Apatite as an indicator for volatile characteristics in the genesis of the Marathon Cu-PGE deposit, northwestern Ontario

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Geological Setting

- Proterozoic intrusive emplaced at 1106.3 ± 1 Ma
- northeast shoulder of the Midcontinent Rift
- unmetamorphosed, undeformed

Murahwi et al., 2010

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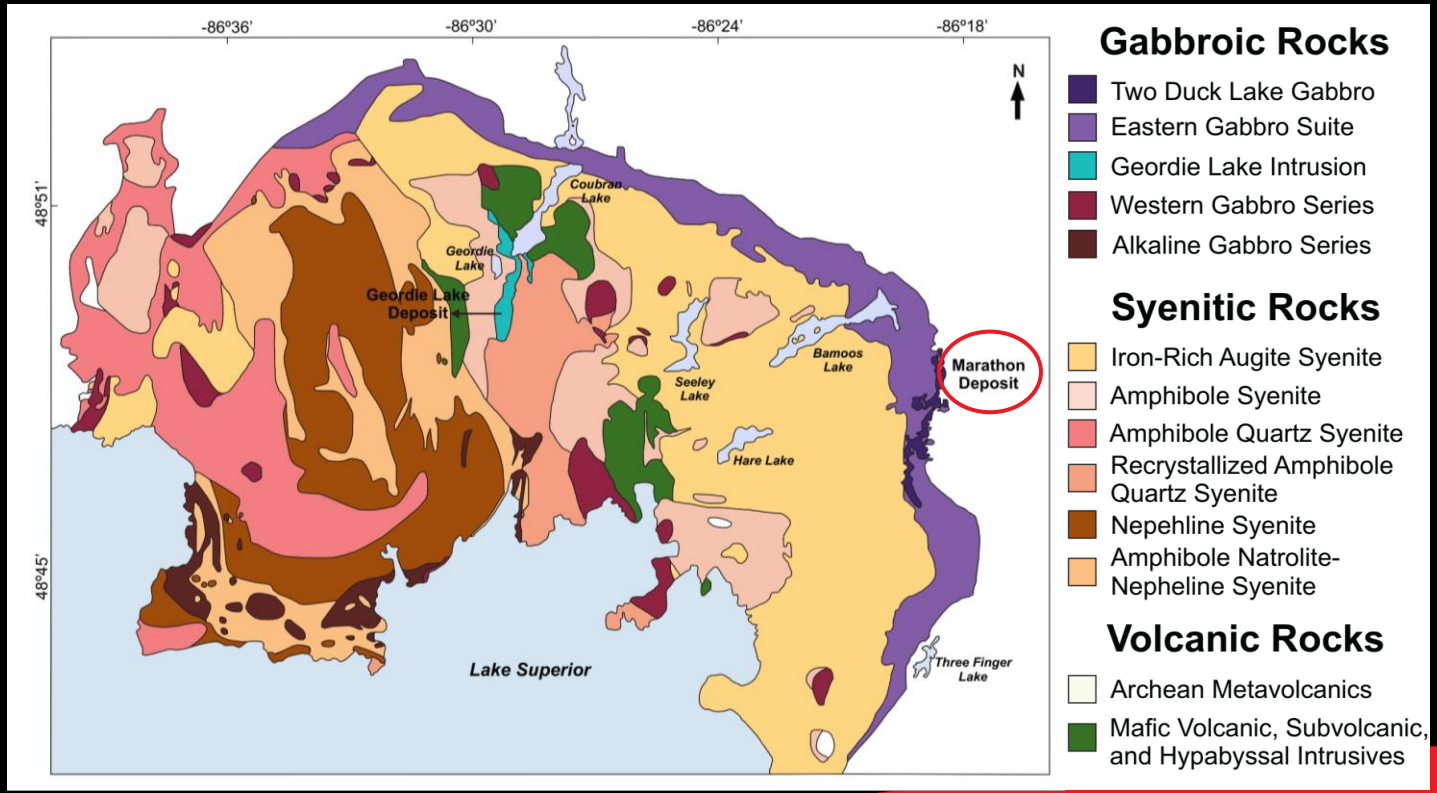
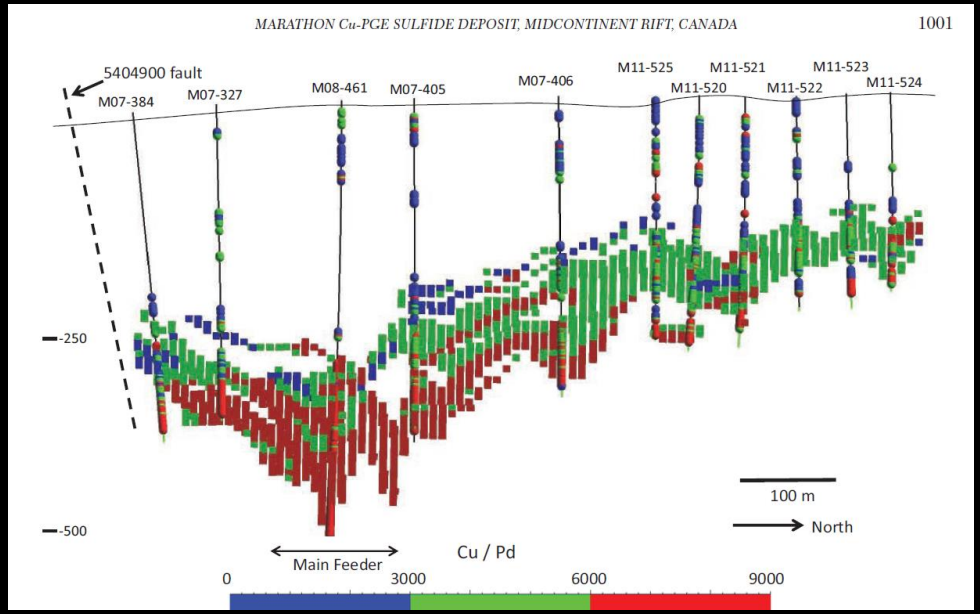
Geology of the Coldwell complex



Modified after Good et al., 2015

Characteristics of mineralized zones forming the Marathon PGE-Cu deposit

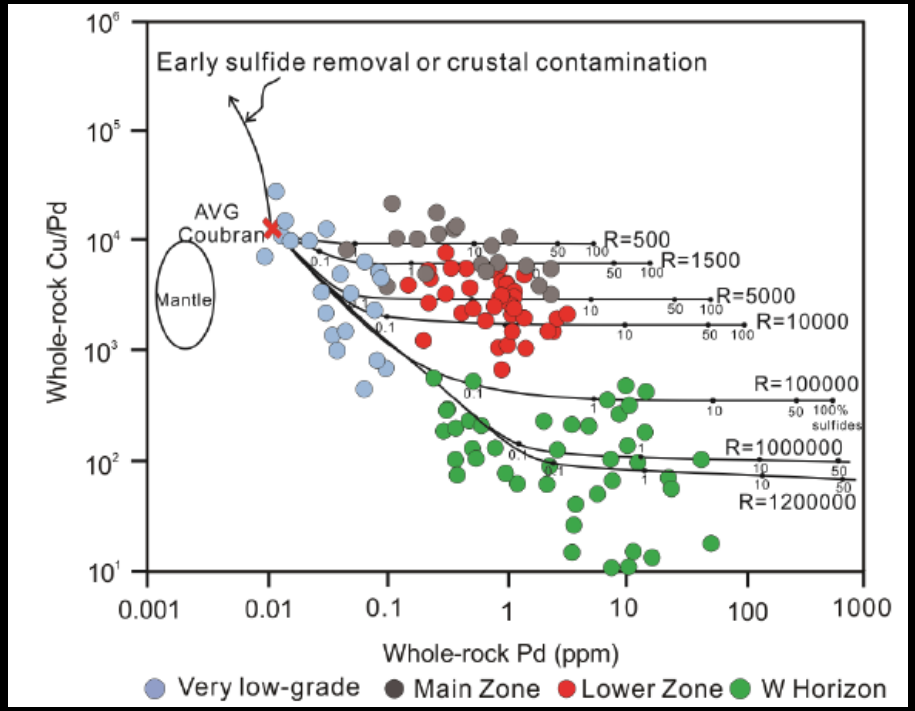


Good et al., 2015

Characteristics of mineralized zones forming the Marathon PGE-Cu deposit

Mineralization Zones	Sulfide Occurrence	PGE Grade (g/t)	S Content (%)	Cu/Pd
Footwall Zone	stringer to net-textured *Po>Ccp ± Pn ± Py*	<0.5	2 to 4 %	> 10000 to 35000
Main Zone	Disseminated *Ccp, Po ± Pn ± Py*	0.8 to 5	0.05 to 1%	1000 to 10000
W Horizon	Disseminated *Ccp, Bn > Po ± Pn ± Dg ± Py*	1 to 70	Trace to <0.4%	< 1000

R-Factor model for Marathon Mineralization



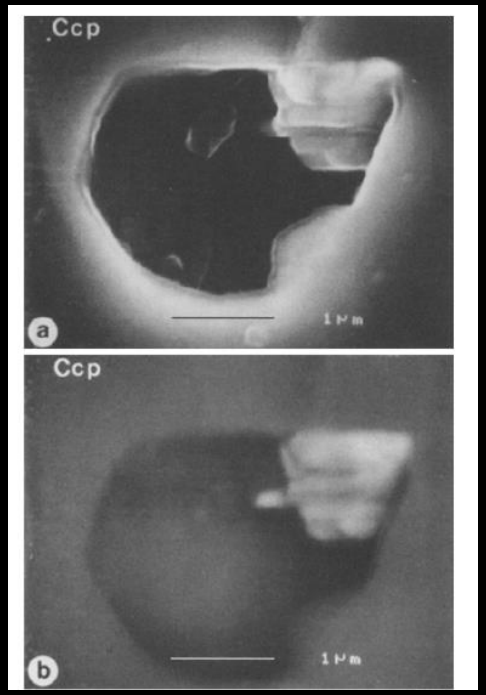
Cao et al., 2019

High R-factors can explain most Cu/Pd data

Kerr-Leitch multistage dissolution upgrading model requires 15 to 25 pulses and > 95% of initial sulfide liquid removal which seems improbable

Therefore, need to examine either Pd addition or Cu loss

Was there Pd-enrichment by some hydrothermal mechanism?



Watkinson and Jones, 1996

- Example, evidence presented by Watkinson and co-workers in 1980's and 1990's such as NaCl rich fluid inclusions on edges of sulphide grains that contain Pd-Ag-Te-Pb mineral

For samples with very low Cu/Pd (60 to 1000)

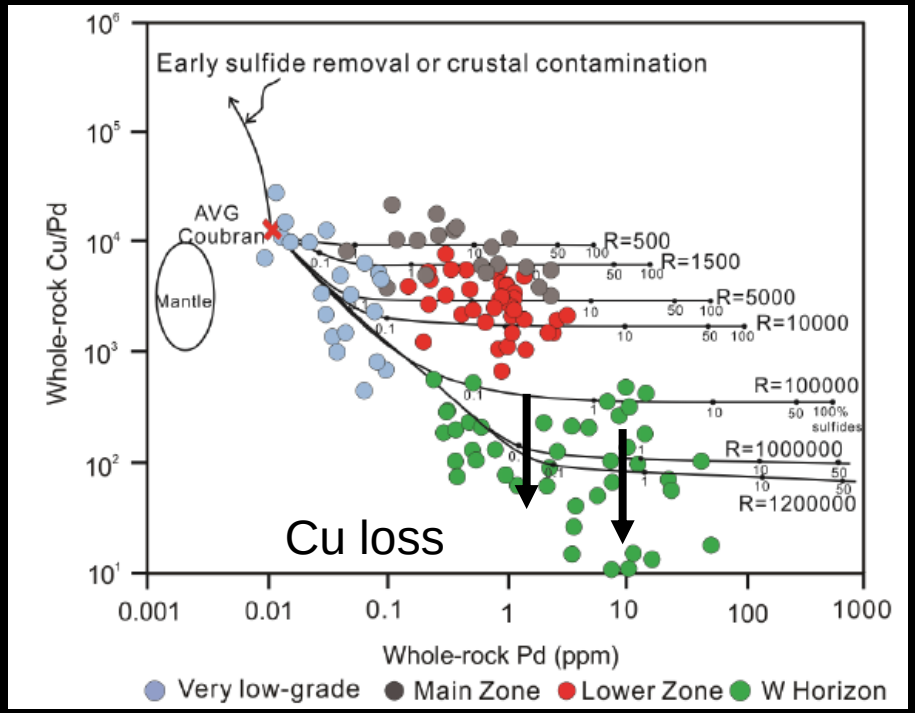
Evidence for Pd-enrichment by magmatic process

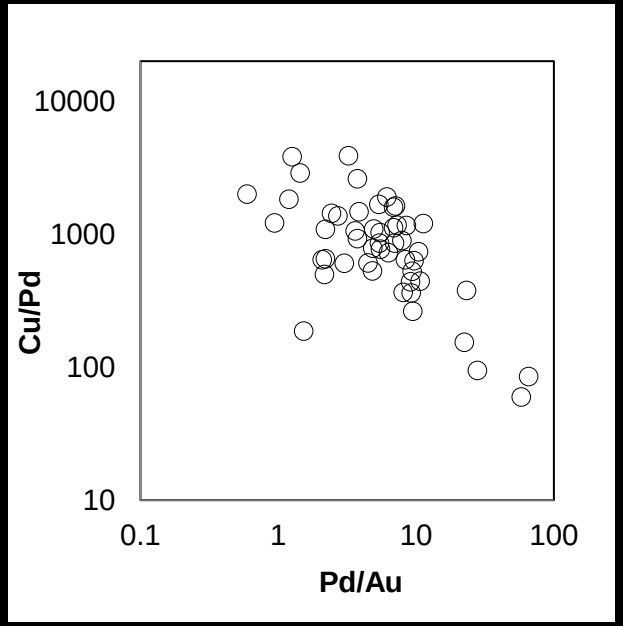
- Correlation between Pd and Pt (Pd/Pt between 2 and 5)
- Positive associative relationship between Te and Pd+Pt

Evidence for S, Cu and Au loss by hydrothermal process

- No correlation between Au and Pd
- No correlation between Cu and Pd
- No correlation between S and Pd
- In extreme cases, very low Cu (~200 ppm), Au (<0.03 ppm) and S (<0.01%) occur in samples with high Pd+Pt (> 2 to 3 ppm and up to 70 ppm)
- Inverse relationship between Cu/Pd and Pd/Au

Therefore, W horizon mineralization best defined by:
(a) magmatic accumulation of PGE at high R-Factor, and
(b) subsequent overprint by hydrothermal mechanism and removal of S, Cu and Au





50 samples from a 19 m thick interval in W Horizon (average grade of 2.5 ppm Pd+Pt over 19 metres)

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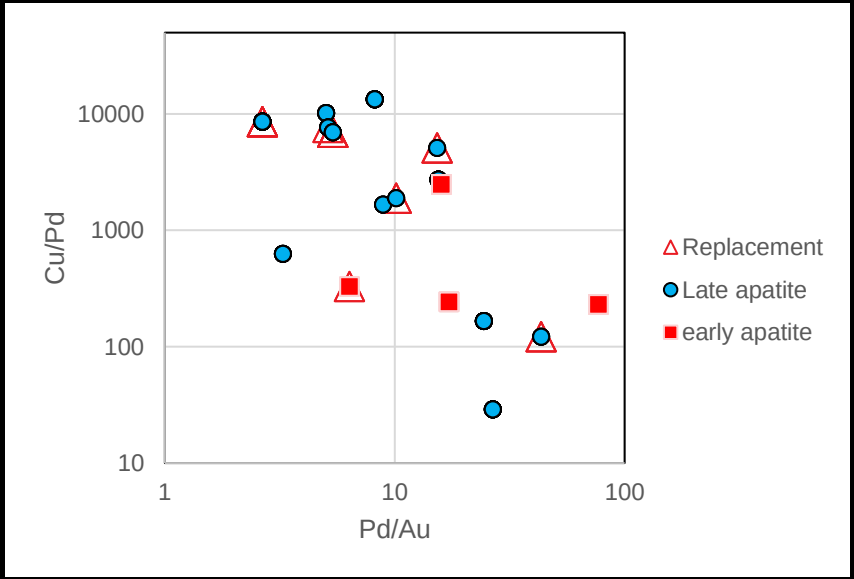
Why Apatite?

- Apatite crystallizes over a very long period during crystallization from early crystallization to very late hydrous stage
- Can apatite textures / compositions tell us the nature of late-stage fluids responsible for S, Cu and Au mobility?
- Samples studied are representative of the complete sequence from high Cu/Pd (Footwall type mineralization) to very low Cu/Pd (W horizon type)



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Petrography of the TDLG

- Vari-textured, medium-grained to pegmatitic gabbro
- plagioclase, olivine, sub-ophitic clinopyroxene
- minor apatite, biotite, and amphibole

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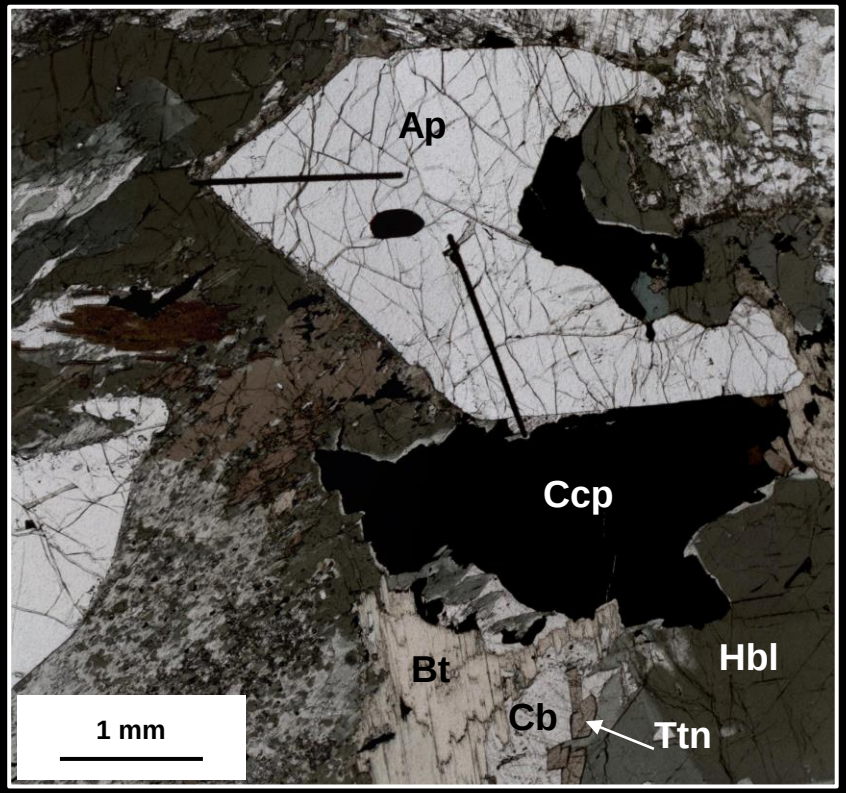
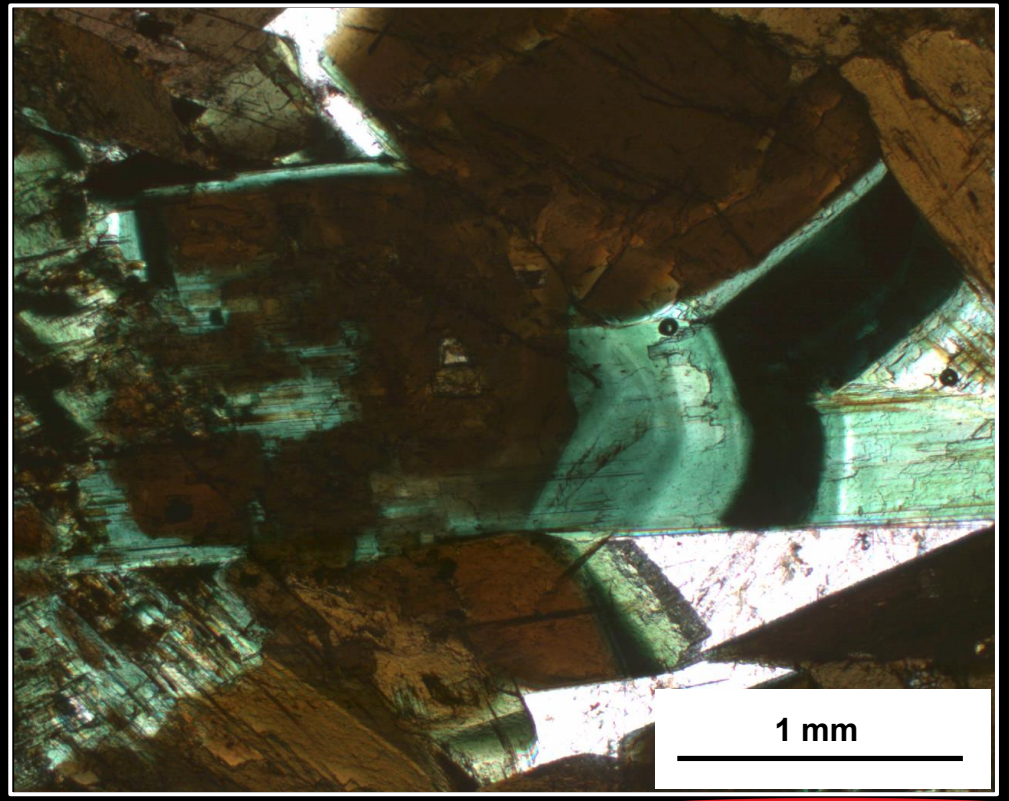
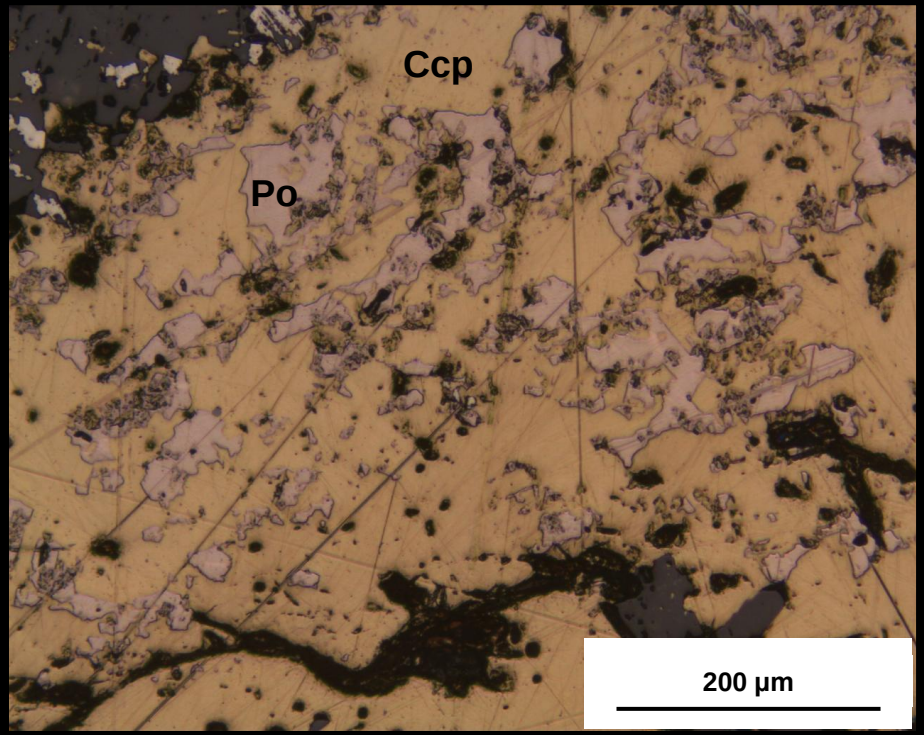
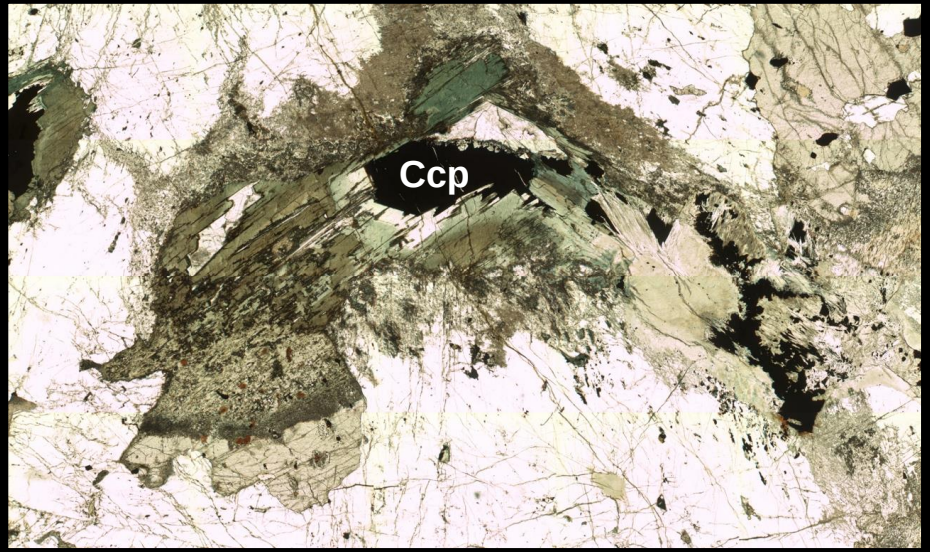
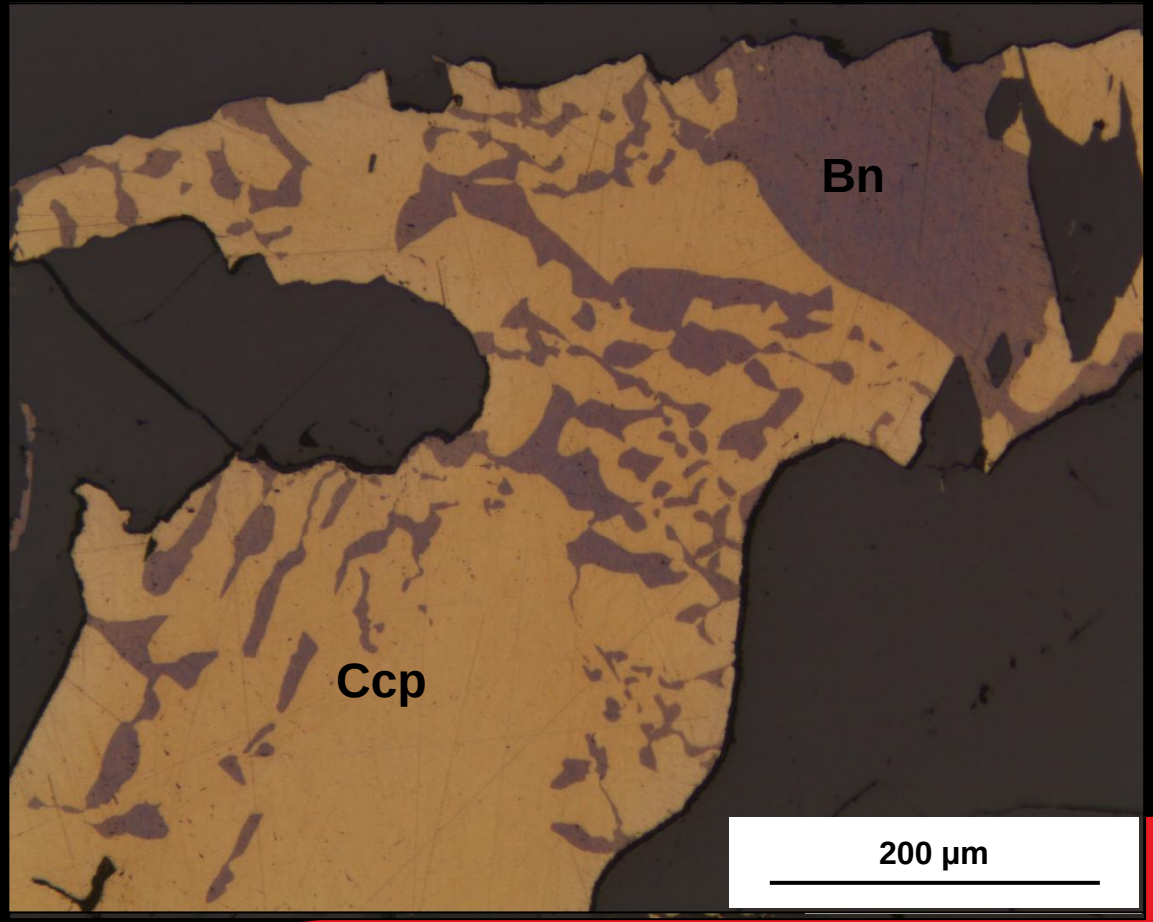

Ap
Ccp
Bt
Hbl
Cb
Ttn
1 mm


1 mm

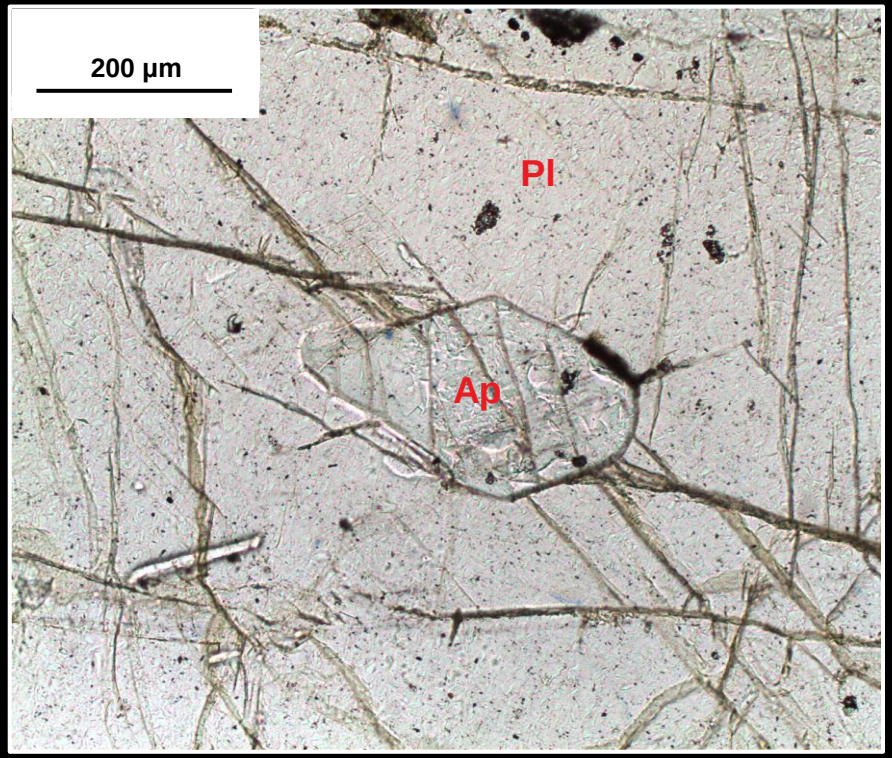

Ccp
Po
200 µm

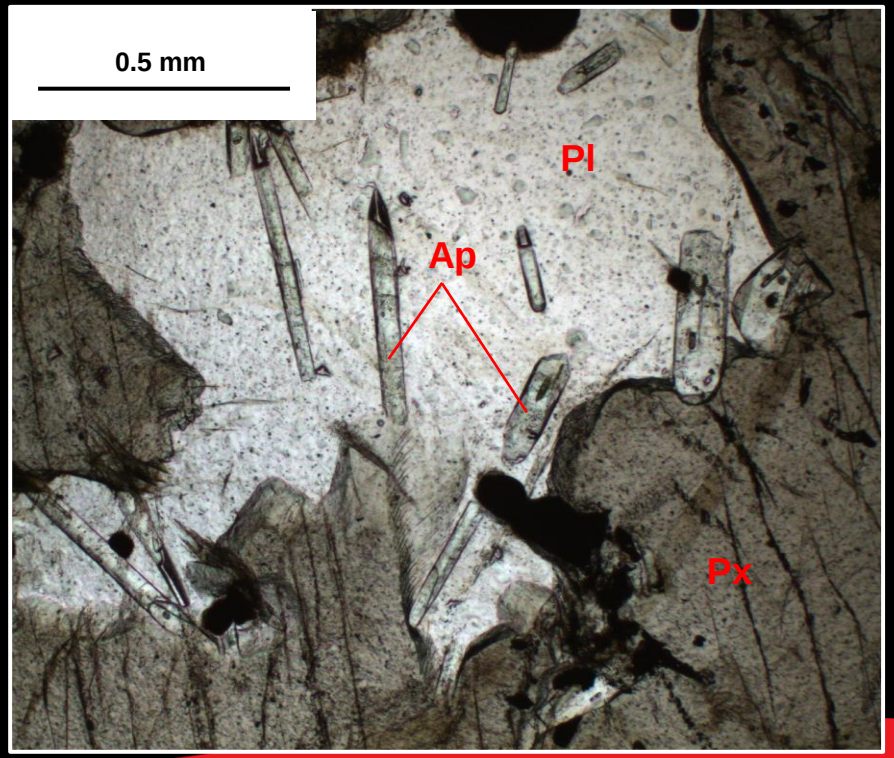

Ccp


Bn
Ccp
200 µm

Apatite Textural and Chemical Variation

Early Apatite (very fine grained includions in plagioclase)





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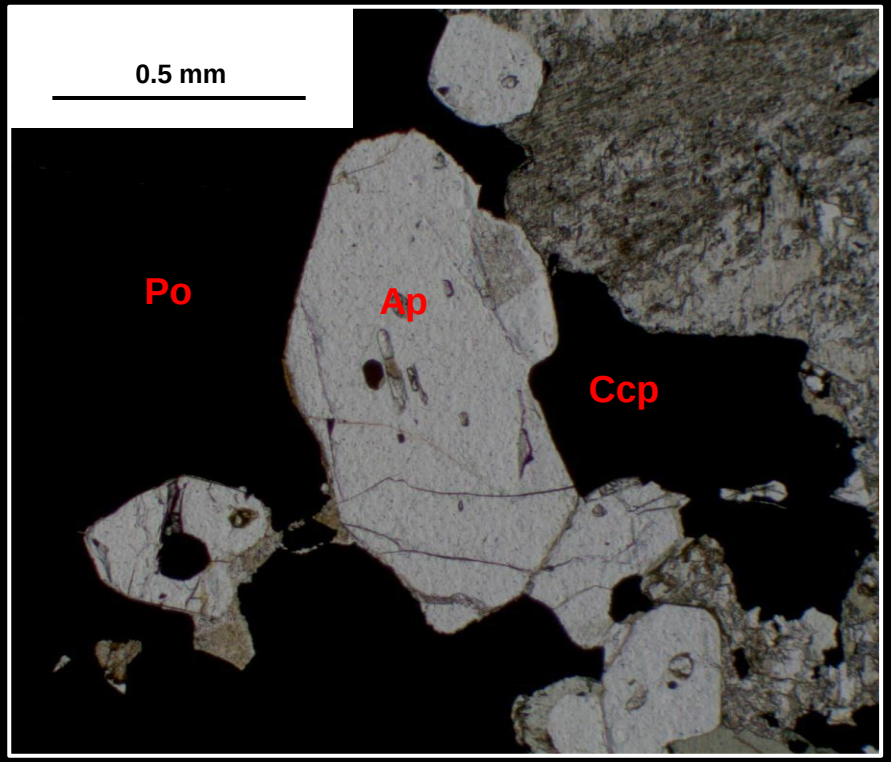
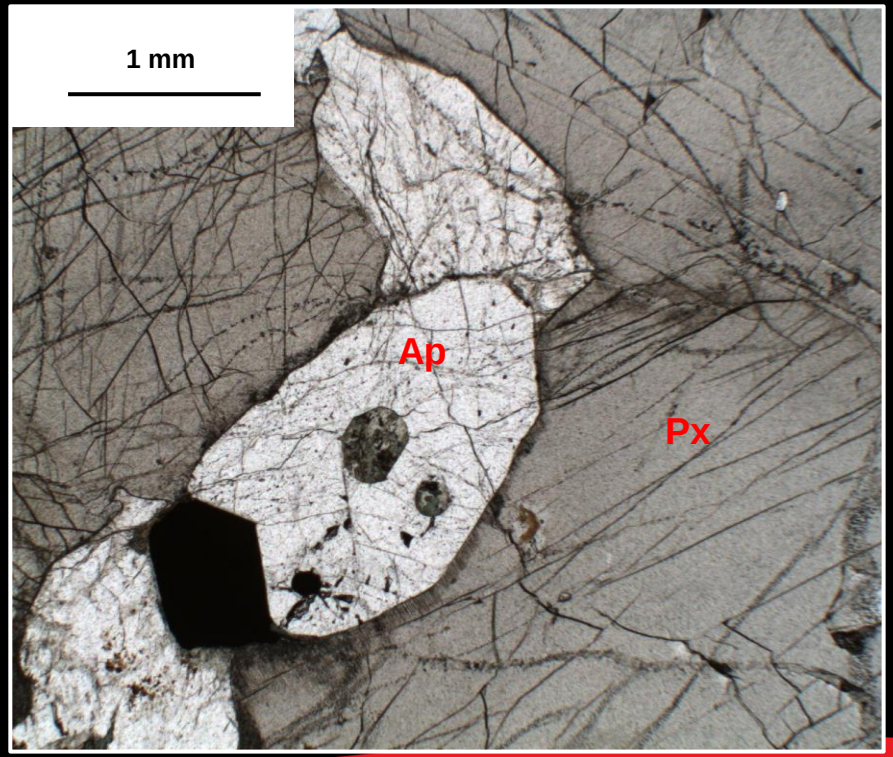
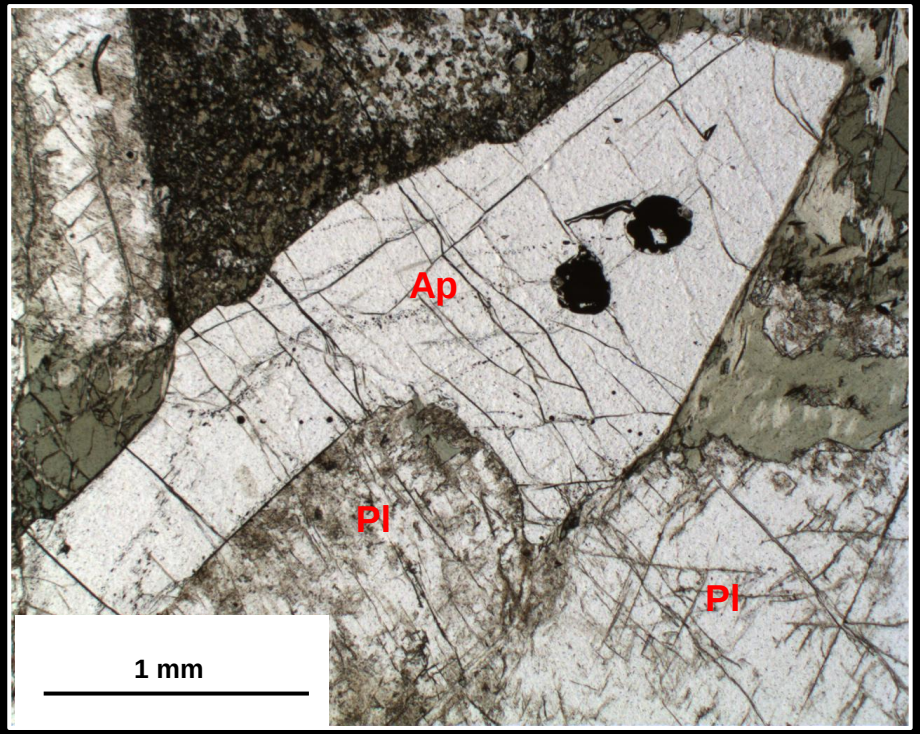
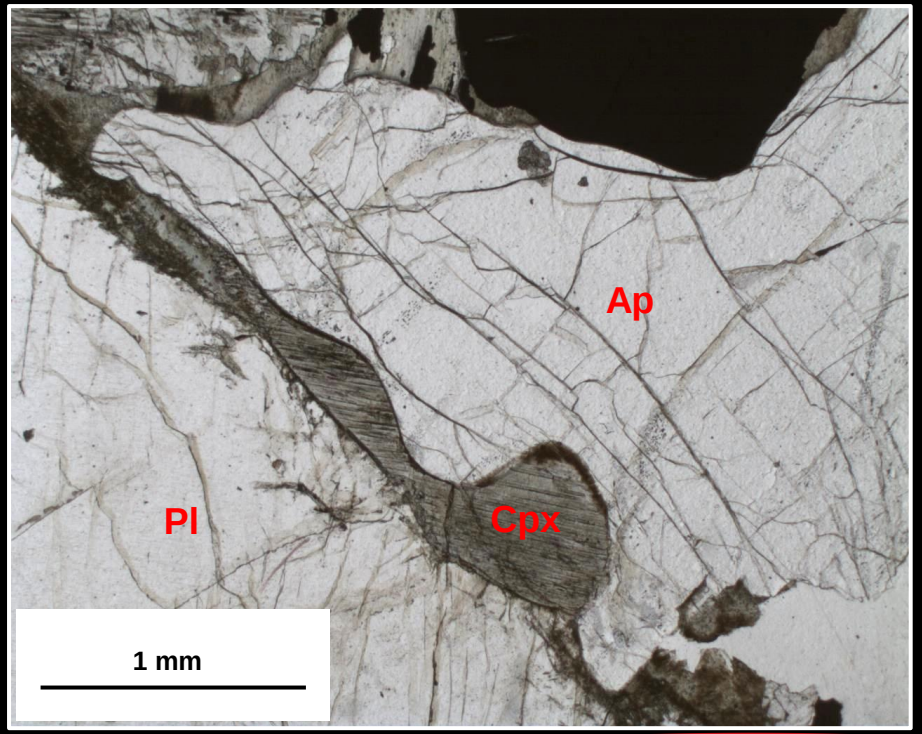
Late Apatite



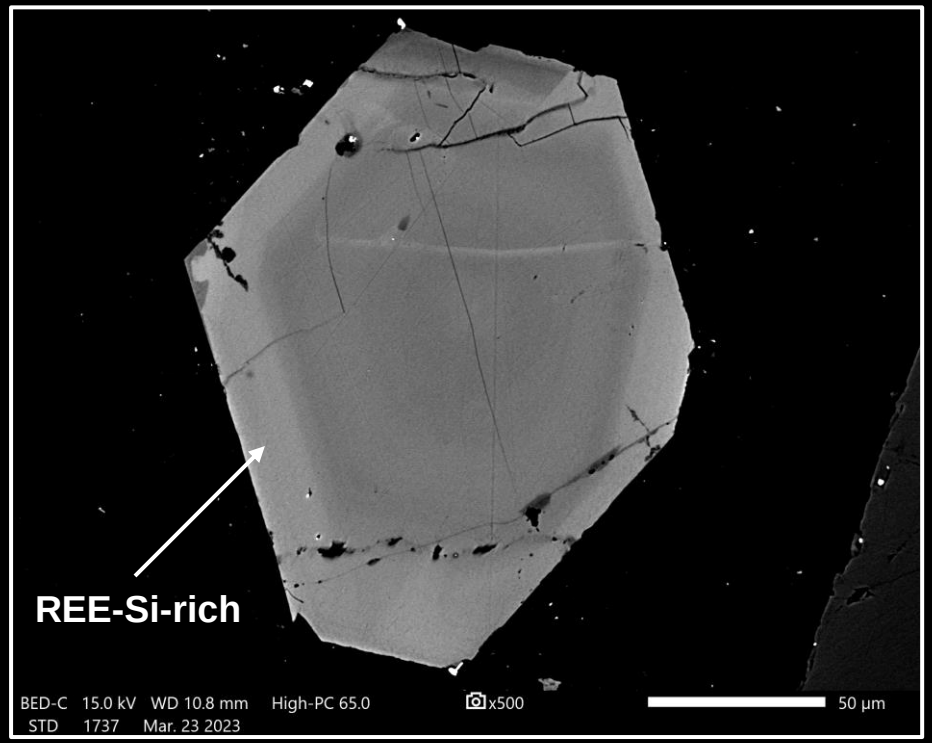


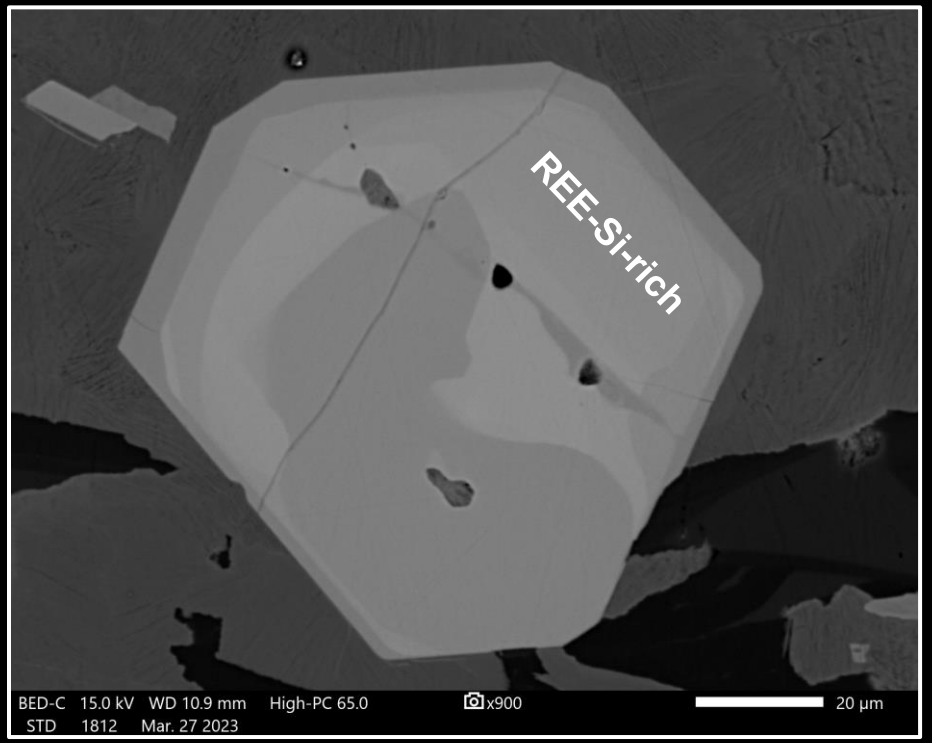
Late Apatite

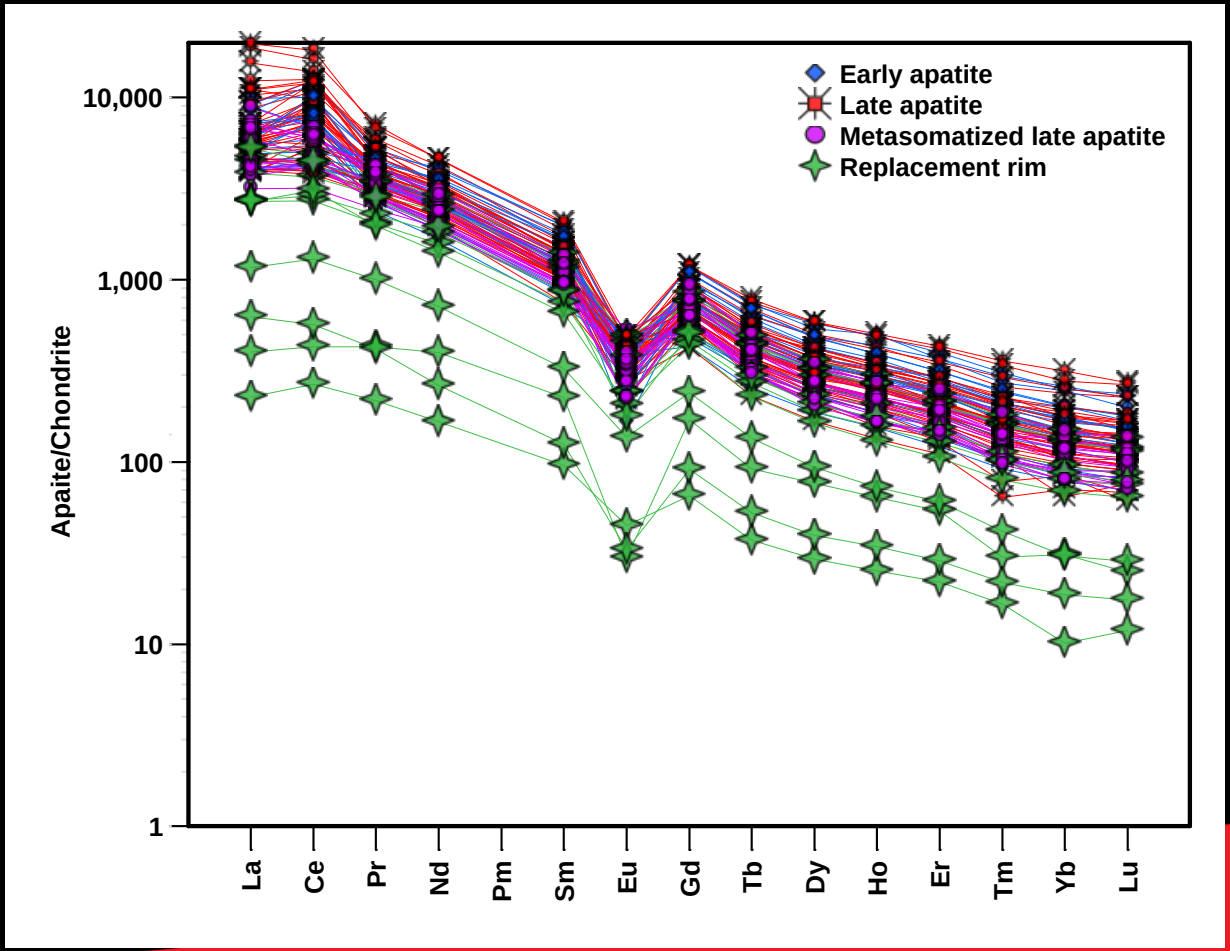


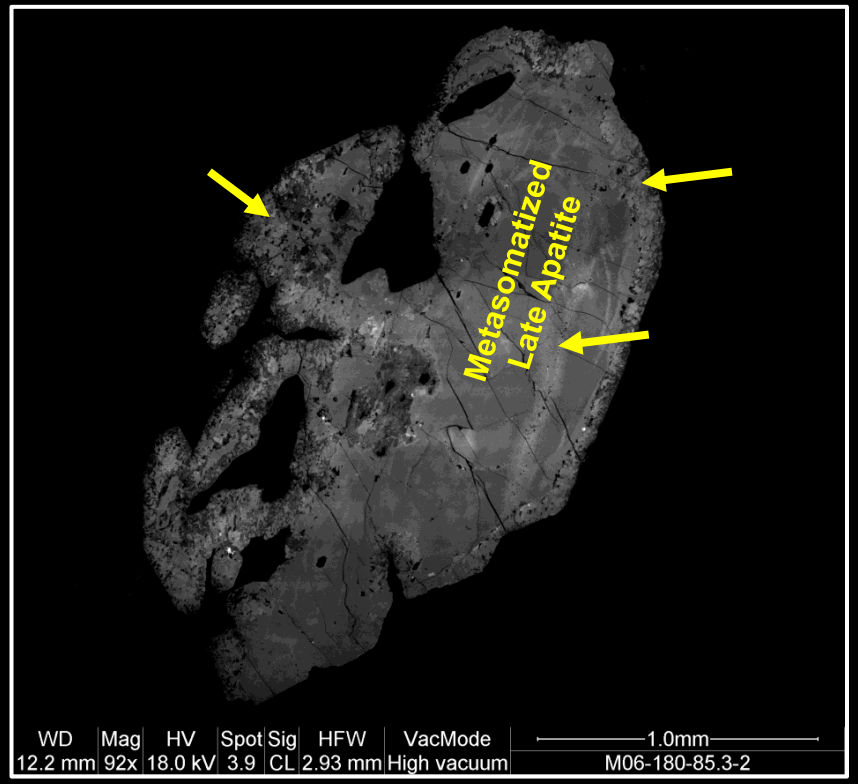


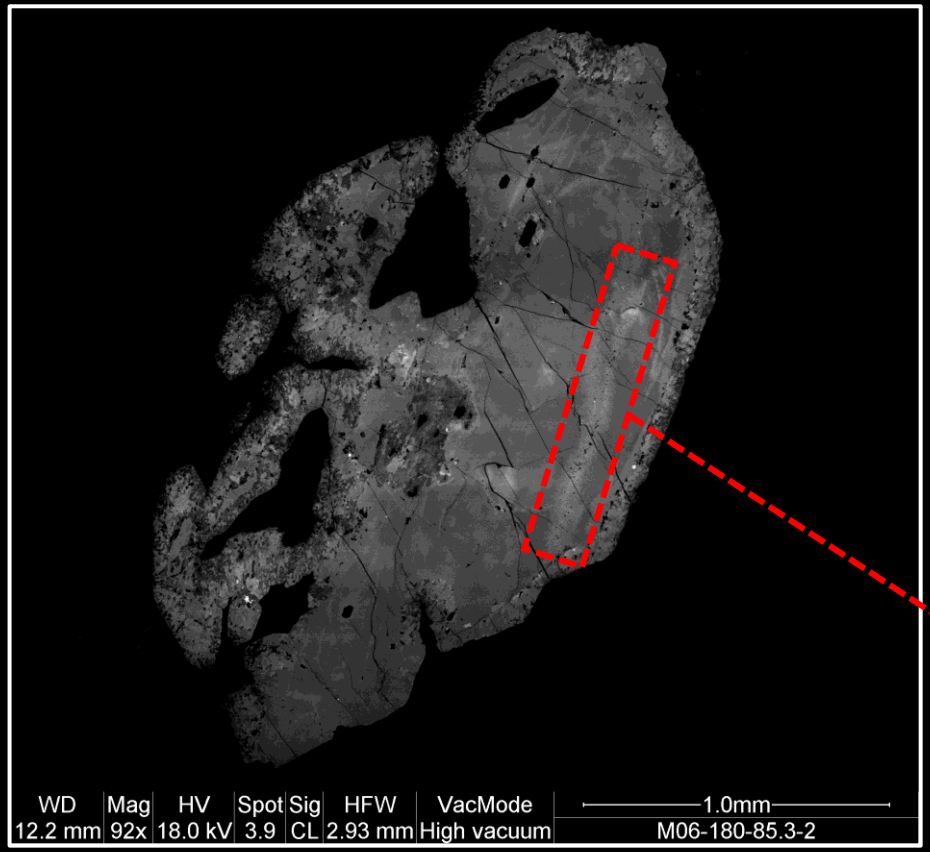
Late apatite (evolved interstitial melt)

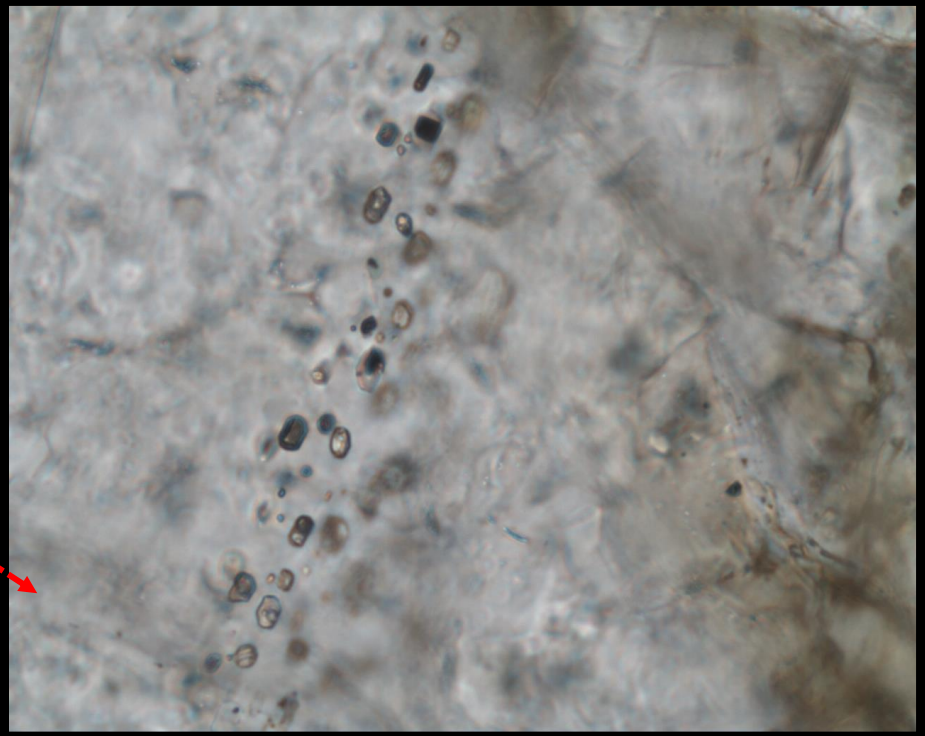


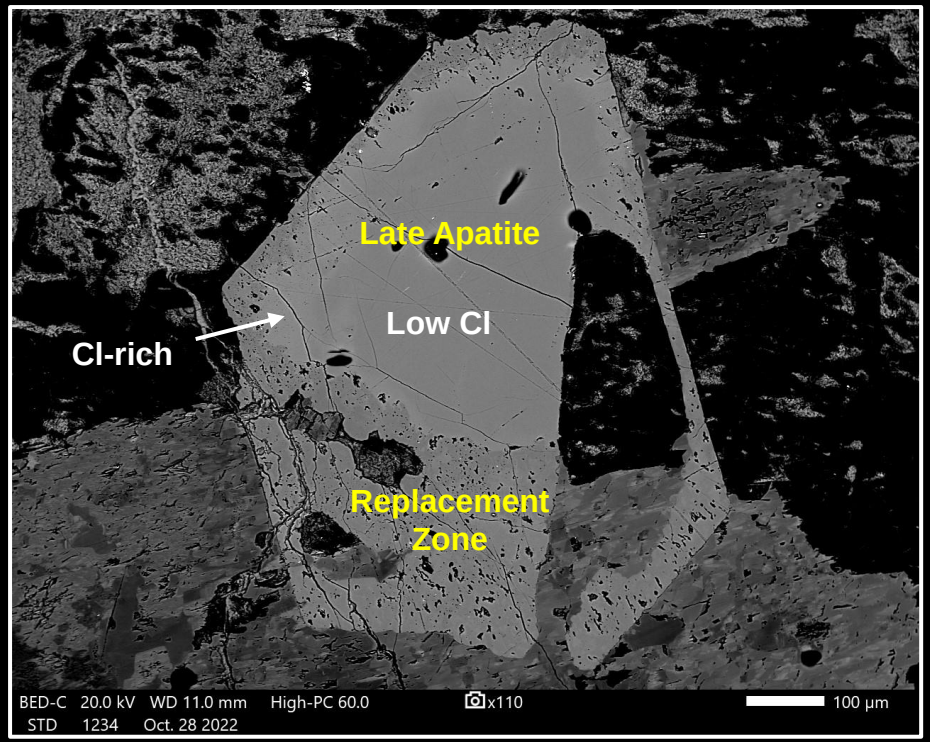


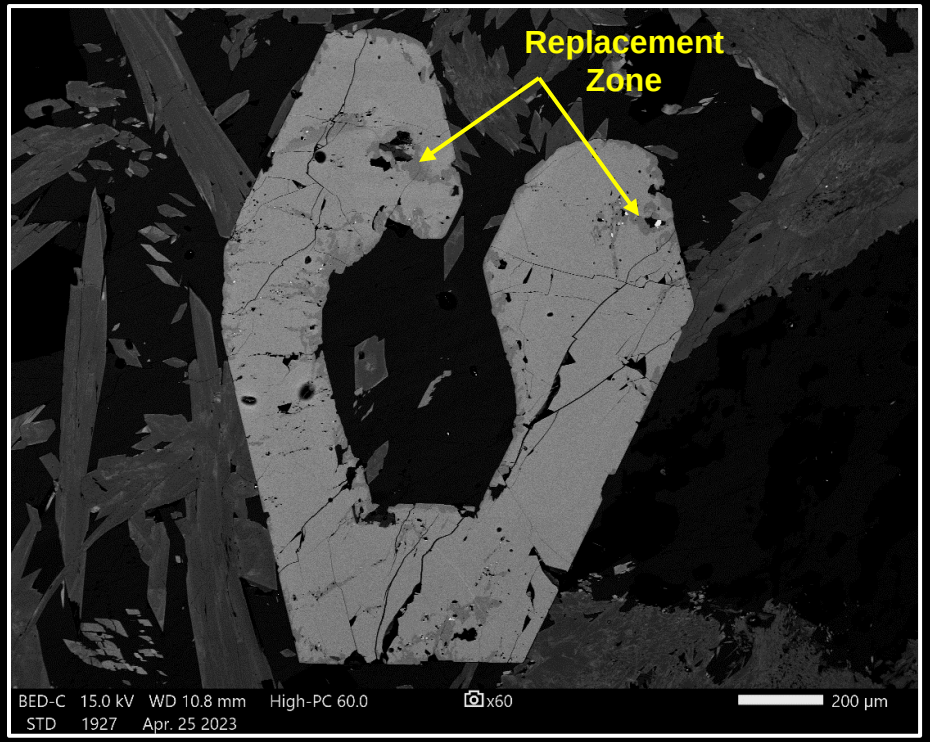

Early apatite
Late apatite
Metasomatized late apatite
Replacement rim
Apaite/Chondrite
10,000
1,000
100
10
1
La
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu

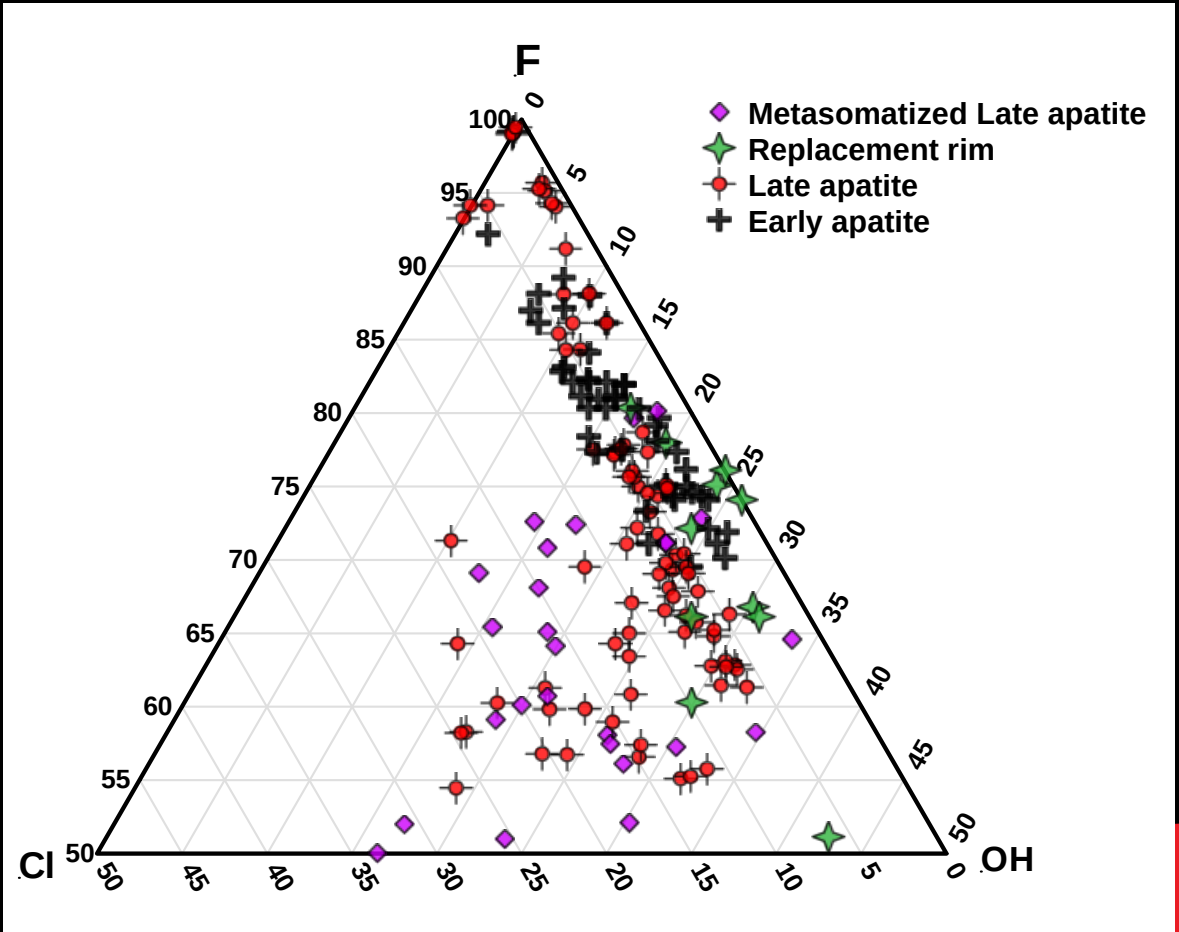

Metasomatized
Late Apatite
WD 12.2 mm
Mag 92x
HV 18.0 kV
Spot 3.9
Sig CL
HFW 2.93 mm
VacMode High vacuum
1.0mm
M06-180-85.3-2

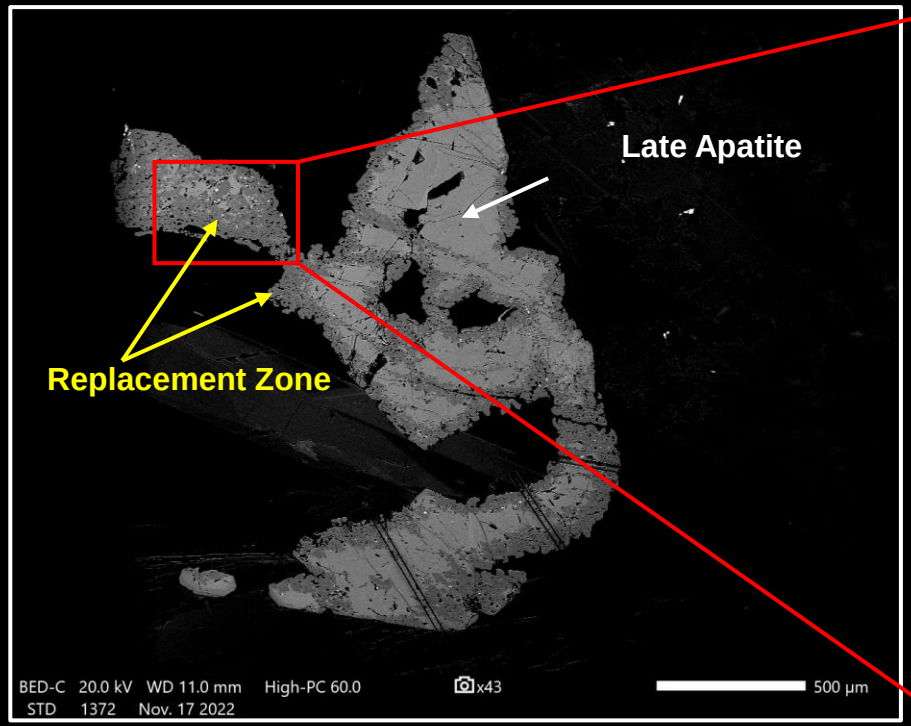

WD
12.2 mm
Mag
92x
HV
18.0 kV
Spot
3.9
Sig
CL
HFW
2.93 mm
VacMode
High vacuum
1.0mm
M06-180-85.3-2

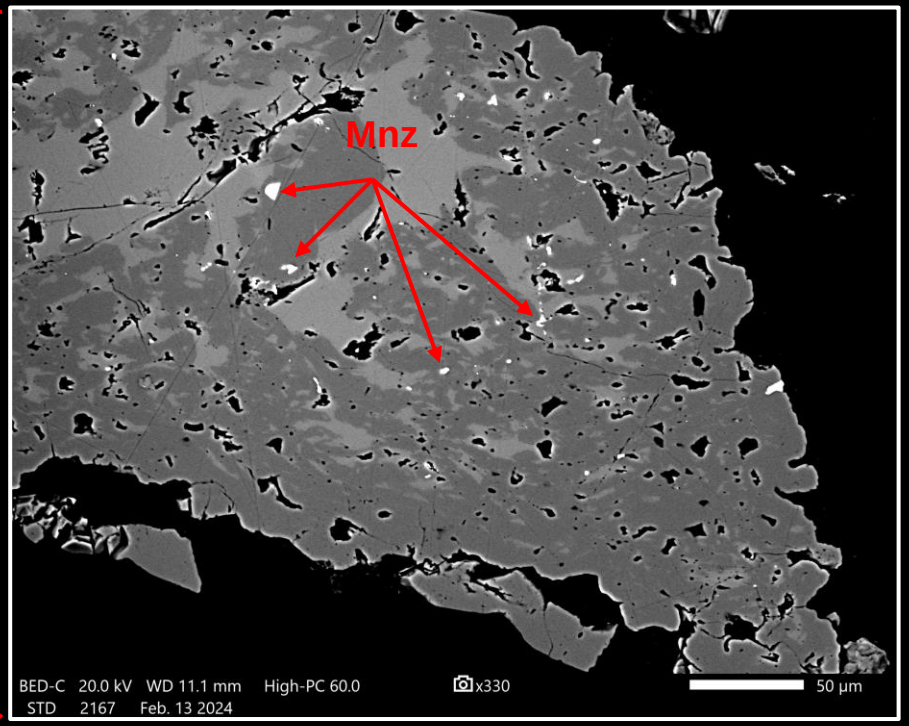



Late Apatite
Low Cl
Cl-rich
Replacement Zone
BED-C 20.0 kV WD 11.0 mm High-PC 60.0 x110 100 µm
STD 1234 Oct. 28 2022


Replacement Zone
BED-C 15.0 kV WD 10.8 mm High-PC 60.0 x60 200 µm
STD 1927 Apr. 25 2023


F
Cl
OH
Metasomatized Late apatite
Replacement rim
Late apatite
Early apatite


Late Apatite
Replacement Zone
BED-C 20.0 kV WD 11.0 mm High-PC 60.0 x43 500 µm
STD 1372 Nov. 17 2022

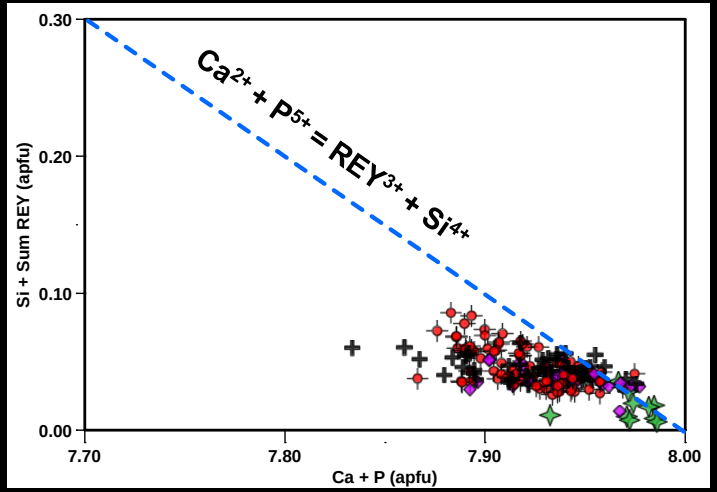

Mnz
BED-C 20.0 kV WD 11.1 mm High-PC 60.0 x330 50 µm
STD 2167 Feb. 13 2024

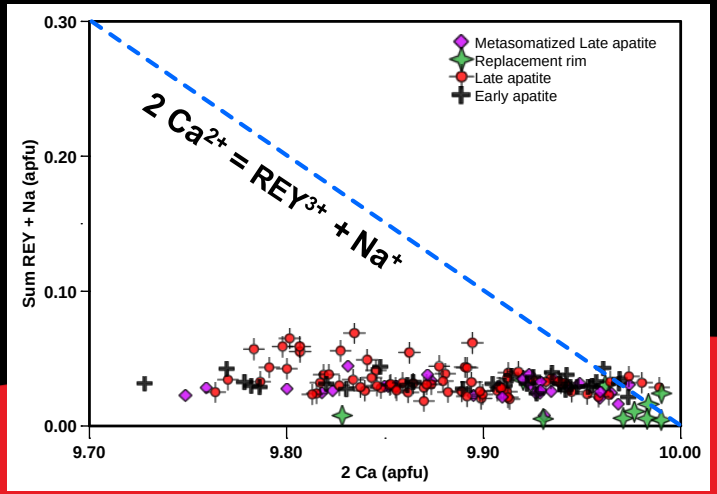
Monazite Formation

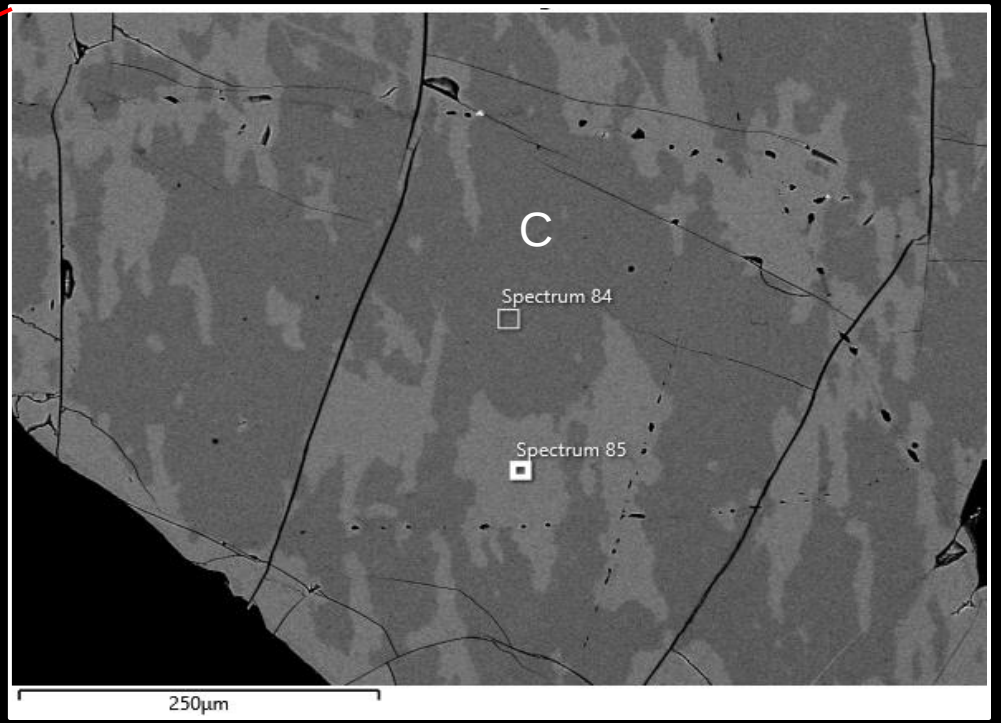
- Fluid-induced coupled dissolution-reprecipitation process
  - F-apatite + H_2O
  - F-apatite + 40/60 CO_2/H_2O
  - F-apatite + KCl

- Coupled substitution:

  1) $Ca^{2+} + P^{5+} = REY^{3+} + Si^{4+}$
  2) $2\ Ca^{2+} = REY^{3+} + Na^{+}$







Spectrum 84

Compare...

	Wt%	σ
Ca	43.6	0.1
O	34.1	0.1
P	18.6	0.1
F	3.5	0.1
Cl	0.3	0.0

Spectrum 85

Compare...

	Wt%	σ
Ca	42.9	0.1
O	34.6	0.1
P	18.5	0.1
F	3.7	0.1
Cl	0.3	0.0

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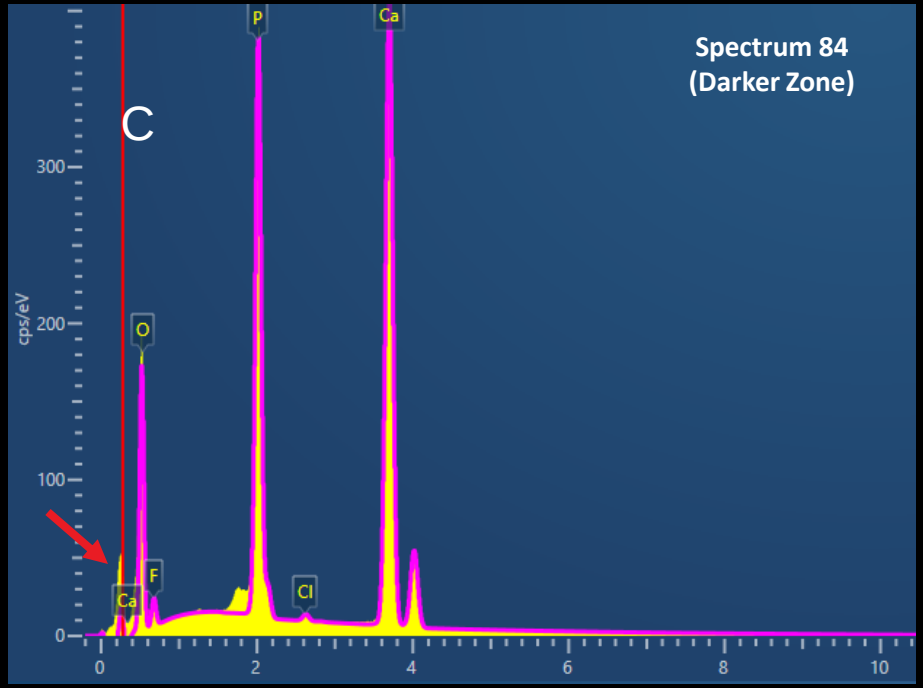
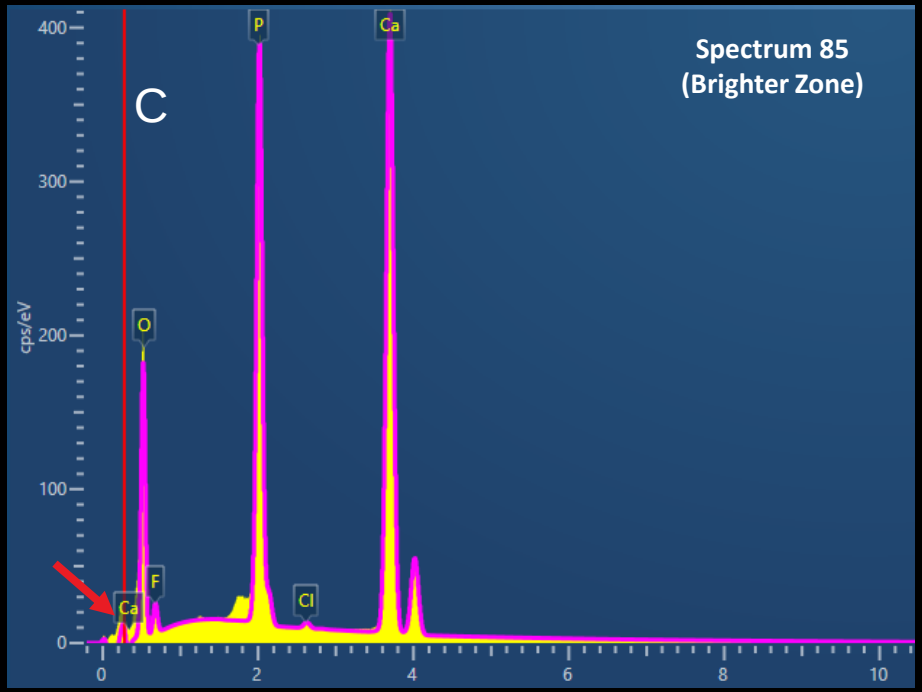
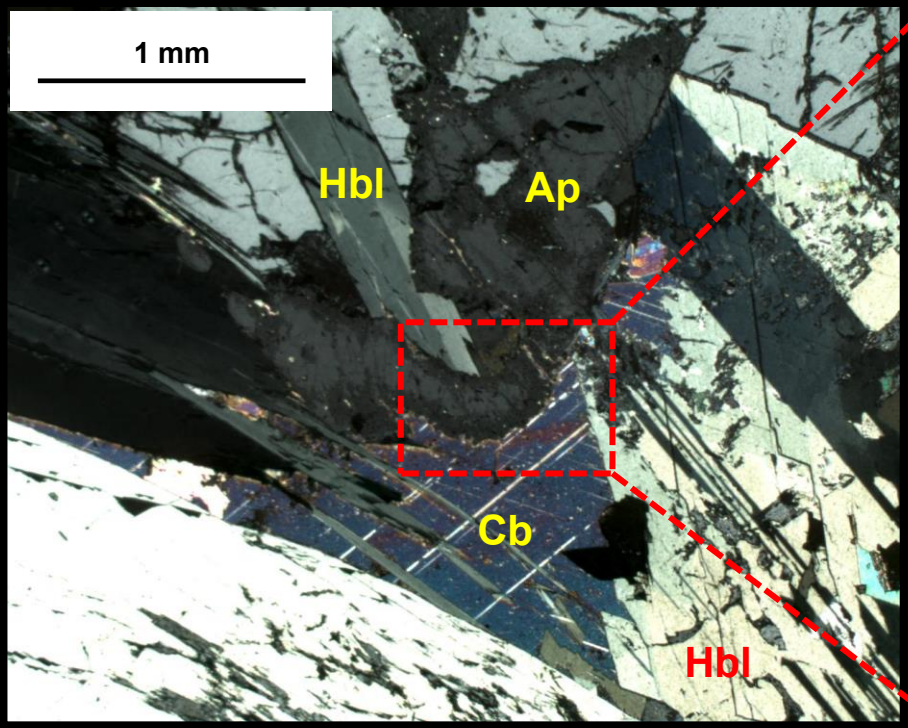
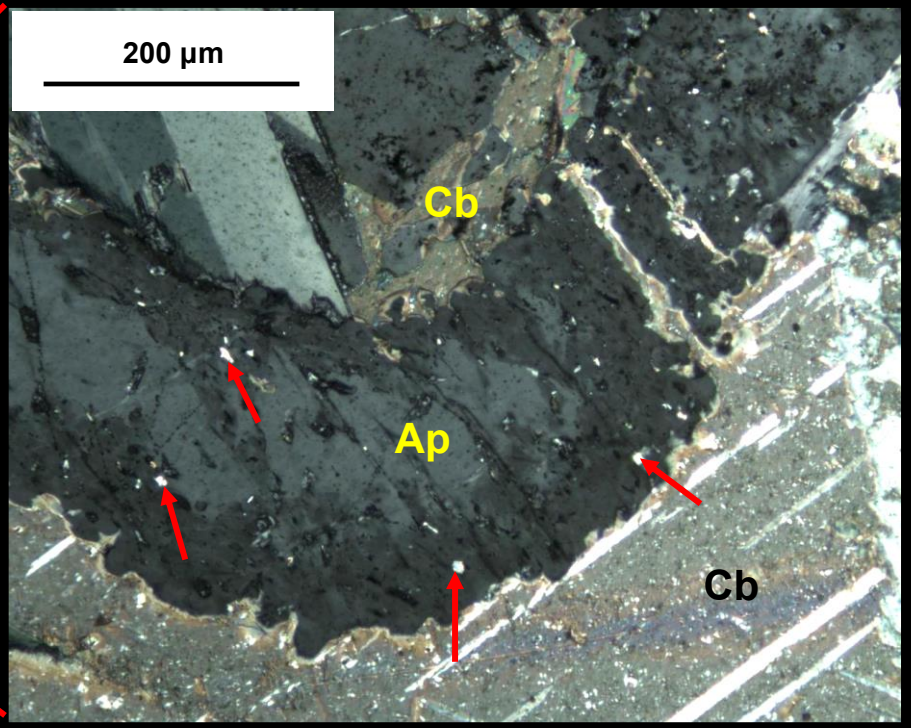
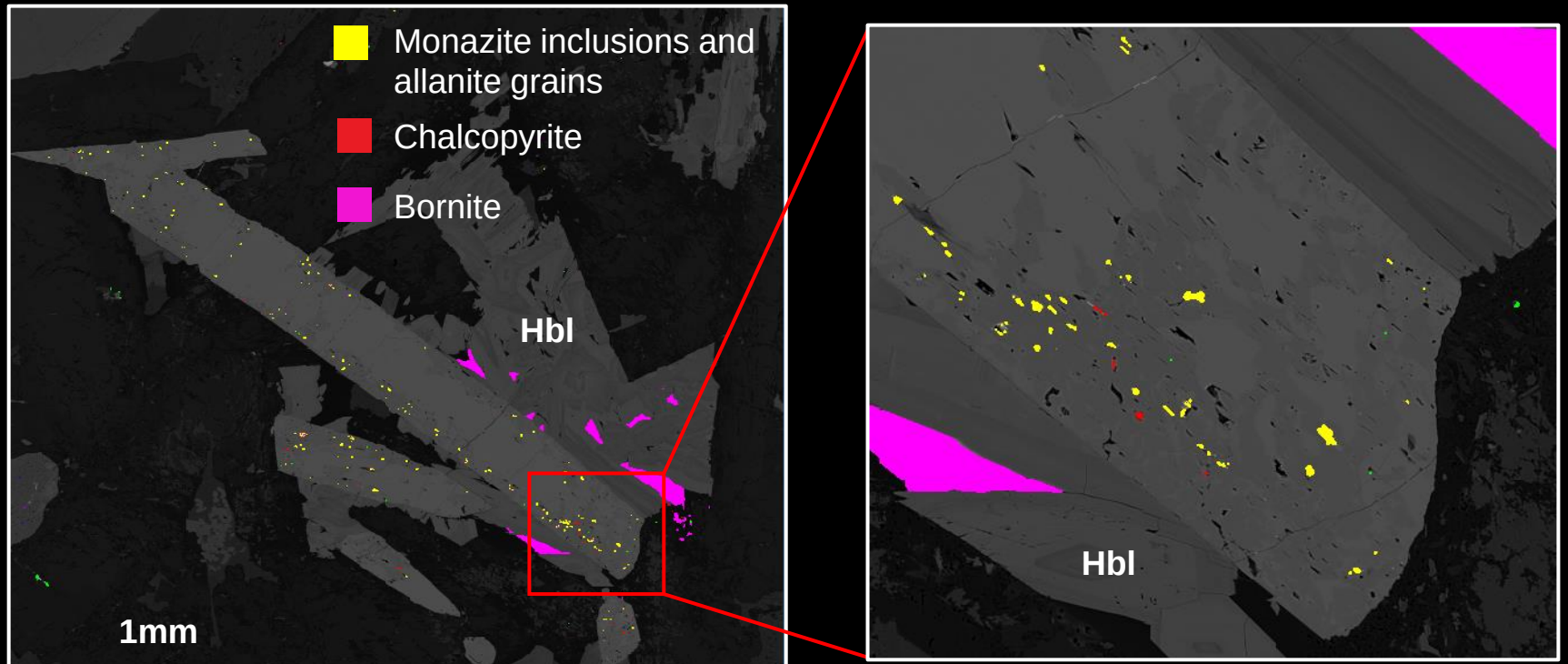

Spectrum 84
(Darker Zone)
C
O
F
Ca
P
Cl
Ca
cps/eV
0
100
200
300
0
2
4
6
8
10


Spectrum 85
(Brighter Zone)
C
O
F
Ca
P
Cl
Ca
cps/eV
0
100
200
300
400
0
2
4
6
8
10


1 mm
Hbl
Ap
Cb
Hbl


200 µm
Cb
Ap
Cb


Monazite inclusions and allanite grains
Chalcopyrite
Bornite
Hbl
1mm
Hbl

Conclusion

Homogeneous Early apatite

Late apatite shows:

1. REE enrichments related to evolving interstitial melt
2. Cl enrichment related to metasomatism by Cl-rich hydrous fluid
3. Patchy carbon enrichment
4. Replacement apatite + monazite +/- allanite

Cu, Au and S loss associated with Cl- and Carbonic -bearing hydrous fluid probably derived during late-stage crystallization of the Two Duck subsolidus of the host gabbroic intrusion

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Carleton University

University of Windsor

Western Science

NSERC CRSNG

GENERATION MINING

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Thank You

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