THE CLUSTERS OF ACCESSORY MINERALS IN GRENVILLE MARBLE CRYSTALIZED FROM GLOBULES OF MELT

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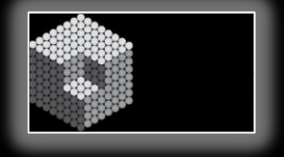

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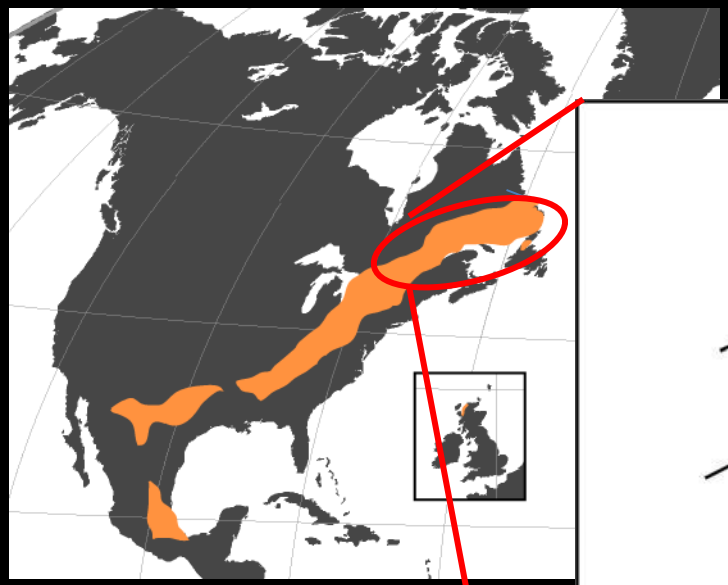
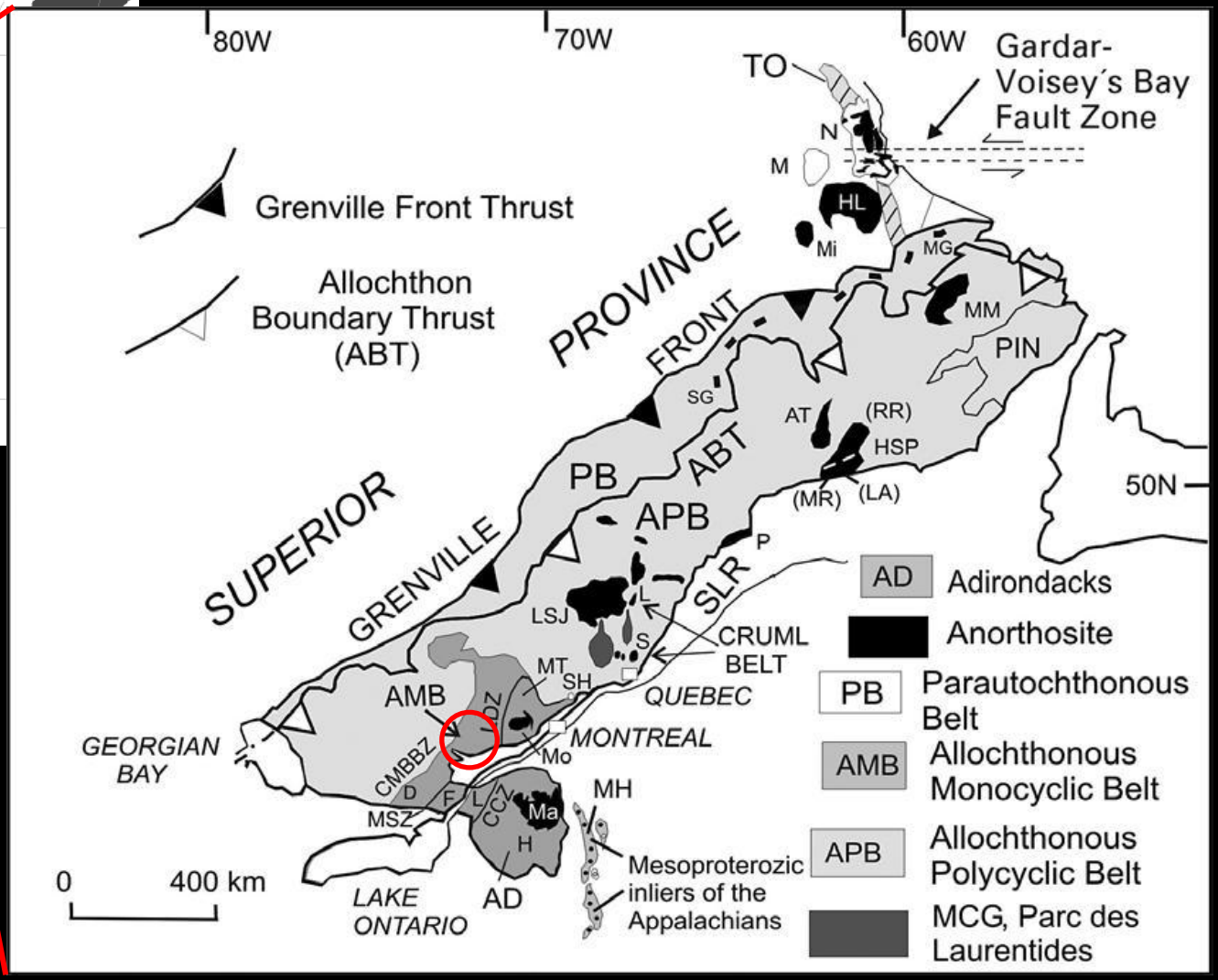
OUTLINE OF MY PRESENTATION

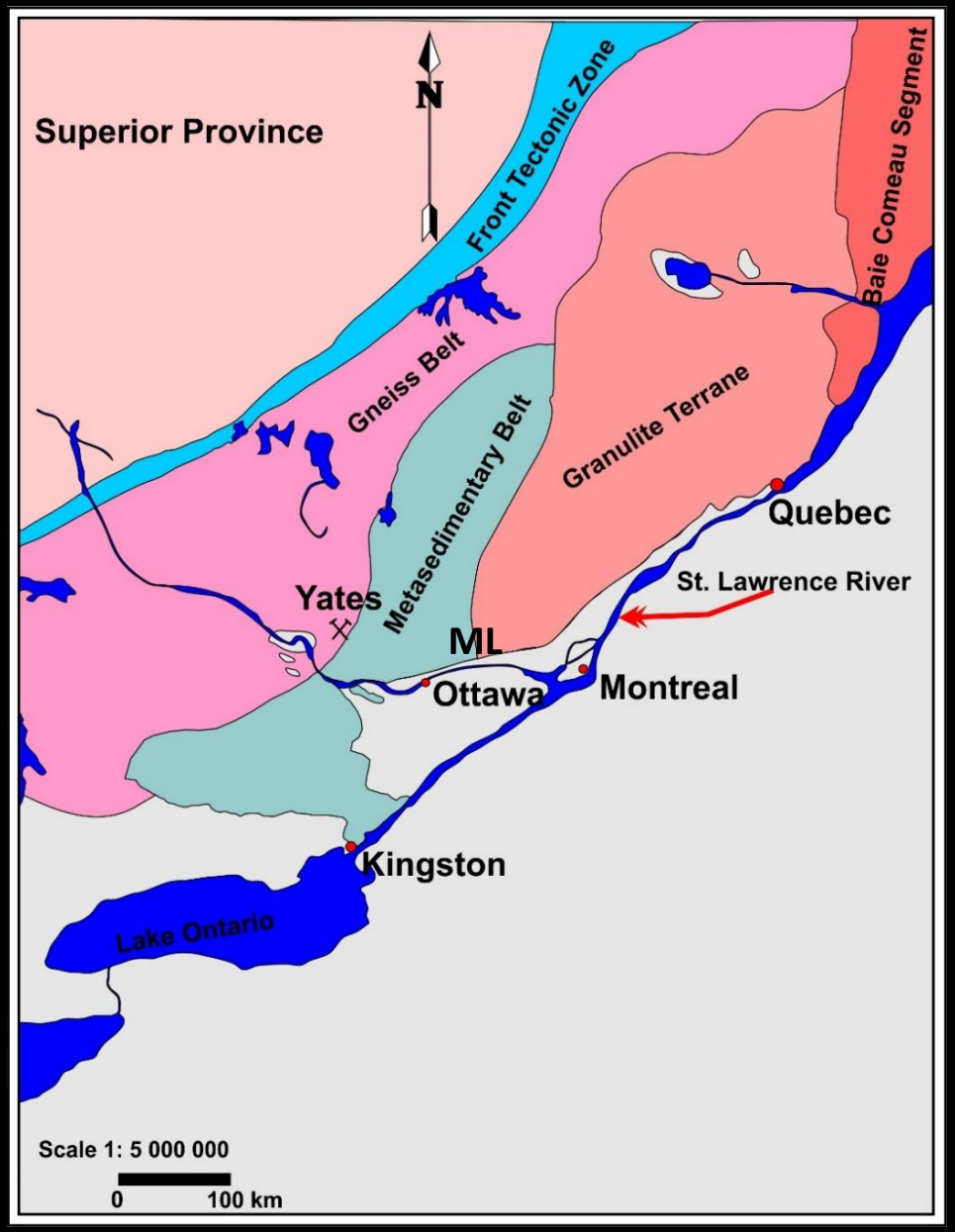
- The geological context of the Grenville orogen
- Our approach: large-area SEM imaging with the Atlas 5 software
- The Yates uranium prospect (Otter Lake): orange calcite
- Autoroute 5 construction (near Meech Lake): blue, orange and pink calcite
- Evidence of melting of marble
- The generation of a crustal silicocarbonatite

In Canada, the Grenville Province extends from the coast of Labrador toward Lake Ontario





One of the major collisional orogens of the world



The Central Metasedimentary Belt contains gneiss and white marble units of Mesoproterozoic age metamorphosed to the granulite facies in the Grenville collisional orogen

We focus on two sites, the Yates U prospect and the Meech Lake (ML) area in western Quebec, where the white marble has been “modified” locally

Otter Lake or Yates prospect Photo: Donald Lapham

Age: 1 Ga, the end of the Grenville orogenic cycle (Rigolet stage)

An intrusive body of carbonate, hematite-stained where in contact with “pyroxenite”. Both rocks were interpreted to be parts of a skarn by Denis Shaw (1958)

Darryl MacFarlane credits John Betts

Unlike the pristine prism shown by John Betts, this prism of fluorapatite has mere vestiges of green, away from the margin; it contains a globule of orange calcite

Is this a melt inclusion? Could this prism have nucleated in a carbonate melt? If so, what is the source of phosphorus?

We study polished thin sections to look at the texture and compositions of the micro-inclusions

Globules of orange calcite

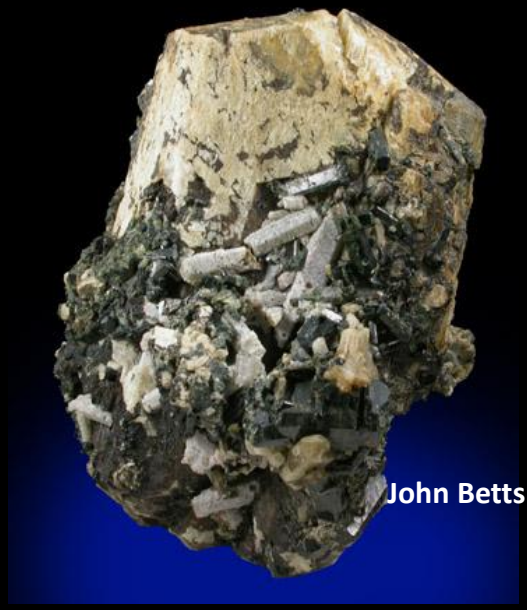
(courtesy Darryl MacFarlane)

Other minerals in a calcite matrix

Titanite

Thorianite Connie Larsson

Diopside



Meionite

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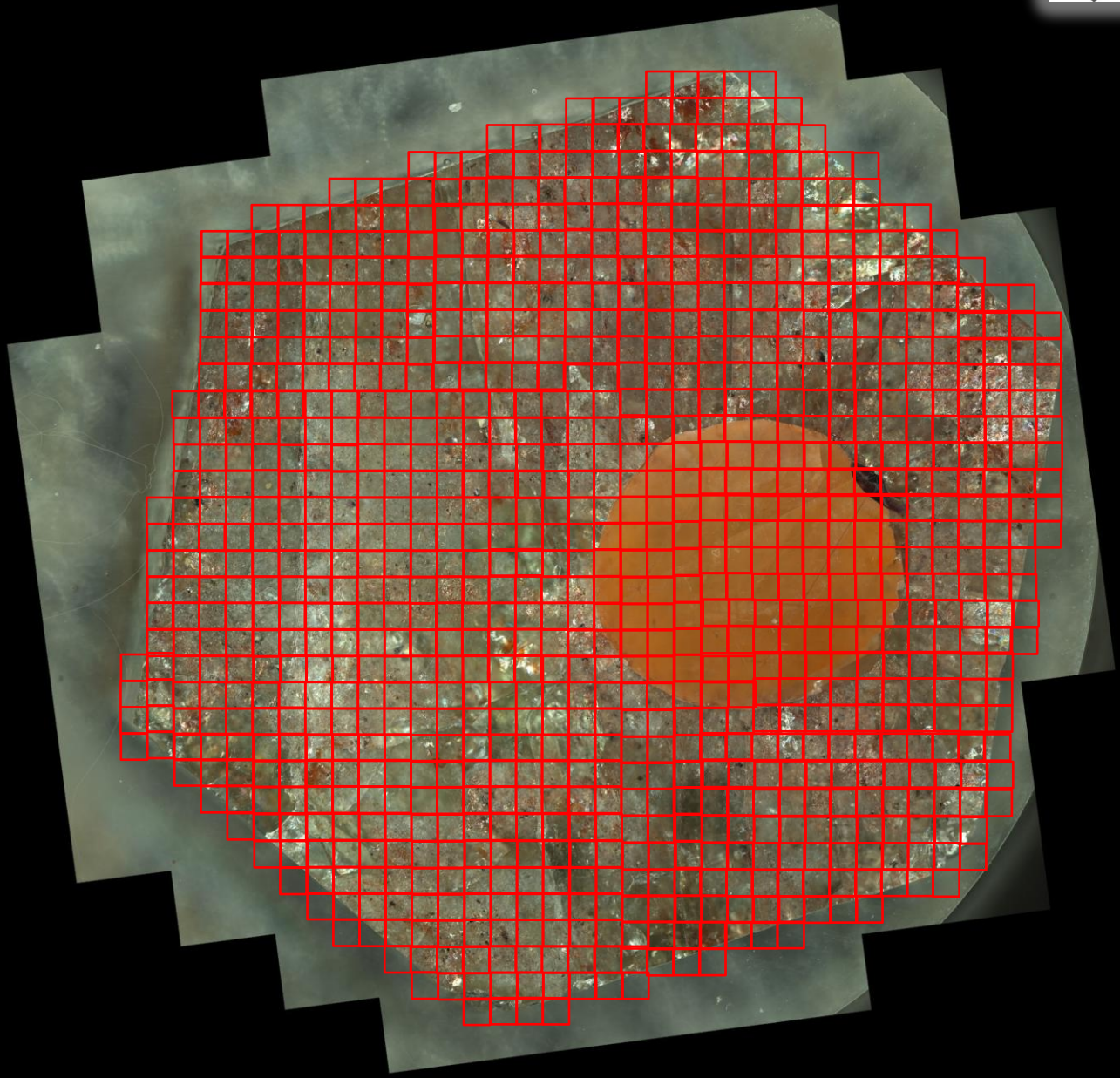
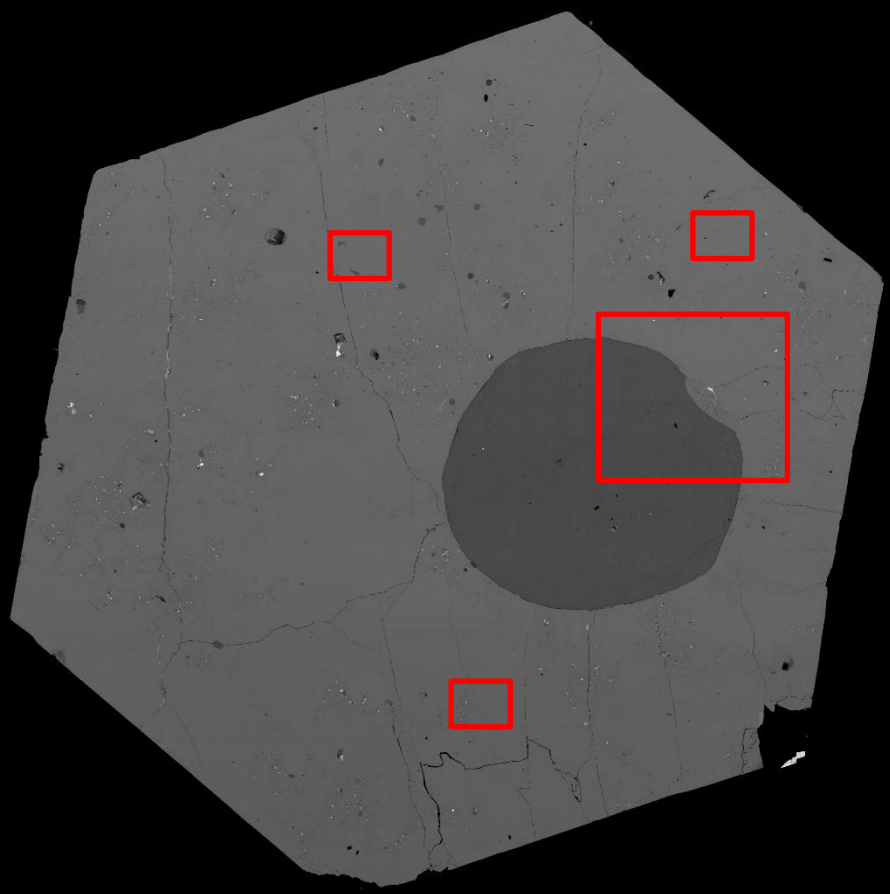
Large-area SEM imaging with Atlas 5



Multi-resolution imaging with Atlas 5

- Overview image mosaic of the entire sample
  - 200 nm/pixel, (~9 h)
  - 150 nm/pixel, (~20 h)
  - 100 nm/pixel (~46 h)

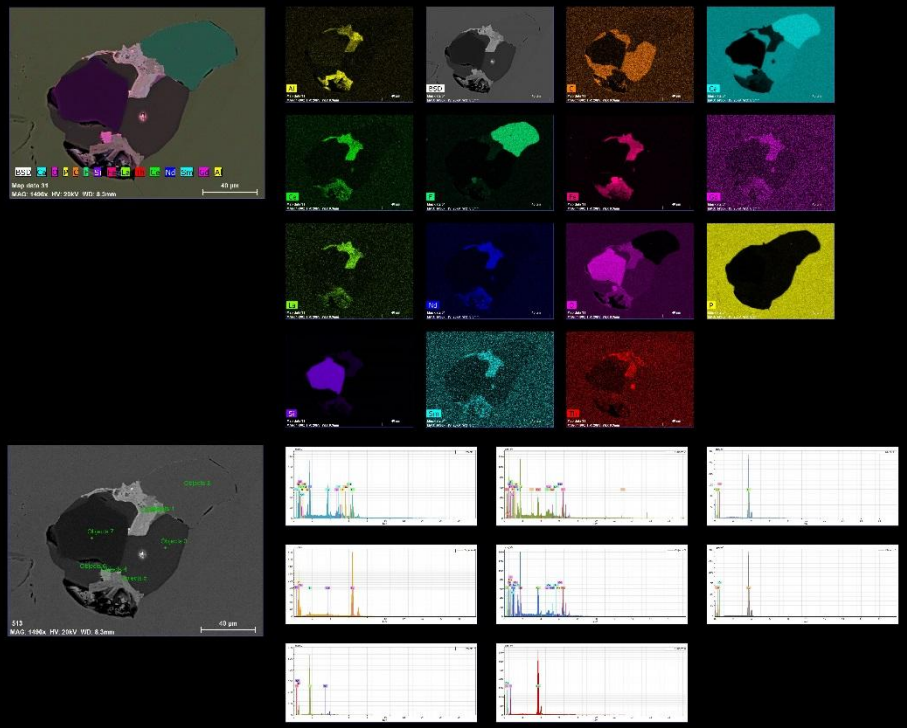
- High-resolution subregions
  - 20 nm/pixel,
  - 10 nm/pixel,
  - 5 nm/pixel



Browser-Based Viewer

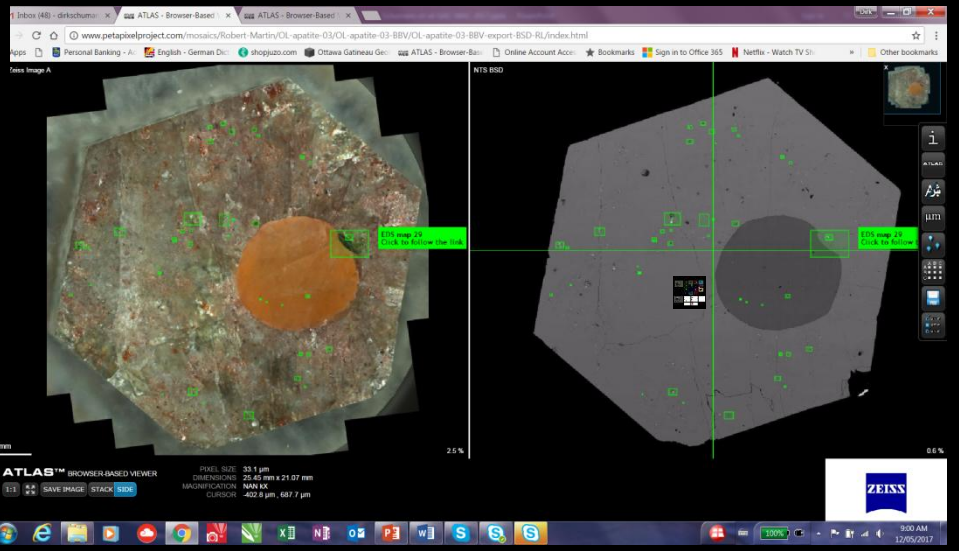
Share the Browser-Based Viewer datasets with colleagues around the world.

Browser-Based Viewer



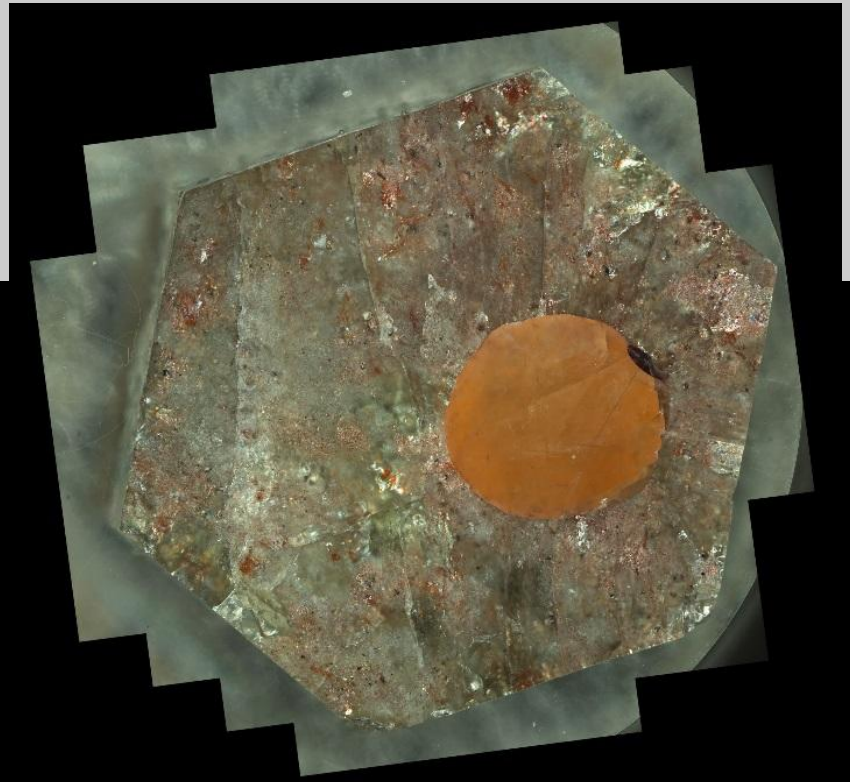
Add chemical information:

- EDS element maps
- EDS spectra
- Annotations
- EMPA
- Synchrotron micro-XRF datasets
- Laser-ablation data
- ……



The result is a BBV dataset of the sample that contains all collected information

Otter Lake Apatite with Orange Calcite Globule



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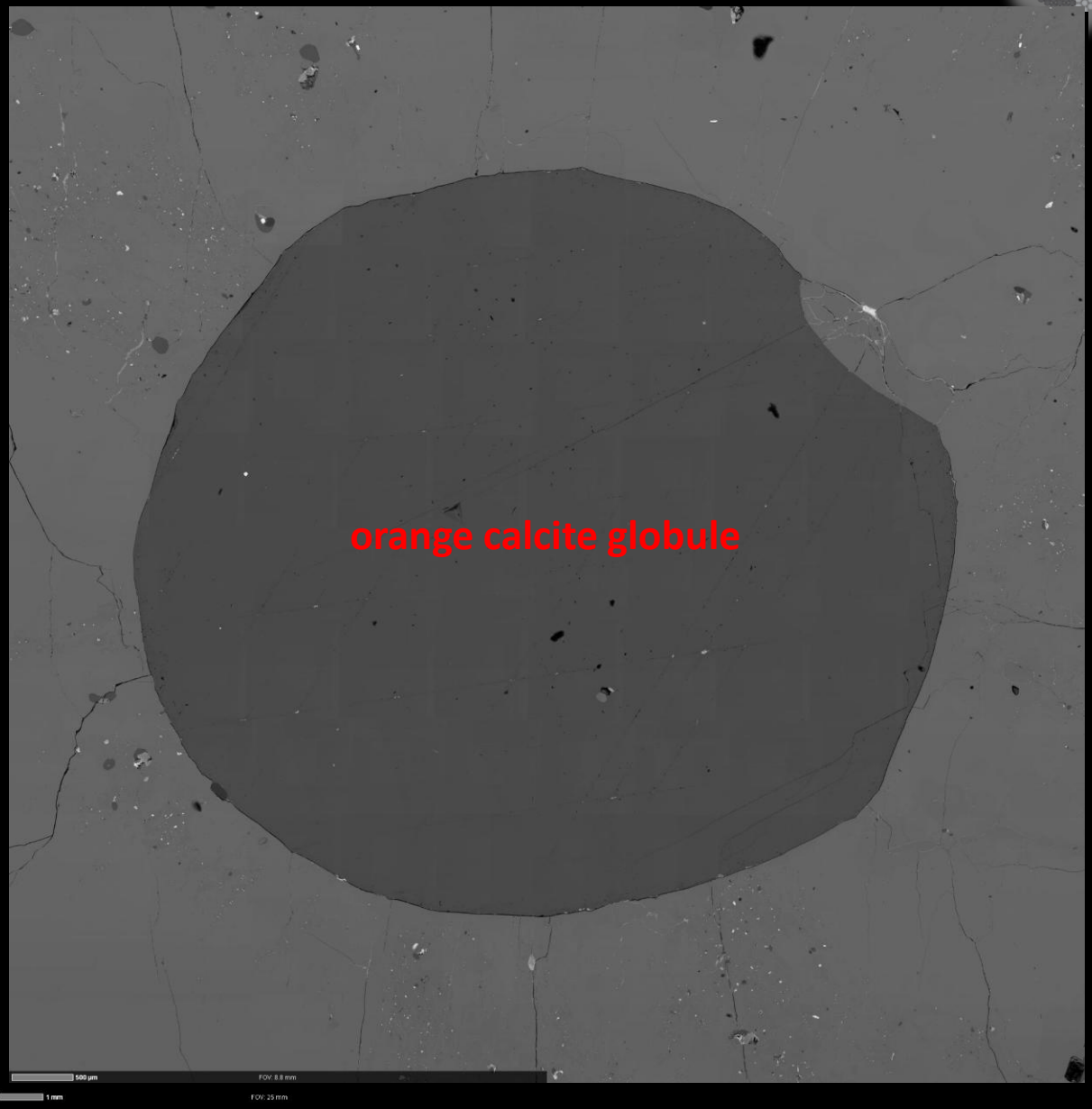
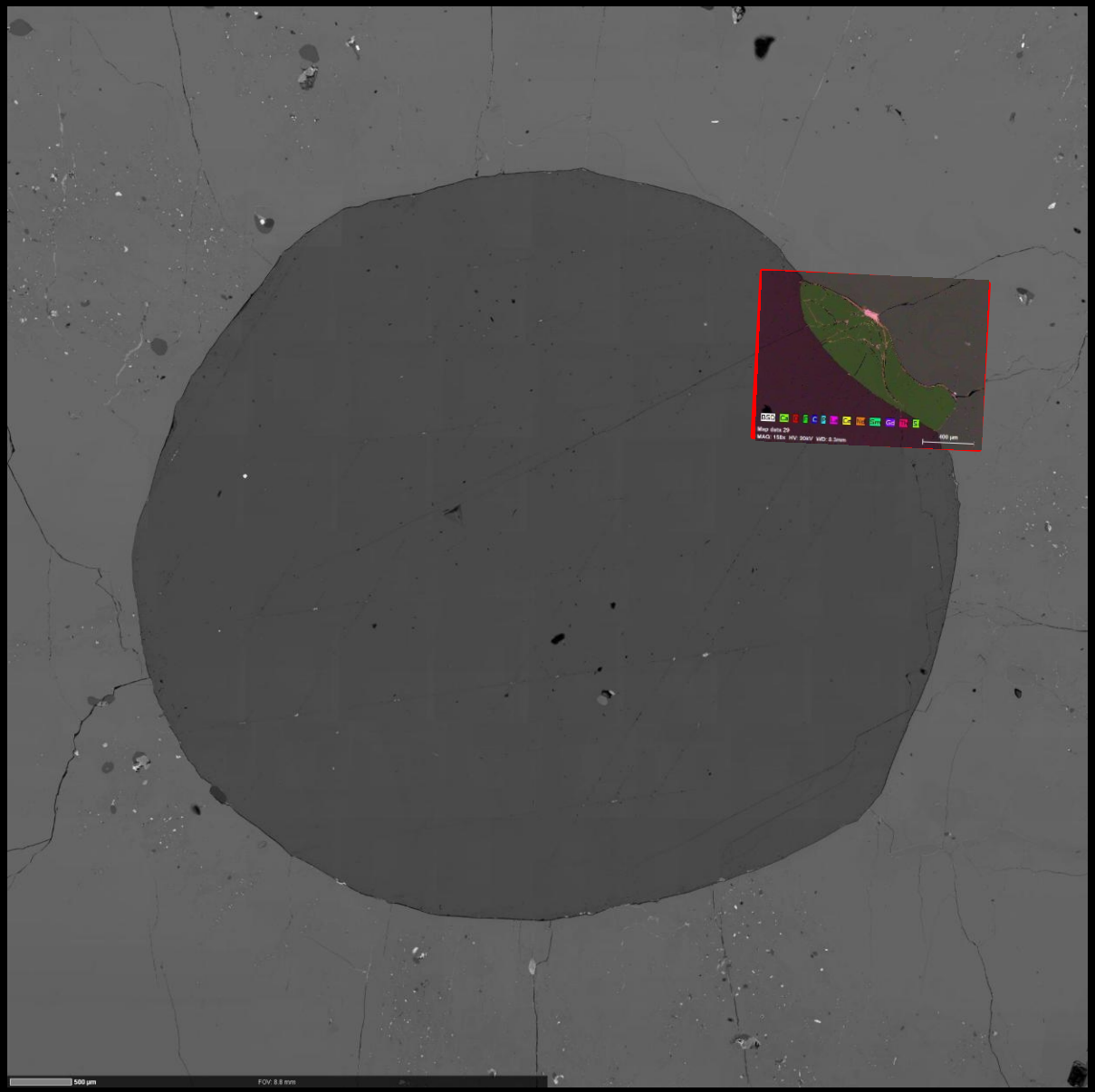
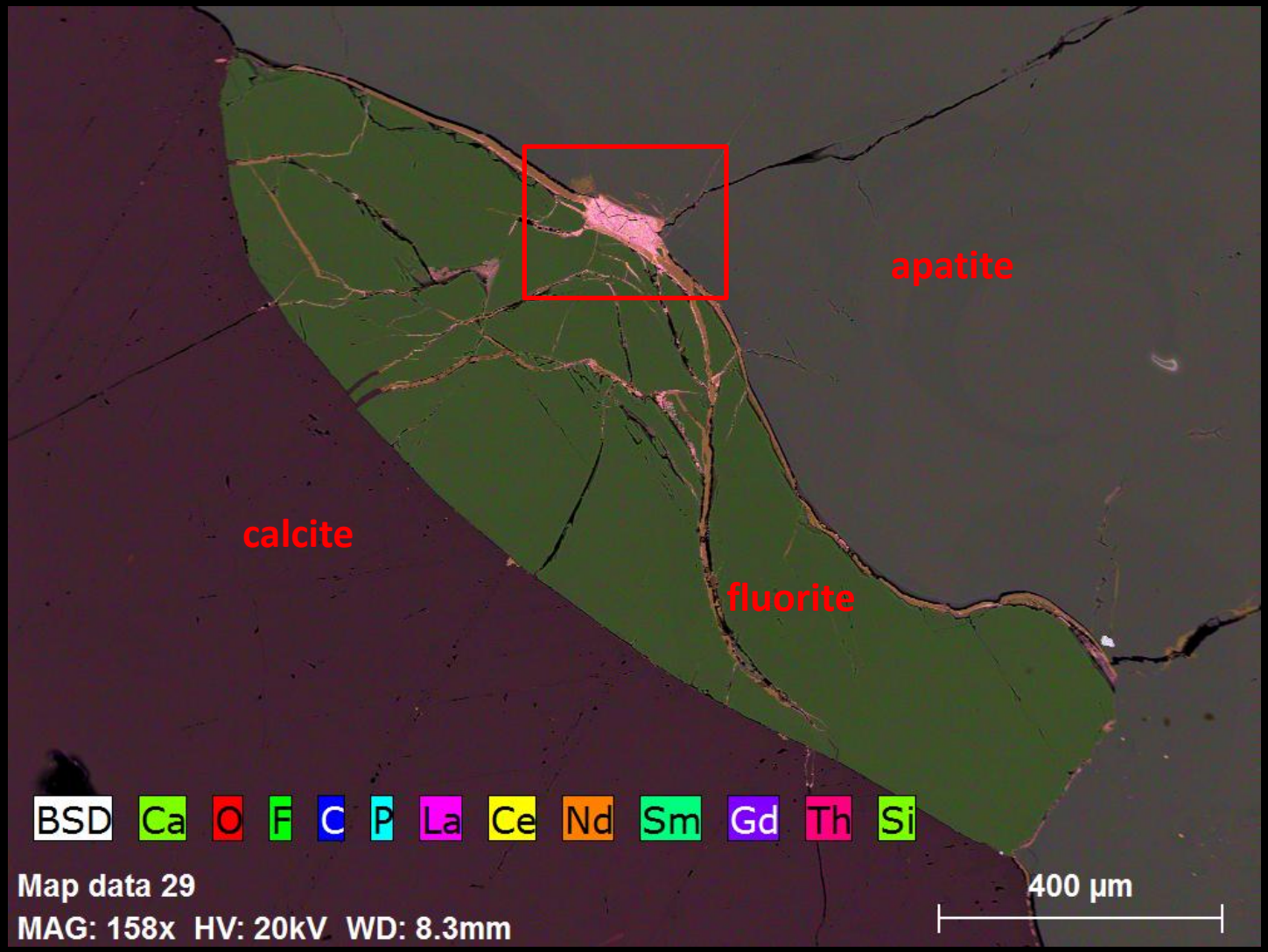
Otter Lake Apatite: Orange Calcite Inclusions

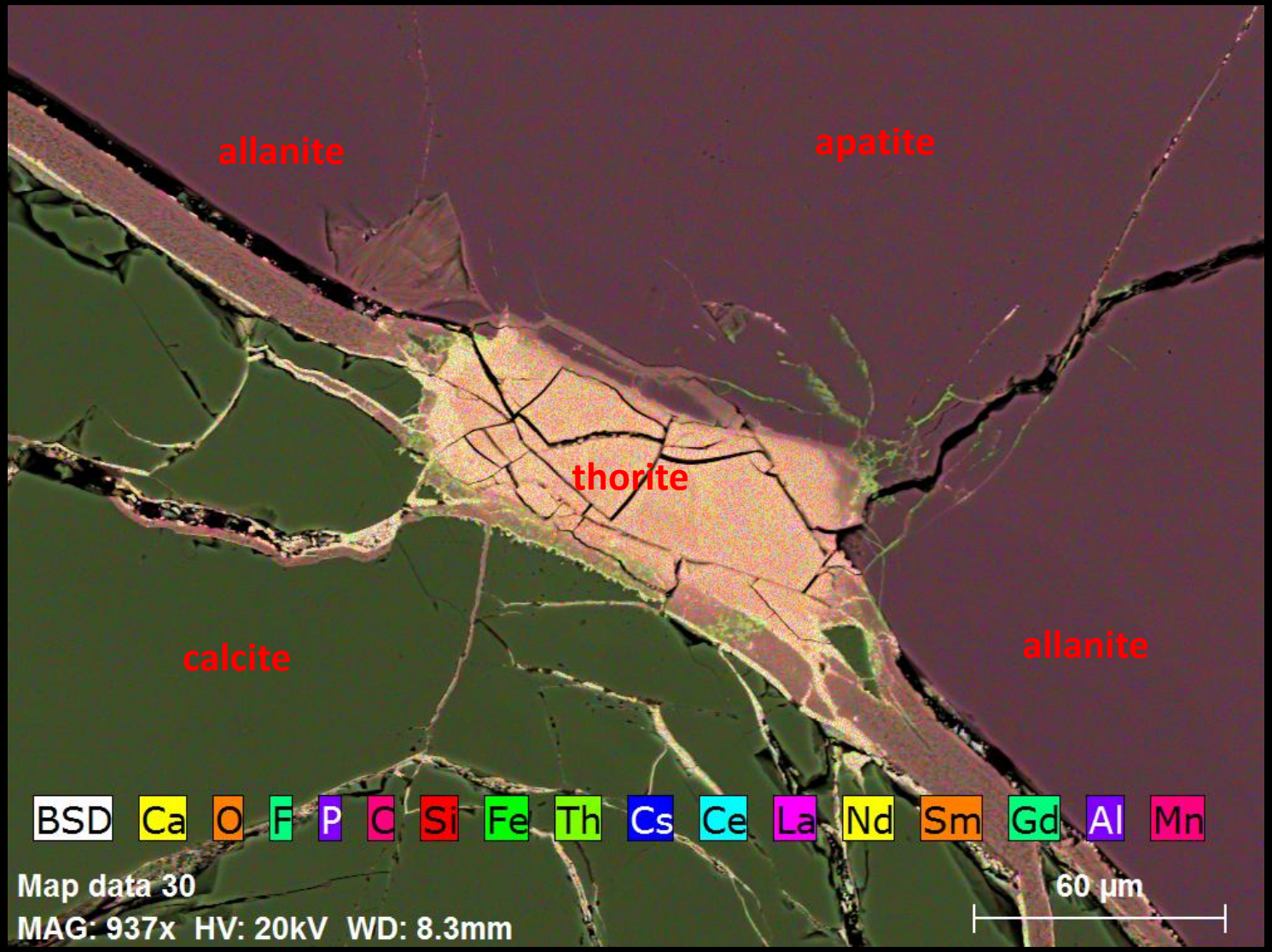



500 µm
FOV: 8.8 mm

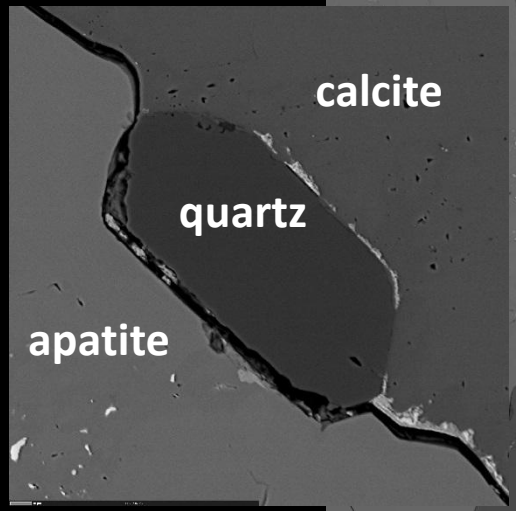
Otter Lake Apatite: Inclusions

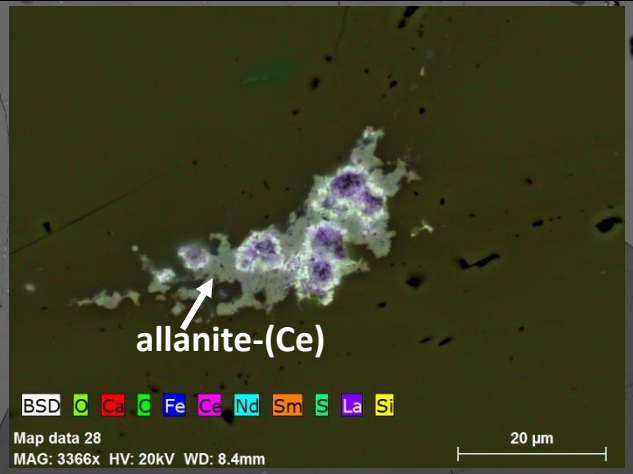


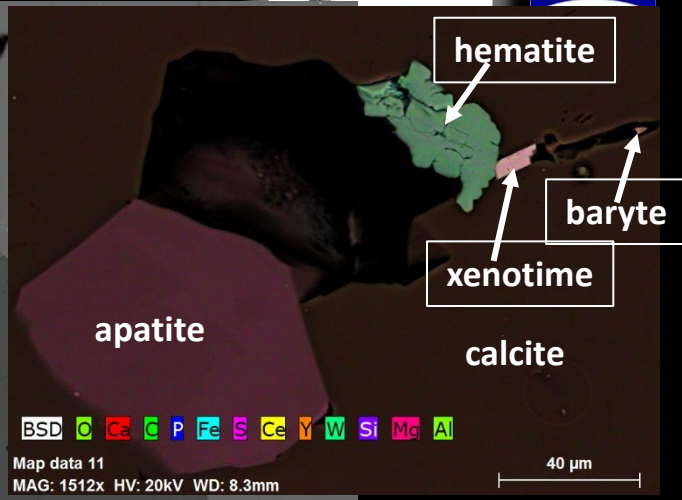
Otter Lake Apatite: Inclusions

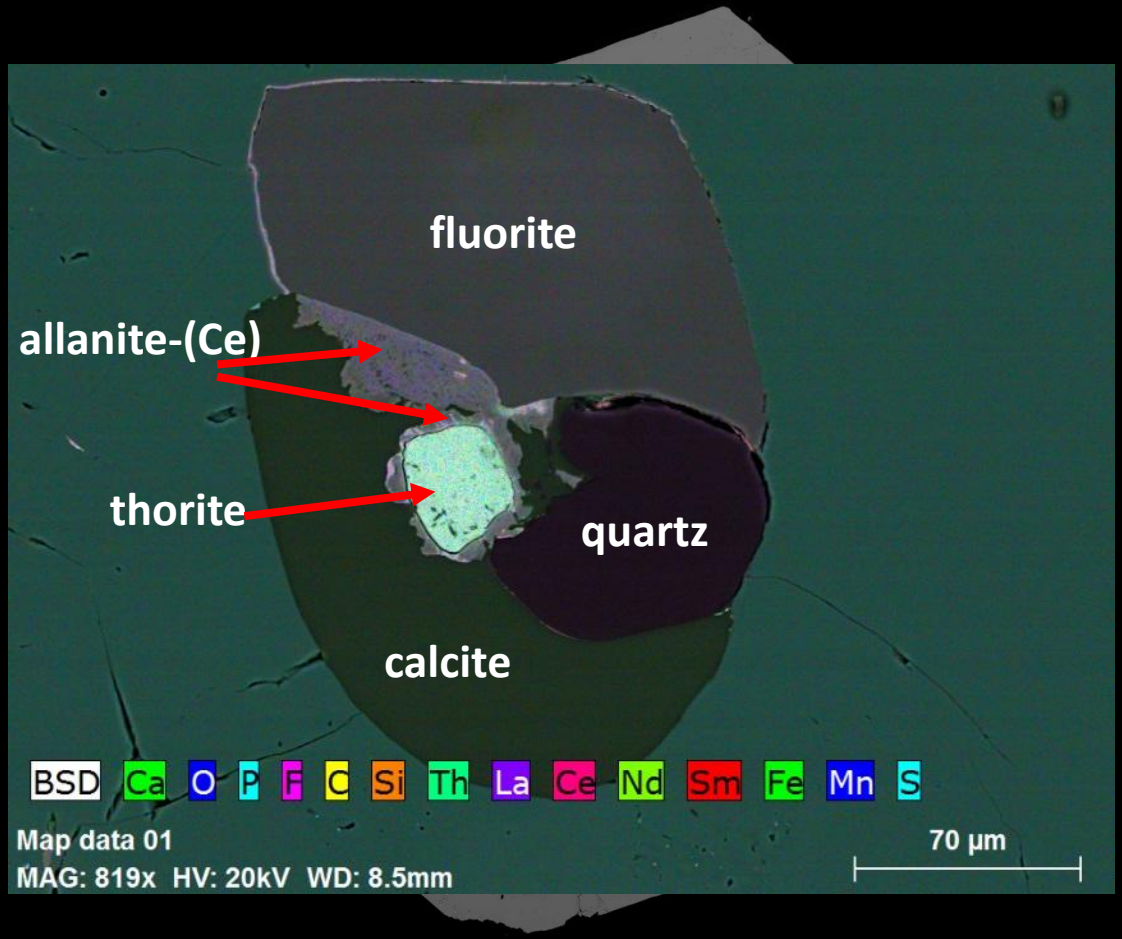


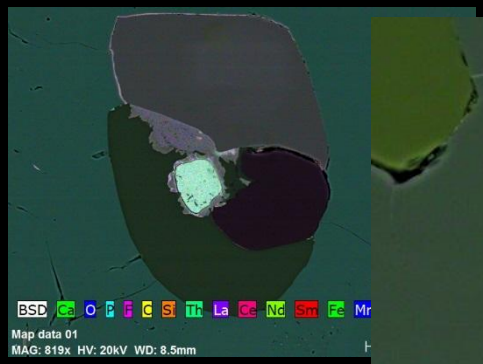
Otter Lake Apatite: Inclusions

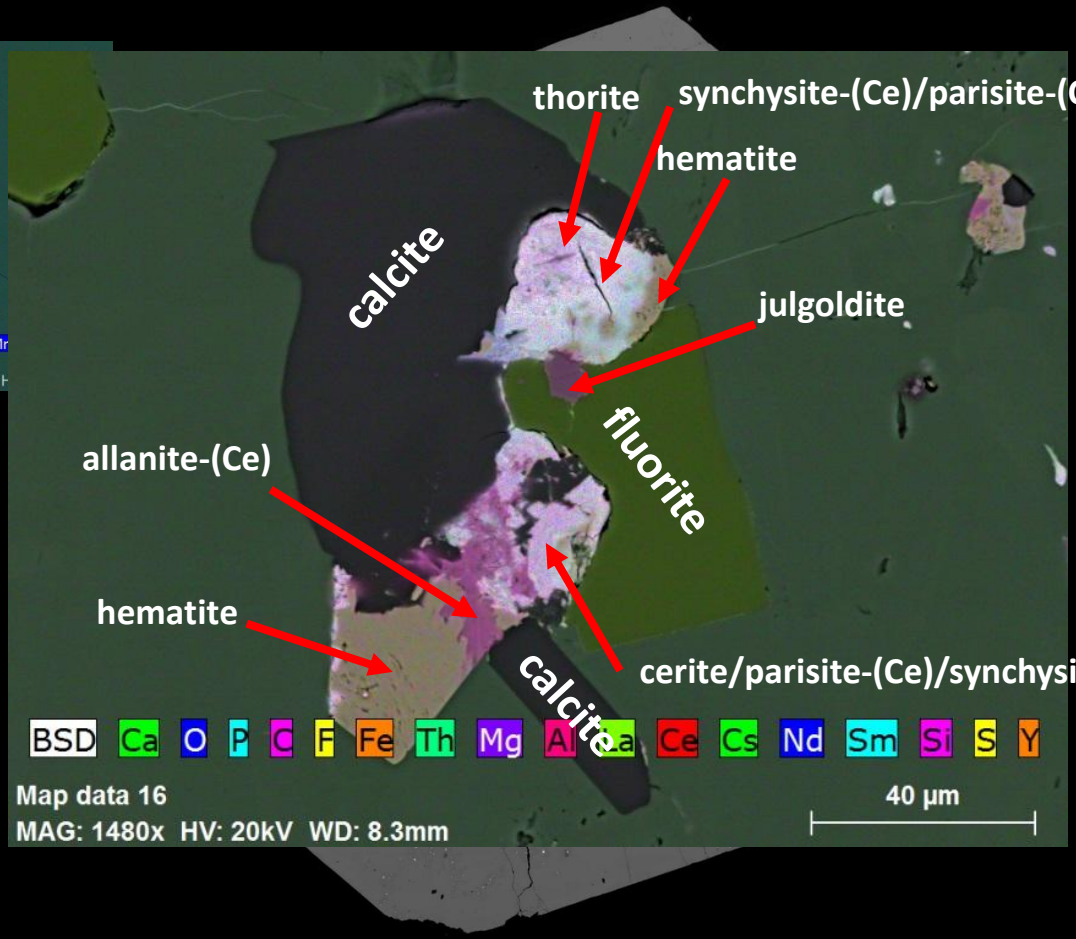


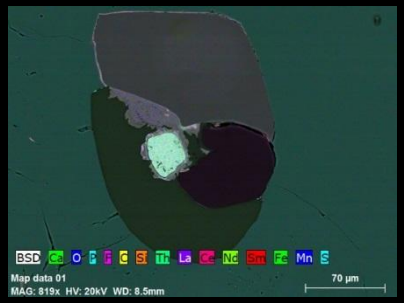




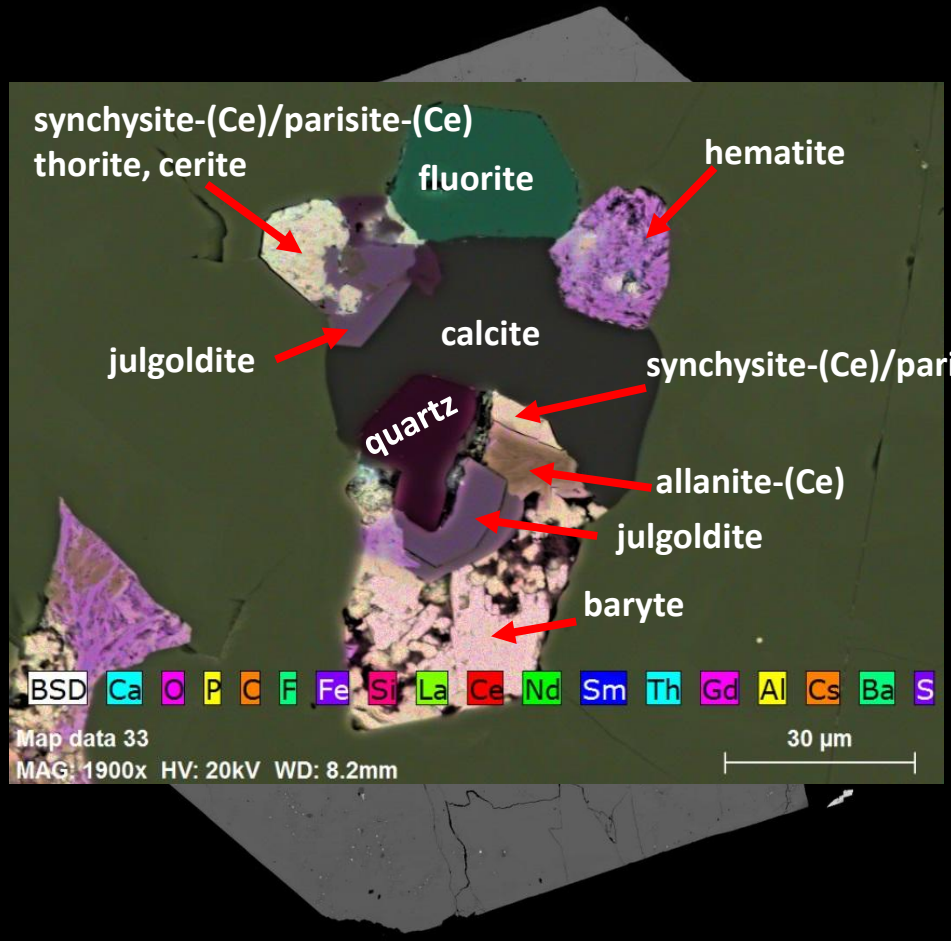

fluorite
allanite-(Ce)
thorite
quartz
calcite
BSD Ca O P F C Si Th La Ce Nd Sm Fe Mn S
Map data 01
MAG: 819x HV: 20kV WD: 8.5mm
70 µm

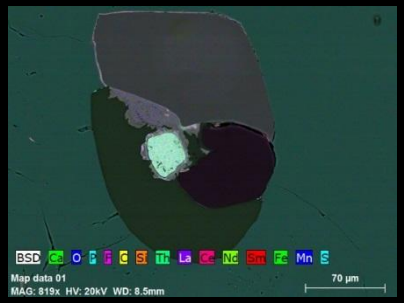

BSD Ca O P F C Si Th La Ce Nd Sm Fe Mn
Map data 01
MAG: 819x HV: 20kV WD: 8.5mm


thorite
synchysite-(Ce)/parisite-(Ce)
hematite
calcite
julgoldite
fluorite
allanite-(Ce)
hematite
calcite
cerite/parisite-(Ce)/synchysite-(Ce)
BSD Ca O P C F Fe Th Mg Al La Ce Cs Nd Sm Si S Y
Map data 16
MAG: 1480x HV: 20kV WD: 8.3mm
40 µm


BSD
Map data 01
MAG: 819x HV: 20kV WD: 8.5mm
70 µm

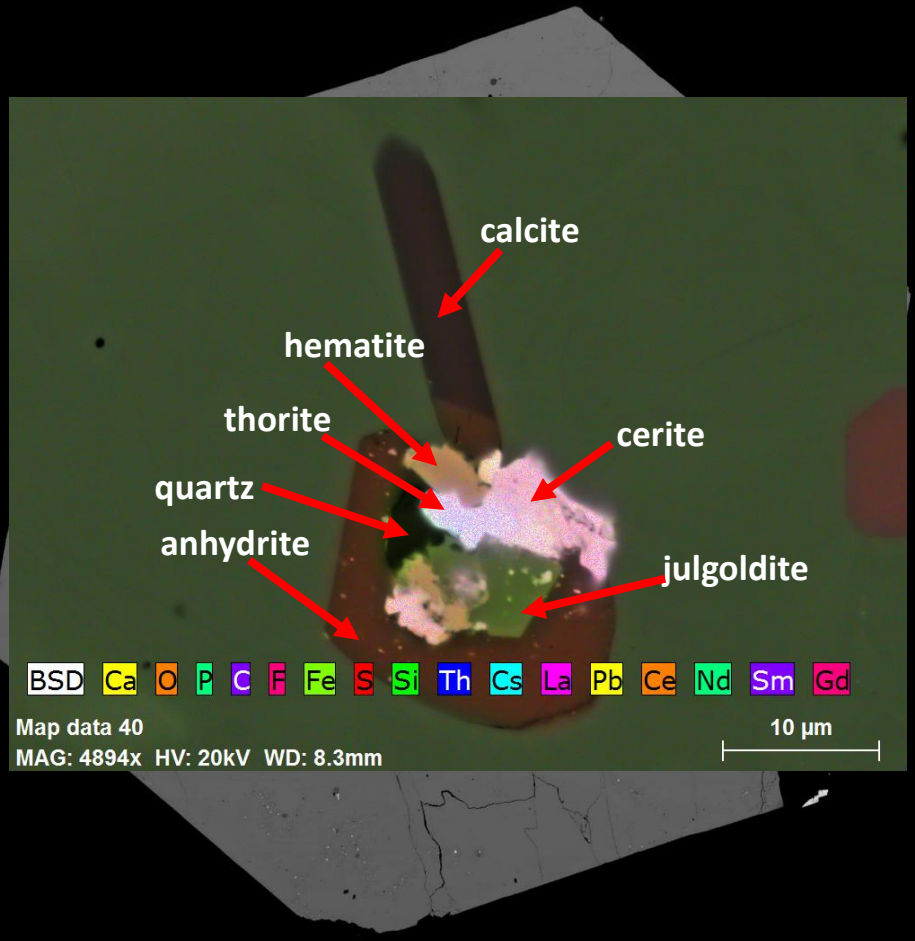

BSD
Map data 16
MAG: 1480x HV: 20kV WD: 8.3mm
40 µm

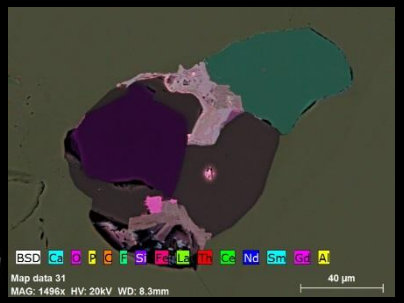

synchysite-(Ce)/parisite-(Ce)
thorite, cerite
fluorite
hematite
julgoldite
calcite
synchysite-(Ce)/parisite-(Ce)
quartz
allanite-(Ce)
julgoldite
baryte
BSD Ca O P C F Fe Si La Ce Nd Sm Th Gd Al Cs Ba S
Map data 33
MAG: 1900x HV: 20kV WD: 8.2mm
30 µm

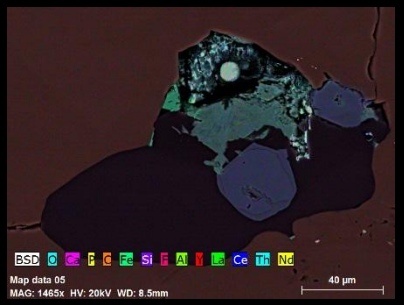

BSD Ca O P C F Fe S Si Th La Ce Nd Sm Fe Mn S
Map data 01
MAG: 819x HV: 20kV WD: 8.5mm
70 µm


BSD Ca O P C F Fe Th Mg Al La Ce Cs Nd Sm Si S Y
Map data 16
MAG: 1480x HV: 20kV WD: 8.3mm
40 µm


BSD Ca O P C F Fe S Th La Ce Nd Sm Th Ce Al Ce Ba S
Map data 33
MAG: 1900x HV: 20kV WD: 8.2mm
30 µm


calcite
hematite
thorite
cerite
quartz
anhydrite
julgoldite
BSD Ca O P C F Fe S Si Th Cs La Pb Ce Nd Sm Gd
Map data 40
MAG: 4894x HV: 20kV WD: 8.3mm
10 µm


BSD Ca O P C F Si Fe La Th Ce Nd Sm Gd Al
Map data 31
MAG: 1496x HV: 20kV WD: 8.3mm
40 µm


BSD O Ce F C Fe Si F Al Y La Ce Th Nd
Map data 05
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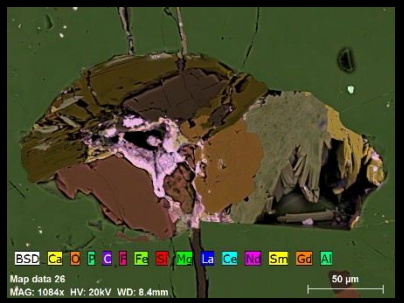
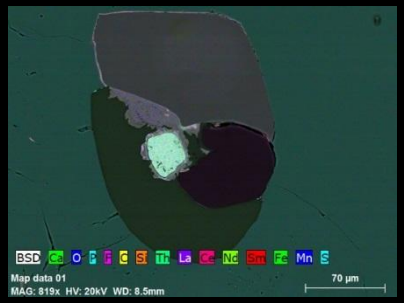
40 µm


BSD Ce O C F C Fe Si Mg La Ce Nd Sm Gd Al
Map data 26
MAG: 1084x HV: 20kV WD: 8.4mm
50 µm


Map data 01
MAG: 819x HV: 20kV WD: 8.5mm
70 µm


Map data 49
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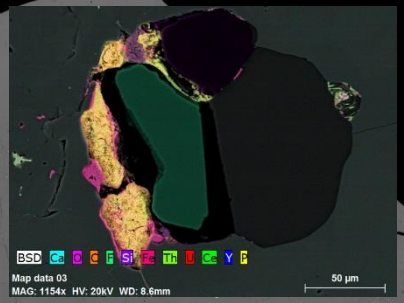
60 µm


Map data 03
MAG: 1154x HV: 20kV WD: 8.6mm
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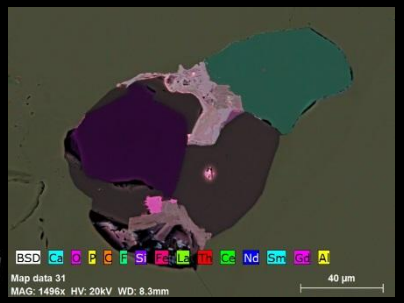
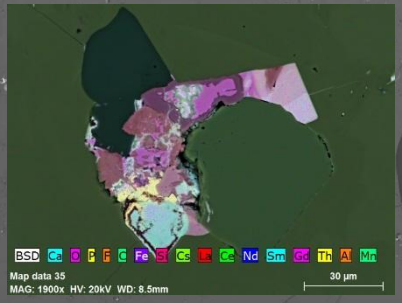
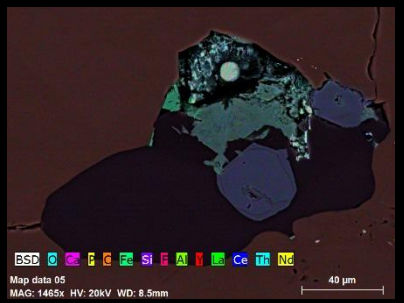

Map data 31
MAG: 1496x HV: 20kV WD: 8.3mm
40 µm

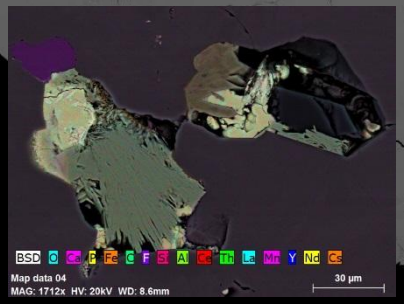

Map data 16
MAG: 1480x HV: 20kV WD: 8.3mm
40 µm


Map data 35
MAG: 1900x HV: 20kV WD: 8.5mm
30 µm


Map data 21
MAG: 672x HV: 20kV WD: 8.6mm
80 µm


Map data 05
MAG: 1465x HV: 20kV WD: 8.5mm
40 µm


Map data 33
MAG: 1900x HV: 20kV WD: 8.2mm
30 µm


Map data 04
MAG: 1712x HV: 20kV WD: 8.6mm
30 µm

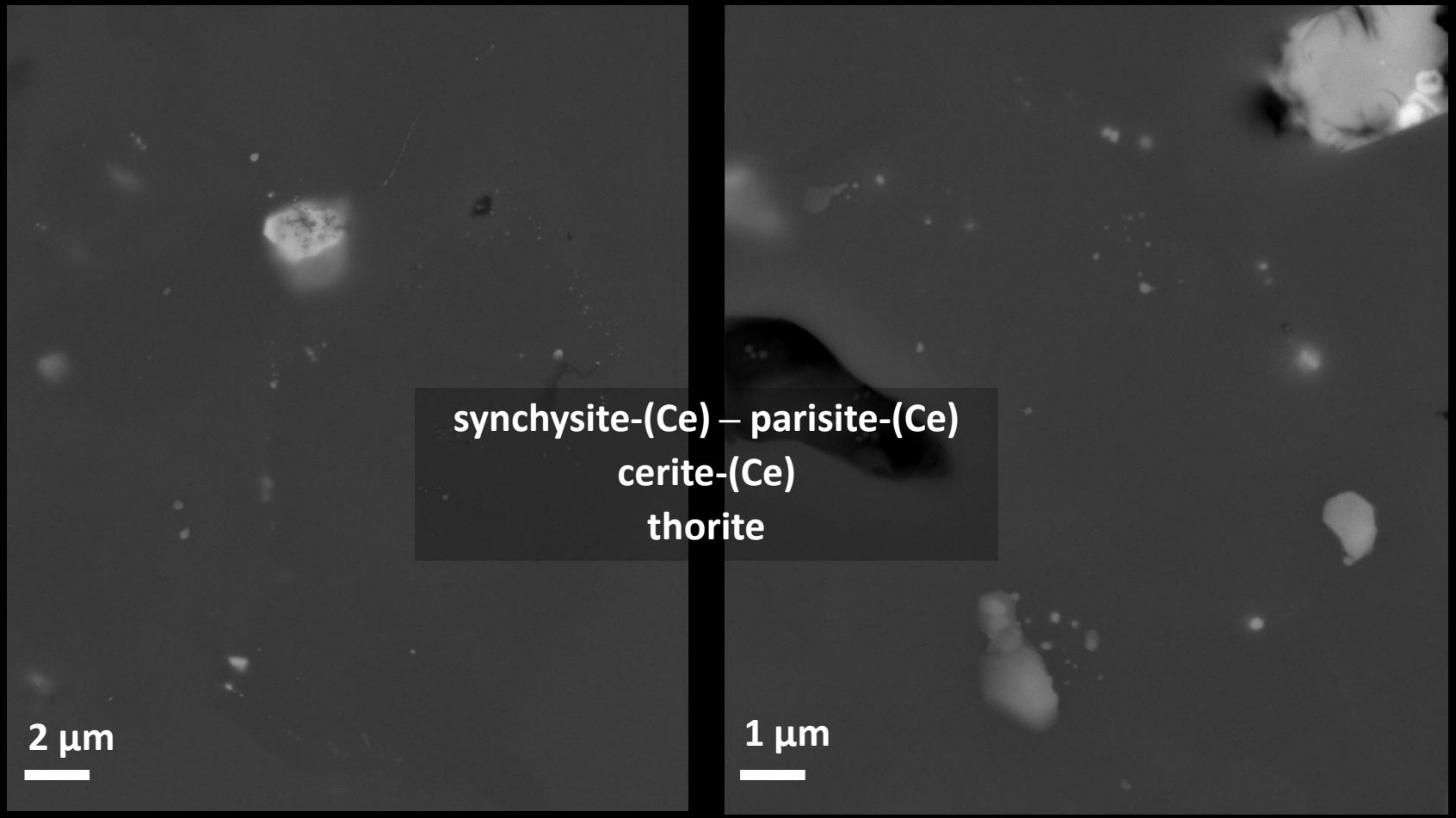

Map data 40
MAG: 4894x HV: 20kV WD: 8.3mm
10 µm


Map data 26
MAG: 1084x HV: 20kV WD: 8.4mm
50 µm

1 mm

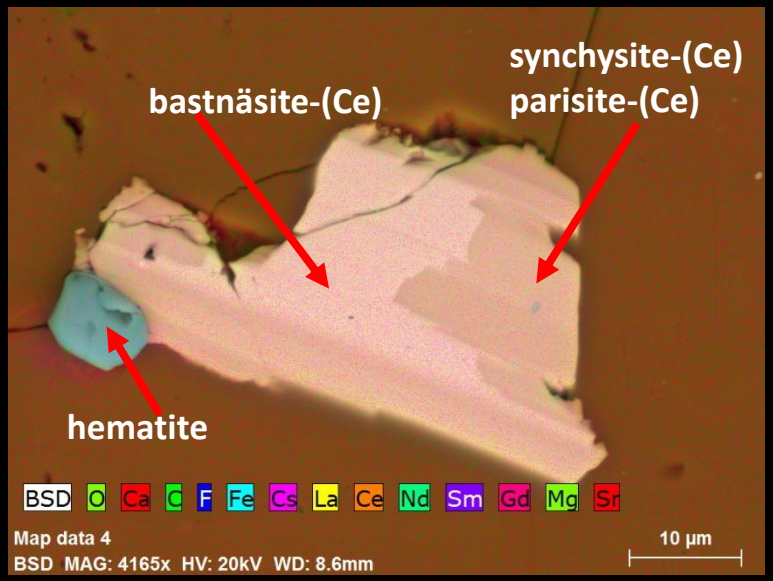
FOV: 25 mm

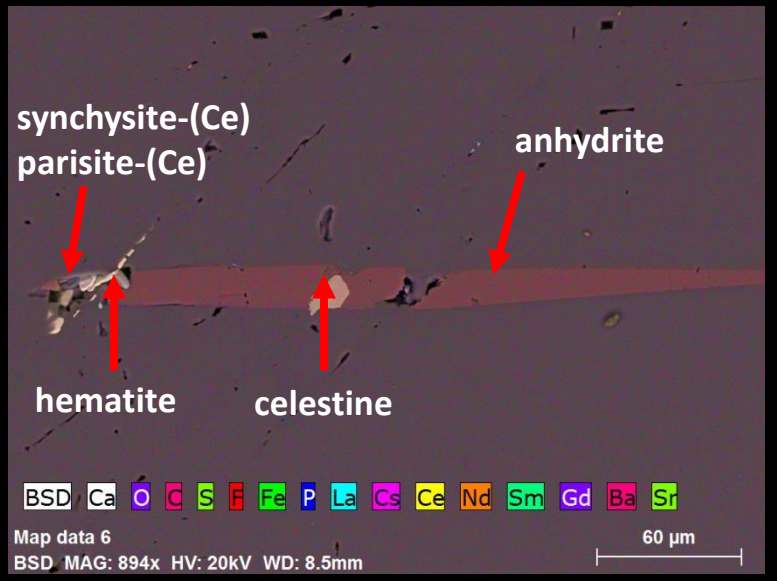
Otter Lake Apatite: submicrometric inclusions

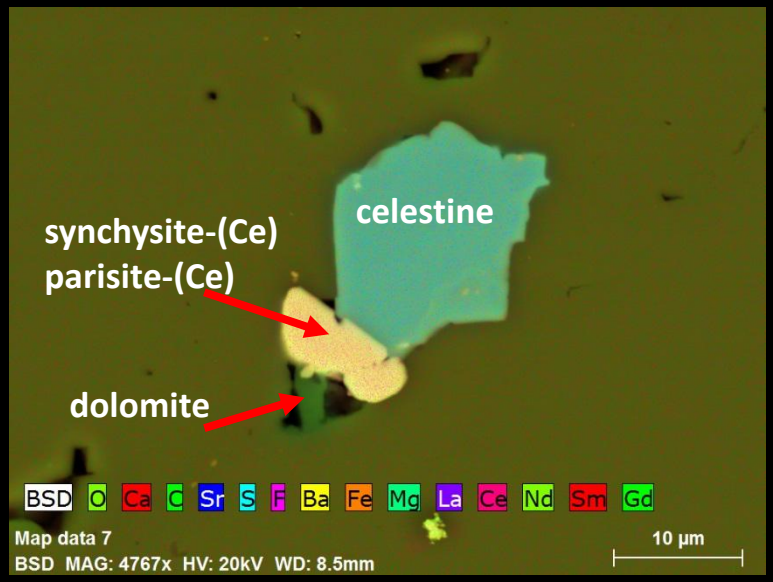


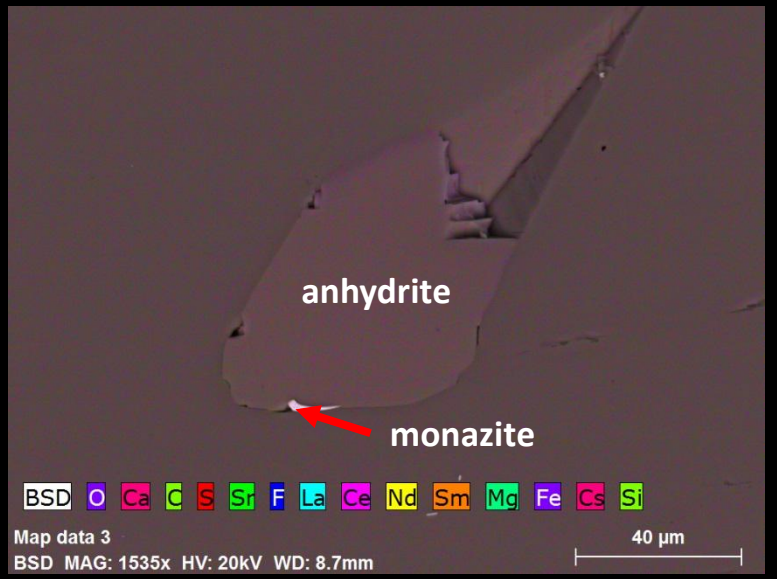
Now, the calcite matrix

Orange calcite (matrix): inclusions



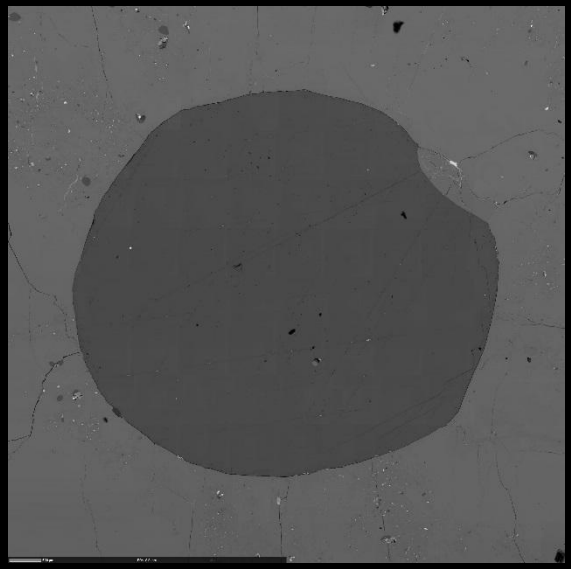


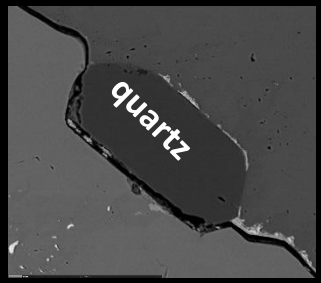




Otter Lake Apatite: Conclusions

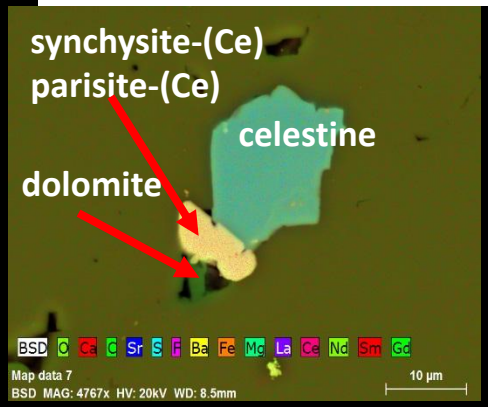
- the results suggest that the apatite grew in a silicocarbonatitic melt

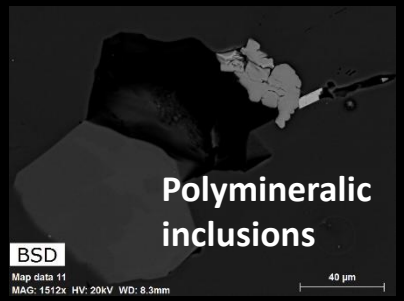


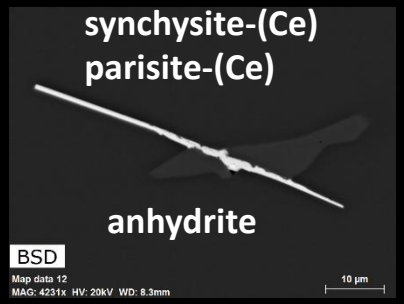


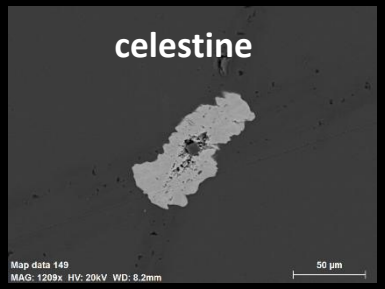
The large orange calcite globules are the largest component of a polymineralic inclusion

The orange calcite globule and the orange matrix calcite in which the apatite is growing have similar inclusions



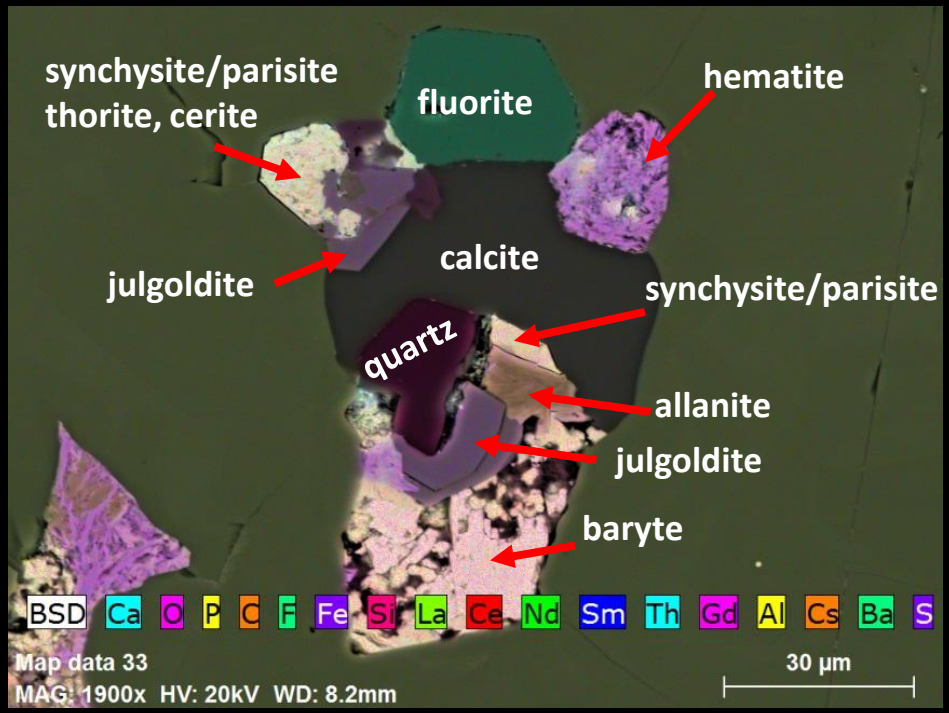




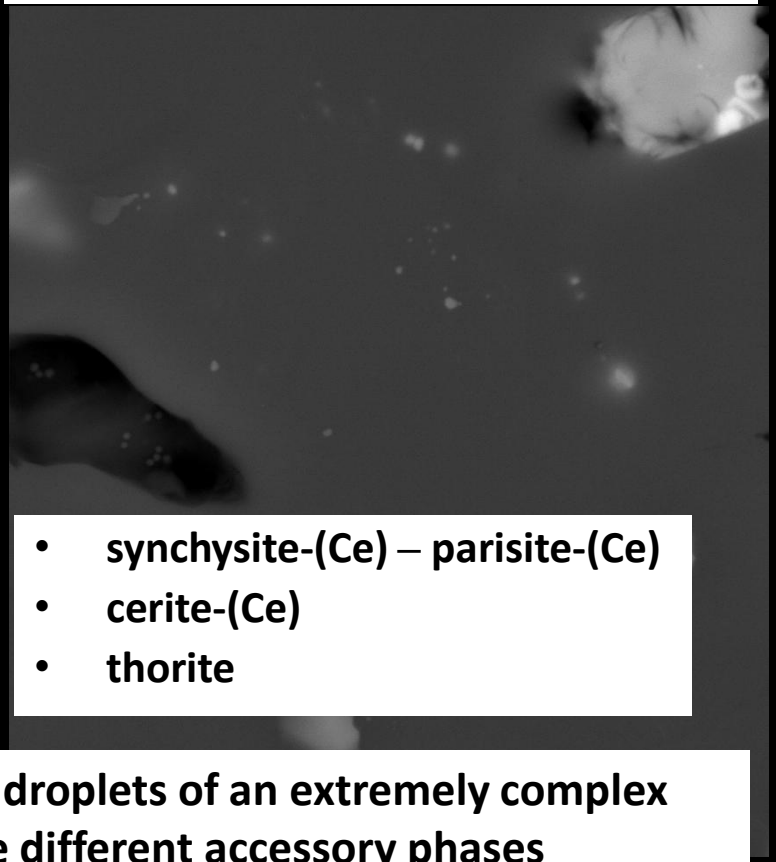


Otter Lake Apatite: Conclusions

polymineralic inclusions



inclusions < 1 µm



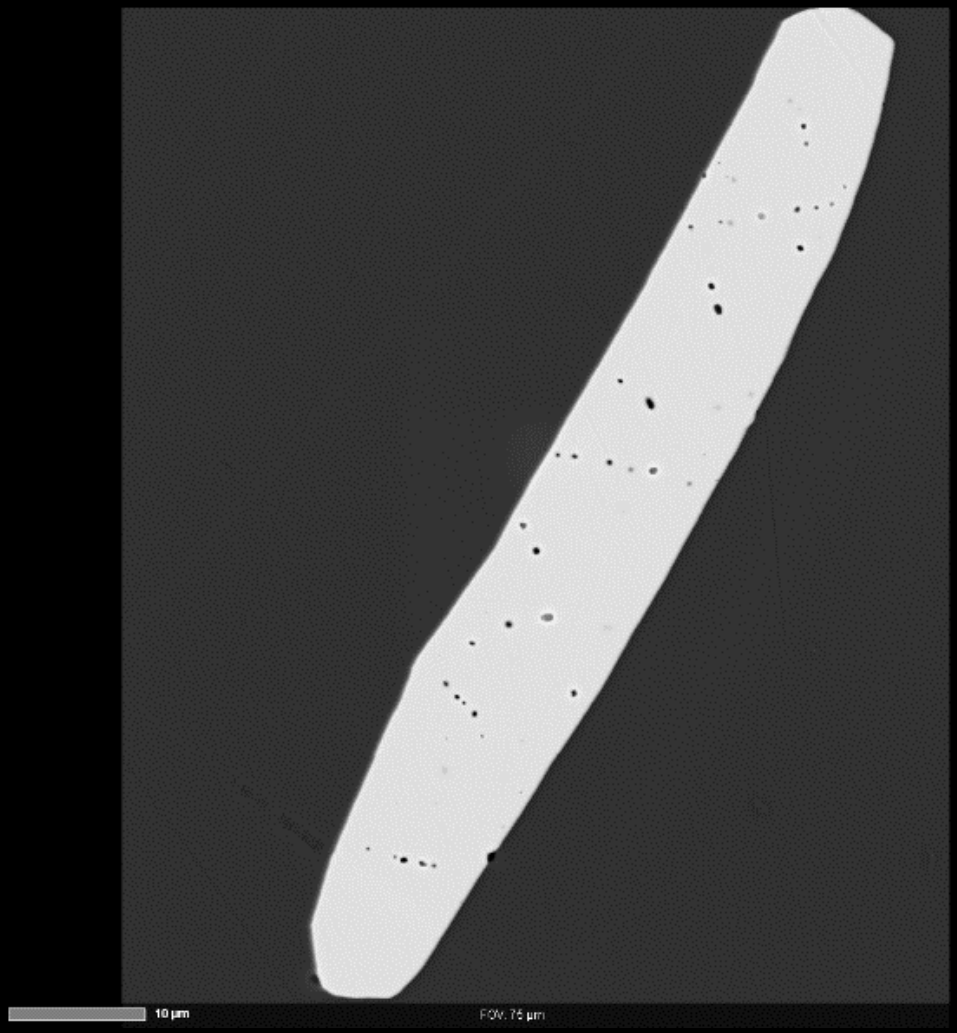
- synchysite-(Ce) – parisite-(Ce)
- cerite-(Ce)
- thorite

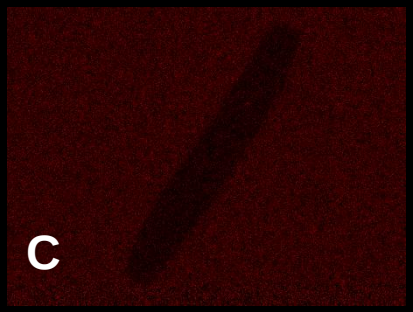
- The micro-inclusions in the apatite are entrapped droplets of an extremely complex silicocarbonatitic melt that crystallized to all these different accessory phases
- They all have a similar mineral assemblages: calcite, fluorite, quartz, julgoldite, diopside, hematite, anhydrite, thorite, cerite-(Ce), synchysite-(Ce) – parisite-(Ce)
- Submicrometric inclusions are also similar (REE minerals)

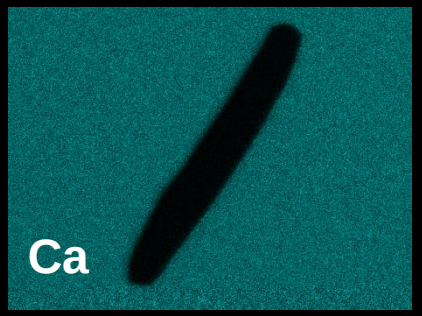
The second locality: Autoroute 5, near Meech Lake, QC

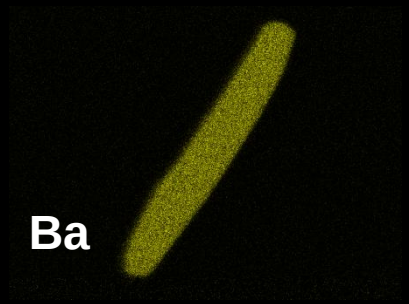
- Highway construction revealed exposures of orange and pink calcite, but also blue calcite
- Blue calcite is devoid of micro-inclusions containing REE, U, Th
- Prominent micro-inclusions of baryte and anhydrite, but also sulfides!

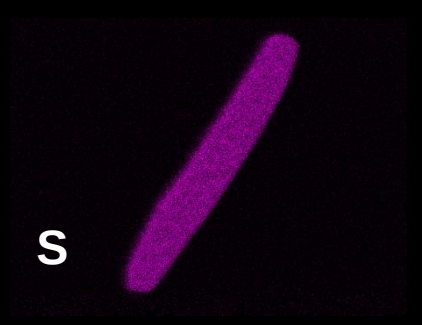
Blue calcite (Autoroute 5): inclusions

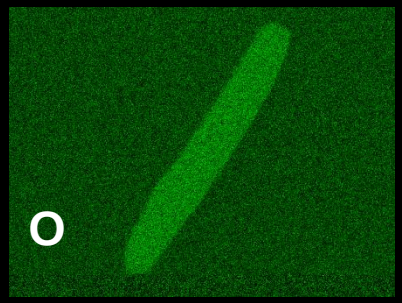






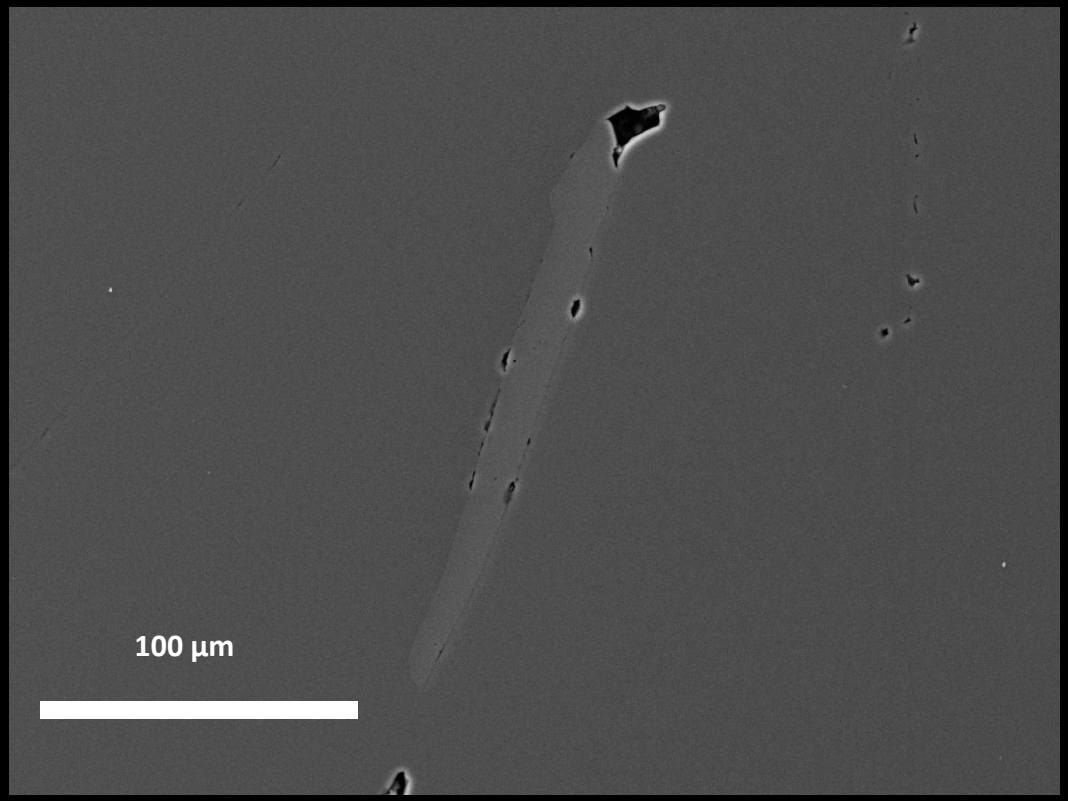


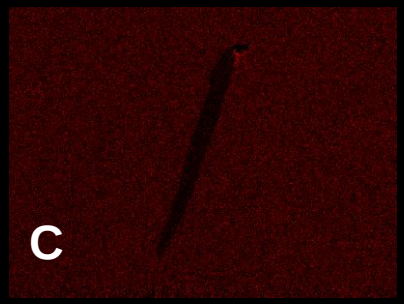


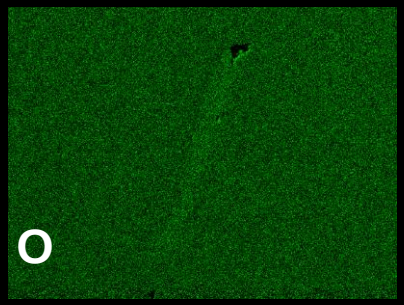


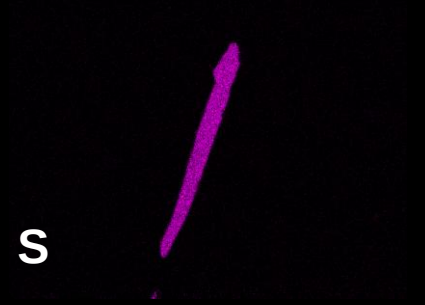
Baryte ($BaSO_4$)

Blue calcite (Autoroute 5): inclusions



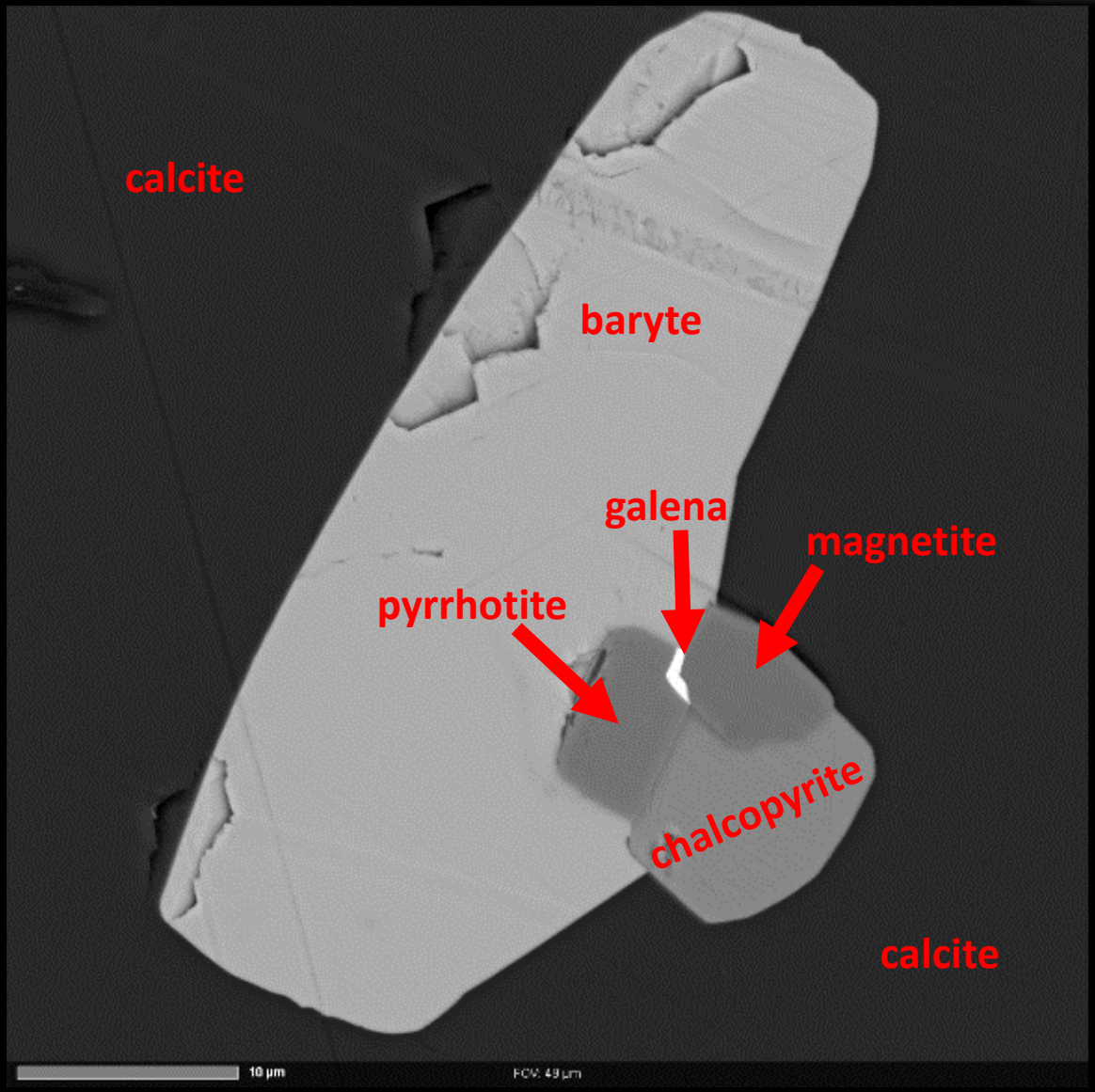






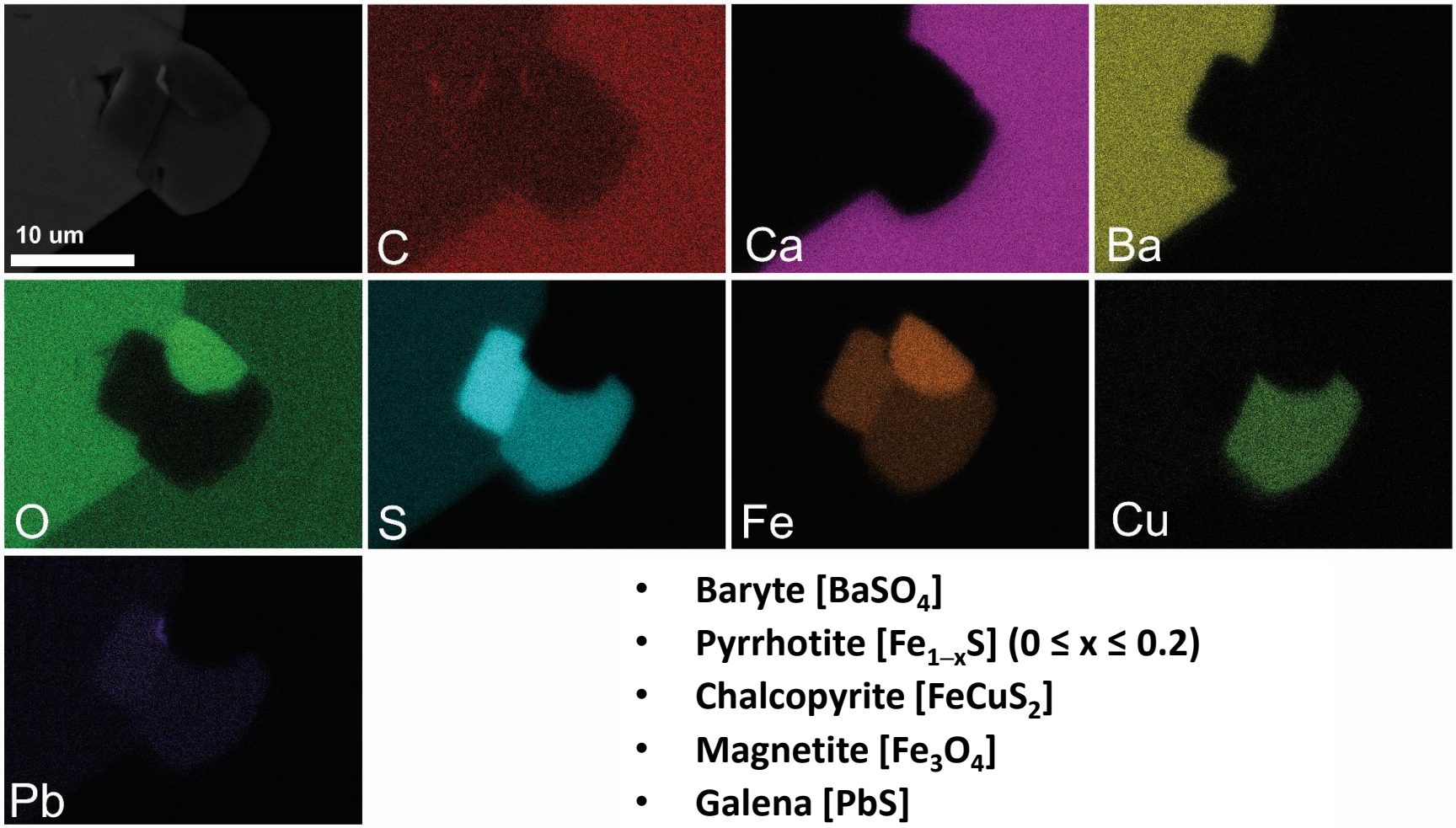
Anhydrite ($CaSO_4$)

Blue calcite (Autoroute 5): inclusions



Blue calcite (Autoroute 5): inclusions

Site 04



- Baryte [$BaSO_4$]
- Pyrrhotite [$Fe_{1-x}S$] ($0 \leq x \leq 0.2$)
- Chalcopyrite [$FeCuS_2$]
- Magnetite [Fe_3O_4]
- Galena [PbS]

OUR INTERPRETATIONS (1)

- Evidence of multiple anatectic melts
- T, P: 700 $\pm$ 50°C and 7 $\pm$ 0.5 kbar (equivalent to 23–25 km)
- Calcite can melt at such conditions (*e.g.*, Durand *et al.* 2015)
- Phosphate, sulfate, fluoride and H_2O are fluxes
- Sulfate component: evaporitic horizons in the marble?
- Fluorine, the REE, and Ba: metasomatic overprint prior to melting ?

Terra Nova

doi: 10.1111/ter.12168

Low melting temperature for calcite at 1000 bars on the join $CaCO_3$-H_2O – some geological implications

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ABSTRACT

Melting experiments of calcite were performed on the join $CaCO_3$-H_2O at a pressure of 1000 bars. The system evolves to the ternary CaO-H_2O-CO_2 system during melting experiments. Our experiments show that partial melting of calcite begins at a low temperature, below 650 °C. Such a low partial melting temperature for carbonates revives the debate about the presence of carbonate melts in the upper crust. More specifically, the conditions for carbonate partial melting are present in carbonate host rocks undergoing contact metamorphism at high temperatures in the presence of water-rich fluid. The presence of carbonate melts influences physical parameters such as viscosity and permeability in contact aureoles, and, furthermore, decarbonation reactions release massive amounts of CO_2.

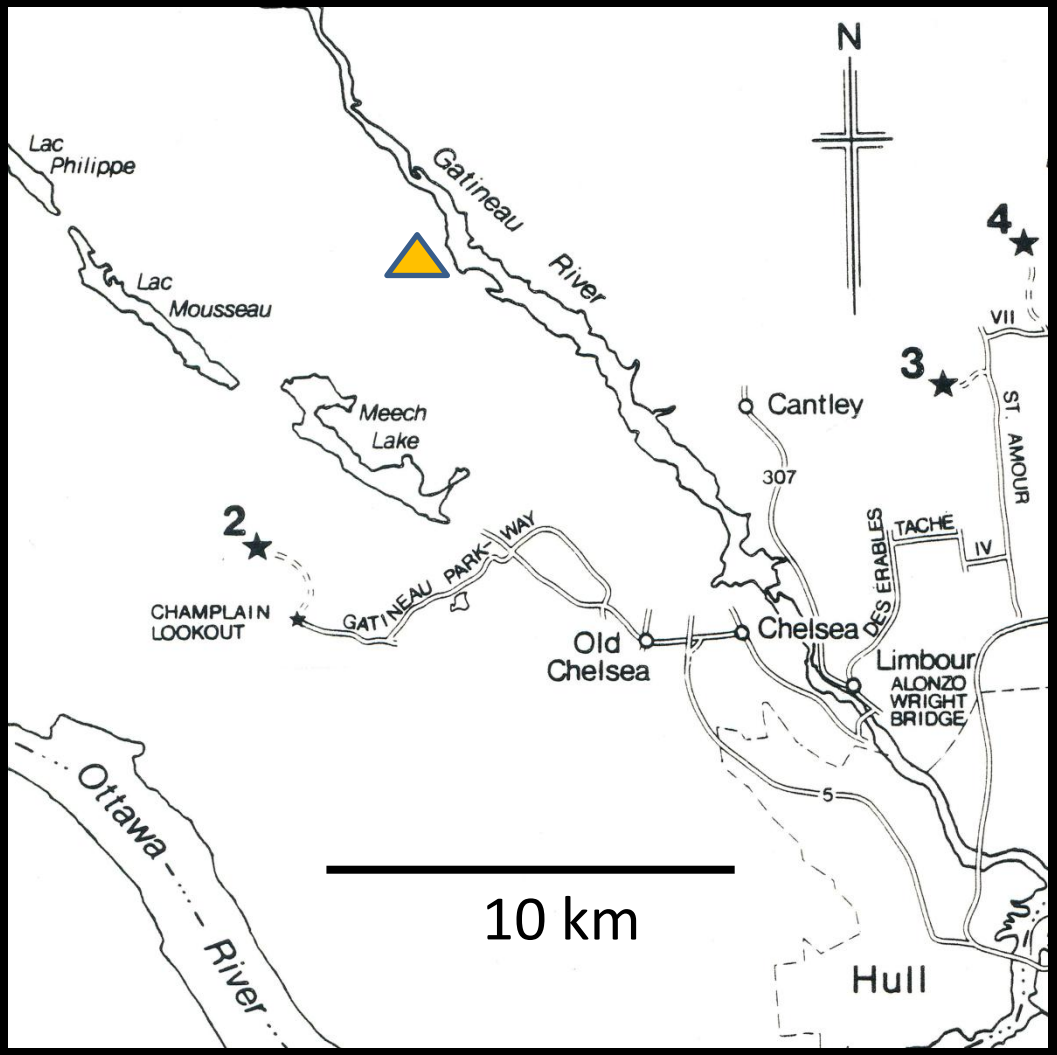
Terra Nova, 00, 1–6, 2015

OUR INTERPRETATIONS (2)

- The carbonate melt is very aggressive toward the enclosing rock, and "reprocesses" it
- That provides the melt with the P, Si, Al, Ti, *etc.* needed to nucleate those euhedral crystals
- Prisms seem aligned (flow-aligned or cumulate)
- Si was also supplied by detritus in the limestone
- Crystallization of the multicomponent "soup" caused a gas phase to appear, leading to rapid crystallization

A CLASSIC CUMULATE, IN MY OPINION, WITH A FILM OF MELT BETWEEN CRYSTALS

The Autoroute 5 occurrence is close to the Meech Lake carbonatite



2 Meech Lake carbonatite (Hogarth (2016)

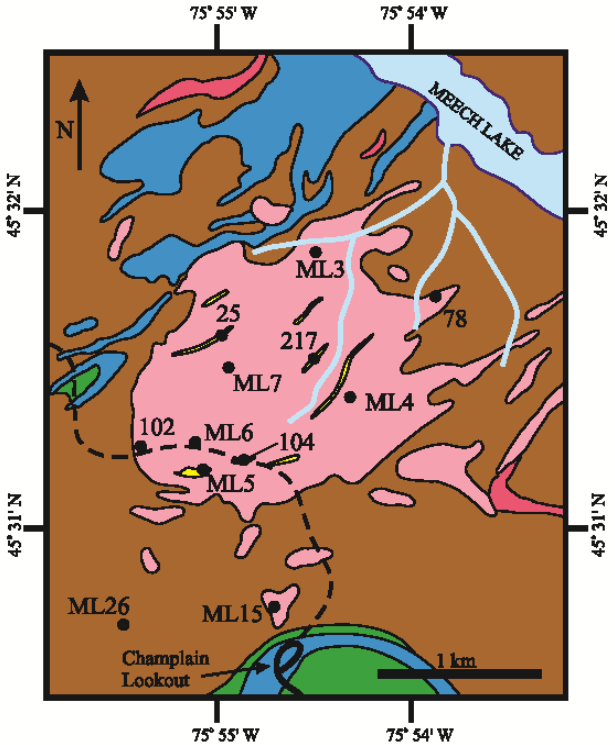
3 Haycock fenite

4 Templeton carbonatite

▲ Autoroute 5 road cuts of orange, pink and blue calcite

Hogarth & Rushforth (1986, Fig. 1)

CARBONATITE DIKES AT MEECH LAKE



Lithological Units (Mesoproterozoic)

- Carbonatite and fenite
- Granite: aplitic / pegmatitic
- Monzonitic orthogneiss
- Marble and skarn / Diopside-plagioclase gneiss

- Gatineau Parkway
- Parkway unfinished
- Petrologic contact
- Sample site (all except ML7, ML15 and ML26 contain pyrochlore)

FIG. 1. Geology and sample sites of Meech Lake carbonatites and fenites.

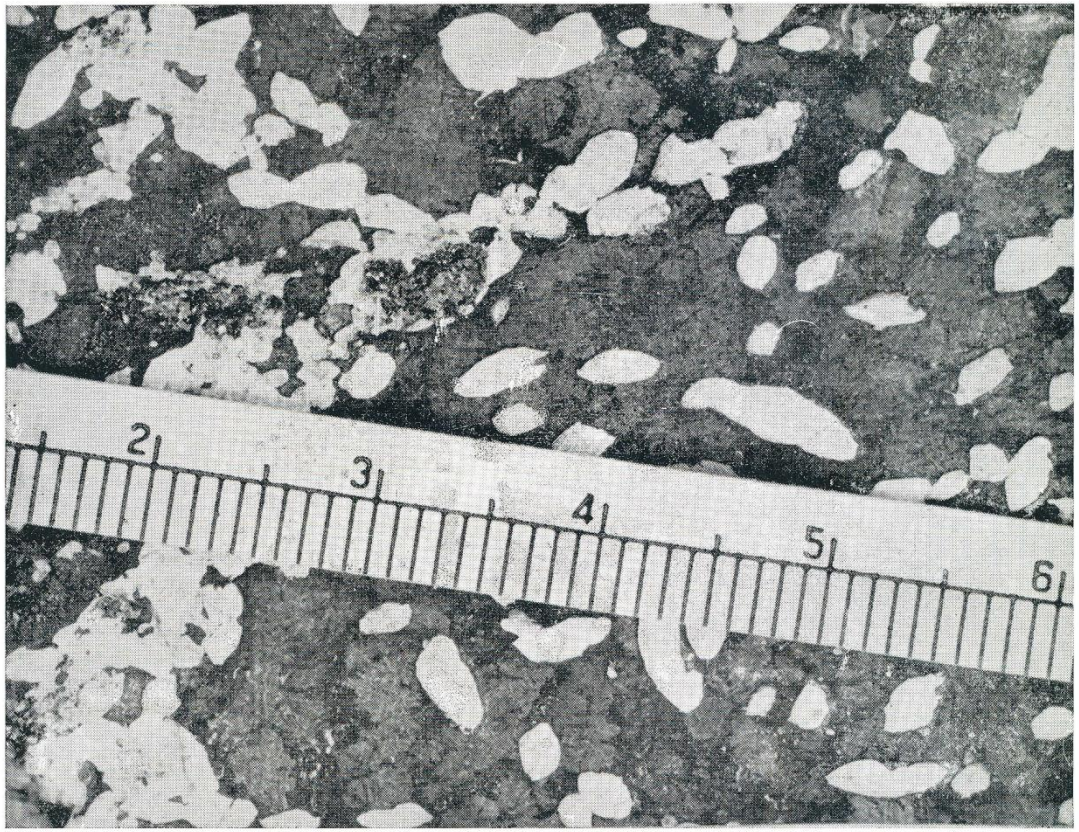


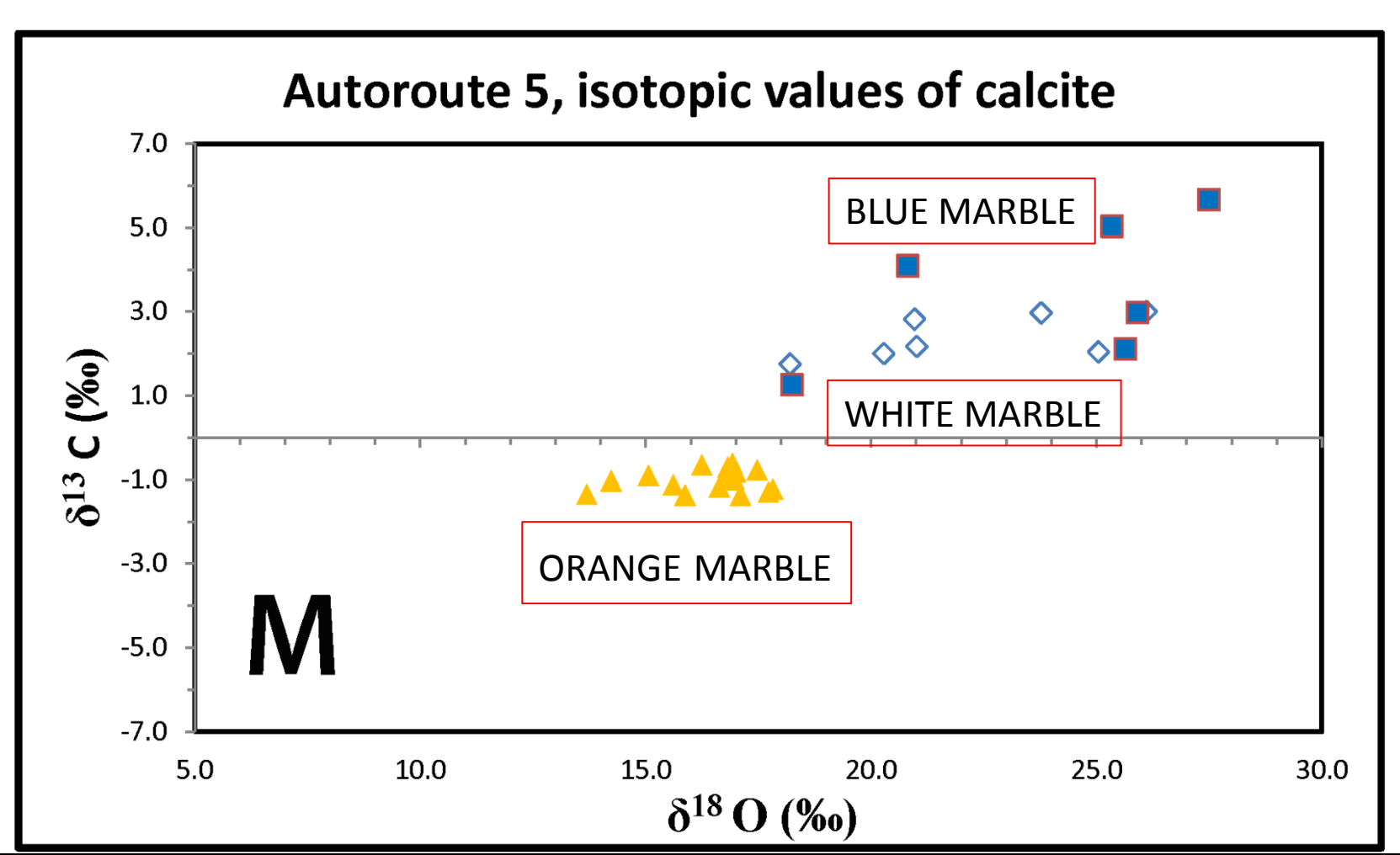
Fig. 3. Crystals of dolomite (light) in calcite (dark). Calcite has been stained by alizarin-red dye.

Hogarth (2016)

Hogarth (1966)


Round Stic Grip

STABLE ISOTOPE EVIDENCE FOR A **CRUSTAL** SILICOCARBONATITE



THANK YOU FOR YOUR ATTENTION!