Canadian Mineralogist
Vol. 19, pp. 177-194 (1981)

PERALUMINOUS PEGMATITIC GRANITES AND THEIR PEGMATITE AUREOLES IN THE WINNIPEG RIVER DISTRICT, SOUTHEASTERN MANITOBA*

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ABSTRACT

Late- to post-tectonic stocks and plugs of pegmatitic granites were intruded along partly dilated fault systems in the Archean Bird River greenstone belt of the English River subprovince in southeastern Manitoba. Each intrusion consists of four phases: (1) fine grained leucogranite locally grading into (2) interlayered sodic aplite and (3) potassic pegmatite, and (4) pegmatitic leucogranite that also contains bands and lenses of potassic pegmatite. This last phase carries occasional Li-, Be-, Nb–Ta-, As-, P-, B-, F- and Zn-bearing minerals. Textural and compositional relationships suggest separation of supercritical fluids from volatile-oversaturated melt as the primary cause of internal diversity. Bulk compositions are silicic, poor in Ca, Fe and Mg and highly fractionated in terms of K/Rb, K/Cs, K/Ba, Ca/Sr, Rb/Sr, Th/U, Mg/Li and Al/Ga. The rocks are peraluminous, as indicated by 0.1 to 5.0% of normative corundum (CIPW) and by the presence of muscovite, garnet, tourmaline, gahnite and cordierite. From fine grained leucogranites through sodic aplites and pegmatitic leucogranites to potassic pegmatites, the peraluminous character increases and ΣREE contents decrease. The genetic evidence available, including *REE* abundances and oxygen-isotope ratios, is inconclusive: juvenile origin of parent melts modified by subsequent fractionation and by reaction with greenstone-belt metasediments is possible, as well as shallow anatexis of greenstone-belt lithologies followed by igneous fractionation and reaction with host rocks. Loss of fluids to the country rocks probably contributed to the enhanced peraluminous character of pegmatitic fractions and to the depletion of their ΣREEs.

Keywords: peraluminous, pegmatitic granites, pegmatites, English River subprovince, Manitoba, trace elements, REE, fractionation.

SOMMAIRE

Des massifs de granite pegmatitique tardi- et post-tectoniques ont été mis en place suivant des systèmes de failles partiellement ouvertes dans la ceinture de roches vertes archéennes Bird River du bloc English River, dans le Sud-Est du Manitoba. Chaque massif comporte quatre phases: (1) leucogranite à grain fin qui passe à (2) une aplite sodique intercalaire et à (3) une pegmatite potassique, et (4) leucogranite pegmatitique à pegmatite potassique zonaire et lenticulaire. Cette dernière phase contient accessoirement des minéraux de Li, Be, Nb–Ta, As, P, B, F et Zn. D'après les relations de texture et de composition, ce serait à la séparation d'une phase fluide supercritique d'un magma saturé d'eau qu'il faudrait au premier chef attribuer la diversité interne. Les roches sont siliceuses, appauvries en Ca, Fe et Mg, et fortement fractionnées d'après les rapports K/Rb, K/Cs, K/Ba, Ca/Sr, Rb/Sr, Th/U, Mg/Li et Al/Ga. Elles sont hyperalumineuses, comme en témoigne la présence de corindon normatif (de 0.1 à 5.0%) et de muscovite, grenat, tourmaline, gahnite et cordiérite. Dans les phases numérotées ci-dessus, le caractère hyperalumineux augmente et les terres rares diminuent dans l'ordre (1), (2), (4), (3). Les indices pétrogénétiques, y compris l'abondance de terres rares et le rapport $^{18}O/^{16}O$, ne sont pas concluants quant à l'origine des magmas primaires: ceux-ci peuvent être juvéniles, ultérieurement modifiés par cristallisation fractionnée et par réaction avec les roches métasédimentaires de la ceinture de roches vertes; ils peuvent tout aussi bien résulter d'une anatexie à faible profondeur de lithologies de ladite ceinture, suivie de cristallisation fractionnée et de réaction avec les roches encaissantes. Une dissipation des fluides dans les roches hôtes a probablement contribué à renforcer le caractère hyperalumineux des fractions pegmatitiques et à diminuer leur teneur en terres rares.

(Traduit par la Rédaction)

Mots-clés: hyperalumineux, granites pegmatitiques, pegmatites, bloc English River, Manitoba, éléments traces, terres rares, cristallisation fractionnée.

INTRODUCTION

Since 1975, the Winnipeg River pegmatite district in southeastern Manitoba has been subjected to an intensive examination aimed at the development of exploration criteria for mineralized pegmatite deposits (Černý *et al.* 1980).

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Deciphering the relationship between the pegmatites and the larger granitoid intrusions of the region was one of the principal tasks of this study. Stocks and plugs of peraluminous pegmatitic granites proved to be parental to most of the mineralized pegmatite groups, as suspected earlier in some cases (Mulligan 1965). The present paper reviews the petrology and geochemistry of the pegmatitic granites and the evidence linking their individual intrusions with specific pegmatite groups; a forthcoming publication will be devoted to the genetic problems.

REGIONAL GEOLOGY

The area of the Winnipeg River pegmatite district is underlain by three major units that constitute the westernmost exposed portions of the English River subprovince: the Manigotagan – Ear Falls gneiss belt, the Bird River greenstone belt and the Winnipeg River batholithic belt (Fig. 1). Rb/Sr isochron dating of regional metamorphism and igneous activity places the evolution of these three units in the Kenoran orogeny (2.7–2.5 *Ga*). Their lithological, structural, metamorphic and igneous features are described by McRitchie (1971), Beakhouse (1977), Ermanovics *et al.* (1979), Trueman (1980) and Černý *et al.* (1981).

The Bird River greenstone belt consists of six formations of metavolcanic and metasedimentary rocks of the Rice Lake Group, which form a broad and complex synclinorium (Fig. 1). Two major episodes of folding affected the greenstone belt, the second correlatable with the diapiric intrusion of the Maskwa Lake and Marijane Lake batholiths and with the peak of the regional metamorphism. The metamorphism attained a greenschist-facies level over most of the map area but reached amphibolite grade in

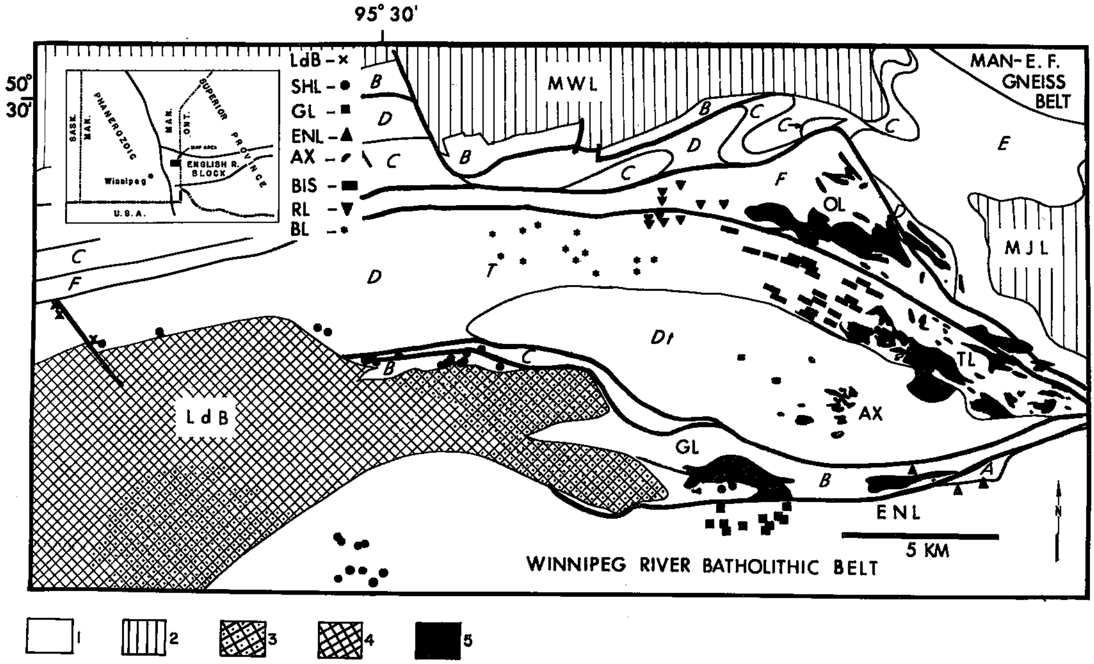


FIG. 1. Location map (insert) and geological sketch of the Winnipeg River pegmatite district. (1) unsubdivided gneisses of the Winnipeg River batholithic belt and the Manigotagan – Ear Falls gneiss belt, and the schists of the Bird River greenstone belt: A Eaglenest Formation, B Lamprey Falls Formation, C Peterson Creek Formation, D Bernic Lake Formation, Dt subvolcanic tonalite, E Flanders Lake Formation, F Booster Lake Formation; (2) composite diapiric batholiths (MWL Maskwa Lake intrusion, MJL Marijane Lake intrusion); (3) early leucogranite and (4) late biotite granite of the Lac-du-Bonnet (LdB) batholith; (5) pegmatitic granites (GL Greer Lake, ENL Eaglenest Lake, AX Axial, TL Tin Lake, and OL Osis Lake intrusions); pegmatite groups: LdB Lac-du-Bonnet, SHL Shatford Lake, GL Greer Lake, BIS Birse Lake, RL Rush Lake, ENL Eaglenest Lake, AX Axial, BL Bernic Lake; T the Tanco pegmatite; heavy lines represent faults, light lines, lithological boundaries.

the eastern and northeastern portions (Fig. 1).

The Flanders Lake Formation of the greenstone belt is equivalent to, and transitional into, the paragneisses of the Manigotagan – Ear Falls belt to the northeast. The tonalitic to granitoid gneisses of Beakhouse's (1977) early gneissic suite constitute the margin of the Winnipeg River batholithic belt adjacent to the greenstone belt from the south. The mutual relationship of these two units is not clear (Ermanovics *et al.* 1979, Trueman 1980).

Tonalite and trondhjemite components of the Maskwa Lake and Marijane Lake diapirs are rimmed and penetrated by undeformed biotite granites. The Lac-du-Bonnet batholith consists predominantly of an analogous late biotite granite, but an early and strained leucogranite makes up its eastern extremity and irregular areas along its southern margin (Fig. 1). The leucogranite phase is alaskitic and highly fractionated, unlike the more primitive biotite granite (Table 1). Trace element and *REE* contents indicate that the two phases are not comagmatic, but that the leucogranite is closely related to the pegmatitic granites described here (Cerny *et al.* 1981).

TABLE 1. REPRESENTATIVE CHEMICAL ANALYSES OF THE MAIN ROCK TYPES OF THE LAC-DU-BONNET BATHOLITH

	Quartz diorite		Leucogranite		Biotite granite	
	AEC-43	PG-151	SR-95	PG-137	AEC-21	PG-133
SiO	68.30	69.60	76.30	77.75	72.65	73.40
TiO_2	0.42	0.11	0.10	0.06	0.17	0.11
Al_2O_3	15.14	16.82	12.10	11.53	14.46	13.62
Fe_2O_3	1.50	0.92	0.96	0.92	0.76	0.97
FeO	2.32	1.40	0.76	0.52	0.76	0.72
MnO	0.09	0.07	0.05	0.01	0.03	0.03
MgO	1.84	0.50	0.04	0.05	0.40	0.45
CaO	2.84	3.13	0.32	0.34	1.01	1.06
Na_2O	4.85	5.43	3.48	3.66	3.65	3.56
K_2O	1.66	1.66	5.17	4.94	5.02	5.63
P_2O_5	0.20	0.13	0.03	0.02	0.09	0.08
CO_2	0.12	0.06	0.08	0.03	0.09	0.04
H_2O^+	0.68	0.39	0.24	0.21	0.51	0.35
	99.96	100.22	99.63	100.04	99.60	100.02
Li	148	46	72	10	49	57
Rb	179	65	370	154	224	231
Cs	4.2	1.6	2.7	2	2.6	4.9
Be	5.0	1.9	2.2	2	2.5	2
Sr	208	136	2	28	150	225
Ba	94	967	52	145	675	926
Pb	5	10	15	12	26	22
Ga	38		34	30	33	28
U	2	8	14	6	26	2
Th	6	nd*	40	15	24	16
Zr	134	406	142	217	217	212
Hf	3.65	11.75	7.75	6.75	6.15	6.0
Sn	10	4	11	12	4	5
K/Rb	77	212	116	266	186	202
K/(Csx100)	32	86	158	205	160	95
K/Ba	147	14.25	825	289	61.8	50
Ba/Rb	0.52	14.9	0.14	0.94	3.0	4
Ba/Sr	0.45	7.1	26	5.2	4.5	4.12
Rb/Sr	0.86	0.48	185	5.5	1.5	1.03
Mg/Li	75	65.6	2.9	30	49	47.4
Zr/Sn	13.4	101.5	12.9	18.1	54.2	42.4
Zr/Hf	36.7	34.6	18.3	32.1	35.3	35.3
Al/Ga	2108		1882	2033	2318	2574
La	55.2	30.6	35.85	39.9	41.4	87.1
Ce	105	61.5	97	76	87.5	153
Nd	39.5	25.5	44	39	33.5	78
Sm	5.60	3.82	9.59	6.79	5.48	5.94
Eu	0.76	1.7	0.18	0.25	0.51	0.69
Dy	2.95	2.45	12.05	6.3	2.2	1.2
Yb	1.7	1.9	7.5	4.95	1.25	1.25
Lu	0.16	0.24	0.92	0.59	0.20	0.13

*not detected

THE PEGMATITIC GRANITES

Four major pegmatitic granite intrusions have been examined during the present study: Tin Lake, Osis Lake, Greer Lake and Eaglenest Lake (Fig. 1; Černý *et al.* 1981, Map 1). The Axial pegmatitic granite was examined in much less detail than the bodies noted above because of its limited exposure and poor internal differentiation. To avoid repetition and to emphasize similarities and differences among the major intrusions, we give individual characteristics jointly below for all four bodies.

Sampling and analytical methods

The pegmatitic granites were sampled on a 300–400 m square grid, modified in swamp and drift areas, for the different rock types and their minerals. In total, 53 whole-rock samples, 155 K-feldspars, 112 garnets, 64 micas, 16 beryls and 20 columbite-tantalites were analyzed chemically, besides a variety of other accessory minerals. Analytical methods, standards and uncertainties are quoted in Černý *et al.* (1981) and Goad (1981); all compositional data are listed in Goad (1981) and are available from the authors. The CIPW system was used to derive corundum values comparable with data in the literature, but a modified MESO 1 program, which includes biotite and garnet but not muscovite, provided felsic components for the triangular plots. Standard optical and X-ray-diffraction methods were used to determine plagioclase compositions and K-feldspar obliquities, respectively.

Intrusive relationships

Several features are common to the structural setting of all four pegmatitic granites. All were intruded along early subvertical faults and shear zones that give the greenstone belt its fault–slice configuration (Fig. 1). Intrusion occurred during a regional dilation event and was combined with stoping; stoping is not directly observable in the Greer Lake and Eaglenest Lake bodies but can be assumed from the sharp and angular character of the contacts. Evidence of forcible injection is scarce and is restricted to the eastern part of the Osis Lake body.

The main body of the Tin Lake pegmatitic granite (TL) is a roughly circular plug, separated into two lobes by a cataclastic shear zone that follows the northern boundary of an elliptical subvolcanic intrusion of tonalite (Fig. 1). Smaller irregular bodies of pegmatitic granite extend west-northwest and east-southeast from the northern lobe, mainly north of the shear zone; they appear to be concordant sills in the clastic volcanic and intrusive rocks of the Bernic Lake Formation, which hosts all members of the intrusion. The northern lobe is virtually free of host inclusions, but in the southern part they are very abundant, giving the pegmatitic granite a local appearance of agmatitic injection breccia.

The Osis Lake intrusion (OL) is located north of the boundary fault separating the Bernic Lake and Booster Lake Formations (Trueman 1980). Except for several dyke-like offshoots in its southwestern extremity, the intrusion is hosted by the turbidite sequence of meta-argillites and metagreywackes of the Booster Lake Formation. From east-central parts to the west, the intrusion grades from a more or less homogeneous inclusion-poor body, through an area with abundant subparallel and subvertical rafts and screens of host rock, into a fingering-out system of mutually subparallel dykes that range from several centimetres to several tens of metres in thickness. In its southeastern extremity, the OL intrusion gives the impression of forcible intrusion; in the western part, dilation and brittle fragmentation of the host rock are evident, but plastic behavior is also documented by local ptygmatic structures.

The Greer Lake pegmatitic granite (GL) is hosted largely by metabasalt of the Lamprey Falls Formation (Trueman 1980). At the eastern and western extremities of the Greer Lake body and at its southwestern offshoot, the contacts trend north at a high angle to the layering and foliation of the metabasalts. These contacts are sharp, truncating both layering and foliation with no evident deformation. Host-rock inclusions are rare in the pegmatitic granite, except for angular blocks of metabasalt in the southwestern offshoot. A fault, striking west-northwest and transecting the Greer Lake body, appears to display predominantly vertical movement and separates the body into two segments (Fig. 1). It seems likely that the pegmatitic granite is also truncated by a fault marking the boundary between the Bird River greenstone belt and the Winnipeg River batholithic belt.

The Eaglenest Lake pegmatitic granite (ENL) lies at the same band of metabasalts as the GL body. The intrusion is also similar to the GL body in that it contains only rare inclusions and has its western extremity sharply truncated against the layering and foliation in the relatively undeformed host rocks. The eastern end, however, displays a predominantly *lit-par-lit* fingering-out pattern in a host rock that has a pronounced foliation.

Internal composition

The pegmatitic granite intrusions are texturally and compositionally heterogeneous, containing bodies of pegmatitic leucogranite, patches of fine grained leucogranite, transitional into sodic aplite, and lenticular to pod-shaped potassium-rich pegmatite.

Pegmatitic leucogranite is always a substantial if not dominant phase of the pegmatitic granites. It consists of megacrystic K-feldspar (5–100 cm in size) intergrown with graphic quartz, embedded in a medium- to coarse-grained (6–25 mm) matrix of albite + quartz + muscovite (± garnet, ± tourmaline). The K-feldspar megacrysts range from perfectly euhedral to subhedral, and are moderately corroded by the matrix. Along contacts with country-rock xenoliths, muscovite is abundant and the graphic K-feldspars tend to grow from the xenolithic substrate into the pegmatitic granite mass. The matrix locally contains patches of plumose muscovite + quartz intergrowths, mostly evenly distributed but occasionally concentrated into diffuse layers suggestive of a replacement origin.

Fine grained leucogranite is an equigranular facies consisting of perthitic microcline, quartz, albitic plagioclase and muscovite; biotite is abundant only in the TL intrusion, rare in the others. Accessory minerals are represented mainly by garnet, zircon and apatite. The rock is mostly massive and homogeneous in mineral distribution, but faint banding of micas and garnet is evident locally. Pegmatitic leucogranite has never been observed in direct contact with the fine grained phase.

The transition from fine grained leucogranite into sodic aplite, which is commonly layered, is marked by an increase in muscovite, albitic plagioclase (which attains a platy habit) and garnet, and by a gradual disappearance of K-feldspar. The unit typically contains, in order of decreasing abundance, albite, quartz, muscovite and garnet, with accessory apatite, gahnite, monazite and possibly Nb–Ta oxide minerals.

Sodic aplite layers are mostly paired or alternate with potassic pegmatite layers. The boundary may be gradational but a sharp separation is more common. Textural features indicate a directed growth of the pegmatitic assemblage normal to, and away from, the aplite surface. The potassic pegmatite facies also develops as lenticular bands and pods inside pegmatitic leucogranites, by the gradual disappearance of graphic quartz from K-feldspar megacrysts and by their accumulation, at the expense of the albite + quartz + muscovite matrix, around lenses of quartz. The potassic pegmatite consists of blocky (or partly graphic) K-feldspars and quartz, commonly in concentrically zoned patterns, with or without coarse platy muscovite and granular to cleavelandite-type albite. Beryl, garnet, tourmaline, cordierite, columbite–tantalite, triphylite, molybdenite and arsenopyrite appear sporadically in central parts of the pegmatite bands.

Pegmatitic assemblages are the only ones that locally display cross-cutting relationships with the other facies of the pegmatitic granites, indicating that they were the last to solidify. Stringers and trains of porphyroblastic K-feldspar, transecting textural patterns of fine grained leucogranites and sodic aplites, probably also belong to the late potassic phase.

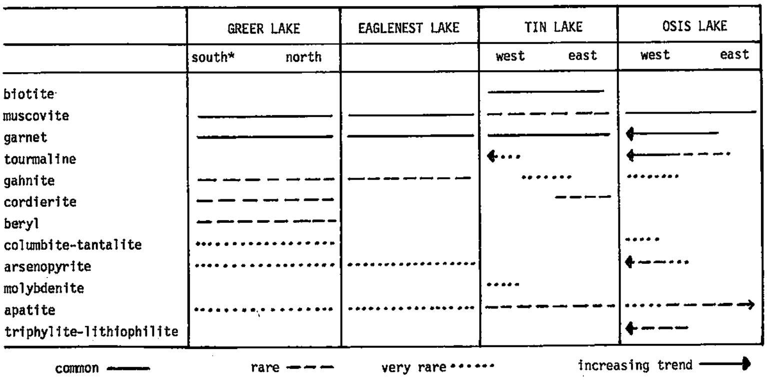
The Greer Lake and Eaglenest Lake intrusions have a good representation of all four phases, with the banded aplitic assemblages oriented roughly parallel to the intrusion margins along the contact but rather chaotic in the interior. The Tin Lake intrusion is exclusively fine grained and leucogranitic in the southern lobe; in the north, pegmatitic material increases in abundance towards the west-northwest, but larger segments of sodic aplite are unusual in all parts of the body. The Osis Lake intrusion is largely pegmatitic; the fine grained leucogranite is scarce. However, it contains a centrally located subcircular plug of biotite granite with a classic subsolvus granite texture and random orientation of all minerals. The contacts with the surrounding pegmatitic granite are eroded and covered by soil and vegetation, but they seem to be gradational and show signs of mild shearing.

Accessory minerals

Accessory minerals typical of the four pegmatitic granites are summarized in Table 2. Garnet and muscovite are ubiquitous but the Greer Lake and Eaglenest Lake bodies lack tourmaline and phosphates, which are characteristic, in variable quantities, in the two northern intrusions. In terms of the typically pegmatitic accessory minerals, the Greer Lake intrusion is the most enriched in Be-, Nb–Ta- and Li-bearing species; the OL body carries abundant Li-, P- and As-bearing minerals, but the Eaglenest Lake and Tin Lake intrusions appear barren in comparison. The accessory mineral assemblages thus suggest significant geochemical differences among the four intrusions.

Two mineralized pods in the southern part of the Greer Lake intrusion deserve particular notice because of their high concentration of rare elements, and because of their paragenetic and geochemical similarity to some of the most fractionated pegmatites in the district. These are the Annie Claim along the southern margin of the intrusion and the Silverleaf Claim southwest of the main body. The western Annie Claim locality is a subellipsoidal pod highly enriched in Li-, Rb-, Cs-, Be-, Nb–Ta- and F-bearing minerals, evolving from the surrounding pegmatitic leucogranite through a narrow transitional zone. The Silverleaf offshoot consists largely of garnetiferous aplite with a large rounded pod of

TABLE 2. ACCESSORY MINERALS IN THE PEGMATITIC GRANITES



*see text for paragenesis of pegmatite pods in the southern part

TABLE 3. REPRESENTATIVE CHEMICAL ANALYSES OF THE PEGMATITIC GRANITES

	Fine grained leucogranite		Pegmatitic leucogranite		Sodic aplite	Potassic pegmatite
	TNL-31	GLW-38A	TL-1006	GL-1003	GLW-6aA	GLW-6aP
SiO_2(%)	77.10	75.90	73.50	75.30	77.50	75.55
TiO_2	0.03	0.01	0.03	0.04	0.06	0.04
Al_2O_3	12.28	13.48	14.40	14.30	12.79	15.01
Fe_2O_3	0.31	0.35	0.47	0.86	0.76	0.56
FeO	0.68	0.26	0.88	0.92	0.80	0.20
MnO	0.01	0.01	0.03	0.08	0.21	0.01
MgO	0.20	0.03	0.09	0.03	0.03	0.05
CaO	0.42	0.31	0.36	0.21	0.40	0.18
Na_2O	3.23	3.68	3.98	5.20	6.22	2.90
K_2O	5.24	5.41	5.63	2.19	0.66	4.65
P_2O_5	0.06	0.08	0.05	0.06	0.04	0.016
CO_2	0.02	0.03	0.09	0.08	0.10	0.22
H_2O+	0.52	0.34	0.23	0.55	0.39	1.15
F_2	0.01	0.01	0.01	0.03	0.02	0.06
	100.11	99.90	99.75	99.85	99.98	100.60
-O = F_2	-	-	-	0.01	-	0.03
Total	100.11	99.90	99.75	99.84	99.98	100.57
CIPW cor.	0.72	1.27	1.44	3.35	1.49	5.48
Li(ppm)	42	57	28	76	45	107
Rb	168	340	275	442	138	735
Cs	4	13.7	3.2	2.3	1.5	4.6
Be	1	3	0.5	1.7	2	1.7
Sr	3	20	43	31	5	13
Ba	244	142	50	1	nd*	nd
Pb	30	33	20	11	4	5
Ga	27	45	62	64	51	102
U	36	9	3	8	6	5
Th	15	25	nd	5	12	3
Zr	130	58	5	16	14	2
Hf	4.35	1.2	0.45	1.25	1.8	0.4
Sn	3	8	13	23	13	20
K/Rb	259	132	170	41.2	39.8	52.5
K/(Csx100)	108	32	145	79	36	83
K/Ba	178	316	934	18200	-	-
Ba/Rb	1.45	0.42	0.18	0.002	-	-
Ba/Sr	81.3	7.10	1.16	0.03	-	-
Rb/Sr	56	17	6.4	14.3	27.6	56.5
Mg/Li	28.7	3.2	20	2.7	4.4	2.8
Zr/Sn	43.3	7.2	0.4	0.7	1.1	0.1
Zr/Hf	29.9	48.3	11.1	12.8	7.8	5
Al/Ga	2407	1584	1229	1183	1327	778
La(ppm)	19.7	5.5	2.85	7.05	7.35	3
Ce	46	16.5	8	18.5	23	6.5
Nd	5.5	5	3.5	6.5	10	3.5
Sm	7.25	2.95	1.64	4.69	5.3	1.09
Eu	0.18	0.08	0.08	0.05	0.10	0.15
Dy	8.9	7.15	2.55	5.85	4.25	0.85
Yb	4.7	3.35	1.3	2.7	2.75	0.6
Lu	0.56	0.32	0.13	0.26	0.45	0.09
Y	61	40	17	32	34	nd

*not detected

TABLE 4. SELECTED GEOCHEMICAL CHARACTERISTICS OF THE FINE GRAINED LEUCOGRANITE PHASES OF THE PEGMATITIC GRANITES

	Tin Lake(13) *	Osis Lake Lake(3)	Greer Lake(5)	Eaglenest Lake(3)
Li	31.8 ** 11-59	63.3 47-74	58 29-86	79.7 27-140
Rb	245 128-338	137 103-193	562 340-1050	536 293-817
Cs	7.2 2.9-11.4	8.4 3.9-17	8.9 5.1-13.7	12.7 3.8-24
Be	2.0 1-3	0.8 0.3-1.2	3.8 1.2-10	5.6 0.7-13
Sr	35.4 3-55	25.7 13-36	18.2 11-28	10.3 5-15
Ba	217 31-416	8 3-18	112 12-150	70 0-110
Ga	30 22-46	48 41-57	53 32-73	58 56-60
U	28 13-40	23 8-52	15 8-30	6 4-8
Th	10.3 0-30	6.7 4-12	7.4 0-25	7 0-18
Zr	103 61-140	38 17-74	44 11-58	53 38-71
Hf	4.0 3.5-4.6	3.0	1.2	2.3 0.8-3.4
Sn	8.7 0-13	13 10-15	13.6 5-25	13 11-15
K/Rb	176 69-327	132 89-156	87 42-132	75 47-112
(K/Cs)x100	68 34-154	28 17-46	51 33-77	44 16-87
K/Ba	279 75-1258	5402 507-9667	767 215-2425	338 325-351
Ba/Sr	11.7 1.1-81.3	0.5 0.08-1.4	7.4 0.4-12.4	8.2 7.3-9.0
Rb/Sr	10.9 3.2-56	6 3.2-7.9	32.1 17.0-61.8	52.8 45.4-58.6
Mg/Li	49 13.5-127	11.5 6.7-19.1	4.7 1.7-9.4	6.0 1.7-12.2
Al/Ga	2351 1742-2909	1674 1520-1885	1526 990-2284	1258 1227-1284
Zr/Hf	30.8 29.3-32.6	24.3	48.3	32.9 14.1-63.7

*number of samples averaged; lower for Hf determinations
**arithmetic mean and range, in ppm

Li-, Rb-, Mn-, Nb–Ta-, Be-, Sn- and F-enriched pegmatitic assemblage. Cs-rich beryl, Li-micas, petalite, spodumene, cassiterite, columbite–tantalite, apatite, triphylite–lithiophilite, amblygonite–montebrasite and sphalerite are the characteristic accessory minerals.

Contact reactions

Reaction of the pegmatite granites with the enclosing rocks varies with the composition of both the intrusion and host. Along the meagre contact exposures of the Greer Lake and Eaglenest Lake intrusions, reaction with metabasalts is restricted to very limited recrystallization of hornblende in the metabasalts and to moderate biotitization. In the southern lobe at Tin Lake, small inclusions of the tonalite and metavolcanic rock tend to develop porphyroblastic garnet, and only in the northeastern extremity where this intrusion is in contact with Booster Lake metaturbidites is altered cordierite found in fine grained leucogranites. In contrast, the tourmaline-bearing Osis Lake intrusion has reacted extensively with the metaturbidites of the Booster Lake Formation: tourmalinization of the latter, coupled with the growth of albitic plagioclase and locally muscovite, is ubiquitous, particularly in thin splinters and screens and on the surface of larger rafts. Thin screens may become completely digested by the pegmatitic granite.

Exomorphic influence of the pegmatitic granites is probably much more pronounced than the effects observed along the intrusive contacts. Post-tectonic growth of biotite or muscovite (or both) is characteristic of most of the greenstone-belt lithologies (A.C. Turnock, pers. comm. 1980), suggestive of widespread alkali metasomatism. Extensive dispersion haloes of K, Li, Rb and Cs can be expected in the schists hosting the pegmatitic granites, as documented for analogous rocks in the Cat Lake and Lilypad Lakes areas (W.C. Hood, pers. comm. 1980).

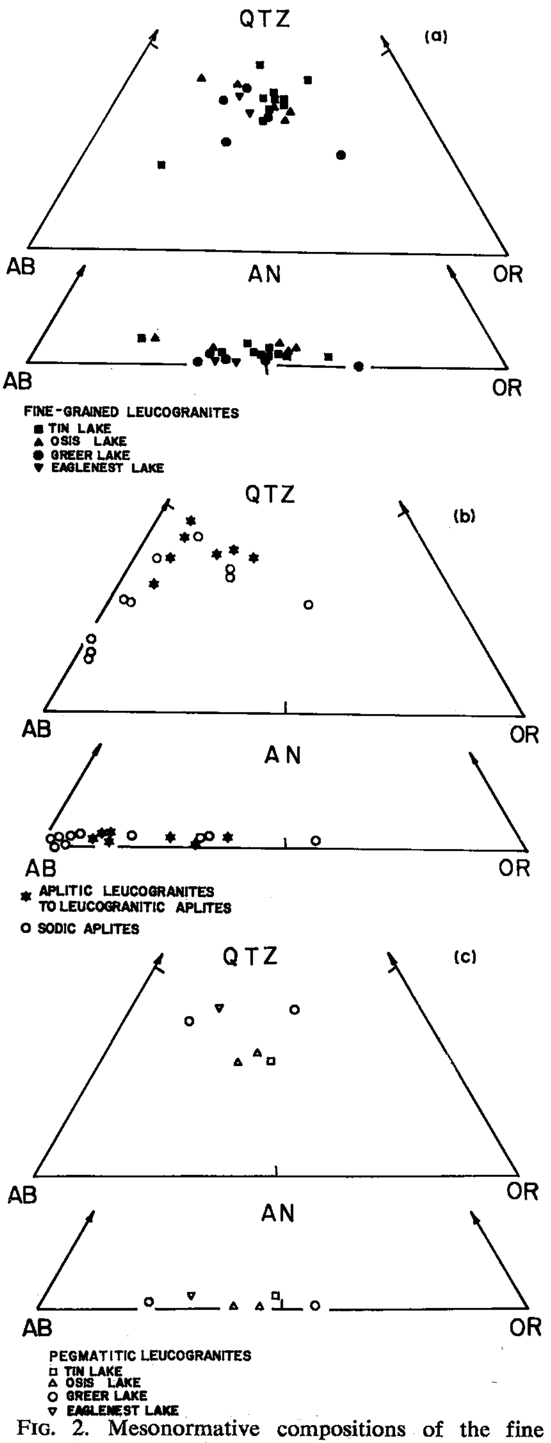


FIG. 2. Mesonormative compositions of the fine grained leucogranite, sodic aplite and pegmatitic leucogranite phases of the pegmatitic granite intrusions in the Ab–Or–Qtz and Ab–Or–An systems.

Petrochemistry

Results of representative analyses of the four phases composing the pegmatitic granites, and covering most of the variation of individual oxides and trace elements, are given in Table 3. Fine grained leucogranites are mostly concentrated around the composition $Ab_{32.5}Or_{32.5}Qtz_{35}$ (Fig. 2). The sodic aplites shift from this composition towards the Ab apex by a decrease in Or, followed by loss of quartz. The pegmatitic leucogranites are somewhat scattered, at least partly because of the difficulties encountered in representative sampling of this coarse grained rock type. On the average, they appear to be slightly more sodic than the fine grained phase. In the ternary feldspar system, most of the fine grained and pegmatitic leucogranites fall into the low-temperature trough; compared with the other two intrusions, the Tin Lake and Osis Lake bodies are slightly enriched in An.

Figure 3 shows the normative corundum contents (CIPW) plotted against SiO_2. No silica-dependent trends can be detected. However, four observations can be made using the data at hand: (1) among the four intrusions, the Osis Lake and much of the Eaglenest bodies are generally more peraluminous than the other two; (2) among the four rock types in each intrusion, pegmatitic leucogranite is more peraluminous than the fine grained phase; (3) generally, the peraluminous character increases from the fine grained leucogranites through their gradual transition into sodic aplites (increasing muscovite and garnet contents); and (4) the excess of Al_2O_3 is variable in the potassic pegmatites but reaches its highest values, greatly surpassing those of the other rock types, in muscovite-rich bodies (Table 3).

The highly fractionated character of the pegmatitic granites, shown by high SiO_2 and alkalis and by low Ca, Fe and Mg, is also expressed in their trace element contents (Tables 3 and 4, Fig. 4). The extremely low values of the K/Rb (42), K/Cs (1600), Mg/Li (1.7) and Al/Ga (990) ratios and the high values of K/Ba ($\gg$ 20000), shown by the pegmatitic granites, are rarely reached in igneous sequences; granitic averages for the above ratios are in the order of 230, 10000, 50, 3000 and 50, respectively. The individual intrusions have different levels of fractionation (at the present erosion surface), and the fine grained leucogranites are relatively

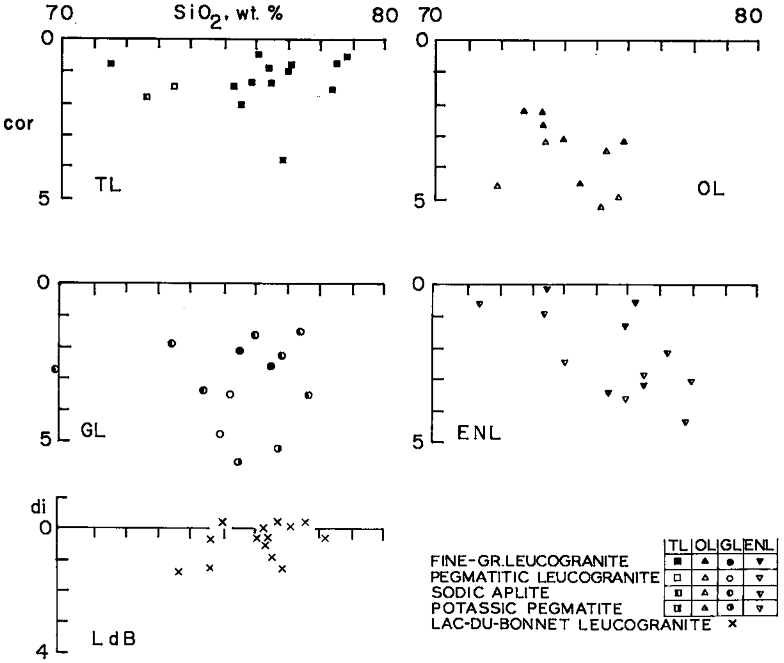


FIG. 3. Normative corundum and diopside (CIPW) in the four phases of the pegmatitic granite intrusions and in the Lac-du-Bonnet leucogranite.

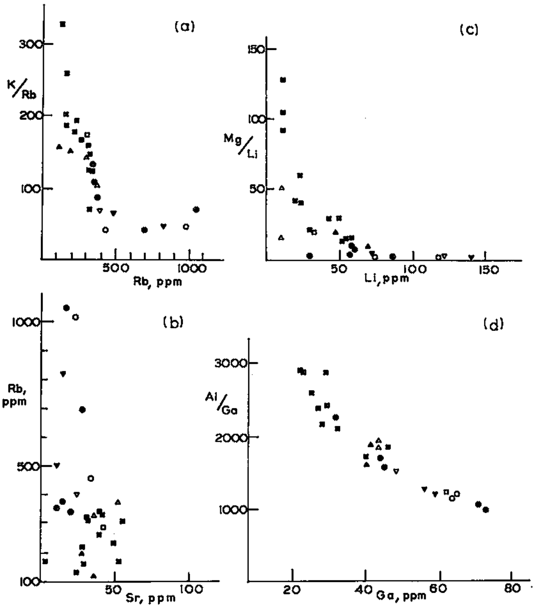


FIG. 4. Selected major and trace element relationships in the fine grained (solid symbols) and pegmatitic (open symbols) leucogranites of the pegmatitic granite intrusions. Symbols as in Figure 3.

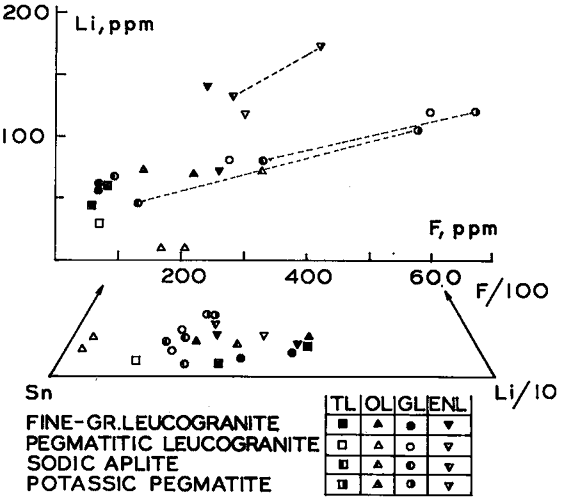


FIG. 5. Li *versus* F and Sn–(Li/10)–(F/100) relationships in the fine grained leucogranite, pegmatitic leucogranite, sodic aplite and potassic pegmatite phases of the pegmatitic granite intrusions. Dashed lines join adjacent pegmatite and aplite samples.

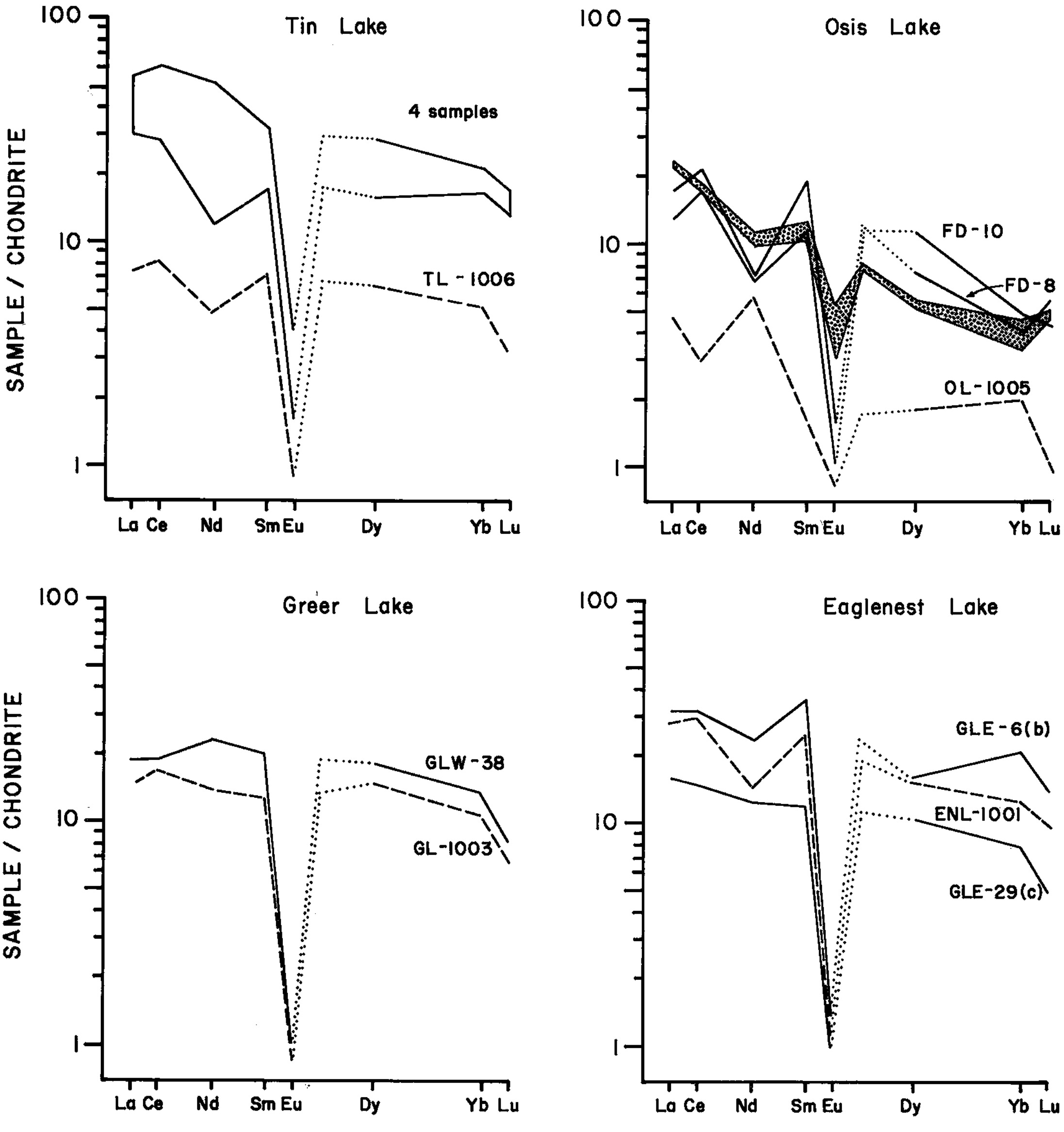


FIG. 6. *REE* abundances in the fine grained (solid lines) and pegmatitic (dashed lines) leucogranites of the pegmatitic granite intrusions. A field of *REE* abundances in the plug of biotite granite central to the Osis Lake intrusion is also shown.

more primitive than their pegmatitic counterparts within the same intrusion.

The F content of the granites examined appears to vary with the Li concentration (Fig. 5). Both elements are low in the Tin Lake and Osis Lake intrusions, whereas most phases of the Greer Lake and Eaglenest Lake bodies are enriched in them. In the triangular projection Sn–(Li/10)–(F/100), the points shift along the Li–Sn sideline from Li-enriched, fine grained leucogranites through aplitic phases to Sn-rich pegmatitic leucogranites. Among the four rock types within each intrusion, the pegmatitic phases tend to be enriched in F and Sn.

Chondrite-normalized *REE* abundances are shown in Figure 6 for the two predominant rock types, the pegmatitic and fine grained leucogranites. Low total *REE* contents and extreme negative Eu anomalies, flanked by rather flat *LREE* and *HREE* distributions with low Ce_N/Yb_N ratios, are predominant. The only exception is the Osis Lake intrusion (including its central plug of biotite granite) which has a more steeply sloping distribution and a moderate Eu anomaly. Within a single intrusion, the *REE* concentration tends to be slightly to distinctly lower in the pegmatitic leucogranites than in the fine grained phase, but the type of pattern is identical for both. The limited data available for the other two phases indicate that the sodic aplites have *REE* contents within the limits of the associated fine grained leucogranites, but the *REE* abundances decrease drastically in the potassic pegmatites (Table 3). The total *REE* contents tend to decrease with increasing normative corundum but the trend shows a wide scatter.

Oxygen-isotope compositions of the pegmatitic granites are remarkably homogeneous within, but vary greatly between individual bodies. Most of the data are correlatable with $\delta^{18}O$ values found for enclosing metasedimentary and metavolcanic rocks. The $\delta^{18}O$ is low in the Greer Lake and Eaglenest Lake intrusions (8.1–8.7 and 8.6–9.3, respectively), and seems related to the low $\delta^{18}O$ of the enclosing metabasalt. The $\delta^{18}O$ ranges for the Tin Lake and Osis Lake bodies (10.3–10.9 and 11.1–12.4, respectively) closely correspond to those of their ^{18}O-rich metasedimentary hosts (Longstaffe *et al.* 1981).

Mineralogy

The chemical composition and structural characteristics of rock-forming and accessory minerals have been studied, mainly in the potassic pegmatite phase of the intrusions, to facilitate direct comparison with neighboring pegmatite groups. However, these data also contribute to the definition of geochemical characteristics and internal fractionation of the pegmatitic granites themselves.

Bulk compositions of the blocky K-feldspars are quite uniform in all four intrusions. They average very close to $Or_{73}Ab_{27}$; the An component is low in the south and higher in the northern occurrences (Greer Lake $An_{0.03}$, Eaglenest Lake $An_{0.05}$, Tin Lake $An_{0.08}$, Osis Lake $An_{0.09}$). Conversely, rare-alkali fractionation of the Greer Lake and Eaglenest Lake bodies is higher than that of the northern intrusions (Fig. 7). Obliquities of K-feldspars commonly range between 0.90 and 1.00, except for the Osis Lake

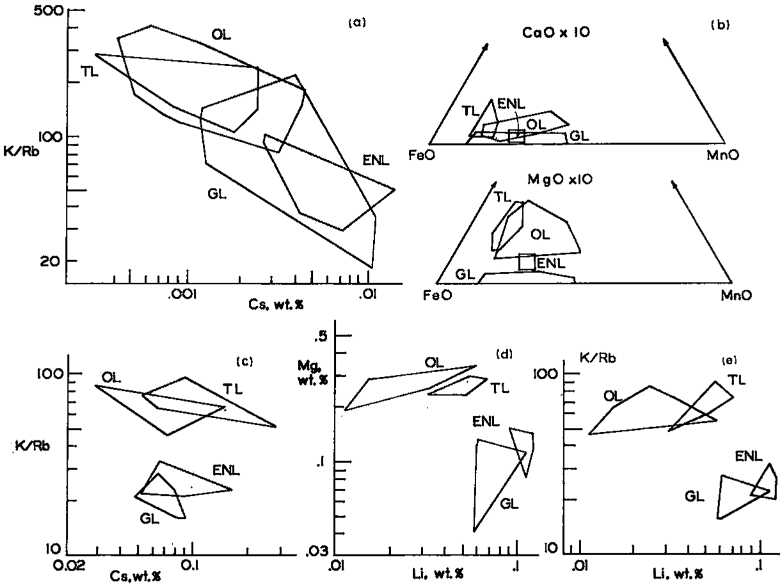


FIG. 7. Selected compositional characteristics of rock-forming minerals: blocky K-feldspar from the potassic pegmatite phase (a), garnet from the pegmatitic leucogranite phase (b) and platy muscovite from the potassic pegmatite phase (c,d,e).

intrusion, in which the values cover a wide span: 0.66-1.00.

Plagioclase is albitic (An$_3$–An$_6$) and of low structural state. The An content is slightly higher in the Tin Lake and Osis Lake intrusions than in the southern bodies. No systematic variation was found among plagioclases from the different rock types within individual intrusions.

Coarse platy muscovite uniformly crystallized in the 2M$_1$ polytype. Li and Rb are highly enriched in this species in the Greer Lake and Eaglenest Lake intrusions, but the ranges of Cs contents are largely overlapping (Fig. 7). The total Fe (expressed as Fe_2O_3) and MgO contents are low (1.24–3.53 and 0.03–0.48 wt. %, respectively), as are those of F (0.17–0.40 wt. %), relative to the celadonitic nature of muscovite in many two-mica granites (Miller *et al.* 1981, Anderson & Rowley 1981).

Within a single intrusion, the Mn enrichment is evident in the garnets from potassic pegmatite layers, but the compositions of other paragenetic types of garnet largely overlap. Among different intrusions, garnets are Mn-poor in the Tin Lake body (Sp$_{7-22}$), intermediate in the Greer Lake and Eaglenest Lake intrusions (Sp$_{14-31}$ and Sp$_{13-34}$, respectively) and most Mn-enriched in the Osis Lake body (Sp$_{16-50}$: Černý *et al.* 1981). In terms of garnets from the pegmatitic leucogranite phase, however, the compositions of the Greer Lake and Osis Lake garnets overlap (Fig. 7). MgO and CaO are distinctly higher in the garnets from the northern intrusions (Fig. 7), and P_2O_5 is particularly enriched in the Osis Lake body (average 0.23 wt. %), whereas the Greer Lake and Eaglenest Lake garnets are enriched in Y_2O_3 (0.10–0.25 wt. %).

Accessory minerals from the potassic pegmatite layers display relatively primitive compositions. Alkali contents of greenish beryl are low (up to 0.45 wt. % Li_2O and 0.20 wt. % Cs_2O), and disordered columbite is poor in Mn and Ta (about $Fe_{0.7}Mn_{0.3}Ta_{0.3}Nb_{1.7}O_6$). However, fractionation reached in the Annie Claim and Silverleaf pegmatite pods along the southern margin of the Greer Lake intrusion is very advanced (K-feldspar with up to 1.20 wt. % Rb_2O; 2M$_1$ > 1M lithian muscovite with 3.77 wt. % Li_2O, 2.14 wt. % Rb_2O and 0.44 wt. % Cs_2O; beryl with 1.05 wt. % Li_2O and 2.30 wt. % Cs_2O; and disordered columbite–tantalite reaching compositions of $Fe_{0.3}Mn_{0.7}Nb_{0.6}Ta_{1.4}O_6$ and $Fe_{0.05}Mn_{0.95}Nb_{1.0}Ta_{1.0}O_6$).

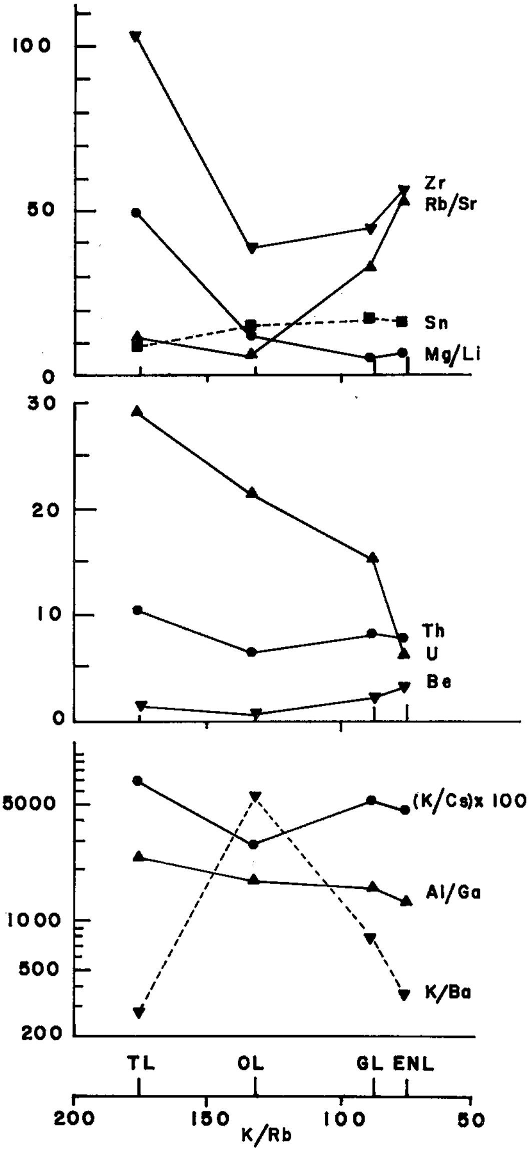


FIG. 8. Fractionation trends and discordances in the fine grained leucogranite phases of the pegmatitic granite intrusions related to the K/Rb ratio. Element contents in ppm.

Internal fractionation trends

Some fractionation trends are expressed by regional changes in accessory mineralogy. Such a trend is shown for the Tin Lake and Osis Lake intrusions in Table 2, indicating changes in abundance of B, Li, P, As and Mo. Much better evidence is available from regional variations in whole rock K/Rb, blocky K-feldspar

K/Rb and K/Cs, muscovite K/Rb, Mg/Li and Be, and garnet Fe/Mn ratios. Fractionation increases from central parts of the Greer Lake and Eaglenest Lake intrusions to their western and eastern extremities, and from the eastern termination of the Osis Lake body to the west and northwest. No vectorial trend can be detected in the Tin Lake pegmatitic granite; however, the part of this body south of the shear zone (Fig. 1) tends to be slightly more fractionated than the northern segment (Goad 1981, Černý *et al.* 1981).

Mutual fractionation relationships

The four intrusions of pegmatitic granites are obviously closely related in general terms of emplacement, internal diversity and compositional characteristics. However, they do not constitute a simple fractionation series, as is readily evident from the irregular distribution of accessory minerals (Table 2). Figure 8 illustrates diverse geochemical indicators plotted against averages of the K/Rb ratio. It is evident from this graph that the Osis Lake intrusion is the most anomalous, deviating from trends that are generally (but not ideally) followed by the three other bodies. This behavior matches some of the previously established anomalies that also contradict simple igneous fractionation, notably the enrichment in Mn, P and B, the extreme peraluminous compositions and the slight deviation in the pattern of *REE* abundances.

PEGMATITE GROUPS

Each of the pegmatitic granites is flanked or partly surrounded by a swarm of pegmatite dykes (Fig. 1). Besides this close spatial relationship, several other features of the individual pegmatitic granites and their respective pegmatite aureoles imply a common genetic link: (1) Accessory mineral assemblages (Table 4). For example, the Greer Lake and Eaglenest Lake pegmatitic granites are virtually free of B-bearing minerals and are very low in P-bearing minerals, as are their pegmatite aureoles. In contrast, these two elements are enriched in the Tin Lake and particularly Osis Lake intrusions, and this is also reflected in the abundance of tourmaline and phosphates in the adjacent pegmatite groups. The Greer Lake intrusion and the pegmatite group adjacent to it are the only ones in the district that carry pseudomorphs after cordierite that are studded with garnet. (2) Texture and zoning: Bands and schlieren of a mineralized potassic pegmatite phase that occur within the pegmatitic granite display the same zonal sequence and textural relationships as do individual bodies in adjacent pegmatite swarms. This is particularly true of the Greer Lake, Eaglenest Lake and Tin Lake intrusions. The last of these is transitional into the Birse Lake pegmatite group in such a gradual manner that only an arbitrary boundary can be drawn between the fingering-out pegmatitic granite and pegmatites proper. Even the most complexly zoned pegmatite types of the Rush Lake and Bernic Lake groups have their petrological and paragenetic analogues inside the pegmatitic granites, in the Li-, Rb-, Cs-, Be-, Nb–Ta- and F-rich Silverleaf and Annie Claim pegmatitic nodules that represent local, gradually evolving facies in the Greer Lake pegmatitic granite. (3) Geochemical relations: The rock-forming minerals from the individual major intrusions and from their respective pegmatite aureoles indicate common fractionation relationships. This is illustrated in Figure 9, where K/Rb and Cs of blocky K-feldspars from the potassic pegmatite phase of three pegmatitic granites and from their pegmatite aureoles exhibit continuous fractionation schemes. Similar sequential trends are shown by other fractionation-sensitive elements in K-feldspars and muscovites. Rough parallelism in averaged geochemical characteristics of the pegmatitic granites and their pegmatite aureoles is also shown in Table 5.

The most fractionated and complex group of pegmatites in the district, the Bernic Lake group, which includes the Tanco deposit (Crouse *et al.* 1979), appears to have no parent body exposed at the present erosional level. The distance from the westernmost parts of the Osis Lake pegmatitic granite is excessive (Fig. 1), and the geochemistry of feldspars and micas in the Rush Lake and Bernic Lake groups suggests a parallel but not sequential fractionation of these pegmatite groups (Fig. 9). A source hidden beneath the central parts of the area populated by the Bernic Lake pegmatites is suggested by the directions of lateral fractionation trends within individual pegmatite dykes (Černý *et al.* 1981). Such a hypothetical source would fit the extreme fractionation and enrichment in rare elements attained by this group: in an idealized 3-dimensional pegmatite aureole flanking and topping a parental intrusion, extreme enrichment in volatile components and associated rare elements should be expected in the topmost part. A pegmatitic granite of the Greer Lake type may be envisaged as a parental body. The Silverleaf and Annie Claim pods in the Greer

TABLE 5. CORRELATION OF ACCESSORY MINERAL CONTENT AND SOME GEOCHEMICAL CHARACTERISTICS OF PARENT INTRUSIONS AND THEIR PEGMATITE AUREOLES

Parent intrusion ←			→ Associated pegmatites		
Typical accessory minerals	Local mineralization	Avg. whole rock K/Rb,K/Cs Mg/Li	Typical accessory minerals	Rare-element association	Avg. K/Rb,Cs (ppm) in blocky K-feldspars
LAC-DU-BONNET LEUCOGRANITE(LdB) ←			→ SHATFORD LAKE GROUP(SHL)		
zircon, allanite, monazite, ((garnet))	((Be))	190; 18,400 28	beryl, garnet, topaz, allanite, monazite, zircon, thorite, uraninite, columbite-tantalite, euxenite, yttrotantalite, gadolinite, cassiterite	Be,Nb-Ta,Sn, REE,Y,U,Th, Zr-Hf	66; 61
TIN LAKE PEGMATITIC GRANITE(TL) ←			→ BIRSE LAKE GROUP(BIS)		
garnet ((tourmaline))	((Mo))	176; 6,800 49	tourmaline, beryl	Be((Li,Nb-Ta))	119; 52
GREER LAKE PEGMATITIC GRANITE(GL) ←			→ GREER LAKE GROUP(GL)		
garnet, cordierite, (gahnite, beryl) ((columbite-tantalite, monazite))	Be,Nb-Ta(Li,Rb, Cs,Zn)	87; 5,110 4.7	garnet, cordierite, beryl, columbite-tantalite (gahnite, monazite, zircon, cassiterite) ((Li-micas))	Be,Nb-Ta (Sn,Zn)((Li))	42; 250
EAGLENEST LAKE PEGMATITIC GRANITE(ENL) ←			→ EAGLENEST LAKE GROUP(ENL)		
garnet		75; 4,460 6	garnet, beryl	Be	38; 53
OSIS LAKE PEGMATITIC GRANITE(OL) ←			→ RUSH LAKE GROUP(RL)		
garnet, tourmaline apatite, (triphylite, arsenopyrite)	(Li,P,As)	131; 2,800 11.5	tourmaline, beryl, spodumene, petalite, amblygonite, triphylite, (Nb,Ta-oxide minerals cassiterite, sulfides) ((polucite))	Li,Rb,(Cs),Be, Sn,Nb-Ta,F,B,P	50; 265
(unexposed; presumed pegmatitic granite) ←			→ BERNIC LAKE GROUP(BL)		
			tourmaline, beryl, petalite (spodumene, eucryptite), lepidolite, pollucite, cassiterite, Nb,Ta-oxide minerals, amblygonite, triphylite	Li,Rb,Cs,Be Sn,Nb-Ta,F,B,P	9.5; 1262

( ) subordinate; (( )) rare

Lake intrusion are not as fractionated as the Bernic Lake pegmatite group, but they exhibit the same low-P assemblage (petalite as the primary Li-aluminosilicate) and similar paragenesis.

Discussion

Although the genetic relationship between the pegmatitic granites and their pegmatite aureoles appears to be established, the internal evolution of the pegmatitic granites and their origin are much less evident, and they should be examined in the light of the data presented earlier.

Internal evolution

In terms of internal composition of each phase, the four rock types distinguished in all four intrusions show the following relationships: (1) The fine grained and pegmatitic leucogranite phases have not been found in mutual contact, and the difference between them was probably established below the final level of emplacement, prior to solidification. The differences in their texture, bulk chemistry and trace element contents suggests that the fine grained phase crystallized from a relatively dry melt, whereas the pegmatitic phase originated from a more fractionated and volatile-oversaturated melt, which did not reach a stage of large-scale spatial separation of supercritical fluids from residual magma. According to Jahns & Burnham (1969), graphic K-feldspar + quartz megacrysts may have grown from local concentrations of supercritical fluids that did not coalesce. (2) Potassic pegmatite bands develop locally by gradual or abrupt change in mineral assemblage and texture of pegmatitic leucogranite. This corresponds to incipient segregation of supercritical fluids into larger pods, preferentially extracting K, Si and some trace elements. (3) Fine grained leucogranites (and, rarely, pegmatitic leucogranites) grade into layered assemblages of garnetiferous sodic aplite alternating with potassic pegmatite. Two interpretations may be applied to this association. One is that proposed by Jahns & Burnham (1969), who consider the sodic aplite to have crystallized from residual melt impoverished in silica, potassium and most rare elements owing to extraction into a separated supercritical fluid that gave rise to the pegmatitic bands. The other possibility is a metasomatic origin of the banded garnetiferous

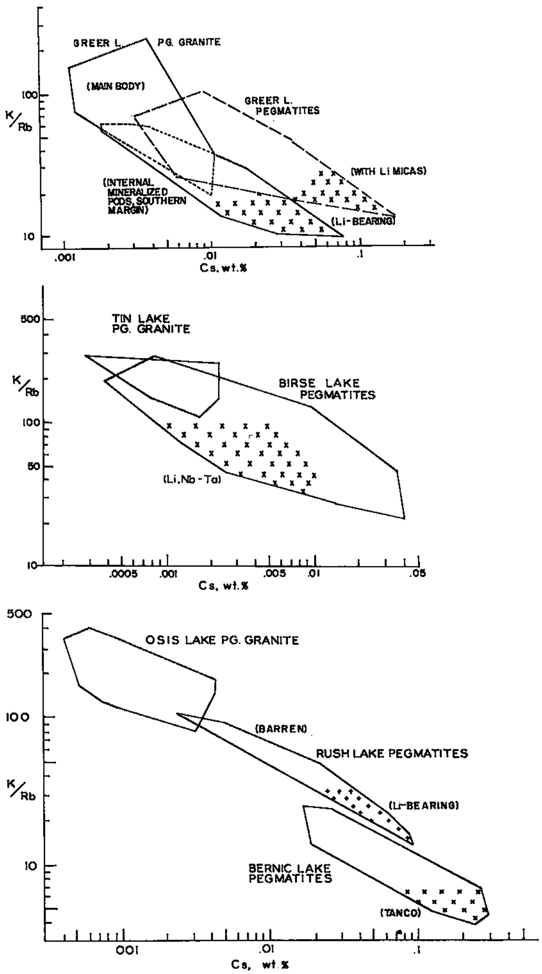


FIG. 9. K/Rb *versus* Cs in blocky K-feldspars of the potassic pegmatite phase of the pegmatitic granites, and of the pegmatite groups adjacent to their individual intrusions (*cf.*, Fig. 1).

aplite assemblage, analogous to saccharoidal albitization fronts in complex pegmatites (*e.g.*, Beus 1961).

Textural and mineral-compositional characteristics of the banded aplite–pegmatite association favor the first mechanism: (1) the surface of aplitic bands commonly serves as a substrate for crystallization of pegmatitic assemblages; (2) pegmatitic assemblages cross-cut and cement broken bands of sodic aplite, but reverse cases are extremely rare; (3) the An content of albite in the sodic aplite is about the same as in the other units composing pegmatitic granite intrusions, whereas metasomatic albite could be expected to be extremely An-poor; (4) the Mn content of garnets is also about the same as, if not lower than, that of garnets in fine grained and pegmatitic leucogranites; enrichment in Mn could be expected in garnet associated with albitization because of continued Fe–Mn fractionation during late metasomatism.

The only feature of the sodic aplites pointing to an analogy with albitization is the assemblage of accessory minerals, which is close to that of many typical albitized units in pegmatites. However, if the layered aplitic assemblages were generated through sodic metasomatism, then their textural relationships with the pegmatitic assemblages noted above would indicate total recrystallization of original rock type(s). The compositional uniformity of albite, garnet and muscovite (Goad 1981, Černý *et al.* 1981) would also suggest a thorough metasomatic reworking of precursor lithologies whose only remnants might be represented by the fine grained leucogranites. Such a profound metasomatism and recrystallization would suggest an analogy with apogranites of Soviet authors, which are, however, decidedly sodic in bulk compositions, extremely enriched in Li, Rb, Cs, Be and F and not associated with mineralized pegmatite swarms (Beus *et al.* 1968).

Thus the concept of igneous and supercritical crystallization from melts and fluids, triggered by a pressure quench in dilation zones, is preferred for all four phases of the pegmatitic granite intrusions, as modeled by Jahns & Burnham (1969).

Conditions of crystallization

An estimate of the P–T regime under which the pegmatitic granite intrusions crystallized is hampered by several compositional characteristics of the different rock types. The procedures applied by Castle & Theodore (1972) and Harris (1974) to similar rocks cannot be used rigorously in our case because of compositional complexities introduced by the presence of Li, B and F. Wyllie & Tuttle (1964) proved the fluxing role of Li, and Chorlton & Martin (1978) established the same for B. The profound influence of F on the granitic solidus, depressing it partly by dissolving more H_2O, was discussed recently by Bailey (1977) and Wyllie (1979). Thus any estimates based on simple experimental systems lacking Li, B and F would yield excessively high P–T values, partly because of an unrealistic granite solidus and partly also because of Mg-, Fe- and F-induced shifts in the stability field of (OH)-muscovite (Miller *et al.* 1981, Anderson & Rowley 1981).

Of the four phases constituting the pegmatitic granite intrusions, the fine grained leucogranite is the most simple and "primitive" rock type, least affected by supercritical leaching and other processes that could have disturbed its original igneous characteristics. In the granite-crystallization grid of Anderson & Cullers (1978), a large part of the fine grained leucogranite compositions clusters near the 0.5–1 kbar minima in the granite system. Considering the lregiona metamorphic grade, this low pressure is probably misleading as to the depth of consolidation (2–4 km), but it may be indicative of the conditions prevalent in large-scale dilation zones into which the pegmatitic granites were emplaced. Regarding the temperature of crystallization, the available experimental grids are even more difficult to use, as indicated earlier. However, the two-feldspar geothermometer of Whitney & Stormer (1977) suggests a reasonable temperature range between 640 and 600°C for the microcline–plagioclase solvus [for 1 to 2 kbar P(H_2O)], and even lower if the K-feldspar equilibrated in a partly disordered state.

Petrogenesis

Derivation of the melts that gave rise to the pegmatitic granites is still controversial. The data base and some details of the present state of argument given in Goad (1981), Černý *et al.* (1981) and Longstaffe *et al.* (1981) may complement the brief review presented here.

Fractionation of batholithic tonalites and biotite granites of the district and single stage partial melting from a variety of possible sources are highly improbable processes because of the incompatible fractionation trends and *REE* abundances (Fig. 10; Černý *et al.* 1981). Also, in a scheme of direct partial anatexis, the extreme fractionation shown by whole-rock and mineral compositions of the pegmatitic granites would require negligible percentages of melt, with consequent problems in restite–melt separation. However, the data collected so far suggest that the examined pegmatitic granites could have formed by either of the following two-stage processes: (1) igneous differentiation from a juvenile source modified by interaction with the greenstone-belt rocks (contaminated I-type magma) or (2) partial melting of the greenstone metasediments followed by igneous and fluid fractionation (differentiated S-type magma). Both processes appear to be compatible with the rather constant bulk composition, erratic accessory mineralogy and trace-element

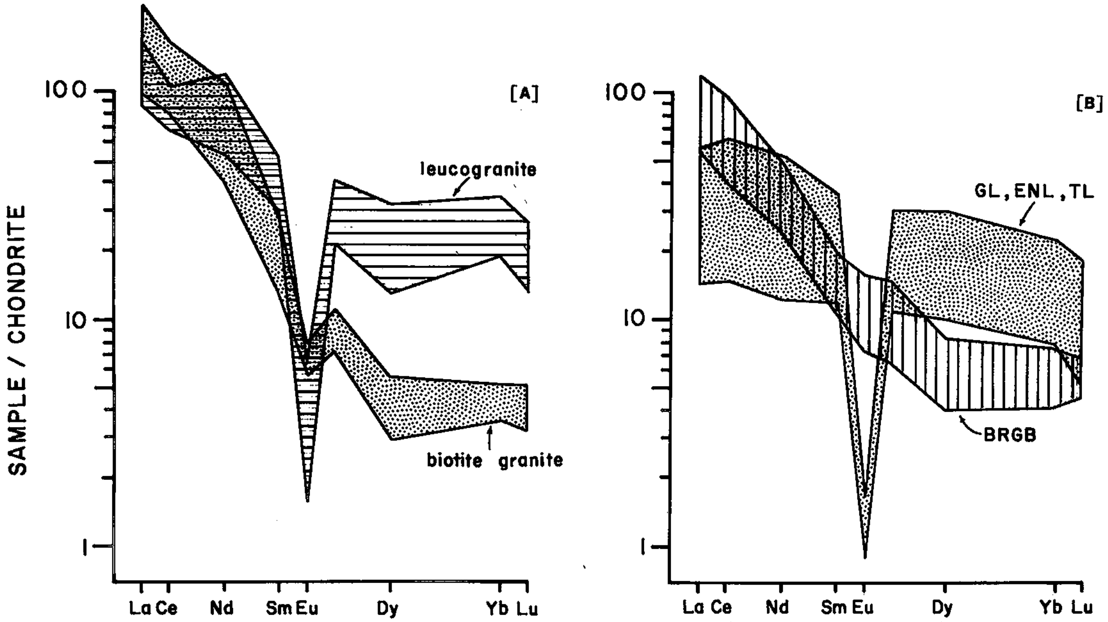


FIG. 10. Comparison of *REE* abundances demonstrating genetic independence [A] between the early leucogranite and late biotite granite of the Lac-du-Bonnet batholith, and [B] between the metaturbidites of the Booster Lake Formation (BRGB) as a possible source for direct partial melting of the three relatively uncontaminated pegmatitic granite intrusions.

content, variations in normative corundum, *REE* abundances and oxygen-isotope ratios. However, testing these two processes by quantitative trace-element modeling is not feasible since experimental data on granitic systems oversaturated with volatile components and on partitioning of *REE* and other trace elements between melt and an evolving supercritical fluid are not available.

In the first model, variable contamination of a fractionated I-type melt by different supracrustal lithologies and their low-temperature partial melts explains the regional distribution of accessory minerals and the deviations of subordinate and trace elements from ideal fractionation trends. Equilibration of juvenile melts with different host rocks explains the variations in oxygen-isotope ratios among the four intrusions The highest degree of hybridization displayed by the Osis Lake body is in accord with its reaction with the metaturbidite host, which is observed even at the emplacement level and conceivably more extensive at depth. The compositional data suggest a genetic link of the pegmatitic granites with a metarhyolite formation in the greenstone belt and with the early leucogranite of the Lac-du-Bonnet batholith (Cerny 1980a, b). These rocks appear to constitute a fractionation series, very close to the compositions of anorogenic, potassic and extremely fractionated rhyolites from eastern Australia (Ewart *et al.* 1976, 1977), which are interpreted as products of tholeiitic magma differentiation that were modified by sialic contamination. The compositions are analogous also to the anorogenic coarse and fine Belongia granites of Wisconsin, interpreted as derivatives by igneous fractionation of granitic magmas formed by partial melting of deep tonalitic crust (Anderson & Cullers 1978). Juvenile origin of compositionaly similar leucogranites is also claimed by Kolbe & Taylor (1966), Proctor & El-Etr (1968), Taylor *et al.* (1968) and McKenzie & Clarke (1975).

The second model, fractionation of S-type melts mobilized from the greenstone-belt metasediments, is analogous to that proposed by Breaks *et al.* (1978) and Drury (1979) for similar occurrences in northwestern Ontario and in the Yellowknife area; it has been tested in the Winnipeg River district by Černý *et al.* (1978). Partial melting of metasedimentary material is also favored for compositionally similar leucogranites and pegmatitic granites by Didier & Lameyre (1969), Dickson (1974), Harris (1974), Dostal (1975) and is experimentally supported by Winkler *et al.* (1975). This model offers a simple explanation for the relationship between individual pegmatitic granites and their host rocks. The northern intrusions could have been generated at depth from subvertical extensions of their volcaniclastic and metaturbidite hosts and adjacent units, and the southern ones from similar sources and metarhyolitic lithologies; however, these were somewhat modified by reaction with metabasalt hosts. The model is in better agreement with restricted mobility of wet granitic magmas than the first interpretation. The apparent rhyolite–leucogranite–pegmatitic granite suite quoted above would have to be dismissed as an incidental convergence.

In either model, the peraluminous nature of the pegmatitic granites seems to be enhanced by loss of alkalis through a vapor phase to the host rocks, over and above the direct effect of metasedimentary hybridization or mobilization. This is supported by the mildly peraluminous to slightly diopside-normative composition of the largely nonpegmatitic Lac-du-Bonnet leucogranite, whose consanguinity with the pegmatitic granites is postulated by both models (Table 1, Fig. 3). Significantly, in this respect, the coarse grained phases of the pegmatitic granites (*i.e.*, the pegmatitic leucogranites and potassic pegmatites) are the most peraluminous, and that the Osis Lake intrusion, which shows the most conspicuous exocontact effects, is the most peraluminous as a whole.

The predominantly pegmatitic character of the intrusions implies large volumes of volatiles, specifically H_2O, involved during and after their emplacement and crystallization. In view of the close relationship between the pegmatitic granites and major fault-systems and their protracted episodic activity, the melting mechanism proposed by Strong & Hanmer (1981) for the leucogranites in Brittany may also have operated in the Winnipeg River district.

Crystal–melt fractionation alone can hardly be responsible for the high enrichment in Li,Rb, Cs,Be,Ga and Sn and depletion in Ba and Sr, as opposed to the relative uniformity of bulk-rock compositions. Liquid-state differentiation could have been a factor; depolymerization would be very effective in volatile-saturated melts, as well as enrichment of apical parts of individual intrusions in rare elements and *HREE* transported in complex anions (Mahood 1979, Crecraft *et al.* 1979, Miller & Mittlefehldt 1979, Muecke & Clarke 1981).

The final deciphering of the process that generated the Winnipeg River pegmatitic granites would benefit from Sr and Pb isotope studies, which were beyond the scope of the present research. Detailed examination of other localities of pegmatitic granites, in different geological settings and igneous assemblages, is required to clarify and generalize their genesis, particularly in Archean and early Proterozoic terrains.

ACKNOWLEDGEMENTS

This study is based on the data collected under the Canada–Manitoba Subsidiary Agreement on Mineral Exploration and Development in Manitoba. The research was also funded by N.S.E.R.C. operating grants and D.E.M.R. research agreements to the second author.

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Received May 1980, revised manuscript accepted December 1980.