INJECTION AND CONTAMINATION OF BIOTITE GRANITE IN THE VERMILION COMPLEX, SOUTHERN QUETICO PROVINCIAL PARK

Mark Newcomb
Carleton College
Northfield, Minnesota

INTRODUCTION

The Archean Vermilion Complex is comprised of granitic rocks and migmatites that straddle the border of northeastern Minnesota and Ontario Province. It includes four intrusive rock types--hornblende quartz diorite, hornblende diorite, biotite granodiorite and biotite granite--along with associated migmatites (Southwick, 1970). Biotite granite, a syn- to post-tectonic intrusive rock, is the dominant rock type within the complex. The interior of the biotite granite batholith is typically homogenous in texture and composition (Southwick, 1972). It is more variable near its margin, however, where it comes into contact with migmatite formed through multiple intrusions of felsic rocks into metasedimentary country rocks (Southwick, 1972). Within these areas, modeling the evolution of the biotite granite entails distinguishing it from the other felsic phases, noting its relationship to the migmatic rocks and quantifying the influence of the country rocks on its chemistry.

This project studies the biotite granite of the Vermilion Complex as it exists in the area northwest of the Burntside Lake fault, between Basswood and Sarah Lakes. The granite is correlated, on the basis of major element composition, to the Lac La Croix Granite, an I-type, biotite-granite which also crops out extensively in northeastern Minnesota (Day and Weiblen, 1986). Trace element variations between the biotite granite in the Basswood-Sarah Lakes region and the Lac La Croix Granite are the result of contamination by country rocks during the injection of the Lac La Croix Granite into the region. During the early phases of implacement, allanite crystallized, further influencing the trace element composition of the biotite granite.

PETROLOGICAL INFORMATION

The two dominant lithologies within the field are a calc-alkaline, potassic, biotite granite (see figure 1) and a related migmatite, containing biotite schist stringers and amphibolite rafts. Estimated modal mineralogy for the biotite granite in the area is 25-35% microcline, 30-40% plagioclase, 20-30% quartz, 2-5% biotite, and trace amounts of myrmekite, magnite, and zircon. Biotite has been extensively altered to pennine chlorite with fine grained magnetite rims, and plagioclase has been extensively altered to sericite and clays. Three specimens (N12, N44.2 and N43) contain sparse allanite crystals, which range from less than 1 mm to 10 mm in size.

Massive outcrops of biotite granite in the McNaught Lake region are cut by pegmatite veins containing crystals up to 5 cm in diameter of perthitic microcline, muscovite and anhedral quartz. The veins are not more than 15 cm wide and vaguely conformed to the orientation of joints, indicating that they are likely late stage fracture-fillings.

Migmatite is made up of biotite-schist stringers and amphibolite rafts in a pink, biotite-granite neosome. Inclusions in the migmatite range from distinct xenoliths, sometimes boudined, to nebulitic inclusions with gradational boundaries and only slight changes in mineralogy and grain size. Since several distinct phases of felsic intrusive rocks have been identified in other parts of the complex, the possibility that older felsic rocks exist within the migmatite paleosome cannot be ruled out Southwick, 1972 and Day and Weiblen, 1986).

The biotite granite is correlated with the Lac La Croix Granite on the basis of field relations, mineralogies and major element compositions (see table 1). The Lac La Croix Granite is a calc alkaline, potassic biotite granite which outcrops extensively in northeastern Minnesota, where it is the later of two syn- to post-tectonic felsic intrusions (Day and Weiblen, 1986). The Lac La Croix Granite is distinguishable from other syn- to post-tectonic rock within the Vermilion Complex in containing no primary muscovite or garnet (Day and Weiblen, 1986). The biotite granite in the Basswood-Sarah Lakes region has no primary muscovite or garnet, indicating it can not correlated with this unit.

In light of field observations and chemical data, the migmatite is interpreted to have formed by the injection of the Lac La Croix Granite into biotite schist country rock. In the field, a sharp contact between the migmatite leucosome and the biotite granite would indicate that the two are not related and that the migmatite may have formed by injection of a felsic phase other than the Lac La Croix Granite. No intrusive contact of this sort exists in the field area. In fact, the biotite granite appears to be contiguous with the migmatite leucosome. Mafic inclusions, absent in the interior of the biotite granite, gradually increase in number towards the margin of the batholith. Trace and major element concentrations generally plot along linear trends, indicating that the collected specimens represent a suite of related rocks. This data is consistent with the presence of only one primary intrusive rock unit which makes up both the biotite granite and the migmatite leucosome.

ROCK CHEMISTRY

To test the hypothesis that the Lac La Croix Granite was injected into the study area, major and trace chemical analysis were carried out on fifteen samples from both the massive portions of the biotite granite and the leucosome of the migmatite. Major element analysis was carried out at Carleton College using x-ray fluoresence technique, and trace element analysis was made at Beloit College using induction coupled plasma technique. A summary of the chemistry of the collected specimens is shown in table 1. The average chemistry of the Lac La Croix Granite and the leucogranite, analyzed by Day and Weiblen (1986), are shown for comparison. The accuracy of the data is within the analytical error of 2% for the major elements and within 10% for the trace elements.

EVIDENCE FOR CONTAMINATION

Major element analysis delineates an apparent anomaly in the nature of the the biotite granite. Day and Weiblen (1986) demonstrated that tonalitic to granodioritic plutonic rocks melted to generate the granitic magma; hence its classification as an I-type granite. The biotite granite, furthermore, contains no primary muscovite, cordierite or garnet, which also implies that it is an I-type granite (Chappel and White, 1974 and White et al, 1986). This conflicts with data which shows that rocks of the La has some characteristics of S-type granites. That is, it is strongly peraluminous (mol $Al_2O_3/(Na_2O+K_2O+Ca) > 1.1$), has CIPW normative corundum around 1 and has slightly low concentrations of Na_2O than are typical for I-type granites (Chappell and White, 1974).

Peraluminous I-type rocks are primarily the result of two process. 1) Peraluminous country rock can contaminate the magma during implacement, and 2) partial melting of volcanic rocks may leave behind metaluminous hornblende and clinopyroxene, creating a peraluminous melt (White et al., 1986). Since much of the hypothetical source rock for the Lac La Croix Granite is hornblende-bearing, and since muscovite-bearing biotite schist rafts are a major mafic constituent of the migmatite, both processes could have given the biotite granite peraluminous characteristics.

The trace element compositons of the biotite granite and migmatite leucosome suggest that anatexis of biotite schist may have generated magmas capable of contaminating those of the Lac La Croix Granite through magma mixing. Chemical mass balance equations using La, Ce, Yb, Ba and Sr show that 10 to 100% partial melting of biotite schist generates magmas with trace element concentrations which, when mixed with magmas of the Lac La Croix granite, would fall within the range observed concentrations (see figure 2).

How this contamination may have occurred is uncertain. Field observations of the varying degrees of schist raft incorporation support the assumption that partial melting occurred to widely varying degrees from area to area, but a model does not exist for the dispersal of contaminated material throughout the area as a whole. It seems likely that viscous magmas, on the verge of complete crystallization, would only partially swirl together, creating a heterogeneous body of magma that shows variations in trace element composition. Moreover, since the calculated concentrations for trace elements in the contaminated rock only cover a part of the range actually displayed, it cannot be assumed that biotite schist was the only type of rock to play a role in the contamination process. The heterogeneity of rocks found in the margin of other parts of the Vermilion Complex suggest that it is unlikely for contamination to have occurred from a single rock type.

AFFECTS OF EARLY ALLANITE CRYSTALLIZATION

The presence of allanite in three specimens, N12, N44.2 and N43 explains why REE concentrations within them are anomalously low. Allanite and sphene in a granodiorite have been found to contain 80 to 95% of a rocks REE (Gromet and Silver, 1983). As a melt is crystallizing allanite, REE content of the rock should decrease rapidly. If the system cannot equilibrate, the rock in the immediate vicinity of the allanite crystals should be depleted in REE. Two specimens each of N12, N44.2 and N43 were taken from the field, one with visible allanite, the other without. To prevent scatter in the results, the samples without visisble allanite were used for geochemical analysis. The results show that the analyzed samples, taken in the vicinity of the allanite-bearing rock, are in fact depleted in REE.

CONCLUSION

The rocks within this portion of the Vermilion Complex formed by injection of Lac La Croix Granite magmas into migmatites which probably contained large amounts of biotite schist paleosome within a leucosome made up of early plutonic rocks. As the magmas were injected, enough latent heat was produced to extensively melt country rock inclusions. Allanite crystallization also took place during the early phases of cooling, causing rocks within small regions of the granite to be depleted in REE.

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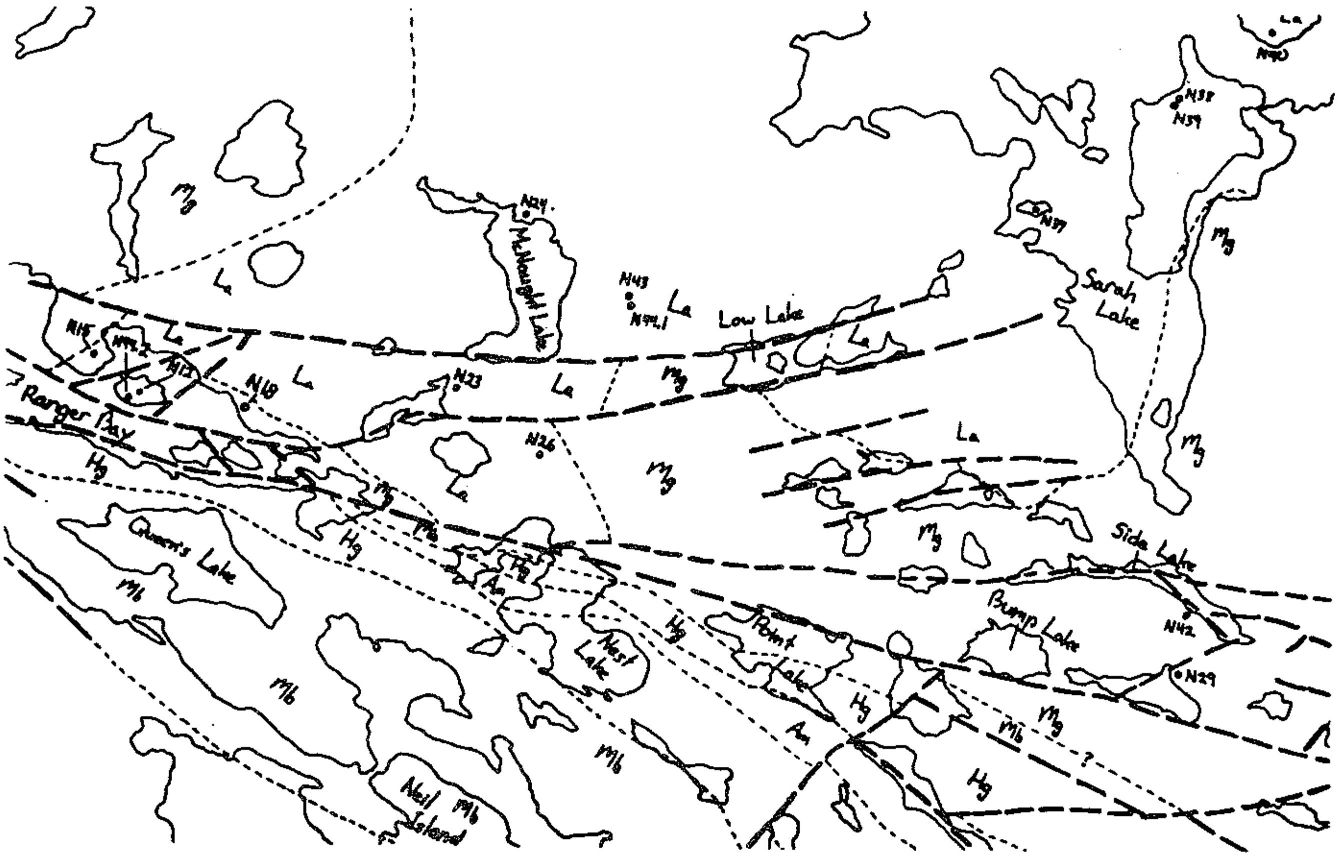


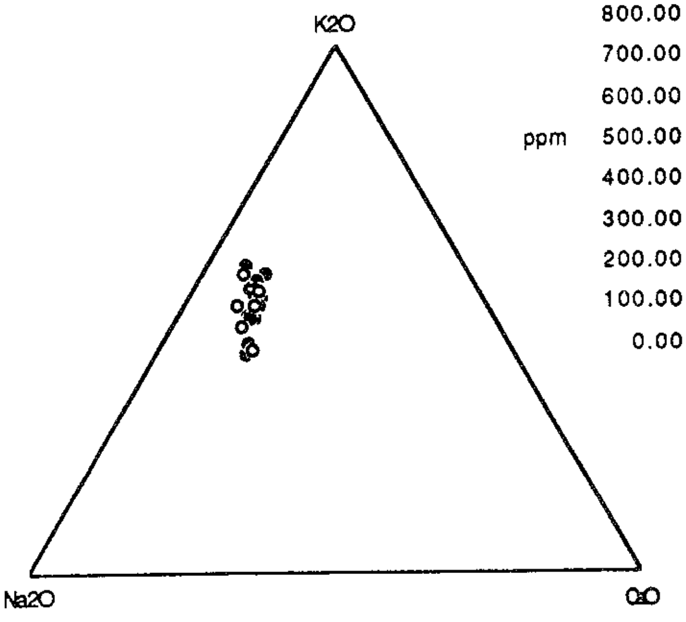
Key: La - pink, biotite granite. Mg - granite migmatite with biotite granite leucosome and less than 50% biotite schist rafts. Mb - biotite schist-rich migmatite with more than 50% biotite schist rafts. Hg - hornblende tonalite gneiss. Am - hornblende tonalite with higher mafic content than Hg. Contacts - - - - . Major faults ▬ ▬

Figure 1. Map of field area showing the locations of samples taken from the biotite granite. N18, N29 and N42 are samples of biotite granite from the migmatite leucosome.

Oes-west: Newcomb's data wt. %	N12	N39	N37	N44.2	N44.1	N29	N30	N24	N26	N42	N23	N18	N43	N40	N15
SiO2	68.71	70.13	71.34	71.88	72.11	72.36	72.63	73.24	73.76	73.76	73.81	73.87	74.98	76.1	76.13
TiO2	0.24	0.34	0.31	0.26	0.29	0.36	0.25	0.25	0.16	0.2	0.15	0.16	0.24	0.09	0.07
Al2O3	16.73	15.32	15.1	15.76	14.33	14.89	14.27	14.43	14.22	14.03	14.32	14.22	13.77	13.59	13.45
Fe2O3	1.86	2.97	2.18	1.59	2.03	1.87	1.56	1.58	1.49	1.58	1.04	1.41	1.36	0.91	0.73
MnO	0.05	0.04	0.04	0.05	0.05	0.02	0.03	0.05	0.02	0.02	0.02	0.02	0.05	0.02	0.01
MgO	0.49	0.79	0.51	0.37	0.48	0.55	0.43	0.48	0.32	0.47	0.29	0.32	0.25	0.26	0.25
CaO	1.61	1.1	1.14	1.43	1.01	1.28	0.92	0.88	1	0.59	1.05	1.02	1.12	0.83	0.59
Na2O	4.81	3.94	3.86	4.37	3.34	3.85	3.4	3.56	3.51	3.37	3.18	3.59	3.67	3.42	3.34
K2O	4.55	4.92	5.25	4.52	5.76	4.76	5.43	5.24	5.27	5.39	4.87	5.18	4.49	5.34	5.53
P2O5	0.08	0.14	0.1	0.05	0.08	0.08	0.07	0.08	0.04	0.04	0.03	0.06	0.03	0.03	0.02
volatiles	0.66	0.71	0.6	0.57	0.56	0.51	0.58	0.41	0.47	0.72	0.57	0.8	0.47	0.93	0.71
total	99.77	100.4	100.4	100.8	100	100.4	99.59	100.1	100.3	100.2	99.14	100.5	100.4	100.9	100.8
Ba	981	810	980	790	1028	921	968	843	952	879	874	984	653	403	858
Be	1.8	2.4	1.8	1.8	1	1.8	1.9	1.2	1.1	1	1.4	1.1	1.4	0.9	0.8
Ce	89	225	191	87	205	148	107	124	106	126	110	126	21	49	38.
Co	1.7	2	2	1	1	1.3	0	0.8	0.2	0	0.3	0.3	0	0	0
Cr	7.9	8.9	6.6	4.5	9.6	9	5.9	6.1	4.9	4	4.2	4.4	2.9	3.5	8.3
La	37.8	103.1	82.8	39.8	91.4	69	46.8	56.6	48.5	55.5	50.2	56.7	11.8	20.4	17.4
Ni	5.6	4.7	4.8	4.3	4.3	4.3	4.2	3.9	4.5	2.9	5.2	2.8	3	2.2	5
Sc	3.8	5.3	4.5	2.9	3.2	3.4	2.8	2.7	1.8	2.2	2.4	2.1	1.9	2.2	0.8
Sr	375	247	268	279	282	256	254	236	277	179	260	307	200	131	225
V	17	25	20	14	18	17	12	15	9	10	0	11	11	5	6
Y	1.8	12.4	9.7	1.4	1.1	3.4	3.8	0	1.5	2.5	8	2.1	0	0.4	0.5
Yb	0	1.09	0.97	0	0.25	0.11	0.45	0.01	0	0	0	0.02	0	0.18	0
Zr	196	272	225	171	225	264	147	161	118	152	134	151	121	67	84
normalized	N_12	N_39	N_37	N_44.2	N_44.1	N_29	N_30	N_24	N_26	N_42	N_23	N_18	N_43	N_40	N_15
Ce	80	260	221	101	237	171	124	143	123	146	127	146	24	57	44
La	114.8	313.4	251.7	121	277.8	209.7	147.7	172	147.4	162.9	153	172.3	35.8	62	52.9
Yb	0	4.86	4.41	0	1.14	0	2.05	0.05	0	0	5.86	0.09	0.73	4.38	3.66
La/Yb	----	63.31	57.07	----	243.7	----	72.05	3440	----	----	26.71	1914	48.30	14.22	14.8
peraluminous	1.233	1.248	1.206	1.236	1.176	1.233	1.2	1.21	1.192	1.206	1.338	1.187	1.297	1.162	1.146

wt. %	Day and Weiblen's: Lac La Croix	leucogranite	Garber's Mg leucosome G10	G18	G13	G28	G24	G19	G29
SiO2	73.16	73.67	74.11	74.16	75.13	72.76	73.76	73.74	75.38
TiO2	0.20	0.13	0.12	0.22	0.02	0.24	0.23	0.22	0.1
Al2O3	14.66	15.52	14.2	14.04	14	14.65	14.31	14.48	13.79
Fe2O3	1.40	0.67	1.54	1.61	2.39	2.39	1.81	1.74	1.03
MnO	0.02	0.02	0.02	0.02	0.03	0.05	0.03	0.02	0.02
MgO	0.34	0.16	0.45	0.44	0.56	0.47	0.38	0.45	0.25
CaO	0.93	1.09	0.94	1.01	0.82	1.21	1.11	1.43	0.84
Na2O	2.46	2.00	3.53	3.38	3.84	3.74	3.71	3.98	3.43
K2O	5.58	5.27	3.96	5.09	4.84	5.08	4.95	3.96	5.35
P2O5		0.04	0.07	0.07	0.09	0.09	0.07	0.07	0.03
volatiles									
total	98.76	98.56	100.5	100.04	100.06	100.08	100.06	100.06	100.02
Ba	584.43	738.86	1325	849	858	940	873	685	494
Be			0.85	0.75	1.1	1.32	1.25	1.3	0.95
Ce	83.17	45.03	82	118	131	219	122	98	84
Co	1.39	5.61	2.8	2	3.3	2	1.9	2.2	1.2
Cr	3.34	1.87							
La	37.65	21.20	41	56	70	109	60	48	29
Ni									
Sc	2.91	2.61	0.95	2.9	1.7	3	3.1	2.5	1.3
Sr	173.71	210.71	880	231	365	272	253	252	173
V			18	16	23	18	17	17	8
Y			8.6	8.8	13	8.5	12.3	8.9	6.3
Yb	0.62	0.55	0	0.032	0.58	0.192	0.365	0.147	0
Zr			173	180	259	231	186	174	107

Table 1. Composition of fifteen specimens of biotite granite and eight specimens of the biotite granite comprising the migmatite leucosome. The average compositions of seven specimens of Lac La Croix Granite and seven specimens of leucogranite collected in northeastern Minnesota are shown for comparison (Day and Weiblen, 1986). REE are normalized to chondrites (Taylor, 1980).



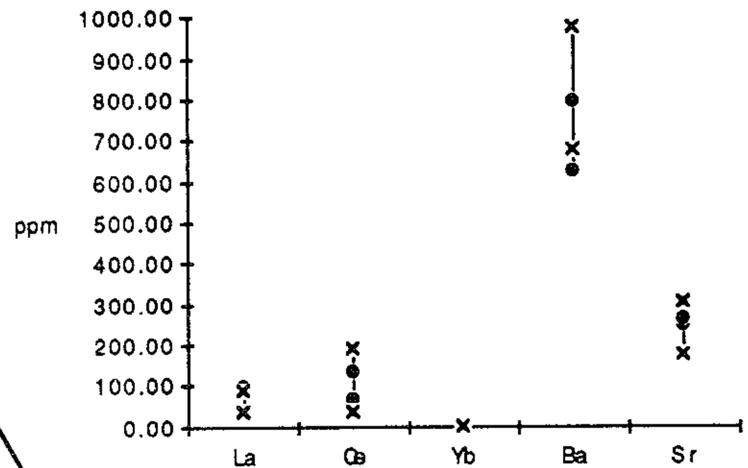


Figure 2. K2O, Na2O, CaO plot for fifteen samples of biotite granite (dark circles) and eight samples of the biotite granite comprising the migmatite leucosome (clear circles). The tight grouping indicates the similarity in composition, for these elements, between the biotite granite of the batholith and the biotite granite in the migmatite.

Figure 3. Spider diagram showing the observed range of compositions for the trace elements La, Ce, Yb, Ba and Sr (area between x's) and the calculated compositions for 10 to 100% partial melting of biotite schist considered to be typical for the area (Day and Weiblen, 1986).