Trace elements and oxygen isotope of quartz from the Nashwaak Granite and dykes, and quartz veins related to the Sisson Brook W-Mo-Cu deposit, west-central New Brunswick

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Abstract: The Sisson Brook W-Mo-Cu deposit, situated in west-central New Brunswick, is hosted by Cambro-Ordovician volcanic and sedimentary rocks of the Miramichi and Tetagouche groups. These rocks have been intruded by the Early Devonian Howard Peak diorite-gabbro, Nashwaak Granite, a phaneritic felsic dyke swarm, and a distinctively younger Late Devonian porphyritic felsic dyke. In order to understand the magma evolution history, the textural and geochemical characteristics of quartz phenocrysts from these felsic rocks were analyzed with the aid of SEM-cathodoluminescence (CL), laser ablation inductively coupled plasma mass spectrometry (LA ICP-MS), and secondary ion mass spectrometry (SIMS).

Four intrusive granitic units in the Sisson Brook deposit area: (1) medium-grained, equigranular two-mica granite with brown biotite that is slightly altered to chlorite; (2) biotite- granite with ca. 20 % greenish brown biotite and accessory zircon, apatite, monazite, magnetite, titanite, sulfide and ilmenite; (3) biotite-granite dykes with similar mineralogical features to the biotite-granite; and (4) porphyry dykes with phenocrysts consisting of approximately 23 % plagioclase, 10 % quartz, 8 % biotite, and 7 % K-feldspar.

Quartz phenocyrsts in two-mica granite and biotite-granite plutonic phases is unzoned indicating that it formed at relatively stable magma chamber. Quartz dissolution textures in the dyke phases might be caused by cooling from 600°C to 300°C at pressure below 1 Kbar. Quartz phenocrysts in porphyry dyke samples are oscillatory-zoned. With the assumption that the activity of Ti in these magmas is 0.8 (based on the presence of ilmenite rather than rutile), Ti-In-quartz geothermometry indicates that the porphyry dykes formed at a temperature above 675°C, two-mica granite and biotite-granite plutons formed at 600°C to 700°C, and the biotite-granite dykes formed at slightly below 600°C. Higher Ge/Ti ratios reflect greater degrees of magma differentiation. This ratio increases from porpyrhy dykes, two-mica granite and biotite-granite pluton phases to biotite dykes. The highest Al content of quartz measured in two-mica granite is consistent with the highest aluminium saturation index of its whole rock. The oxygen isotope of quartz is from 8-8.5 ‰ for biotite-granite, 9-10 ‰ for biotite dykes and porphyry dykes, and 10-10.5 ‰ for the two-mica granites. The later mineralization quartz veins in the dykes have oxygen isotope values between 8.5 ‰ to 9.5 ‰, indicating the hydrothermal fluids related to the Sisson Brook deposit are dominantly magmatic fluids.

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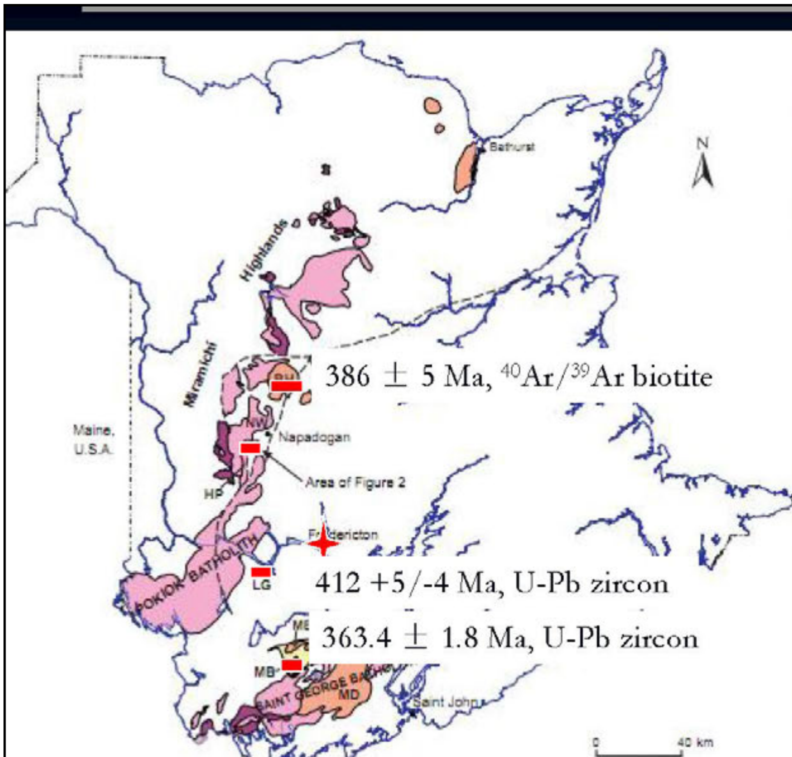
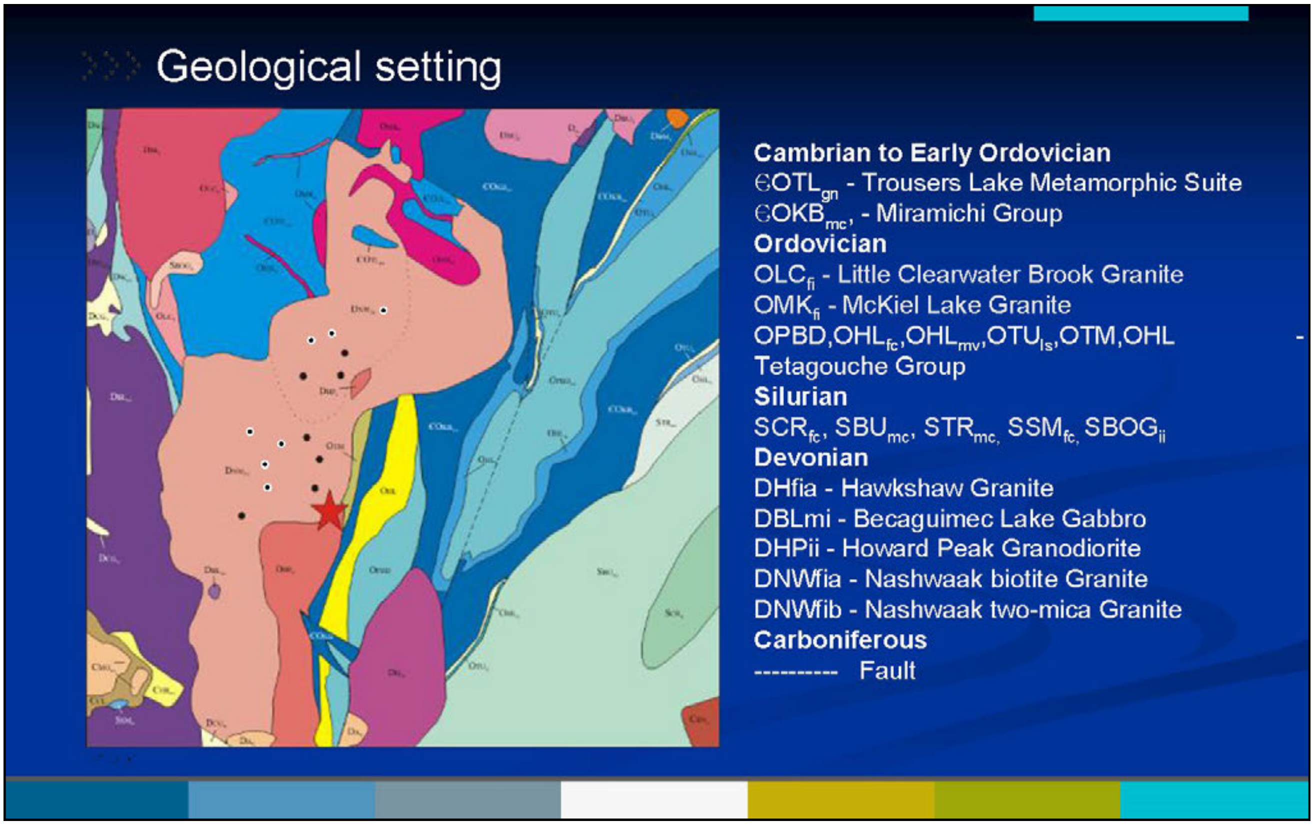
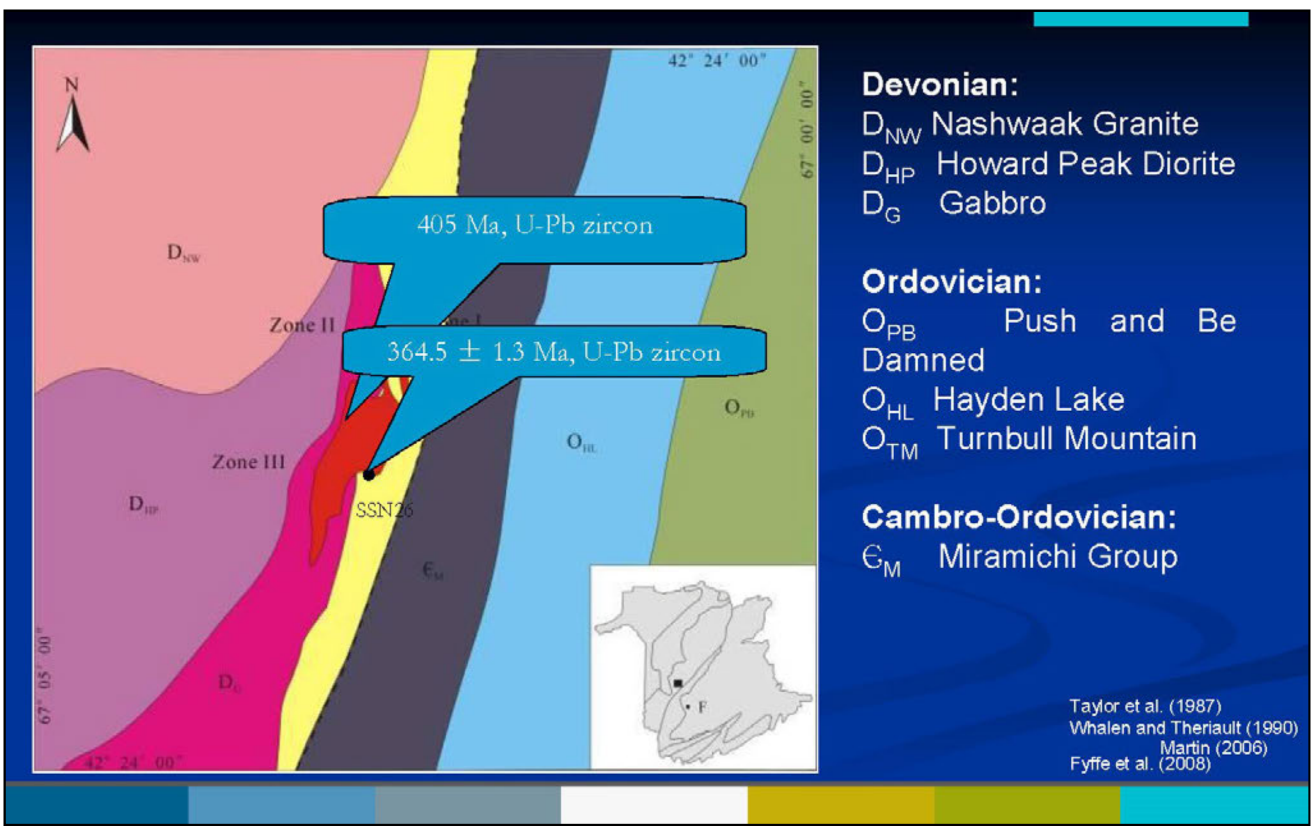


The Sisson Brook W-Mo-Cu deposit is situated in west-central New Brunswick, along the eastern margin of an extensive belt of "Acadian" plutonic rocks that underlie the Miramichi Highlands

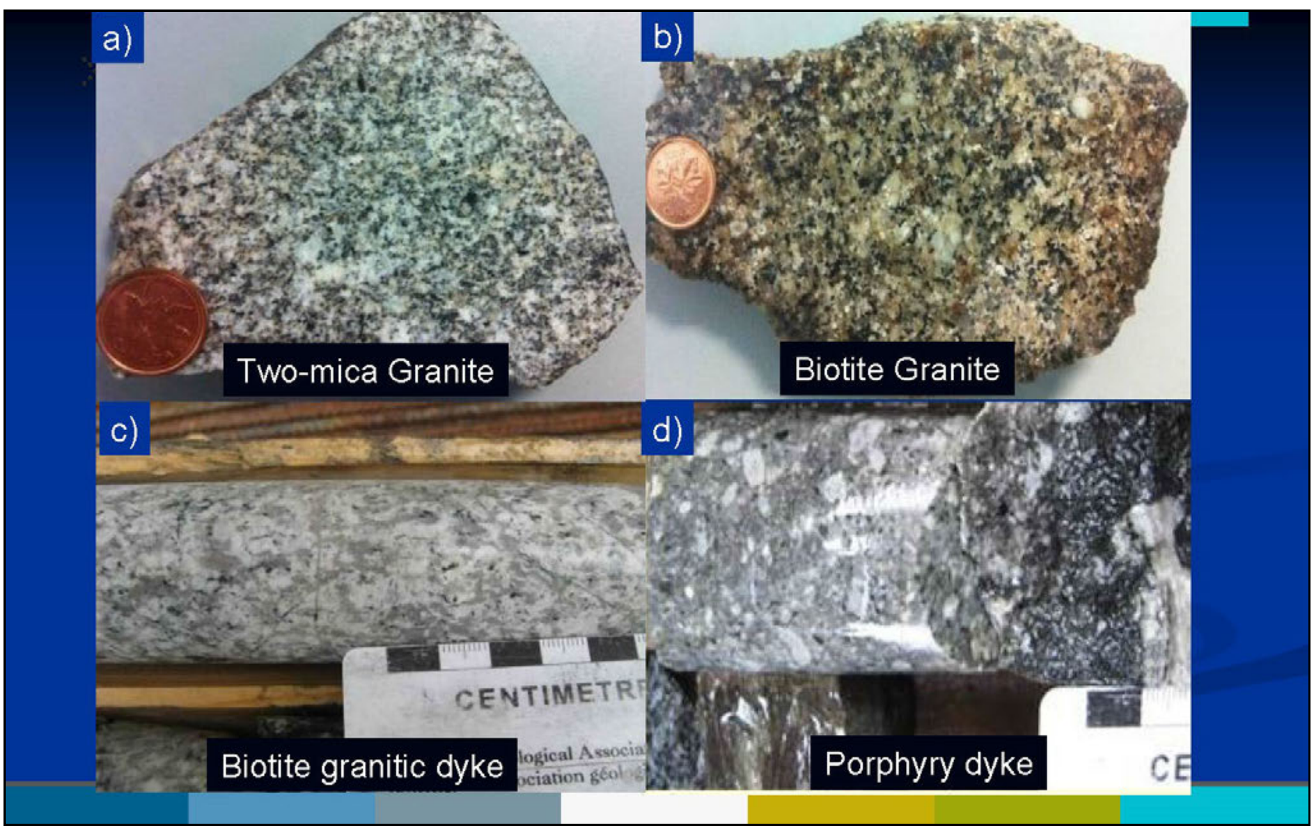

Geological setting
Cambrian to Early Ordovician
ЄOTLgn - Trousers Lake Metamorphic Suite
ЄOKBmc, - Miramichi Group
Ordovician
OLCfi - Little Clearwater Brook Granite
OMKfi - McKiel Lake Granite
OPBD,OHLfc,OHLmv,OTUls,OTM,OHL -
Tetagouche Group
Silurian
SCRfc, SBUmc, STRmc, SSMfc, SBOGii
Devonian
DHfia - Hawkshaw Granite
DBLmi - Becaguimec Lake Gabbro
DHPii - Howard Peak Granodiorite
DNWfia - Nashwaak biotite Granite
DNWfib - Nashwaak two-mica Granite
Carboniferous
---------- Fault


N
42° 24′ 00″
67° 00′ 00″
67° 05′ 00″
42° 24′ 00″
405 Ma, U-Pb zircon
364.5 ± 1.3 Ma, U-Pb zircon
DNW
Zone II
Zone III
DHP
DG
OHL
OPB
ЄM
SSN26
F
Devonian:
DNW Nashwaak Granite
DHP Howard Peak Diorite
DG Gabbro
Ordovician:
OPB Push and Be Damned
OHL Hayden Lake
OTM Turnbull Mountain
Cambro-Ordovician:
ЄM Miramichi Group
Taylor et al. (1987)
Whalen and Theriault (1990)
Martin (2006)
Fyffe et al. (2008)

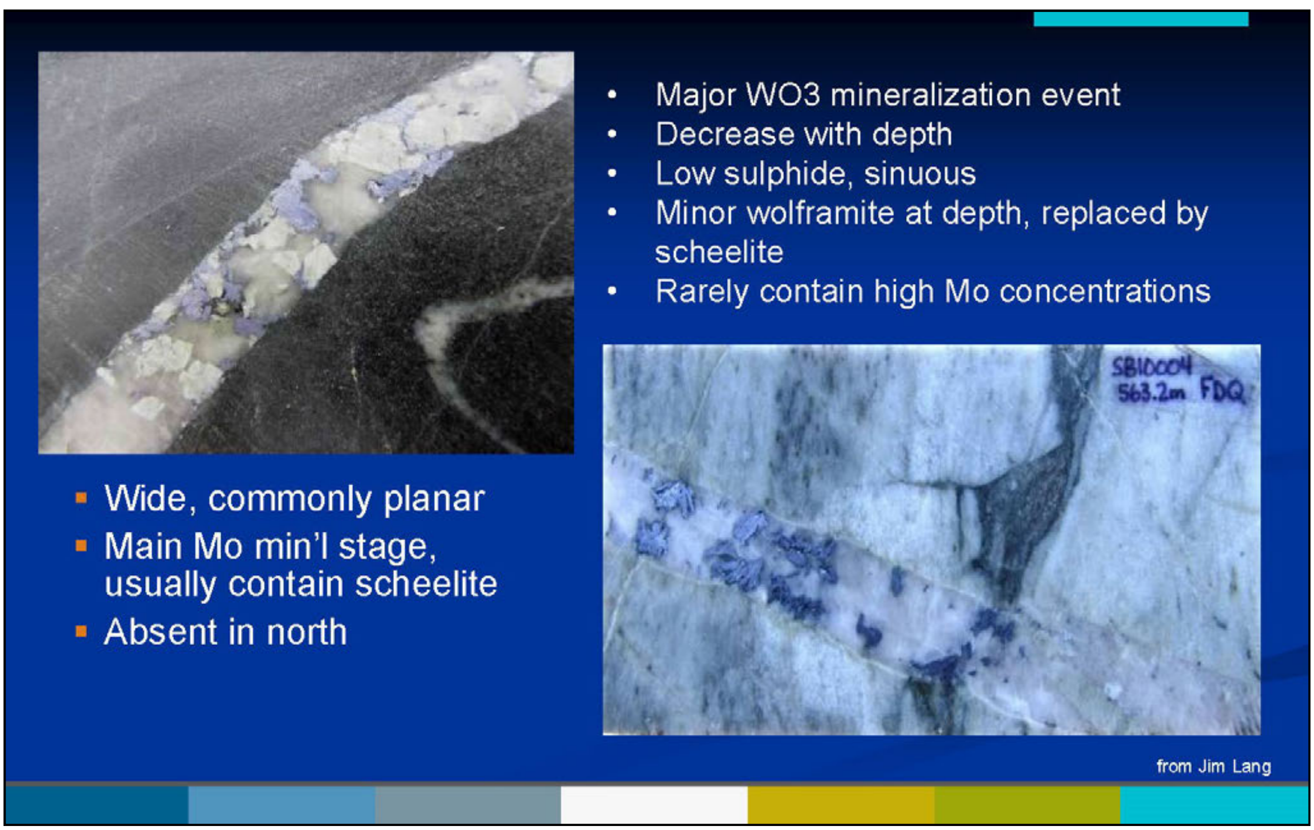
Resource Estimate
for Sisson Brook deposit (Zone I, II, and III)

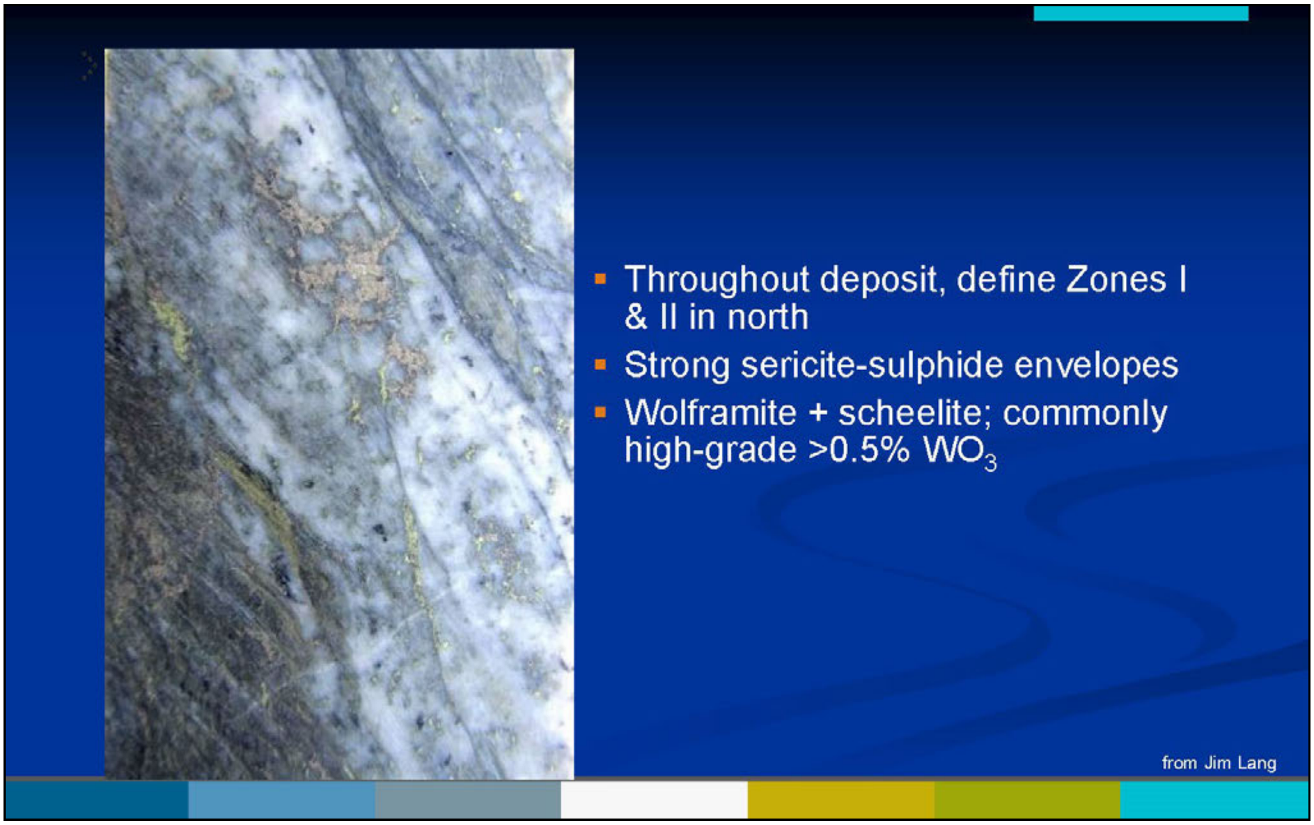
	Tonnage (Mt)	WO_3 (%)	Mo (%)	WO_3 (M mtu)	Mo (m lb)	Agv NSR (US$/t)
Measured	107	0.072	0.024	7.7	56.6	21.11
Indicated	276	0.065	0.020	17.94	121.7	18.76

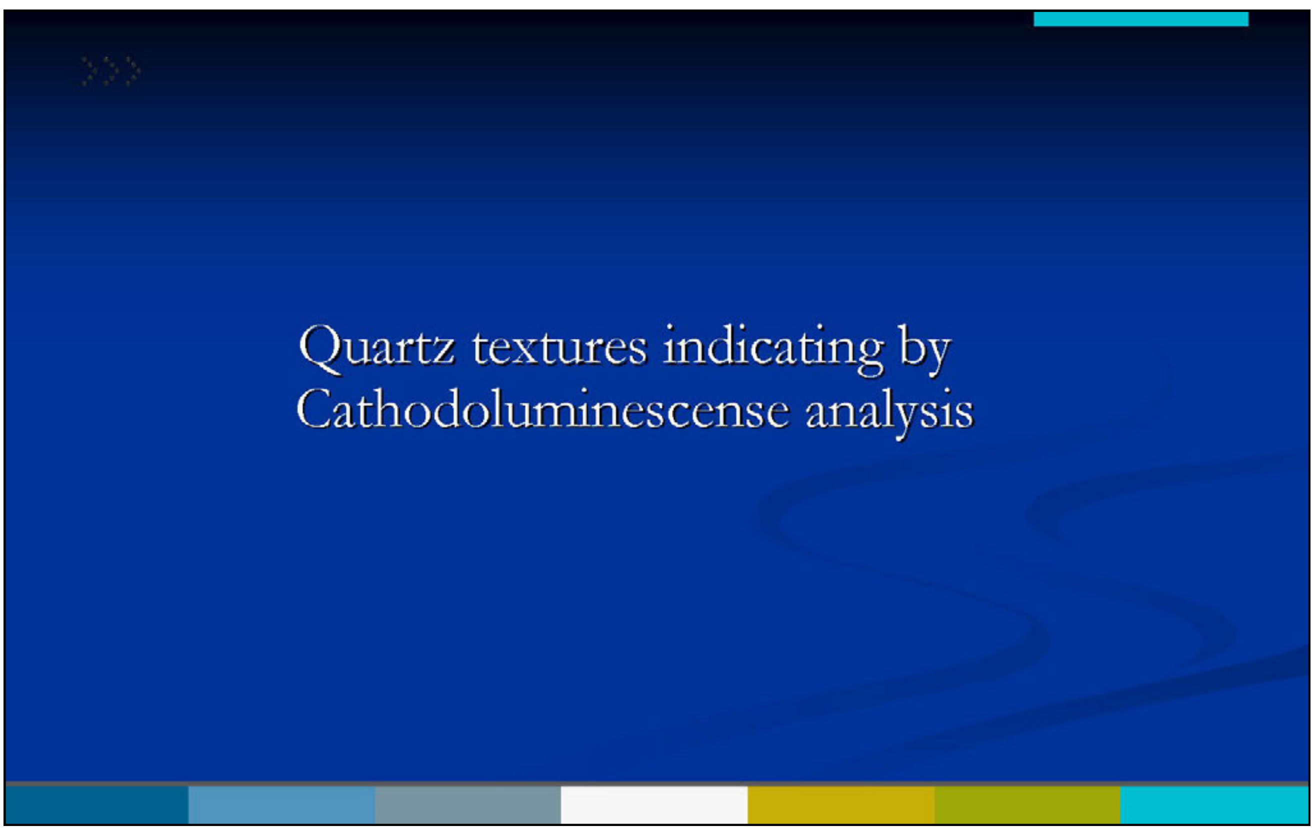
Resource Estimate: ROSCOE POSTLE ASSOCIATES INC., 43-101, June 29, 2012

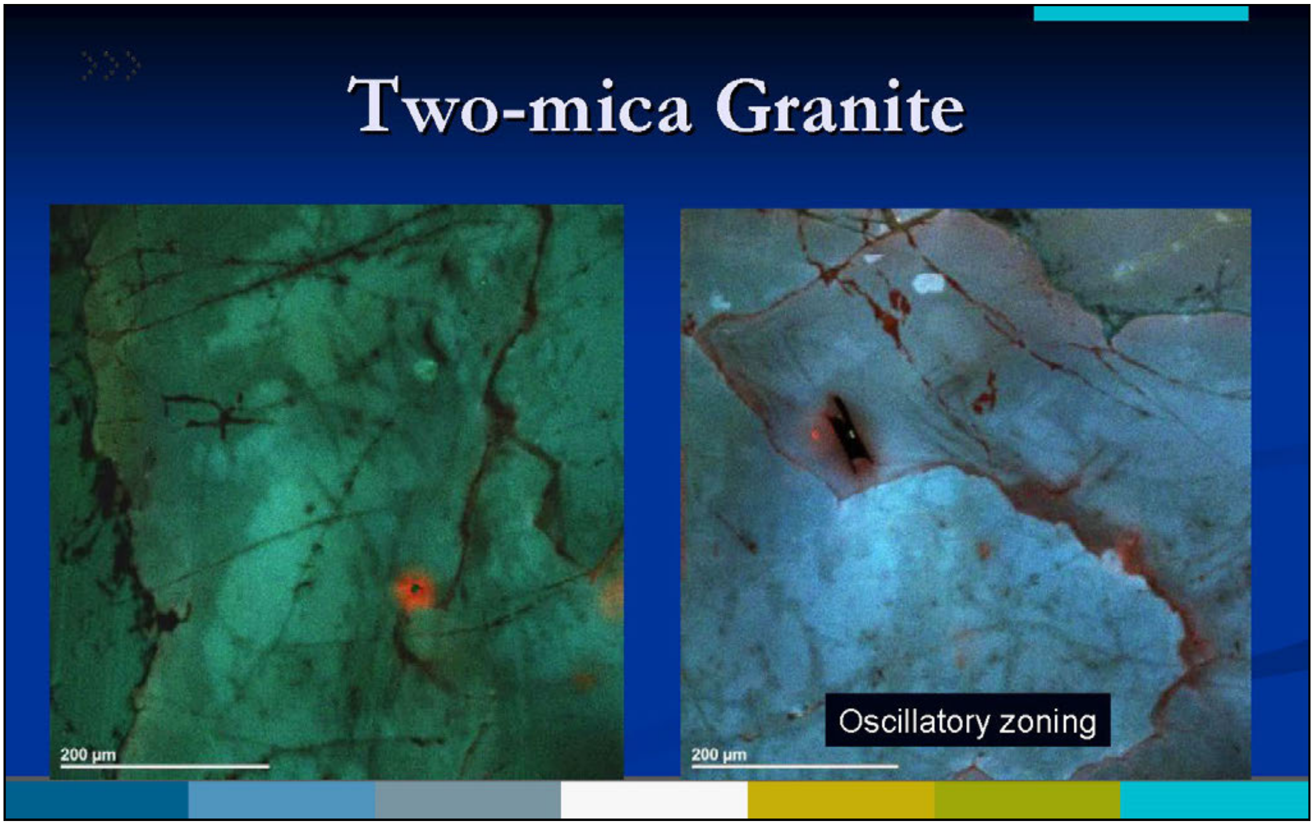


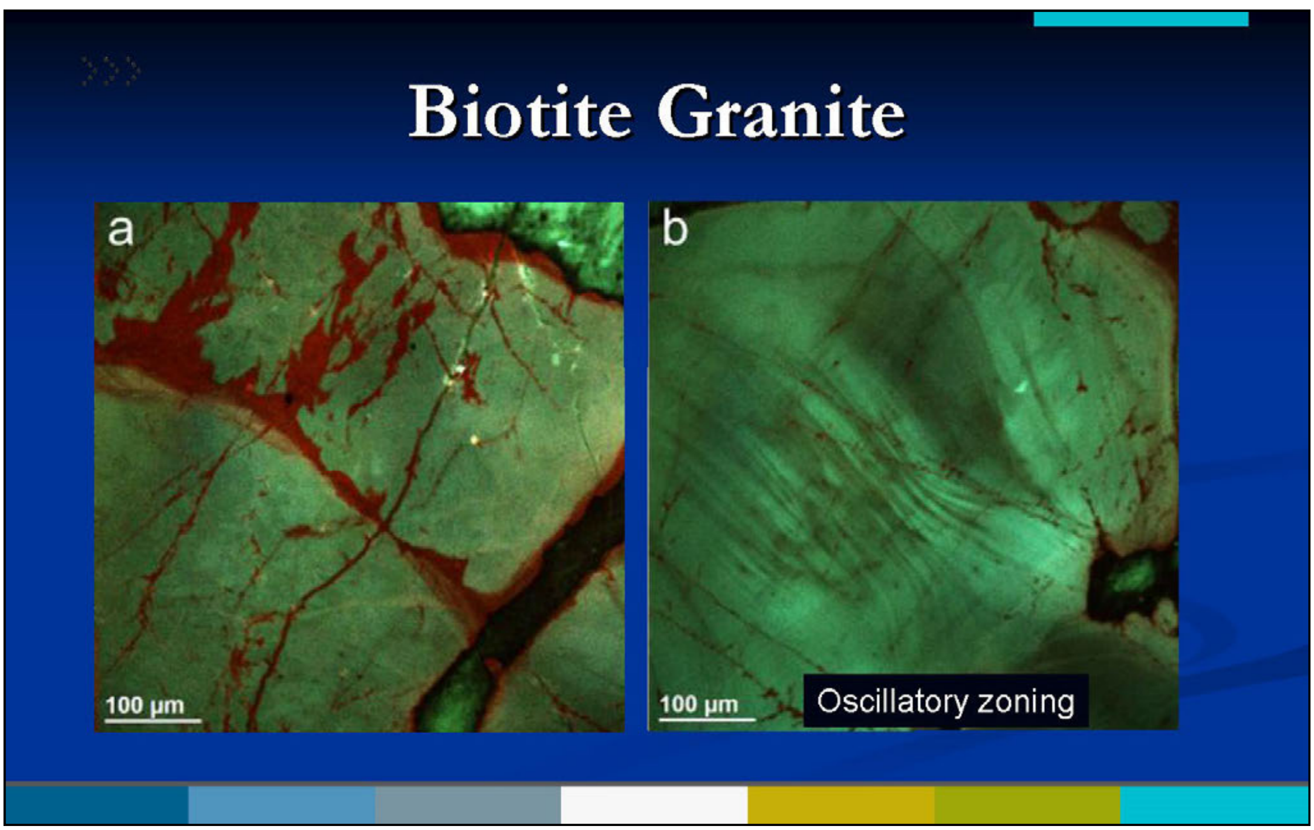

Pegmatoidal dyke

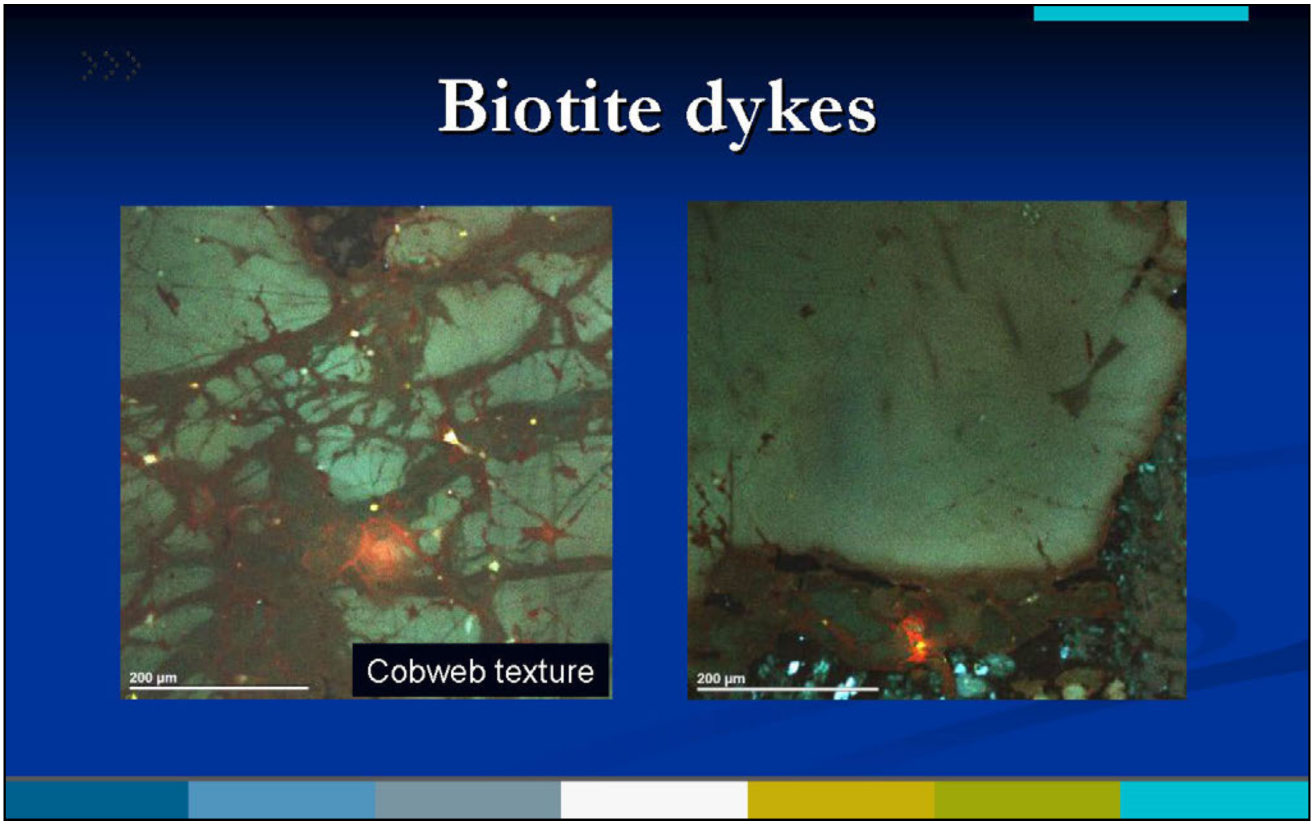

• Major WO3 mineralization event
• Decrease with depth
• Low sulphide, sinuous
• Minor wolframite at depth, replaced by scheelite
• Rarely contain high Mo concentrations
▪ Wide, commonly planar
▪ Main Mo min'l stage, usually contain scheelite
▪ Absent in north
SB10004
563.2m FDQ
from Jim Lang

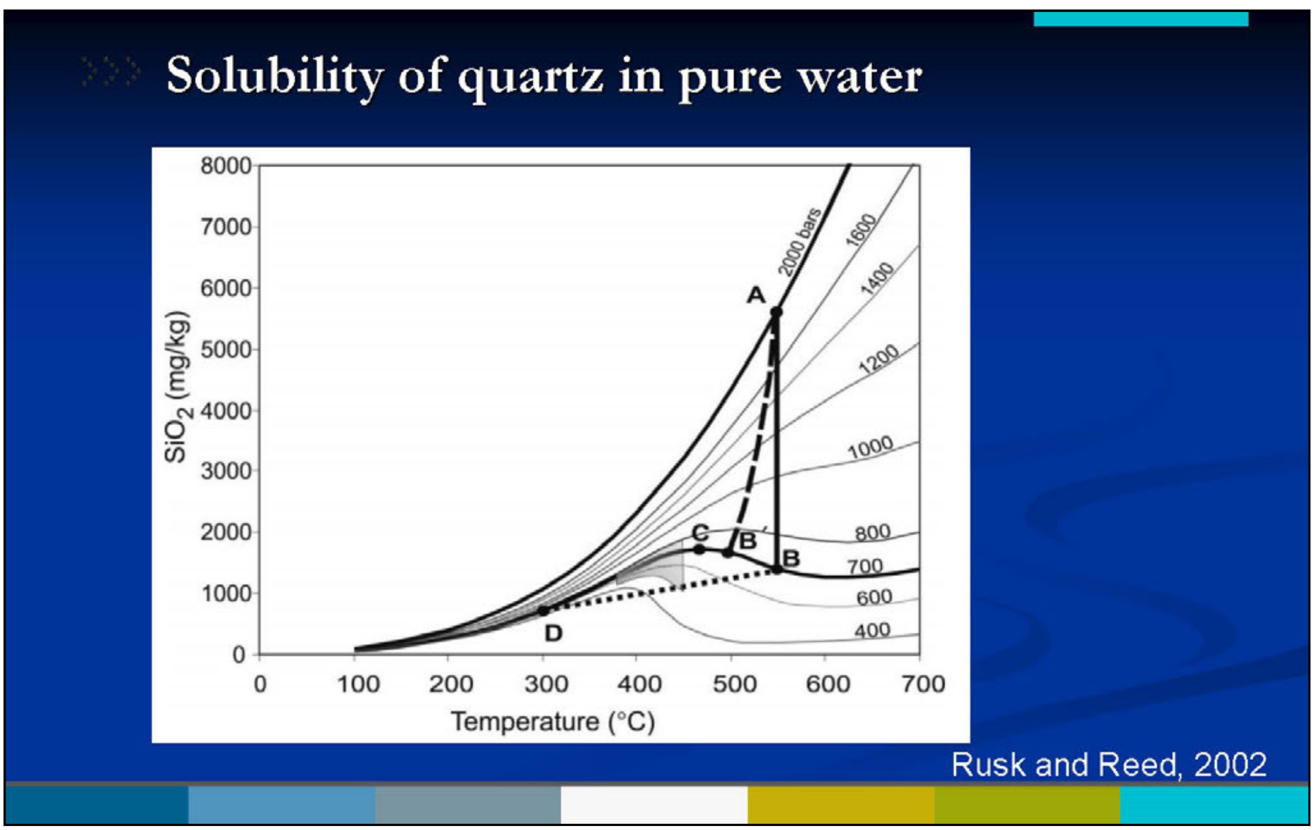

Throughout deposit, define Zones I & II in north
Strong sericite-sulphide envelopes
Wolframite + scheelite; commonly high-grade >0.5% WO_3
from Jim Lang


Quartz textures indicating by Cathodoluminescense analysis

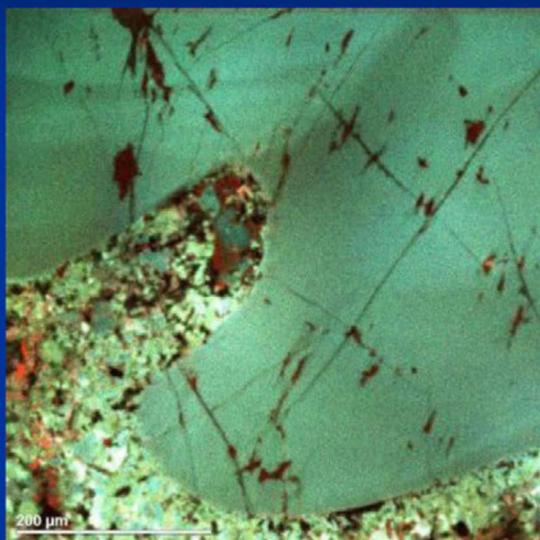

Two-mica Granite
200 µm
200 µm
Oscillatory zoning


Biotite Granite
a
b
100 µm
100 µm
Oscillatory zoning

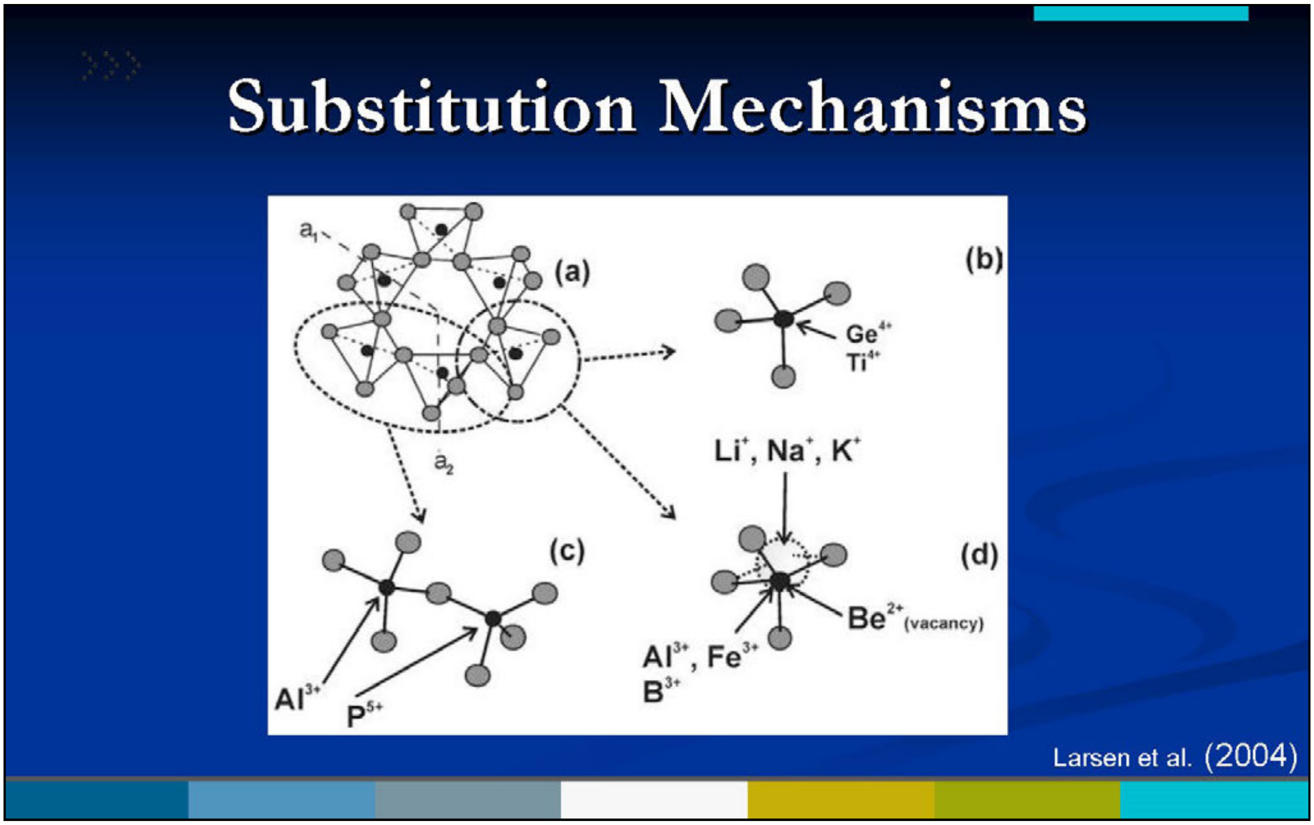

Biotite dykes
Cobweb texture
200 µm
200 µm


Solubility of quartz in pure water
8000
7000
6000
5000
4000
3000
2000
1000
0
SiO2 (mg/kg)
0
100
200
300
400
500
600
700
Temperature (°C)
2000 bars
1600
1400
1200
1000
800
700
600
400
A
B
B
C
D
Rusk and Reed, 2002

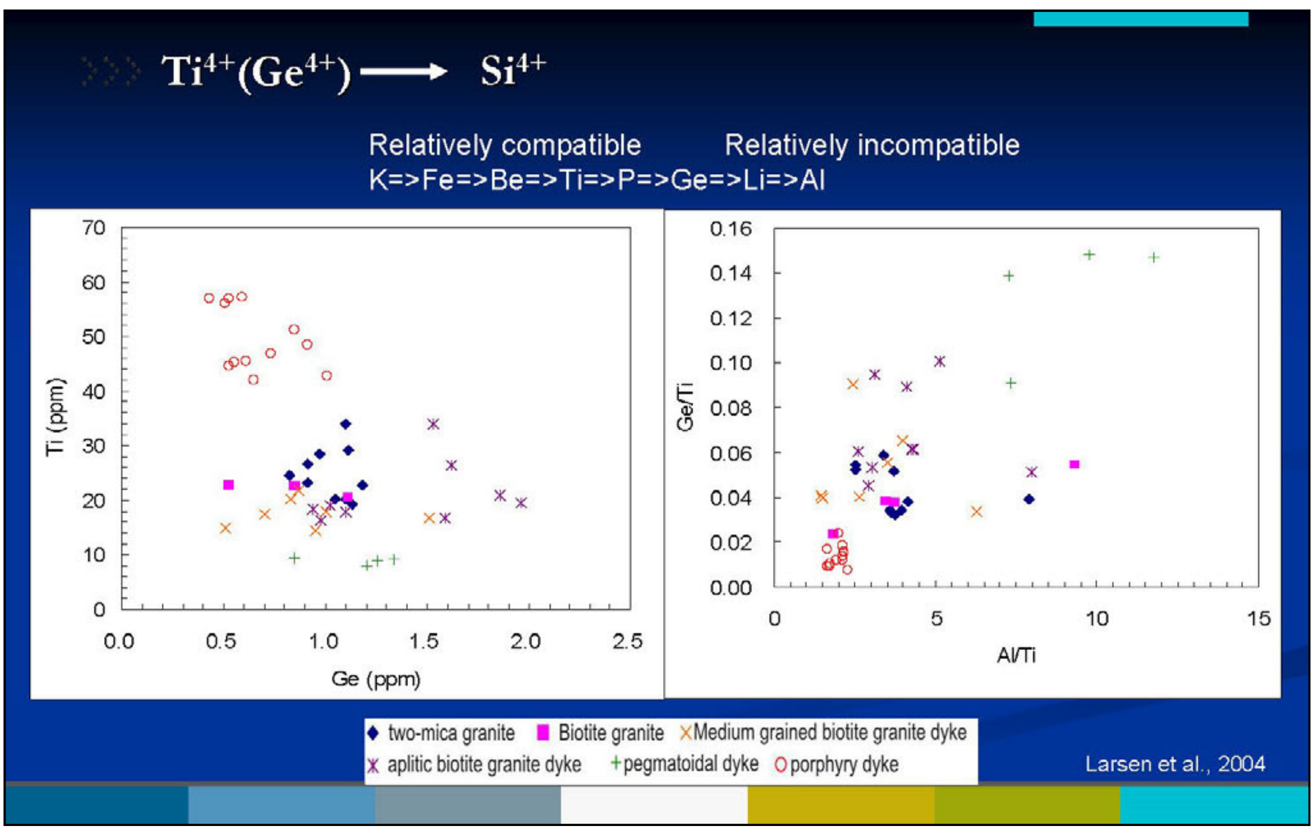
Porphyry dyke



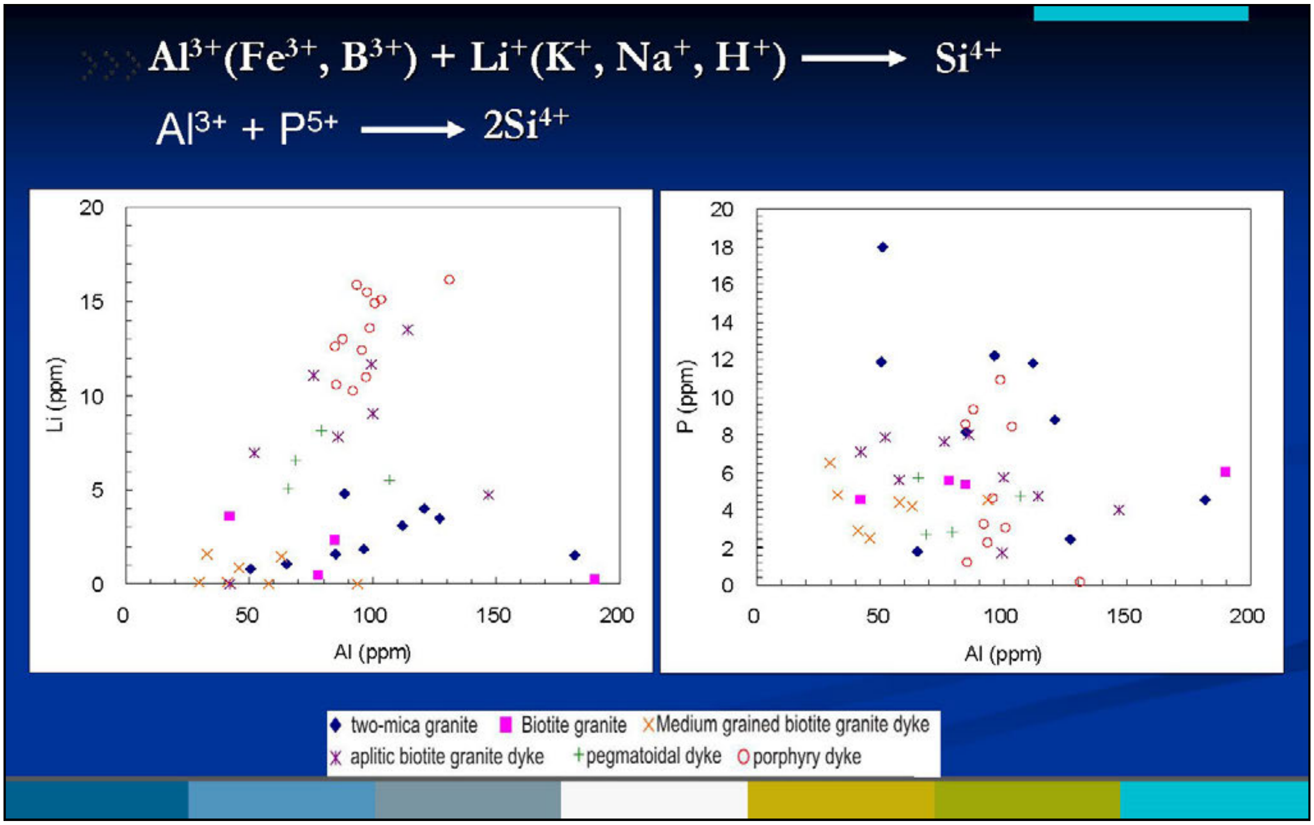
Trace elements of quartz analyzed by Laser ablation ICP-MS

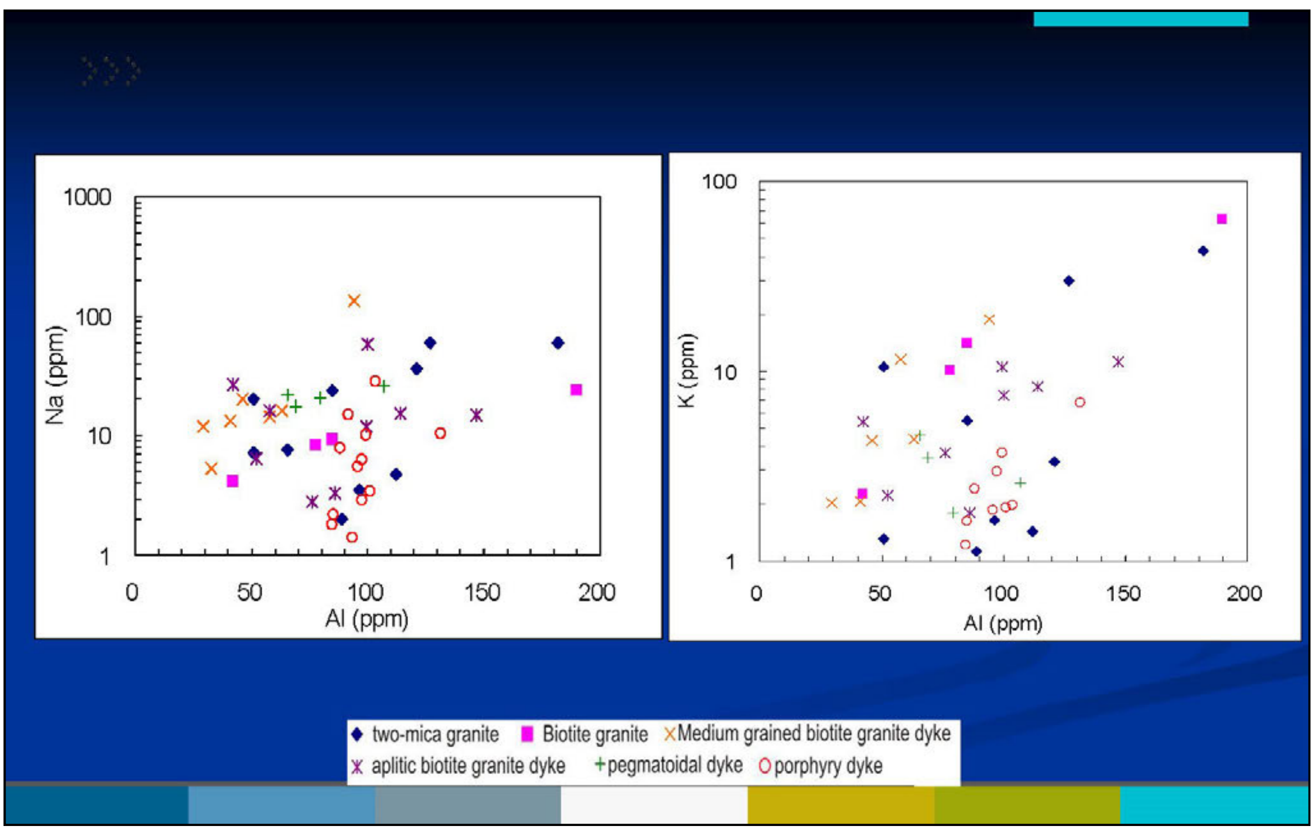


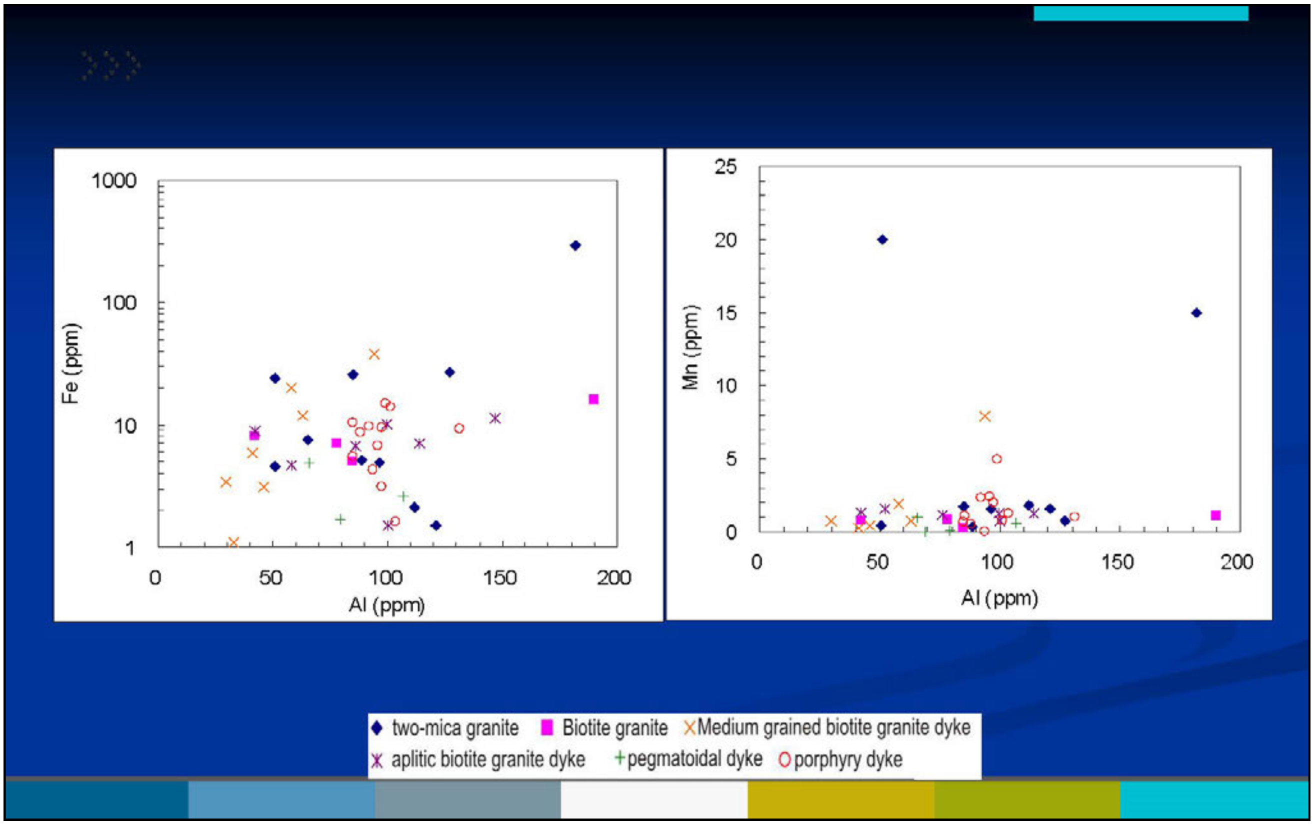
Substitution Mechanisms
a1
a2
(a)
(b)
Ge4+
Ti4+
Li+, Na+, K+
(c)
(d)
Al3+
P5+
Be2+ (vacancy)
Al3+, Fe3+
B3+
Larsen et al. (2004)

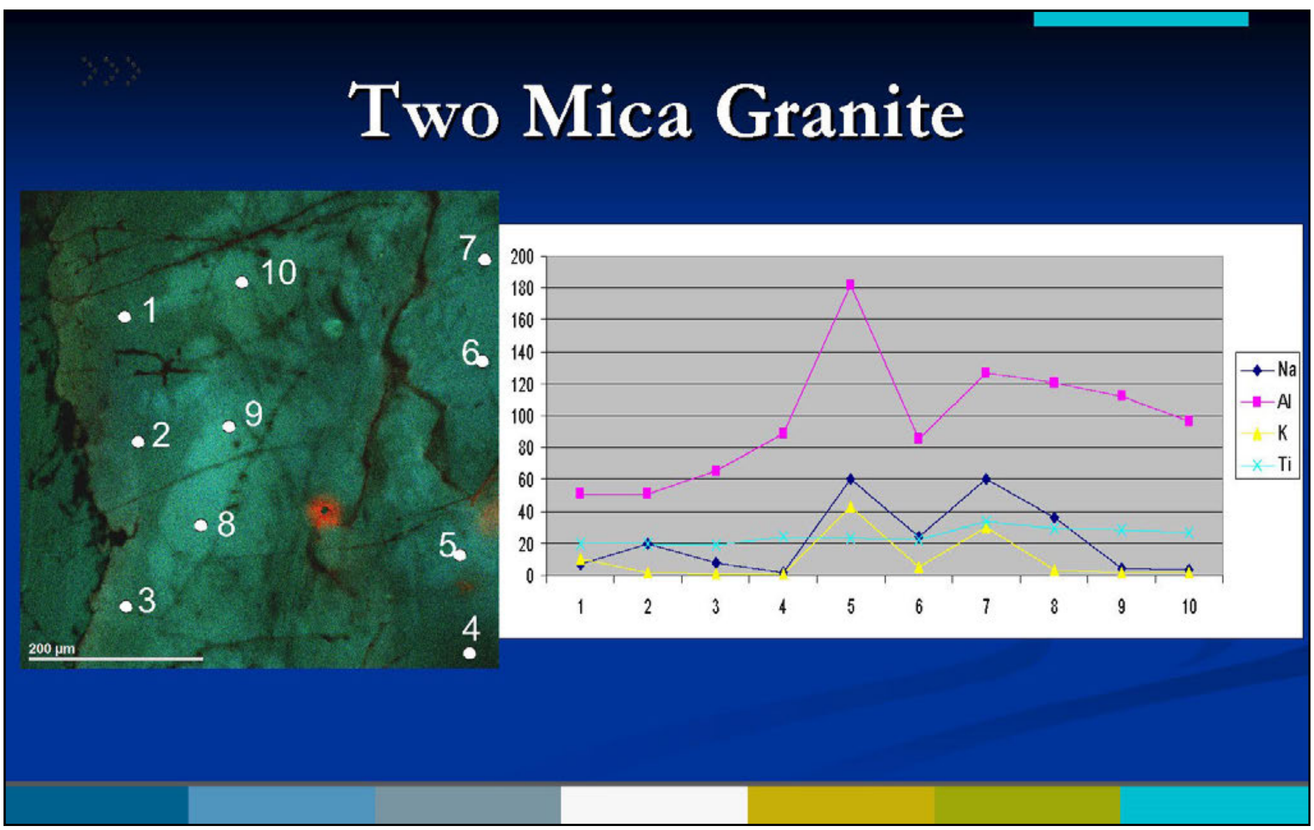


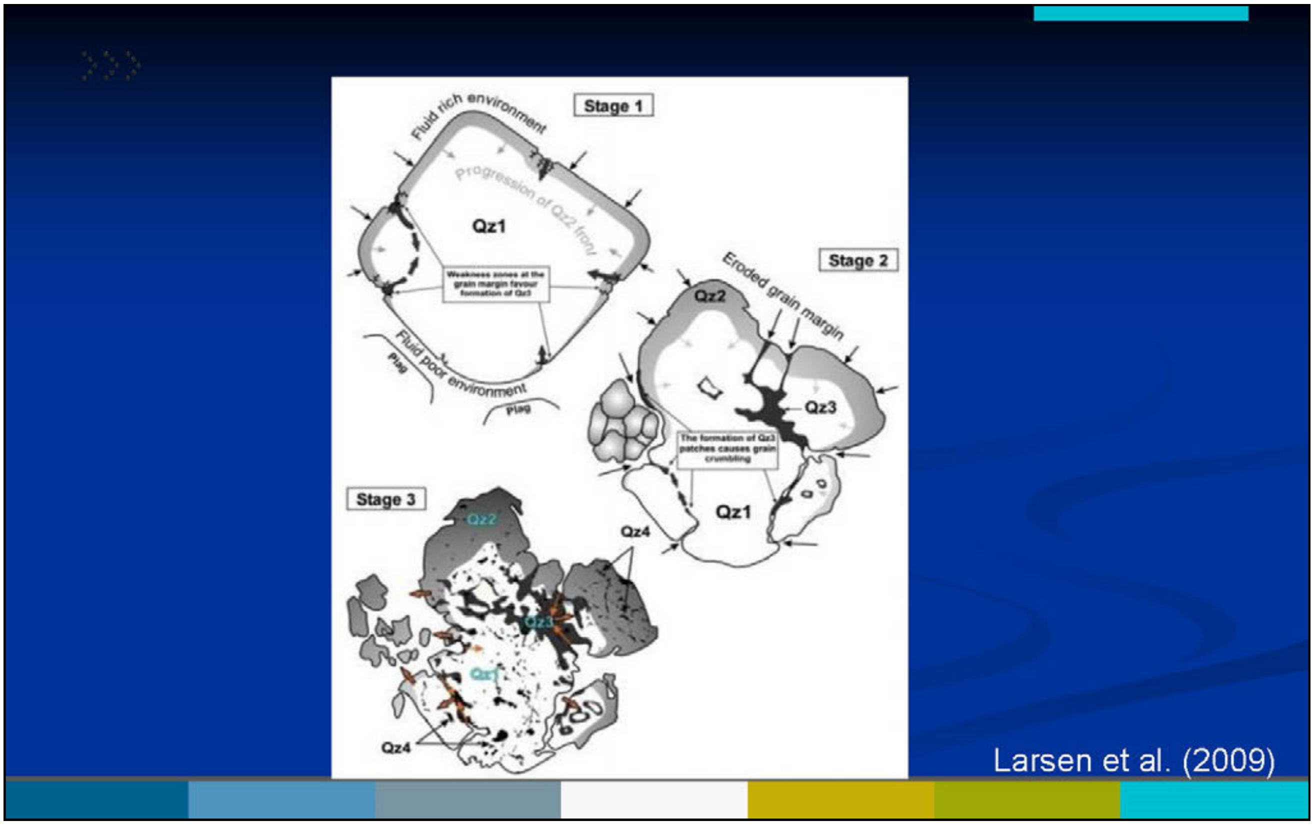
Ti4+(Ge4+) ⟶ Si4+
Relatively compatible
Relatively incompatible
K=>Fe=>Be=>Ti=>P=>Ge=>Li=>Al
Ti (ppm)
Ge (ppm)
Ge/Ti
Al/Ti
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke
Larsen et al., 2004

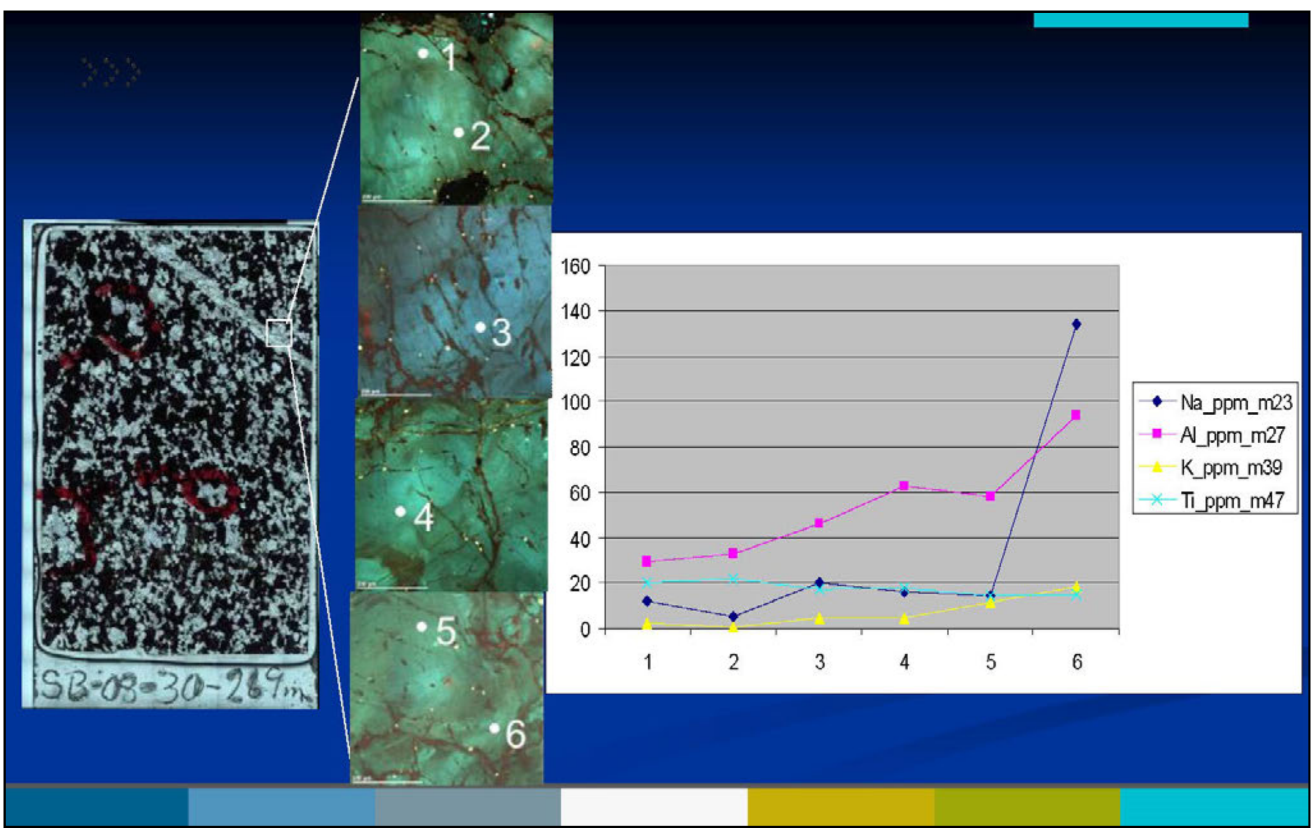

$Al^{3+}(Fe^{3+}, B^{3+}) + Li^{+}(K^{+}, Na^{+}, H^{+}) \longrightarrow Si^{4+}$
$Al^{3+} + P^{5+} \longrightarrow 2Si^{4+}$
Li (ppm)
Al (ppm)
P (ppm)
Al (ppm)
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke

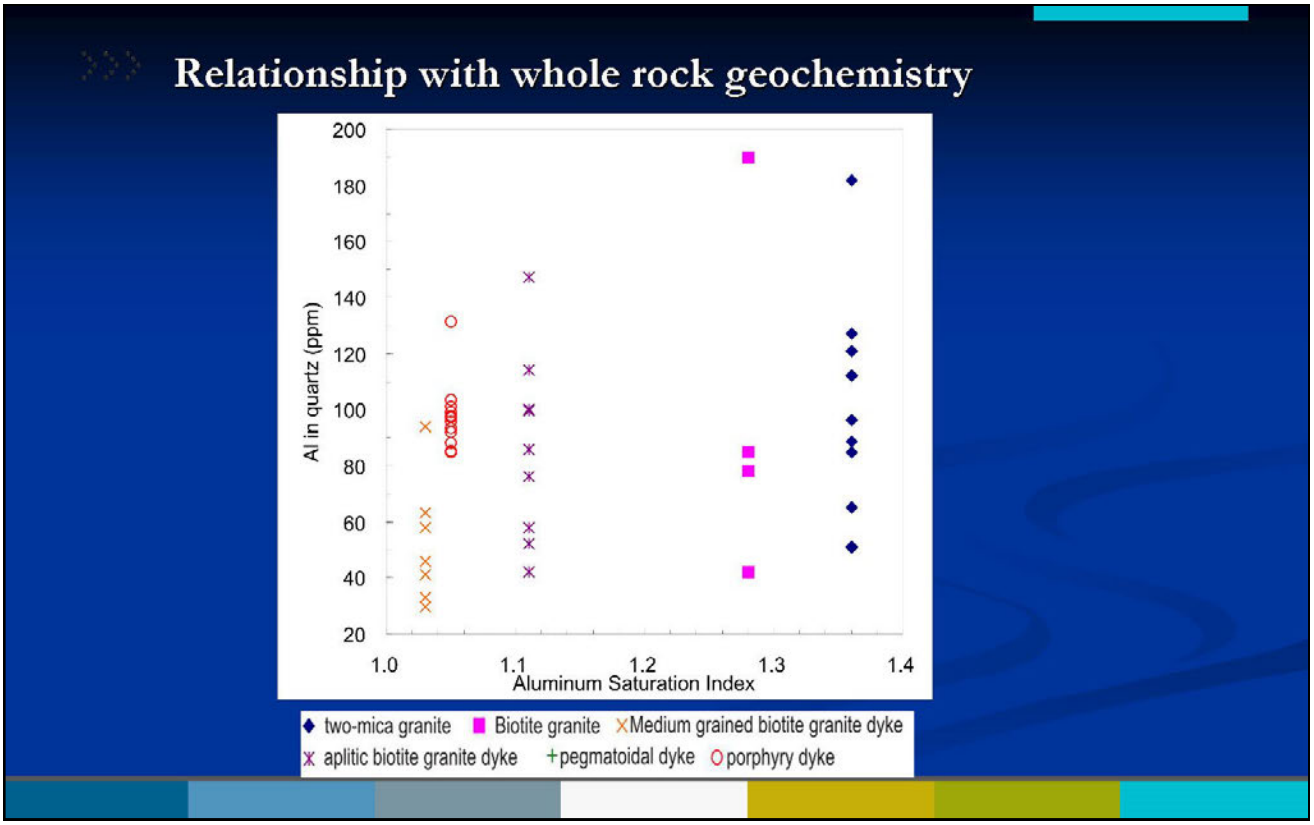

Na (ppm)
Al (ppm)
K (ppm)
Al (ppm)
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke

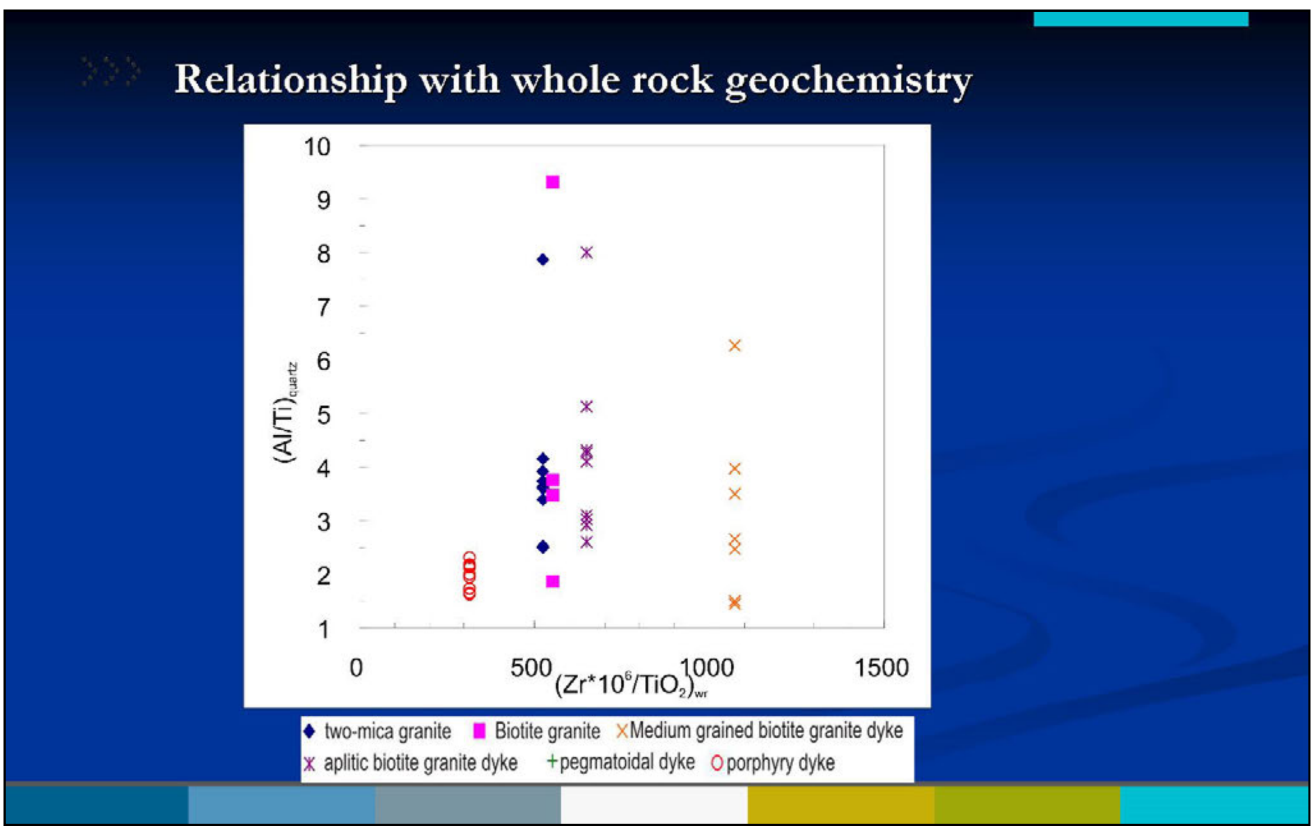

Fe (ppm)
Al (ppm)
Mn (ppm)
Al (ppm)
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke

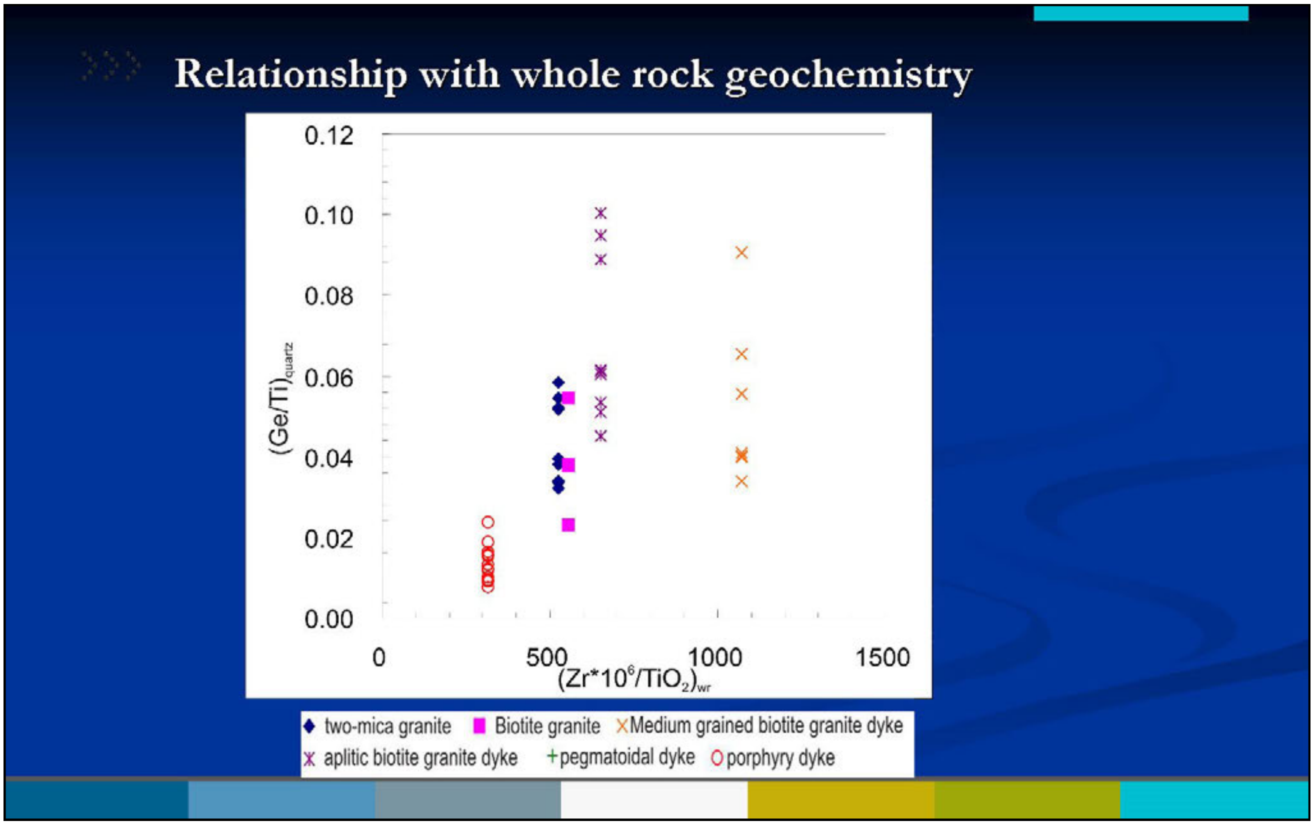

Two Mica Granite
200 µm
Na
Al
K
Ti

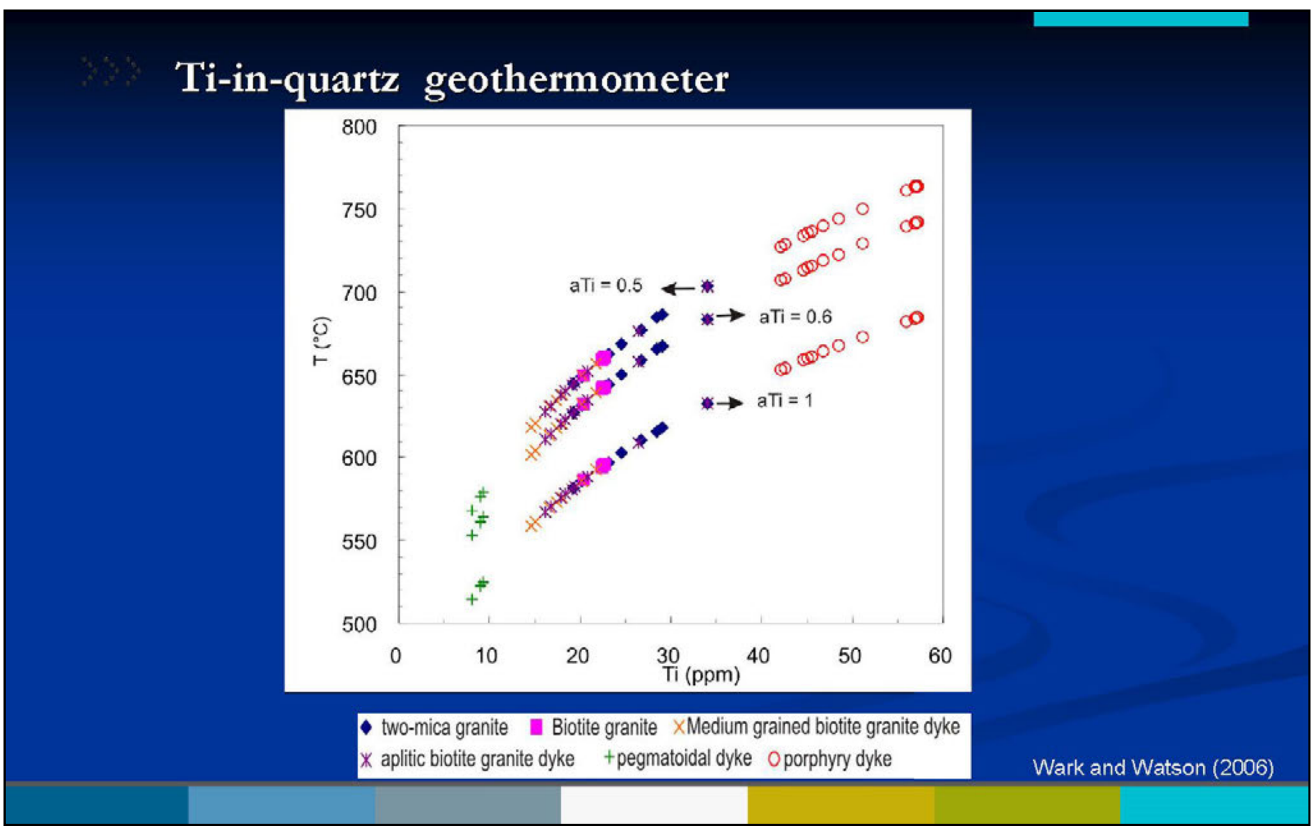

Stage 1
Fluid rich environment
Progression of Qz2 front
Qz1
Weakness zones at the grain margin favour formation of Qz3
Fluid poor environment
Plag
Plag
Stage 2
Eroded grain margin
Qz2
Qz3
The formation of Qz3 patches causes grain crumbling
Qz1
Qz4
Stage 3
Qz2
Qz3
Qz1
Qz4
Larsen et al. (2009)

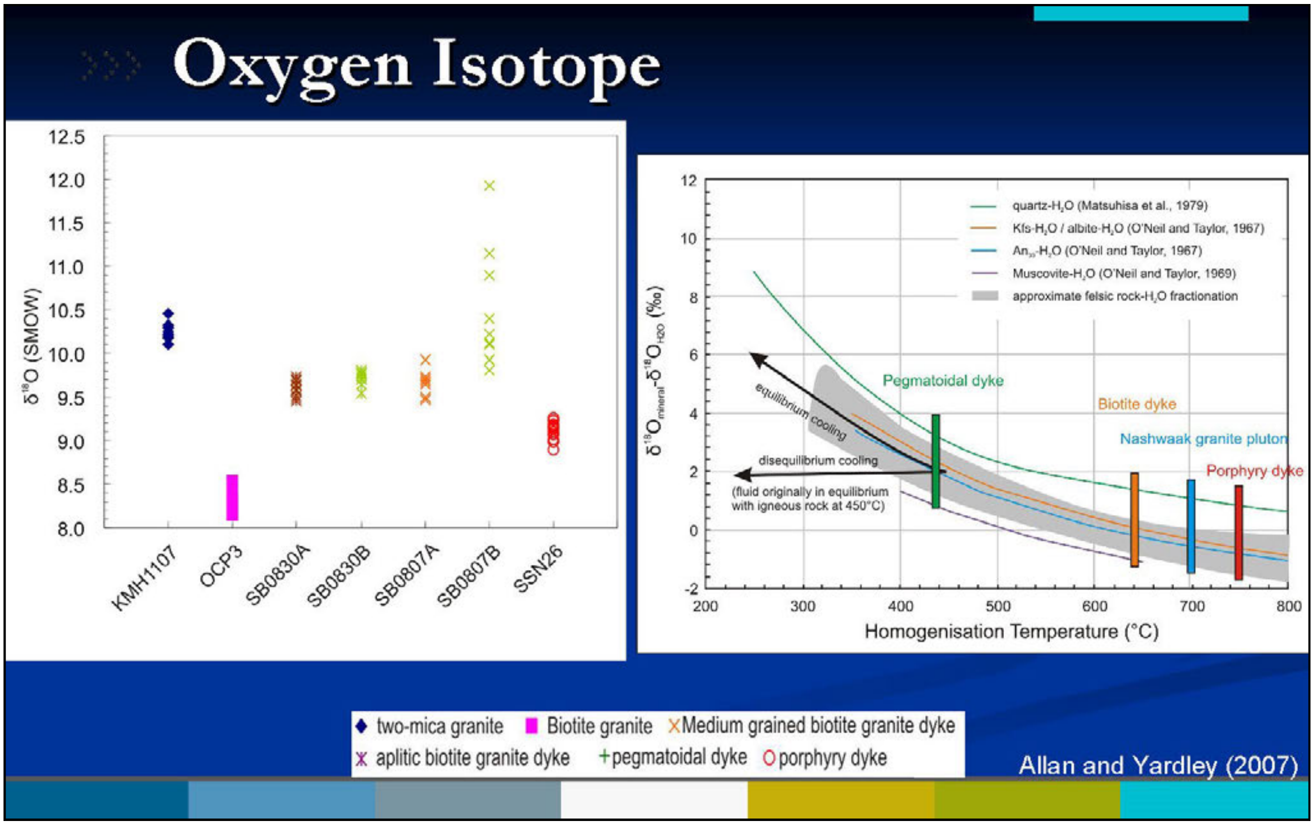

1
2
3
4
5
6
SB-08-30-269m
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
Na_ppm_m23
Al_ppm_m27
K_ppm_m39
Ti_ppm_m47

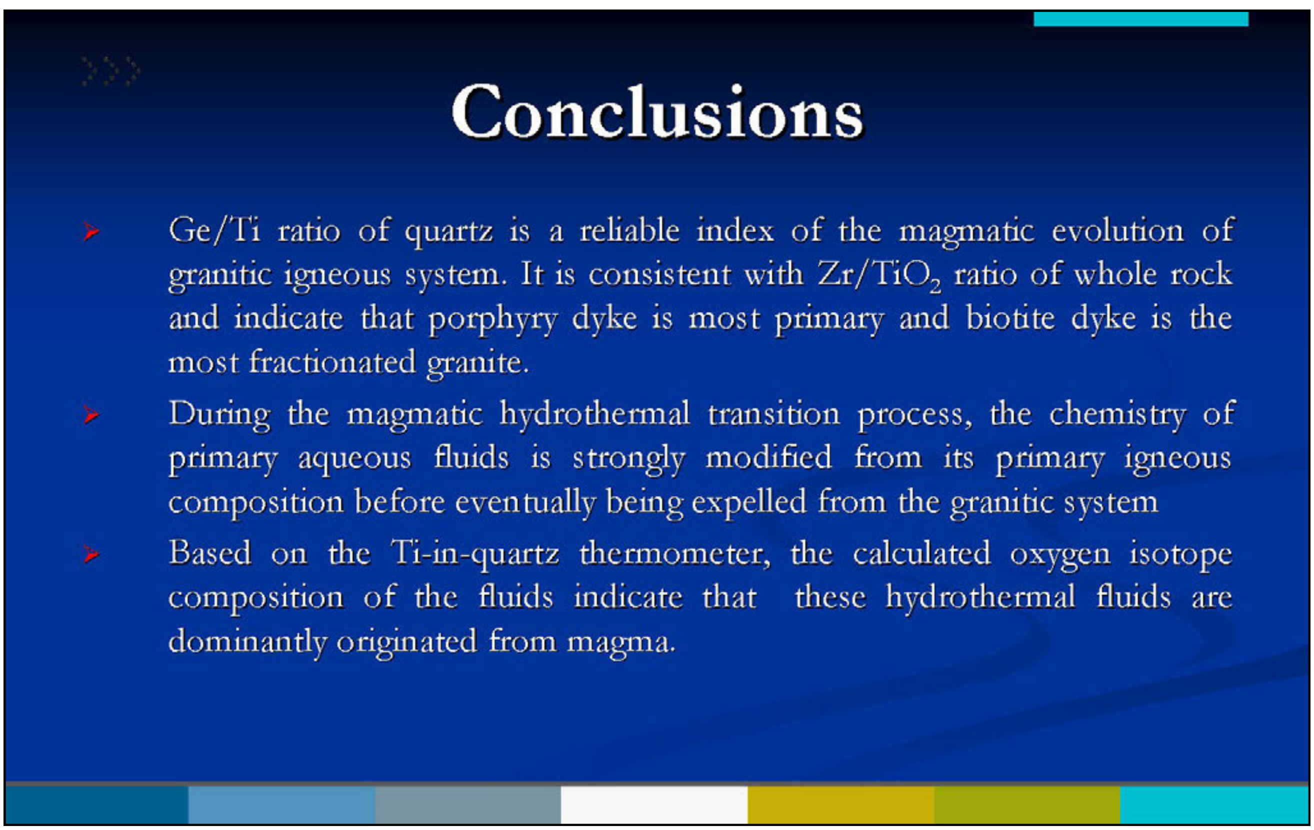

Relationship with whole rock geochemistry
Al in quartz (ppm)
200
180
160
140
120
100
80
60
40
20
1.0
1.1
1.2
1.3
1.4
Aluminum Saturation Index
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke


Relationship with whole rock geochemistry
$(Al/Ti)_{quartz}$
10
9
8
7
6
5
4
3
2
1
0
500
1000
1500
$(Zr*10^6/TiO_2)_{wr}$
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke


Relationship with whole rock geochemistry
0.12
0.10
0.08
0.06
0.04
0.02
0.00
(Ge/Ti)quartz
0
500
1000
1500
(Zr*10^6/TiO2)wr
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke


Ti-in-quartz geothermometer
800
750
700
650
600
550
500
T (°C)
0
10
20
30
40
50
60
Ti (ppm)
aTi = 0.5
aTi = 0.6
aTi = 1
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke
Wark and Watson (2006)


Oxygen Isotope
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
δ18O (SMOW)
KMH1107
OCP3
SB0830A
SB0830B
SB0807A
SB0807B
SSN26
quartz-H2O (Matsuhisa et al., 1979)
Kfs-H2O / albite-H2O (O'Neil and Taylor, 1967)
An30-H2O (O'Neil and Taylor, 1967)
Muscovite-H2O (O'Neil and Taylor, 1969)
approximate felsic rock-H2O fractionation
δ18Omineral-δ18OH2O (‰)
equilibrium cooling
disequilibrium cooling
(fluid originally in equilibrium with igneous rock at 450°C)
Pegmatoidal dyke
Biotite dyke
Nashwaak granite pluton
Porphyry dyke
Homogenisation Temperature (°C)
two-mica granite
Biotite granite
Medium grained biotite granite dyke
aplitic biotite granite dyke
pegmatoidal dyke
porphyry dyke
Allan and Yardley (2007)


Conclusions
Ge/Ti ratio of quartz is a reliable index of the magmatic evolution of granitic igneous system. It is consistent with Zr/TiO2 ratio of whole rock and indicate that porphyry dyke is most primary and biotite dyke is the most fractionated granite.
During the magmatic hydrothermal transition process, the chemistry of primary aqueous fluids is strongly modified from its primary igneous composition before eventually being expelled from the granitic system
Based on the Ti-in-quartz thermometer, the calculated oxygen isotope composition of the fluids indicate that these hydrothermal fluids are dominantly originated from magma.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GEODEX MINERALS
HDI NORTHCLIFF
New Nouveau
Brunswick
CANADA