Mineral markers of porphyry processes: regional and local signatures of porphyry prospectivity

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Abstract: Porphyry-style mineralisation occurs chiefly as a consequence of the release of large volumes of metal-bearing aqueous brine during the cooling and crystallization of plutonic and intrusive magmatic systems. In addition to the metals of economic interest, many additional elements are preferentially incorporated into the aqueous fluid during its segregation from the parent magma, or are gained from interactions with proximal county rocks. During its segregation, pooling and ascent, this magmatic-hydrothermal fluid also deposits many of its elemental components; either through direct precipitation of new minerals or by metasomatic interactions with existing minerals.

The elemental and mineralogical signatures of each of these fluid generation, mineral precipitation and hydrothermal alteration processes may be recorded within the resultant mineral residues at each stage, and will likely reflect a complex and evolving suite of physicochemical influences that operated during the formation of each ore deposit. Modern analytical methods are increasingly able to interrogate these signatures at smaller scales and lower cost, thus bringing effective and efficient mineral analysis within the scope of even small scale mineral exploration programs. In this presentation we will discuss a suite of mineralogical and mineral chemistry studies performed in the last few years as part of the Government of Canada's Geomapping for Energy and Minerals and Targeted Geoscience Initiative Programs. All are targeted toward increasing both the efficiency and effectiveness of porphyry mineral exploration within Canada.

Late Triassic to early Jurassic plutonic rocks of British Columbia are genetically associated with the great majority of Canada's porphyry copper, molybdenum and gold resources and producing mines, forming the 'Copper Pine of the Cordillera'. Within Yukon they host the sole currently producing copper-gold mine in the territory. However, additional exploration activity within Yukon has been largely unsuccessful and, away from Minto mine itself, the metal endowment of Triassic-Jurassic plutonic suites remains uncertain. In order to assess the prospectivity of these rocks and to provide a tool whereby future exploration in the region could be focused, our study examined the Ce^{4+}/Ce^{3+} composition of igneous zircon samples taken from across the district, as well as comparative samples from the late Cretaceous Casino deposit. Our results indicate that physicochemical conditions which prevailed during formation of the Minto deposit occurred widely across the Yukon Triassic-Jurassic plutonic suites, but that mineralisation may have occurred at much deeper crustal depths than expected for 'typical' porphyry deposits.

Within central and southern British Columbia, many known porphyry deposits are partly or entirely covered by Quaternary glacial sediments. However, a suite of indicator minerals in till in areas around these deposits can detect diagnostic mineralogical signatures of porphyry mineralisation many kilometres down-ice of the deposit location. In addition to indicator minerals, chemical analysis of the till can be used to fingerprint the type of mineralisation expected. A combination of till geochemistry and mineralogy might potentially be developed to provide preliminary information on the metal endowment of a buried mineralized body. At the Woodjam porphyry Cu-Au±Mo deposits of central BC, we can demonstrate that mineralogical complexity in bedrock tourmaline minerals – associated with both ore-forming and distal hydrothermal alteration processes – can be detected in surficial materials, providing context and refined detail to the broad exploration target produced.

Within porphyry and greisen-style tin-tungsten-base metal systems of the Canadian Appalachian district, zones of high indium content are significant exploration targets. However, despite apparent bulk mineralogy and base metal grade similarities between indium-rich and -poor ore, these zones do not occur evenly throughout the region. As a part of a detailed inventory and mineralogical assessment of indium distribution within southern New Brunswick and Nova Scotia we have identified distinct mineralogical fingerprints associated with indium enrichment.

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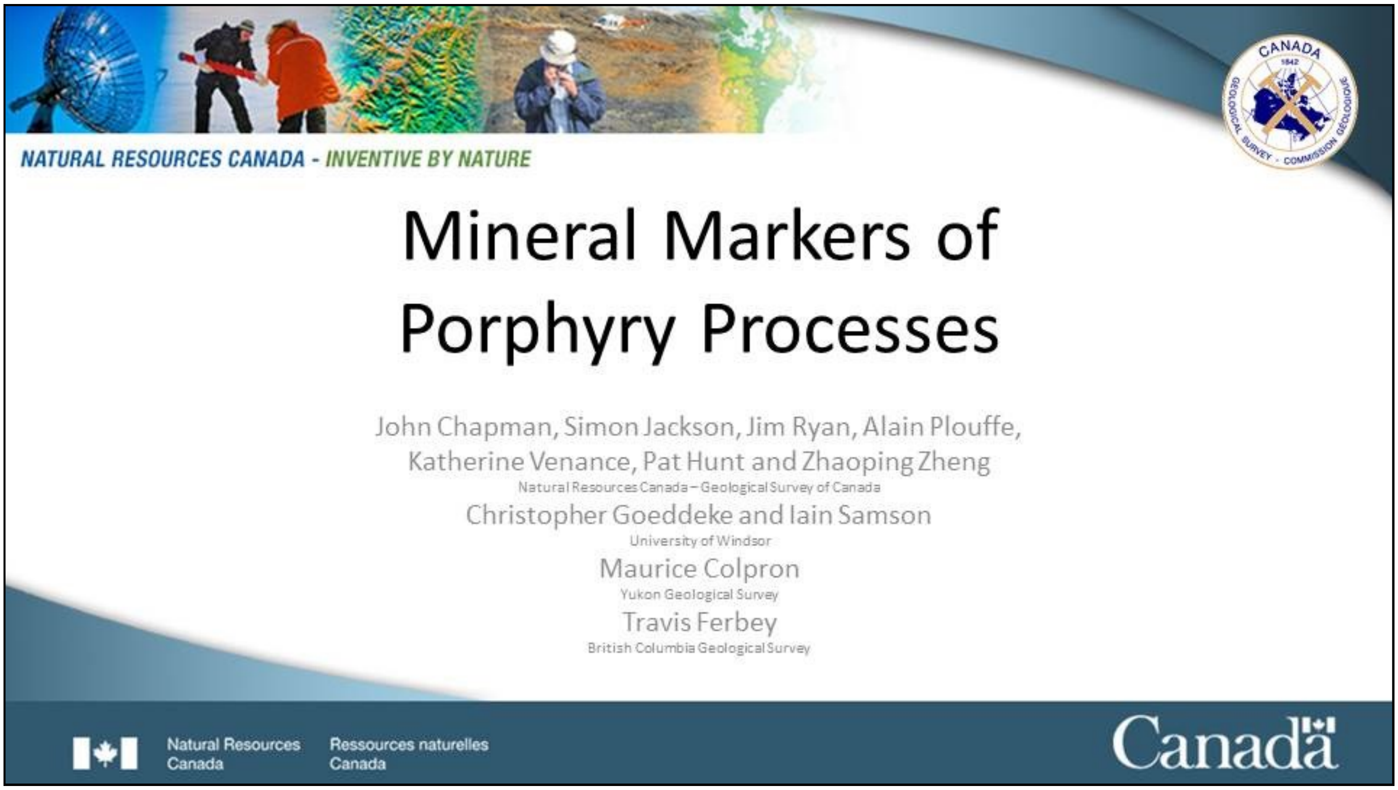
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Mineral Markers of Porphyry Processes
John Chapman, Simon Jackson, Jim Ryan, Alain Plouffe, Katherine Venance, Pat Hunt and Zhaoping Zheng
Natural Resources Canada – Geological Survey of Canada
Christopher Goeddeke and Iain Samson
University of Windsor
Maurice Colpron
Yukon Geological Survey
Travis Ferbey
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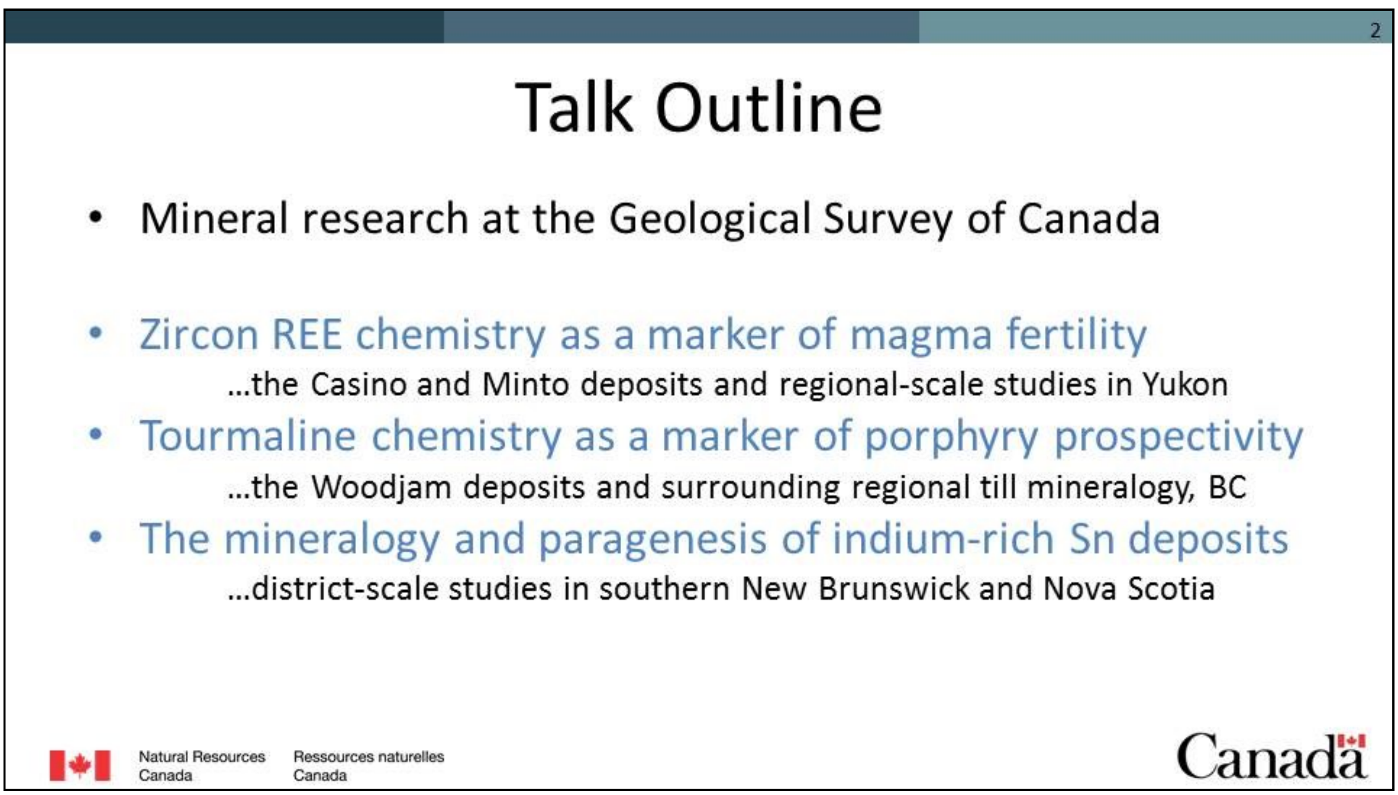
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Talk Outline
• Mineral research at the Geological Survey of Canada
• Zircon REE chemistry as a marker of magma fertility
…the Casino and Minto deposits and regional-scale studies in Yukon
• Tourmaline chemistry as a marker of porphyry prospectivity
…the Woodjam deposits and surrounding regional till mineralogy, BC
• The mineralogy and paragenesis of indium-rich Sn deposits
…district-scale studies in southern New Brunswick and Nova Scotia
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Zircon as a Redox Proxy

- Zircon ($ZrSiO_4$) is a common accessory mineral in igneous rocks of intermediate to felsic composition.
- Tetravalent cations of similar ionic radius to Zr^{4+} (0.84 Å) substitute readily into the lattice.
  - e.g. U, Th, Hf, etc.
- Trivalent cations (e.g. REE) will do so as well, with distribution coefficients dominated by ionic radius.
- Eu^{3+} will substitute more readily than Eu^{2+}, but abundances are governed by the redox state of the parent magma.
- Similarly, Ce^{4+} will substitute more readily than Ce^{3+}.

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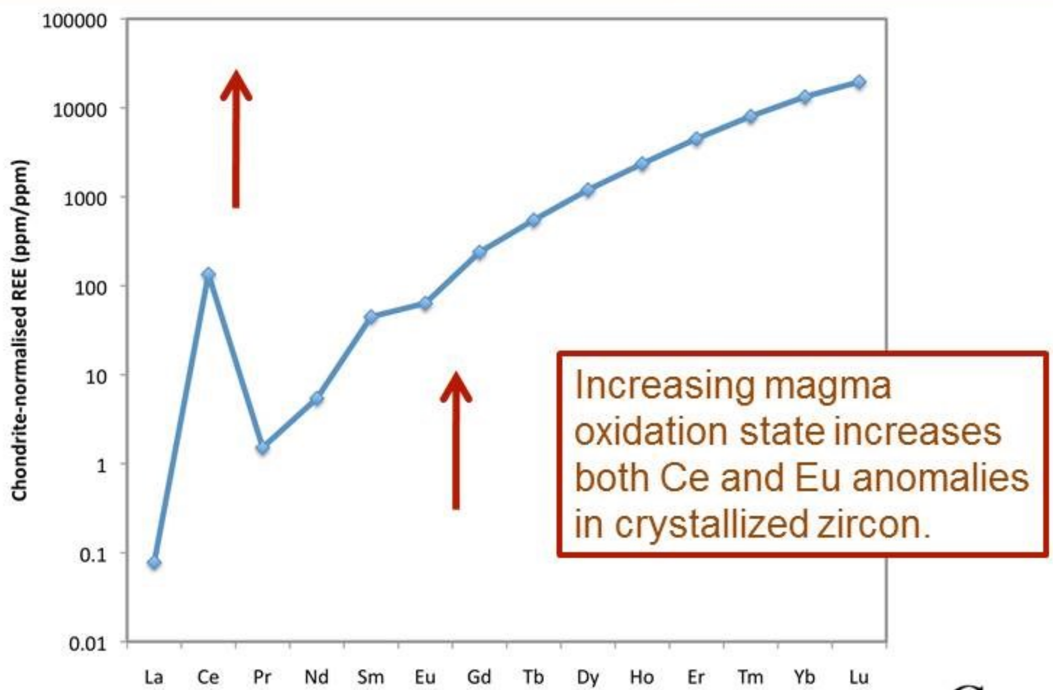

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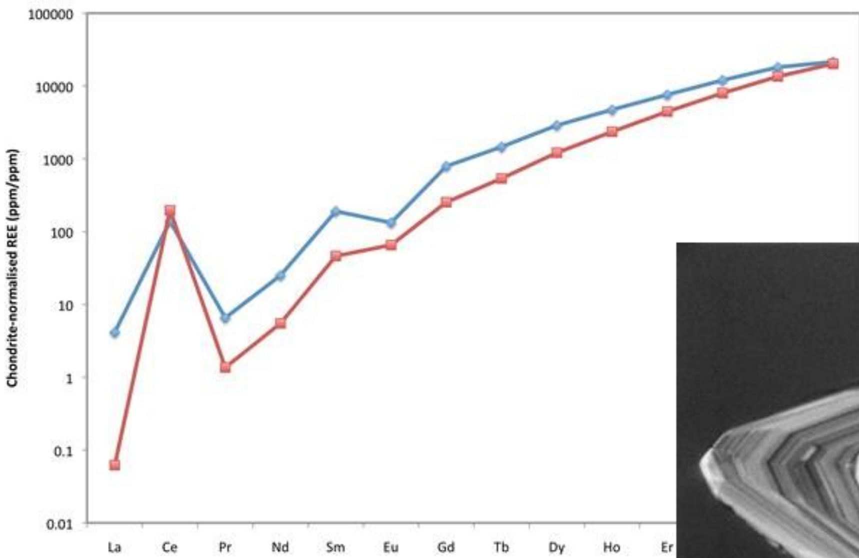
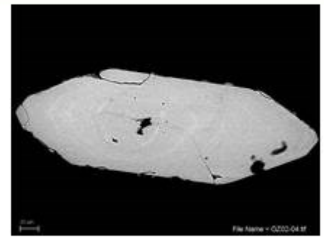
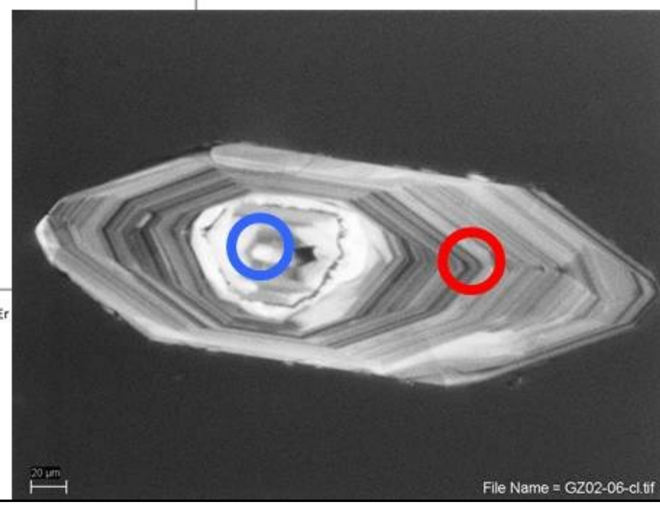


	GZ02-06-1	GZ02-06-2
Ce/Ce*	26.68	674.84
Eu/Eu*	0.341	0.605
Age (Ma)	305	189





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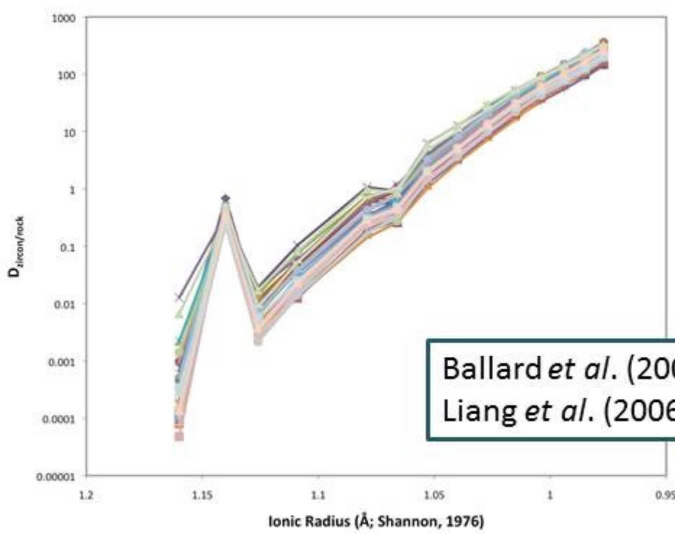
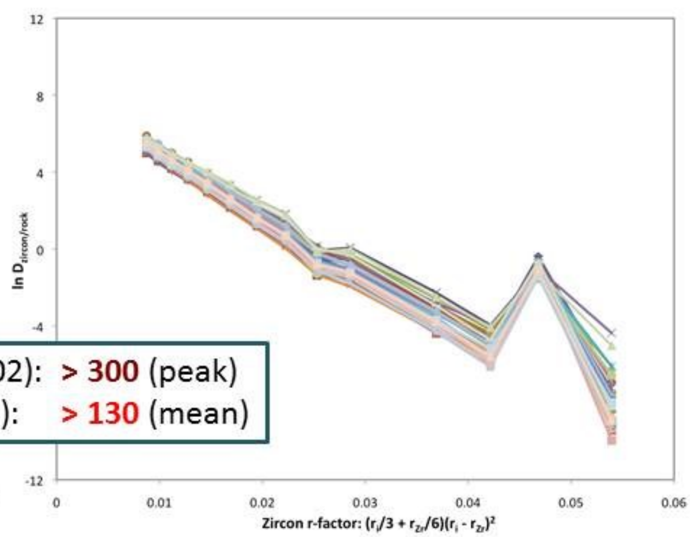
Calculation of Ce^{4+}/Ce^{3+}





Ballard *et al*. (2002): **> 300** (peak)
Liang *et al*. (2006): **> 130** (mean)

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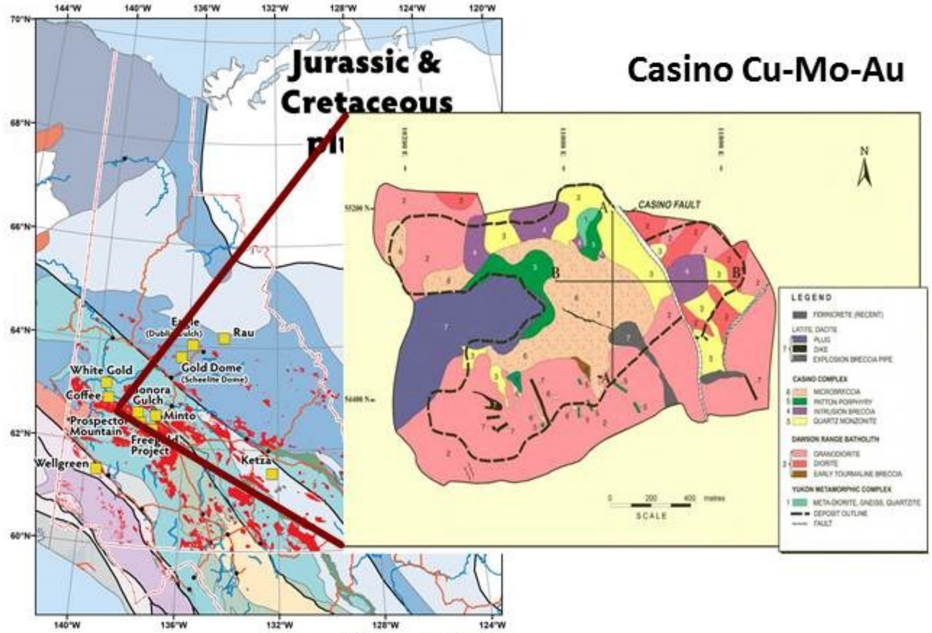
- Abundant granitoid intrusions throughout central and southern Yukon
- Dominantly Triassic-Jurassic, Cretaceous and Tertiary
- Host major mineral occurrences, including Minto mine, Casino, Carmacks Copper, Sonora Gulch and many more…
- BUT… exploration activity is spotty between different plutonic bodies



(Colpron & Bennett, 2010)

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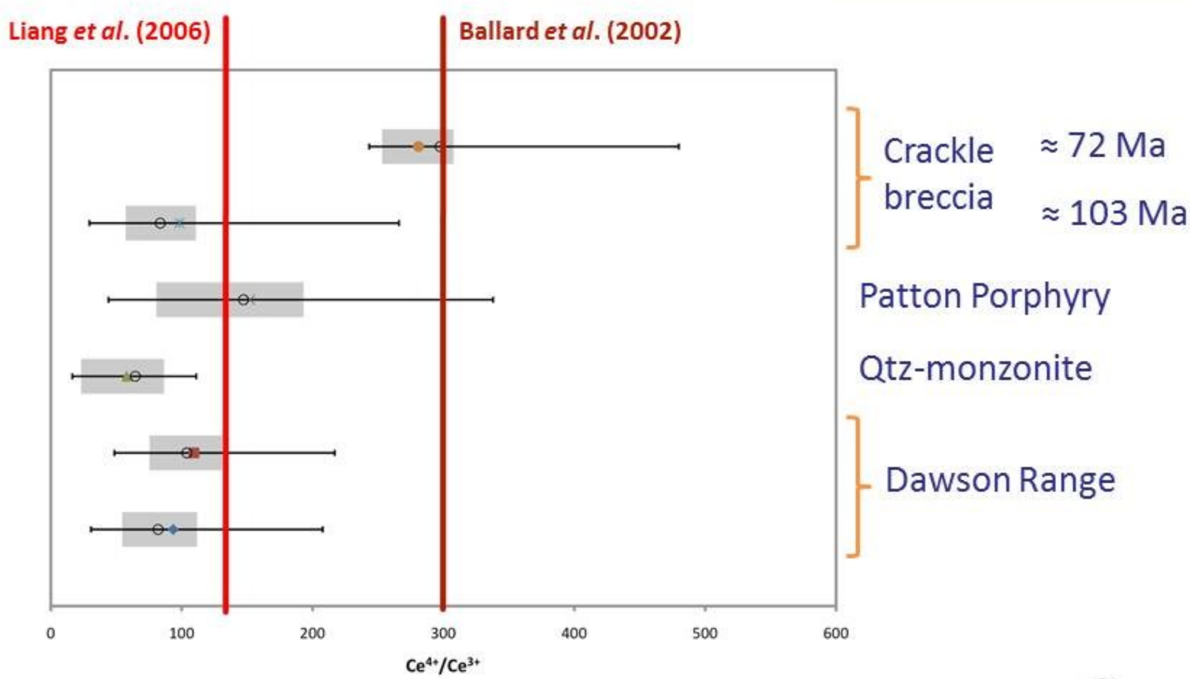

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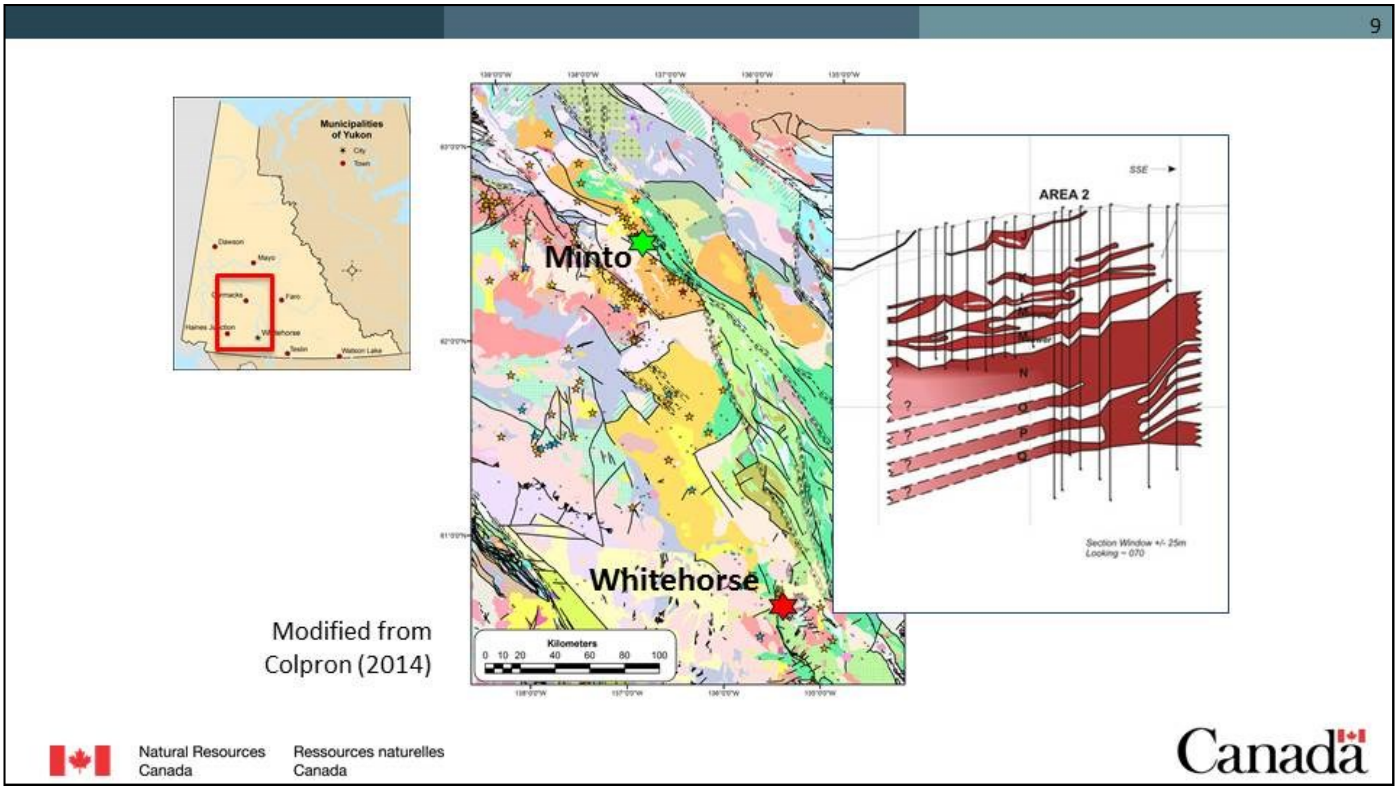
9
Municipalities of Yukon
City
Town
Dawson
Mayo
Carmacks
Faro
Haines Junction
Whitehorse
Teslin
Watson Lake
Minto
Whitehorse
Kilometers
0 10 20 40 60 80 100
AREA 2
SSE
N
O
P
Q
Section Window +/- 25m
Looking ~ 070
Modified from
Colpron (2014)
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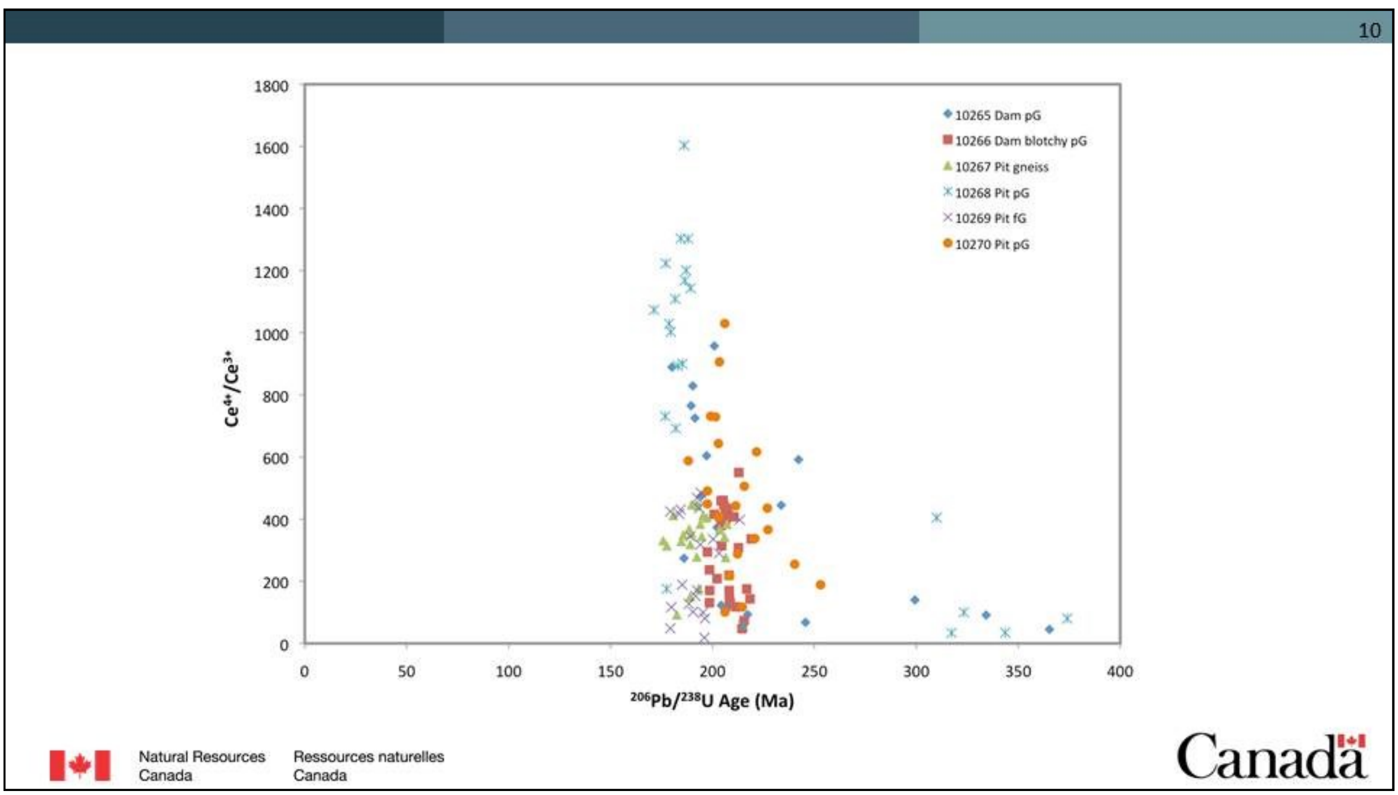
10
10265 Dam pG
10266 Dam blotchy pG
10267 Pit gneiss
10268 Pit pG
10269 Pit fG
10270 Pit pG
Ce^{4+}/Ce^{3+}
0
200
400
600
800
1000
1200
1400
1600
1800
0 50 100 150 200 250 300 350 400
$^{206}Pb/^{238}U$ Age (Ma)
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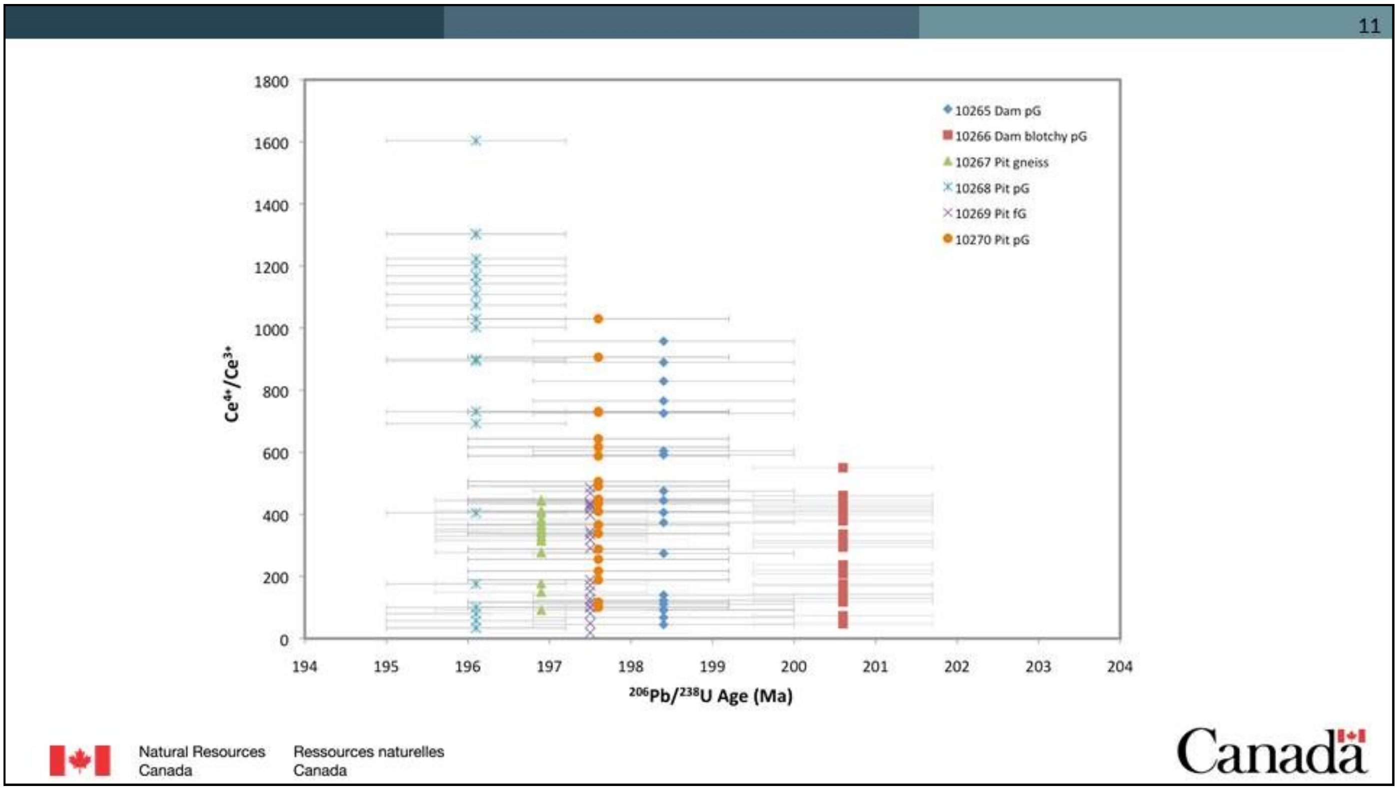
11
1800
1600
1400
1200
1000
800
600
400
200
0
Ce⁴⁺/Ce³⁺
194
195
196
197
198
199
200
201
202
203
204
²⁰⁶Pb/²³⁸U Age (Ma)
10265 Dam pG
10266 Dam blotchy pG
10267 Pit gneiss
10268 Pit pG
10269 Pit fG
10270 Pit pG
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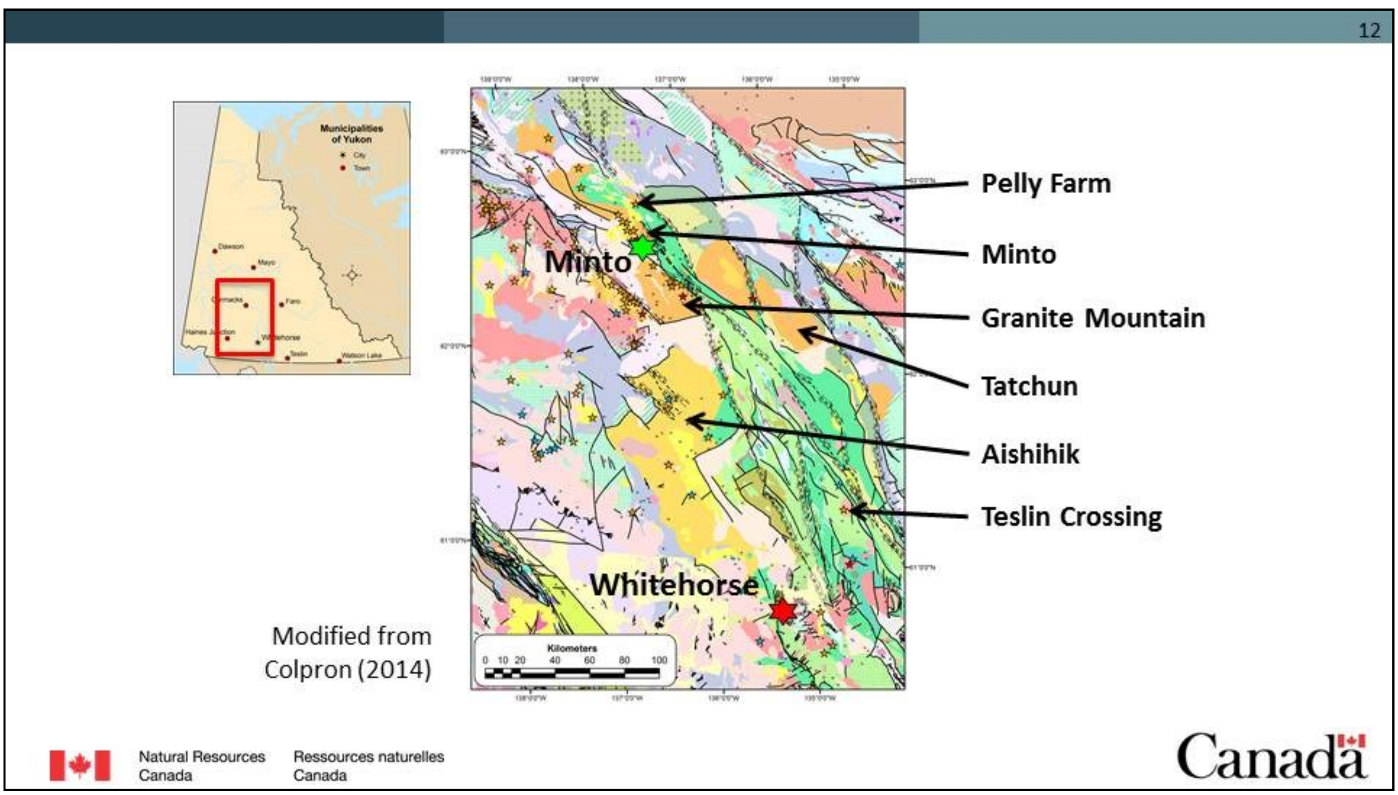
12
Municipalities of Yukon
Pelly Farm
Minto
Granite Mountain
Tatchun
Aishihik
Teslin Crossing
Minto
Whitehorse
Kilometers
0 10 20 40 60 80 100
Modified from Colpron (2014)
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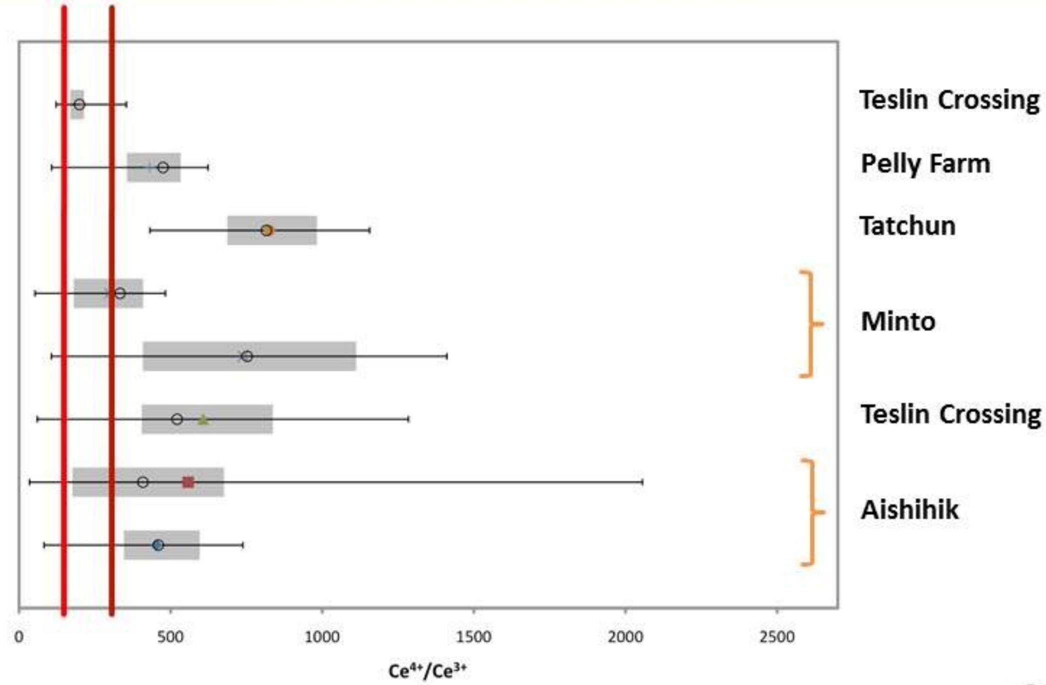

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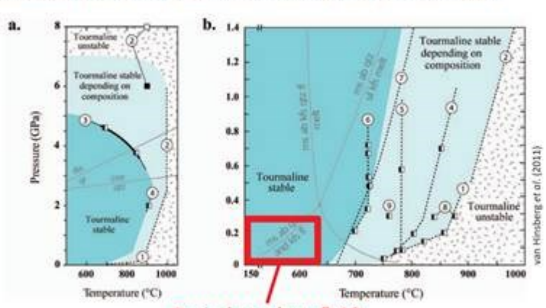
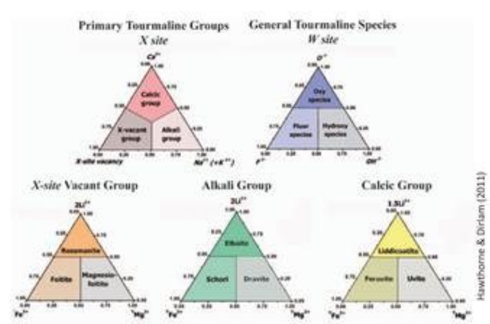
Why use tourmaline?

- 'Tourmaline' is not a single mineral, but a related group
- Common gangue and matrix mineral in porphyry deposits
- Occur over a wide range of temperatures and pressures
- Structurally and chemically complex, versatile geological record
- Chemically and physically resistent, will preserve data



Tourmalines are stable over a very wide range of pressures and temperatures. They are therefore well able to record and preserve porphyry-related ore-forming



$XY_3Z_6[T_6O_{18}][BO_3]_3V_3W$

The tourmaline crystal structure contains numerous sites that can accommodate a large number of different elements. Major element variation in the Y site results in the major species present in porphyry environments:

Dravite: $NaMg_3Al_6Si_6O_{18}(BO_3)_3(OH)_3(OH)$
Schorl: $NaFe_3Al_6Si_6O_{18}(BO_3)_3(OH)_3(OH)$
Elbaite: $Na(Li_{1.5}Al_{1.5})_3Al_6Si_6O_{18}(BO_3)_3(OH)_3(OH)$

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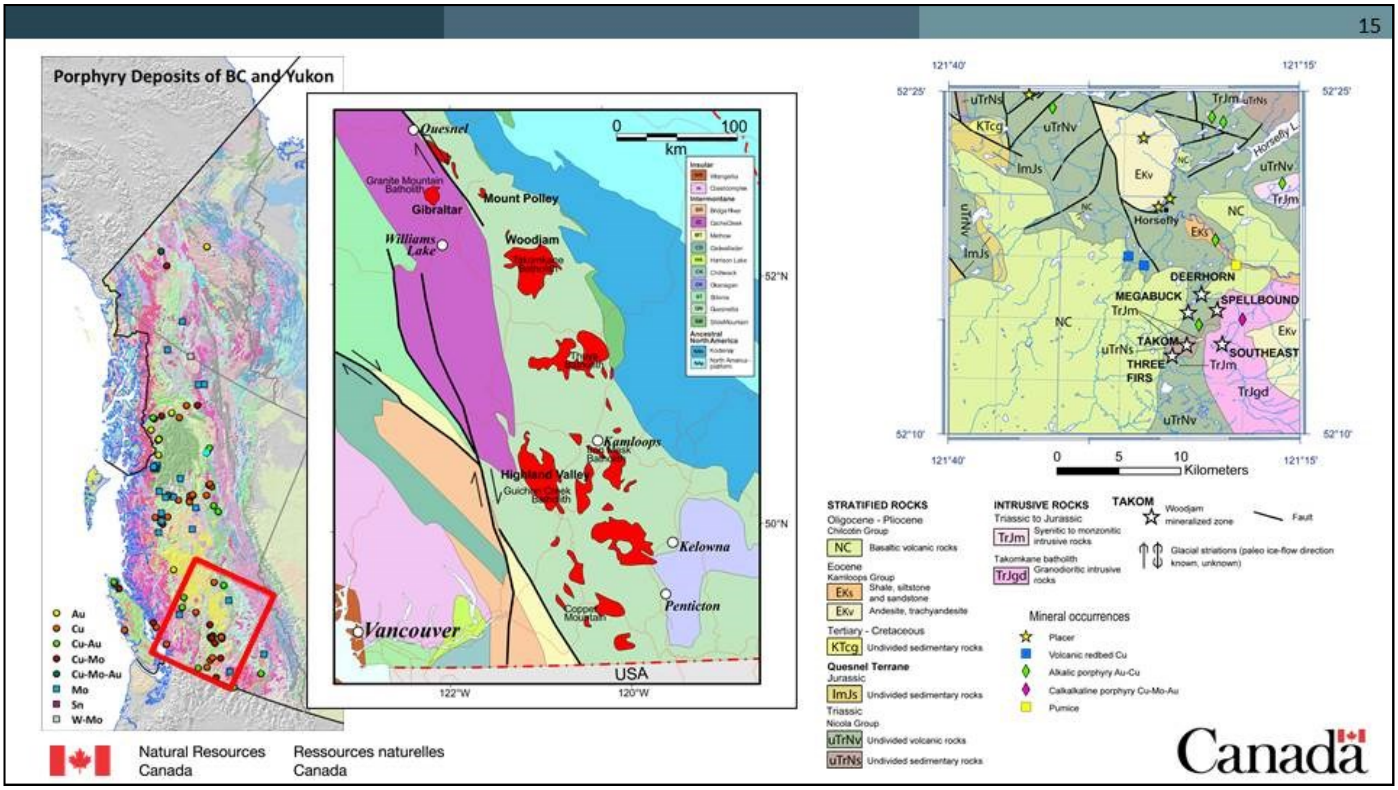
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Porphyry Deposits of BC and Yukon
Au
Cu
Cu-Au
Cu-Mo
Cu-Mo-Au
Mo
Sn
W-Mo
Quesnel
Granite Mountain Batholith
Gibraltar
Mount Polley
Williams Lake
Woodjam
0 100 km
Kamloops
Highland Valley
Guichon Creek Batholith
Kelowna
Penticton
Copper Mountain
Vancouver
USA
122°W
120°W
52°N
50°N
121°40'
121°15'
52°25'
52°10'
uTrNs
KTcg
uTrNv
ImJs
EKv
NC
TrJm
TrJgd
EKs
Horsefly
Horsefly L.
DEERHORN
MEGABUCK
SPELLBOUND
TAKOM
THREE FIRS
SOUTHEAST
0 5 10 Kilometers
STRATIFIED ROCKS
Oligocene - Pliocene
Chilcotin Group
NC Basaltic volcanic rocks
Eocene
Kamloops Group
EKs Shale, siltstone and sandstone
EKv Andesite, trachyandesite
Tertiary - Cretaceous
KTcg Undivided sedimentary rocks
Quesnel Terrane
Jurassic
ImJs Undivided sedimentary rocks
Triassic
Nicola Group
uTrNv Undivided volcanic rocks
uTrNs Undivided sedimentary rocks
INTRUSIVE ROCKS
Triassic to Jurassic
TrJm Syenitic to monzonitic intrusive rocks
Takomkane batholith
TrJgd Granodioritic intrusive rocks
TAKOM Woodjam mineralized zone
Fault
Glacial striations (paleo ice-flow direction known, unknown)
Mineral occurrences
Placer
Volcanic redbed Cu
Alkalic porphyry Au-Cu
Calkalkaline porphyry Cu-Mo-Au
Pumice
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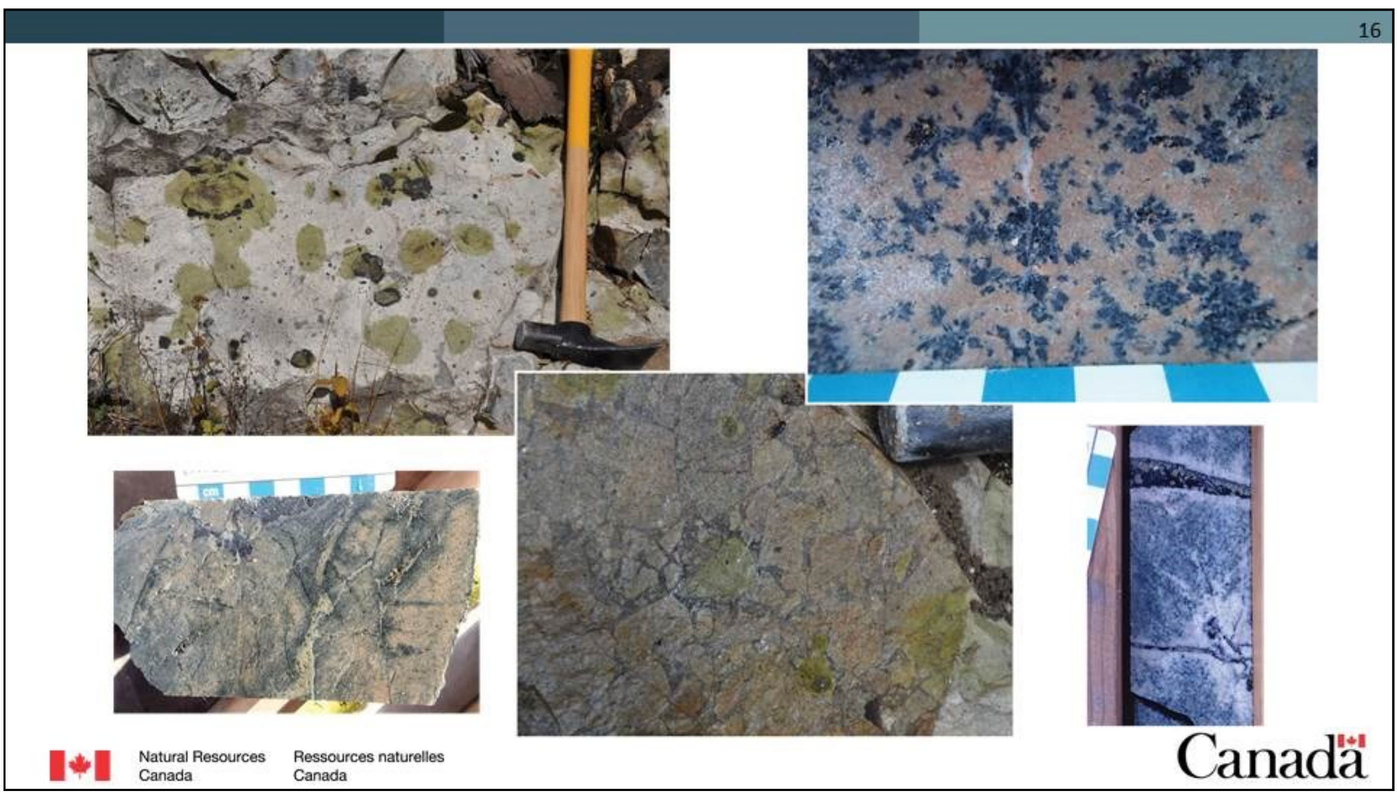
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cm
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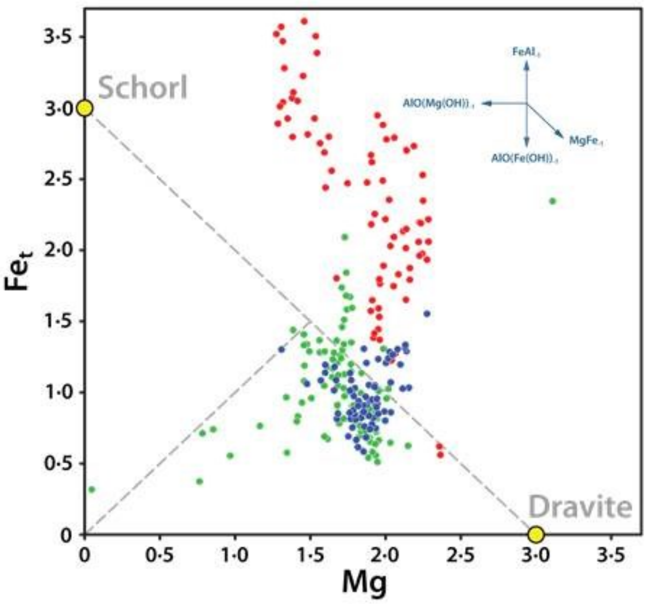

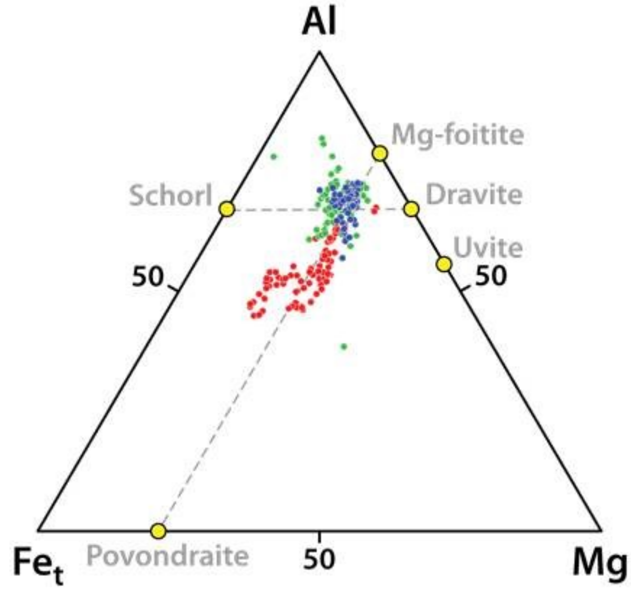

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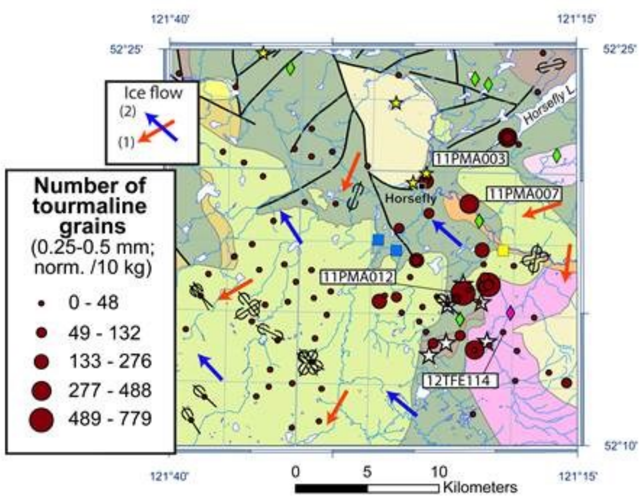
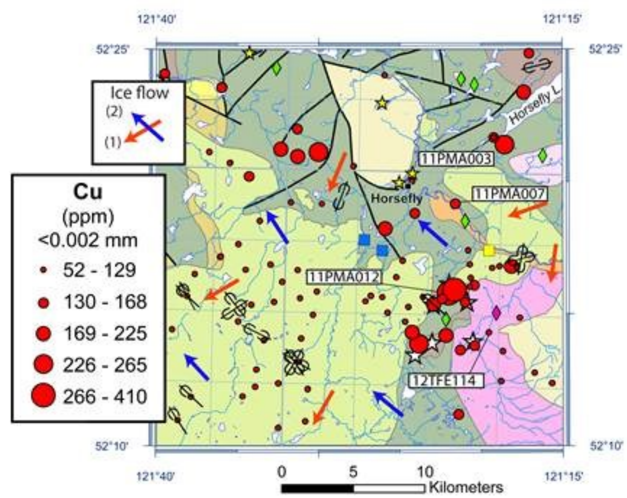
Till Sampling – Can we increase precision?





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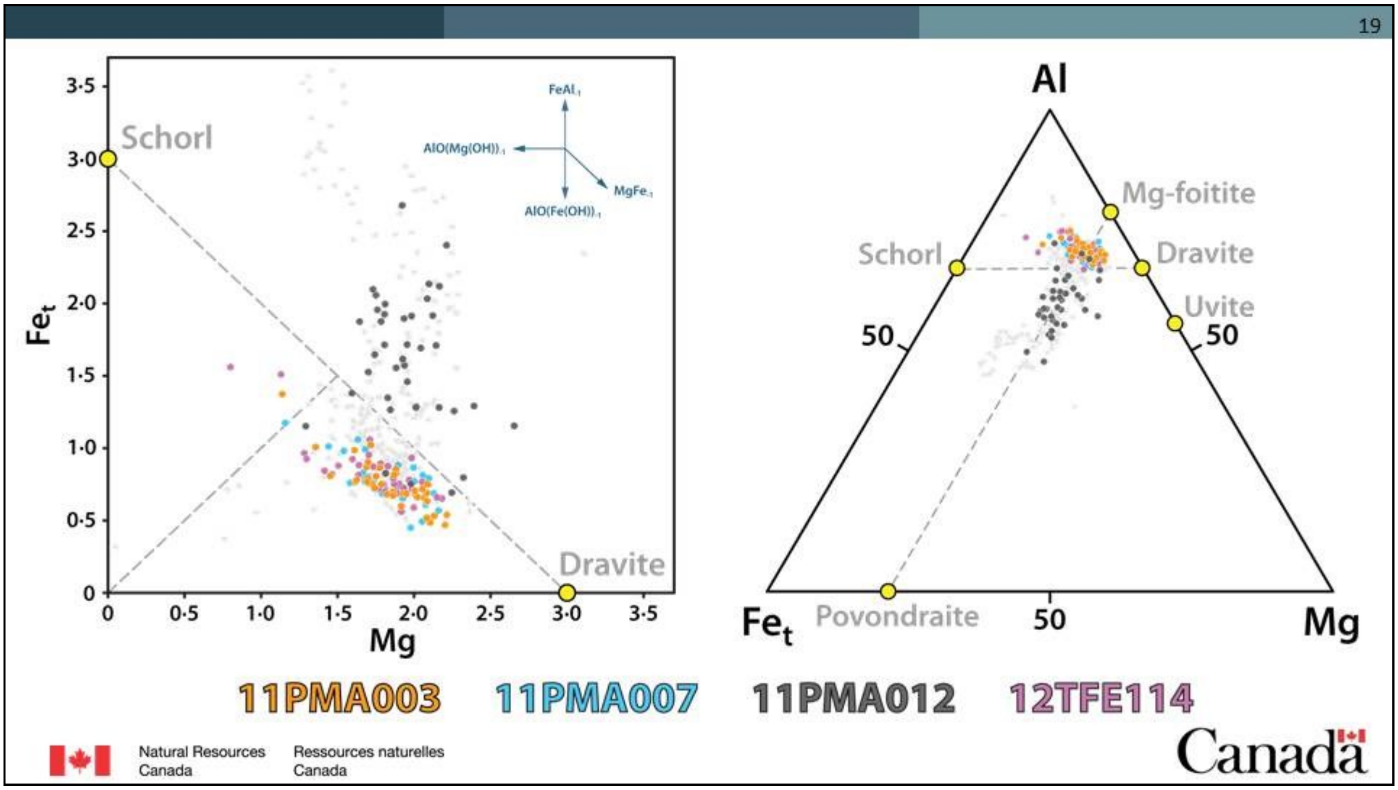
19
Schorl
Dravite
Fe$_t$
Mg
AlO(Mg(OH))$_{-1}$
MgFe$_{-1}$
AlO(Fe(OH))$_{-1}$
Al
Mg-foitite
Schorl
Dravite
Uvite
50
50
Fe$_t$
Povondraite
50
Mg
11PMA003
11PMA007
11PMA012
12TFE114
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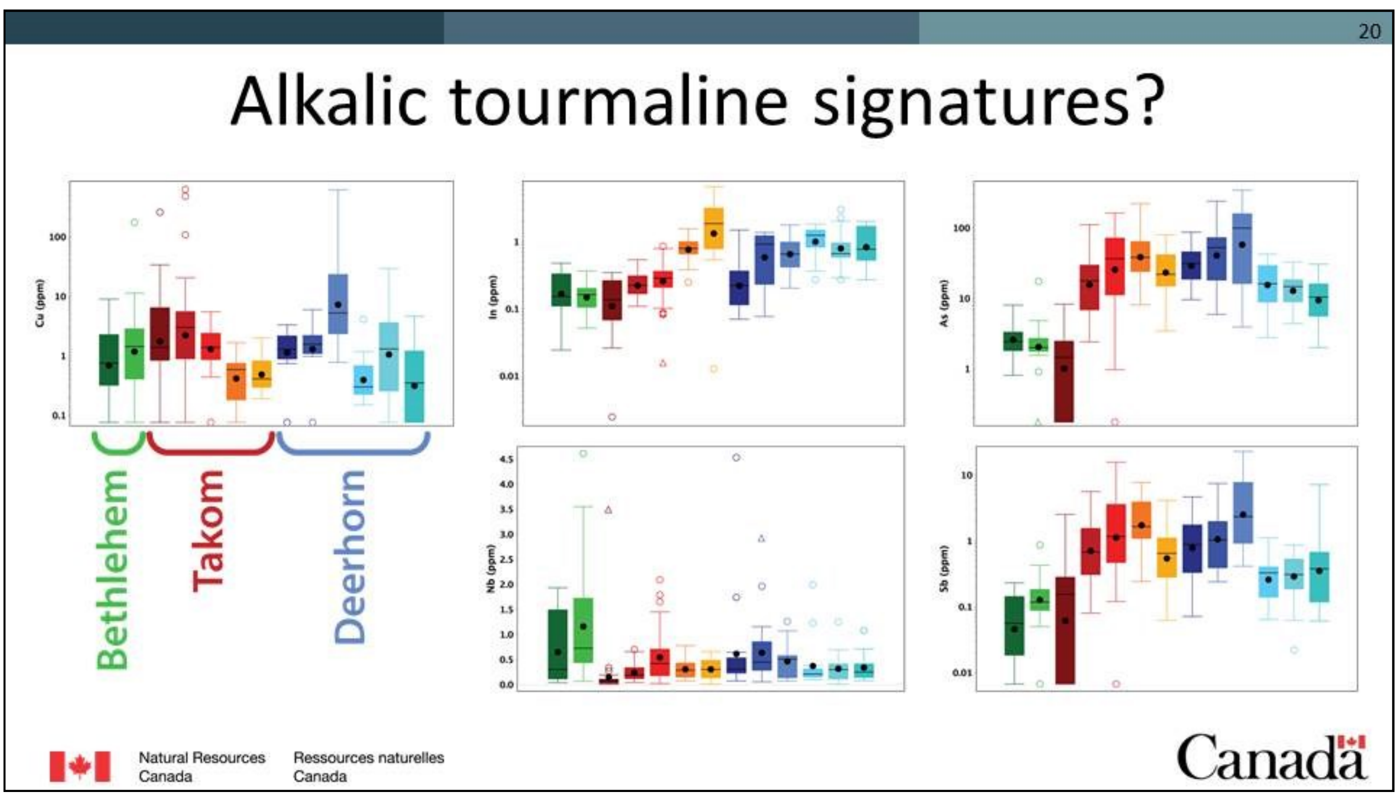
20
Alkalic tourmaline signatures?
Cu (ppm)
In (ppm)
As (ppm)
Nb (ppm)
Sb (ppm)
Bethlehem
Takom
Deerhorn
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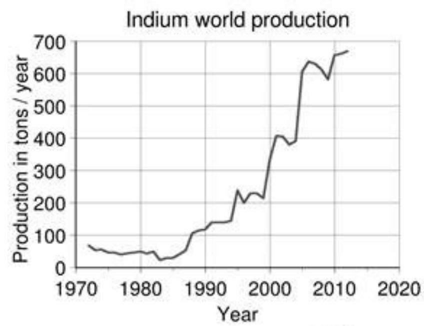
Indium in Sn-W Systems

- Global primary ≈ 670 t/yr
- Recycling ≈ 850 t/yr
- 55-60% from China
- Canada 2nd largest producer
- Teck Trail Smelter (BC) produces ≈ 75 t/yr
- Falconbridge (latterly Xstrata) Kidd Met. Site (ON) produced ≈ 40 t/yr
- Adex pilot trials produced Zn con at 5310 ppm In, and hydrometallurgical indium sponge at 96.25%



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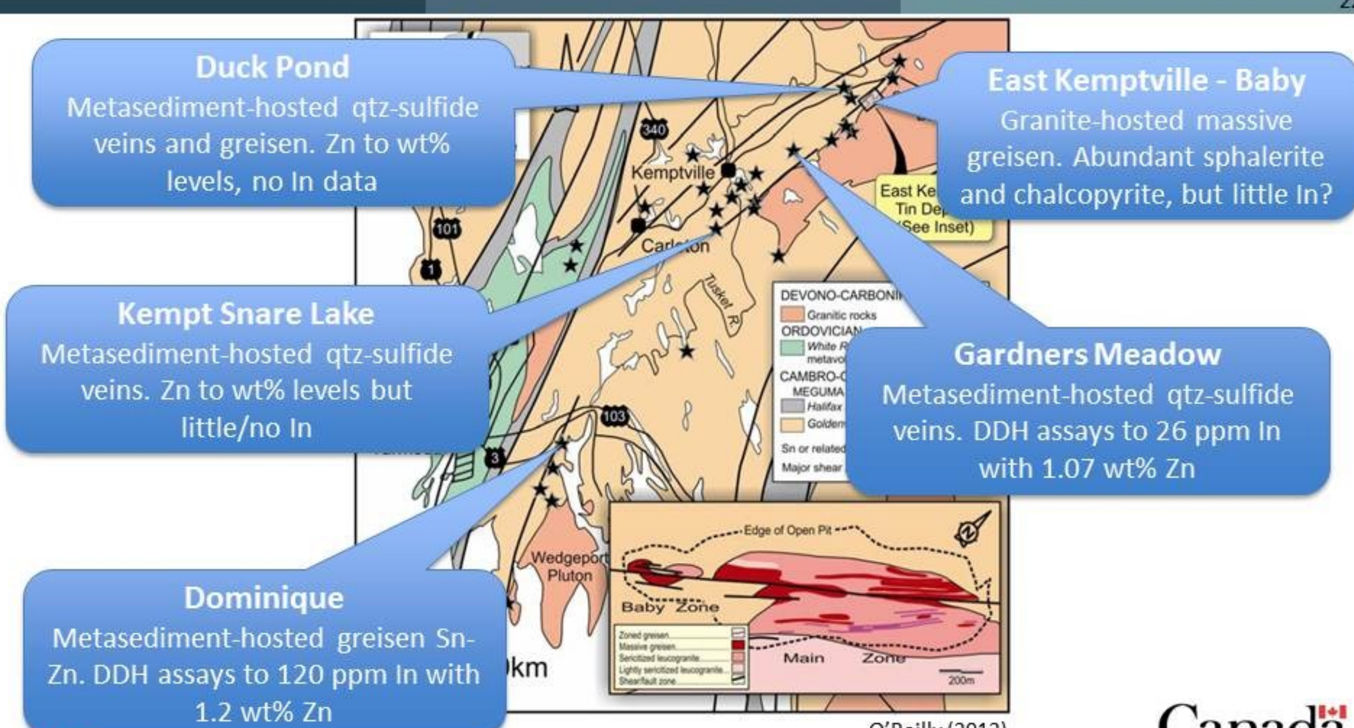
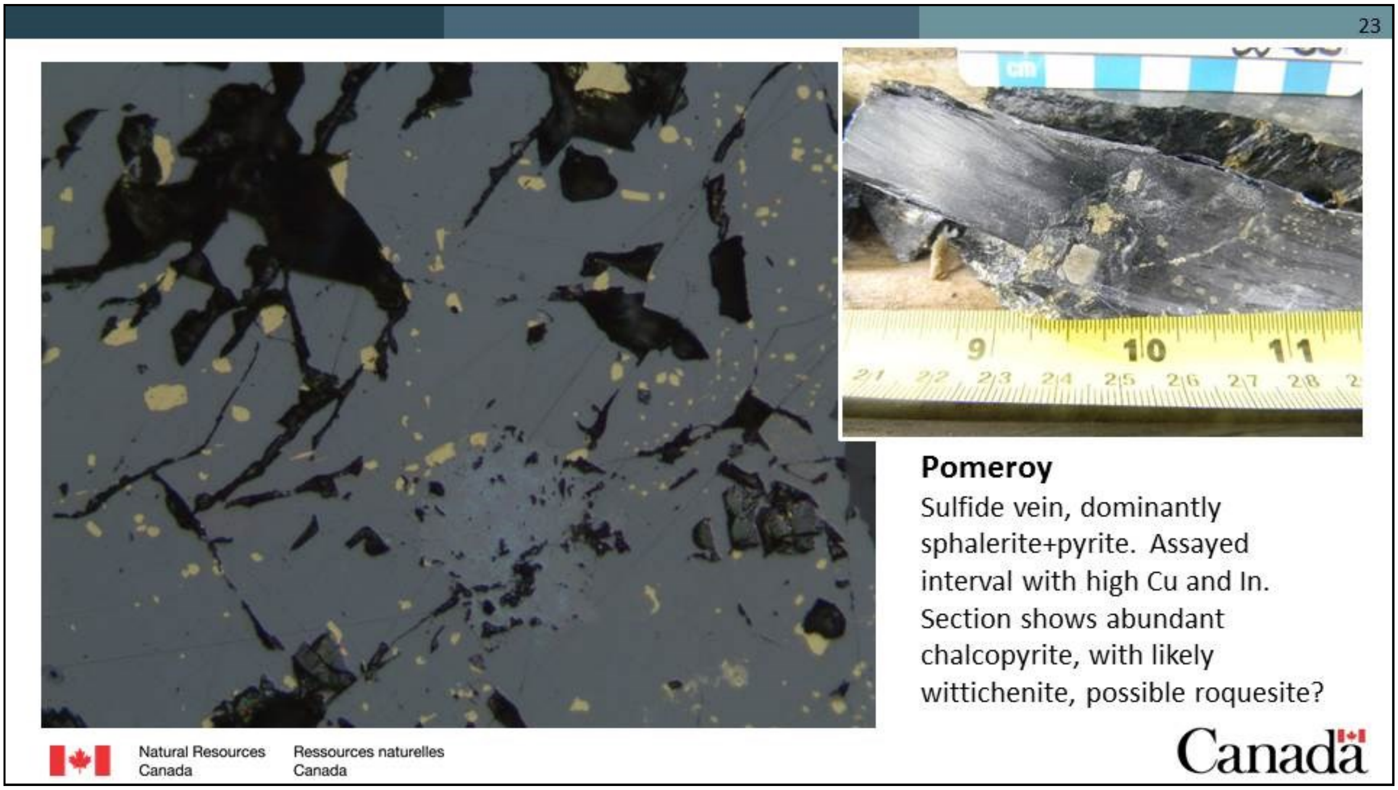


O'Reilly (2012)

Canada


23
Pomeroy
Sulfide vein, dominantly sphalerite+pyrite. Assayed interval with high Cu and In. Section shows abundant chalcopyrite, with likely wittichenite, possible roquesite?
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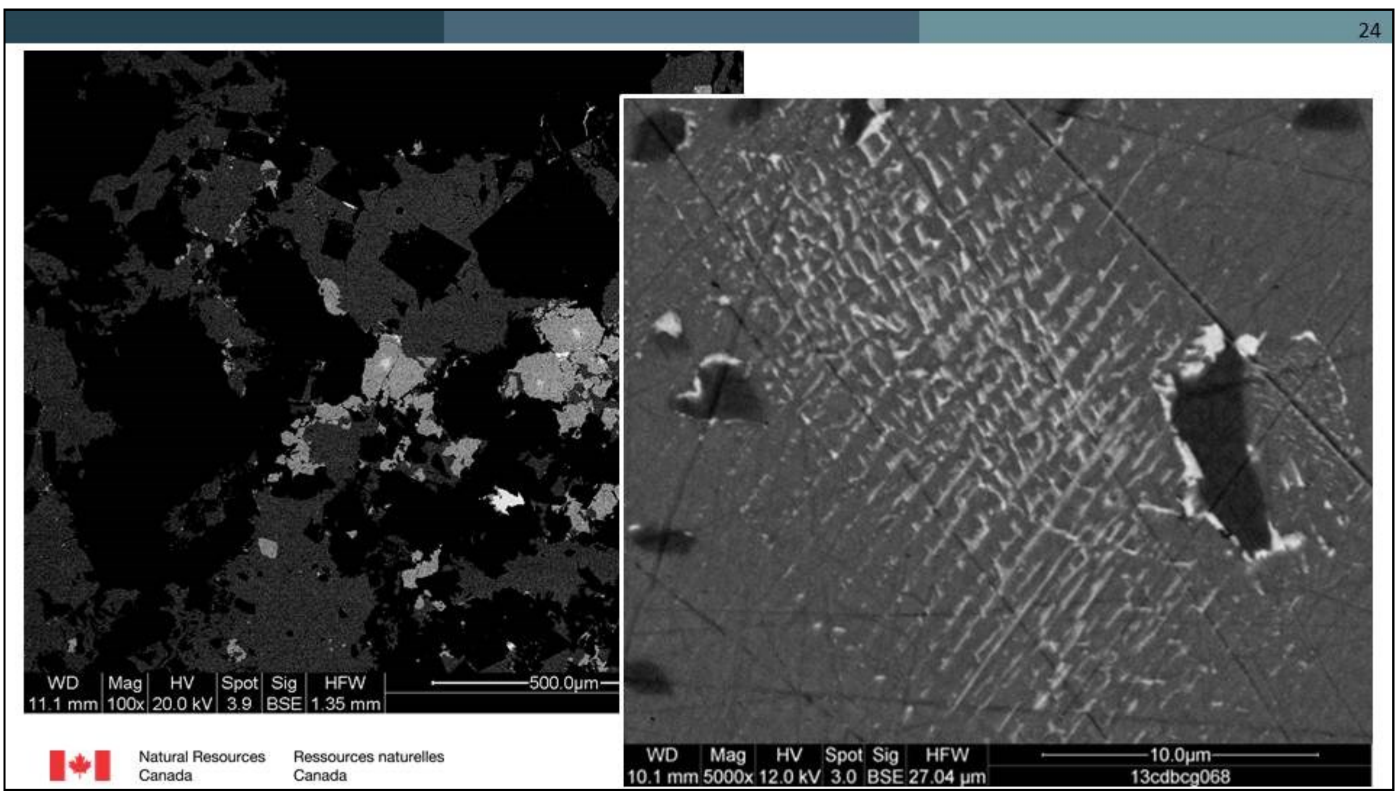
24
WD 11.1 mm Mag 100x HV 20.0 kV Spot 3.9 Sig BSE HFW 1.35 mm
500.0μm
WD 10.1 mm Mag 5000x HV 12.0 kV Spot 3.0 Sig BSE HFW 27.04 μm
10.0μm
13cdbcg068
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What can mineral studies do for us?

- Provide regional-scale information for assessing the prospectivity of intrusive suites and associated lithologies
  - …helps to refine and inform regional mapping and staking
- Provide district-scale information for locating prospective and unprospective zones
  - …refinement of district-specific genetic and exploration models to inform early-stage and mature exploration
- Provide deposit-scale information on intrusion fertility, metal paragenesis and distribution
  - …vectoring toward ore during development and production