Exploring British Columbia’s Porphyry Copper Deposits using Zircon, Apatite and Titanite

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and contribution by

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Acknowledgement

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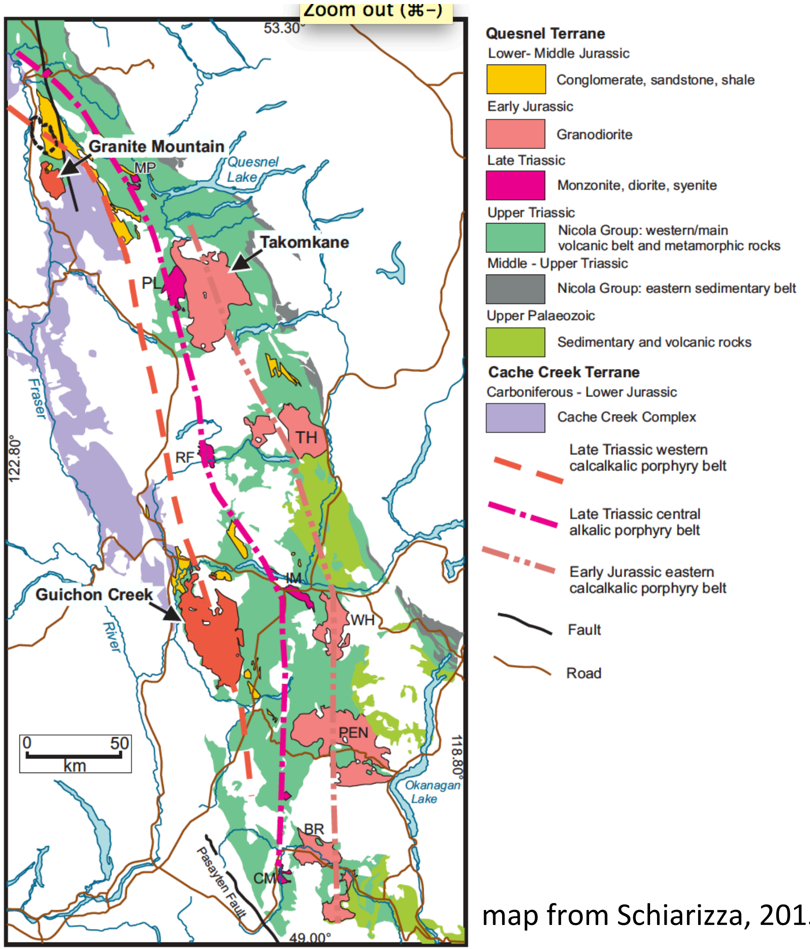
Geoscience BC

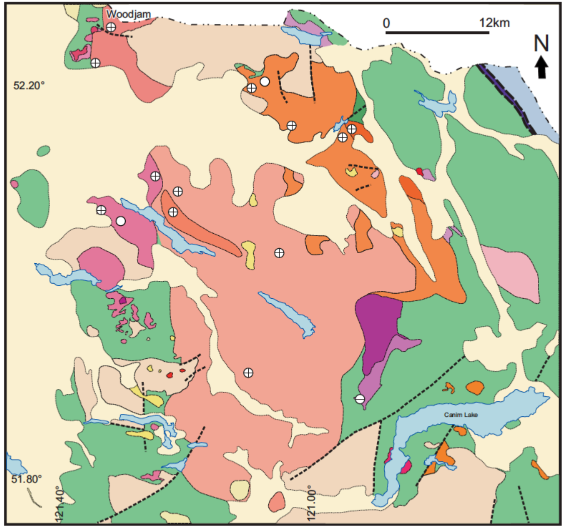
British Columbia's Fertile Plutons

In British Columbia many porphyry systems occur within or around the edges of large batholiths.



map from Schiarizza, 2015

Takomkane



Quaternary
- Glacial, alluvial, colluvial
- Basalt, basalt tephra

Miocene-Pliocene
- Chilcotin Olivine basalt

Eocene
- Diorite
- Kamloops volcanic-sedimentary

Early Cretaceous
- Monzonite, granodiorite

Early Jurassic

Quesnel Monzonite Suite
- Monzonite, quartz monzonite

Quesnel Diorite Suite
- Diorite, Gabbro

Quesnel Ultramafic Suite
- Diorite, gabbro, monzodiorite
- Gabbro, diorite, hornblendite, clinopyroxenite
- Clinopyroxenenite, hornblendite, dunite

Takomkane batholith
- Quartz-feldspar porphyry
- Schoolhouse Lake megacryst granodiorite
- Woodjam Creek granodiorite, quartz monzonite

Late Triassic - Early Jurassic

Takomkane batholith
- Boss Creek monzodiorite, granodiorite
- Buster Lake gabbro-diorite

Late Triassic

Spout Lake Pluton
- Quartz monzonite
- Coarse crowded plagioclase porphyry
- Monzonite, diorite, syenite

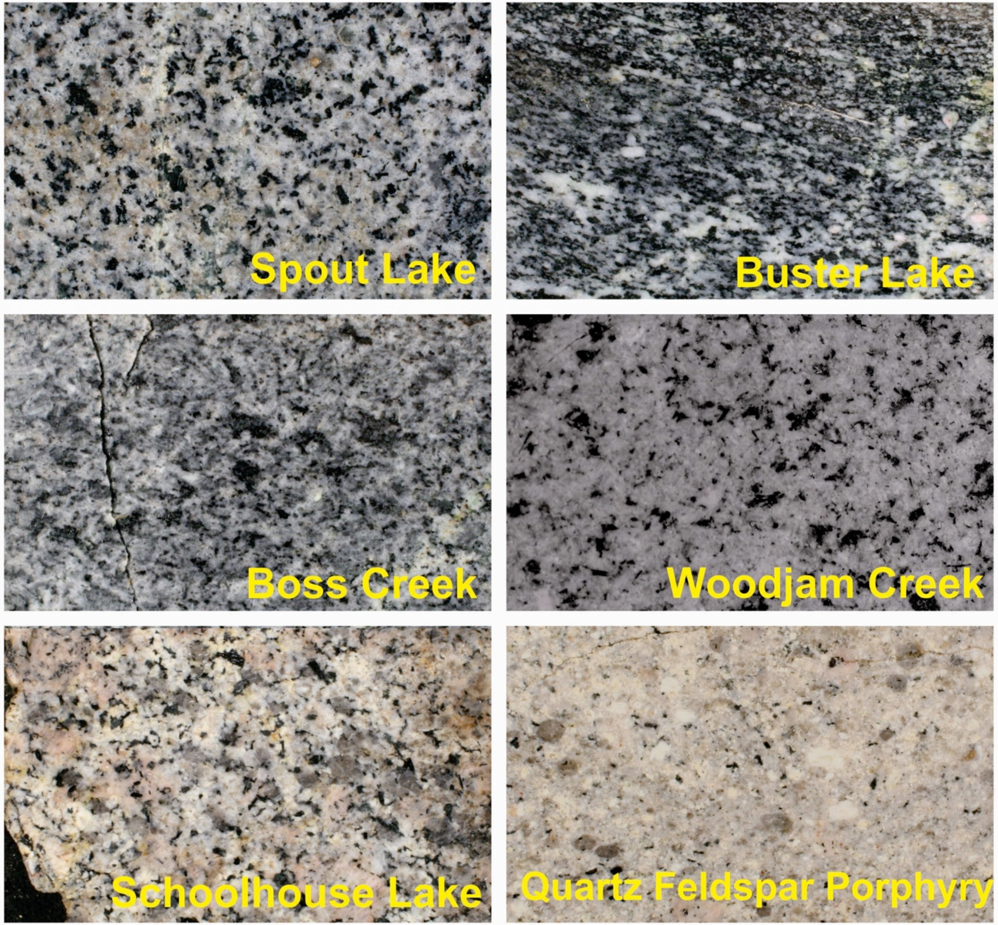
Middle and Late Triassic
- Nicola Group

Carboniferous - Permian
- Slide Mountain Group: Crooked schist

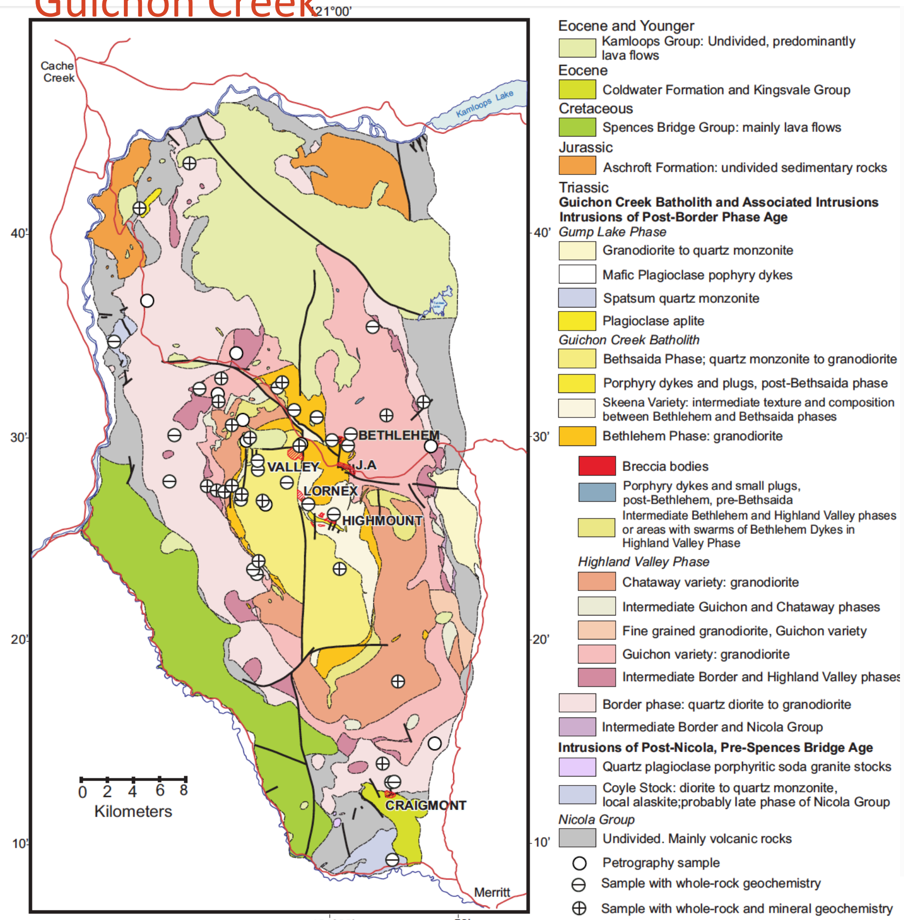
Proterozoic and/or Paleozoic
- Snowshoe Group: quartzite, schist, marble

○ Petrography sample ⊖ Sample with whole-rock geochemistry ⊕ Sample with whole-rock and mineral geochemistry

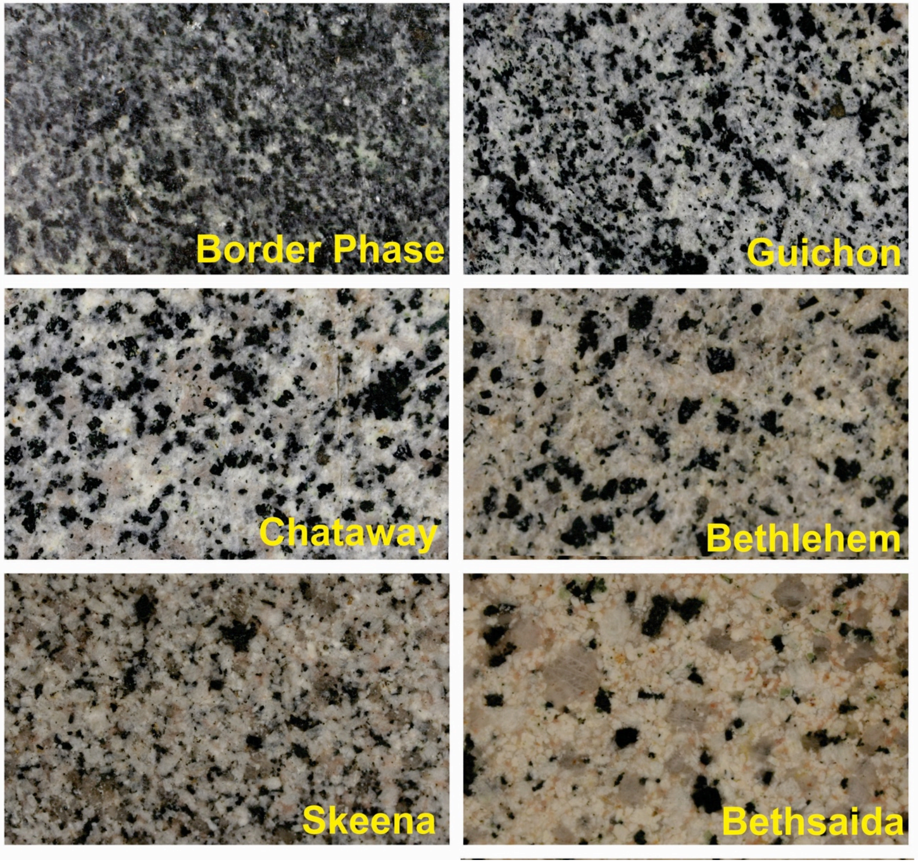
map from Schiarizza, 2013



Guichon Creek

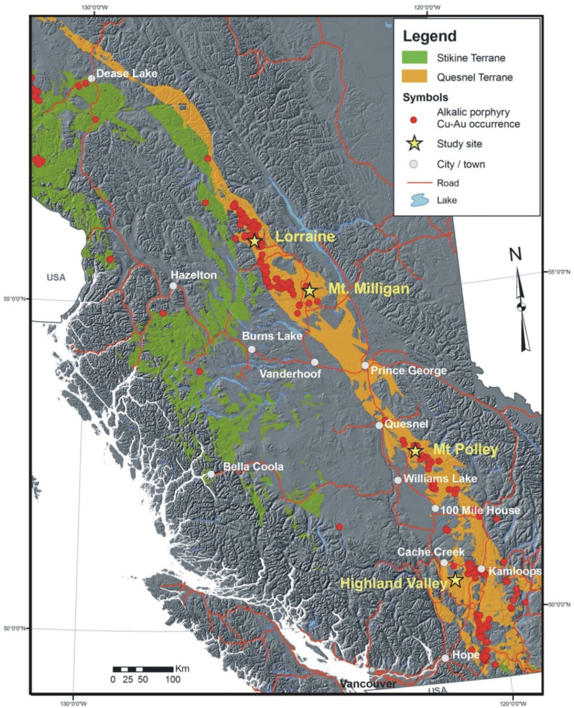


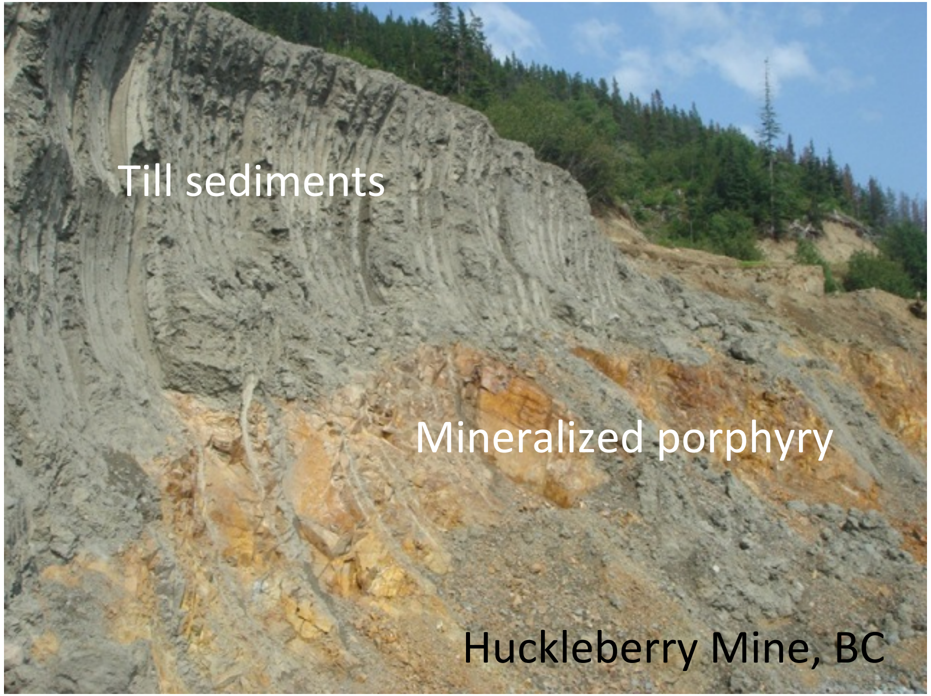
Map from McMillan et al., 2009



Exploring Under Cover

Exploration success in BC’s porphyry belts has been limited due to thin, but extensive veneers of till and related glacial sediments.

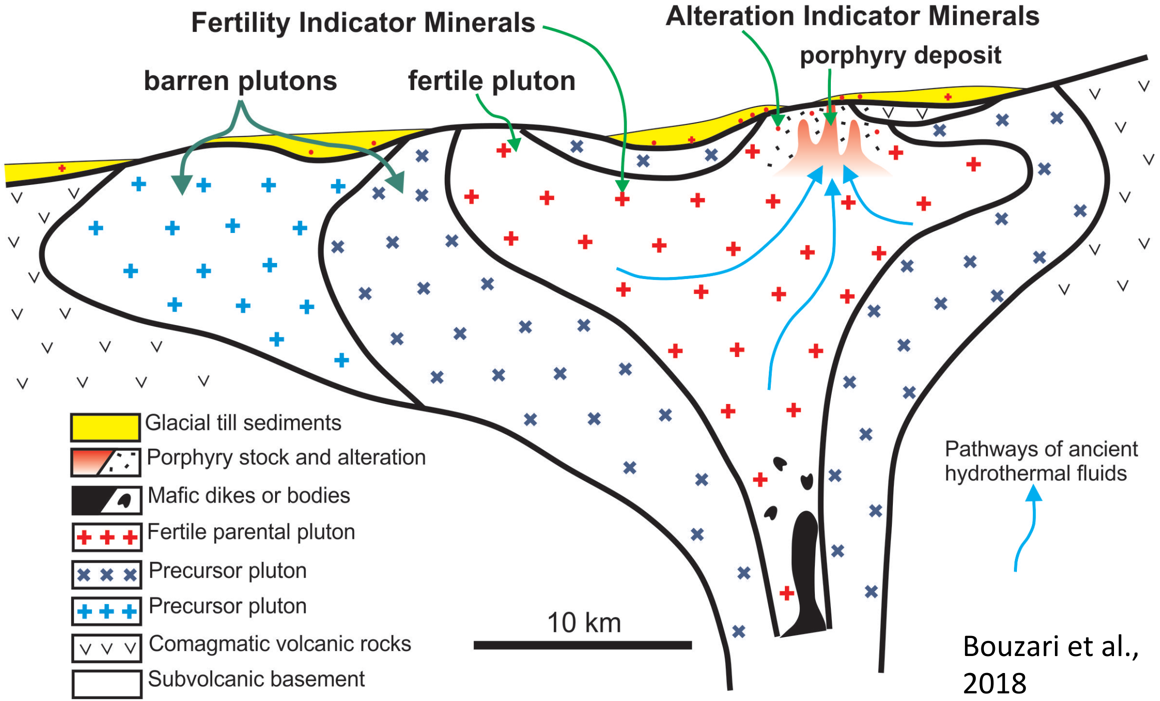




Porphyry Deposits and PIMS

Key Factors:
1. Oxidation state
2. Temperature
3. Pressure (depth)
4. Water
5. Metal
6. Chlorine
7. Sulphur

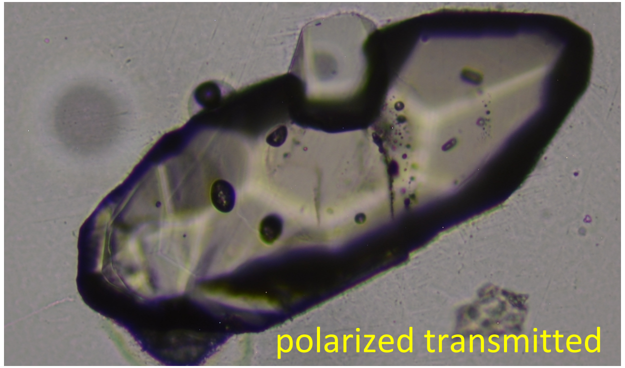
Key Minerals*:
1. Zircon
2. Titanite
3. Apatite
4. Magnetite
5. Rutile

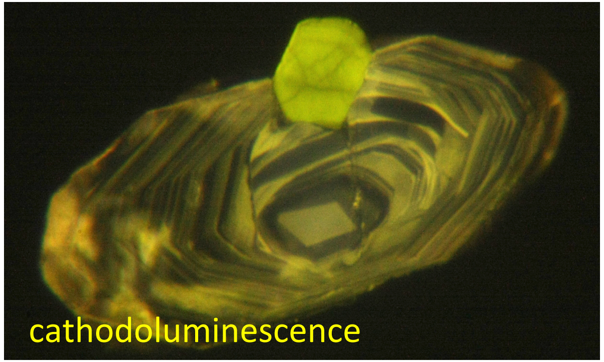


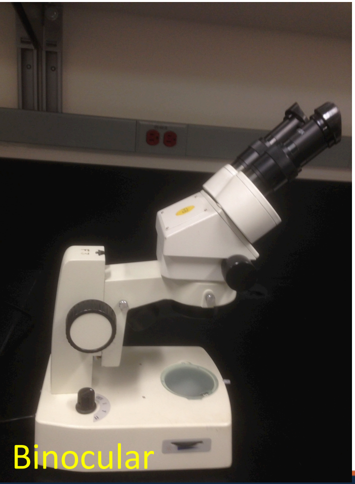
*PIMS display **unique physical and chemical properties** that allow their presence in surficial materials to be linked back to a porphyry deposit, related intrusion or alteration assemblage.*

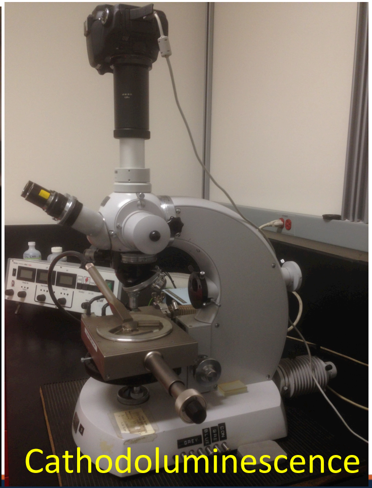
Research Tools: to study texture and composition


Binocular-polished grain


polarized transmitted

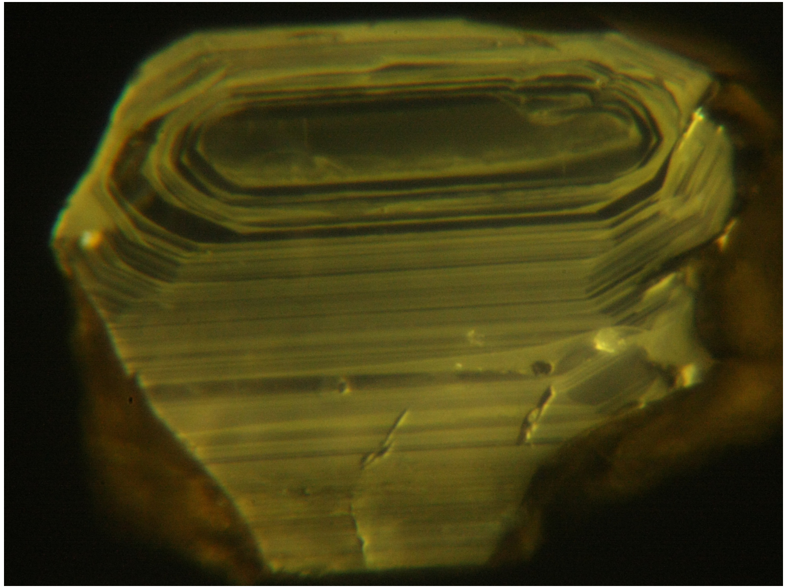

cathodoluminescence


Binocular


Cathodoluminescence


UBC-PCIGR Resolution M-50-LR and Agilent 7700 Series quadrupole ICP-MS

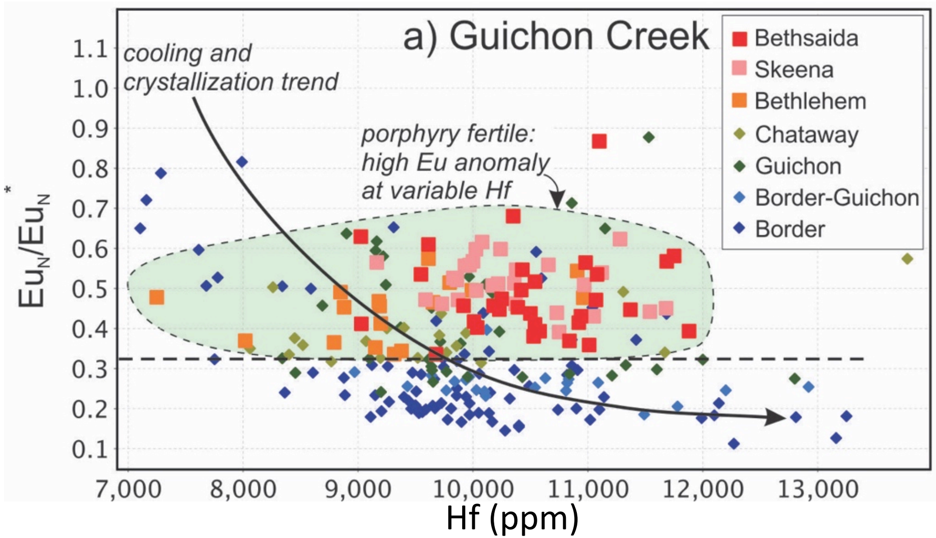
Zircon

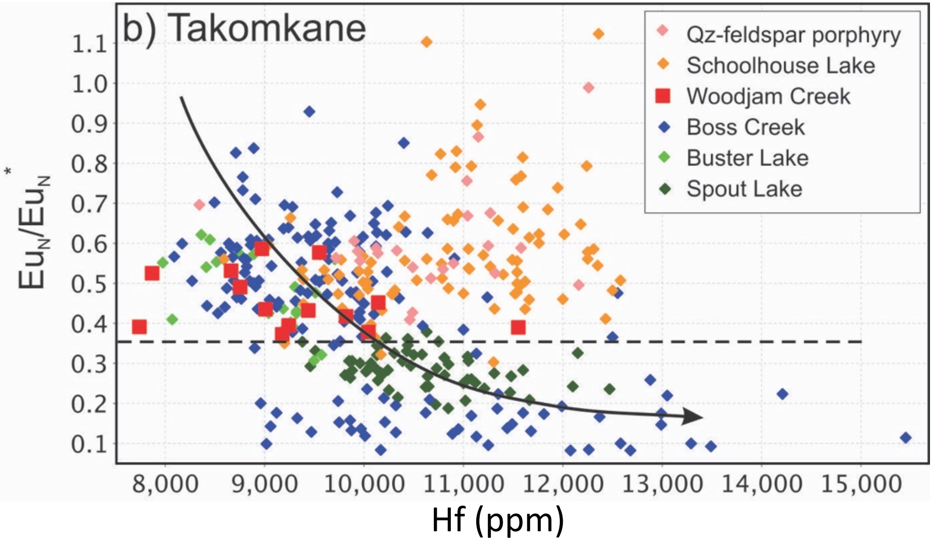


- Geochronology: U-Pb
- Thermometer: Ti activity
- Fractionation (Hf)
- Oxidation state (Eu, Ce)

Zircon: Oxidation Sate and Water Content

Bouzari et al., 2020

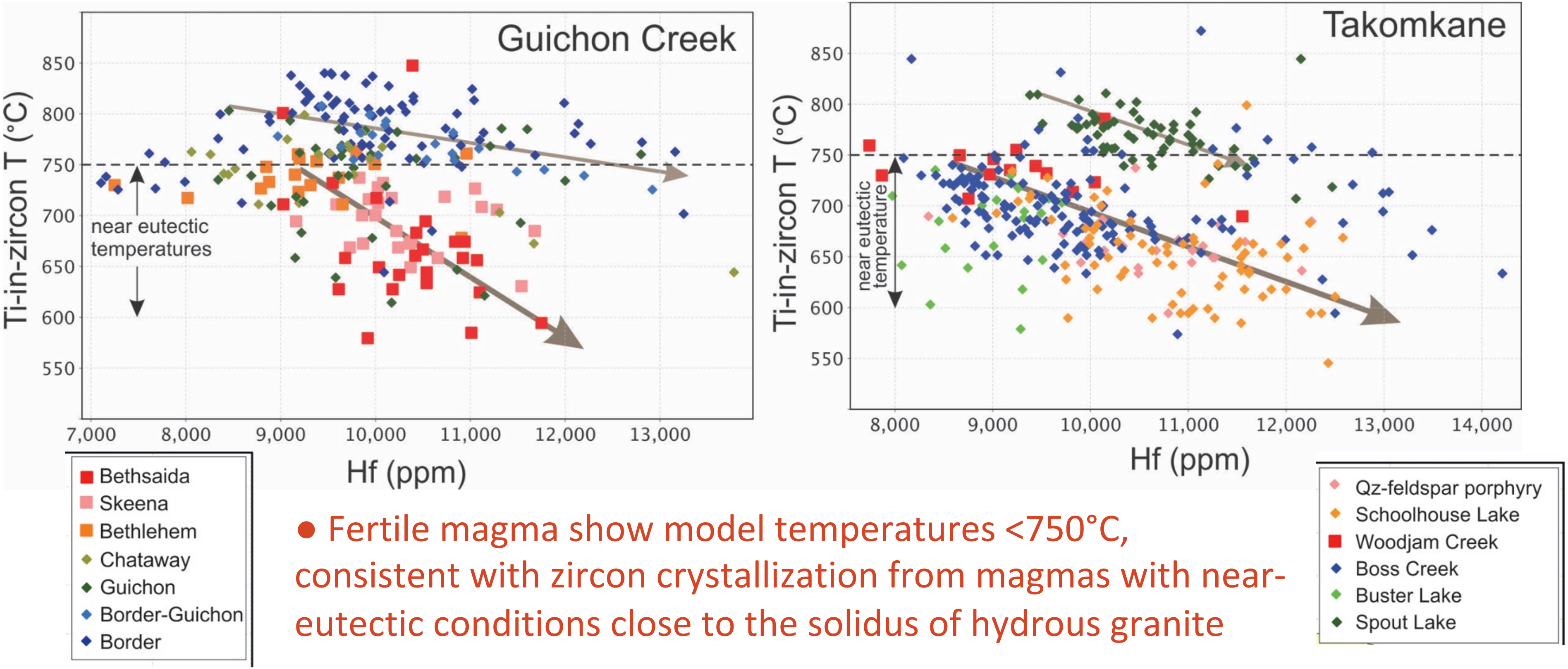




The nonmineralized plutons show variable Eu anomaly values as a result of crystal fractionation whereas the mineralized phases show less variations suggesting crystal fractionation effects were suppressed by a high water content of the magma and SO_2 degassing (Dilles et al., 2015).

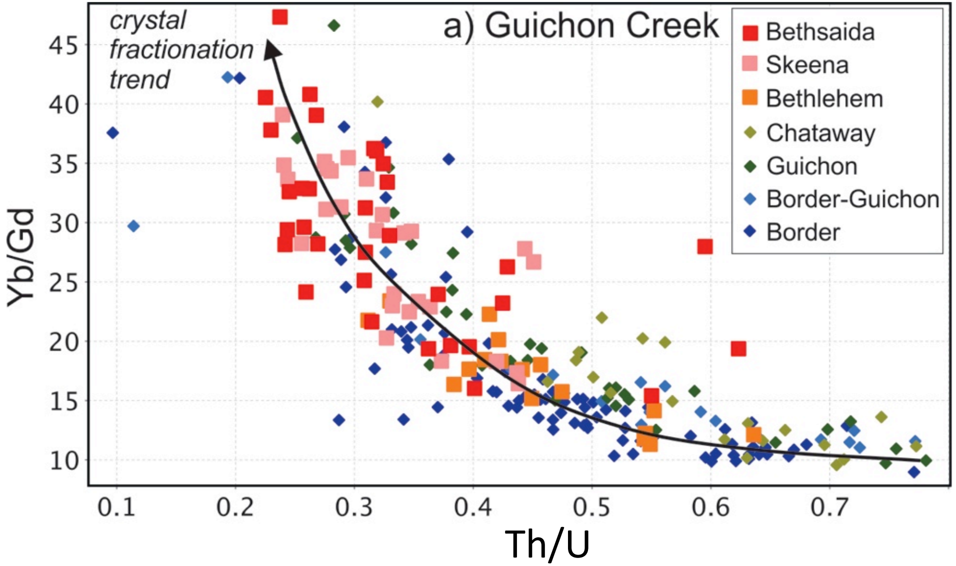
- Fertile magmas are more oxidized AND water rich

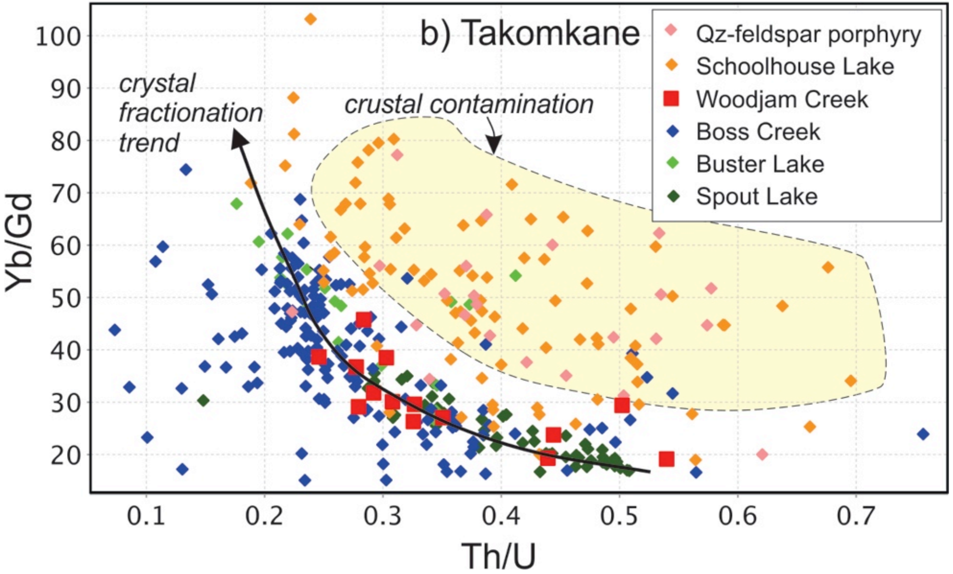
Zircon: Temperature



● Fertile magma show model temperatures <750°C, consistent with zircon crystallization from magmas with near-eutectic conditions close to the solidus of hydrous granite

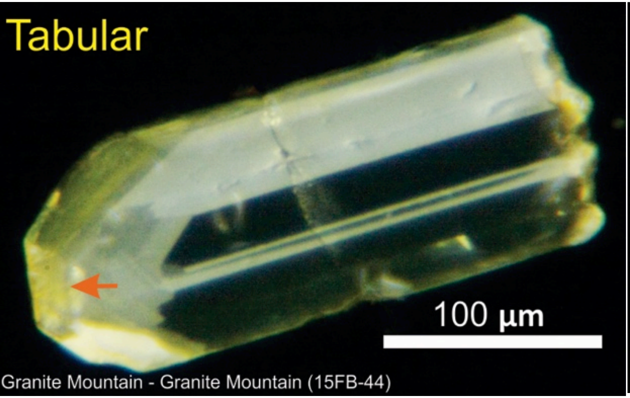
Zircon: Crystal Fractionation

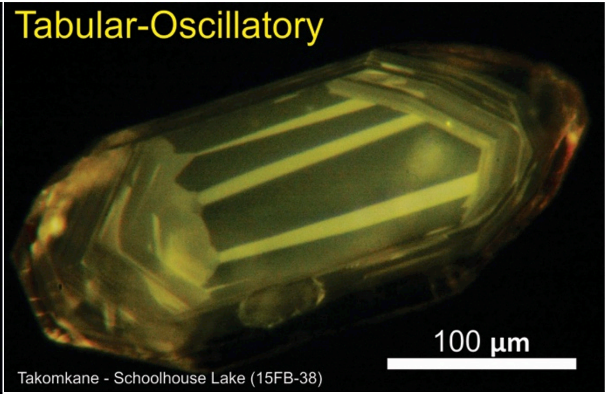


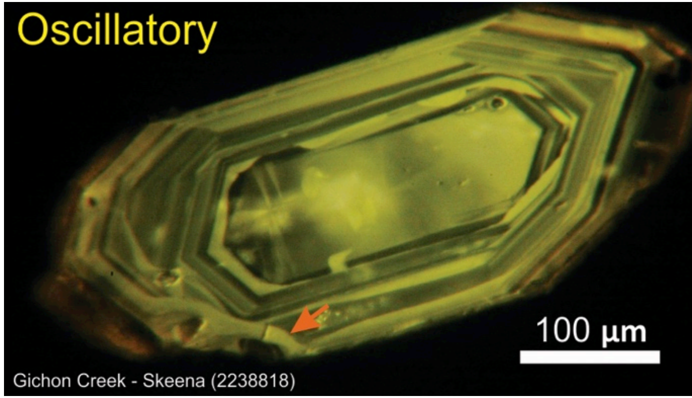


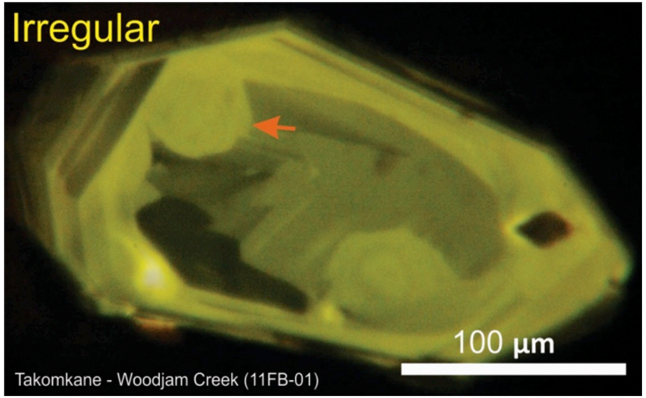
- Fertile magmas show simple crystal fractionation with no evidence of crustal mixing and contamination

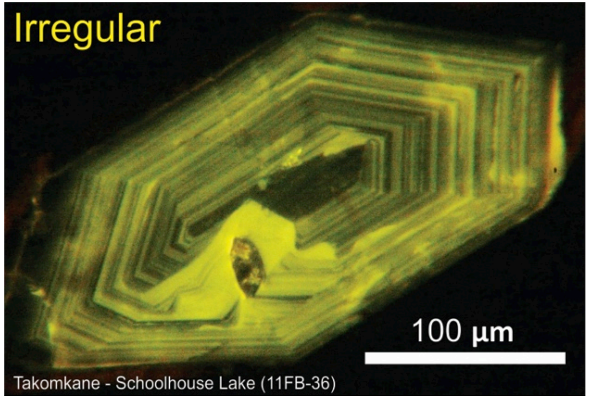
Zircon Fertility Textures











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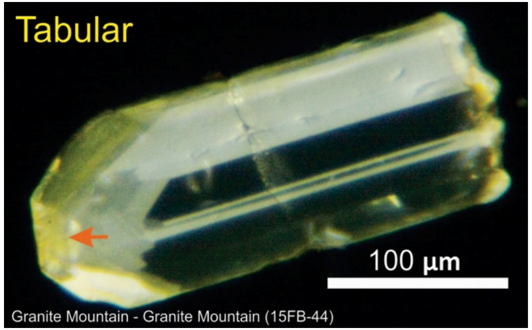
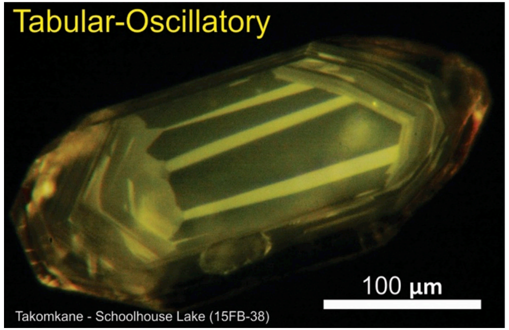
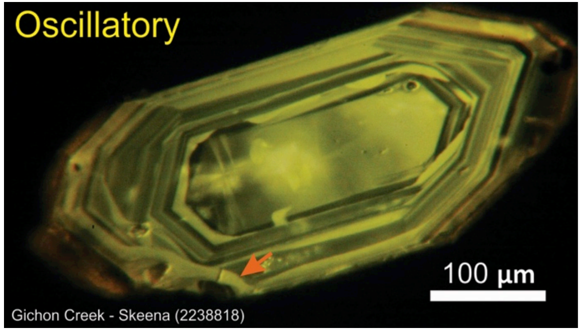
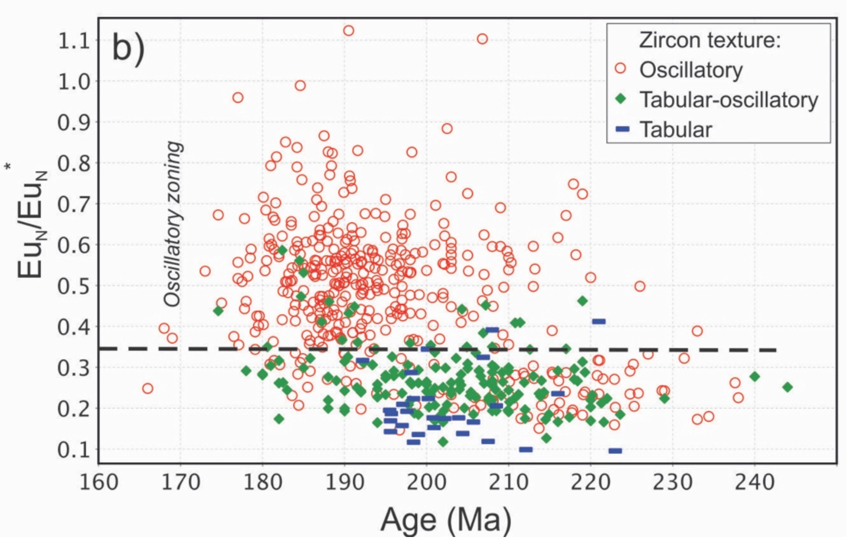
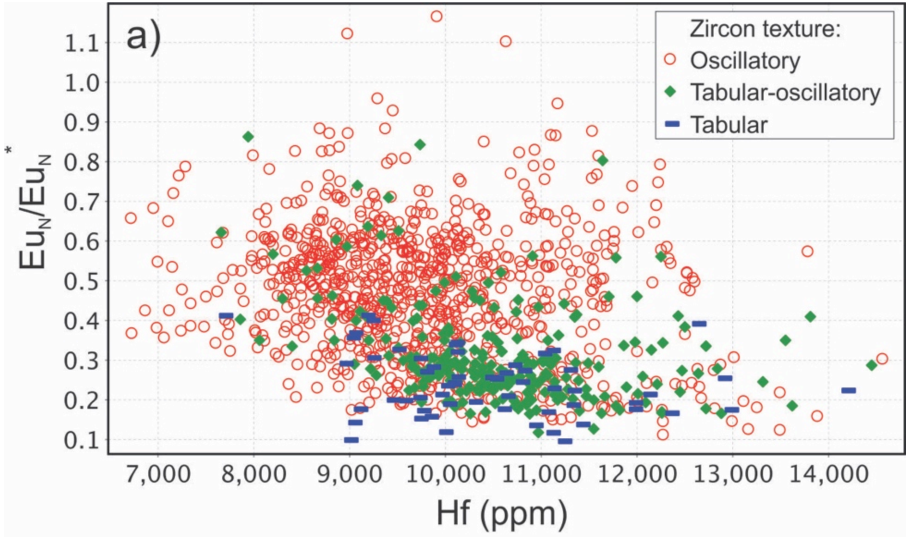


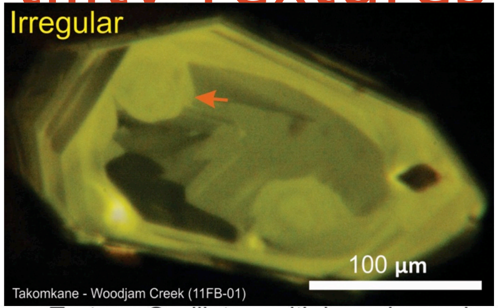


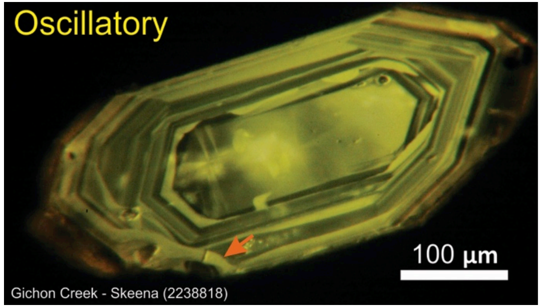


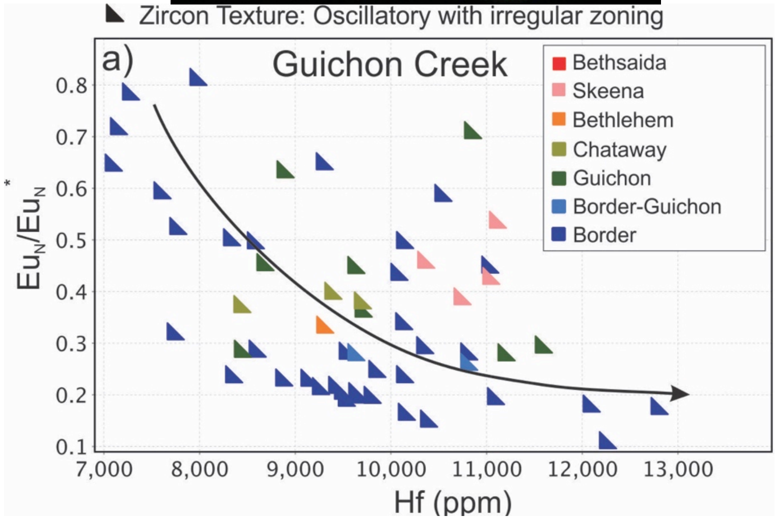


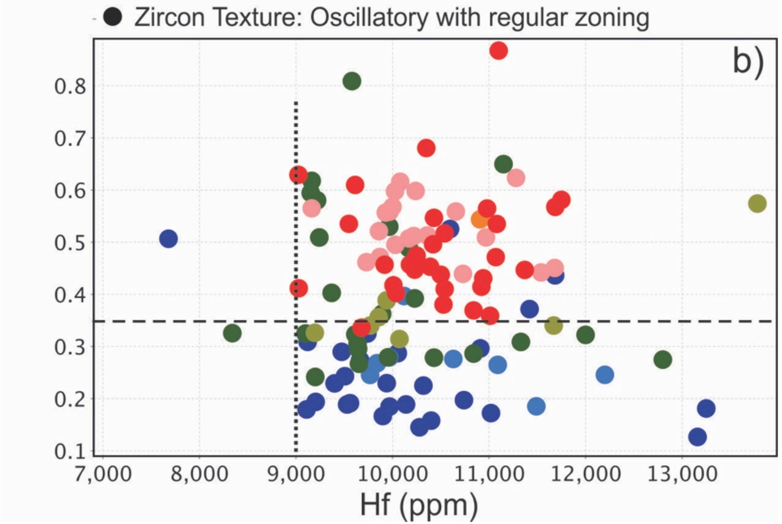


Zircon Fertility Textures



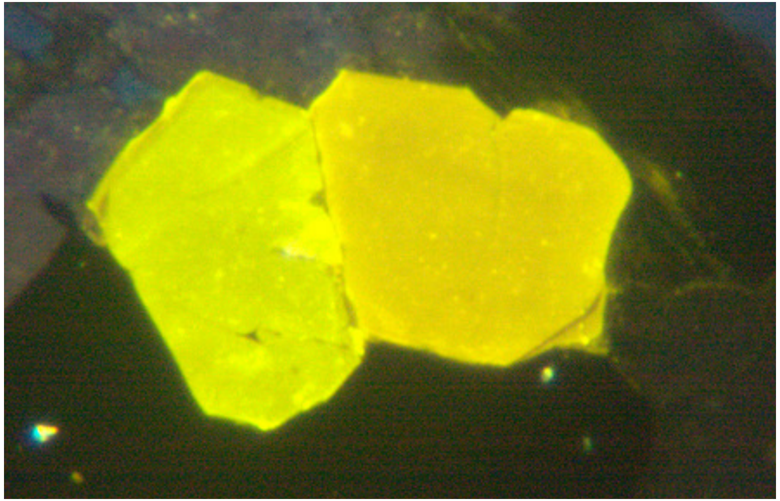






- Fertile plutons have zircons with oscillatory zoning, particularly those with regular zoning.

Apatite: Clues to sulphur and chlorine in magma



Apatite -$Ca_5(PO_4)_3(F,OH,Cl)$- structure can incorporate transition metal, REE and anion impurity activators which in granitoid rocks commonly cause strong yellow, green brown luminescence.

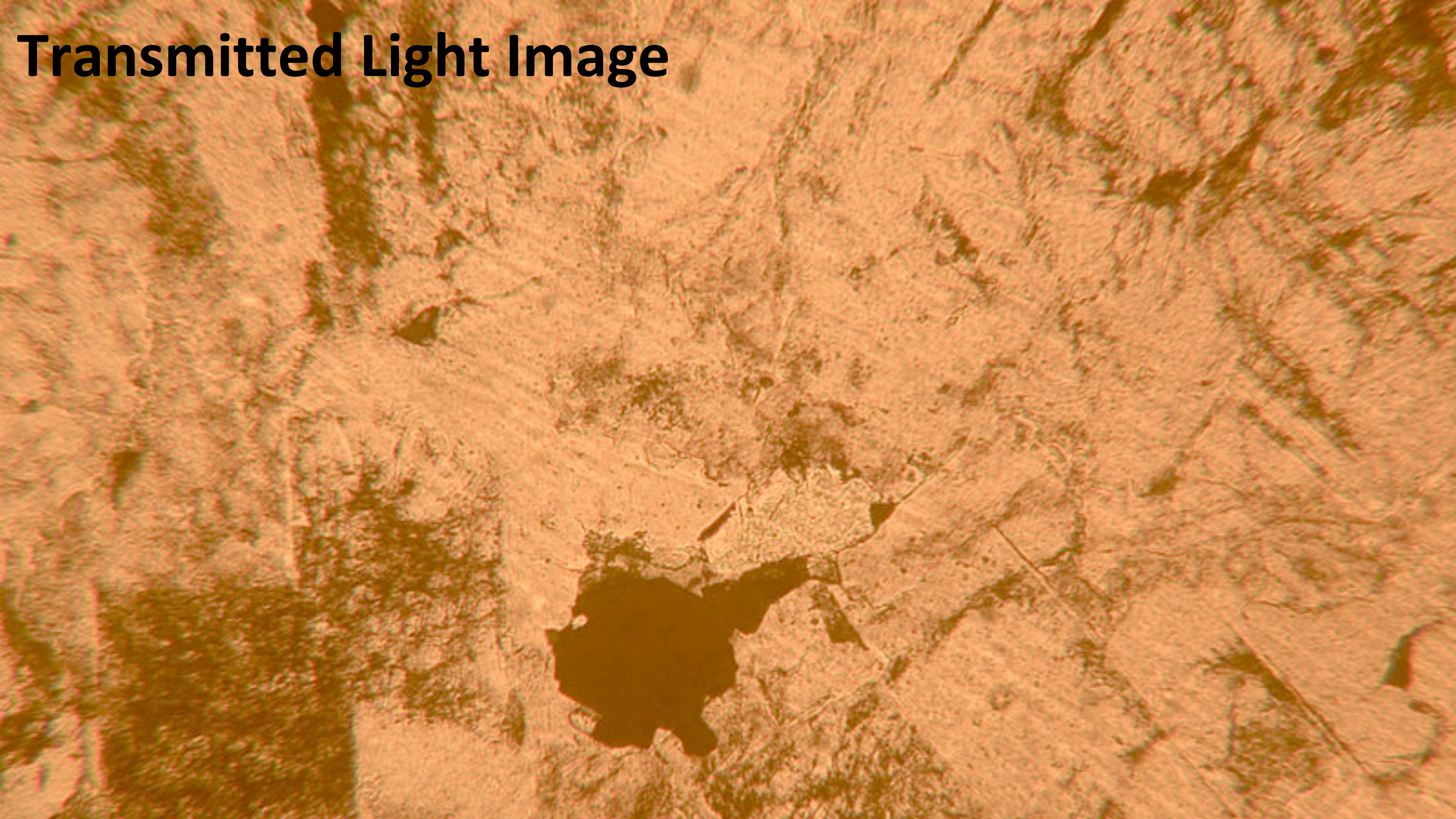
Porphyry deposits are associated with magmas rich in sulphur

"Sulphur is genetically, if not economically, a more critical factor than the metals. As Hunt (1977) has pointed out, porphyry copper deposits are really large sulfur anomalies with lower Cu/S that most ordinary crustal rocks." *Lew Gustafson, 1979*

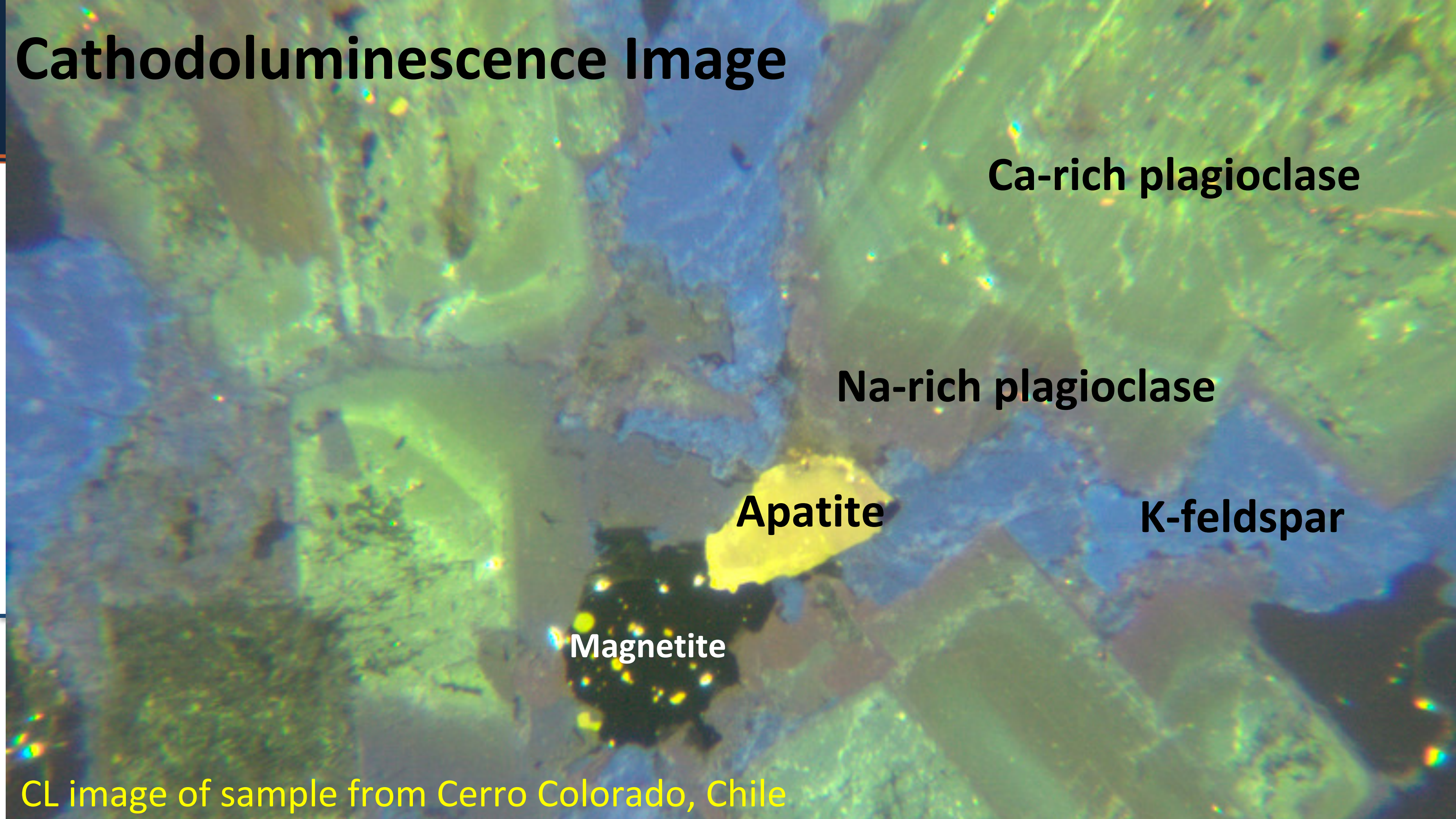
	Cu(Mt)	S(t)	Cu/S
Average crust			*1/5 to 1/20*
El Salvador, Chile	15	10^9	1/100

from Dilles

Transmitted Light Image

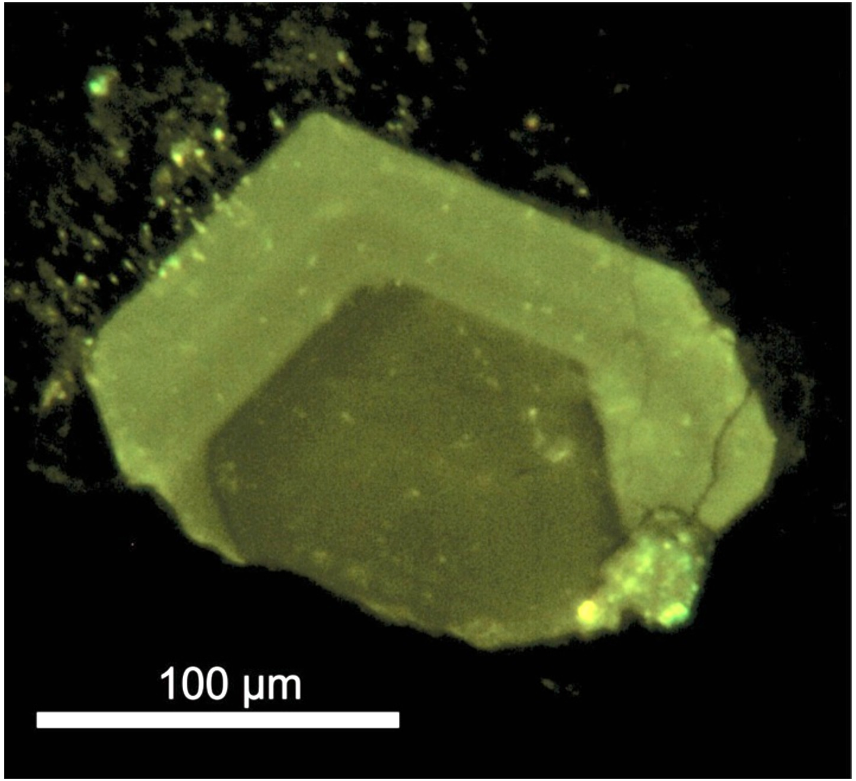


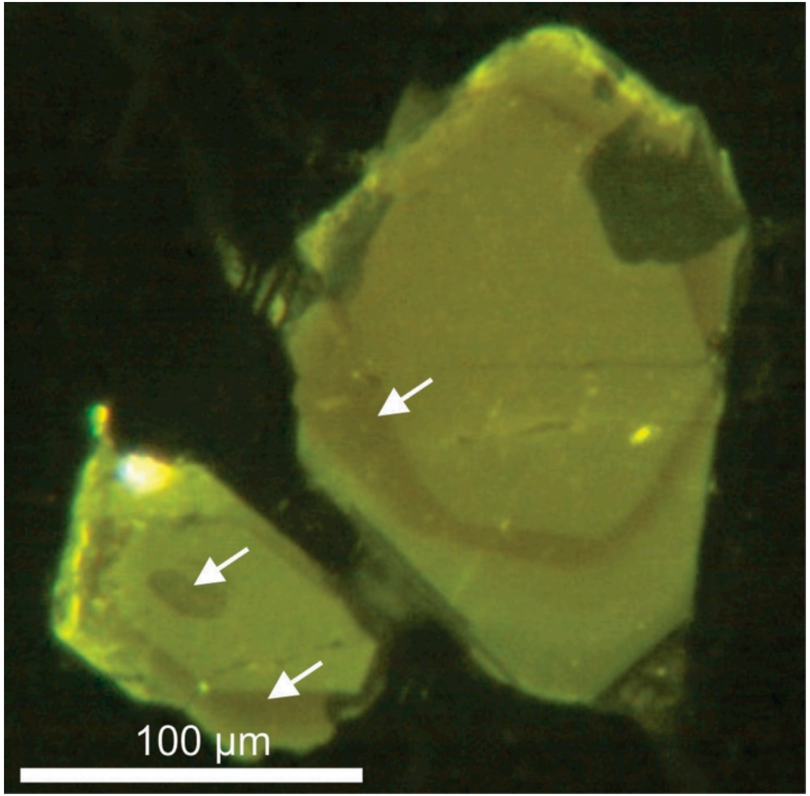
Cathodoluminescence Image



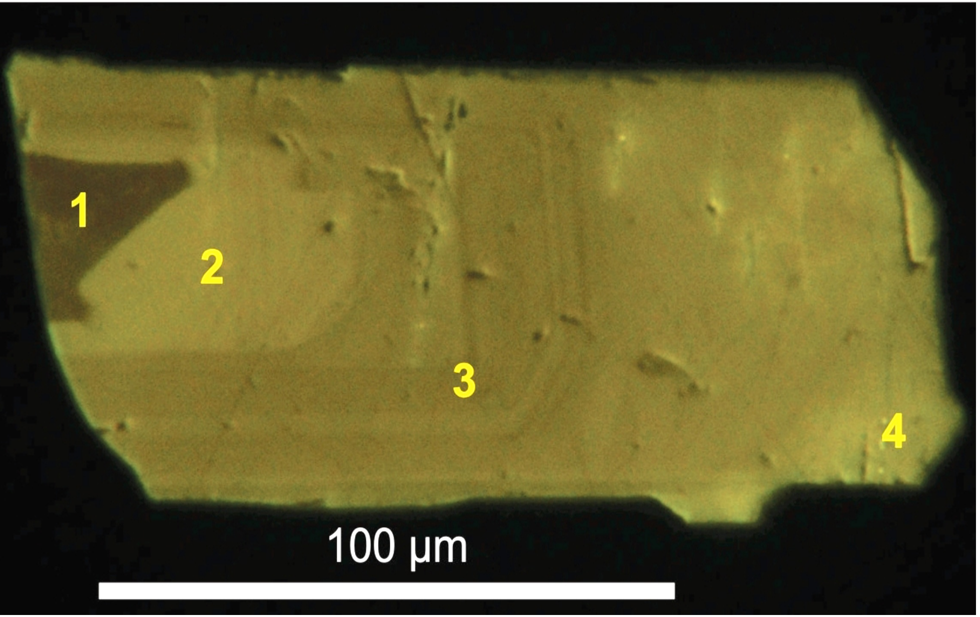
CL image of sample from Cerro Colorado, Chile

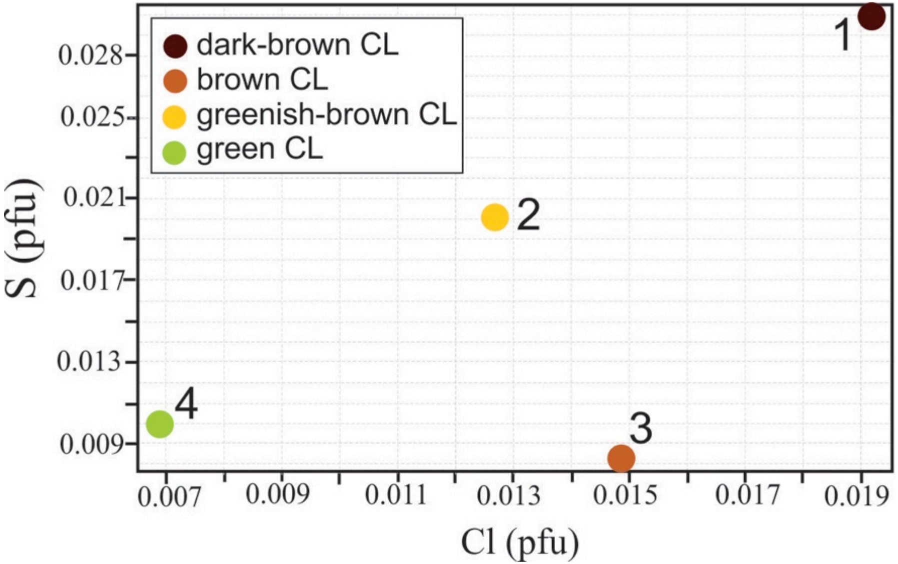
Apatite Fertility Texture by Cathodoluminescence





Apatite Fertility Texture by Cathodoluminescence



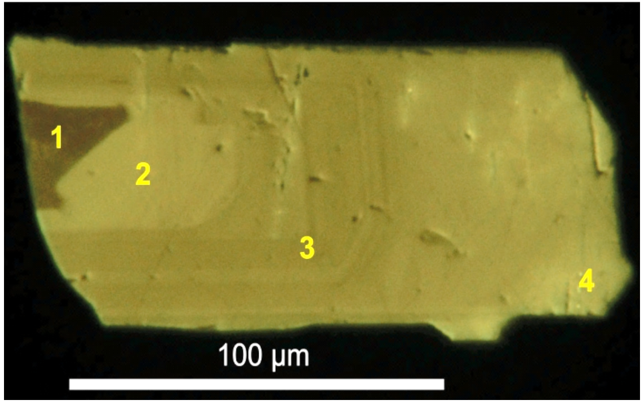


Apatite is commonly zoned.

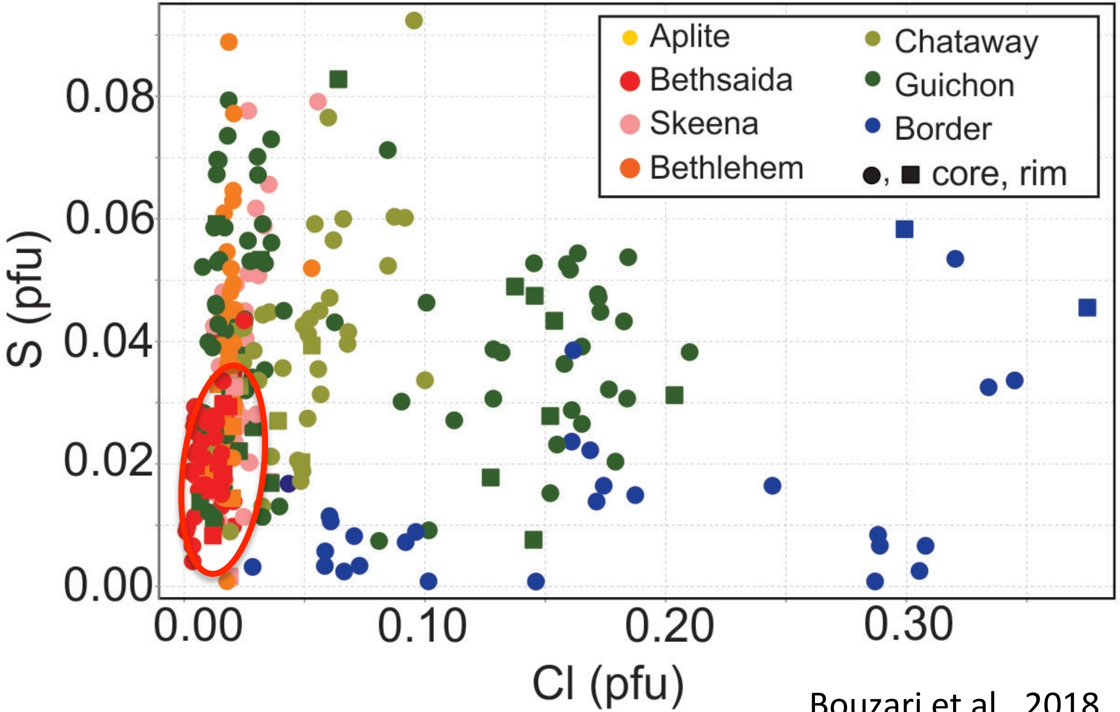
Brown luminescent core or zones are enriched in S and Cl.

Light brown-green luminescent rims are depleted in S and Cl.

Apatite Fertility Composition



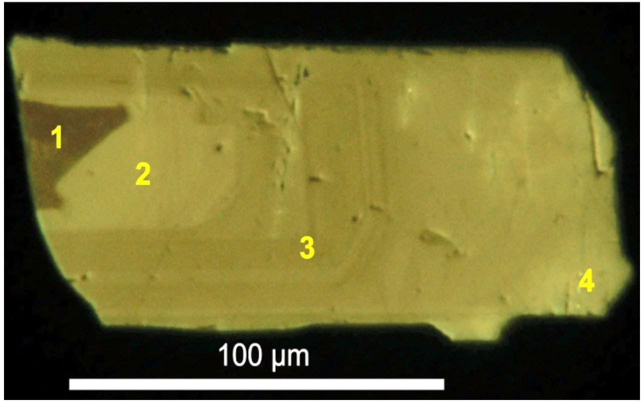
Guichon Creek host to Highland Valley PCD



Bouzari et al., 2018

- Fertile rocks have apatite with remnants of high S and Cl in its core but largely depleted in the rim due to degassing processes.

Apatite Fertility Composition



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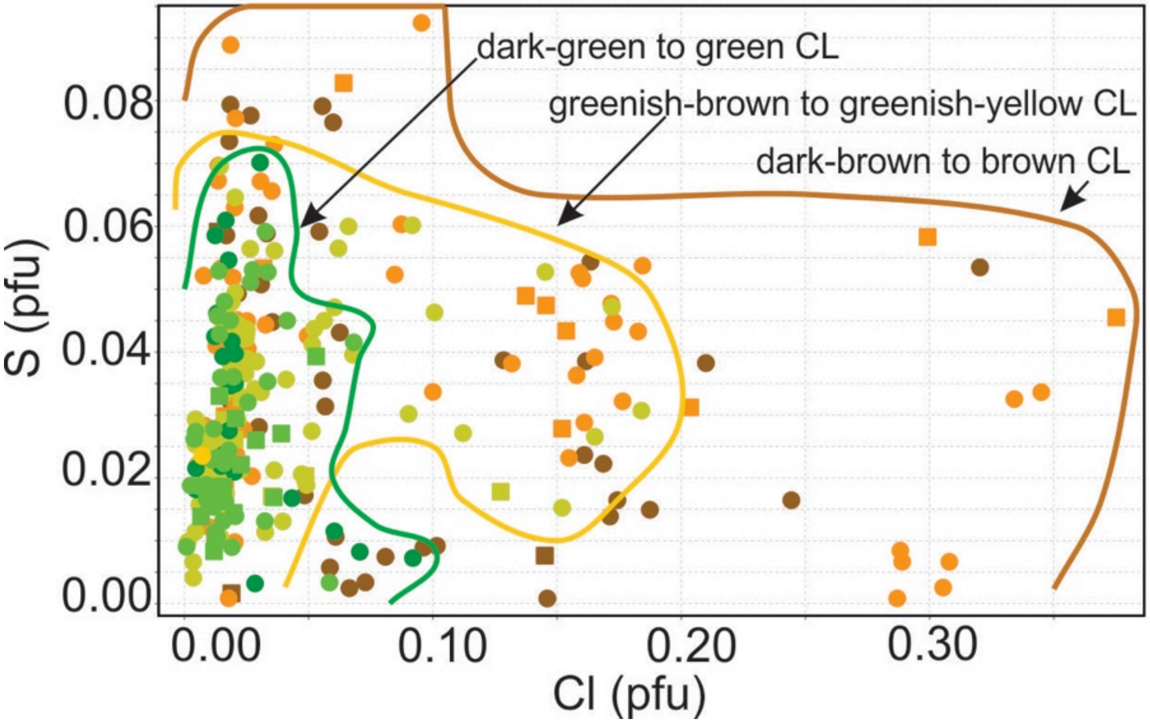
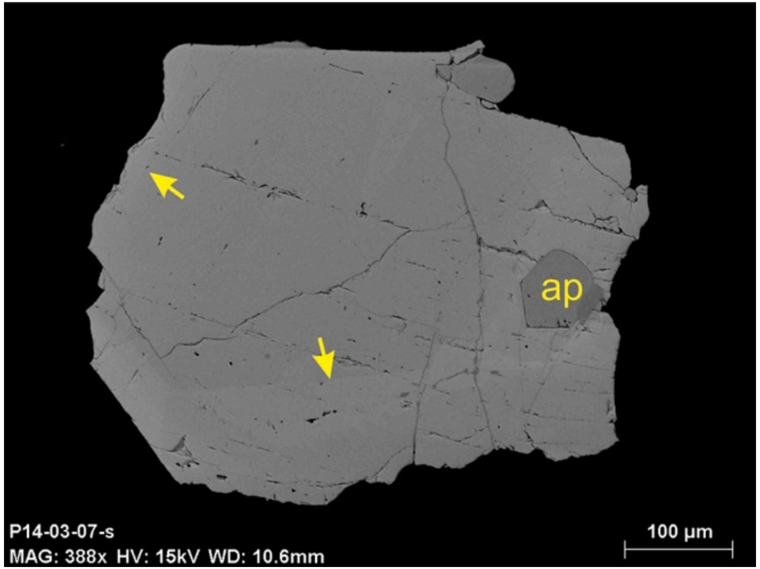


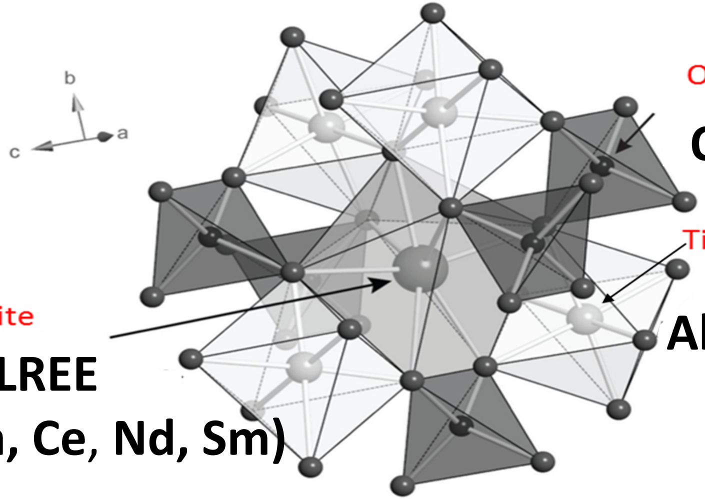
- Fertile rocks have apatite with remnants of high S and Cl in its core but largely depleted in the rim due to degassing processes.

Titanite ($CaTiSiO_5$)

- Titanite occurs in oxidized rocks (Wones, 1989)
- Titanite is more common in hornblende-bearing rocks than in anhydrous rocks (Frost et al., 2000):

Hedenbergite + Ilmenite + Quartz + H_2O = Titanite + Fe-actinolite





O-site

OH, F

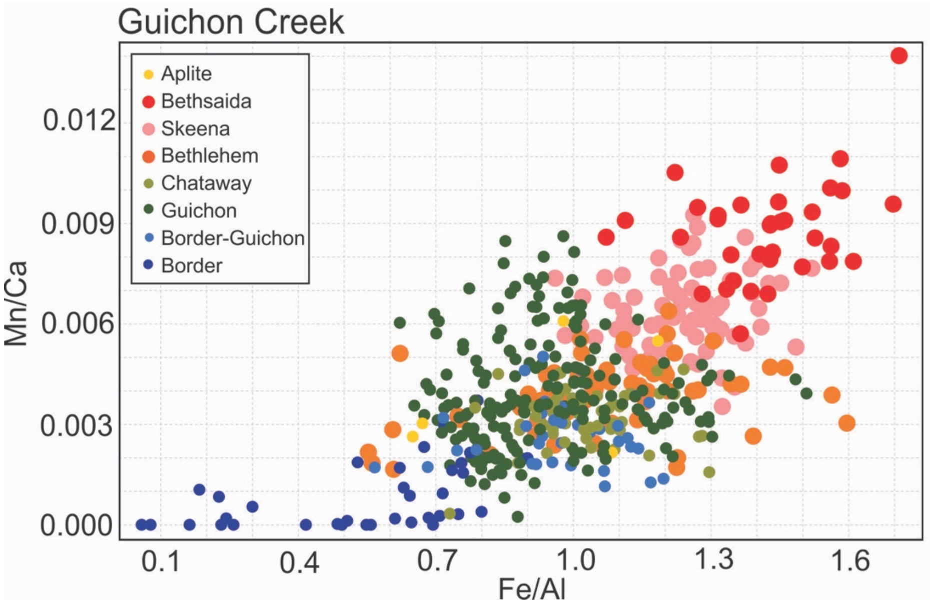
Ti-"octahedral" site

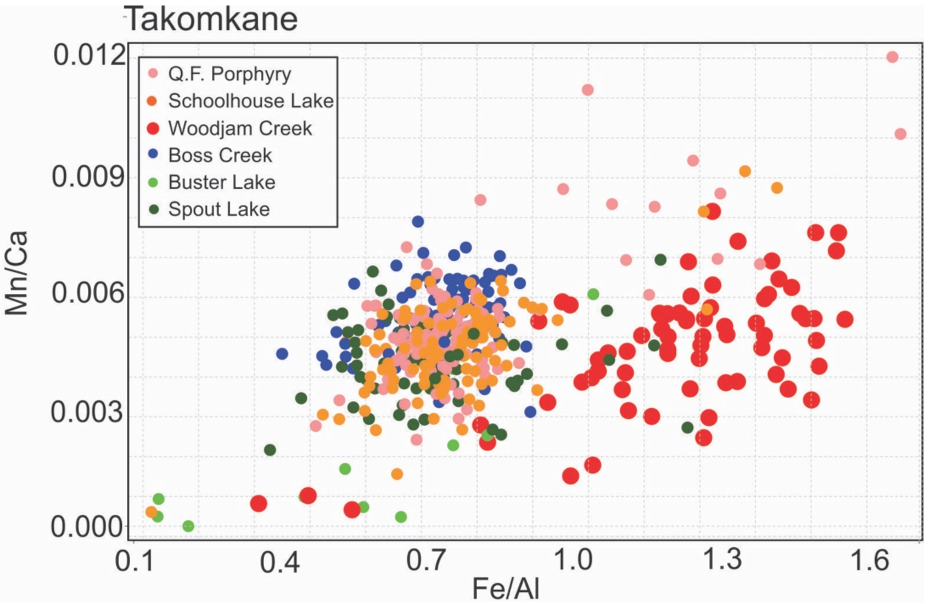
Al, Fe^{3+}, V, (HFSE) (Nb, Ta, Th, U, Hf, Zr)

Ca-site

Y, LREE (La, Ce, Nd, Sm)

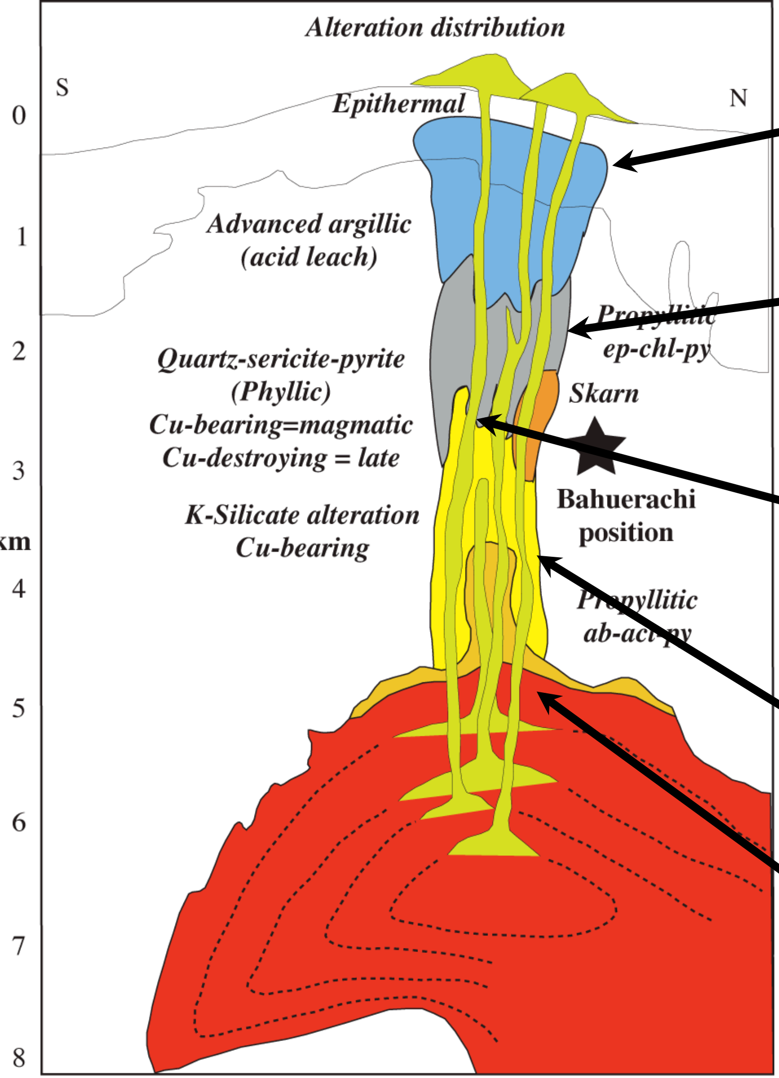
Titanite: Clues to the oxidation State

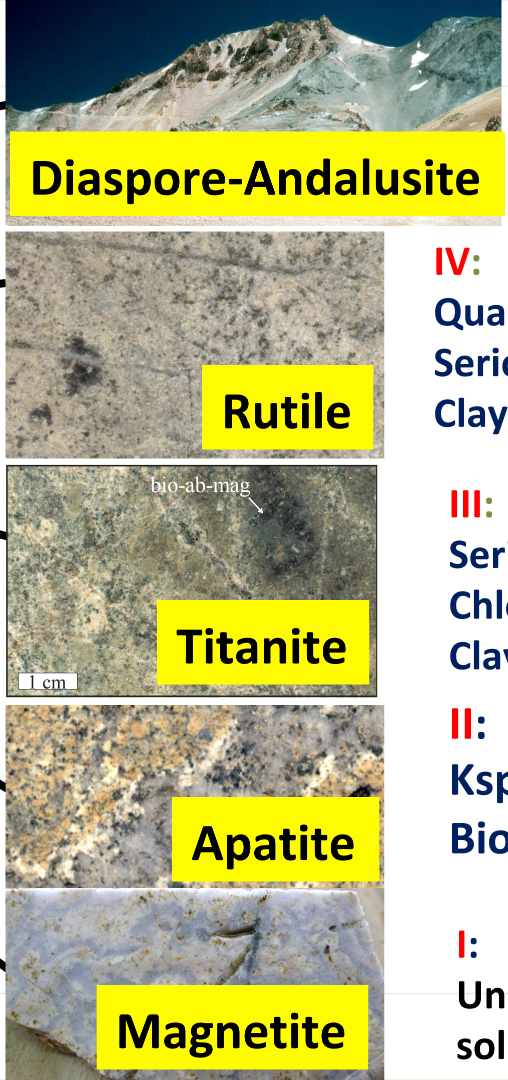




- Titanites of fertile plutons are more oxidized (Fe/Al > 1)

Identifying Porphyry Alteration with Apatite and Titanite





V: Quartz-Andalusite-Pyrophyllite

IV: Quartz-Sericite-Clay

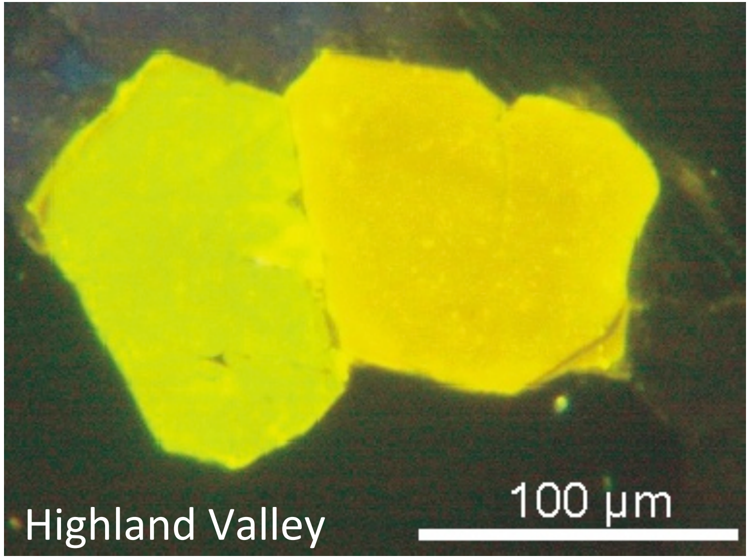
III: Sericite-Chlorite-Clay

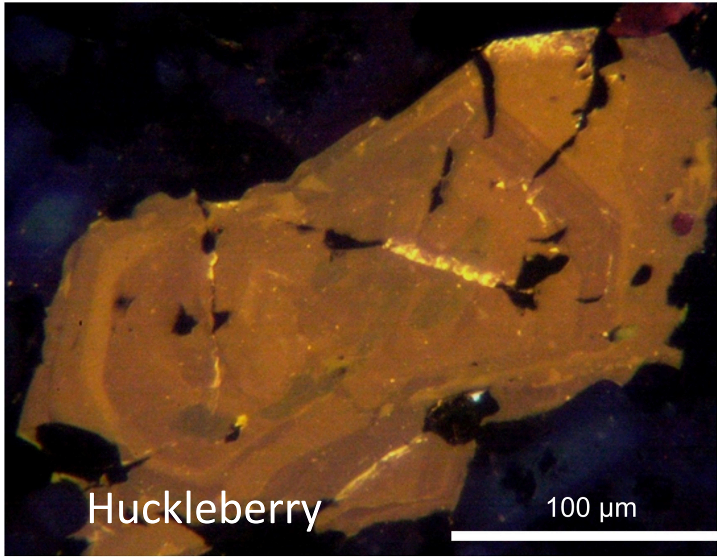
II: Kspar-Biotite

I: Unidirectional solidification (USTs)

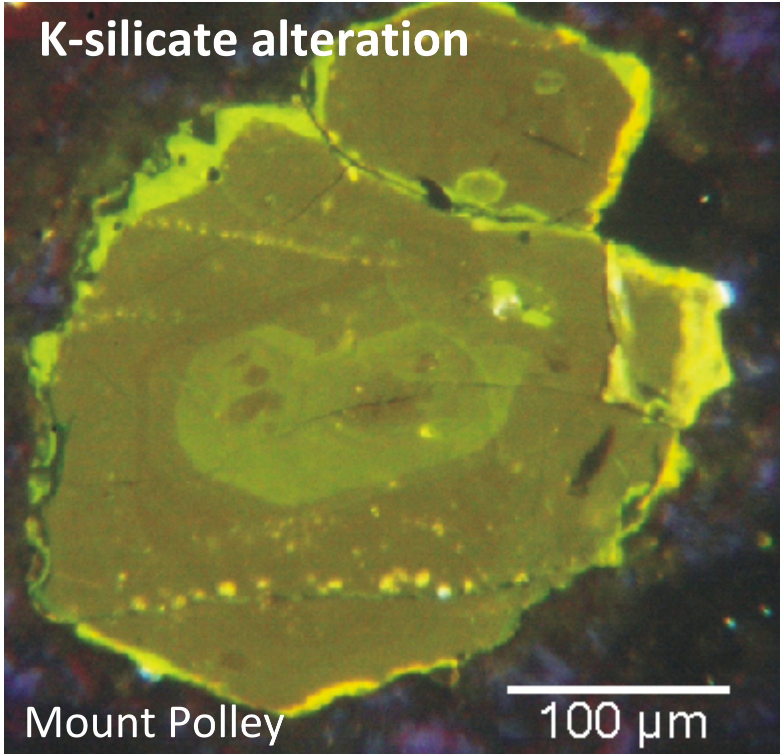
Decrease in fluid:
Temperature
Density,
pH,
Salinity

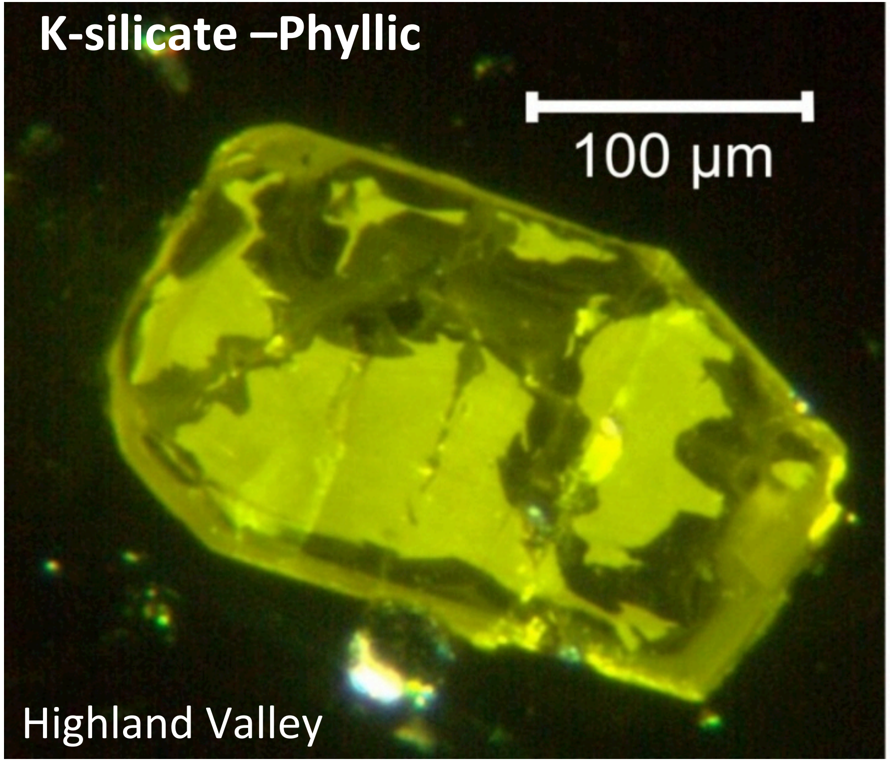
Apatite Alteration Texture





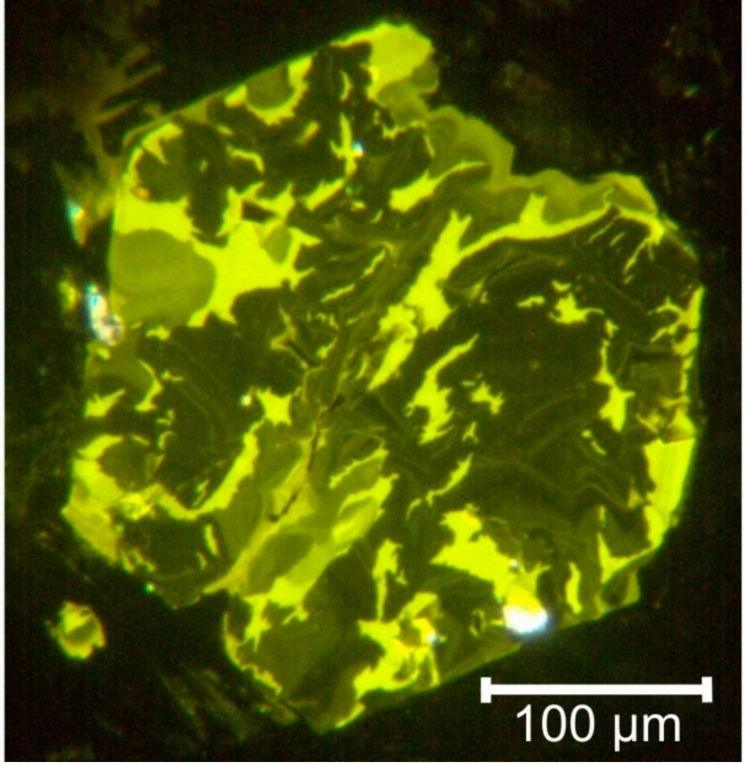
Apatite in unaltered host-rock:
Displays strong luminescence of yellow to yellow-green and sometimes brown. No major internal structures, except zoning, were observed using either cathodoluminescence (CL) or SEM.

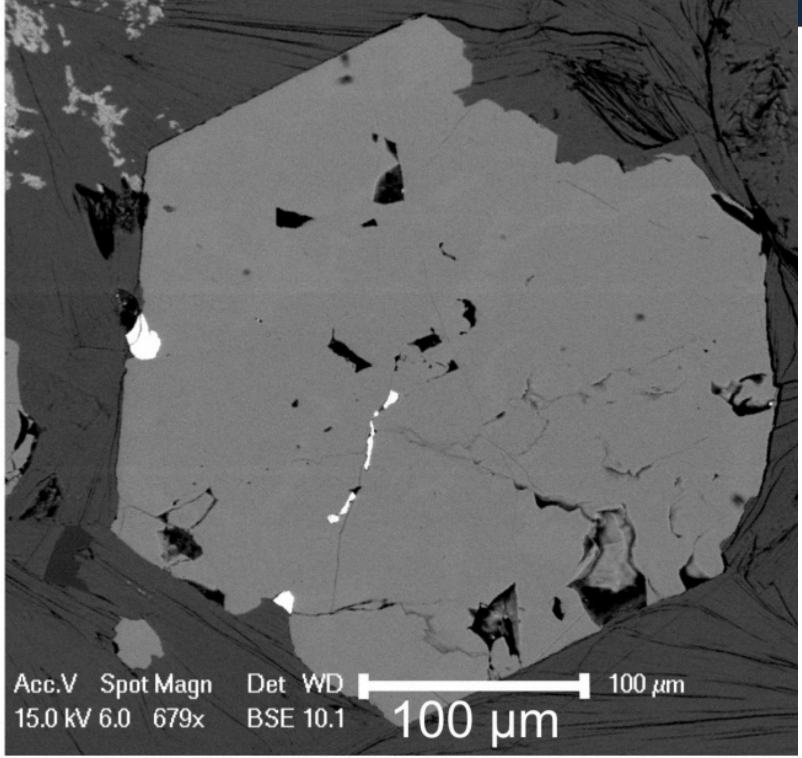




Apatite in K-silicate altered host-rock:

- Displays yellow-green luminescence due to varying proportion of Mn/Fe.

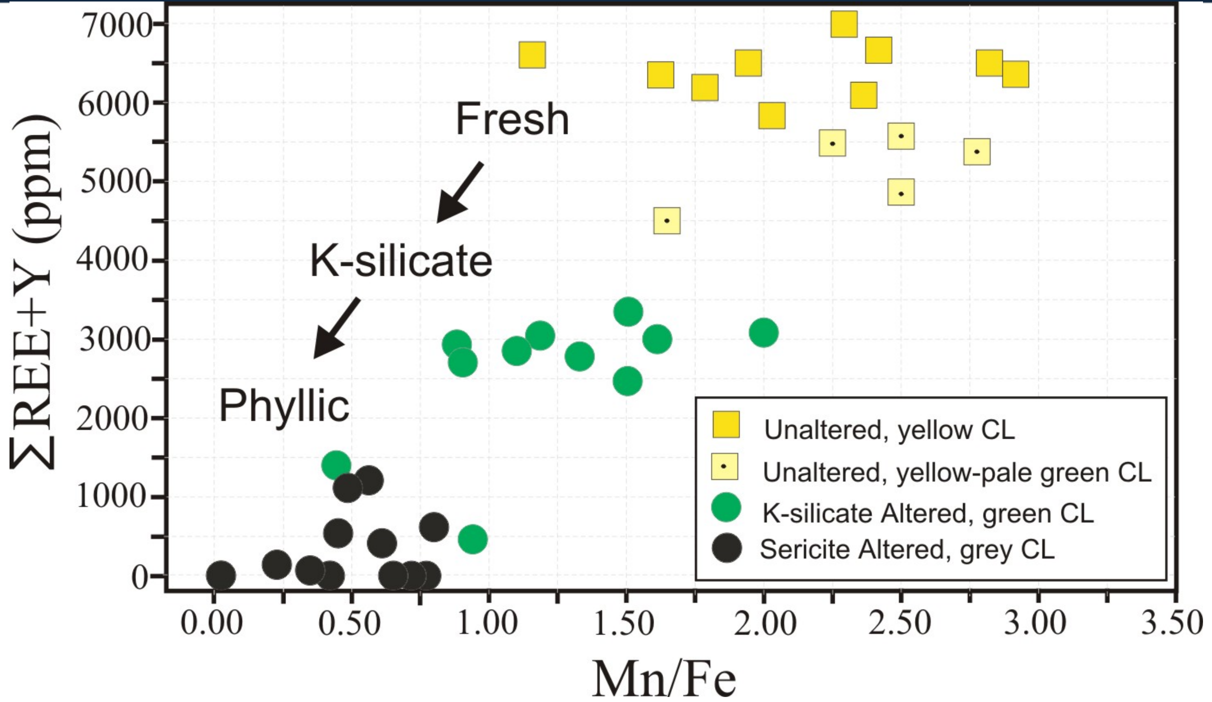




Apatite in muscovite altered host-rock:

• Displays grey-green luminescence and in strongly altered host-rock is overprinted by bodies of dark-green to grey-luminescent domains.

Apatite Alteration Index



- Fresh yellow luminescent apatite has higher Mn:Fe (>1) and REE.
- Apatite of the K-silicate alteration has green luminescence, lower Mn:Fe and REE
- Apatite of the phyllic alteration has grey luminescence and lowest Mn:Fe (<0.5) and REE

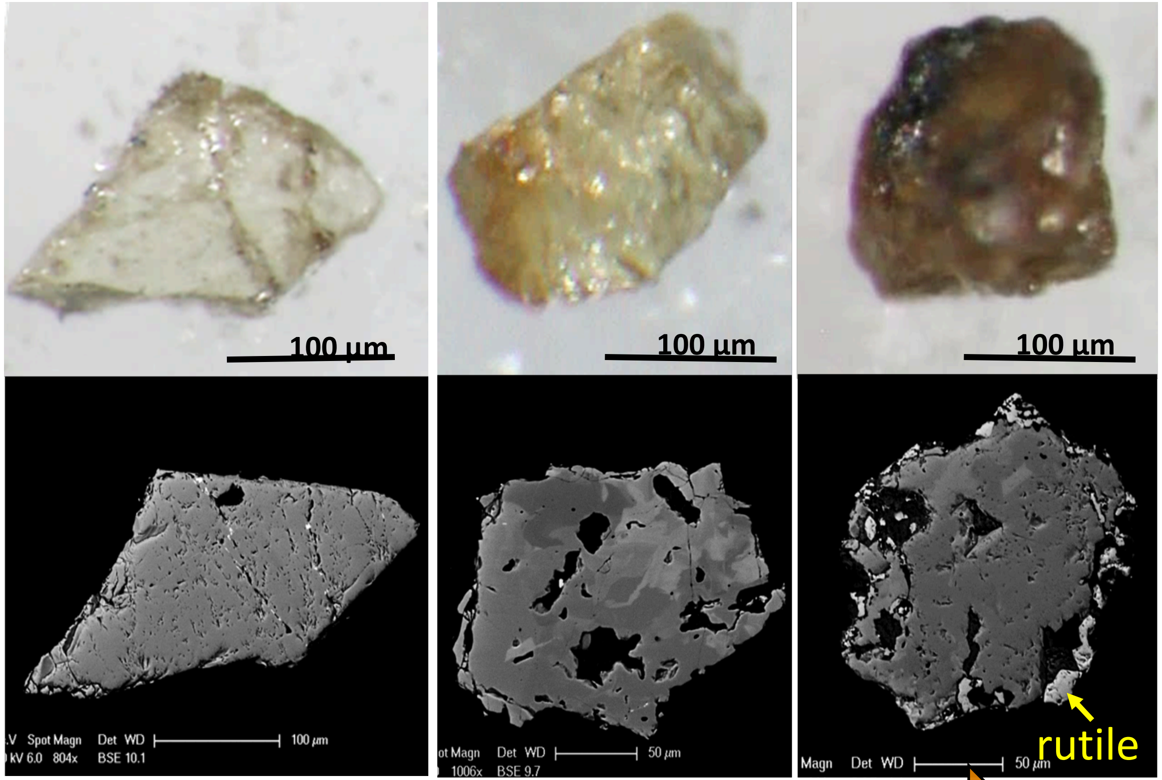
Bouzari et al., 2015

Titanite indicating alteration

Magmatic: Colourless

Secondary: Blond

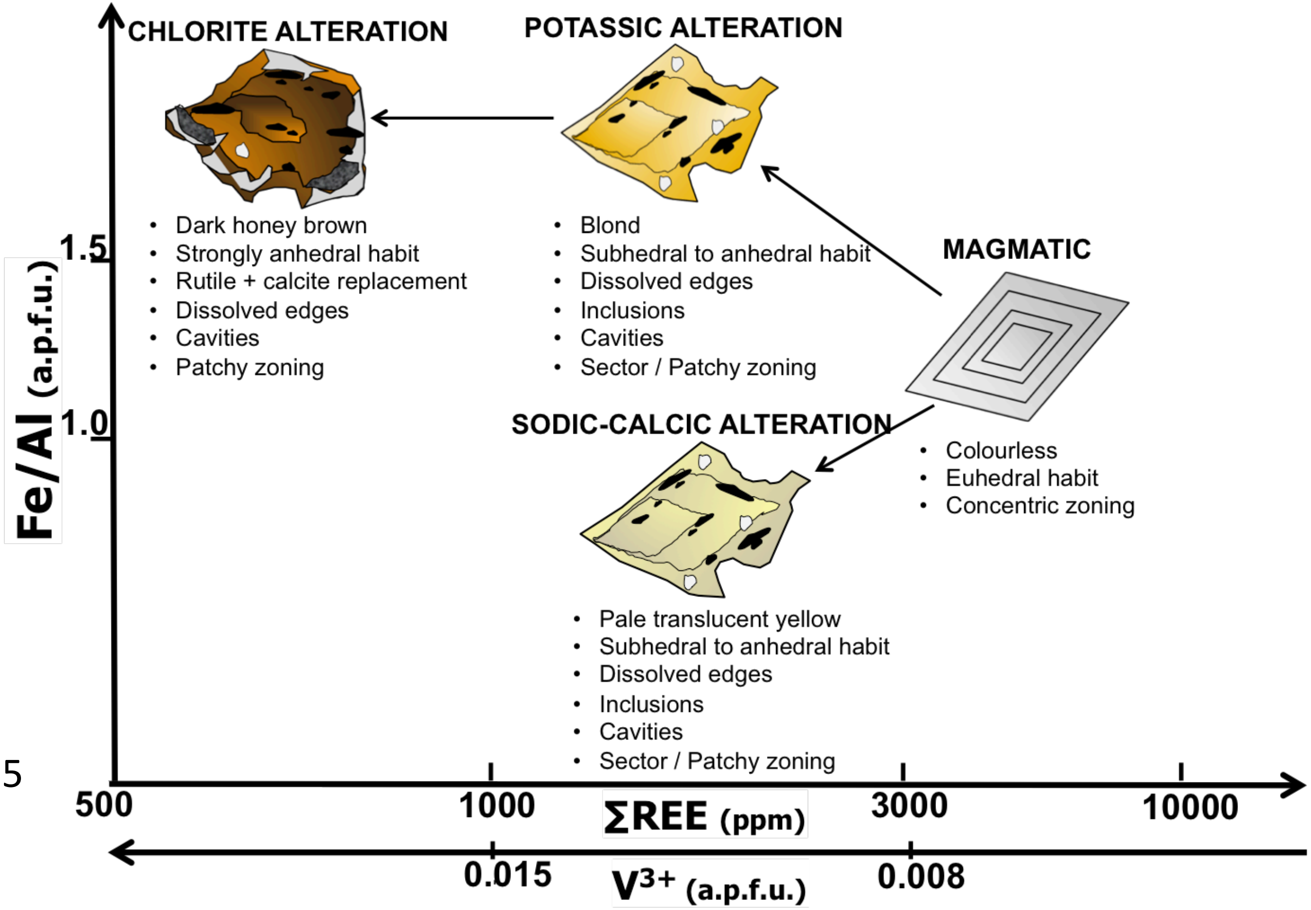
Strongly Altered: Dark brown



Celis, 2015

Increasing alteration intensity

Titanite indicating alteration



Celis, 2015

Porphyry Fertile Plutons have:

Zircon:

- zircons with oscillatory zoning, particularly those with regular zoning patterns;
- zircons with evidence of simple crystal fractionation without crustal contamination;
- zircons with Ti-in-zircon model temperatures <750°;
- zircons with Eu anomaly values ≥0.35 that suggest a high oxidation state and high magmatic water content; and not dependent on Hf concentration or Yb/Gd values

Apatite:

- apatite with remnants brown luminescent core with high S and Cl but largely depleted in the rim.

Titanite:

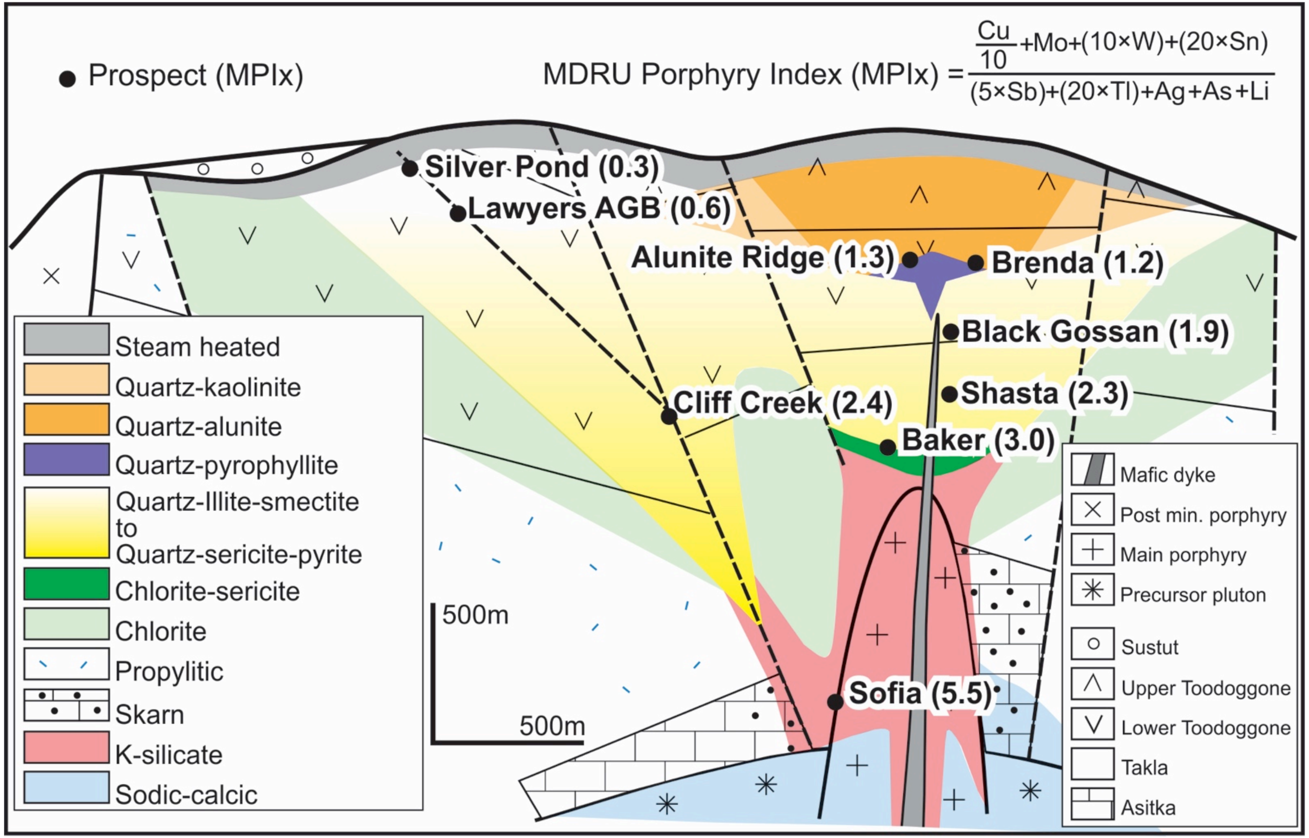
- Titanite with high Fe:Al (>1) reflecting more oxidized magma.

*Eu anomaly in apatite and titanite is not a robust indication of oxidation state of magma.

Porphyry Altered Plutons Have:

- apatite characterized by green to grey luminescent color, depleted REE, low Mn/Fe, Na and S concentrations.
- titanites with blond to honey-brown color, cavities, dissolved edges, rutile inclusions and low REE, high V and high Fe:Al

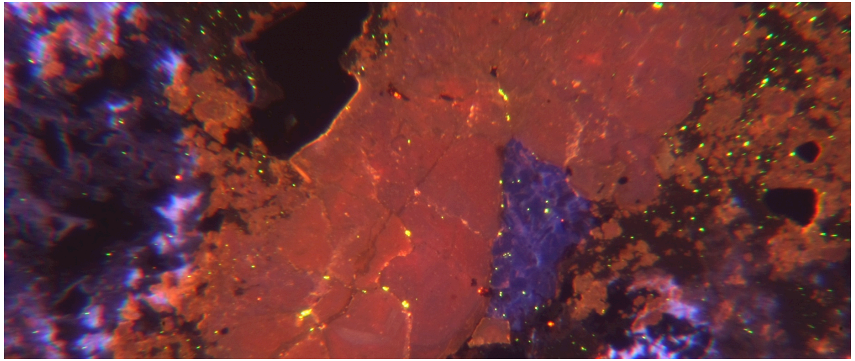
Vectoring Towards Porphyry



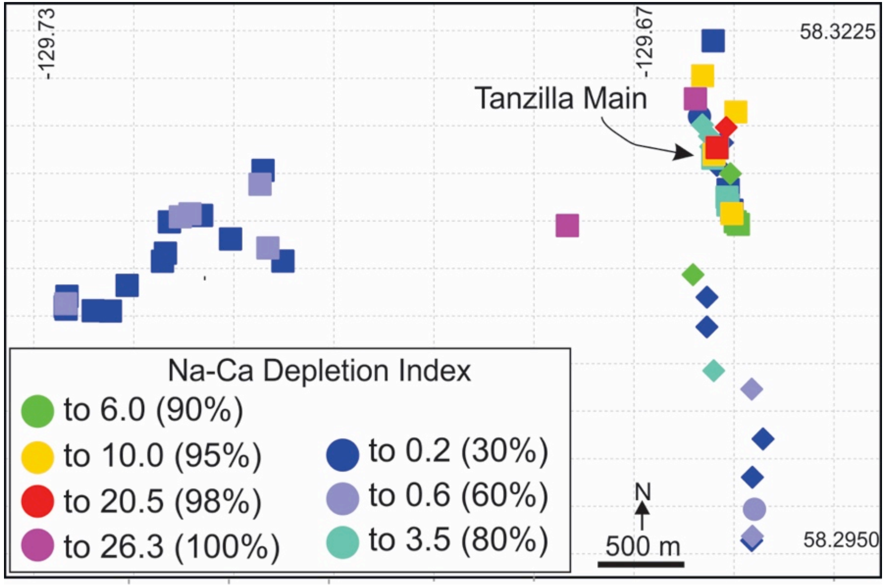
Toodoggone Project

Bouzari et al., 2019

Vectoring Towards Porphyry



Advanced Argillic Alteration Project



Bouzari et al., current research

Bouzari, F., Hart, C.J.R. and Bissig, T. (2020). Assessing British Columbia Porphyry Fertility in British Columbia Batholiths using Zircons. Geoscience BC Report 2020-08, MDRU Publication 450, 24p. http://www.geosciencebc.com/i/project_data/GBCReport2020-08/GBC%20Report%202020-08%20Assessing%20Porphyry%20Copper%20Deposit%20Fertility%20in%20British%20Columbia%20Batholiths%20using%20Zircons.pdf

Bouzari, F., Bissig, T., Hart, C.J.R., Leal-Mejía, H., 2019, An Exploration Framework for Porphyry to Epithermal Transitions in the Toodoggone Mineral District (94E). Geoscience BC Report 2019-8, MDRU Publication 424, 101 p. http://www.geosciencebc.com/wp-content/uploads/2019/11/Geoscience-BC-Report-2019-08.pdf

Bouzari, F., Hart, C.J.R., Bissig, T. and Lesage, G., 2018. Mineralogical and geochemical characteristics of porphyry-fertile plutons: Guichon Creek, Takomkane and Granite Mountain Batholiths, south-central British Columbia (NTS 092i, P; 093a, b). Geoscience BC Publication 2018-17. MDRU publication 412 – 36 p. http://www.geosciencebc.com/i/project_data/GBCR2018-17/GBCreport2018-17.pdf

Celis, A, 2015, Titanite as an indicator mineral for alkalic Cu-Au porphyry deposits in south central British Columbia, M.Sc. Thesis, The University of British Columbia, 266p. https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0166663

Bouzari, F., Hart, C.J.R., Bissig, T., and Barker, S., 2016, Hydrothermal alteration revealed by apatite luminescence and chemistry: A potential indicator mineral for exploring covered porphyry copper deposits: Economic Geology, v. 111, p.1397-1410. http://econgeol.geoscienceworld.org/content/econgeo/111/6/1397.full.pdf

Bouzari, F., Hart, C.J.R., Barker, S. and Bissig, T., 2010, Porphyry Indicator Minerals (PIMS): A New Exploration Tool for Concealed Deposits in South-Central British Columbia (NTS 092I/06, 093A/12, 093N/01, /14); Geoscience BC Publication 2011-17. 31p. http://cdn.geosciencebc.com/project_data/GBC_Report2011-17/GBCReport2011-17_report.pdf