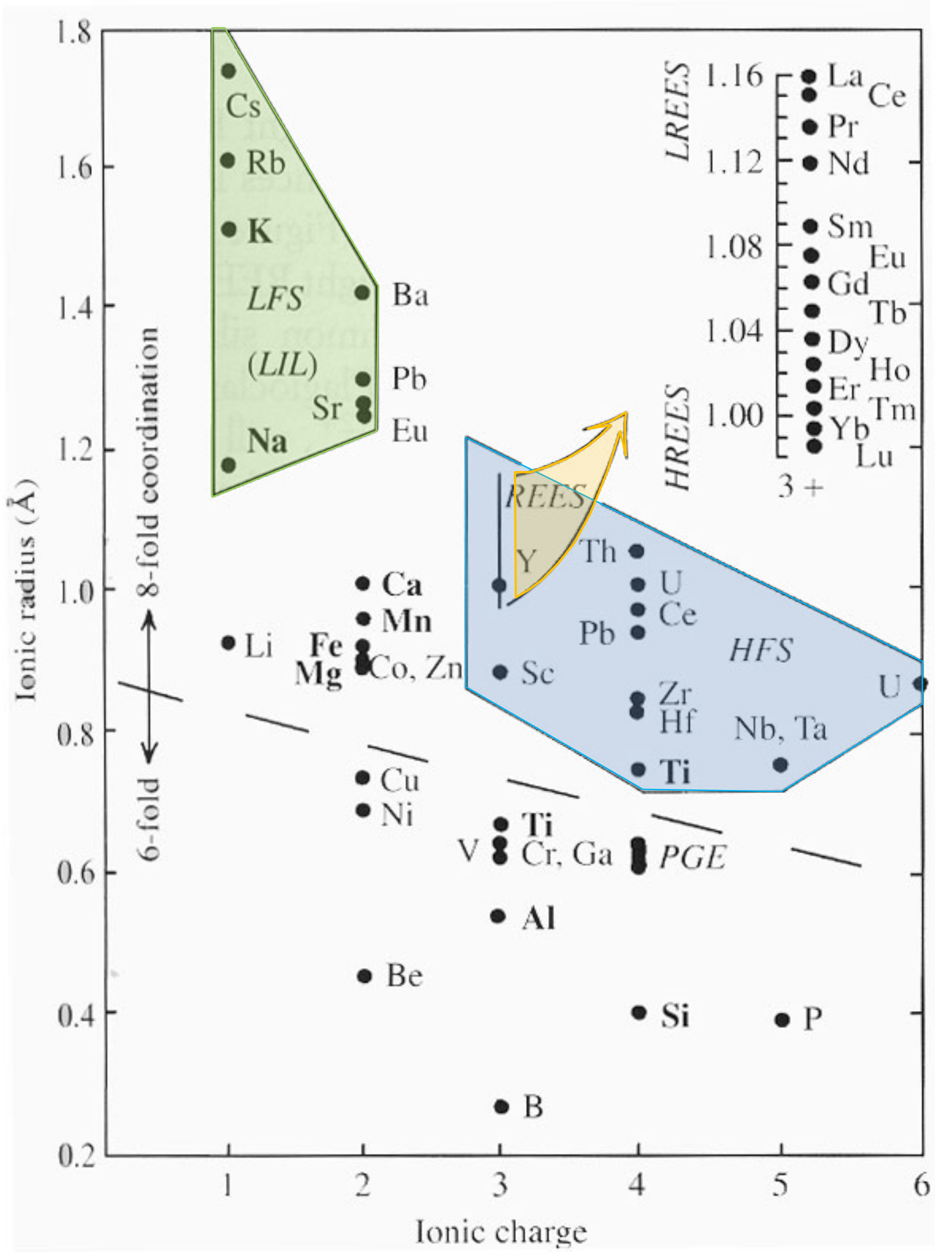
The summary diagrams at the end come from :

Samson, I.M., 2013, Fluid inclusion studies of rare earth element deposits (*abstract).* Geological Society of America, 125th Anniversary Meeting, Denver, Colorado, Oct. 27-30.

“Rare Metals”


Lanthanides (Ce-Lu)
Lanthanons (La-Lu + Y)
H 1
He 2
Li 3 Be 4
B 5 C 6 N 7 O 8 F 9 Ne 10
Na 11 Mg 12
Al 13 Si 14 P 15 S 16 Cl 17 Ar 18
K 19 Ca 20 Sc 21 Ti 22 V 23 Cr 24 Mn 25 Fe 26 Co 27 Ni 28 Cu 29 Zn 30 Ga 31 Ge 32 As 33 Se 34 Br 35 Kr 36
Rb 37 Sr 38 Y 39 Zr 40 Nb 41 Mo 42 Tc 43 Ru 44 Rh 45 Pd 46 Ag 47 Cd 48 In 49 Sn 50 Sb 51 Te 52 I 53 Xe 54
Cs 55 Ba 56 La 57 Hf 72 Ta 73 W 74 Re 75 Os 76 Ir 77 Pt 78 Au 79 Hg 80 Tl 81 Pb 82 Bi 83 Po 84 At 85 Rn 86
Fr 87 Ra 88 Ac 89 Rf 104 Db 105 Sg 106 Bh 107 Hs 108 Mt 109 Ds 110 Uuu 111 Uub 112 Uuq 114
LREE
HREE
Ce 58 Pr 59 Nd 60 Pm 61 Sm 62 Eu 63 Gd 64 Tb 65 Dy 66 Ho 67 Er 68 Tm 69 Yb 70 Lu 71
Th U 91 Pa 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr

Classification of Elements Based on Charge and Radius



Ionic Potential - charge/radius –

low solubility in aqueous solutions?

"immobile"?

High Field Strength (HFS) – Zr, Nb, Ta, Ti, REE

Can they be mobile?
What is the scale of mobility?

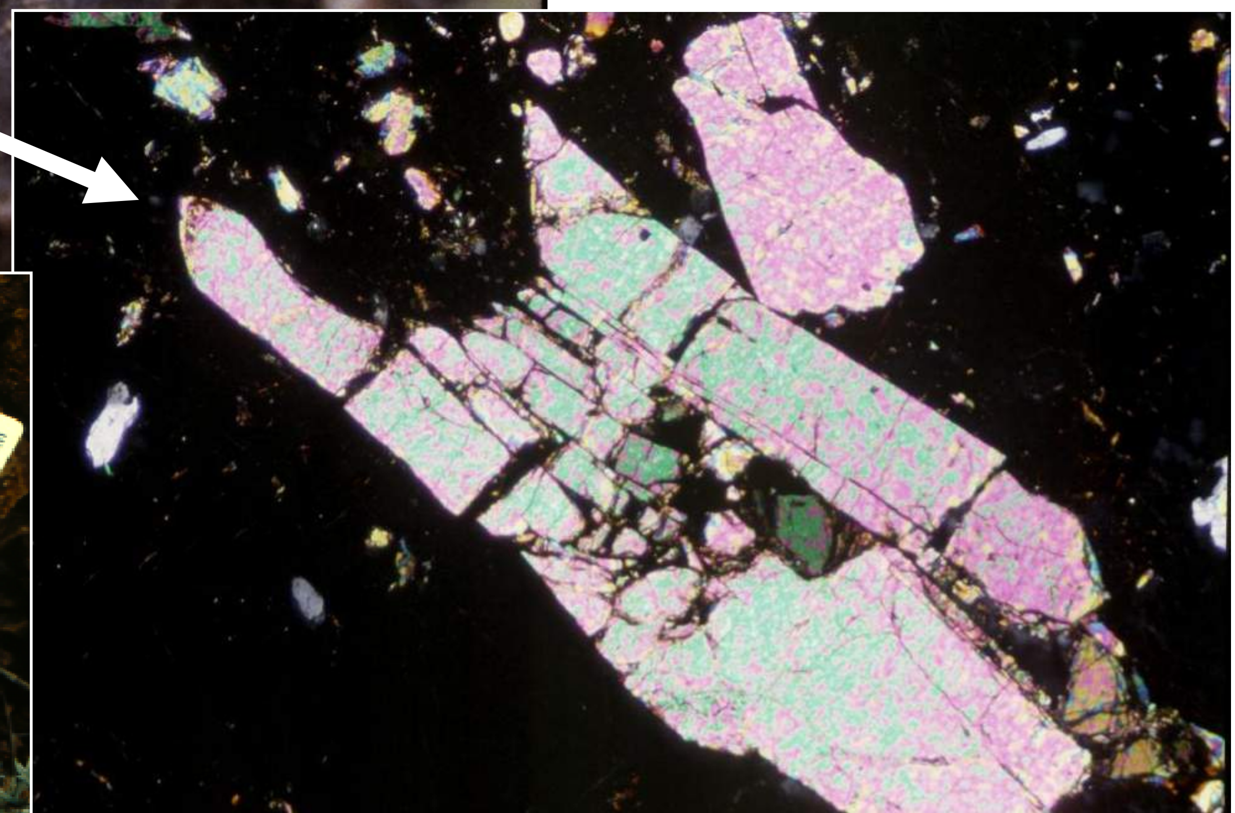
after Rollinson, 1993

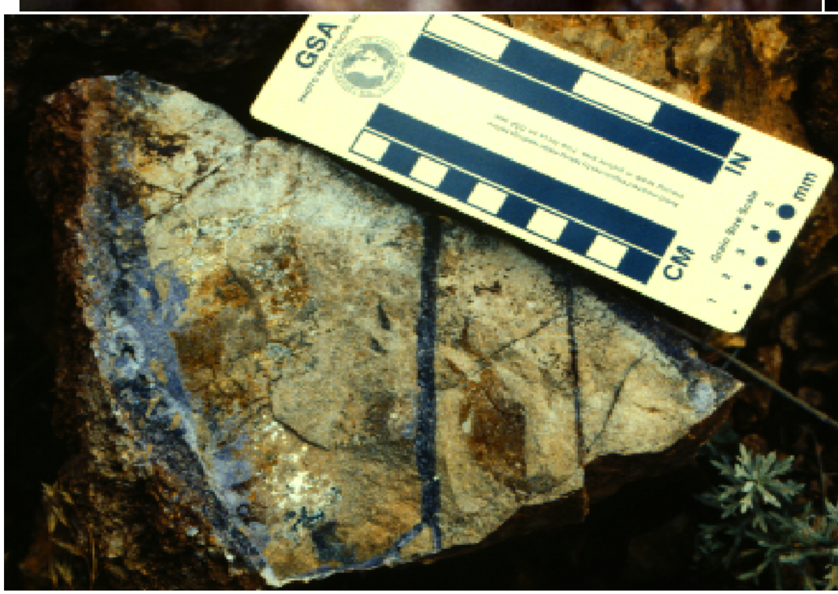
Hydrothermal REE

Gallinas Mountains, New Mexico

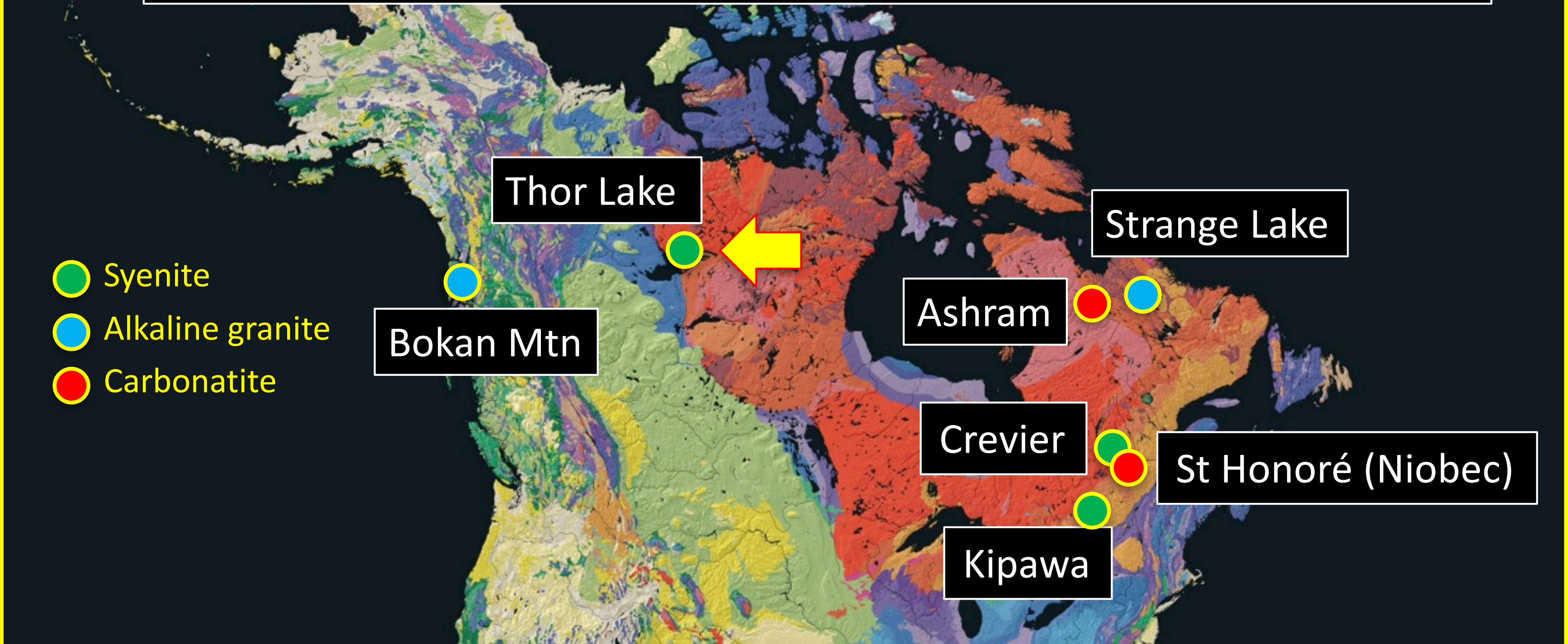
Hydrothermal veins and breccias

abundant bastnäsite





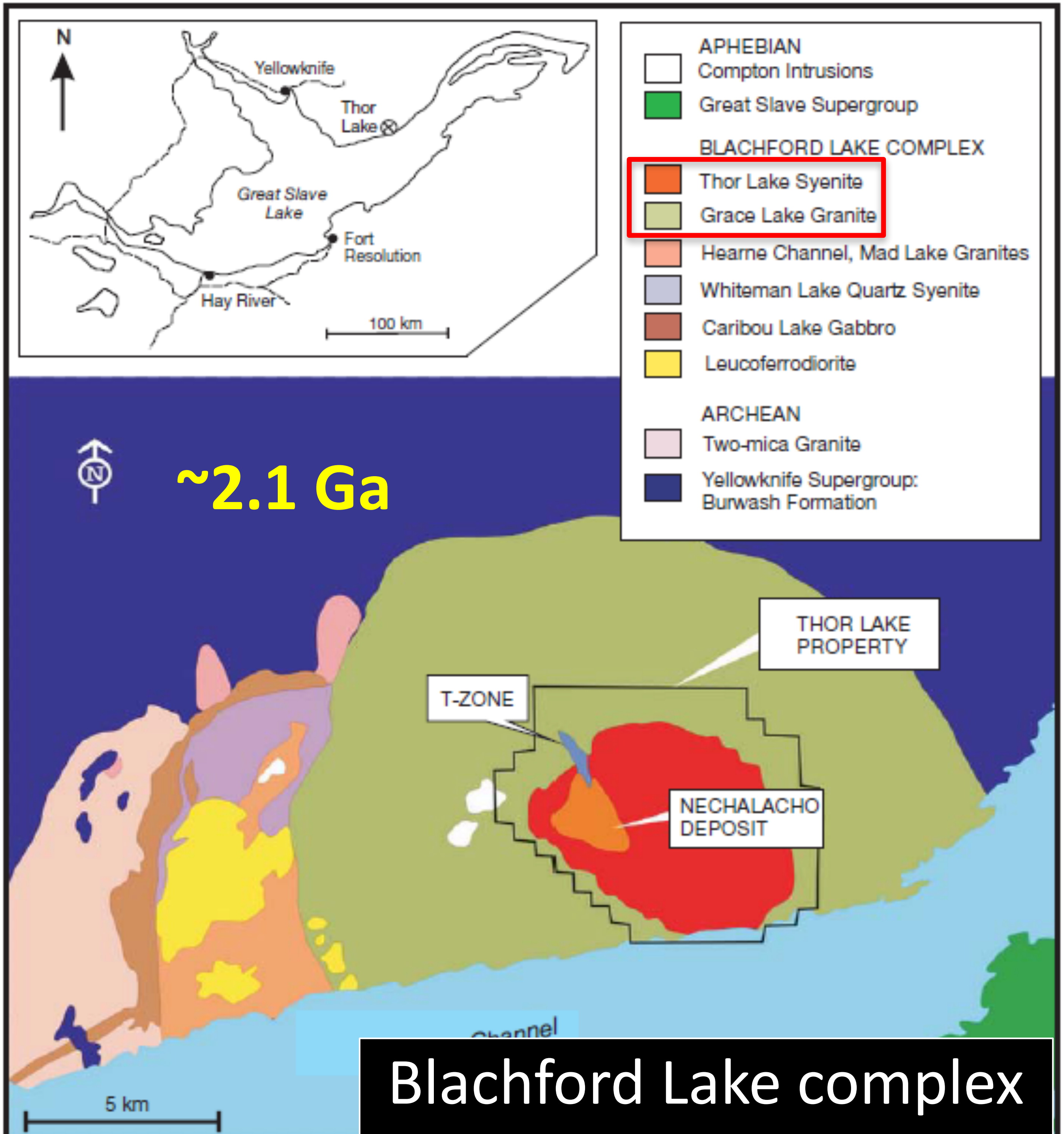
Alkaline-rock related rare metal deposits



Questions: what roles do fluids play?

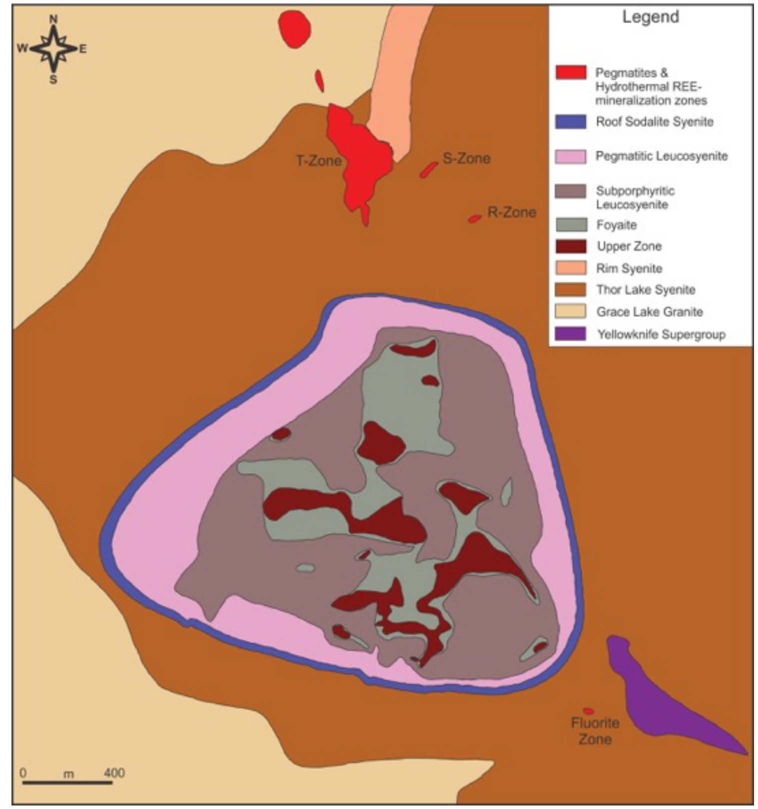
- Primary vs secondary concentration and enrichment?
- What types of fluids are capable of mobilizing significant rare metals?
- What is the evidence for this?
- Are rare metals present in the fluids?
- What concentrations?
- What controls enrichment?

Thor Lake Location



modified after Sheard et al., 2012; Davidson, 1982

The Nechalacho Layered Series

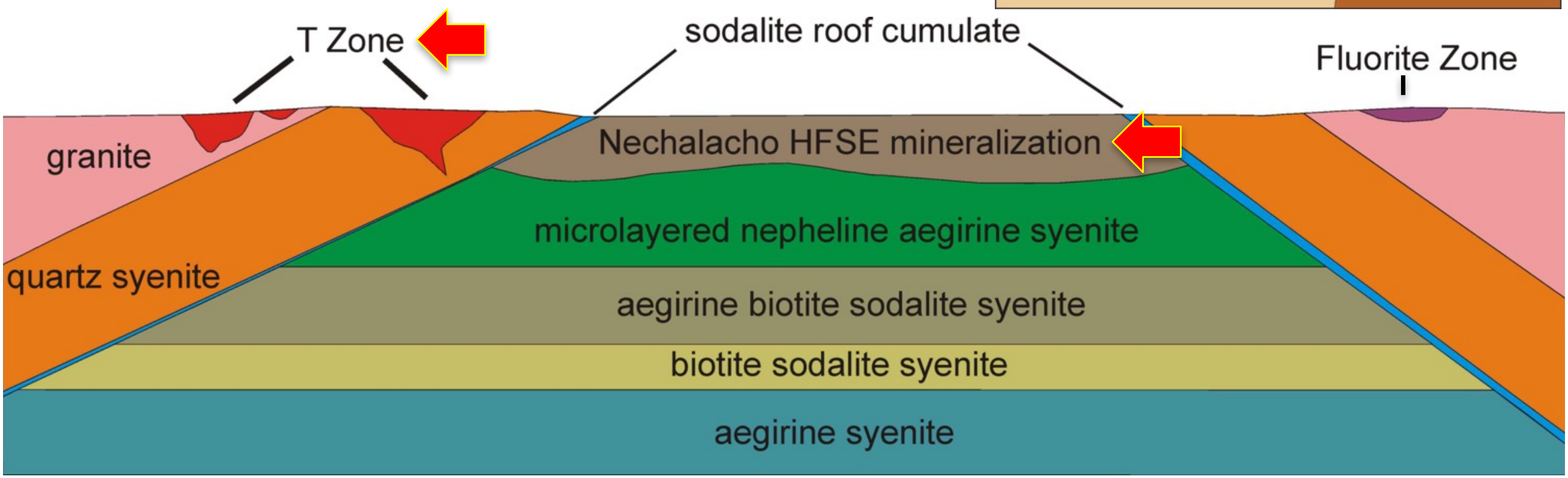


Two Main Mineralized Zones

Nechalacho: REE, Zr, Nb

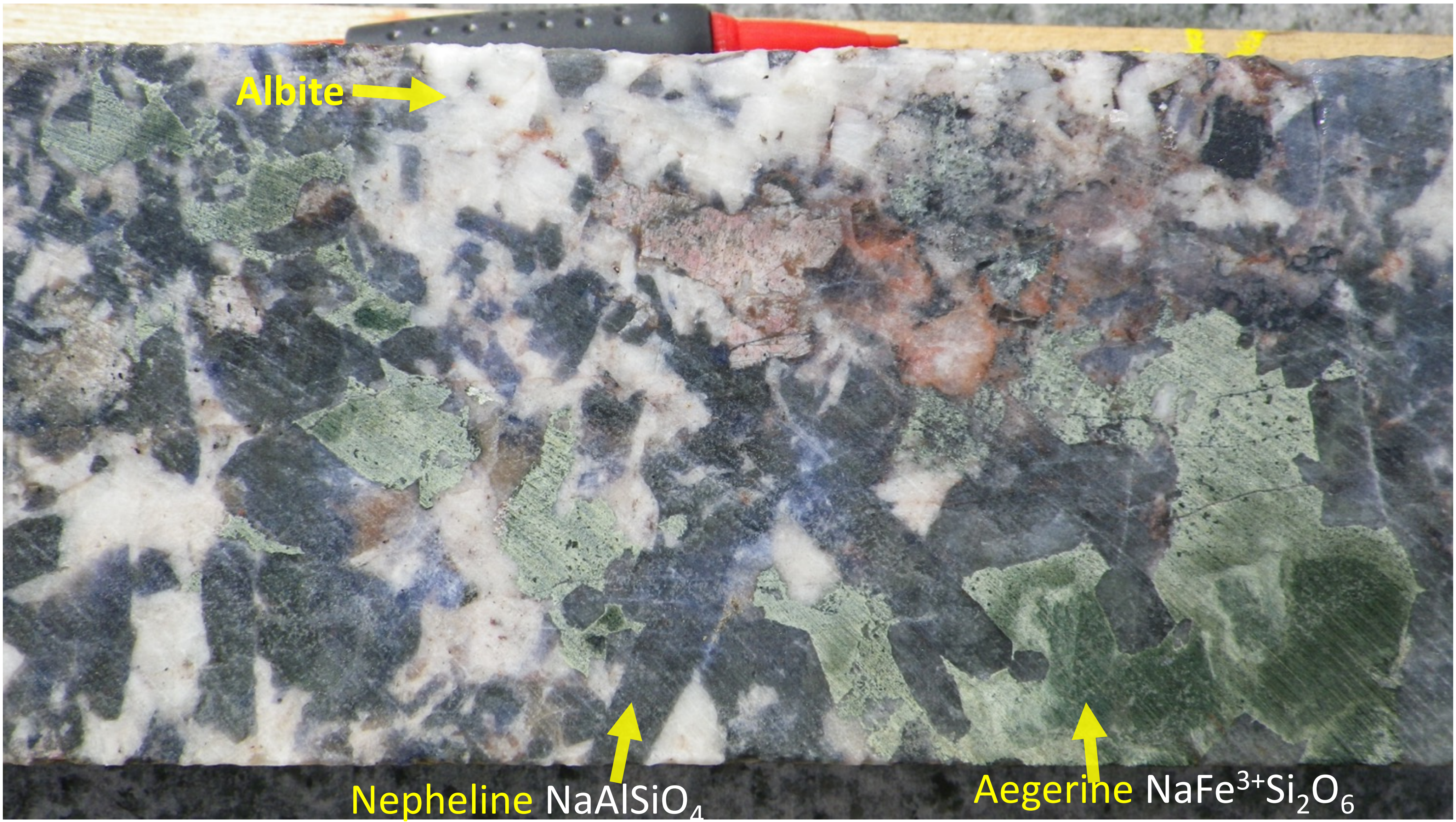
T Zone: REE, Zr, Nb, Li, Be

Schematic cross-section

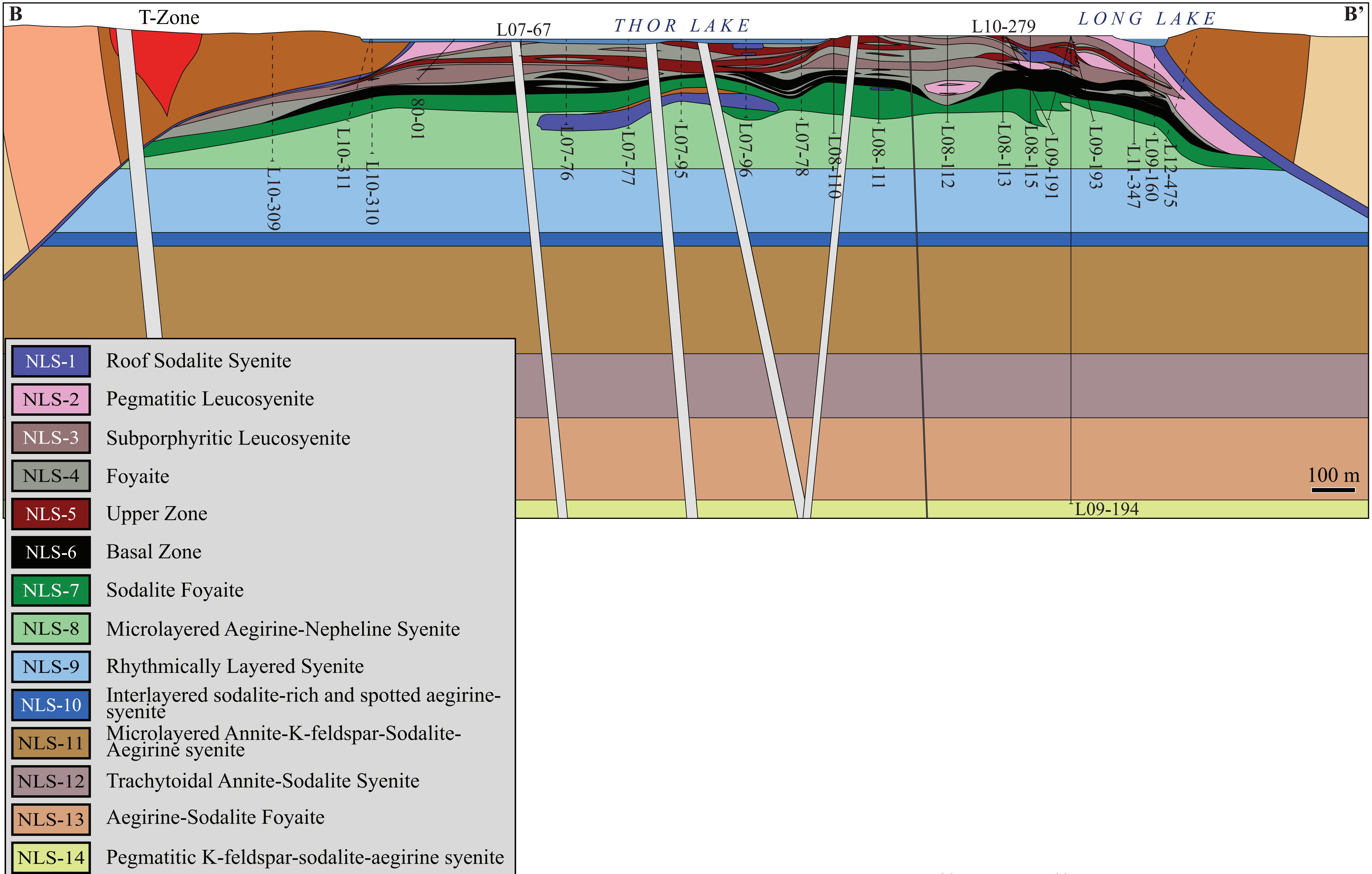


Modified after Möller and Williams-Jones (2012)

Nechalacho Layered Series: aegirine-nepheline-sodalite-biotite syenites

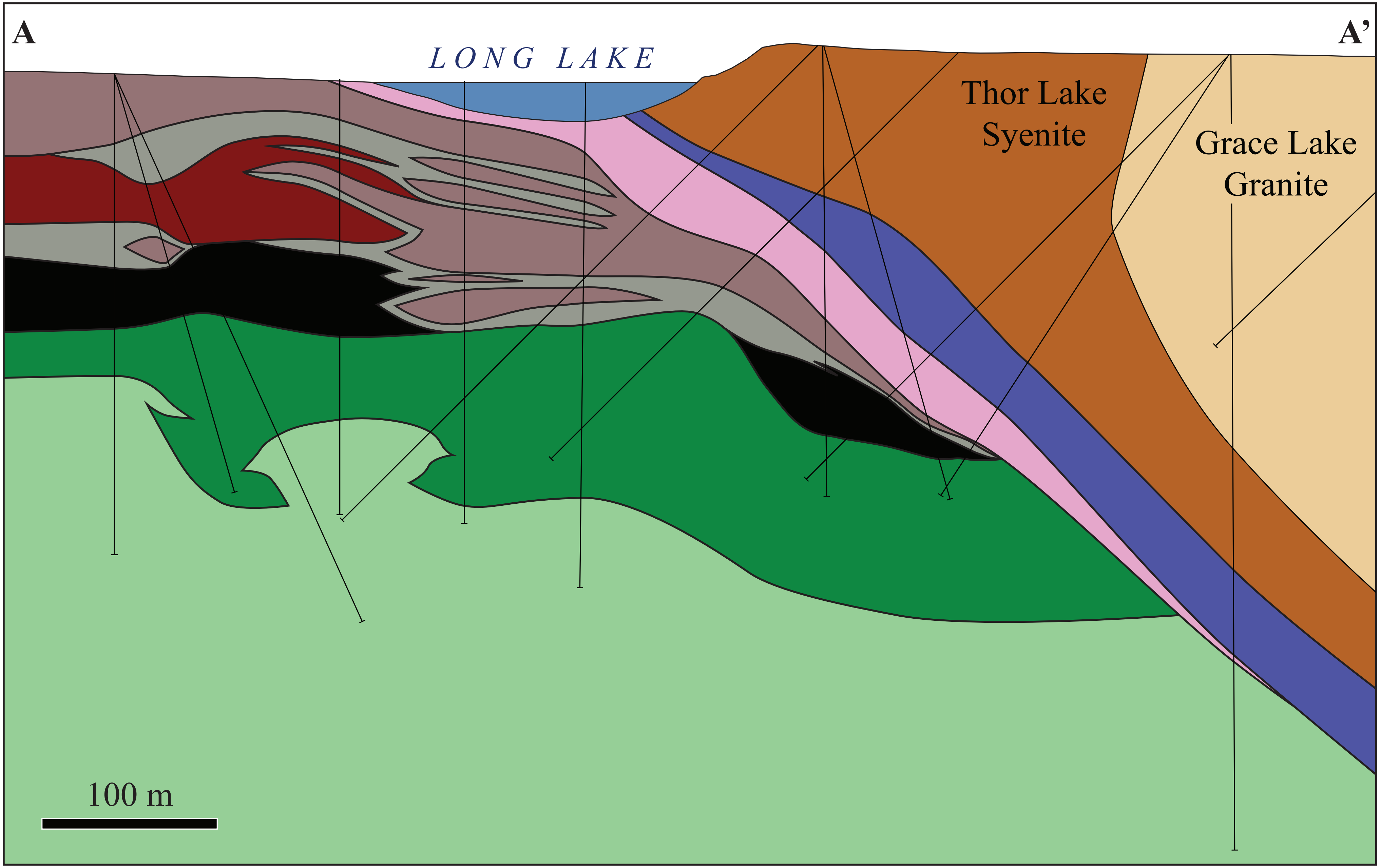


The Nechalacho Layered Suite



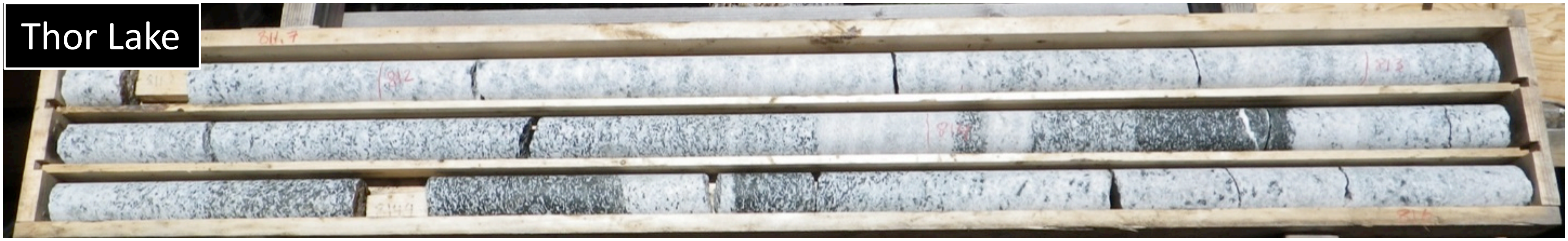
Möller & Williams-Jones, 2016, J. Pet.

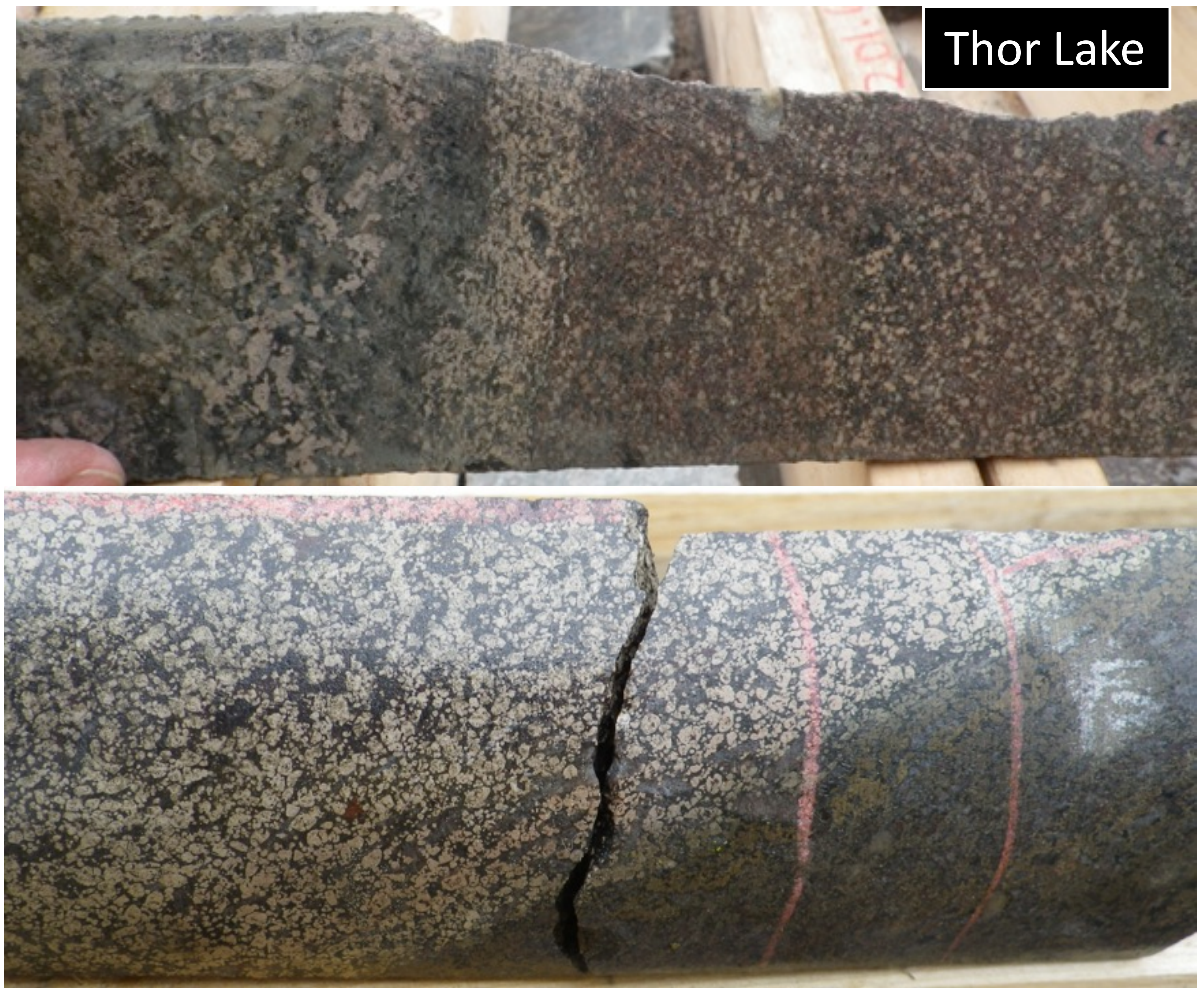
The Nechalacho Deposit

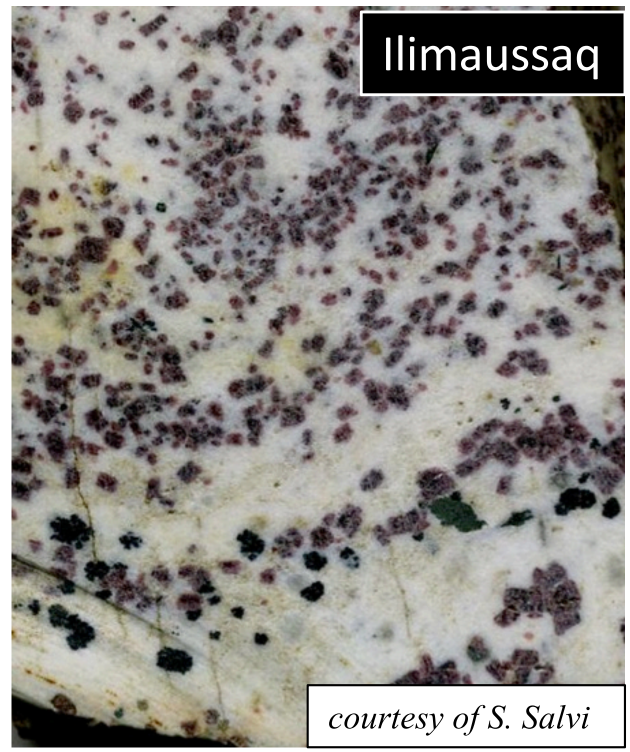


Möller & Williams-Jones, 2016, J. Pet.

Nechalacho Deposit: Cumulates

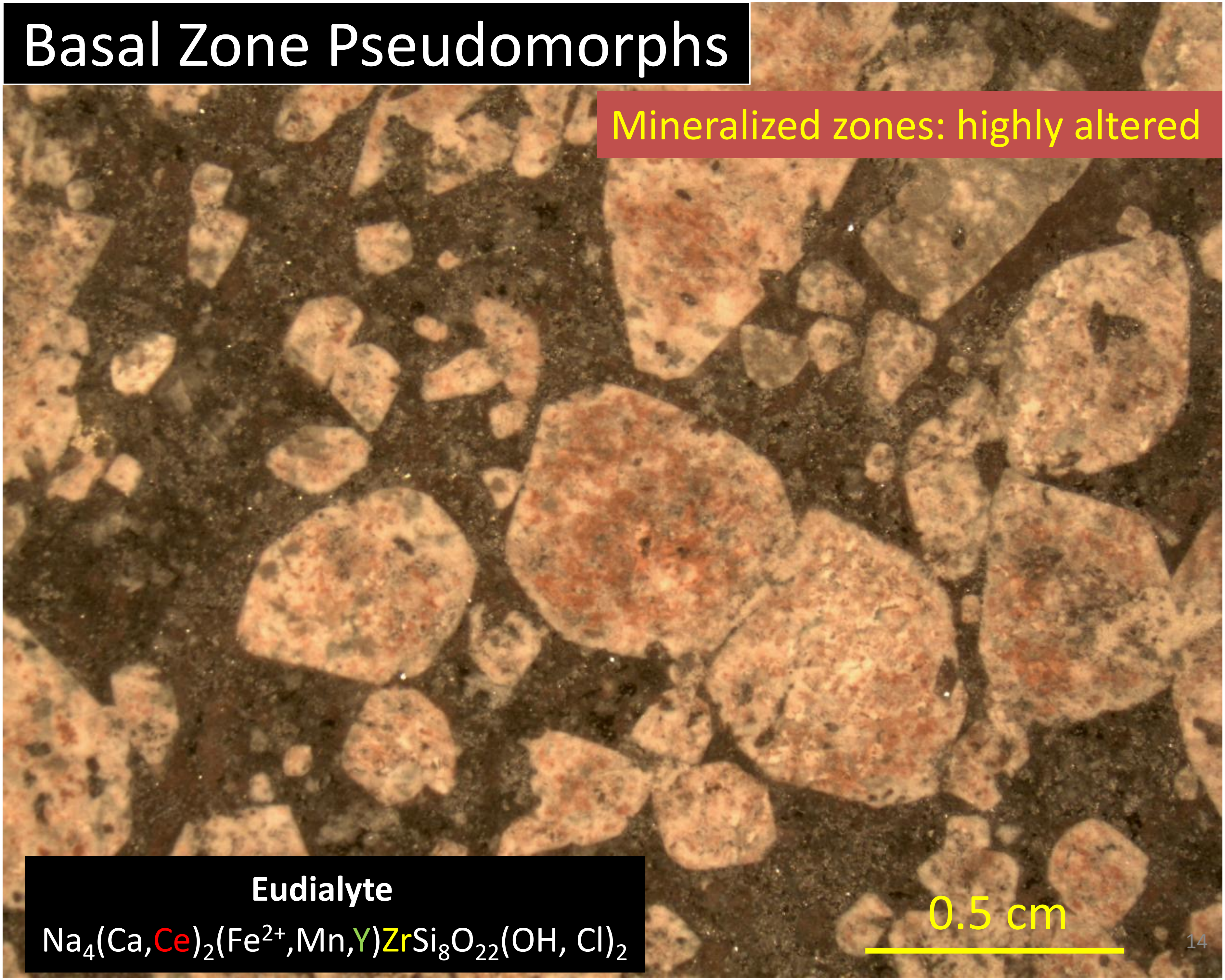






courtesy of S. Salvi

Basal Zone Pseudomorphs



Eudialyte

$Na_4(Ca,Ce)_2(Fe^{2+},Mn,Y)ZrSi_8O_{22}(OH, Cl)_2$

Nechalacho: secondary rare-metal minerals

zircon $ZrSiO_4$

fergusonite $LnNbO_4$

columbite $(Fe,Mn)(Nb,Ta)_2O_6$

allanite $(Ca,Na)_2Ln_3Si_6O_{18}\cdot 2H_2O$

bastnäsite $Ln(CO_3)F$

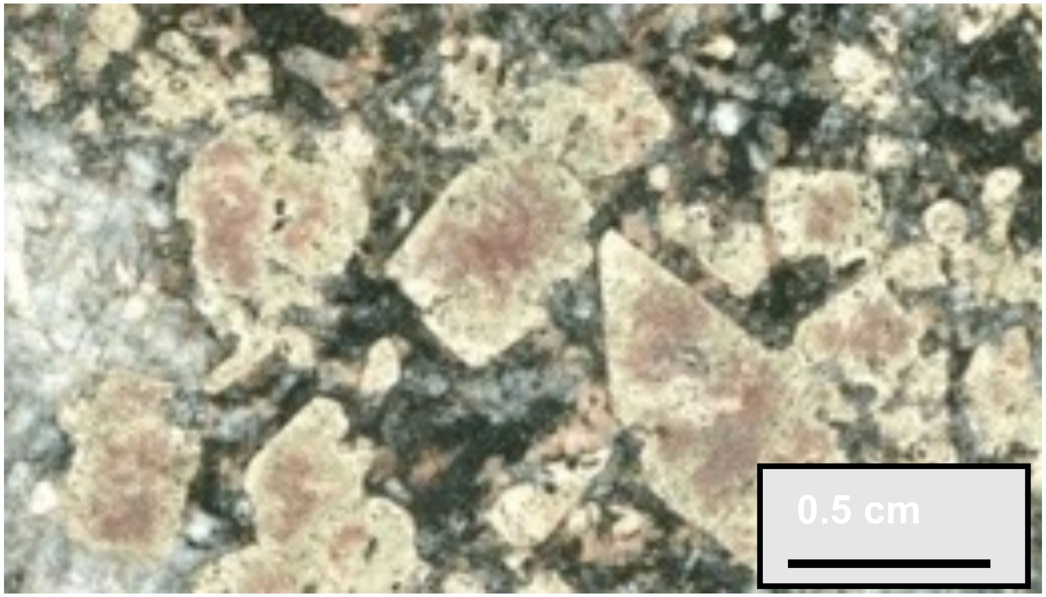
monazite $LnPO_4$ (LREE-enriched)

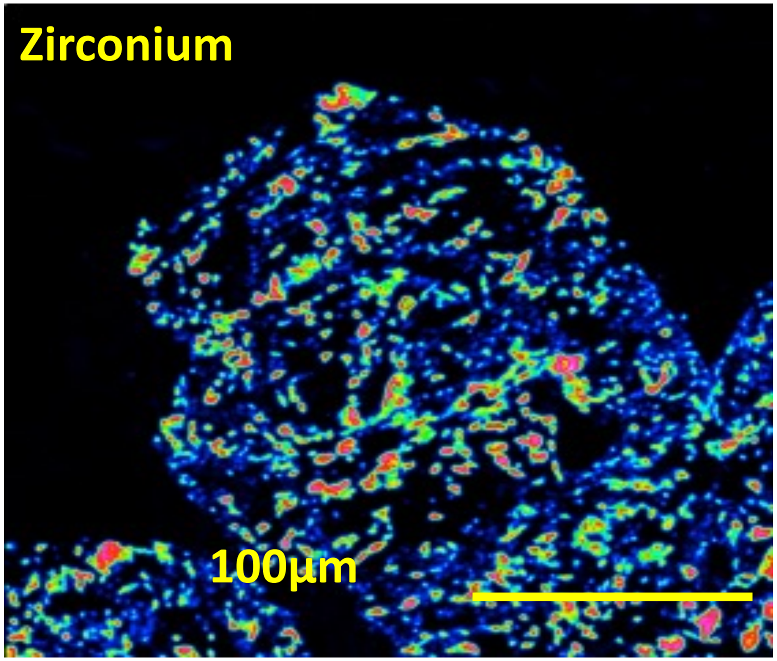
xenotime $(Y,Ln)PO_4$ (HREE-enriched)

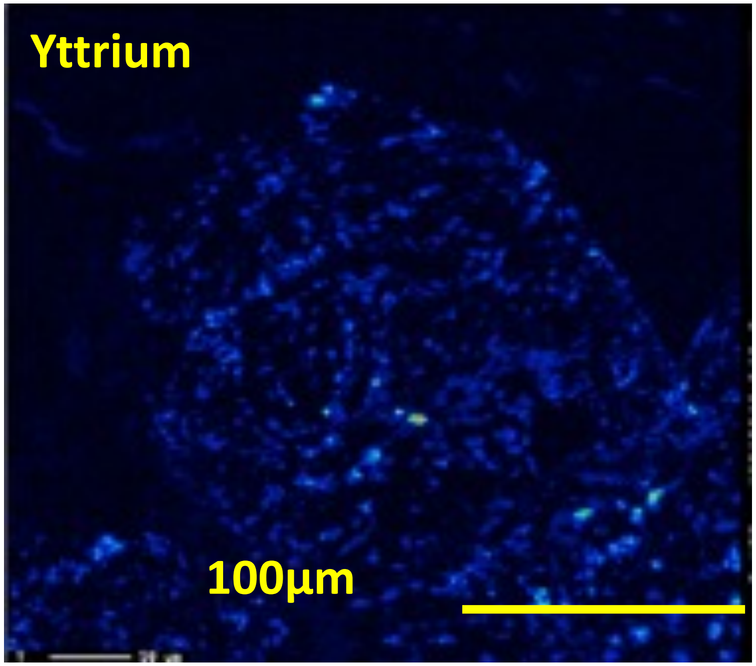
Ln = lanthanide

eudialyte pseudomorphs

Courtesy of E. Sheard

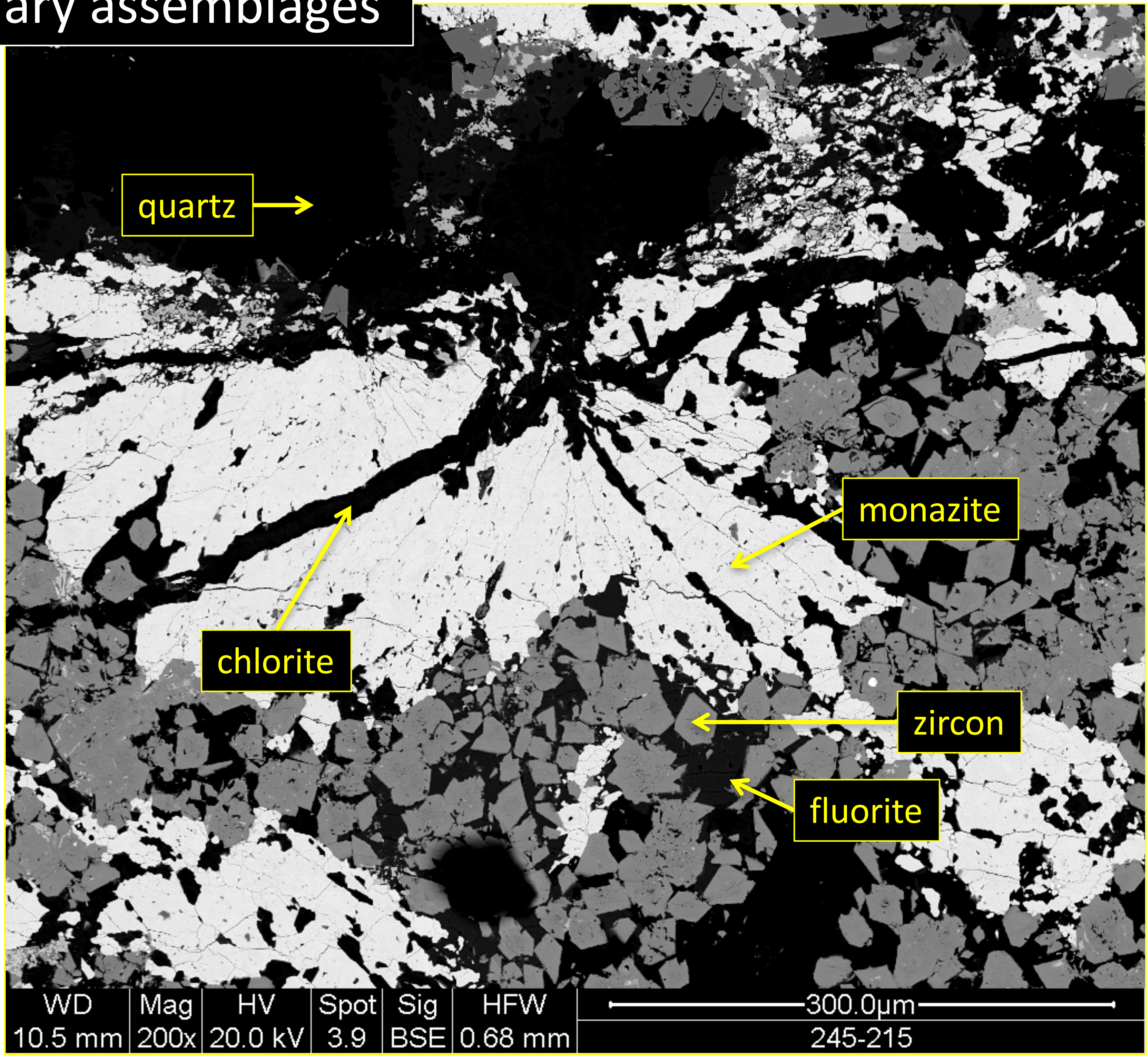


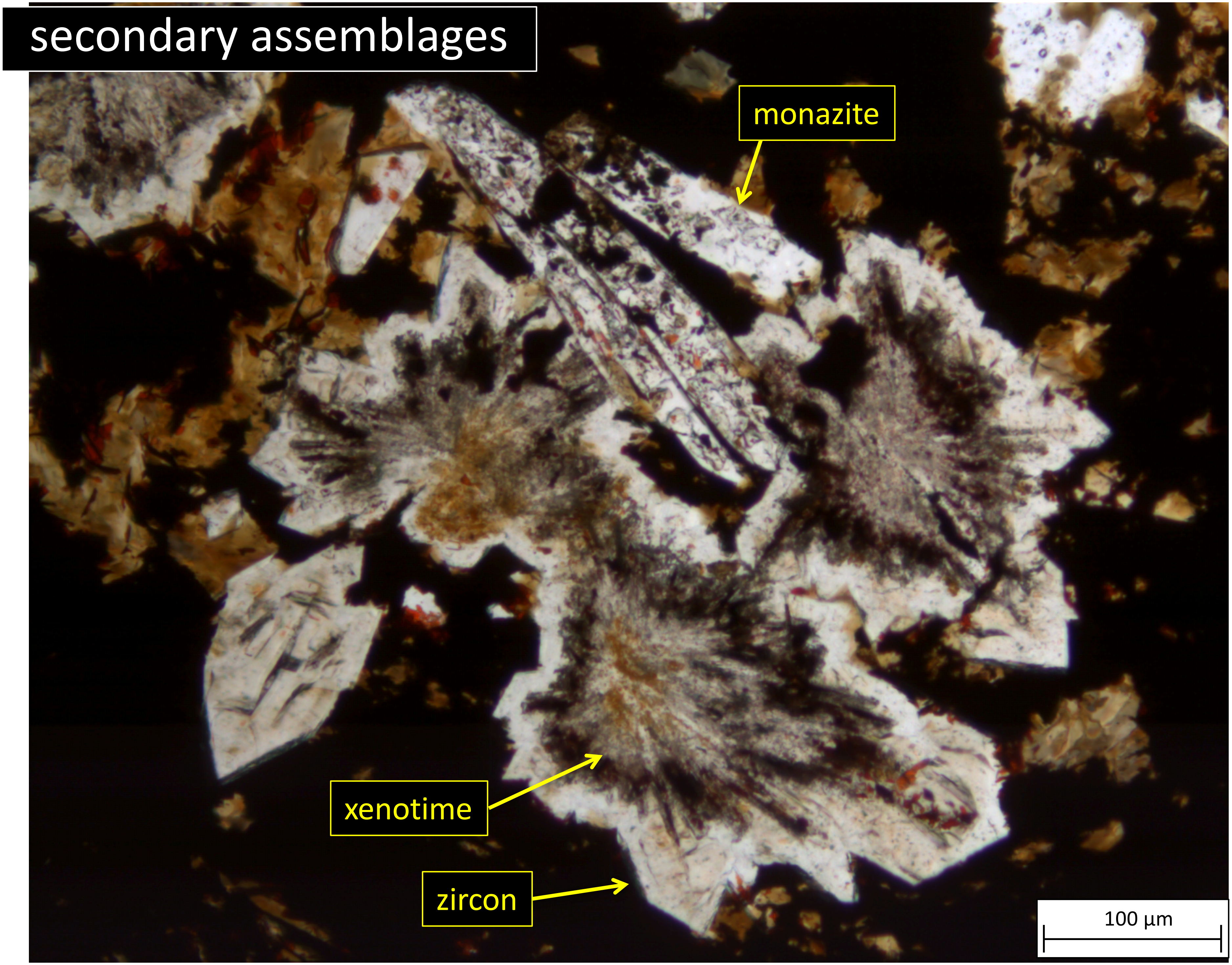




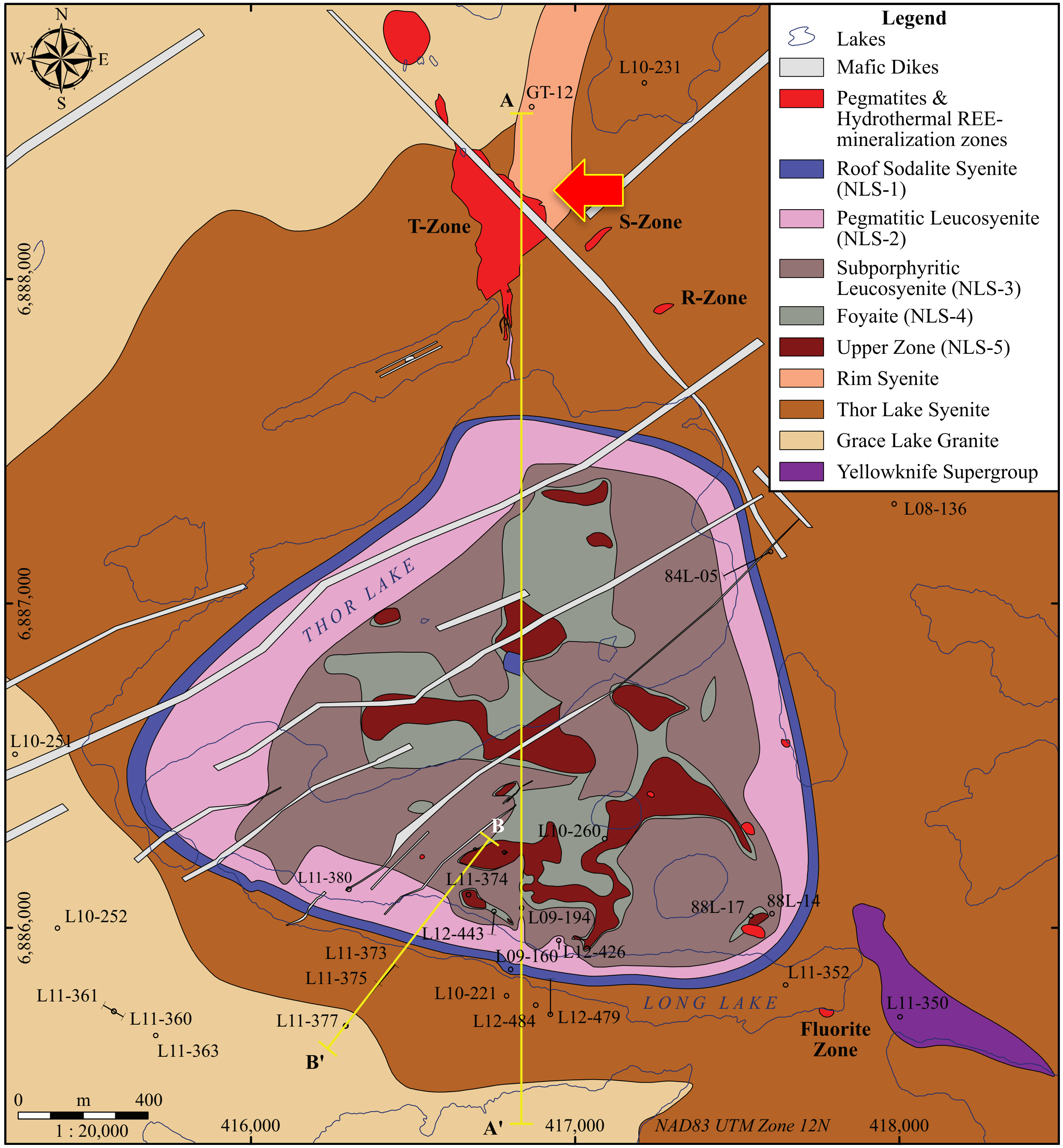
Heavily altered Basal Zone

secondary assemblages



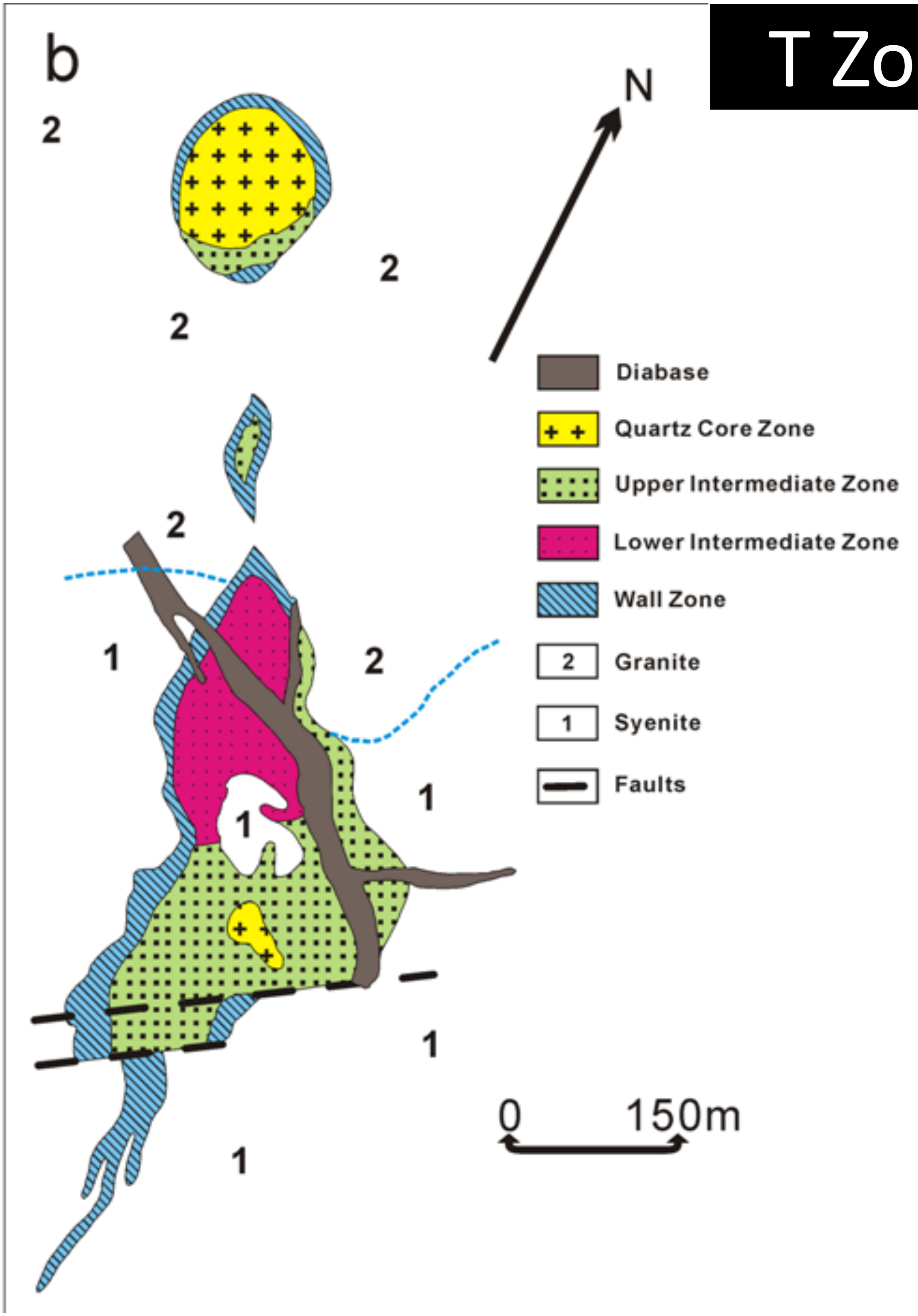

secondary assemblages
monazite
xenotime
zircon
100 µm

T Zone

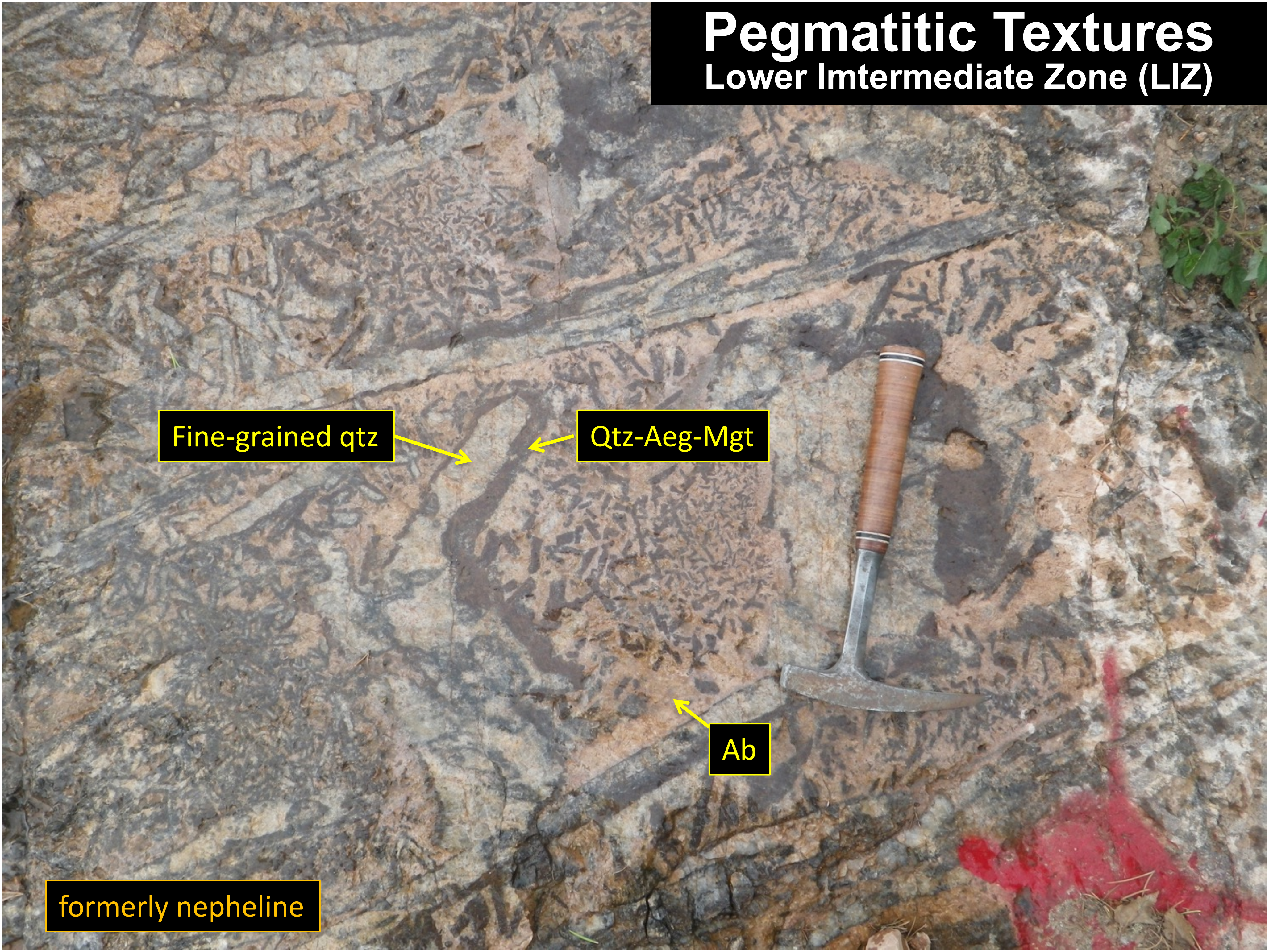


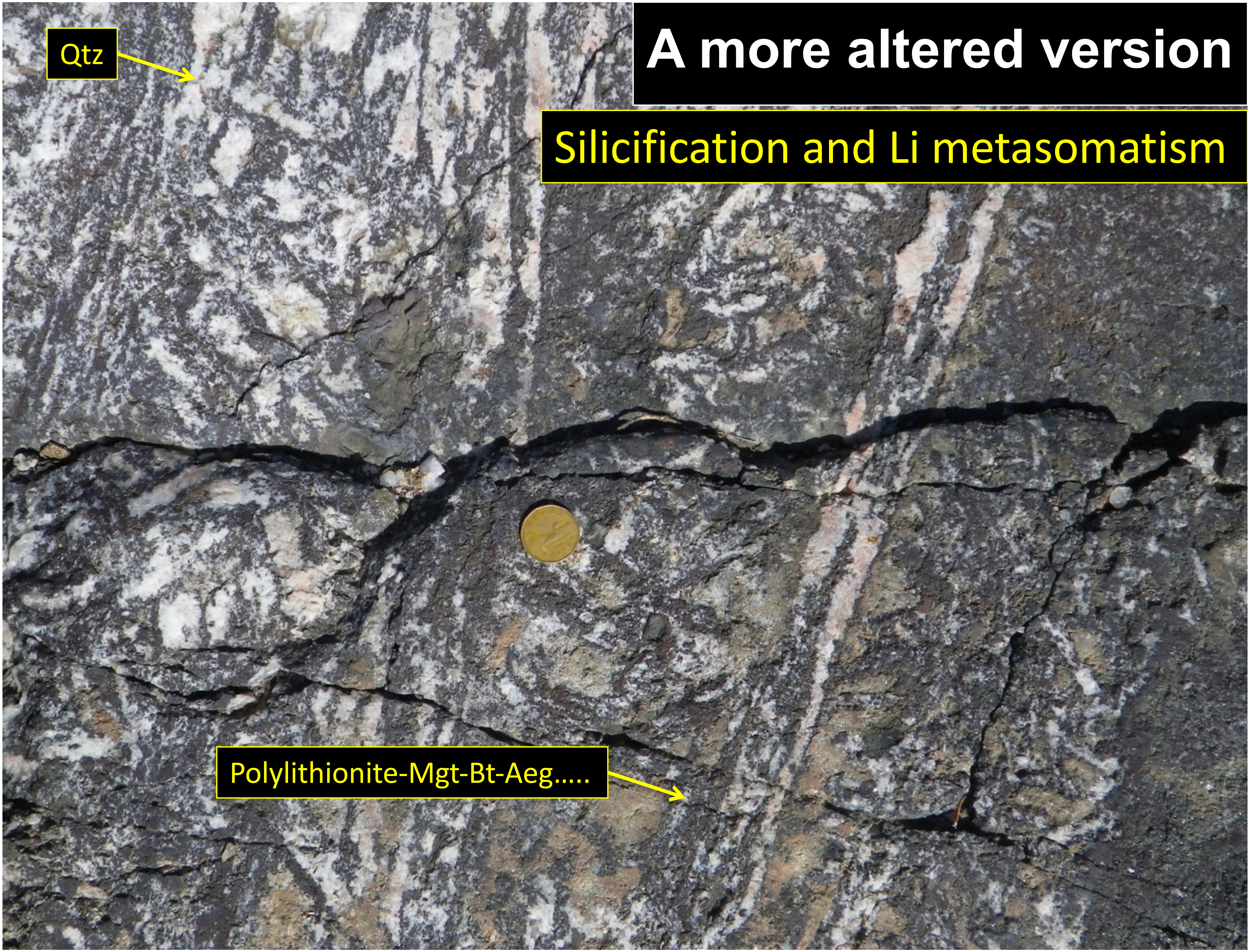
Möller & Williams-Jones, 2016, J. Pet.

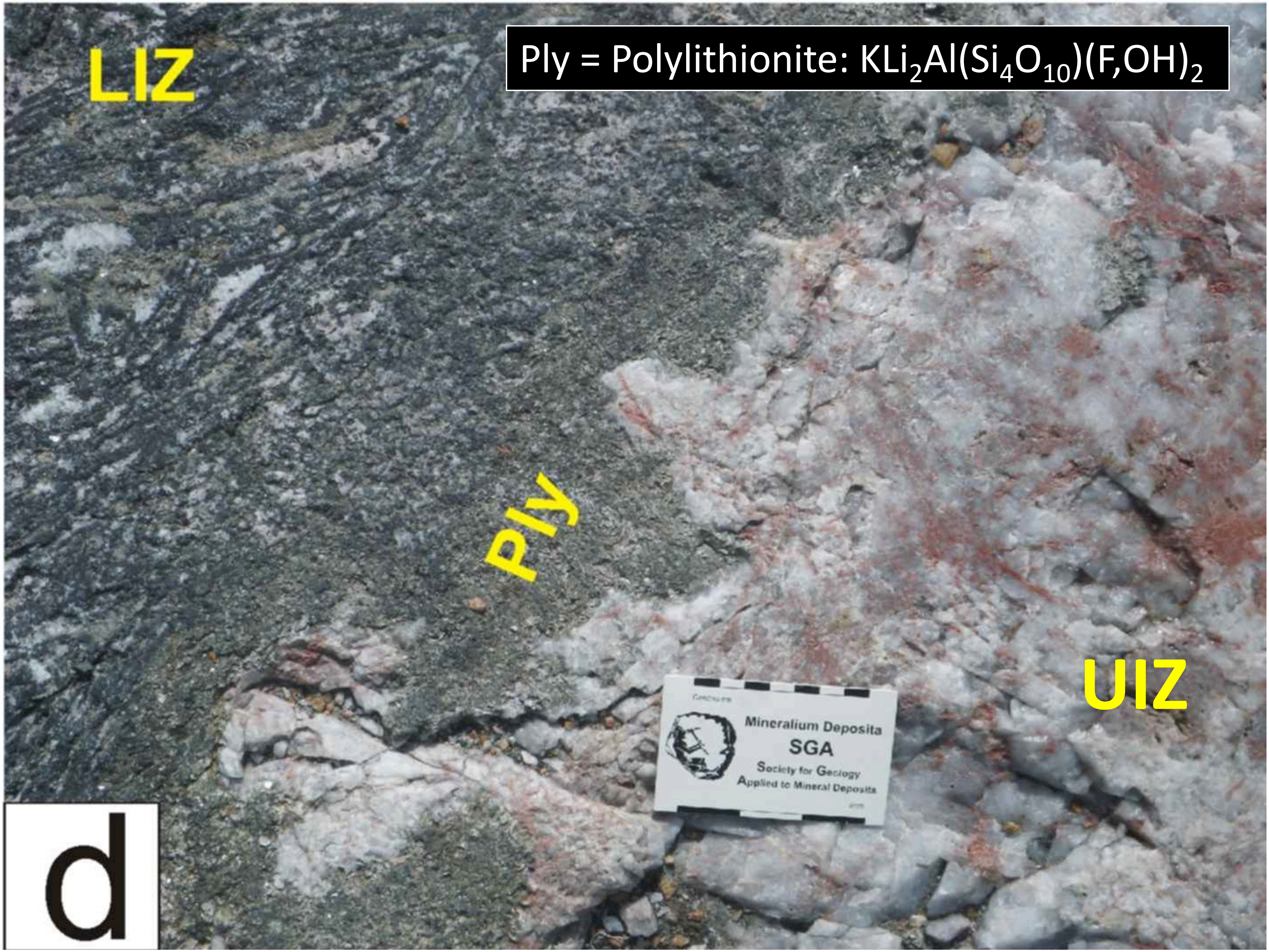
T Zone Geology



Pegmatitic Textures
Lower Imtermediate Zone (LIZ)




A more altered version
Silicification and Li metasomatism
Qtz
Polylithionite-Mgt-Bt-Aeg.....



Ply = Polylithionite: $KLi_2Al(Si_4O_{10})(F,OH)_2$
LIZ
Ply
UIZ
d
Mineralium Deposita
SGA
Society for Geology
Applied to Mineral Deposits

T Zone rare-metal minerals

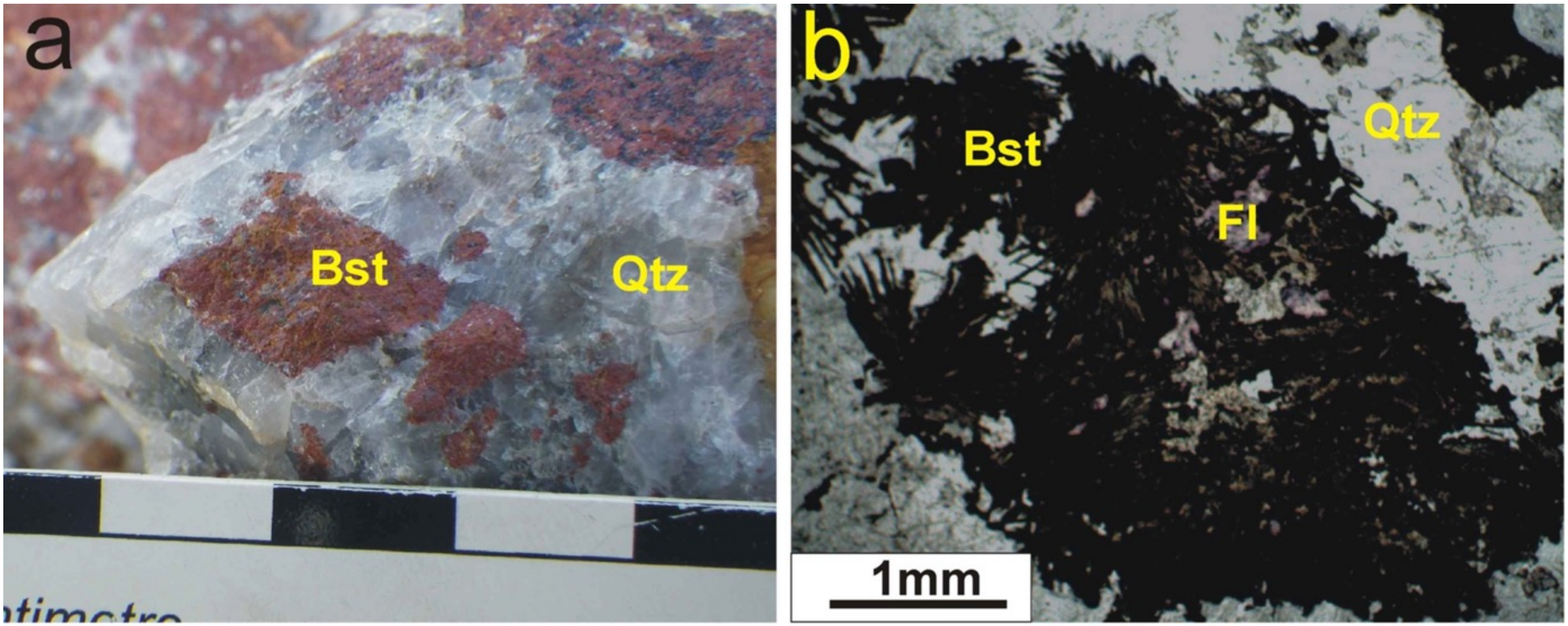
zircon $ZrSiO_4$
columbite $(Fe,Mn)(Nb,Ta)_2O_6$

bastnäsite $Ln(CO_3)F$
monazite $LnPO_4$
xenotime $(Y,Ln)PO_4$

phenakite Be_2SiO_4
polylithionite $KLi_2AlSi_4O_{10}(F,OH)_2$

How do the rare-metal minerals occur?
are they primary or secondary?

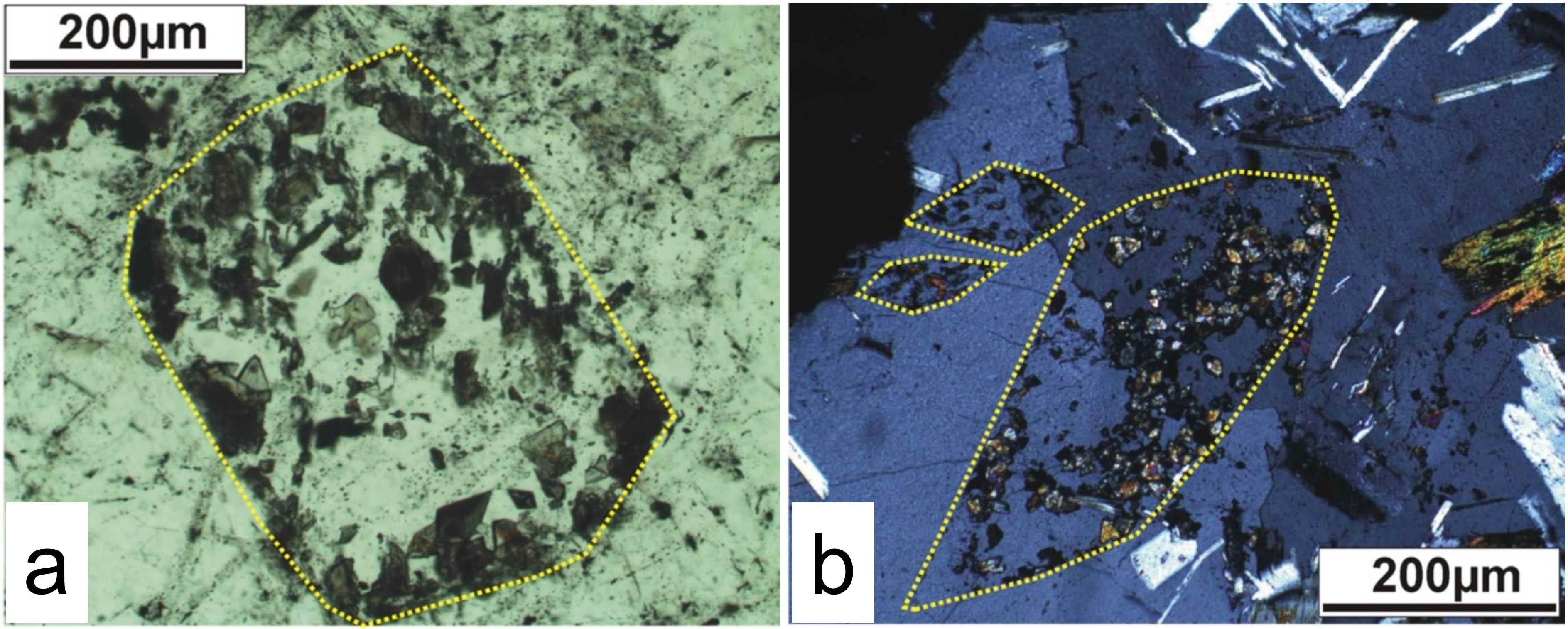
REE-minerals in pseudomorphs

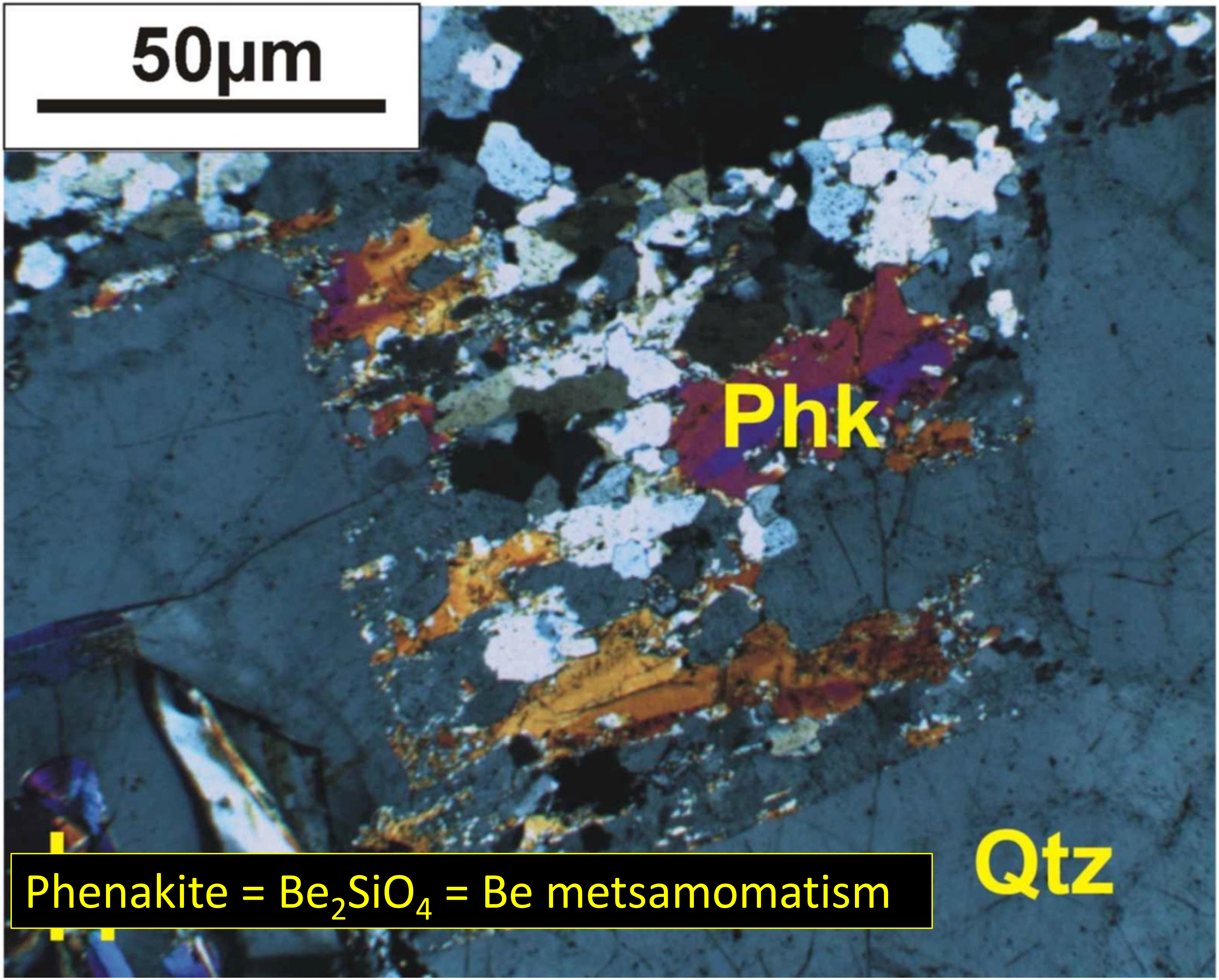


Bst = bastnäsite ($REECO_3F$), LREE-rich mineral

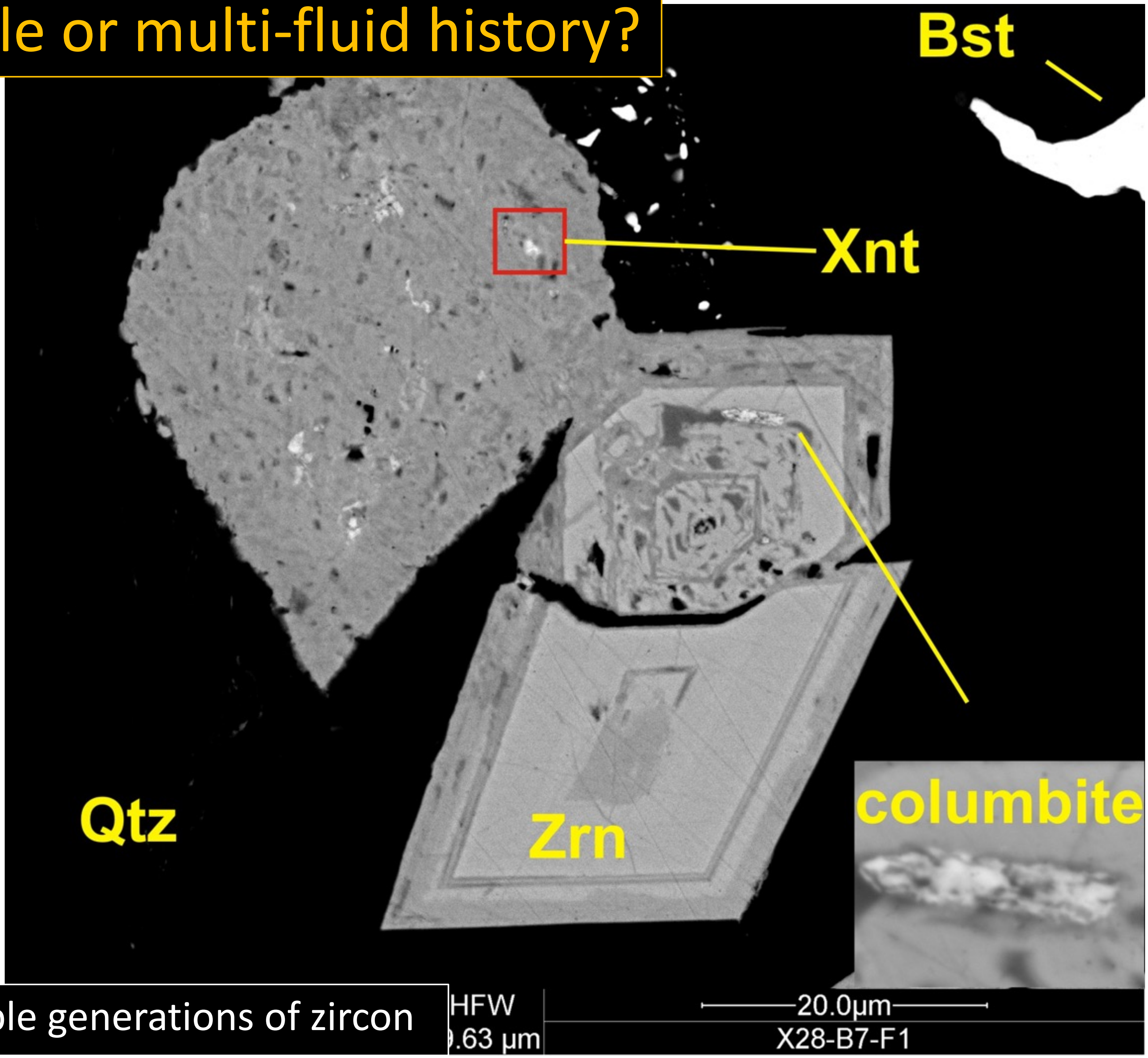
Also: monazite, xenotime

Zircon in pseudomorphs




50µm
Phk
Qtz
Phenakite = Be_2SiO_4 = Be metsamomatism

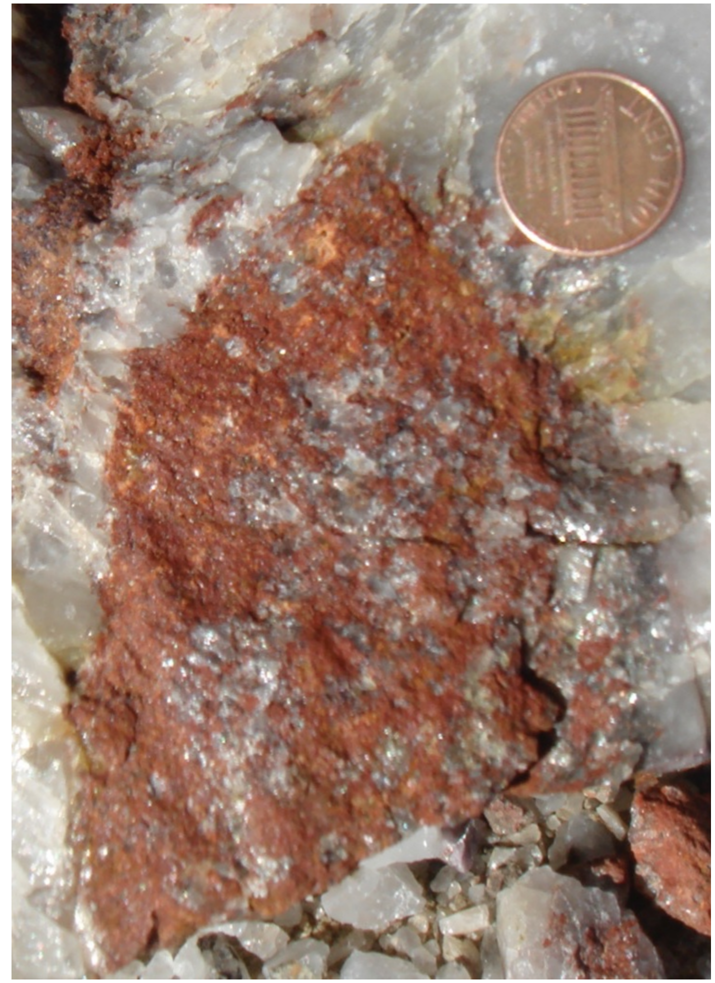
Simple or multi-fluid history?



multiple generations of zircon

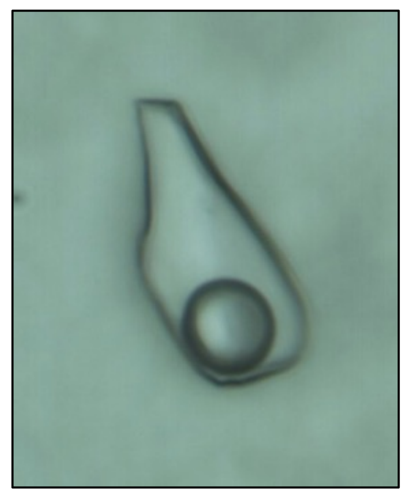
What was the character of the fluids and did they contain rare-metals?

Does the fluid record bear-out the mineralogical complexity?

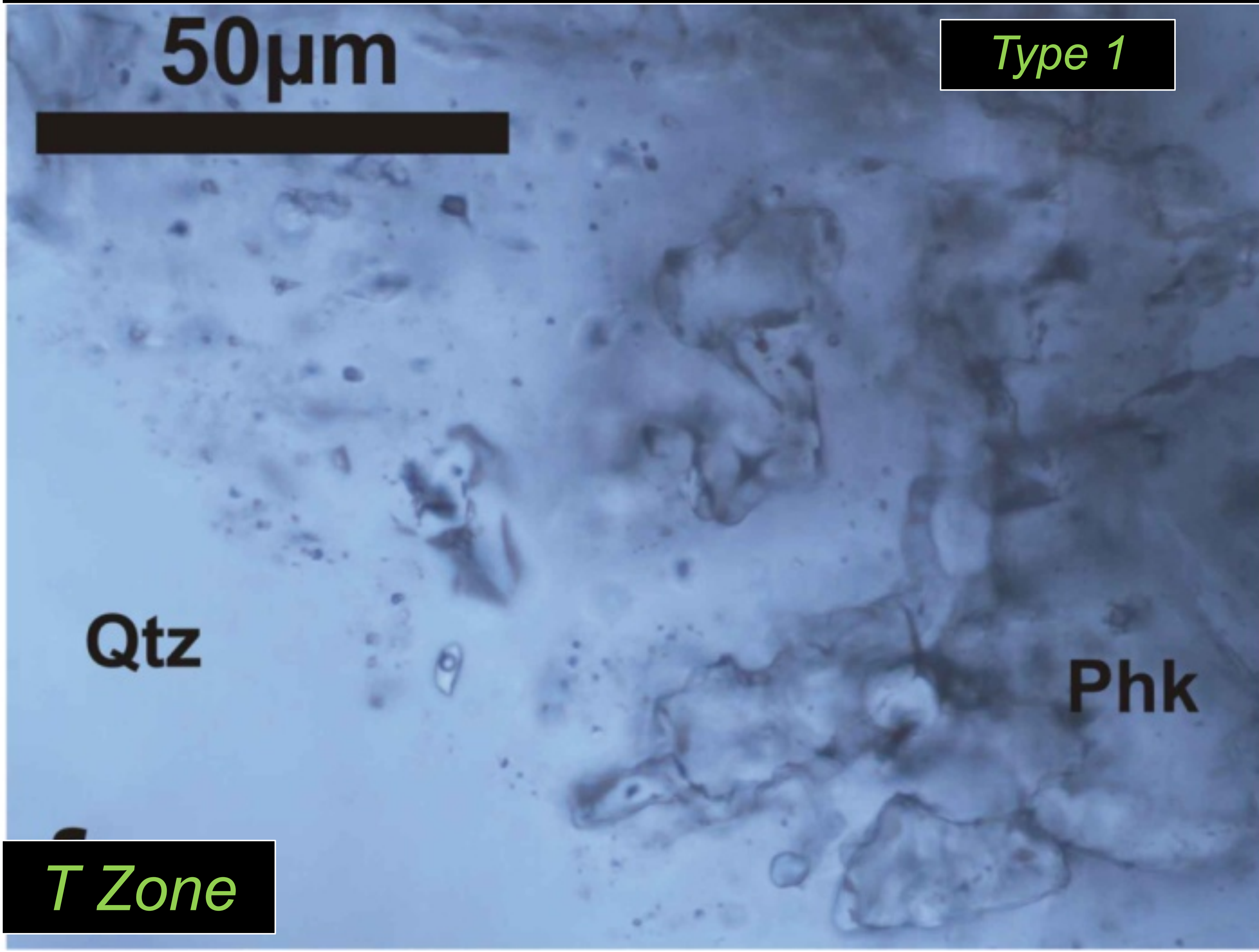


Approach = fluid inclusions

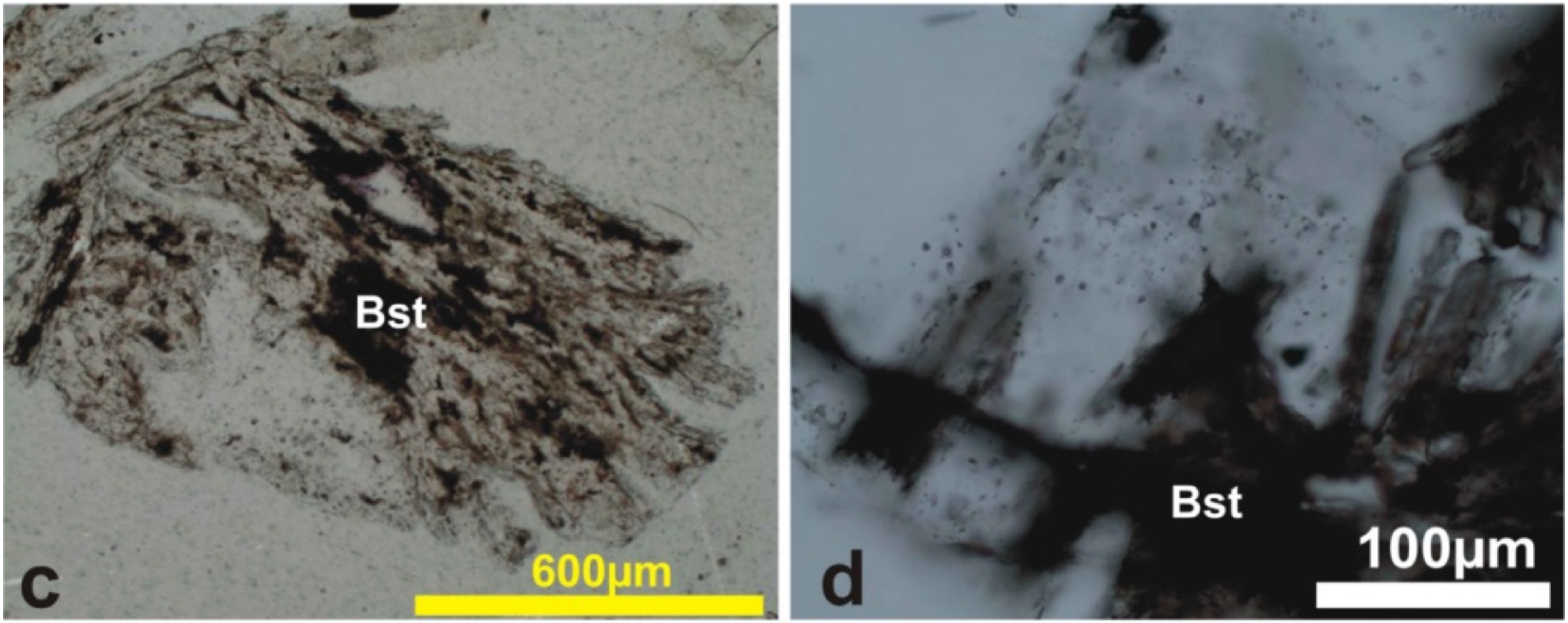
How can we tie the fluid inclusions to the rare-metal minerals?



fluid inclusions restricted to pseudomorphs

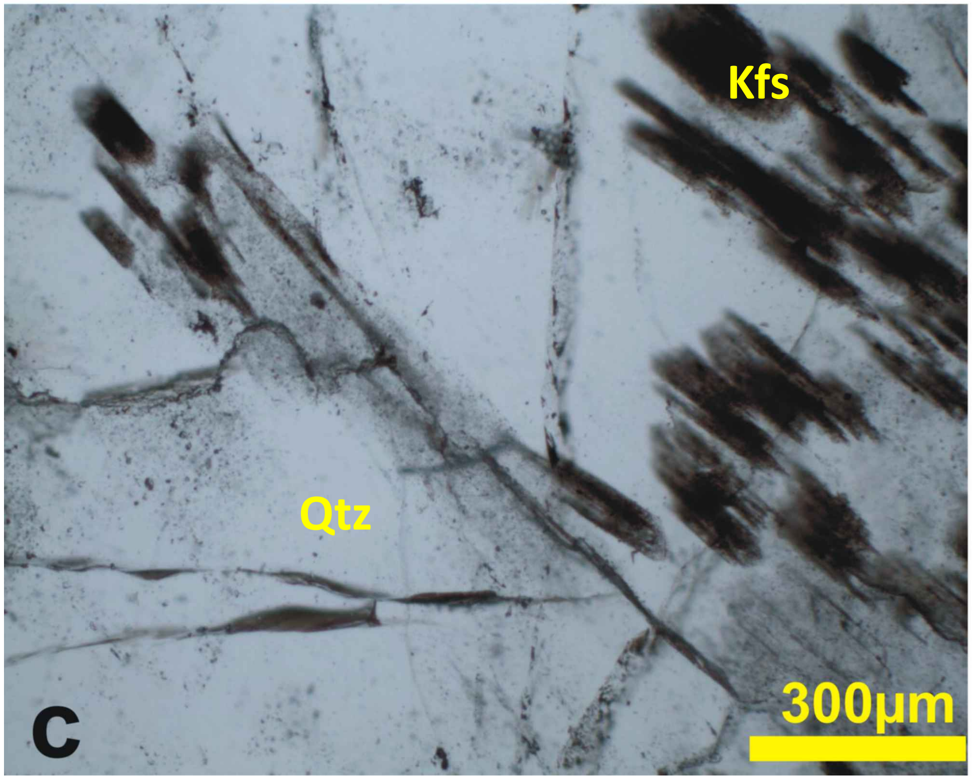


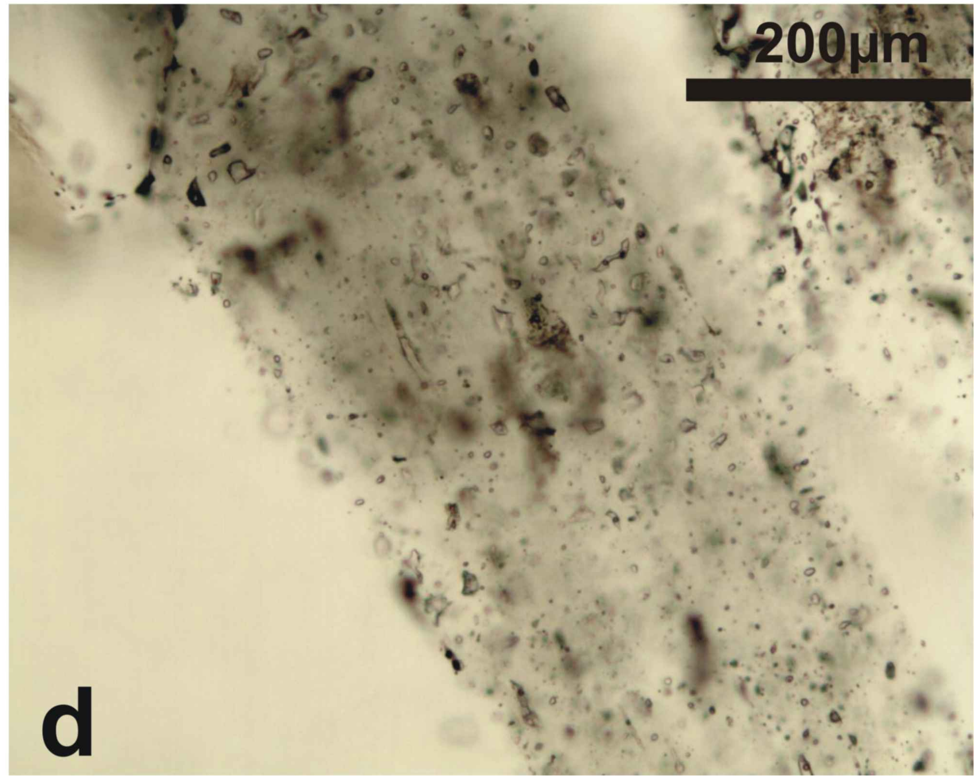
fluid inclusions restricted to pseudomorphs



pseudomorphs defined by fluid inclusions

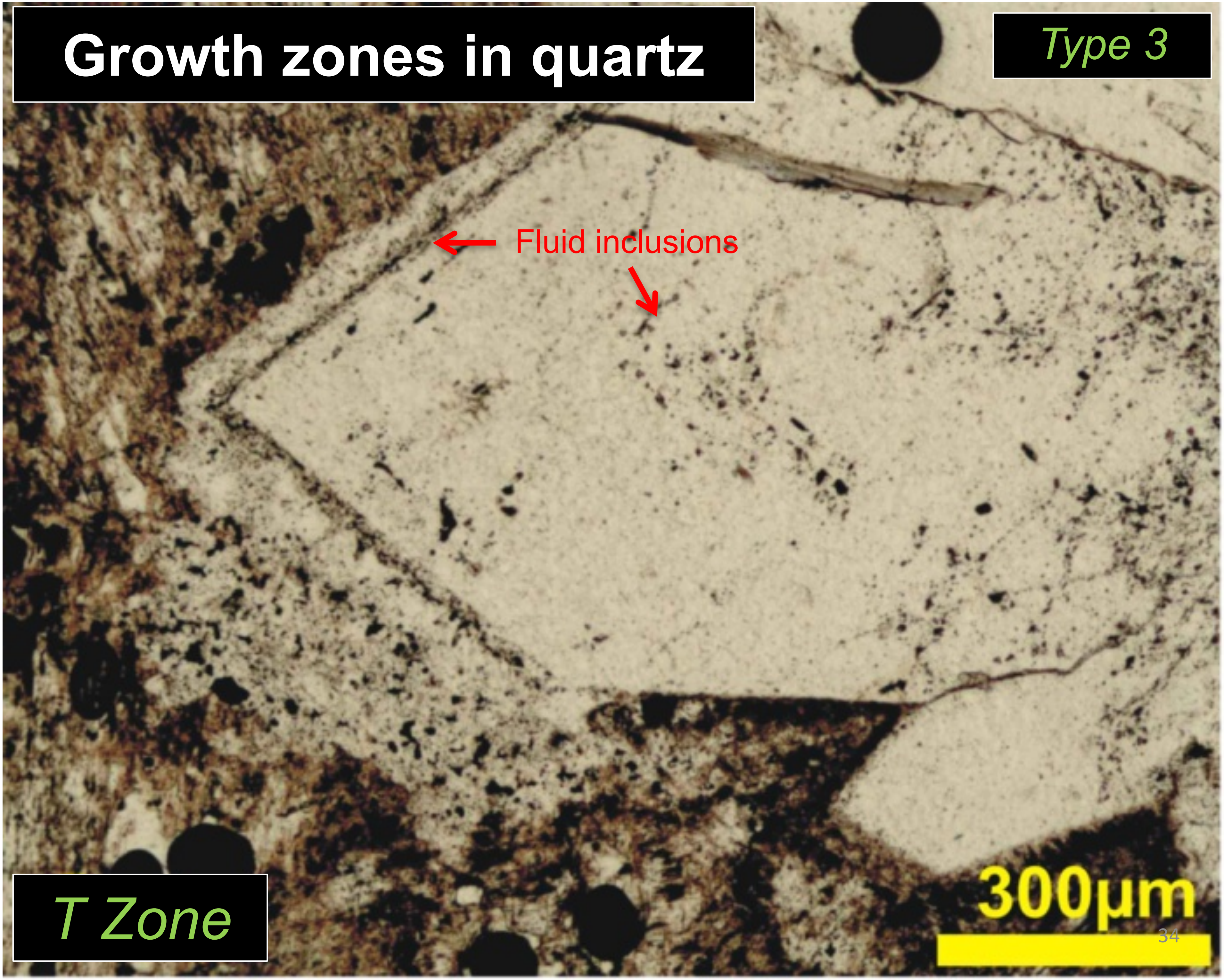
Type 2





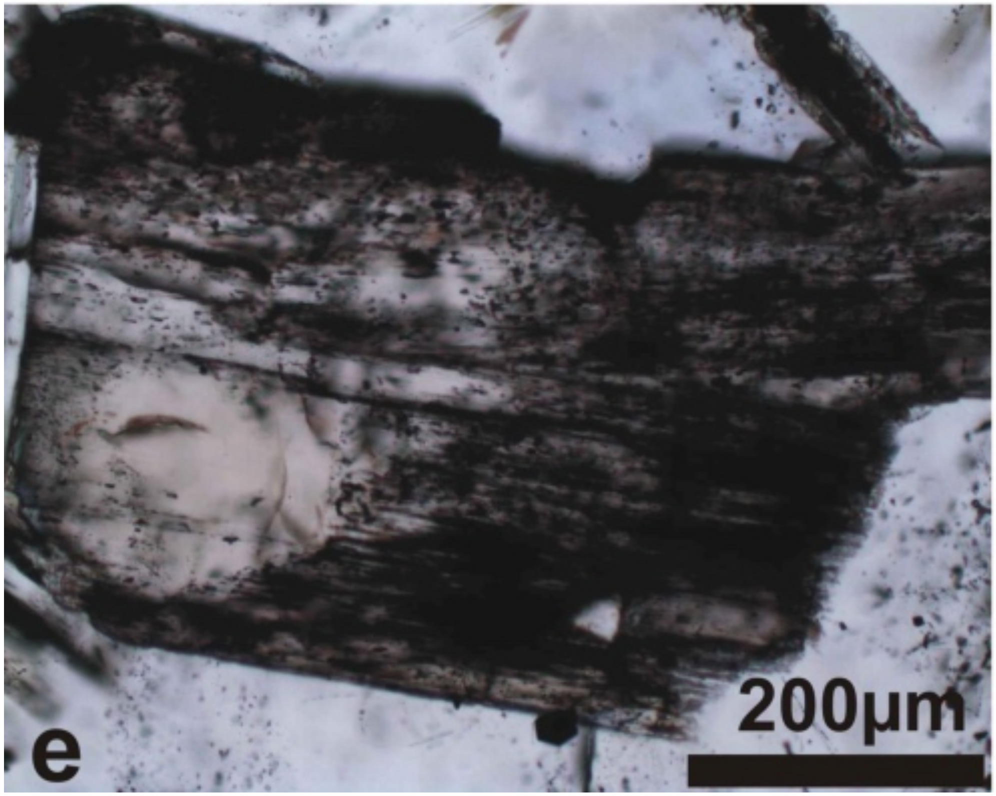
T Zone

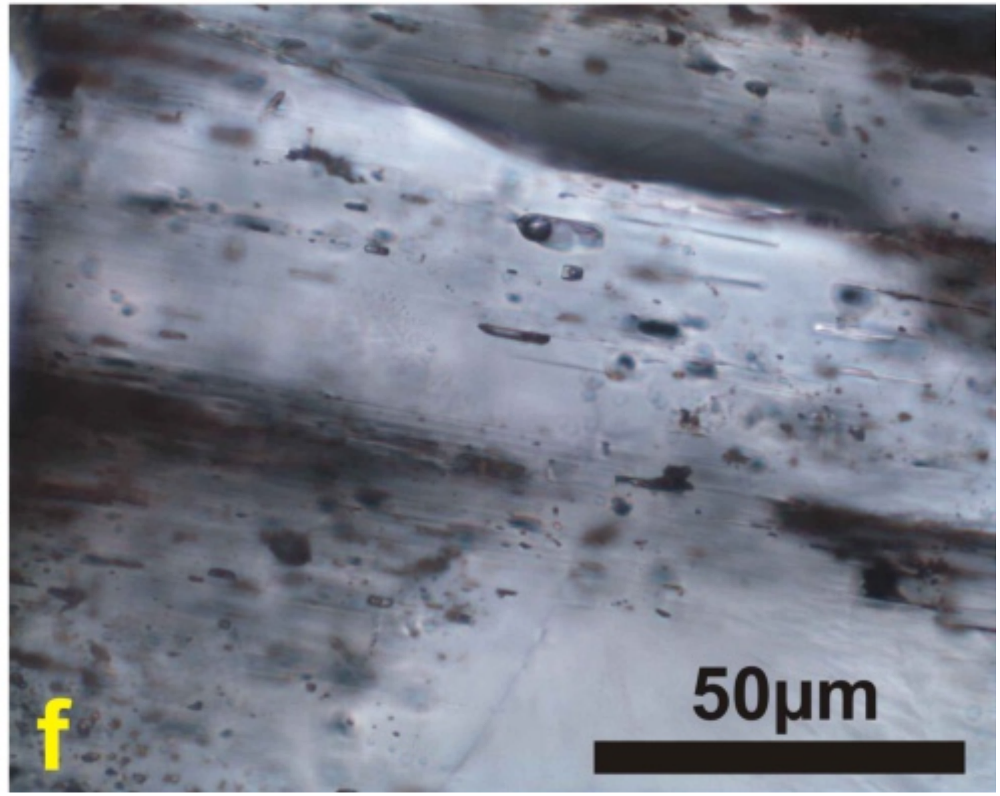
Growth zones in quartz

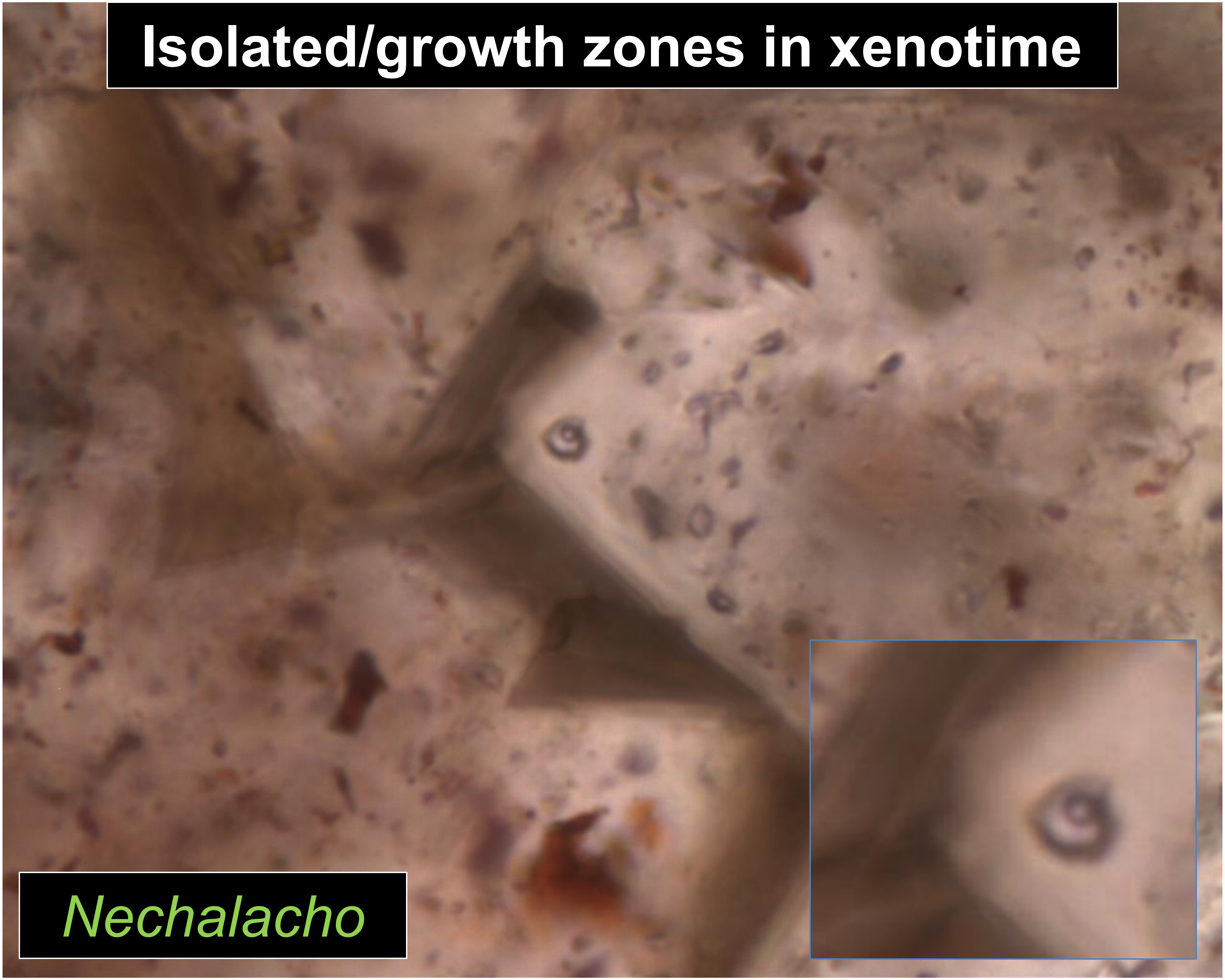


Oriented inclusions in bastnäsite

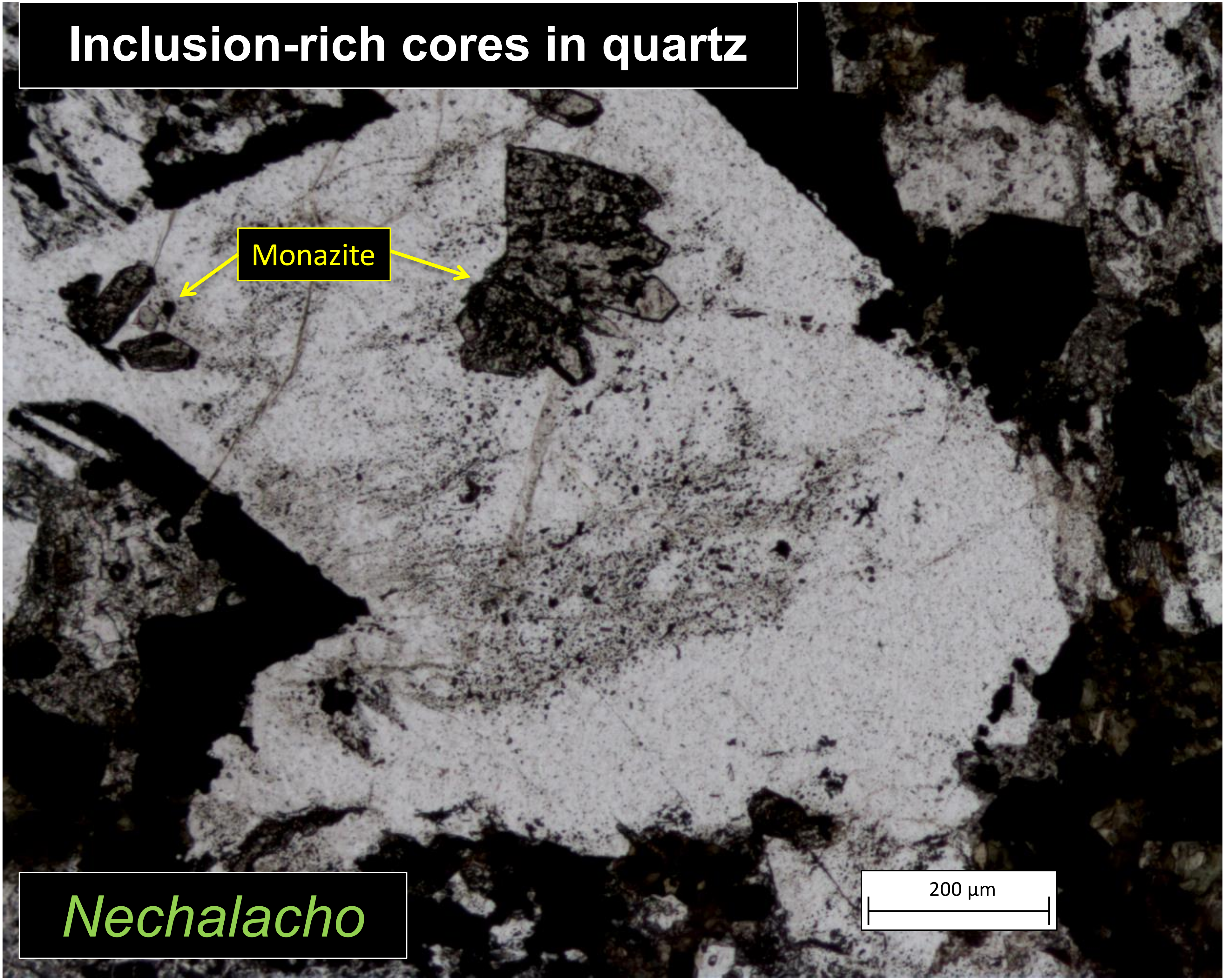
Type 6






Isolated/growth zones in xenotime
Nechalacho

Inclusion-rich cores in quartz



Nechalacho

Fluid Inclusion Assemblage (FIA) Classification

Pseudomorphs in *quartz*

Growth Zones in *quartz* (rarely in *fluorite*)

Isolated Inclusions in *xenotime + quartz*

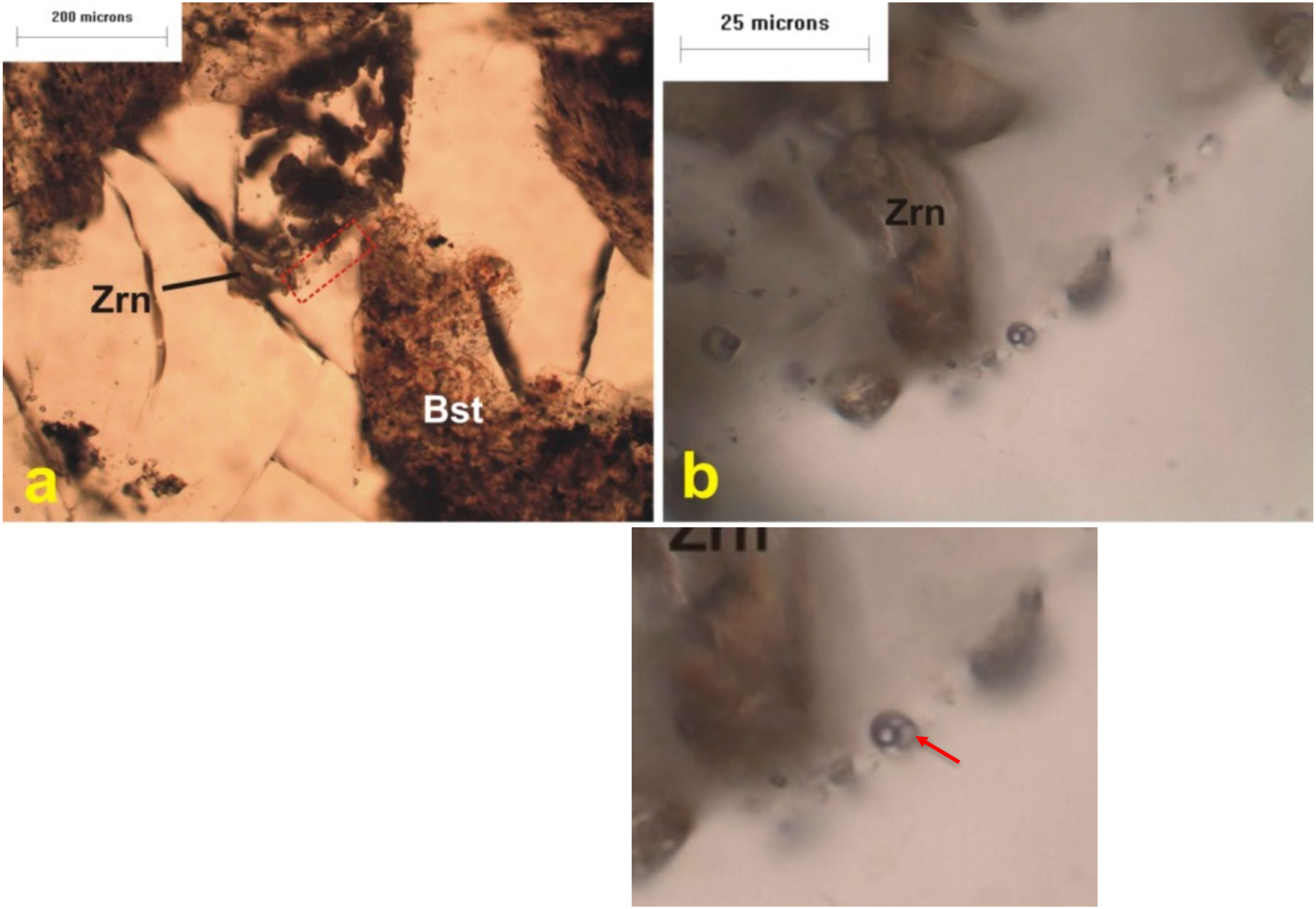
Elongate inclusions parallel to the c-axis of *bastnäsite*

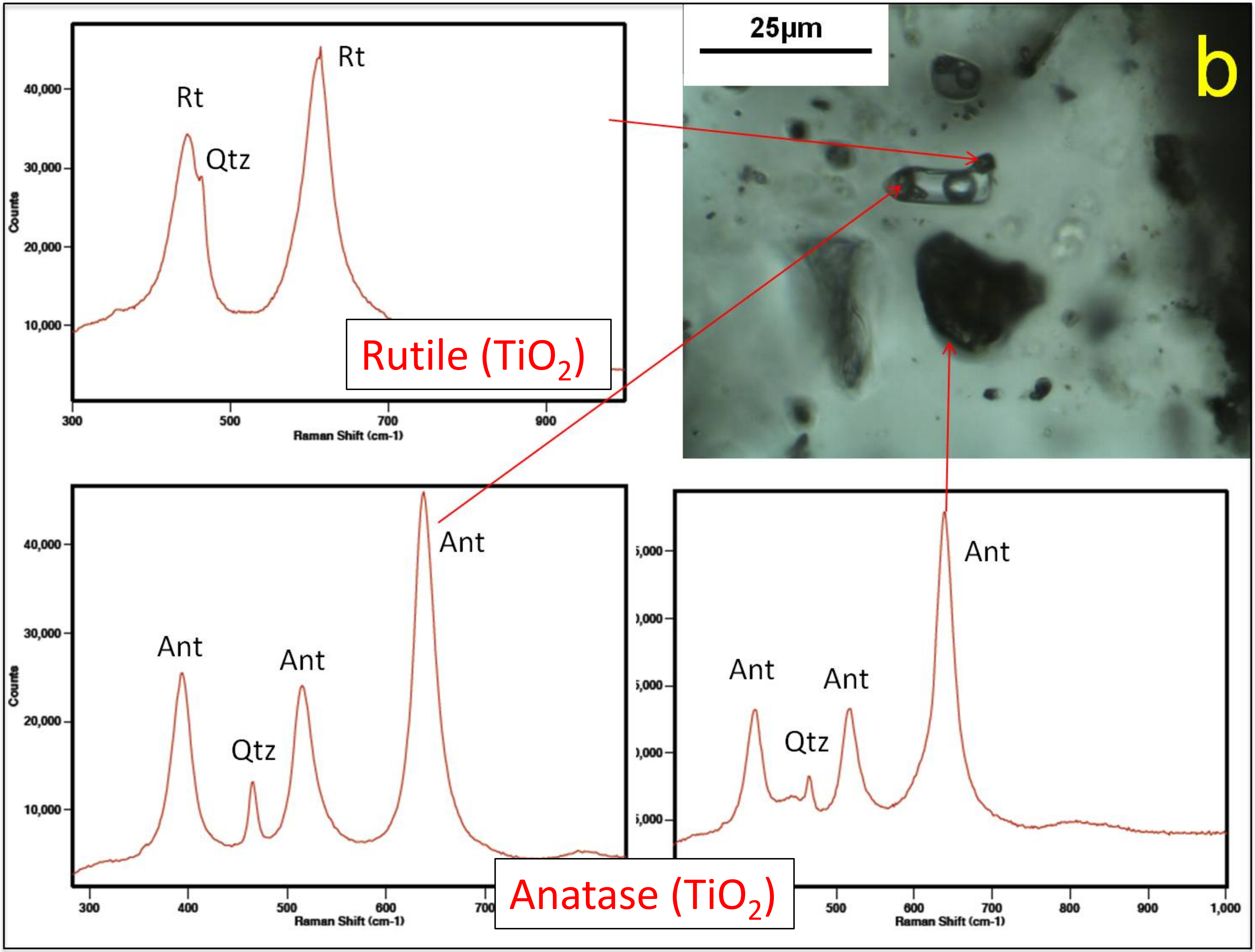
Aqueous, Liquid-rich Liquid-Vapor ± Solid (LV ± S)

Very minor CO_2 and CH_4

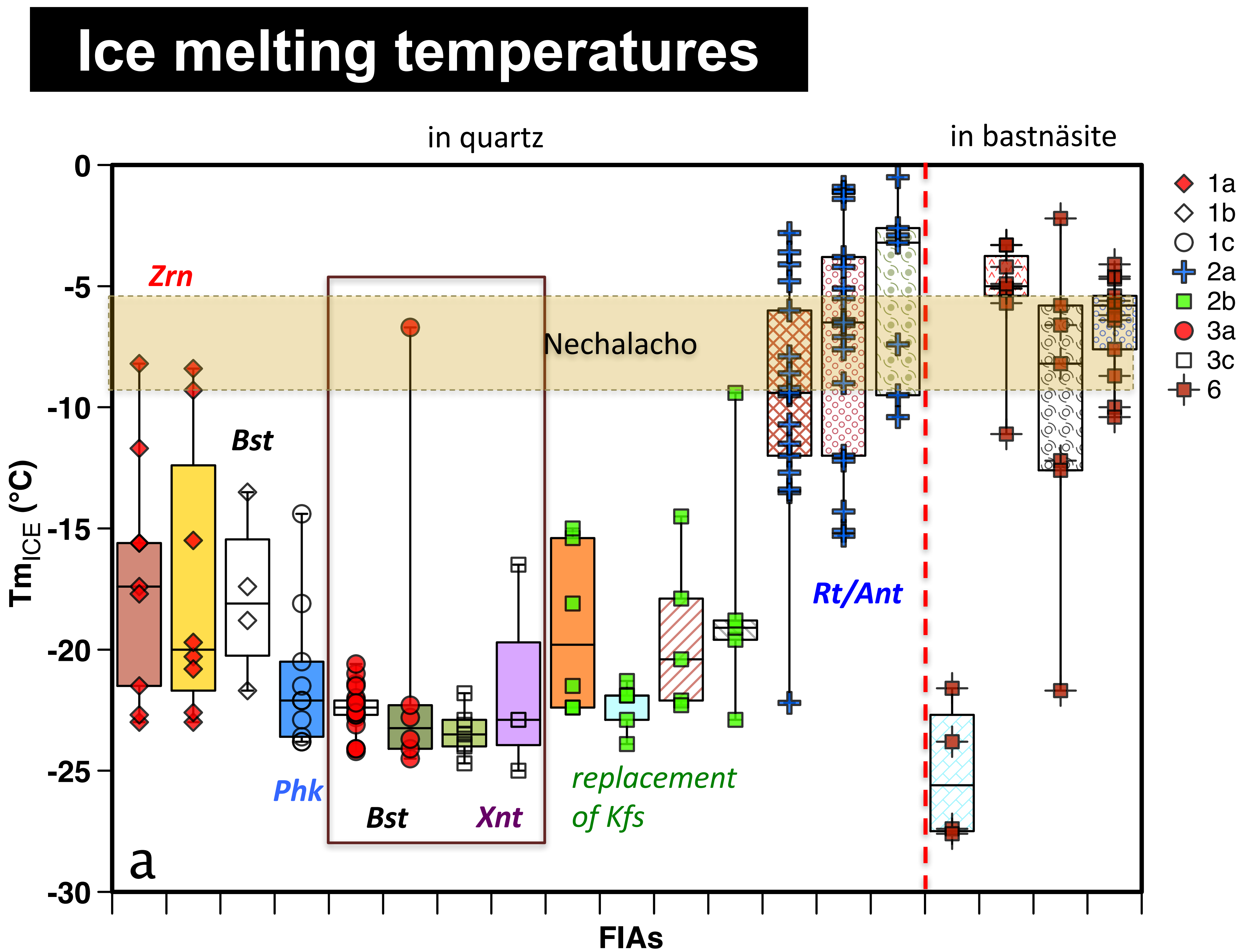
Trapped = zircon, anatase, rutile + ?

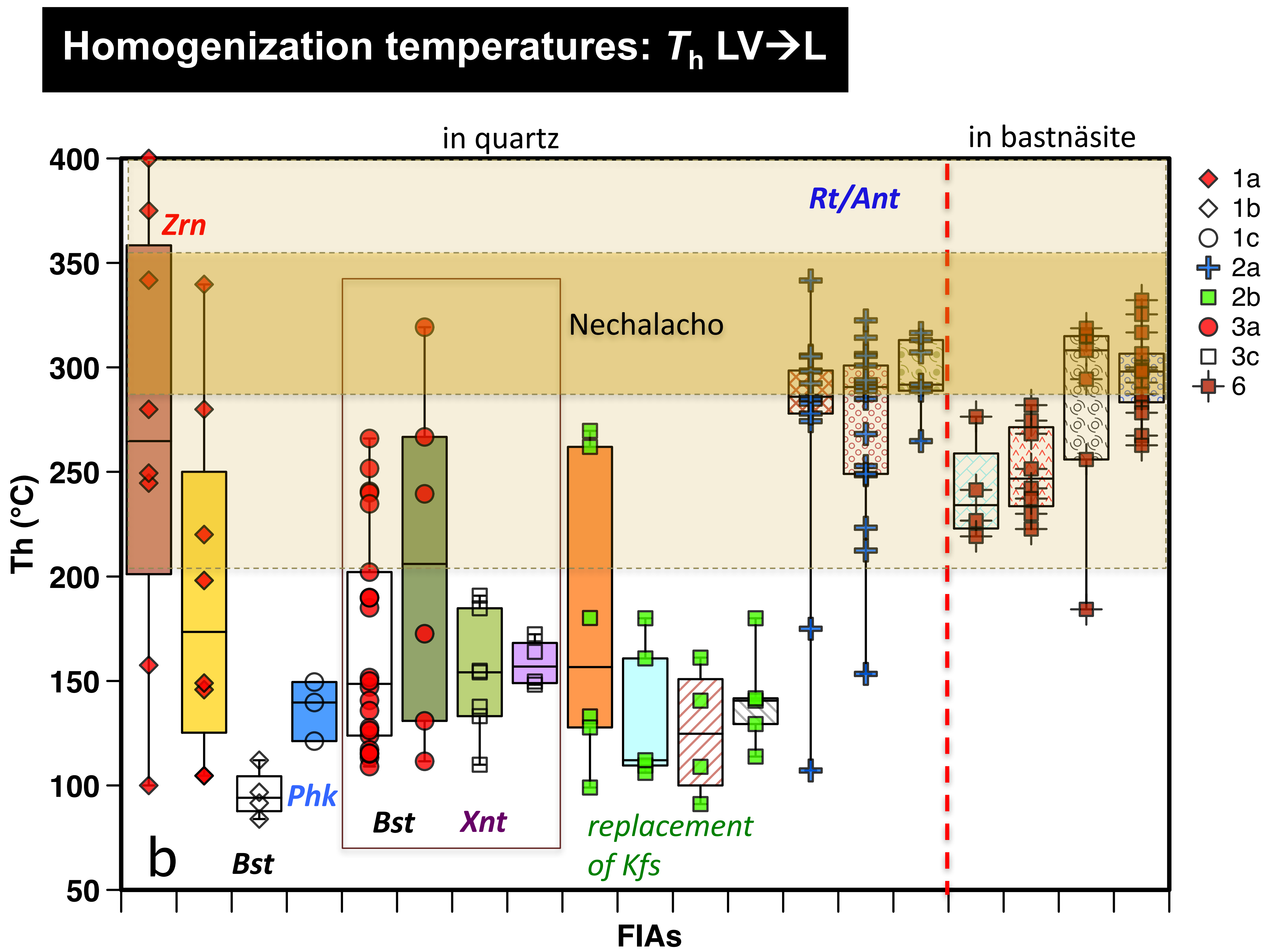
Trapped zircon in fluid inclusions





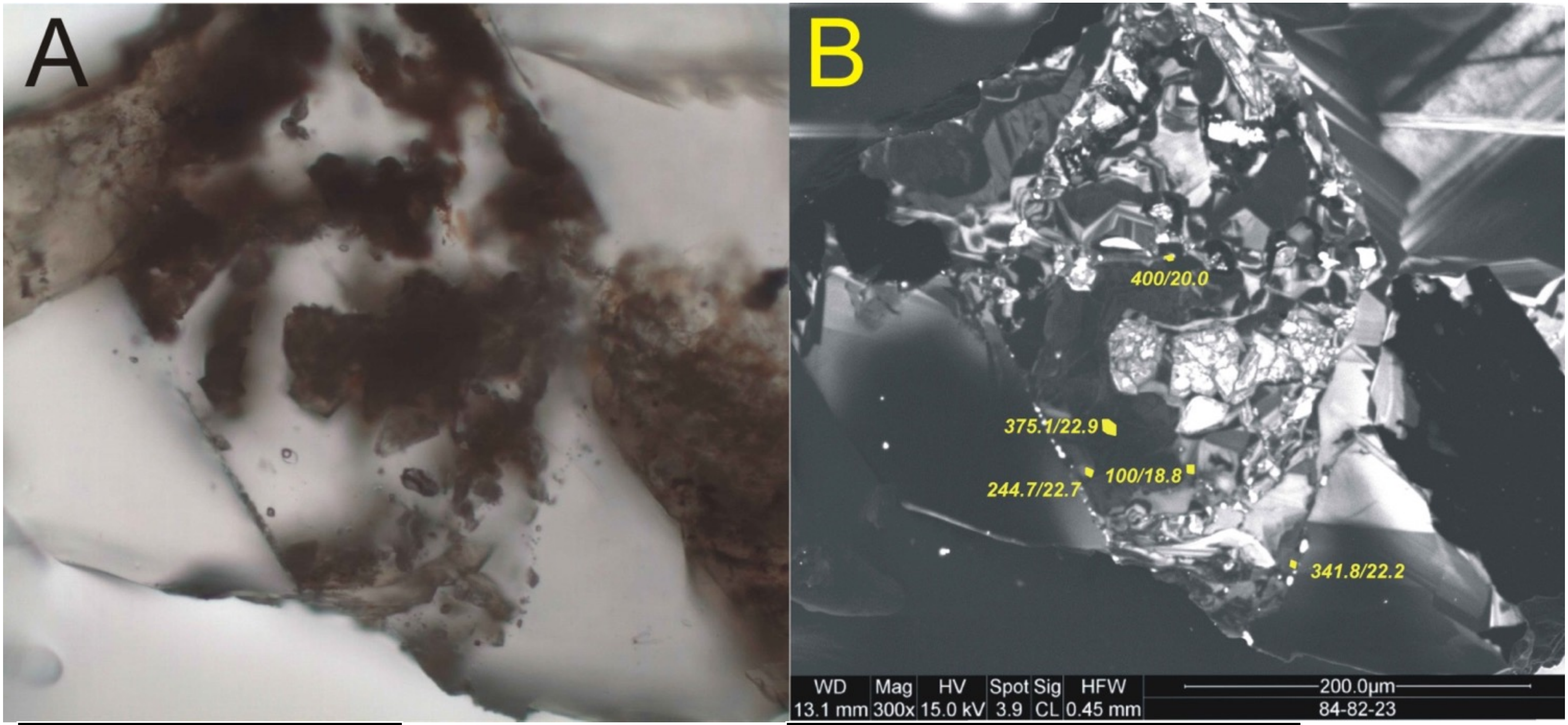
25µm
b
Rt
Rt
Qtz
Rutile (TiO_2)
Counts
Raman Shift (cm-1)
Ant
Ant
Ant
Qtz
Ant
Ant
Ant
Qtz
Anatase (TiO_2)
Raman Shift (cm-1)


Ice melting temperatures
in quartz
in bastnäsite
0
-5
-10
-15
-20
-25
-30
Tm$_{ICE}$ (°C)
FIAs
Zrn
Bst
Phk
Bst
Xnt
Nechalacho
replacement of Kfs
Rt/Ant
a
1a
1b
1c
2a
2b
3a
3c
6



Homogenization temperatures: T_h LV→L
in quartz
in bastnäsite
Zrn
Rt/Ant
Nechalacho
Phk
Bst
Bst
Xnt
replacement
of Kfs
b
Th (°C)
FIAs
400
350
300
250
200
150
100
50
1a
1b
1c
2a
2b
3a
3c
6

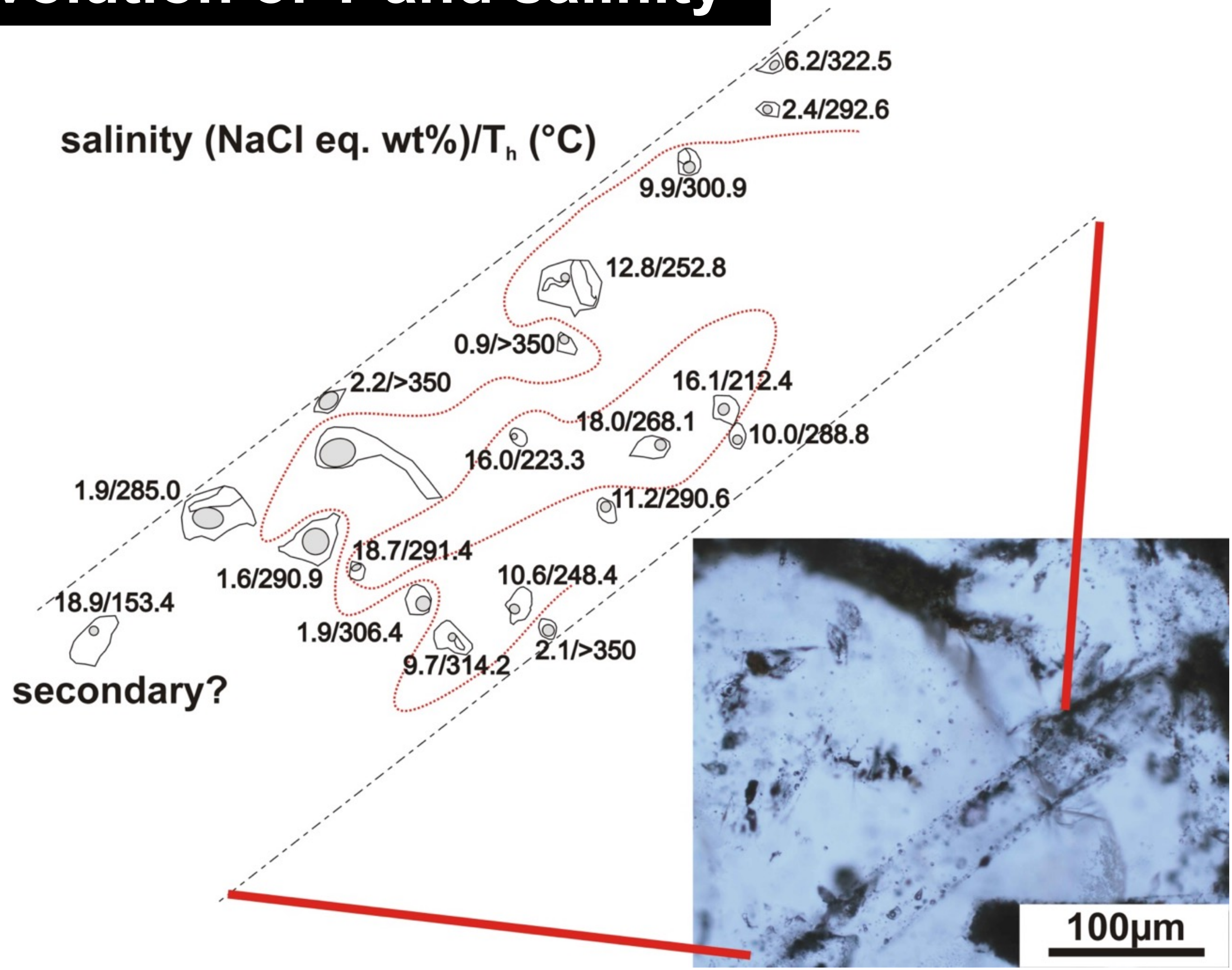
Complex growth and fluid history



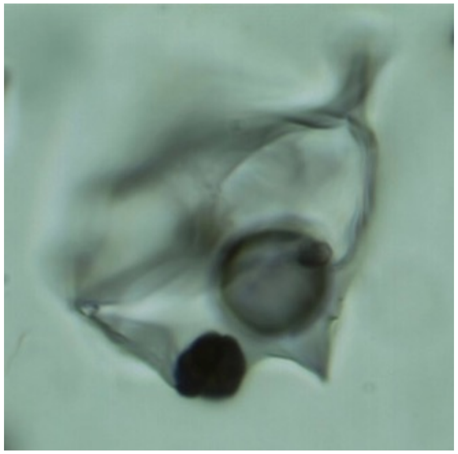
transmitted light

cathodoluminescence

Evolution of T and salinity



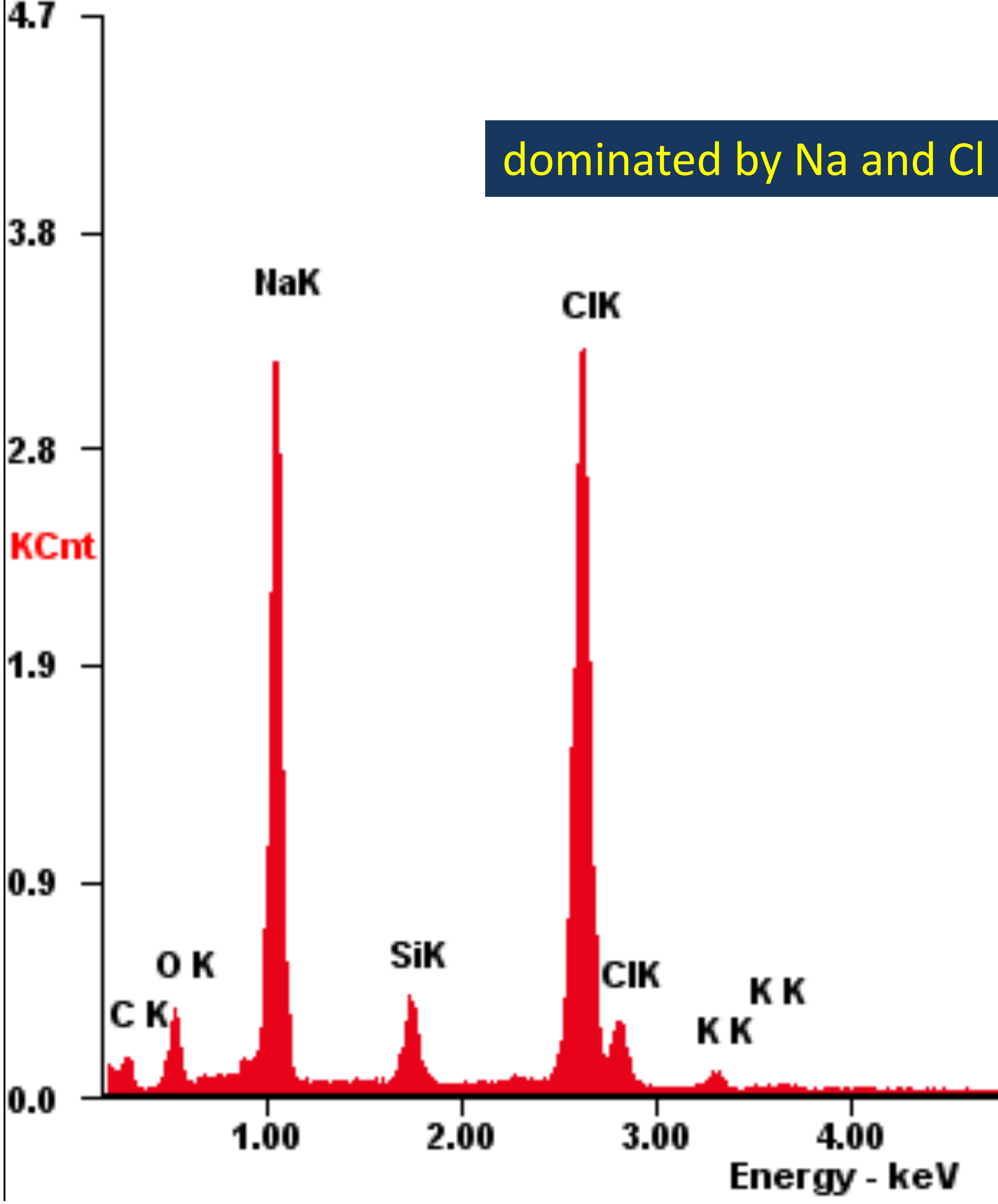
What about fluid chemistry?

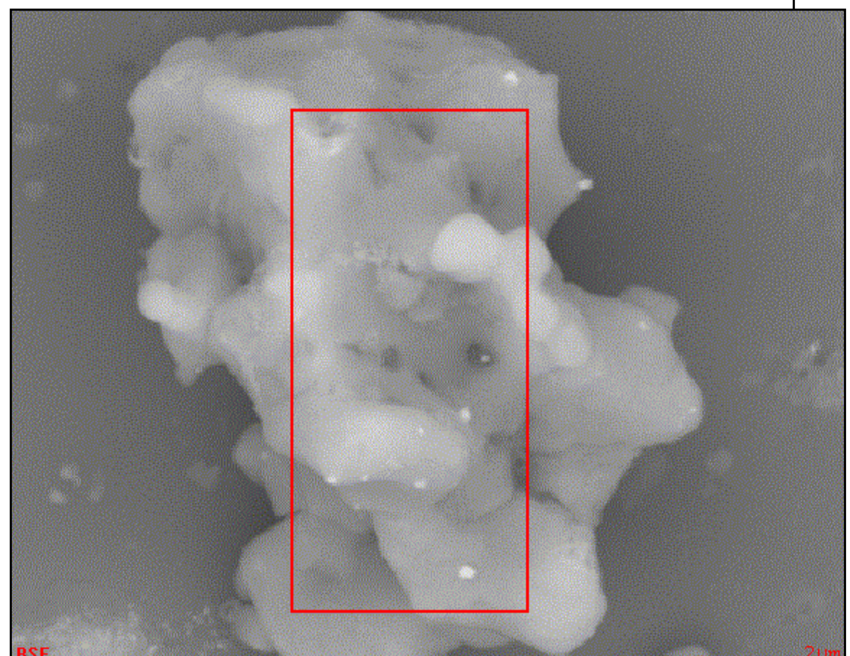


Energy-dispersive spectroscopy of decrepitates

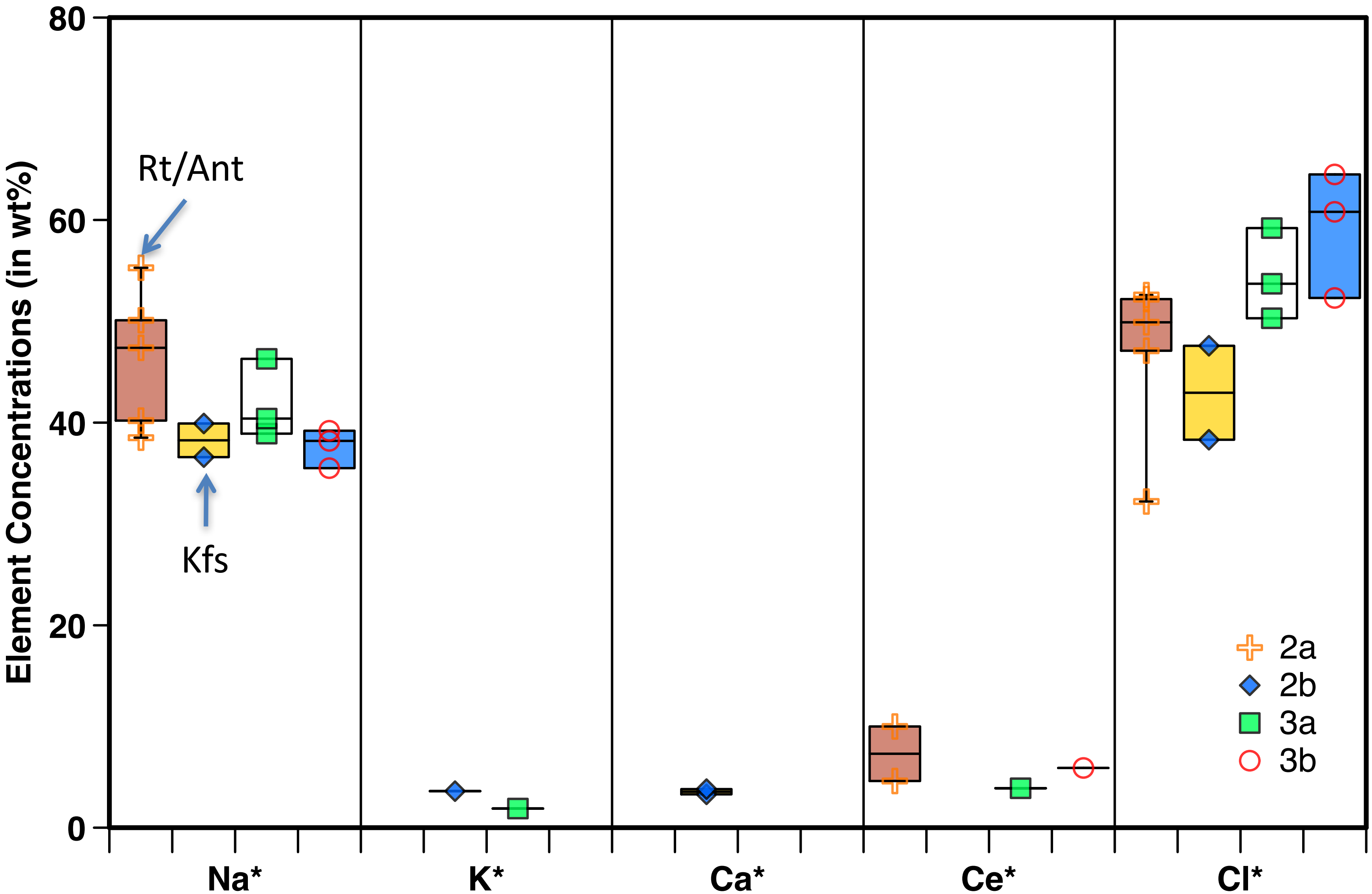
dominated by Na and Cl

Element	Wt%
CK	19.94
OK	07.80
NaK	26.80
SiK	03.40
ClK	40.78
KK	01.28



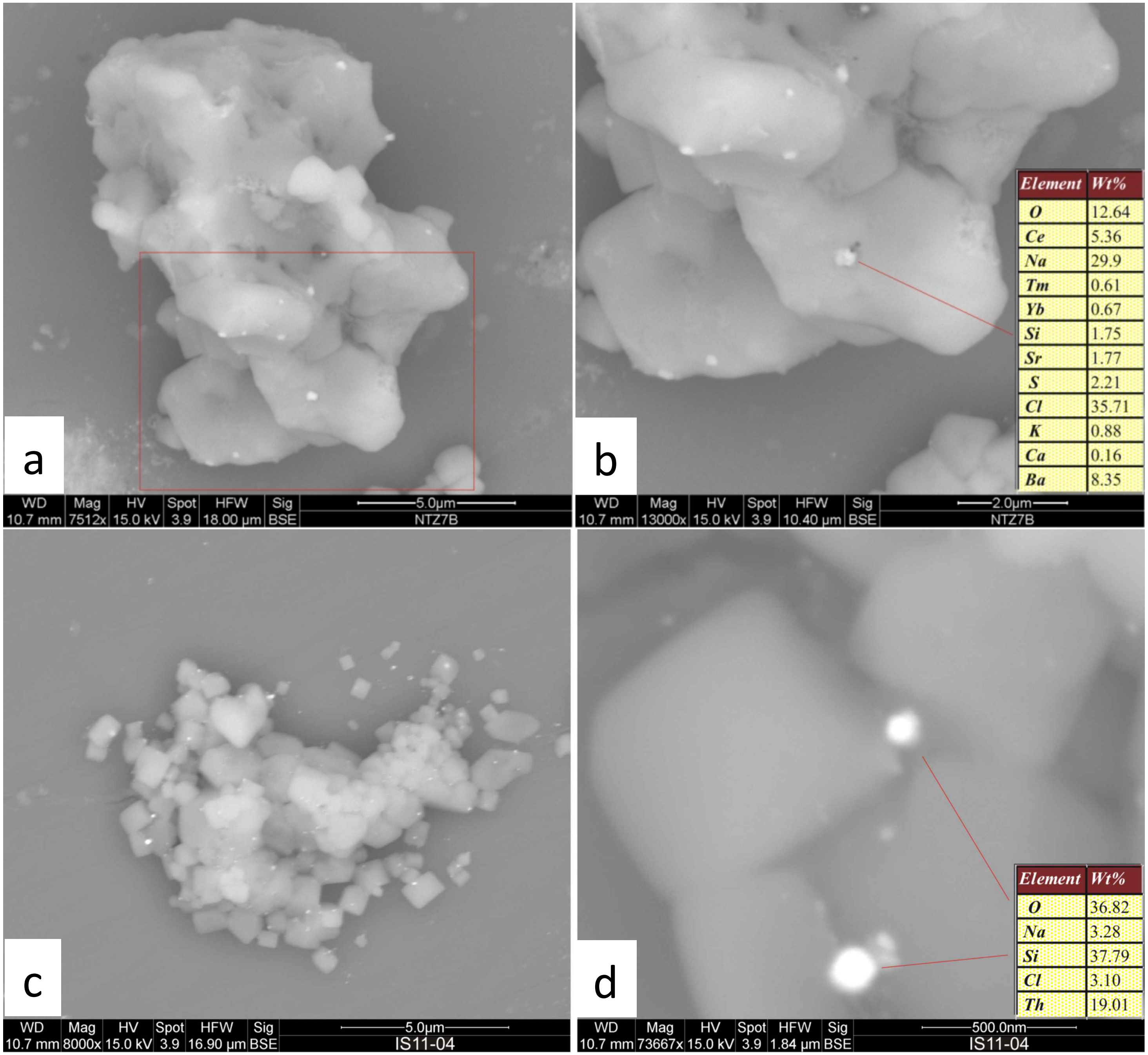


EDS analysis of decrepitates

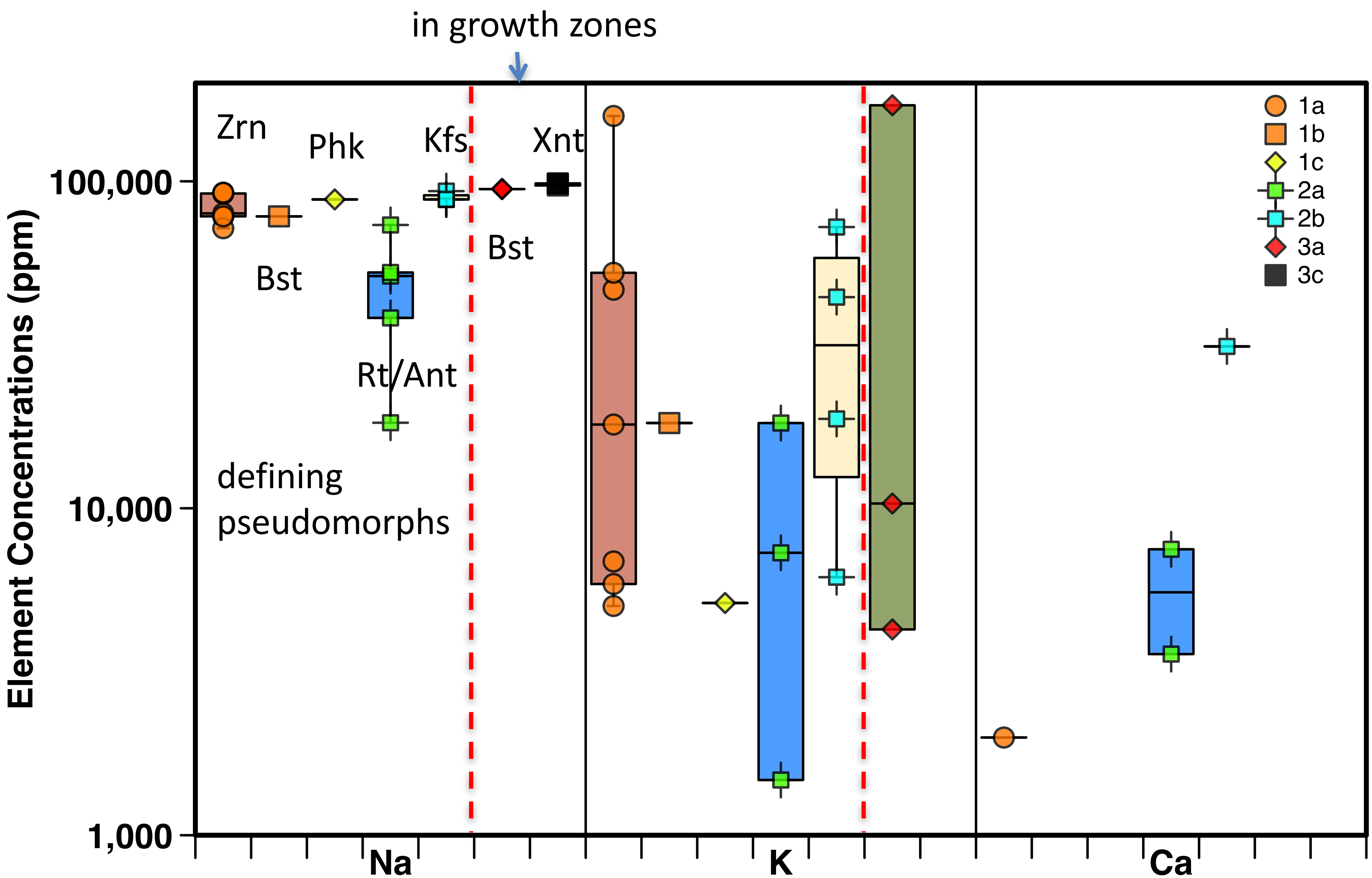


other elements: S, Ba, Sr, Ti, Th, other REE

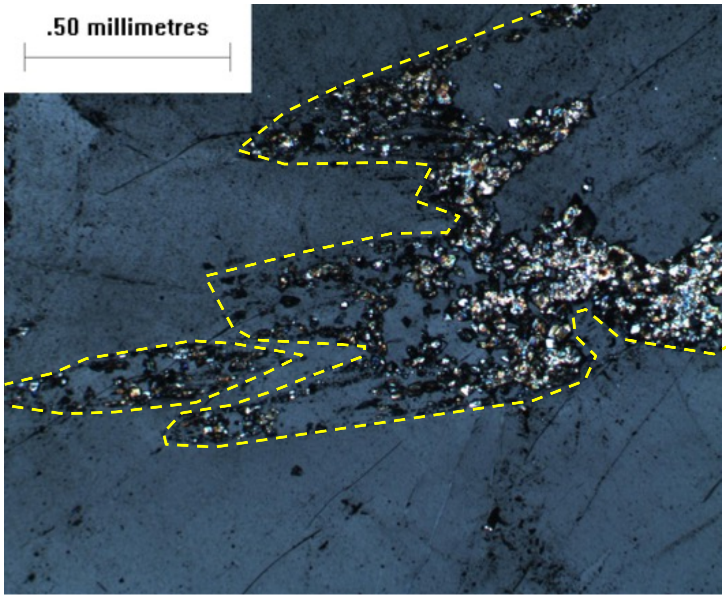
Little F

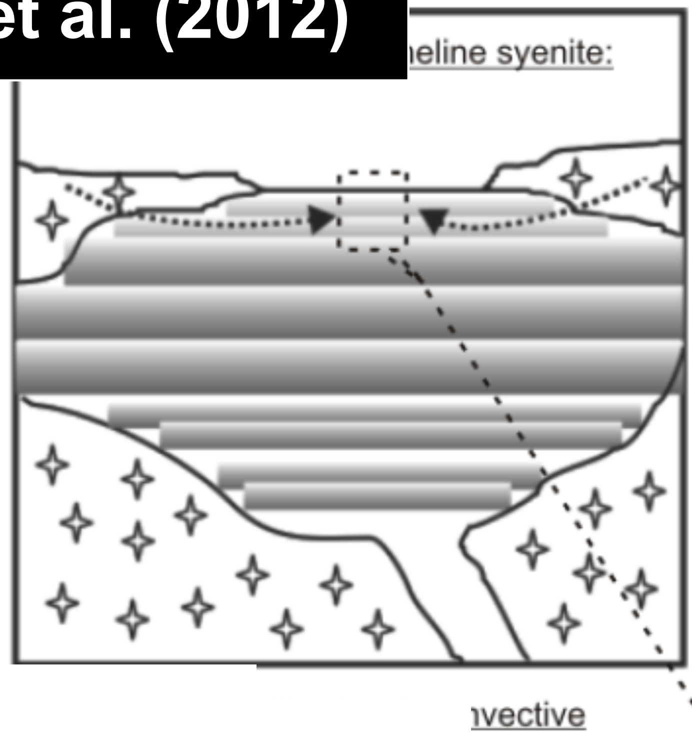

a
WD 10.7 mm Mag 7512x HV 15.0 kV Spot 3.9 HFW 18.00 µm Sig BSE
5.0µm
NTZ7B
b
Element Wt%
O 12.64
Ce 5.36
Na 29.9
Tm 0.61
Yb 0.67
Si 1.75
Sr 1.77
S 2.21
Cl 35.71
K 0.88
Ca 0.16
Ba 8.35
WD 10.7 mm Mag 13000x HV 15.0 kV Spot 3.9 HFW 10.40 µm Sig BSE
2.0µm
NTZ7B
c
WD 10.7 mm Mag 8000x HV 15.0 kV Spot 3.9 HFW 16.90 µm Sig BSE
5.0µm
IS11-04
d
Element Wt%
O 36.82
Na 3.28
Si 37.79
Cl 3.10
Th 19.01
WD 10.7 mm Mag 73667x HV 15.0 kV Spot 3.9 HFW 1.84 µm Sig BSE
500.0nm
IS11-04

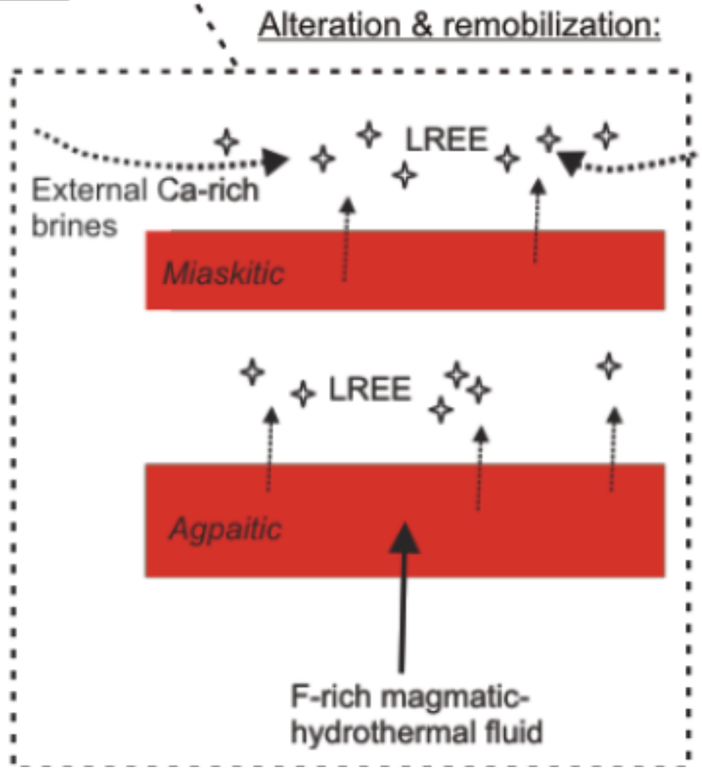
LA-ICP-MS analysis of fluid inclusions: Na, K, Ca



Mixing Model: Sheard et al. (2012)



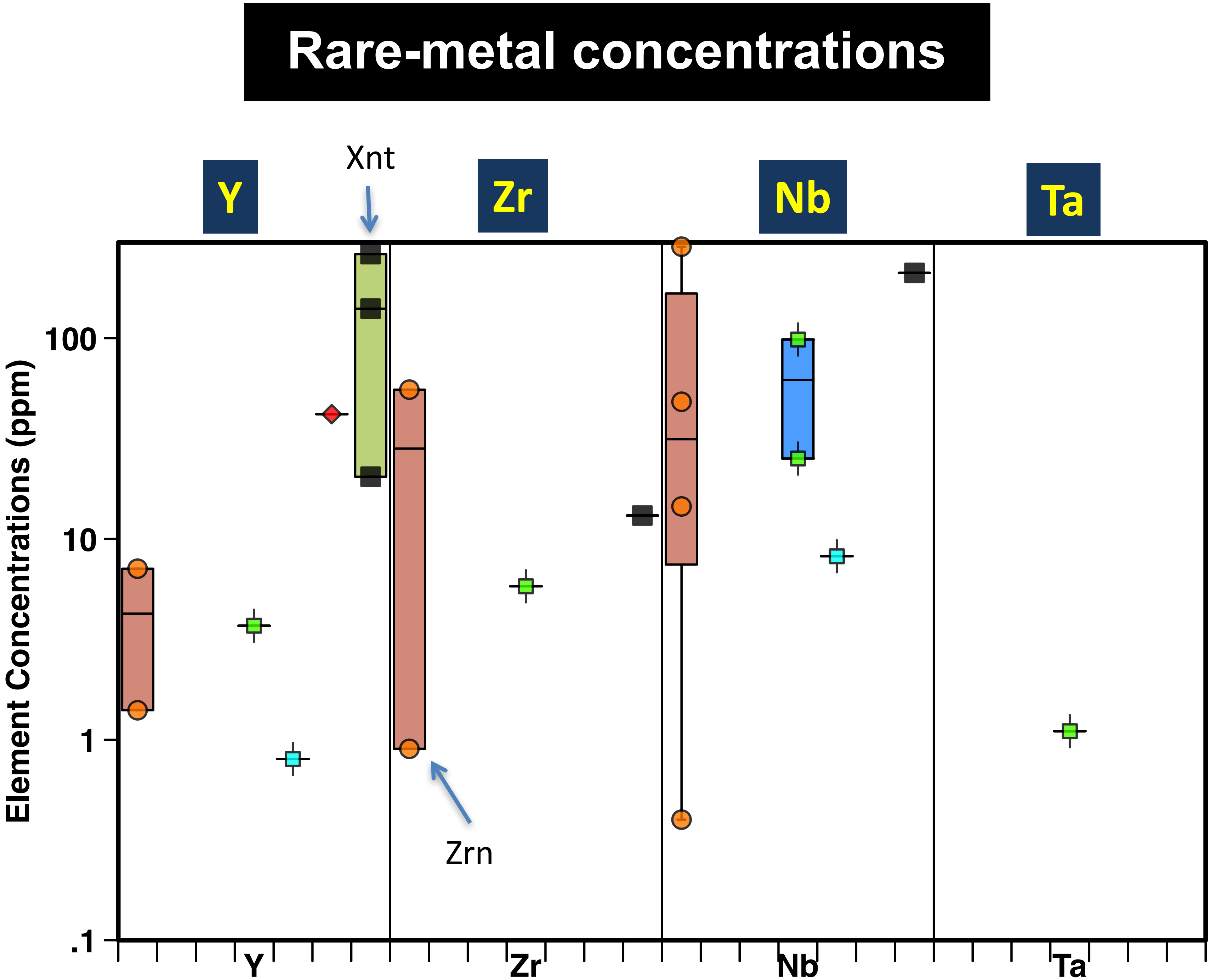




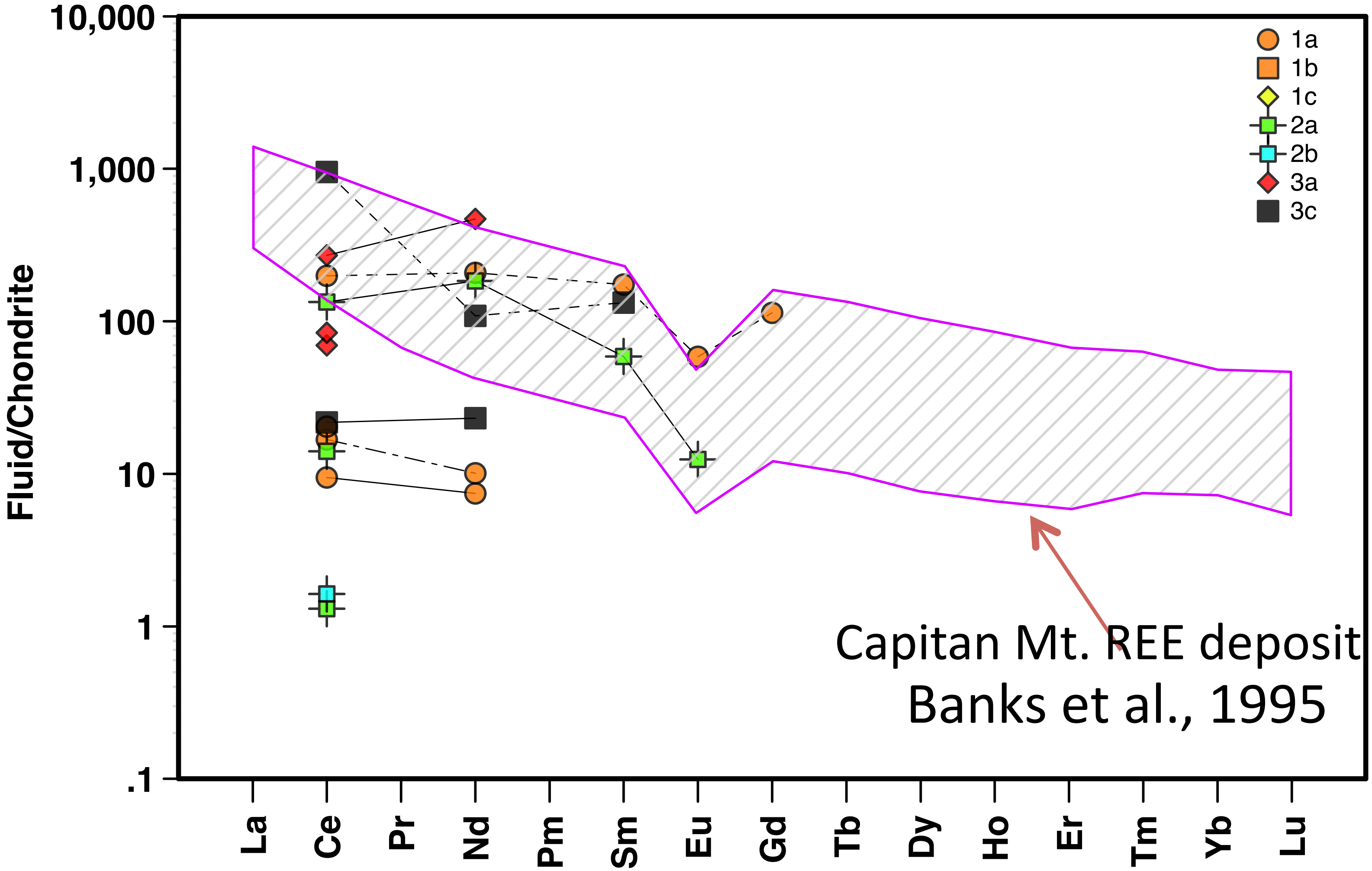
$$LnF_2^{+} + PO_4^{3-} \Leftrightarrow LnPO_4 + 2F^{-}$$

$$Ca^{2+} + 2F^{-} \Leftrightarrow CaF_2$$

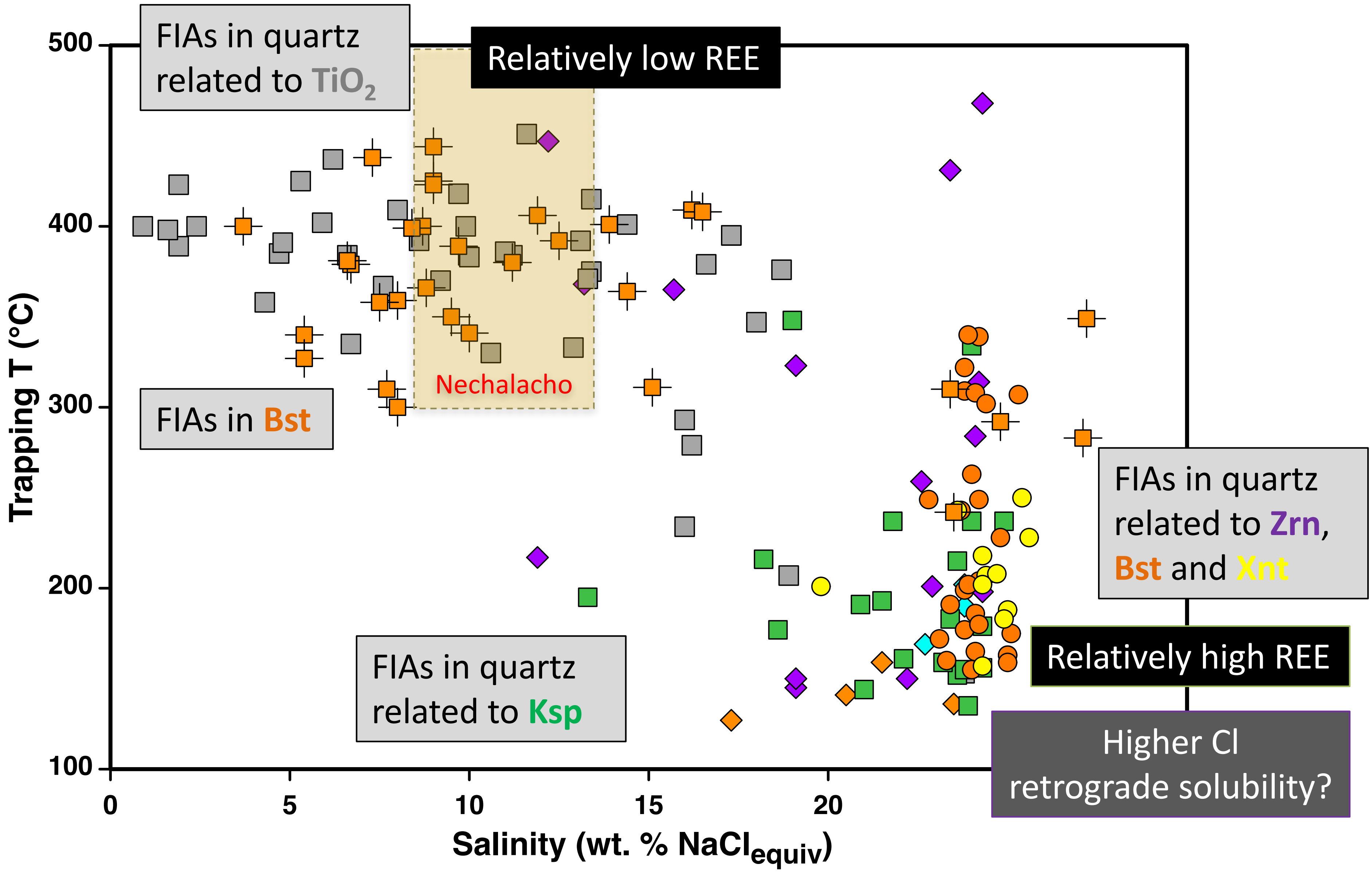
T Zone fluids: low F, Ca


Rare-metal concentrations
Y
Xnt
Zr
Nb
Ta
100
10
1
.1
Element Concentrations (ppm)
Zrn
Y
Zr
Nb
Ta

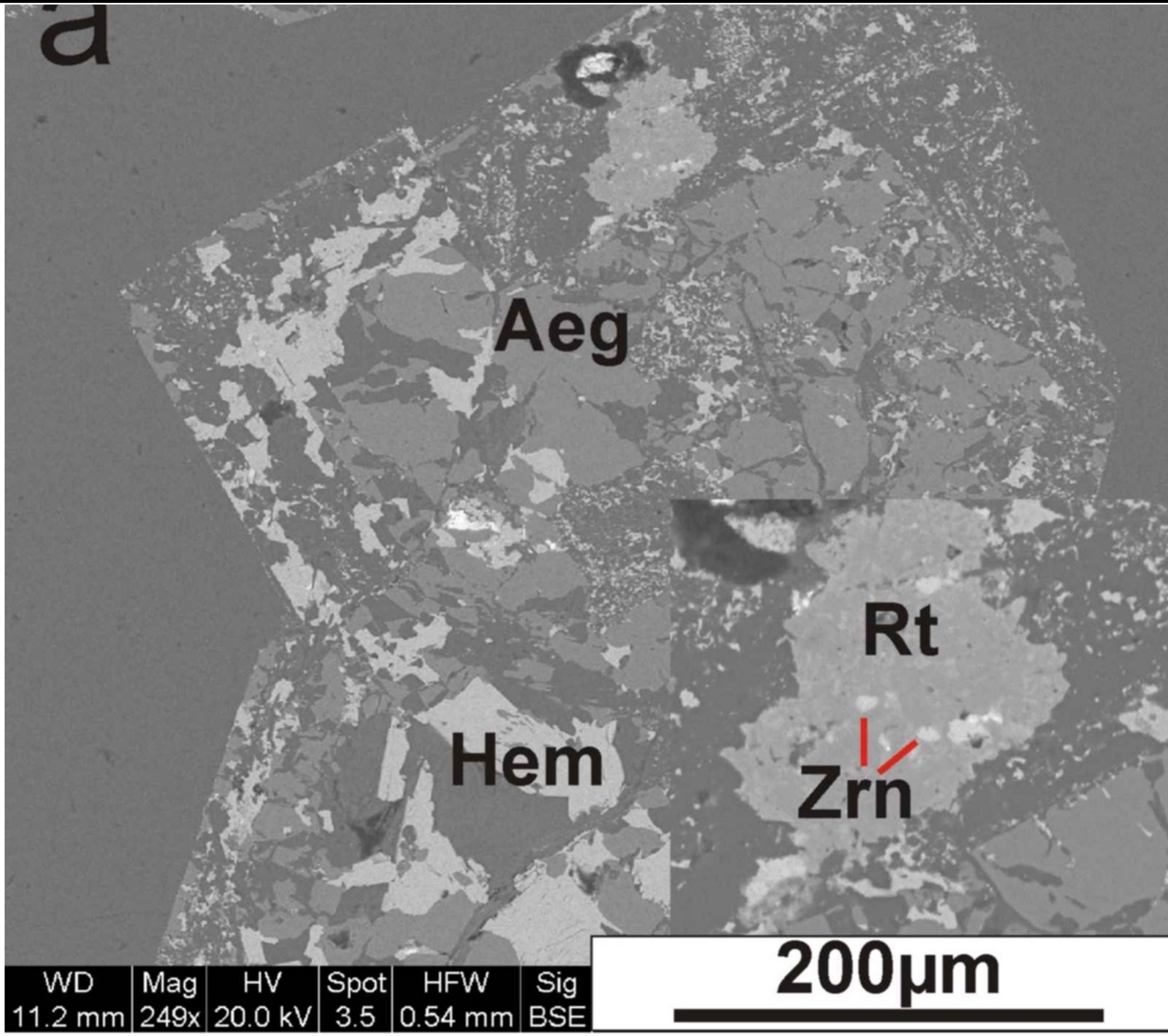
REE concentrations



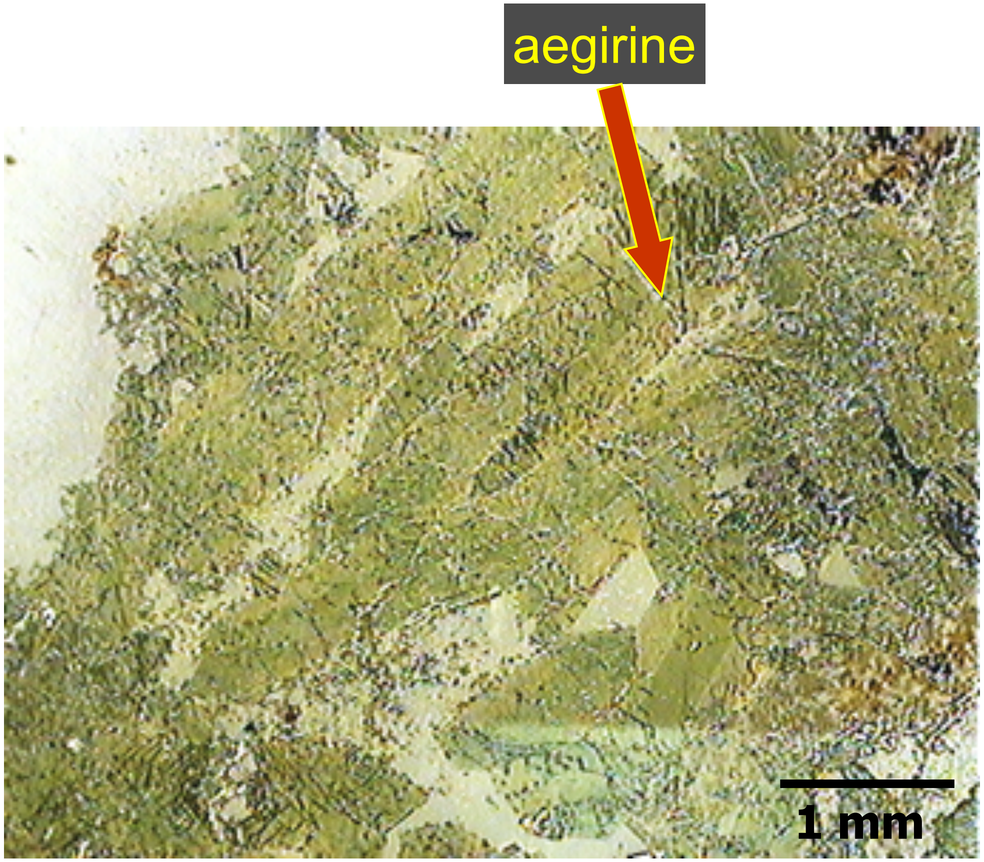
Two Populations

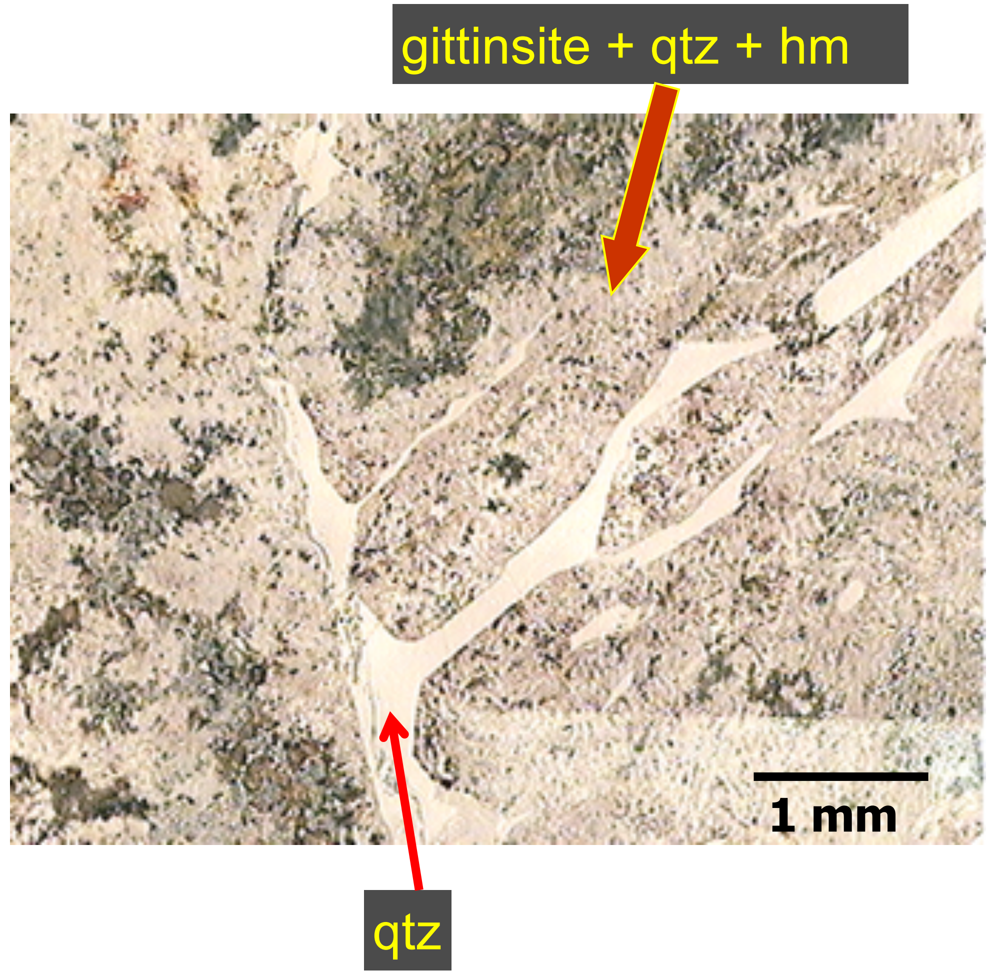


Reasons for Enrichment?: Aegirine and Mica replacement



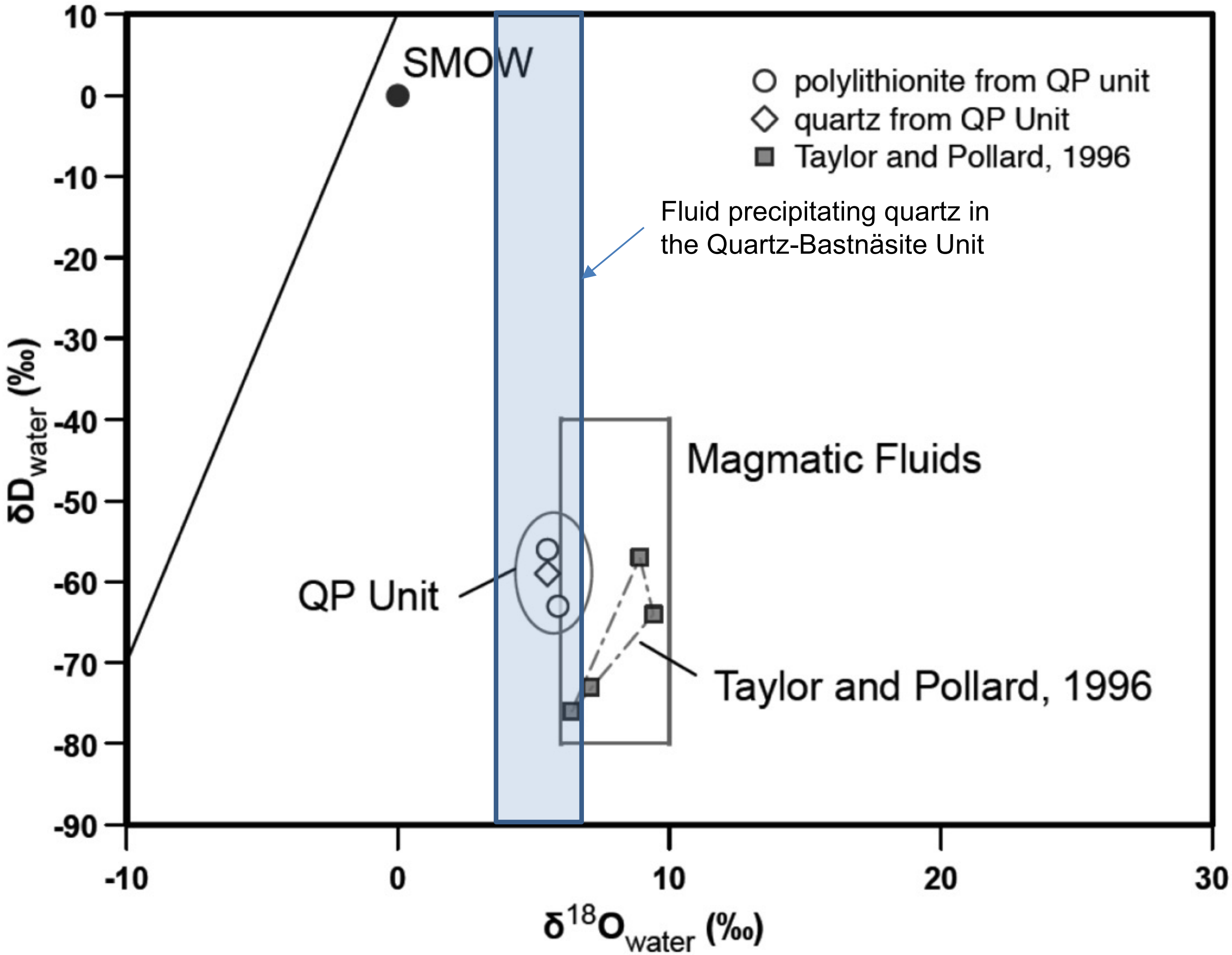
Strange Lake, Quebec/Labrador





Photos courtesy of J. Gagnon

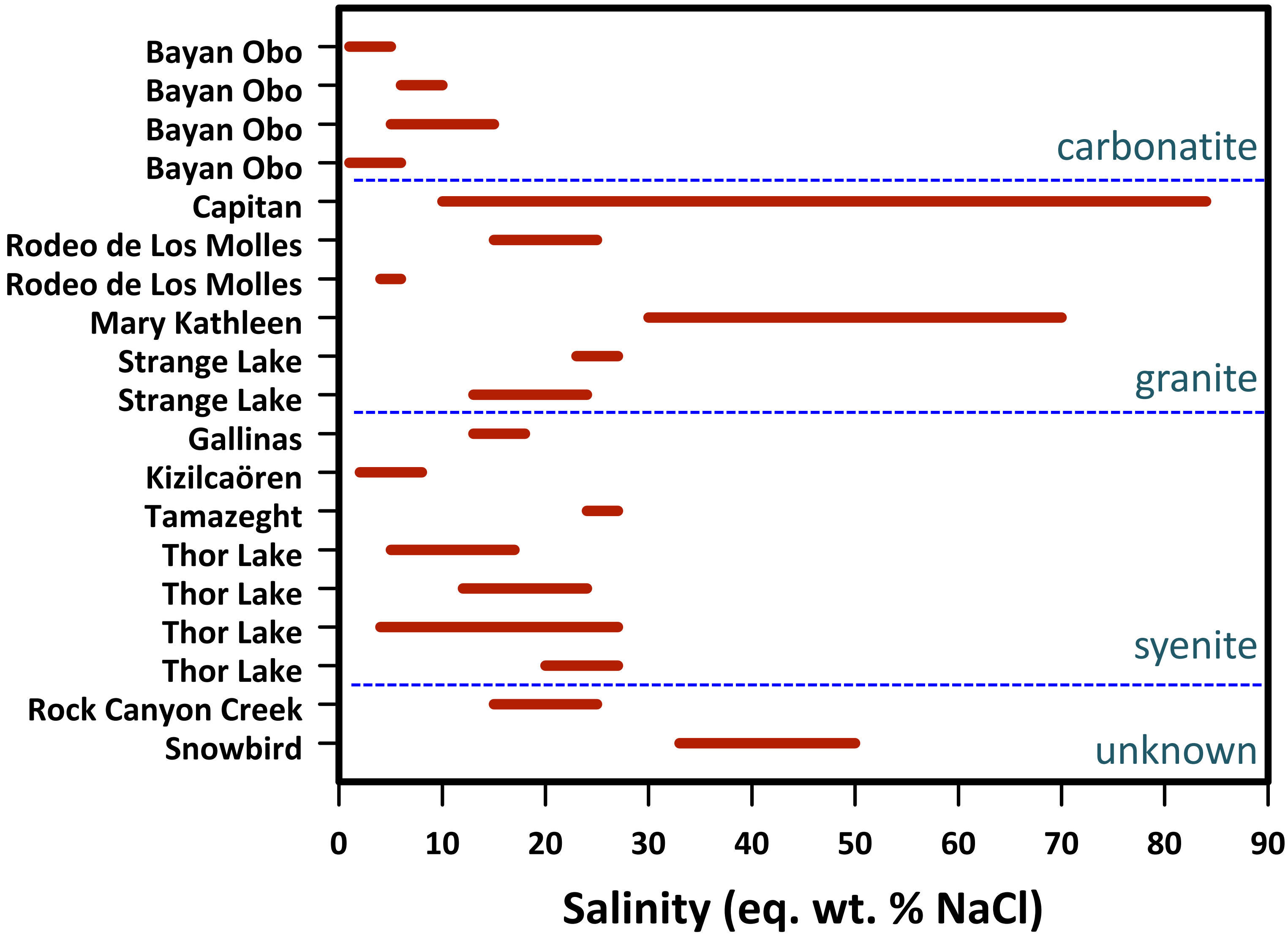
A magmatic source?
Li and Be?



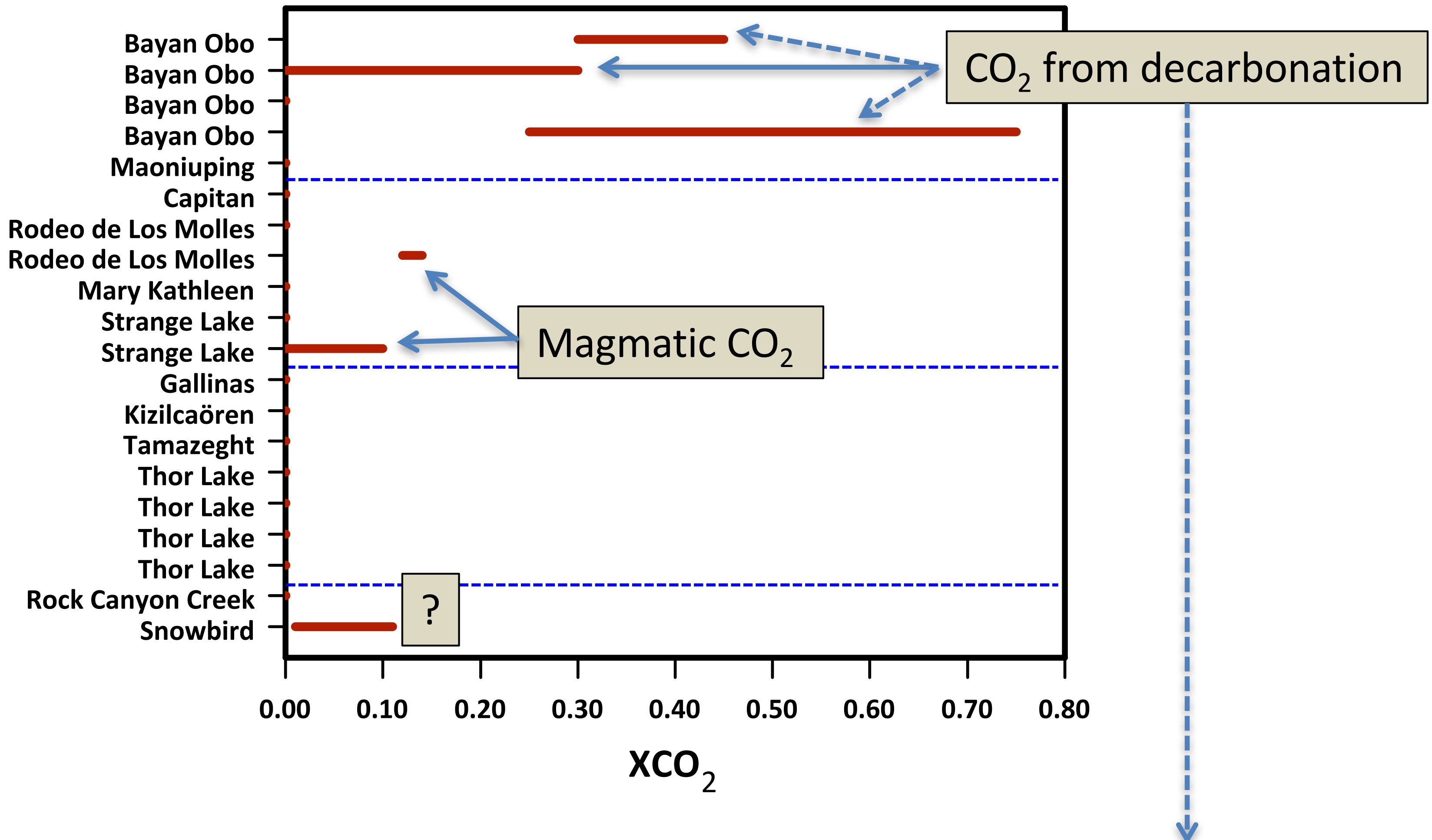
Questions: what roles do fluids play?

- Primary vs secondary concentration and enrichment?
  - Secondary at Thor Lake
- What types of fluids are capable of mobilizing significant rare metals?
  - Aqueous, low to moderate T and salinity
  - Low CO_2 and CH_4
- What is the evidence for this?
  - Ubiquitous replacement of primary minerals by hydrothermal assemblages
  - Primary fluid inclusions in pseudomorphs with rare-metal minerals, in rare-metal minerals, and in growth zones in quartz
- Are rare metals present in the fluids?
  - yes
- What concentrations?
  - 10s → 1000s ppm
  - Highest concentrations: ~ 150 to 250 °C and from ~ 20 to 25 wt. % $NaCl_{equiv}$
- What controls enrichment?
  - Replacement of mafic minerals and micas

Salinity of fluids in rare-metal systems



XCO_2 of fluids in rare metal systems



Bayan Obo: CO_2 from carbonate dissolution (Smith & Henderson, 2000)

$$5CaCO_3 + 3H_3PO_4 + HF \rightleftharpoons Ca_5(PO_4)_3F + 5CO_2 + 5H_2O$$

calcite *apatite*

Thank You

AVALON

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