Siluro-Devonian Mafic-Ultramafic Intrusions in New Brunswick, Northern Appalachians, and their Associated Nickel-Copper-Cobalt Sulphide Deposits:

A preliminary review

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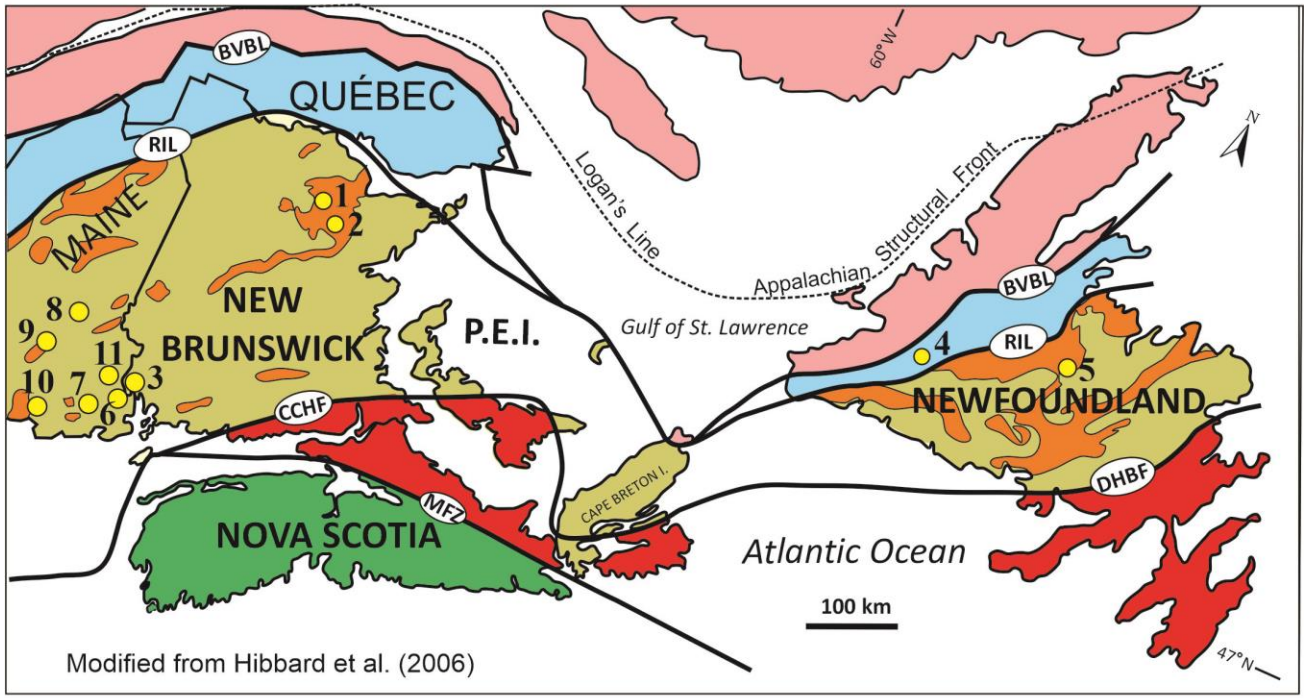
Introduction

- Distribution of Devonian mafic-ultramafic intrusions associated with Ni-Cu sulphide, cobalt, and platinum group element (PGE) mineralization in Maine (USA), New Brunswick, and Newfoundland, situated within the Canadian Appalachians (Modified after Hibbard and Karabinos, 2013).

Major tectonic zones of the Canadian Appalachians



LAURENTIAN REALM
- Grenville/Humber (Basement / passive Laurentia margin)
- DUNNAGE
  - Notre-Dame & Dashwoods (Active margin of Laurentia)
  - Exploits (Active margin of Ganderia)

GONDWANAN REALM
- Ganderia
- Avalonia
- Meguma

Devonian Mafic-ultramafic intrusions (Ni-Cu Sulfide, Co and PGE mineralization)

1: Portage Brook
2: Goodwin Lake
3: St Stephen
4: Portage Cu-Co Occurrence
5: Powderhorn Lake
6: Moosehorn Plutonic Suite
7: Pocomoonshine Gabbro-Diorite
8: Katahdin
9: Moxie
10: Union
11: Alexander

BVBL- Baie Verte-Brompton line
RIL- Red Indian line
MFZ- Minas Fault zone
DHBF- Dover-Hermitage Bay fault
CCHF- Caledonia-clover Hill fault
P.E.I. Prince Edward Island

Mafic intrusions-hosted Ni-Cu(-Co-PGE) in Maine

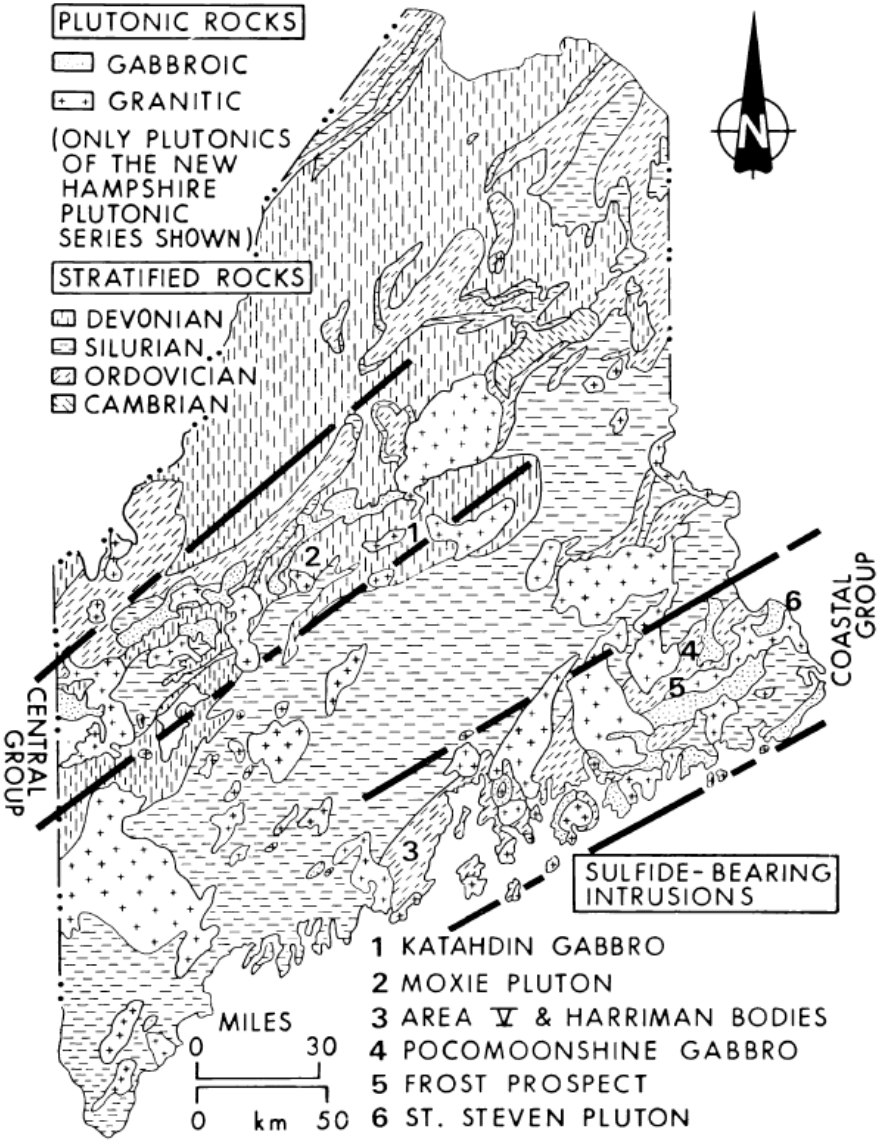
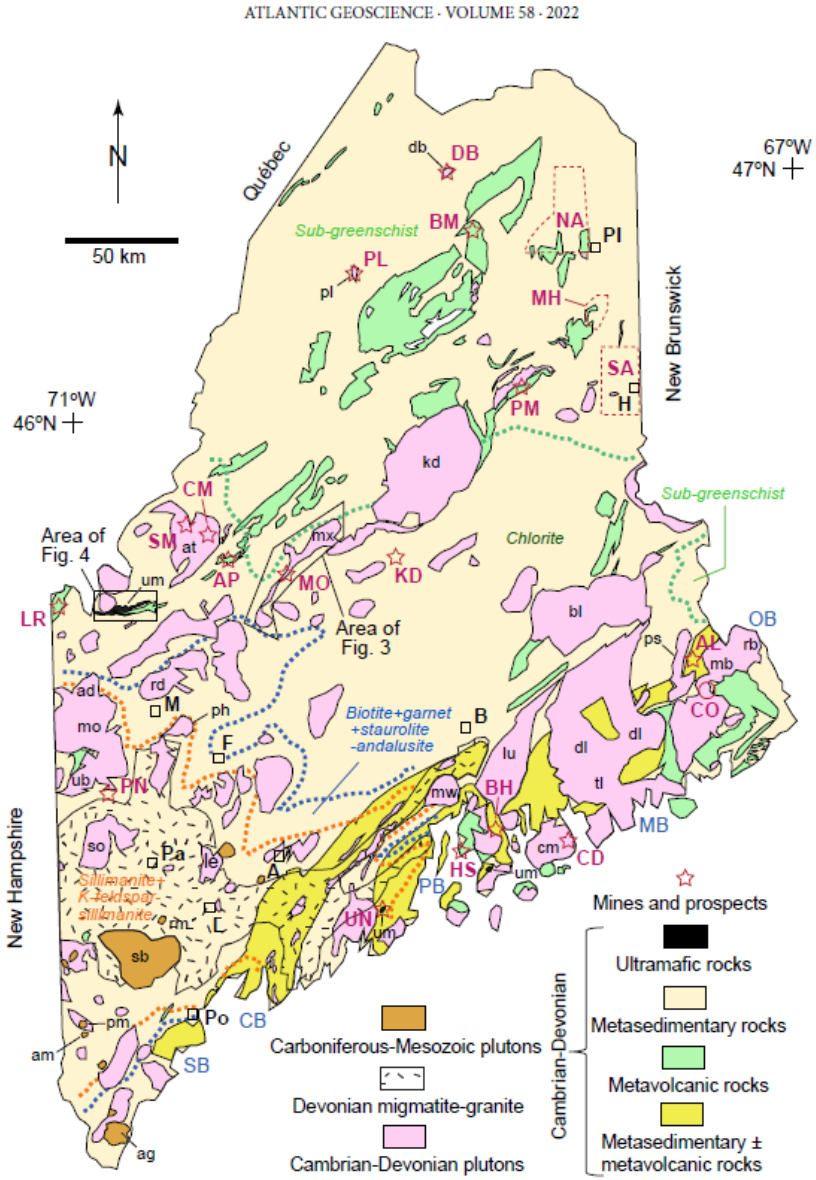
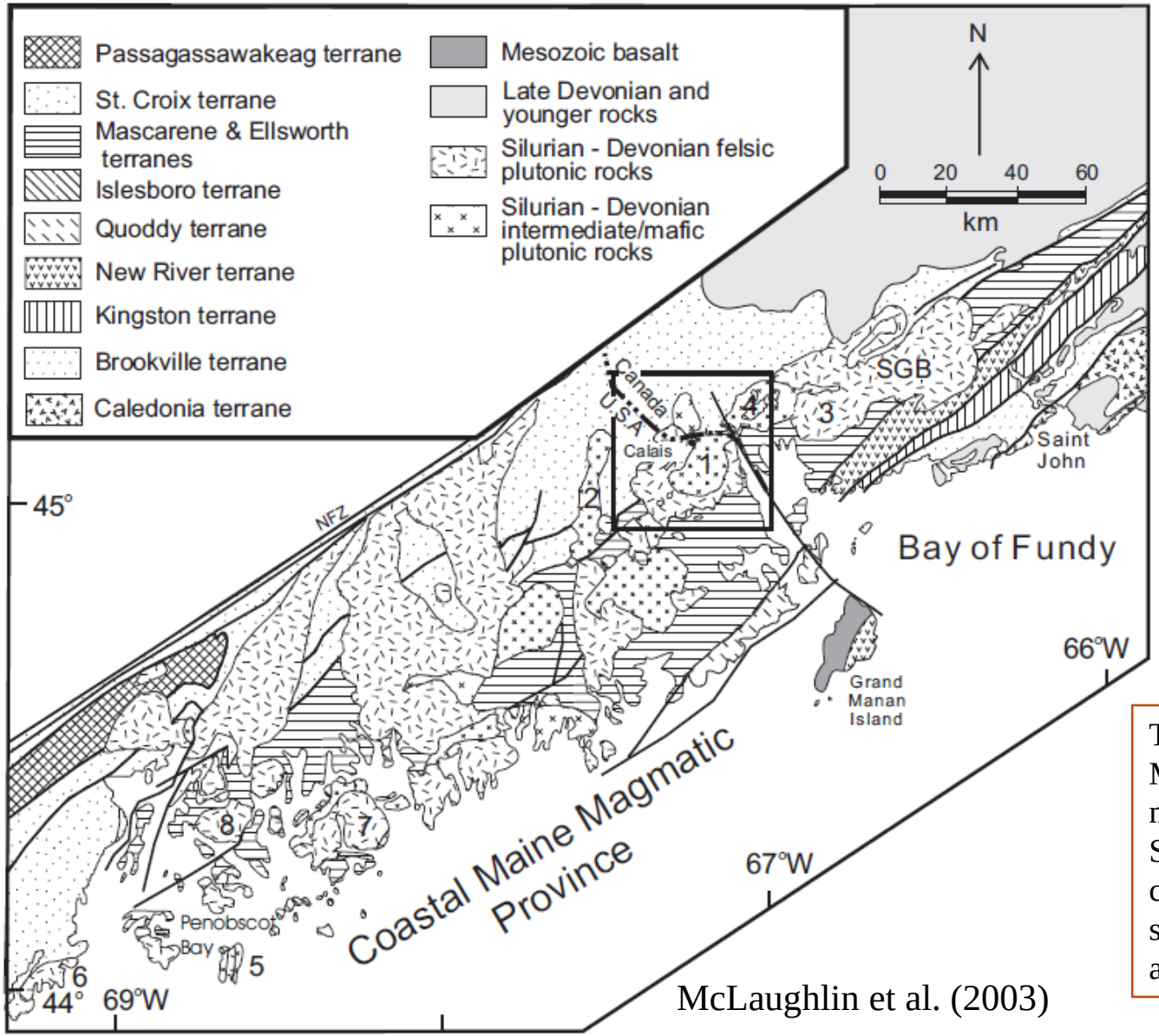


Fig. 1. The geology of Maine indicating the two belts of Acadian mafic intrusions and associated magmatic sulfide occurrences.

Thompson (1984)



Slack et al. (2022)



McLaughlin et al. (2003)

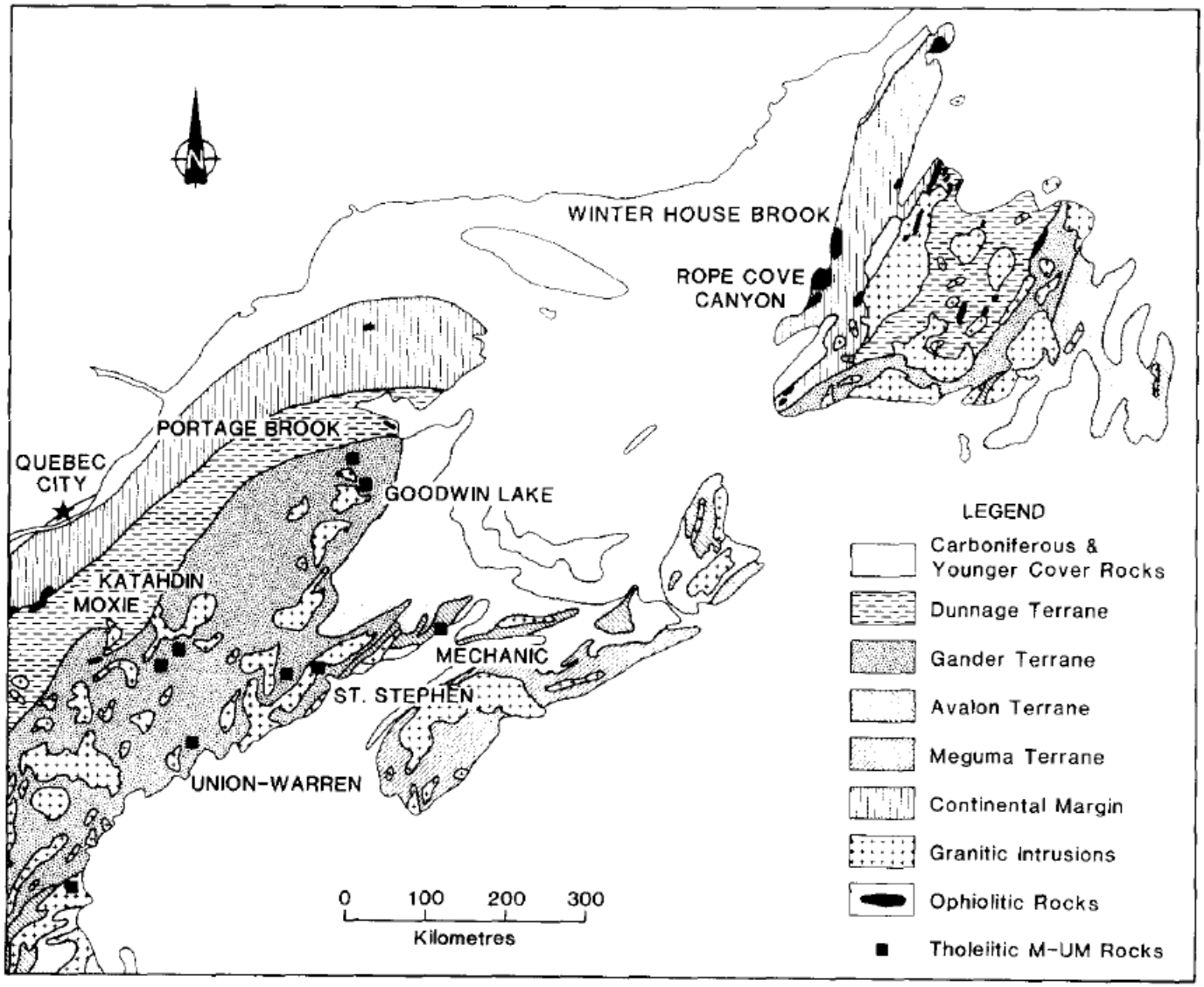
Moosehorn plutonic Suite:

- Staples Mountain Gabbro,
- St. Stephen Gabbro (421±4 Ma, $^{40}Ar/^{39}Ar$)
- Calais Quartz Diorite,
- Baring Granite (421±8 Ma-U-Pb zircon),
- Elliott Mountain Diorite.

The layered, sill-like Staples Mountain Gabbro is mainly mafic, whereas the larger St. Stephen Gabbro consists of a core of dunite and troctolite, surrounded by olivine gabbro and gabbro layers.

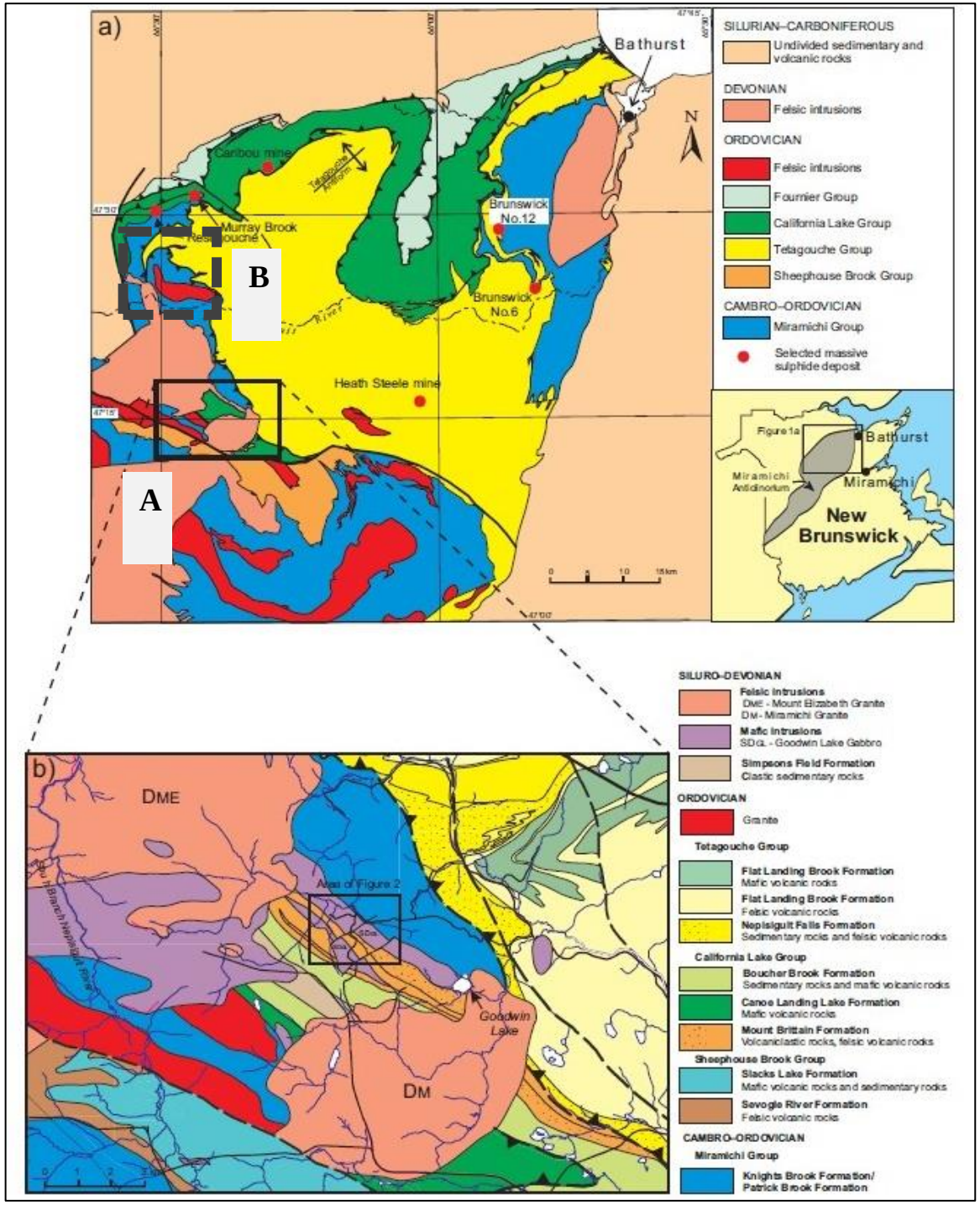
Fig.1 Simplified geological map of southern New Brunswick and southeastern Maine, showing the location of the study area (box) and other features referred to in the text. Units: 1, Moosehorn Plutonic Suite; 2, Pocomoonshine Gabbro-Diorite; 3, Utopia Granite; 4, Bocabec Pluton; 5, South Penobscot Pluton; 6, Spruce Head Pluton; 7, Cadillac Mountain intrusive complex; 8, Sedgewick Pluton. Abbreviations: SGB, Saint George Batholith; NFZ, Norumbega fault zone. Terranes are from Fyffe and Fricker (1987), Robinson *et al.* (1998), and Barr *et al.* (2002). Map is modified from Hogan and Sinha (1989).

Comparative geochemistry of platinum-group elements of nickel-copper sulfide occurrences associated with mafic-ultramafic intrusions in the Appalachian Orogen[1]



Paktunc (1990)

Fig. 1. Distribution of the mafic-ultramafic intrusions with respect to tectono-stratigraphic terranes of the Appalachian Orogen. Subdivision of the Orogen is after Williams (1978).



A: Maliseet occurrences (Goodwin Lake deposit).

B: Portage Brook deposit (Popple Deposit Area).

History of works on these areas in NB

Goodwin Lake

Location: 42 Miles S-SW of the city of Bathurst (47.27887, -66.39275)

- SLAM Exploration Ltd reported preliminary results from the third hole (GW24-03) drilled on its wholly owned Goodwin Project in the Bathurst Mining Camp (BMC) of New Brunswick. Pyrrhotite (15%), Pentlandite, and Chalcopyrite are dominant sulfide minerals.

- Previous works reported: 1.79% copper plus 1.51% nickel which Noranda in a 1960 drilling program drilled some areas to test for pyrrhotite and associated nickel mineralization in the Farquharson zone (Noranda).

Assays and Resource Assessment

Assay

Commodity	Value
Copper	0.7 %
Nickel	1.07 %

Details: HOLE CL-200 DRILLED BY CLEARWATER MINES IN 1967/INTERSECTION OVER A WIDTH OF 3.05 METRES.
Source: ASSESSMENT # 471547 - CLEARWATER MINES
Start Year: 1967
End Year:

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Tonnage

Commodity	Value
Bismuth	0.03 %
Cobalt	0.03 %
Copper	0.34 %
Nickel	0.28 %

Resource/Reserve Type: Inferred resource
Tonnes (x 1000): 5500
Details: ATLANTIC COAST COPPER ESTIMATED POTENTIAL ORE RESERVES
Source: THOMAS(1984) BSC THESIS, UNIVERSITY OF N.B.
NI 43-101 Compliant?: ☐
Start Year: 1971
End Year:

Goodwin Lake

Slam drilled 35 meters grading 1.36% copper equivalent in the first hole GW24-01 at Goodwin. Individual assays range up to 6.86% copper over 0.5 meters and 3.31 grams/tonne gold over 0.5 meters. GW24-01 is one of 3 holes recently drilled on SLAM's wholly owned Goodwin claims located 5 kilometers southwest of the Half Mile copper zinc silver deposit in the Bathurst Mining Camp of New Brunswick.

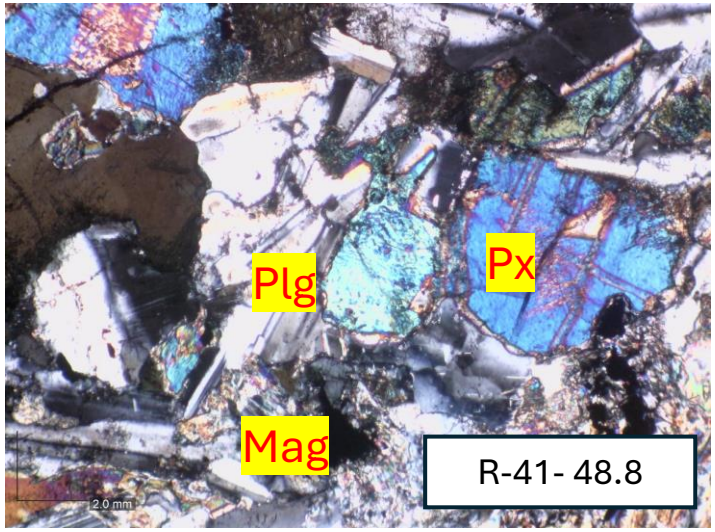
These assay results are from 38 samples of core samples sawn from hole GW24-01 and delivered to ALS Chemex Inc. who analyzed using ME-ICP41 and PGM-ICP23 methods.

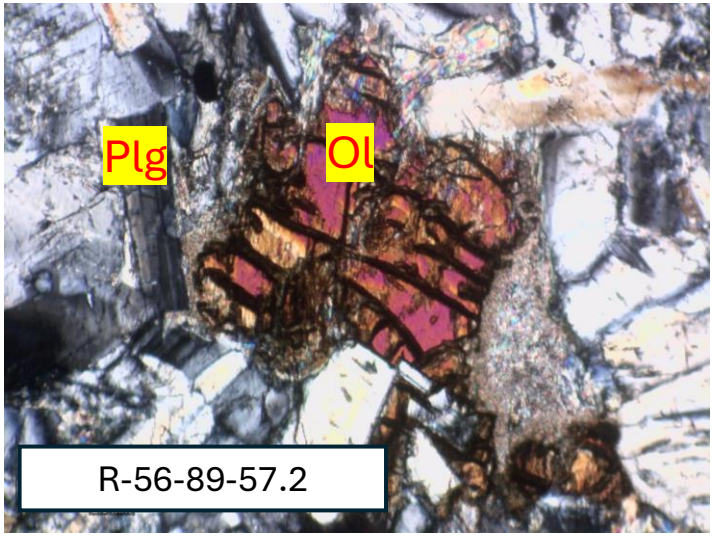
Assays are pending on 176 additional samples represent 141.4 meters of sawn core from hole GW24-02 and 112.5 meters of sawn core from hole GW24-03.

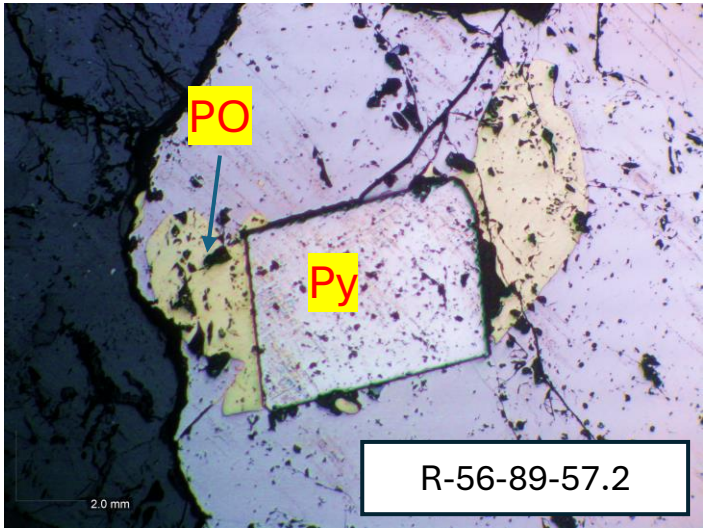
DDH GW24-02

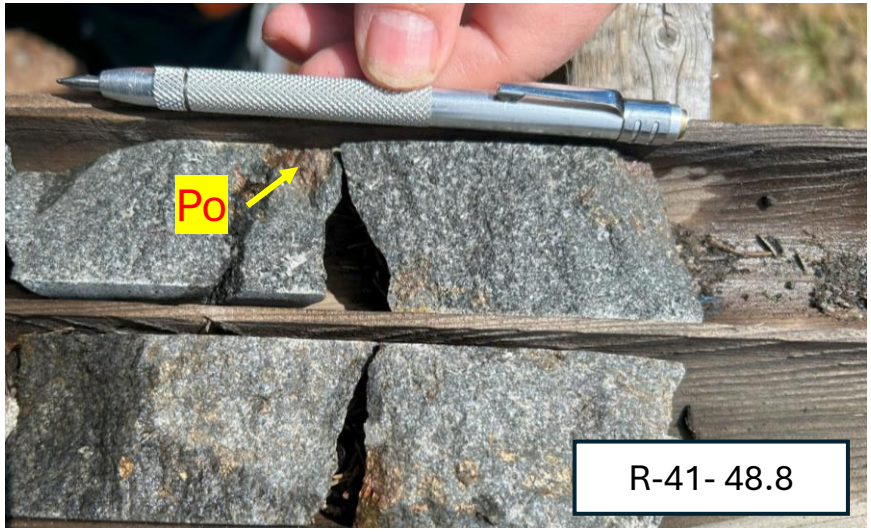
24.5 m to 41.0 m

Goodwin Lake Petrography









Gabbro

Portage Brook/Popple Deposit

Location: 50 Miles SW of the city of Bathurst (47.36862, -66.50664)

- In 1956, Leitch Gold Mines Ltd also mentioned Ni-Cu anomalies.
- In 1972, Geoterrex LTD completed an induced polarization survey on behalf of Cities Service Minerals Corp. Geochemical samples in the northern and southern zones of the area exhibited anomalous Ni values.
- In 1973, Cities Service Minerals Corporation mentioned the existence of considerable sulfides such as Pentlandite, pyrrhotite, pyrite with chalcopyrite. During this investigation, they reported 0.18% Cu and 0.15% Ni.

Classification

Class List	Primary/Secondary	Classification
Canadian	Primary	Magmatic Ni, Cu, Pt group elements
New Brunswick	Primary	Intramagmatic deposits in mafic intrusions; includes segregations & injections of sulphides (Ni, Cu, Co, PGE)

Metal / Non-Metal / Alteration Minerals

Type	Description
Commodities	Copper, Nickel
Metal(s)	Chalcopyrite, Pentlandite, Pyrite, Pyrrhotite
Alteration Metal(s)	Serpentine

Assays and Resource Assessment

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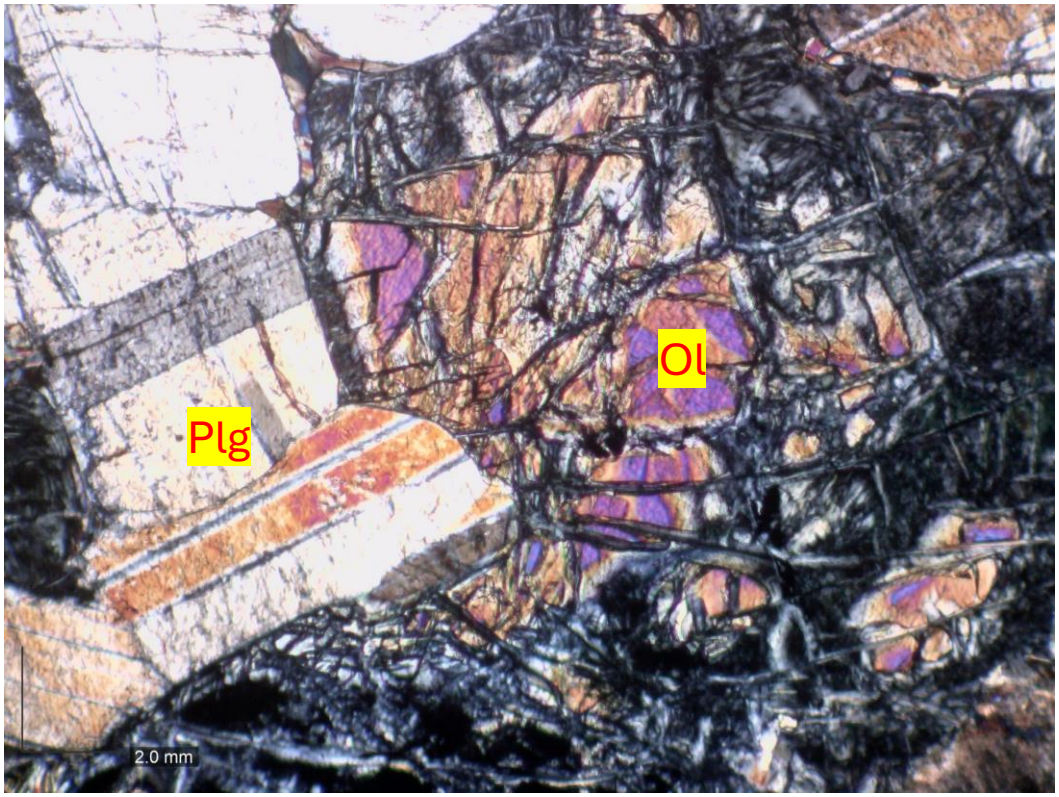
Assay

Commodity	Value
Nickel	0.1 %

Details: MAXIMUM GRADE. "NICKEL IN THE FORM OF PENTLANDITE NEVER EXCEEDED 0-1%"
Source: ASSESSMENT # 470844 -CITIES SERVICES MINERALS
Start Year: 1972
End Year:

Portage Brook Petrography



Troctolite

R-56-89-57.2

St Stephen

Location: (45.20447, -67.26887)

St. Stephen Ni-Cu deposits, was trenched in the 1940's and re-examined in 1988 by ABITEX RESOURCES INC. Pyrrhotite and chalcopyrite occur as disseminations and segregations within the St. Stephen intrusion, a differentiated complex of peridotite, anorthositic gabbro, troctolite, norite and gabbro.

Classification

Class List	Primary/Secondary	Classification
Canadian	Primary	Magmatic Ni,Cu,Pt gp. elements - Gabbroid-associated Ni,Cu,PGEs - Stock
New Brunswick	Primary	Intramagmatic deposits in mafic intrusions; includes segregations & injections of sulphides (Ni, Cu, Co, PGE)

Metal / Non-Metal / Alteration Minerals

Type	Description
Commodities	Cobalt, Copper, Nickel
Metal(s)	Chalcopyrite, Cobaltite (?), Pyrrhotite

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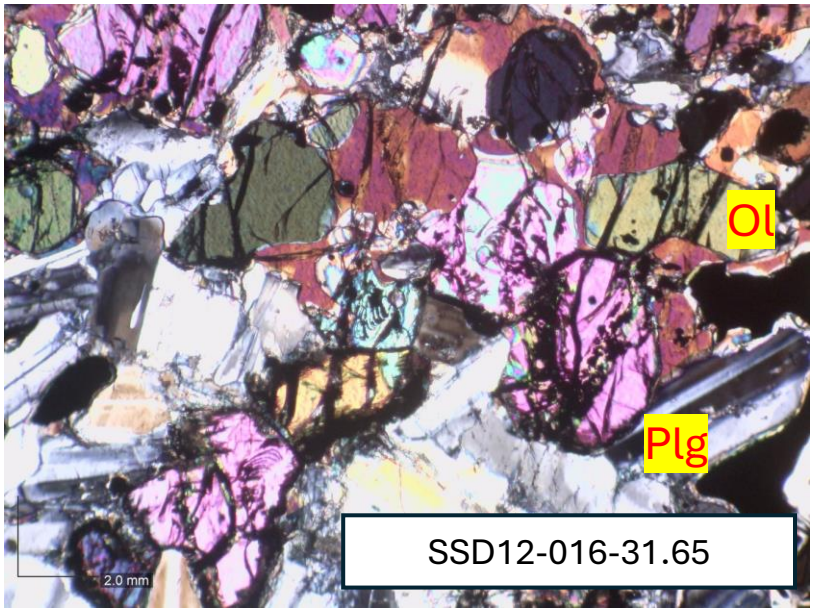
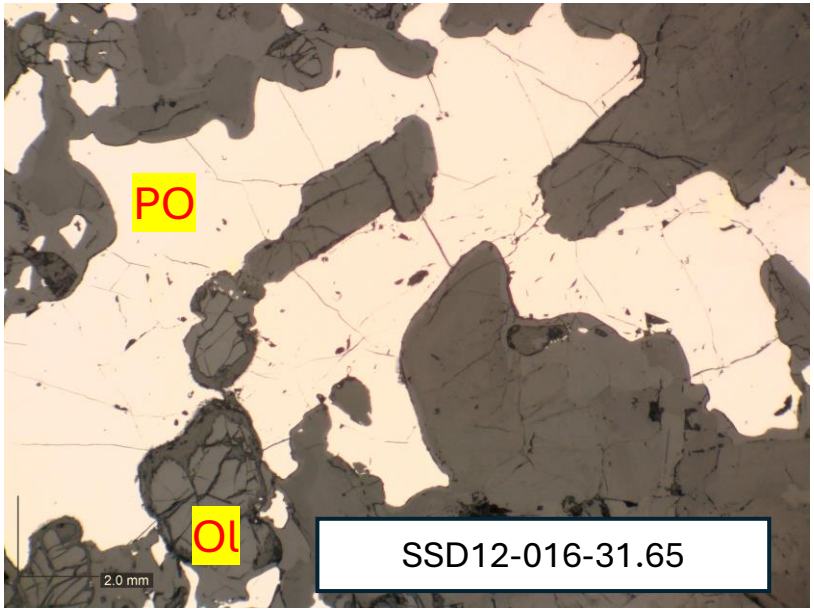
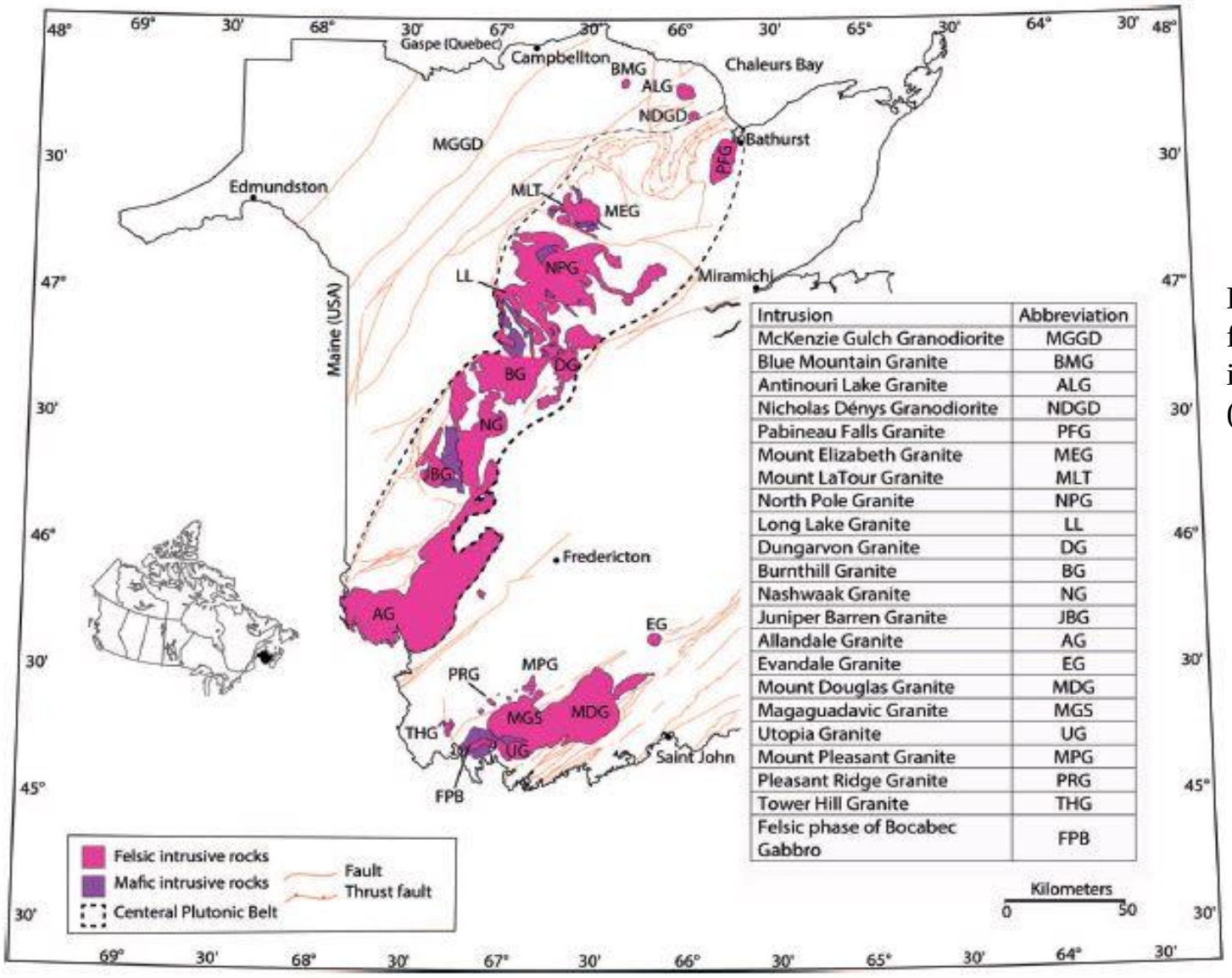
St Stephen Petrography





The question that has always existed is the age of the host (gabbro-gabbronorite) of the Ni-Cu mineralization is *Devonian*?

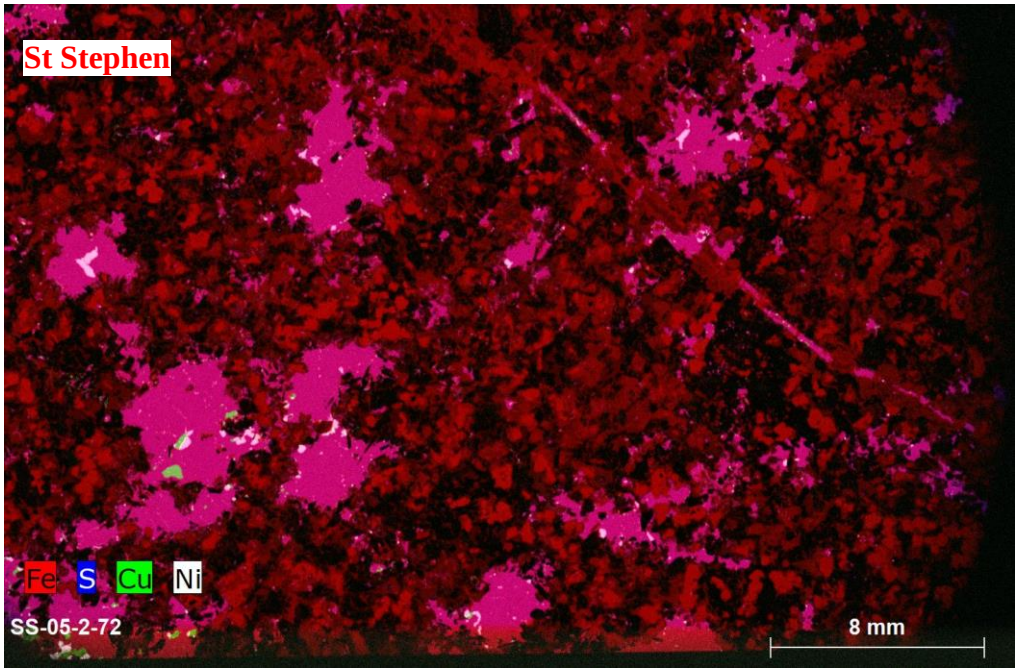


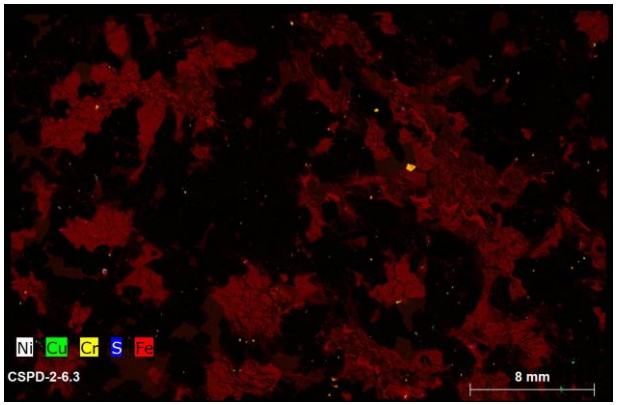
Intrusion	Abbreviation
McKenzie Gulch Granodiorite	MGGD
Blue Mountain Granite	BMG
Antinouri Lake Granite	ALG
Nicholas Dénys Granodiorite	NDGD
Pabineau Falls Granite	PFG
Mount Elizabeth Granite	MEG
Mount LaTour Granite	MLT
North Pole Granite	NPG
Long Lake Granite	LL
Dungarvon Granite	DG
Burnthill Granite	BG
Nashwaak Granite	NG
Juniper Barren Granite	JBG
Allandale Granite	AG
Evandale Granite	EG
Mount Douglas Granite	MDG
Magaguadavic Granite	MGS
Utopia Granite	UG
Mount Pleasant Granite	MPG
Pleasant Ridge Granite	PRG
Tower Hill Granite	THG
Felsic phase of Bocabec Gabbro	FPB

Distribution of some of felsic-intermediate intrusive rocks in NB (Azadbakht et al., 2019).

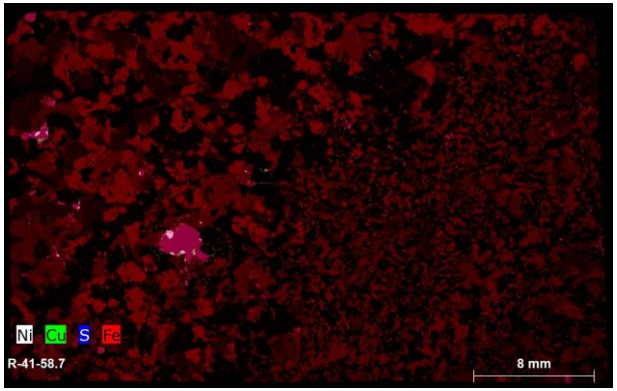
MicroXRF-EDS maps & Mineralization

M4 Tornado µ-XRF to produce Energy Dispersive Spectrometry (EDS) elemental maps



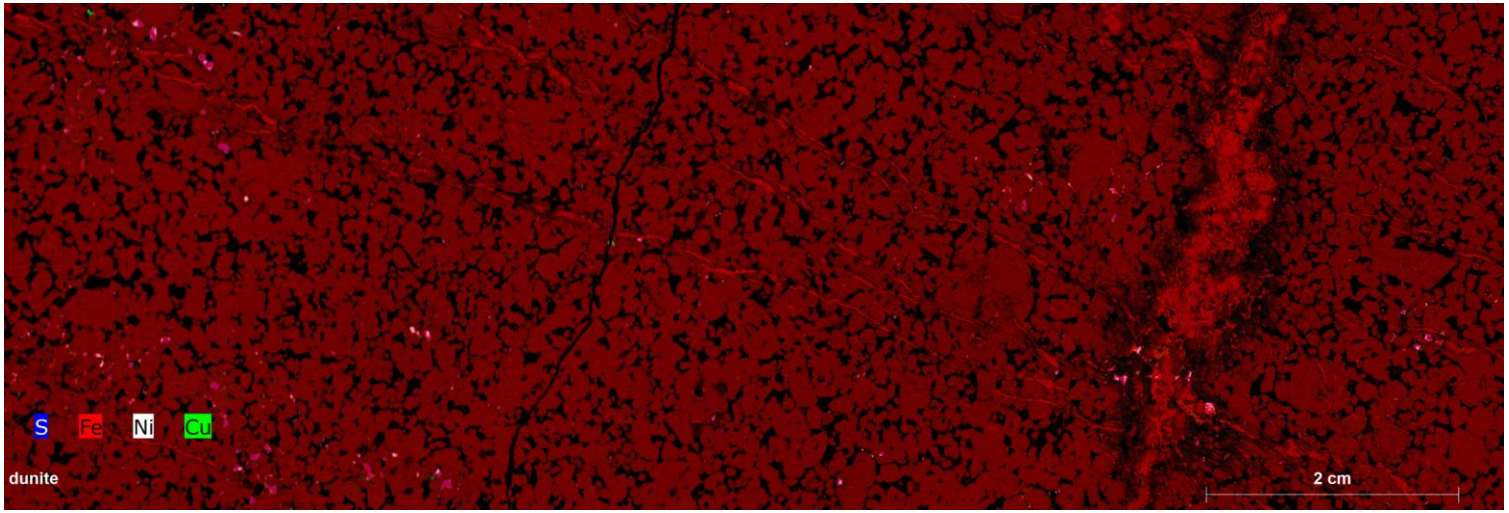


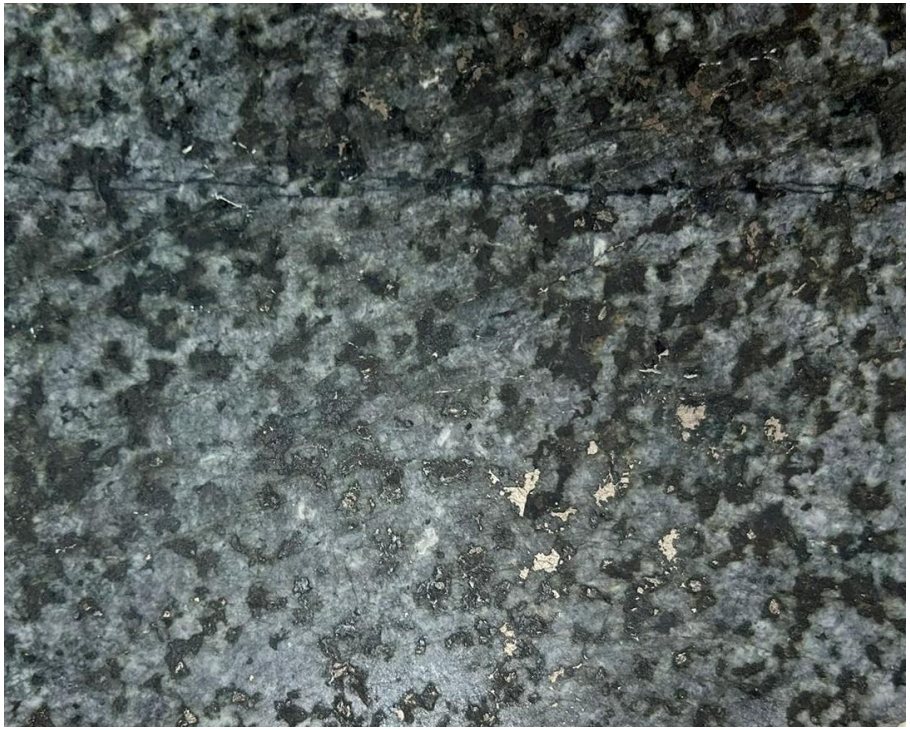
Portage Brook



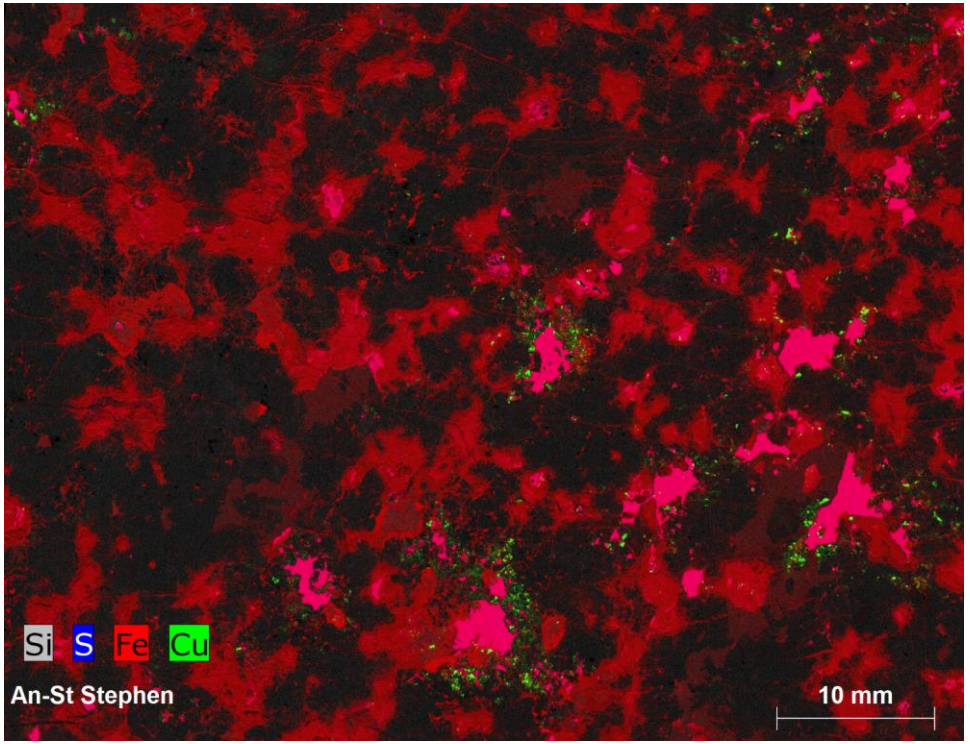
Goodwin Lake

Dunite, SW of NB

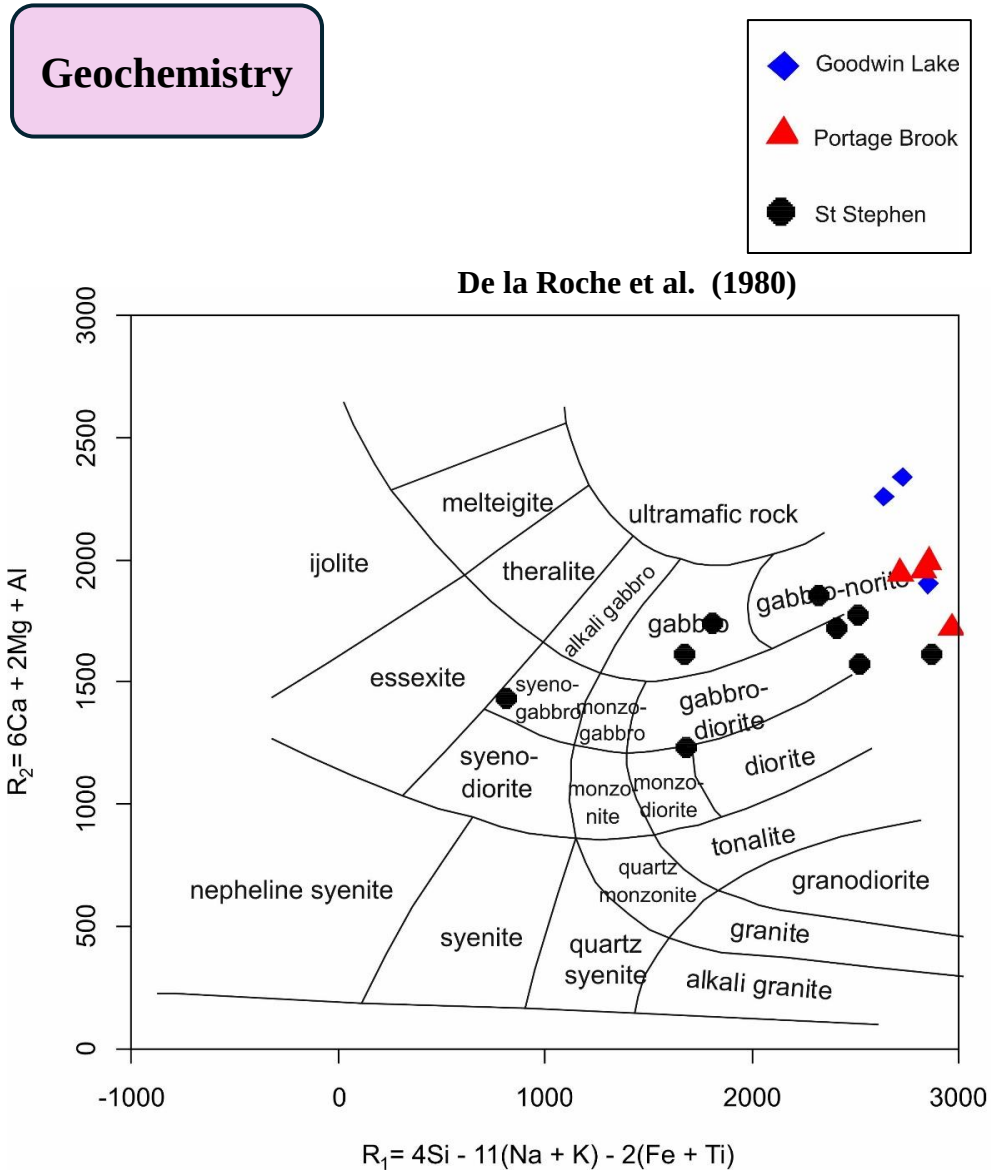


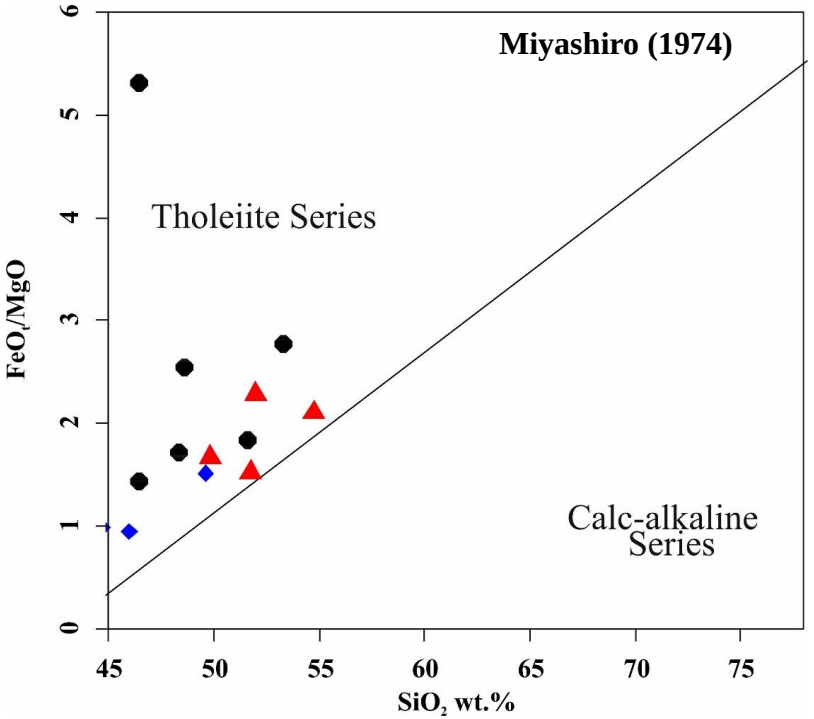


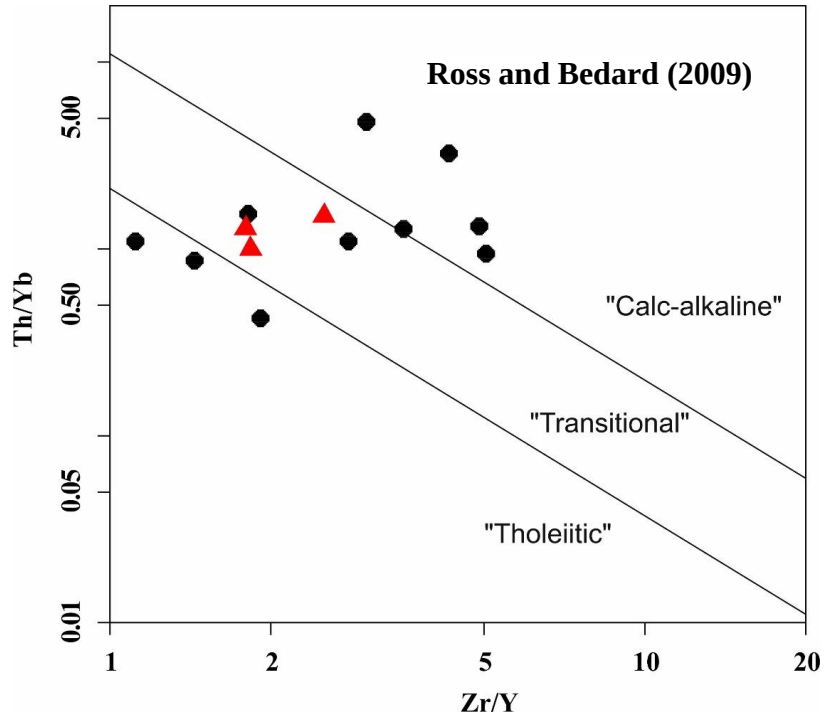
Anorthosite Gabbro, St Stephen, SW of NB



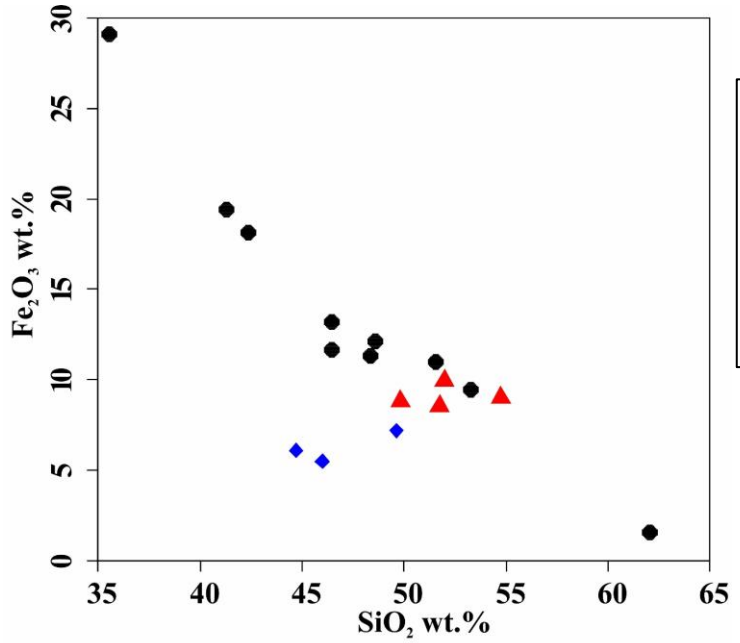
Geochemistry

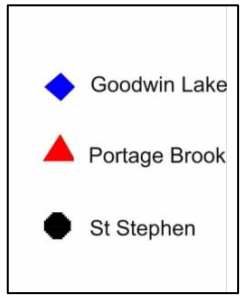


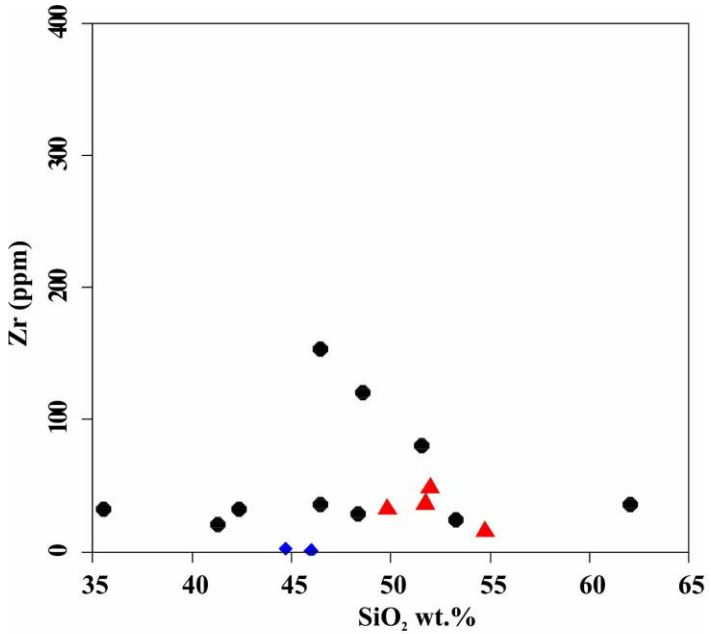


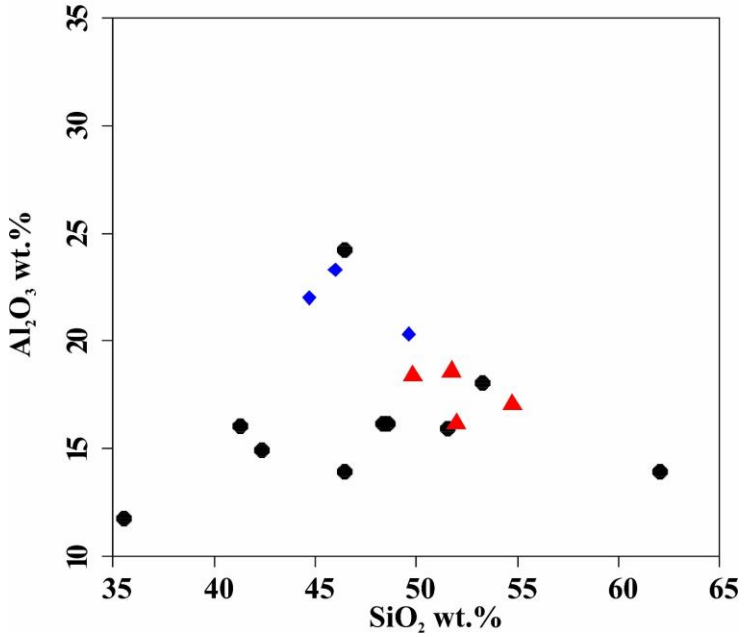


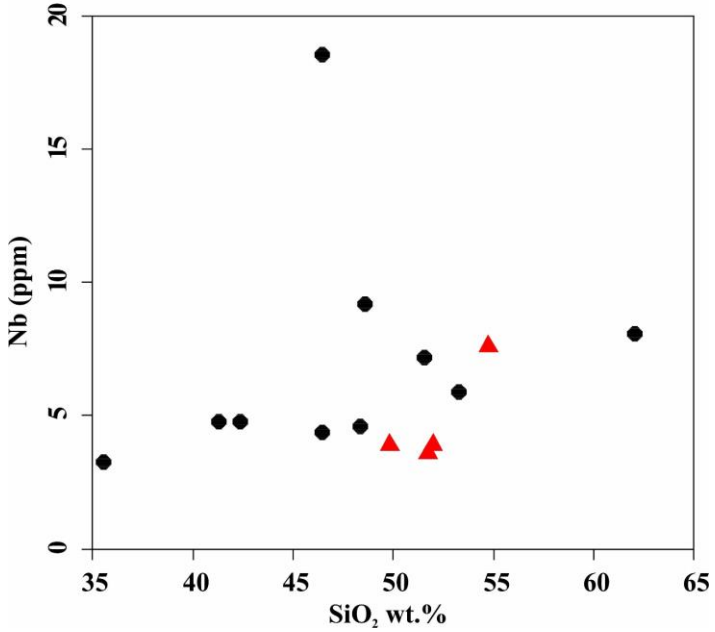
Selected geochemical data are from non-mineralized samples.



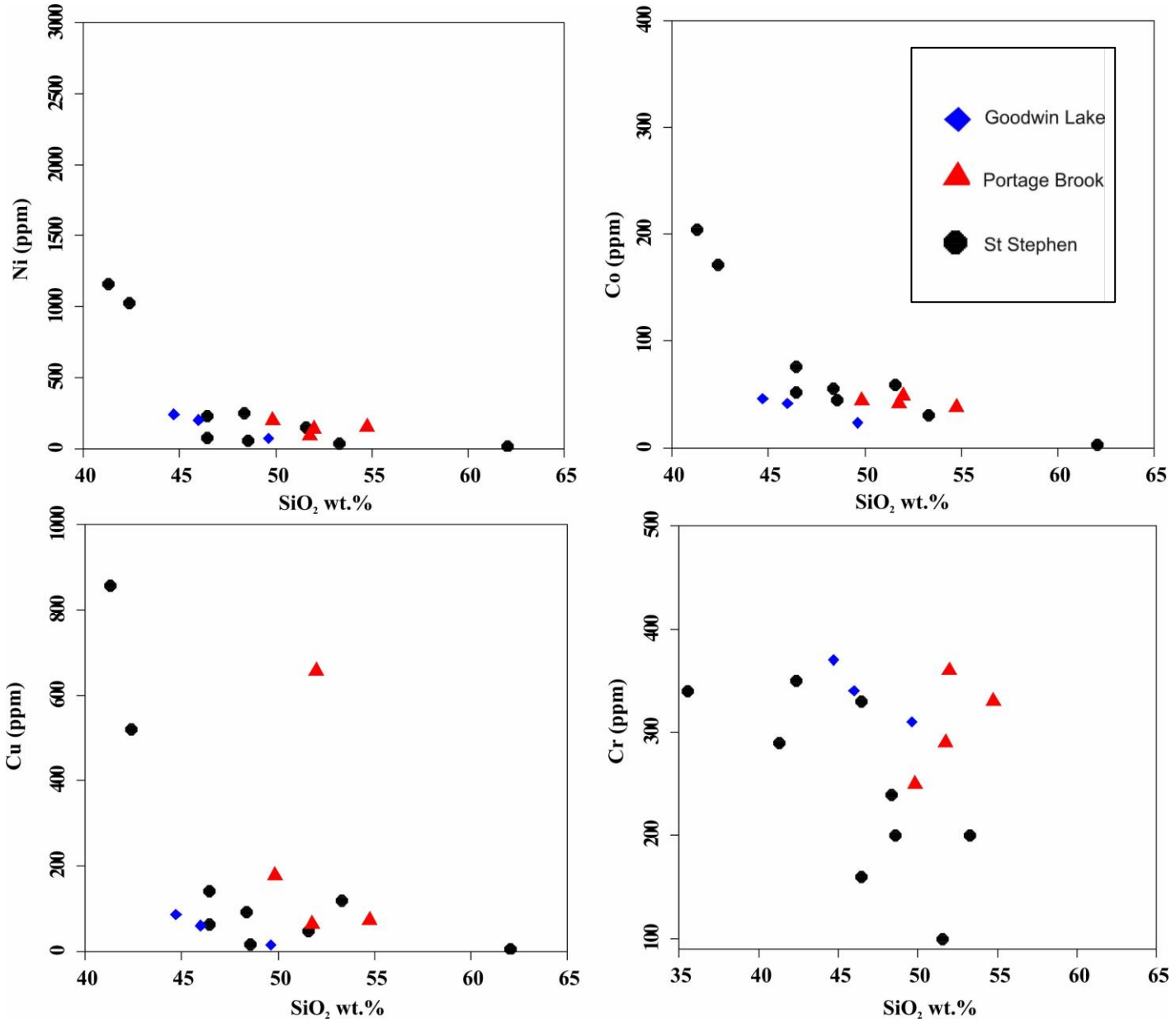




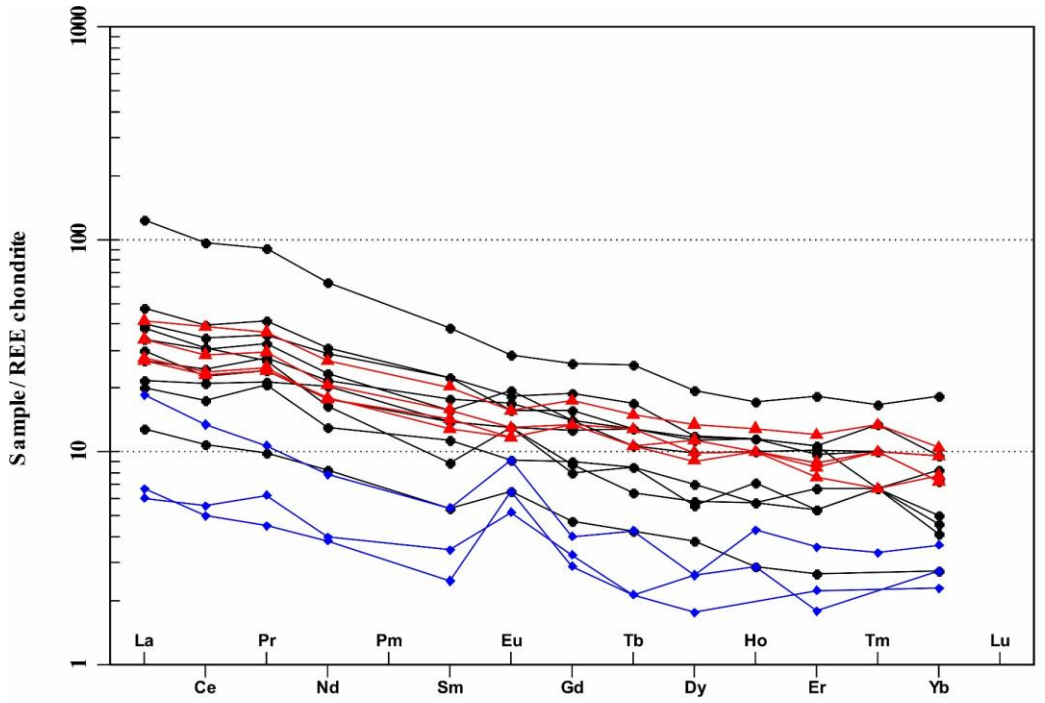




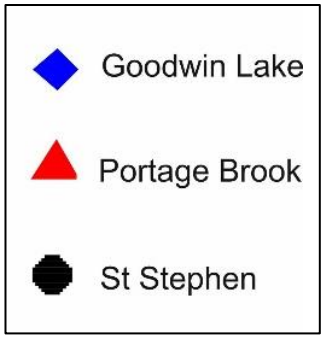
- Plots of major element oxides and trace elements against SiO_2 (weight %) to illustrate chemical variation in these studied rocks.

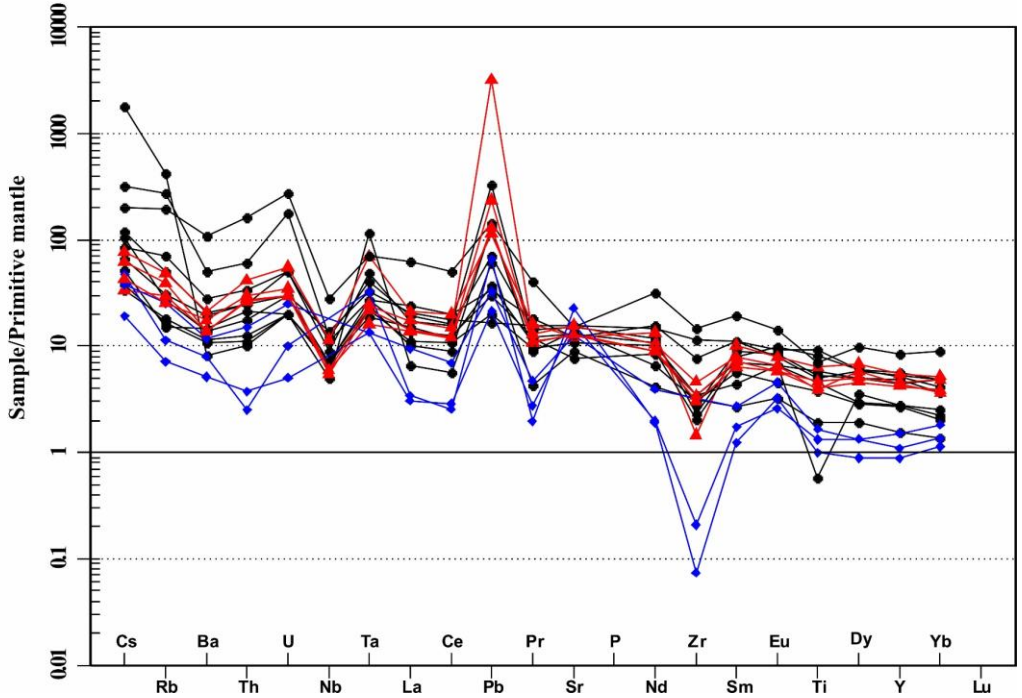


- Plots of Ni, Co, Cu, and Cr (ppm) vs. SiO_2 (weight %) to illustrate chemical variation in these studied rocks.
- The variation of Ni, and Cr vs. Silica will be controlled by pyroxene, and olivine.



Chondrite-normalized REE profiles (Nakamura, 1974) for these mafic intrusions in NB.

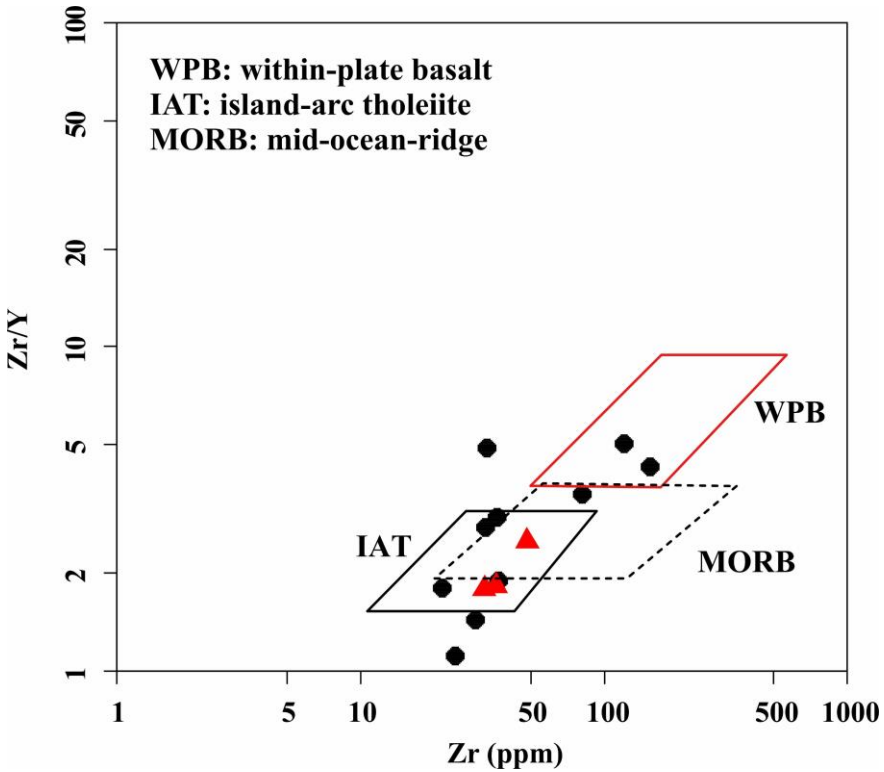




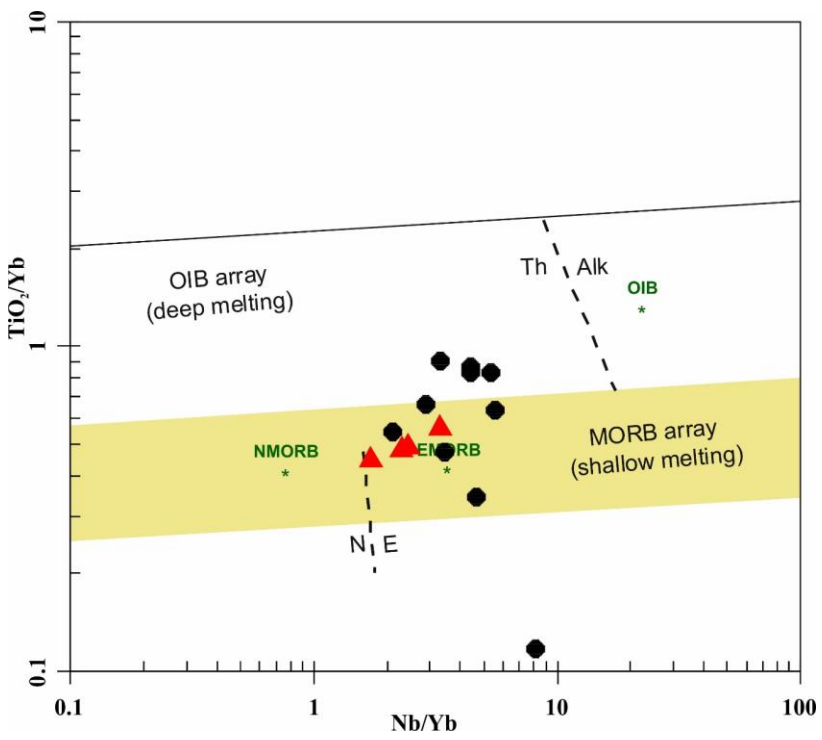
Primitive mantle-normalized trace element (McDonough and Sun, 1995) patterns for these mafic intrusions in NB.

Tectonic setting of the studied mafic-ultramafic intrusions in NB.

(Pearce and Norry , 1979)



(Pearce, 2008)



Source of sulphur

THE MALISEET SOUTH ZN MASSIVE-SULPHIDE OCCURRENCE, SOUTHWESTERN BATHURST MINING CAMP, NEW BRUNSWICK

J.A. WALKER
Geological Surveys Branch, New Brunswick Department of Natural Resources,
P.O. Box 50, Bathurst, New Brunswick, CANADA E2A 3Z1 *(jim.walker@gnb.ca)*

WALKER, J.A. 2004. The Maliseet South Zn massive-sulphide occurrence, southwestern Bathurst Mining Camp, New Brunswick. *In* Geological Investigations in New Brunswick for 2003. *Edited by* Gwen L. Martin. New Brunswick Department of Natural Resources; Minerals, policy and Planning Division, Mineral Resource Report 2004-4, pp. 105–130.

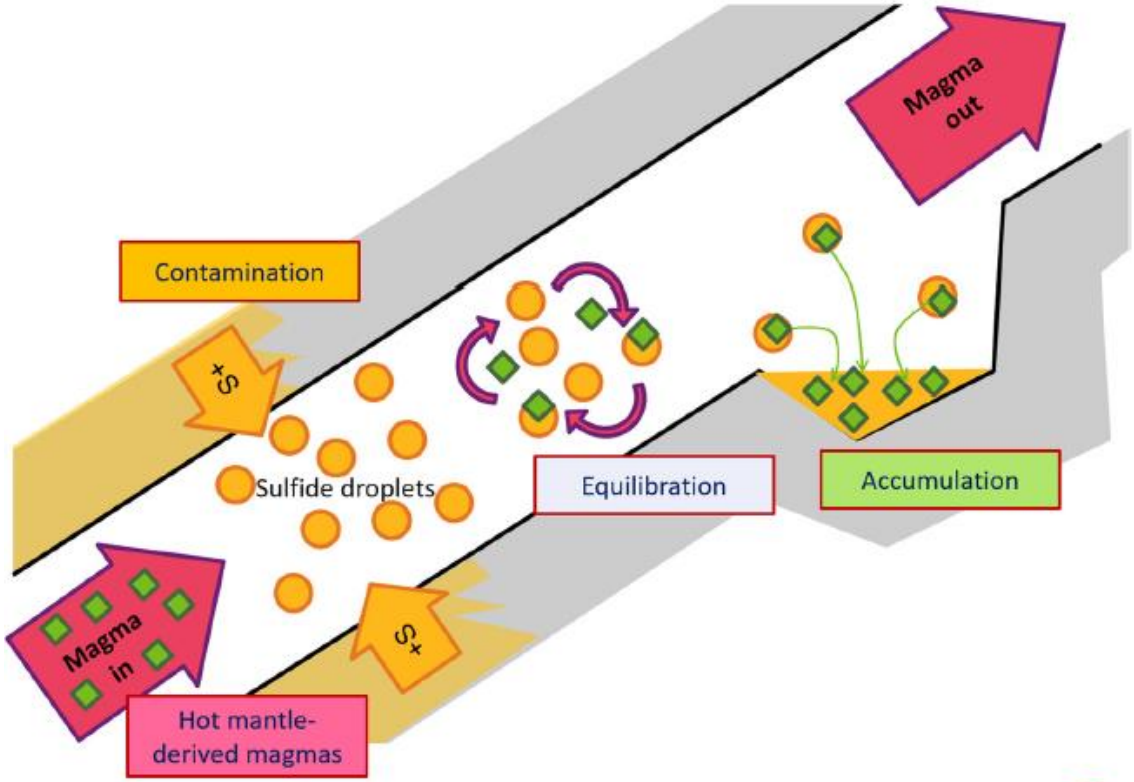
A possible source of sulphur can be seen in the hanging wall of the Maliseet South Zn occurrence, which consists of volcanic rocks belonging to the Mount Brittain Formation of the California Lake Group (Cambro-Ordovician sedimentary in Gander Zone).

Table 2. $\delta^{34}S$ data from Maliseet South Zn occurrence, drillhole ML-97-2.

Depth (m)	Rock Type	$\delta^{34}S$
30.4	gabbro	9.33
100.4	gabbro	9.32
122.5	mineralized sulphide zone	8.78
124.0	mineralized sulphide zone	8.16
126.5	mineralized sulphide zone	8.41
129.5	mineralized sulphide zone	8.31
137.1	Zn-rich lens	9.03
	Average $\delta^{34}S$	8.76

Note: Analyses were conducted by Alison Pye, Memorial University of Newfoundland.

The mechanism for formation of Ni–Cu–PGE element-dominated magmatic sulfide ores.



Barnes (2023)

- A magma passing through some kind of transcrustal conduit system, assimilating S, usually in the form of sulfide, from the country rocks.
- The sulfide melt so formed reacting with this 'carrier' magma to sequester chalcophile elements.
- A physical mechanism of segregation and accumulation of the sulfide liquid.
- A variety of physical processes including re-entrainment, gravity flow, country rock infiltration, and in some cases tectonic mobilization, giving rise to the final disposition of the ores.

Funding for this project was provided by:

- University of New Brunswick
- NB Geological Survey (NB Dept. of Natural Resources and Energy Development)
- New Brunswick Innovation Foundation
- NSERC

Thank you all!