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Petrology and geochemistry of the Canadian Shield of northeastern Alberta

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Cover:
Contorted granite gneiss.
John D. Godfrey

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Abstract

The Alberta Shield is considered to represent an Archean gneissic terrain, which was partially melted during a period of Aphebian metamorphism at about 1900 Ma, to produce four major peraluminous intrusive complexes. The remnant, central belt of granodioritic to quartz-monzonitic gneiss, of I-type granitoid composition, is flanked on its western margin by fairly homogeneous plutons of biotite quartz monzonite to granite (Slave and Arch Lake Granitoids), and on its eastern margin by heterogeneous hornblende, biotite granodiorite to quartz monzonite (Wylie Lake and Colin Lake Granitoids). Field relationships, normative-feldspar compositions, modeling of large-ion lithophile elements, and comparisons with relevant experimental data, combined to indicate that the Slave and Arch Lake Granitoids could have been derived from about 40 percent partial melting of the central gneiss belt at approximately five kb P_{H_2O}. A restite assemblage of plagioclase, biotite, and hornblende was partially incorporated into this crystal-melt system, which was sufficiently ductile to be emplaced diapirically, while quartz-K-feldspar-plagioclase cotectic crystallization took place in the melt. R-mode factor analysis suggested that the Nb, Y, and Zr compositions of the Slave and Arch Lake Granitoids were directly inherited from heterogeneities in the gneissic progenitor and were unrelated to crystal fractionation/partial melting processes. The Wylie Lake and Colin Lake Granitoids are similar in composition to the central gneiss belt and were probably produced by a more limited partial melting of the same source.

The mean composition of the Alberta Shield is significantly higher in Si, K, and Ba than an estimate for the whole Churchill Province but is similar in composition to the exposed Saskatchewan Shield. The central gneiss belt is enriched in Ba and Si, compared to the mean composition of the Canadian Shield, but has similar concentrations of alkalies, Sr, Zn, and the high field strength elements Ti, Zr, Y, and Nb.

Introduction

This bulletin forms part of a series of Alberta Research Council publications on the geology of the Precambrian Shield of northeastern Alberta. Mapping covered the period 1957 to 1975. District geological maps have been either published or are going to press.

This study summarizes the petrology and geochemistry of the exposed Precambrian Shield of northeastern Alberta (the Alberta Shield), excluding the Helikian sediments of the Athabasca Group, which mainly occur south of Lake Athabasca. The gneisses, plutonic complexes and amphibolites were first classified petrologically. Attempts were then made to place constraints on their petrogenesis through major and trace element models. Second, a combination of detailed mapping and aeromagnetic interpretation of covered areas allowed a precise estimate to be made of the chemical composition of the Alberta Shield.

Location and access

The study area (figure 1) is located in northeastern Alberta, Canada, between 58°40′ and 60°N, and 110° and 112°W. The area forms parts of the Fitzgerald and Fort Chipewyan map sheets (NTS 74M and NTS 74L, respectively). Additional data are presented for the much smaller Marguerite River inlier, which is located 100 km south of Fort Chipewyan. This area forms part of the McKay map sheet (NTS 74E).

Regularly scheduled flights to both Fort Smith, Northwest Territories, and Fort Chipewyan, Alberta, provide access to the area.

Methods

Five hundred and ninety-one standard samples of gneisses, granitoid rocks, and amphibolites, along with 69 aggregate standard samples from metasedimentary rock layers, were carefully chosen to establish a geochemical data base. At the Alberta Research Council laboratories, each sample was analyzed for major and minor elements by classical wet-chemical techniques. Trace element analyses were carried out at the University of Durham by X-ray fluorescence, using the method of Brown et al. (1977). Magnetic susceptibility, bulk density, and a modal analysis were also determined for each standard sample.

Previous work

In 1957, the Alberta Research Council began systematic mapping of the Alberta Shield, and published several district maps in this series (Godfrey, 1961, 1963, 1966, 1970, 1980a, 1980b, 1984; Godfrey and Peikert, 1963, 1964; Godfrey and Langenberg, in press a and in press b)). Geochronological studies have been published on those portions of the Shield initially mapped by the Alberta Research Council (Baadsgaard and Godfrey, 1967, 1972; Kuo, 1972; Day, 1975). Godfrey (1958b) reported mineral showings in the Andrew, Waugh, and Johnson Lakes areas. Godfrey (1958a) also made a structural interpretation of the Alberta Shield, north of Lake Athabasca, based on stereoscopic vertical air photographs.

In 1959, the Geological Survey of Canada conducted a reconnaissance geological survey of the Alberta Shield and published a map with accompanying notes (Riley, 1960).

Peikert (1961, 1963) studied the petrogenesis of certain granitoid rocks in the Colin Lake area. Watanabe (1961) described metasedimentary rocks of the Waugh Lake area and, later (1965), cataclastic rocks of the Charles Lake area. Klewchuk (1972) reported on the petrogenesis of several granitoid rocks from the Fort Chipewyan district.

In 1977, the Alberta Research Council was invited, by the Geological Survey of Canada, to participate in a project to compile a metamorphic map of the Canadian Shield (GSC Map 1475A). The symposium volume accompanying the metamorphic map included a paper on the metamorphic history of the Alberta Shield (Godfrey and Langenberg, 1978). Langenberg and Nielsen (1982) prepared a more detailed account of the metamorphic history of the area. Langenberg and Ramsden (1980) discussed the geometry of macroscopic folds in the Tulip Lake and Hooker Lake areas, and Langenberg (1983) extended this work to the entire Alberta Shield area. Nielsen et al. (1981) discussed the crustal evolution of the area in a regional framework. A study of the regional radiometric, magnetic, and gravity anomalies of northeastern Alberta was recently completed by Sprenke et al. (1986).

General geology

The Alberta Shield, which consists of massive to foliated granitoids, gneisses, and metasedimentary rocks, forms part of the Churchill Structural Province of the Canadian Shield, and is situated in the Athabasca Mobile Belt (Burwash and Culbert, 1976). The main rock units are outlined in figure 1. A central gneiss belt, containing numerous amphibolite pods, is flanked on the west by plutons of the Slave and Arch Lake Granitoids, and on the east by the smaller and more heterogeneous Colin Lake and Wylie Lake Granitoids.

The geological history involved sedimentation, deformation, and metamorphism: processes which have operated during different orogenic periods, resulting in the formation of complex polymetamorphic rocks. Bulk compositions and field contact relationships, that is, apophyses and inclusions of gneiss within the granitoids and vice versa, suggest that the migmatitic granitic gneisses and high-grade metasedimentary rocks were possible parent materials for several of the granitoid rocks (for example, see Klewchuk, 1972). Thus, the granitoid rocks appear to represent Archean basement remobilized during the Aphebian (see also Davidson, 1972). Lewry and Sibbald (1980) discussed the thermotectonic evolution in adjacent parts of Saskatchewan.

Geochronological studies of rocks from the Charles Lake, Andrew Lake, and Colin Lake districts (Baadsgaard and Godfrey, 1967 and 1972) have identified two distinct orogenic events in northeastern Alberta. Rb-Sr whole rock isochron on pegmatites within granitoids, gneisses, and metasedimentary rocks in the Charles Lake area gives an age of 2470 $\pm$26 Ma (Nielsen et al. 1981).* Thus, they are considered part of an Archean basement gneiss complex. The low initial $^{87}Sr/^{86}Sr$ ratio (0.7030) of the pegmatites suggests a granitoid source derived from the lower crust. Rb and Sr isotopic determinations on Colin Lake Granitoids plot on a well-defined isochron giving an age of 1853 $\pm$6 Ma. A high initial $^{87}Sr/^{86}Sr$ ratio of 0.7083 $\pm$0.0002 indicates derivation of these rocks by anatexis of sedimentary rocks (Baadsgaard and Godfrey, 1972, p. 870). The immediate parent materials for the Colin Lake Granitoids are probably the nearby Archean granite gneisses and high-grade metasedimentary rocks.

The Slave Granitoids have been dated at 1938 $\pm$29 Ma (Nielsen et al., 1981). Most other granitoids (Wylie Lake, Arch Lake, Thesis Lake, and minor Granitoids) also show Aphebian Rb-Sr ages (Baadsgaard, pers. comm.).

K-Ar determinations on muscovite, biotite, and hornblende indicate a narrow distribution of ages. The average age of mica from many rock units is 1790 $\pm$40 Ma, which indicates that the K-Ar dates for all rocks within the region were effectively reset as a consequence of the Hudsonian orogeny. Thus, the existence of both an Archean and an Aphebian orogenic cycle is firmly established for the Shield rocks of northeastern Alberta.

Two distinct cycles of metamorphism (Langenberg and Nielsen, 1982) also represent these orogenic cycles. The Archean cycle resulted in high-pressure granulite facies conditions ($P = 7.5 \pm 2.0$ Kb, $T = 900 \pm 100$°C). The Aphebian cycle produced a cooling sequence which can be traced through three stages, from moderate-pressure granulite facies ($P = 5.0 \pm 0.7$ Kb, $T = 740 \pm 30$°C), to low-pressure amphibolite facies ($P = 3.0 \pm 0.3$ Kb, $T = 555 \pm 55$°C), and greenschist facies ($P \cong 2$ Kb, $T = 260 \pm 35$°C) conditions.

Low-grade metasedimentary rocks and metavolcanics in the Waugh Lake area (southeast of Andrew Lake), show primary sedimentary and igneous structures, respectively. An unconformity is assumed between the low-grade metasedimentary rocks and the Archean granite gneisses and high-grade metasedimentary rocks, based on a narrow contact zone (now a shear zone) between the two groups. The age relationship between the low-grade metasedimentary rocks and the nearby Colin Lake Granitoids is uncertain. Peikert (1961, 1963) postulated that the Colin Lake Granitoids formed by anatexis of the low-grade metasedimentary rocks. This explanation, however, is ruled out, because temperatures in the greenschist facies were too low for even partial melting to occur. Therefore, a mixture of high-grade metasedimentary rocks and granite gneisses are the likely parent materials for the Colin Lake and other nearby granitoids. Based on a sharp contact zone, an unconformity is also postulated between the low-grade metasedimentary rocks and the Colin Lake Granitoids. The Hudsonian K-Ar date of 1760 Ma for biotite from the low-grade prograde greenschist facies metasedimentary rocks (Baadsgaard and Godfrey, 1972) corresponds to a date for the regional retrograde greenschist facies of the area.

Major faults affect most of the rock units and are younger than the macroscopic fold structures in the granitoids and gneisses. These faults are expressed as shear zones characterized by mylonites (Watanabe,

*All Rb-Sr isotopic ages have been recalculated using a decay constant: $^{87}Rb2 = 1.42 \times 10^{-11}$ yr^{-1}.

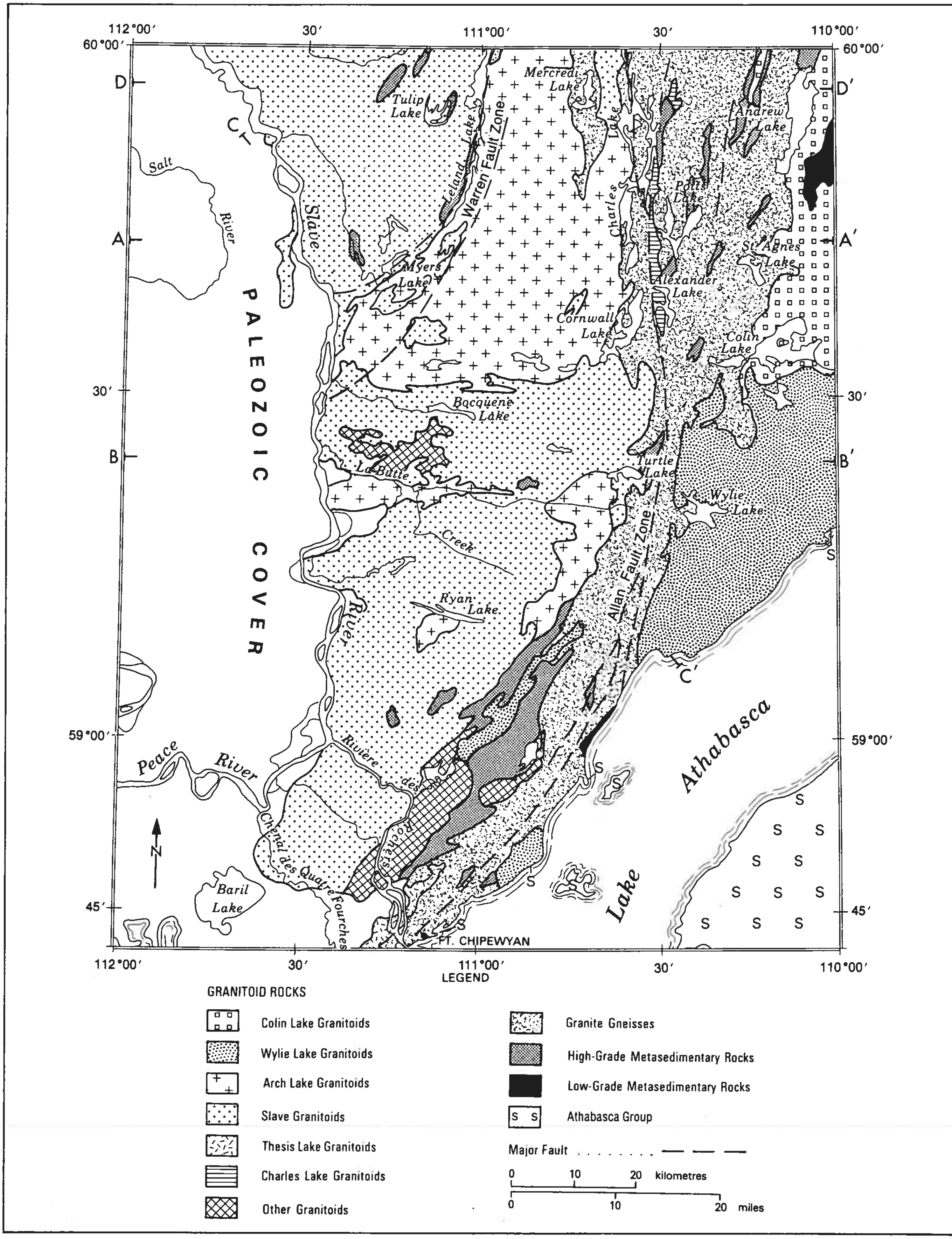

Figure 1. Location of the Alberta Shield north of Lake Athabasca (from Langenberg and Nielsen, 1982).

1965). Retrograde greenschist facies minerals in the mylonitic zones suggest a late Aphebian age for this large-scale faulting. Breccias along some transverse faults may indicate still younger fault movements at higher crustal levels.

Continental conditions prevailed during deposition of the clastic sediments of the Helikian Athabasca Group, which lies unconformably on the older crystalline basement rocks.

Glacial scouring during the Pleistocene has left a high proportion of fresh outcrops, which greatly facilitate geologic studies in the area.

Mineralogical and chemical classification of gneisses and granitoids

General methods

The chemical and modal classifications were calculated for the five major lithological groupings (Granite Gneiss; Slave, Arch Lake, Wylie Lake, and Colin Lake Granitoids). Each mappable subdivision (rock unit) was given a three digit code (Godfrey, 1980a and 1980b) (table 1). The mean modal composition for each unit was calculated (table 2) along with a plutonic rock classification. The classification used is that of Streckeisen (1976), except that granites with a plagioclase/alkali feldspar ratio higher than 0.35 are classed as quartz monzonites. Modal QKP plots of all granitoid lithologies, except those from the Colin Lake Granitoids, are given in Godfrey (1980a, 1980b and 1984).

Mean major and trace element compositions for each unit (tables 3 and 4) were compared by a cluster analysis, based on the weighted mean of the product-moment correlation coefficients. A moderate cophenetic coefficient of 0.72 was obtained; therefore, only first to third order clusters were considered significant.

Table 1. Digital identification codes used for each rock unit within the Alberta Shield

A. North of Lake Athabasca

010 Granite Gneisses
- 11 Biotite Granite Gneiss
- 12 Hornblende Granite Gneiss
- 13 Pegmatite

020 Amphibolite

030 Metasedimentary Rocks (high-grade)
- 31 Quartzite
- 32 Biotite Schist

100 Slave Granitoids
- 101 Slave Granite
- 102 Mafic Slave Granite
- 103 Red Slave Granite
- 104 Speckled Slave Granite
- 105 Slave PQ Granite
- 106 Slave Raisin Granite
- 107 Pegmatite

110 Thesis Lake Granite

120 Colin Lake Granitoids
- 121 Granite A
- 122 Granite B
- 123 Quartz Diorite C
- 124 Granodiorite D
- 125 Colin Lake Massive Granite
- 126 Colin Lake Leucocratic Granite
- 127 Sheared Leucocratic Granite
- 128 Pegmatite-aplite

130 Wylie Lake Granitoids
- 131 Wylie Lake Granodiorite
- 132 Granite E
- 133 Fishing Creek Quartz Diorite
- 134 Wylie Lake PQ Granite
- 135 Wylie Lake Leucocratic Granite
- 136 Undifferentiated (131 and 133)
- 137 Granodiorite D
- 138 Pegmatite

140 La Butte Granodiorite

150 Chipewyan Red Granite

160 Arch Lake Granitoids
- 161 Arch Lake Granite
- 162 Arch Lake Transitional Granite
- 164 Francis Granite

170 Charles Lake Granitoids
- 171 Granite F
- 172 Charles Lake PQ Granite
- 173 Gray Hornblende Granite
- 174 Leucocratic Granite
- 175 Foliated Hornblende Granite

200 Metasedimentary Rocks (low-grade) Waugh Lake and Burntwood Groups
- 201 Quartzite, arkose
- 202 Biotite Schist, phyllite, slate, argillite
- 203 Phyllonite

210 Metavolcanic Rocks

220 Recrystallized Mylonitic Rocks
- 221 Granite Gneiss parent
- 222 Metasedimentary Rock parent
- 223 Granitoid parent
- 224 Gray Hornblende Granite parent

230 Basic Dykes

240 Athabasca Group

B. South of Lake Athabasca (Marguerite River)

300 Recrystallized Mylonitic Rocks
- 301 Mafic
- 302 Felsic

310 Granitoid Group - Marguerite River
- 311 Fishing Creek type
- 312 Slave type
- 313 Biotite Granite/PQ/type
- 314 Wylie Lake type
- 315 Arch Lake type
- 320 Amphibolite

Table 2. Mean petrographic modal compositions for each rock unit

	Rock Unit	Q	Kf	Pl	Bi	Ch	Hb	Ep	Mu	Sp	Gn	Px	Crd	And	Sil	Acc	Modal Classification Mean	Modal Classification Range
Granite Gneisses	11	26.9	24.1	37.4	6.7	1.0	1.0	1.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.1	QM	GN-QD
	12	19.9	13.1	42.2	8.9	2.3	9.7	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.5	GD	QM-QD
Amphibolite	20	2.6	3.6	29.6	8.4	3.5	46.8	1.2	0.9	0.0	0.8	0.6	0.0	0.0	0.0	1.9	-	-
Metasedimentary Rocks	30	37.3	8.8	23.5	11.8	2.2	2.3	0.4	7.5	0.1	2.0	0.5	1.8	0.1	0.4	1.3		
Slave Granitoids	101	29.1	42.0	22.4	1.8	0.6	0.1	0.1	1.7	0.2	1.1	0.0	0.3	0.0	0.3	0.3	GN/QM	AG-QD
	102	28.6	31.2	29.4	5.5	0.8	2.3	0.4	0.2	0.0	0.5	0.1	0.0	0.0	0.0	1.0	QM	GN-QM
	103	27.5	40.6	27.2	1.2	1.1	0.3	0.3	0.4	0.1	0.3	0.0	0.1	0.0	0.1	0.8	QM	GN, GD
	104	29.2	40.2	18.1	5.5	2.0	0.0	0.1	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.8	QM	AG, GD
	105	21.3	36.9	28.4	8.2	1.3	0.3	0.5	1.6	0.0	0.0	0.0	0.0	0.0	0.0	1.4	QM	AG-GD
	106	26.4	23.1	41.7	1.0	3.0	0.0	2.5	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.3	QM/GD	QM-QD
Thesis Lake Granite	110	23.6	20.2	28.8	17.5	1.5	4.2	1.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	2.0	QM	QM-GD
Colin Lake Granitoids	121	27.1	22.5	33.2	14.7	0.1	1.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	QM	QM-GD
	122	20.7	32.1	32.5	9.4	1.5	0.8	2.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.6	QM	QM
	123	24.2	4.0	38.9	23.8	0.3	6.1	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	GD/QD	GD-QD
	124	26.1	13.8	42.2	14.0	1.3	0.4	0.5	0.5	0.0	0.2	0.0	0.0	0.0	0.0	0.9	GD	QM-QD
	125	27.6	32.2	33.8	2.7	0.7	0.4	0.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	QM	GN-GD
	126	32.8	34.2	29.1	0.4	1.1	0.0	0.0	2.1	0.0	0.2	0.0	0.0	0.0	0.0	0.2	QM	AG-GD
	127	29.8	28.8	37.2	2.8	0.3	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	QM	QM
	128	26.4	40.7	29.9	0.2	0.5	0.1	0.1	1.7	0.0	0.2	0.0	0.0	0.0	0.0	0.2	QM	AG-QD
Wylie Lake Granitoids	131	22.9	5.9	50.8	17.2	0.7	0.3	0.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	GD/QD	GN-QD
	132	25.6	17.3	42.0	11.8	1.4	0.7	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4	GD	QM-GD
	133	24.4	11.0	48.9	13.2	0.4	0.6	0.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.2	GD	GN-QD
	134	23.0	26.3	35.2	5.6	2.5	0.1	3.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0	2.1	QM	QM
	135	26.3	32.8	39.0	0.4	0.6	0.0	0.0	0.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	QM	QM, QD
	137	25.4	14.0	44.4	12.5	1.3	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	GD	QM-QD
La Butte Granodiorite	140	25.1	14.3	53.3	3.5	1.3	1.1	0.3	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.9	GD	QM-QD
Chipewyan Red Granite	150	28.1	37.4	30.6	2.2	0.6	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.8	QM	AG, QM
Arch Lake Granitoids	161	27.1	36.3	29.4	4.1	1.0	0.0	0.2	1.1	0.0	0.4	0.0	0.0	0.0	0.0	0.3	QM	GN-QD
	162	26.5	37.1	30.8	2.9	1.0	0.0	0.2	0.7	0.0	0.4	0.0	0.0	0.0	0.0	0.4	QM	GN-GD
	164	29.2	25.4	29.4	14.3	0.2	0.0	0.1	0.4	0.0	0.7	0.0	0.0	0.0	0.0	0.6	QM	GN-GD
Foliated Hornblende Granite	175	32.2	40.9	11.1	4.4	0.0	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	GN	GN
Recrystallized Mylonitic Units	221	27.2	20.4	38.1	3.5	3.6	0.0	2.7	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.9	QM/GD	AG-QD
	222	31.2	14.0	32.7	10.3	2.0	0.0	0.3	7.4	0.0	0.0	0.0	0.0	0.0	0.0	2.1	GD	QM-GD
	223	26.8	8.9	46.9	10.8	3.4	0.0	0.6	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	GD	GD-QD
	224	19.5	14.5	55.1	1.9	3.1	0.3	4.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	GD	GD
Basic Dykes	230	1.3	0.7	43.3	0.0	16.0	29.2	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	-	-

Q = quartz, Kf = feldspar, Pl = Plagioclase, Bi = biotite, Ch = chlorite, Hb = hornblende, Ep = epidote, Mu = muscovite (mainly sericite alteration), Sp = spinel, Gn = garnet, Px = orthopyroxene and clinopyroxene, Crd = cordierite, And = andalusite, Sil = sillimanite, Acc = accesory magnetite, ilmenite, zircon, and apatite. Classification scheme is that of Streckeisen (1976), except that granite, which has plagioclase/K-feldspar >0.35, is quartz monzonite. AG = alkali granite, GN = granite, QD = quartz diorite, QM = quartz monzonite, GD = granodiorite. Within the range values, a dash refers to a continuous distribution, a comma refers to discrete distributions.

Mean CIPW normative compositions were calculated for all units (table 5). In order to classify the possible magmatic types involved, a cation norm was also calculated for each mean and a name was applied, according to the classification scheme of Irvine and Baragar (1971), to represent the extrusive equivalent of that rock unit. Using the normative feldspar classification of Barker (1979), all granitoid rock units were classified as granite, with the exception of the La Butte pluton (140), which is a granodiorite. No high Na/K trondhjemitic compositions were observed.

An attempt was made to use classification schemes recently developed for Phanerozoic granites of the circum-Pacific region, because of their potential

Table 3. Mean major element compositions (in weight %) for each rock unit. N = number of samples.

	Rock Unit	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	L.O.I.	H_2O-	Total	N
Granite	11	68.97	0.45	14.54	3.35	1.13	2.30	3.68	4.10	0.06	0.13	0.68	0.05	99.44	61
Gneisses	12	63.52	0.76	15.10	5.79	2.36	4.30	3.33	2.97	0.15	0.31	0.90	0.03	99.52	10
Amphibolite	20	50.35	1.39	14.77	11.52	6.86	8.78	2.25	1.91	0.21	0.26	1.39	005	99.74	38
Metasedimentary Rocks	30	66.63	0.68	15.20	5.77	2.39	2.02	2.01	3.35	0.09	0.11	1.45	0.09	99.78	68
	101	72.99	0.18	14.77	1.21	0.34	0.87	3.36	5.22	0.03	0.11	0.44	0.09	99.60	142
Slave	102	69.81	0.68	13.84	3.87	0.80	1.45	2.99	5.35	0.07	0.11	0.54	0.09	99.59	13
Granitoids	103	72.80	0.16	14.35	1.26	0.38	0.95	3.47	5.27	0.02	0.12	0.50	0.08	99.35	10
	104	72.64	0.23	13.67	1.76	0.51	0.40	2.41	7.13	0.02	0.18	0.49	0.00	99.47	2
	105	66.95	0.56	16.23	3.11	1.12	1.49	2.98	6.08	0.04	0.15	0.83	0.13	99.68	6
	106	68.86	0.47	14.81	3.15	1.09	1.88	2.89	4.89	0.03	0.10	1.33	0.01	99.49	5
Thesis Lake Granite	110	63.19	0.57	14.17	5.52	3.68	3.57	3.06	4.04	0.12	0.17	0.86	0.12	99.09	6
	121	68.51	0.40	14.76	3.50	1.81	2.30	3.30	3.88	0.08	0.17	0.69	0.00	99.41	6
Colin Lake	122	68.18	0.38	14.47	3.39	1.82	2.04	3.26	4.66	0.06	0.12	0.78	0.00	99.15	7
Granitoids	123	61.63	0.72	15.27	6.42	3.73	3.99	2.51	3.07	0.10	0.21	1.00	0.00	98.66	6
	124	67.45	0.52	15.09	4.05	2.00	2.65	2.95	3.55	0.06	0.16	0.94	0.00	99.43	12
	125	70.78	0.24	14.76	2.34	0.85	1.57	3.52	4.73	0.05	0.08	0.53	0.00	99.45	9
	126	74.49	0.07	14.07	0.90	0.44	0.73	3.48	4.96	0.04	0.03	0.44	0.00	99.65	9
	127	75.60	0.07	13.39	1.31	0.32	0.69	3.97	4.12	0.02	0.03	0.23	0.00	99.78	2
	128	74.02	0.03	14.23	0.70	0.30	0.62	3.91	5.89	0.06	0.24	0.28	0.00	100.29	8
	131	64.61	0.56	15.39	4.90	2.64	2.52	3.23	3.80	0.09	0.21	1.61	0.20	99.78	6
Wylie Lake	132	64.08	0.70	15.17	5.94	2.41	2.73	2.93	3.93	0.10	0.31	1.12	0.09	99.50	7
Granitoids	133	66.55	0.44	15.68	3.80	2.06	2.54	3.28	3.87	0.05	0.18	1.06	0.17	99.69	20
	134	66.17	0.80	15.18	4.27	1.39	2.28	3.53	4.59	0.08	0.25	0.80	0.00	99.33	6
	135	74.78	0.29	12.41	1.38	0.26	0.47	4.14	5.44	0.02	0.09	0.62	0.11	99.99	5
	137	64.21	0.51	15.97	4.29	2.14	2.32	2.94	5.42	0.07	0.14	1.42	0.27	99.70	5
La Butte Granodiorite	140	67.76	0.39	15.32	2.78	0.99	2.82	4.19	3.15	0.06	0.29	0.37	0.09	99.22	13
Chipewyan Red Granite	150	73.54	0.23	13.46	1.17	0.42	0.93	3.34	5.24	0.05	0.09	0.52	0.13	99.04	10
Arch Lake	161	71.91	0.37	14.50	1.90	0.63	1.06	3.02	5.41	0.02	0.13	0.60	0.07	99.63	71
Granitoids	162	72.81	0.26	14.39	1.64	0.50	1.01	3.32	5.06	0.02	0.12	0.47	0.09	99.68	21
	164	67.07	0.88	14.49	4.64	1.45	2.22	2.15	5.12	0.07	0.37	0.43	0.01	98.90	6
Foliated Hornblende Granite	175	70.96	0.34	12.69	5.12	0.35	1.89	2.87	4.65	0.07	0.05	0.22	0.00	99.24	2
Recrystallized	221	69.40	0.50	14.25	3.40	1.50	1.80	3.85	3.54	0.06	0.11	1.17	0.06	99.64	24
Mylonitic Units	222	69.59	0.46	13.76	3.55	2.46	1.61	2.06	4.43	0.05	0.17	1.18	0.01	99.33	8
	223	65.86	0.57	15.50	4.35	2.36	3.00	3.33	3.14	0.08	0.16	1.16	0.01	99.52	9
	224	67.28	0.20	17.08	2.15	1.14	3.22	4.94	2.91	0.08	0.09	0.71	0.00	99.80	3
Basic Dykes	230	53.22	1.62	14.40	9.67	5.66	6.86	2.16	1.49	0.12	0.62	4.43	0.00	100.25	1
	301	65.23	0.75	16.19	4.09	1.47	2.84	3.68	4.24	0.06	0.32	0.82	0.19	99.88	4
	302	72.57	0.18	15.78	0.84	0.31	0.73	4.36	5.99	0.02	0.09	0.44	0.17	100.00	2
Marguerite	310	72.20	0.20	14.08	1.82	0.61	1.18	4.11	5.40	0.02	0.06	0.36	0.15	100.19	1
River Inlier	311	68.50	0.46	16.61	2.51	1.31	2.59	3.39	4.05	0.04	0.13	0.62	0.09	100.30	4
	312	73.81	0.09	14.10	1.10	0.28	0.63	3.34	5.91	0.02	0.09	0.46	0.10	99.94	5
	313	73.72	0.03	14.93	0.21	0.07	0.28	5.51	4.58	0.01	0.09	0.28	0.12	99.83	1
	314	60.27	1.94	14.74	7.76	1.58	3.50	3.02	4.87	0.07	0.86	1.13	0.19	99.93	1
	315	69.42	0.41	14.47	3.51	1.31	2.14	3.41	4.18	0.06	0.18	0.85	0.12	100.08	2
	320	51.73	0.70	14.51	11.90	8.29	10.21	1.98	0.83	0.25	0.09	0.43	0.07	100.99	1

economic importance. White and Chappell (1977 and 1983) divided the granitoid rocks of east Australia into S-types and I-types, that is, those formed by partial melting of sedimentary and igneous rocks, respectively. The S-type granites have a high K/Na ratio, a C/(A + C + F) ratio of less than 0.3 (see figure 2), and a modal $Al_2O_3/(CaO + K_2O + Na_2O)$ ratio greater than 1.05. Normative corundum is usually greater than one

Table 4. Mean trace element compositions (in ppm) for each rock unit. N = number of samples, ND = element not detected.

	Rock Unit	Ba	Nb	Zr	Y	Sr	Rb	Zn	N
Granite Gneisses	11	1344	23	283	25	355	136	50	61
	12	1659	24	342	43	576	90	89	9
Amphibolite	20	643	19	124	29	334	83	111	36
Metasedimentary Rocks	30	802	25	241	29	192	155	80	69
Slave Granitoids	101	633	19	97	15	193	224	32	142
	102	1239	36	449	42	204	156	66	13
	103	1008	16	124	16	238	177	27	10
	104	820	7	195	12	138	156	16	2
	105	1658	19	350	24	349	202	41	6
	106	1184	26	257	17	293	166	58	5
Thesis Lake Granite	110	1744	17	206	25	510	157	77	6
Colin Lake Granitoids	121	1228	16	148	23	424	196	74	6
	122	1473	15	148	16	474	166	66	4
	123	922	16	234	31	349	191	104	5
	124	975	19	196	25	323	170	68	11
	125	1192	13	203	25	334	197	48	8
	126	209	15	51	33	89	251	18	9
	127	914	13	70	14	355	266	20	1
	128	1027	25	11	9	195	294	27	8
Wylie Lake Granitoids	131	745	23	207	28	392	166	83	6
	132	952	23	255	36	339	183	86	7
	133	888	21	186	24	327	158	71	20
	134	2036	51	655	47	340	174	71	4
	135	414	21	120	16	109	171	14	5
	137	1402	20	221	28	321	175	85	5
La Butte Granodiorite	140	1952	21	203	13	777	84	58	13
Chipewyan Red Granite	150	1209	15	175	12	227	147	19	10
Arch Lake Granitoids	161	950	22	210	17	182	232	43	71
	162	901	18	151	11	228	206	36	21
	164	1887	32	367	35	337	221	73	6
Foliated Hornblende Granite	175	1079	55	686	63	63	100	95	2
Recrystallized Mylonitic Units	221	1190	27	272	31	278	126	53	23
	222	814	24	198	25	189	217	62	7
	223	1064	24	193	20	367	131	73	9
	224	2868	18	103	10	1165	51	41	3
Basic Dykes	230	2441	23	285	28	821	95	91	1
Marguerite River Inlier	301	1503	33	486	23	432	160	79	4
	302	541	30	65	13	193	162	34	2
	310	1697	23	123	15	354	129	6	1
	311	684	27	226	21	235	181	73	4
	312	478	23	111	22	121	211	18	5
	313	64	18	5	8	23	253	ND	1
	314	2029	50	1190	27	418	193	128	1
	315	820	23	183	22	245	239	61	2
	320	161	7	38	19	151	36	105	1

percent. The I-type granites are correspondingly richer in Na and Ca, and poorer in Al. I-type and S-type granites have been associated with Mo-Cu mineralization and Sn-W mineralization, respectively (Pitcher, 1979). Ishihara (1977) found that Mo-Cu and Sn-W mineralization in Japan were associated, respectively, with ilmenite and ilmenite/magnetite accessory minerals. These oxides were used to define two granitoid suites which can be separated according to magnetic susceptibility (Ishihara, 1979). The magnetite granites (that is, those having modal magnetite and ilmenite), have a magnetic susceptibility greater than 50 $\times 10^{-6}$ emu g^{-1}, whereas the ilmenite granites fall below this value. Takahashi et al. (1980) found that all magnetite granites were a subset of the I-type, but that ilmenite granites included all S-types and part of the I-type population.

An attempt was made to classify the granitic rocks of the Alberta Shield according to the above criteria (figures 2, 3 and 4). In addition, the variation of total alkalies and CaO against SiO_2 was used to determine the relative alkalinity of each suite (figure 5). Magnetic susceptibility values for all granitoids range from 220 $\times 10^{-6}$ to 833 $\times 10^{-4}$ emu g^{-1}—values that are far above the threshold of Ishihara (1979) and would therefore classify all units as magnetite granites or I-type granites, based on this criterion alone. Additional statistical methods used to study the chemical effects of mylonitization apply only to the Granite Gneiss belt, and will be described in the following section. A detailed chemical classification for each mappable unit is outlined below.

Granite Gneiss belt

The Granite Gneiss terrain forms a north-south belt, up to 20 km wide, centrally located within the exposed Alberta Shield. Based on a Kenoran date from a Rb-Sr isochron for cross-cutting pegmatites, the Granite Gneiss and included metasedimentary bands are shown to be the oldest rock units present (Nielsen et al., 1981). The gneiss is typically banded and consists of alternating felsic and mafic layers. Incipient melting is indicated by locally developed migmatites.

The major lithology is a Biotite Granite Gneiss unit (011), having a modal composition of quartz monzonite with seven percent biotite and minor hornblende. Lensoid domains of a granodioritic gneiss, containing a similar biotite content but with greater than five percent hornblende (012), make up 12 percent of the outcrops of gneissic composition. A gradational boundary exists between the two units. Prominent bands of a porphyroblastic, recrystallized mylonitic unit (221) cut the gneiss subparallel to the trend of the foliation.

Langenberg and Nielsen (1982) stated that the Granite Gneisses were derived from sediments; however, the modal compositions are typically igneous and display a linear trend towards the plagioclase apex in a Streckeisen classification diagram (Godfrey, 1984; figure 4), which is typical of the trend for a moderately potassic, calc-alkaline granodioritic series (Lameyre and Bowden, 1982). This modal classification is sup-

Table 5. Mean CIPW norms for each rock unit.

	Rock Unit	Q	Cor	Or	Ab	An	Di	He	En	Fs	Mt	Ilm	Hm	Ap	D.I.
Granite Gneisses	11	25.9	0.2	24.6	31.6	10.7	-	-	2.9	0.1	2.9	0.9	-	0.3	82
	12	20.3	-	17.9	28.7	17.8	1.0	0.5	5.5	2.8	3.3	1.5	-	0.7	67
Amphibolite	20	0.5	-	11.6	19.5	25.2	9.3	5.2	13.2	8.4	3.8	2.7	-	0.6	32
Metasedimentary Rocks	30	33.6	5.0	20.3	17.4	9.5	-	-	6.1	3.3	3.2	1.3	-	0.3	71
	101*	31.7	2.3	31.2	28.7	3.6	-	-	0.9	-	-	0.1	1.2	0.3	92
Slave Granitoids	102	28.8	2.0	32.0	25.6	3.3	-	-	3.7	-	3.2	1.3	-	0.3	86
	103	30.6	1.5	31.5	29.7	3.9	-	-	1.0	-	-	-	1.3	0.3	92
	104	28.1	1.1	45.9	20.5	0.7	-	-	1.3	-	-	0.1	1.7	0.4	94
	105	22.2	2.4	36.5	25.6	6.5	-	-	2.8	-	1.5	1.1	1.0	0.4	84
	106	28.6	1.6	29.5	24.9	8.8	-	-	2.8	-	2.2	0.9	0.5	0.2	83
Thesis Lake Granite	110	16.9	-	24.4	26.5	13.3	2.2	0.7	8.3	3.0	3.1	1.1	-	0.4	68
	121	27.5	1.4	23.3	28.3	10.4	-	-	4.6	0.6	2.8	0.8	-	0.4	79
Colin Lake Granitoids	122	24.9	0.7	28.1	28.1	9.5	-	-	4.6	0.5	2.8	0.7	-	0.3	81
	123	20.4	1.1	18.7	21.9	18.9	-	-	9.6	4.2	3.3	1.4	-	0.5	61
	124	28.6	2.0	21.3	25.4	12.3	-	-	5.1	0.9	3.0	1.0	-	0.4	75
	125	28.1	1.2	28.3	30.1	7.4	-	-	2.1	-	1.2	0.5	0.9	0.2	87
	126	33.1	1.7	29.0	29.6	4.2	-	-	1.2	-	-	0.1	1.0	0.1	92
	127	35.0	1.2	24.5	33.8	3.2	-	-	0.8	-	-	0.1	1.3	0.1	93
	128	27.6	0.9	34.9	33.1	1.5	-	-	0.7	-	0.1	0.1	0.6	0.5	96
	131	22.0	1.9	23.0	27.9	11.4	-	-	6.7	2.3	3.1	1.1	-	0.5	73
	132	22.4	1.9	23.7	25.3	11.7	-	-	6.1	3.5	3.3	1.4	-	0.7	71
Wylie Lake Granitoids	133	24.7	1.9	23.3	28.3	11.6	-	-	5.2	0.9	2.9	0.8	-	0.4	76
	134	22.1	0.9	27.6	30.4	9.9	-	-	3.5	0.2	3.4	1.5	-	0.6	80
	135†	29.3	-	32.4	33.8	-	0.7	0.7	0.3	0.4	0.2	0.6	-	0.2	96
	137	18.4	1.4	32.8	25.5	10.8	-	-	5.4	1.4	3.0	1.0	-	0.3	77
La Butte Granodiorite	140	25.0	1.6	18.9	35.9	12.3	-	-	2.5	-	1.7	0.7	0.8	0.7	80
Chipewyan Red Granite	150*	32.2	0.8	31.5	28.7	4.1	-	-	1.1	-	-	0.1	1.2	0.2	92
	161*	31.1	2.1	32.3	25.8	4.5	-	-	1.6	-	-	0.1	1.9	0.3	89
Arch Lake Granitoids	162*	31.9	1.9	30.2	28.3	4.2	-	-	1.3	-	-	-	1.7	0.3	90
	164	29.4	2.3	30.8	18.5	8.7	-	-	3.7	0.5	3.5	1.7	-	0.9	79
Foliated Hornblende Granite	175	31.0	-	27.9	24.6	8.1	0.2	0.7	0.8	3.2	2.7	0.7	-	0.1	83
	221	28.2	1.1	21.3	33.2	8.4	-	-	3.8	-	2.9	1.0	0.1	0.3	83
Recrystallized Mylonitic Units	222	34.5	3.1	26.7	17.8	7.1	-	-	6.3	0.4	2.9	0.9	-	0.4	79
	223	24.9	1.6	18.9	28.7	14.1	-	-	6.0	1.3	3.1	1.1	-	0.4	73
	224	19.2	0.2	17.4	42.2	15.6	-	-	2.9	-	1.0	0.4	1.1	0.2	79
Basic Dykes	230	12.6	-	9.3	19.2	26.5	3.0	1.1	13.4	5.5	4.8	3.2	-	1.5	41
	301	20.4	1.1	25.4	31.6	12.2	-	-	3.7	0.1	3.3	1.4	-	0.7	77
	302*	22.3	1.0	35.1	36.6	3.0	-	-	0.8	-	-	0.1	0.8	0.2	94
Marguerite River Inlier	310‡	24.7	-	32.0	34.9	4.0	1.1	-	1.0	-	-	0.3	1.7	0.1	92
	311	26.3	2.3	24.1	28.8	12.1	-	-	3.3	-	0.4	0.9	1.7	0.3	79
	312‡	30.4	1.3	35.2	28.4	2.5	-	-	0.7	-	-	0.1	1.1	0.2	94
	313	23.8	0.6	27.2	46.9	0.8	-	-	0.2	-	-	-	0.2	0.2	98
	314	16.4	0.2	29.3	26.0	12.0	-	-	4.0	1.2	5.1	3.8	-	2.0	72
	315	27.6	0.9	25.0	29.0	9.6	-	-	3.3	0.5	2.8	0.8	-	0.4	82
	320	1.6	-	4.9	16.8	28.4	11.4	6.5	15.5	10.1	3.2	1.3	-	0.2	23

† includes 1.3% Ac, * includes 0.2% Ru, ‡ includes 0.1% Ru. D.I. = Thornton and Tuttle differentiation index. Normative minerals: Q = quartz, Cor = corundum, Or = orthoclase, Ab = albite, An = anorthite, Di = diopside, He = hedenbergite, En = enstatite, Fs = ferrosilite, Mt = magnetite, Ilm = ilmenite, Hm = hematite, Ap = apatite, Ac = acmite, Ru = rutile.

ported by the normative composition, which for unit 011 is that of a calc-alkaline dacite; the more basic unit (012), which is low in Si and alkalies, has the composition of a tholeiitic andesite. To test whether the gneiss is of igneous or sedimentary origin, a discriminate function was used, based on six major elements. This function was derived from a test set of several hundred analyses of igneous and sedimentary rocks (Shaw, 1972). The density distribution of the function, when applied to the Granite Gneisses, clearly indicated an igneous origin: only 1.4 percent of the data were classified as being from sedimentary rocks (figure 6). The accuracy of the function was tested by applying it to known high-grade metasedimentary rocks (figure 7), 84 percent of whose distribution was classified as sedimentary.

A mylonitic unit (221) shows a regional gradational contact with the Granite Gneisses (011 and 012), which are described as the main, but not necessarily exclusive, parent rock types to unit 221 (Godfrey, 1980a). Mineralogically, the mylonitic gneisses differ by having a significantly higher content of muscovite, chloritized

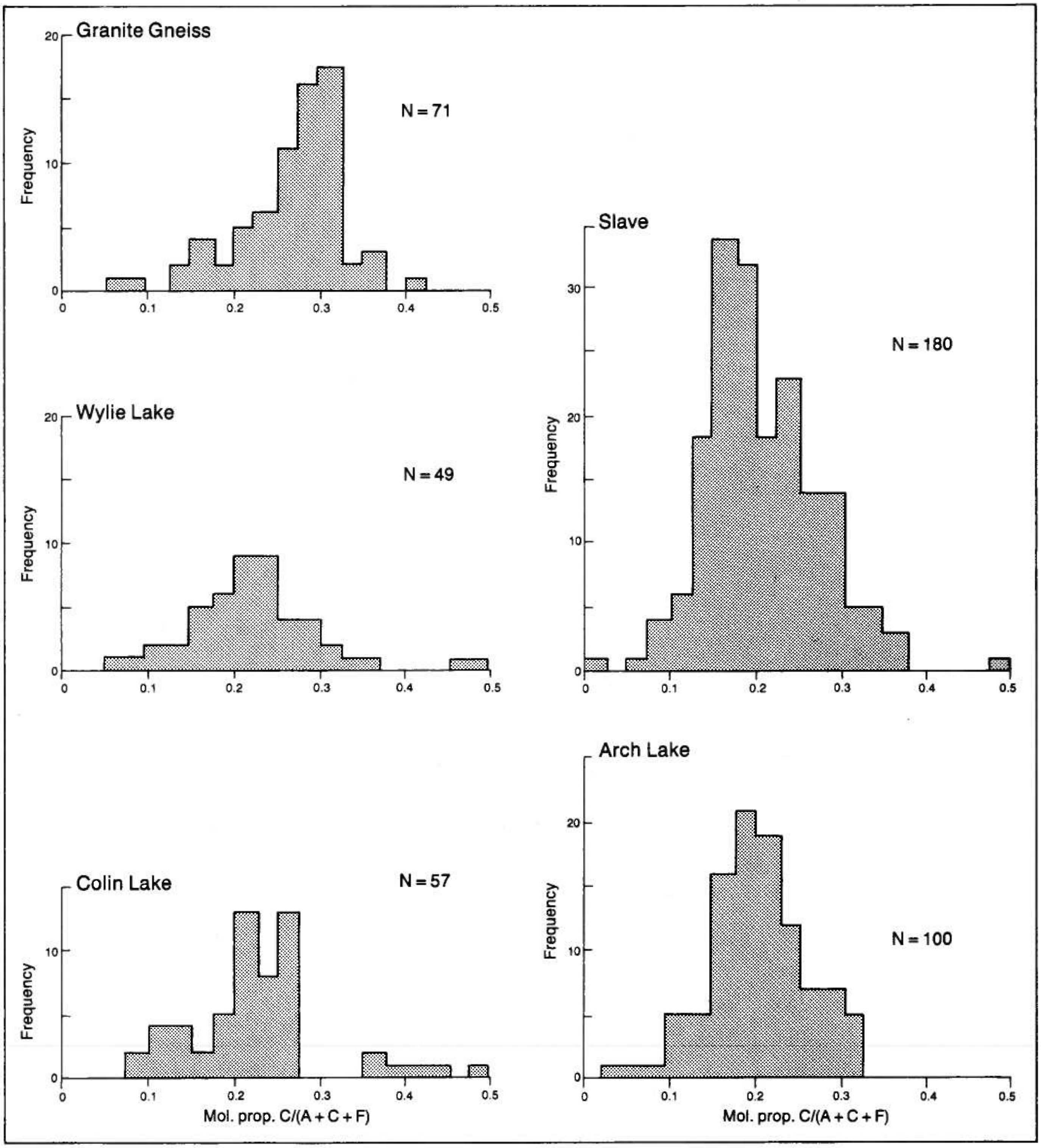

Figure 2. Frequency distribution of molar $CaO/(Al_2O_3 - Na_2O - K_2O + CaO + FeO\ total + MgO)$ for each major lithological group.

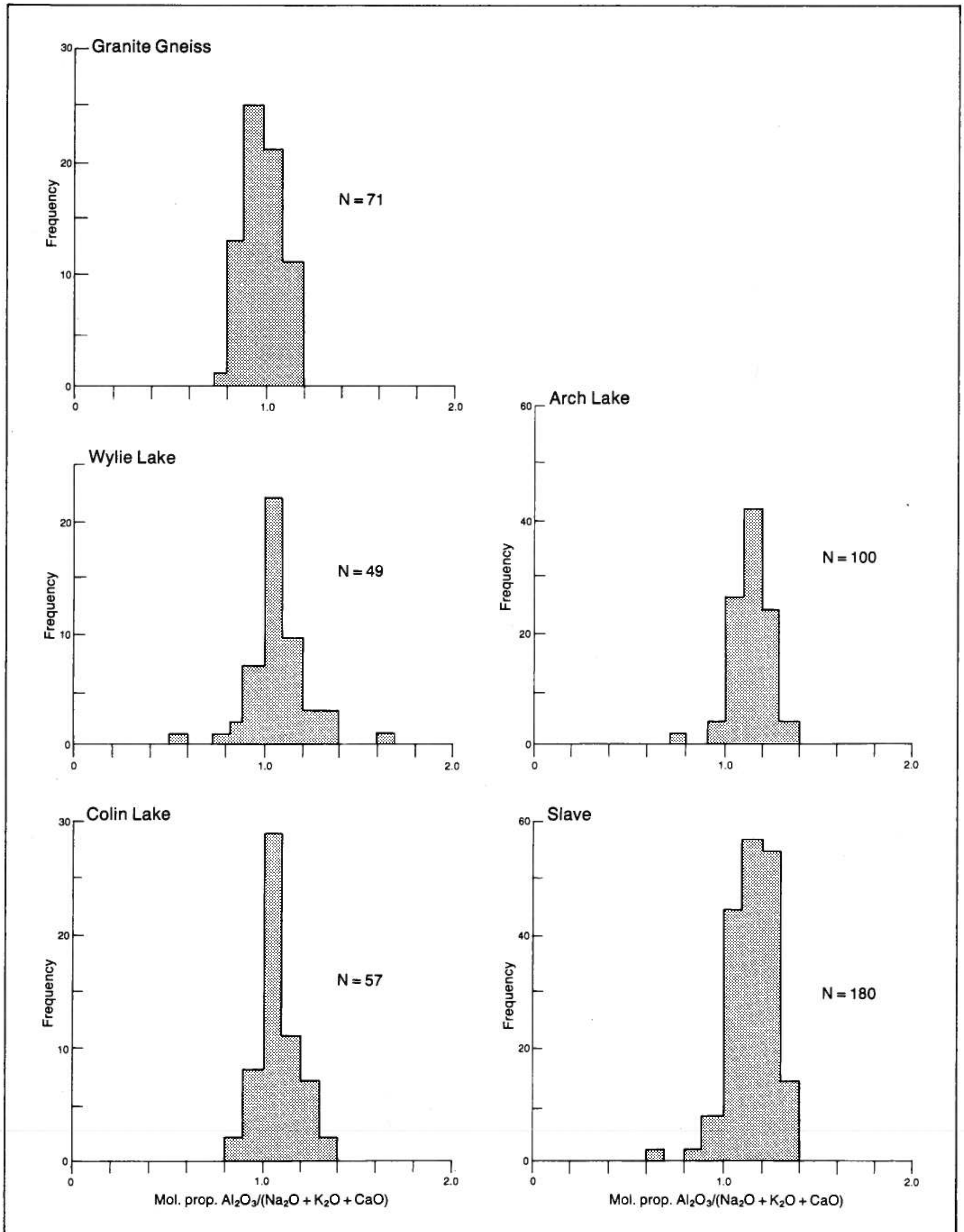

Figure 3. Frequency distribution of molar $Al_2O_3/(Na_2O + K_2O + CaO)$ for each major lithological group.

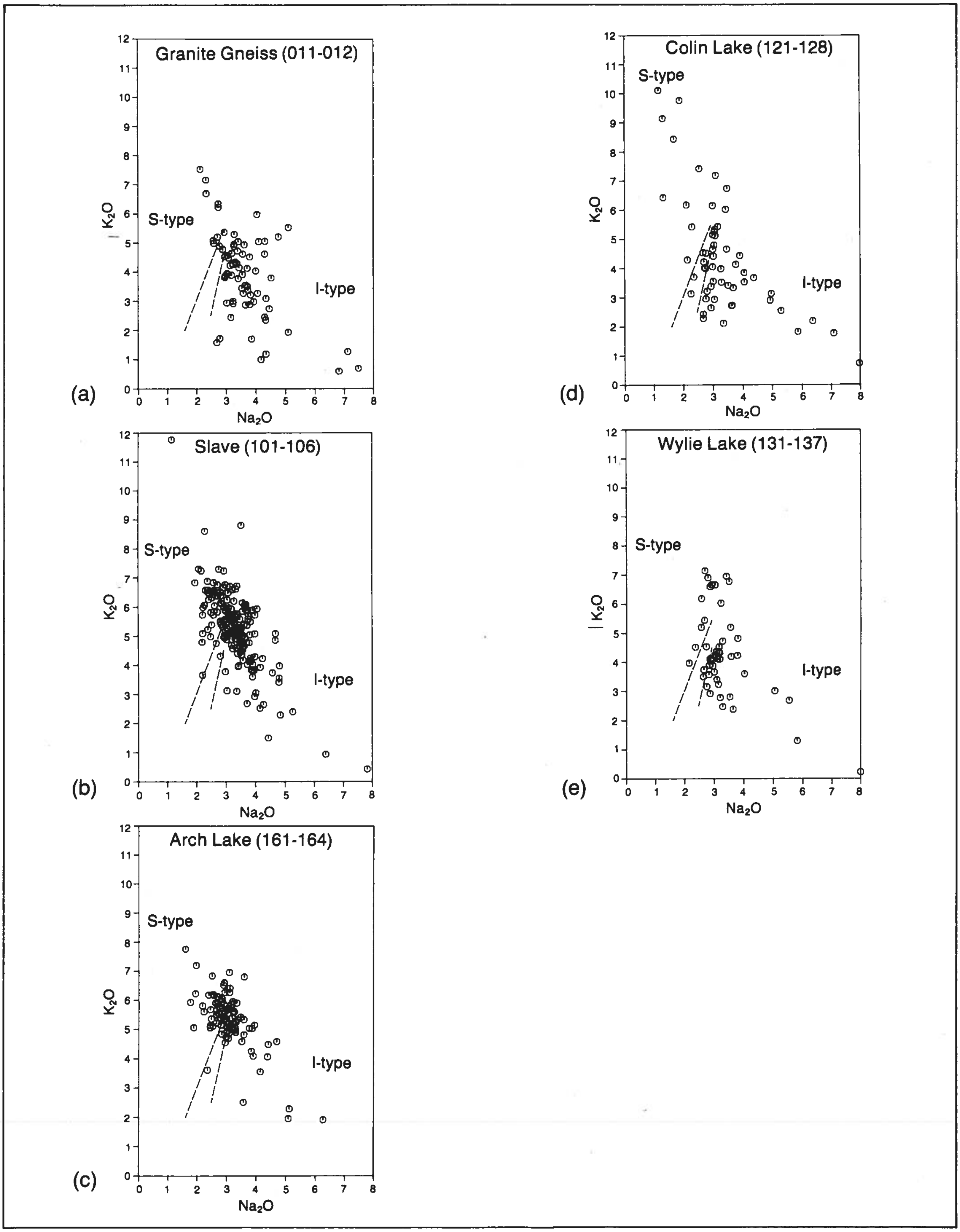

Figure 4. Na_2O vs. K_2O for each major lithological group. Fields for I-type and S-type granites are after White and Chappell (1983).

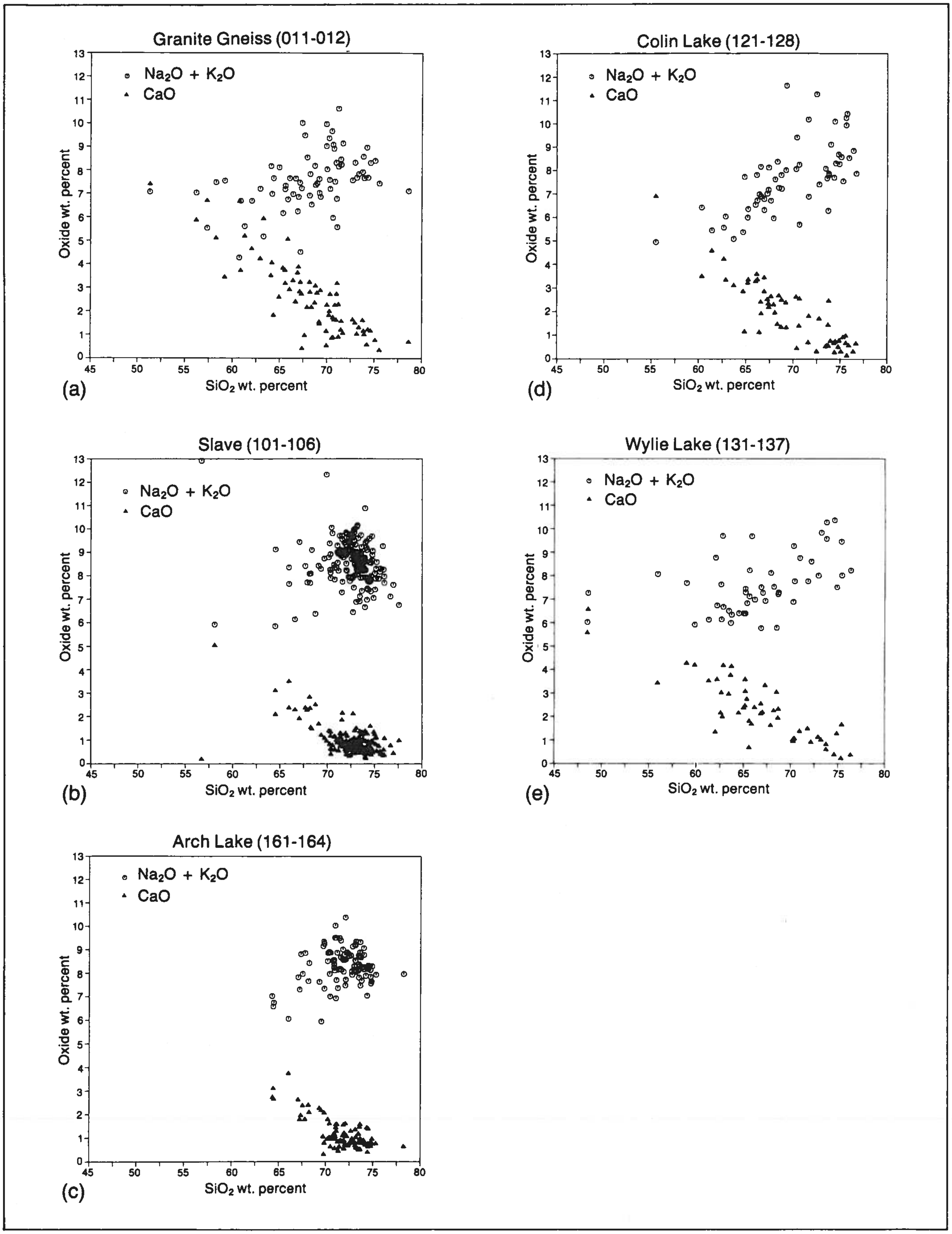

Figure 5. Na_2O + K_2O and CaO vs. SiO_2 for each major lithological group.

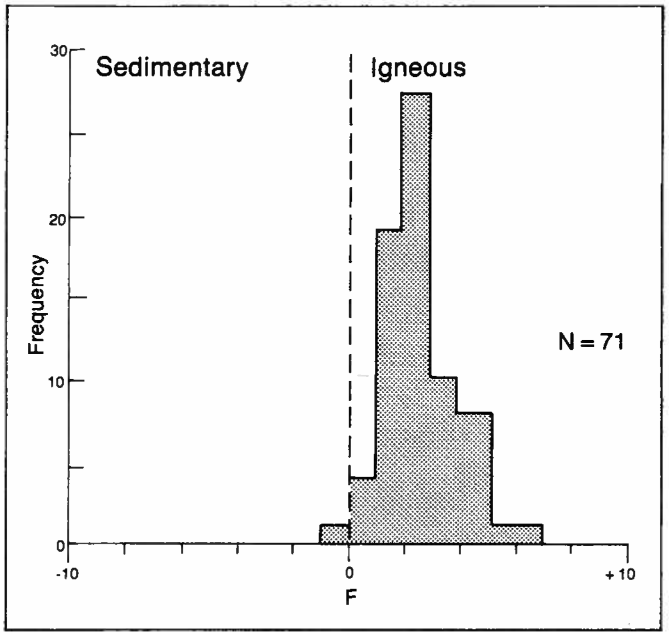

Figure 6. Frequency distribution of discriminant function for Granite Gneiss belt (011 and 012). Function = 10.44 − 0.21 SiO_2 − 0.32 Fe_2O total − 0.98 MgO + 0.55 CaO + 1.46 Na_2O + 0.54 K_2O (Shaw, 1972).

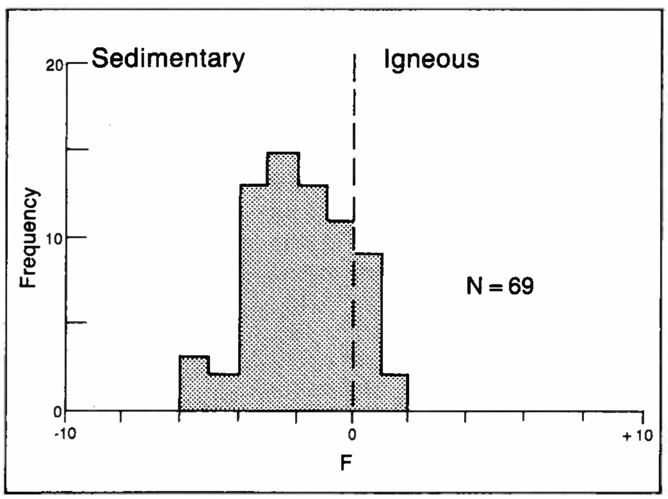

Figure 7. Frequency distribution of discriminant function for high-grade metasedimentary rocks (030). See figure 6 for details.

biotite, and epidote. The mean composition of unit 221 is that of a corundum-normative dacite (table 5) which forms a first order cluster-analysis pair with the mean composition of unit 011.

Additional statistical techniques were used to compare the compositions of the Granite Gneisses (011 and 012) and the mylonitic gneisses (221) as two distinct groups. Nonparametric Mann-Whitney U tests on all major and trace elements indicated that the two groups were from the same population. Only Ca and Sr were different at the 0.05 level of significance: these are generally the least stable elements in most types of alteration. Another attempt to distinguish the two groups of gneisses was made by using discriminate function analysis. This produced a function by which 65 percent of the mylonitic gneiss samples were misclassified, again illustrating that the two groups could not be distinguished with any reasonable degree of confidence. Mylonitic gneisses were excluded from further classification, to avoid the effect of Ca mobility on the results.

The Granite Gneiss yields a typically calc-alkaline value of 60 for the alkali-lime index (figure 5a). The modal value for the C/(A + C + F) ratio, which is slightly higher than 0.3 (figure 2), is similar to that observed in both magnetite and I-type granites (Takahashi et al., 1980). The Granite Gneiss has the highest magnetic susceptibility of any rock unit in the area, and the range in values (153 × 10^{-3} to 936 × 10^{-4} emu g^{-1}) is well within the magnetite granite field of Ishihara (1979). Although the mean chemical composition of the gneiss is slightly corundum normative (table 5), a plot of the peraluminous index (figure 3) indicates that 55 percent of the distribution is metaluminous (that is, has a peraluminous index of less than one). Compared to Phanerozoic plutons (Takahashi et al., 1980), the Granite Gneiss shows a high but acceptable range in peraluminous index for I-type granites: 75 percent of the distribution falls below the threshold value of 1.05. Finally, a plot of Na_2O versus K_2O (figure 4a) was used to distinguish I-type from S-type granites (White and Chappell, 1983). The Granite Gneiss clearly plots in the I-type granite field. A few of the Biotite Granite Gneiss samples display high K_2O and fall into the S-type field, but this is caused by subsequent alkali metasomatism (see below).

In conclusion, the Granite Gneiss belt (011 and 012) is igneous in origin and is chemically equivalent to an I-type or magnetite-type granite. Part of this belt (unit 221) underwent late-stage mylonitic deformation which was largely isochemical.

Slave and Arch Lake Granitoids

The Slave Granitoids form two large plutons, west of the gneiss belt, which are separated from each other by the Arch Lake Granitoids, but probably join to form one body west of the Slave River. The Arch Lake Granitoids are mineralogically similar to the Slave Granitoids, but form a structurally distinct synformal body (Langenberg, 1983).

The Slave Granitoids display a relatively limited textural and compositional range. The dominant rock unit is a medium-grained, foliated granite to quartz monzonite (101), which forms 95 percent of the plutons, and contains two percent biotite and one percent garnet. Gradational contacts exist with a localized unit of quartz monzonite (102) that contains six percent biotite and two percent hornblende. This less-silicic unit, which forms 3.5 percent of the area of the plutons, is present as a series of elongated lenses along the east margin of the southern pluton. The remainder of the Slave Granitoid plutons comprise four quartz-monzonitic units (103 to 106) that show textural and mineralogical differences from the main phase: 104 and 105 have higher biotite and K-feldspar than the other units, 103 is mineralogically similar to 101, and 106 is a borderline granodiorite. Lenses of mafic-rich mineral concentrations occur within the Slave Granitoids and have been interpreted as metasedimentary rock relicts. These range in size from a few centimetres to mappable metasedimentary layers, 8 km long.

The Arch Lake Granitoids form a texturally distinct pluton flanked on the south and northwest by the Slave Granitoid plutons. The main rock unit (161) is a quartz-monzonite with four percent biotite and minor garnet. This unit forms 67 percent of the pluton, has a penetrative shear and contains up to 25 percent of microcline megacrysts. A subtype (162) of this unit, which makes up 25 percent of the pluton, has slightly less biotite and is distinguished by the absence of an augen texture. In outcrop this unit forms an arcuate zone parallel, and close to, the margin of the Arch Lake Granitoid plutons. Units 161 and 162 also occur as small plugs within the Slave Granitoid pluton. An additional unit, the Francis Granite (164), was grouped with the Arch Lake Granitoids. This unit of biotite-rich quartz monzonite forms a stock, 16 km long by 6 km wide, enclosed by Slave Granitoids.

The Slave Granitoid lithologies are all corundum normative and have the composition of calc-alkaline dacites, except for units 105 and 106, which have lower Si and higher Fe, Mg, and Ca. They have the normative compositions of a dacite and an andesite, respectively. The two main units of the Arch Lake Granitoids (161 and 162), classify as calc-alkaline rhyolites, whereas 163 and 164 display the higher Fe and Ca, and lower Si and Na of calc-alkaline dacites. Ba, Nb, Zr, Y, and Zn are also higher in the latter two units. Cluster analysis shows that the nonmegacrystic unit (162) has the closest similarity to the main lithology of the Slave Granitoids (101), whereas the minor, more mafic lithologies (104, 105, 106, and 164) form a separate cluster. The mean composition of the Slave Granitoids is higher in Si and Na, but poorer in all other elements, than that of the Arch Lake Granitoids.

The mineralogical and chemical similarity between the Slave and Arch Lake Granitoids suggests that they may be texturally distinct subsets of the same pluton. However, nonparametric statistical comparisons of each of the major and trace elements do not support this. Using Mann-Whitney U tests, mean concentrations for only K, Rb, and Mn could be considered similar at the 0.05 level, with the addition of Al, P, and Y at the 0.01 level.

Despite the two granitoid groups being compositionally distinct, standard chemical classification techniques give similar results for both the Slave and Arch Lake Granitoids. Both granitoid groups have higher alkalies and lower Ca than does the Granite Gneiss belt, and they have estimated alkali-lime indices of 55 to 60 (figure 5b and c)—typically calc-alkaline values. The lower Ca is indicated by a $C/(A+C+F)$ index of less than 0.3 (figure 2), which is a typical value for ilmenite or S-type granites (Takahashi et al., 1980). Both granitoid groups are notably peraluminous, with 84 percent of the Arch Lake and 87 percent of the Slave Granitoids samples having an S-type peraluminous index of greater than 1.05 (figure 3). The Na/K ratio fails to give either granitoid group an unequivocal I-type or S-type classification (figure 4b and c). All lithologies plot in both fields, except for 162, which plots in only the S-type field. Samples with extreme values of Na_2O and K_2O can be explained by subsolidus alkali migration during metamorphism. However, the bulk of data points for both granitoid groups straddles the I versus S classification boundary. Furthermore, the high magnetic susceptibility for these granitoids (220×10^{-6} to 394×10^{-4} emu g^{-1}) would place all of them well within the field of magnetite granites. Because magnetite granites are a subset of I-type granites, both granitoid groups should also classify as I-type granites. Clearly, this discrepancy in data interpretation indicates that the widely accepted classification schemes for the Phanerozoic plutons of the circum-Pacific belt are not applicable here.

The Slave and Arch Lake Granitoids are therefore calc-alkaline, peraluminous, biotite quartz monzonites to granites. They have a moderate K content and are notably lower in Ca and higher in Al than the belt of older gneisses.

Colin Lake Granitoids

The Colin Lake Granitoids form one of two major granitoid groups east of the Granite Gneiss belt (figure 1) and are approximately equivalent to the Colin Granite-Granodiorite of Koster (1971) in Saskatchewan. Within Alberta, this group can be divided into two regions, representing separate phases of instrusion. The first (minor) region is at the north end of the complex, at Andrew Lake. It consists of two elongated, differentiated plutons of foliated, porphyroblastic quartz monzonites that are enclosed within a metasedimentary rock envelope. A thick marginal unit of each pluton consists of foliated granodiorite to quartz monzonite (121), containing 15 percent biotite and 1 percent hornblende. It shows a gradational contact to a central core of quartz monzonite (122) having less than 10 percent biotite (122). These units are Biotite Granites A and B of Godfrey (1961) and will be combined and referred to below as the Andrew Lake Plutons. Both lithologies are cut by veins of microgranite and aplite.

The second (and larger) region of the Colin Lake Granitoids lies south of the low-grade metasedimentary rocks at Waugh Lake (figure 1), and is referred to as the Colin Lake Pluton. The main lithology, forming 62 percent of the main Colin Lake Pluton, is a fairly homogeneous, foliated to gneissic textured granodiorite with prominent microcline megacrysts (124: Biotite Granite D of Godfrey and Peikert, 1963). Two large areas on the north and west margins of the pluton, forming 12 percent of its total area, are composed of a porphyroblastic, foliated granodiorite to quartz diorite, rich in biotite (24 percent) and hornblende (6 percent). This unit (123: Biotite Microgranite and Biotite Granite C of Godfrey, 1963) shows a gradational contact with unit 124, towards which there is a decrease in mafic mineral content and an increase in the number and size of microcline megacrysts.

A minor group of leucocratic quartz monzonite stocks intrudes the porphyroblastic lithologies with a sharp contact, whereas smaller leucocratic bodies form concordant veins and pods. An elongated, heterogeneous, massive granite to granodiorite (125: Biotite Granite and Muscovite Granite of Godfrey, 1963), containing minor biotite or biotite and muscovite, constitutes 16 percent of the pluton and extends northward from the main body to Andrew Lake. The unit is locally hornblende-bearing and porphyroblastic. A leucocratic unit (126: Leucocratic Granite of Godfrey and Peikert, 1963), containing less than 2 percent biotite and chlorite, makes up 7 percent of the pluton. A sheared, foliated, sericite-bearing leucocratic unit (127), forming 3 percent of the total area, intrudes the northern edge of the pluton and grades into a porphyroblastic variant of unit 125. Finally, a minor pegmatite unit (128: Granite Pegmatite of Godfrey, 1963), with sparse biotite and muscovite, forms small lensoidal bodies which are found intruding all major rock units.

The means of the major and trace element analyses of each mappable unit form 3 distinct cells by cluster analysis. These cells represent the Andrew Lake Plutons, the Colin Lake Pluton, and the leucogranitic suite. All units are corundum normative (table 5). The Andrew Lake Plutons (units 121 and 122) yield a normative composition of calc-alkaline dacite. The augen-textured granodiorite of the Colin Lake Pluton (unit 124) yields a tholeiitic dacite composition with significantly higher Fe, Mg, Ti, and Ca, and lower alkalies (table 3). The Colin Lake Pluton shows an increase in Ca and mafic components, reaching a tholeiitic andesite composition within the sparsely megacrystic border phase (unit 123). The Colin Lake Pluton also contains higher Nb, Zr and Y, and lower Ba and Sr than the Andrew Lake Pluton. The leucocratic suite is notably higher in alkalies and Si than the host pluton, and yields mean normative compositions of calc-alkaline rhyolite. An exception is the dominant, hornblende-bearing, massive quartz monzonite phase (unit 125), which has a mean composition of calc-alkaline dacite.

The three major lithologic groups with the Colin Lake Granitoids (the Colin Lake Pluton, the Andrew Lake Plutons, and the leucocratic group) were considered as a single suite for further classification. The alkali-lime index yields a typical calc-alkaline value of 60-62 for all three major groups (figure 5d). This value is very similar to that obtained for the gneisses. The low, modal $C/(A + C + F)$ values of 0.2 to 0.25 (figure 2) are typical of S-type granites. The bimodal peak within this distribution is caused by the bimodal compositional variation within the Colin Lake Pluton. A cluster of values around 0.4 is caused by one peak of a bimodal compositional variation in the leucocratic suite. This reflects the wide variation in K-feldspar to plagioclase ratios within the leucocratic group (table 2), and probably represents a high percentage of solid contaminants from the varied parent materials in these minor partial melts. Each of the three groups are peraluminous, and all have modal values for the peraluminous index of 1.0 to 1.1, which straddle the boundary between S-type and I-type granites (Takahashi et al., 1980). Although over 85 percent of the samples of both the Andrew Lake Plutons and Colin Lake Pluton are peraluminous, 50 percent of the pegmatite samples (unit 128) have a peraluminous index of less than one. The Andrew Lake Plutons and the Colin Lake Pluton both indicate an I-type classification on the Na_2O versus K_2O diagram (figure 4d). The extreme Na-rich and K-rich samples which trend, respectively, into the I and S fields, are all from the leucocratic suite.

The classification is again equivocal. Both the Andrew Lake and Colin Lake Plutons have the moderately low Ca of S-type granites, but also exhibit the low Al, high Na/K and high magnetic susceptibility of I-type granites.

Wylie Lake Granitoids

The Wylie Lake Granitoids, which form a semi-circular pluton on the east side of the gneiss belt, are cut by sinistral wrench faults which are parallel with the main trend of the Granite Gneiss belt. The dominant lithology, forming an estimated 50 percent of the pluton, is the Fishing Creek Quartz Diorite (unit 133): a massive, equigranular unit ranging in composition from quartz diorite to granite. The commonest rock type, however, is a granodiorite containing 13 percent biotite and minor hornblende. The northern half of the pluton is dominated by a differentiated granodiorite/quartz diorite (unit 131), containing 17 percent biotite and a trace of hornblende. This unit, which forms 30 percent of the pluton, occurs as concentric, arcuate lenses up to 2 km wide, which are parallel with, and include, the margins of the pluton. Unit 131 interdigitates with wide bands of a less-mafic, differentiated granodiorite (unit 132), containing microcline megacrysts, 12 percent biotite, and one percent hornblende. The latter is a massive-to-foliated unit which forms 15 percent of the complex. A gradational contact exists between units 131 and 132. An increase in the size of the microcline megacrysts and the degree of foliation in unit 132 produces a separate mappable unit (137) which forms only five percent of the complex. Unit 137 has a similar range in modal composition and color index to unit 132. The three units (131, 132, and 137), situated towards the margin, are considered to represent a continuous lithological series (Godfrey, 1980a). The prominent foliation in these marginal rocks conforms with the regional synformal structure at Colin Lake (Langenberg, 1983).

A change in style of deformation, from an east-west to a north-south foliation, was chosen as the criterion for distinguishing between the Colin Lake and the Wylie Lake Granitoids. The northern margin of the Wylie Lake Granitoids was taken as the boundary between the foliated-to-massive granodiorite (unit 132) to the south, and the main body of Colin Lake augen-textured granodiorite (unit 124) to the north. Units 124 and 137 were formerly mapped as equivalents (Biotite Granite D, Godfrey and Peikert, 1963; Godfrey, 1980a), but they probably have had a different petrogenesis (see below) and are classified separately.

A suite of minor, leucocratic, lensoid bodies of quartz monzonite (unit 134) is widely dispersed and cuts all major rock units of the Wylie Lake Granitoids. The high hornblende content (2.5 percent) and bimodal feldspar content indicate a heterogenous composition similar to that of unit 125. Unit 135 is a localized quartz monzonite with a very low color index.

The major and trace element means of units 131 and 132 form a primary couple by cluster analysis, and both have a mean normative composition of tholeiitic andesite. Granodiorite 137 has lower Fe, Mg, Ca and Sr, and higher K, Ba, and Rb than the 131-132 group, and has a calc-alkaline dacite composition. The main body of Fishing Creek Quartz Diorite (133) is also poorer in Fe and Mg than unit 132 and has a calc-alkaline dacite composition. All lithologies except unit 135 have normative corundum. Unit 135, which has over one percent normative acmite (table 5) and has the composition of a peralkaline dacite, was excluded from the following classification scheme, which does not apply to alkaline rocks.

The Wylie Lake Granitoids show an overall alkali-lime index of 56 (figure 5e). When plotted separately, all lithologies except unit 135 yield typically calc-alkaline values of 55 to 60 for the alkali-lime index. The C/(A + C + F) index shows the typically low values of S-type granites, although some units have values over 0.3 (figure 2); they are heterogenous leucocratic units. The modal value of the peraluminous index is 1.05 (figure 3), and falls on the boundary between S-type and I-type granites. However, 76 percent of the distribution has a peraluminous index greater than 1.05, compared to only 61 percent for the Colin Lake Pluton and 54 percent for the Andrew Lake Plutons. The bulk of the analyses plot in the I-type field on the Na_2O versus K_2O diagram (figure 4e). However, all units except 131 and 132 are distributed in both fields. No consistent I-type versus S-type classification can be applied to the Wylie Lake Granitoids.

Minor lithologies

In addition to the five major rock groups, several minor lithologies occur within the Alberta Shield (figure 1).

High-grade metasedimentary rocks (031 and 032) occur as heterogeneous biotite-quartz-feldspar layers within the gneiss belt and as minor lenses within the larger granitoid bodies. Garnet, cordierite, and Al_2SiO_5 polymorphs occur within these bands and were used as the basis of a thermobarometric study which identified two distinct metamorphic events (Langenberg and Nielsen, 1982). Owing to the negligible outcrop area of unit 032, data for units 031 and 032 were combined under 030 for tables 2 to 15. Individual chemical analyses were made of aggregated powder samples from each band. The mean of these analyses has very high normative corundum (table 5) and shows high Mg, Fe and K, and low Ca and Na (table 4), which reflects the high biotite and low plagioclase content.

Three minor granitoid plutons occur with the Alberta Shield. At Thesis Lake is a 10 km by 3 km pluton of granodiorite to quartz monzonite (110), which contains 17 percent biotite and 4 percent hornblende. It has a normative composition similar to tholeiitic andesite. The La Butte Granodiorite (140) is composed of hornblende and biotite quartz diorite to quartz monzonite with a mean color index of less than 5. It forms an irregularly shaped stock, 20 km by 8 km, within the Slave Granite, but aeromagnetic maps suggest that it might be a much larger body at depth. Its mean normative composition is that of calc-alkaline dacite. The Chipewyan Red Granite (150) is a quartz monzonite to alkaline granite stock at least 30 km long and 6 km wide. It has a mean color index of less than 3 and a normative composition similar to calc-alkaline rhyolite.

In addition, a small stock of Foliated Hornblende Granite (175), 6 km by 1 km, occurs at the north end of Charles Lake. This unit is texturally similar to the Arch Lake Granitoids, but has 10 percent hornblende and no accessory garnet. It has been grouped with the Archean Charles Lake Granitoids (table 1; Godfrey and Langenberg, 1986 and in press).

Table 6. Summary classification table for the mean mineralogical and chemical compositions of each rock unit of the Granite Gneiss belt and the main granitoid intrusions.

	Slave Granitoids	Arch Lake Granitoids	Colin Lake Granitoids: Colin Lake Pluton	Colin Lake Granitoids: Andrew Lake Plutons	Wylie Lake Granitoids	Granite Gneisses
Rock Unit	101-106	161-164	123-127	121-122	131-137	011-012
Petrographic Classification	Quartz-Monzonite to Granite	Quartz-Monzonite to Granite	Hornblende-Granodiorite to Leuco-granite	Granodiorite to Quartz Monzonite	Quartz diorite to Grano-diorite	Biotite and Hornblende Gneisses
Normative Classification (magma type)	CA-dacite to CA-rhyolite	TH-dacite to CA-rhyolite	TH-andesite to CA-rhyolite	CA-dacite	TH-andesite to CA-dacite	TH-andesite to CA-dacite
Differentiation Index	84-92	78-90	61-93	79-81	72-80	67-71
Norm. Color Index	8-2	9-3	18-2	9	14-9	15-7
% Norm. Corundum	1.5-2	2	1-2	1-1.5	1-2	0-0.2

TH - tholeiitic, CA - calc alkaline.

Summary

A summary of classifications is given in table 6. The Granite Gneisses are diopside to corundum normative, I-type quartz monzonitic rocks, which have the composition of calc-alkaline dacites. The Slave and Arch Lake Granitoids are chemically distinct, homogeneous quartz monzonites with high normative corundum and the normative composition of calc-alkaline rhyolites. The eastern Colin Lake and Wylie Lake Granitoids are composed of differentiated, corundum-normative, calc-alkaline hornblende-biotite granodiorites with the normative composition of andesite to dacite. Both of these complexes have a suite of minor, localized partial melts, represented by heterogeneous leucocratic quartz monzonites.

Classification schemes developed for the Phanerozoic granites of the circum-Pacific basin are apparently not applicable to the major granitoid plutons of the Alberta Shield. This discrepancy may result from the limited data set used to define the discrimination parameters, but it is probably more dependent on the nature of the parent materials. Field relationships between the gneisses and the major and minor granitoid plutons have been used to suggest that the latter were formed from the gneissic parent material (Godfrey, 1980a and 1980b; Klewchuk, 1972). If this is the case, the mixture of igneous and sedimentary materials in the Granite Gneiss belt may indeed produce partial melts which cannot be rigorously classified using classification schemes suited to Phanerozoic-age plutons. New criteria should be developed to identify chemical associations of potential economic importance in crystalline shield areas.

Petrogenesis

Methods

The petrogenesis of each of the five major rock groups is discussed separately. Major and trace element variations between the components of each group were compared, using a modification of the Larsen Index (MLI = $1/3\ SiO_2 + K_2O - CaO - MgO$) as an index of differentiation. Two R-mode factor analyses were carried out on each major rock group for both the chemical variables and the combined chemical and modal data, in order to elucidate the processes controlling chemical variation. Only factors with eigenvalues greater than or equal to 1.0 were extracted for orthogonal rotation. Only the factor analyses based on the chemical variables are referred to below.

The variation in key trace elements is an important aid in identifying the residual phases involved in either fractionation or partial melting processes. An important group of high-field-strength elements (HFSE)—Nb, Zr, Y, and Ti—are stable under most conditions of alteration and show high partition coefficients for biotite and/or hornblende and accessory minerals in intermediate to felsic melts (Pearce and Norry, l979). Correlations between key elements and mineral phases were noted from similar factor loadings. However, a more quantitative view of their association was obtained by calculating a multiple regression equation for each HFSE, using the modal values of all relevant minor phases as dependent variables. Only the dependent variables which yield a significant correlation at the 0.05 level were considered. Ti was not included in this study because of its known high concentrations in biotite and hornblende.

On the other hand, the large-ion lithophile (LIL) trace elements Ba, Rb, and Sr are particularly useful for modeling purposes in granitic systems because they occur only in the major silicate phases and not in the accessory phases. They also vary over a wide range in concentration. The partition coefficients for these elements are based largely on measurements made on felsic extrusive rocks. Because the magnitude of crystal-liquid partition coefficients is generally inversely proportional to temperature, partition coefficients applicable to a plutonic environment are likely to be larger than those measured on lavas. The Ba, Rb and Sr variations were analyzed semi-quantitatively by using two sets of vectors (from Brown et al., 1981) that indicate the theoretical change in composition of a felsic melt that is due to either fractional crystallization, or to equilibrium partial melting of specific phases (figures 8 and 9).

Estimates of the formation pressure of each of the rock units of the five main plutons were made by plotting normative compositions and relevant cotectic surfaces within the quartz-K-feldspar-albite-anorthite system.

The field relationships of the Slave Granitoids and their high initial $^{87}Sr/^{86}Sr$ ratio (0.710, Nielsen et al., 1981) suggest that both the Slave and Arch Lake Granitoids were derived by partial melting of the Granite Gneiss belt. This theory was tested by comparing: 1) chemical trends between the plutons and the gneiss belt; 2) the composition of relevant, experimentally produced partial melts with those of the Slave Granitoids; and 3) the Ba, Rb, and Sr variations in the Slave Granitoids with those produced by the modeling of such partial melts. Mylonitic gneisses were excluded from further study to avoid the effect of Ca mobility on the results.

Granite Gneiss belt

When each element or oxide is plotted against a modification of the Larsen Index (appendix), coherent trends, characteristic of an igneous suite are displayed. Plots of increasing MLI correlate with: 1) an increase in Si, K, and Rb; 2) a pronounced decrease in Ti, Fe, Mn, Mg, Ca, Al, and Sr; and 3) a less distinct decrease in Y and Zn. P, Ba, Nb, and Zr may show a maximum in their trends. Unit 012, which is rich in

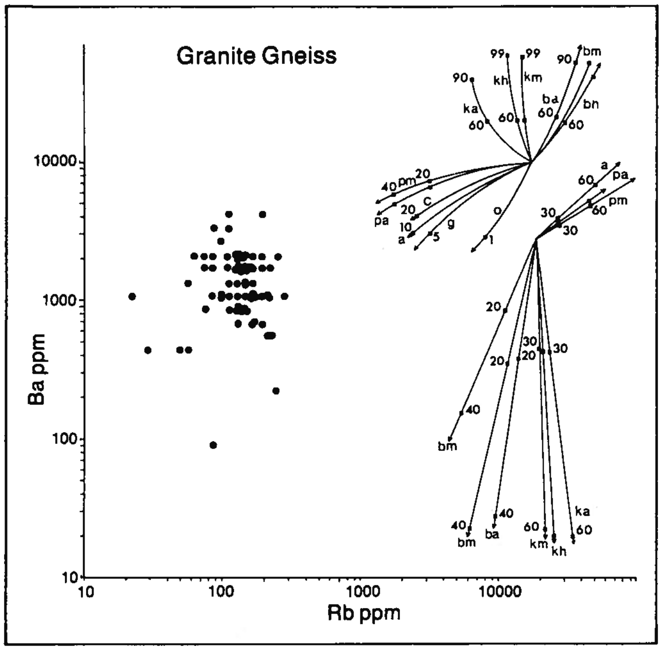

Figure 8. Plot of Ba against Rb for the Granite Gneiss belt. Also shown are straight-line vectors which indicate the change in composition of a silicic melt as a result of Rayleigh fractional crystallization of the named phases, and curved-line vectors which show the equivalent results of equilibrium partial melting (after Brown et al., 1981). The percentage of fractional crystallization or of partial melting needed to produce the corresponding changes in Ba and Rb is marked along the relevant vectors. The vectors were calculated using partition coefficients listed by various authors: g = garnet, o = orthopyroxene, c = clinopyroxene, a = hornblende, bh = biotite (Hanson, 1978), ba = biotite (Arth, 1976), bm = biotite (McCarthy, 1976), Kh = K-feldspar (Hanson, 1978), Ka = K-feldspar (Arth, 1976), Km = K-feldspar (McCarthy, 1976), ph = plagioclase (Hanson, 1978), pa = plagioclase (Arth, 1976), and pm = plagioclase (McCarthy, 1976).

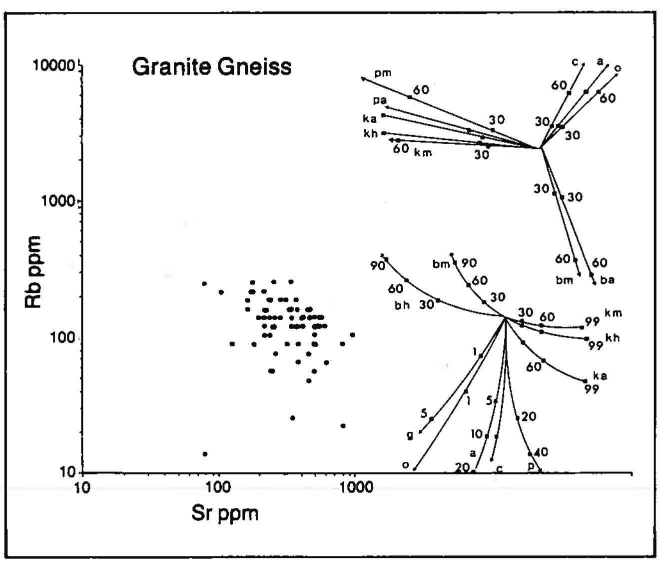

Figure 9. Plot of Rb against Sr for the Granite Gneiss belt. Straight-line Rayleigh fractional crystallization vectors and curved equilibrium partial melting vectors are shown for specific phases in silicic rocks (after Brown et al., 1981). See caption to figure 8 for key and explanation.

hornblende, biotite, and calcic plagioclase, plots at the low-MLI end of these trends and is notably richer in the ferromagnesian group of elements. Within the 011 rock unit, a cross-cutting trend of K, Rb, and Na lies on an albite-microcline tieline. This suggests that, during metamorphism, a phase of localized alkali metasomatism took place, which involved the coupled exchange of Na and K. The decrease in Ca, Al, and Sr indicates residual plagioclase; the increase in the K/Ba ratio and constant Na is characteristic of K-feldspar fractionation. Trends of HFSE on binary logarithmic plots indicate that the partition coefficients of the fractionation of residual mineral assemblage were of the order $Ti \approx Y > Nb > Zr$. The decrease of ferromagnesian components and notably of the HFSE with fractionation indicates residual biotite. However, the compatibility of Y indicates residual hornblende (Hanson, 1978; Pearce and Norry, 1979).

If the chemical and modal data are grouped according to SiO_2 content (table 7), the gneiss ranges in composition from trachy basalt, containing high modal hornblende and biotite, to a K-rich rhyolite. The trend shows a change from diopside-normative to corundum-normative compositions. Such a change is common in calc-alkaline suites and has been attributed to hornblende fractionation (Cawthorn et al., 1976).

Multiple regression analysis between each HFSE and key modal phases indicated low but significant correlations between Zr and biotite, and Y and secondary epidote. However, both elements showed higher correlations with accessory minerals (magnetite, ilmenite, zircon and apatite). R-mode factor analysis of the major trace elements produced three factors which explain 72 percent of the variance. F1 represents a mafic to felsic trend of hornblende and plagioclase (Ca, Mg, Sr, Al) versus quartz (Si), whereas F3 represents plagioclase (Na) versus K-feldspar (K, Rb, and Ba) fractionation or subsolidus alkali migration (see above). Nb, Y, and Zr form a separate factor (F2) which shows no significant correlation with any of the major phases involved in fractional crystallization/partial melting and reflects a variation in trace accessory minerals. Wide variations in the concentrations of these elements are characteristic of a heterogeneous source material (Pearce and Norry, 1979).

The dacitic composition and chemical variation within the Granite Gneiss belt suggests that it was formed by partial melting of an andesitic or mafic source leaving biotite, hornblende, and plagioclase as residual phases. Phanerozoic granodiorites to quartz diorites of Nova Scotia (which have a similar composition to the Alberta Shield granite gneisses) were explained by Rare Earth Elements (REE) modeling as 60 percent partial melting of a gneiss of andesitic composition, at 5 Kb P H_2O, leaving a hornblende-orthopyroxene-biotite-plagioclase residuum (Albuquerque, 1977). Alternatively, the gneisses may have been produced by a lower degree of partial melting of a mafic source. If the gneiss was produced from a parent of mafic or intermediate composition, various degrees of partial melting of hornblende and plagioclase plus subsequent fractionation of 30 percent plagioclase

Table 7. Mean major and trace element compositions and mean modal and normative compositions for the Granite Gneiss belt, classed according to silica content.

	Granite Gneisses (011, 012)					
SiO_2 %	50-55	55-60	60-65	65-70	70-75	75-80
SiO_2	51.30	57.75	62.89	67.67	71.93	76.44
TiO_2	1.55	1.23	0.77	0.50	0.28	0.12
Al_2O_3	16.95	16.60	15.36	15.14	13.68	12.73
Fe_2O_3	9.29	7.98	5.74	3.69	2.40	0.89
MgO	4.20	2.57	2.26	1.36	0.70	0.47
CaO	7.40	5.27	4.23	2.62	1.58	0.60
Na_2O	3.18	3.55	3.47	3.69	3.41	5.89
K_2O	3.89	3.35	3.18	3.80	4.70	1.75
MnO	0.15	0.12	0.10	0.61	0.06	0.01
P_2O_5	0.80	0.54	0.19	0.14	0.91	0.03
Ba	3197	2458	1458	1332	1277	500
Nb	36	39	26	22	19	18
Zr	387	605	298	320	217	195
Y	60	57	38	27	18	13
Sr	1308	672	491	403	265	175
Rb	109	73	108	133	152	77
Zn	161	106	73	59	36	6
Mode						
Q	2.6	12.3	17.9	24.7	30.0	52.1
Kf	25.7	16.4	14.9	19.2	30.3	15.1
Pl	32.2	42.9	45.4	42.4	31.5	30.0
Bi	11.6	10.3	11.4	8.0	4.5	0.7
Ch	0.3	0.3	2.0	1.2	1.1	1.3
Hb	21.1	10.0	4.0	1.7	0.6	0.1
Ep	0.8	3.8	2.8	0.7	0.7	0.1
Mu		0.3	0.1	0.8	0.4	0.1
Sp						
Gn				tr.		
Acc	5.7	3.8	1.6	1.2	0.9	0.5
Norm						
Q	-	9.4	18.4	24.0	32.4	33.9
Cor	-	-	-	0.5	2.3	0.1
Or	23.6	20.1	19.2	22.7	27.9	10.5
Ab	27.4	30.5	30.0	31.5	29.0	50.4
An	20.9	19.8	17.3	12.2	1.9	2.8
Di	6.2	1.6	1.6	-	-	-
He	2.9	1.0	0.7	-	-	-
En	2.7	5.8	5.0	3.4	1.8	1.2
Fs	1.4	4.1	2.5	1.5	-	-
Fo	3.6	-	-	-	-	-
Fa	2.1	-	-	-	-	-
Mt	4.5	4.0	3.4	2.9	1.2	-
Il	3.0	2.4	1.5	1.0	0.5	tr.
Hm	-	-	-	-	1.0	1.0
Ap	1.9	1.3	0.45	0.3	2.1	0.1
D.I.	51	60	68	78	89	95
N	1	4	10	26	27	3

D.I. = Thornton and Tuttle differentiation index. Mu = muscovite, mainly sericite alteration, Acc = magnetite, ilmenite, apatite and ziron, tr. = trace amounts of mineral. See captions for tables 2 and 5 for full index of modal and normative phases.

and 30 percent K-feldspar and biotite could explain the variation in Ba, Rb, and Sr (figures 8 and 9). However, these estimates of fractionation are maximum values because much of the scatter could be caused by subsequent alteration.

Slave and Arch Lake Granitoids

MLI plots for the Slave Granitoids (appendix) show that most of the data points cluster towards the most differentiated end of the trend of the Granite Gneisses for all elements. With an increase in MLI, a decrease occurs in the concentration of all analyzed elements except Si, K, and Rb, which increase, and Y, which has an unclear trend. Rock unit 102, which has a high biotite and hornblende content, tends to be lower in Si and higher in Fe, Mg, Ca, and Mn than the other Slave Granitoid units. However, it shows separate trend lines for Ba, Ti, Y, Zn, Zr, and Nb; these are distinct from the trend between the gneiss and the main Slave Granitoid units. This latter group of elements is typically concentrated in hornblende and biotite, and the distinct chemical trend of unit 102 suggests that it is not residual material from the partial melting of the Granite Gneiss. Fe and Mn also show subsidiary trends towards the compositions of biotite and garnet (taken from Peikert, l963) and a mean hornblende composition. This may indicate metamorphic alteration unless, in the case of garnet, it was a subsidiary phase during partial melting. Intersecting trends in K, Na, and to a lesser extent in Ca, are caused by migration of these elements during metamorphism, involving subsolidus recrystallization of the feldspars. This may also explain the intersecting trends in Rb, Sr, and Ba. A marked increase in K/Ba with increase in MLI indicates K-feldspar fractionation. The trends appear to be caused by the presence of residual biotite, hornblende, and a plagioclase of composition An_{24}, very similar to the mean plagioclase composition (An_{25}) of unit 011.

Binary logarithmic plots of HFSE (not shown) yield a nonlinear scatter for Y versus Zr and a low positive slope for Nb versus Zr. The relative slopes of the trends on these plots suggest bulk partition coefficients for the residual assemblage of $Ti > Y \approx Nb > Zr$. The high partition coefficient for Y and the wide variation of Zr with a moderate change in Nb indicates partial melting of a source with varied amounts of residual hornblende and possibly magnetite (Pearce and Norry, 1979). The highest concentrations of Ti, Y, Zr, and Nb in the main rock units of the Slave Granitoids correspond to the mean concentrations of these elements in the Granite Gneiss.

If the chemical and modal data for the Slave Granitoids are grouped according to SiO_2 content (table 8), then a compositional range is observed from biotite and K-feldspar-rich tholeiitic andesite to calc-alkaline rhyolite. A decline in Zr and Y corresponds to a decrease in biotite, whereas a peak in Nb and Zn correlates with a maximum of hornblende and accessory minerals.

Multiple regression analyses of each HFSE on the minor phases shows that Nb, Zr, and Y all have their highest significant correlations with hornblende. Significant correlations also occur between Zr and biotite and accessories, and between Y and accessories.

The MLI plots for the main units of the Arch Lake Granitoids (161 and 162) essentially form a subset of those of the Slave Granitoids, but without the subsidiary trace element trends characteristic of the biotite and hornblende-rich rock unit 102. These trends

Table 8. Mean major and trace element compositions and mean modal and normative compositions for the Slave Granitoids, classed according to silica content.
See caption to table 7 for key.

	Slave Granitoids (101-106)				
SiO_2 %	**55-60**	**60-65**	**65-70**	**70-75**	**75-80**
SiO_2	57.42	64.55	68.08	72.84	75.82
TiO_2	1.08	1.05	0.72	0.17	0.11
Al_2O_3	19.49	16.56	15.10	14.70	13.63
Fe_2O_3	5.58	4.99	3.46	1.30	0.83
MgO	2.19	1.43	0.93	0.36	0.22
CaO	2.61	2.61	2.03	0.82	0.74
Na_2O	2.79	2.69	3.61	3.31	3.10
K_2O	6.63	4.80	4.72	5.36	4.86
MnO	0.05	0.08	0.05	0.03	0.02
P_2O_5	0.21	0.13	0.15	0.11	0.10
Ba	2221	1657	1601	658	471
Nb	16	29	27	20	16
Zr	536	392	283	119	91
Y	29	22	23	16	15
Sr	498	271	529	175	100
Rb	215	161	131	221	222
Zn	44	63	61	33	29
Mode					
Q	8.9	28.9	22.2	28.8	36.7
Kf	46.0	19.0	25.6	42.1	41.2
Pl	23.2	34.4	42.6	22.5	16.8
Bi	14.3	11.7	2.7	2.0	1.6
Ch	2.8	1.7	1.4	0.6	0.6
Hb	0.9		1.3	0.2	
Ep	1.0	0.5	1.3	0.1	tr.
Mu	1.3	0.5	0.9	1.6	1.6
Sp				0.2	tr.
Gn		0.1	1.1	0.9	0.9
Px		0.5		0.1	
Crd				0.2	tr.
And				tr.	
Sill				0.3	0.2
Acc	1.3	2.6	0.8	0.4	0.2
Norm					
Q	7.2	23.3	21.6	31.4	37.8
Cor	3.6	2.5	0.8	2.2	2.2
Or	40.1	28.8	29.2	32.0	28.9
Ab	24.2	23.1	31.9	28.3	26.4
An	11.8	12.3	9.5	3.4	3.0
En	5.6	3.6	2.4	0.9	0.6
Fs	1.2	0.4	-	-	-
Mt	3.8	3.8	1.7	-	-
Il	2.1	2.0	1.4	0.1	tr.
Hm	-	-	1.1	1.3	0.8
Ap	0.5	0.3	0.4	0.3	0.2
Ru	-	-	-	0.1	0.1
D.I.	71	75	83	92	93
N	2	2	15	146	15

Table 9. Mean major and trace element compositions and mean modal and normative compositions for the Arch Lake Granitoids, classed according to silica content.
See caption to table 7 for key.

	Arch Lake Granitoids (161-164)			
SiO_2 %	**60-65**	**65-70**	**70-75**	**75-80**
SiO_2	64.42	68.39	72.52	76.78
TiO_2	1.07	0.61	0.31	0.16
Al_2O_3	14.92	14.78	14.40	13.15
Fe_2O_3	5.70	3.67	1.69	0.93
MgO	1.99	1.10	0.53	0.32
CaO	2.82	1.94	0.94	0.69
Na_2O	2.02	2.94	3.09	2.63
K_2O	4.77	5.04	5.37	5.34
MnO	0.07	0.05	0.02	-
P_2O_5	0.44	0.21	0.12	0.08
Ba	2206	1413	888	797
Nb	33	28	21	17
Zr	383	344	191	118
Y	33	27	16	9
Sr	398	272	179	161
Rb	208	179	231	218
Zn	95	58	41	28
Mode				
Q	27.6	27.0	27.1	31.7
Kf	17.9	27.1	37.8	47.5
Pl	32.6	33.6	28.8	19.1
Bi	20.3	7.9	3.4	0.5
Ch	0.3	1.1	0.9	0.6
Hb		1.0	0.1	
Ep	0.2	0.4	0.1	
Mu	0.4	0.6	1.1	0.6
Sp			tr	
Gn	0.1	0.8	0.4	
Px			tr	
Acc	0.5	0.5	0.3	
Norm				
Q	26.5	27.2	31.8	39.3
Cor	2.4	1.5	2.1	2.0
Or	28.8	30.2	32.1	31.6
Ab	17.5	25.2	26.4	22.2
An	11.4	8.4	3.9	2.9
En	5.1	2.8	1.3	0.8
Fs	1.4	-	-	-
Mt	3.8	3.0	-	-
Il	2.1	1.2	tr	-
Hm	-	0.1	1.7	0.9
Ap	1.0	0.5	0.3	0.2
Ru	-	-	0.3	0.2
D.I.	73	83	90	93
N	3	14	81	2

can be explained by fractionated and/or residual biotite, plagioclase, and K-feldspar. If the chemical and modal data for the Arch Lake Granitoids are grouped according to SiO_2 content, a range in composition from tholeiitic andesite, containing high modal biotite and plagioclase, to K-feldspar-rich calc-alkaline rhyolite is observed (table 9). The minimum observed in Rb concentration in the Arch Lake Granitoids, which is also observed in the Slave Granitoids, probably represents a decrease in biotite and an increase in K-feldspar with increasing SiO_2 content: Rb is concentrated in both phases.

Factor analysis of the major and trace elements for the Arch Lake Granitoids produced three factors explaining 69 percent of the variance. F1 represents the variation of plagioclase (Sr and Ca), biotite (Mg, Ti, and

Ba) and apatite (P) versus quartz (Si). Zr, Y, and Nb form a separate factor (F2) which correlates with hornblende if modal contents are added to the factor analysis. F3 represents K-feldspar fractionation and subsequent sericite alteration (K, Rb) versus plagioclase (Na).

Estimates of the pressures of formation of the Slave and Arch Lake plutons and their possible gneissic parents can be made from normative feldspar plots (figures 10 and 11), which depict the mean normative

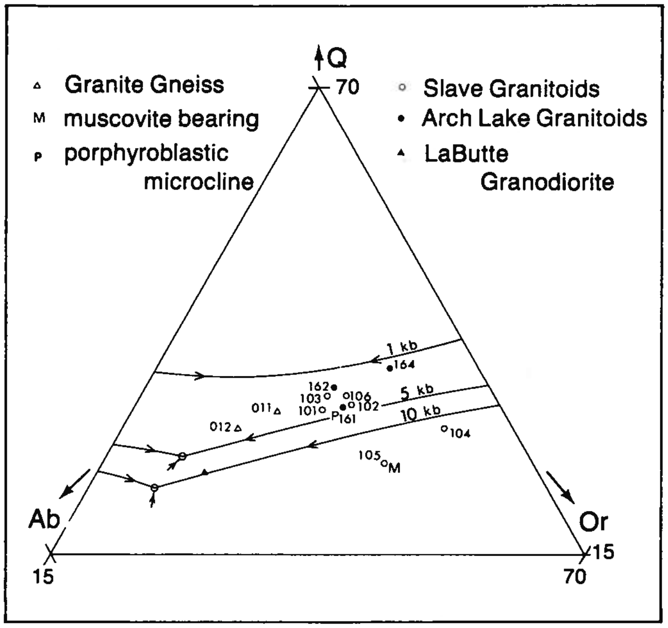

Figure 10. Normative quartz (Q) - albite (Ab) - orthoclase (Or) diagram of the mean compositions of the major rock units within the Granite Gneiss belt and the Slave and Arch Lake Granitoids and in an associated minor pluton. H_2O-saturated liquidus field boundaries, at various pressures, in the system Q-Ab-Or-H_2O are from Luth et al. (1964).

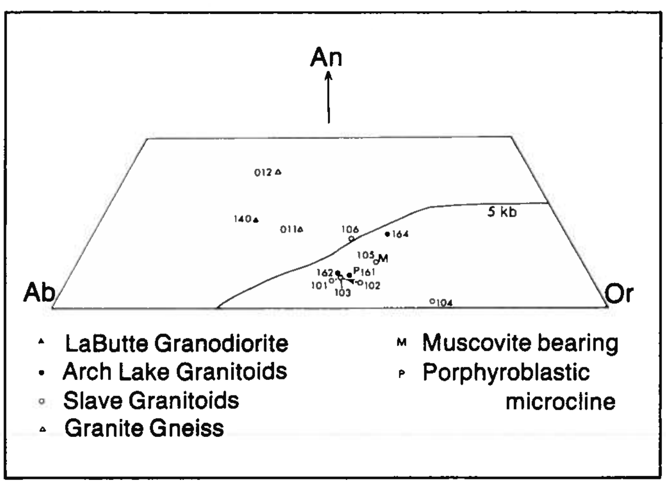

Figure 11. Normative anorthite (An) - albite (Ab) - orthoclase (Or) diagram of the mean composition of the major rock units within the Granite Gneiss belt, the Slave and Arch Lake Granitoids, and in an associated minor pluton. The 5kb, H_2O-saturated cotectic surface in the system Q-Ab-Or-An, projected from Q, is from Winkler et al. (1975).

compositions of each major lithological unit projected onto two faces of the Q-Or-Ab-An tetrahedron. The H_2O-saturated cotectics shown in figure 10 are those for the An-free system (Luth et al., 1964). However, addition of Ca to the system will cause three-phase eutectics to become univariant cotectic lines. When projected onto the Q-Or-Ab face of the tetrahedron, primary melt compositions, produced isobarically along this cotectic, will form a locus of piercing points which vary in composition according to the Ab/An ratio of the parent material (Winkler, 1974; James and Hamilton, 1969). The first melts will have a restricted composition as long as the parent contains quartz, plagioclase, and K-feldspar. A decrease in the Ab/An ratio of the starting composition, at a given pressure, causes the projected Ab content of the first melt to rapidly decrease. Therefore, projections of these cotectics into the Q-Or-Ab system will intersect the cotectics of the Ca-free system at a high angle.

The mean compositions for the Granite Gneiss lithologies (figure 10) lie along a locus of 5 kb P_{H_2O} piercing points. The main units of the Slave and Arch Lake Granitoids plot between the loci of 5 to 7 kb P_{H_2O}

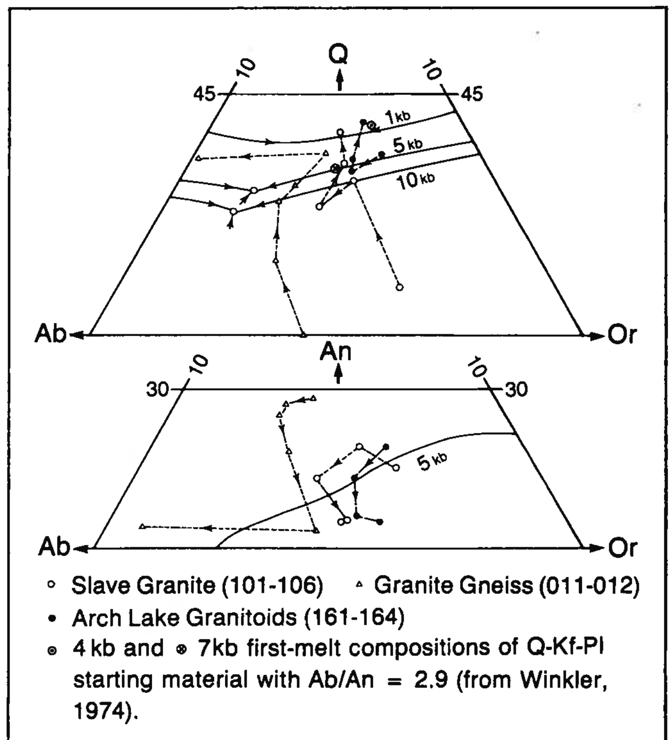

Figure 12. Normative Q-Ab-An-Or compositions of the Granite Gneiss belt and Slave and Arch Lake Granitoids, categorized according to silica content. These data are taken from tables 7, 8, and 9. Each category contains a 5% spread in SiO_2 content and the categories show a range from 50-55% SiO_2 to 75-80% SiO_2 for the Granite Gneiss. The most silica-rich category is 75-80% SiO_2 for all three lithologies. The arrows indicate increasing silica content within each rock group. H_2O-saturated liquidus field boundaries, at various pressures, in the system Q-Ab-Or-H_2O are from Luth et al. (1964). The 5kb, H_2O-saturated cotectic surface in the system Q-Ab-Or-An, projected from Q, is from Winkler et al. (1975).

piercing points, with the exception of the microcline- and biotite-rich units 104 and 105. These latter units suggest unrealistic pressures of formation, probably indicating the mechanical concentration of K-rich minerals during intrusion.

A simplified view of the variation in normative feldspar composition within the Slave and Arch Lake Granitoids, as compared to that within the gneisses, is seen in figure 12, where the mean normative composition of each SiO_2 subdivision (from tables 7, 8, and 9) is plotted. This does not indicate differentiation trends, but offers a means of comparison using the component which has the highest variance in each suite. For any SiO_2 content, a notable increase in normative Or is observed from the gneiss, through the Slave Granitoids to the Arch Lake Granitoids. The notable break in each trend next to the interval representing the densest concentration of data points in both plutons (at 70-75 percent SiO_2), indicates cotectic quartz-K-feldspar-plagioclase crystallization.

The Granite Gneiss can be modeled as a possible parent material for the Slave and Arch Lake Granitoids by comparing the normative feldspar composition of these granitoids with that of melts produced experimentally by the partial melting of graywackes of similar bulk composition to the Granite Gneiss belt. From the data of Winkler (1974), a quartz-K-feldspar-plagioclase starting material with an Ab/An = 2.9 (which is similar to the mean granite gneiss composition of 2.7), produces a first melt, at a P_{H_2O} of 7 kb, which is slightly more Ab rich than the 70-75 percent SiO_2 fraction of the Slave Granitoids (figure 12). By extrapolation, the piercing points for the main data concentration of the Slave and Arch Lake Granitoids in the Q-Or-Ab projection suggest a pressure of formation of approximately 6 kb P_{H_2O}. However, because the final composition of the Slave Granitoids is likely to be a mixture of melt plus source material, the real composition of the first melt is likely to have been less albite-rich than the bulk composition of the Slave Granitoids and possibly produced at an even lower P_{H_2O}. Furthermore, it is rare that quartz monzonites are H_2O-saturated; therefore, it is likely that P_{H_2O} was less than total pressure during melting. However, for quartz monzonite compositions, An-free anhydrous and hydrous 5 kb cotectics occupy similar positions (Luth et al., 1964; Steiner et al., 1975), although at higher pressures (30 kb) the anhydrous cotectic is notably less quartz-rich (Huang and Wyllie, 1975). The extrapolated pressure of 5 to 6 kb may therefore be a maximum pressure, given the possibility of P_{H_2O} less than P total. Similarly, the most SiO_2-rich fraction of the Arch Lake pluton is close in composition to that of the first partial melt produced by the same starting material at 2 kb P_{H_2O}. Therefore the latter may represent late-stage quartz-K-feldspar-plagioclase crystallization at higher crustal levels than that of the initial partial melt.

The estimated equilibrium pressure of formation of the Slave Granitoids (5 to 6 kb) is in the same range as mineralogical thermobarometric estimates of the first phase of Proterozoic granulite-grade metamorphism in this area (5 kb and 740°C, Langenberg and Nielsen, 1982). At 5 kb P_{H_2O}, a molten graywacke, similar in composition to the gneiss, would begin to melt at 655-670°C (Winkler, 1974), and would be 40 to 50 percent molten at 740°C. Melt fractions of 15-25 percent (Compston and Chappell, 1979) or 30-35 percent (Van der Molen and Patterson, 1979) are considered necessary to reduce the strength of a partially melted rock sufficiently for it to deform, flow, and rise at a rate consistent with movement and emplacement of a granitoid pluton. Therefore, granitoid plutons could be very largely solid material at the early stages of migration and emplacement, and be very close in composition to the bulk source. If so, sufficient partial melting of the Granite Gneiss belt could have taken place during regional metamorphism to have produced a melt with a composition similar to that of the Slave Granitoids.

The major and trace element trends for the Slave and Arch Lake Granitoids indicate either fractionation or partial melting, involving plagioclase, biotite and hornblende—in that order of importance—as residual phases. These phases are present in the Granite Gneiss belt, which is regarded as the possible parent material. The assumption of a gneissic parent can be tested further by modeling the Ba, Rb, and Sr contents of a primary melt (composed of equal amounts of quartz, K-feldspar, and plagioclase) produced by equilibrium partial melting of a biotite-quartz-monzonitic source, similar in modal composition to the Granite Gneiss. The partition coefficients used are those from McCarthy (1976), and the biotite is assumed not to melt during continuous liquid extraction with accumulation of melt increments. The first melt has Sr, Rb, and Ba contents of 140, 290, and 400 ppm, respectively, and on figures 13 and 14 would plot in the main density distribution of the Slave Granitoids, towards the high Rb, low Sr, and Ba end of the trend. In figure 13, this first melt lies on a change in direction of the Ba versus Rb trend. Even with 40 percent partial melting, the melt composition will not change significantly (Sr, Rb, and Ba contents are 160, 210, and 470 ppm, respectively). However, with continued partial melting, the trend shows a too-rapid depletion in Rb to explain the Rb versus Sr variation of the Slave Granitoids, and its negative slope would become even steeper if a considerable amount of biotite is melted (as can be estimated from the equilibrium partial melt vectors of figure 14). The congruent melting of residual biotite (and/or K-feldspar) is suggested by the decrease in K/Rb (Hanson, 1978) between the gneiss and the Slave Granitoids (269 to 225), which is accompanied by an increase in Rb/Sr (0.5 to 1.8) and K/Ba (46 to 163). Therefore, the composition of the Slave Granitoids cannot be explained by equilibrium partial melting alone.

Compositional changes in melts caused by continued, equilibrium partial melting can also be semi-quantitatively assessed by superimposing the origin of the relevant binary network of equilibrium partial melt vectors, from figures 13 and 14, over the theoretical first melt composition of the Granite Gneiss. Similarly, the Rayleigh fractionation vectors can be used to model subsequent fractional crystallization of these melts. The high Rb parts of the distributions (greater than 290 ppm Rb, the composition of the first melt) for the Slave Granitoids, in figures 13 and 14, can be explained by fractional crystallation of 30 percent K-feldspar and 30 percent plagioclase from the initial melt. However, the high Sr and Ba segment of the distribution, which lies on a noticeably different trend, can only be explained by partial melts with unrealistically high ratios of K-feldspar to plagioclase (greater than 10 to 1). Because the trend in this segment of the data is towards the center of the distribution for the Granite Gneiss (see figures 8 and 9), the Ba, Rb, and Sr variations within the Slave Granitoids can be explained by mixing different proportions of partial melts with the parent gneiss. Therefore, much of the gneissic restite material would form a solid suspension within the partial melts and would be represented within the Slave Granitoids by calcic plagioclase cores and zones rich in mafic minerals. Mixing of high proportions of gneiss with melt is to be expected if the Slave Granitoids formed a largely solid diapir during emplacement (see above). The curvilinear trend to a positive slope, at the low-Ba end of the Ba versus Rb plot (figure 13), does not fit simple crystal fractionation models. Such trends can be better explained by mixing the fractionating melt with varied percentages of cumulus crystals (McCarthy and Hasty, 1976). The Arch Lake Granitoids show a more restricted distribution in Ba, Rb, and Sr (figures 15 and 16). No clear trends are observed, but the composition of the Arch Lake Granitoids could be derived by mixing of the first partial melt of the Granite Gneiss with at least 50 percent gneissic components.

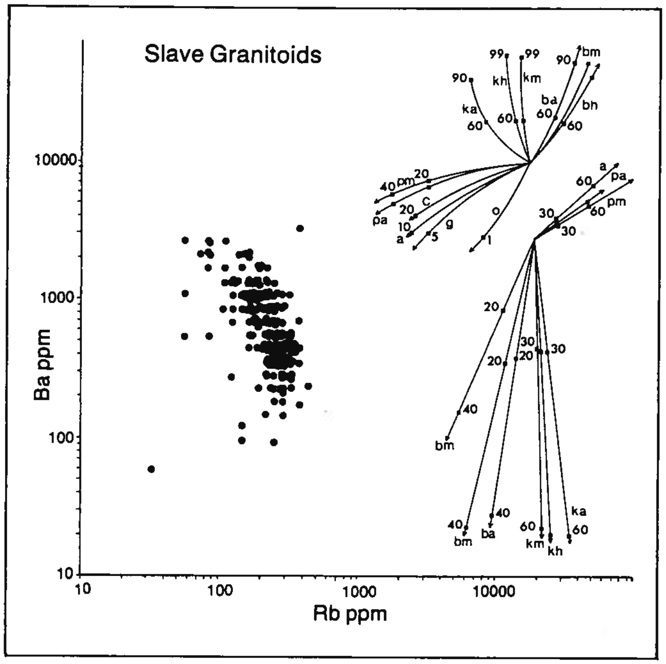

Figure 13. Plot of Ba against Rb for the Slave Granitoids. Straight-line Rayleigh fractionation vectors and curved equilibrium partial melting vectors are shown for specific phases in silicic rocks (after Brown et al. 1981). See caption to figure 8 for key and explanation.

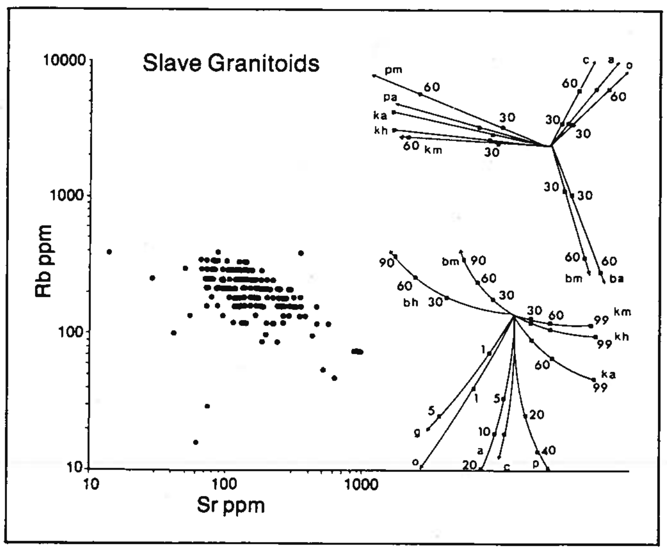

Figure 14. Plot of Rb against Sr for the Slave Granitoids. Straight-line Rayleigh fractionation vectors and curved equilibrium partial melting vectors are shown for specific phases in silicic rocks (after Brown et al. 1981). See caption to figure 8 for key and explanation.

Major and trace elements of the Slave and Arch Lake Granitoids and of the Granite Gneiss belt were considered as a single group for R-mode factor analysis, in order to identify the processes which could explain variations between these groups. Four orthogonal factors, which explain 72 percent of the variance, were extracted for varimax rotation. Significant loadings of each variable on these factors are given in table 10 and illustrated in figure 17. Inspection of this factor matrix reveals a bipolarity between a ferromagnesian-centered group (which includes some of the variance of Zn and Zr) and silica along the

Table 10. Varimax-rotated R-mode factor matrix for the Granite Gneiss belt and Slave and Arch Lake Granitoids, considered as a single group.
Only significant factor loadings are listed (>0.3 or < −0.3). The percentage of the total variance in the data explained by each factor is displayed.

	Factor 1	Factor 2	Factor 3	Factor 4
SiO_2	-.805	-.341		-.375
Ba	.804			
MgO	.804			
CaO	.751		.411	
Fe_2O_3	.751	.511		
Sr	.749		.367	
TiO_2	.681	.403		
P_2O_5	.524			
MnO	.440			
Nb		.866		
Y		.820		
Zr	.488	.696		
Zn	.433	.565		
K_2O			-.892	
Na_2O			.852	
Rb	-.457		-.725	
Al_2O_3				.897
% eigen value	43.0	14.2	8.7	6.0

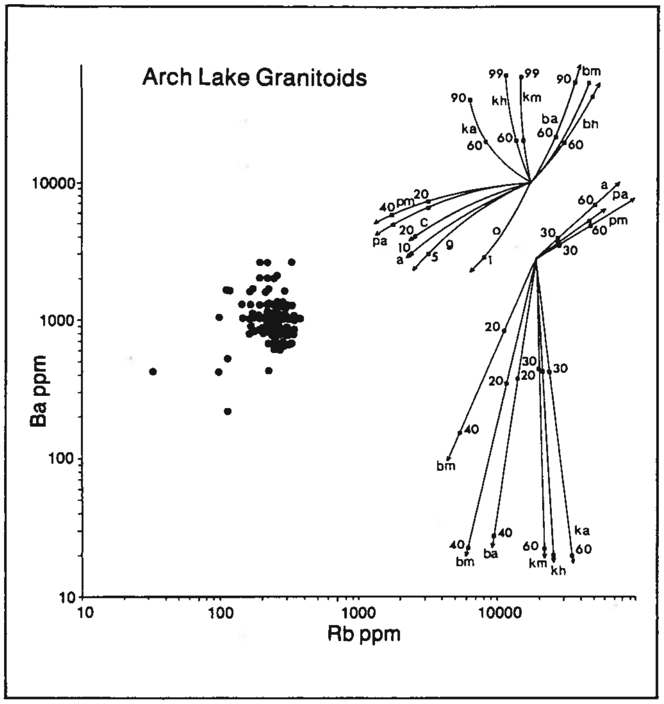

Figure 15. Plot of Ba against Rb for the Arch Lake Granitoids. Straight-line Rayleigh fractionation vectors and curved equilibrium partial melting vectors are shown for specific phases in silicic rocks (after Brown et al. 1981). See caption to figure 8 for key and explanation.

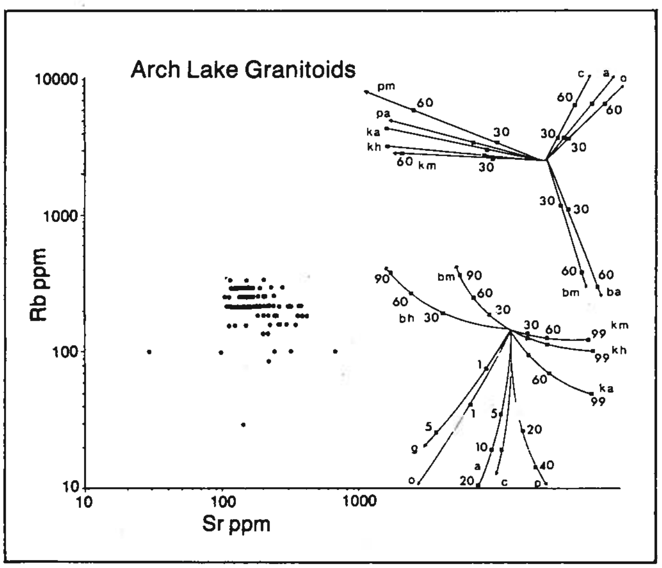

Figure 16. Plot of Rb against Sr for the Arch Lake Granitoids. Straight-line Rayleigh fractionation vectors and curved equilibrium partial melting vectors are shown for specific phases in silicic rocks (after Brown et al. 1981). See caption to figure 8 for key and explanation.

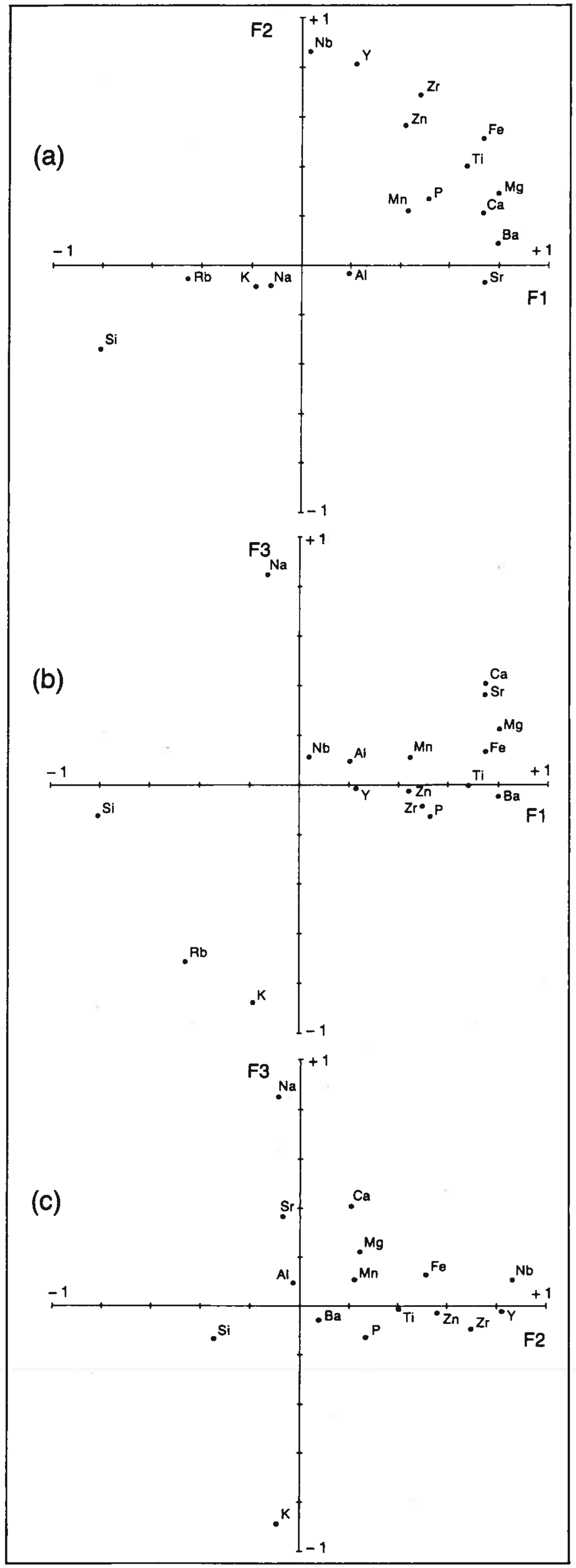

Figure 17. Varimax-rotated R-mode factor matrix for the Granite Gneiss belt and Slave and Arch Lake Granitoids, considered as a single group. The three binary plots consist of factor loadings for each element plotted against each of the three primary factors. See table 10 for precise loadings.

primary factor (F1). This factor, which explains 43 percent of the variance, represents the variation of hornblende plus biotite and calcic plagioclase versus quartz and represents partial melt extraction. A factor (F3) explaining 8.7 percent of the variance, reflects the strong bipolarity between K, Rb, and Na. It indicates K-feldspar fractionation and/or local migration of these elements, caused by subsolidus recrystallization of the alkali feldspar during metamorphism. A further factor (F2) explains 14.2 percent of the variance and links Nb, Y, Zr, and Zn by correlation. This factor is not correlated with the partial-melting/fractional-crystallization factors of either F1 or F3, although a significant component of the Zr and Zn variance is explained by hornblende-biotite fractionation (F1). In both felsic and mafic volcanic suites, Nb and Y show less variation with fractionation than does Zr, but the magnitude of their concentrations varies significantly between rock suites (Winchester and Floyd, 1977; Pearce and Norry, 1979). Therefore, these elements are particularly sensitive to variations of the source composition, upon which subsequent chemical variations caused by crystal fractionation and partial melting can be superimposed. Consequently, F2 represents compositional variation in the original gneiss, where the key elements of this factor show a higher correlation with accessory phases than with any common mafic or felsic minerals.

Plots of the factor scores (figure 18) reveal a considerable overlap between the populations of the Granite Gneiss and the Slave and Arch Lake Granitoids, producing an essentially continuous distribution. The absence of discrete clusters in gneissic terrains suggests homogeneous, rather than mixed, data, indicating a possible common origin (Holland and Lambert, 1975). The granitoids show considerably lower scores in F1 and F3 than the gneisses (figure 18a and b), indicating a higher K-feldspar and quartz content. However, the variation in F2 is identical for all three units. This indicates that for every HFSE composition in the Granite Gneiss, an equivalent composition occurs in the Slave and Arch Lake plutons. Furthermore, these compositional variations are independent of the main partial melting/crystal fractionation processes. These data suggest that the gneiss is a suitable parent material for the Slave and Arch Lake Granitoids, because partial melting of any part of the Granite Gneiss belt, and subsequent crystal fractionation, produces a granitoid which largely retains the HFSE composition of the parent gneiss.

From other studies, based largely upon REE modeling, the partial melting of andesitic gneiss or graywacke under granulite-grade conditions of metamorphism has been proposed extensively as a model for the production of peraluminous quartz monzonites from the Archean of Minnesota (Arth and Hanson, 1975), the Slave Province (Condie, 1981) and South Africa (McCarthy, 1976); and from the Phanerozoic of Nova Scotia (Albuquerque, 1977), and Australia (Price, 1983). Elsewhere in the Churchill Province, massive to foliated peraluminous granodiorite to granite crustal melts commonly occur as migmatites and allochthonous plutons within reworked Archean gneisses.

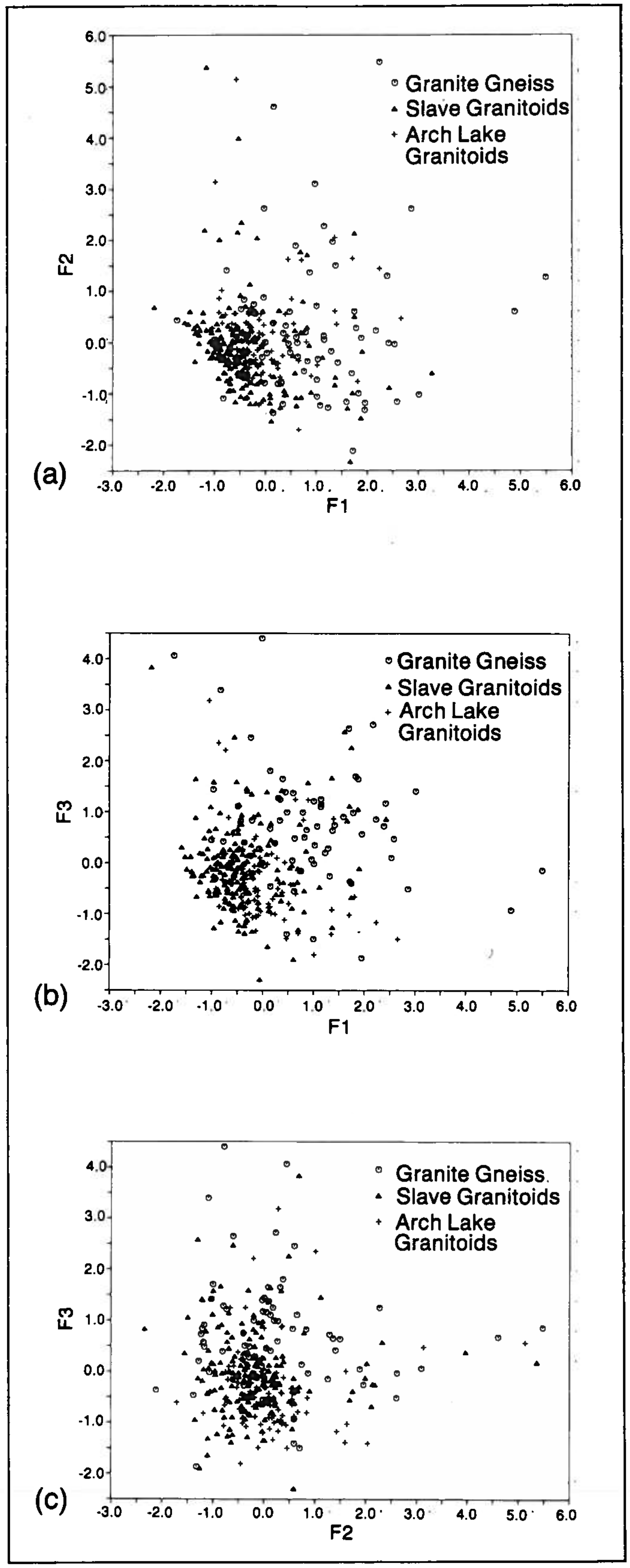

Figure 18. R-mode factor analysis scores of the Granite Gneiss belt and Slave and Arch Lake Granitoids, considered as a single group. The three binary plots represent factor scores, for the three major rock groups, plotted against each of the three primary factors.

These have been interpreted as partial melts of an intermediate to felsic source (Ayres and Cerny, 1982).

The production of silicic granitoids from an intermediate to silicic parent should leave a correspondingly SiO_2-poor restite material. The compositions of melts, source, and restite should all lie on a straight line for binary linear plots for most elements (White and Chappell, 1977). Therefore, the hornblende-bearing gneisses (unit 012) and amphibolites (unit 020) were tested in this way as suitable restite material, using CaO as the plotting base. There is a good correlation between Si, Ti, Fe, Mg, Ca, K, Y, Sr, Rb, and Zn for the mean composition of gneissic units 012, 011, and the Slave Granitoids, but Al, Na, Ba, Nb, and Zr are too low, and Mn and P are too high in the hornblende gneiss for it to be a suitable restite. Similarly, the amphibolites cannot be considered the restite material because Mg is too high and Mn, P, Ba, Nb, Zr, Y, Sr, and Zn are too low. Furthermore, when the amphibolites were grouped with Granite Gneiss and Slave and Arch Lake Granitoids for factor analysis, their scores formed a distinct and separate cluster, suggesting no genetic connection with these rock groups. As explained above, if much of the original gneiss has been incorporated into the Slave and Arch Lake Granitoids, the most suitable restite material will be calcic plagioclase and hornblende-biotite clots, which are now partly incorporated into the granitoids. Unfortunately, no chemical analyses of these clots were available.

In summary, major and trace element trends, modeling of Ba, Rb and Sr, normative felspar compositions, as well as field evidence, all suggest that the Slave and Arch Lake Granitoids were produced by the partial melting of the Granite Gneiss belt at 5 to 6 kb P_{H_2O}, probably during the M2.1 phase of granulite-grade metamorphism (Langenberg and Nielsen, 1982). Some of the more refractory part of the gneiss was retained as a crystal mush within the melts, and subsequent fractional crystallization of quartz, K-feldspar, and plagioclase took place. A subsequent metamorphic event at lower temperatures caused localized alkali metasomatism, which involved coupled exchange of Na and K. This event was probably the amphibolite-grade overprint M2.2 of Langenberg and Nielsen (1982).

Colin Lake Granitoids

The Andrew Lake Plutons (units 121 and 122) show higher MLI values than the Colin Lake Pluton (units 123 and 124), whereas the leucocratic suite (units 125 to 128) yields still higher values (appendix). The leucocratic suite yields clearly discrete secondary trends which transect the most salic segments of the MLI trends for Na, K, Ba, Sr, and Rb in the Colin Lake and Andrew Lake Plutons. The migration of these elements is probably a result of the subsolidus recrystallization of feldspars during metamorphism. The Colin Lake and Andrew Lake Plutons display an increase in Si, K, and Rb with increasing MLI but with a corresponding decrease in Ti, Fe, Mn, Mg, Zn, Zr, Ca, Sr, Al, and P. Na, Nb, and Y yield unclear trends. The Andrew Lake Plutons show an increase in Ba and constant K/Ba with increasing MLI; this indicates negligible K-feldspar fractionation. On the other hand, K-feldspar fractionation in the Colin Lake Pluton is indicated by a corresponding increase in K/Ba and a constant Ba concentration. The lack of a clear decrease in Nb and Y, notably in the Andrew Lake Pluton, emphasizes a differentiation trend of increasing plagioclase rather than K-feldspar and quartz, which control the increase in MLI in the Slave and Arch Lake Granitoids. Similar flat trends for HFSE in differentiated granodiorite are seen in the Tuolumne Batholith in the Sierra Nevadas (Bateman and Chappell, 1979).

Multiple regression analysis indicates that Zr was the only HFSE in the Andrew Lake Plutons, with the exception of Ti, to show significant correlations with biotite, hornblende, and accessory minerals. Factor analysis of the major and trace elements of these plutons yields a factor (F1) expressing the variation of biotite, hornblende, and apatite (Mg, Ti, Zr, and P) versus sodic plagioclase (Na and Si). F2 represents calcic plagioclase (Ca and Sr) versus Y, Nb, Zn, Mn, and Fe. This shows that hornblende and plagioclase fractionation have opposite effects on Nb and Y concentrations. These first three factors represent 87 percent of the variance. Therefore, chemical variations in the Andrew Lake plutons can be explained by fractionation of biotite, plagioclase, and minor hornblende from a single source.

Normative Q-Ab-Or plots (figure 19) emphasize the differences between the two major plutons. The main lithologies of the Andrew Lake Plutons (units I21 and 122) lie between the 4 to 7 kb P_{H_2O} loci of piercing points (see above) and indicate a trend towards in-

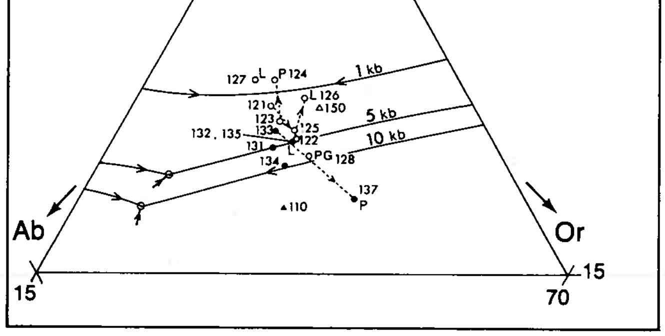

Figure 19. Normative Q-Ab-Or diagram of the mean compositions of the major rock units within the Colin Lake and Wylie Lake Granitoids and in associated minor plutons. H_2O-saturated liquidus field boundaries, at various pressures, in the system Q-Ab-Or-H_2O are from Luth et al. (1964).

creasing normative orthoclase. In contrast, the main Colin Lake Pluton (units 123 and 124) shows an opposite trend, between the 5 and 2 kb P_{H_2O} loci of piercing points, which indicates that these compositions were already in the primary phase volume for orthoclase. The highly calcic nature of both plutons, as well as the differences in their compositional trends, is outlined in figure 20. Because the plutons are of similar age, the relevant ambient pressure during fractional crystallization would have been restricted to the range 5 to 7 kb if P_{H_2O} equals total pressure. This pressure of formation is similar to those estimated for the M2.1 phase of regional metamorphism (Nielsen et al., 1981), and for the crystallization of the Slave and Arch Lake Plutons. In addition, the trend to decreasing normative orthoclase and Ba depletion in unit 124, indicates that the megacrysts are K-feldspar phenocrysts. The detailed textural study by Peikert (1961) supports this suggestion. He noted that K-feldspar depletion in a zone surrounding each megacryst cannot account for the growth of that megacryst. However, it is explained if the megacrysts are mantled phenocrysts and not porphyroblasts.

Both the Andrew and Colin Lake Plutons are similar in their overall compositional range to the Granite Gneiss belt, as revealed by both the MLI plots and by their similar, restricted distribution of Ba, Rb and Sr (figures 21 and 22). The trend of data points below concentrations of 700 ppm Ba and 200 ppm Sr is caused entirely by the leucocratic rock suite. However, the high Ba and Sr end of this trend comprises all three rock groups, which show similar, limited variations in LIL element composition. Most of the Ba and Sr variation in the Andrew Lake and Colin Lake Plutons can be explained by the fractionation of plagioclase, K-feldspar, and minor biotite. The notable variation in Rb suggests that varied partial melting of plagioclase also occurred; however, much of this variation could have been caused by subsequent metamorphic alteration. The trend to Ba and Sr depletion within the leucocratic rock suite, and away from LIL element compositions similar to those of the Colin Lake and Andrew Lake Plutons, suggests a comagmatic origin. Possibly, residual melts, formed by crystal fractionation in the plutons, underwent subsequent fractional crystallization of K-feldspar and plagioclase to produce the leucocratic rock suite.

The chemical variation within the Colin Lake and Andrew Lake Plutons suggests an origin by partial

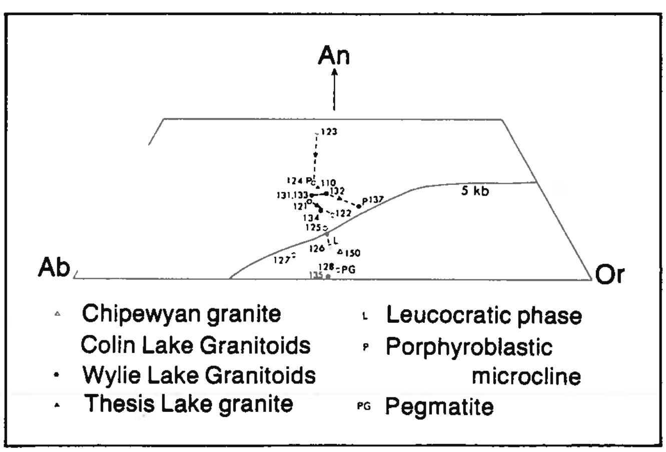

Figure 20. Normative An-Ab-Or diagram of the mean compositions of the major rock units within the Colin Lake and Wylie Lake Granitoids and in associated minor plutons. The 5kb, H_2O-saturated cotectic surface in the system Q-Ab-Or-An, projected from Q, is from Winkler et al. (1975).

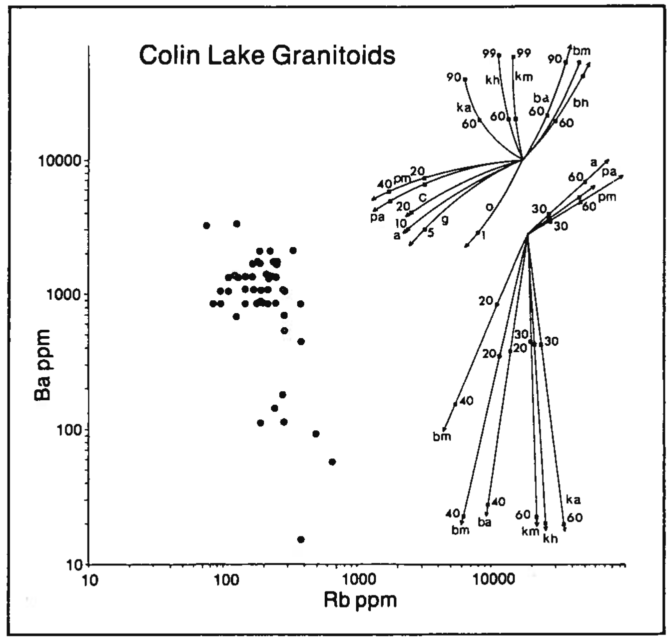

Figure 21. Plot of Ba against Rb for the Colin Lake Granitoids (the Andrew Lake and the Colin Lake plutons). Straight-line Rayleigh fractionation vectors and curved equilibrium partial melting vectors are shown for specific phases in silicic rocks (after Brown et al., 1981). See caption to figure 8 for key and explanation.

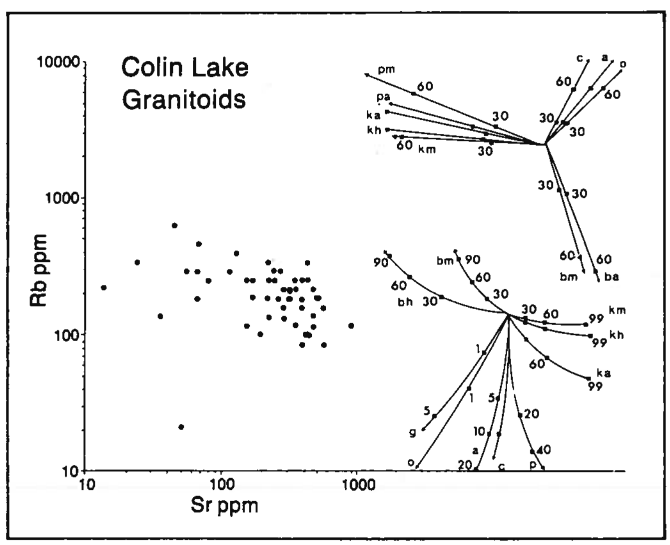

Figure 22. Plot of Rb against Sr for the Colin Lake Granitoids (the Andrew Lake and the Colin Lake plutons). Straight-line Rayleigh fractionation vectors and curved equilibrium partial melting vectors are shown for specific phases in silicic rocks (after Brown et al., 1981). See caption to figure 8 for key and explanation.

melting, possibly with additional fractional crystallization, which involved plagioclase, biotite, and hornblende as residual phases. The plutons were possibly formed from the Granite Gneiss belt during the M2.1 phase of regional metamorphism (Langenberg and Nielsen, 1982). Assuming that the Granite Gneiss belt could be mobilized by only 15 to 25 percent contained melt, and that the partial melt was largely retained by the restite (see above), the resultant diapirs would have a similar overall composition to that of their gneissic protolith. A decreasing thermal gradient is implied from west to east across the Alberta Shield, but the concept cannot be clearly supported from the data of Langenberg and Nielsen (1982). However, such a change in thermal gradient accords with the increasing depth to the Curie isotherm, from west to east across this area, measured by Sprenke (1982). Alternatively, the Andrew Lake and Colin Lake Plutons may have been produced by the partial melting of a mafic to intermediate source material with the subsequent retention of only a minor restite component in the melt. Field evidence does not exist for this source material.

Wylie Lake Granitoids

The main lithological unit of the Wylie Lake Granitoids, the Fishing Creek Quartz Diorite (unit 133, mainly granodiorite), covers a wider range in MLI (see appendix) than the biotite-rich marginal units (131 and 132) and the microcline-megacrystic unit (137). These units display a decrease in Ti, Fe, Mn, Mg, Zn, Y, Ca, Al, Sr and P, and an increase in Si and K with increasing MLI. K/Ba, Na, Nb, and Zr all show no definitive variation with increasing MLI. The effects of a plagioclase-biotite-hornblende residuum are evident in the elemental trends noted above. However, the steady increase of Ba indicates no K-feldspar fractionation in any of the marginal units, including the megacrystic granodiorite (unit 137), even though a maximum in the Ba trend of the Fishing Creek Quartz Diorite indicates K-feldspar fractionation at the center of the pluton. In contrast, the leucocratic suite (units 134 and 135) displays a maximum in Ba and a marked increase in K/Ba, which clearly indicates K-feldspar fractionation. The suite also shows a decline in Zr with increasing MLI. The MLI plots for the Wylie Lake Granitoids as a whole show essentially the same compositional range as for the Granite Gneiss belt.

The decrease in Y versus a corresponding increase in MLI suggests that hornblende is an important residual phase, although modally it is far less abundant than biotite, which in contradistinction does not fractionate Y significantly. The only significant correlations found between trace HFSE and minor modal phases, by multiple regression analysis, were between accessory minerals and Nb and Zr: two elements which remain constant with differentiation, despite a marked decrease in biotite.

Factor analysis on major and trace elements produced: a factor (F1) which represents the variation in biotite plus calcic plagioclase and apatite (Ca, Sr, Mn, Fe, Ti, Mg, Zn, and P) versus quartz (Si); a factor (F3) representing sodic plagioclase (Na and Al) versus K-feldspar (K and Rb); and, factor F2 (Nb, Zr, and Y), which appears to represent variations in the original source composition. Therefore, the Wylie Lake Granitoids do not appear to represent either a fractional crystallization sequence from one magma or a partial melting sequence from a homogeneous source. The first three factors explain 72 percent of the variance.

The normative feldspar plots for the Wylie Lake Granitoids (figures 19 and 20) display a trend from the

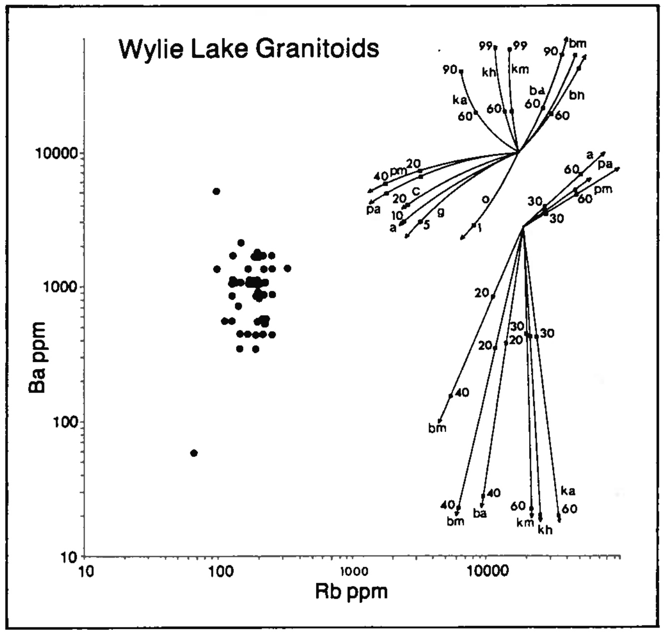

Figure 23. Plot of Ba against Rb for the Wylie Lake Granitoids. Straight-line Rayleigh fractionation vectors and curved equilibrium partial melting vectors are shown for specific phases in silicic rocks (after Brown et al., 1981). See caption to figure 8 for key and explanation.

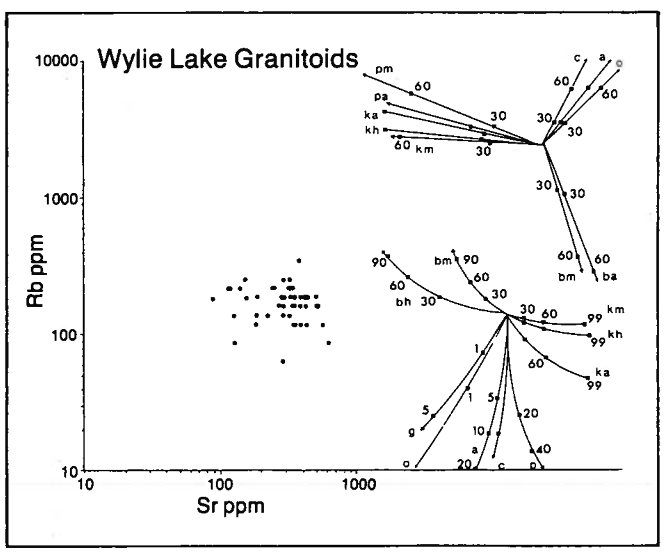

Figure 24. Plot of Rb against Sr for the Wylie Lake Granitoids. Straight-line Rayleigh fractionation vectors and curved equilibrium partial melting vectors are shown for specific phases in slicic rocks (after Brown et al., 1981). See caption to figure 8 for key and explanation.

more biotite-rich marginal units (131 and 132) to the more quartz-rich core (unit 133), which corresponds to the 7 to 5 kb P_{H_2O} loci of piercing points. However, the microcline-megacrystic unit (137) shows a trend towards the Or apex, indicating an unreasonably high pressure of formation and an inexplicable compositional trend if cotectic K-feldspar-quartz crystallization were involved. Despite the textural similarity to the Colin Lake megacrystic unit (124), unit 137 has unusually high contents of normative orthoclase and Ba. This indicates that the megacrysts in unit 137 are true porphyroblasts that grew in the solid state during metamorphism and involved K and Ba metasomatism.

The variation of Ba, Rb, and Sr in the main pluton can be explained by fractional crystallization of plagioclase, K-feldspar and biotite, although the variation in Rb (figures 23 and 24) also requires some variable partial melting of plagioclase and/or hornblende. The distribution of these elements is essentially identical to that of the Granite Gneiss belt. The Ba, Rb, and Sr distribution in the leucocratic suite is similar to that of the predominant units of the Wylie Lake Complex and can be explained by K-feldspar and plagioclase fractionation.

In summary, the Wylie Lake Granitoids form a heterogeneous pluton, derived by variable partial melting and subsequent fractional crystallization of a source containing hornblende, biotite, and plagioclase. Like the Colin Lake Granitoids, the overall chemical similarity to the Granite Gneiss belt suggests that it was possibly formed by the mobilization of the gneiss, consequent upon limited partial melting. Alternatively, the Wylie Lake Granitoids may have formed by the partial melting of a mafic to intermediate material with limited retention of restite in the melt. Unlike the Colin Lake Granitoids, the Wylie Lake Granitoids show evidence of K-metasomatism (for example unit 137) within a marginal synform structure.

Estimate of the mean chemical composition of the Alberta Shield

Introduction

A knowledge of the regional, background abundances of major, and especially, trace elements in the Canadian Shield plays a vital role in the search for low-grade mineral deposits. Previous work on the establishment of regional elemental abundance patterns has been of a broader scope. Data have been extrapolated from selected areas of regional sampling to estimate the composition of a structural province, or even of the whole Canadian Shield. The general scope of such work has meant that estimates of elemental abundances have been based on very few chemical analyses (particularly of major elements), even within these selected areas.

In contrast, the present data set includes a large number of major and trace element analyses combined with detailed mapping (scale 1:31 680) for a limited area of the Churchill Province (9772 km²). Thus, a highly accurate estimate of geochemical abundances is available for a section of the Churchill Structural Province. The Alberta Shield is composed of reworked Archean gneisses and supercrustals intruded by Aphebian silicic plutons, a common association in the Churchill Province (Ayres and Cerny, 1982). Therefore, with some legitimacy, the composition of this shield segment could be considered to be an estimate for the composition of the Churchill Province.

Previous work and methods

Previous estimates of elemental abundances within specific segments of the Canadian Shield have been produced as parts of projects to estimate the composition of the entire Canadian Shield. However, the low and varied sampling density and even lower analytical density causes difficulties in estimating the variance of the resultant mean compositions.

Shaw et al. (1967 and 1976) calculated the mean compositions of six shield segments ranging from approximately 2500 to 350 000 km² in area. The sparse and varied sampling density (approximately one sample per 20 km² to 2800 km²) precluded any accurate estimate of the areal abundance of each rock unit; therefore, the latter was assumed to be proportional to the percentage of samples collected. An even more restricted analytical program used the grouping of the sample suite into seven lithological categories. Duplicate analyses were then produced for each lithological category from seven representative composite rock powders. An estimate of the mean chemical composition for any one shield segment was subsequently made by weighting the mean of each duplicate analysis by the proportion of samples collected from each lithological category. This procedure provided an accurate estimate of the mean composition of the sample population. However, because composite samples were used, the procedure could not be used to assess the considerable compositional variation which must occur in such heterogenous rock categories. For example, 87 percent of the samples collected from the exposed shield of northern Saskatchewan, an area adjacent to northeastern Alberta, fit into a single "quartzo-feldspathic" category and, as such, were used as an estimate for the composition of that shield area.

As part of a 1:250 000 scale mapping survey, Eade and Fahrig (1971 and 1973) sampled nine segments of shield, ranging in size from 4145 to 461 740 km² with a sampling density from one per 15 km² to one per 134 km². The estimates of the compositional means of each segment were, again, based on single analyses of composite powders for each lithological category. However, the detailed sampling allowed the areal proportions of each of the twelve main lithological categories to be used as weighting factors.

A more-detailed level of sampling is needed to estimate the chemical contribution of very minor lithologies which show strong compositional contrasts with their hosts. For example, estimates of the composition of a segment of the Quebec Shield by Eade and Fahrig (1971) omit analyses for diabase dykes.

The most detailed compositional estimate of a specific area of the Canadian Shield is that of Reilly and Shaw (1967). They sampled 111 000 km² of Ontario at a density of one sample per 15 km², and used areal proportions of only eight rock categories to weight the means of 110 trace element analyses and 16 major element analyses of representative composite samples.

If composite samples are representative of the initial sample set, they should be equally accurate for estimating the mean composition of the set. It is noteworthy that estimates for the overall shield composition from both Shaw et al. (1967 and 1976) and Eade and Fahrig (1971 and 1973) are very similar. In both cases the largest shield segment is in northern Quebec, and the same analytical data for Ontario are included in both studies. However, the higher CaO and CO_2 from Shaw et al. (1967), appears to be caused by the inclusion of calcareous supercrustals from the circum-Ungava belt and indicates the bias towards minor lithologies inherent in low-density sampling schemes.

Whether generalized or detailed rock categories are used as a weighting factor, the accuracy of the estimates of mean geochemical abundances within an area depends on the sampling density. A decrease in sampling density will tend to emphasize minor rock types, especially if overburden causes deviations from a strict grid pattern. In addition, if only a few analyses of representative composite samples are used, regional variation, anomalous values, and the statistical significance of chemical composition estimates are unobtainable.

In the present study, the 9772 km² Alberta Shield was sampled at an average density of one per 0.7 km², allowing a highly accurate delineation of 46 mappable lithological units (table 11). A representative set of 638 samples was selected for wet chemical and XRF analyses to provide one analysis point per 15 km². An additional 21 reference samples were selected from the Marguerite River inlier, a 220 km² area south of Lake Athabasca. Areal proportions of each rock unit could not be accurately calculated here owing to extensive mylonitization.

The average composition of the Alberta Shield was calculated by two methods. The first method employed the arithmetic sample mean of all analyzed reference samples; in the second, the major and trace element means of each rock unit were weighted according to the proportion of the study area underlain by that rock unit. An area-weighted, pooled standard error was also calculated, using the method of Holland and Lambert (1972).

Compositional variation within the Alberta Shield was assessed by combining, where necessary, published map sheets into units approximately equal in area, and by calculating the mean of all analyzed reference samples within that map sheet. An equivalent area-weighted mean could not be calculated because areally important lithological units were not always sampled in every map sheet. The location and numbering of each map sheet is given in figure 25.

The areal proportion of each lithological unit for each map sheet and for the total area are given in table 11. These areal data were determined by planimeter. Using aeromagnetic maps, lithological boundary extrapolation below water and drift-covered areas (which combined accounted for 43.8 percent of the mapped Alberta Shield) allowed these areas to be incorporated into the abundance estimates for each rock unit.

In order to use the data of table 11 for calculating the area-weighted chemical composition of the Alberta Shield, the following modifications were made. The areal contributions of both the Charles Lake intrusions (171, 172 and 173) and the low-grade metavolcanic group (210) were deleted because they form only 0.34 percent of the total area. The high-grade metasedimentary rocks (031 and 032) were grouped together (030) because the composite analyses for each metasedimentary band cannot be subdivided on an areal distribution basis. Low-grade quartzites (201) and biotite schist (202) were also included in unit 030 for the purpose of calculating the average shield composition, because they represent only 0.32 percent of the total study area.

Results

Table 12 displays two estimates of the mean compositions for major and trace elements from the Alberta Shield. These estimates were produced by weighting the mean chemical composition of each rock unit by either the number of analyzed samples, or the areal proportion of that rock unit. Normative compositions of these estimates are given in table 13. The area-weighted chemical composition is that of a calc-alkaline dacite (using the classification scheme of Irvine and Baragar, 1971), with over 70 percent SiO_2, a high K_2O content (4.63 percent) and a normative color index of 7. This chemical composition illustrates the obvious influence of the Slave Granitoids, which form 37 percent of the outcrop area, as opposed to 20 percent for the Granite Gneiss belt and 18 percent for the Arch Lake Granitoids. The Wylie Lake and Colin Lake Granitoids have only a minor influence upon the overall composition of the Alberta Shield, and form 10.3 percent and 3.5 percent of the total area, respectively (table 11). The mean modal composition is that of a hornblende biotite quartz monzonite.

At the 0.01 level of significance, the area-weighted chemical composition is higher in Si and K, and lower in Mg, Fe, Ca, Ti and Zn, than is the sample-weighted mean. This clearly indicates that the sample-weighted scheme underestimated lithological units with the largest outcrop areas—in this case, the silicic Slave Granitoids. Although this bias is to be expected, the sampling density was fairly uniform, except for map sheets 1 to 8, 31, and 36. Those areas were mapped early in the program and the data points are more closely spaced than in the other map sheets (figure

Table 11. Areal percentages of lithological units within each map sheet and for the entire Alberta Shield north of Lake Athabasca.

Rock Unit	Map Sheet 1	2	3	4	5	6	7	8	13	14	15	16	17	18	19	20	21
011	41.34	38.76	28.27	7.44	60.3	68.5	44.0	75.6	39.8	0.0	13.4	26.5	25.9	4.3	1.7	0.0	0.1
012	0.55	4.70	3.61	0.32	10.7	13.7	35.6	3.9	1.2	0.0	0.9	2.3	0.3	0.0	0.0	0.1	0.0
020	0.0	0.13	0.40	0.0	1.1	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
031	27.35	6.53	0.98	0.29	13.5	11.7	12.2	10.1	6.7	0.0	10.3	22.4	3.3	0.2	1.3	0.9	6.3
032	2.8	0.10	0.57	tr	0.1	0.1	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
101	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	95.7	28.3	0.0	0.0	0.0	0.0	98.0	76.8
102	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.4	0.0	0.0	0.0	0.0	0.8	7.0
103	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
104	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
106	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.6	0.0	3.1	0.4	0.0	0.0	0.0	0.0	0.0
121	16.88	6.36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
122	8.78	0.68	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
123	0.0	4.54	13.80	2.70	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
124	0.0	0.64	40.98	58.62	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125	1.95	13.45	9.41	1.30	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
126	0.0	0.0	0.31	5.05	0.2	tr	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
127	0.0	3.80	1.67	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
131	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.7	1.0	14.5	15.6	5.1	0.0	0.1
132	0.0	0.0	0.0	24.28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	18.2	0.7	0.0	0.0
133	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	tr	0.0	2.4	15.5	8.7	12.8	38.9	0.0	0.2
134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
136	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	24.2	46.4	52.0	0.0	0.0
137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	2.2	0.1	0.0	0.0
140	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.2	34.9	9.8	tr	0.0	0.0	0.0	1.3
161	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.2	8.0
162	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.8	0.0	0.0	0.0	0.0	tr	0.3
164	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
171	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
172	0.0	0.0	0.0	0.0	2.2	0.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
173	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
175	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
201	0.35	10.59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
202	0.0	4.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
203	0.0	2.68	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
210	0.0	3.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
221	0.0	0.0	0.0	0.0	10.0	5.0	0.6	2.9	22.9	0.0	0.9	21.5	6.6	0.0	0.0	0.0	0.0
222	0.0	0.0	0.0	0.0	0.5	0.0	1.5	1.0	0.7	0.0	tr	tr	0.7	0.0	0.0	0.0	0.0
223	0.0	0.0	0.0	0.0	1.4	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.0
224	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Area km^2	187.8	188.6	187.8	193.0	190.6	188.6	107.2	278.7	71.7	279.5	489.8	293.4	398.1	367.0	223.0	246.8	402.0

26). Map sheets in the drift-covered areas of the extreme south were less well-represented (see figures 25 and 26 and table 14).

The mean composition of major and trace elements for each map area, or of grouped maps of approximately equivalent area, is given in table 14. One way analysis of variance both on the major element compositions and on logarithmic transforms of the trace element compositions of each map area indicates that no single element has a constant abundance in all map sheet areas at this scale of subdivision. Compositional variation across the Alberta Shield can be most easily demonstrated by comparing the mean composition in each map area with the mean composition of the entire Alberta Shield, weighted according to the areal proportions of each rock unit. Table 15 compares these estimates using t-tests at the 0.01 level of significance. Map area 31, which is underlain by approximately equal proportions of Arch Lake Granitoids (43 percent), Slave Granitoids (33 percent), and Granite Gneiss (27 percent), closely represents the mean composition of the Alberta Shield, as does map area 26, which is predominantly underlain by the Slave Granitoids (87 percent) and minor Arch Lake Granitoids. The mylonitized Marguerite River inlier (map area 12) is also chemically similar to the mean composition of the

Table 11. (continued)

Rock Unit	Map Sheet 22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	Total Area
011	13.2	54.7	0.0	0.0	0.4	15.8	0.0	0.0	0.1	19.3	0.0	0.0	1.1	1.4	26.5	15.07
012	0.4	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	0.0	0.0	10.1	2.05
020	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	tr	0.2	0.0	0.0	0.0	0.0	0.5	0.08
031	21.4	4.5	0.0	0.7	2.1	6.7	3.5	0.5	0.1	0.6	tr	1.7	9.8	1.9	4.2	5.60
032	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	tr	0.10
101	31.1	tr	63.5	71.6	84.4	37.4	63.9	30.6	8.4	16.3	99.95	98.2	84.4	2.8	8.4	35.24
102	4.4	0.0	0.1	1.0	2.2	5.7	0.1	0.1	0.0	2.9	0.0	0.0	0.3	0.2	0.3	1.25
103	0.0	0.0	1.0	0.1	0.2	1.4	0.2	0.1	tr	0.1	0.0	0.0	0.0	0.1	0.2	0.13
104	0.0	0.0	0.0	0.0	0.0	0.0	tr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
105	0.1	0.0	tr	0.3	0.1	1.2	0.0	0.0	0.3	2.0	0.0	tr	0.0	0.0	0.0	0.16
106	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.18
110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.37
121	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.45
122	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.18
123	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.41
124	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.05
125	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.50
126	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	1.5	0.22
127	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10
128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
131	2.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.49
132	1.1	0.0	0.0	0.0	0.0	tr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.57
133	7.4	5.7	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.85
134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
136	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.00
137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.37
140	0.0	0.0	10.5	15.6	1.1	0.0	0.0	1.4	0.0	0.1	0.0	tr	tr	0.1	0.0	1.10
150	3.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.33
161	3.6	2.5	tr	0.0	6.6	19.9	7.9	32.1	72.6	33.1	0.0	0.0	1.7	85.9	28.8	12.14
162	8.0	0.0	0.0	0.4	1.7	3.6	24.4	35.2	18.4	10.1	0.0	0.0	2.7	7.3	2.6	4.51
164	0.0	0.0	24.8	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.88
171	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	2.6	0.13
172	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.07
173	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	tr	0.08
175	0.0	0.0	0.0	10.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.46
201	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.24
202	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.08
203	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05
210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.06
221	3.4	23.7	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	6.2	2.93
222	0.2	0.2	0.0	0.0	0.0	tr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.11
223	0.0	3.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	1.8	0.38
224	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.5	0.03
Area km^2	424.8	281.5	326.3	399.4	397.8	398.3	321.7	392.6	393.2	391.9	183.6	392.4	392.1	393.7	389.0	9772

entire Alberta Shield north of Lake Athabasca.

Regional compositional variation is also apparent within the major lithological units. For instance, map area groups 5 plus 6 and 7 plus 8 lie within the northern part of the Granite Gneiss belt and are notably richer in cafemic components, Zr, Y, and Zn than is the extreme south of the Granite Gneiss belt (map area 13). The latter is similar to the Alberta Shield in its mean composition. In like manner, map areas 20, 21, 32, and 33, underlain by Slave Granitoids, are correspondingly lower than the Alberta Shield in Mg, Ca, and Sr. However, although they are underlain by the same lithology, these four map areas show significantly different mean concentrations for most elements. Furthermore, the northern pluton of the Slave Granitoids is lower in P than is the southern pluton, and the extreme northwest of the northern pluton is higher in Si and lower in Ti, Fe, Mn, Nb, and Zr than are the other areas of the Slave Granitoids.

Table 16 shows the two estimates for the chemical composition of the Alberta Shield and other estimates for the Churchill Province, the Proterozoic Canadian Shield, the entire Canadian Shield, and the total crust. The accuracy of comparisons is commonly uncertain because the variance of these estimates is not normally available.

The potassic nature of the Alberta Shield is apparent even where compared to either the adjacent shield of

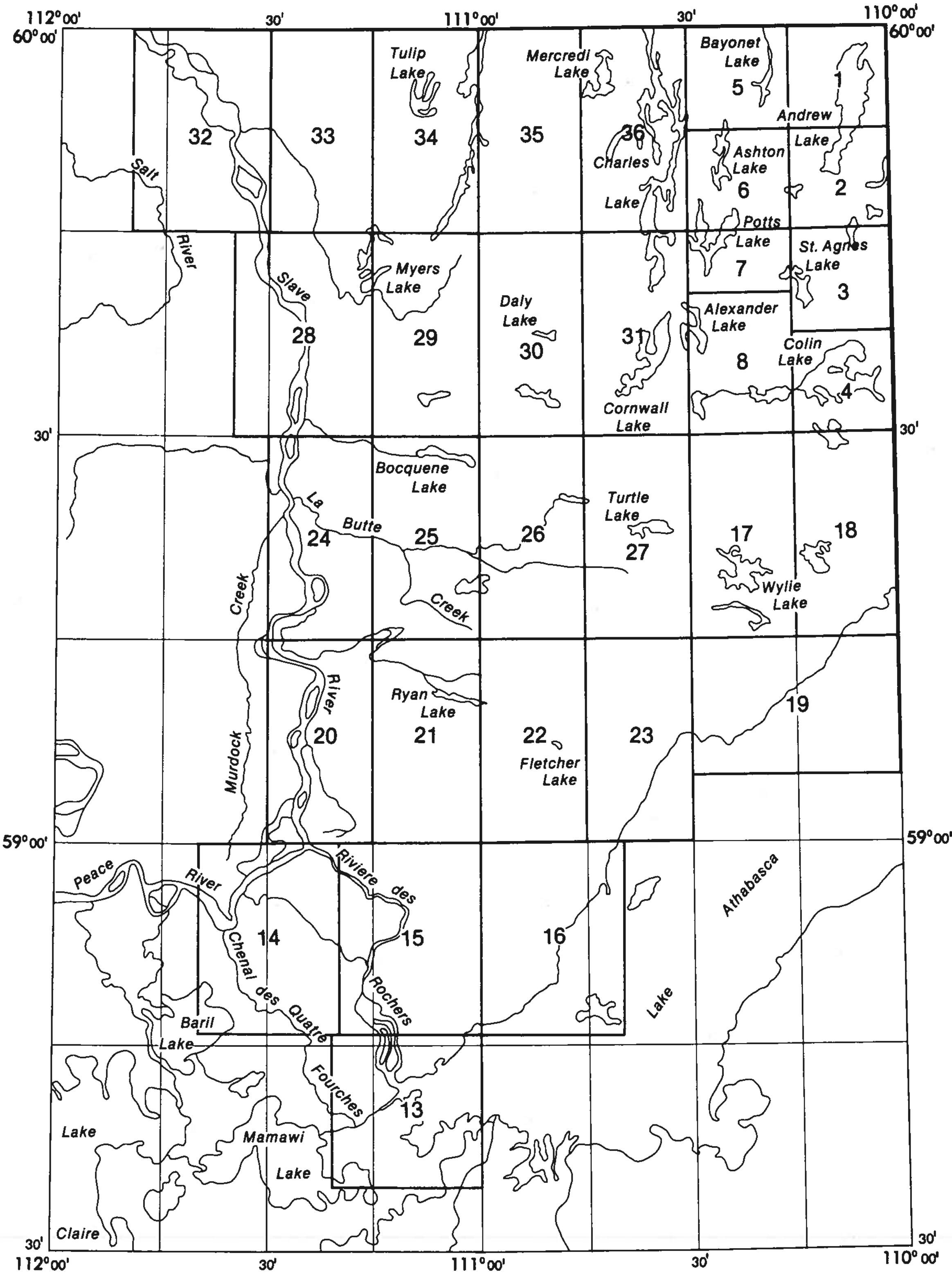

Figure 25. Index and location of maps (1:31 680) of the Alberta Shield. Map sheet 12 (Marguerite River) is south of Lake Athabasca and is not illustrated.

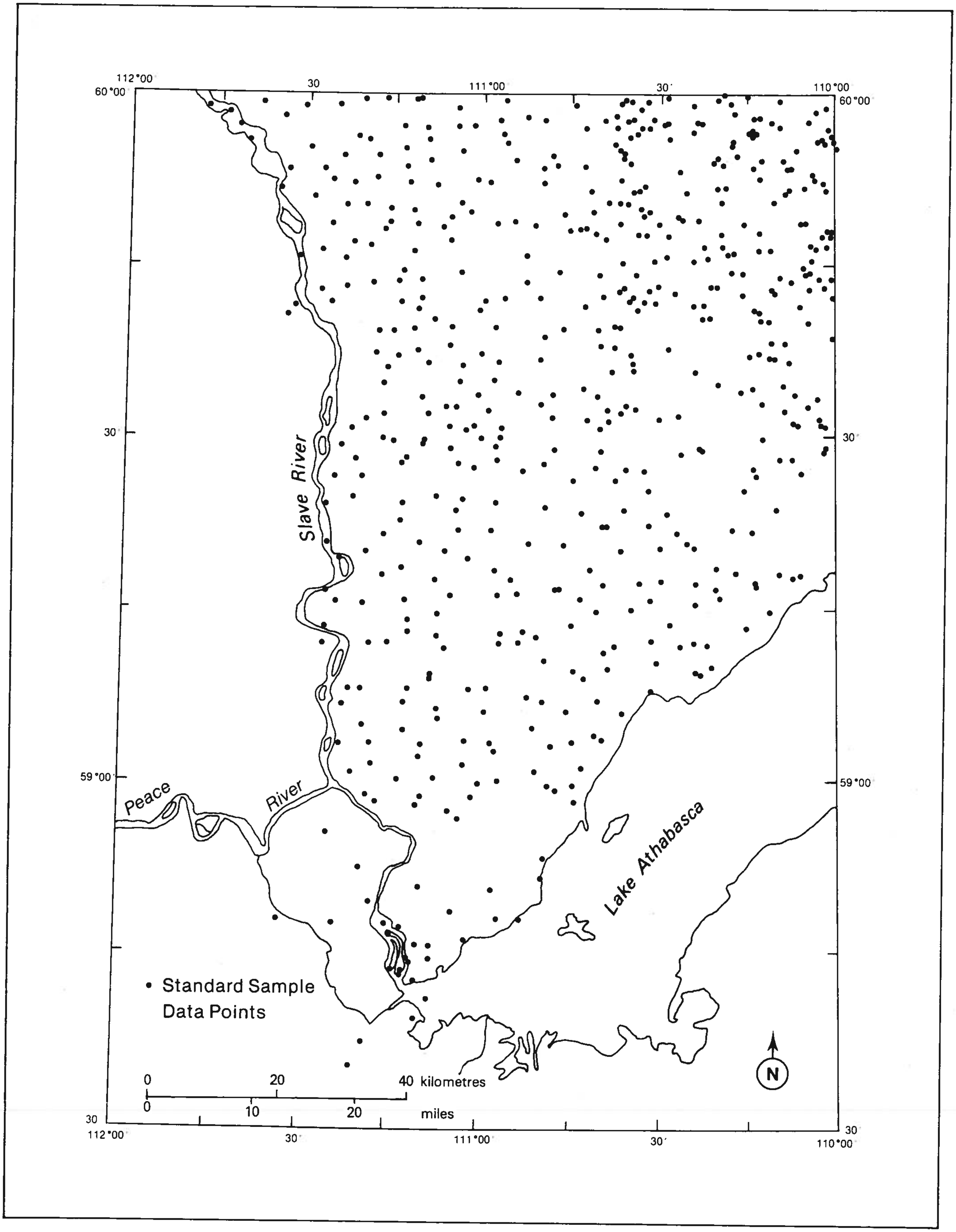

Figure 26. Distribution of standard-sample locations for the Alberta Shield.

Table 12. Two estimates of the mean major and trace element compositions of the Alberta Shield compared with the Granite Gneiss belt of Alberta and with the upper continental crust.

	Alberta Shield						Upper Continental Crust
	All rock units (weighted by area)		All rock units (weighted by sample number)		Granite Gneiss Belt (weighted by area)		
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$
SiO_2	70.35	0.15	68.75	0.26	68.20	0.59	66.0
TiO_2	0.37	0.01	0.46	0.02	0.50	0.04	0.6
Al_2O_3	14.76	0.06	14.77	0.06	14.62	0.16	16.0
Fe_2O_3	2.66	0.07	3.42	0.12	3.69	0.23	4.95
MgO	1.02	0.03	1.50	0.07	1.31	0.10	2.3
CaO	1.60	0.04	2.09	0.08	2.58	0.19	3.5
Na_2O	3.26	0.04	3.14	0.04	3.63	0.12	3.8
K_2O	4.63	0.06	4.40	0.06	3.94	0.18	3.5
MnO	0.05	0.00	0.06	0.00	0.07	0.01	0.08
P_2O_5	0.14	0.01	0.14	0.01	0.15	0.02	-
H_2O-	0.08	0.00	0.07	0.00	0.71	0.04	-
L.O.I.	0.70	0.02	0.79	0.02	0.05	0.01	-
Ba	938	25	970	26	1385	96	700
Nb	21	2.4	22	0.5	23	1.3	25
Zr	189	5	197	6	290	21	240
Y	21	0.6	22	0.6	27	2.5	22
Sr	261	8	270	8	383	25	350
Rb	188	3	179	3	130	7	115
Zn	49	1.3	55	1.5	55	4	52

The means for each rock unit are weighted according to either the areal proportion of that rock unit, or to the number of analyses per rock unit. The standard error for each area-weighted mean is a pooled estimate, calculated as follows. The simple standard error for each rock unit was multiplied by the corresponding areal proportion of that rock unit to give a series of area-weighted standard errors. The pooled estimate was then calculated by taking the square root of the sums of the squares of each member in this series (see Holland and Lambert, 1972). The upper crustal composition is from Taylor and McLennan (1981).

Table 13. CIPW norms of two compositional estimates of the Alberta Shield compared with the Granite Gneiss belt of Alberta and with the upper continental crust.

	Alberta Shield			Upper Continental Crust
	All rock units (weighted by area)	All rock units (weighted by sample number)	Granite Gneiss Belt (weighted by area)	
	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
Q	28.4	26.1	23.8	17.7
C	1.8	1.4	0.1	-
Or	27.8	26.4	23.7	20.6
Ab	28.0	26.9	31.2	32.0
An	7.1	9.5	12.0	16.2
En	2.6	3.8	3.3	5.5
Fs	2.4	3.6	3.3	4.3
Mt	0.9	1.2	1.3	1.6
Il	0.7	0.9	1.0	1.1
Ap	0.3	0.4	0.4	-
An %	19	25	27	32
C.I.	6.6	9.4	8.9	13.5

C.I. - normative color index. An Fe_2O_3/FeO ratio of 0.33 is assumed. The upper crustal composition is from Taylor and McLennan (1981), and includes 0.9% Di and Hd. Owing to the highly representative distribution of sample locations within the Granite Gneiss belt, the number-weighted and area-weighted means are essentially identical, hence only the latter is given.

northern Saskatchewan, or the remainder of the Churchill Province. Northern Saskatchewan has higher Al, but lower K, Nb, and Zn than does northeastern Alberta (the unusually low Nb for northern Saskatchewan may result from the exclusion of mafic and intermediate rock types from the estimate). The whole Churchill Province is notably higher in Ca, Mg and Fe, and lower in Si, K, and Ba than is its Alberta segment. Kasmere Lake in northern Manitoba (Eade and Fahrig, 1971 and 1973) is the only area of the Churchill Pro-

Table 14. Mean major and trace element compositions for each map sheet group of the Alberta Shield. Simple means are used with no areal weighting factor according to rock unit.

Map Sheet	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	L.O.I.	H_2O-	Total	N
1+2	66.90	0.50	14.66	4.73	2.40	2.58	2.91	4.03	0.10	0.14	0.94	0.00	99.90	60
3+4	65.91	0.60	14.11	4.96	2.77	3.12	2.69	4.07	0.10	0.22	1.00	0.00	99.54	30
5+6	66.65	0.59	14.67	4.90	2.07	2.96	3.24	3.26	0.08	0.14	0.97	0.00	99.52	34
7+8	64.80	0.71	15.33	4.86	2.35	2.99	3.25	3.60	0.09	0.22	1.07	0.07	99.34	24
12	68.85	0.44	15.26	2.97	1.25	2.18	3.58	4.70	0.05	0.19	0.61	0.13	100.07	21
13	67.12	0.46	14.15	4.09	2.03	2.17	3.77	3.95	0.07	0.14	0.87	0.13	98.97	12
14	71.68	0.25	14.25	2.05	0.71	1.15	3.70	4.39	0.15	0.06	0.62	0.20	99.23	4
15	67.91	0.49	13.21	3.95	2.40	2.45	2.95	4.12	0.13	0.13	0.81	0.19	98.73	15
16	68.03	0.46	14.24	3.89	1.81	2.22	3.15	3.43	0.09	0.15	1.26	0.25	98.97	14
17	66.46	0.52	15.27	4.05	2.24	2.28	2.95	4.36	0.06	0.16	1.46	0.19	100.01	21
18	66.23	0.54	14.87	4.80	1.93	2.70	3.19	4.11	0.07	0.18	1.10	0.17	99.90	14
19	67.77	0.37	16.14	2.65	1.51	1.72	4.13	4.27	0.04	0.11	1.00	0.22	99.93	9
20	72.05	0.34	14.54	1.53	0.43	1.04	3.39	5.64	0.02	0.09	0.31	0.11	99.51	12
21	71.52	0.38	13.59	2.66	0.76	1.36	3.31	5.15	0.03	0.11	0.69	0.07	99.63	25
22	71.65	0.32	14.61	2.15	0.91	1.09	3.16	4.77	0.03	0.09	0.74	0.07	99.57	18
23	67.25	0.75	15.11	3.69	1.64	2.47	3.03	4.35	0.07	0.15	1.01	0.07	99.59	20
24	72.21	0.30	14.23	1.82	0.53	1.26	3.28	4.64	0.04	0.21	0.33	0.05	99.89	16
25	70.02	0.40	15.20	2.35	0.85	1.94	3.71	3.71	0.05	0.24	0.44	0.05	98.98	22
26	70.57	0.36	15.46	2.29	0.78	1.37	3.66	4.29	0.04	0.16	0.49	0.08	99.56	18
27	69.98	0.43	14.51	3.57	1.05	1.53	2.79	4.98	0.06	0.09	0.68	0.09	99.75	20
28	71.42	0.28	14.97	1.97	0.67	0.95	3.07	5.34	0.05	0.10	0.56	0.17	99.60	23
29	70.45	0.35	14.53	2.34	1.06	1.45	3.31	5.09	0.02	0.13	0.58	0.17	99.43	25
30	72.10	0.28	14.89	1.69	0.51	0.90	3.10	5.31	0.03	0.15	0.47	0.08	99.51	18
31	68.94	0.35	15.09	3.06	1.17	2.39	3.39	4.12	0.05	0.14	0.74	0.03	99.47	32
32	73.71	0.16	14.72	1.33	0.24	0.78	2.90	5.91	0.02	0.10	0.44	0.05	100.36	14
33	72.44	0.26	15.16	1.85	0.48	0.63	2.59	5.55	0.03	0.09	0.53	0.08	99.69	22
34	72.43	0.22	15.35	1.75	0.47	0.80	2.97	5.07	0.02	0.12	0.47	0.07	99.75	26
35	70.39	0.51	14.77	2.61	0.86	1.79	2.92	5.37	0.01	0.11	0.66	0.06	99.97	21
36	64.84	0.70	15.07	5.12	2.37	3.77	3.01	3.54	0.08	0.15	0.99	0.01	99.66	48

vince in which the sampling density, for composite samples, matches the analytical density of the Alberta Shield within an area of similar size. Its mean composition (weighted according to rock unit abundance) is higher in Mg, Ca and Fe, and lower in K, Na, P, Ba and Sr than in the Alberta Shield, and is underlain by a higher proportion of metasedimentary rocks. The composition of the entire Proterozoic Canadian Shield is dominated by the contribution of the Churchill Province and is significantly higher in Ca, Mg, Fe, Al, Ti and P, and lower in Si, K and Ba than is the Alberta Shield.

Comparisons of northeastern Alberta with the entire Canadian Shield are more difficult, owing to uncertainties in estimates of the composition of the whole Shield. Notably, estimates vary according to whether sampled areas are given equal weight, or weighted according to the size of the relevant structural province (Eade and Fahrig, 1971). In addition, the compositions presented by Shaw et al. (1967 and 1976) and Eade and Fahrig (1971 and 1973) are estimates of the composition of the surface of the Canadian Shield and are not necessarily valid estimates for the upper crust. Varied weighting factors applied to supercrustal materials by Shaw et al. (1967 and 1976) and Eade and Fahrig (1971 and 1973) have caused substantial disparities in their estimates of the concentrations of Ca, Al, Cu, and Cr. On the assumption that the shield surface is a representative cross section of the upper continental crust, a combination of compositions F and

Table 14. (continued)

Map Sheet	Ba	Nb	Zr	Y	Sr	Rb	Zn	N
1+2	959	17	163	23	262	196	76	53
3+4	957	17	199	30	321	192	67	35
5+6	1152	25	252	28	325	139	64	42
7+8	1397	28	354	36	371	130	74	24
12	848	27	250	20	243	182	57	21
13	1267	23	295	29	359	124	49	12
14	611	22	138	23	182	188	32	4
15	974	20	170	18	241	152	45	15
16	835	36	184	24	203	119	60	14
17	967	23	238	26	296	162	68	21
18	863	23	209	27	367	147	65	14
19	788	22	179	22	255	160	57	8
20	731	19	162	17	175	211	35	12
21	706	19	147	15	207	180	36	25
22	696	22	139	18	179	182	38	18
23	1423	22	265	22	310	136	57	20
24	1226	22	158	17	274	188	46	16
25	1434	21	170	14	467	138	51	22
26	1076	23	170	20	388	143	44	17
27	1013	27	317	32	184	146	65	20
28	722	17	144	18	196	213	36	23
29	818	18	154	16	197	212	43	25
30	1082	20	196	18	189	237	38	18
31	1275	25	194	23	409	160	56	31
32	442	16	97	18	111	236	26	14
33	540	17	134	17	128	266	39	22
34	437	20	100	16	133	277	42	26
35	993	24	202	17	213	236	59	21
36	1081	24	226	24	327	134	66	48

Table 15. t-test comparisons of the mean compositions of each map sheet group, from table 14, with the mean composition of the entire Alberta Shield, using a weighting factor for the proportional area of each rock unit. Elements which are significantly larger or smaller ($p = 0.01$) than the shield mean, are denoted by a plus or minus sign, respectively.

Map Sheet	Si	Ti	Al	Fe	Mg	Ca	Na	K	Mn	P	Ba	Nb	Zr	Y	Sr	Rb	Zn	N
1+2	–			+	+	+			+								+	60
3+4	–		–	+	+	+			+					+			+	40
5+6	–	+		+	+	+		–	+				+	+		–	+	45
7+8	–	+		+	+	+		–	+				+	+		–	+	24
12																		21
13																–		12
14											–							4
15			–															15
16																–		14
17	–	+		+	+											–		21
18																–		14
19																		9
20					–	–		+		–					–		–	12
21			–								–			–	–			25
22						–				–					–			18
23		+														–		20
24					–													16
25								–						–				22
26																		18
27										–								20
28						–				–			–					23
29									–			–	–	–	–			25
30	+	–		–	–	–		+	–						–	+	–	18
31																		32
32	+	–		–	–	–		+	–	–	–	–	–		–		–	14
33					–	–	–			–					–	+		22
34	+				–	–			–		–	–	–		–	+		26
35								+	–									21
36	–			+	+	+		–	+							–		48

G (see table 16) were used by Taylor and McLennan (1981) to provide an estimate for the composition of the upper crust (H in table 16). Compared with northeastern Alberta, the upper crust is lower in Si, K, Ba and Rb, and higher in Ti, Al, Fe, Mg, Ca, Na, Mn, P, Nb, Zr and Sr. Only Y and Zn show similar concentrations in both the Alberta Shield and the upper crust as a whole.

The various estimates for the composition of the entire continental crust, in table 16, indicate a decrease in K, Th, and U with depth in the crust. This constraint has been imposed on these crustal models by independent methods: the interpretation of heat flow data in continental environments (Lambert and Heier, 1968); and, the compositions of both high-pressure granulite terrains (Holland and Lambert, 1972) and crustally derived xenoliths (Kay and Kay, 1980). Although dependent upon a variety of models, these estimates of crustal composition are fairly consistent and indicate a lower crust richer in cafemic components plus Ti and P, whereas progressively newer segments of the upper crust display increasing concentrations of Si, K, Ba, and Rb. However, Y and Zn do not appear to vary significantly throughout the crust, even when comparing a notably potassic segment of the Churchill Province (the Alberta Shield) with the entire continental crust. By contrast, Nb and Zr show very little variation throughout the upper crust but appear to be comparatively depleted in the lower crust. This feature probably reflects the instability of biotite in the lower crust.

If the Granite Gneiss belt within the Alberta Shield is the parent material of the dominant Proterozoic plutons, and is representative of this segment of the Churchill Province before partial melting, then the effect of plutonism has been to significantly increase Rb, Si and K, and to decrease most other elements, except for Al, P, Nb and Zn, which have remained similar at the 0.01 level of significance (table 12). Compared to a model for upper continental crust, this gneissic precursor is significantly higher in Si and Ba, and lower in Al, Ca, Fe, and notably Mg, at the 0.01 level of significance. It is also slightly corundum normative, rather than diopside normative, and has the composition of dacite rather than tholeiitic andesite (table 13). However, the contents of K, Na, Ti, Nb, Zr, Y, Sr, Rb, and Zn are similar in both the Granite Gneiss belt and the upper continental crust. The same conclusion is reached by comparing the Granite Gneiss belt to the Churchill Province, except that Ca content is not significantly different in those structural units.

Table 16. Two estimates for the mean major and trace element compositions of the Alberta Shield compared with similar estimates for the Canadian Shield and the continental crust.

	N.E. Alberta		Proterozoic Shield			Canadian Shield			Continental Crust			
	A	B	C	D	E	F	G	H	I	J	K	L
SiO_2	70.35	68.75	70.63	65.9	65.0	64.93	65.2	66.0	61.9	60.3	62.5	58.0
TiO_2	0.37	0.46	0.33	0.56	0.62	0.52	0.57	0.6	0.8	1.0	0.68	0.8
Al_2O_3	14.76	14.77	15.30	15.5	16.0	14.63	15.8	16.0	15.6	15.6	15.6	18.0
Fe_2O_3	2.65	3.42	2.45	4.9	4.98	4.42	4.98	4.95	6.9	7.9	6.1	8.3
MgO	1.02	1.50	1.05	2.0	2.1	2.24	2.2	2.3	3.1	3.9	3.2	3.5
CaO	1.60	2.09	2.28	3.2	3.3	4.12	3.3	3.5	5.7	5.8	6.0	7.5
Na_2O	3.26	3.14	3.10	3.6	3.5	3.46	3.7	3.8	3.1	3.2	3.4	3.5
K_2O	4.63	4.40	3.64	3.43	3.51	3.45	3.23	3.5	2.9	2.5	2.3	1.5
MnO	0.05	0.06	0.05	0.08	0.09	0.07	0.09	0.08	0.1	0.1	0.13	0.14
P_2O_5	0.14	0.15	0.11	0.18	0.19	0.15	0.17	-	0.3	0.2	0.18	-
H_2O tot.	-	-	0.79	0.7	0.7	0.92	0.8	-	-	-	-	-
L.O.I.	0.78	0.86	-	-	-	-	-	-	-	-	-	-
Ba	938	970	973	680	810	-	730	700	-	425	-	350
Nb	21	22	14	-	-	26	-	25	-	20	-	11
Zr	189	197	237	-	-	237	-	240	-	165	-	100
Y	21	22	16	-	-	21	-	22	-	33	-	22
Sr	261	270	285	280	310	316	320	350	-	375	-	400
Rb	188	179	122	-	-	110	-	115	-	90	-	42
Zn	49	55	27	57	63	52	60	52	-	70	-	-
Cu	-	-	13	19	20	14	26	25	-	55	-	60
Ni	-	-	7	15	11	19	19	20	-	75	-	30
Cr	-	-	5	49	45	35	59	35	-	100	-	55
U	-	-	-	2.6	2.2	2.5	2.1	2.9	-	2.7	-	1.25
Th	-	-	-	15.5	13.6	10	13	11.1	-	9.6	-	4.8

A - Alberta Shield, area-weighted mean compositon of over 620 samples. The total area represented is 9772 km^2 (present work); B - Alberta Shield, sample number-weighted mean of at least 641 samples. The total area represented is approximately 9990 km^2 and includes the Marguerite River inlier (present work); C - northern Saskatchewan, mean of 18 composite "quartzofeldspathic" samples (Shaw *et al.*, 1967 and 1976); D - Churchill Province, mean of 41 composite samples (representing 1648 samples) area-weighted according to rock type. Seven tracts of the Churchill Province are represented, totaling 127,325 km^2 (Eade and Fahrig, 1971 and 1973); E - Proterozoic Canadian Shield, mean of 59 composite samples, area-weighted according to rock type. Seven areas from the Churchill Province, two from the Grenville and one from the Great Bear Province were chosen, totaling 191,995 km^2 (Eade and Fahrig, 1971 and 1973); F - Canadian Shield, mean of 32 major and trace element analyses of composite samples plus 275 Mn and Ti analyses, from 5 districts, weighted according to the total number of samples collected from each rock type. These are added to 16 major element analyses and 110 Mn and Ti analyses of composites, from Ontario, weighted according to the area of each rock type. N.B. includes 1.28% CO_2 (Shaw *et al.*, 1967 and 1976); G - Canadian Shield, mean of 235 composite samples from 9 mapped terrains, the composition of each terrain being area-weighted according to the size of the enclosing structural province (Eade and Fahrig, 1971 and 1973); H - Upper continental crust, based on F. and G. (Taylor and McLennan, 1981). This estimate is similar in major elements to that of Poldervaart (1955) and of Ronov and Yaroshevski (1967) except for the lower total Fe of the latter (i.e. 2.7% Fe_2O_3); I - Continental crust, equivalent to an area-weighted mean of average igneous rock types (Ronov and Yaroshevski, 1969); J - Continental crust, using a 1:1 basalt-granite model (Taylor, 1964); K - Continental crust, using a weighted mean of upper crustal estimates plus analyses of granulite terrains (Holland and Lambert, 1972); L - Continental crust, assuming a Phanerozoic island - arc model (Taylor and McLennan, 1981).

Summary

The mean composition of the Alberta Shield, weighted according to the areal proportions of each lithological unit, is equivalent to that of a calc-alkaline dacite. It is similar to, but more potassic than, the northern Saskatchewan Shield, but significantly higher in Si, K, and Ba than the Churchill Province. The probable gneissic parent of the Aphebian granitoids which intruded the Alberta Shield was already enriched in Si and Ba compared to either the mean composition of the Churchill Province or the Canadian Shield. However, the content of alkalies Ti, Zr, Y, Nb, Zn, Sr, and Rb were not significantly different. Y and Zn show similar concentrations in northeastern Alberta to those observed within the Granite Gneiss belt and throughout the crust. They appear to be the elements least affected by anatexis in the crust.

Conclusions

The Precambrian Shield of northeastern Alberta represents an Archean gneissic terrain remobilized during a period of Aphebian metamorphism. The terrain essentially comprises a Granite Gneiss belt plus four major Aphebian plutons. Major and trace element constraints have been used to determine the petrogenesis of each of these four major granitoid groups.

The central Granite Gneiss belt is composed entirely of orthogneisses and matches the criteria for I-type granites (White and Chappell, 1977). It ranges in composition from metaluminous basaltic-andesite to peraluminous calc-alkaline dacite and was probably formed from the partial melting of a mafic to intermediate source. A subsequent, localized phase of mylonitization was largely isochemical, but the entire belt was affected by subsolidus feldspar recrystallization and alkali migration during metamorphism.

The western group of granitoid plutons (the Slave and Arch Lake Granitoids) are fairly homogeneous, peraluminous biotite quartz monzonites to granites whose compositions correspond to calc-alkaline rhyolites. The eastern two granitoid groups (Wylie Lake and Colin Lake) are heterogenous, peraluminous hornblende-biotite granodiorites to quartz monzonites, with overall compositions corresponding to andesite to dacite. However, using the economically orientated I versus S scheme of classifying Phanerozoic plutons, the plutons yield equivocal conclusions. This problem underlines the need to develop an economically useful classification scheme for granitoids in the Precambrian Churchill Province.

All plutons appear to have been derived by partial melting of the gneiss belts at 5 to 7 kb P_{H_2O}, leaving a restite or hornblende, biotite, and plagioclase. This crystal-liquid system was mobilized while quartz-K-feldspar-plagioclase cotectic crystallization took place in the melt, notably within the western plutons. The partial melting occurred during regional metamorphism in the Proterozoic (M2.1 of Nielsen et al. 1981), and a progressive regional increase in partial melting (probably caused by a steepening of the geothermal gradient) took place from east to west.

The Nb, Zr, and Y compositions of the western plutons appear to have been inherited from heterogeneities in the Granite Gneiss belt. The microcline megacysts towards the margin of the Wylie Lake pluton are porphyroblasts, whereas a similar texture in the Colin Lake Granitoids results from inherited phenocrysts. Minor leucocratic pods in the eastern complexes appear to be formed by fractional crystallization of highly differentiated melts, although one unit is peralkaline.

The mean composition of the exposed Alberta Shield is equivalent to that of a calc-alkaline dacite. It is significantly higher in Si, K, and Ba than an estimate for the whole Churchill Province but is similar in composition to the north Saskatchewan Shield. The Granite Gneiss belt, from which the Aphebian plutons were probably derived, is enriched in Si and Ba, compared to the mean composition of the Canadian Shield, but has similar concentrations of alkalies, Sr, Rb, Ti, Zr, Y, Nb, and Zn. Y and Zn appear to be the elements least affected by crustal anatexis. The most accurate estimate of the mean composition of the exposed Alberta Shield is that derived by weighting the composition of each rock unit according to its proportionate area. This estimate is significantly higher in Si and K, and lower in Fe, Mg, Ca, Ti and Zn, than the simple arithmetic mean, thereby indicating a sampling bias against rock units having a large outcrop area, even for detailed sampling schemes.

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Appendix

Major and trace element variation diagrams for the Granite Gneiss belt, and the Slave, Colin Lake and Wylie Lake Granitoids

The concentrations of ten major and minor element oxides (in weight percent) and seven trace elements (in ppm) are plotted against a modification of the Larsen Index (MLI = $SiO_2 + K_2O - CaO - MgO$).

Each of the following pages illustrates four plots for a single element. Each of the four diagrams on each page represents one of the four major lithological groups. Rock units within each major lithological group are represented by capital letters. The numbered plot character on each diagram refers to the number of samples, from any rock unit, which fall on the same grid point. The numbered rock units below are named according to their petrography rather than the field terms used in table 1.

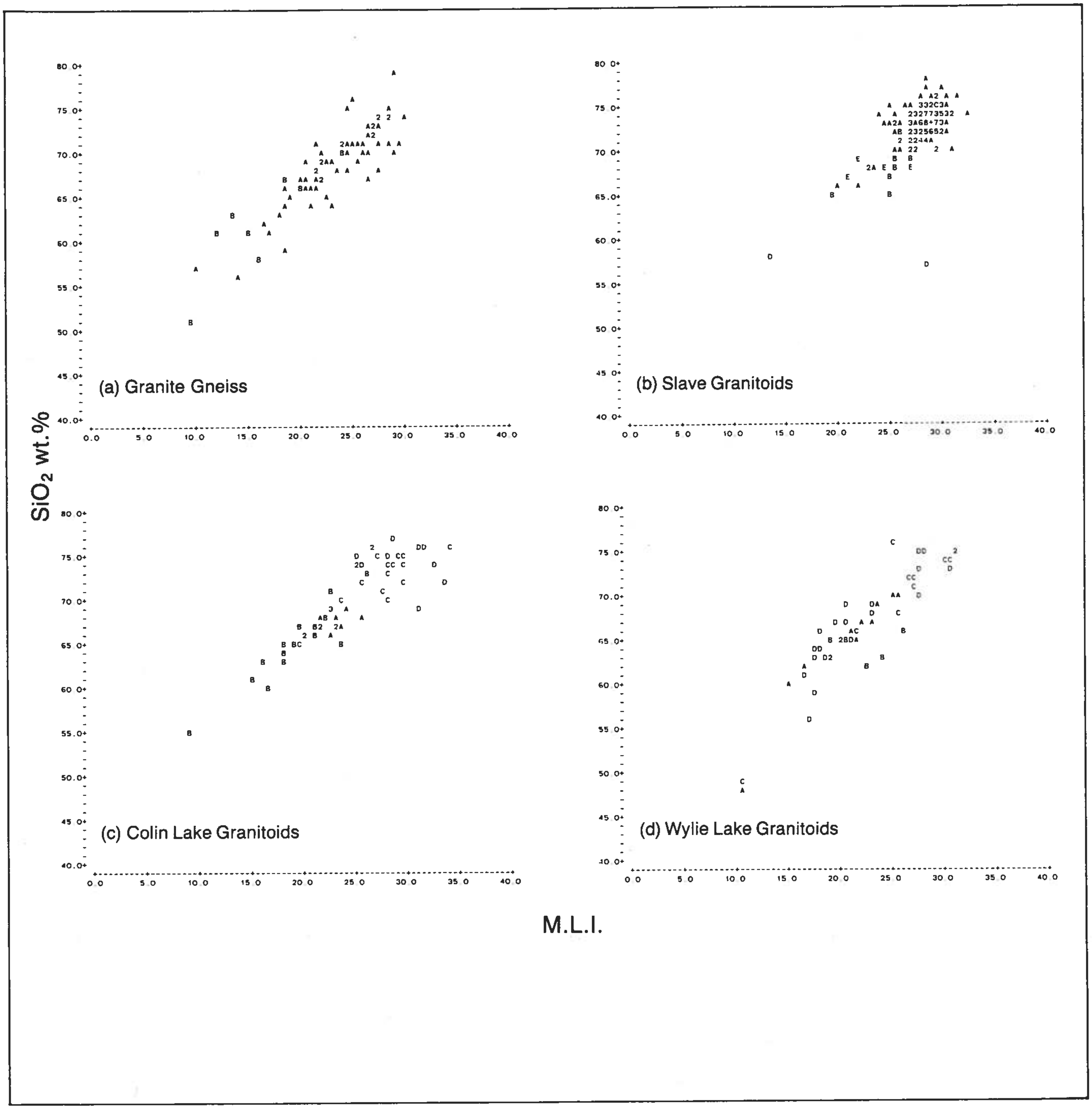
The index for this set of diagrams is as follows:

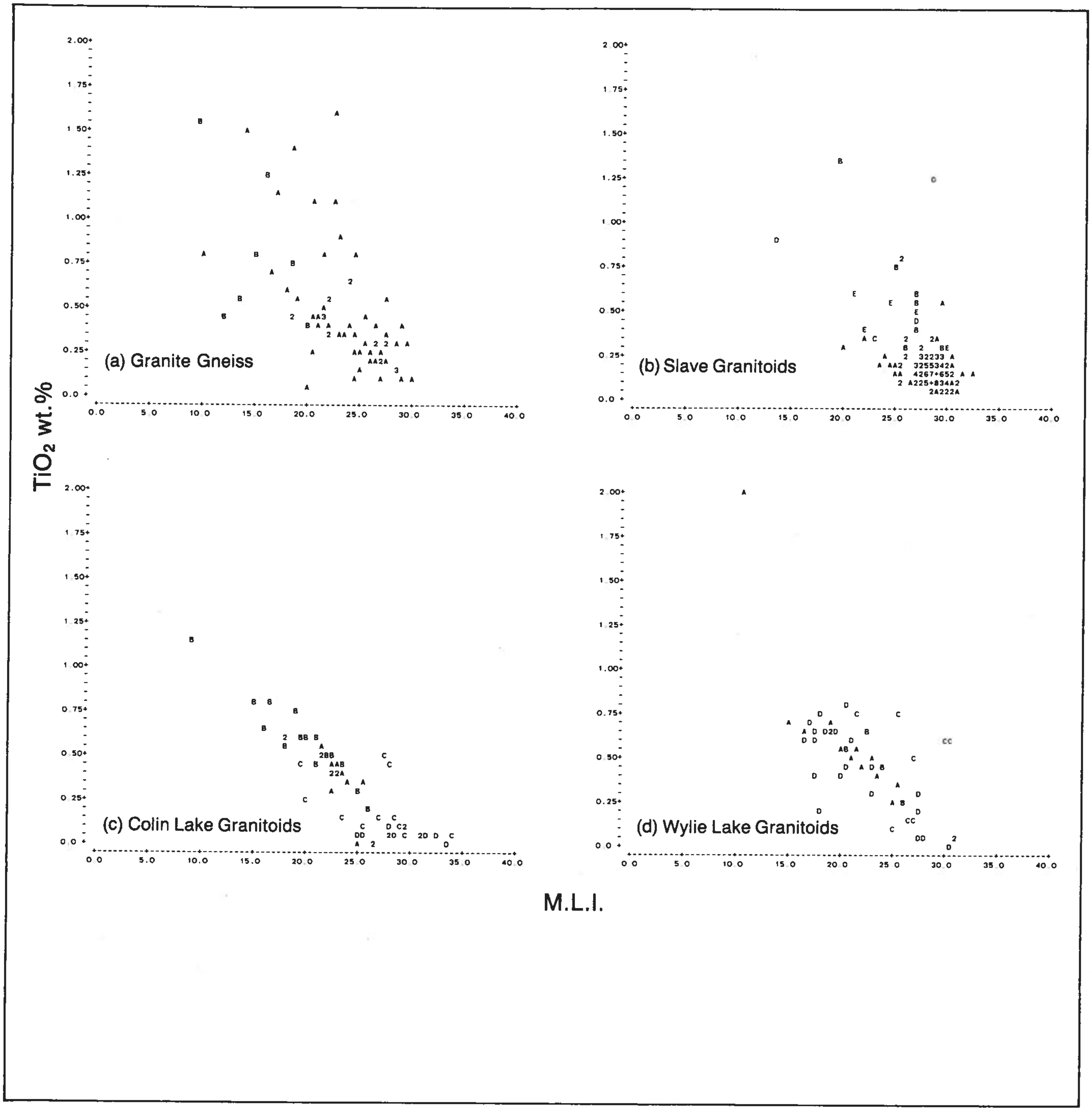
a) Granite Gneiss belt
- A - biotite quartz monzonitic gneiss (011);
- B - biotite hornblende granodioritic gneiss (012).

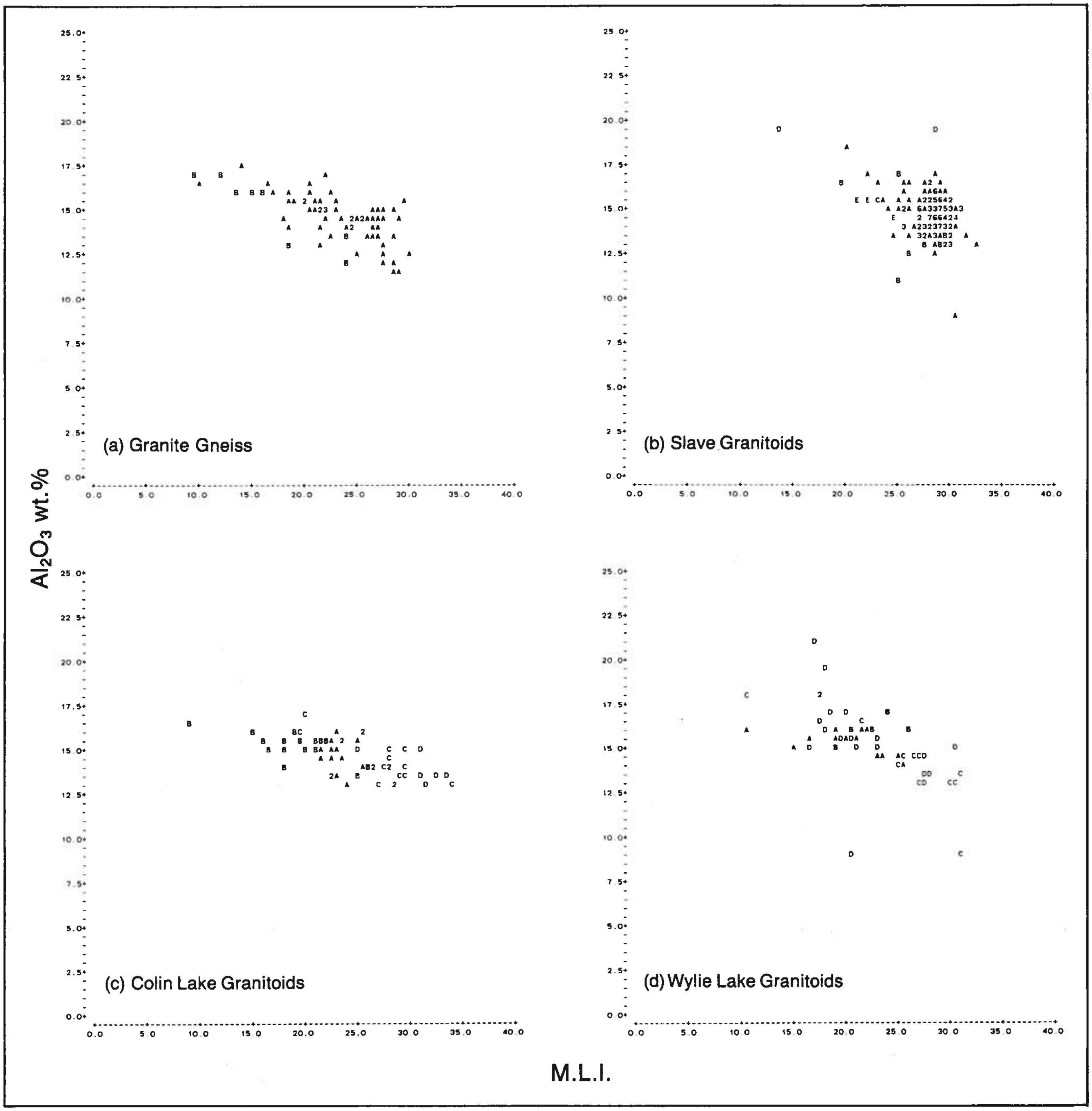
b) Slave Granitoids
- A - main Slave pluton quartz monzonite/granite (101);
- B - mafic quartz monzonite (102);
- C - red quartz monzonite (103);
- D - PQ biotite quartz monzonite (105);
- E - raisin-textured granodiorite/quartz monzonite (106).

c) Colin Lake Granitoids
- A - Andrew Lake pluton quartz monzonite (121 & 122);
- B - Colin Lake pluton granodiorite (123 & 124);
- C - leucocratic quartz monzonite (125 & 126);
- D - sheared leucocratic and pegmatitic quartz monzonite (127 & 128).

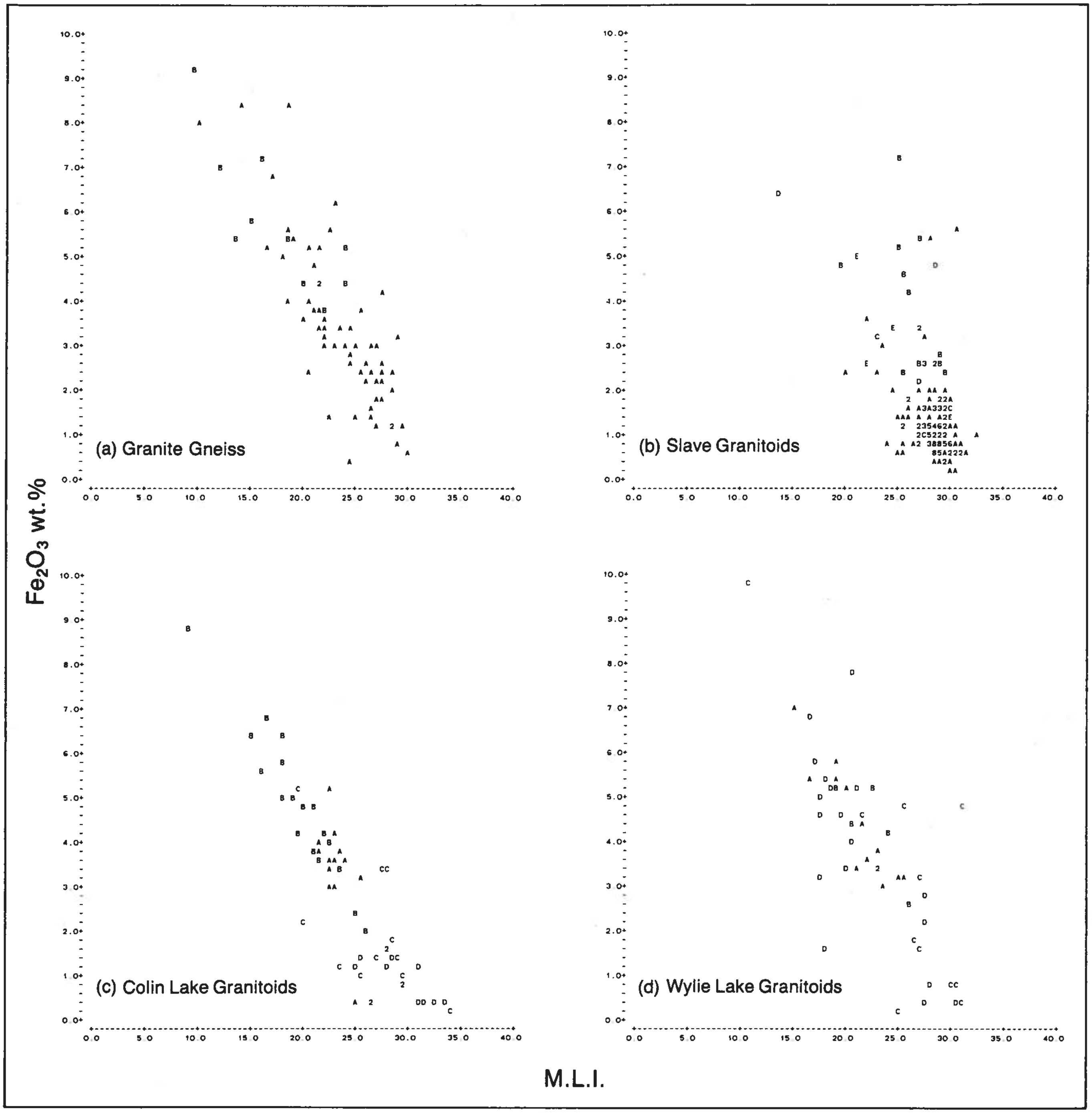
d) Wylie Lake Granitoids
- A - biotite-rich marginal granodiorite (131 & 132);
- B - porphyroblastic marginal granodiorite (137);
- C - PQ and leucocratic quartz monzonite (134 & 135);
- D - Fishing Creek granodiorite (133).

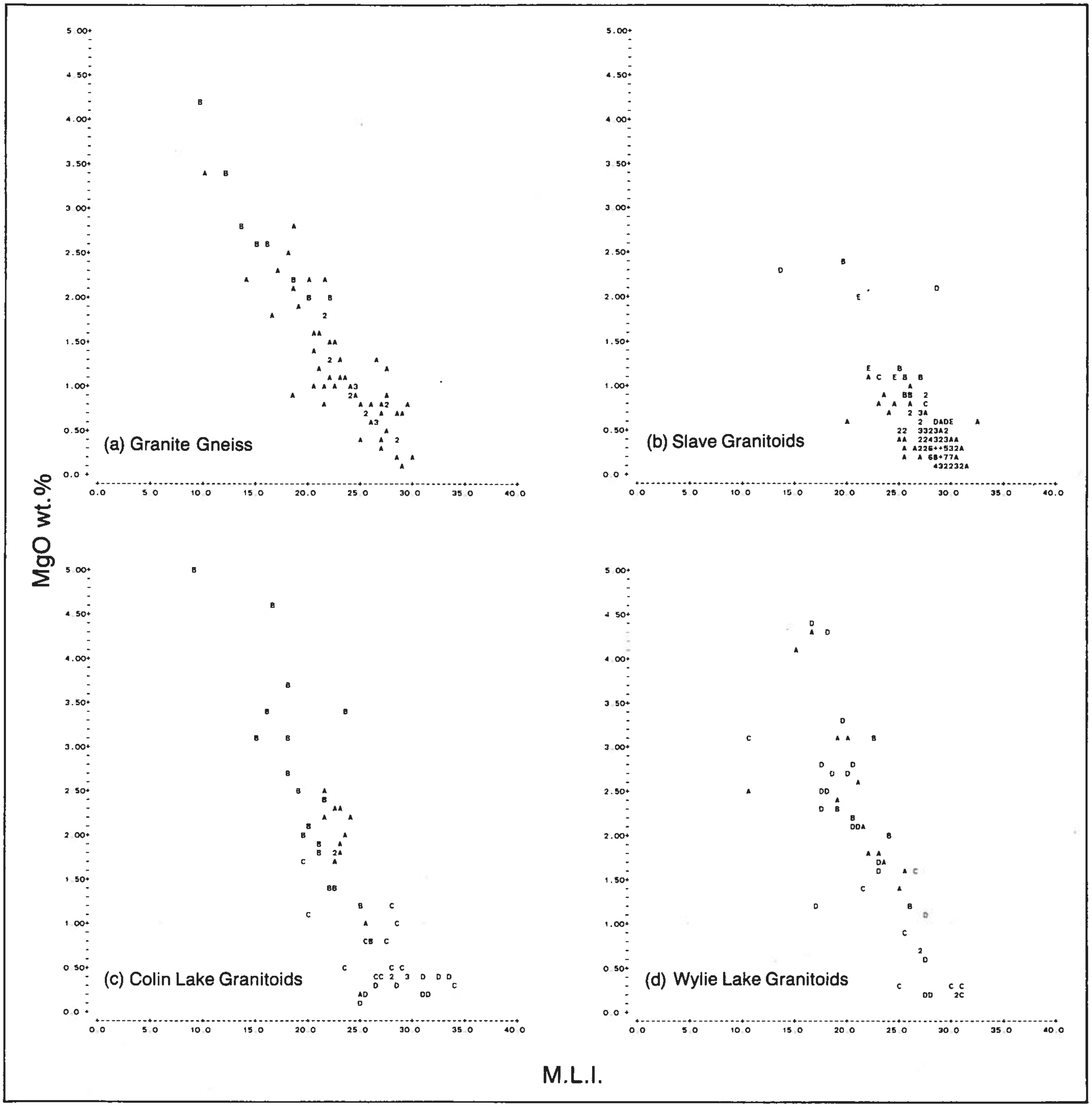

(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
SiO2 wt. %
M.L.I.

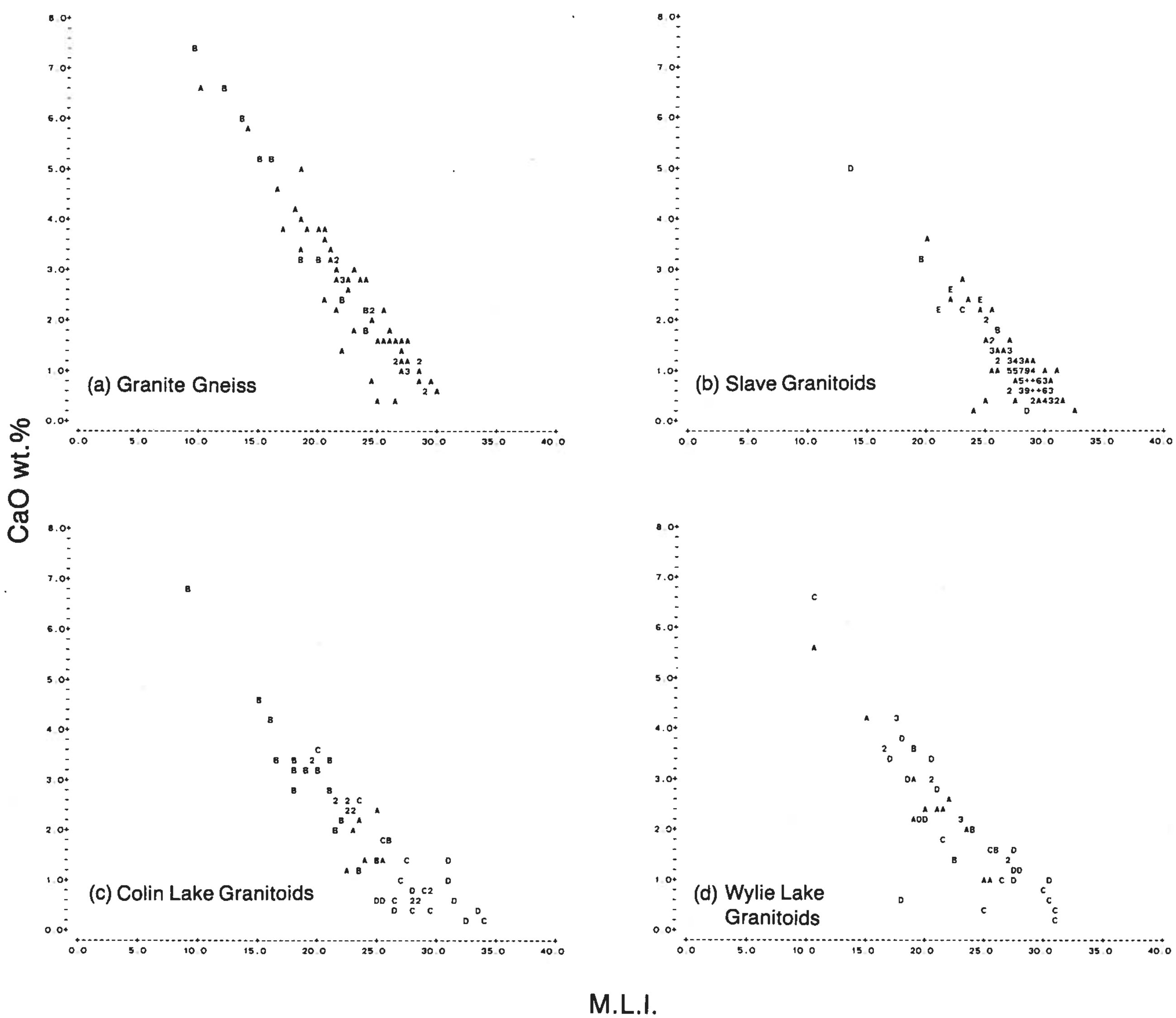

(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
TiO2 wt.%
M.L.I.

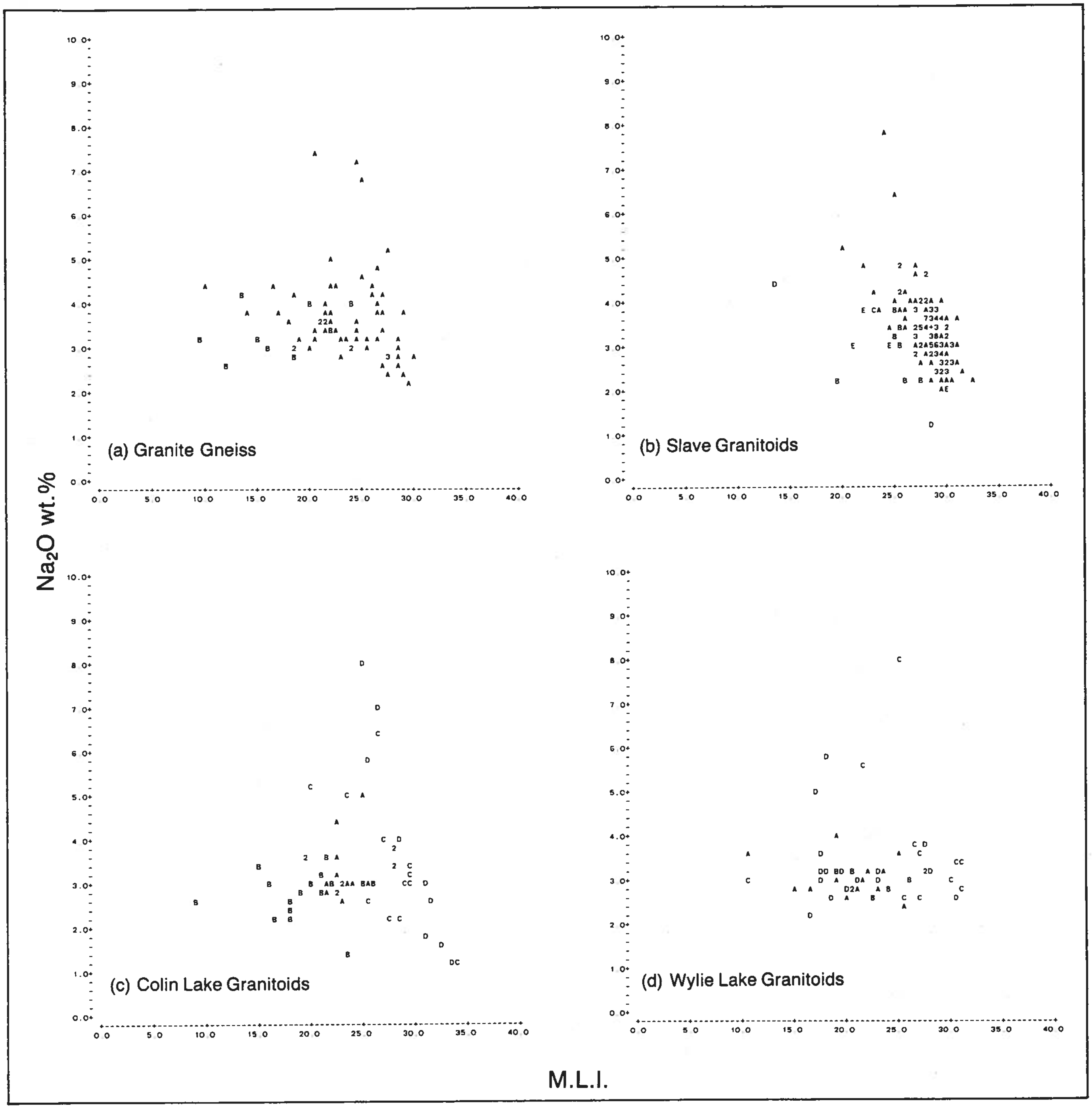


(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
Al_2O_3 wt.%
M.L.I.
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0

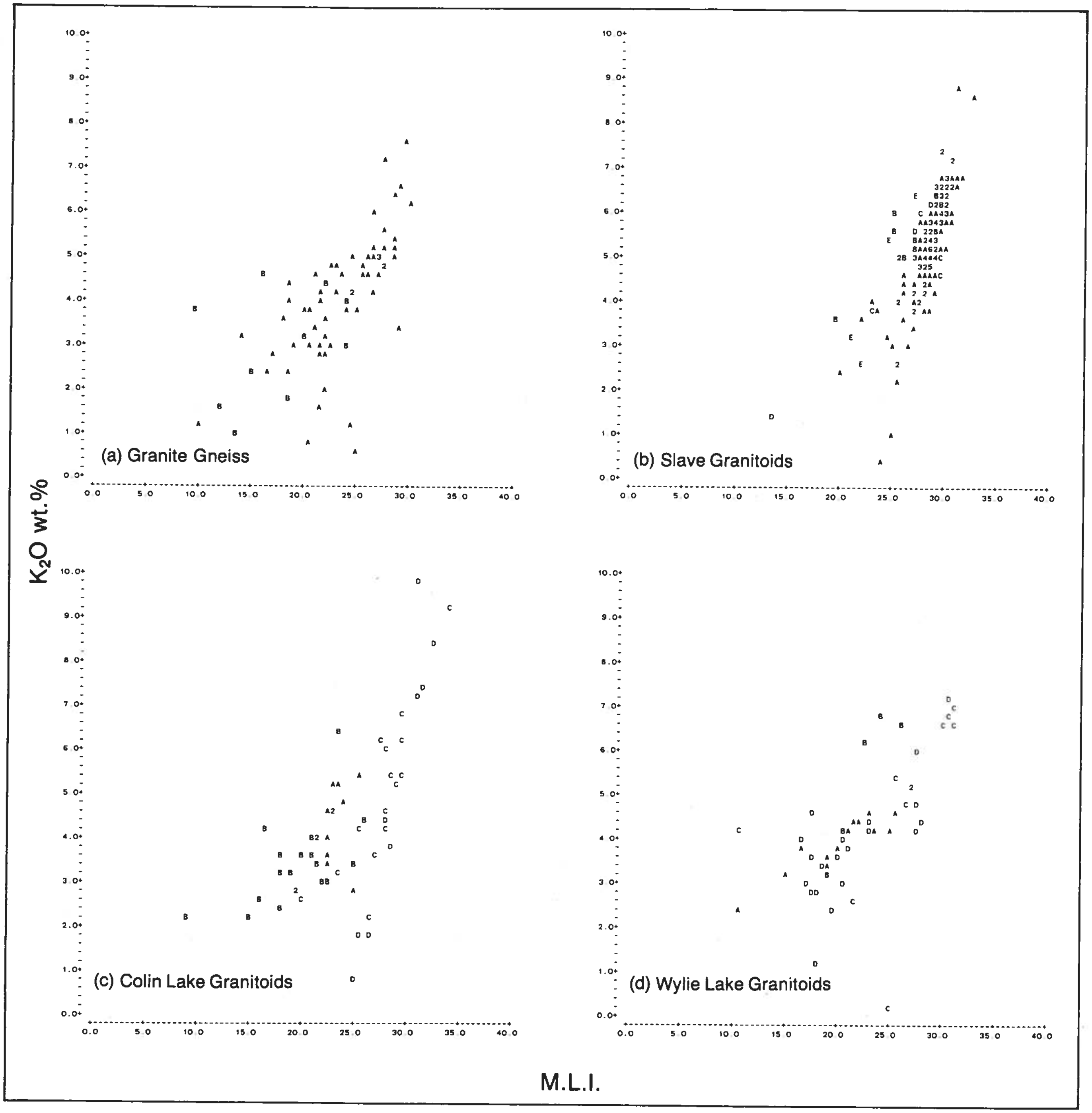

(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
Fe_2O_3 wt.%
M.L.I.

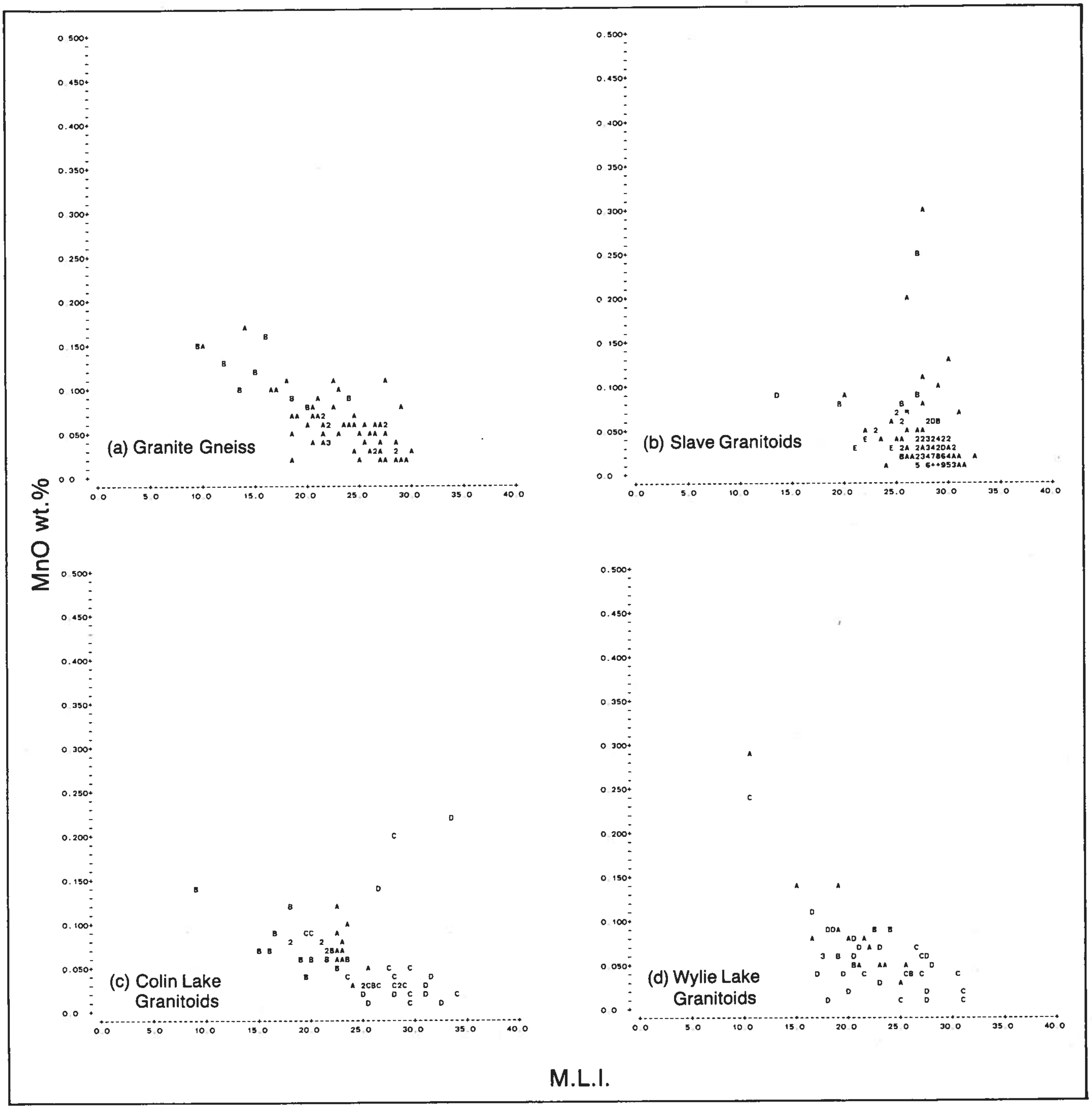

MgO wt.%
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
M.L.I.

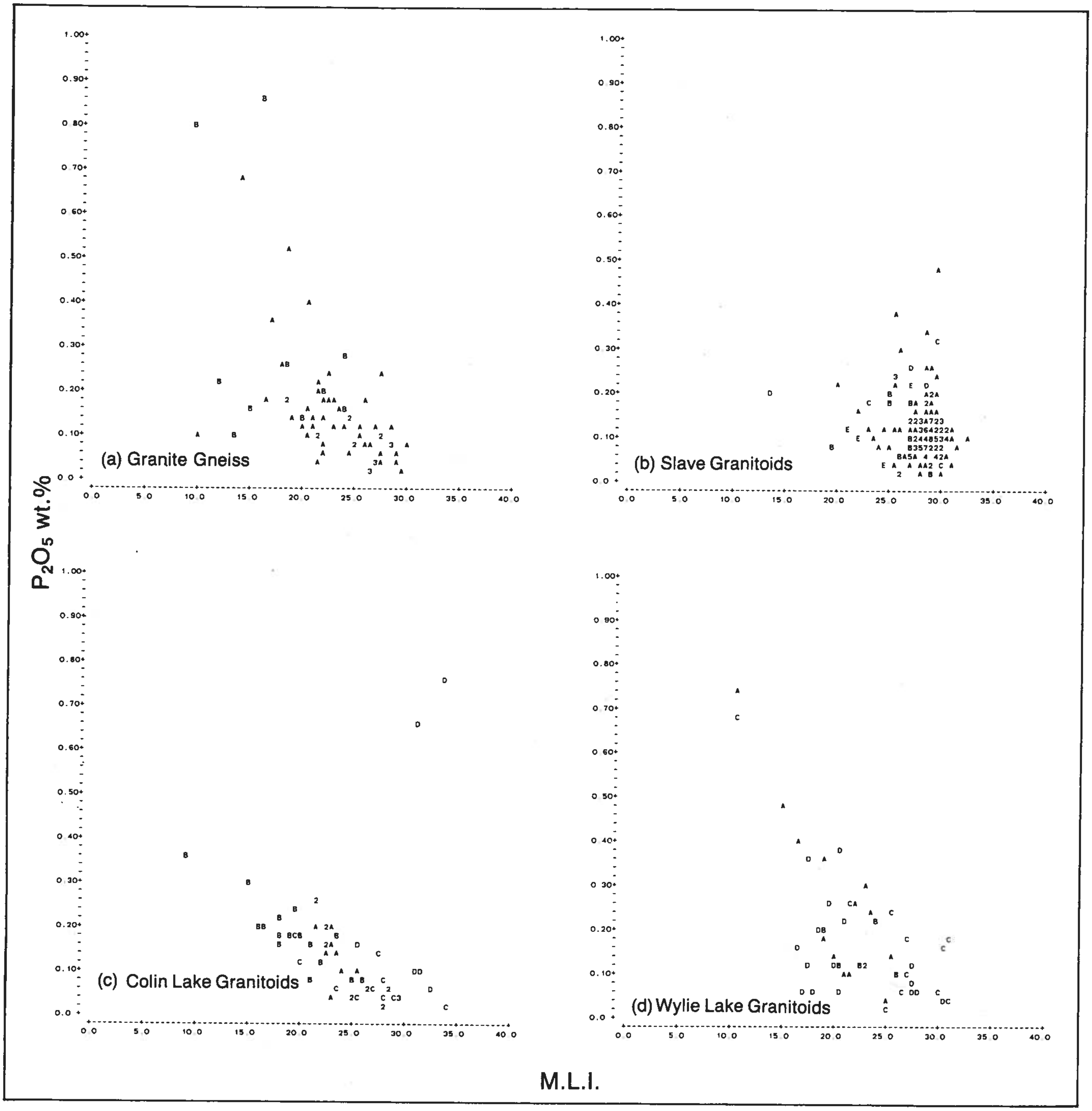

CaO wt.%
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
M.L.I.

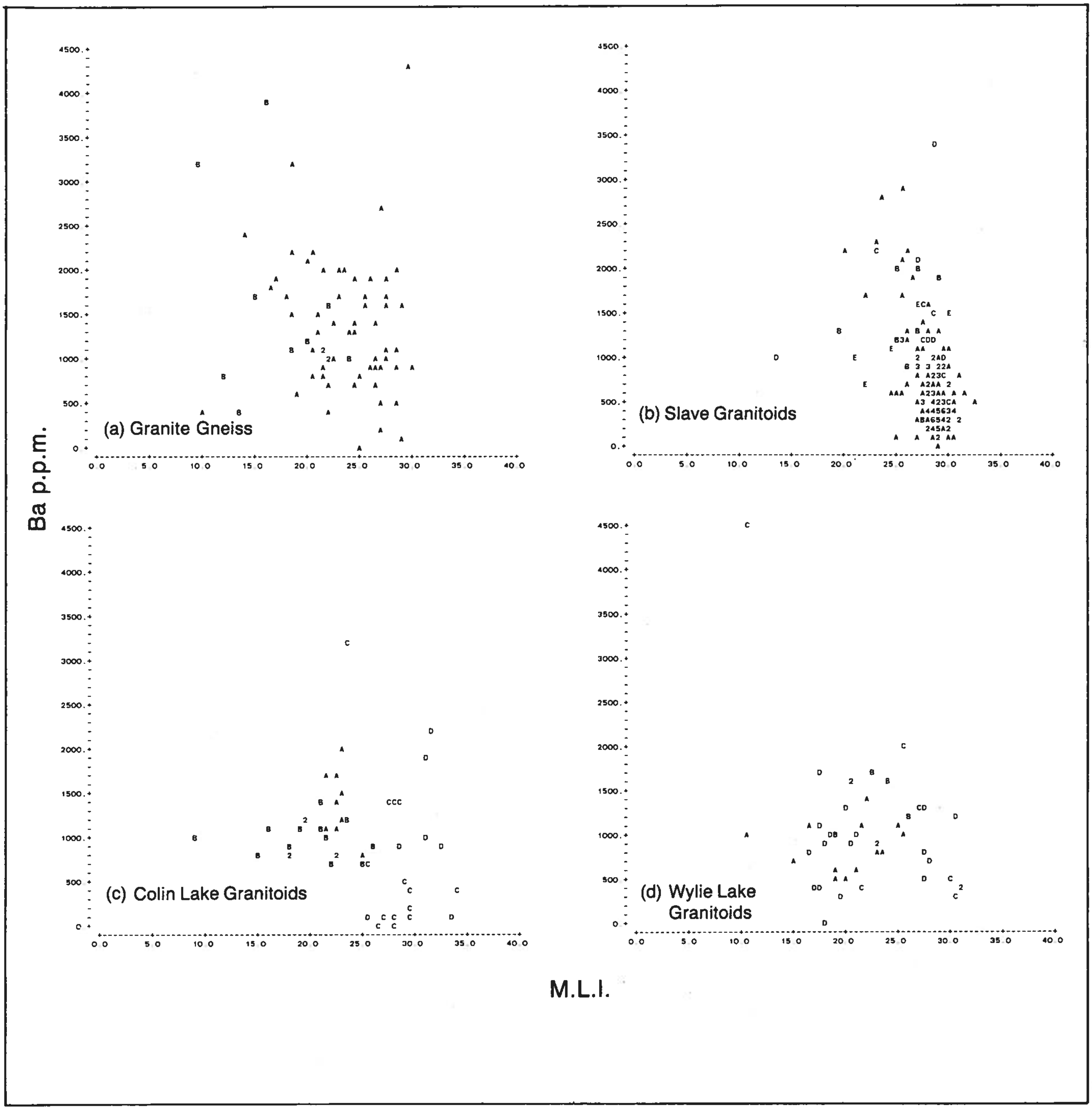


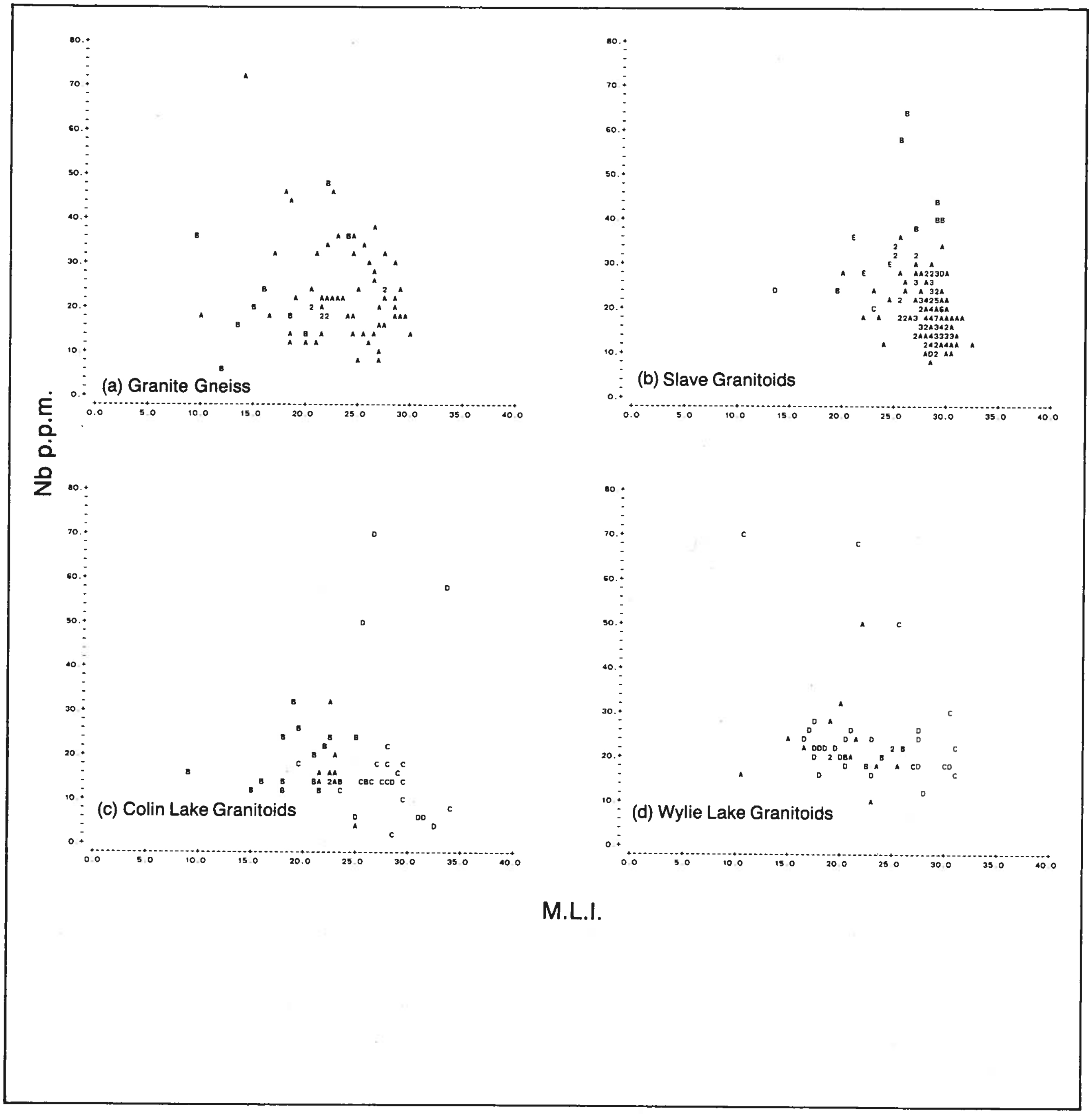
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
Na2O wt.%
M.L.I.

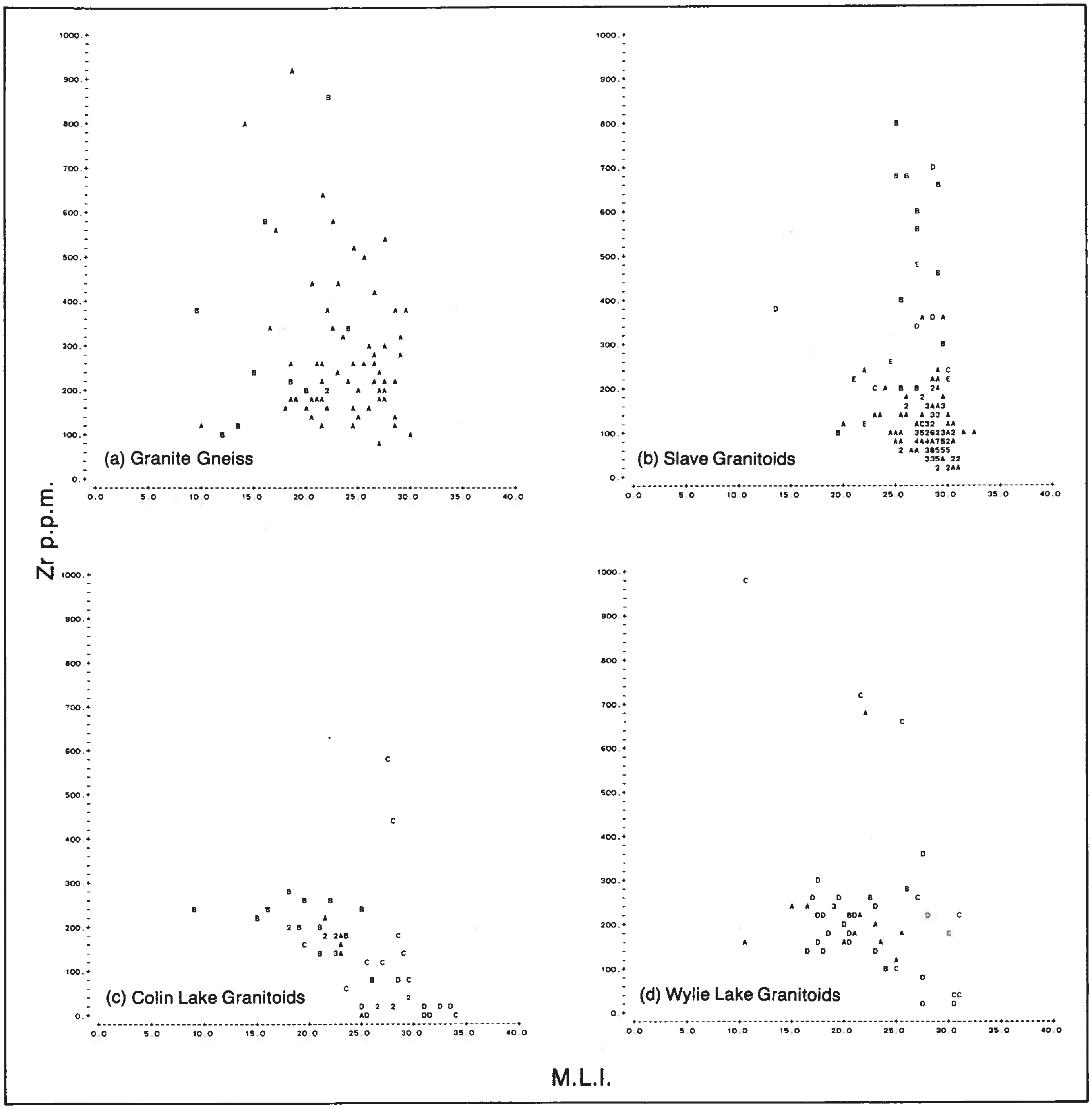

K2O wt.%
M.L.I.
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids

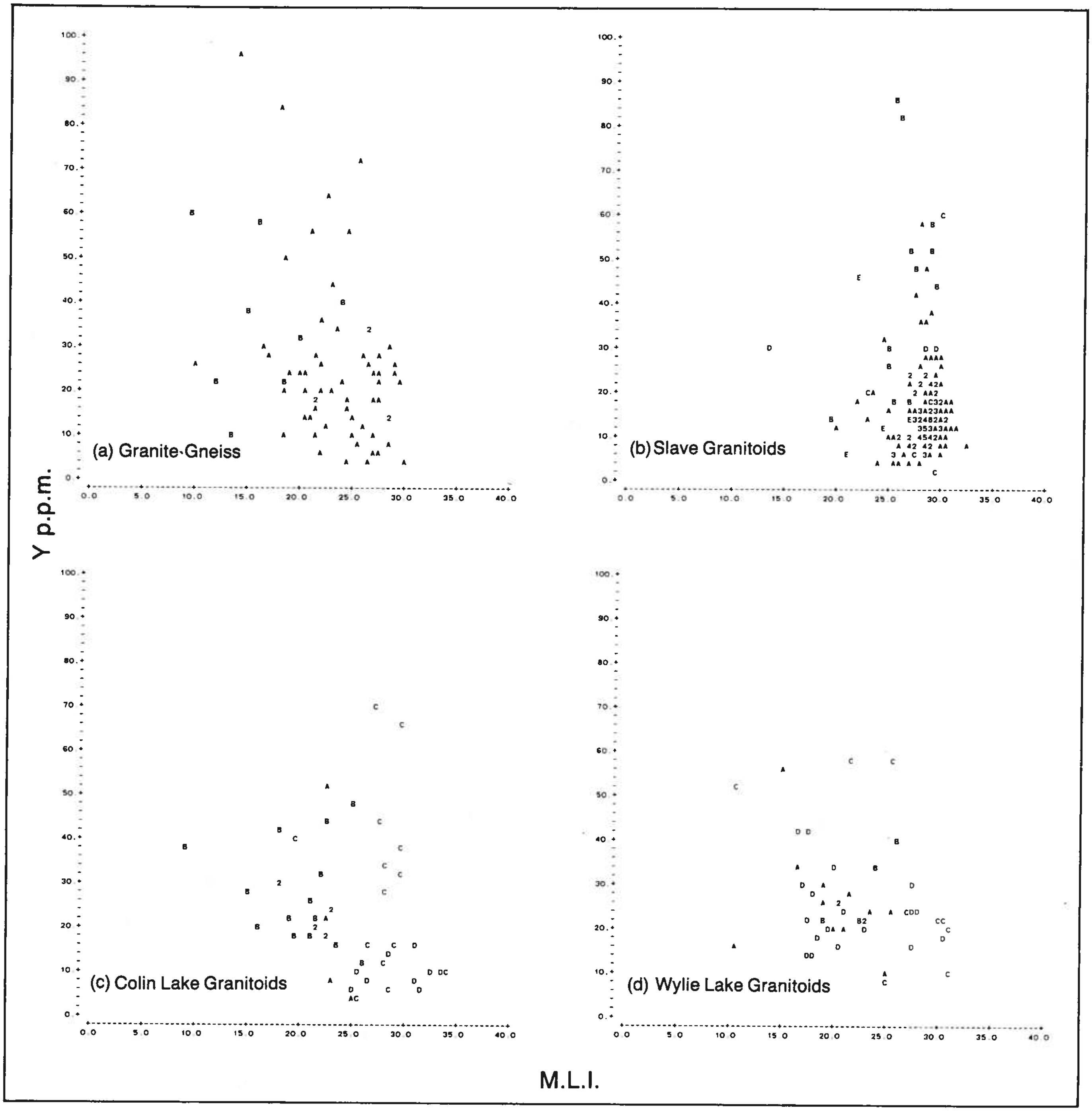

MnO wt.%
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
M.L.I.

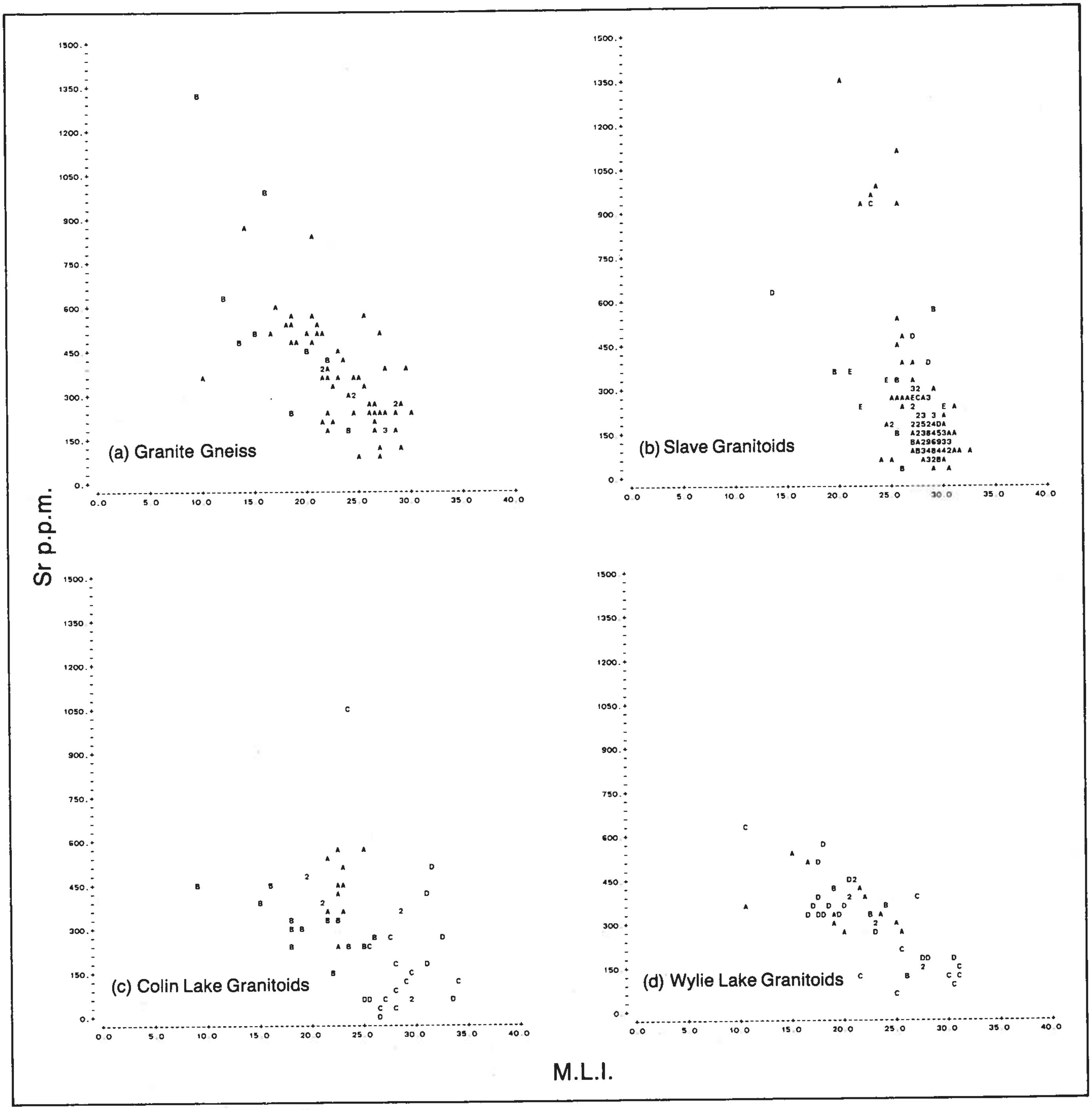

(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
P_2O_5 wt.%
M.L.I.

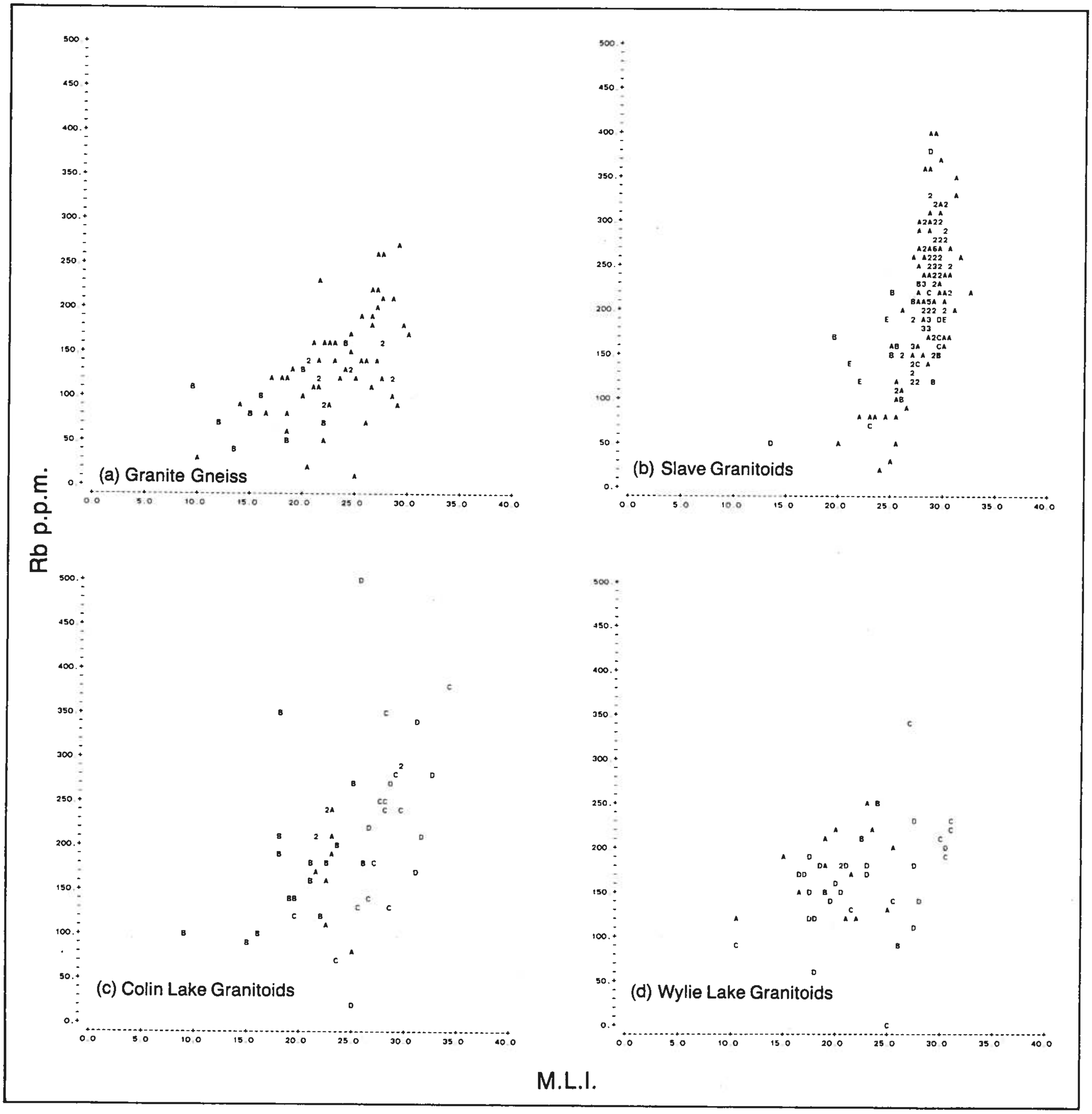

Ba p.p.m.
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
M.L.I.

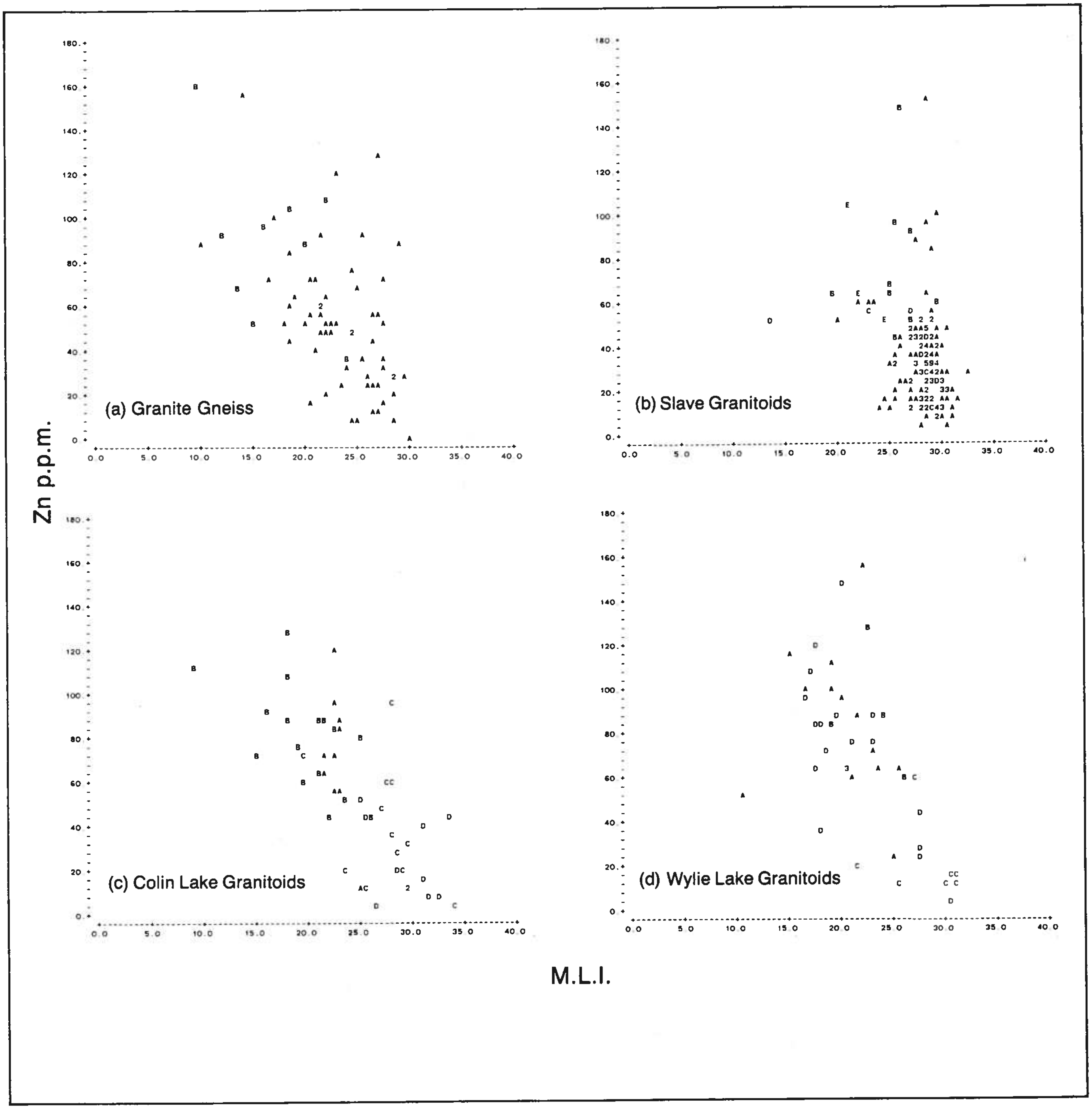

(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
Nb p.p.m.
M.L.I.


Zr p.p.m.
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
M.L.I.


(a) Granite-Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
Y p.p.m.
M.L.I.


Sr p.p.m.
M.L.I.
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids


Rb p.p.m.
(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
M.L.I.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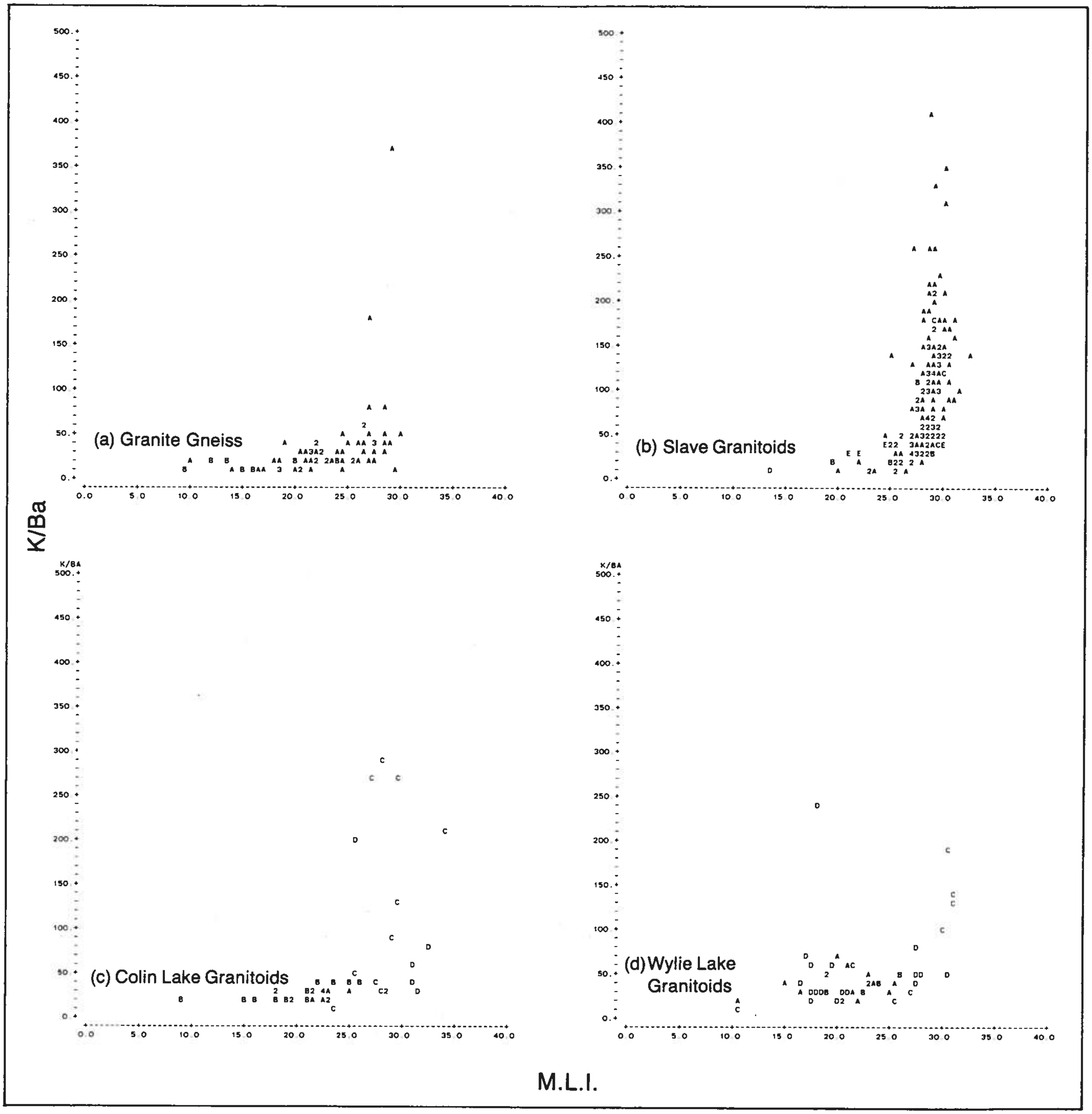
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
Zn p.p.m.
M.L.I.



(a) Granite Gneiss
(b) Slave Granitoids
(c) Colin Lake Granitoids
(d) Wylie Lake Granitoids
K/Ba
M.L.I.
K/BA