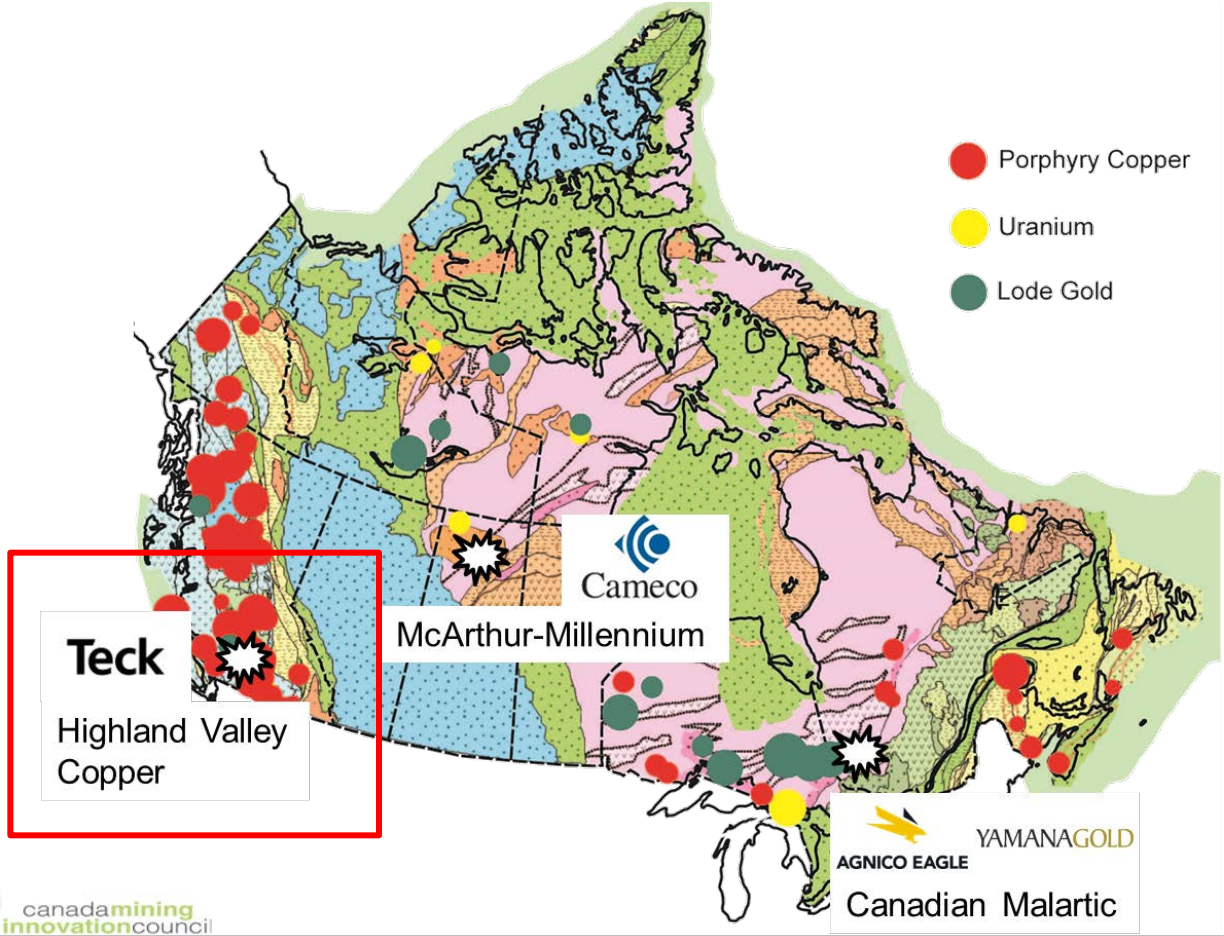
cmic-footprints.ca

NSERC-CMIC FOOTPRINTS

Exploration Footprint of the Highland Valley Porphyry Copper Deposit

Robert G. Lee – Mineral Deposit Research Unit – UBC
Craig J.R. Hart – Mineral Deposit Research Unit – UBC
Pete Hollings – Lakehead University
Sarah A. Gleeson – GFZ Helmholtz Centre Potsdam Germany

Location of Cu Site



HVC is a calc-alkaline porphyry copper deposit located in South-Central British Columbia hosted in the late Triassic Guichon Creek batholith

D'Angelo et al., 2017 (SEG)

Objectives CMIC Cu Site

NSERC-CMIC FOOTPRINTS

Develop comprehensive and robust models of the footprints of large-scale ore-forming systems at the Highland Valley Copper deposit, combining geological, mineralogical, geochemical, and physical rock properties from the local to the camp scale

Develop novel methods for integrating and interrogating multiple data sets that will enhance the exploration process and, at the same time, answer fundamental questions about the origins of large-scale ore-forming systems

Identify the best combinations of geological, geophysical, petrophysical, mineralogical, and geochemical tools to detect the footprints of major ore-forming systems

Research Team

NSERC-CMIC FOOTPRINTS

- **Integrated expertise across multiple disciplines**

Geologists
Guillaume Lesage – MDRU-UBC
Kevin Byrne – Alberta
Michael D'Angelo – Lakehead
Darius Kamal – MDRU-UBC

Site Geologists
John Ryan – Teck Resources Limited
Miguel Alfaro – Teck Resources Limited

Hyperspectral
Philip Lypaczewski – Alberta
Benoit Rivard – Alberta

Modeller
Julia King – Geoscience North

Inversion Modelling
Marc Vallée – Memorial University

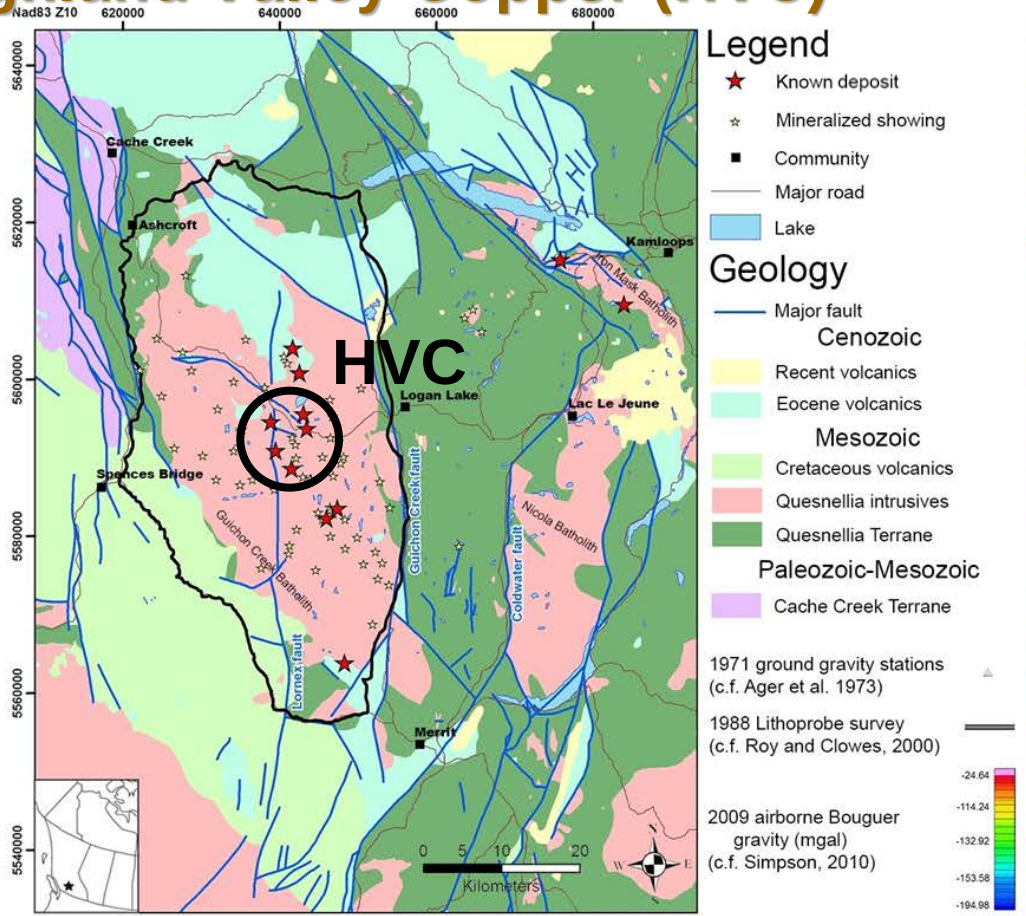
Physical Properties
Christophe Grenon – Polytechnique
Michel Chouteau - Polytechnique
Randy Enkin – GSC Sydney B.C.

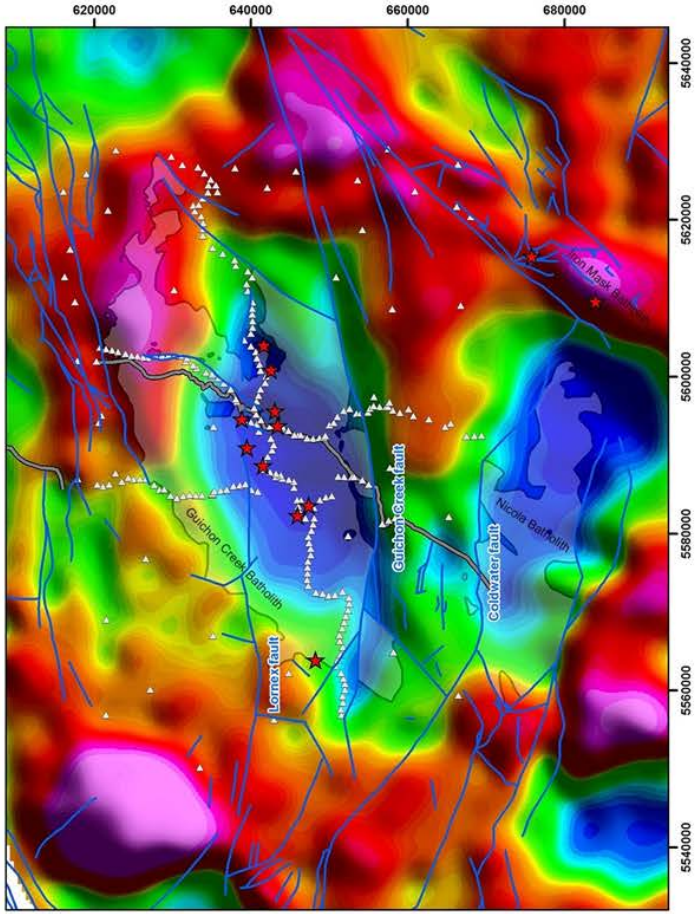
Geophysics
Reza Mir – University of Toronto
William Morris – McMaster University

Surface soil/till:
Rachel Chouinard – MDRU-UBC
Peter Winterburn – MDRU-UBC
Andrea Reman – Waterloo
Martin Ross – Waterloo
Alain Plouffe – Geological Survey of Canada
Travis Ferbey – B.C. Geological Survey

Guichon Creek batholith – south-central B.C.
Highland Valley Copper (HVC)

NSERC-CMIC FOOTPRINTS





Legacy data GCB

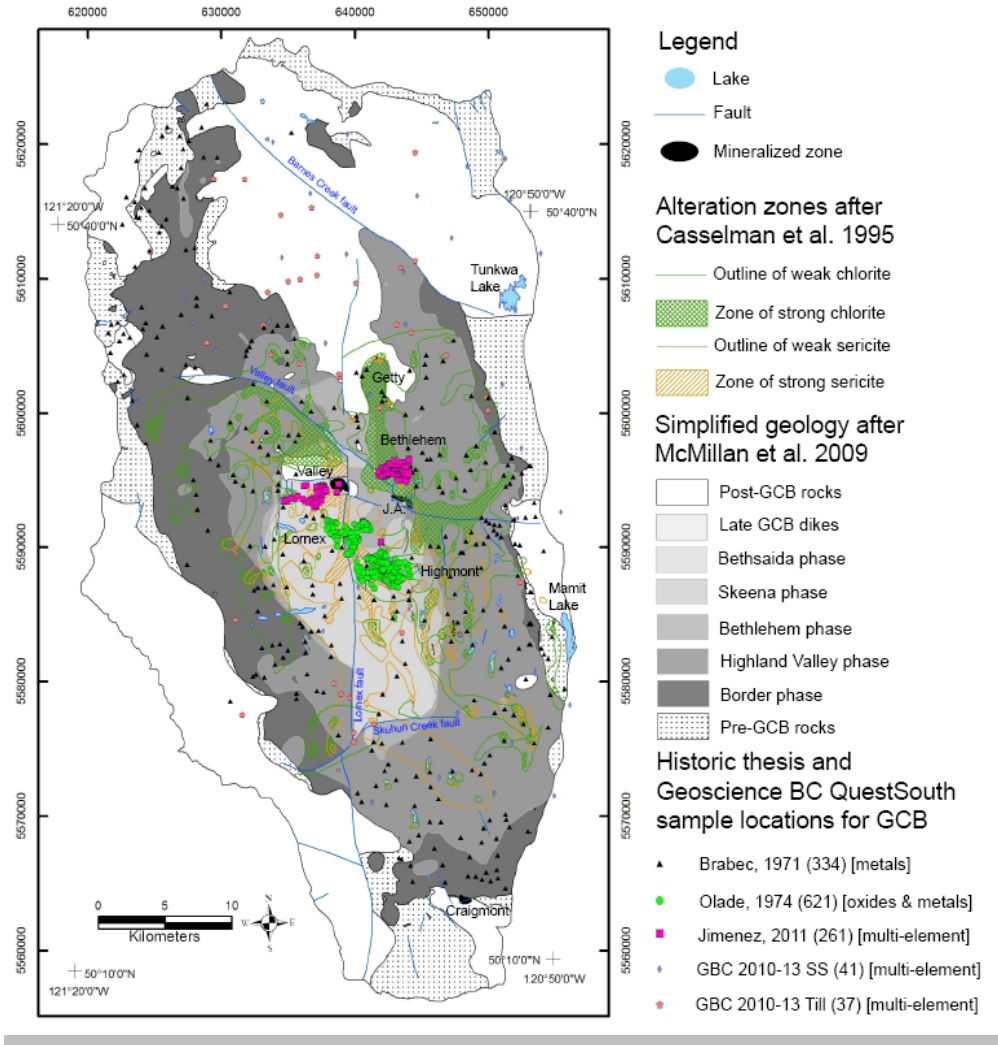
Concentrically zoned batholith 60 x 30 km

Data distribution concentrated around mineralized deposits

Limited assay type (metals, oxides, multi-element)

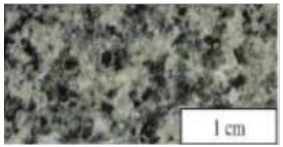
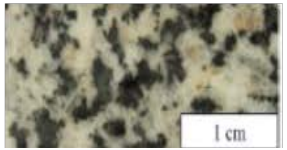
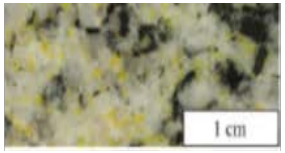
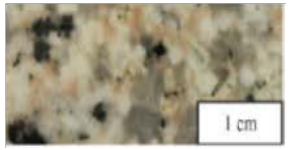
Five known deposits: Valley, Lornex, Highmont, Bethlehem, J.A.

Distal alteration features: Chlorite vs. sericite



Major rock units

NSERC-CMIC FOOTPRINTS

Name	Gump Lake	Border	Guichon	Chataway	Bethlehem	Skeena	Bethsaida	Dykes
Rock Type	granodiorite Qtz monzonite	gabbro to Qtz diorite	granodiorite	granodiorite Qtz monzonite	granodiorite	granodiorite monzogranite	granodiorite monzogranite	FPM-QFP aplite
SiO_2%	68-72	48-56	63-68	63-68	64-66	65-73	68-75	60-78
TiO_2%	0.36-0.42	0.79-1.26	0.42-0.80	0.40-0.60	0.33-0.45	0.22-0.39	0.10-0.26	0.10-0.37
Mag Sus (SI)	0.019-0.032	0.026-0.099	0.020-0.050	0.019-0.084	0.001-0.036	0.018-0.036	0.013-0.036	0.001-0.05
Age (Ma)	218.0±0.2	211.0±0.2	210.7±0.2	210.5±0.3	209.5±0.5	208.4±0.3	208.6±0.2	209-207
image								

Byrne et al., 2013 SEG fieldtrip guide; D'Angelo et al. 2017 SEG December issue; Lee et al., 2017 SGA

GCB & HVC

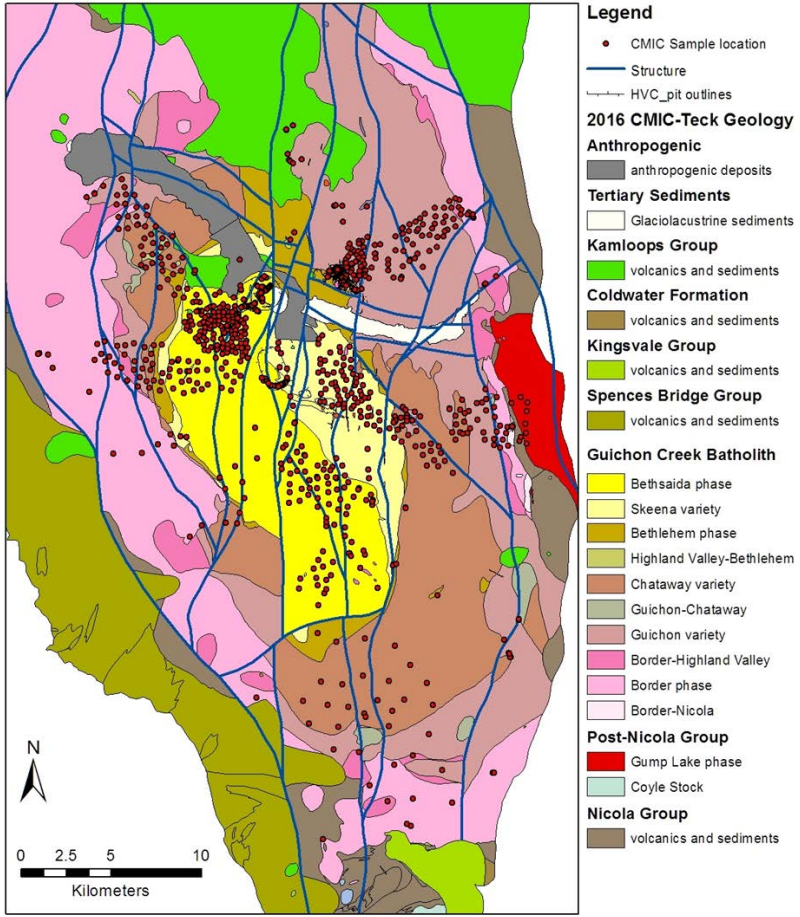
NSERC-CMIC FOOTPRINTS

New geologic and structure map of region from five+ transects

1:5000 & 1:10,000

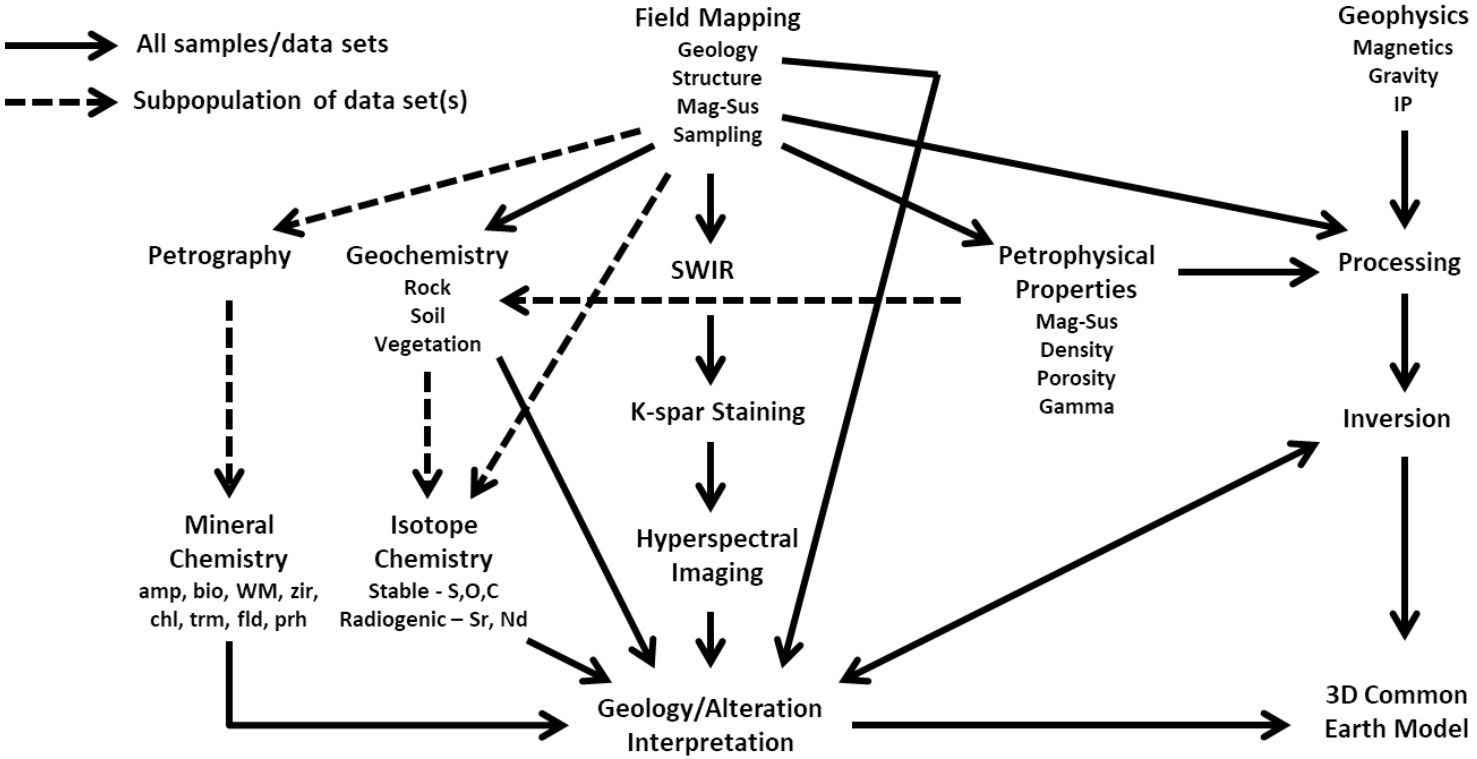
Over 1000 samples collected for project

- **Field measurements**
- **Field mag sus**
- **Rock (soil/till/vegetation)**



Work Flow – 1000 samples

NSERC-CMIC FOOTPRINTS



Deliverables – Lithology Model; Structural Model; Alteration Map; Integrated database

Field Mapping

NSERC-CMIC FOOTPRINTS

Outcrop limited by glacial and surface cover

Grid mapping
Tablet/field book

Outcrop mag sus
Orientations
Sampling

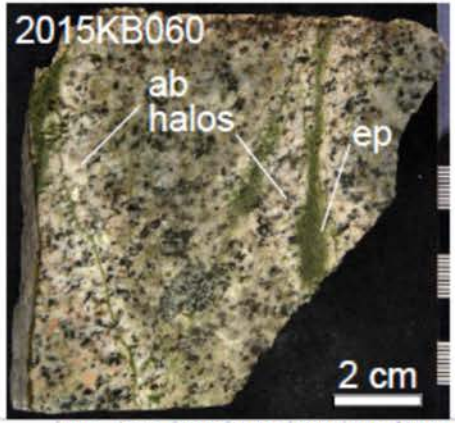
Petrography - Integration

NSERC-CMIC FOOTPRINTS

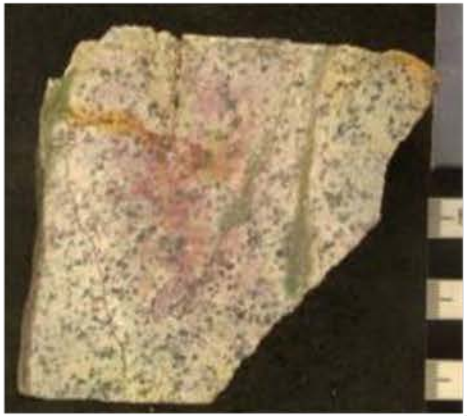
Petrography -> K-staining -> Spectral -> chemical composition

Lithochem -> petrophysical properties -> proxies for model

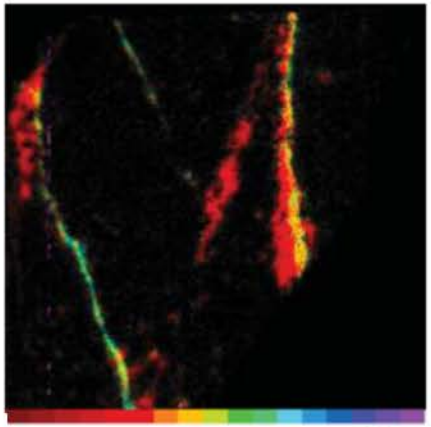
Data combined with field observations to define alteration maps



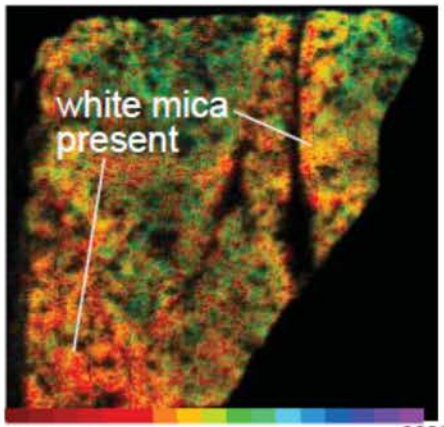
	Al/Ti	Ca/K	Na/K	Na/Ba	Sr/Ba	K/Th	Rb/Ti
stg. Na	26.7	10.0	9.3	3.9	4.4	0.1	28.0
least alt.	24.8	2.8	1.9	0.6	1.0	0.4	82.6



Feldspar staining



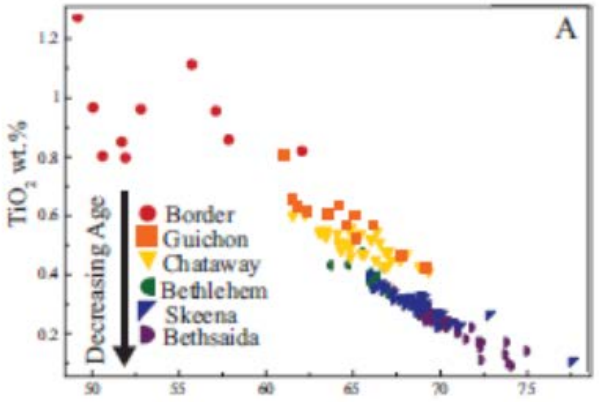
1540nm Epidote composition 1556nm

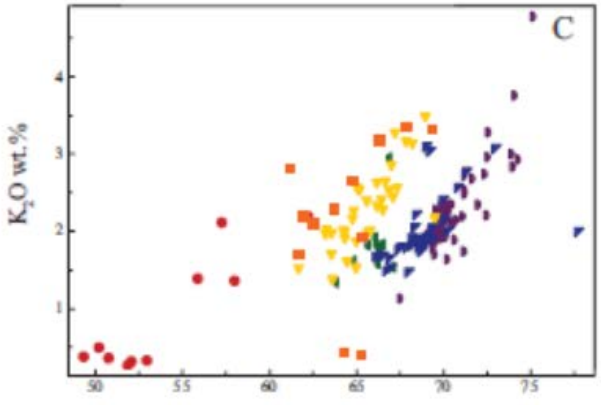


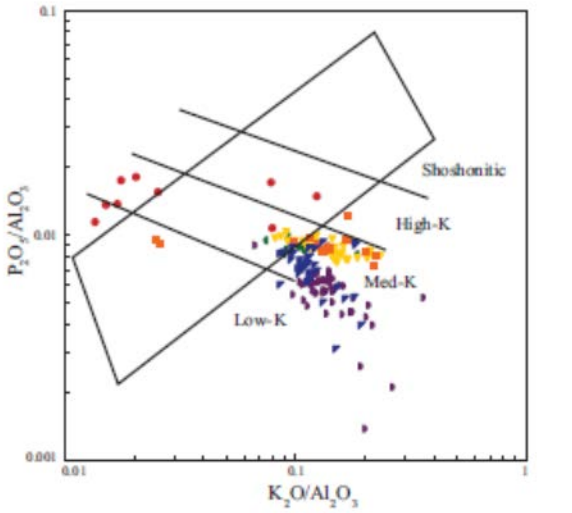
2190nm Al-OH variation 2220nm

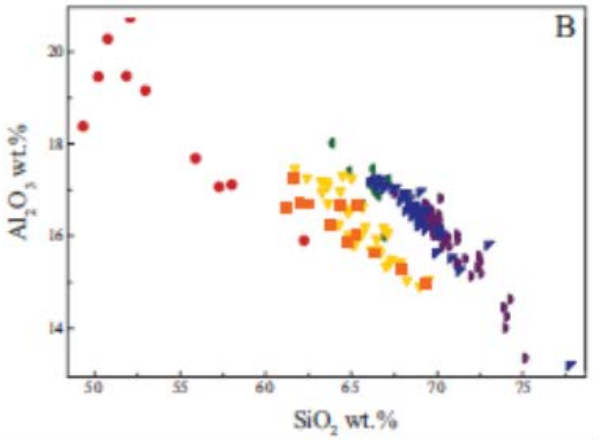
Whole Rock Lithochemistry

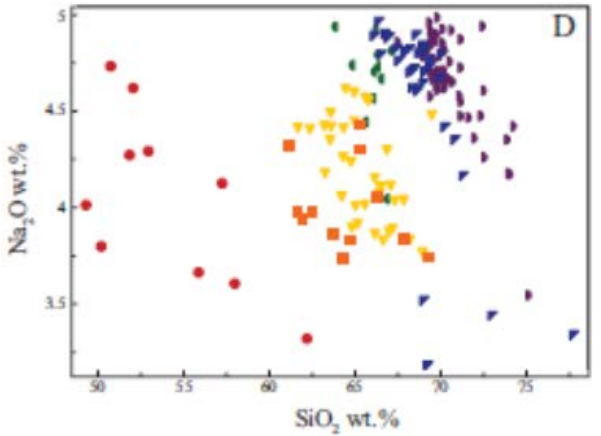
NSERC-CMIC FOOTPRINTS









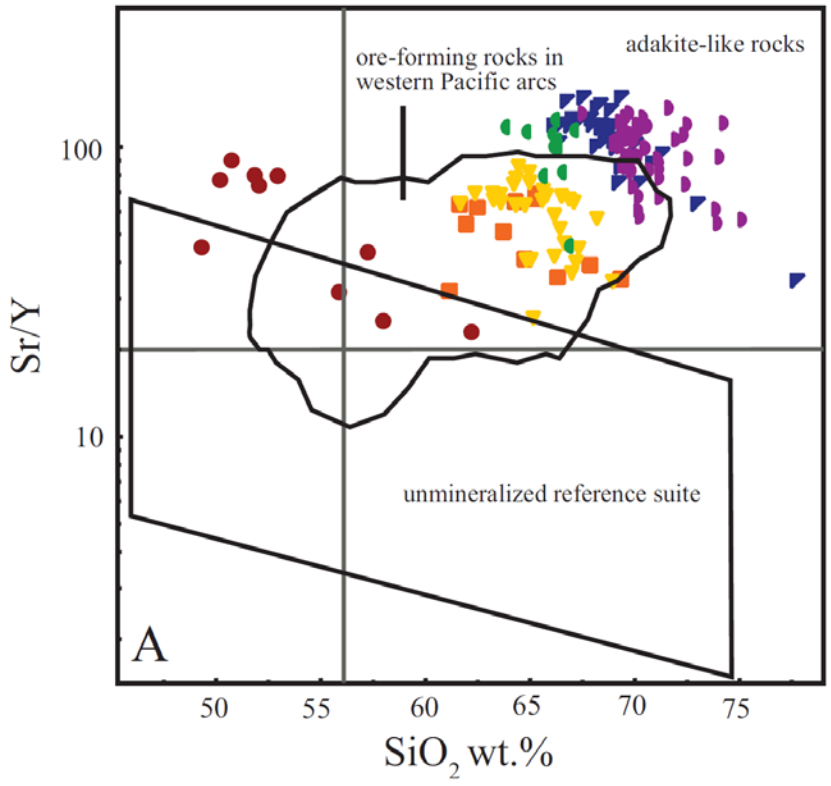


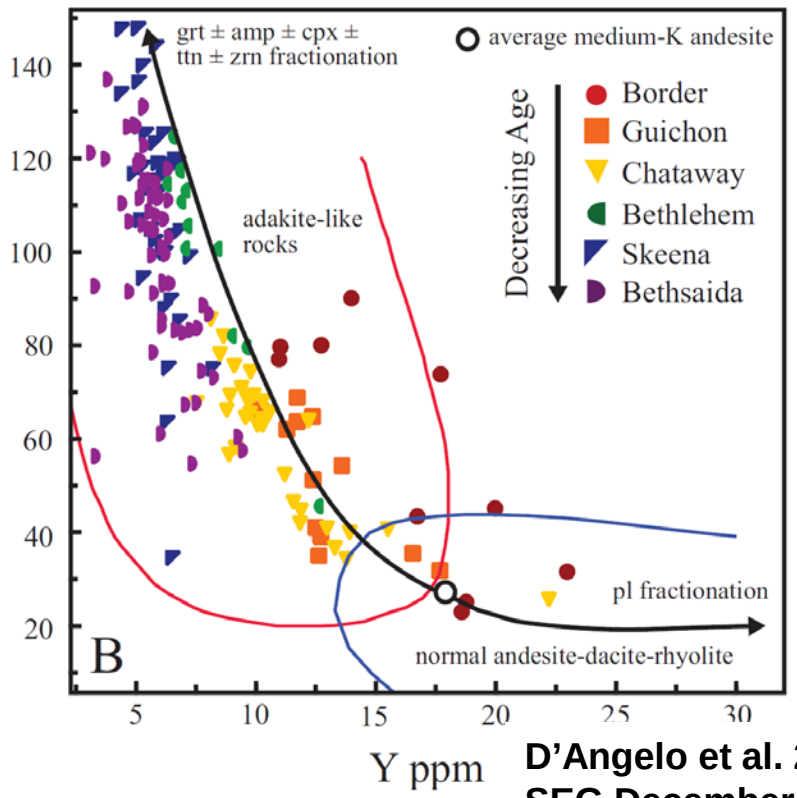
- **Major element distribution of GCB samples**

D'Angelo et al. 2017 SEG December issue

Trace Element Chemistry

NSERC-CMIC FOOTPRINTS



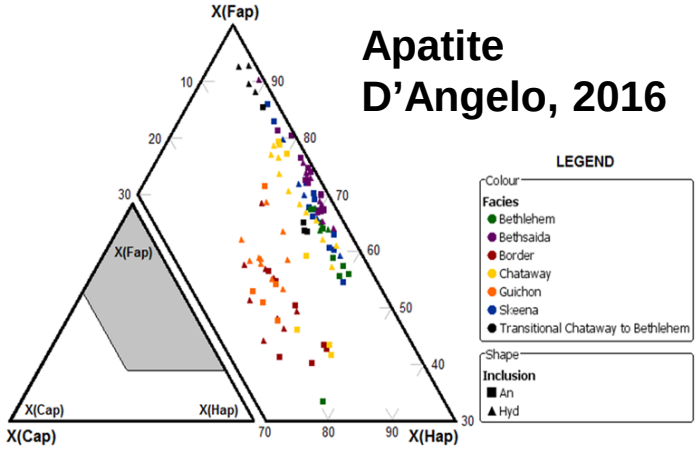


D'Angelo et al. 2017
SEG December issue

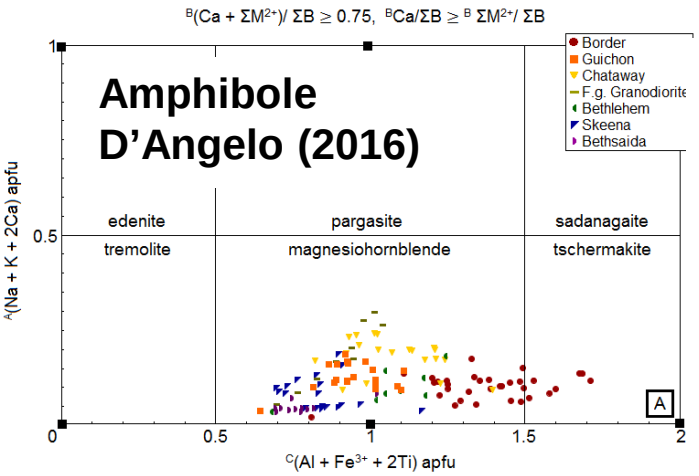
- **Elevated fluid content based on trace element composition**

Mineral Chemistry

NSERC-CMIC FOOTPRINTS



Apatite
D'Angelo, 2016

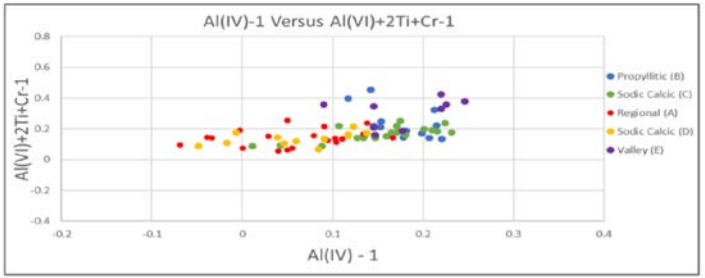


Amphibole
D'Angelo (2016)

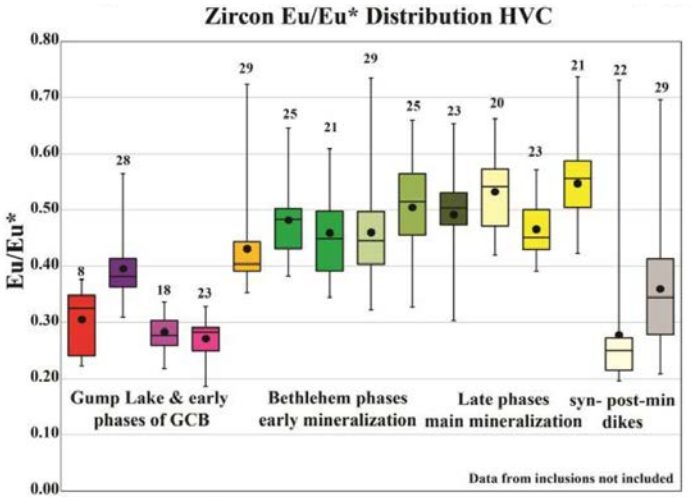
GCB Mineral composition show distinct compositional differences between rock type & alteration

Minerals Analyzed:

- chlorite
- zircon
- amphibole
- feldspar
- white mica
- prehnite
- apatite
- tourmaline
- sulfides
- carbonate



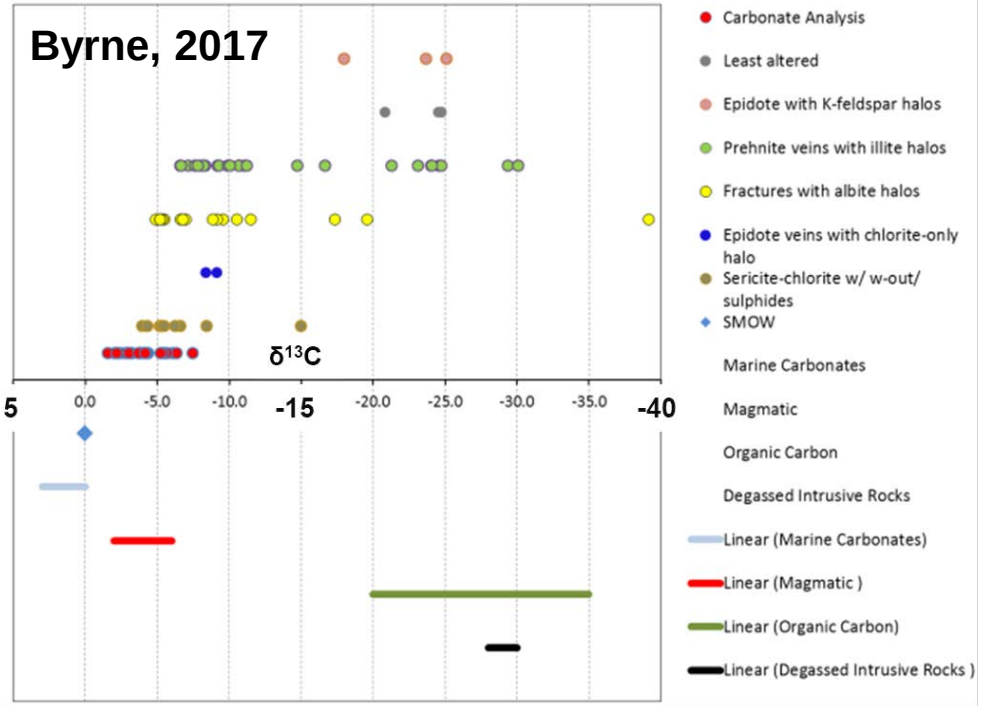
Chlorite - Kamal (2017)

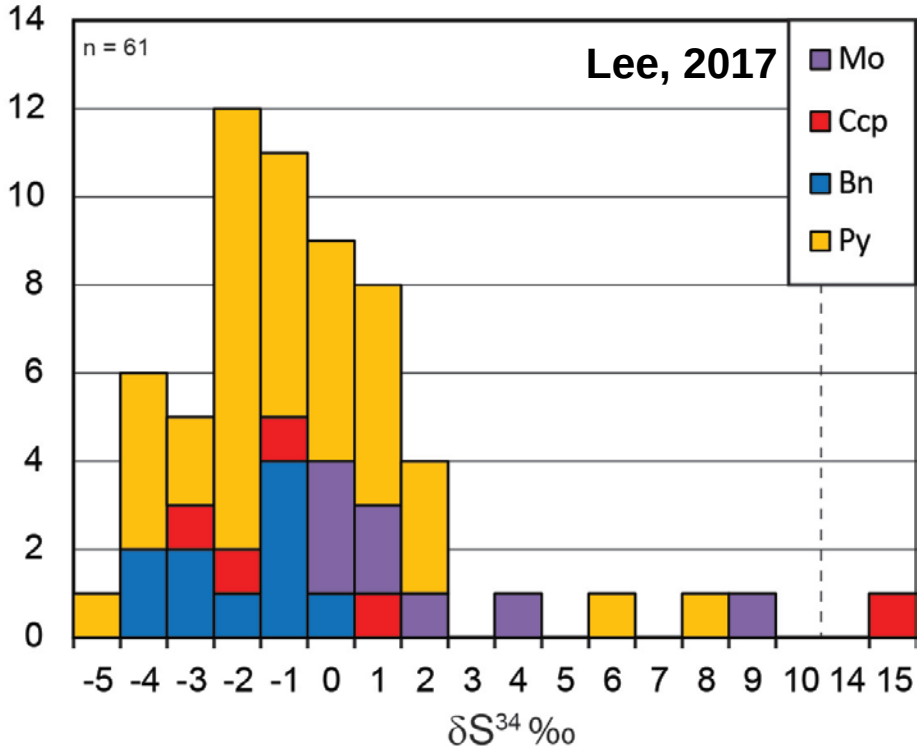


Zircon - Lee et al. 2017 SGA; SEG submitted

Stable Isotopes

NSERC-CMIC FOOTPRINTS





$\delta^{13}C_{total}$ values and $\delta^{13}C_{carbonate}$ values from rock pulps. Also shown are the common C isotope reservoirs.

Magmatic values in core of GCB and HVC deposit fractionated to higher values in distal showings

Alteration Assemblage Map

NSERC-CMIC FOOTPRINTS

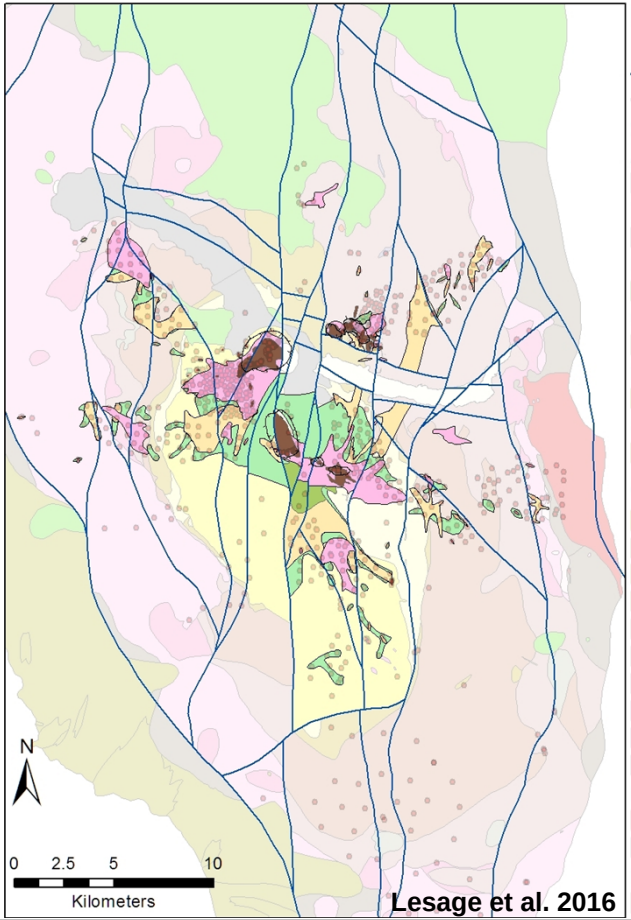
New alteration map defining fluid pathways and footprint vectors

Distribution of mapping and sampling extends ~30km east-west and ~20km north-south

Structural bound

Alteration mineral assemblage

- Fracture-controlled Ms-Qz+-Ccp+-Bn
- Fracture-controlled Kfs+-bt+-Qtz+-Ccp+-Bn
- Pervasive Ab-Chl-Act+-Grt+-Di
- Fracture-controlled Ab-Chl-Ep
- Fracture-controlled WM-Chl-Prh



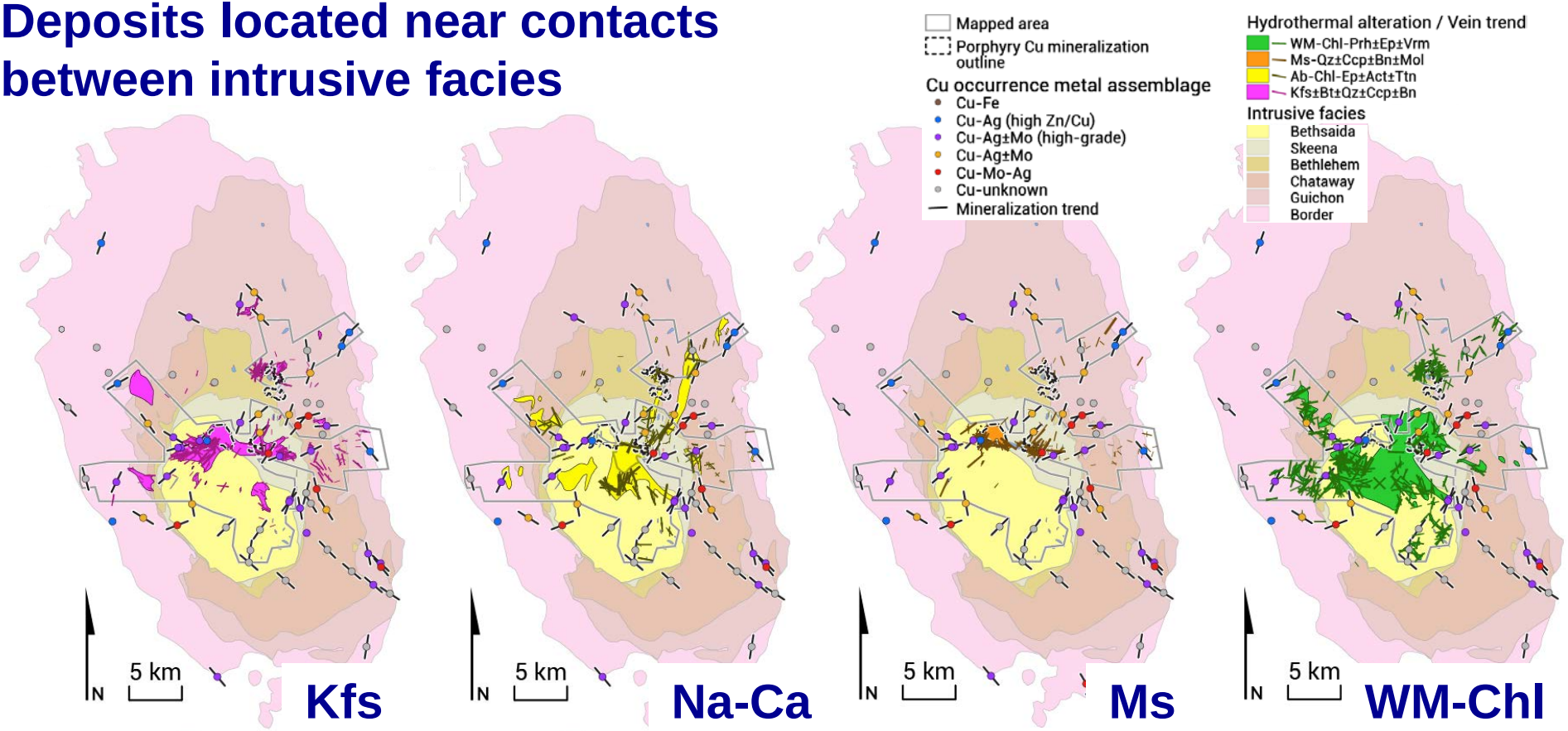
Lesage et al. 2016

NSERC CRSNG

Palinspastic reconstruction

NSERC-CMIC FOOTPRINTS

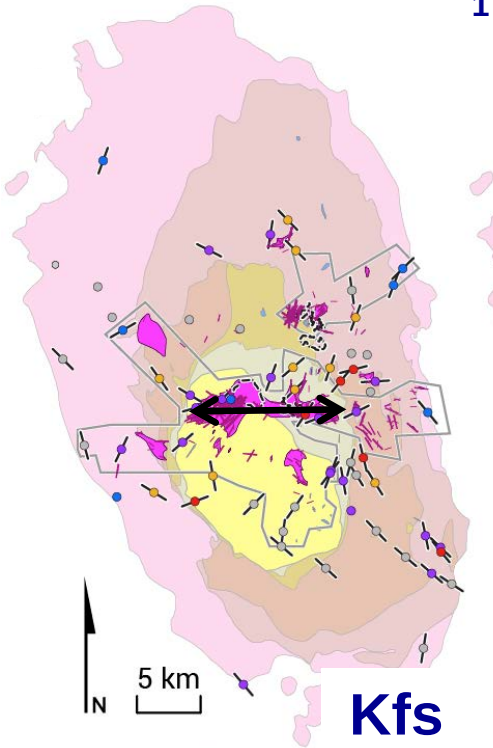
Deposits located near contacts between intrusive facies



Palinspastic Reconstruction

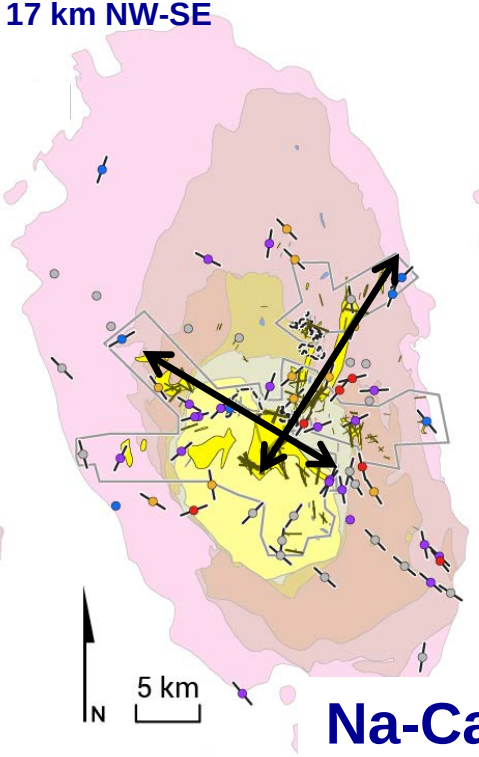
NSERC-CMIC FOOTPRINTS

Kfs zone centered on main HVC deposits
12 km x 2 km



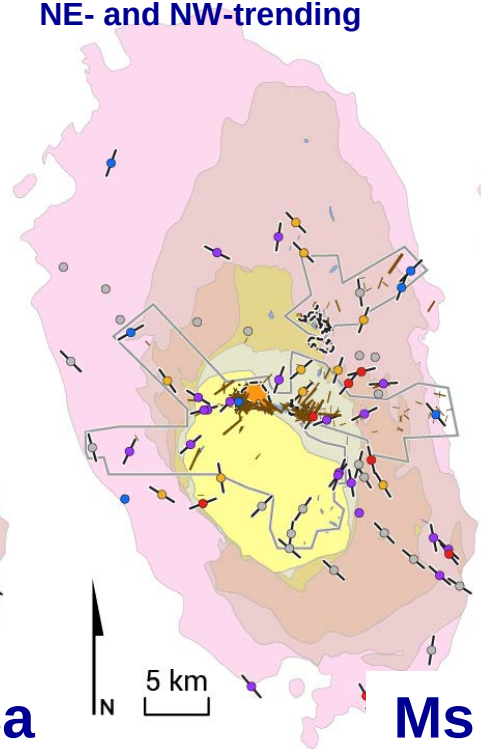
Kfs

Na-Ca - long and narrow structural control
20 km NE-SW x
17 km NW-SE



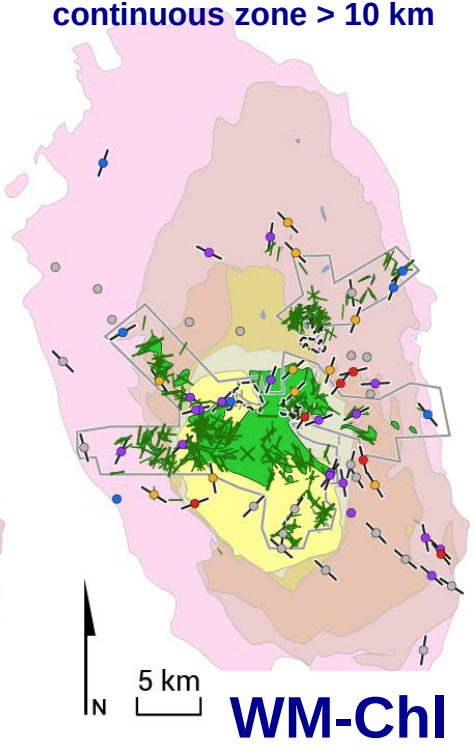
Na-Ca

Coarse Ms vein orientations similar to district showing mineralized trends
NE- and NW-trending



Ms

WM-Chl-Prh high intensity over main HVC deposits
continuous zone > 10 km

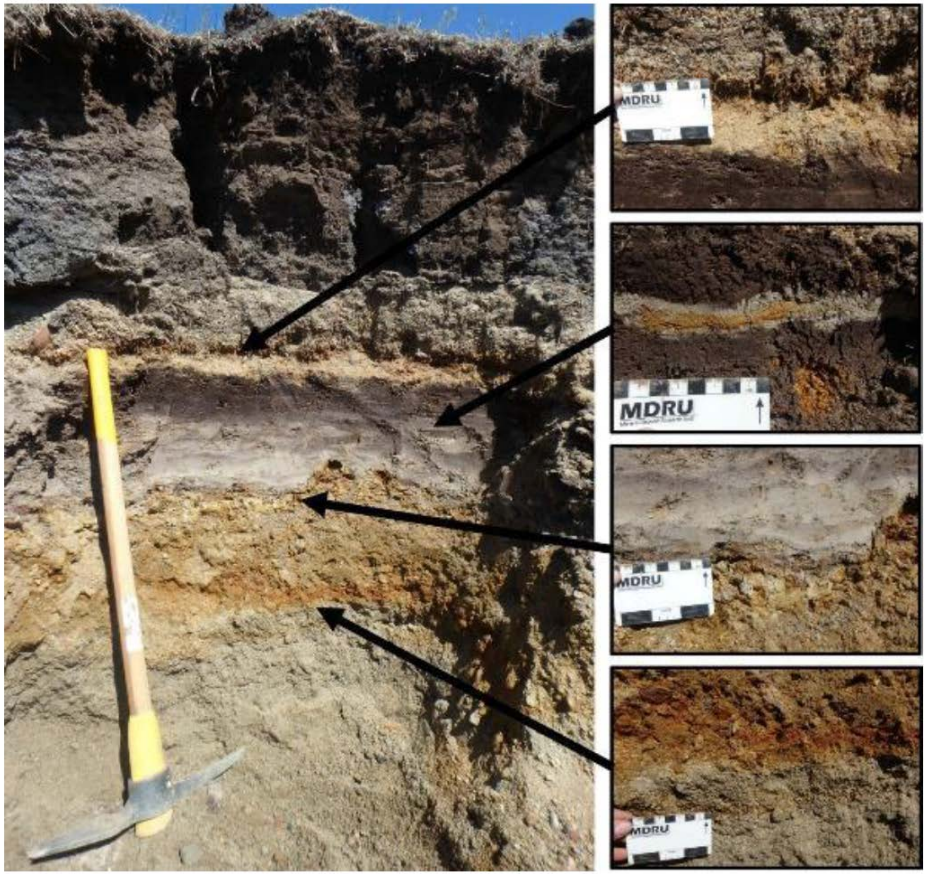


WM-Chl

Surficial Work

NSERC-CMIC FOOTPRINTS

- Soil sampling over J.A. and Highmont South targets
- Core logging and sampling of cover material from J.A. and Valley drill holes
- Evaluation of detrital mineral chemistry from joint BCGS/GSC collaboration



Soil Profile - Example

NSERC-CMIC FOOTPRINTS

Soil Cu

Soil Mo

-180 mesh, aqua regia, ICP-MS

Legend

- Fault
- Mineralization outline
- Till blanket
- Waterlogged till blanket
- Hummocky till
- Waterlogged depositional clay
- Waste rock

Identified population breaks by probability: ~75%;~87%;~93%;~98%

- Background
- Excluded waterlogged sample

Avg. depth to bedrock 5m

Chouinard, 2018

Soil Profile - Example

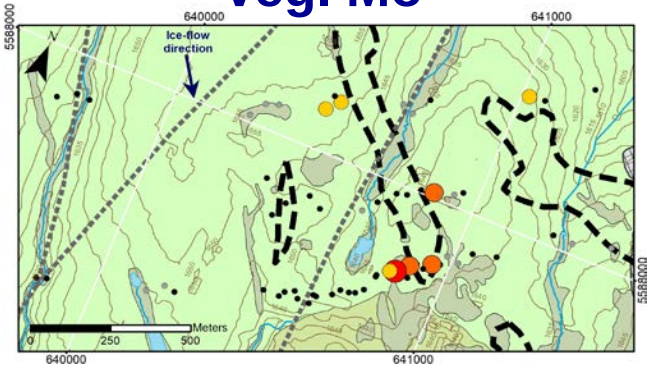
NSERC-CMIC FOOTPRINTS

Soil Cu

Veg. Cu

Soil Mo

Veg. Mo



-180 mesh, aqua regia, ICP-MS

pine needle, aqua regia, ICP-MS

Chouinard, 2018

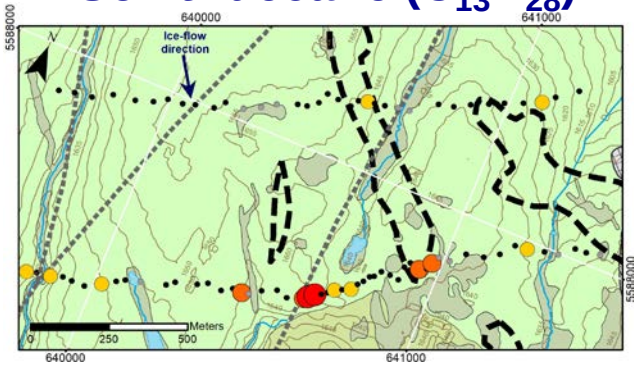
Soil Profile - Example

NSERC-CMIC FOOTPRINTS

Soil Cu

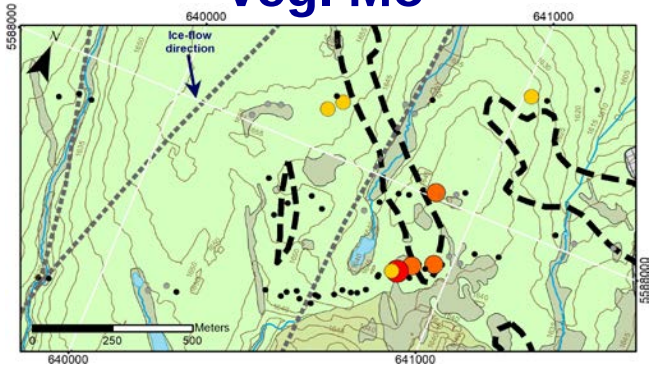
Veg. Cu

Soil tridecane ($C_{13}H_{28}$)

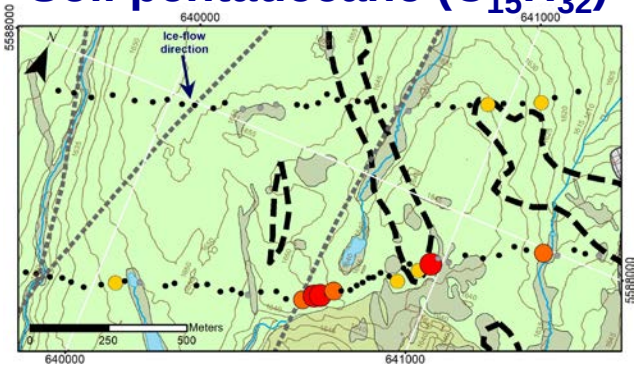


Soil Mo

Veg. Mo



Soil pentadecane ($C_{15}H_{32}$)



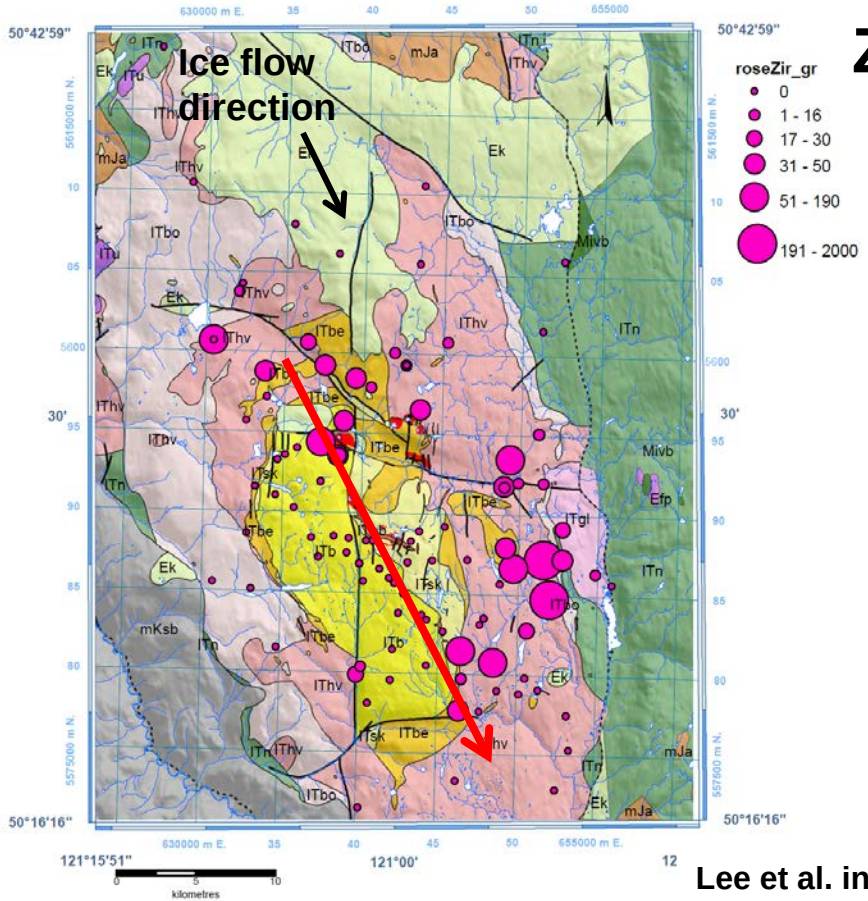
-180 mesh, aqua regia, ICP-MS

pine needle, aqua regia, ICP-MS

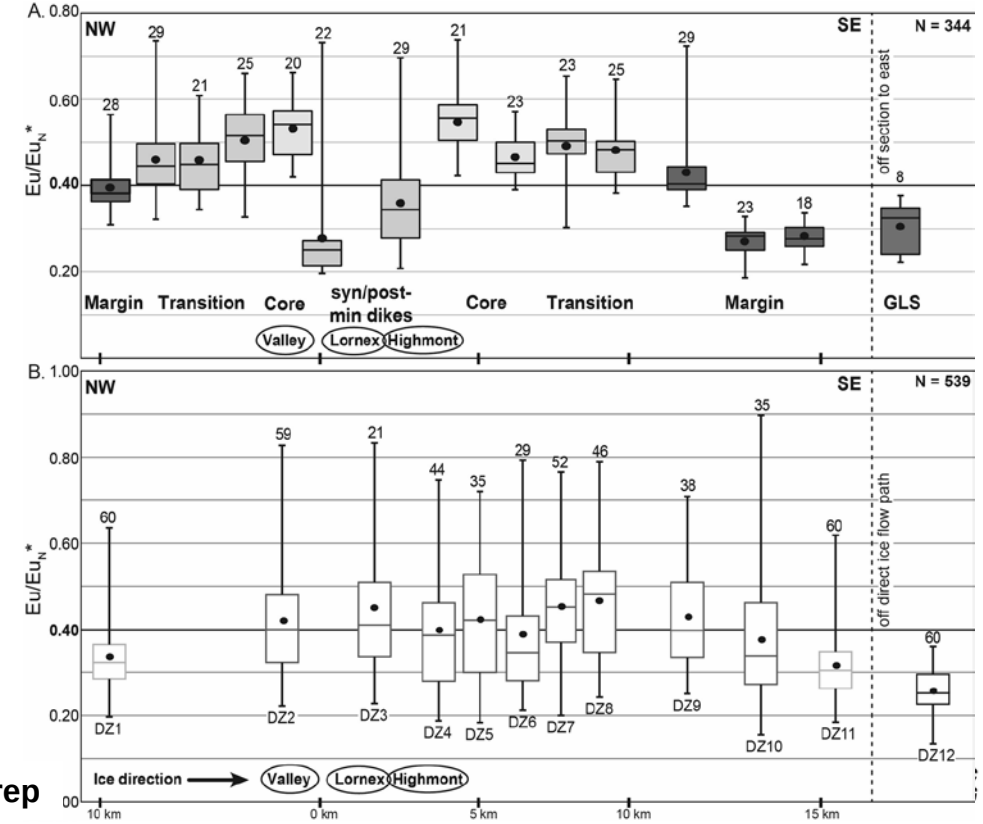
AGI Sampler, TD-GC/MS

Till – Mineral Composition

NSERC-CMIC FOOTPRINTS



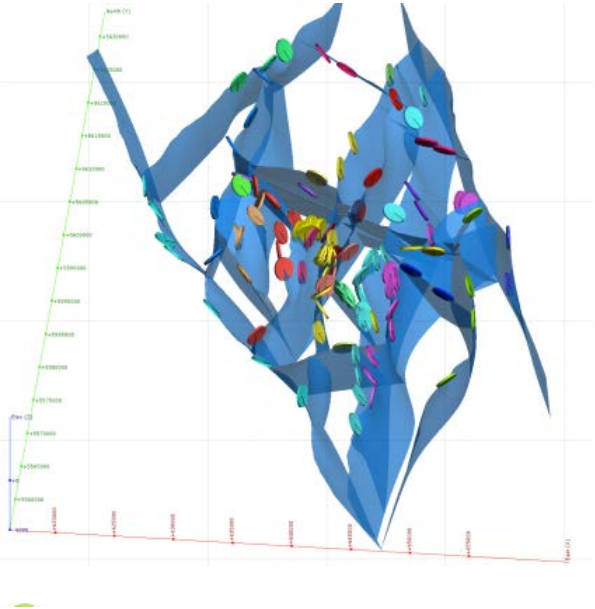
Zircon composition bedrock vs till



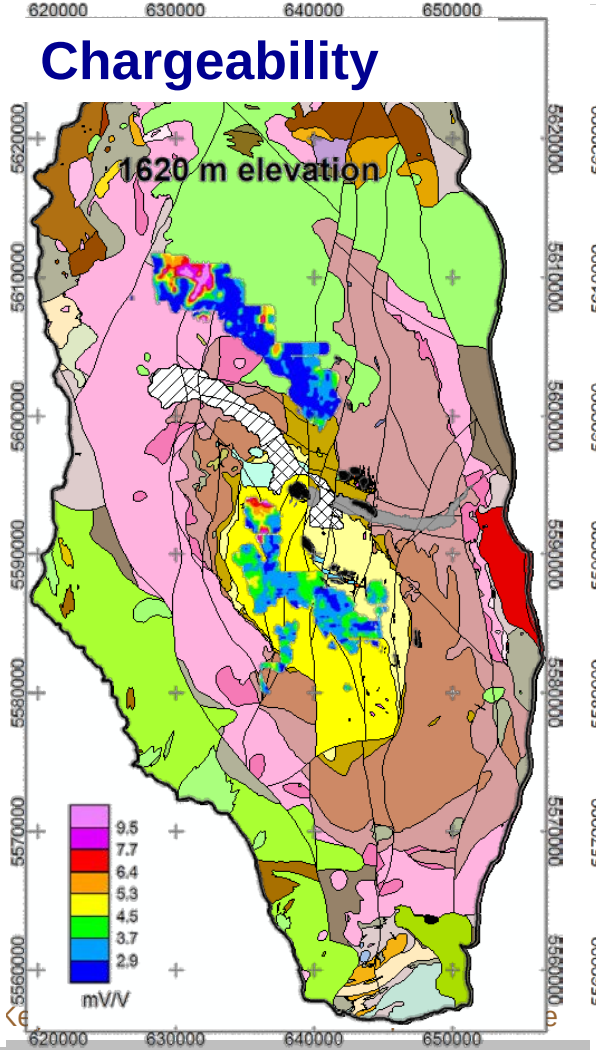
Lee et al. in-prep

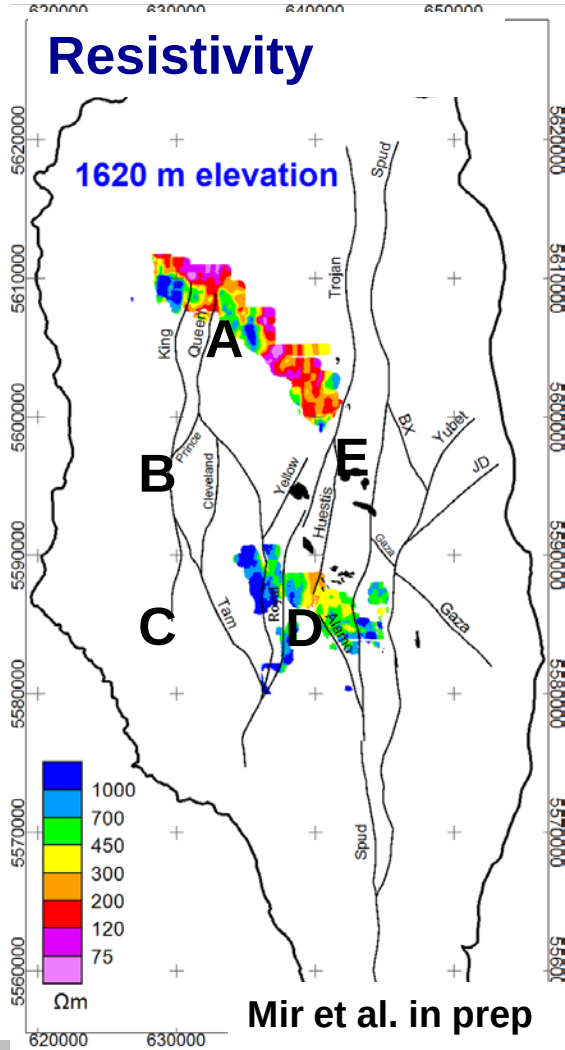
Geophysics

Geophysical compilations of legacy and recent IP, gravity, and magnetic data



Lesage et al. Structural control of GCB





Mir et al. in prep

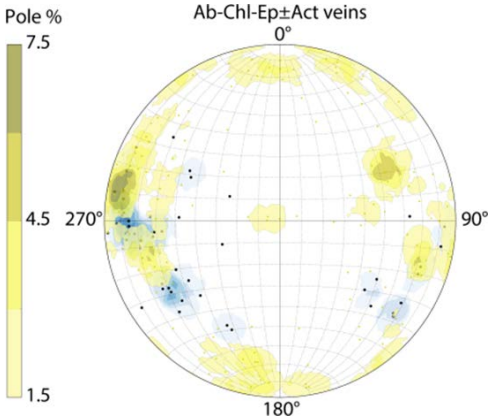
Geophysics Correlating Alteration

Ab-Chl-Ep±Act veins

Magmatic fluid pressure wanes following early Kfs±Bt±Qz±Ccp±Bn veins

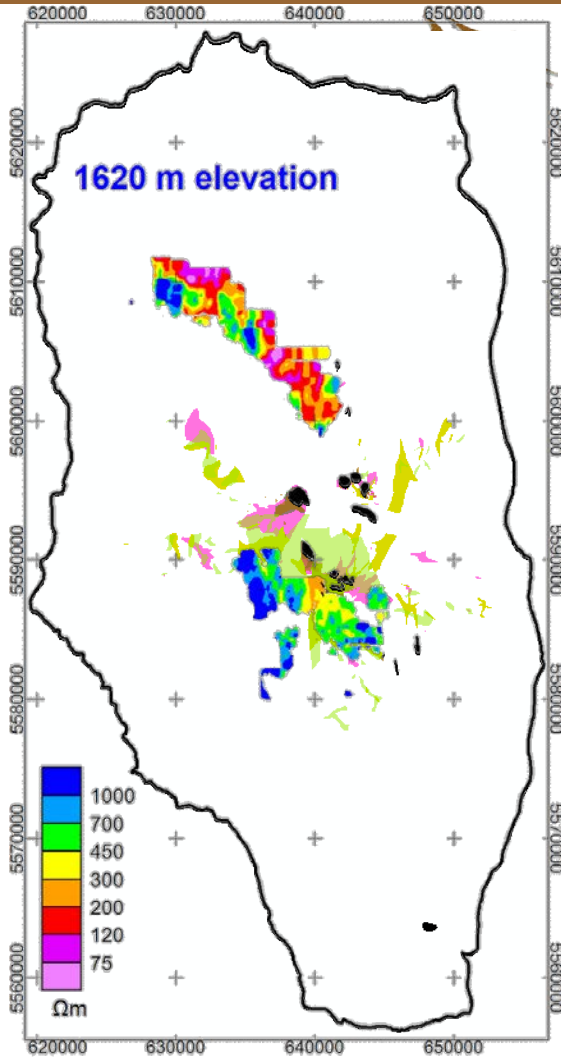
External fluids brought into the system

Lesage et al. in prep



Good match between vein orientations and syn-mineralization faults

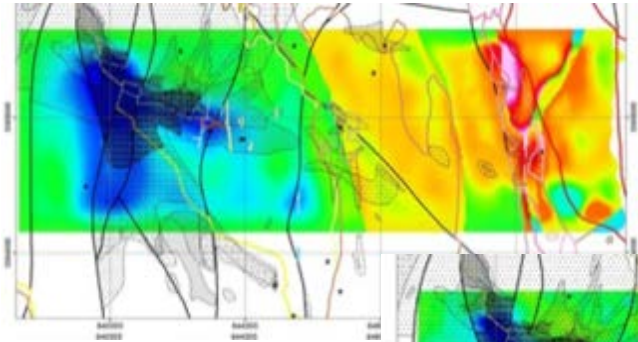
Fracture-controlled Albite-Chlorite-Epidote is associated with consistent decrease in resistivity at depth (< 500 Ωm).



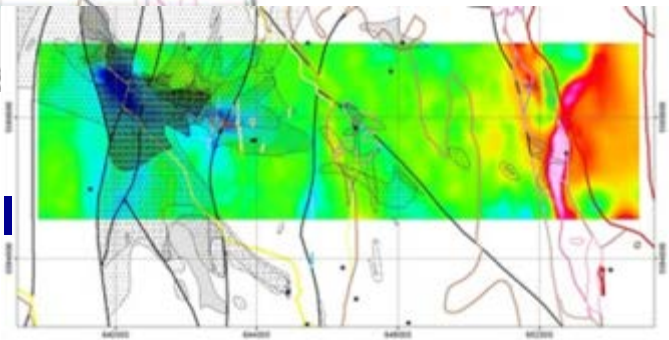
Petrophysical properties

NSERC-CMIC FOOTPRINTS

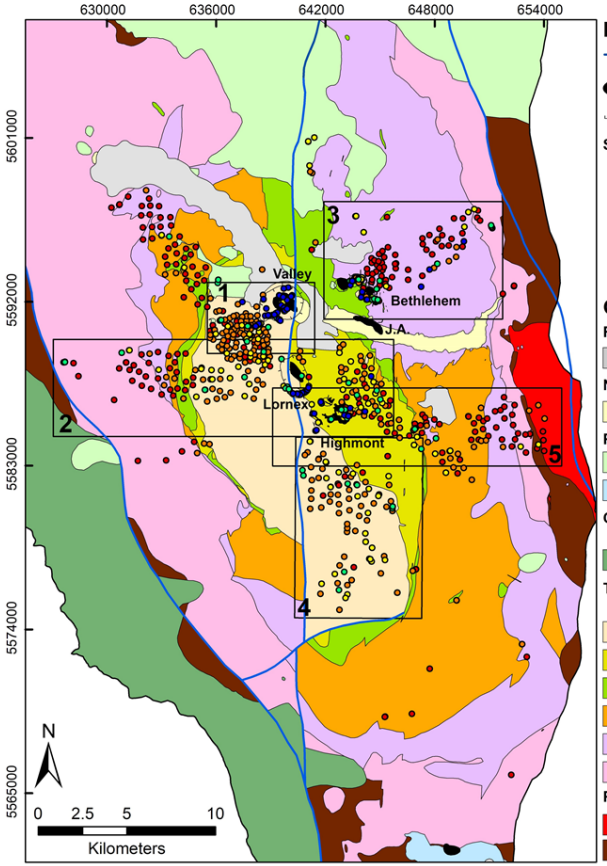
- Magnetic susceptibility
- Tie between geophysics and bedrock
- Sample density and sample type dependent



Block 5 Inversion



Forward Model

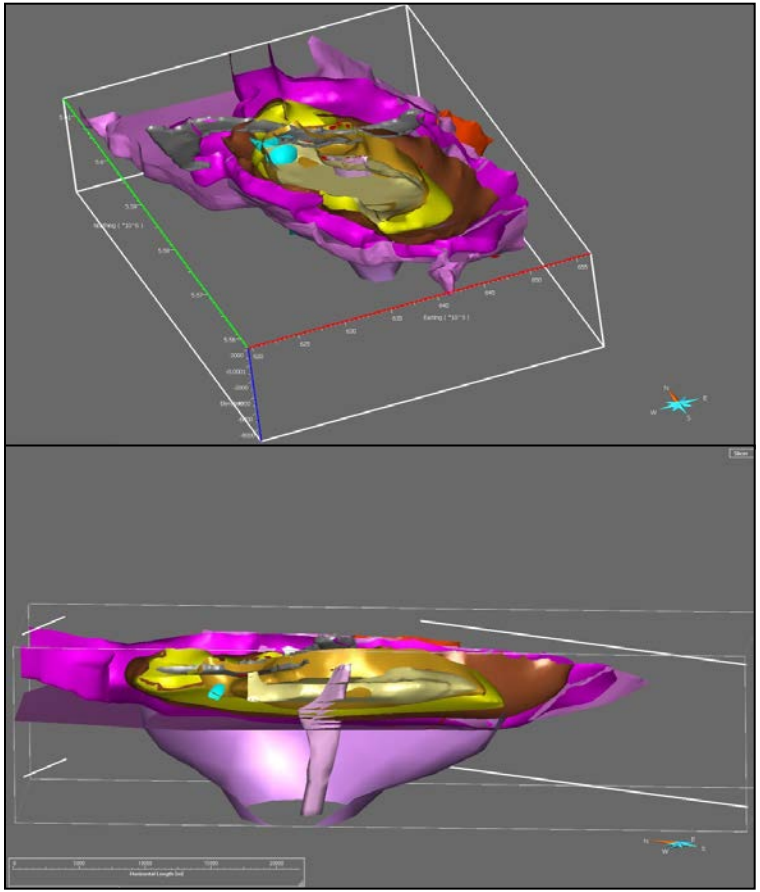


Vallée et al. 2017 SEG Houston '17

3D Common Earth Model

NSERC-CMIC FOOTPRINTS

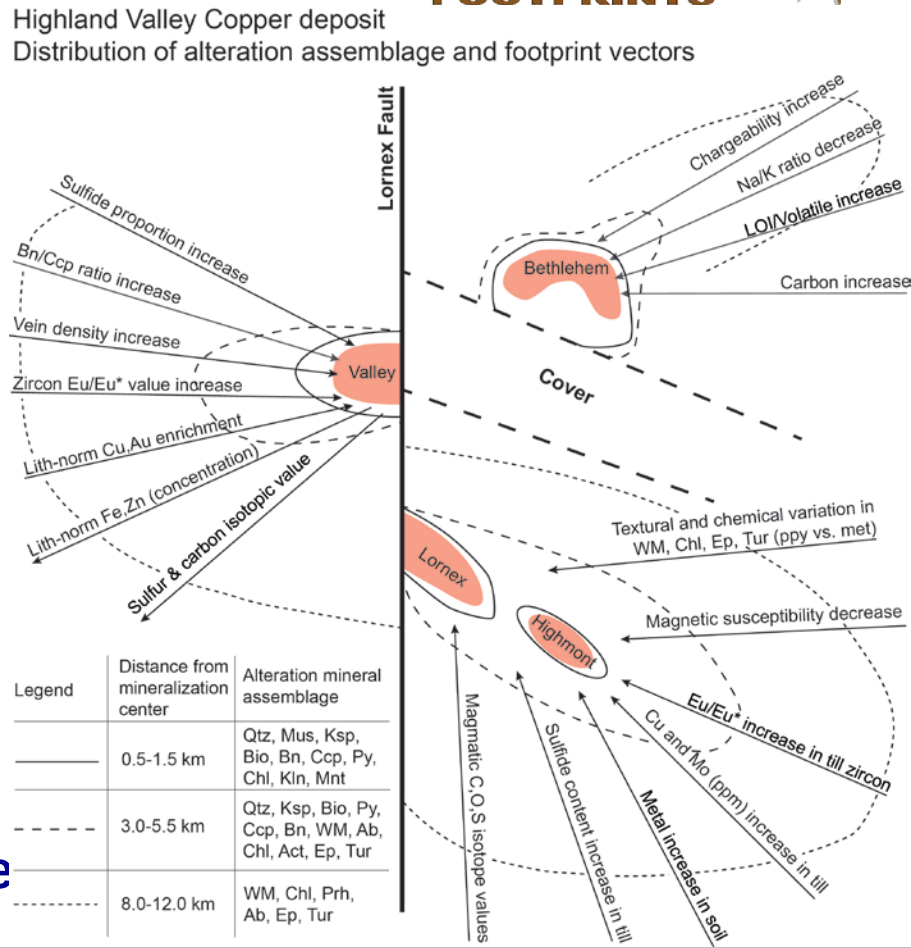
- GOCAD® and INTEGRATOR® models
- Constrained surfaces and structures
- All mapped orientations, sections, stations
- Database with chemistry, petrophysical properties, spectral
- Block model - interpretations



Summary

- **Alteration assemblage**
  - high temperature: Ksp, Qtz, Bio, Mus in core;
  - low temp sodic/propylitic distal: Alb, Ep, Chl, WM, Prh, Tur
- **Normalized lithochemical concentration increase from margin to core Cu, Ag, Mo**
- **Isotopic change S, C, O**
- **Mineral chemistry change in Chlorite, Zircon, White Mica, Epidote**

NSERC-CMIC FOOTPRINTS



Summary

- Mineral first approach to mapping – Assemblages define distal vs proximal (regional) alteration; K vs Na-Ca vs Prop
- Distal alteration mineral assemblage extend up to 12 km
- Spectral imaging and feldspar staining can identify subtle features not observable in the field
- Shallow surface response evident (soil/till)
- Models constrained by integrating petrophysical properties with geophysical surveys
- Old IP/gravity/magnetic surveys still valuable

Sponsors/Collaborators

Collaborators: GSC TGI4 Program
MRNQ
Saskatchewan Geol Survey
BC Geological Survey

Supporters: Fullagar Geophysics
UBC Geophysical Inversion Facility