Identifying new vectors to hidden porphyry-style mineralisation

N. Rogers[1], A. Plouffe[1], J.B. Chapman[2], M.B. McClenaghan[1], D.A. Kellett[1] and R.A. Anderson[2]

1 Geological Survey of Canada, 601 Booth St. Ottawa, Ontario

2. Geological Survey of Canada, 605 Robson St., Vancouver, British Columbia

Abstract: Intrusion related (e.g., porphyry) deposits are the most important sources for Cu, Mo, W and Sn, along with Au, Ag, and PGEs. Porphyry deposits are large, low- to medium-grade deposits in which mineralisation is hosted within and immediately surrounding distinctive intrusive phases within larger intrusive complexes that commonly have prolonged emplacement histories. To develop more effective exploration criteria to identify and evaluate deeply buried and/or hidden fertile intrusive mineralizing systems, studies into Cu-Mo/Au and W-Mo-Sn systems are aimed at answering the following questions: i) Are there distinctive proximal and distal footprints for each deposit type that will allow identification of, and vectoring towards hidden economic deposits?; ii) Is there evidence of fertility within the root system of intrusions, i.e. what are the triggering conditions and indicators of an hydrothermal-magmatic system of size and duration sufficient to develop a large porphyry deposit? To help answer these questions studies are being undertaken at sites associated with the Triassic-Jurassic porphyry deposits of the British Columbia interior and for the array of mineralised Canadian Appalachian Siluro-Devonian intrusions, for which the fundamental geoscience knowledge is often lacking.

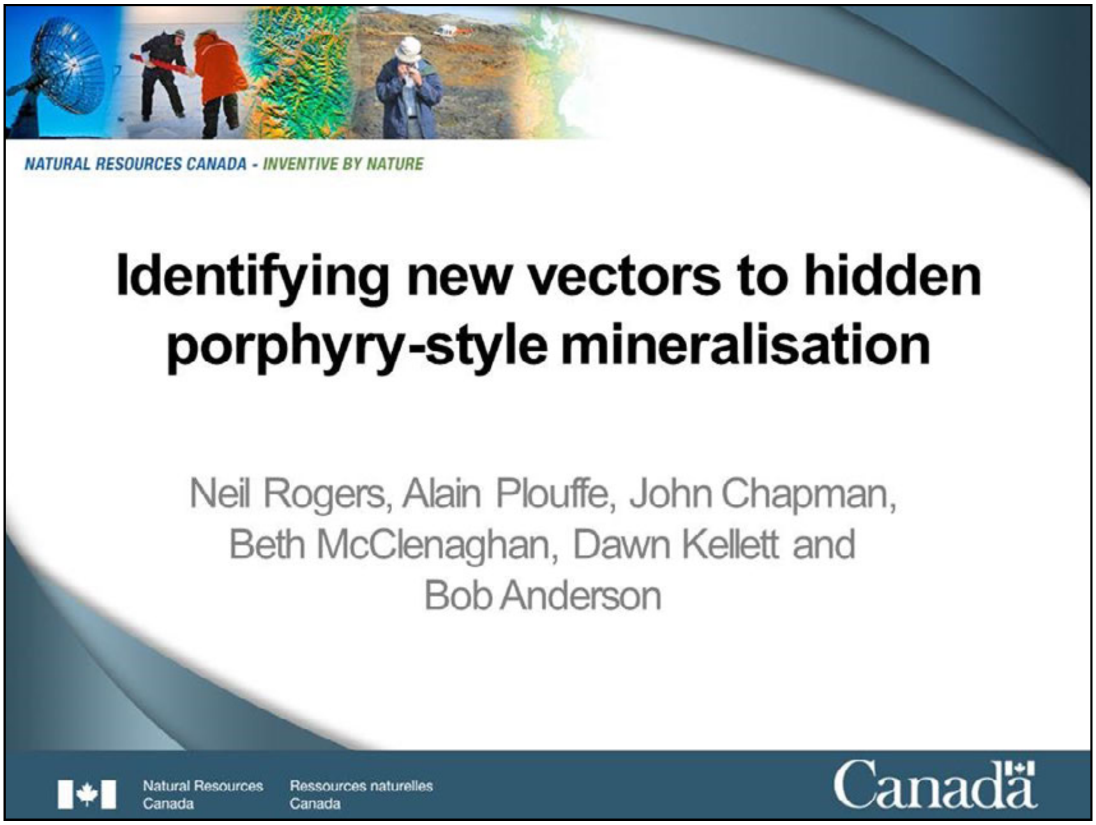
A common problem facing Cordilleran and Appalachian exploration is how to detect intrusion-related mineralization through the extensive glacial sediment cover. Consequently, research activities are focussing at identifying key geochemical and mineral indicators in till near known mineralization and their detrital dispersal down-ice. Indicators are being developed for the detection of mineralization, but also the alteration halos and vein systems associated with mineralization, which represent much larger exploration targets than the actual economic orebody itself. Once identified in till, these indicators can be traced to their bedrock source using reconstructed ice movement vectors.

Structural relationships indicate that Sn-W-Mo mineralised intrusive systems can form due to extension associated with far removed non-orthogonal accretion. Deposits within these bodies form along fluid pathways such as the intersection of high-angle syntectonic breaks. Mineral potential can also be resolved through trace element fingerprinting. Subtle compositional changes in commonly occurring minerals (i.e., biotite) and fluid inclusions provide evidence of chemical variations related to magma fertility and vectors to mineralisation.

Originally presented Fredericton 2014: Geological Association of Canada - Mineralogical Association of Canada Joint Annual Meeting, Special Session 3: Discovering the Next Generation of Porphyry Deposits: Advancements in Locating and Understanding Hidden Intrusion-related Mineralization. May 21, 2014.

Corresponding author: Neil Rogers (nrogers@nrcan.gc.ca)

Rogers, N., Plouffe, A., McClenaghan, M.B., Kellett, D.A., Anderson, R.A., 2015. Identifying new vectors to hidden porphyry-style mineralisation; *in* TGI 4 – Intrusion Related Mineralisation Project: New Vectors to Buried Porphyry-Style Mineralisation, (ed.) N. Rogers; Geological Survey of Canada, Open File 7843, p. 249-291.


NATURAL RESOURCES CANADA - INVENTIVE BY NATURE
Identifying new vectors to hidden porphyry-style mineralisation
Neil Rogers, Alain Plouffe, John Chapman, Beth McClenaghan, Dawn Kellett and Bob Anderson
Natural Resources Canada
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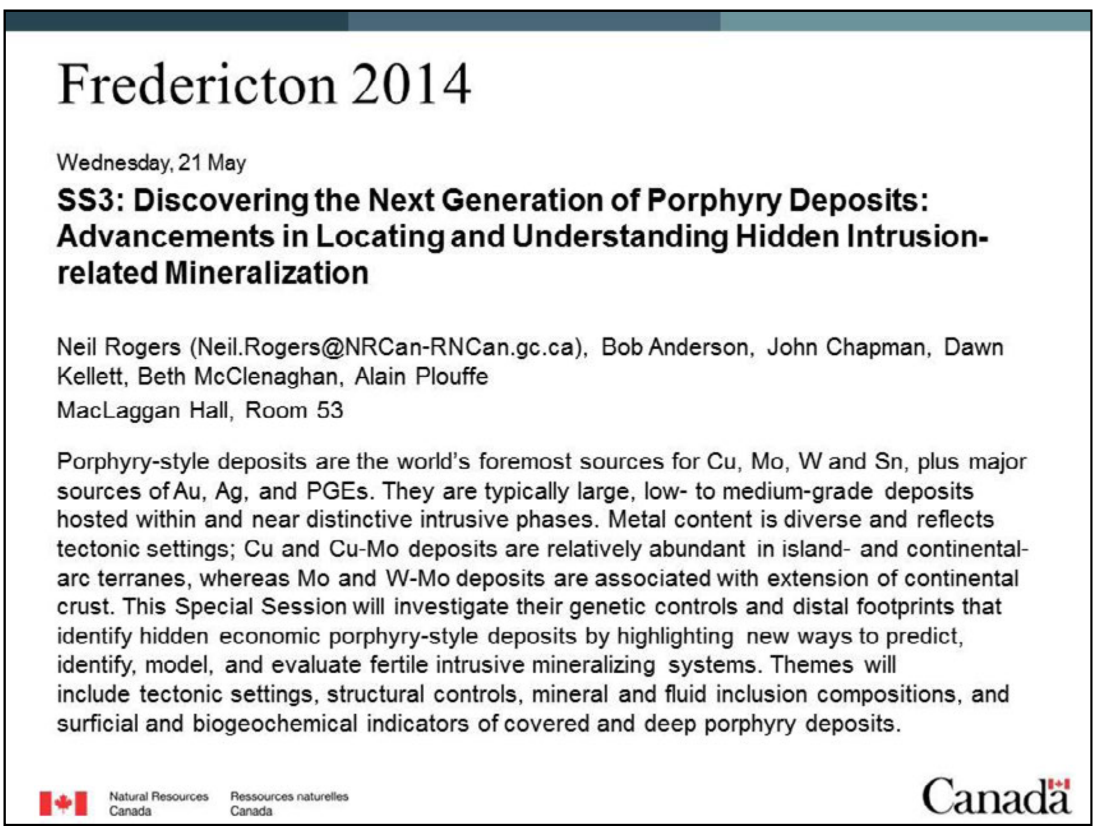
Canadä


Fredericton 2014
Wednesday, 21 May
SS3: Discovering the Next Generation of Porphyry Deposits: Advancements in Locating and Understanding Hidden Intrusion-related Mineralization
Neil Rogers (Neil.Rogers@NRCan-RNCan.gc.ca), Bob Anderson, John Chapman, Dawn Kellett, Beth McClenaghan, Alain Plouffe
MacLaggan Hall, Room 53
Porphyry-style deposits are the world's foremost sources for Cu, Mo, W and Sn, plus major sources of Au, Ag, and PGEs. They are typically large, low- to medium-grade deposits hosted within and near distinctive intrusive phases. Metal content is diverse and reflects tectonic settings; Cu and Cu-Mo deposits are relatively abundant in island- and continental-arc terranes, whereas Mo and W-Mo deposits are associated with extension of continental crust. This Special Session will investigate their genetic controls and distal footprints that identify hidden economic porphyry-style deposits by highlighting new ways to predict, identify, model, and evaluate fertile intrusive mineralizing systems. Themes will include tectonic settings, structural controls, mineral and fluid inclusion compositions, and surficial and biogeochemical indicators of covered and deep porphyry deposits.
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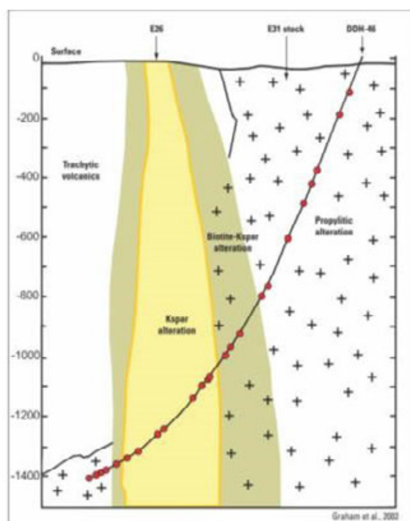
TGI 4 Objectives

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

TGI 4 Objectives

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

1) Develop more robust measures of whether a geological system may contain deeply buried ore (**system fertility**), as well as indicators that provide the direction to that ore (**exploration vectors**), in order to reduce exploration risk



TGI 4 Objectives

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

2) Develop <u>new geoscience knowledge</u> and **<u>innovative techniques</u>** to model and detect Canada's major mineral systems.

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Canada

TGI 4 Objectives

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

3) <u>Train and mentor students</u> to increase the number of HQP available to the mineral industry.

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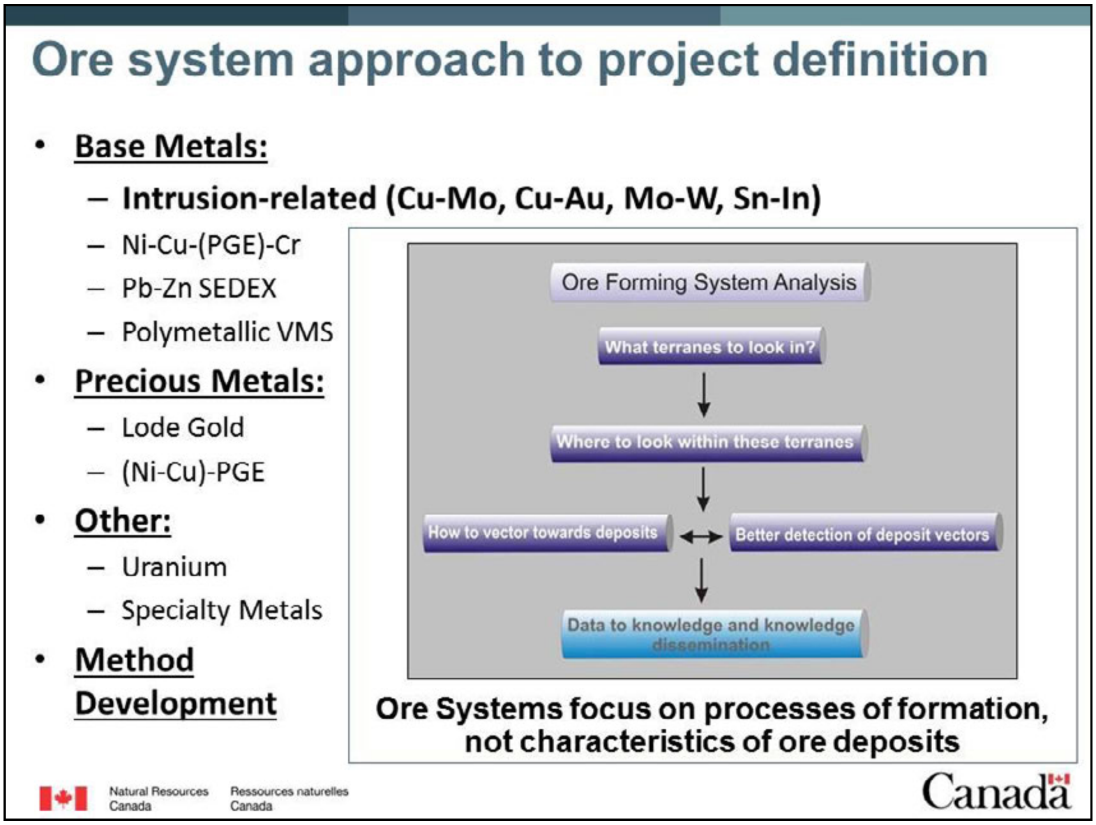
Ore system approach to project definition
• Base Metals:
– Intrusion-related (Cu-Mo, Cu-Au, Mo-W, Sn-In)
– Ni-Cu-(PGE)-Cr
– Pb-Zn SEDEX
– Polymetallic VMS
• Precious Metals:
– Lode Gold
– (Ni-Cu)-PGE
• Other:
– Uranium
– Specialty Metals
• Method Development
Ore Forming System Analysis
What terranes to look in?
Where to look within these terranes
How to vector towards deposits
Better detection of deposit vectors
Data to knowledge and knowledge dissemination
Ore Systems focus on processes of formation, not characteristics of ore deposits
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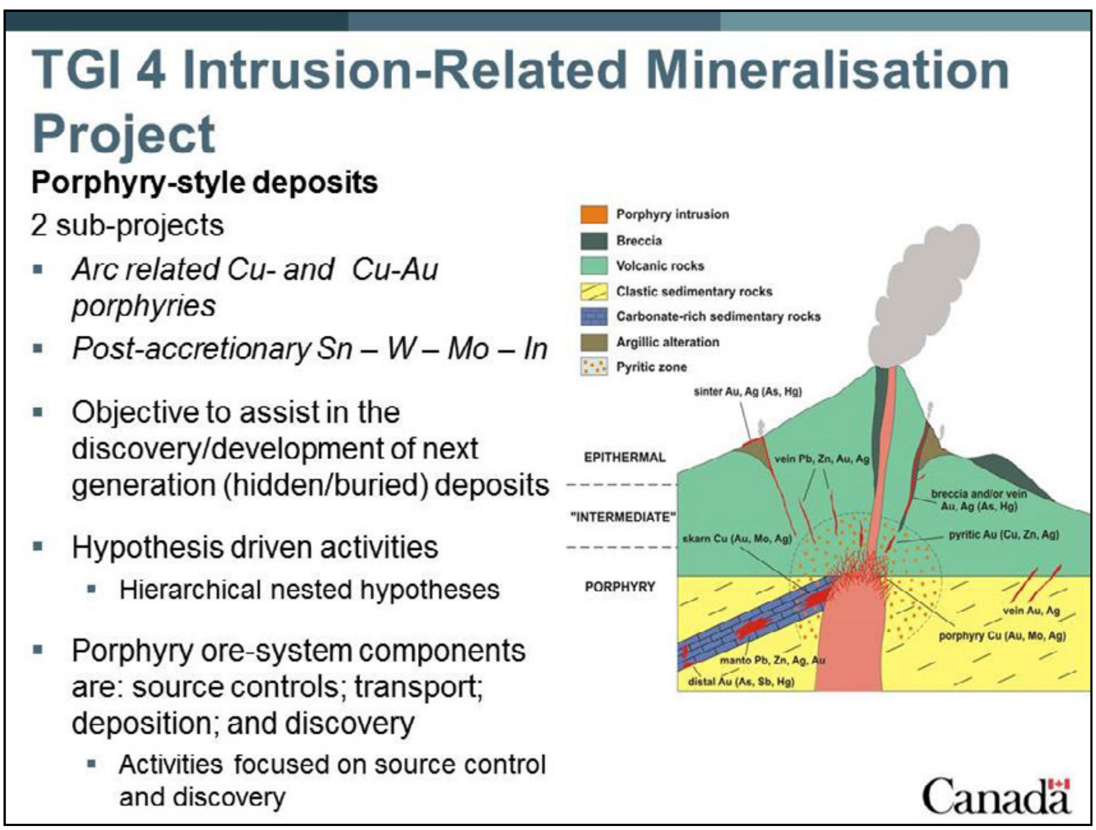
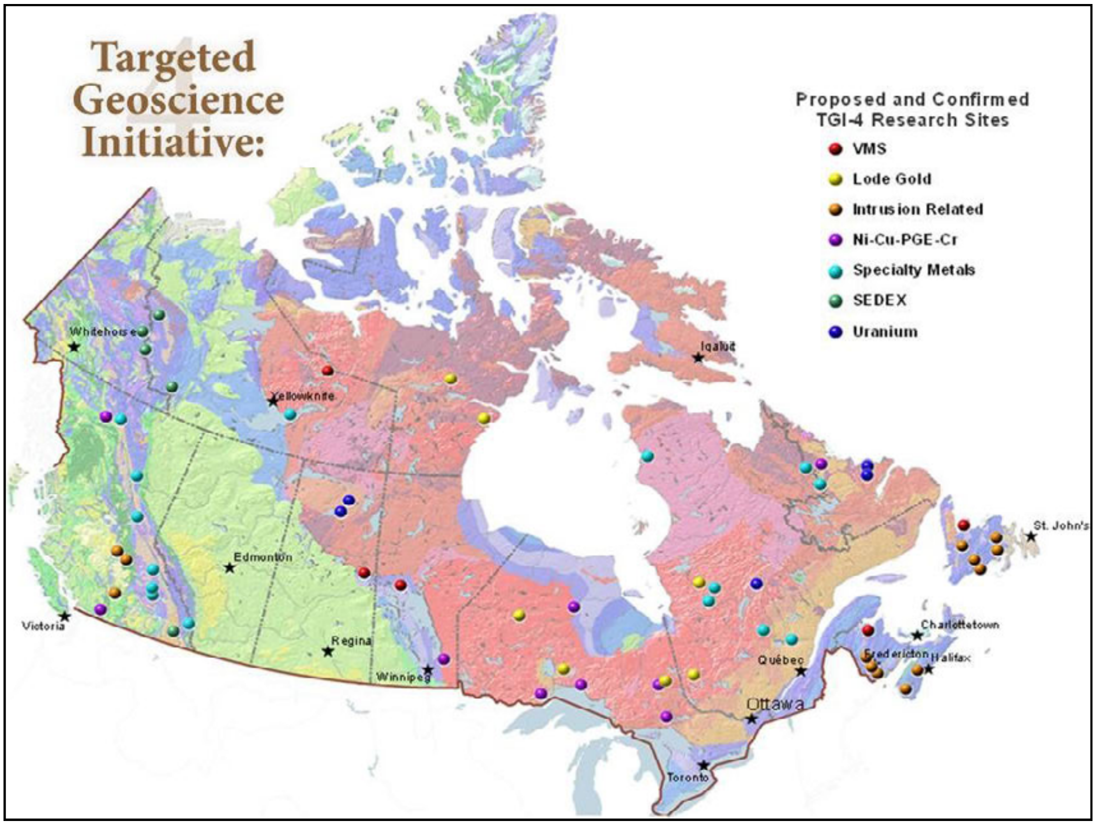
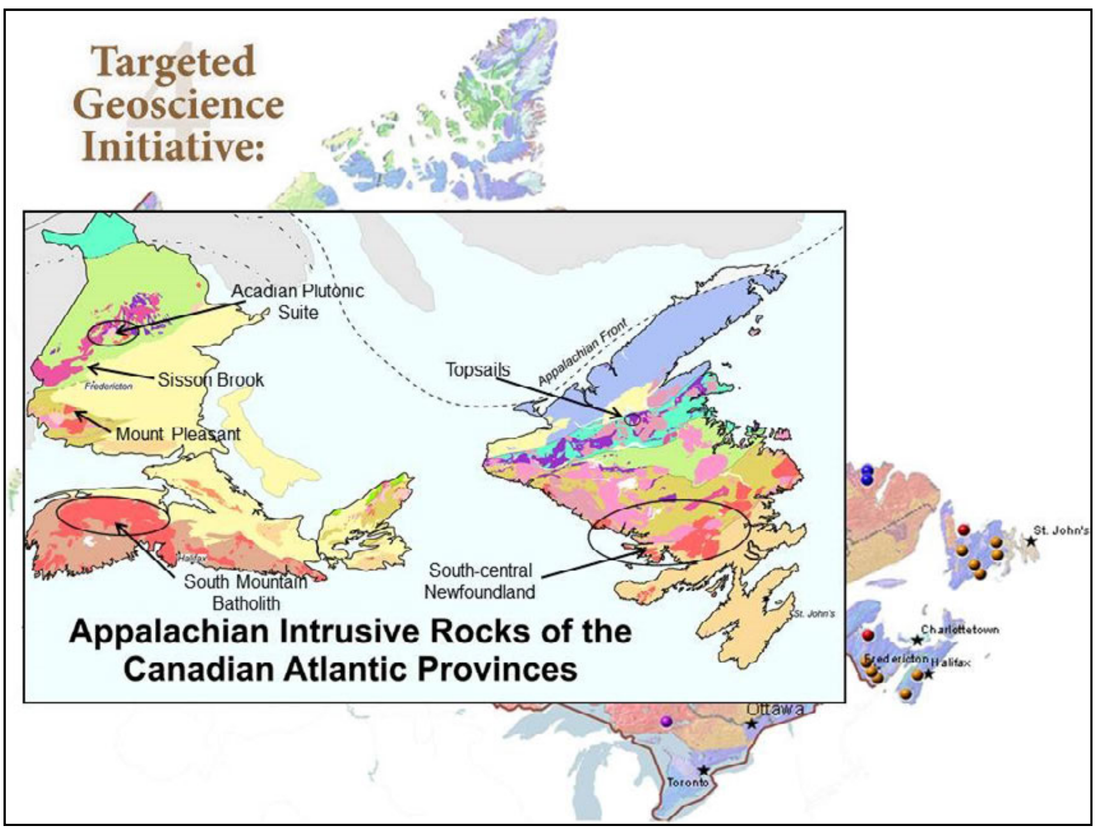
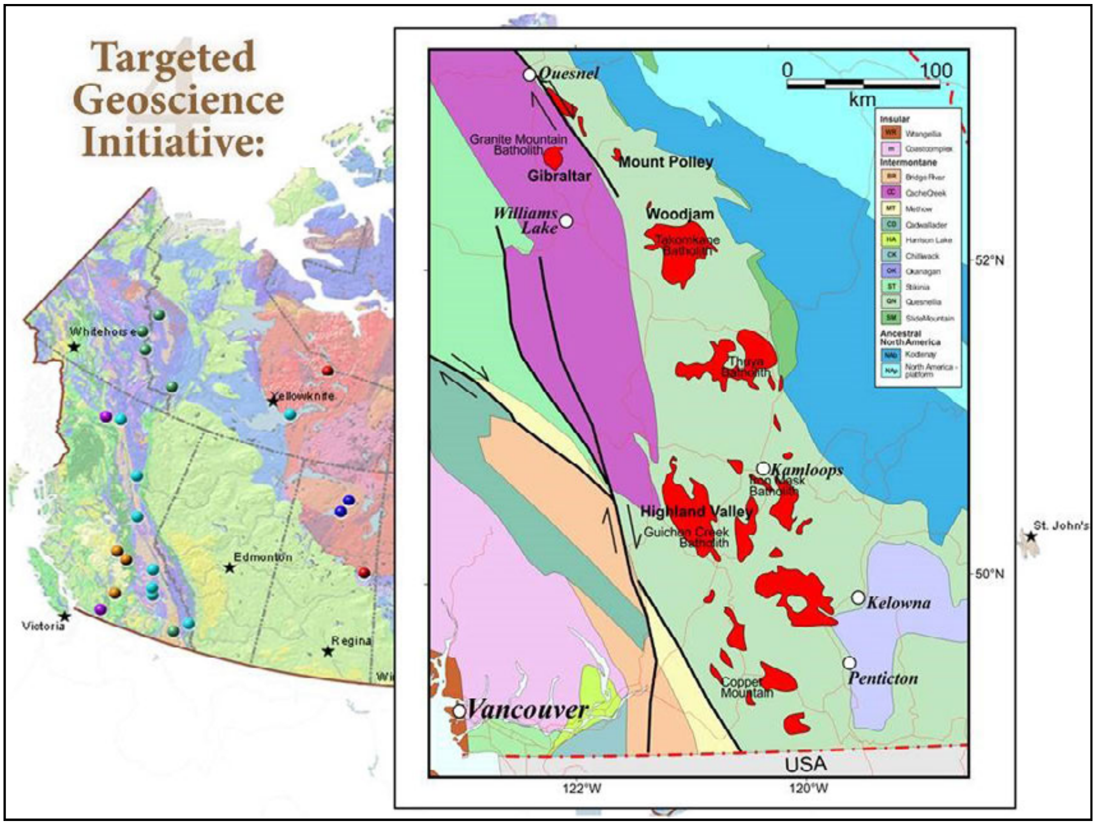
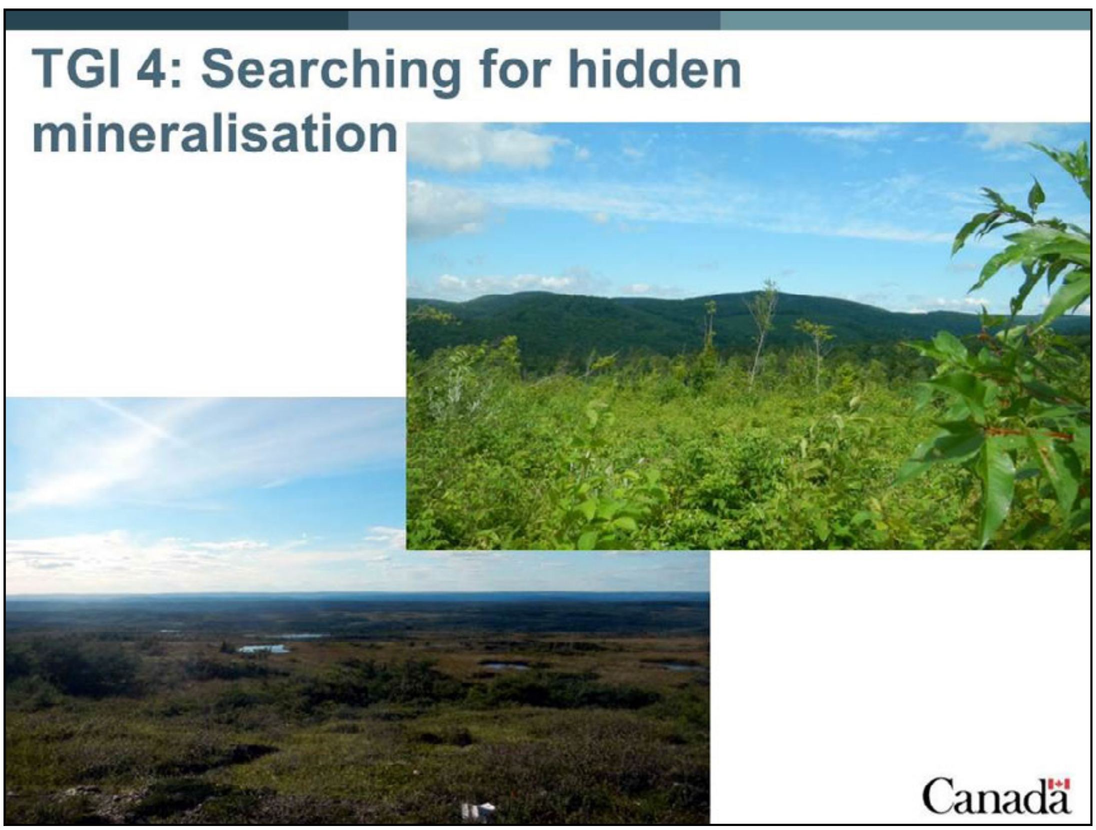
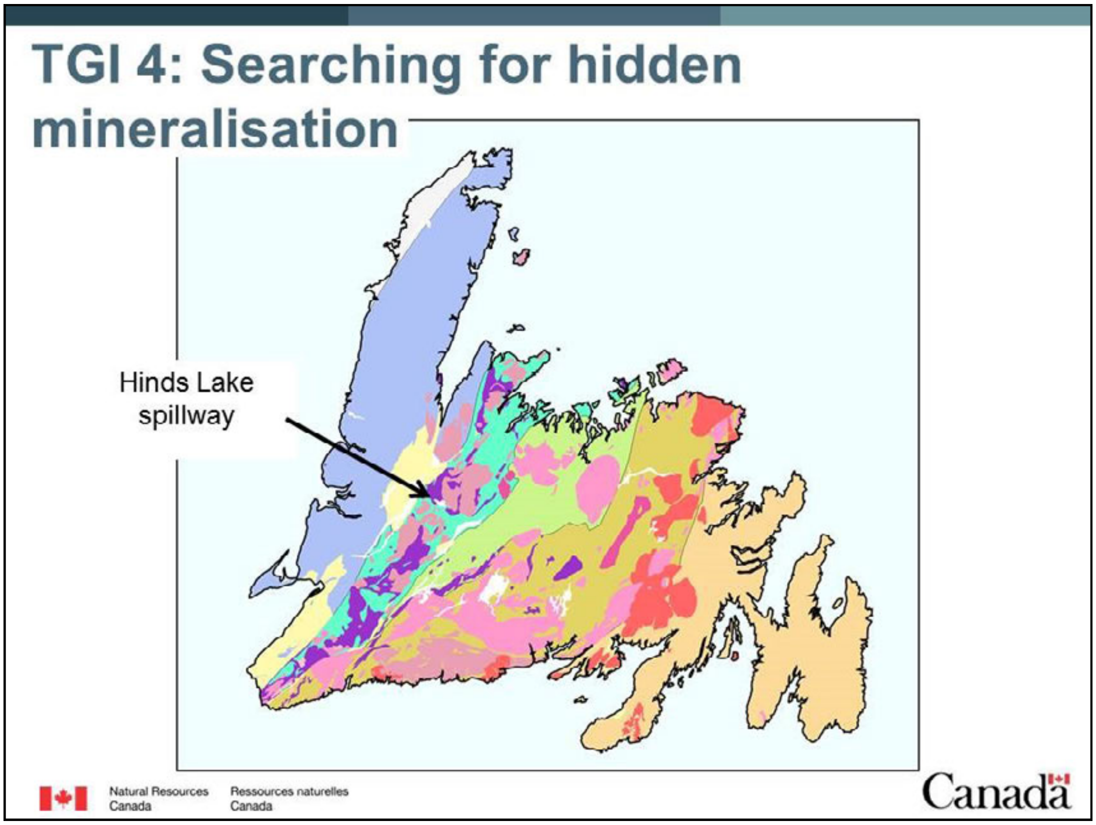

TGI 4 Intrusion-Related Mineralisation Project
Porphyry-style deposits
2 sub-projects
▪ Arc related Cu- and Cu-Au porphyries
▪ Post-accretionary Sn – W – Mo – In
▪ Objective to assist in the discovery/development of next generation (hidden/buried) deposits
▪ Hypothesis driven activities
▪ Hierarchical nested hypotheses
▪ Porphyry ore-system components are: source controls; transport; deposition; and discovery
▪ Activities focused on source control and discovery
Porphyry intrusion
Breccia
Volcanic rocks
Clastic sedimentary rocks
Carbonate-rich sedimentary rocks
Argillic alteration
Pyritic zone
sinter Au, Ag (As, Hg)
EPITHERMAL
vein Pb, Zn, Au, Ag
breccia and/or vein Au, Ag (As, Hg)
"INTERMEDIATE"
skarn Cu (Au, Mo, Ag)
pyritic Au (Cu, Zn, Ag)
PORPHYRY
vein Au, Ag
porphyry Cu (Au, Mo, Ag)
manto Pb, Zn, Ag, Au
distal Au (As, Sb, Hg)
Canada

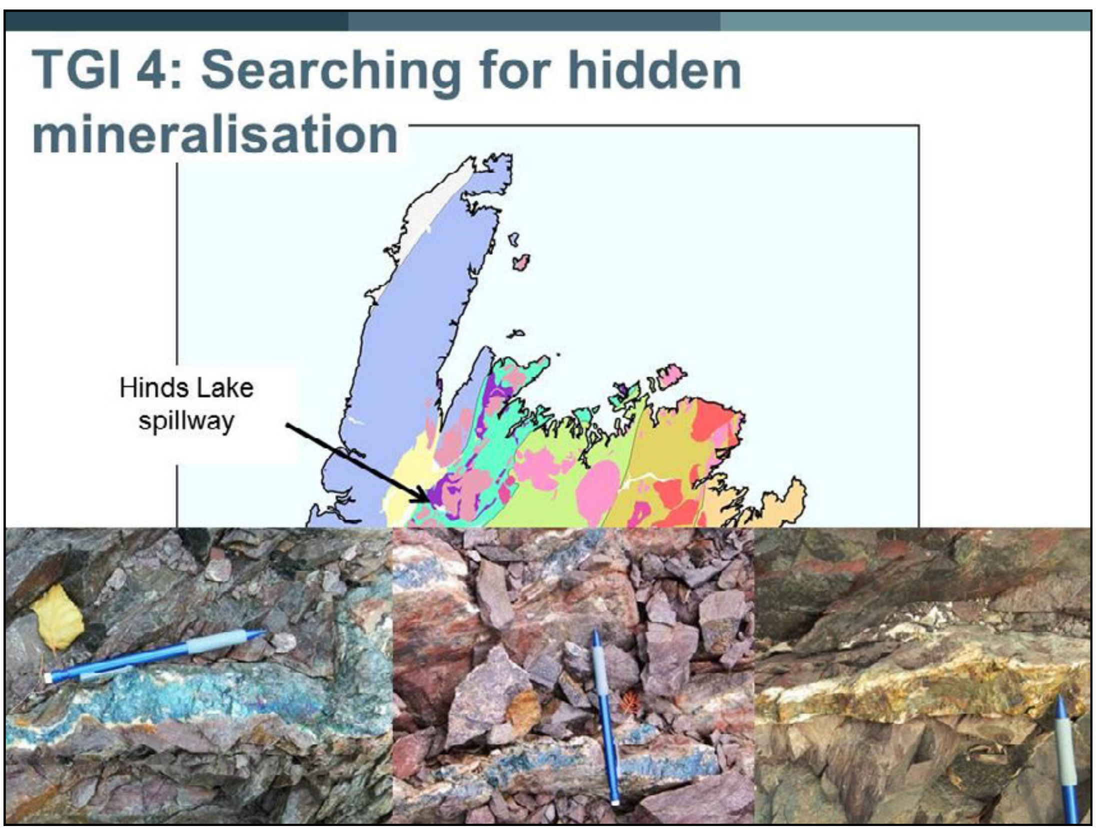

Targeted Geoscience Initiative:
Proposed and Confirmed TGI-4 Research Sites
VMS
Lode Gold
Intrusion Related
Ni-Cu-PGE-Cr
Specialty Metals
SEDEX
Uranium
Whitehorse
Yellowknife
Iqaluit
Edmonton
Victoria
Regina
Winnipeg
Québec
Ottawa
Toronto
St. John's
Charlottetown
Fredericton
Halifax

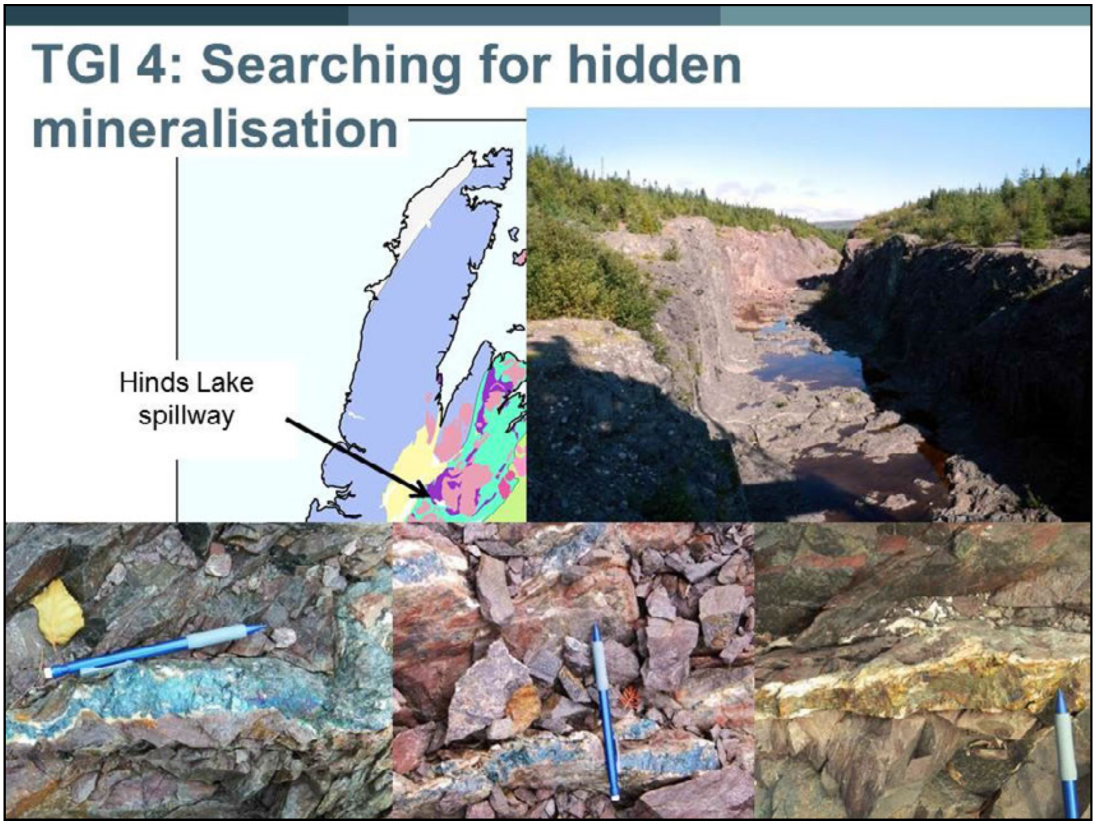

Targeted Geoscience Initiative:
Acadian Plutonic Suite
Sisson Brook
Fredericton
Mount Pleasant
South Mountain Batholith
Halifax
Topsails
Appalachian Front
South-central Newfoundland
St. John's
Appalachian Intrusive Rocks of the Canadian Atlantic Provinces

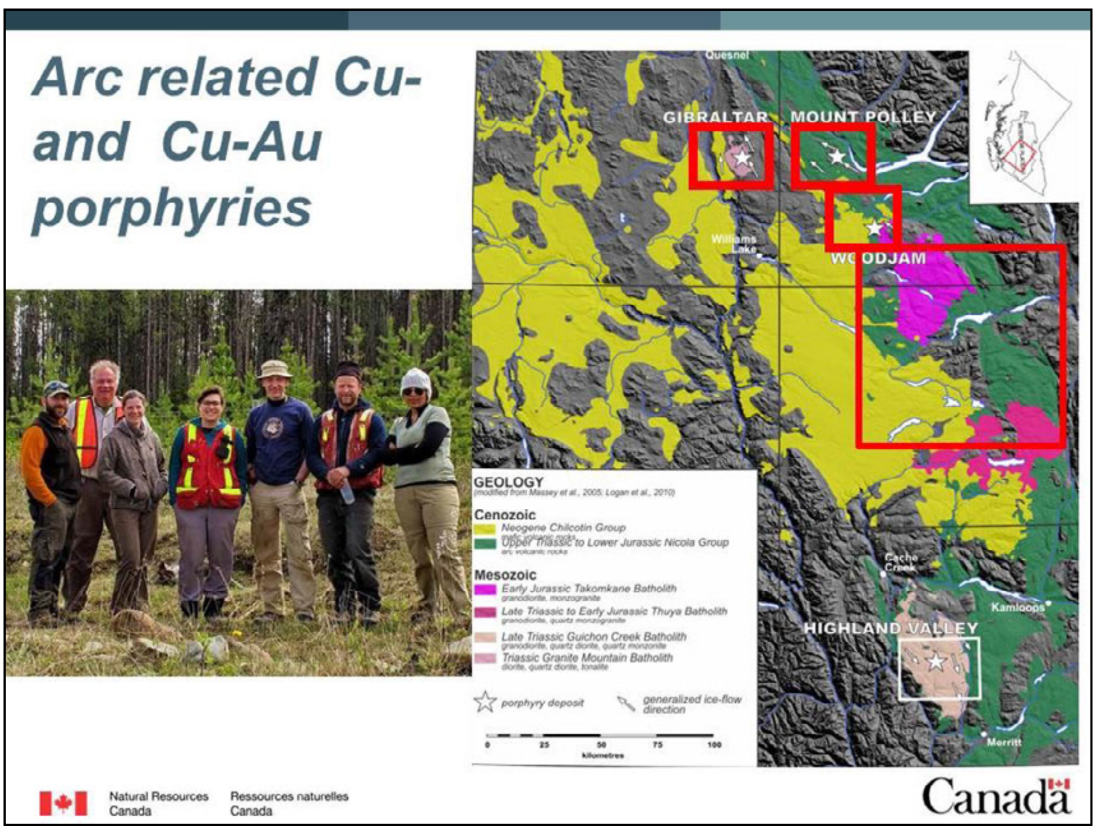

Targeted Geoscience Initiative:
Whitehorse
Yellowknife
Edmonton
Victoria
Regina
St. John's
Quesnel
Granite Mountain Batholith
Gibraltar
Mount Polley
Williams Lake
Woodjam
Takomkane Batholith
Thuya Batholith
Kamloops
Highland Valley
Guichon Creek Batholith
Kelowna
Penticton
Copper Mountain
Vancouver
USA
0
100
km
Insular
Intermontane
Ancestral North America
52°N
50°N
122°W
120°W


TGI 4: Searching for hidden mineralisation
Canada

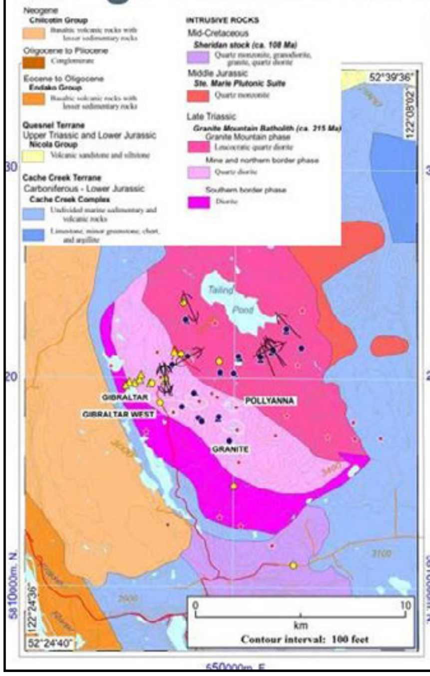

TGI 4: Searching for hidden mineralisation
Hinds Lake spillway
Natural Resources Canada
Ressources naturelles Canada
Canada

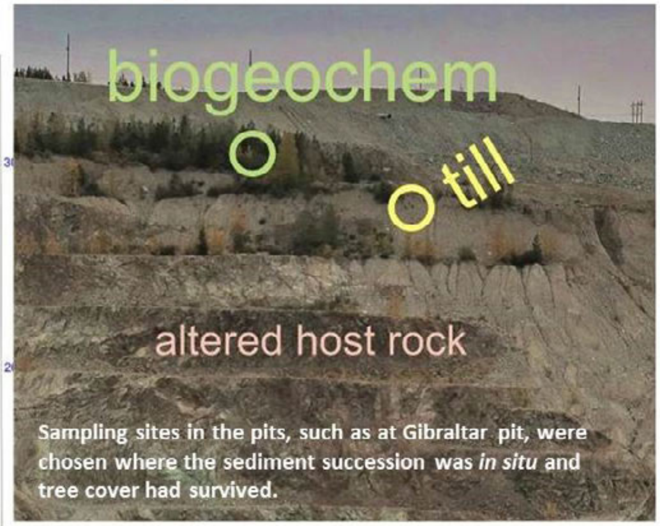

TGI 4: Searching for hidden mineralisation
Hinds Lake spillway


TGI 4: Searching for hidden mineralisation
Hinds Lake spillway


Arc related Cu- and Cu-Au porphyries
Quesnel
GIBRALTAR
MOUNT POLLEY
Williams Lake
WOODJAM
Cache Creek
Kamloops
HIGHLAND VALLEY
Merritt
GEOLOGY
(modified from Massey et al., 2005; Logan et al., 2010)
Cenozoic
Neogene Chilcotin Group
mafic volcanic rocks
Upper Triassic to Lower Jurassic Nicola Group
arc volcanic rocks
Mesozoic
Early Jurassic Takomkane Batholith
granodiorite, monzogranite
Late Triassic to Early Jurassic Thuya Batholith
granodiorite, quartz monzogranite
Late Triassic Guichon Creek Batholith
granodiorite, quartz diorite, quartz monzonite
Triassic Granite Mountain Batholith
diorite, quartz diorite, tonalite
porphyry deposit
generalized ice-flow direction
0
25
50
75
100
kilometres
Natural Resources Canada
Ressources naturelles Canada
Canada

Gibraltar: Integrated bedrock, surficial and biogeochemical mapping





Geology from: Ash et al., 1999

Canada

Gibraltar: Moly Re-Os dates

Location	Rock Type	Structure	Alteration	Mineralization

Re-Os age: 215.0 +/- 1.0 Ma

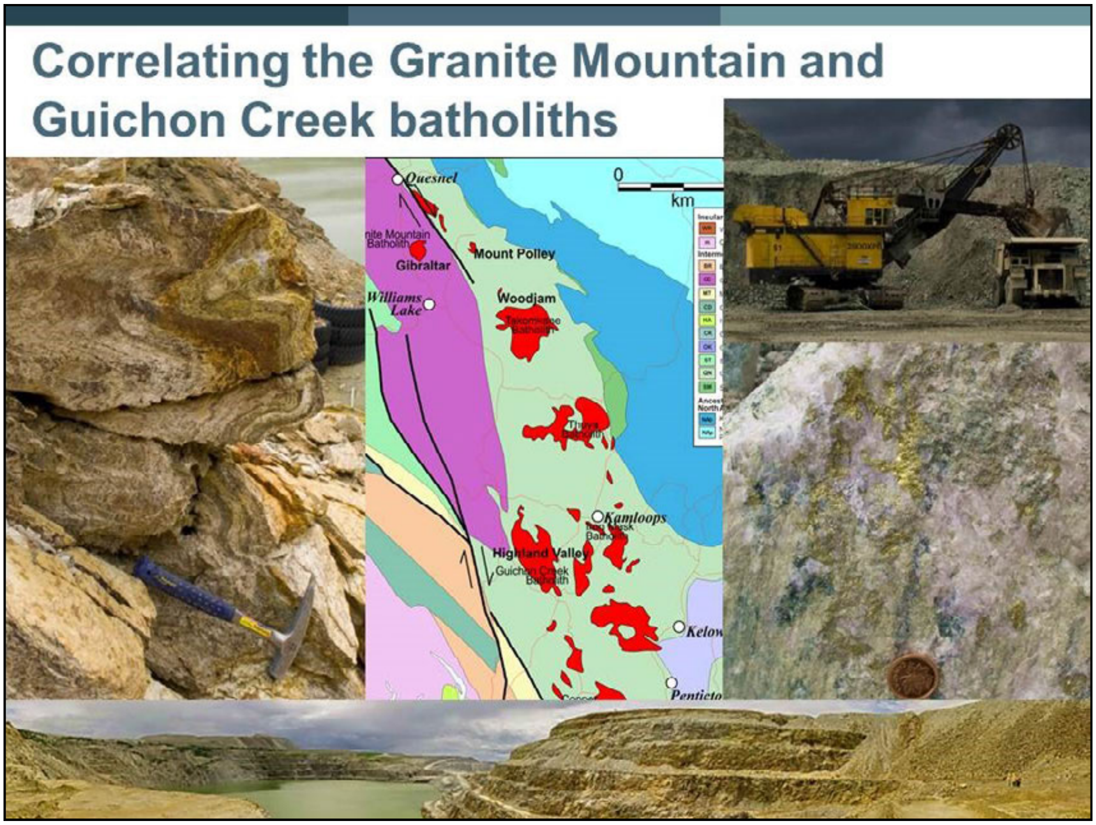
Granite	Tonalite	Weakly to moderately foliated	Weak to moderate QS +/- Chl	Weak to moderate

Re-Os age: 212.7 +/- 0.9 Ma

Granite	Tonalite	Weakly to moderately foliated	Moderate CQ	Strong

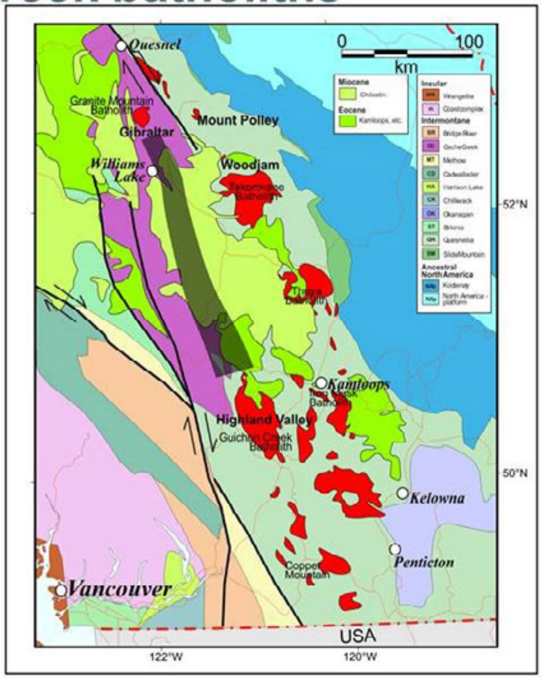
Re-Os age: 210.1 +/- 0.9 Ma

Gibraltar	Tonalite	Weakly to moderately foliated	Weak to Moderate QSC	Weak

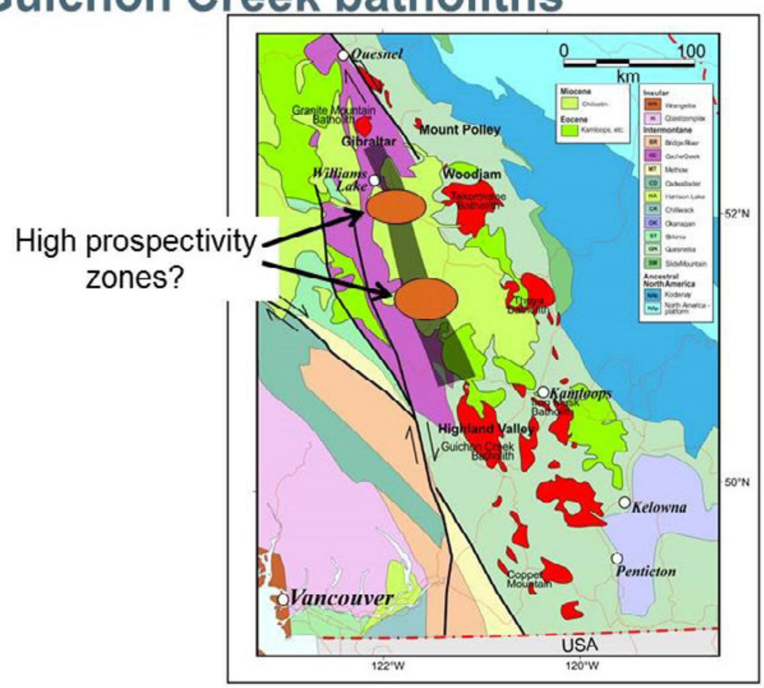

Correlating the Granite Mountain and Guichon Creek batholiths
Quesnel
Mount Polley
Gibraltar
Williams Lake
Woodjam
Kamloops
Highland Valley
Guichon Creek Batholith
0
km

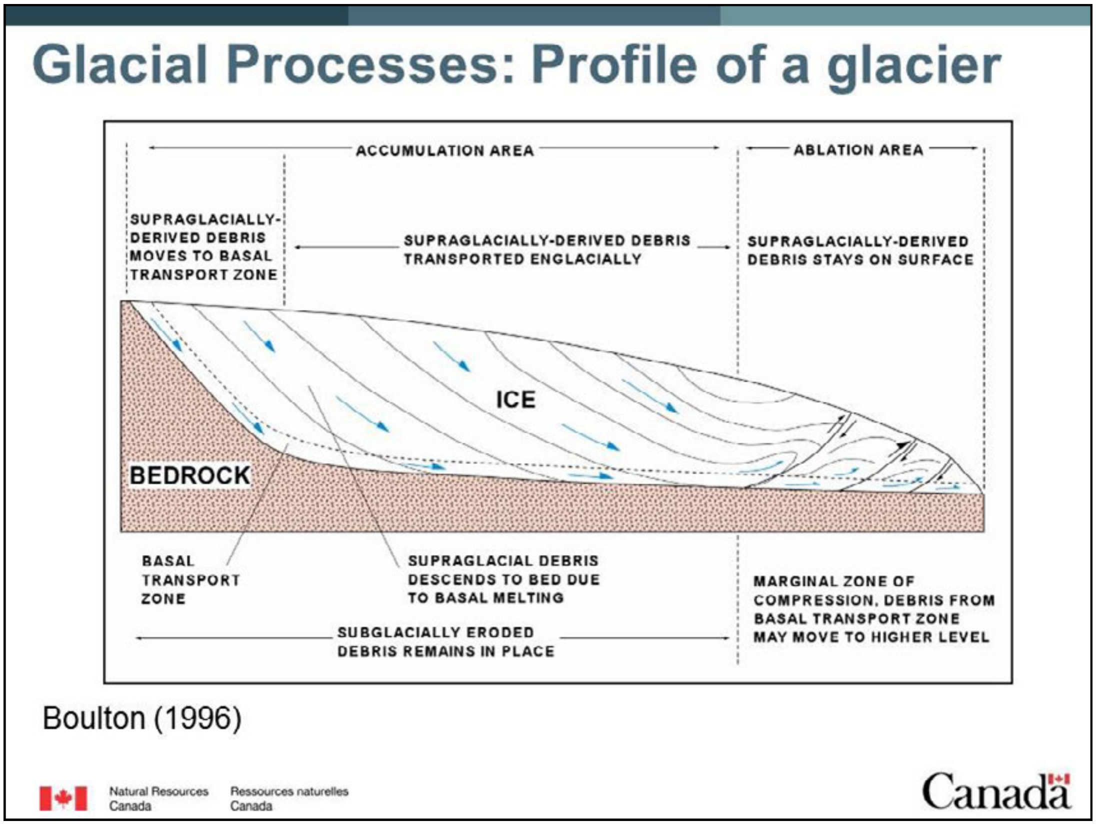

Correlating the Granite Mountain and Guichon Creek batholiths
Quesnel
Mount Polley
Gibraltar
Williams Lake
Woodjam
Kamloops
0
km
Nader Mostaghimi (MSc – UBC):
Structural controls on the style and distribution of ore mineralisation at the Gibraltar Mine, BC

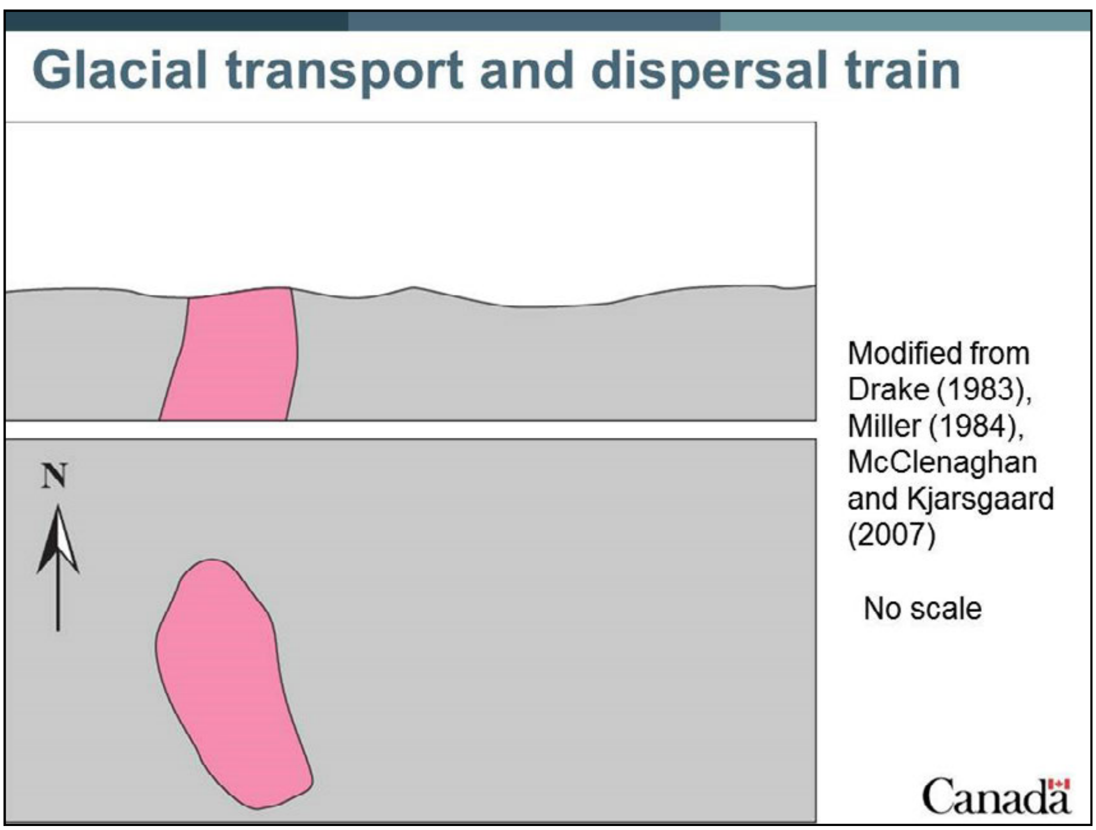
Correlating the Granite Mountain and Guichon Creek batholiths

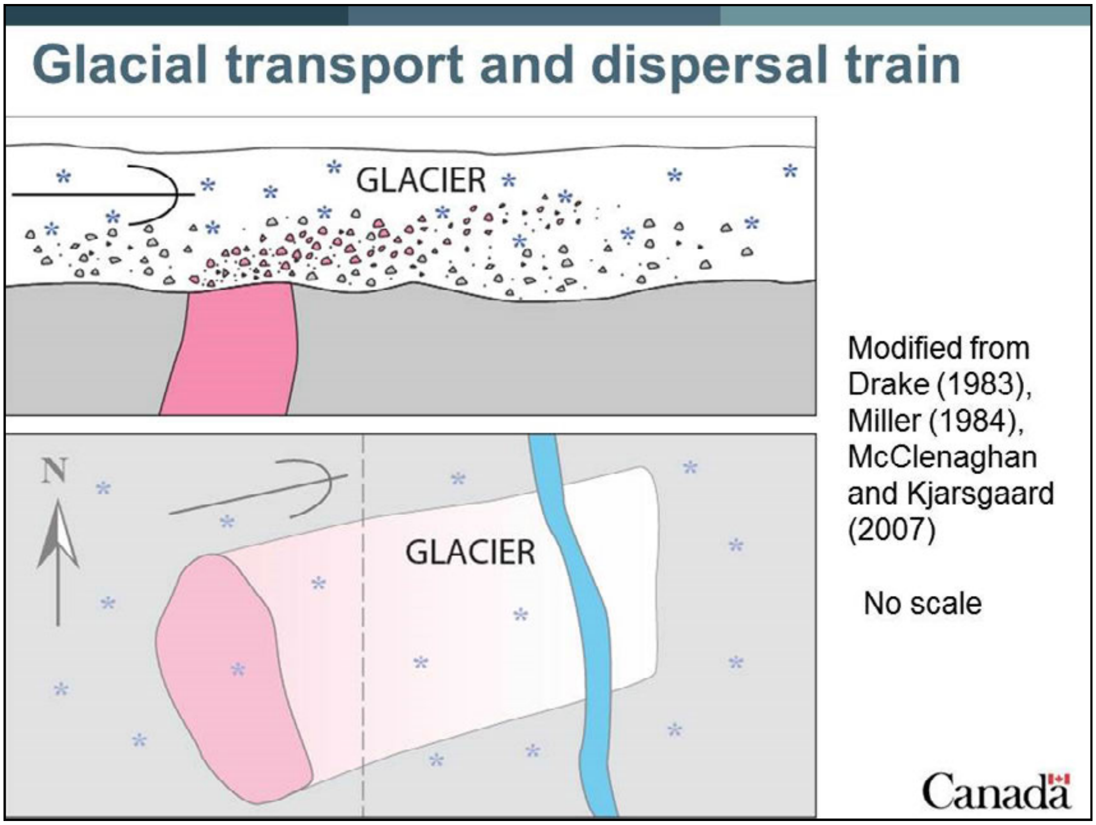


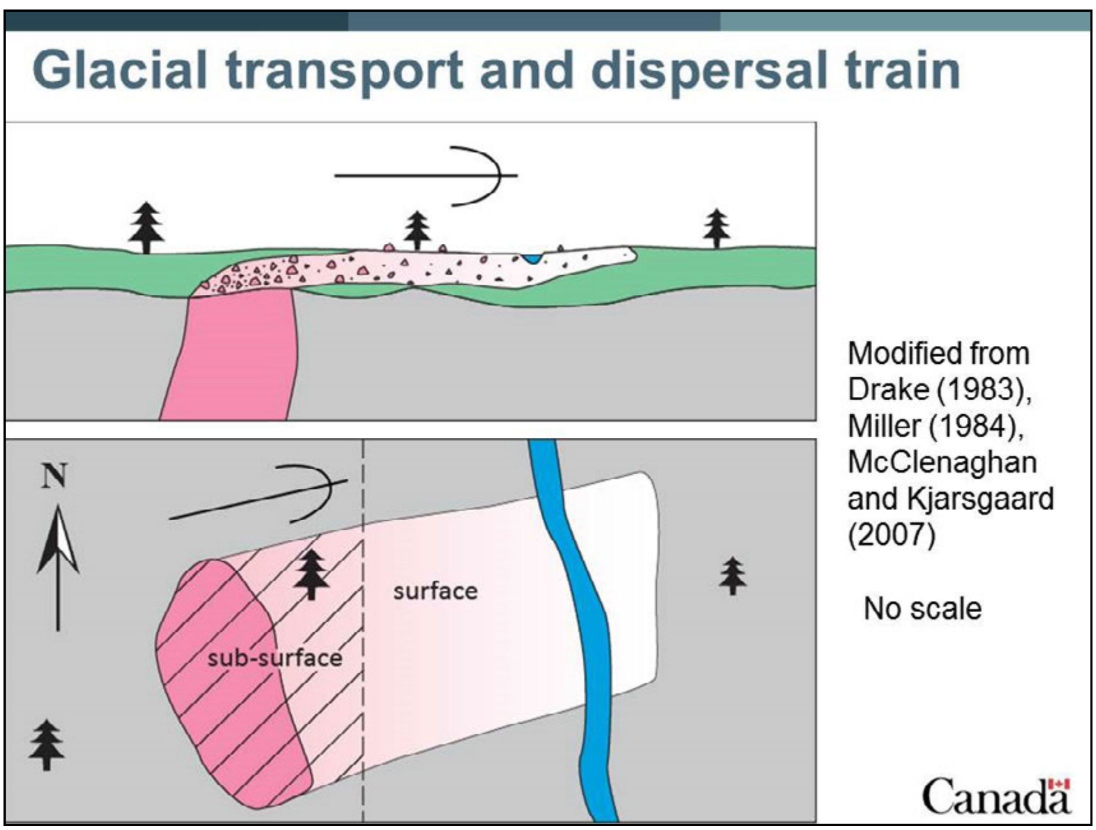
Correlating the Granite Mountain and Guichon Creek batholiths



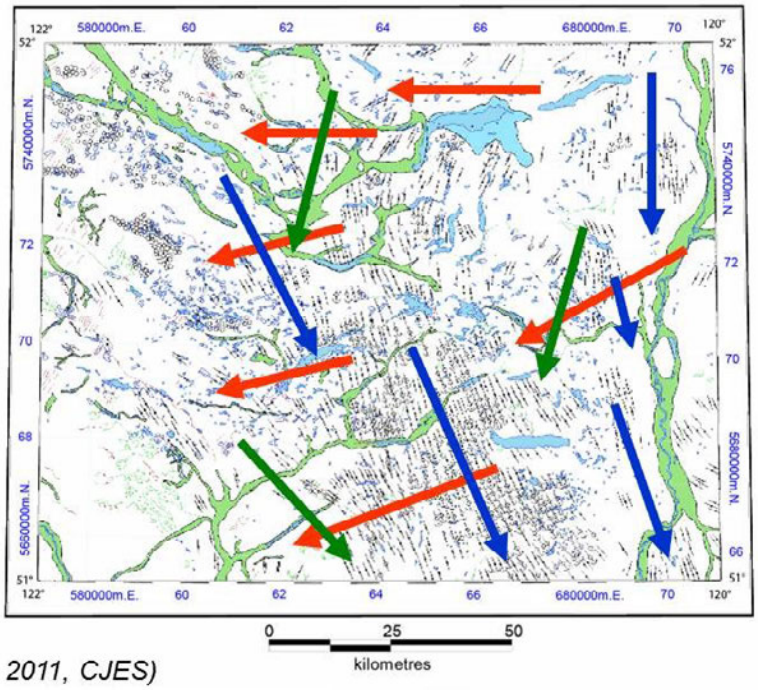

Glacial Processes: Profile of a glacier
ACCUMULATION AREA
ABLATION AREA
SUPRAGLACIALLY-DERIVED DEBRIS MOVES TO BASAL TRANSPORT ZONE
SUPRAGLACIALLY-DERIVED DEBRIS TRANSPORTED ENGLACIALLY
SUPRAGLACIALLY-DERIVED DEBRIS STAYS ON SURFACE
ICE
BEDROCK
BASAL TRANSPORT ZONE
SUPRAGLACIAL DEBRIS DESCENDS TO BED DUE TO BASAL MELTING
MARGINAL ZONE OF COMPRESSION, DEBRIS FROM BASAL TRANSPORT ZONE MAY MOVE TO HIGHER LEVEL
SUBGLACIALLY ERODED DEBRIS REMAINS IN PLACE
Boulton (1996)
Natural Resources Canada
Ressources naturelles Canada
Canada


Glacial transport and dispersal train
N
Modified from Drake (1983), Miller (1984), McClenaghan and Kjarsgaard (2007)
No scale
Canada


Glacial transport and dispersal train
GLACIER
N
GLACIER
Modified from Drake (1983), Miller (1984), McClenaghan and Kjarsgaard (2007)
No scale
Canada

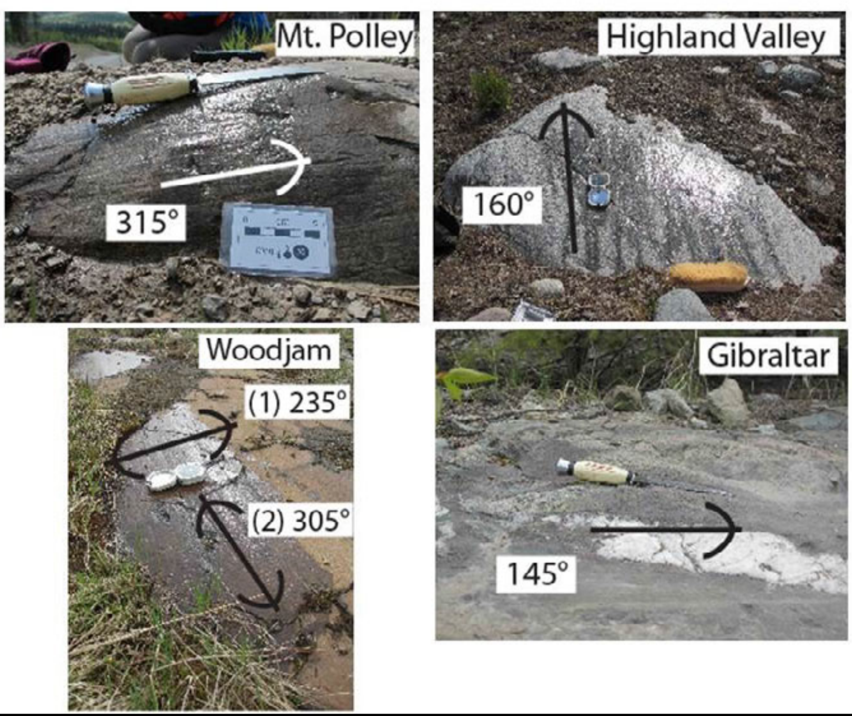

Glacial transport and dispersal train
N
surface
sub-surface
Modified from Drake (1983), Miller (1984), McClenaghan and Kjarsgaard (2007)
No scale
Canada

Ice-flow history: Bonaparte Lake area



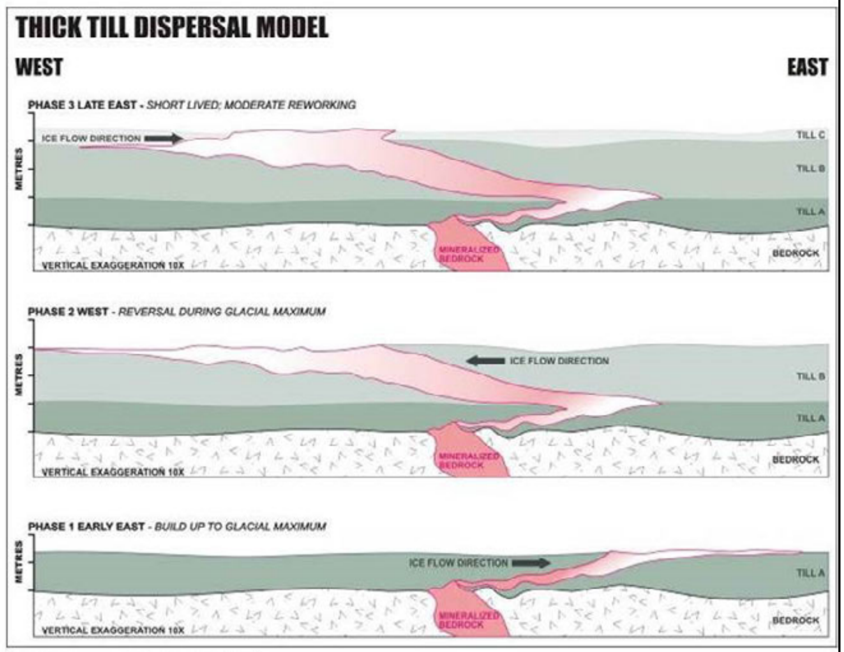
(Plouffe et al., 2011, CJES)

Ice-flow Indicators



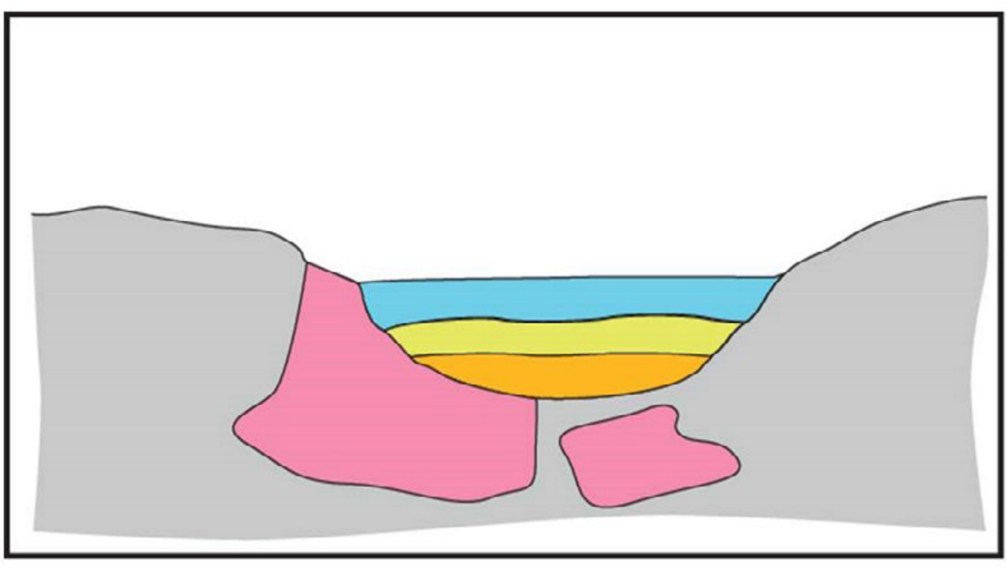
Ice-divide Migration and effect on glacial dispersal

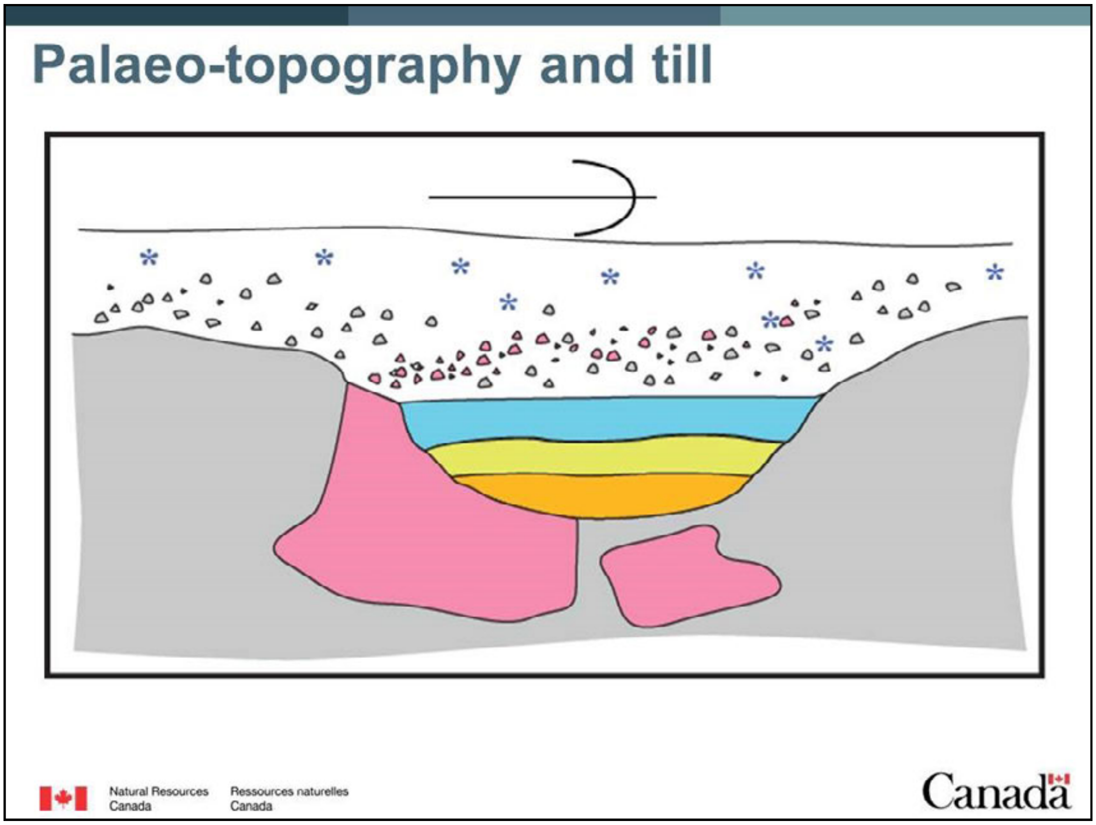
Based on dispersal at Huckleberry Mine

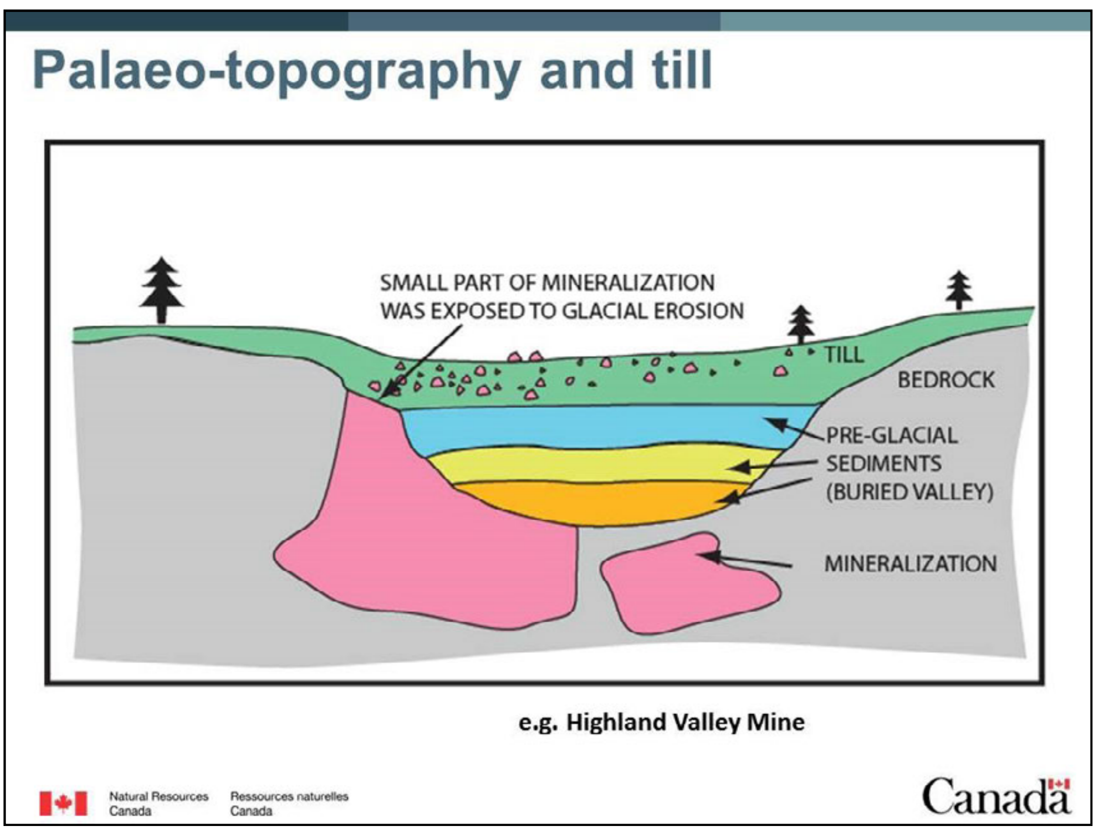


Ferbey et al. (2012; BCGS Open File 2012-02)

Palaeo-topography and till




Palaeo-topography and till
Natural Resources Canada
Ressources naturelles Canada
Canada


Palaeo-topography and till
SMALL PART OF MINERALIZATION
WAS EXPOSED TO GLACIAL EROSION
TILL
BEDROCK
PRE-GLACIAL
SEDIMENTS
(BURIED VALLEY)
MINERALIZATION
e.g. Highland Valley Mine
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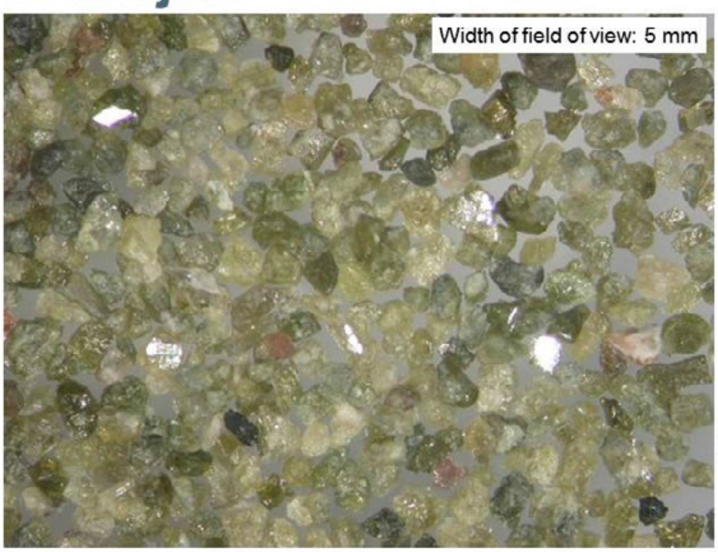
Canada

Highland Valley Mine: Valley Pit

Natural Resources Canada | Ressources naturelles Canada

Canada

Porphyry Indicator Minerals (PIM) – Woodjam



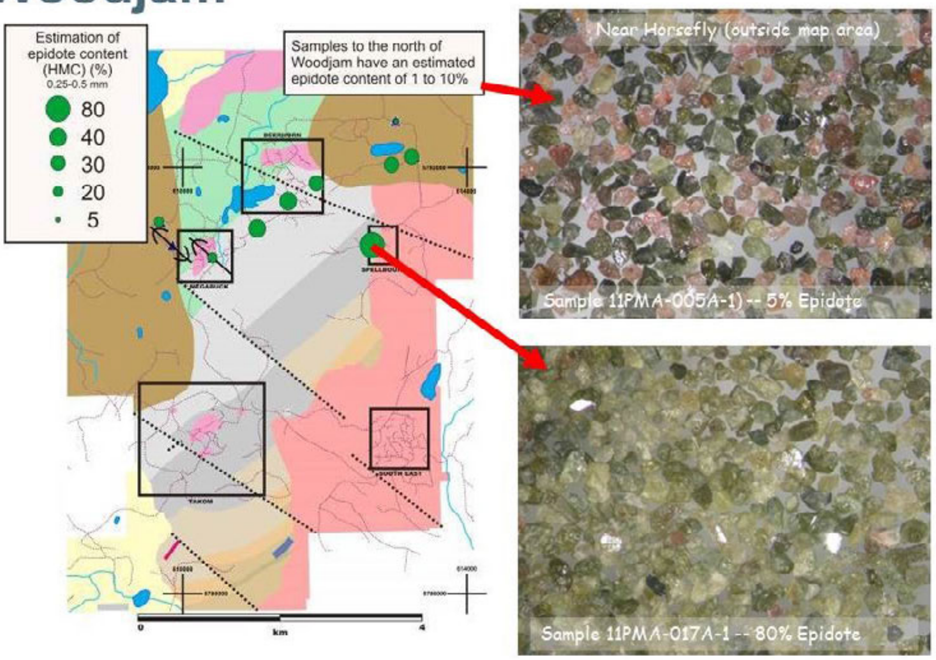
Sample 11PMA-017A-1 (WOODJAM)

80% Epidote (0.25-0.50 mm)

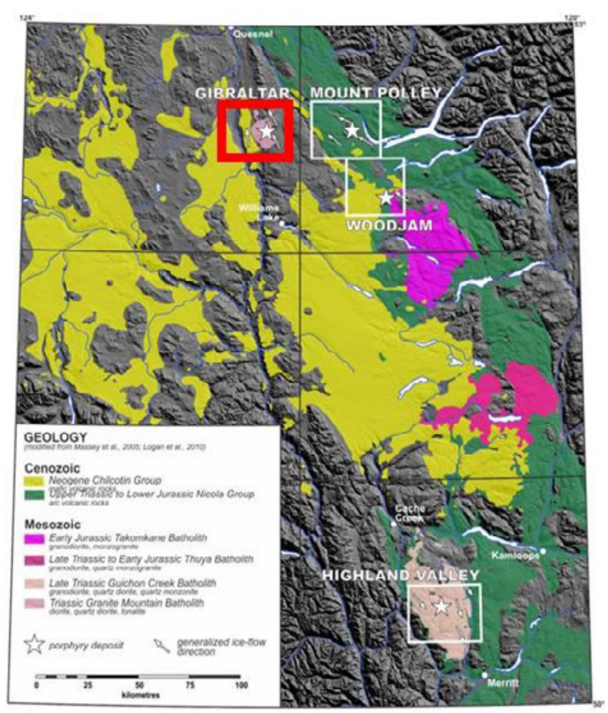
Source: ODM, March 2012; modal estimates +/-10% precision

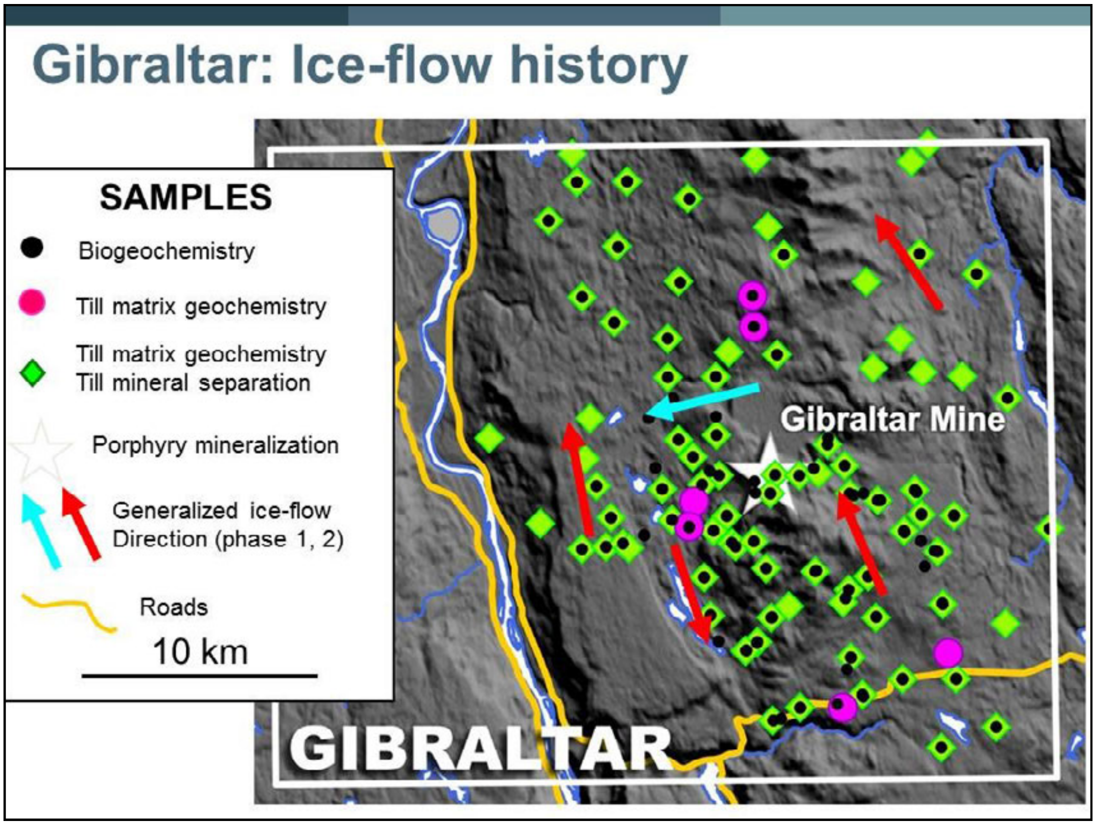
Percentage of epidote in HMC of till could provide a key indication of the presence of propylitic alteration; this could become a regional indicator mineral for buried porphyry mineralization

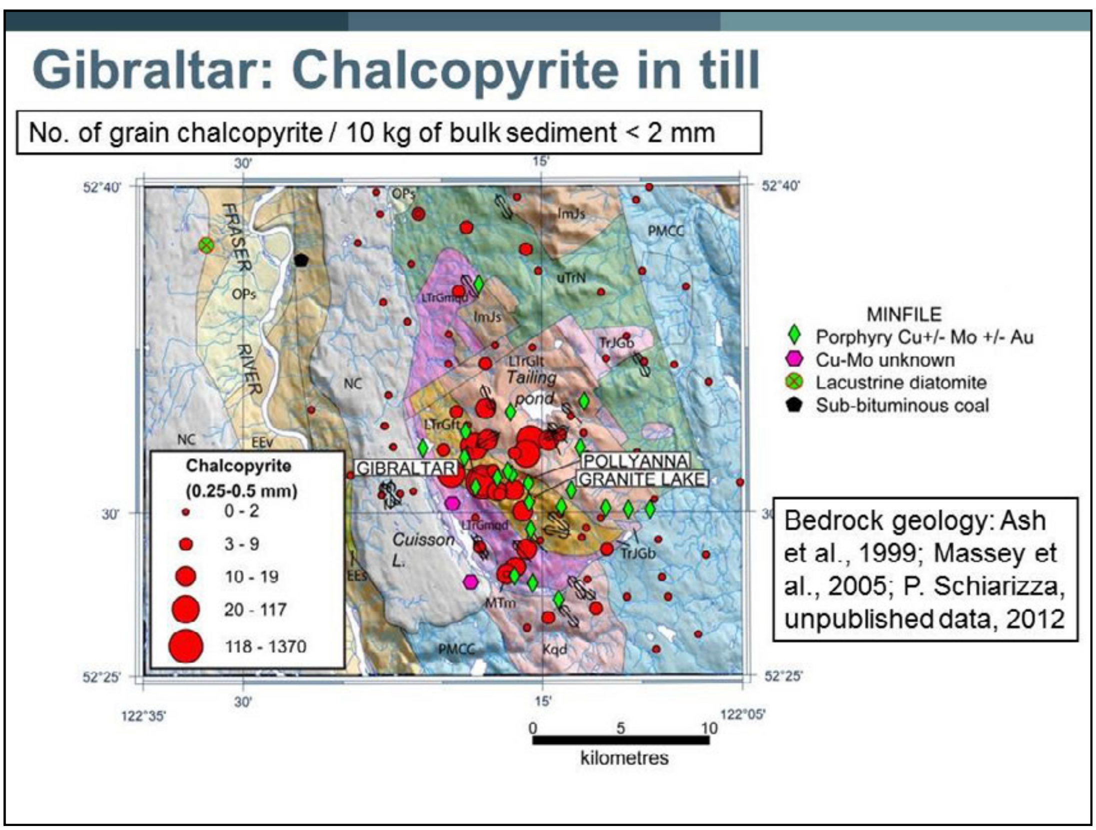
Porphyry Indicator Minerals (PIM) – Woodjam



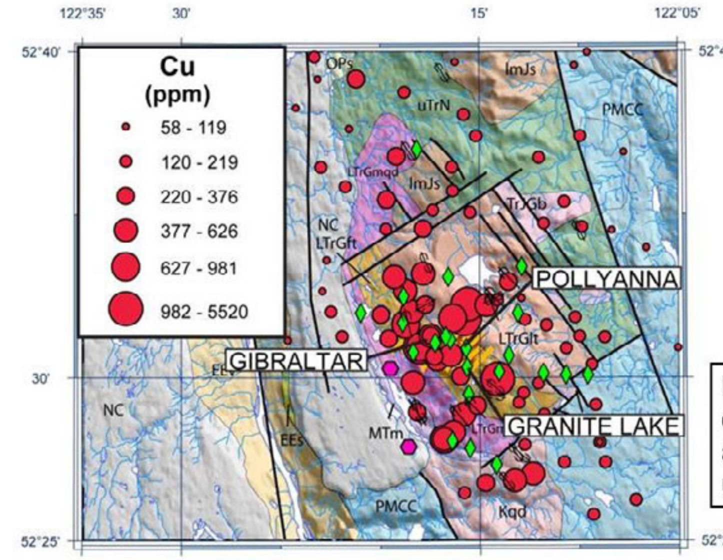
Gibraltar




Gibraltar: Ice-flow history
SAMPLES
Biogeochemistry
Till matrix geochemistry
Till matrix geochemistry
Till mineral separation
Porphyry mineralization
Generalized ice-flow
Direction (phase 1, 2)
Roads
10 km
Gibraltar Mine
GIBRALTAR


Gibraltar: Chalcopyrite in till
No. of grain chalcopyrite / 10 kg of bulk sediment < 2 mm
52°40'
52°25'
30'
15'
122°35'
122°05'
FRASER
RIVER
Tailing pond
GIBRALTAR
POLLYANNA
GRANITE LAKE
Cuisson L.
Chalcopyrite
(0.25-0.5 mm)
0 - 2
3 - 9
10 - 19
20 - 117
118 - 1370
MINFILE
Porphyry Cu+/- Mo +/- Au
Cu-Mo unknown
Lacustrine diatomite
Sub-bituminous coal
Bedrock geology: Ash et al., 1999; Massey et al., 2005; P. Schiarizza, unpublished data, 2012
0
5
10
kilometres

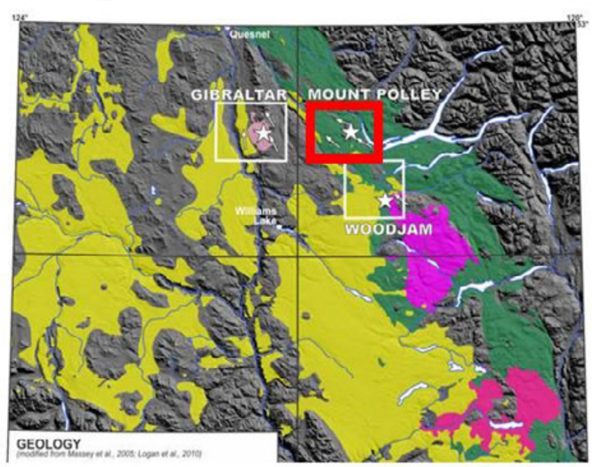
Gibraltar: Cu in clay from till



Bedrock geology: Ash et al., 1999; Massey et al., 2005; P. Schiarizza, unpublished data, 2012

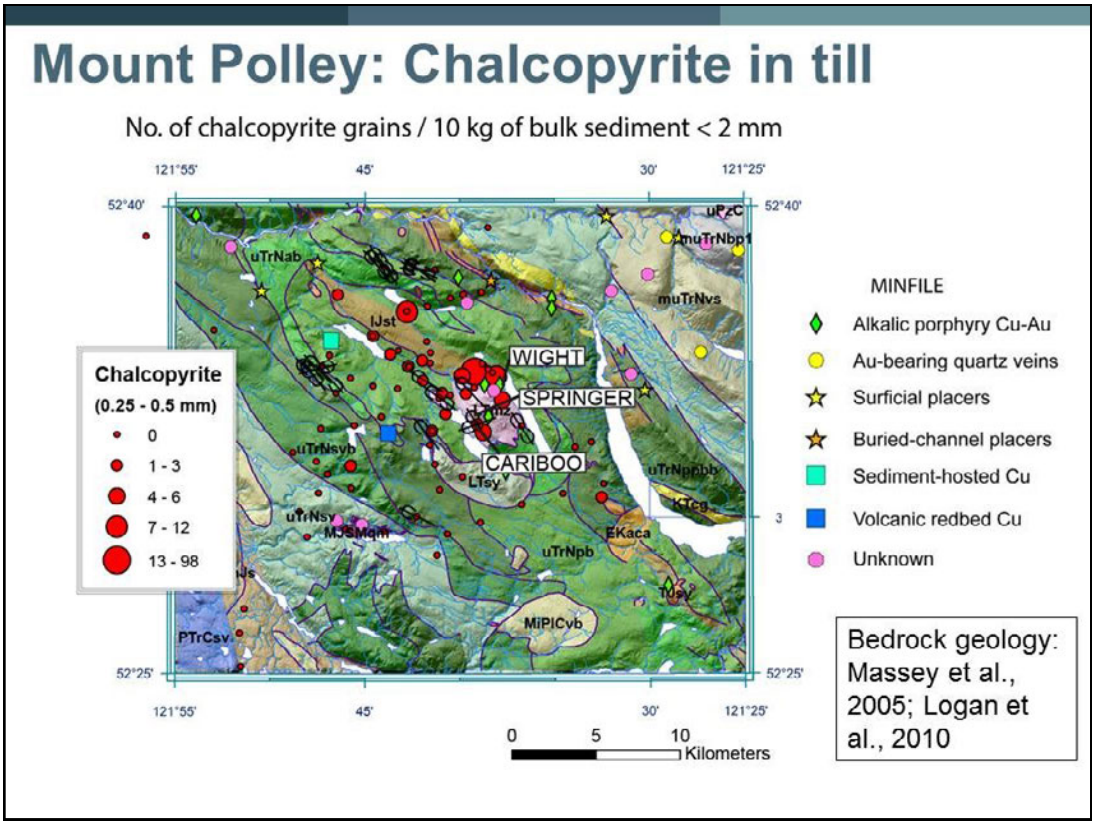
$LiBO_2$ / LiB_4O_7 HNO_3 fusion
ICP-ES

Mount Polley

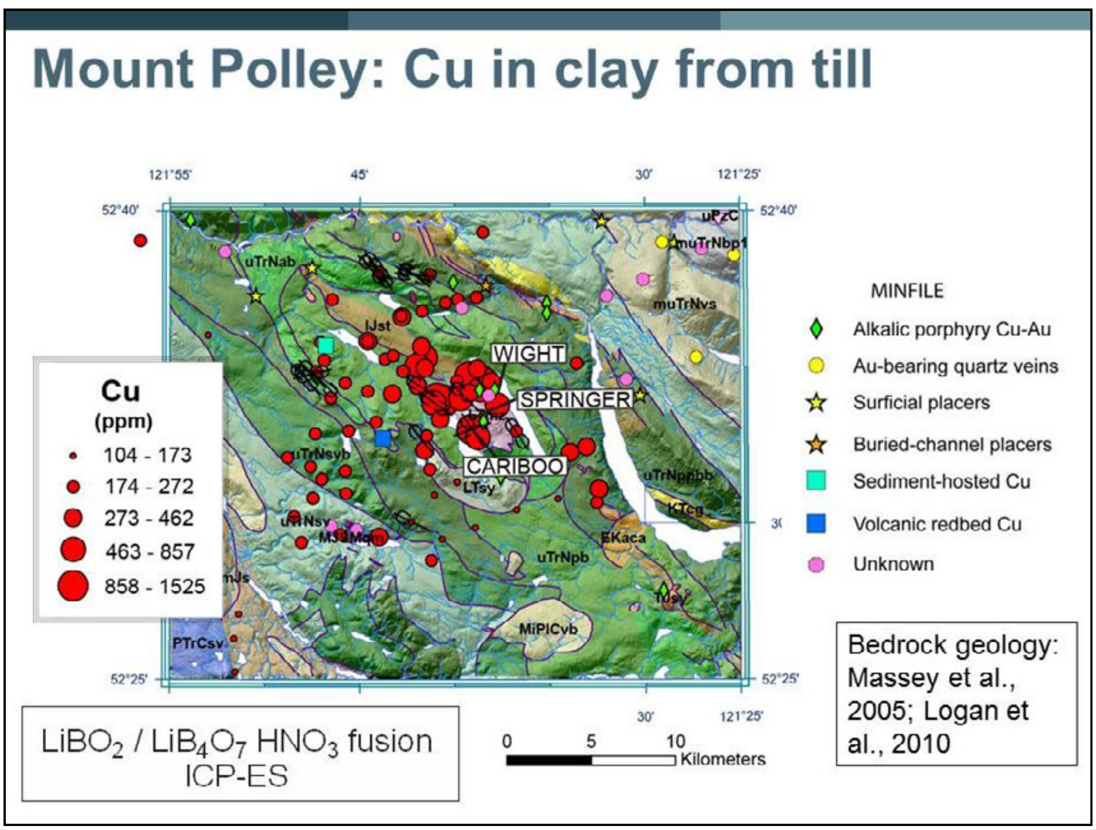


Sarah Hashmi (MSc – SFU):

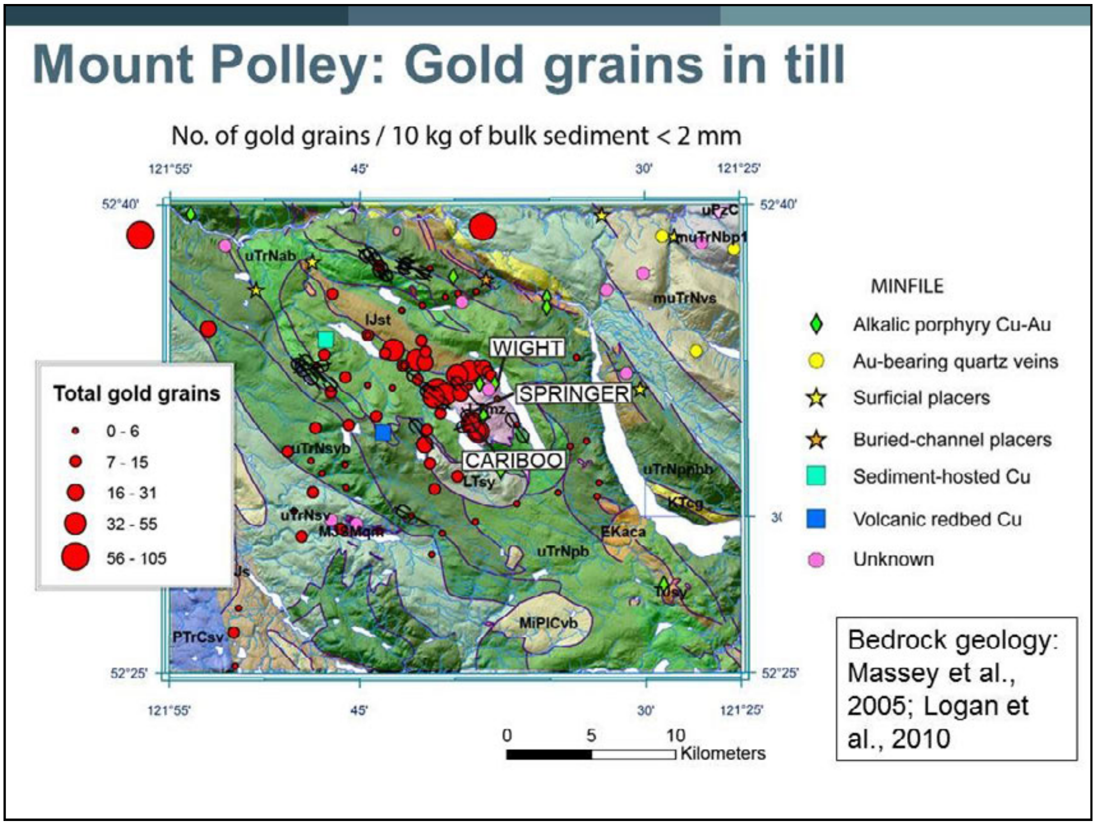
Geochemical and mineralogical dispersal in till from the Mount Polley Cu-Au porphyry deposit, central British Columbia, Canada

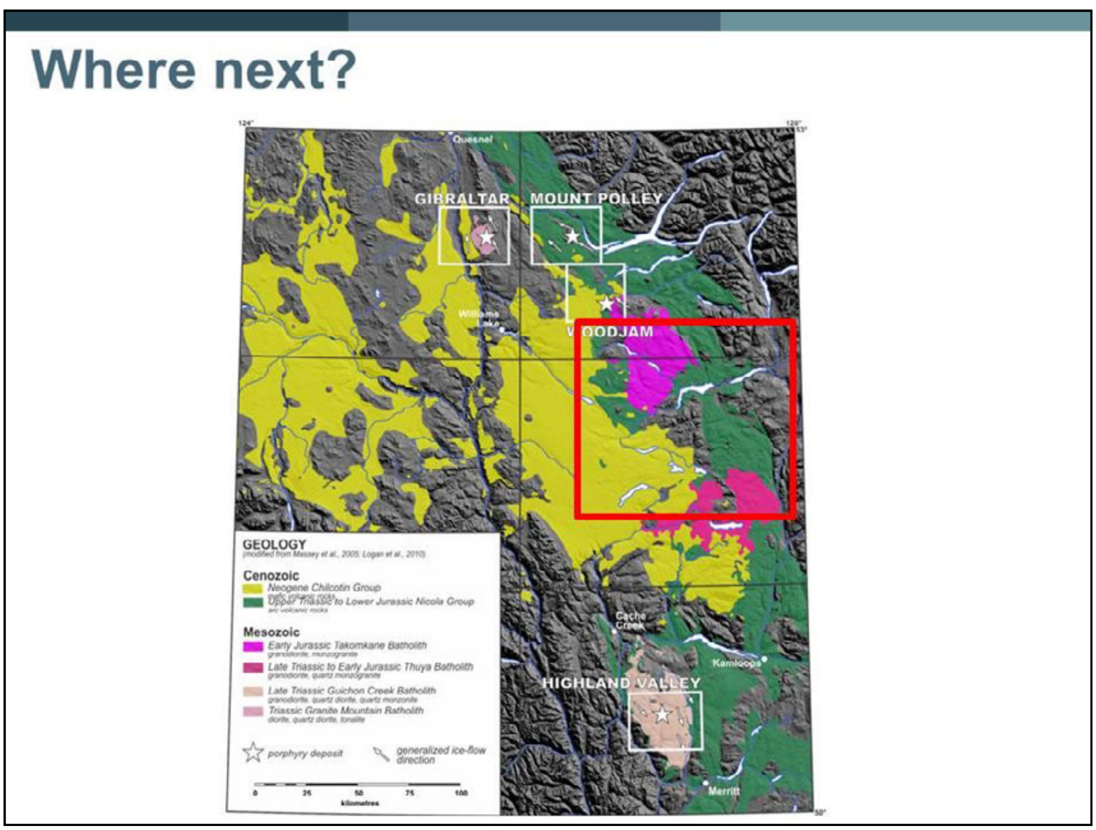


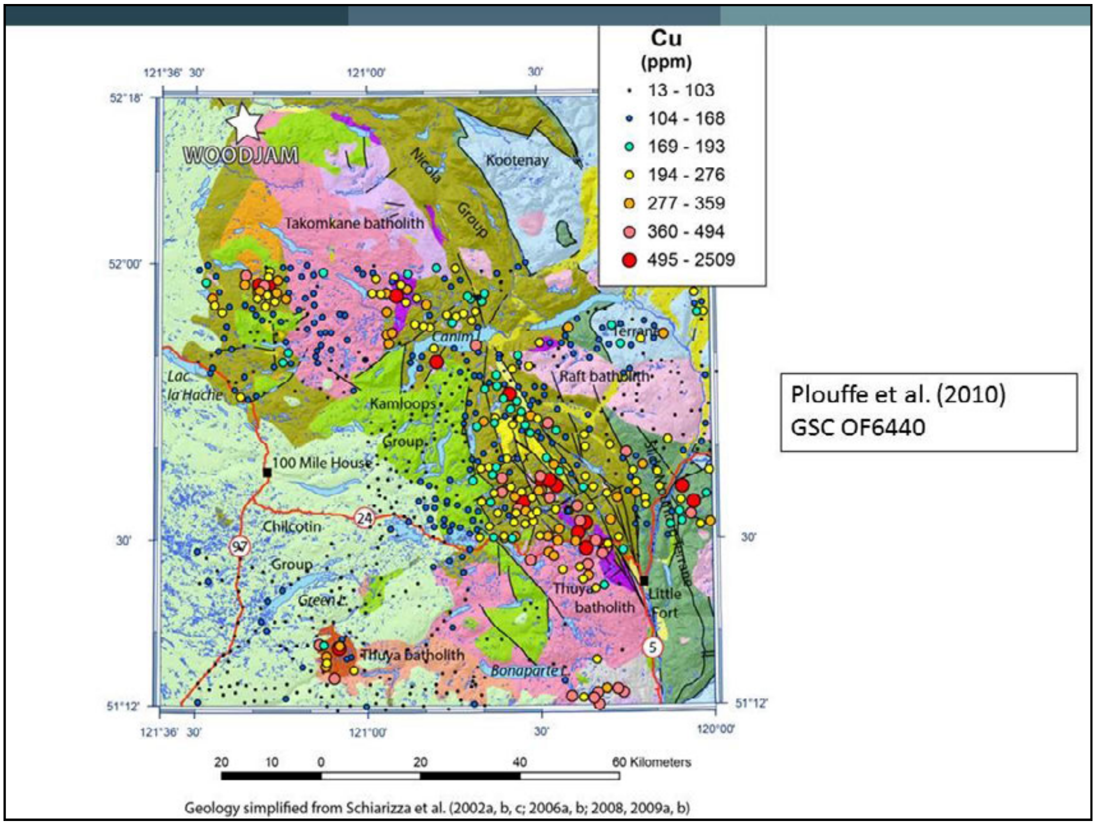
Mount Polley: Chalcopyrite in till
No. of chalcopyrite grains / 10 kg of bulk sediment < 2 mm
Chalcopyrite
(0.25 - 0.5 mm)
0
1 - 3
4 - 6
7 - 12
13 - 98
WIGHT
SPRINGER
CARIBOO
MINFILE
Alkalic porphyry Cu-Au
Au-bearing quartz veins
Surficial placers
Buried-channel placers
Sediment-hosted Cu
Volcanic redbed Cu
Unknown
Bedrock geology: Massey et al., 2005; Logan et al., 2010
0 5 10 Kilometers

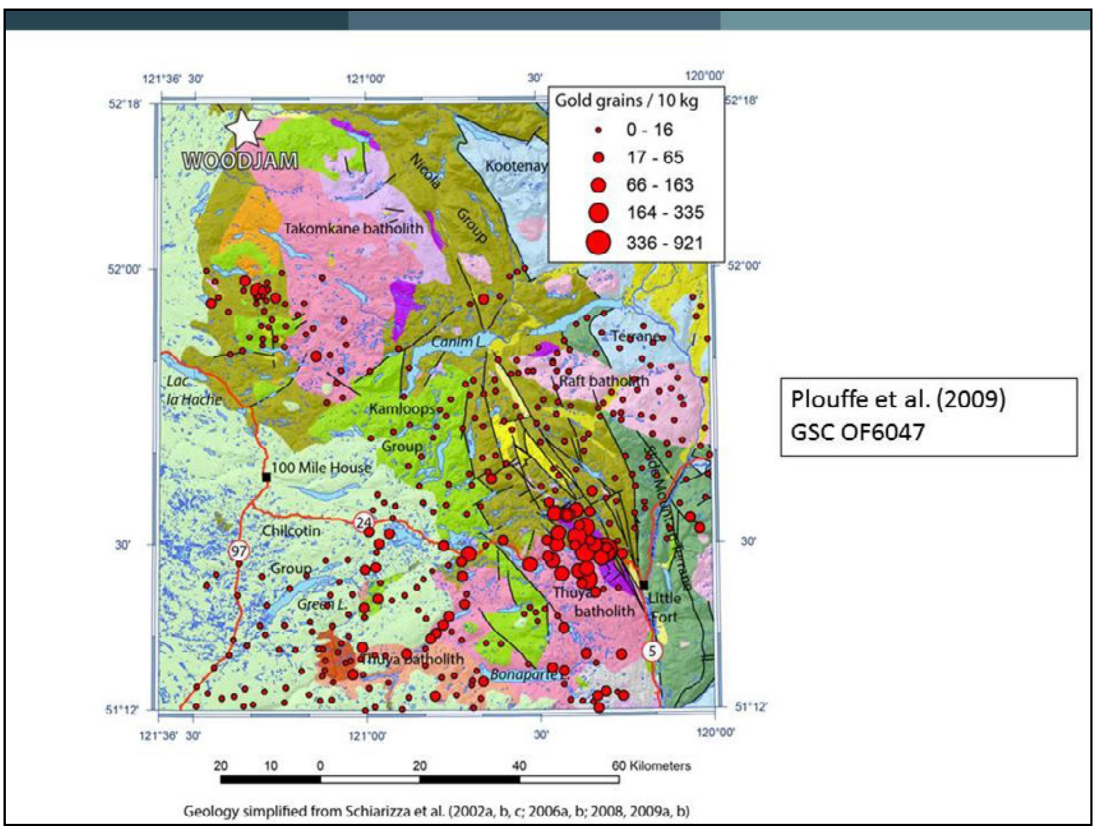


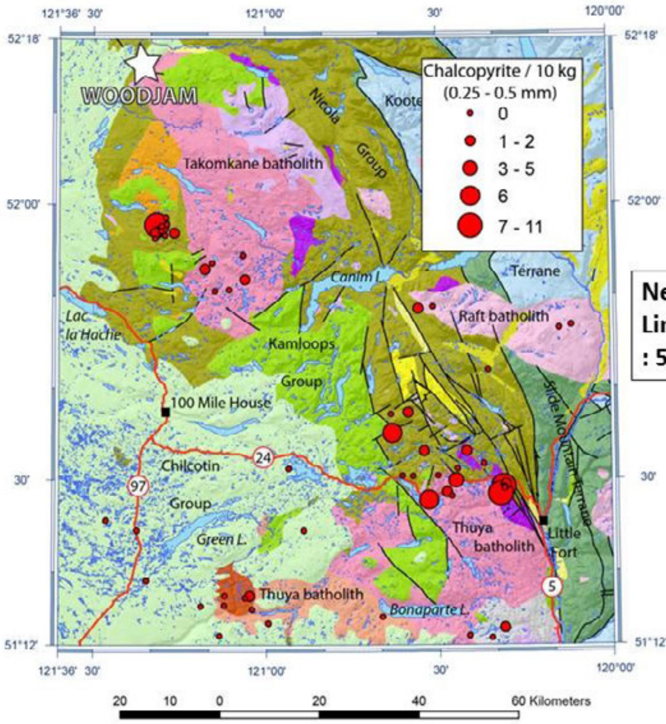
Mount Polley: Cu in clay from till
Cu
(ppm)
104 - 173
174 - 272
273 - 462
463 - 857
858 - 1525
WIGHT
SPRINGER
CARIBOO
MINFILE
Alkalic porphyry Cu-Au
Au-bearing quartz veins
Surficial placers
Buried-channel placers
Sediment-hosted Cu
Volcanic redbed Cu
Unknown
Bedrock geology: Massey et al., 2005; Logan et al., 2010
LiBO2 / LiB4O7 HNO3 fusion ICP-ES
0 5 10 Kilometers


Mount Polley: Gold grains in till
No. of gold grains / 10 kg of bulk sediment < 2 mm
121°55'
45'
30'
121°25'
52°40'
52°25'
Total gold grains
0 - 6
7 - 15
16 - 31
32 - 55
56 - 105
WIGHT
SPRINGER
CARIBOO
uTrNab
lJst
uTrNsvb
uTrNsv
uTrNpb
uTrNpnbb
muTrNvs
muTrNbp1
uPzC
EKaca
KTcg
MiPlCvb
PTrCsv
LTsy
MINFILE
Alkalic porphyry Cu-Au
Au-bearing quartz veins
Surficial placers
Buried-channel placers
Sediment-hosted Cu
Volcanic redbed Cu
Unknown
0 5 10 Kilometers
Bedrock geology: Massey et al., 2005; Logan et al., 2010


Where next?
Quesnel
GIBRALTAR
MOUNT POLLEY
WOODJAM
Williams Lake
Cache Creek
Kamloops
HIGHLAND VALLEY
Merritt
GEOLOGY
(modified from Massey et al., 2005; Logan et al., 2010)
Cenozoic
Neogene Chilcotin Group
Upper Triassic to Lower Jurassic Nicola Group
arc volcanic rocks
Mesozoic
Early Jurassic Takomkane Batholith
granodiorite, monzogranite
Late Triassic to Early Jurassic Thuya Batholith
granodiorite, quartz monzogranite
Late Triassic Guichon Creek Batholith
granodiorite, quartz diorite, quartz monzonite
Triassic Granite Mountain Batholith
diorite, quartz diorite, tonalite
porphyry deposit
generalized ice-flow direction
0 25 50 75 100
kilometres


Cu
(ppm)
13 - 103
104 - 168
169 - 193
194 - 276
277 - 359
360 - 494
495 - 2509
WOODJAM
Takomkane batholith
Nicola Group
Kootenay
Canim L.
Terrane
Raft batholith
Lac la Hache
Kamloops Group
100 Mile House
Chilcotin Group
Green L.
Thuya batholith
Little Fort
Bonaparte L.
Plouffe et al. (2010)
GSC OF6440
20 10 0 20 40 60 Kilometers
Geology simplified from Schiarizza et al. (2002a, b, c; 2006a, b; 2008, 2009a, b)

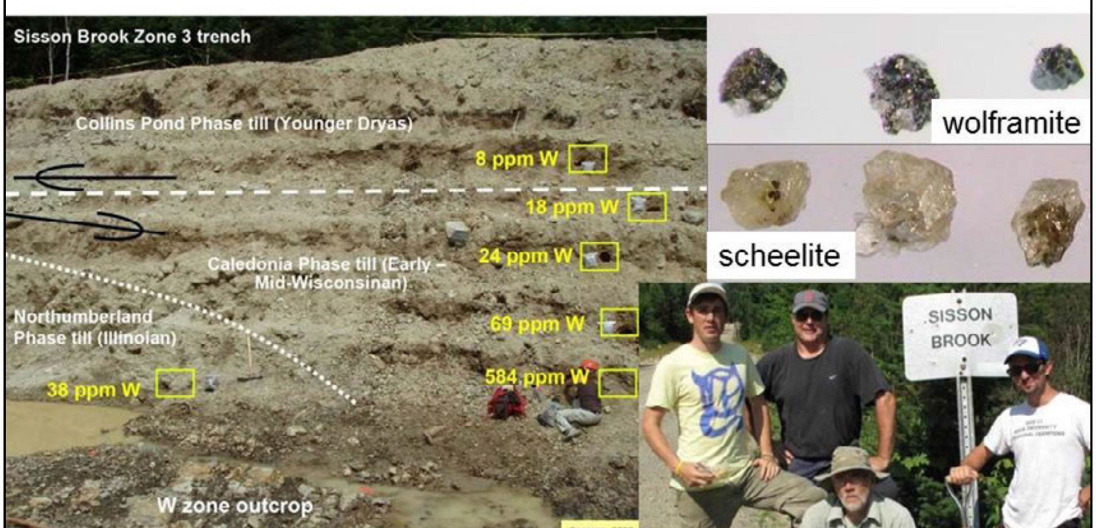

Gold grains / 10 kg
0 - 16
17 - 65
66 - 163
164 - 335
336 - 921
WOODJAM
Takomkane batholith
Nicola Group
Kootenay
Canim L.
Terrane
Raft batholith
Lac la Hache
Kamloops Group
100 Mile House
Chilcotin Group
Green L.
Thuya batholith
Little Fort
Bonaparte L.
Plouffe et al. (2009)
GSC OF6047
20 10 0 20 40 60 Kilometers
Geology simplified from Schiarizza et al. (2002a, b, c; 2006a, b; 2008, 2009a, b)



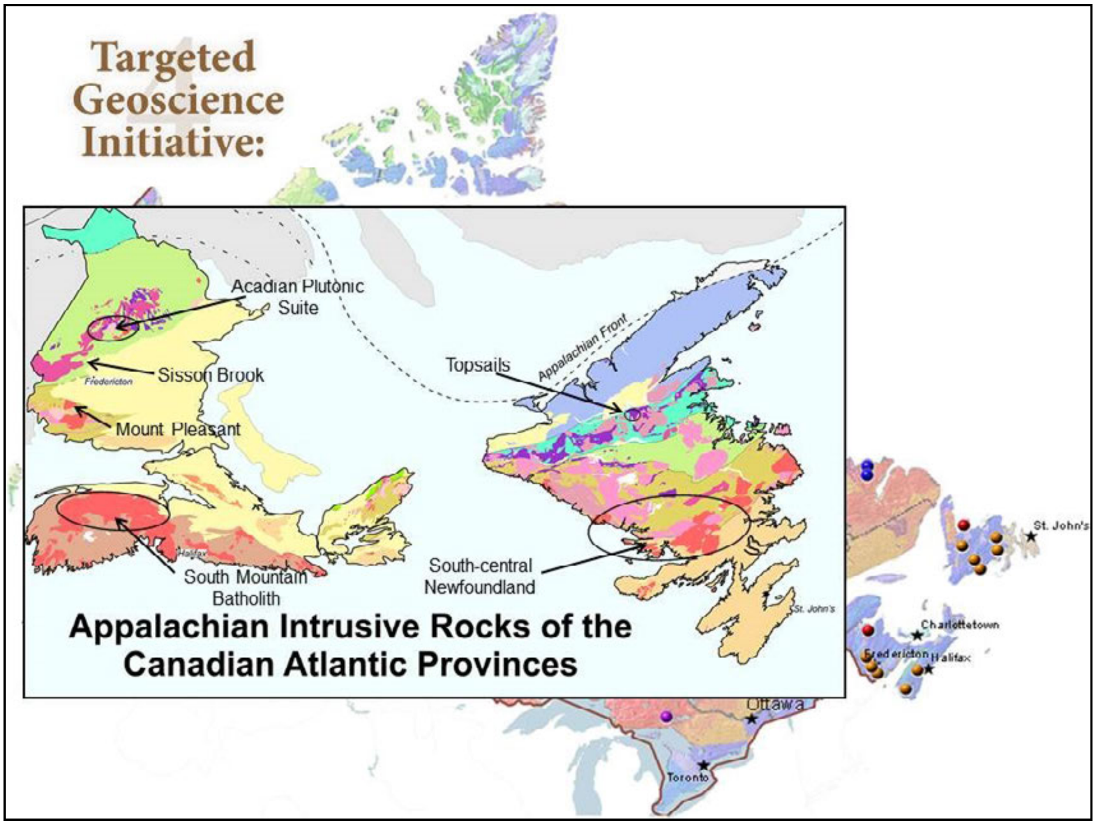
Geology simplified from Schiarizza et al. (2002a, b, c; 2006a, b; 2008, 2009a, b)

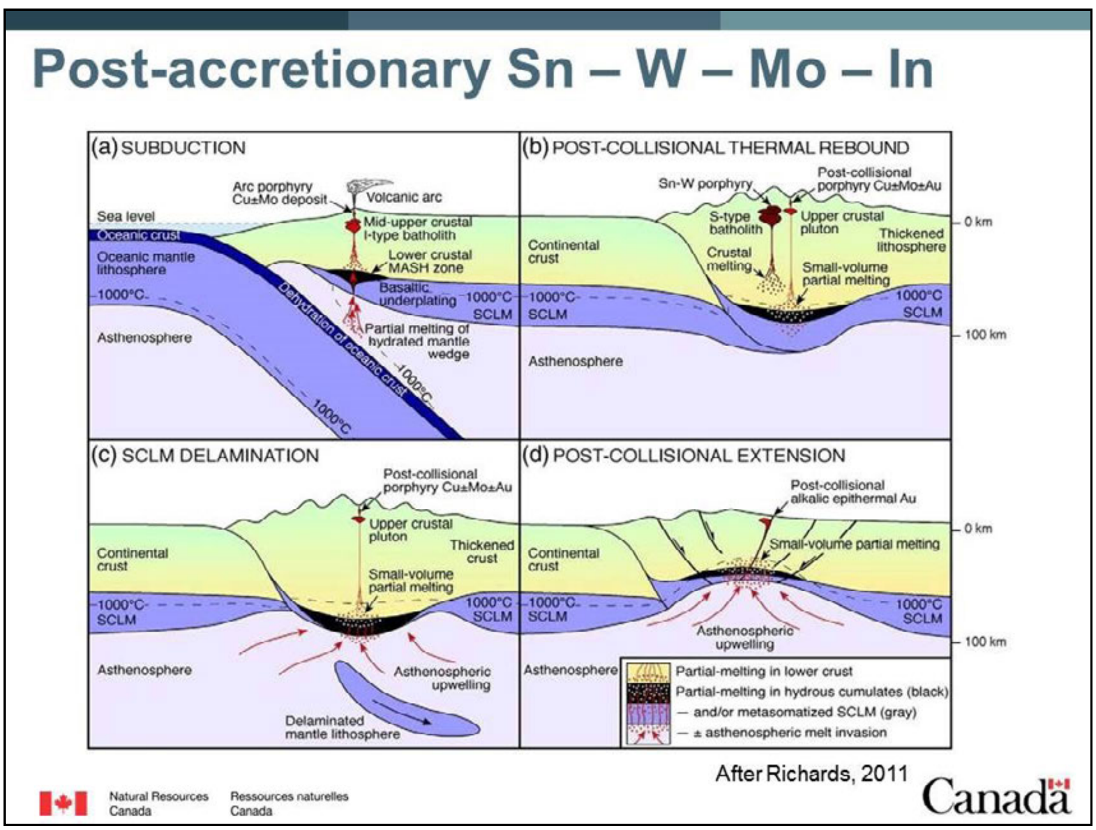
New data: unpublished
Limited number of samples : 55

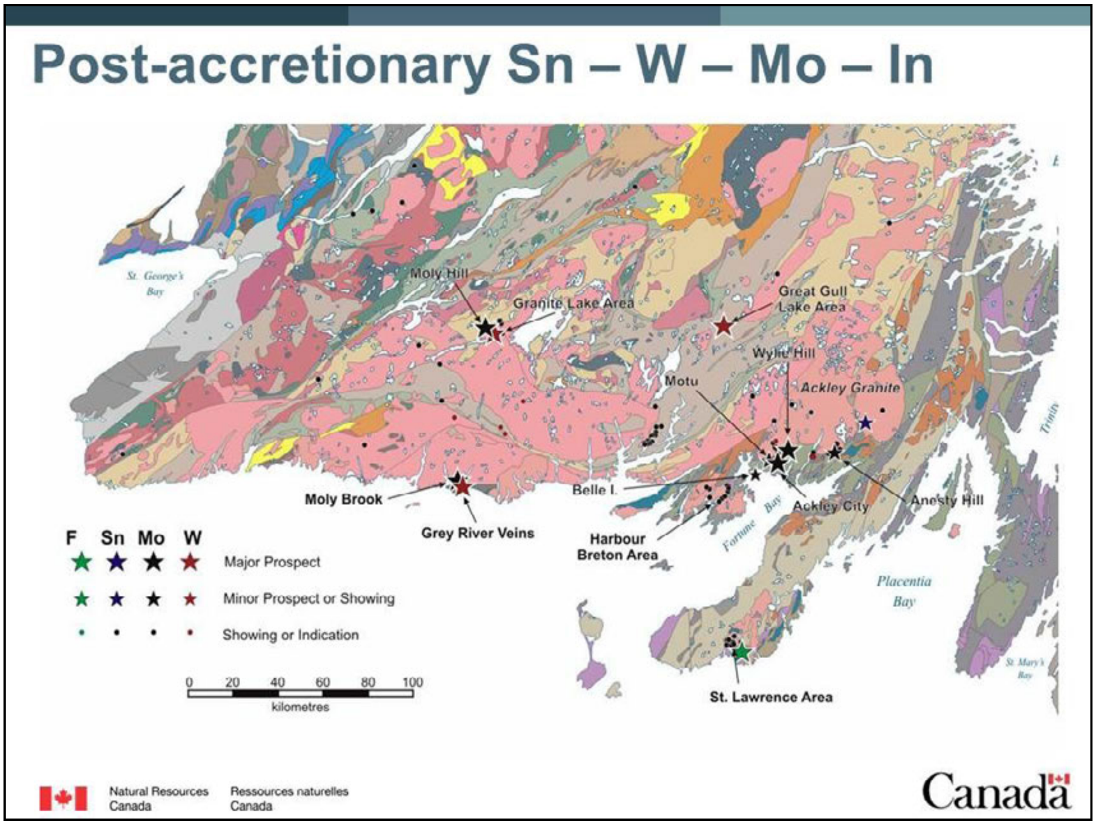
W-Mo Indicator Minerals – Sisson Brook

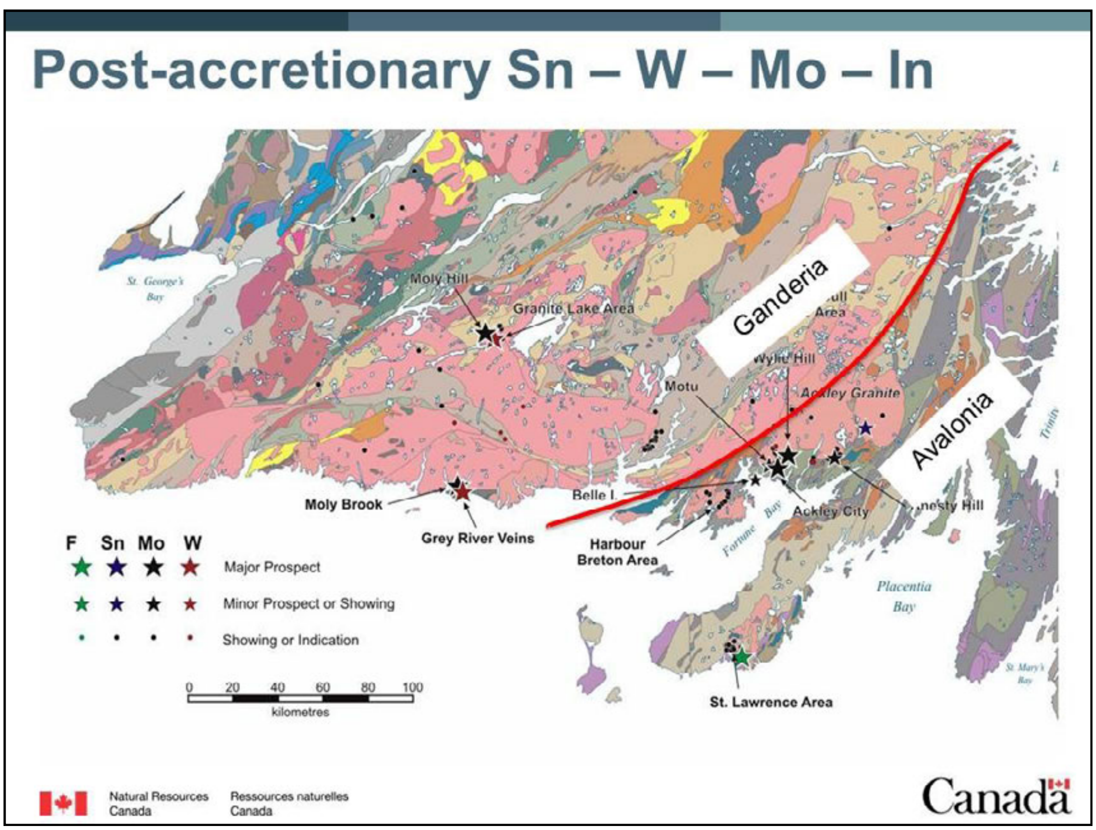


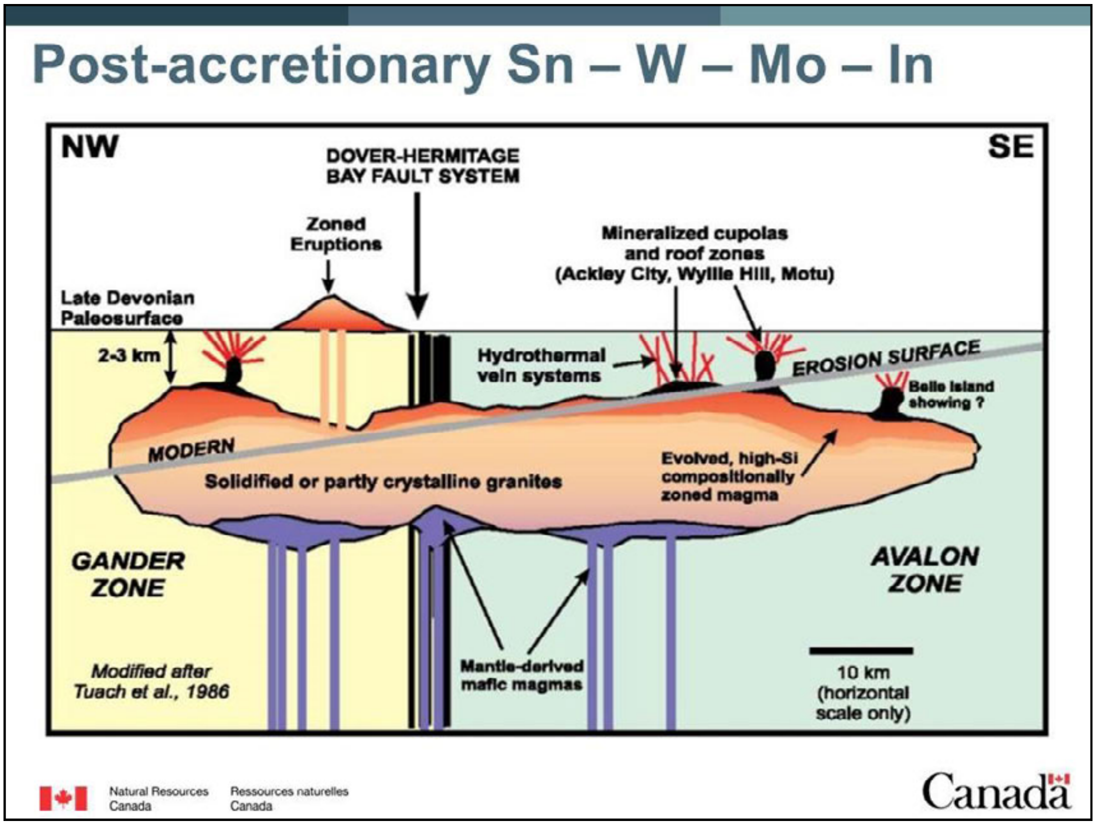
8:40 Parkhill, M.A.*, McClenaghan, M.B., Seaman, A.A., Pronk, A.G. and Rice, J.M. Glacial stratigraphic, till geochemical, and indicator mineral studies at the Sisson W-Mo and Mount Pleasant Sn-W-Mo-Bi-In polymetallic deposits, southwestern New Brunswick

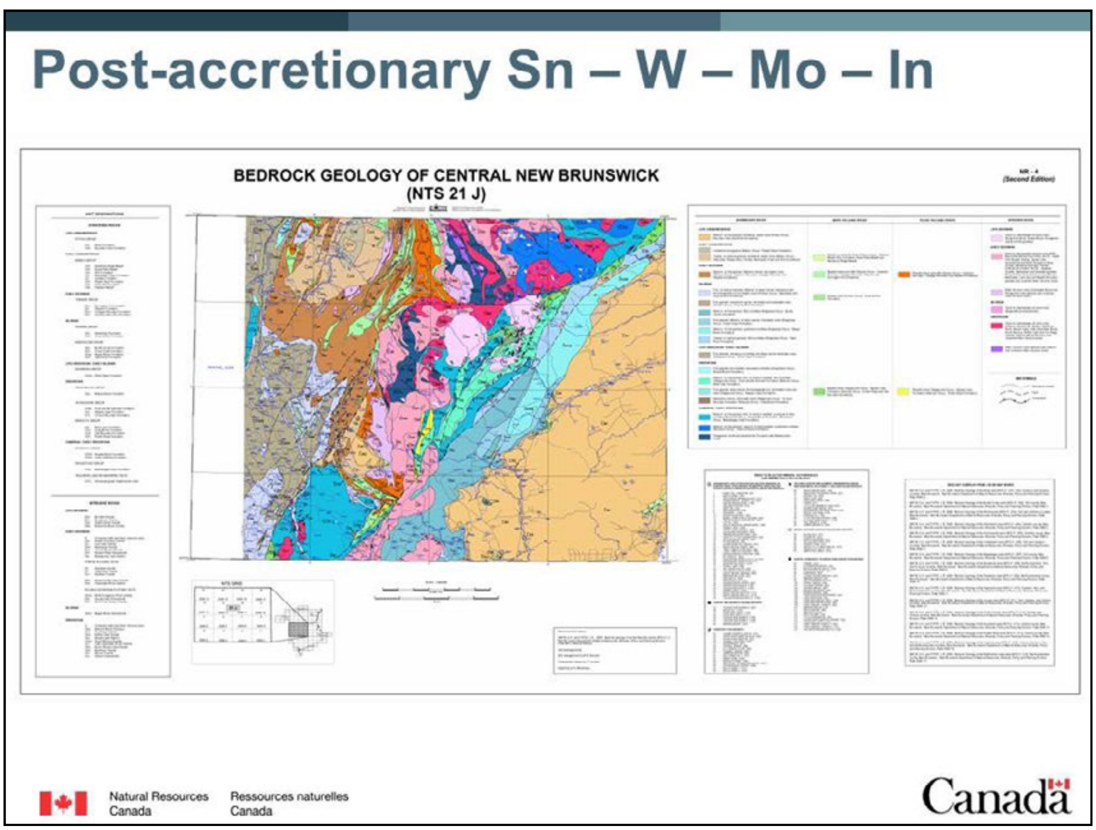

Targeted Geoscience Initiative:
Acadian Plutonic Suite
Sisson Brook
Fredericton
Mount Pleasant
Topsails
Appalachian Front
South Mountain Batholith
Halifax
South-central Newfoundland
St. John's
Appalachian Intrusive Rocks of the Canadian Atlantic Provinces
Charlottetown
Ottawa
Toronto


Post-accretionary Sn – W – Mo – In
(a) SUBDUCTION
Arc porphyry Cu±Mo deposit
Volcanic arc
Sea level
Oceanic crust
Oceanic mantle lithosphere
Mid-upper crustal I-type batholith
Lower crustal MASH zone
Basaltic underplating
1000°C
SCLM
Asthenosphere
Dehydration of oceanic crust
Partial melting of hydrated mantle wedge
(b) POST-COLLISIONAL THERMAL REBOUND
Sn-W porphyry
Post-collisional porphyry Cu±Mo±Au
S-type batholith
Upper crustal pluton
Continental crust
Thickened lithosphere
Crustal melting
Small-volume partial melting
0 km
100 km
(c) SCLM DELAMINATION
Post-collisional porphyry Cu±Mo±Au
Upper crustal pluton
Thickened crust
Continental crust
Small-volume partial melting
Asthenospheric upwelling
Delaminated mantle lithosphere
(d) POST-COLLISIONAL EXTENSION
Post-collisional alkalic epithermal Au
Small-volume partial melting
Asthenospheric upwelling
Partial-melting in lower crust
Partial-melting in hydrous cumulates (black)
— and/or metasomatized SCLM (gray)
— ± asthenospheric melt invasion
After Richards, 2011
Natural Resources Canada
Ressources naturelles Canada
Canada


Post-accretionary Sn – W – Mo – In
St. George's Bay
Moly Hill
Granite Lake Area
Great Gull Lake Area
Wylie Hill
Motu
Ackley Granite
Belle I.
Ackley City
Anesty Hill
Moly Brook
Grey River Veins
Harbour Breton Area
Fortune Bay
Placentia Bay
St. Lawrence Area
F Sn Mo W
Major Prospect
Minor Prospect or Showing
Showing or Indication
0 20 40 60 80 100
kilometres
Natural Resources Canada
Ressources naturelles Canada
Canada


Post-accretionary Sn – W – Mo – In
St. George's Bay
Moly Hill
Granite Lake Area
Ganderia
Avalonia
Wylie Hill
Motu
Ackley Granite
Belle I.
Ackley City
Moly Brook
Grey River Veins
Harbour Breton Area
Fortune Bay
Placentia Bay
St. Lawrence Area
F Sn Mo W
Major Prospect
Minor Prospect or Showing
Showing or Indication
0 20 40 60 80 100
kilometres
Natural Resources Canada
Ressources naturelles Canada
Canada


Post-accretionary Sn – W – Mo – In
NW
SE
DOVER-HERMITAGE BAY FAULT SYSTEM
Zoned Eruptions
Mineralized cupolas and roof zones (Ackley City, Wyllie Hill, Motu)
Late Devonian Paleosurface
2-3 km
Hydrothermal vein systems
EROSION SURFACE
Belle Island showing ?
MODERN
Solidified or partly crystalline granites
Evolved, high-Si compositionally zoned magma
GANDER ZONE
AVALON ZONE
Modified after Tuach et al., 1986
Mantle-derived mafic magmas
10 km (horizontal scale only)
Natural Resources Canada
Ressources naturelles Canada
Canada


Post-accretionary Sn – W – Mo – In
BEDROCK GEOLOGY OF CENTRAL NEW BRUNSWICK
(NTS 21 J)
NR - 4
(Second Edition)
Natural Resources Canada
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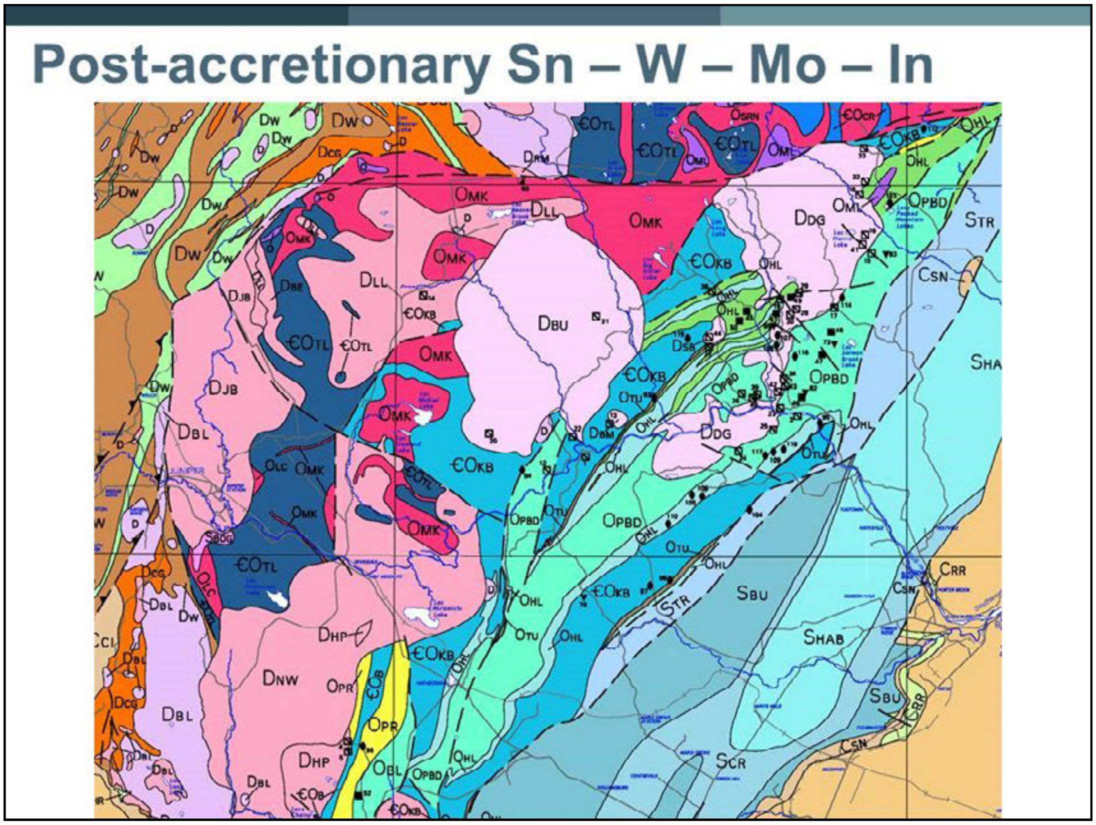
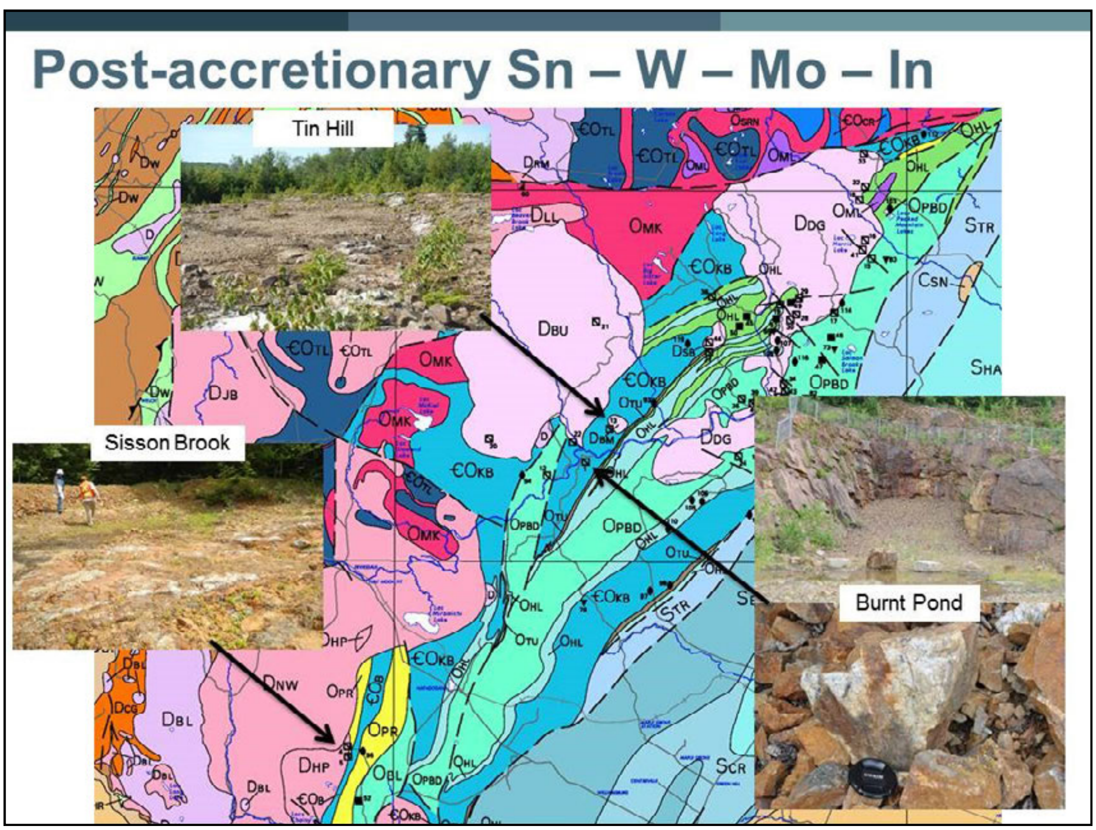
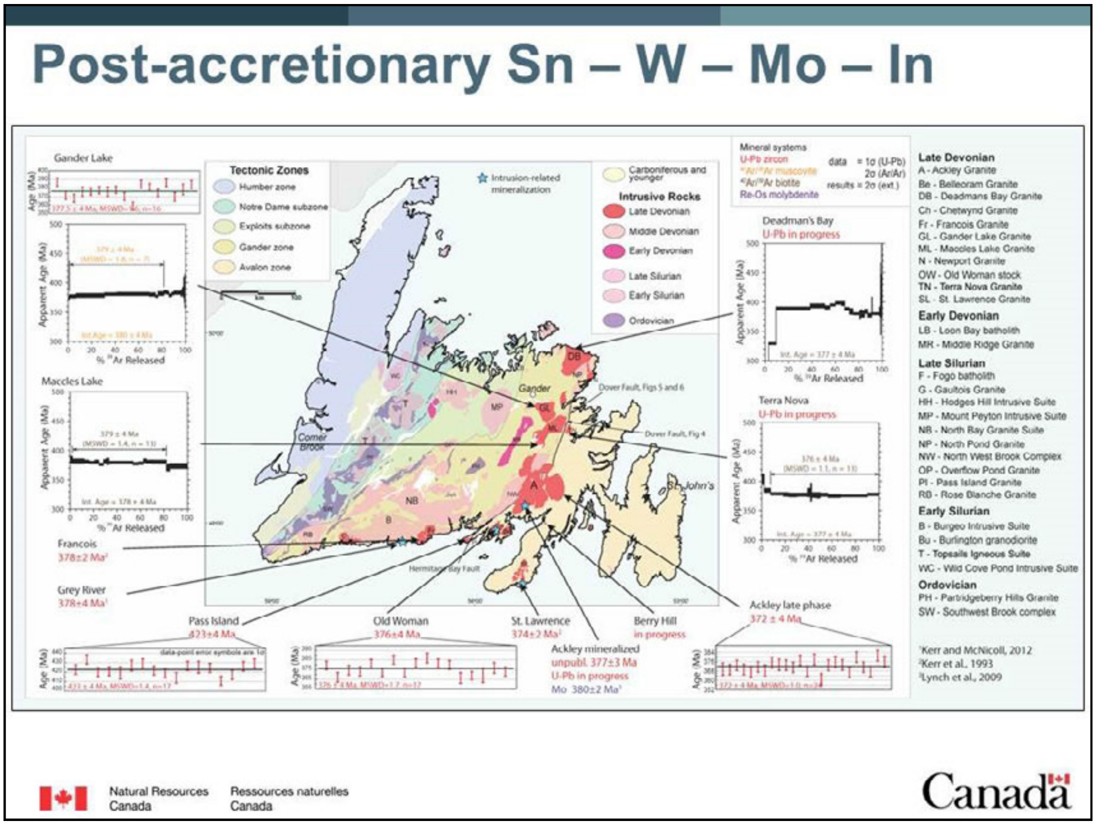
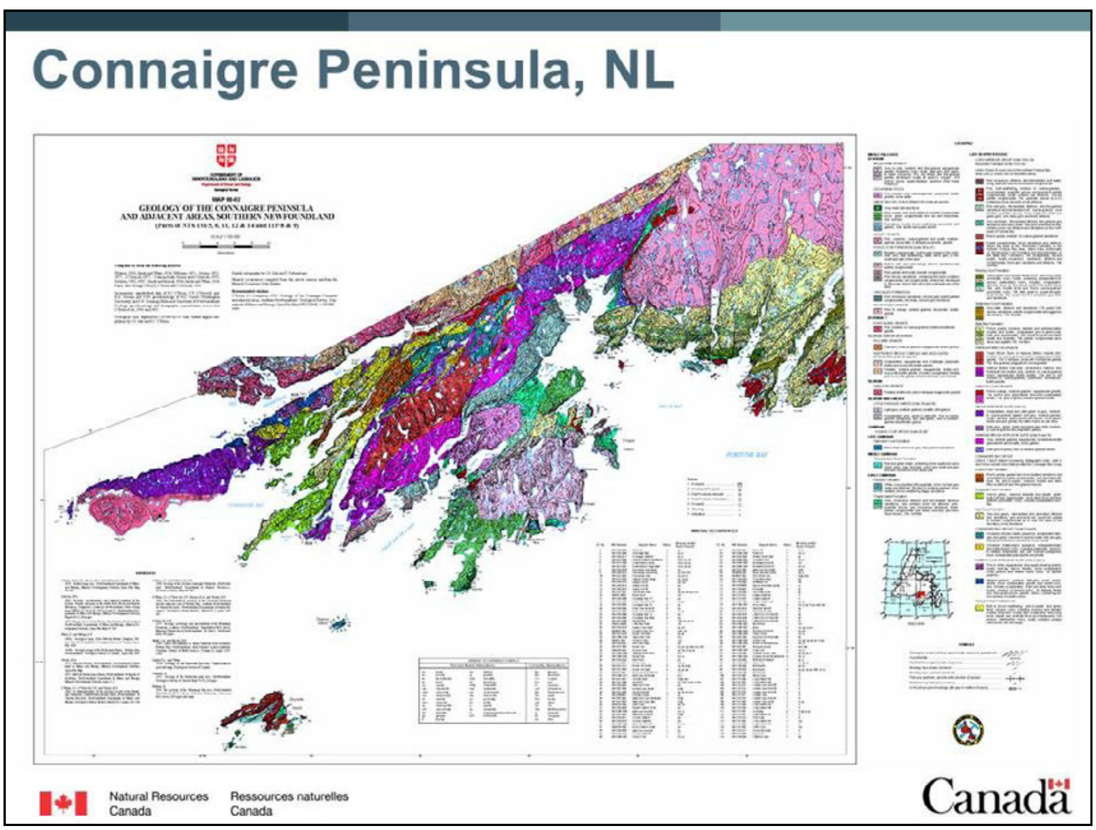
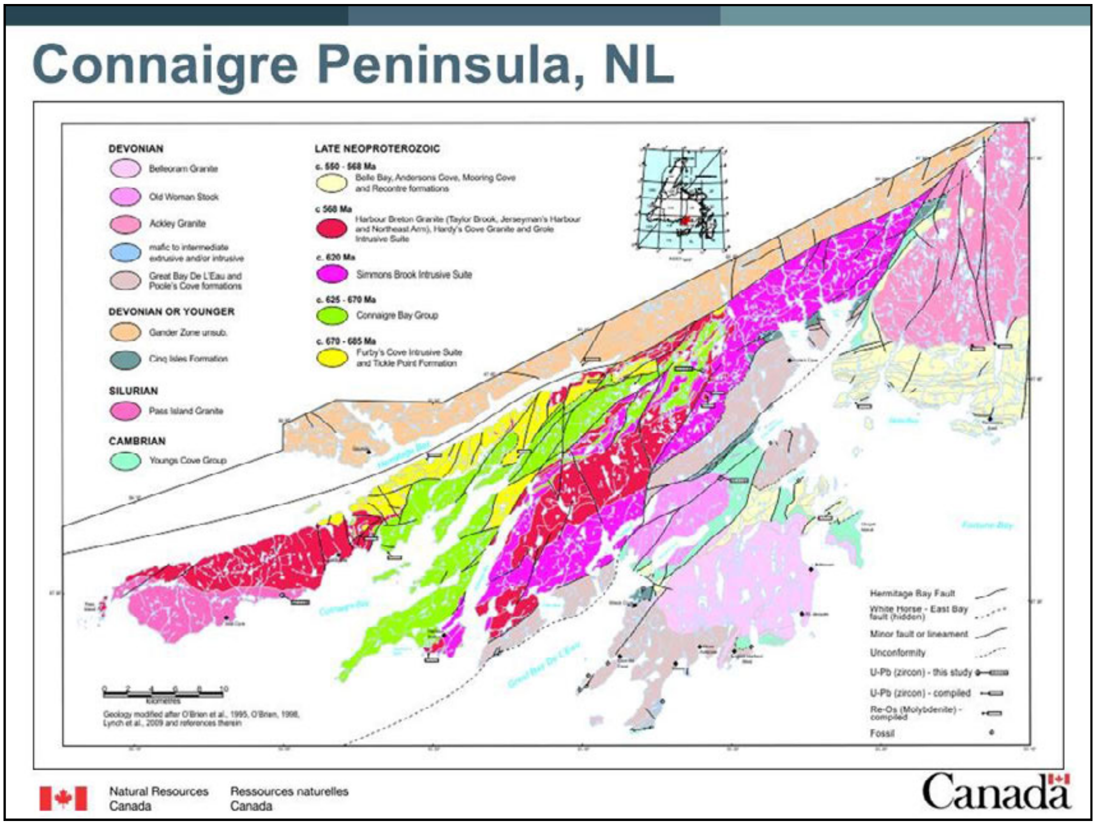
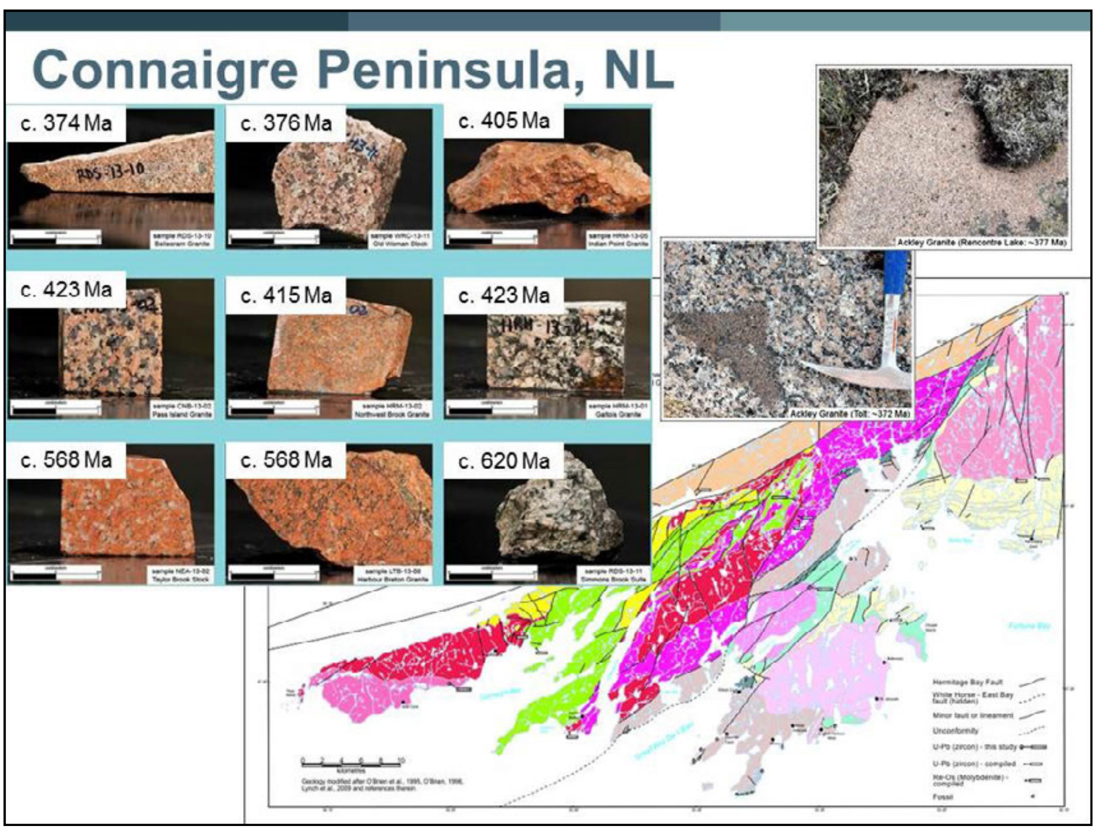

Post-accretionary Sn – W – Mo – In

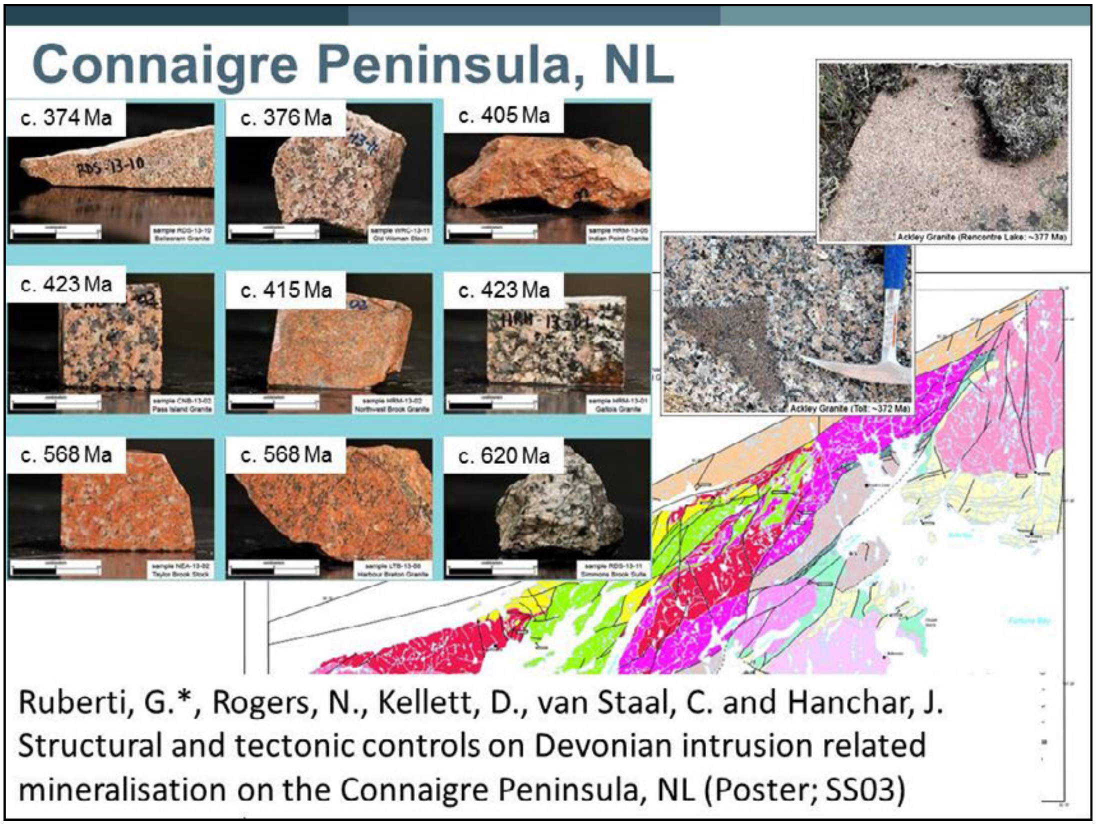

Post-accretionary Sn – W – Mo – In
Tin Hill
Sisson Brook
Burnt Pond

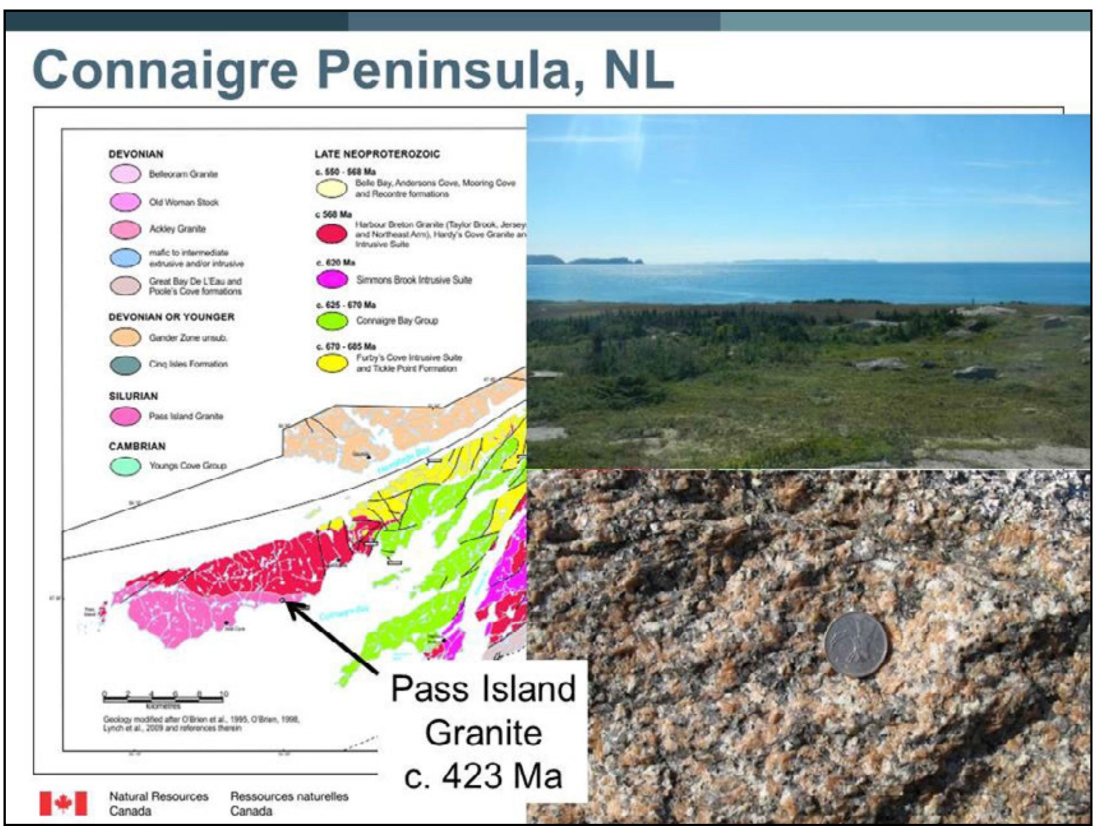

Post-accretionary Sn – W – Mo – In
Gander Lake
Tectonic Zones
Humber zone
Notre Dame subzone
Exploits subzone
Gander zone
Avalon zone
Intrusion-related mineralization
Carboniferous and younger
Intrusive Rocks
Late Devonian
Middle Devonian
Early Devonian
Late Silurian
Early Silurian
Ordovician
Mineral systems
U-Pb zircon
Ar/Ar biotite
Re-Os molybdenite
Deadman's Bay
U-Pb in progress
Maccles Lake
Terra Nova
U-Pb in progress
Gander
Corner Brook
St. John's
Dover Fault, Figs 5 and 6
Dover Fault, Fig 4
Hermitage Bay Fault
Francois
378±2 Ma
Grey River
378±4 Ma
Pass Island
423±4 Ma
Old Woman
376±4 Ma
St. Lawrence
374±2 Ma
Berry Hill
in progress
Ackley late phase
372 ± 4 Ma
Ackley mineralized
unpubl. 377±3 Ma
U-Pb in progress
Mo 380±2 Ma
Late Devonian
A - Ackley Granite
Be - Belleoram Granite
DB - Deadmans Bay Granite
Ch - Chetwynd Granite
Fr - Francois Granite
GL - Gander Lake Granite
ML - Maccles Lake Granite
N - Newport Granite
OW - Old Woman stock
TN - Terra Nova Granite
SL - St. Lawrence Granite
Early Devonian
LB - Loon Bay batholith
MR - Middle Ridge Granite
Late Silurian
F - Fogo batholith
G - Gaultois Granite
HH - Hodges Hill Intrusive Suite
MP - Mount Peyton Intrusive Suite
NB - North Bay Granite Suite
NP - North Pond Granite
NW - North West Brook Complex
OP - Overflow Pond Granite
PI - Pass Island Granite
RB - Rose Blanche Granite
Early Silurian
B - Burgeo Intrusive Suite
Bu - Burlington granodiorite
T - Topsails Igneous Suite
WC - Wild Cove Pond Intrusive Suite
Ordovician
PH - Partridgeberry Hills Granite
SW - Southwest Brook complex
Kerr and McNicoll, 2012
Kerr et al., 1993
Lynch et al., 2009
Natural Resources Canada
Ressources naturelles Canada
Canada


Connaigre Peninsula, NL
GEOLOGY OF THE CONNAIGRE PENINSULA AND ADJACENT AREAS, SOUTHERN NEWFOUNDLAND
Natural Resources Canada
Ressources naturelles Canada
Canada


Connaigre Peninsula, NL
DEVONIAN
Belleoram Granite
Old Woman Stock
Ackley Granite
mafic to intermediate extrusive and/or intrusive
Great Bay De L'Eau and Poole's Cove formations
DEVONIAN OR YOUNGER
Gander Zone unsub.
Cinq Isles Formation
SILURIAN
Pass Island Granite
CAMBRIAN
Youngs Cove Group
LATE NEOPROTEROZOIC
c. 550 - 568 Ma
Belle Bay, Andersons Cove, Mooring Cove and Recontre formations
c 568 Ma
Harbour Breton Granite (Taylor Brook, Jerseyman's Harbour and Northeast Arm), Hardy's Cove Granite and Grole Intrusive Suite
c. 620 Ma
Simmons Brook Intrusive Suite
c. 625 - 670 Ma
Connaigre Bay Group
c. 670 - 685 Ma
Furby's Cove Intrusive Suite and Tickle Point Formation
Hermitage Bay Fault
White Horse - East Bay fault (hidden)
Minor fault or lineament
Unconformity
U-Pb (zircon) - this study
U-Pb (zircon) - compiled
Re-Os (Molybdenite) - compiled
Fossil
Kilometres
Geology modified after O'Brien et al., 1995, O'Brien, 1998, Lynch et al., 2009 and references therein
Natural Resources Canada
Ressources naturelles Canada
Canada


Connaigre Peninsula, NL
c. 374 Ma
c. 376 Ma
c. 405 Ma
c. 423 Ma
c. 415 Ma
c. 423 Ma
c. 568 Ma
c. 568 Ma
c. 620 Ma
Ackley Granite (Rencontre Lake: ~377 Ma)
Ackley Granite (Tolt: ~372 Ma)


Connaigre Peninsula, NL
c. 374 Ma
c. 376 Ma
c. 405 Ma
c. 423 Ma
c. 415 Ma
c. 423 Ma
c. 568 Ma
c. 568 Ma
c. 620 Ma
Ackley Granite (Rencontre Lake: ~377 Ma)
Ackley Granite (Tolt: ~372 Ma)
Ruberti, G.*, Rogers, N., Kellett, D., van Staal, C. and Hanchar, J.
Structural and tectonic controls on Devonian intrusion related
mineralisation on the Connaigre Peninsula, NL (Poster; SS03)


Connaigre Peninsula, NL
DEVONIAN
Belleoram Granite
Old Woman Stock
Ackley Granite
mafic to intermediate extrusive and/or intrusive
Great Bay De L'Eau and Poole's Cove formations
DEVONIAN OR YOUNGER
Gander Zone unsub.
Cinq Isles Formation
SILURIAN
Pass Island Granite
CAMBRIAN
Youngs Cove Group
LATE NEOPROTEROZOIC
c. 550 - 568 Ma
Belle Bay, Andersons Cove, Mooring Cove and Recontre formations
c 568 Ma
c. 620 Ma
Simmons Brook Intrusive Suite
c. 625 - 670 Ma
Connaigre Bay Group
c. 670 - 685 Ma
Furby's Cove Intrusive Suite and Tickle Point Formation
Pass Island Granite c. 423 Ma
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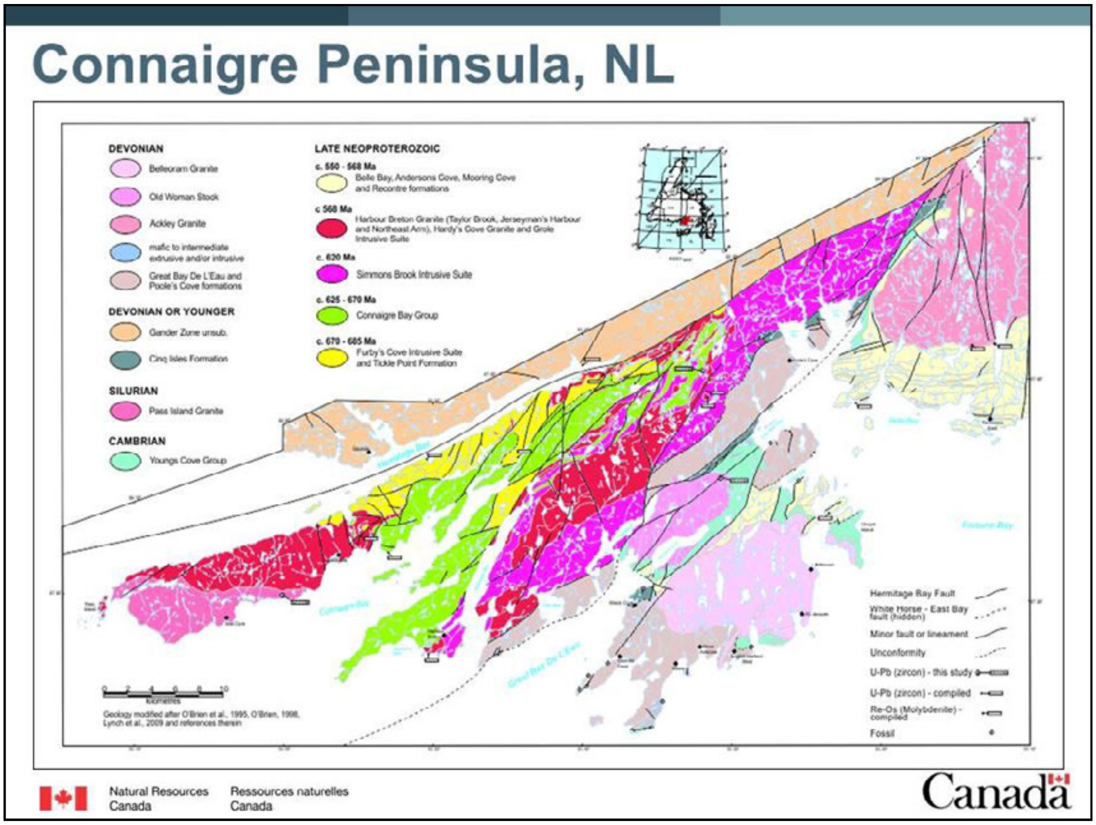
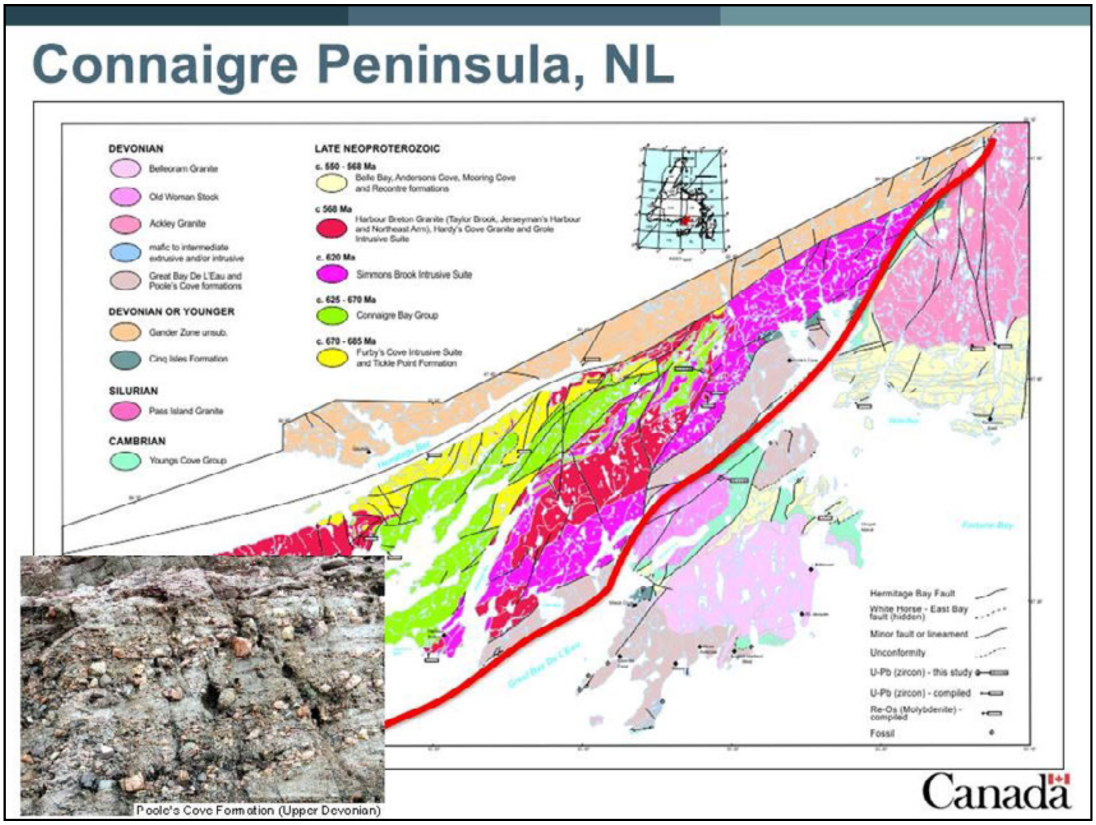
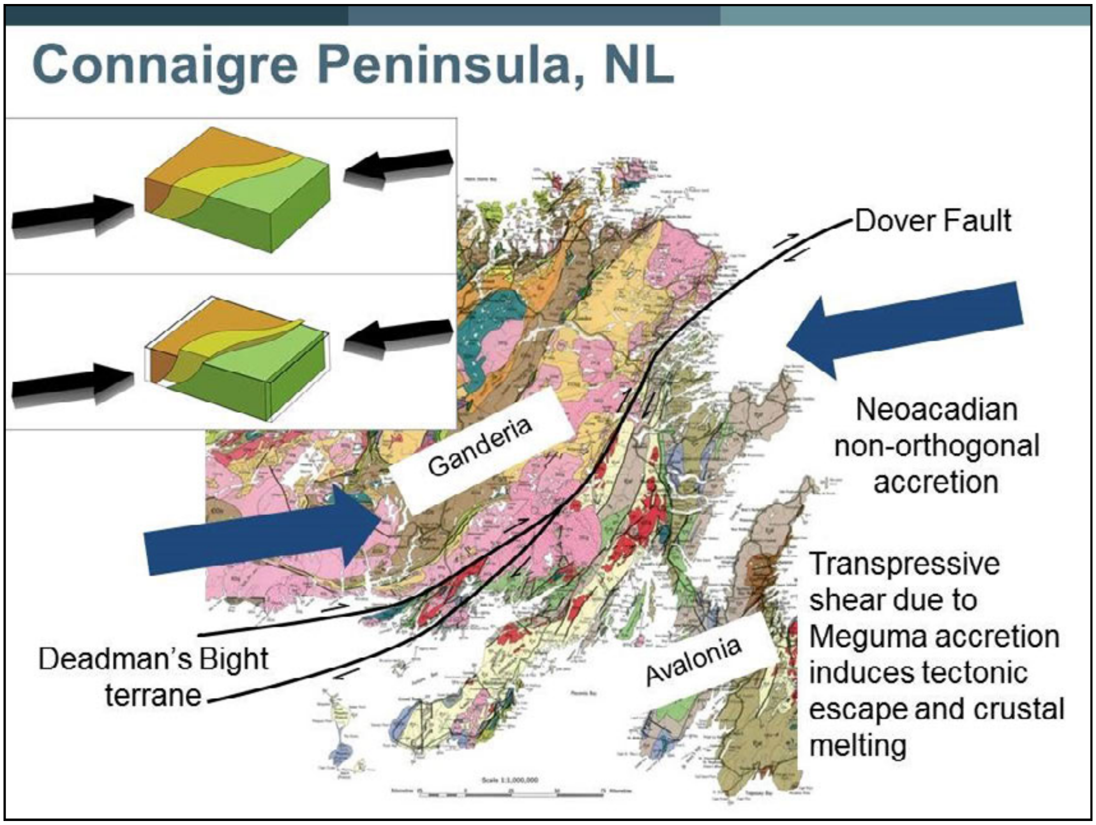
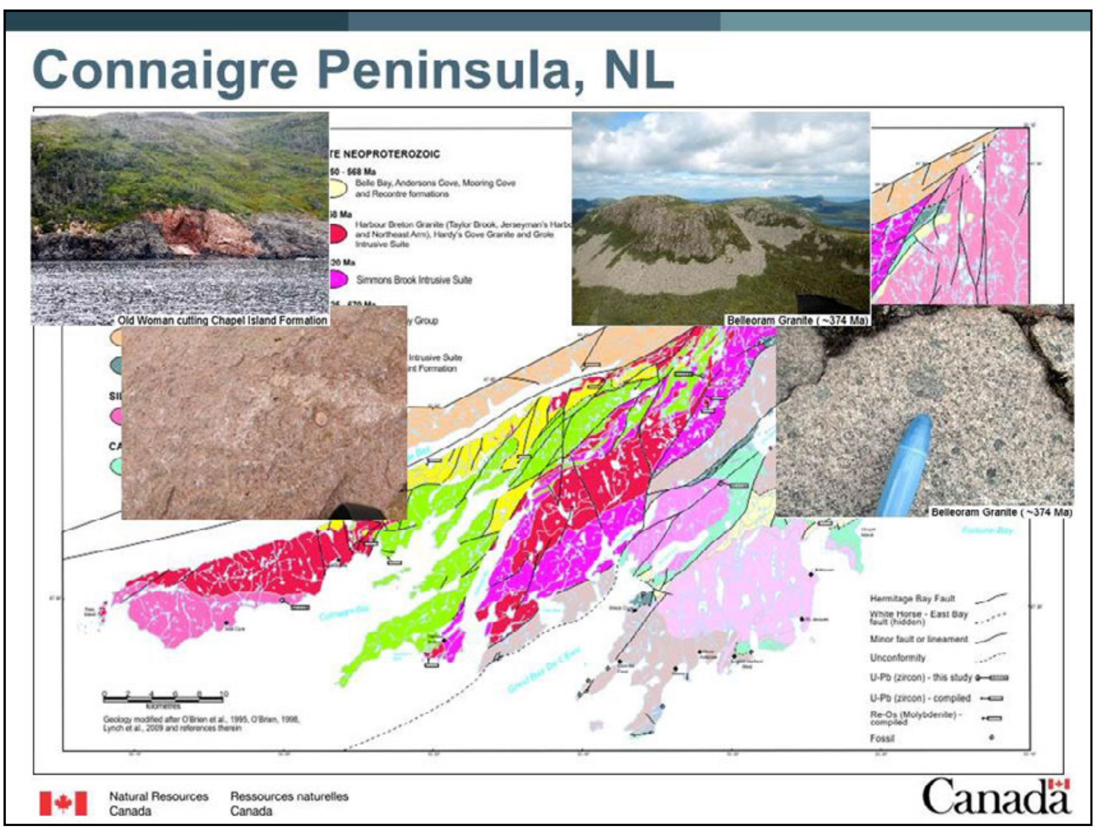
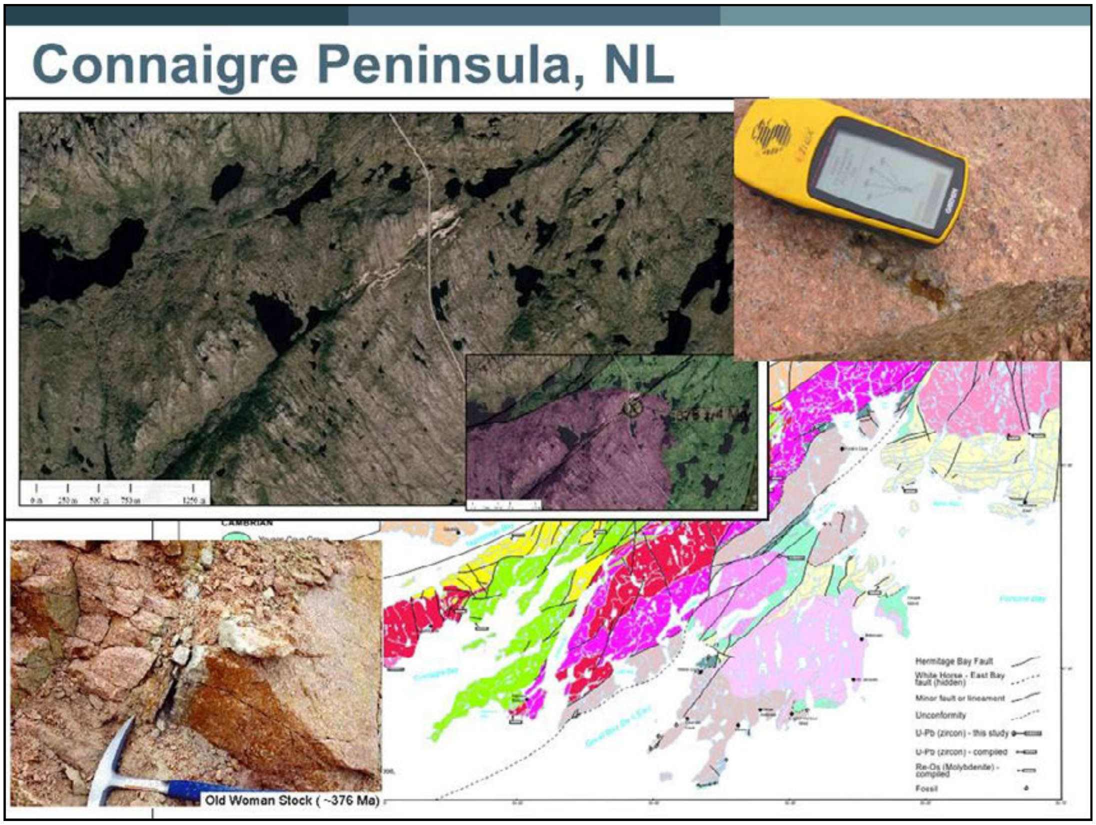
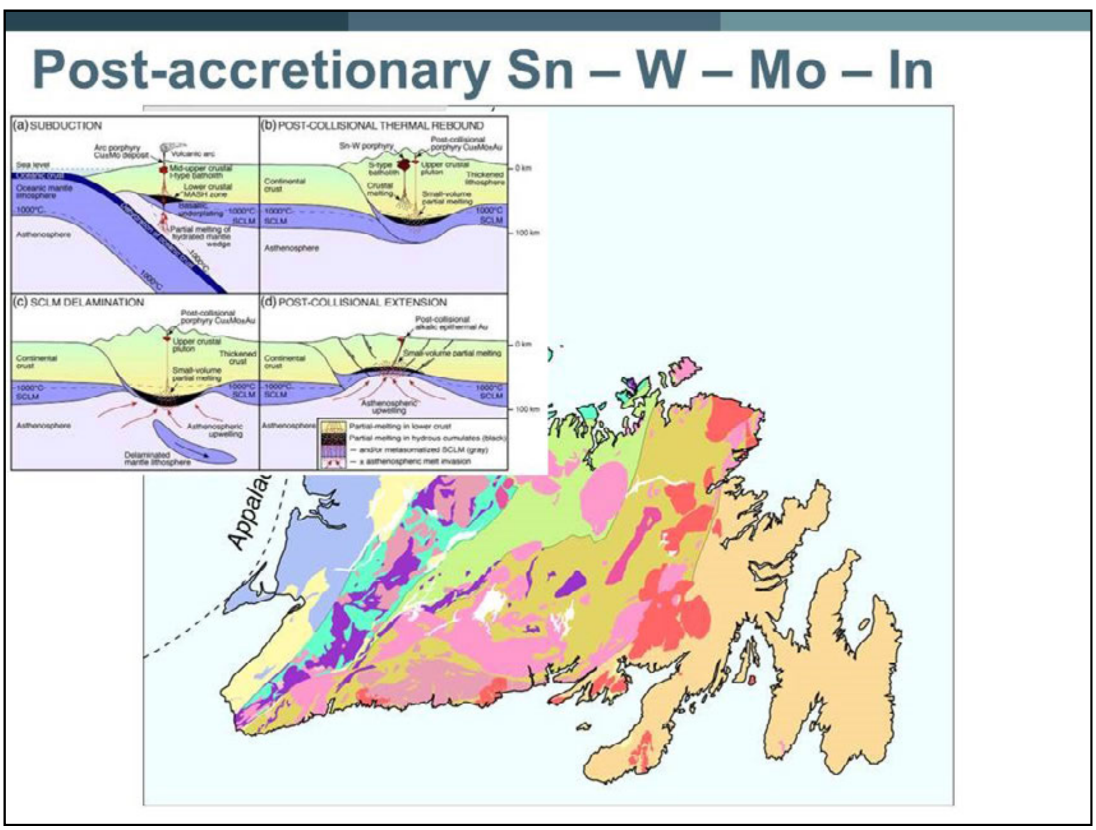

Connaigre Peninsula, NL
DEVONIAN
Belleoram Granite
Old Woman Stock
Ackley Granite
mafic to intermediate extrusive and/or intrusive
Great Bay De L'Eau and Poole's Cove formations
DEVONIAN OR YOUNGER
Gander Zone unsub.
Cinq Isles Formation
SILURIAN
Pass Island Granite
CAMBRIAN
Youngs Cove Group
LATE NEOPROTEROZOIC
c. 550 - 568 Ma
Belle Bay, Andersons Cove, Mooring Cove and Recontre formations
c 568 Ma
Harbour Breton Granite (Taylor Brook, Jerseyman's Harbour and Northeast Arm), Hardy's Cove Granite and Grole Intrusive Suite
c. 620 Ma
Simmons Brook Intrusive Suite
c. 625 - 670 Ma
Connaigre Bay Group
c. 670 - 685 Ma
Furby's Cove Intrusive Suite and Tickle Point Formation
Hermitage Bay Fault
White Horse - East Bay fault (hidden)
Minor fault or lineament
Unconformity
U-Pb (zircon) - this study
U-Pb (zircon) - compiled
Re-Os (Molybdenite) - compiled
Fossil
0 2 4 6 8 10
Kilometres
Geology modified after O'Brien et al., 1995, O'Brien, 1998, Lynch et al., 2009 and references therein
Natural Resources Canada
Ressources naturelles Canada
Canada

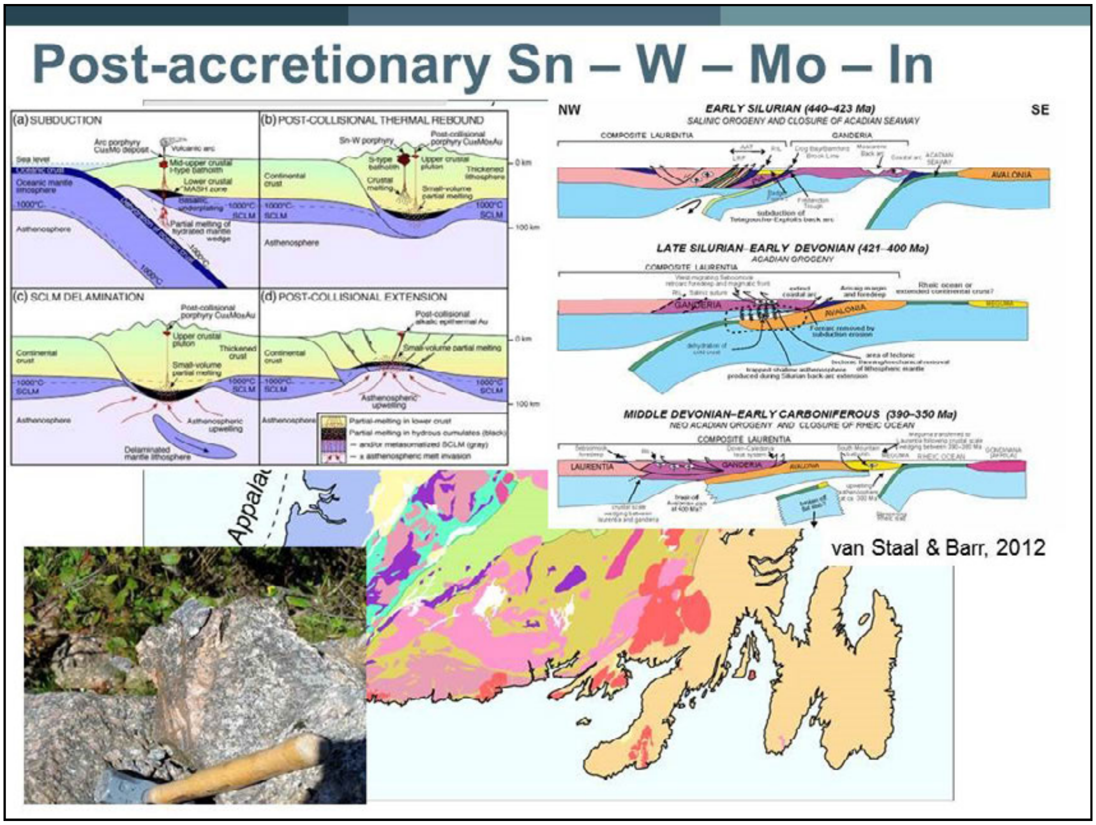

Connaigre Peninsula, NL
DEVONIAN
Belleoram Granite
Old Woman Stock
Ackley Granite
mafic to intermediate extrusive and/or intrusive
Great Bay De L'Eau and Poole's Cove formations
DEVONIAN OR YOUNGER
Gander Zone unsub.
Cinq Isles Formation
SILURIAN
Pass Island Granite
CAMBRIAN
Youngs Cove Group
LATE NEOPROTEROZOIC
c. 550 - 568 Ma
Belle Bay, Andersons Cove, Mooring Cove and Recontre formations
c 568 Ma
Harbour Breton Granite (Taylor Brook, Jerseyman's Harbour and Northeast Arm), Hardy's Cove Granite and Grole Intrusive Suite
c. 620 Ma
Simmons Brook Intrusive Suite
c. 625 - 670 Ma
Connaigre Bay Group
c. 670 - 685 Ma
Furby's Cove Intrusive Suite and Tickle Point Formation
Hermitage Bay Fault
White Horse - East Bay fault (hidden)
Minor fault or lineament
Unconformity
U-Pb (zircon) - this study
U-Pb (zircon) - compiled
Re-Os (Molybdenite) - compiled
Fossil
Poole's Cove Formation (Upper Devonian)
Canada

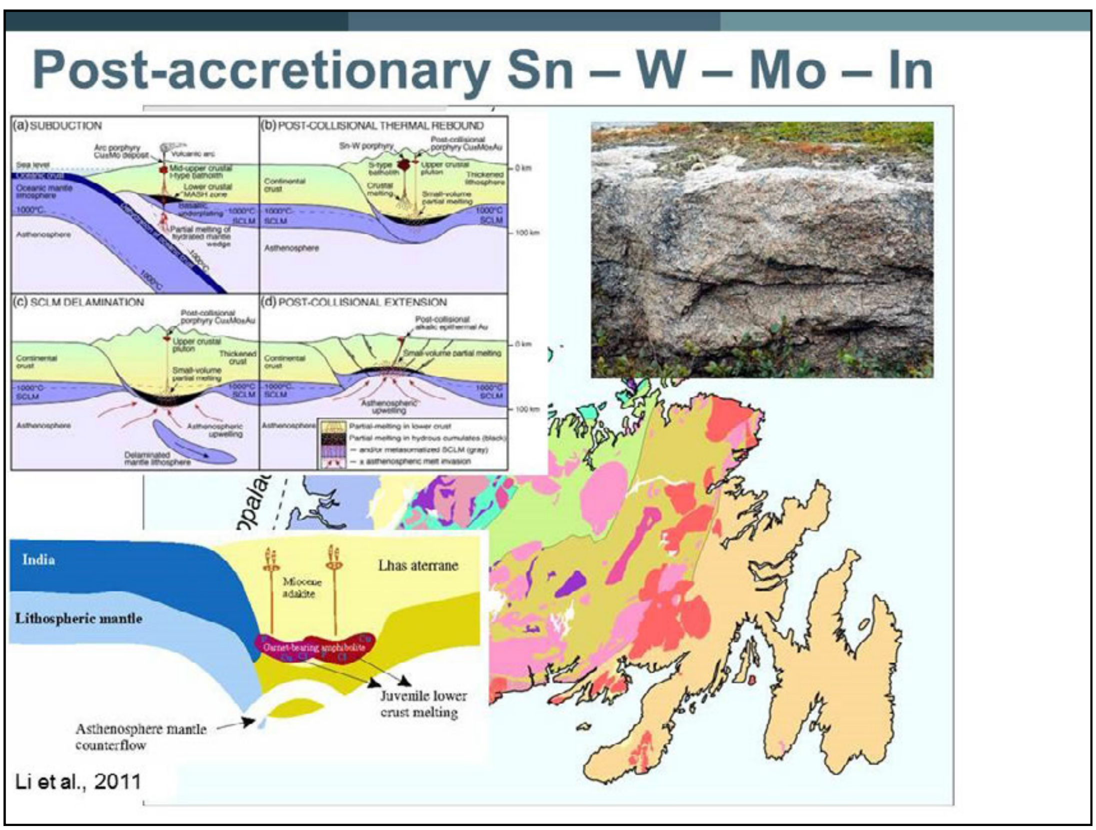

Connaigre Peninsula, NL
Dover Fault
Neoacadian
non-orthogonal
accretion
Ganderia
Transpressive
shear due to
Meguma accretion
induces tectonic
escape and crustal
melting
Deadman's Bight
terrane
Avalonia

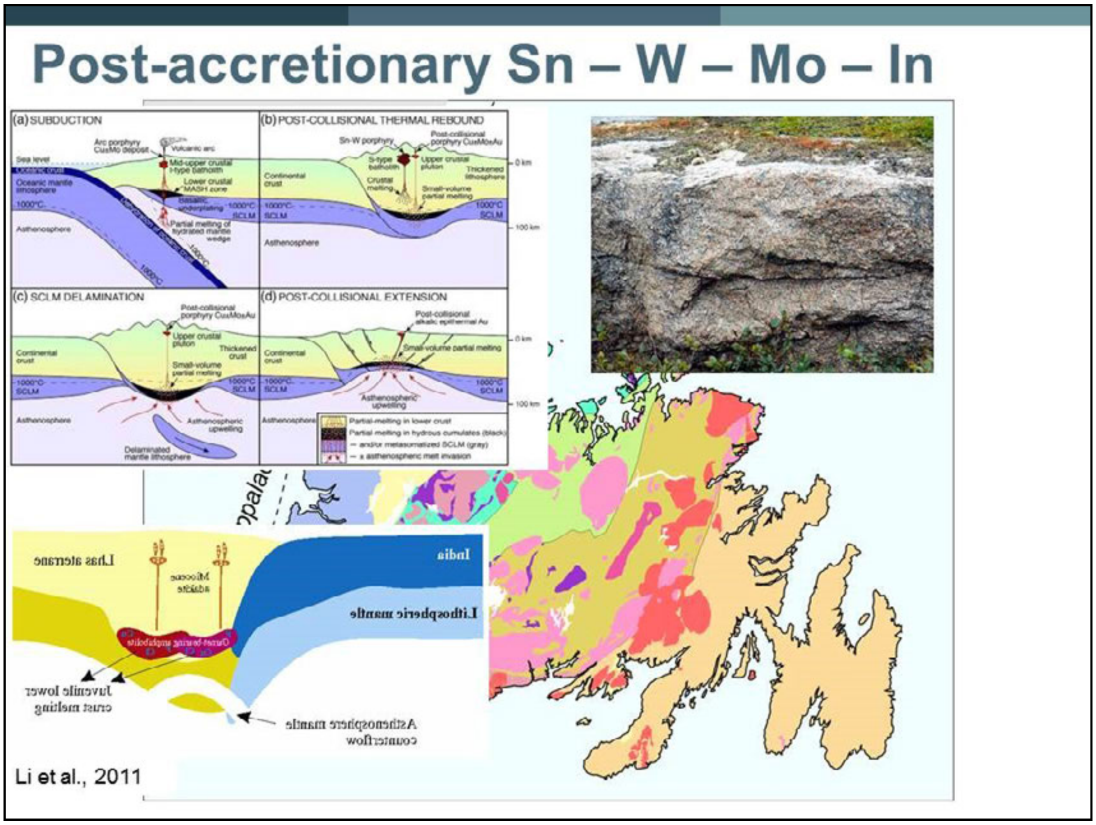

Connaigre Peninsula, NL
Old Woman cutting Chapel Island Formation
TE NEOPROTEROZOIC
Belle Bay, Andersons Cove, Mooring Cove
and Recontre formations
Harbour Breton Granite (Taylor Brook, Jerseyman's Harb
and Northeast Arm), Hardy's Cove Granite and Grole
Intrusive Suite
Simmons Brook Intrusive Suite
Belleoram Granite (~374 Ma)
Belleoram Granite (~374 Ma)
Hermitage Bay Fault
White Horse - East Bay fault (hidden)
Minor fault or lineament
Unconformity
U-Pb (zircon) - this study
U-Pb (zircon) - compiled
Re-Os (Molybdenite) - compiled
Fossil
Natural Resources Canada
Ressources naturelles Canada
Canada

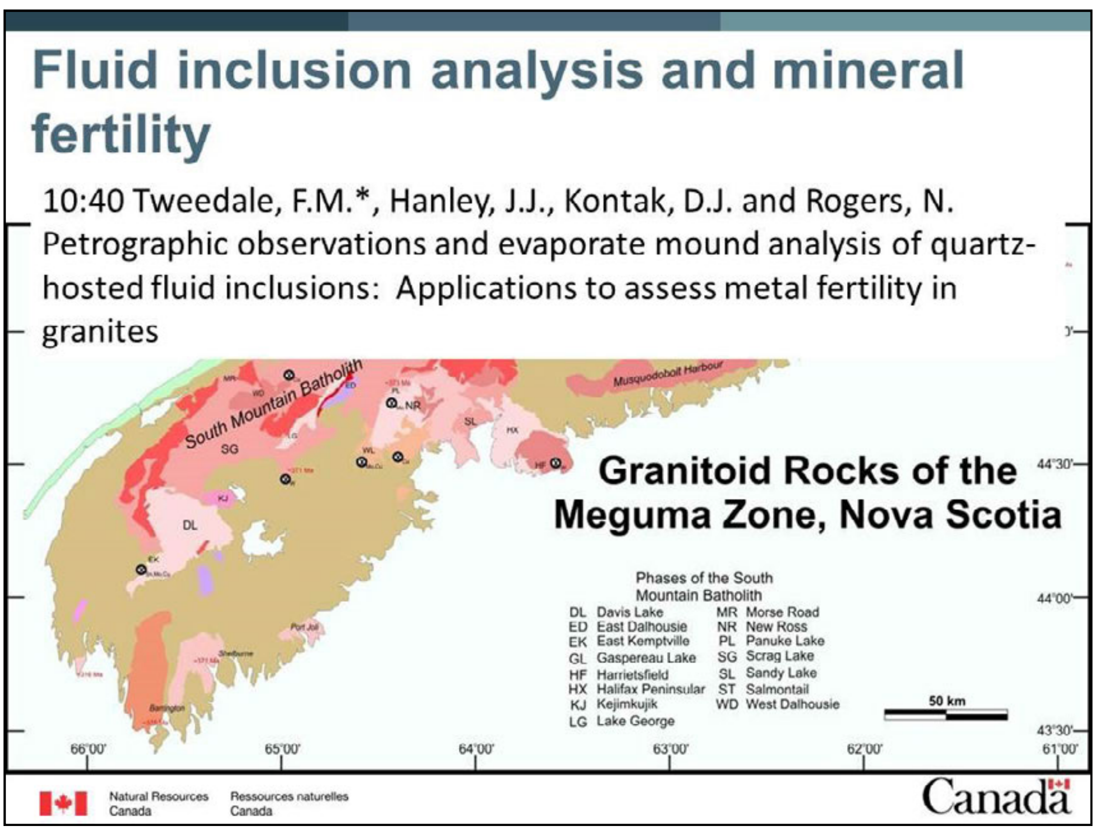

Connaigre Peninsula, NL
Hermitage Bay Fault
White Horse - East Bay fault (hidden)
Minor fault or lineament
Unconformity
U-Pb (zircon) - this study
U-Pb (zircon) - compiled
Re-Os (Molybdenite) - compiled
Fossil
CAMBRIAN
Old Woman Stock (~376 Ma)


Post-accretionary Sn – W – Mo – In
(a) SUBDUCTION
Arc porphyry Cu±Mo deposit
Volcanic arc
Sea level
Oceanic crust
Oceanic mantle lithosphere
Mid-upper crustal I-type batholith
Lower crustal MASH zone
Basaltic underplating
1000°C
SCLM
Asthenosphere
Partial melting of hydrated mantle wedge
(b) POST-COLLISIONAL THERMAL REBOUND
Sn-W porphyry
Post-collisional porphyry Cu±Mo±Au
S-type batholith
Upper crustal pluton
Thickened lithosphere
Continental crust
Crustal melting
Small-volume partial melting
0 km
100 km
(c) SCLM DELAMINATION
Post-collisional porphyry Cu±Mo±Au
Upper crustal pluton
Thickened crust
Small-volume partial melting
Asthenospheric upwelling
Delaminated mantle lithosphere
(d) POST-COLLISIONAL EXTENSION
Post-collisional alkalic epithermal Au
Small-volume partial melting
Asthenospheric upwelling
Partial melting in lower crust
Partial melting in hydrous cumulates (black)
– and/or metasomatized SCLM (gray)
– ± asthenospheric melt invasion
Appalac


Post-accretionary Sn – W – Mo – In
(a) SUBDUCTION
(b) POST-COLLISIONAL THERMAL REBOUND
(c) SCLM DELAMINATION
(d) POST-COLLISIONAL EXTENSION
NW
SE
EARLY SILURIAN (440–423 Ma)
SALINIC OROGENY AND CLOSURE OF ACADIAN SEAWAY
LATE SILURIAN–EARLY DEVONIAN (421–400 Ma)
ACADIAN OROGENY
MIDDLE DEVONIAN–EARLY CARBONIFEROUS (390–350 Ma)
NEO ACADIAN OROGENY AND CLOSURE OF RHEIC OCEAN
van Staal & Barr, 2012


Post-accretionary Sn – W – Mo – In
(a) SUBDUCTION
(b) POST-COLLISIONAL THERMAL REBOUND
(c) SCLM DELAMINATION
(d) POST-COLLISIONAL EXTENSION
India
Lhas aterrane
Miocene adakite
Lithospheric mantle
Juvenile lower crust melting
Asthenosphere mantle counterflow
Li et al., 2011


Post-accretionary Sn – W – Mo – In
(a) SUBDUCTION
(b) POST-COLLISIONAL THERMAL REBOUND
(c) SCLM DELAMINATION
(d) POST-COLLISIONAL EXTENSION
Li et al., 2011


Fluid inclusion analysis and mineral fertility
10:40 Tweedale, F.M.*, Hanley, J.J., Kontak, D.J. and Rogers, N.
Petrographic observations and evaporate mound analysis of quartz-hosted fluid inclusions: Applications to assess metal fertility in granites
South Mountain Batholith
Granitoid Rocks of the Meguma Zone, Nova Scotia
Phases of the South Mountain Batholith
DL Davis Lake
ED East Dalhousie
EK East Kemptville
GL Gaspereau Lake
HF Harrietsfield
HX Halifax Peninsular
KJ Kejimkujik
LG Lake George
MR Morse Road
NR New Ross
PL Panuke Lake
SG Scrag Lake
SL Sandy Lake
ST Salmontail
WD West Dalhousie
50 km
Musquodoboit Harbour
44°30'
44°00'
43°30'
66°00'
65°00'
64°00'
63°00'
62°00'
61°00'
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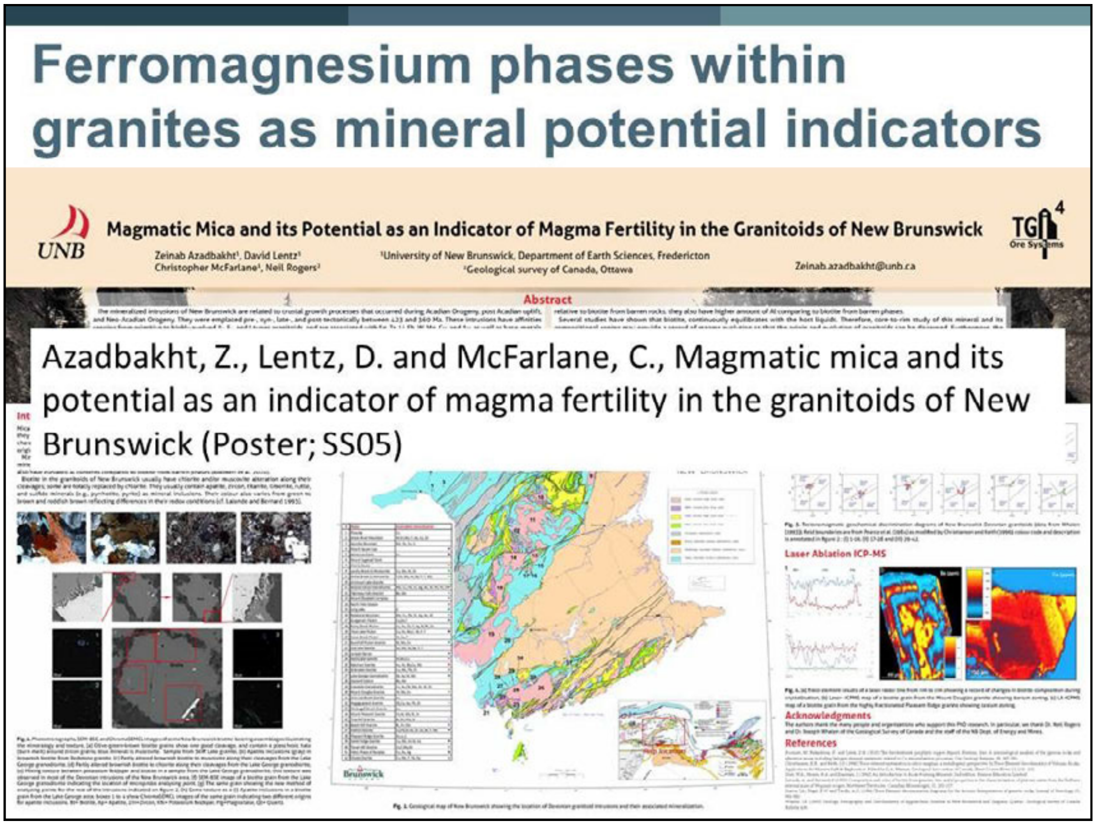
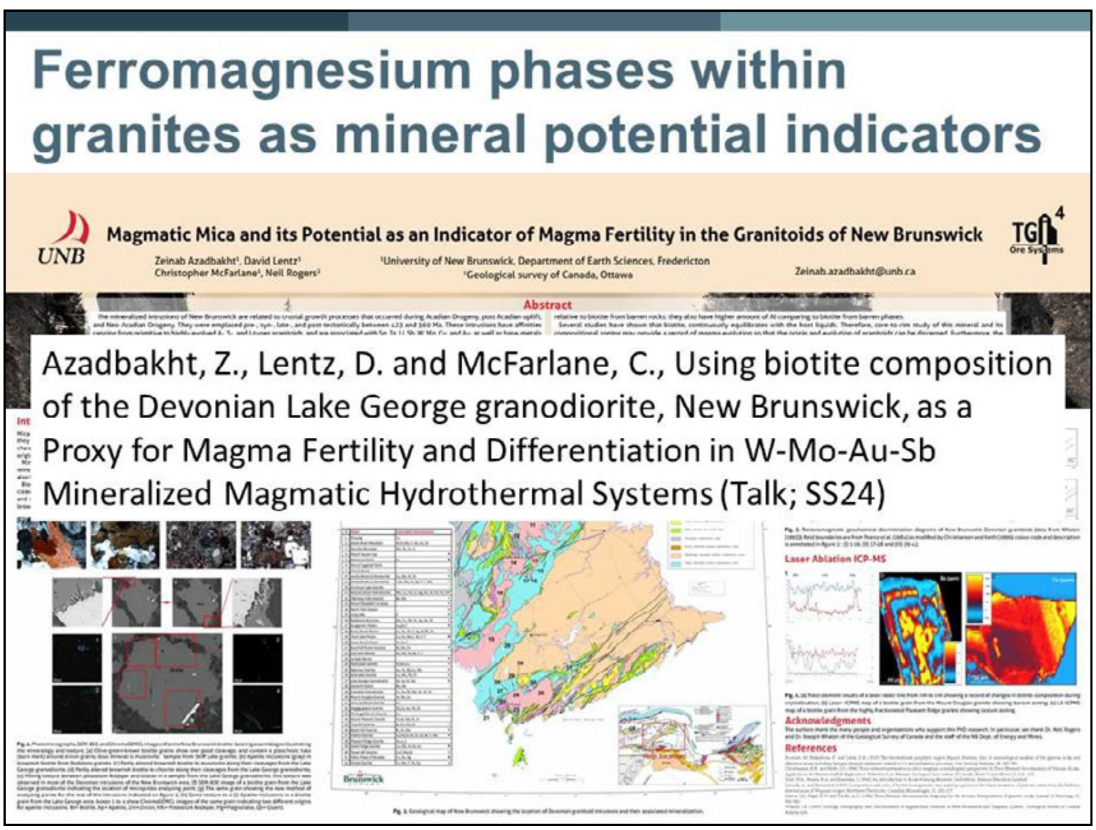
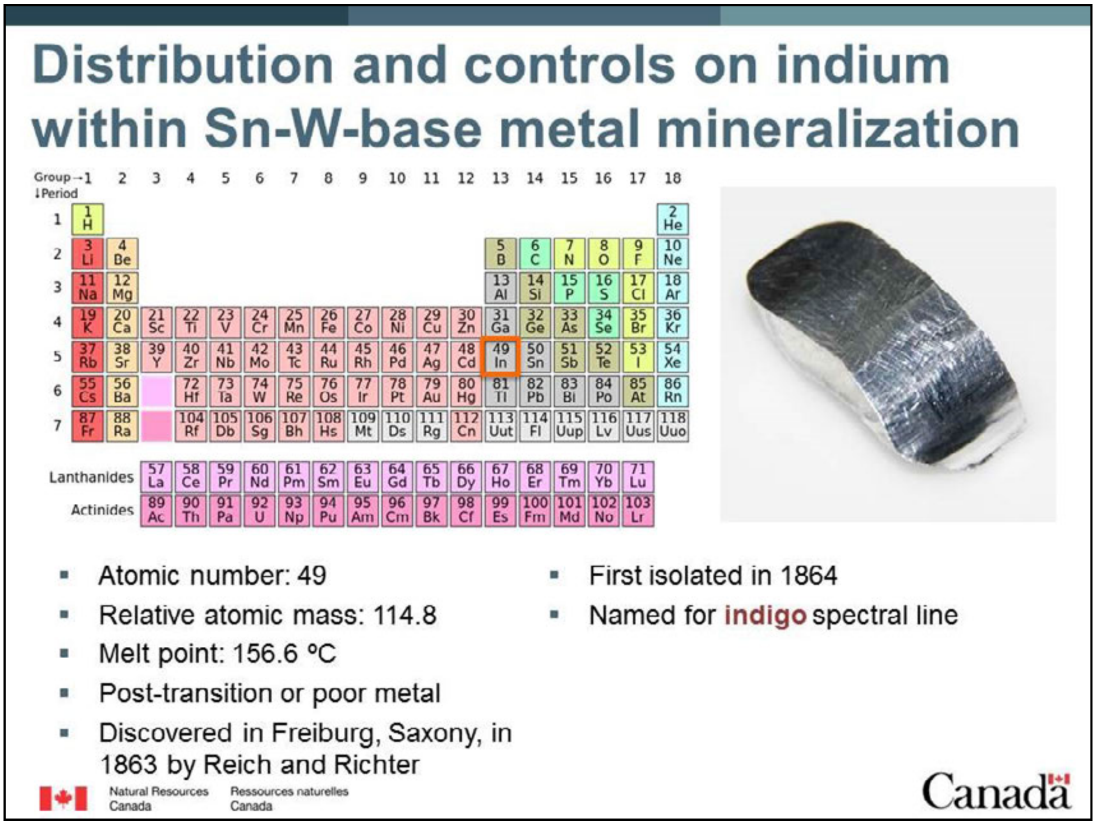
Canada


Ferromagnesium phases within granites as mineral potential indicators
Magmatic Mica and its Potential as an Indicator of Magma Fertility in the Granitoids of New Brunswick
UNB
Zeinab Azadbakht¹, David Lentz¹
Christopher McFarlane¹, Neil Rogers²
¹University of New Brunswick, Department of Earth Sciences, Fredericton
²Geological survey of Canada, Ottawa
Zeinab.azadbakht@unb.ca
Abstract
Azadbakht, Z., Lentz, D. and McFarlane, C., Magmatic mica and its potential as an indicator of magma fertility in the granitoids of New Brunswick (Poster; SS05)
Laser Ablation ICP-MS
Acknowledgments
References


Ferromagnesium phases within granites as mineral potential indicators
Magmatic Mica and its Potential as an Indicator of Magma Fertility in the Granitoids of New Brunswick
UNB
Zeinab Azadbakht¹, David Lentz¹
Christopher McFarlane¹, Neil Rogers²
¹University of New Brunswick, Department of Earth Sciences, Fredericton
²Geological survey of Canada, Ottawa
Zeinab.azadbakht@unb.ca
Abstract
Azadbakht, Z., Lentz, D. and McFarlane, C., Using biotite composition of the Devonian Lake George granodiorite, New Brunswick, as a Proxy for Magma Fertility and Differentiation in W-Mo-Au-Sb Mineralized Magmatic Hydrothermal Systems (Talk; SS24)
Laser Ablation ICP-MS
Acknowledgments
References


Distribution and controls on indium within Sn-W-base metal mineralization
Atomic number: 49
Relative atomic mass: 114.8
Melt point: 156.6 °C
Post-transition or poor metal
Discovered in Freiburg, Saxony, in 1863 by Reich and Richter
First isolated in 1864
Named for indigo spectral line
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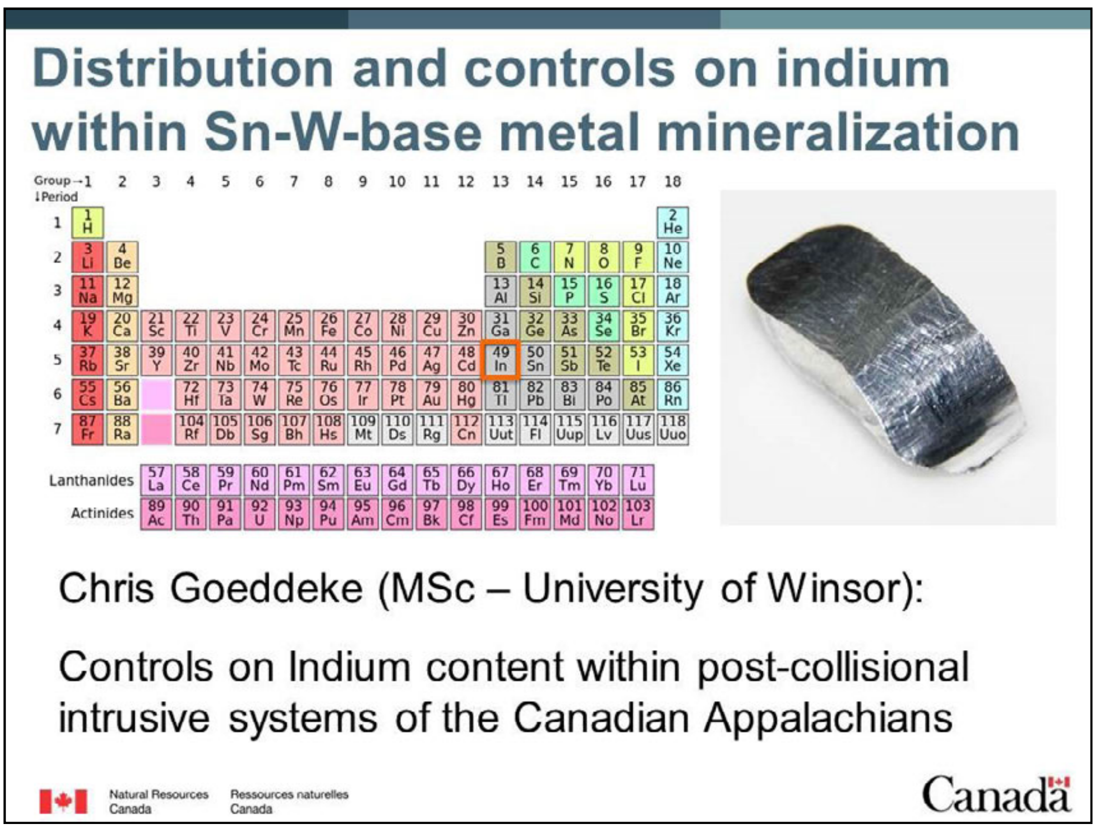
Distribution and controls on indium within Sn-W-base metal mineralization
Chris Goeddeke (MSc – University of Winsor):
Controls on Indium content within post-collisional intrusive systems of the Canadian Appalachians
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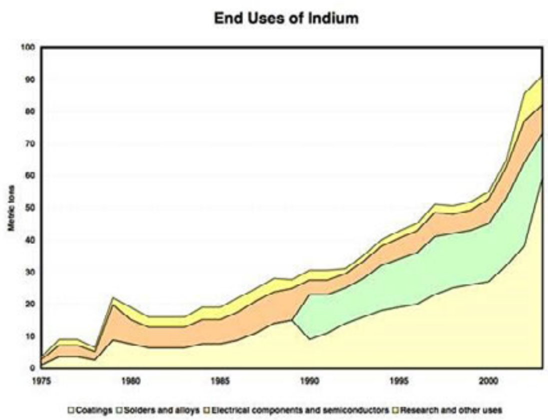
Uses of Indium



- The primary use of indium is for thin film coatings, principally indium-tin oxide (ITO)
  - Approximately 85% of global indium consumption
  - ITO is commonly 90% In_2O_3 and 10% SnO
  - Transparent, electrically conductive, low IR transmissibility

Second greatest use is for specialist solders and low melt-point alloys (≈ 8%)

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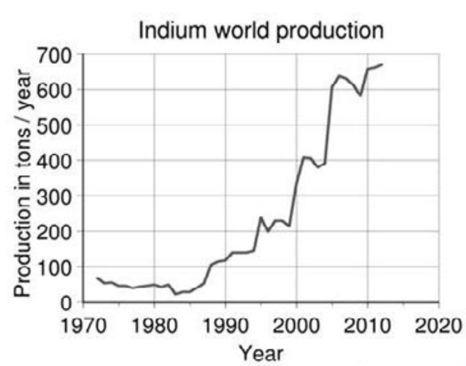
Indium Supply

- 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 concentrate with 5310 ppm In, and hydrometallurgical indium sponge at 96.25%



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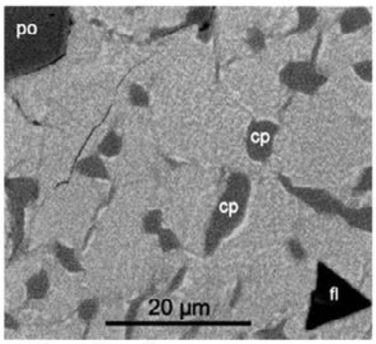
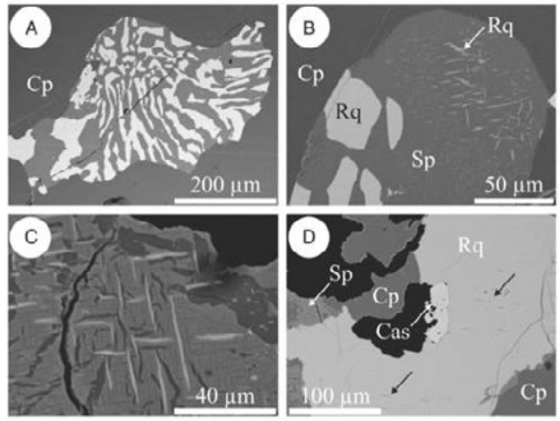
Indium Mineralogy



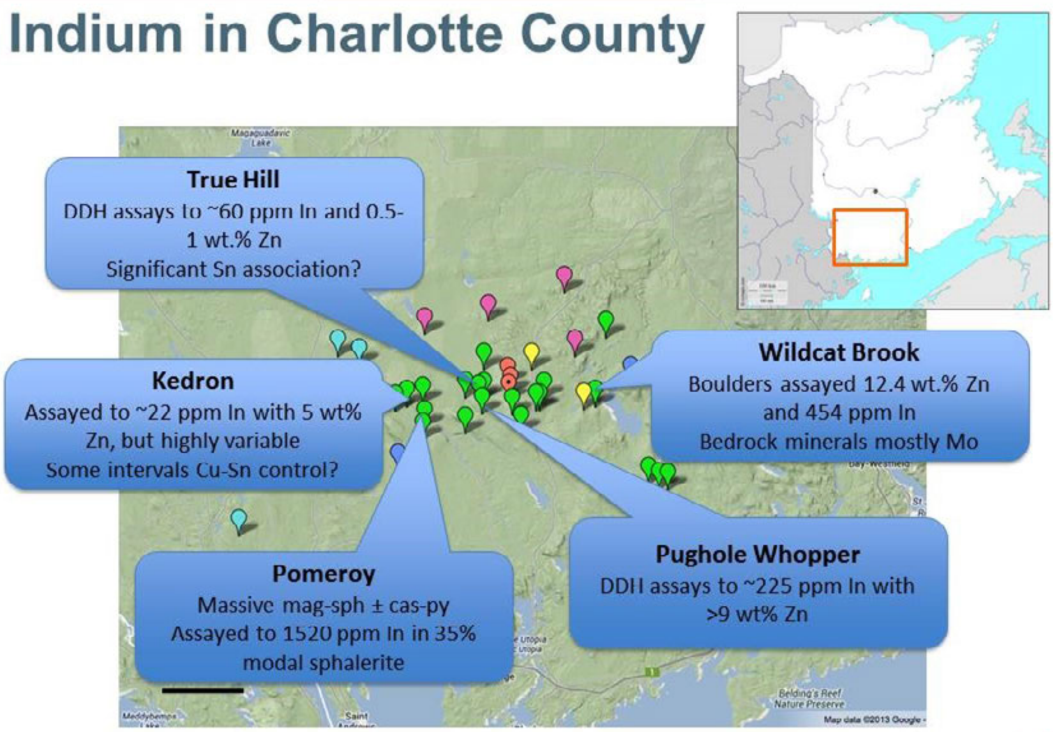
Sinclair *et al.* (2006)



Cook *et al.* (2011)

- Most In sequestered into sphalerite, coupled substitution:
- 2(Zn2+,Fe2+) ⇔ In3+ + Cu+
- Rapidly quenched high-temperature sphalerite has been shown to contain up to 14 wt.% In
- Slow cooling rates allow almost complete exsolution

Indium in Charlotte County



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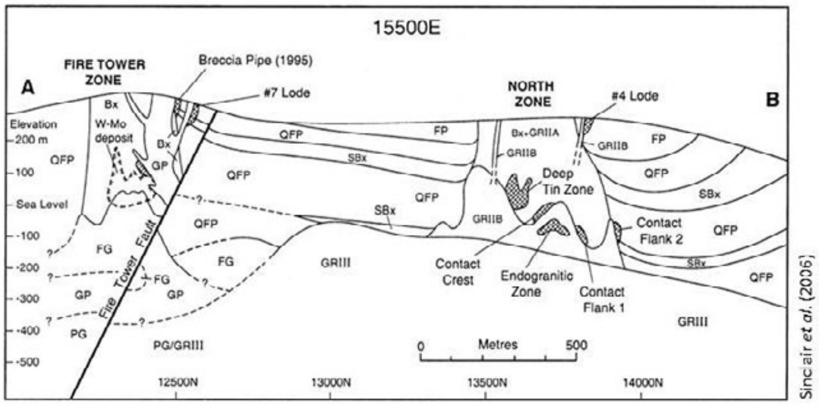
Indium in the Mount Pleasant Deposits



- Updated 2012 NI 43-101 indium resource estimate:
  - Indicated = 12.4 Mt @ 64 ppm
  - Inferred = 2.8 Mt @ 70 ppm
- Total contained In metal ≈ 987,000 kg ($0.6 – 0.7 bn)

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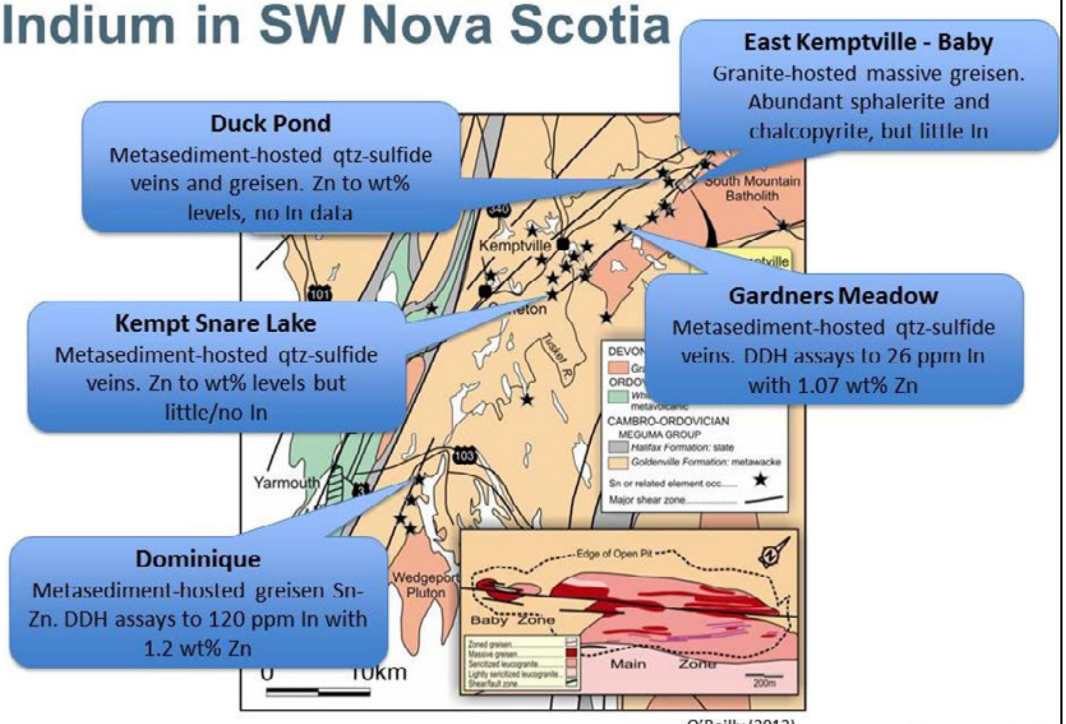
Indium in SW Nova Scotia



O'Reilly (2012)

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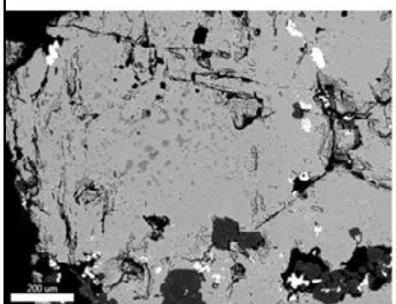
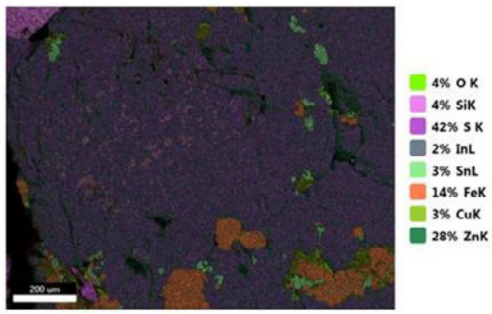
Project Outline

- What controls indium distribution within granite-associated Sn-W-Zn-Cu mineralization?
  - Do indium-rich zones simply reflect indium-rich fluid sources?
  - Is indium sequestration controlled by abundance of other elements (e.g. Cu, S, Zn) or a particular PT window?
  - Do high In+Cu zones reflect proximity to heat and fluid sources?
  - PTX conditions during mineral precipitation determined by fluid inclusion microthermometry and single inclusion LA-ICP-MS





Project Outline

- In distribution is decoupled from W mineralisation, and likely from the main phase of Sn mineralisation
- Decoupling suggests that secondary enrichment/metasomatism by late stage In-rich, Zn-poor fluids are a primary control
- Kesterite is thought to be the mineral giving the best indication of high-temperature, high-copper fluids most conducive to the high-indium content
  - Kesterite - $Cu_2(Zn,Fe)SnS_4$