Using biotite composition of the Devonian Lake George granodiorite, New Brunswick, as a case study for W-Mo-Au-Sb mineralized magmatic hydrothermal systems

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Abstract: The granodioritic Lake George polymetallic deposit is located approximately 35 km southwest of Fredericton, New Brunswick. This intrusion is a metaluminous to weakly peraluminous, calc-alkaline body that shows an evolved I-type, volcanic arc affinity. Based on an Early Devonian age determination, (412 +5/-4 Ma, zircon U-Pb) it is related to the Hakshaw granite phase of the Pokiok Batholith. The Lake George stock is cut by Hibbard stibnite -quartz veins and quartz-scheelite-molybdenite veinlets that contain significant amounts of gold. Fresh biotites from this intrusion were analyzed at both the core and rim by electron microprobe, and along rim to rim transects by laser ablation ICP-MS at the University of New Brunswick to build an understanding of the halogens responsible for mineralization and trace element distribution within this deposit.

Biotites of this intrusion are reddish brown in colour (indicative of reduced I-type source) and mostly altered to chlorite. They usually contain apatite, zircon, titanite, ilmenite, rutile, and sulphide minerals as mineral inclusions. Temperature was calculated with the Ti-In-biotite geothermometer, in which the results showed a variation between 583 and 745°C.

Two depths of emplacement were determined based on the Al in hornblende and biotite geobarometries confirming the porphyritic texture of this intrusion (4.3 and 1.5 km, respectively). Forming amphiboles at that depth clearly indicates a high water content of the source magma; in addition, hydroxyl is the most dominant component of the hydroxyl site (Average 1.89 wt%) in biotites. The limited range of IV(F/Cl) values of the Lake George biotites suggested that they all equilibrated with one fluid.

Even though there is no noticeable difference in major elements from core to rims, evidence of magma evolution is recorded by biotite grains by their trace elements. For instance, Cu, Rb, Cr, K, Mo, Sn, Cs and W increase from core to rims, whereas Ba, Ni, Mn, and Li act inversely. Sb has a negligible variation from core to rim. Interestingly, the partition coefficient (biotite/whole-rock) is significantly small for Sb, W, and Mo (main associated mineralization) with 0.06, 0.28 and 0.13 in pure magmatic biotites and increase to 0.77, 1.93 and 0.20 in more altered biotites reflecting enrichment of these elements towards the late stage fluid.

Based on these observations, the concept of using mica composition to help identify fertile Acadian magma systems was proved; this method may be a useful tool to indicate the difference between barren and mineralized granophile-element rich systems.

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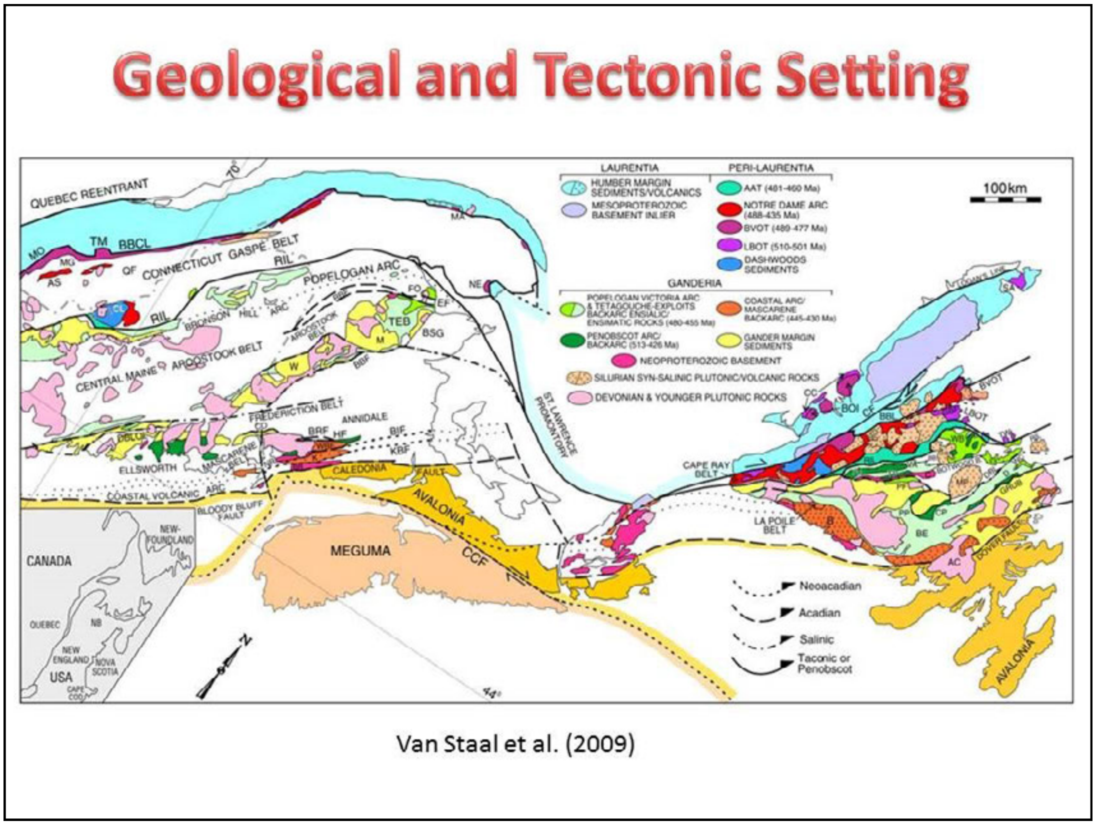
Project Goals

- Document detailed chemistry of coexisting phyllosilicate mineral phases to reveal distinctive element signatures that may be specific to fertile granitoids.
- Provide a geochemical fingerprint for more-specific mineralization styles and prospectivity in the Acadian Plutonic Complex.


Geological and Tectonic Setting
LAURENTIA
PERI-LAURENTIA
HUMBER MARGIN SEDIMENTS/VOLCANICS
MESOPROTEROZOIC BASEMENT INLIER
AAT (481-460 Ma)
NOTRE DAME ARC (488-435 Ma)
BVOT (489-477 Ma)
LBOT (510-501 Ma)
DASHWOODS SEDIMENTS
GANDERIA
POPELOGAN VICTORIA ARC & TETAGOUCHE-EXPLOITS BACKARC ENSIALIC/ ENSIMATIC ROCKS (480-455 Ma)
COASTAL ARC/ MASCARENE BACKARC (445-430 Ma)
PENOBSCOT ARC/ BACKARC (513-486 Ma)
GANDER MARGIN SEDIMENTS
NEOPROTEROZOIC BASEMENT
SILURIAN SYN-SALINIC PLUTONIC/VOLCANIC ROCKS
DEVONIAN & YOUNGER PLUTONIC ROCKS
100km
QUEBEC REENTRANT
CONNECTICUT GASPÉ BELT
POPELOGAN ARC
BRONSON HILL ARC
CENTRAL MAINE AROOSTOOK BELT
FREDERICTON BELT
ANNIDALE
ELLSWORTH
COASTAL VOLCANIC ARC
BLOODY BLUFF FAULT
CALEDONIA
AVALONIA
MEGUMA
CCF
ST. LAWRENCE PROMONTORY
CAPE RAY BELT
LA POILE BELT
Neoacadian
Acadian
Salinic
Taconic or Penobscot
CANADA
QUEBEC
NEW-FOUNDLAND
NB
NEW ENGLAND
NOVA SCOTIA
USA
CAPE COD
Van Staal et al. (2009)

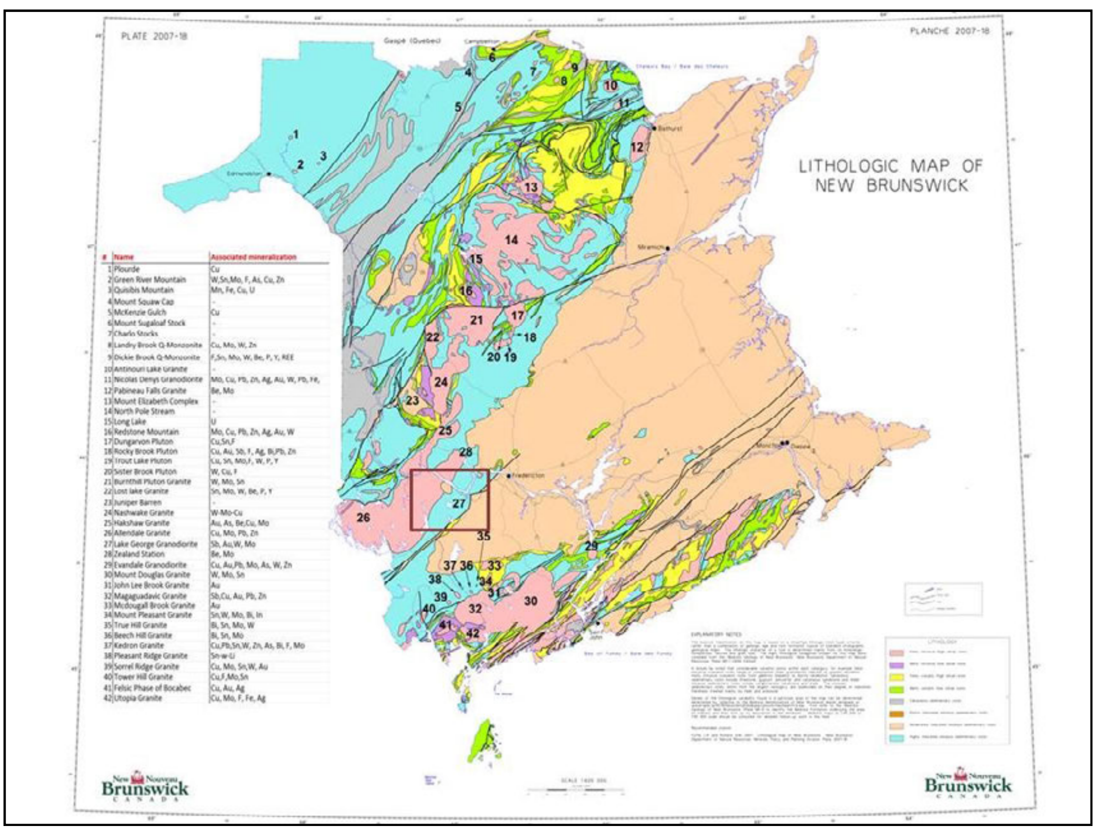
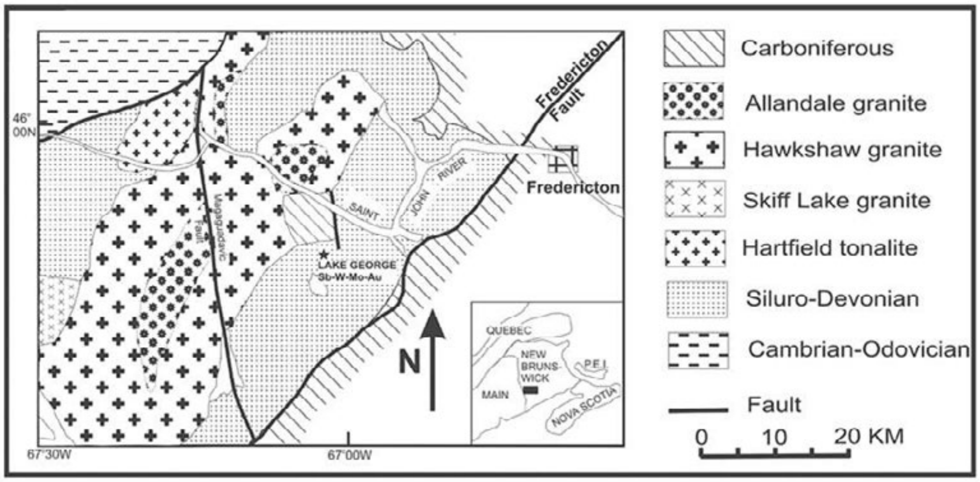


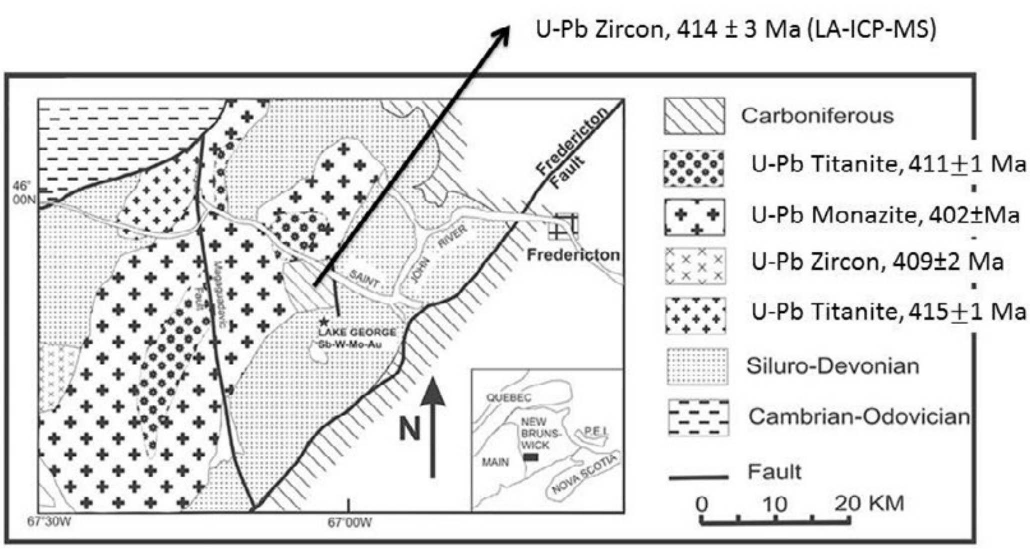
PLATE 2007-18
PLANCHE 2007-18
LITHOLOGIC MAP OF NEW BRUNSWICK
Name Associated mineralization
1 Plourde Cu
2 Green River Mountain W,Sn,Mo, F, As, Cu, Zn
3 Quisibis Mountain Mn, Fe, Cu, U
4 Mount Squaw Cap -
5 McKenzie Gulch Cu
6 Mount Sugaloaf Stock -
7 Charlo Stocks -
8 Landry Brook Q-Monzonite Cu, Mo, W, Zn
9 Dickie Brook Q-Monzonite F,Sn, Mo, W, Be, P, Y, REE
10 Antinouri Lake Granite -
11 Nicolas Denys Granodiorite Mo, Cu, Pb, Zn, Ag, Au, W, Pb, Fe,
12 Pabineau Falls Granite Be, Mo
13 Mount Elizabeth Complex -
14 North Pole Stream -
15 Long Lake U
16 Redstone Mountain Mo, Cu, Pb, Zn, Ag, Au, W
17 Dungarvon Pluton Cu,Sn,F
18 Rocky Brook Pluton Cu, Au, Sb, F, Ag, Bi,Pb, Zn
19 Trout Lake Pluton Cu, Sn, Mo,F, W, P, Y
20 Sister Brook Pluton W, Cu, F
21 Burnthill Pluton Granite W, Mo, Sn
22 Lost lake Granite Sn, Mo, W, Be, P, Y
23 Juniper Barren -
24 Nashwake Granite W-Mo-Cu
25 Hakshaw Granite Au, As, Be,Cu, Mo
26 Allendale Granite Cu, Mo, Pb, Zn
27 Lake George Granodiorite Sb, Au,W, Mo
28 Zealand Station Be, Mo
29 Evandale Granodiorite Cu, Au,Pb, Mo, As, W, Zn
30 Mount Douglas Granite W, Mo, Sn
31 John Lee Brook Granite Au
32 Magaguadavic Granite Sb,Cu, Au, Pb, Zn
33 Mcdougall Brook Granite Au
34 Mount Pleasant Granite Sn,W, Mo, Bi, In
35 True Hill Granite Bi, Sn, Mo, W
36 Beech Hill Granite Bi, Sn, Mo
37 Kedron Granite Cu,Pb,Sn,W, Zn, As, Bi, F, Mo
38 Pleasant Ridge Granite Sn-w-Li
39 Sorrel Ridge Granite Cu, Mo, Sn,W, Au
40 Tower Hill Granite Cu,F,Mo,Sn
41 Felsic Phase of Bocabec Cu, Au, Ag
42 Utopia Granite Cu, Mo, F, Fe, Ag
New Nouveau Brunswick CANADA

Geological Setting



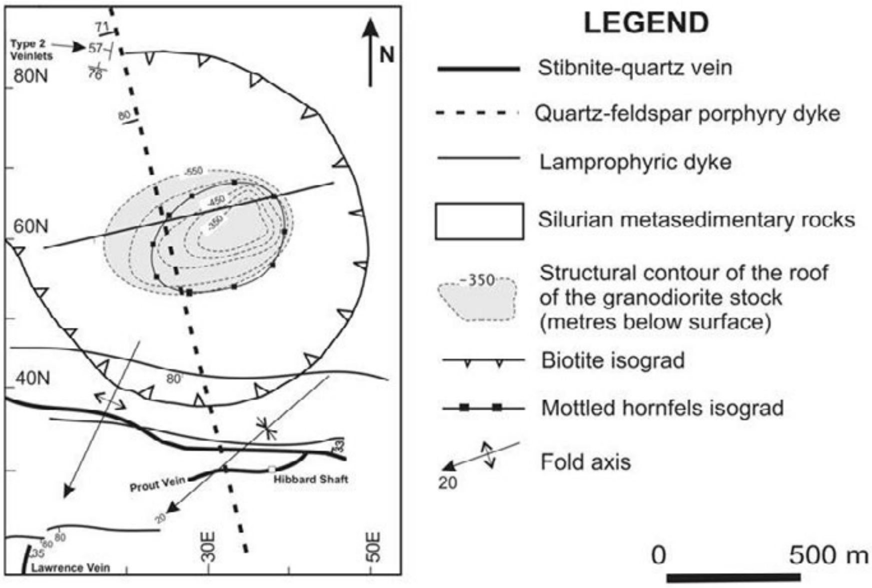
Yang et al. (2002)

Geological Setting



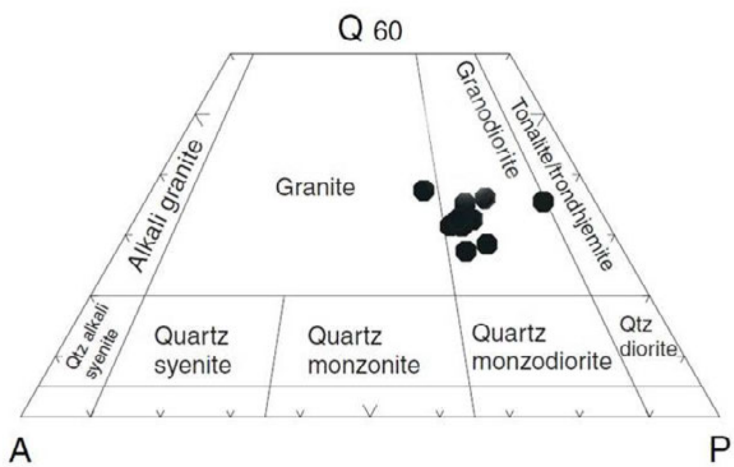
Yang et al. (2002)

Geological Setting



Leonard et al. 2005

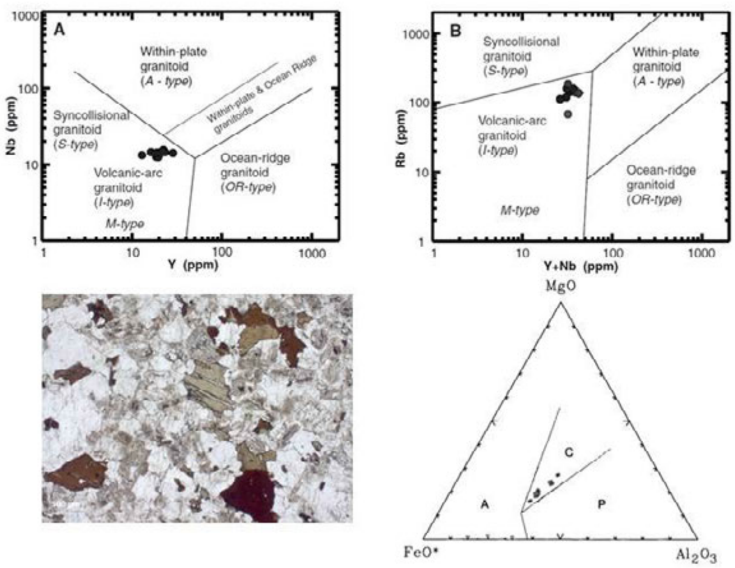
Wholerock Geochemistry



Quartz (Q)-Alkali feldspar (A)- Plagioclase (P) mesonormative classification diagram(after Le Maitre et al., 1989) (Yang et al.(2002)

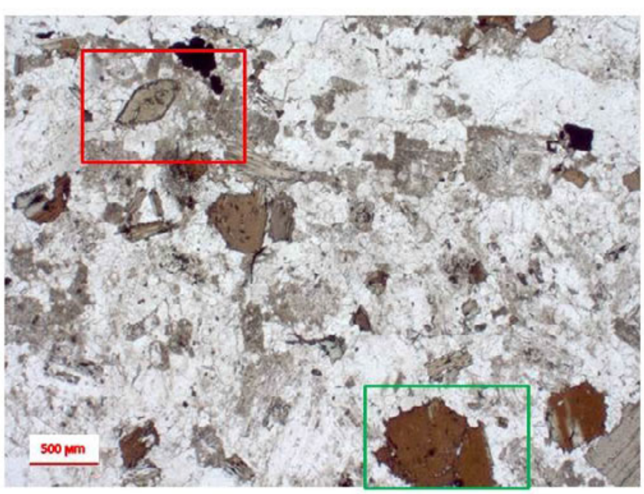
Tectonic Setting

Yang et al. (2002)



Lalonde and Bernard (1993) Abdel-Rahman (1994)

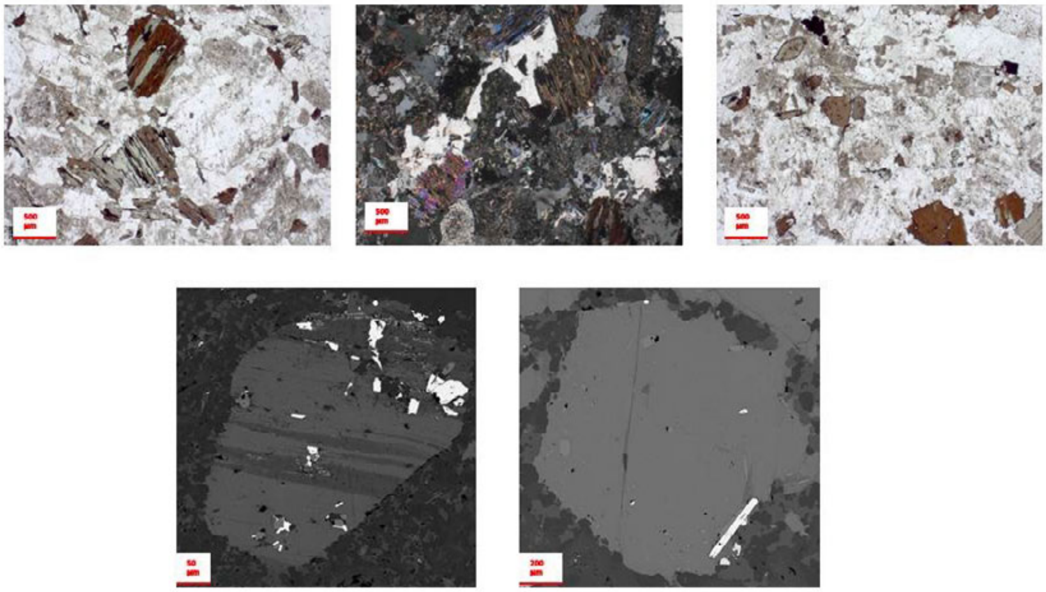
Geobarometry



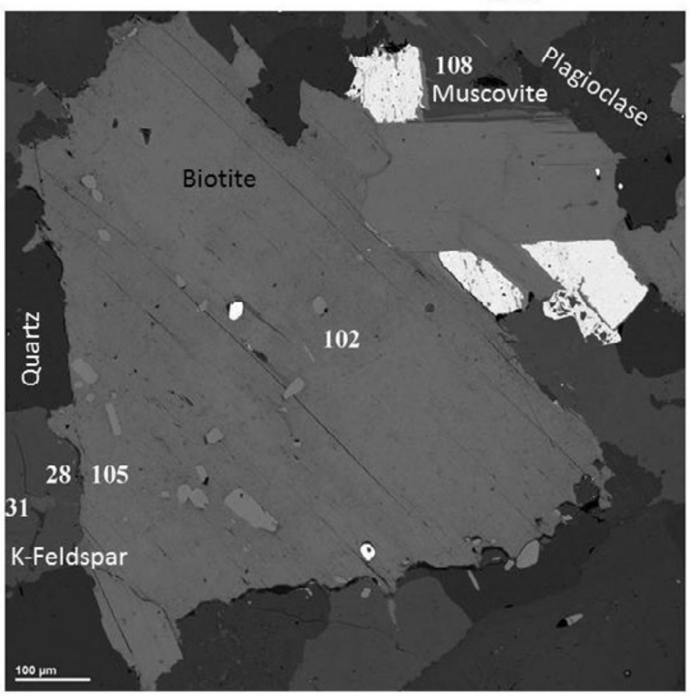
(~3.4 - 4.6 kb)
Done by Yang et al.(2002)

1~2 kb
Uchida et al.(2007)

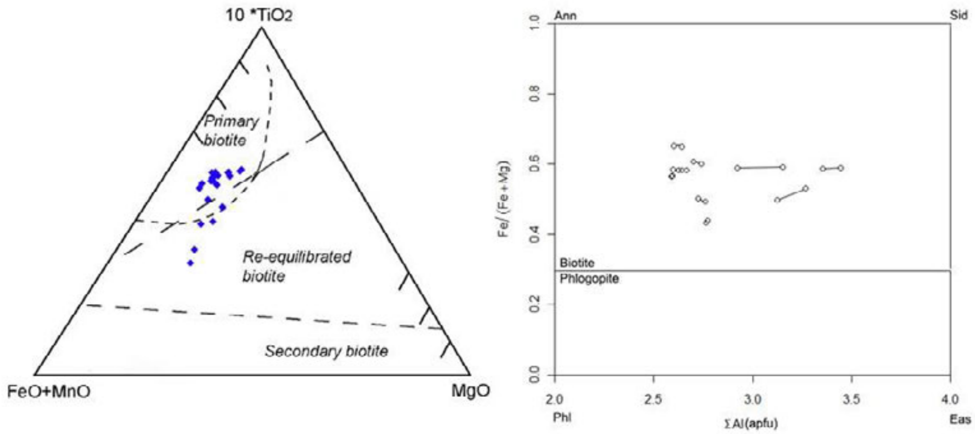
Petrography



Methodology

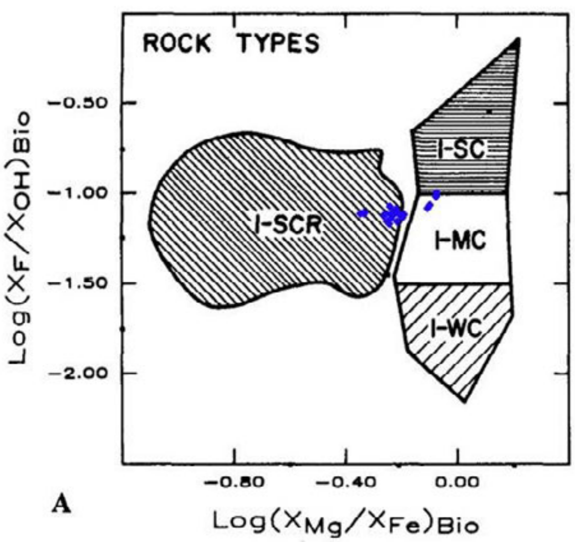


Biotite Classification



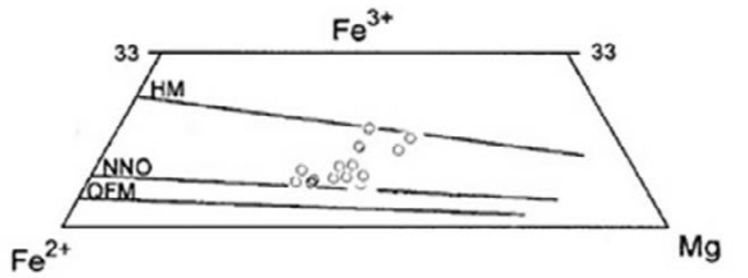
10×TiO_2 – (FeO + MnO) – MgO ternary plot of biotite composition from the Lake George granodiorite; the discrimination field boundaries are from Nachit et al. (2005).

Biotite Classification



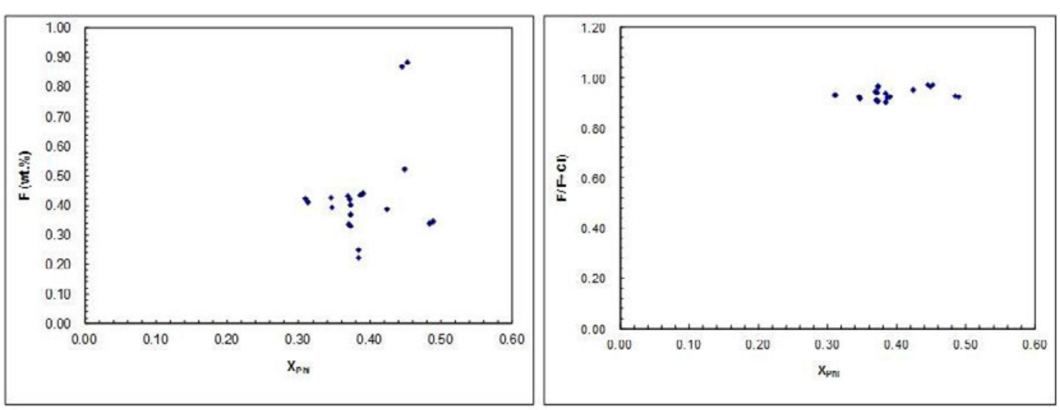
Plot of log (X_{Mg}/X_{Fe}) *and log* (X_F/X_{OH}) *of the magmatic* biotite I-SC, strongly contaminated I-type; I-SCR, strongly contaminated and reduced I-type; I-WC, weakly contaminated I-type; after Ague and Brimhill (1987).

Oxygen Fugacity



Mica+
Yavuz (2003 a and b)

Biotite Halogen Study



Composition of the biotite plotted with respect to F Wt% vs. X_{phl} for granodiorite samples of Lake George. X_{phl} = Mg/Sum octahedral site

Biotite Halogen Study

Munoz 1984

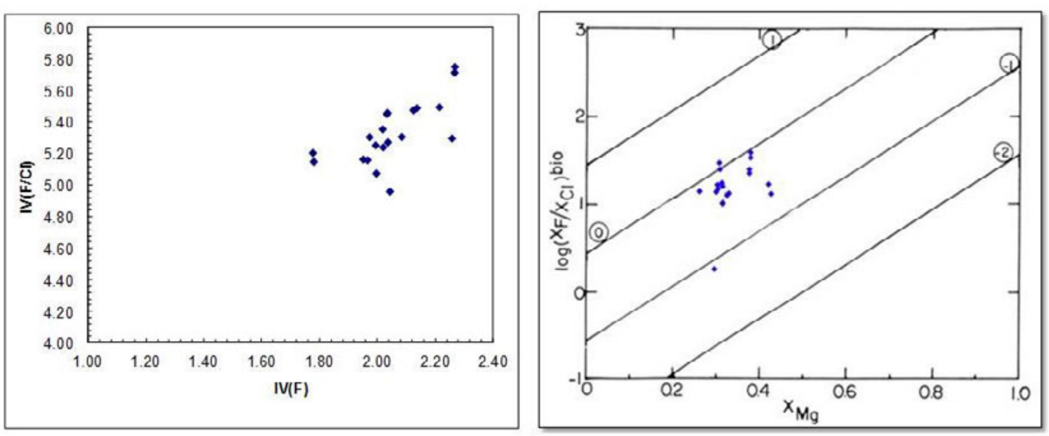
$IV(F) = 1.25\ X_{phl} + 0.42X_{ann} + 0.20X_{sid} - \log\ (X_F/X_{OH})$

$X_{sid} = [(3\text{-}Si/Al)/1.75]\ (1 - X_{phl})$

$X_{ann} = 1 - (X_{phl} + X_{sid})$;

X_F and X_{OH} = mole fractions of F and OH respectively on the hydroxyl site

Biotite Halogen Study



Plot showing values of IV(F) vs. IV(F/Cl) of biotite grains from granodiorite of Lake George

Magmatic Hydrothermal Fluid

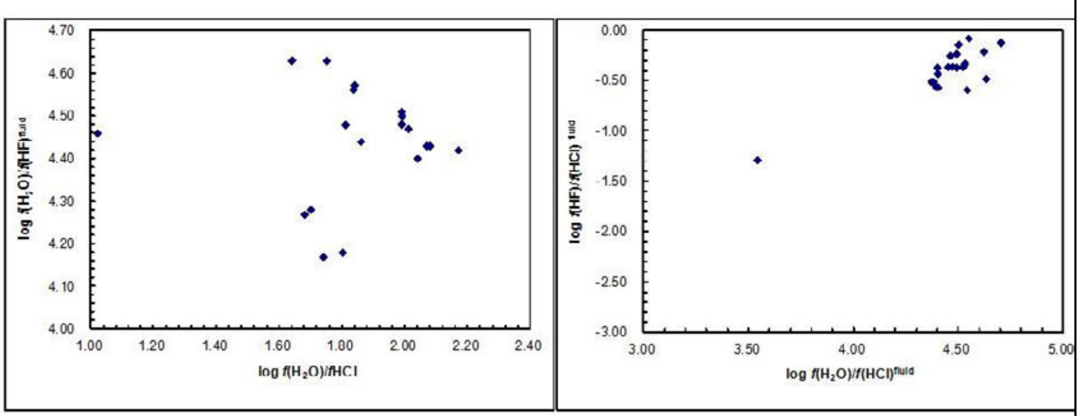
$$\log(f\mathrm{H_2O})/(f\mathrm{HF})\mathrm{fluid} = 1000/T[2.37 + 1.1(X_{\mathrm{Mg}})\mathrm{biotite}] + 0.43 - \log(X_{\mathrm{F}}/X_{\mathrm{OH}})\mathrm{biotite},$$

$$\log(f\mathrm{H_2O})/(f\mathrm{HCl})\mathrm{fluid} = 1000/T[1.15 + 0.55(X_{\mathrm{Mg}})\mathrm{biotite}] + 0.68 - \log(X_{\mathrm{Cl}}/X_{\mathrm{OH}})\mathrm{biotite},$$

$$\log(f\mathrm{HF})/(f\mathrm{HCl})\mathrm{fluid} = -1000/T[1.22 + 1.65(X_{\mathrm{Mg}})\mathrm{biotite}] + 0.25 + \log(X_{\mathrm{F}}/X_{\mathrm{Cl}})\mathrm{biotite},$$

Munoz 1992

Magmatic Hydrothermal Fluid

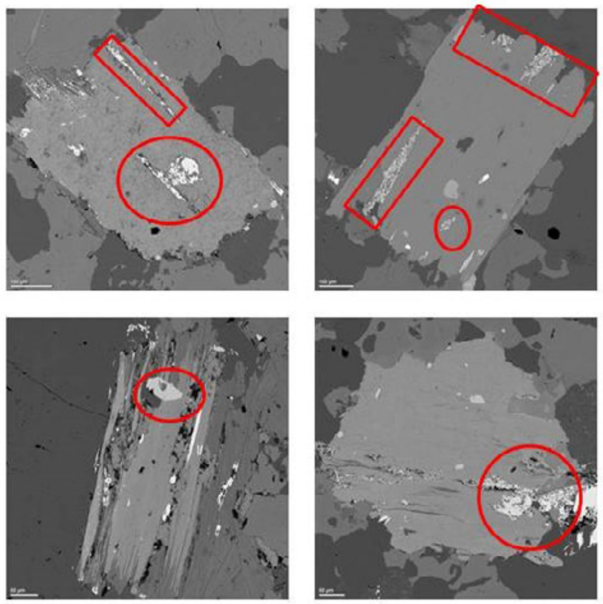


Ti in Biotite Thermometry

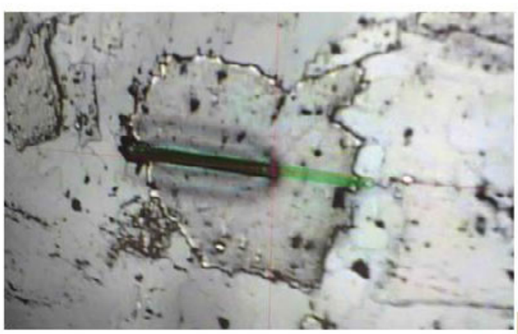
#	Core	Rim
1351	725	725
1190	744	746
1886	719	718
1741	726	729
1291	735	729
1647	720	717
80-33-A	710	711
612	748	746
1567	718	716
80-33-B	719	719

Henry et al.2005

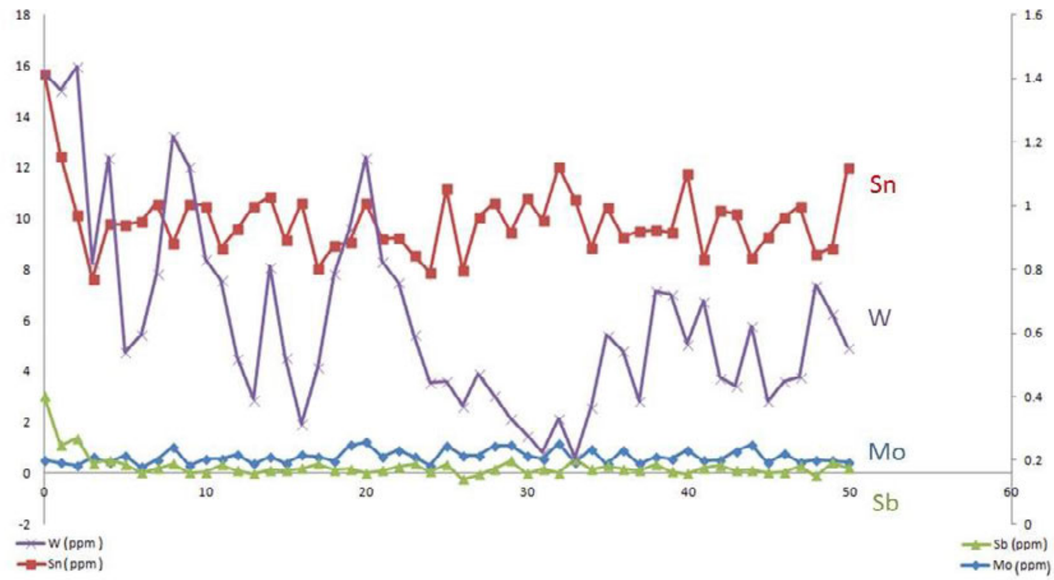
Biotite grains containing secondary rutile show a lower calculated temperature following the Henry method.



Trace Elements



Trace Elements



Concentration of W, Sn, Sb, and Mo in a biotite from sample LG81-1647

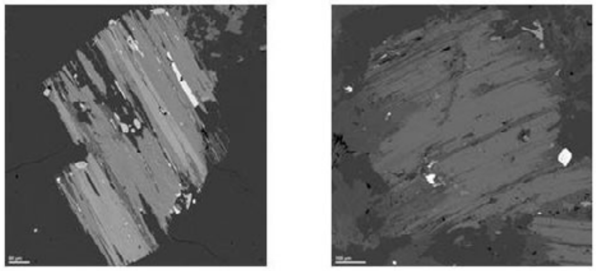
Trace Elements

(ppm)	80-33A	1291	1351	1647	1741	1886
Li	257.42	265.23	275.35	321.72	281.47	392.44
P	2.93	23.86	14.04	72.06	19.43	2174.51
Ca	292.38	452.92	347.68	266.09	732.63	6141.64
Ti	24872.94	31702.44	27927.93	27990.00	28495.14	27782.75
V	385.32	640.43	454.60	523.67	486.95	544.28
Cr	47.51	130.86	60.52	69.05	70.14	63.88
Mn	6634.01	2263.85	4287.13	4652.31	3940.02	4649.05
Co	44.53	31.43	58.46	49.38	62.84	45.65
Ni	44.84	46.29	61.08	48.67	62.42	40.49
Cu	3.66	4.99	1.15	0.55	3.81	12.50
Zn	531.73	391.19	455.21	476.70	449.32	484.71
Ga	50.72	63.22	46.02	49.68	45.97	50.80
Rb	802.79	843.97	733.01	763.71	755.35	746.56
Sr	1.73	5.65	1.59	1.70	2.32	5.69
Mo	0.97	0.34	0.74	0.35	0.62	0.32
Sn	63.94	18.77	8.02	10.57	8.21	12.11
Sb	0.77	2.36	0.27	0.07	0.33	-0.09
Cs	90.91	58.39	17.94	26.41	20.55	42.73
Ba	1304.40	1439.19	1885.19	2053.30	1466.99	2468.81
W	1.07	1.29	0.78	0.76	0.59	0.84

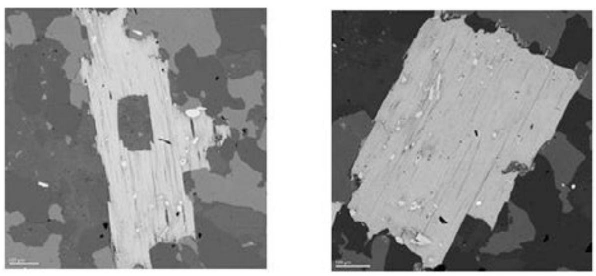
Yellow: Highest concentration

Orange: lowest concentration

Trace Elements



1291- Sb-W



80-33A Sn-Mo

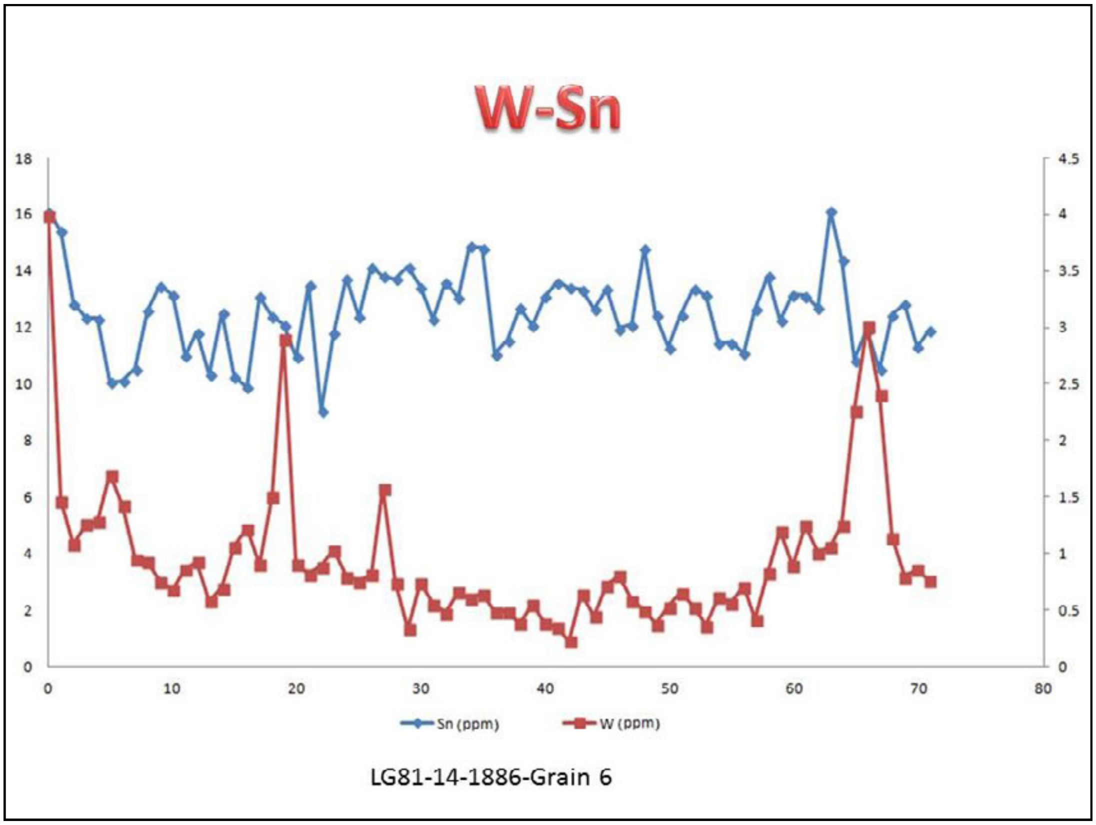
Trace Elements

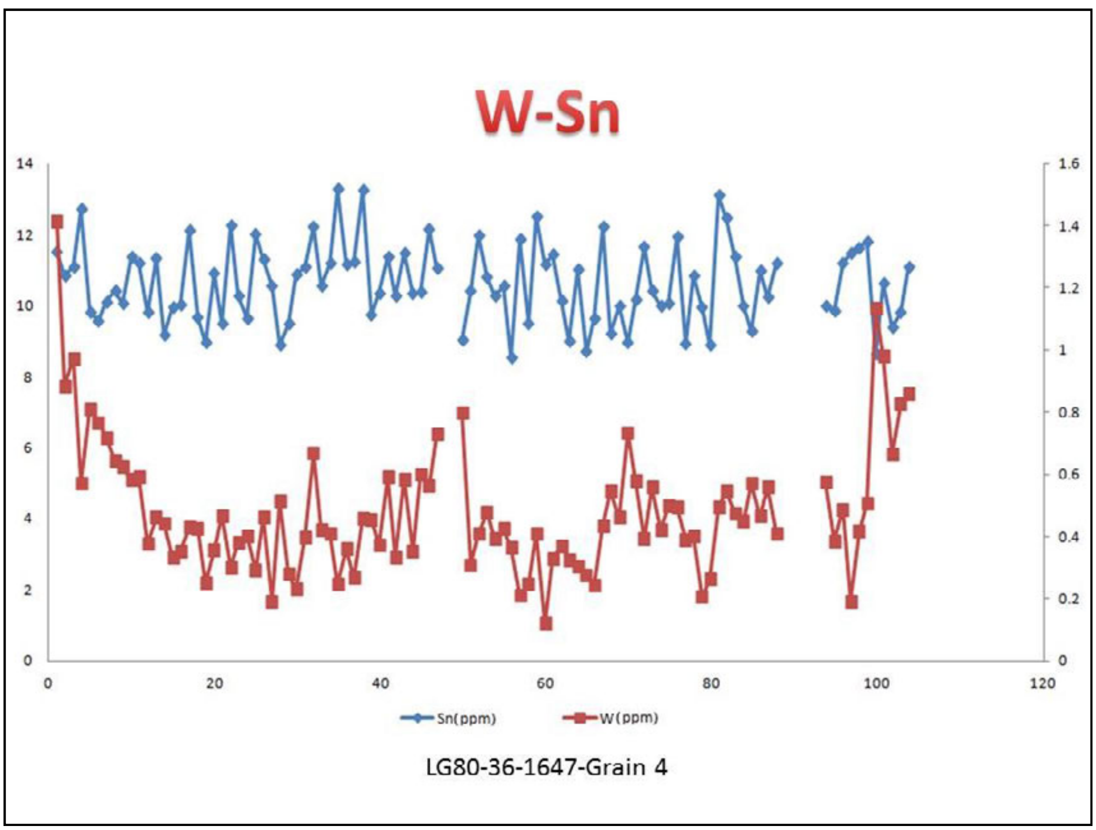
	Mo	Sn	Sb	W
1351	6	<1	4.8	<1
1741	3	<1	4.3	8
1647	7	<1	6	6
1291	6	1	6.5	<1
1886	2	<1	5.6	5

Whole rock trace element Yang et al. (2002)

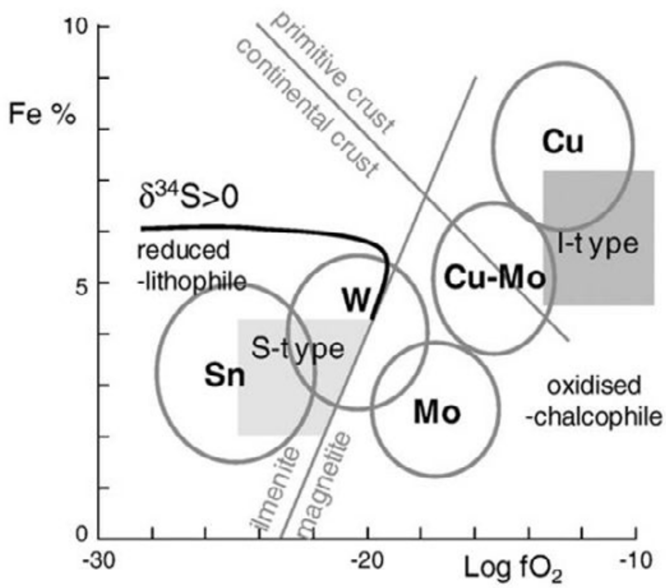
Averages of Mo, Sn, Sb and W in biotites of the Lake George granodiorite (Right)

	Mo	Sn	Sb	W
1351-6	0.64	9.91	0.26	0.64
1351-7	0.75	9.31	0.22	0.67
1351-8-1	0.71	6.89	0.33	0.92
1741-2	0.64	8.66	0.47	0.64
1741-4	0.54	8.05	0.75	0.69
1741-5	0.65	8.01	0.4	0.59
80-33-A-2	1.00	66.18	0.76	1.30
80-33-A-3	1.12	62.56	0.66	1.06
80-33-A-5	0.74	62.82	1.16	0.92
1647-3	0.33	10.82	0.06	0.56
1647-4	0.44	10.62	0.01	0.48
1647-5	0.29	10.14	0.16	1.54
1291-2	0.29	20.78	0.32	0.64
1291-7	0.39	16.37	3.59	2.24
1291-8	0.34	17.18	11.14	2.91
1886-4	0.33	11.70	-0.2	0.77
1886-6	0.29	12.56	0.11	0.95


W-Sn
Sn (ppm)
W (ppm)
LG81-14-1886-Grain 6


W-Sn
Sn(ppm)
W(ppm)
LG80-36-1647-Grain 4

What I think



Conclusion

- Biotite chemistry reflects whole rock geochemistry
- fH_2O is higher than fHF and $fHCl$
- Disequilibrium partitioning of halogens and high metal concentrations in biotite, good reflection of contamination?
- Internal zoning of trace element good record of physio-chemical changes during biotite crystallization
- Proof of concept that mica chemistry may aid in identification of fertile Acadian magma systems