Geological Report GR87-3

Geology of the Barrington Lake-Melvin Lake-Fraser Lake Area

By H.P. Gilbert

Manitoba
Energy and Mines
Geological Services

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By H.P. Gilbert
Winnipeg, 1993

Energy and Mines

Hon. James E. Downey
Minister

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Deputy Minister

Geological Services

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Director

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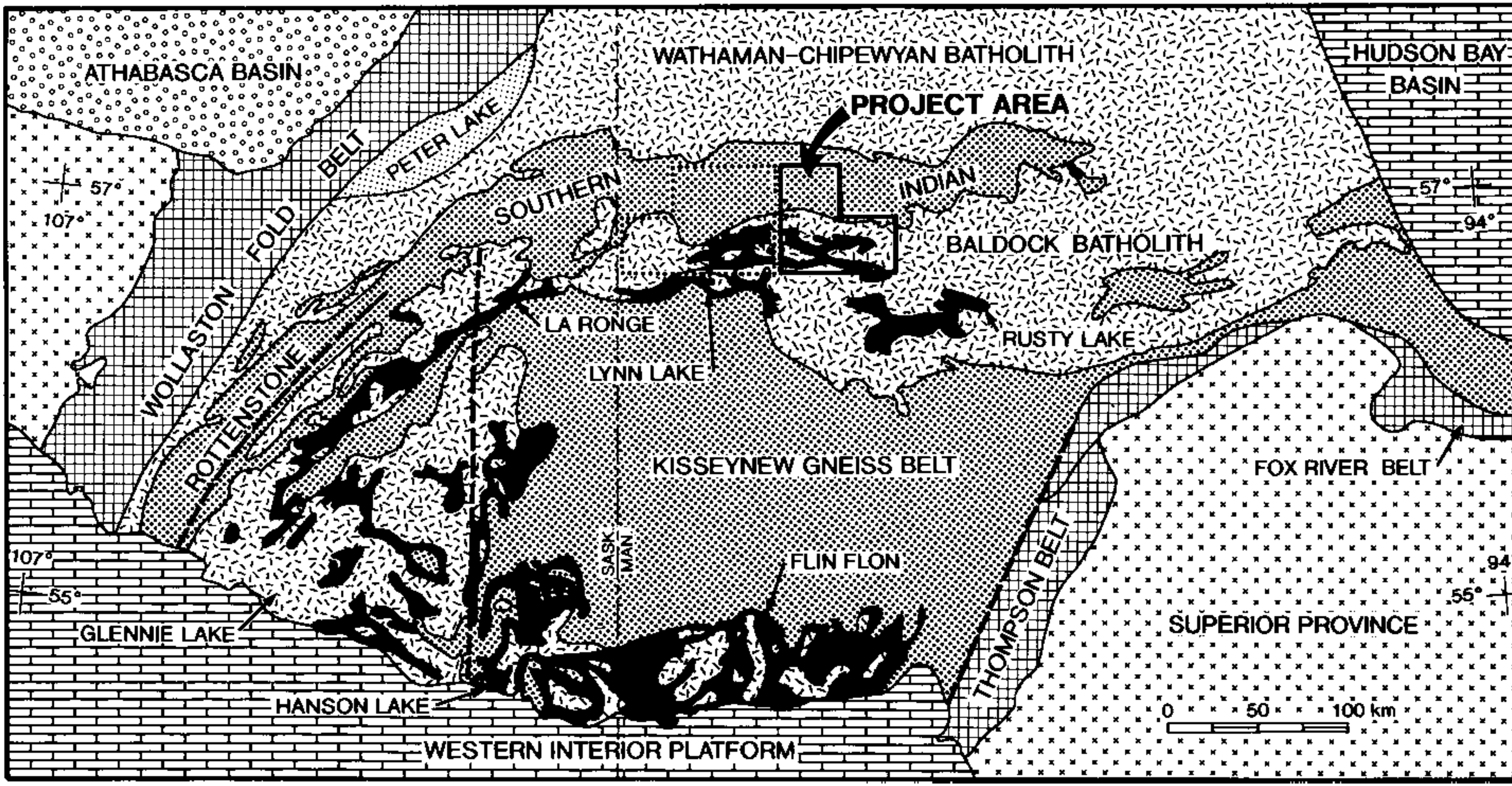


Figure 1: Structural setting of the Lynn Lake greenstone belt; tectonic elements of the Trans-Hudson Orogen are from Hoffman (1988). Volcanic belts are shown in black; major faults are indicated by bold dashed lines. The project area lies immediately east of the area mapped during the Lynn Lake project (dotted lines).

INTRODUCTION

This report describes the geology of an approximately 1860 km^2 area of Proterozoic supracrustal and intrusive rocks that compose the eastern part of the Lynn Lake greenstone belt. The project was initiated following completion of mapping in the Lynn Lake area (Gilbert *et al*., 1980). The objectives of the project were: to extend and complement the mapping of the Lynn Lake area and provide an improved geological data base for the mineral exploration industry; to investigate the volcanic geochemistry of the supracrustal rocks; and to investigate the relationship between the Lynn Lake greenstone belt and metasedimentary rocks of the contiguous Southern Indian gneiss belt to the north (Fig. 1).

PREVIOUS WORK

Geological reconnaissance was initiated in the Granville Lake area (NTS 64C) by J.F. Henderson in 1932 and Norman (1933), following the earlier mapping of Stockwell (1928) in the Reindeer Lake area to the west. Active exploration for gold in the Lynn Lake district in the 1930's expanded into gold and base-metal exploration in the early 1940's, which culminated in the historic discovery at Lynn Lake and subsequent confirmation of the Ni-Cu deposit at Farley Mine in 1945. In the same year, Bateman published a report on the McVeigh Lake area where the Wasekwan Series was defined as a volcanic and sedimentary assemblage overlain by the sedimentary Sickle Series that had been defined earlier by Norman (1933). A regional mapping program was initiated in 1946 by the Manitoba Mines Branch in support of the increasing exploration activity in the Lynn Lake district. Among the earliest products of this initiative are the maps of Farley Lake (Stanton, 1948) and Barrington Lake (Crombie, 1948), which correspond to the west and east halves of Map GR87-3-1 respectively. The maps of Melvin Lake (Hunter, 1952) and MacBride Lake (Kilburn, 1956) correspond to Map GR87-3-2 and the west half of GR87-3-3 respectively. Hunter (1958) carried out a detailed study of the Tow Lake gabbro in the south part of the Barrington Lake area. Fourteen 15-minute map sheets were published in this mapping program and they provided the base for the later regional synthesis of Milligan (1960). Emslie and Moore (1961) mapped a part of the Lynn Lake area (NTS 64C-14) at a scale of 1 inch = 2000 feet in 1958-59. A review of the economic geology of the Lynn Lake district is contained in Davies *et al*. (1962).

In the Uhlman Lake area (NTS 64B) mapping proceeded more slowly. Wright (1953) mapped this area at a scale of 4 inches = 1 mile in 1948. Part of this area was also covered by mapping during the Southern Indian Lake project in 1969 and 1970, in an extensive area (including parts of NTS sheets 64B, C, G and O) that was destined for flooding by Manitoba Hydro. The map of the Fraser Lake area (Hinds, 1972) corresponds to the east part of the Barrington-Melvin-Fraser lakes project area, and has been utilized, together with the map of Kilburn (1956), for information in the extensive granitoid terrane that encompasses the east end of the Lynn Lake greenstone belt (Map GR87-3-3). Southeast of the Fraser Lake area, the discovery of the Ruttan Lake deposit in 1969, at the margin of the Rusty Lake greenstone belt, spurred renewed mapping in that area by Manitoba Energy and Mines (Gilbert, 1974). In the same area, D.A. Baldwin conducted detailed mapping from 1978 to 1981, provided a report on the mineral deposits (Baldwin, 1982) and completed a doctoral thesis on the felsic volcanic rocks (Baldwin, 1987a).

Zwanzig (1974) continued investigations in the Lynn Lake area and in 1976 initiated the Lynn Lake mapping project (Gilbert *et al.,* 1980). A geophysical survey was carried out in 1976-1977 by Questor Surveys Ltd. Koo (1977) conducted an economic geology study in the Lynn Lake and Rusty Lake greenstone belts. Pinsent (1977) provided a brief review of gabbroic intrusions in the Lynn Lake belt, and investigated the Ni-Cu mineralization in the Lynn Lake gabbro (Pinsent, 1980). Fedikow began an investigation of the Agassiz gold deposit in 1982, followed by geochemical and biochemical surveys that, together with airborne geophysical information, led to the delineation of the Agassiz Metallotect (Fedikow, 1984) that extends for 65 km through the north part of the Lynn Lake greenstone belt, as far east as Spider Lake near the east margin of the Barrington Lake area (Fedikow, 1986a; Map GR87-3-1). Nielsen collaborated in the investigation of the Agassiz Metallotect with a geochemical survey of glacial till (Nielsen and Graham, 1985; Nielsen *et al*., 1985; Nielsen and Fedikow, 1986; Fedikow and Nielsen, 1987). Further mapping of Wasekwan Group felsic volcanic rocks was conducted in the vicinity of Lynn Lake by Baldwin (1983), and stratigraphic mapping was carried out by Ferreira (1986a, 1986b). Gale (1983a) conducted mineral deposit investigations at several localities in the belt. A detailed study of the geochemistry of the Wasekwan Group, based on sampling carried out during the Lynn Lake mapping project, was published by Syme (1985). U/Pb zircon age determinations were reported by Baldwin *et al.* (1987).

Various publications of an interpretative nature on aspects of the geology of Lynn Lake greenstone belt include discussions of the stratigraphy by Campbell (1972) and McRitchie (1974), and evaluations of geophysical data by Hosain (1980, 1981). Gale (1983b) described the Ruttan Lake deposit in a review of Proterozoic massive sulphide deposits. Other investigations in the Lynn Lake district include mineral deposit documentation by Baldwin (1986, 1987b, 1989), studies of stratigraphy (Parbery, 1988) and alkaline intrusions (McRitchie, 1988), and volcanic geochemistry investigations in the Lynn Lake area (Fedikow and Ferreira, 1987) and in the vicinity of Ruttan Mine (Gale, 1990). Thematic maps of mineral deposits have been published by Fedikow *et al*. (1989, 1991) and M.Sc. studies have been carried out by Barham (1987), Gagnon (1991), and Sherman (1992). Economic geology papers include those of Barham (1985), Fedikow *et al.* (1986) and Barham and Froese (1986).

PRESENT WORK AND ACKNOWLEDGEMENTS

The Lynn Lake area report (Gilbert *et al.,* 1980) covers the major part of the Lynn Lake greenstone belt from the Manitoba and Saskatchewan boundary east to Hughes Lake (Fig. 1). The present work extends coverage east through Barrington Lake to Opachuanau Lake (at the southwest end of Southern Indian Lake) and north to Melvin Lake (Fig. 2). The Lynn Lake greenstone belt consists largely of the volcanic and sedimentary Wasekwan Group[1] (Bateman, 1945) that is unconformably overlain by Sickle Group[1] fluvial conglomerate and sandstone (Norman, 1933; Table 1). Granitoid and lesser gabbroic intrusions underlie extensive areas within and peripheral to the belt. The report on the Lynn Lake area (Gilbert *et al.,* 1980) focuses on the Proterozoic metavolcanic and metasedimentary rocks of the Wasekwan Group.

The present report maintains the same focus, with additional descriptions of several conglomerate and sandstone deposits at Melvin Lake, northern Barrington Lake and Soltowski Lake (unit 6). These occurrences are interpreted to be late Wasekwan Group or Sickle Group on the basis of the regional stratigraphy and lithologic similarities between the conglomerates and the Zed Lake-Hughes River conglomerate of the Lynn Lake area (unit 10 - "Sickle or Wasekwan Group" - Gilbert *et al.,* 1980). The norite and gabbro stock at Melvin Lake ("Melvin Lake norite") has been examined in detail because of its general similarity to the economically important gabbroic stock at the past-producing Farley Mine at Lynn Lake. Minor mafic intrusive rocks elsewhere in the project area are briefly described (unit 10).

The classification of granitoid intrusive rocks on the accompanying maps (Fig. 2) is based partly on mapping by the author and partly on the work of Stanton (1948), Crombie (1948), Hunter (1952), Kilburn (1956), Milligan (1960) and Hinds (1972).

Granitoid units (8, 9, 11) are described only briefly in this report.

Mapping of the Melvin Lake area and part of the Barrington Lake area was completed in 1979. The Fraser Lake area and Barrington Lake area were completed in 1980. Five short fly-in camps in the Fraser Lake area facilitated coverage by pace and compass traverses of areas that contain supracrustal rocks and related gneisses; helicopter-supported reconnaissance was carried out in the granitoid terranes in the Fraser Lake and Barrington Lake areas. Melvin and Barrington lakes each provided extensive shoreline exposures and a convenient base for waterborne access to

1 The Wasekwan Series and Sickle Series of Bateman and Norman were revised to Wasekwan Group and Sickle Group by Campbell (1969).

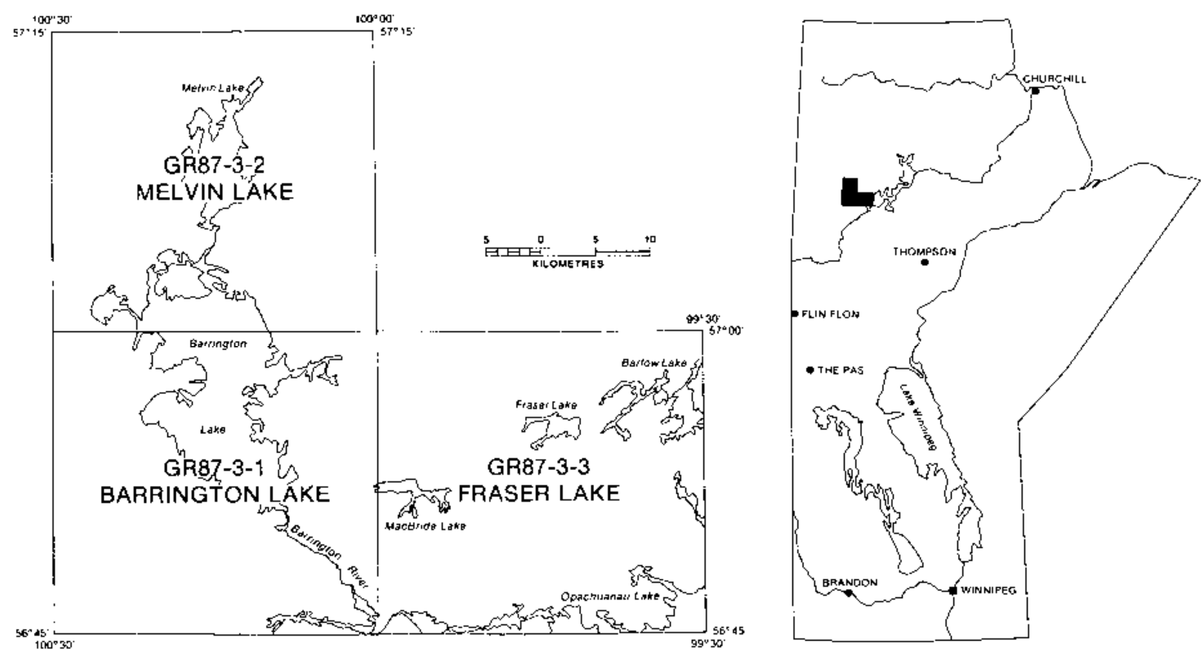


Figure 2: Index map of the project area showing the 1:50 000 scale maps accompanying this report.

Table 1: Table of Formations

	PLEISTOCENE AND RECENT		Sand, gravel, till, clay, boulders
			unconformity
PRECAMBRIAN	INTRUSIVE ROCKS (PRE- AND POST-SICKLE GROUP)	11	Granite and granodiorite, pegmatite, related cataclasite.
		10	Gabbro, norite, amphibolite, hornblendite, diorite, related gneiss (includes Melvin Lake norite).
		9	Tonalite, granodiorite, granite; pegmatite and aplite; quartz diorite, diorite, related gneiss.
		8	Quartz-plagioclase porphyry, felsite, tonalite.
	SICKLE GROUP	*7	Conglomerate, arkosic sandstone.
	SICKLE OR WASEKWAN	6	Conglomerate, feldspathic greywacke, siltstone.
	PROBABLE WASEKWAN AGE	5	Amphibolite, schist, gneiss, related migmatite.
		4	Paragneiss, schist, related migmatite.
	WASEKWAN GROUP	3	Greywacke, siltstone, conglomerate, argillite, oxide iron formation.
		2	Rhyolite, dacite, intermediate to felsic tuff and volcanic breccia; related intrusive rocks.
		1	Basalt, andesite, flow breccia, intermediate to mafic tuff and volcanic breccia; related gabbro.

*The Sickle Group (7) rests unconformably on the Wasekwan Group (1 to 3) and some phases of unit 9.

inland areas. Regulation of water levels by Manitoba Hydro prior to 1980 flooded almost all shoreline exposures along Barrington River in the Fraser Lake area. This resulted in reconnaissance level information in that part of the map. Bedrock exposures constitute 20 to 30% of Barrington Lake area, and approximately 20% of Fraser Lake area, but their distribution is irregular. The exposure level is similar in the central part of the Melvin Lake area, but beyond the boundaries of geological mapping in that area outcrops are much less abundant. Field maps were prepared utilizing vertical aerial photographs at a scale of 1 inch = 1/2 mile, and preliminary maps published at 1:50 000; these have been revised and redrafted at 1:50 000 to accompany this report.

Twenty-four volcanic rock samples were taken for geochemical analysis during mapping in the Barrington Lake and Fraser Lake areas; these have been supplemented by 15 analyses of volcanic rocks provided by H.V. Zwanzig from sampling at Barrington Lake in 1974. Five representative samples of the Melvin Lake norite were also collected for analysis. Geochemical analyses were provided by the Manitoba Energy and Mines Analytical Laboratory. Approximately 1,000 thin sections and 650 stained slabs were prepared by the department's Rock Preparation Laboratory. The anorthite content of plagioclase in 18 thin sections was determined by C.R. McGregor, who also confirmed or corrected the identification of various metamorphic minerals by X-ray methods. Typing of the original manuscript was undertaken by B. Rigby and subsequent revisions made by L. Chudy, W. Baker and S. Weselak. Maps were drafted by M. Timcoe, and figures were drafted by M. Timcoe, D. McShane, B. Lenton and M. McFarlane. Report layout and map preparation were supervised by D.A. Baldwin and R. Sales respectively. Sincere thanks are extended to all of the above, and to field assistants B. Stobbe and E. Simonds whose cheerful and competent work is much appreciated. Thanks are also due to W.D. McRitchie, W. Weber, H.V. Zwanzig, A.H. Bailes, E.C. Syme and J.J. Macek for their constructive criticism during the preparation of this report, and to B. Bannatyne and D.A. Baldwin for reviewing and editing the text.

SUMMARY OF GEOLOGY

The Barrington-Melvin-Fraser lakes area lies in the Churchill Structural Province, and is part of the Trans-Hudson Orogen (Hoffman, 1988, 1990). It is underlain in the north by rocks of the Southern Indian gneiss belt and in the south by the Lynn Lake greenstone belt (Fig. 1); the greenstone belt is up to 60 km wide and extends for 130 km through the Lynn Lake district to Laurie Lake in the west. The La Ronge belt in Saskatchewan is stratigraphically very similar to the Lynn Lake greenstone belt, but these belts are separated by a granitoid terrane (Fig. 1). Southeast of the Lynn Lake greenstone belt, the Rusty Lake belt is stratigraphically and structurally distinct, and is apparently slightly younger than the Lynn Lake belt (Baldwin *et al*., 1987). The eastern termination of the Lynn Lake greenstone belt in the Fraser Lake area (Map GR87-3-3) is characterized by pervasive granitoid intrusions that encompass the volcanic and sedimentary rocks at the west end of the Baldock batholith.

U/Pb zircon geochronology has established two ages of magmatism in the Lynn Lake greenstone belt (Baldwin *et al*., 1987). A rhyolite flow dated at 1910 +15/-10 Ma is considered to represent the age of the older magmatism that produced mafic to felsic volcanic rocks and synvolcanic plutons of the Wasekwan Group. These rocks are intruded by younger tonalite and quartz diorite dated at 1876 +8/-7 Ma. The age of the granitoid intrusions is almost identical to that of a rhyolite flow in the Rusty Lake greenstone belt, dated at 1878 ±3. This age is comparable with U/Pb zircon ages of metavolcanic rocks in the La Ronge belt ranging from 1876 ±10 Ma to 1882 ±9 Ma (Van Schmus *et al*., 1987). The La Ronge and Rusty Lake belts are thus similar in age and significantly younger than the Wasekwan Group of the Lynn Lake greenstone belt. Granitoid intrusions in this part of the Churchill Province include older synvolcanic types (1910 Ma), younger tonalite and granodiorite coeval with the La Ronge and Rusty Lake volcanic rocks (1876 to 1882 Ma) and later granitoid intrusions ranging from 1836 to 1872 Ma (Baldwin *et al*., 1987) including the 1855 Ma Chipewyan Batholith (Van Schmus and Schledewitz, 1986).

Stratigraphic subdivision of the Wasekwan Group has been described in the Lynn Lake area (Gilbert *et al*., 1980) where the northern and southern belts of supracrustal rocks extend east from the area west of Lynn Lake to the area east of Barrington Lake, and are separated by a series of granitoid plutons. In the Lynn Lake area the thickness and lithologic diversity of the Wasekwan Group is greater than in the Barrington Lake area, where the northern and southern belts diminish and converge eastwards, and extend into the Fraser Lake area as zones of supracrustal remnants and synformal keels within an extensive granitoid terrane. The Wasekwan Group in the Barrington Lake area consists largely of basaltic flows and related breccia with subordinate tuff and sporadic lensoid felsic volcanic units. Epiclastic rocks are rare in this area (Map GR87-3-1) except for siltstone and argillite occurrences near the west margin at Farley Lake (within oxide iron formation) and in the southwest corner of the area where Wasekwan Group greywacke and Sickle Group conglomerate have been mapped by E.C. Syme (Syme and Gilbert, 1977). Metasedimentary rocks are also more prominent close to the eastern termination of the northern belt at Hollingworth and Soltowski lakes (Map GR87-3-3).

Alteration attributed to penecontemporaneous interaction with seawater, and subsequent regional metamorphism is widely recognized in Wasekwan Group volcanic rocks. There is a progressive loss of preservation of primary features eastward from Barrington Lake to Soltowski Lake, due to increasing metamorphic grade and deformation. The southern belt is also characterized by increasing recrystallization and loss of primary features eastwards. Volcanic and sedimentary lithologies (units 1, 2, and 3, Table 1) grade into rocks devoid of primary features, that have been described as metamorphites (*e.g.* amphibolite and paragneiss, units 4 and 5). Occurrences of metamorphites in the Fraser Lake area, on-strike with the northern and southern belts in the Barrington Lake area, are considered to be part of the Wasekwan Group. Similar paragneiss (4) occurs in the Melvin Lake area, within the Southern Indian gneiss belt immediately north of the Lynn Lake greenstone belt; the age of these rocks is not firmly established.

The Southern Indian Lake gneiss belt comprises paragneiss, amphibolite, migmatite and pervasive (mainly granitoid) intrusive rocks. Metasedimentary rocks are the predominant supracrustal lithology and are derived from greywacke-siltstone turbidites. The paragneiss is generally considered to be stratigraphically equivalent to the Wasekwan Group, although Rb/Sr metamorphic ages indicate these rocks may be older than the adjacent Wasekwan Group to the south (Clark, 1984). The contact between the Lynn Lake and Southern Indian Lake belts is marked by a persistent conglomeratic unit that extends for over 75 km from Lynn Lake to Barrington Lake. This unit (Zed Lake-Hughes River conglomerate, Gilbert *et al*., 1980) is considered to be late Wasekwan Group or Sickle Group in age, and is interpreted to occupy a synclinal structure generally coincident with the abrupt facies change between volcanic rocks to the south and turbiditic sedimentary rocks to the north. The conglomerate is exposed at a few localities at northern Barrington Lake (Map GR87-3-2) where extreme attenuation has resulted in transformation of the clastic rock to a laminated gneiss less than 25 m thick.

Three periods of deformation have been recognized in the Barrington-Melvin-Fraser lakes area. D_1 is characterized by the development of regional foliation and major, tight to isoclinal folds with west- to northwest-trending, steeply-dipping axial planes. The regional foliation is deformed by D_2 folds subparallel to the earlier folds, and associated with localized fracture cleavage. A major phase of granitoid plutonism is interpreted to be syn- to post-D_2. D_3 is characterized by northeast- to northwest-trending faults that postdate granitoid plutonism and are locally intruded by late diabase dykes. Deformation and plutonism in the Lynn Lake region occurred during and after deposition of the Wasekwan Group, and again after deposition of the Sickle Group (Gilbert *et al.*, 1980).

Three regional metamorphic events have been recognized in the project area. The earliest event (M_1), characterized by greenschist to middle amphibolite facies conditions, resulted in regional foliation (S_1) defined variously by green hornblende, anthophyllite, tremolite-actinolite, biotite, muscovite and locally chlorite. The primary mineralogy of volcanic rocks was largely altered, but rare relicts of magmatic pyroxene have been recognized in one mafic flow and a synvolcanic diabase dyke. Several occurrences of granulite facies gneiss in the vicinity of Hollingworth Lake (Fraser Lake area) have been interpreted as pre-M_1. Regional M_2 metamorphism resulted in widespread recrystallization of the earlier S_1 foliation and development of a variety of porphyroblasts that range from early- to post-tectonic types. The highest grade of M_2 metamorphism is represented by the association sillimanite + K-feldspar within a paragneiss terrane east of Melvin Lake; this high grade metamorphism is associated with the development of concordant quartzofeldspathic anatectic *lits* in the paragneisses.

In the Barrington Lake area M_2 attained only middle amphibolite facies conditions, characterized by porphyroblasts of green hornblende, garnet, grunerite, anthophyllite, andalusite, cordierite and muscovite. Granitoid plutonism and the development of migmatites in the mafic volcanic rocks southeast of Barrington Lake are interpreted to be contemporaneous with M_2. M_3 regional metamorphism resulted in alteration of earlier assemblages to greenschist facies minerals including albite, epidote, chlorite, muscovite, sericite and prehnite. The extent of this alteration is variable, and is locally complete in minor shear zones (probably contemporaneous with the retrogression).

Localized contact metamorphism by granitoid intrusions (9) has been recognized east of Barrington Lake; some hornfels is attributed to post M_3 metamorphism. Staurolite and kyanite porphyroblasts in an alteration zone at the west side of Barrington Lake may also be due to late contact metamorphism associated with unit 9.

Geochemical investigations show Wasekwan Group basalts are similar to modern island arc tholeiites. A distinctive suite of high-alumina basalt (>17% Al_2O_3) is intercalated with basalt that contains "normal" amounts of Al_2O_3; the high-alumina basalt corresponds to a similar suite identified in the northern belt in the Lynn Lake area (Gilbert *et al.,* 1980). Low Ni and Cr contents indicate olivine and pyroxene fractionation were important controls in the evolution of the source magma. Depletion of Ni + Cr, REE and HFS elements, together with decoupling of LIL- and HFS-element groups indicate an affinity with modern island arc tholeiites. The pattern of trace element depletion in Barrington Lake-Fraser Lake area volcanic rocks is similar to that of the low-HFS element group of rocks in the modern Fiji arc (Gill, 1987). Barrington Lake area volcanic rocks show relatively greater depletion of REE and HFS elements compared to Wasekwan Group volcanic rocks in the (stratigraphically equivalent) northern belt in the Lynn Lake area; this feature is attributed to less fractionation and/or a higher degree of partial melting in the development of the source magma. A komatiitic flow in the southeast part of the Barrington Lake area occurs near the east end of the Agassiz Metallotect (Fedikow, 1984). High-Mg intrusive units further east at Magrath Lake are possibly related to the komatiitic flow.

TERMINOLOGY

Volcanic rocks are classified according to composition based on weight per cent of SiO_2 (LeMaitre, 1976): basalt = 46-54; andesite = 54-62; dacite = 62-70; rhyolite = 70-78. High-alumina basalts are arbitrarily defined as those that contain more than 17% Al_2O_3. Classification according to magma series is after Irvine and Baragar (1971), Miyashiro (1974) and Jensen (1976). Total iron is indicated by FeO*. Terminology of volcaniclastic rocks is after Parsons (1969) and Fisher and Schminke (1984). Classification of pyroclastic fragment size is after Fisher (1966). Epiclastic rocks are classified according to Pettijohn (1957). The definitions of fragment size in sedimentary rocks is according to the Wentworth Scale (Wentworth, 1922); terminology of fragment size in volcanic fragmental rocks is after Schmid (1981). Intrusive rocks are classified according to mineral content after Streckeisen (1976).

REPORT STRUCTURE

Following the Introduction, this report contains three sections, corresponding to the accompanying maps of Barrington, Melvin and Fraser lakes areas, in which rock descriptions are provided for units 1 to 6 and 10. Granitoid rock units 8, 9 and 11 are briefly described following these three sections.

Discussions of the Structural History, Metamorphic History and Geochemistry of the Wasekwan Group follow the sections of descriptive geology. The Appendix lists chemical analyses of volcanic rock samples taken by the author in 1979 and 1980 and by H.V. Zwanzig in 1974; sample locations are shown on Map GR87-3-4. For reports on the economic geology and mineral deposits of the area, the reader is referred to publications cited in the foregoing section "Previous Work".

BARRINGTON LAKE AREA

INTRODUCTION

Mafic to intermediate volcanic rocks compose over 90% of the supracrustal rocks in the Barrington Lake area; subordinate felsic volcanic and minor epiclastic deposits make up the remainder. These rocks occur in several branching belts within extensive areas of granitoid rocks. One belt, the northern belt, extends east to southeast across the area (Map GR87-3-1) along the south shore of Barrington Lake, and a second belt, the southern belt, trends east to northeast in the area to the south, between One Island Lake and July Lake. A branch extends east from the northern belt south of Brooks Bay and another branch extends north from the same belt from Webb Lake to Star Lake and Camp Bay. Supracrustal remnants (mainly basaltic) occur sporadically in the granitoid terranes northwest of Brooks Bay and east of Camp Bay. The southern belt is 4 km wide at Barrington River. The maximum width of the northern belt is 4.5 km, but the true stratigraphic thickness is probably less than 2 km allowing for attenuation and structural repetition. An anticlinal fold axis has been mapped in the central part of the northern belt. Both belts extend for over 30 km across the Barrington Lake area and terminate in the granitoid terrane in the Fraser Lake area (Map GR87-3-3). These belts extend west for up to 90 km to the areas west of Lynn Lake and west of Tod Lake (Gilbert *et al.,* 1980).

WASEKWAN GROUP

Mafic to intermediate volcanlc extruslve and fragmental rocks; minor gabbro and diabase (1)

Aphyric basalt (1a1);
Porphyritic plagioclase (± hornblende) basalt and andesite (1a2);
Porphyritic hornblende basalt (1b)

Basaltic flows are interlayered with widespread mafic to intermediate tuff and subordinate felsic units. Distinction between mafic flows and tuff is not always clear, but flows are predominant, probably 2 to 3 times the volume of mafic fragmental rocks. Porphyritic and subordinate aphyric basalt are interlayered at a scale of 10 cm to 5 m; the aphyric phase comprises flows and minor intrusive bodies.

Primary structures are commonly well preserved in the northern belt, but further north (Brooks Bay-Camp Bay area) and south (southern belt) the mafic flows have been recrystallized to amphibolite that is generally devoid of primary features. Flow contacts are locally identified by the development of flow breccia and alteration (silicification, epidotization; see Figure 3). The breccia units (5-50 cm thick) consist of densely packed subangular to subrounded clasts (generally 1-6 cm across, up to 15 cm) that compose up to 70% of the rock. The clasts generally contain abundant quartz amygdales (up to 80%) and are variously altered to epidote; the brecciated zone is represented by epidotic stringers and irregular bodies in strongly deformed rocks. Stratification and flow lamination are also locally characteristic of flow contacts; layering (at a scale of 1-20 cm) is defined by variable contents of plagioclase phenocrysts, hornblende pseudomorphs and/or quartz amygdales (Fig. 4 and 5). The stratification is interpreted to be the result of differentiation related to relatively strong laminar flow at the margins of the mafic flows. Marginal zones with abundant plagioclase phenocrysts occur at the top of some

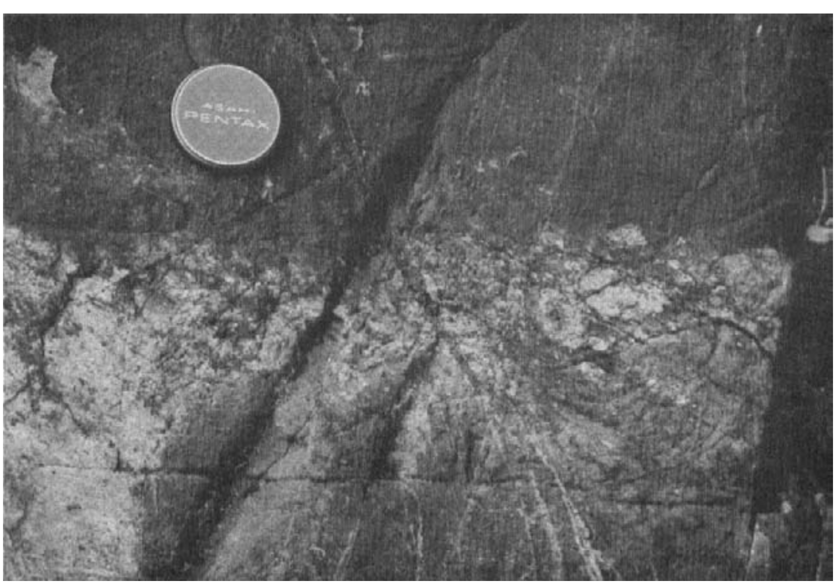


Figure 3: Contact between plagioclase phyric basalt and aphyric basalt flows (unit 1a) north of Nickel Lake. The contact is marked by a 10-40 cm wide epidotized flow breccia unit overlying the silicified upper margin of the porphyritic flow.

flows, which are locally scoured (Fig. 6), and finely laminated aphyric layers occur locally between plagioclase phyric basalt flows. The central parts of flows commonly contain trails and irregular streaky zones of plagioclase phenocrysts or quartz amygdales; these are locally gradational with discrete lenses defined by the concentration of phenocrysts and/or amygdales.

Amygdales are widely distributed in the mafic volcanic rocks at southern and central Barrington Lake. These are most commonly quartz-filled, spheroid to ovoid, 0.5 to 5 mm across, and compose 10 to 25% of the rock (up to 80%). Some flows contain two sets of amygdales, distinguished by size (0.5-1.5 mm; 2-10 mm). Large amygdales and quartz-filled vugs up to 3 cm across occur in several flows. Amygdales that contain plagioclase, or quartz with plagioclase rims are less common than quartz amygdales.

Ovoid to irregular, elongate (1-20 mm) hornblendic aggregates (+ pyrite) compose up to 20% of the mafic flows in the area 4 to 5 km north of Webb Lake (Fig. 7). The plagioclase phyric texture of the matrix is locally continuous through these structures, indicating they are probably an alteration feature rather than vesicle fillings. These mafic flows are also locally affected by silicification.

Plagioclase phenocrysts (An_{35-45}, up to An_{63}) occur in the majority of mafic flows in the Barrington Lake area. The phenocrysts (0.5-4 mm) compose 5 to 40% of the rock. Euhedral plagioclase phenocrysts up to 2 cm across occur at the north shore of Camp Bay and in one flow 3 km west of

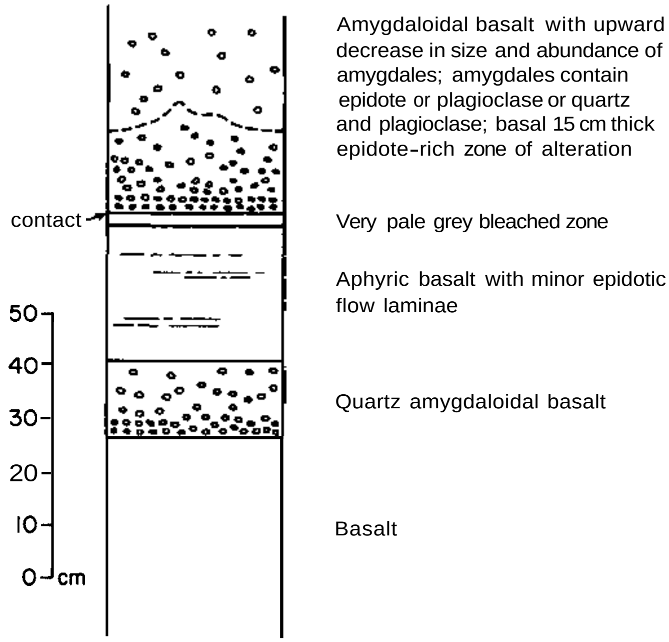


Figure 5: Section through the contact between two amygdaloidal basalt flows; 2.5 km northwest of Webb Lake.

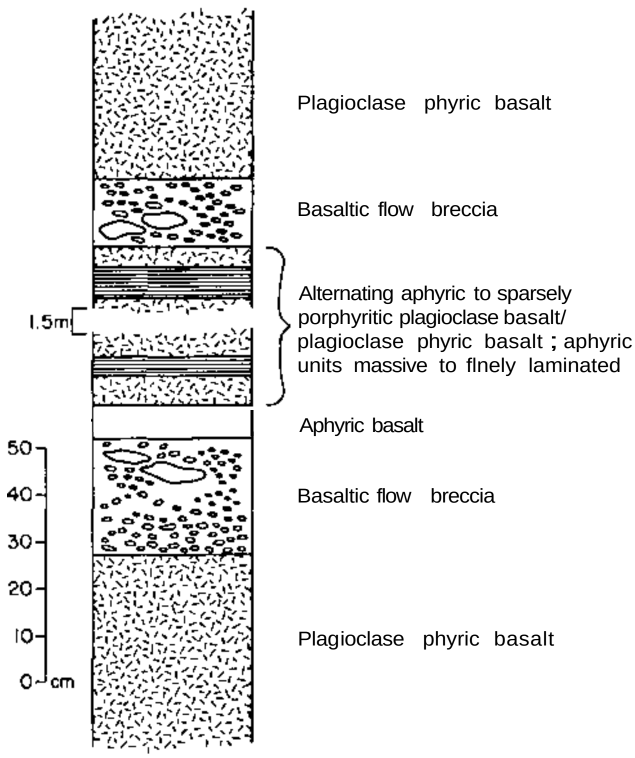


Figure 4: Section through interflow contact zone showing stratification and development of flow breccia, 250 m north of Nickel Lake.

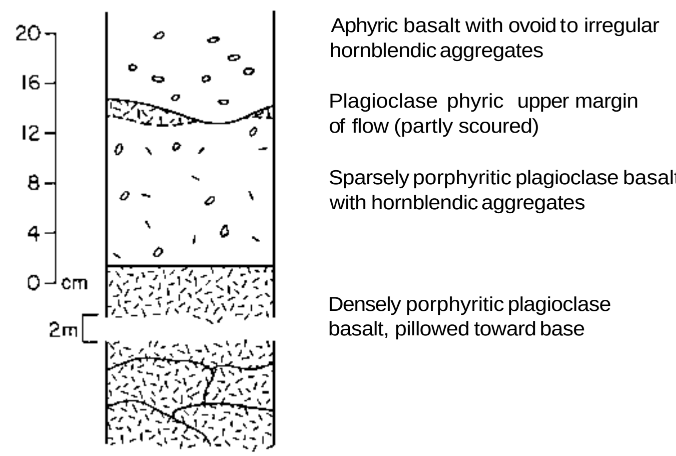


Figure 6: Section showing two flow contacts in basalt, and localized plagioclase phyric upper margin, partly scoured by the overlying flow; 5 km northwest of Webb Lake.

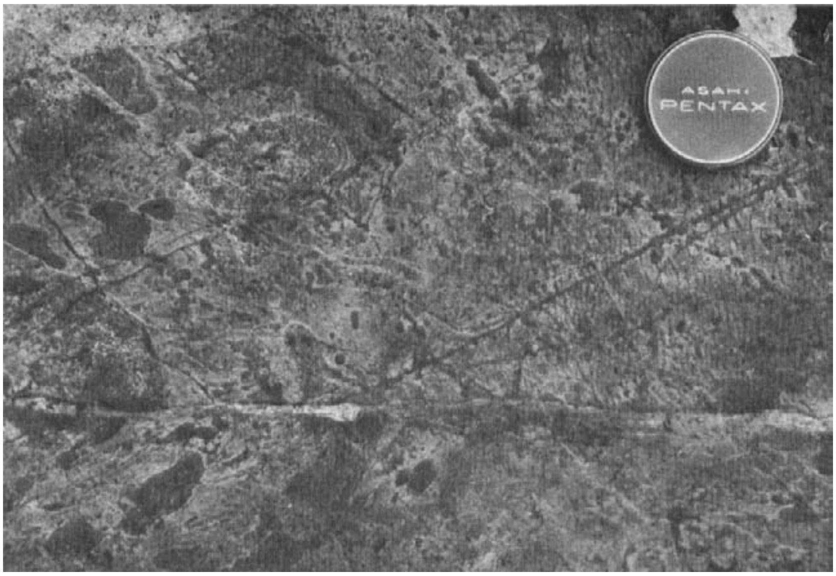


Figure 7: Alteration in mafic volcanic breccia (unit 1g) south-southwest of Star Lake showing silicification and development of hornblende in irregular aggregates, stringers, laminae and subparallel fractures. Outcrop surfaces are also locally iron stained due to minor sulphide concentrations.

Brooks Island. Green hornblende pseudomorphs (after pyroxene) are common, but less widespread than plagioclase phenocrysts. The pseudomorphs (1-2mm) occur as single crystals (commonly twinned) or as fine grained aggregates that compose 5 to 20% of the rocks. Clinopyroxene relicts within hornblende occur in one flow 2 km south of Star Lake.

The mafic flows in the Barrington Lake area have been metamorphosed to at least lower amphibolite facies, and subsequently retrograded to greenschist facies. The matrix is recrystallized to amphibolite or hornblendite (Table 2). The original basaltic texture of randomly oriented plagioclase laths is locally preserved. Basalt is coarsely recrystallized in the vicinity of granitic or gabbroic intrusions, where sporadic garnet and green hornblende porphyroblasts (commonly randomly-oriented within the plane of the foliation) and hornblendic stringers and veinlets are developed. The retrograde metamorphism resulted in alteration of hornblende to biotite (± chlorite), and plagioclase to sericite, epidote, clinozoisite, or chlorite.

Table 2: Mineralogical composition of metamorphosed volcanic rocks (1) in the Barrington Lake area

Mineral	Content (approx. %) Average	Range
Green hornblende	50	30-90
Plagioclase	40	5-60
Magnetite-ilmenite	3	0-7
Pyrite	1	0-5
Sphene	2	0-7
Biotite	1	0-10
Quartz	2	0-8

Disseminated sulphides are widespread in the mafic volcanic rocks and minor gossan zones (10-50 cm thick) with pyrite-pyrrhotite (± chalcopyrite ± malachite) occur sporadically; these are generally discontinuous, and can be traced for only a few metres. Silicification in the mafic volcanic rocks is locally associated with sulphide mineralization. South of Farley Lake, mafic volcanic rocks are locally highly altered; the alteration resulted in irregular epidotized and silicified zones, associated with carbonate-filled fractures and complete loss of primary structures.

Mafic flow breccia (1a3)

Flow breccia is intimately interlayered with massive basalt in the northern belt; autoclastic rocks are less widely developed in the southern belt. Breccia is commonly developed in flows that contain abundant quartz amygdales. Several massive flows display anastomosing basaltic screens within amygdaloidal zones; these flows are gradational with breccia that contains discrete clasts of densely amygdaloidal basalt in an amygdale-poor matrix (Fig. 8). Flow breccia also commonly contains various basaltic fragments distinguished by different porphyritic textures, and aphyric fragments that are relatively paler green than the basaltic matrix. Fragments are subangular to subrounded, randomly distributed, and compose 10 to 40% of the rock (Fig. 9). Most fragments are 5 to 20 cm long; some exceed 30 cm. Autoclastic breccia is distinguished from pyroclastic types by a magmatic matrix (± amygdales), generally lower fragment/matrix ratio, and gradation with massive flows; flow breccia is never fragment-supported, in contrast to some pyroclastic deposits (1g) (Table 3). Flow breccia includes thin (5-50 cm) units at the tops of massive flows (Fig. 10) and thicker deposits (up to 5 m). These breccia units are particularly susceptible to epidote alteration, which is generally initiated in the cores of the fragments and commonly results in complete alteration of the fragments to epidosite (Fig. 11). Contacts between flow breccia and massive flows are sharply defined, or gradational through zones of massive flows that contain minor sporadic fragments.

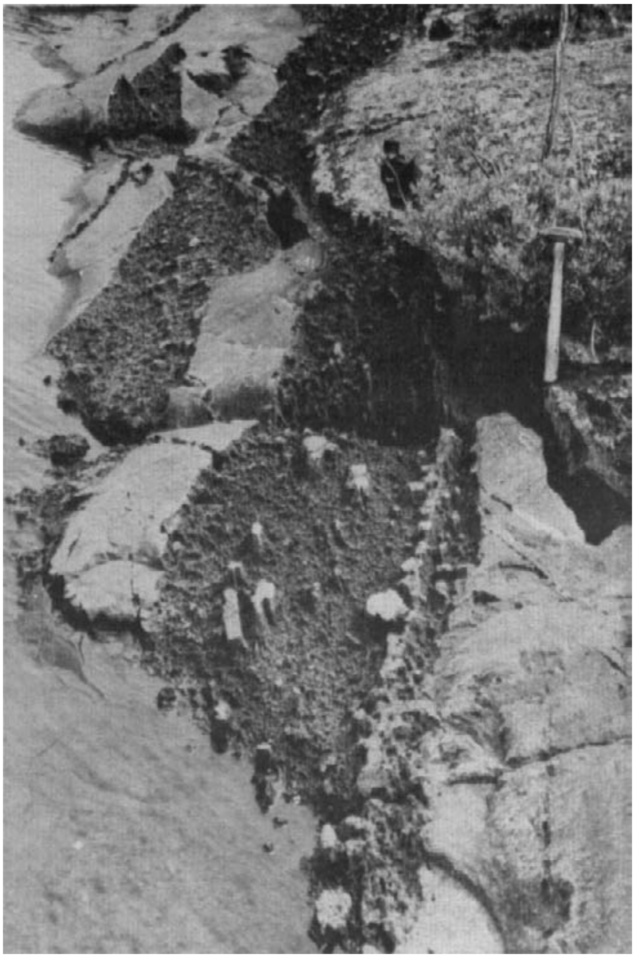


Figure 8: *Mafic flow breccia (unit 1a3) in the southeast part of Barrington Lake with ovoid fragments that contain densely packed quartz amygdales and amygdale-free rims (2-5 mm wide), within an amygdale-poor basaltic matrix.*

Table 3: Criteria for distinction between mafic to intermediate pyroclastic breccia (1g) and mafic flow breccia (1a3)

Pyroclastic breccia	Flow breccia
1. Fragmental matrix devoid of amygdales.	1. Magmatic matrix, commonly amygdaloidal.
2. Flow structures absent.	2. Flow structures occur locally *(e.g.* trails and irregular zones of phenocrysts or amygdales).
3. Generally matrix supported, locally fragment supported.	3. Fragments are matrix supported.
4. Commonly associated with mafic tuff.	4. Generally associated with mafic volcanic flows.

Pillowed porphyritic and aphyric basalt (1c)

Pillow basalt is well developed in two areas: north and northwest of Gordon Lake; and at several islands 2 to 4 km northwest of Webb Lake. Sporadic pillowed flows occur elsewhere in the Barrington Lake area.

Pillows are common within a 1.5 km wide section northwest of Gordon Lake. North-facing ovoid pillows up to 75 cm across occur in pillowed zones up to 100 m wide. The flows contain plagioclase phenocrysts and amygdales (quartz or hornblende ± plagioclase) and have been extensively altered to epidote (initiated at pillow cores). Selvages are generally dark green to grey; northwest of Webb Lake, hornblendic pillow selvages contain central feldspathic zones. A fine feldspathic and hornblendic lamination, attrib-

Figure 9: *Mafic flow breccia (unit 1a3) intercalated with massive porphyritic basalt in the southeast part of Barrington Lake. The distribution of fragmental and massive zones is accentuated by carbonatization of the breccia.*

uted to flow differentiation, is developed locally within partly disrupted pillows. The lamination is locally deformed in flame-like structures with "tails" to the west, coincident with the pillow-facing direction.

Massive porphyritic and aphyric andesite (1d)

A 280 m thick andesite unit occurs within the mafic volcanic section near the southeast corner of Barrington Lake. The andesite extends laterally for at least 1.25 km and terminates against basaltic flows to the east, where a fault contact has been inferred; the andesite is either faulted or wedges out to the west. Elsewhere in the Barrington Lake area, occurrences of andesite are limited to rare thin interlayers (0.5-5 m) within the mafic volcanic rocks.

The andesite at southeastern Barrington Lake is pale to medium grey weathering, and contains euhedral green hornblende porphyroblasts (10-35%), plagioclase phenocrysts (0-25%) and pyrite + pyrrhotite (up to 7%) in a very fine grained matrix of quartz + plagioclase + chlorite + opaque minerals. The andesite unit contains sporadic remnants of amygdaloidal basaltic flow breccia; both andesite and breccia have been coarsely recrystallized and contain abundant green hornblende porphyroblasts and hornblendic aggregates, stringers and veins. Rusty gossan zones, 20 cm to 1 m thick, constitute 10 to 15% of the andesitic section.

The gossans[2] contain pyrite and pyrrhotite (see Map GR87-3-1); sulphides are partly or completely altered to hydrated iron oxides. The sulphides are disseminated and also occur as irregular aggregates (0.5-1 cm), as minor fracture-fillings, or concentrated in irregular hornblende-chlorite stringers. The rock is locally strongly foliated, fractured, and invaded by quartz veinlets.

2 Assay of a grab sample from one gossan gave 0.03% Cu, 0.02% Zn, and traces of Au and Pb.

Figure10: Epidotized flow-top breccia (unit 1a3) north of Nickel Lake as a 0.5 m thick unit within plagioclase phyric basalt flows. Fragments contain up to 20% quartz amygdales.

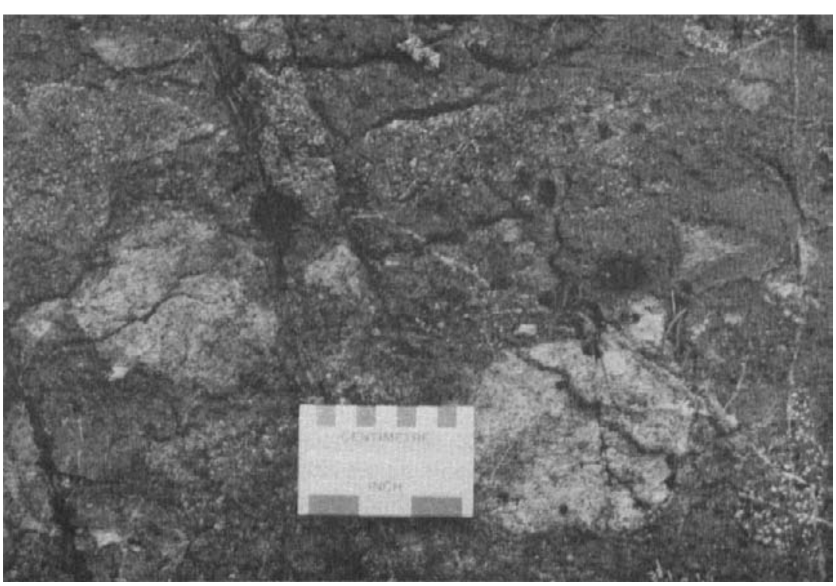


Figure 11: Flow breccia (unit 1a3) north of White Owl Lake showing ovoid to amoeboid quartz-amygdaloidal fragments that have been selectively epidotized (e.g. clast at lower right). F

Environment of deposition of mafic to intermediate flows (1a, b, c, d).

Mafic volcanic flows in the Barrington Lake area are considered to be subaqueous on the evidence of local pillow structure. Epiclastic sedimentary rocks are rare in the volcanic section, indicating the area was remote from sources of epiclastic detritus. The widespread occurrence of highly vesicular (amygdaloidal) phases and sporadic large amygdales preclude a deep water environment (Jones, 1969). The limited evidence indicates an offshore environment of medium depth (500-2000 m) removed from the influence of any continental land mass.

Mafic tuff and crystal tuff (1e)

Mafic tuff and crystal tuff are widely distributed in the Barrington Lake area and probably represent less than one half the total amount of mafic volcanic rocks in that area. Tuff units (typically 50 cm to 15 m thick) are intimately interlayered with related coarser fragmental deposits (1f, g) and/or with mafic flows. Prominent laminated or massive tuff units have been mapped at the south shore of Barrington Lake north of Nickel Lake (65 m thick), and west of Larson Lake (>200 and <350 m). Mafic tuff is also abundant in the sections north and south of Farley Lake, southwest of MacBride Lake, and in the Camp Bay-Star Lake section. Mafic tuff occurs sporadically elsewhere in the northern belt, but equivalent rocks are rare in the southern belt. Mafic to intermediate schists and gneisses (5) locally display traces of fragmental structure and may be derived from volcanic tuff and breccia *(e.g.* east of Brooks Bay, and south of Star Lake).

Massive tuff is distinguished from mafic magmatic rock by fragmental texture, commonly only recognized in thin section (plagioclase grains are more anhedral, less evenly distributed, and commonly have greater size range than phenocrysts in mafic flows). Bedding in tuff is defined by differences in grain size (very fine grained to medium grained) and composition (relative contents of hornblende, plagioclase, epidote and locally carbonate) (Fig. 12). Alternating laminae weather medium to dark green (hornblendic), yellow (epidotic), grey and beige. Beds are generally 0.5 to 10 cm thick (locally up to 2m). Fine grained, dark laminae (1-5 mm) occur sporadically; one bed displays small-scale rip-ups, scour and truncated bedding (Fig. 13). Mafic to felsic lapilli and/or interbeds of lapilli tuff occur in some sections. Graded bedding defined by plagioclase grains, and less commonly by lapilli, occurs sporadically (Fig. 14). Lateral gradation between mafic tuff and crystal tuff occurs locally. Sporadic intraclasts and rip-ups of these lithologies have also been observed in alternating tuff and crystal tuff sequences.

Mafic crystal tuff contains 1 to 3 mm grains of plagioclase (± hornblende). Small plagioclase grains (<l mm) occur together with medium grained plagioclase crystals in some beds as two distinct populations. Sporadic plagioclase aggregates (2-8 grains) and plagioclase megacrysts (up to 8 mm) are less common. Plagioclase crystals (An_{40-46}) are subhedral to anhedral, subangular to ovoid and locally corroded. Subordinate quartz grains (<10%) are present in some units. Hornblende pseudomorphs and pseudomorphic aggregates compose up to 15% of some beds, and are generally subordinate to plagioclase crystals (plagioclase content averages 10-25%, up to 40%). Amphibole is subhedral to anhedral, and pseudomorphs pyroxene. The fine- or very fine-grained matrix is gradational with the coarser mineral grains of plagioclase and hornblende and consists largely of green hornblende (20-75%), plagioclase (20-60%), quartz (2-10%), and biotite (0-10%). Magnetite and/or pyrite are generally subordinate (1-5%), but magnetite content is 5 to 10% in tuff north and south of the iron formation at Farley Lake. Highly mafic tuff (green hornblende >90%) has locally been mapped, *e.g.* within pillowed flows northwest of Gordon Lake.

Mafic tuff is massive to finely foliated, locally strongly foliated. At the south margin of the northern belt west of Larson Lake, schistose tuff contains highly attenuated lapilli; metamorphism has locally resulted in the development of a gneissic layering parallel to the bedding in this area. Garnet and/or hornblende porphyroblasts are locally developed in

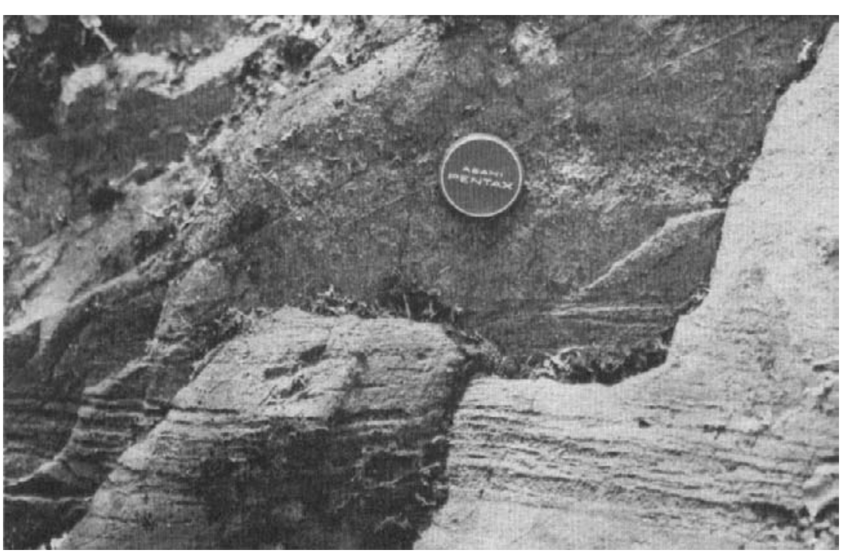


Figure 12: Mafic crystal tuff (unit 1e) north of Nickel Lake that contains a finely layered zone; laminae are defined by differences in size and abundance of crystal fragments and by variable carbonate content resulting in differential weathering.

Figure 13: ***Crossbedded mafic tuff (unit 1e) showing fine lamination defined by variable ratios of green hornblende (hb) to plagioclase (pg). Magnetite (white spots) is disseminated throughout the tuff. Sample 703-1. Negative image photomicrograph, plane polarized light.***

fragmental rocks in the sections at Camp Bay and south of Star Lake. Alteration of hornblende to biotite or actinolite occurs locally; minor disseminated biotite is widespread and some beds contain ovoid aggregates or irregular stringers of biotite (± sphene). Disseminated carbonate is generally subordinate, but laminae with up to 40% carbonate occur locally.

Mafic to intermediate lapilli tuff (1f)
Mafic to intermediate pyroclastic breccia (1g)

Lapilli tuff and subordinate pyroclastic breccia occur in many parts of the northern belt, but equivalent rocks are unknown in the southern belt, except in the area northwest of One Island Lake (Syme and Gilbert, 1977). In the northern belt, the distribution of lapilli tuff (1f) corresponds generally to that of mafic tuff (1e). Pyroclastic breccia is mainly confined to the sections west of White Owl Lake and south of Star Lake. Lapilli tuff units occur within pyroclastic breccia and also within sections of mafic tuff devoid of breccia. Pyroclastic breccia is less abundant than flow breccia, but the breccia type is uncertain in many cases because of alteration and deformation. Criteria used to distinguish pyroclastic breccia from flow breccia (1a3) are indicated in Table 3.

Lapilli tuff and pyroclastic breccia units are interlayered at a scale of 50 cm to 5 m; tuffaceous units are commonly well bedded, but pyroclastic breccia is typically poorly sorted or massive and forms units up to 25 m thick. Fragment types in units 1f and 1g are listed in Table 4. Mafic fragments are largely hornblendic, but increasing amounts of biotite occur in relatively more felsic lithologies. Felsic to intermediate fragments are generally more abundant than mafic types, but this feature is locally exaggerated by the greater resistance of the more felsic lithologies to deformation and alteration, and their clearer distinction from the generally mafic matrix. Lapilli tuff locally contains vesicular, pumiceous or amygdaloidal fragments, locally with densely packed quartz micro-amygdales (Table 4; Fig. 15).

Fragment size range in pyroclastic breccia is typically 5 to 25 cm (estimated pre-deformation diameter), but larger

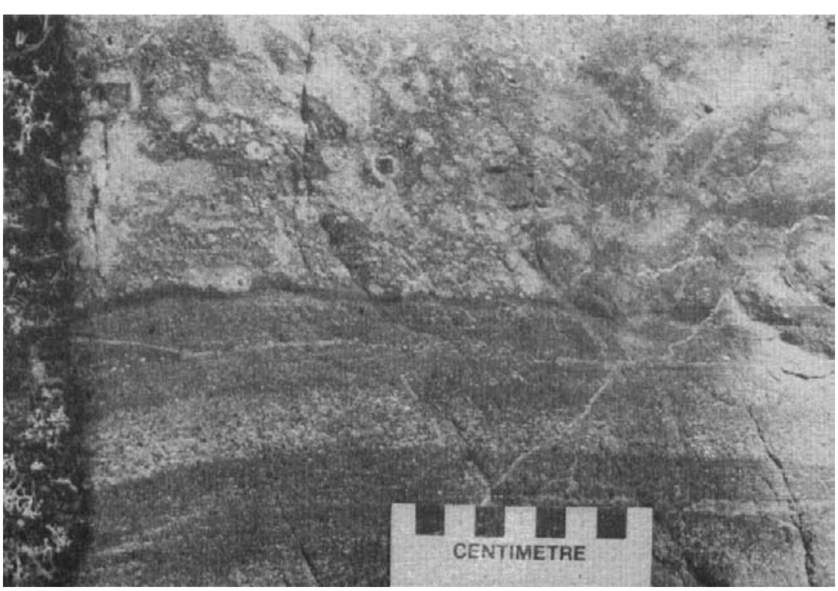


Figure 14: *Intermediate to mafic tuff and lapilli tuff (units 1e,f) northeast of White Owl Lake. The feldspathic unit above the scale card is graded (tops toward the lapilli tuff bed).*

Table 4: Clast types in mafic to intermediate lapilli tuff and pyroclastic breccia (1f, 1g) in the Barrington Lake area

Clast type	Petrography	Notes
Aphyric mafic volcanic		Porphyritic lithologies more common than aphyric; mafic fragments generally subordinate.
Porphyritic mafic volcanic	± Plagioclase phenocrysts ± hornblende pseudomorphs ± quartz amygdales.	Some fragments contain early quartz veinlets (pre-incorporation in breccia).
Amygdaloidal mafic to felsic volcanic	Quartz-amygdales (20-80% of fragments) occur in a very fine grained hornblendic or quartzo-feldspathic matrix (± plagioclase phenocrysts).	Largely confined to the section north of White Owl Lake.
Intermediate volcanic	± Plagioclase phenocrysts.	Felsic and intermediate fragments commonly predominant; some deposits consist exclusively of felsic fragments in a mafic tuff matrix.
Aphyric felsic volcanic	Very fine grained; some fine- to medium-grained.	
Porphyritic felsic volcanic	± Plagioclase ± quartz phenocrysts ± hornblende porphyroblasts ± quartz-filled vesicles (rare).	
Epidotic		Partly to completely altered volcanic lithologies.
Intermediate tuff	Fine grained, with plagioclase fragments.	Sporadic occurrences.

fragments occur locally (*e.g.* up to 40 x 18 cm south of Webb Lake; up to 90 x 3 cm south of Star Lake). Lapilli tuff and pyroclastic breccia typically contain 10 to 35% fragments (locally up to 65%). Lapilli are well graded in some units (*e.g.* north of Nickel and White Owl lakes). Fragments are angular to subrounded and variously attenuated, with elongation ratios commonly 3/1 to 10/1 (Fig. 16). Strongly foliated rocks display extreme attenuation, with gradation to banded gneiss that contains alternating white (felsic) and green (hornblendic) laminae (corresponding generally to clasts and matrix, respectively).

Microscopic features of fragments in units 1f and 1g are similar to those of equivalent extrusive rocks (1a, b, d; 2a, b). The matrix is mafic to intermediate and consists of amphibolite ± biotite (up to 15%). South of Farley Lake, volcanic breccia is commonly micaceous, with biotite in place of hornblende in the matrix; plagioclase (An_{45-50}) and hornblende crystals are subhedral to anhedral, subangular or locally ovoid. Abundant carbonate (up to 50%) is present in the matrix at several localities, and pyrite stringers and aggregates constitute up to 8% of the matrix of some deposits. Alteration of mafic fragments to micaceous aggregates and stringers (biotite + sphene) occurs locally, and secondary epidote and chlorite are widespread. Some units display extensive saussuritization of plagioclase phenocrysts and intermediate to felsic fragments. Randomly distributed porphyroblasts of green hornblende that overprint chlorite occur locally.

Environment of deposition of mafic to intermediate fragmental rocks (1e,f, g)

Fragmental rocks (units 1e, 1f and 1g) in the Barrington Lake area probably include pyroclastic deposits (units characterised by angular fragment shapes and/or subhedral to angular crystal grains) and reworked volcanic deposits (with variously rounded fragments and subhedral to subrounded crystal grains). There is little evidence in the fragmental rocks to indicate either subaerial or subaqueous deposition, but contiguous units of pillowed basalt and iron formation, and rare sporadic epiclastic interlayers demonstrate part, at least, of the Barrington Lake area was under water.

Gabbro, quartz gabbro, diabase (1h)

Gabbro and diabase dykes and sills (0.5-10 m thick) occur sporadically within the volcanic rocks of unit 1 and they are interpreted to be hypabyssal equivalents of the mafic extrusive rocks; the central parts of some flows are gabbroic, and lithologically similar to the intrusions. Fine feldspathic and hornblendic lamination (2-20 mm) in zones up to 10 cm wide occurs at several dyke margins; some intrusions display chilled margins (1-5 cm thick). Contacts with basaltic host rocks are generally straight; an irregular embayment of basaltic host rock into one diabase dyke is attributed to intrusion of the dyke into a flow that had not completely solidified (Fig. 17). Quartz amygdales were identified in several thin (<50 cm) dykes. The mafic intrusive rocks are characterized by an interlocking mosaic of plagioclase and green hornblende with up to 8% magnetite andlor ilmenite and subordinate pyrite. Sphene is locally prominent (up to 5%) and interstitial quartz constitutes up to 10% of some intrusions.

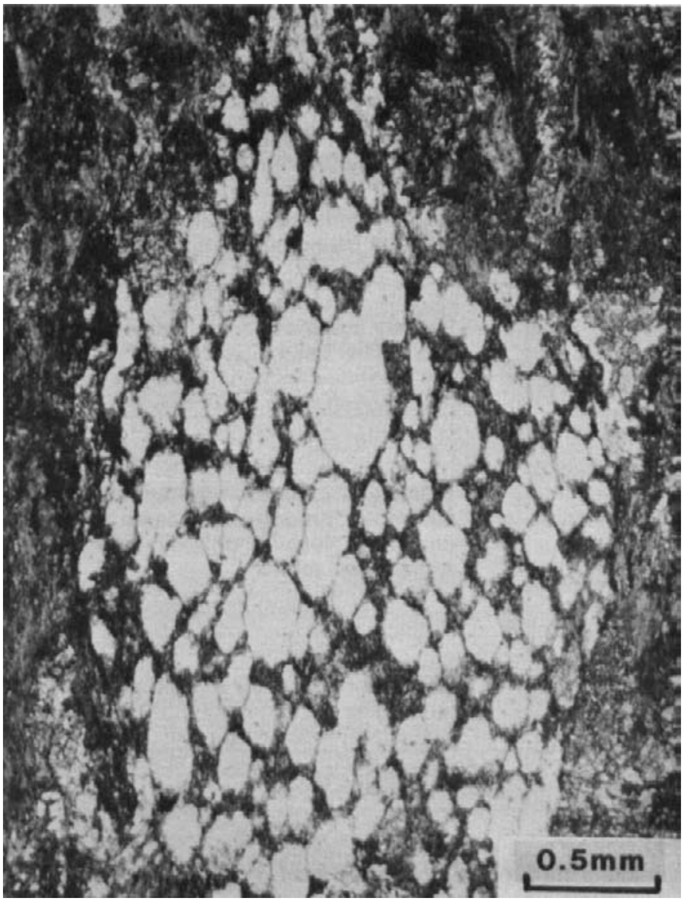


Figure 15: Granule in mafic lapilli tuff (unit 1f) contains a myriad of quartz amygdales in a hornblende-epidote matrix. Sample 1131-1, plane polarized light.

Intermediate to felsic volcanic extrusive, intrusive and fragmental rocks (2)

Aphyric rhyolite and dacite (2a)
Porphyritic rhyolite and dacite (2b)

Intermediate to felsic volcanic rocks (units 2a and 2b) include flows, discordant intrusions and massive units of uncertain origin (extrusive or intrusive). These rocks are widely distributed, but are subordinate lithologies in the Barrington Lake area; they compose 5 to 10% of the Wasekwan Group in the northern belt, and approximately 3% of the southern belt. The felsic units range from minor veins to major units (up to 140 m thick and several km long) that are most abundant in the area between Larson and Nickel lakes, and west of Webb Lake. The composition ranges from dacite to rhyolite; some intermediate derivatives may be a result of contamination by adjacent mafic volcanic rocks. Local brecciated zones within the generally massive felsic rocks are probably autoclastic, in contrast to fragmental deposits of unit 2c that have been interpreted to be pyroclastic.

Felsic volcanic rocks are typically cream, beige or pale grey weathering units, 20 cm to 5 m thick that alternate with intermediate to mafic volcanic rocks. Contacts are generally sharp, but mafic xenoliths apparently derived from adjacent basalt flows occur at the margins of several units. Micaceous lenticles and stringers are ubiquitous in the felsic rocks, and ovoid aggregates of green hornblende and/or biotite (± garnet) commonly compose up to 5% of the rocks. Dark irregular zones and diffuse streaks (5 mm - 5 cm wide) that correspond to increased biotite and/or hornblende content probably result from contamination and flow lamination.

Several massive felsic units have been locally brecciated in elongate zones up to 3 m wide. The breccia consists of cream-weathering fragments (subangular to ellipsoidal, up to 15 cm long) in a slightly darker matrix. Contacts between the fragmental and massive felsic rocks are locally

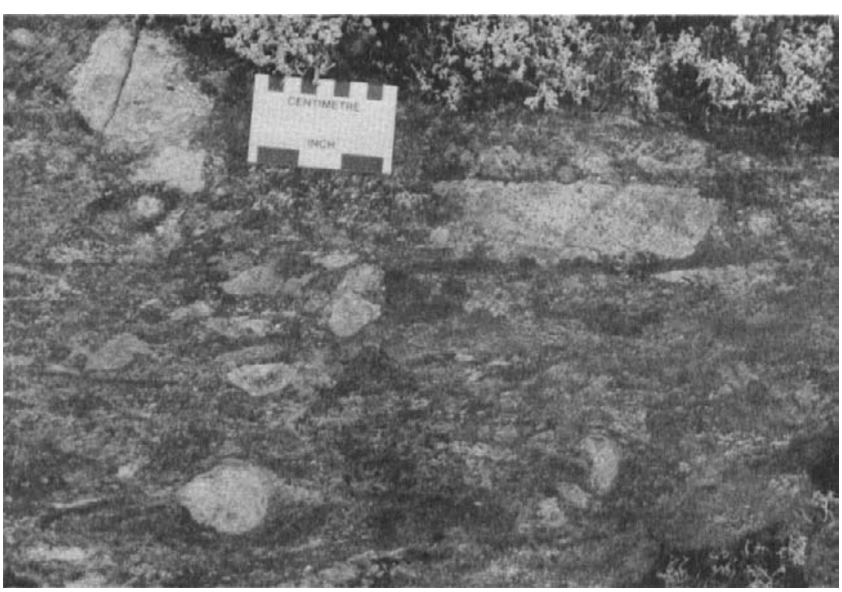


Figure 16: Heterolithic volcanic breccia (unit 1g) in the southeast part of Barrington Lake that contains angular to ovoid fragments in a tuffaceous matrix. Mafic fragments are relatively more attenuated than feldspathic and felsic types due to greater incompetence.

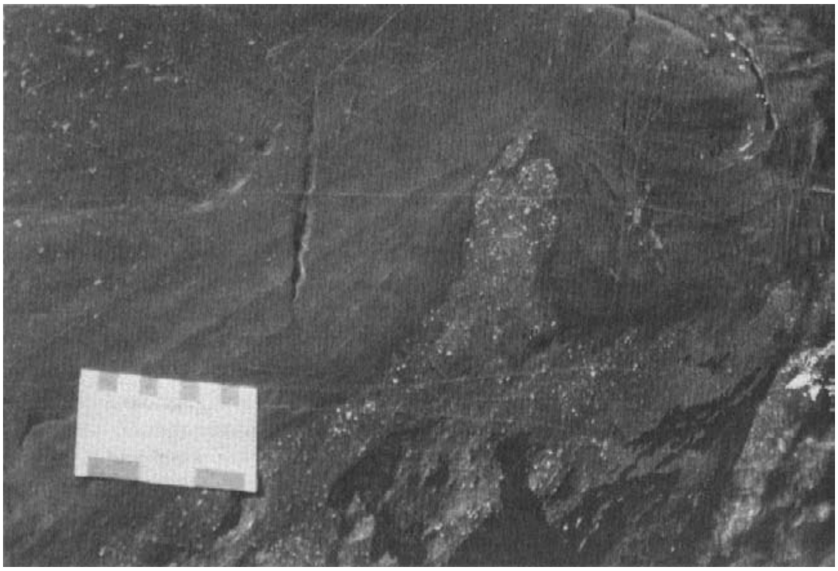


Figure 17: Contact between a synvolcanic diabase dyke (unit 1h) and a plagioclase phyric basalt flow (unit 1a2) in the southeast part of Barrington Lake. The 2 m wide dyke has a marginal laminated zone that has been locally disrupted by a protrusion from the host rock, attributed to emplacement of the dyke into a flow that had not completely cooled.

gradational, consistent with an autoclastic mode of origin. Recognition of brecciated zones was generally dependent upon unusually fresh exposure (*e.g.* beneath uprooted trees) and the breccia may be more widely developed than indicated by the few sporadic observations. Rhyolite breccia gradational with massive rhyolite occurs 3 km northwest of Webb Lake. The rock consists of subangular very felsic fragments in a felsic to intermediate matrix that contains biotite and muscovite porphyroblasts.

A massive rhyolite flow at Webb Lake locally contains hornblende-filled, irregular branching fractures, attributed to stress during cooling. Prominent jointing (spaced at 1-10 cm) is widespread in the felsic volcanic rocks and may be due to cooling or tectonic stress. Minor zones of tectonic breccia (2-5 cm thick) occur in some units.

Porphyritic felsic volcanic rocks (2b) are locally associated with subordinate aphyric rhyolite and dacite (2a) in the same stratigraphic or intrusive unit. Euhedral to subhedral plagioclases are almost ubiquitous in rocks of unit 2b, and quartz phenocrysts (subhedral to ovoid) occur in at least 80% of the rocks. The phenocrysts are typically 0.5 to 2.0 mm (up to 4 mm) long. Plagioclase phenocrysts (oligoclase to andesine), compose 10 to 30% of the felsic rocks, and are invariably more abundant than quartz (5-15%). Rare vesicles (0.5-1.0 mm long, up to 1 cm) that contain quartz ± plagioclase and/or hornblende constitute up to 5% of several felsic units. Euhedral hornblende porphyroblasts, (5-10%), and irregular stringers and fracture fillings of hornblende (± epidote) are widely developed. Magnetite grains (0.5 mm) are prominent in some units. Disseminated pyrite (± pyrrhotite ± chalcopyrite) constitutes up to 10% of some felsic rocks; these minerals occur locally in stringers and aggregates (up to 2 cm long). Garnet, chlorite and cummingtonite porphyroblasts occur sporadically and porphyroblastic muscovite is common. The very fine grained matrix comprises quartz, plagioclase, sericite, magnetite and biotite (± hornblende ± carbonate).

Intermediate to felsic volcanic breccia and lapilli tuff (2c)
Intermediate to felsic tuff (2d)

Intermediate to felsic fragmental deposits form a very minor part of the Wasekwan Group in the northern belt and in the volcanic sections further north. The fragmental rocks are interlayered with massive felsic volcanic rocks or occur as layers (up to 8 m) within mafic volcanic rocks. Fragment types include porphyritic rhyolite or dacite, intermediate volcanic rock, and minor basalt. These lithologies are similar to extrusive rocks of equivalent composition (2b; 1a, b, d).

Intermediate to felsic volcanic breccia (2c) in the northern belt is largely confined to the section north and northwest of Larson Lake. These rocks occur both as discrete units (up to 85 m thick) within mafic to intermediate volcanic sections and as subordinate layers within massive felsic volcanic rocks. Fragments are predominantly intermediate to felsic and plagioclase (± quartz) phyric; mafic types occur sporadically. The fragmental rocks (2c) are commonly well foliated and variously altered to biotite-chlorite-sericite-schist. Fragments are generally deformed and attenuated, and cataclastic foliation is locally developed.

A unit of intermediate volcanic breccia (2c) 1 km northwest of Webb Lake is unusually well preserved. The breccia occurs in a section of mafic volcanic flows and fragmental rocks with minor porphyritic rhyolite. Several mineralized felsitic layers[3] up to 1 m thick occur within basalt 15 m south of the intermediate fragmental unit. The breccia contains subangular fragments of rhyolite (predominant), plagioclase phyric basalt and aphyric basalt in an intermediate,

3 One assayed sample yielded 0.07% Cu, 0.04% Zn.

hornblendic matrix with pyritic stringers. Fragments (lapilli to small blocks up to 25 x 8 cm) constitute approximately 60% of the rock.

Intermediate to felsic tuff (2d) has been mapped by E.C Syme in the southwest corner of the Barrington Lake area; for a description of these rocks, the reader is referred to the report by Gilbert *et al.* (1980).

Sedimentary rocks (3)

Greywacke, siltstone (3a)
Conglomerate (3b)
Argillite (3c)

Epiclastic rocks compose less than 1% of the Wasekwan Group in the Barrington Lake area. These deposits are commonly well preserved and display detrital textures, in contrast to gneiss and schist (5b, c), which are interpreted, in part, as the metamorphosed equivalents of the epiclastic rocks (3). Intermediate feldspathic greywacke units have been mapped within mafic flows north of Nickel Lake and greywacke and argillite occur within rhyolite northwest of Webb Lake. Several greywacke and siltstone units occur in mafic tuff north of Farley Lake, and greywacke and pebble conglomerate are interlayered with basalt and rhyolite east of Brooks Bay.

Feldspathic greywacke contains subangular to ovoid detrital quartz and plagioclase grains and felsic granules in a felsic to intermediate matrix that contains up to 30% biotite and up to 25% green hornblende. Sporadic garnets and chloritic aggregates occur in the sedimentary rocks east of Brooks Bay, which include conglomerate with rhyolite and amphibolite pebbles, and saussuritized volcanic clasts. Intermediate to mafic greywacke and finely laminated micaceous argillite occur within massive rhyolite 1 km northwest of Webb Lake. These epiclastic units (50 cm to 1 m thick) have been tectonically brecciated together with the adjacent rhyolite. This has resulted in the occurrence of angular rhyolite fragments within the sheared greywacke. Several massive hornblendic greywacke and siltstone beds up to 15 m thick occur within mafic crystal tuff 1 km north of Farley Lake. A unit of chloritic schist (5b) at least 50 cm thick within the same section is interpreted to be an altered sediment. Greywacke and siltstone (3a) are within the compositional range of mafic tuff in the Barrington Lake area (Table 5), but the occurrence of abraded, subhedral to anhedral mineral grains suggests these deposits (3a) have been reworked.

Hematite-magnetite-bearing iron formation (3d)

Extensive iron formation underlies Gordon and Farley lakes, within the predominantly mafic volcanic section west of Barrington Lake. The associated aeromagnetic anomaly indicates the unit is approximately 1.5 km wide and 6.25 km long (Barrington Lake area, Questor Surveys Ltd.; Manitoba Energy and Mines, 1977). The maximum exposed width of the iron formation (at the west end of the body) is 450 m; this width is probably at least twice the true thickness of the formation, due to folding. An anticlinal fold axis has been mapped west of the iron formation. The formation at Farley Lake is distinguished from magnetiferous iron formation further west (Lynn Lake-Arbour Lake area) by the presence of abundant hematite and the local occurrence of nodular structures in amphibolitic laminae.

The iron formation is characterized by alternating laminae of chert, argillite, siltstone, amphibolite and subordinate massive magnetite that result in conspicuous banding of white, grey, green and rusty brown (ferruginous) units (Fig. 18). Laminae are generally 1 to 15 mm thick, but some argillite and siltstone beds attain 10 cm. Hematite and magnetite are widely distributed as stringers, aggregates, and disseminations. The layering is commonly deformed in tight, similar or disharmonic folds with amplitudes of 1 to 3 cm (up to 15 cm). The incompetent chert laminae are locally disrupted and tectonically fragmented.

Table 5: Average compositions of hornblendic greywacke and siltstone (3a) and chloritic schist (5b) north of Farley Lake. The compositional range of mafic tuff (le) in the Barrington Lake area is shown for comparison. Figures are estimated percentages.

		Greywacke (3a)	Siltstone* (3a)	Chloritic schist (5b)	Mafic tuff (le)
PLAGIOCLASE	detrital angular grains	40	10		20 - 60
QUARTZ		10	5		2 - 10
GREEN HORNBLENDE		20	45		20 - 75
BIOTITE + CHLORITE		10	10		0 - 10
EPIDOTE		8	20		0 - 10
HEMATITE		5			0 - 2
MAGNETITE + PYRITE + PYRRHOTITE		7	10	7	1 - 10
PLAGIOCLASE + QUARTZ	very fine grained			50	
CHLORITE				18	
EPIDOTE				5	
BIOTITE, POIKILOBLASTIC				20	

*One assayed sample yielded 0.02% Cu, 0.02% Zn, and a trace of Au.

Figure 18: Finely bedded iron formation (unit 3d) west of Gordon Lake that contains chert, siltstone, amphibolite and magnetite laminae.

Nodular structures (2-8 mm across) occur in irregular discontinuous zones up to 10 cm wide within well laminated sections (Fig. 19). The ovoid to irregular nodules consist largely of cream-weathering actinolite + grunerite, with rusty brown magnetite cores and magnetite (± hematite) outer shells. One or two concentric zones of epidote occur in some bodies. Several dumbell-shaped, yoked structures were also observed. The nodules are locally stratabound, and associated with very fine chlorite, epidote or graphite laminae and trails of magnetite euhedra (up to 0.5 mm). Ovoid to irregular carbonate, sericite and hematite aggregates (1-2 mm) were also observed, but they are less common than the amphibole-magnetite nodules. Chert generally occurs in thin layers with planar or irregular, lobate margins, and less commonly as discrete lenses. Some chert beds contain fine radiating grunerite needles nucleated on magnetite aggregates. Chert commonly contains hematite that locally defines fine laminae, and subordinate chlorite and carbonate. Some argillitic units are altered to strongly foliated chloritic schist. Amphibolite laminae consist of grunerite in radiating aggregates or sub-parallel prisms perpendicular to bedding, which is locally cut by vertically discontinuous, syndepositional microfaults and later cross fractures filled with chlorite or hematite.

The iron formation at Farley Lake is interpreted to be a volcanic-associated Algoman type deposit (as defined by Gross, 1965). The nodular and lobate structures in amphibole and chert suggest an originally gelatinous deposit that possibly resulted from direct precipitation from an iron- and silica-rich solution. The structures are not analogous to oolitic, pisolitic or peloidal texture developed in many cherty iron formations. The Farley Lake iron formation is thus considered to include both a chemogenic component and detrital deposits (siltstone and argillite). The composition, structure and stratigraphic association of the iron formation indicate an affinity with Algoman type deposits. Ferruginous and cherty (chemogenic) units are intercalated with fine grained sedimentary rocks that probably represent distal

Figure 19: Nodular structures that contain amphibole and magnetite in iron formation (unit 3d) west of Gordon Lake.

turbidites. A turbidite association has been described elsewhere for iron formations (Shegelski, 1975), and the uppermost (E) division of Bouma sequences is represented by ferruginous sedimentary rocks in some turbidites. The Farley Lake iron formation may be stratigraphically equivalent to the sedimentary division (middle Wasekwan Group) in the Lynn Lake area that has been interpreted to be a turbidite sequence (Gilbert *et al.,* 1980). The Farley Lake area may thus represent a relatively distal part of the sedimentary basin where the supply of detrital material was intermittent. The development and preservation of delicate structures in the chemogenic and fine clastic material could have occurred in this tranquil environment at water depths below storm wave-base.

ROCKS OF PROBABLE WASEKWAN GROUP AGE

Amphibolite, schist, gneiss and related mlgmatite (5)

Amphibolite, hornblende-plagioclase gneiss and migmatite (5a)

Amphibolite devoid of original features occurs in the northern and southern belts, and in minor supracrustal enclaves in the extensive granitoid terranes in the Barrington Lake area. Where these rocks are continuous with mafic volcanic lithologies (recognized by primary features) they are included in unit 1 (flows, and fragmental and minor intrusive rocks). Amphibolites that are not continuous with volcanic lithologies, but are interpreted to be volcanic, are mapped as unit 5a. These amphibolites are most abundant in the southern belt east of Hughes River. East of Barrington River the southern belt is invaded by extensive granitoid intrusions and further east in the Fraser Lake area (Map GR87-3-3), the belt is represented by enclaves of amphibolite (5a) within a largely granitoid terrane.

Fine- to medium-grained amphibolite is massive to gneissoid, and composed of green hornblende and plagioclase, with subordinate biotite and minor accessories (Table 6). The rocks are generally aphyric, but locally some amphibolite is plagioclase phyric. Concordant and minor discordant tonalitic *lits* are common. Agmatitic structure is locally developed, but hornblendic gneiss, hybrid rocks and migmatite derived by partial assimilation of the amphibolite are more common where the amphibolite is intruded by granitoid phases (Fig. 20). Micaceous amphibolite and minor related schists are interpreted to be alteration products of basaltic lithologies. Minor dioritic phases associated with tonalite and quartz diorite intrusions in the amphibolite may, in part, be a result of assimilation of mafic rocks.

Hornblende-plagioclase gneiss occurs where amphibolite has been extensively intruded by granitoid rocks, *e.g.* south of July Lake, at the margins of the greenstone belts, and in minor supracrustal enclaves in the granitoid terranes around Barrington Lake (Fig. 21). Metasomatic quartz dioritic zones and tonalitic *lits* in amphibolite apparently represent an early stage in the development of the gneiss. Feldspar and hornblende lamination (1-20 mm) is common in the medium grained, speckled gneiss; at least two phases of tonalitic to quartz dioritic intrusions and minor posttectonic pink pegmatites have been distinguished.

Table 6: Mineralogy and petrography of amphibolite and related gneiss (5a) in the Barrington Lake area

Mineral	Notes	Abundance (approx. %)
GREEN HORNBLENDE	Defines foliation, locally poikiloblastic.	20-60
PLAGIOCLASE	Andesine, rare labradorite. Commonly zoned (normal).	25-60
BIOTITE	Subparallel or parallel to foliation, locally randomly oriented.	0-10, up to 20% of minor laminae
QUARTZ		0-10
MICROCLINE		0-10
MAGNETITE		2-5, rarely 10
SPHENE, EPIDOTE, APATITE, PYRITE	Common accessories.	
HEMATITE	Commonly associated with magnetite and pyrite.	generally less than 5% each
SERICITE. CHLORITE SAUSSURITE	Minor secondary minerals, locally in narrow zones parallel to the foliation.	

Figure 20: *Migmatite (unit 5a) at July Lake. The tight to isoclinal fold (D_2) contains amphibolite in the core and hornblende-plagioclase gneiss on the limbs; pervasive, thin tonalitic lits (parallel to the S_1 foliation) occur throughout the rock.*

Mafic to intermediate schist and gneiss (5b)
Intermediate to felsic schist and gneiss (5c)

Schist and gneiss (5) occur mainly in the central part of Barrington Lake (at Camp Bay and east of Brooks Bay). These rocks have been metamorphosed to amphibolite facies and contain diagnostic minerals such as anthophyllite, staurolite, andalusite and garnet.

Chloritic schist and gneiss occur in a 60 m thick section east of Brooks Bay (Map GR87-3-1). The section occurs immediately north of a pronounced lineament that corresponds to an east-trending fault, and contains a subeconomic Cu-bearing massive sulphide deposit (H.B.E.D. Barrington Lake deposit, reported to be 15 ft. thick and 350 ft. long - Northern Miner, April 13, 1972). Mafic volcanic flows and flow breccia occur north and south of the schist and gneiss. The latter contain relicts of felsic to intermediate clasts (up to 1 x 6 cm). Subordinate amphibolite interlayers contain ovoid quartz aggregates (probably amygdales). The chloritic schist and gneiss unit is interpreted to be an alteration zone, associated with the massive sulphide deposit, within volcanic fragmental rocks. The following assemblages were observed:

(i) Quartz-biotite-muscovite-andalusite ± plagioclase
(ii) Quartz-biotite-muscovite-andalusite-kyanite-staurolite
(iii) Quartz-biotite-muscovite-andalusite-garnet ± kyanite
(iv) Quartz-biotite-andalusite-garnet-staurolite ± kyanite
(v) Quartz-plagioclase-biotite-staurolite ± garnet
(vi) Biotite-anthophyllite-cordierite-staurolite
(vii) Quartz-biotite-garnet-anthophyllite-cordierite-staurolite
(viii) Quartz-plagioclase (An_{46})-biotite-anthophyllite-cordierite ± garnet
(ix) Quartz-plagioclase-biotite-anthophyllite-andalusite
(x) Biotite-garnet-magnetite (with corundum inclusions)
(xi) Biotite-green hornblende-magnetite

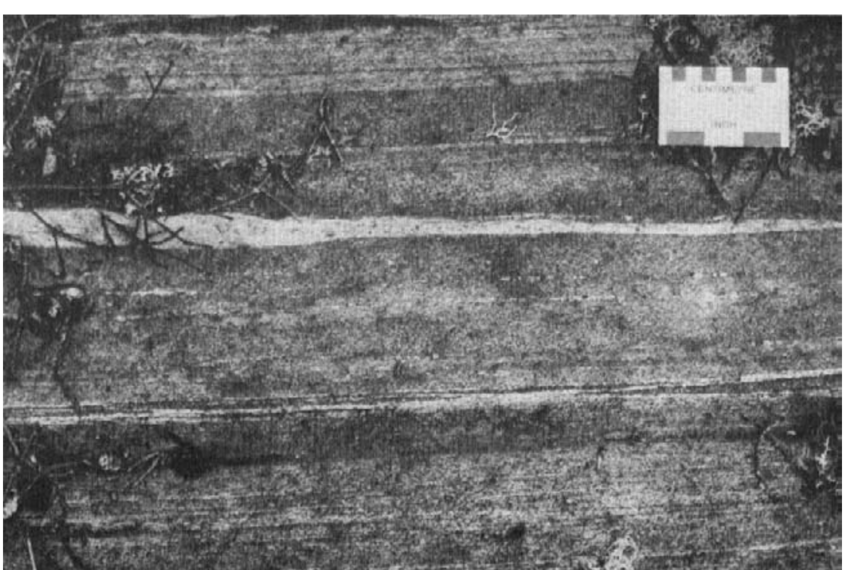


Figure 21: *Homblende-plagioclase gneiss (unit 5a) southeast of July Lake with diffuse gneissic layering and concordant tonalitic lits.*

Garnets in the above assemblages have been optically identified as almandine. Secondary minerals include chlorite, sericite, and sporadic clinozoisite. Pyrite and pyrrhotite are common accessories.

Garnetiferous amphibolite and schist, interpreted to be altered mafic volcanic rocks, occur 400 m north of the lineament east of Brooks Bay at the contact between granitoid and felsic porphyry intrusions to the north, and gneissoid tonalite to the south, and are interlayered with porphyritic basalt at a scale of 50 cm to 2 m in a 10 m thick section. Massive garnet layers up to 2 cm thick occur in these rocks. Subhedral plagioclases in the amphibolite and schist are probably phenocrysts. The assemblage at this locality is:

(xii) Quartz-plagioclase-biotite-chlorite ± green hornblende ± garnet

Intermediate gneiss and subordinate schist are interlayered with mafic flows and minor breccia at the peninsula north of Camp Bay. The gneiss and schist are interpreted to be volcanic fragmental deposits. The fine- to medium-grained gneisses are characterized by pale blue-grey to medium grey 1 to 20 mm lamination and micaceous or hornblendic stringers. Fine grained felsic fragments (up to 0.5 x 3 cm) compose up to 30% of some units; these are locally attenuated and partly obliterated suggesting that fragmental structures may originally have been more widespread prior to deformation. Garnet is stratabound and locally concentrated in ovoid to irregular feldspathic zones. Subordinate hornblende porphyroblasts are randomly distributed or stratabound. Minor strain-slip cleavage is associated with rotation of garnets, which also locally display rotational structure (Fig. 22) (Spry, 1969). Minor quartz or carbonate stringers occur sporadically. Assemblage (xii) and the following assemblage (xiii) were recorded at Camp Bay:

(xiii) Quartz-plagioclase-biotite-chlorite-green hornblende-cummingtonite-garnet

Garnetiferous biotite-chlorite schist occurs adjacent to a gabbroic body 3 km north of the southeast corner of Barrington Lake. Garnet porphyroblasts (up to 2 cm) compose up to 40% of the schist, which is interlayered with mafic tuff and basalt. The 3 m thick schist unit is interpreted to be an altered tuff.

Intermediate garnetiferous schist and gneiss occur within an ovoid plug of tonalite and felsic porphyry 2 km south-southwest of Star Lake. Garnet occurs sporadically in the granitoid rocks and garnet-chlorite schist occurs at the margin of a large enclave (at least 5 x 50 m) of intermediate volcanic breccia and basalt within the plug. The schist is interpreted to be a reaction product due to partial assimilation of the volcanic rocks by the tonalite. The eastern part of the plug, 700 m east-southeast of the volcanic enclave, is characterized by a 100 m wide marginal zone of tonalite and related gneiss that contains sporadic garnet, chlorite and rare chloritoid. A 5 m thick unit of garnetiferous amphibolite and schist with garnetite layers up to 10 cm thick occurs at the contact between the tonalite and basaltic flows to the east. The schist and tonalite-derived gneiss include the following assemblages:

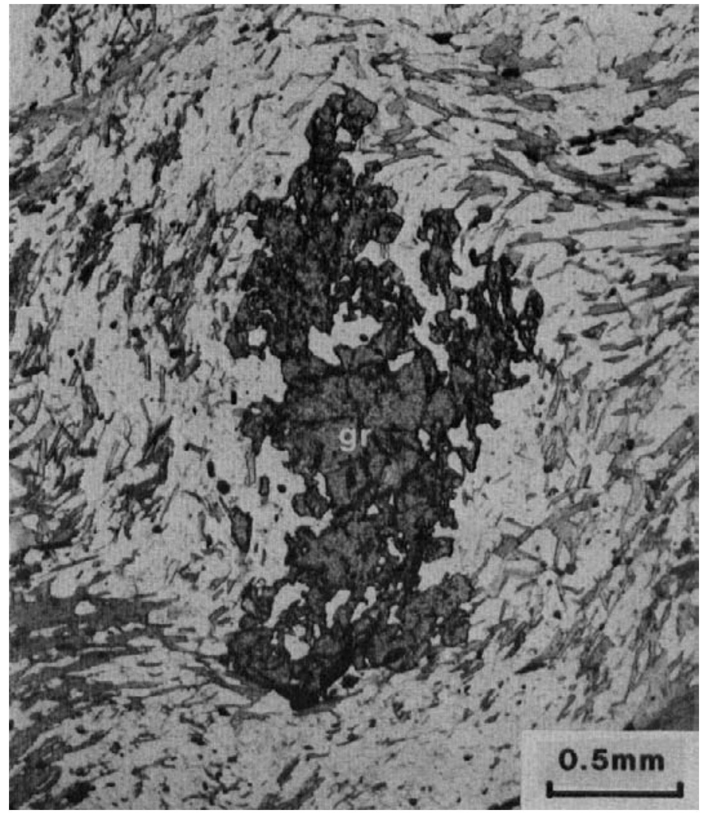


Figure 22: Garnet (gr) poikiloblast in intermediate schist (unit 5b) showing rotational structure with biotite-green hornblende-chlorite foliation, characteristic of synkinematic growth. Sample 1061-1, plane polarized light.

(xiv) Quartz-garnet-biotite-cummingtonite

(xv) Quartz-garnet-chlorite ± plagioclase

(xvi) Quartz-garnet-biotite-muscovite-chloritoid-chlorite

Relict structures and the stratigraphic associations of the schists and gneisses (5b, 5c) indicate a largely volcanic origin. However, most of the mineral assemblages (i) to (xvi) are also consistent with a pelitic origin and some porphyroblastic schists may be derived from minor sedimentary interlayers within the volcanic rocks or from volcanic units contaminated by sediment. Garnetiferous rocks within the granitoid plug south of Star Lake are interpreted to be products of contamination of the intrusive rocks by intermediate to mafic volcanic rocks at or close to the margins of the intrusion.

SICKLE GROUP

Conglomerate with quartz-feldspar porphyry, sedimentary, volcanic and granitoid clasts; sandstone (7)

Conglomerate, arkose matrix (7a)
Arkosic sandstone, pebbly sandstone (7b)

A major unit of Sickle Group conglomerate and sandstone at Hughes Lake (Syme and Gilbert, 1977) extends into the southeast corner of the Barrington Lake area. The geology of this part of Map GR87-3-1 was mapped by E.C. Syme and has been reproduced, with minor modifications, from the Cockeram Lake map, GP80-1-2 (Gilbert *et al.,* 1980).

INTRUSIVE ROCKS

Gabbro, norite, amphibolite and related gneiss; hornblendite, diabase and minor diorite (10)

Norite, gabbronorite, minor gabbro; hornblende gabbro, biotite-hornblende gabbro (10a)

A prominent gabbro sill extends along the south side of the northern belt at Nickel Lake and another body occurs at Larson Lake, along strike to the southeast. The Tow Lake gabbro extends along the north side of the southern belt west of Barrington River; this body is described by Hunter (1958). The Nickel Lake, Larson Lake and Tow Lake gabbros were mapped (together with the Lynn Lake gabbro) as post-Wasekwan Group and pre-Sickle Group by Milligan (1960); however, there is some doubt concerning the age of intrusion (Milligan, 1960, p. 53). These gabbros have been assigned to unit 10 in the present mapping, together with the Melvin Lake norite and minor mafic to ultramafic intrusions in the Fraser Lake area (Maps GR87-3-2 and GR87-3-3). The age relationships of the various intrusions are commonly not well defined and it is probable that intrusions of several ages have been included in this unit.

The Nickel Lake, Larson Lake and Tow Lake gabbros were not investigated in the present mapping and their outlines (on Map GR87-3-1) have been taken from Milligan (1960); smaller gabbroic stocks occur sporadically in the northern belt. A hornblende gabbro intrusion 1 km east of Nickel Lake indicates possible continuity between the Nickel Lake and Larson Lake gabbros; another hornblende gabbro occurs at the south margin of the southern belt 1.5 km south of More Lake. The latter intrusion and the Tow Lake gabbro are associated with marked aeromagnetic anomalies. Gradiometer survey maps by the Geological Survey of Canada have been utilized to define the outlines of several mafic to ultramafic intrusions in the southeast part of the Barrington Lake area (Geological Survey of Canada Open File 1047, 1984).

The medium- to coarse-grained, massive hornblende gabbros are generally mesocratic, and locally melanocratic to hornblenditic (up to 92% green hornblende). An irregular network of feldspathic zones and veins occurs in part of the intrusion 1 km east of Nickel Lake. Minor pyrite mineralization occurs in a 30 cm wide zone close to the south margin of the intrusion, where the gabbro is locally gneissic. The gabbros east of Nickel Lake and south of More Lake locally display minor very coarse grained to pegmatitic zones and contain sporadic granophyric and aplitic dykes. Green hornblende in the gabbros displays cloudy zones of very fine grained opaque inclusions that indicate derivation from pyroxene (Table 7); ophitic to subophitic texture occurs locally. The gabbro east of Nickel Lake contains up to 10% magnetite that is disseminated or occurs as lenticular aggregates; apatite is locally conspicuous (up to 5%) in the gabbro south of More Lake, in which hornblende poikiloblasts are partly deformed and recrystallized.

Table 7: Mineralogy and petrography of hornblende gabbro (10a) in the Barrington Lake area

Mineral	Notes
GREEN HORNBLENDE	Poikiloblasts up to 1.5 cm; locally zoned with paler green cores and/or zones of very fine opaque inclusions.
BIOTITE	0-5%; locally in minor aggregates.
PLAGIOCLASE	Calcic andesine to labradorite; alteration generally minor, locally complete.
QUARTZ	Minor, interstitial or as inclusions in green hornblende.
APATITE	0-5%, up to 1 mm.
MAGNETITE	May include ilmenite (locally associated with sphene).
EPIDOTE	Generally minor, locally 60% of altered rock (after plagioclase).
CHLORITE	Minor, after biotite.
MICROCLINE SPHENE CARBONATE PYRITE	Minor accessories

INTRODUCTION

Melvin Lake is located within an extensive metasedimentary gneiss terrane extending from Northern Indian Lake west into Saskatchewan (Southern Indian gneiss belt, Gilbert *et al.,* 1980). The gneiss terrane is 50 to 70 km wide and extends laterally for approximately 600 km. The terrane comprises predominantly semipelitic paragneisses variously intruded and assimilated by granitoid intrusions that are generally gneissoid and strongly deformed. The sedimentary rocks comprise an older greywacke section (4) that is interpreted to be a turbidite sequence overlain by conglomeratic and arkosic rocks (6) probably deposited in shallow water. This subdivision corresponds to the stratigraphy described in the area north of Lynn Lake, where the Zed Lake greywacke is overlain by conglomeratic and arkosic gneisses of the Sickle Metamorphic Suite (Gilbert *et al.,* 1980). The migmatitic paragneisses contain minor amphibolitic units, and are intruded by posttectonic granitoid phases and a later gabbronorite stock in central Melvin Lake.

The Zed Lake greywacke in the Southern Indian gneiss belt has been correlated with the Burntwood River Metamorphic Suite in the Kisseynew gneiss belt (Gilbert *et al.,* 1980). The latter rocks are interpreted to be partly contemporaneous with the Wasekwan Group, but the lower part of the greywacke section may be pre-Wasekwan Group (McRitchie, 1974).

ROCKS OF PROBABLE WASEKWAN GROUP AGE

Paragneiss, schist and related migmatite (4)

Psammitic gneiss (4a)
Semipelitic gneiss (4b)
Pelitic gneiss (4c)

Greywacke-derived gneisses at Melvin Lake are similar to the Zed Lake greywacke within the gneiss belt further west. The Melvin Lake section is more highly metamorphosed. Bouma turbidite divisions were recognized at one locality east of Melvin Lake. Compositional layering is common, with pale to medium grey semipelitic units (2-50 cm) and dark grey pelitic partings and thin laminae (1-20 mm) (Fig. 23 and 24). Graded beds with thin pelitic upper zones are rare. Attenuated pebbles and cobbles (pale to dark grey, up to 10 cm long) were observed at a few localities in the area east of the conglomerate (6a) at the east shore of Melvin Lake. The semipelitic gneisses contain quartz, andesine and biotite (± microcline ± muscovite) with accessory apatite, sphene, zircon and magnetite (± pyrite) and rare tourmaline. Green hornblende (5-15%) occurs sporadically (*e.g.* close to the polymictic conglomerate (6a) at eastern Melvin Lake). An isolated occurrence of pink psammitic gneiss (4a) with minor micaceous laminae occurs at the south end of the peninsula in west-central Melvin Lake; the paragneisses further north on this peninsula and sporadic frost-heaved outcrops at northeastern Melvin Lake are predominantly semipelitic.

Tonalitic to granitic intrusions are ubiquitous in the paragneiss. The fine- to medium-grained (locally pegmatitic) granitoid rocks typically make up 10 to 25% of paragneiss outcrops. Abundant early- to syn-tectonic concordant *lits* are commonly isoclinally folded, attenuated and disrupted (Fig. 25). The paragneiss foliation is deformed by these folds and later open flexures associated with incipient strain-slip cleavage discordant to the earlier foliation. The paragneiss has been variously assimilated by the granitoid rocks, resulting locally in stromatic migmatite or granitoid gneiss that contains thin micaceous screens derived from the sedimentary rocks (Fig. 26). A late phase of potassium metasomatism is evident locally at southern Melvin Lake, where migmatites contain sporadic microcline porphyroblasts, myrmekitic plagioclase and antiperthite; pre-tectonic microcline veinlets also occur in these rocks. Rare zoned calc-silicate bodies up to 30 cm across in the same section consist

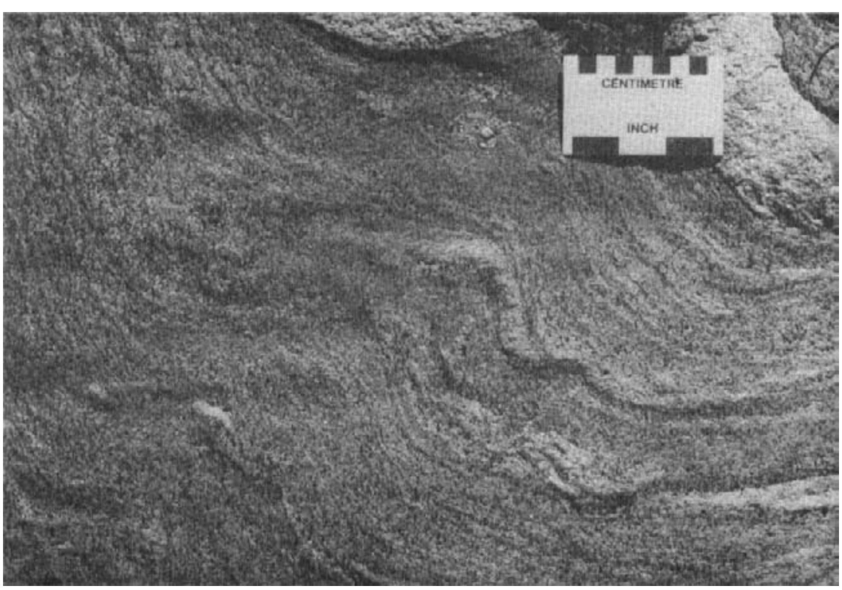
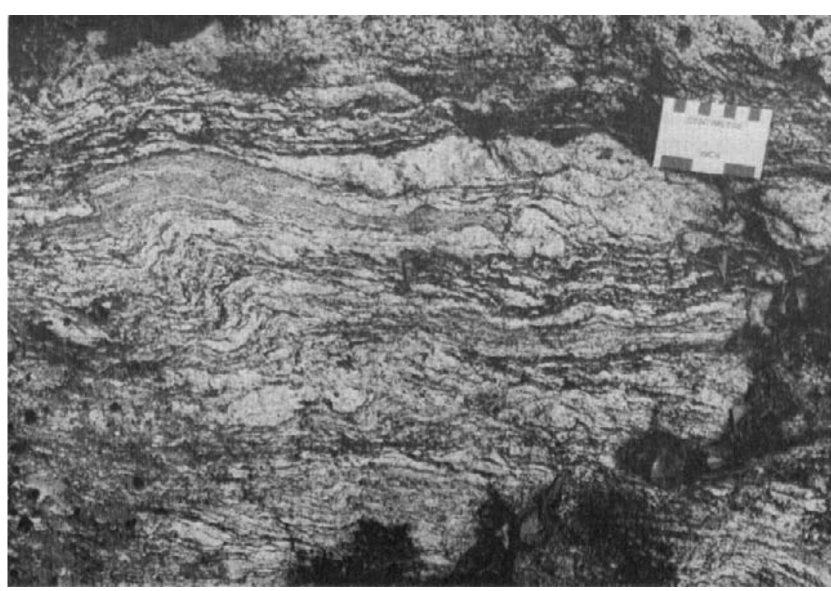


Figure 23: Semipelitic gneiss (unit 4b) at Melvin Lake showing diffuse bedding and parallel foliation (S_1) deformed by minor folds (D_2).

Figure 24: *Semipelitic gneiss (unit 4b) at Melvin Lake showing bedding, parallel foliation (S_1) and early concordant tonalitic /its deformed by a D_2 disharmonic fold.*

Figure 25: *Contorted semipelitic gneiss (unit 4b) at Melvin Lake with ptygmatically folded tonalitic lits, truncated by later massive granodiorite (unit 9e).*

Figure 26: *Stromatic migmatite resulting from pervasive tonalitic veining of paragneiss (unit 4) represented by discontinuous layers and thin micaceous screens within quartzo-feldspathic gneiss. Located at the south end of Melvin Lake.*



largely of epidote with hornblendic margins. Late- to post-tectonic granitoid rocks occur extensively within the paragneisses as massive concordant to discordant intrusions (tonalitic to granitic) (Fig. 25).

Sillimanite gneiss and schist (4d)

Greywacke-derived paragneisses (4) at east-central Melvin Lake contain interlayers of sillimanite gneiss and schist (4d) in a 600 m wide section. The following assemblage was observed at the east shore of Melvin Lake:

quartz-andesine-sillimanite-microcline-biotite-muscovite -garnet

Sillimanite occurs as small prisms (up to 1.5 mm long) and as fibrolitic aggregates within biotite. Muscovite-sillimanite knots (5-20 mm x 1-2 mm) occur in pelitic gneisses east of Melvin Lake, and constitute up to 30% of 0.5 m thick layers that also contain biotite (20-35%) and subordinate muscovite. Fibrolitic sillimanite with irregular pale brown staining occurs within muscovite and as knots rimmed by sericite and muscovite. These knots (*faserkiesel*) are aligned parallel to the biotite-muscovite foliation, and are locally deformed by isoclinal microfolds. Brown-green spinel occurs locally as an additional phase in the cores of *faserkiesel*.

The sillimanite gneisses (4d) may be divided into those with muscovite; those with cordierite + almandine + relict staurolite (2.5 km east of Paulson Island); and garnet ± muscovite-bearing gneisses at the east shore of Melvin Lake. The garnet ± muscovite-bearing sillimanite gneisses are relatively coarser grained and interpreted to be of slightly higher metamorphic grade than the former varieties of sillimanite gneiss (see Metamorphic History).

Amphibolite, schist, gneiss and related migmatite (5)

Amphibolite, hornblende-plagioclase gneiss and migmatite (5a)

Minor units of amphibolite (5a) occur within granitoid rocks (9) at northern Barrington Lake, and one occurrence was mapped in the central part of Melvin Lake within paragneisses (4b, c). The mafic units at northern Barrington Lake occur in, or close to, a 600 m wide west-northwest-trending zone of quartz diorite to diorite within leucocratic granitoid rocks that also contain several minor enclaves of highly attenuated conglomerate (6a). These enclaves (5a, 6a) are interpreted (on the basis of aeromagnetic trends) to be the lateral equivalents of mafic to intermediate volcanic rocks and conglomerate that extend along the north margin of the Lynn Lake greenstone belt in the Zed Lake-Hughes River area (Gilbert *et al*., 1980, p. 58; and Barrington Lake area, Questor Surveys Limited; Manitoba Energy and Mines, 1977).

The fine- to medium-grained amphibolite units (1-10 m, locally over 20 m thick) are interpreted to be metavolcanic, probably contemporaneous with the Wasekwan Group. Some units display remnant plagioclase phyric texture and contain hornblendic aggregates probably derived from pyroxene phenocrysts (up to 0.2 x 1 cm, 10% of the rock). Most amphibolite units are moderately to well foliated and devoid of primary structures. Green hornblende is predominant (40-50% of the rocks); epidote and chlorite (15-20% each) and biotite (up to 10%) are locally prominent. Some minor amphibolite units within granitoid rocks (9) that display equivocal contact relationships could be younger dykes (*e.g.* unit 10), but mostly the mafic units are demonstrably older than the granitoid rocks. Invasion and assimilation of the amphibolite by the granitoid rocks (9) apparently removed most of the original volcanic section, leaving only sporadic remnants of volcanic-derived amphibolite.

SICKLE OR WASEKWAN GROUP

Conglomerate, feldspathic greywacke and siltstone (6)

Polymictic conglomerate with minor feldspathic greywacke interlayers (6a)

Polymictic conglomerate occurs in a unit up to 140 m thick at the east shore of central Melvin Lake at the contact between greywacke-derived paragneiss (4) and younger granitoid rocks (9) to the southwest. Related, highly attenuated, gneissic conglomerate occurs at a small island 7 km to the northwest. The conglomerate has been correlated with similar rocks at Dino and Dunsheath Lakes; the latter units occur at the contact between paragneiss (equivalent to unit 4) and arkosic gneisses (McRitchie, 1976). The contact between conglomerate (6) and paragneiss (4) at Melvin Lake is characterized by interlayering of the two lithologies, but it is not known whether this contact is conformable or disconformable, and the relative ages of units 6 and 4 are uncertain. A syncline has been mapped in the paragneiss northeast of the conglomerate, and additional folds probably exist in this section. The conglomerate is considered to be late Wasekwan Group or Sickle Group, and is interpreted to overlie the greywacke-derived paragneiss on the basis of regional stratigraphic relationships (Gilbert *et al.*, 1980).

Highly deformed conglomerate at northern Barrington Lake forms minor enclaves within younger granitoid rocks (9). The conglomerate represents the eastern extension of the Zed Lake-Hughes River conglomerate that has been mapped for approximately 45 km along the north margin of the Lynn Lake greenstone belt. The conglomerate is best developed in the areas north of Minton Lake and north of Motriuk Lake, where the maximum width of the unit is 2650 m (Maps GP80-1-1 and GP80-1-2, Gilbert *et al.*, 1980). Remnants of this unit at northern Barrington Lake, 70 km to the east-northeast are less than 25 m thick. The stratigraphic position of this conglomerate is uncertain because no definitive contact relationships are exposed with the Zed Lake greywacke (to the north) or Wasekwan Group rocks (to the south). The Zed Lake-Hughes River conglomerate is interpreted to be late Wasekwan Group or Sickle Group in age (Gilbert *et al.,* 1980, p. 58).

Clast types in the conglomerate at east-central Melvin Lake are described in Table 8; the occurrence of a quartz gabbro clast is enigmatic, since the only known correlative unit for this lithology is the apparently younger Melvin Lake norite (10). The matrix of the conglomerate is intermediate biotite-hornblende-bearing feldspathic greywacke, similar to subordinate greywacke interlayers (8-30 cm thick). Clasts are

Table 8: Clast types in conglomerate (6a) at Melvin Lake

Abundance (% total clasts)	Clast type	Notes
5-20	Tonalite, granodiorite, granite	Fine- to medium-grained; massive to gneissoid; biotite- and/or hornblende-bearing; ± quartz eyes.
<5	Quartz porphyry, plagioclase porphyry	Phenocrysts 0.5 - 2 mm, 10-20% of the rock.
60-80	Felsic volcanic	Fine grained, extrusive or possibly shallow intrusive origin; ± plagioclase phenocrysts ± hornblende porphyroblasts.
<5	Basalt	Fine grained, hornblendic.
10-25	Intermediate volcanic or sedimentary rock	Fine grained, ± hornblende porphyroblasts.
<5	Quartz	Translucent.
<5	Quartz gabbro	Fine- to medium-grained, massive, mesocratic; contains fresh clinopyroxene.

are pebbles and cobbles (up to 30 x 3 cm), with sporadic granitoid boulders (up to 45 x 20 cm). The conglomerate is generally unsorted, but locally vaguely layered with pebble- and cobble-beds 10 to 50 cm thick. Poorly defined graded bedding was observed in several greywacke interlayers. Clasts are generally flattened parallel to the foliation in the conglomerate, but locally granitoid clasts are subangular to rounded (Fig. 27, 28). The foliation is axial planar to isoclinal folds in greywacke interlayers. Subsequent deformation has resulted in crenulation of the clasts and strain-slip cleavage discordant to the earlier foliation. The frequency of minor greywacke interlayers within the conglomerate increases northeastward, where the conglomerate is in contact with semipelitic and pelitic paragneiss and schist (4b, c); sporadic felsic pebbles occur in some paragneiss units.

Conglomerate at northern Barrington Lake contains the same diversity of clast types as the Melvin Lake conglomerate, including subordinate epidotized fragments derived from granitoid and possible basaltic lithologies. Clasts are strongly attenuated (average 2-10 cm x 1-4 mm, up to 25 x 2 cm); the matrix is mafic hornblende greywacke. Subordinate greywacke interlayers (up to 8 cm thick) and pebble conglomerate beds (15 cm thick) within cobble conglomerate occur locally. The west part of the conglomerate unit at northern Barrington Lake is highly attenuated and the rock consists of banded gneiss with pale to dark grey, white, pink, green and yellow laminae (1-20 mm thick), that correspond to variations in quartz, plagioclase, microcline, hornblende and epidote content. The conglomerate contains isoclinally folded and disrupted microcline-quartz stringers, concordant quartz veinlets and late feldspathic fracture fillings.

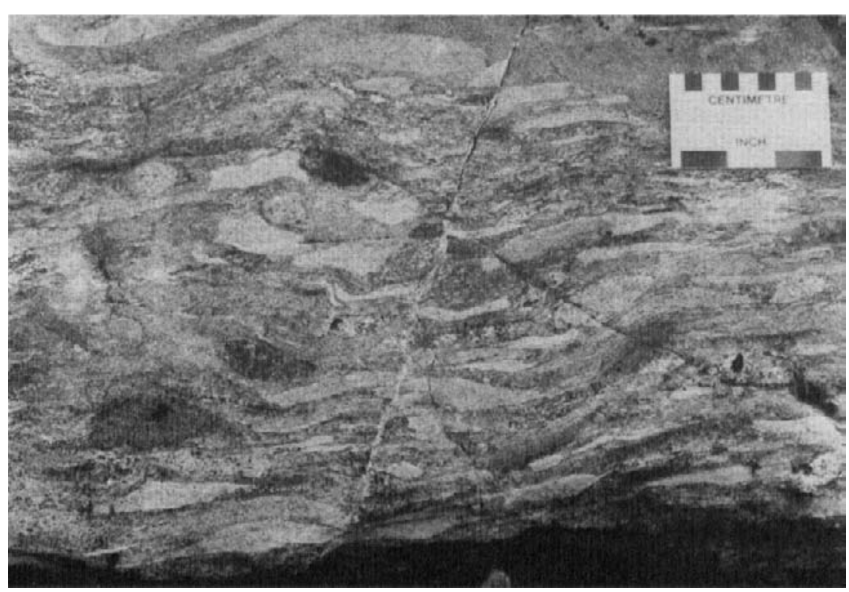


Figure 27: Polymictic conglomerate (unit 6a) at the east shore of Melvin Lake showing angular to ovoid or attenuated cobbles in an intermediate greywacke matrix. Several flattened fragments display minor D_2 folds.

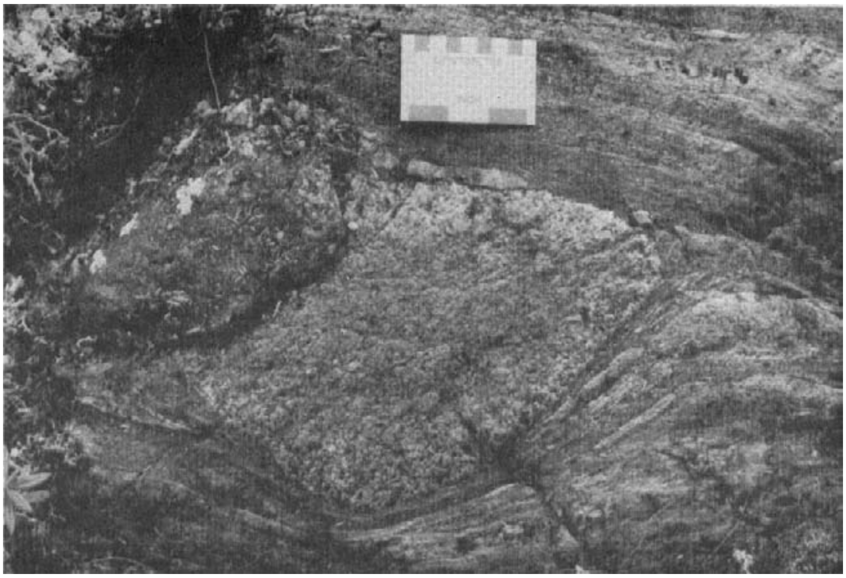


Figure 28: *Rounded, coarse grained, granitoid boulder in polymictic conglomerate (unit 6a) at the east shore of Melvin Lake. Finer grained, felsic clasts and mafic fragments have been strongly attenuated, in contrast to the relatively undeformed boulder.*

INTRUSIVE ROCKS

Gabbro, norite, amphibolite and related gneiss, hornblendite, diabase and minor diorite (10)

Norite, gabbronorite, minor gabbro; hornblende gabbro, biotite-hornblende gabbro (10a)
Pegmatitic hornblende gabbro (10b)
Amphibolite, garnet amphibolite and hornblende gneiss (10c)
Hornblendite, biotite hornblendite (10d)

The Melvin Lake norite is an elongate intrusion (8 km long x 2 km wide) that extends through the central part of Melvin Lake. The north part of the intrusion is largely covered by the lake. The better-exposed south part is characterized by an aeromagnetic "low" relative to the surrounding granitoid rocks, due to the occurrence of ilmenite rather than magnetite in the norite (Fig. 29). The norite apparently intrudes the contact between paragneiss (4) and granitoid rocks (9) in the central part of Melvin Lake, indicating the norite may be younger than unit 9 (Melvin Lake area, Map GR87-3-2). A relatively young age for the norite is also indicated by its generally massive character (compared to units 4 and 9) and the widespread preservation of primary minerals (*e.g.* pyroxene, labradorite). Related dykes of gabbro (10a) and associated biotite amphibolite (10c) intrude semipelitic gneisses (4b, d) 1.5 km east of the entrance of Paulson Bay. Another minor mafic intrusion possibly cogenetic with the norite (10), was observed in granitoid rocks (9) at Melvin Lake. Minor, medium grained to pegmatitic granitoid phases (11) intrude the norite.

The age of the Melvin Lake norite relative to the Sickle Group is uncertain. The norite is lithologically similar to mafic intrusions that occur sporadically throughout the Lynn Lake greenstone belt that have been variously interpreted as pre- and post-Sickle Group. Early workers attributed a post-Sickle Group age to gabbroic intrusions in the

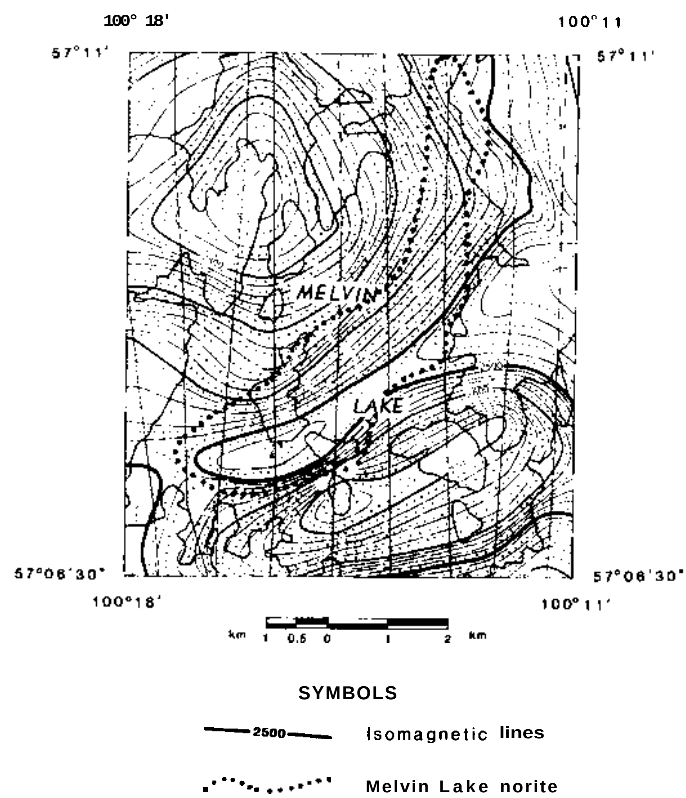


Figure 29: *Aeromagnetic map of part of the Melvin Lake area showing the outline of the Melvin Lake norite.*

Hughes, Farley and Barrington lakes areas (Allan, 1948; Stanton, 1948; Crombie, 1948). Milligan (1960) re-interpreted these intrusions as pre-Sickle Group, although noting some cases of uncertainty (Nickel Lake and Tow Lake gabbros) and several younger intrusions that are emplaced in the Sickle Group (*e.g.* Black Trout diorite). Hulbert (1978) re-interpreted the Fraser Lake gabbro (in the Lynn Lake area) as post-Sickle Group; however, granitoid rocks that locally intrude the gabbro are unconformably overlain by the basal Sickle Group conglomerate, which indicates the Fraser Lake gabbro is pre-Sickle Group (Gilbert *et al.,* 1980). Hunter (1958) and Pinsent (1980) noted evidence of deformation and metamorphism in the Tow Lake and Lynn Lake gabbros, that suggests emplacement occurred before the last regional deformation in the greenstone belt. The Melvin Lake norite similarly predates the last deformation phase in that area, and has been subjected to limited alteration possibly due to regional metamorphism.

U-Pb zircon geochronology (Van Schmus and Schledewitz, 1986) in the Reindeer Lake area, 100 km west of Melvin Lake, indicates an age of 1832 ± 11 Ma for the Paskwachi Bay quartz diorite that is emplaced in a paragneiss-migmatite terrane. The migmatites are intruded by the Chipewyan Batholith that has been dated at 1855 ± 10 Ma in the area north of Melvin Lake (Van Schmus and Schledewitz, 1986). It is possible that the ages of the norite and granitoid rocks at Melvin Lake approximate those obtained from the quartz diorite and Chipewyan Batholith, respectively, in the area to the west and northwest.

The south part of the Melvin Lake norite contains a marginal zone of coarse grained to pegmatitic hornblende gabbro (10b) that, in part, intrudes the main gabbronorite and norite phase (Fig. 30). The main phase contains a zone of medium grained hornblende gabbro (± biotite) and leucogabbro that extends from the core to the south margin of the intrusion; a small area of leucocratic rocks in the axial zone of the intrusion occurs mainly within the hornblende gabbro zone (Fig. 30). The leucocratic rocks (leucogabbronorite and anorthositic hornblende gabbro) are gradational with surrounding mesocratic rocks and represent plagioclase-rich cumulates. Gabbro (*sensu stricto*) occurs only at two known localities (close to the south margin of the stock), although clinopyroxene is a common accessory in the noritic phases. Alteration of pyroxene to tremolite and/or hornblende is widespread (Fig. 31), and much or all of the hornblende gabbro is derived from pyroxene-bearing rocks. The hornblende gabbro zone may represent an area of elevated pH_2O that resulted in complete alteration of pyroxene, pene-contemporaneous with emplacement of the norite and gabbro. Petrographic details of these phases are given in Table 9, and modal compositions of representative phases of the intrusion are shown in Figures 32 and 33. Whole rock chemical analyses of five samples selected to display the compositional range of the Melvin Lake norite are given in Table 10; sample locations are shown in Figure 30. The following assemblage is representative of the Melvin Lake norite and related gabbroic phases:

Orthopyroxene (hypersthene)-plagioclase (labradorite) K-feldspar-biotite-ilmenite-quartz ± clinopyroxene ± green hornblende

The main norite to gabbronorite phase (10a) is a massive, medium- to dark-grey weathering rock; fresh surfaces vary from yellow brown or green to pale grey (reflecting variable contents of orthopyroxene, hornblende and plagioclase, respectively). These medium grained rocks display widespread layering interpreted to be gravity stratification, in part probably influenced by convection currents. Igneous lamination (defined by subparallel plagioclases) concordant with the layering is common and probably resulted from convection currents (Wager and Brown, 1968). Both uniform and rhythmic layering are recognized; cryptic layering is defined by plagioclase compositions that range from An_{39} to An_{67}. Compositional layering, at a scale of 5 cm to 1 m (Fig. 34), is defined by variable pyroxene/plagioclase ratios, or more rarely, by variable ilmenite content; fine laminae (1-10 mm) are developed at several localities in sections up to 5 m thick (Fig. 35, 36). Interlayer contacts are generally very sharp, but grading is locally developed (melanocratic to leucocratic), associated in some units with a slight upward decrease in grain size. Discordant, finely layered units, which were observed at two localities, have been interpreted to be crossbedding produced by convection currents. Diffuse feldspathic, hornblendic and pegmatitic zones and stringers, parallel to the rhythmic layering, occur sporadically within homogeneous norite and gabbronorite. Rare minor gossan zones (up to 30 cm thick) are also parallel to the primary layering.

Medium- to coarse-grained hornblende gabbro occurs both as a major phase in the axial zone of the stock, and elsewhere as interlayers within norite and gabbronorite of the main phase. In the marginal zone, massive units of pegmatitic hornblende gabbro (up to 20 m thick) occur within norite and gabbronorite (Fig. 37).

The marginal zone in the northern part of the intrusion is locally altered to garnetiferous amphibolite and related gneiss (10c; Table 9) that contain relicts of primary pyroxene altered to cummingtonite, which has been subsequently altered to tremolite. The assemblage is as follows:

Green hornblende-cummingtonite-plagioclase-garnet-biotite (+ relict pyroxene + secondary tremolite)

The massive to well foliated garnetiferous amphibolite is closely associated with norite equivalent to the main phase in the south part of the intrusion and is interpreted to be contaminated mafic intrusive rock. Crystallization of the garnetiferous amphibolite may be contemporaneous with intrusion of the Melvin Lake norite, possibly due to thermal metamorphism of the solidified marginal noritic zone by an influx of "fresh", hot magma into the cooling magma chamber (see below). Alternatively, the amphibolite may be due to regional metamorphism (M_2), although the norite apparently postdates M_2; the available evidence suggests M_2 metamorphism was contemporaneous with the emplacement of granitoid rocks (unit 9), which are apparently older than the Melvin Lake norite (see Metamorphic History).

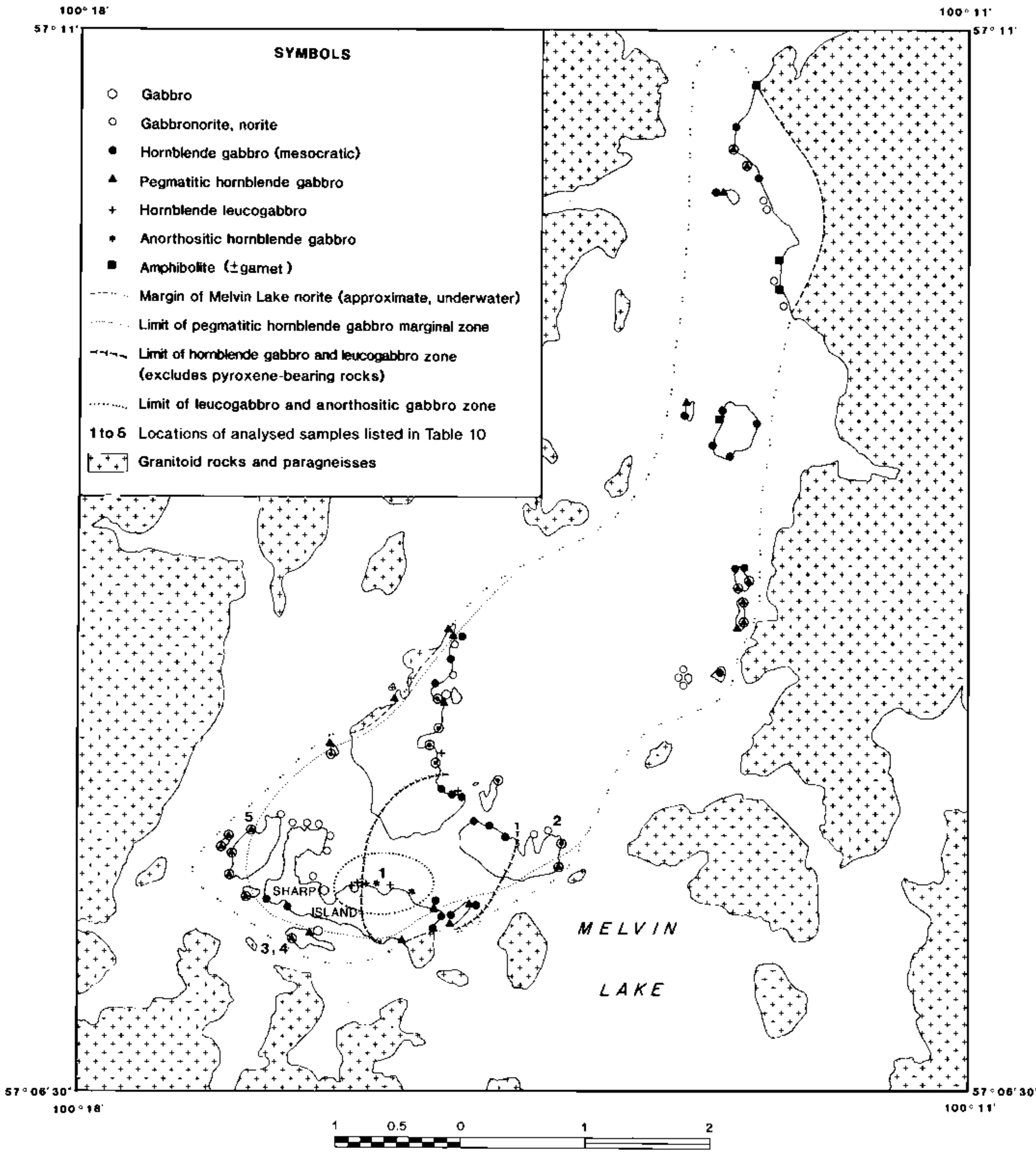


Figure 30: Distribution of noritic and gabbroic phases of the Melvin Lake norite.

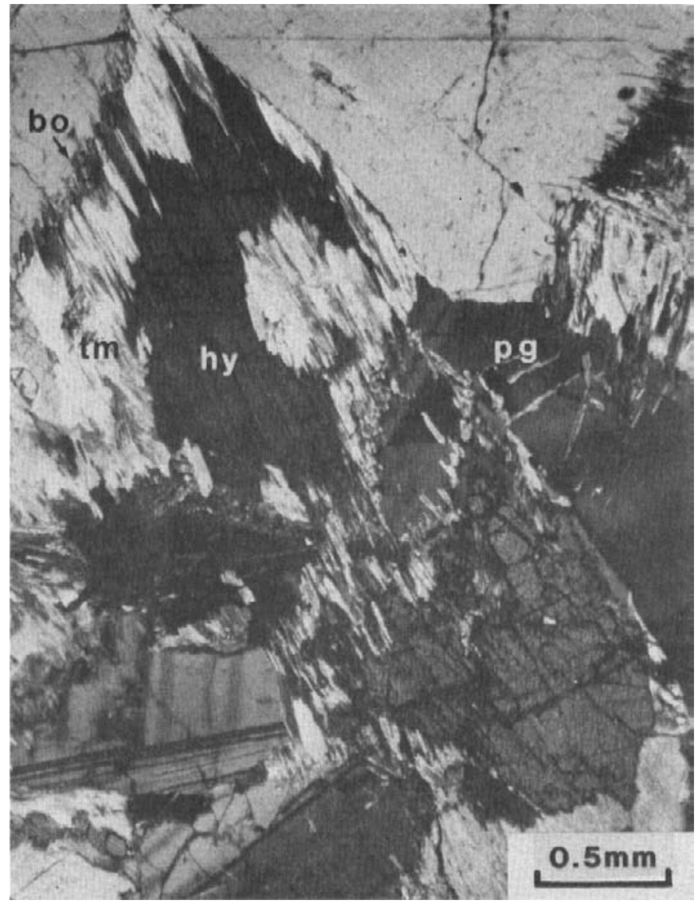
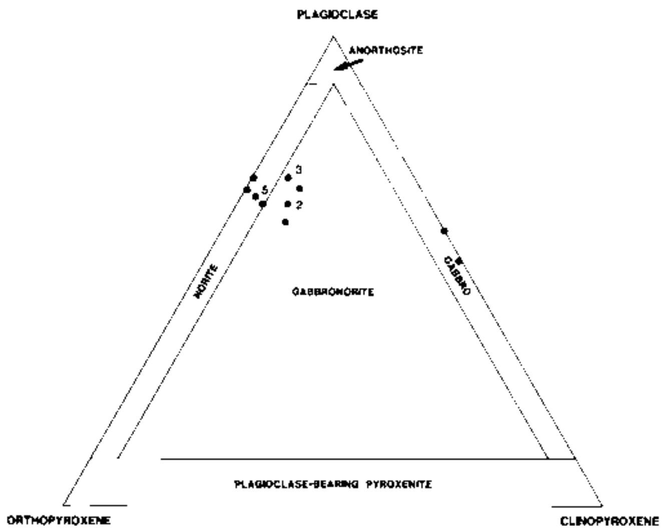


Figure 31: *Leucogabbronorite (unit 10a, Melvin Lake norite) showing alteration of hypersthene (hy) to tremolite (tm) and biotite (bo). Plagioclase (pg) is also partly overgrown by tremolite. Sample 3 in Table 10 and Figures 30, 32, 33 and 41. Crossed polarizers.*

Table 9: Mineralogy and petrography of the Melvin Lake norite (10)

Phase	Norite, gabbronorite, minor gabbro (10a).
Assemblage	Hypersthene-plagioclase (An_{39-67})-ilmenite-apatite-sphene (± clinopyroxene ± green hornblende ± biotite ± quartz ± tremolite).
Petrography	Ophitic to subophitic hypersthene (± fine clinopyroxene lamellae) with subordinate clinopyroxene; locally with orthopyroxene inclusions in (later) clinopyroxene. Pyroxenes variously altered to green hornblende and/or cummingtonite and later tremolite. Red-brown biotite (up to 5%) disseminated or in ovoid aggregates (0.5-2 cm) in minor (contaminated?) phase. Ilmenite (5-10%) disseminated or in rare sporadic aggregates (0.5-3 cm), locally with rims of sphene. Minor plagioclase sericitization (5-10%).
Phase	Hornblende gabbro (10a)
Assemblage	Green hornblende-plagioclase-ilmenite-apatite-sphene (± hypersthene ± clinopyroxene ± biotite ± quartz ± tremolite).
Petrography	Similar to norite and gabbronorite; pyroxenes replaced by green hornblende pseudomorphs or fine grained aggregates. Hornblende locally contains relict pyroxene or zones of very fine grained opaques (derived from pyroxene alteration) and minor inclusions of later quartz and biotite.
Phase	Pegmatitic hornblende gabbro (10b)
Assemblage	As for hornblende gabbro.
Petrography	Green hornblende prisms (1-4 cm; ± pyroxene relict inclusions) occur randomly or in radiating aggregates. Biotite (up to 10%) in blades (0.5-1 cm) and larger aggregates. Ilmenite prominent, locally up to 10%. Plagioclase sericitization up to 20%. Biotite locally contains secondary prehnite.
Phase	Garnet amphibolite, related gneiss (10c)
Assemblage	Green hornblende-plagioclase (An_{48-60})-ilmenite-biotite-apatite-sphene (± hypersthene ± clinopyroxene ± garnet ± cummingtonite ± quartz ± tremolite).
Petrography	Garnet poikiloblastic (up to 2 cm) with inclusions of amphibole, plagioclase, ilmenite and quartz. Massive or with foliation of green hornblende ± biotite (up to 15%). Apatite locally prominent (up to 1 mm, up to 8%). Variable sericitization of plagioclase (5 - 90%). Lithologies gradational with hornblende gabbro.



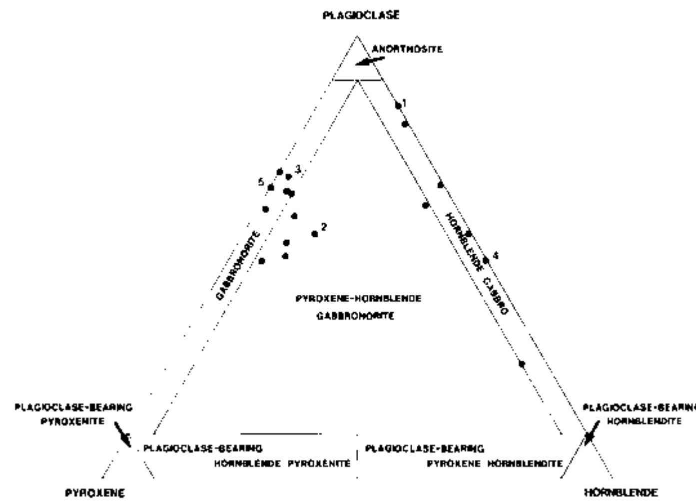


Figure 32: Orthopyroxene-clinopyroxene-plagioclase ternary diagram for the Melvin Lake norite (modal compositions). Numbered samples correspond to those shown in Table 10.

Figure 33: Pyroxene-hornblende-plagioclase ternary diagram for the Melvin Lake norite (modal compositions). Numbered samples correspond to those shown in Table 10.

Figure 34: Igneous layering enhanced by differential weathering in the Melvin Lake norite (unit 10a).

Table 10: Whole rock chemical analyses and plagioclase compositions of phases of the Melvin Lake norite (10)

	1 92-1 ANORTHOSITIC HORNBLENDE GABBRO	2 105-2 PYROXENE-HORNBLENDE GABBRONORITE	3 73-2 LEUCOGABBRONORITE	4 73-1 HORNBLENDE GABBRO	5 82-7 NORITE
OXIDE (wt.%)					
SiO_2	50.0	51.8	52.3	50.1	52.1
Al_2O_3	28.2	17.9	17.7	17.5	17.8
Fe_2O_3 (total Fe)	3.37	9.70	11.30	12.52	11.91
CaO	10.32	9.93	8.35	8.97	9.17
MgO	4.02	6.88	6.66	4.58	6.62
Na_2O	3.14	2.65	2.88	2.99	2.63
K_2O	0.59	0.23	0.39	0.58	0.26
TiO_2	0.13	0.44	0.77	3.79	1.01
P_2O_5	0.02	0.04	0.06	0.14	0.08
MnO	0.06	0.15	0.17	0.19	0.17
CO_2	0.40	0.28	0.35	0.30	0.19
Loss on ignition	2.1	0.5	0.4	0.3	0.0
Ni (ppm)	36	34	32	22	36
Cr (ppm)	33	33	51	31	62
Plagioclase composition	An_{67}	An_{55}	An_{55}	An_{50}	An_{51}

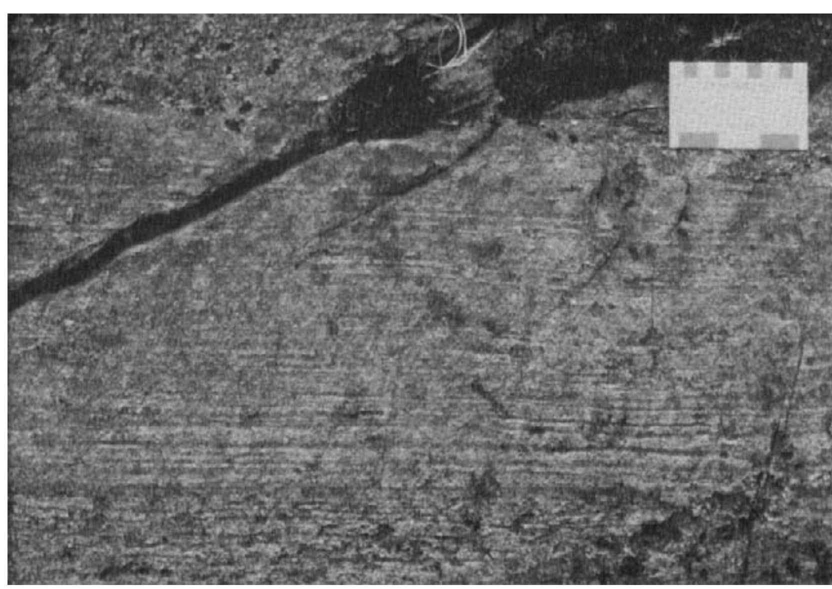


Figure 35: Fine mesocratic and leucocratic layering in norite to gabbronorite near the west margin of the Melvin Lake norite.

Structure of Melvin Lake norite

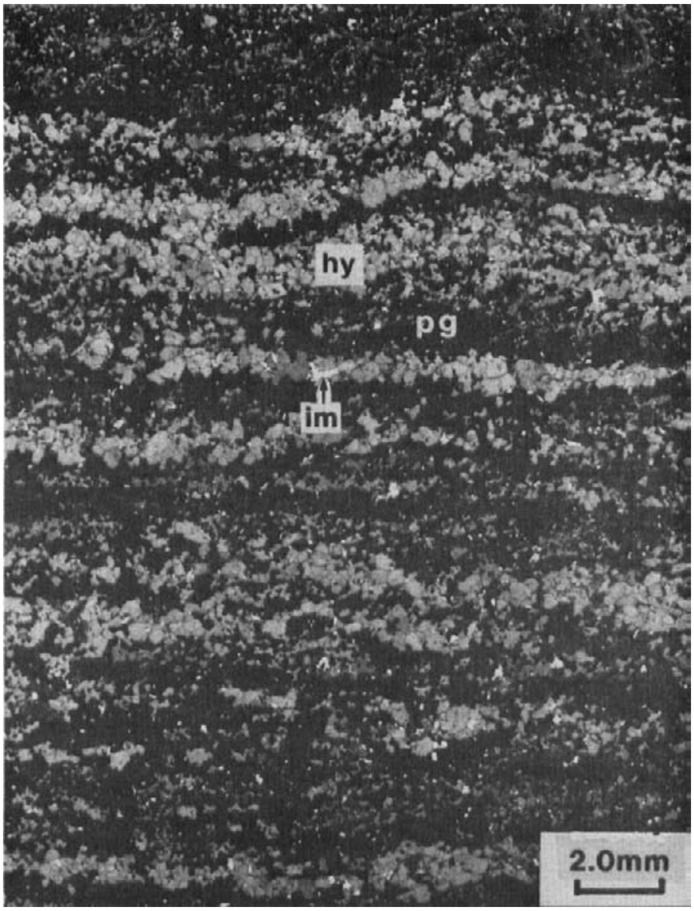


Figure 36: Norite (unit 10a) showing fine igneous layering defined by alternating units of hypersthene (hy) and plagioclase (pg). Traces of disseminated ilmenite (im) occur throughout the rock. Sample 82-3 (Melvin Lake norite). Negative image photomicrograph, plane polarized light.

The disposition of igneous layering in the south part of the Melvin Lake norite indicates a roughly symmetrical, synformal structure (Fig. 38, 39); sections ABC and DE are based on attitudes of igneous layering (subsurface projections are conjectural). Wager and Brown (1957) introduced the term "funnel intrusion" for similar bodies. Subhorizontal strata in the axial zone of the intrusion are considered to be essentially undeformed, and the generally symmetrical increase in dip of the layering away from this zone is consistent with a funnel-shaped structure, with moderately to steeply dipping strata in the marginal zone.

Original dips increasing up to 30° might occur in subhorizontal strata where these are banked up toward the marginal zones of the intrusion. Subsequent downfolding could result in structures similar to those shown in sections ABC and DE (Fig. 39). Alternatively, the intrusion may represent a lopolith that has subsequently been downfolded (Fig. 40); the preservation of subhorizontal strata in the axial zone would require some dislocation of these layers from the folded section to allow for the preservation of their inferred, near-original attitudes.

The existing, moderately inclined to vertical layering of the Melvin Lake norite may be attributed to either:

(a) congelation of successive layers on the shallow- to steep-dipping walls of the magma chamber due to convection currents; or

(b) crystal settling and subsequent downfolding.

The present study favours model (b). There is no evidence for widespread, strong convection currents, such as scours, trough bands, fluxion banding, and autoliths, to support model (a). Crossbedding, attributed to localized convection, is rare. There is also a lack of slump-structures and turbidite-type features that commonly accompany deposition on inclined surfaces in magma chambers. It is more likely that the layering was initially subhorizontal and subsequent downfolding has occurred.

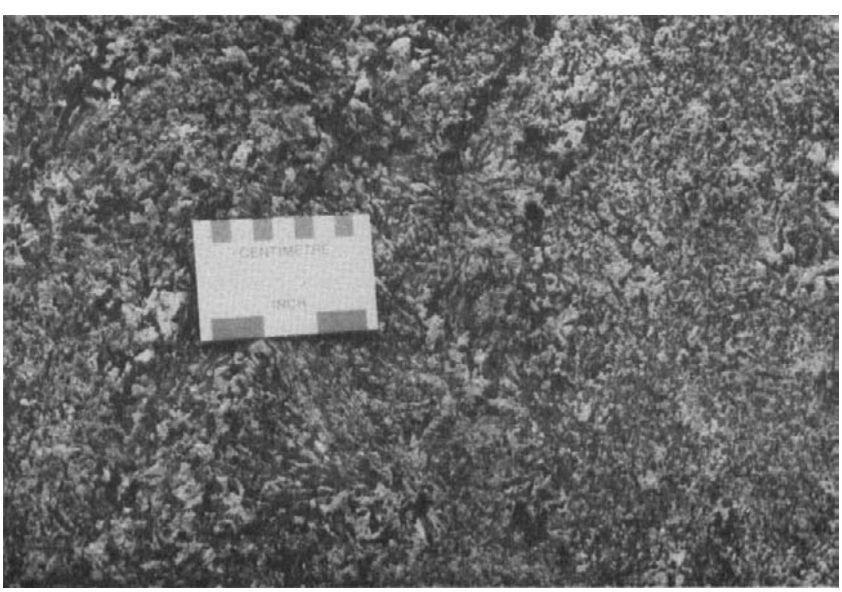


Figure 37: Pegmatitic hornblende gabbro (unit 10b) at the south margin of the Melvin Lake norite. The texture grades from coarse grained to pegmatitic with sporadic, partly radiating hornblende-plagioclase intergrowths.

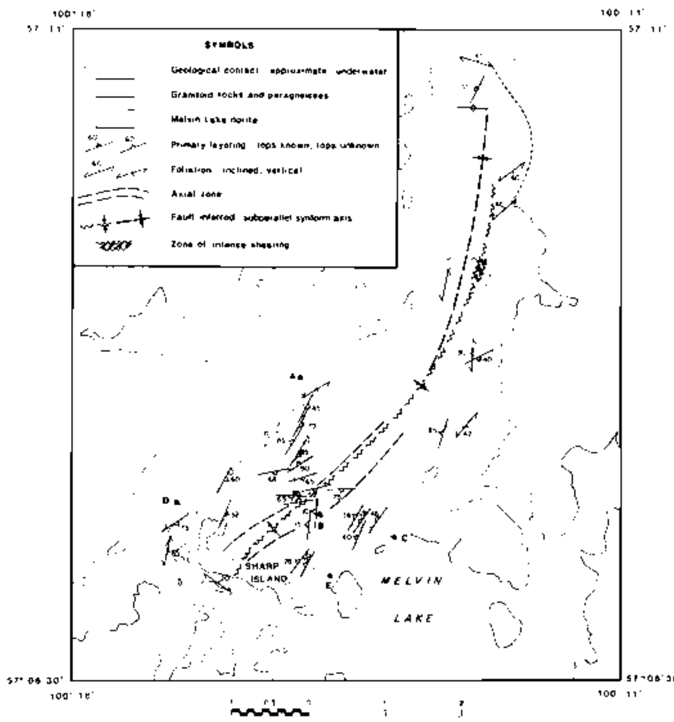


Figure 38: *Structural geology of the Melvin Lake norite.*

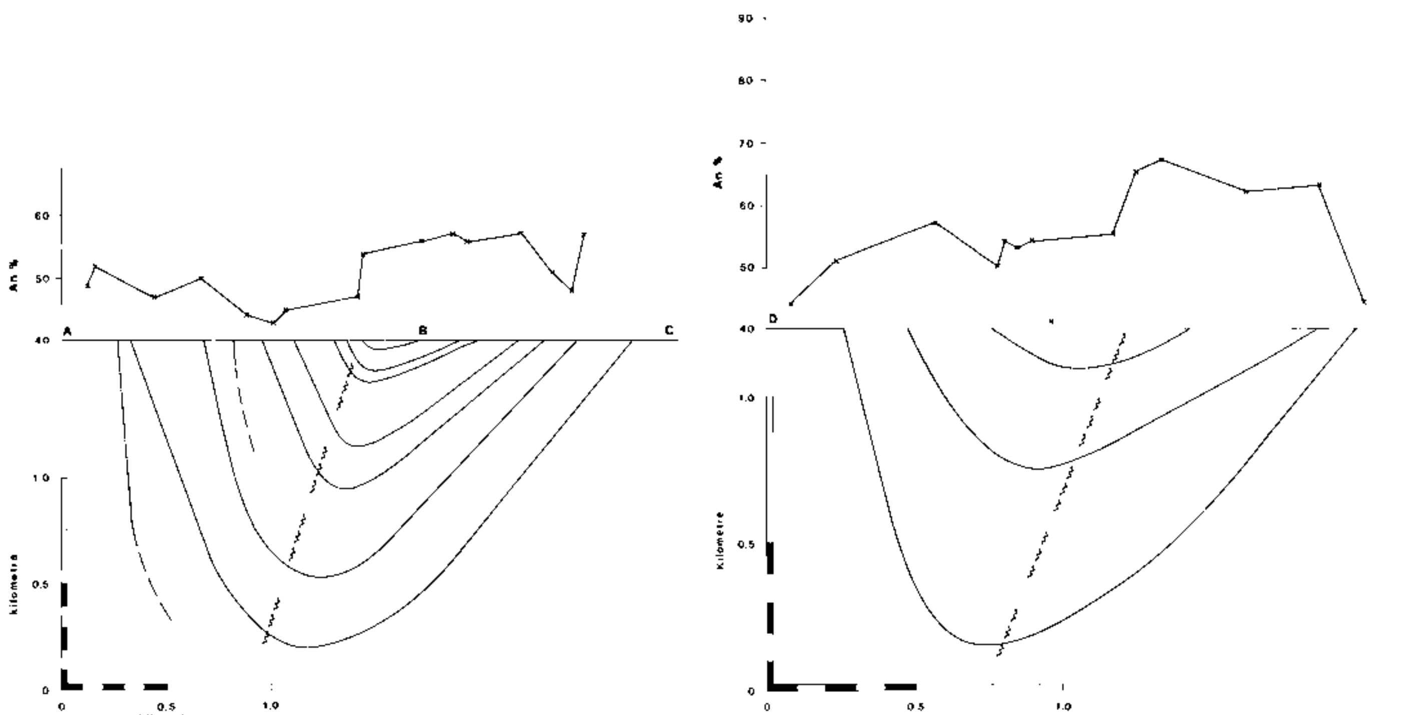


Figure 39: *Transverse sections through the Melvin Lake norite showing the inferred fault and projected synform (based on attitudes of igneous layering) and variation of plagioclase composition along section lines ABC and DE (shown in Fig. 38).*

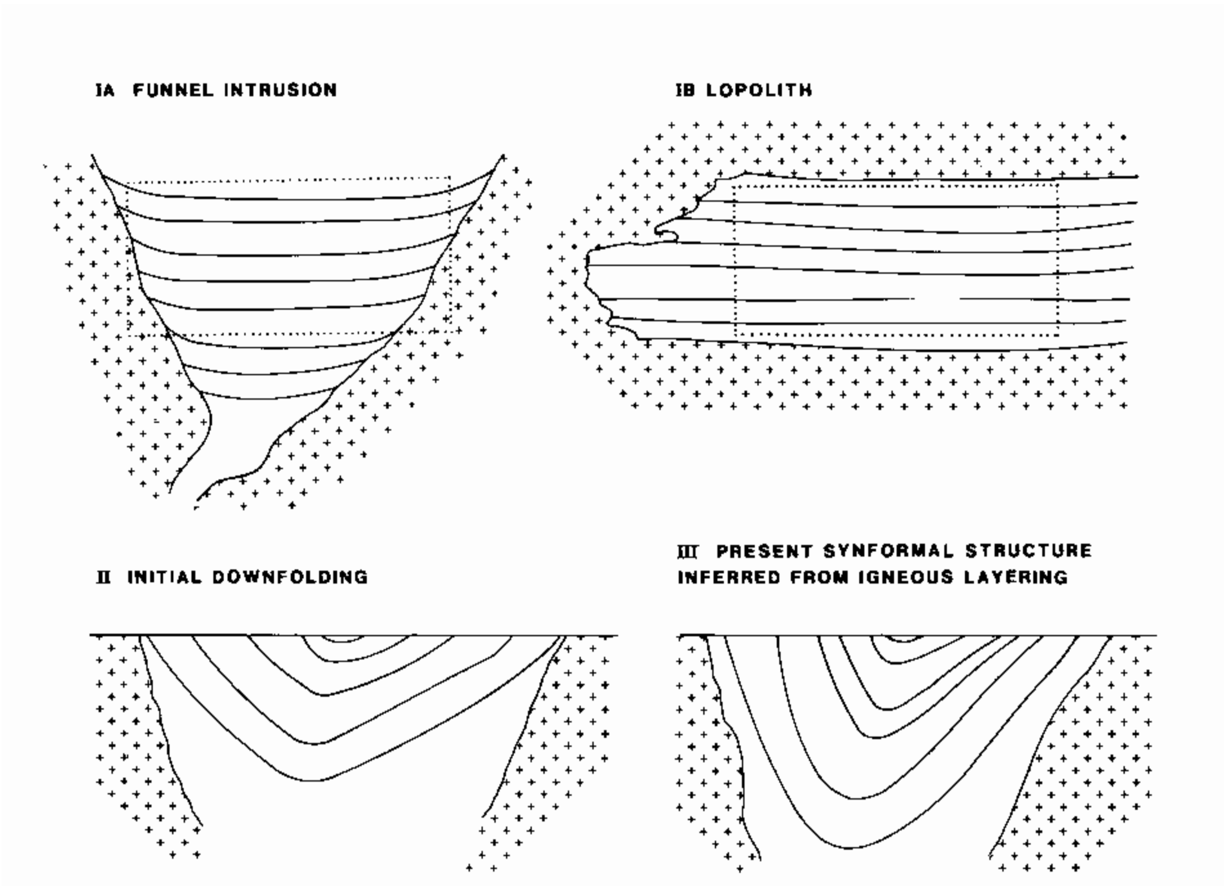


Figure 40: Structural interpretations of the Melvin Lake norite.

The axial zone of the stock contains an inferred major fault (Fig. 38) that bisects a small island in the north part of the intrusion; a wide (>30 m) zone of cataclasite derived from medium grained to pegmatitic granitoid rocks (11) occurs at the island. The southern extension of the fault is based on a marked discontinuity in the cryptic layering of plagioclase defined in sections ABC and DE (Fig. 39).

Petrogenesis of Melvin Lake norite

Petrographic and geochemical data indicate the Melvin Lake norite has undergone limited fractional crystallization. Adcumulate and localized mesocumulate textures are characteristic; ophitic to subophitic textures occur sporadically. Pyroxene, interpreted to be a cumulus phase, is locally interstitial between plagioclase.

Modal and chemical analyses of various phases in the stock show variations attributed to fractional crystallization. Plots on the AFM ternary (Fig. 41) indicate limited fractionation occurred along a trend subparallel to part of the Skaergaard trend, but relatively depleted in Na and K. Samples 2 and 5 represent compositions of the main gabbronorite to norite phase (Table 10); sample 4 in the marginal zone has a higher Fe/Mg ratio than the main phase and has been enriched in ilmenite due to fractionation (TiO_2 = 3.79%, Table 10). Sample 1 in the axial zone of the stock is a feldspar-rich cumulate (Al_2O_3 = 28.2%; plagioclase = 80%, Fig. 33) and is at the centre of the leucogabbro and

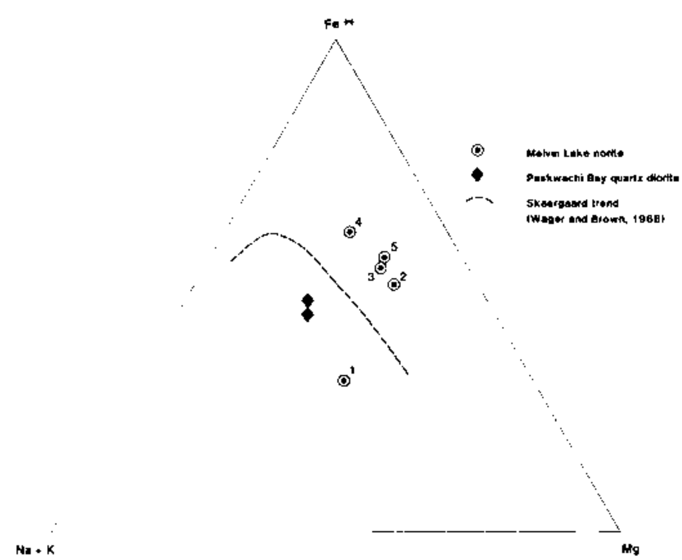


Figure 41: AFM plots of norite and gabbro from the Melvin Lake norite and two samples of the Paskwachi Bay quartz diorite. Numbered samples correspond to those shown in Table 10.

anorthositic gabbro zone (Fig. 30). This zone, in the core of the synformal structure, might reasonably be interpreted to be the youngest, most leucocratic part of the stock, but the rocks contain the most calcium-rich plagioclase in the intrusion indicating a relatively early stage of crystallization (Fig. 42).

A survey of plagioclase compositions in the south part of the Melvin Lake norite was conducted by C. R. McGregor, using a Universal Stage. The results obtained are considered to represent original compositions since there is no evidence to indicate significant alteration of plagioclase. The highest anorthite contents are in the range An_{63-67}; an isolated occurrence of anorthite (An_{90}) close to sample 1 in Figure 30, which was confirmed by several measurements, remains unexplained.

A zone of calcium-rich plagioclase ($An_{>60}$) is centered on the east part of Sharp Island (Fig. 42). The data also suggest a marginal zone of less basic plagioclase in this part of the stock and a gradient up to maximal values of calcic labradorite (An_{65-67}) at the north shore of central Sharp Island. The distribution of plagioclase compositions is not consistent with the roughly synformal structure inferred from primary layering. In the case of a single intrusive phase that conforms to either a funnel-shape or a downfolded lopolith, the most calcic plagioclase would occur peripheral to younger rocks with less basic plagioclase in the axial or core zone, assuming an uninterrupted fractional crystallization trend.

The magmatic evolution of mafic to ultramafic intrusions is influenced by various factors such as contamination by host rocks, influxes of "fresh" undifferentiated magma, and escape of magma through fractured host rocks that results in extrusive phases. These factors lead to changes in composition and pT conditions in the crystallizing magma. Repeated influxes of undifferentiated magma have been recognized in the history of several stratiform intrusions (Campbell, 1977; Irvine, 1980; Scoates, 1990). In the Melvin Lake norite, Ca-rich plagioclase in the structurally youngest rocks could be due to a late pulse of undifferentiated magma that raised the temperature of the magma chamber and changed the composition of the crystallizing phase, and resulted in more calcic plagioclase in the subsequent cumulate. A late influx of "fresh" hot magma, after cooling of the margins of the initial intrusion, may also have resulted in thermal metamorphism and development of garnetiferous amphibolite at the margin of the north part of the Melvin Lake norite (see above).

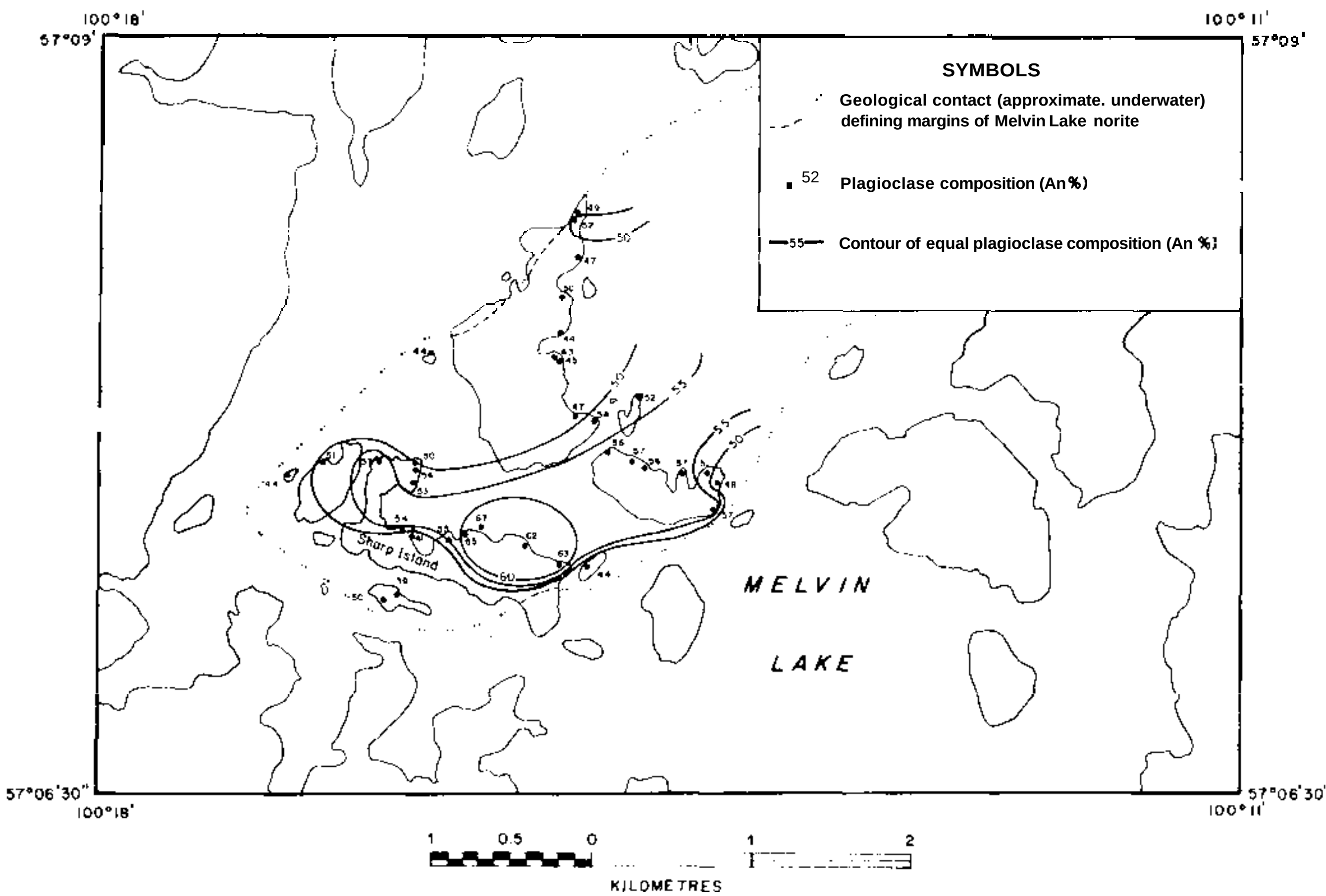


Figure 42: Map of the south part of the Melvin Lake norite showing variation of plagioclase composition.

Sections ABC and DE (Fig. 39) each show an abrupt change in plagioclase compositions at about the midpoints of each section and suggest an alternative interpretation to the smooth contouring of anorthite contents shown in Figure 42. An inferred major fault through the axial zone of the stock (Fig. 38) may be responsible for the apparent breaks in plagioclase composition in these sections. On the basis of comparison with other small layered mafic intrusions (Wager and Brown, 1968), the displacement would be at least 100 to 200 m to account for the approximately 10% anorthite change at these breaks.

Further geochemical work on the Melvin Lake norite might investigate the enigmatic distribution of plagioclase composition in which the structurally youngest rocks contain the most An-rich plagioclase. Future mapping should investigate the extent of folding and possible faulting, and the origin of garnetiferous amphibolite at the margin of the north part of the stock, which appears to be derived from the intrusive rocks.

Granite and granodiorite, medium grained to pegmatitic; related cataclasite (11)

Minor intrusions of granite and granodiorite (11) are widespread in the northern Barrington Lake and Melvin Lake areas. These intrusions (generally 1-5 m wide dykes and related veins) intrude paragneiss (4), conglomerate (6), and granitoid rocks (9), where they locally compose up to 10% of the outcrops. These occurrences of unit 11 are massive and undeformed and include; pale to bright pink aplite, fine- to medium-grained granite, and pegmatite. In the Melvin Lake norite (10), white to pink, massive and gneissoid granite and pegmatite intrusions occur sporadically, mainly in the axial zone. Most late granitoid intrusions (11) are parallel to the igneous layering in the norite.

In the north part of the Melvin Lake norite, a 30 m wide, north- northeast-trending unit of pink pegmatite displays alternating massive and protomylonitic interlayers at a scale of 10 cm to 2 m. Protomylonitic layers consist of anastomosing zones of cataclasite with remnants of massive pegmatite. These rocks are attributed to localized stress due to the inferred fault through the axial zone of the noritic stock (Fig. 38).

Medium grained and pegmatitic granite are interlayered (at 2-20 cm) in an east-trending body at least 45 m wide close to the axial zone of the stock 1 km north of Sharp Island. A similar intrusion occurs within the axial zone 0.5 km further east (Melvin Lake area, Map GR87-3-2). The granitic and granodioritic rocks are generally massive to slightly deformed, with minor straining of quartz and feldspars, and warping of red-brown biotite blades. Development of myrmekite, albitized rims on plagioclase, and moderate sericitization of plagioclase indicate these rocks have undergone limited alteration, possibly during localized stress associated with late movements.

FRASER LAKE AREA

INTRODUCTION

The east end of the Lynn Lake greenstone belt extends into the Fraser Lake area (Map GR87-3-3), where the northern and southern belts (defined in the description of the Barrington Lake area) terminate just west of Southern Indian Lake. The supracrustal rocks wedge out in an extensive granitoid terrane. Volcanic and sedimentary rocks of the northern belt are relatively well preserved in the vicinity of MacBride Lake, but deformation and metamorphic effects increase toward the belt margins where the rocks are altered to amphibolitic gneisses and schists. East of MacBride Lake the granitoid terrane contains a number of enclaves of volcanic and sedimentary rocks and derived gneisses representing remnants of the northern belt. Relatively small bodies are generally devoid of primary features; larger enclaves, which are better preserved, include volcanic and sedimentary rocks at Hollingworth Lake, mafic volcanic rocks at southeast Magrath Lake and north of Soltowski Lake, and the Soltowski Lake conglomerate, a lensoid enclave over 5 km long that represents the eastern extremity of the northern belt.

The eastward extension of the southern belt comprises amphibolitic enclaves and related dioritic zones within tonalite and quartz diorite in a 4 km wide zone north of Barrington River. Primary structures are rarely preserved in these mafic rocks. Paragneiss and schist outcrop sporadically along the south shore of Barrington River. The amphibolite units extend east to Southern Indian Lake in the southeast corner of the Fraser Lake area.

Classification of the supracrustal rocks in the northern and southern belts has been based on the presence or absence of primary features - where these are preserved the rocks have been mapped as volcanic or sedimentary lithologic types (units 1, 2, and 3); rocks devoid of primary structures have been classified as metamorphic lithologies (units 4 and 5). Unit 5 may include some amphibolite that has a post-Wasekwan Group intrusive origin.

WASEKWAN GROUP

Mafic to intermediate volcanic extrusive and fragmental rocks; minor gabbro and diabase (1)

Aphyric basalt (1a1)
Porphyritic plagioclase (± hornblende) basalt and andesite (1a2)
Mafic flow breccia (1a3)
Porphyritic hornblende basalt (1b)
Pillowed porphyritic and aphyric basalt (1c)
Mafic tuff and crystal tuff (1e)
Intermediate tuff (1e1)
Mafic to intermediate lapilli tuff (1f)
Mafic to intermediate pyroclastic breccia (1g)
Gabbro, quartz gabbro, diabase (1h)

Mafic to intermediate volcanic rocks with subordinate felsic volcanic and sedimentary interlayers occur in a 1.2 km wide supracrustal belt south and southwest of MacBride Lake at the west margin of the Fraser Lake area. This section wedges out 2 km further east within younger granodiorite. The mafic to intermediate volcanic rocks include flows, tuff and breccia that are comparable to equivalent lithologies described in the northern belt at Barrington Lake. Features that distinguish this section from that at Barrington Lake are as follows:

1. greater frequency of minor interlayers of biotite greywacke and siltstone (3a);
2. attenuation and alteration of volcanic rocks is more widespread. Breccia has commonly been transformed to laminated gneisses comprising 1 to 5 mm green micaceous layers (biotite-chlorite) derived from the matrix and mafic fragments, and cream to pale grey laminae (quartz-plagioclase-muscovite) that represent felsic to intermediate clasts. Massive mafic flows and tuff have been altered to amphibolite or amphibolitic schist;
3. pillows are rare; only one occurrence of pillowed basalt was encountered in the belt south of MacBride Lake. At the eastern termination of the belt, porphyritic basalt (1c) displays epidotic pillow selvages over a 100 m wide zone; and
4. sporadic occurrences of garnetiferous amphibolite, and garnet and rare clinopyroxene in mafic volcanic rocks.

North of MacBride Lake, a northwest-trending volcanic belt, approximately 2.5 km wide, comprises predominantly mafic to intermediate tuff and breccia, interlayered with subordinate mafic flows. Continuity between this belt and amphibolitic enclaves in the Wellmet Lake area (to the northwest) and volcanic and sedimentary rocks in the Hollingworth Lake area (to the east) is indicated by aeromagnetic trends (Barrington Lake area, Questor Surveys Ltd.; Manitoba Energy and Mines, 1977). In the volcanic belt north of MacBride Lake, mafic to intermediate tuff (1e, 1e1) occurs in massive or thinly laminated, 10 to 50 cm layers, locally altered to garnet schist (5b). Sporadic garnets (up to 5 mm) also occur locally in the matrix of volcanic breccia and in mafic flows. Basalt flows and breccia fragments include both aphyric and porphyritic types, with plagioclase phenocrysts, and (less abundant) hornblende pseudomorphs after pyroxene that compose up to 40% of the rock. Quartz or plagioclase amygdales occur locally. Some fragmental units (1e, f, g) are characterised by 15 cm to 1 m thick beds that locally display grading of breccia fragments and phenoclasts; however, most breccia is very poorly sorted or unsorted. Angular to subangular fragments, which range up to 30 cm x 8 cm, constitute 10 to 60% of the rocks. The fragments are aphyric to porphyritic and range from mafic to felsic compositions (Fig. 43).

A mineralized zone occurs just north of MacBride Lake 2 km east of MacBride River (Kilburn, 1956); abundant disseminated magnetite and pyrite, with minor pyrrhotite and chalcopyrite occur in muscovite schist in a shear zone at least 60 x 12 m (Kilburn, 1956). Exploration of this zone led to the discovery of ore reserves estimated at 1 819 700 tonnes grading 8.77% Zn, 0.35% Cu, 11.65 g/t Ag and 0.14 g/t

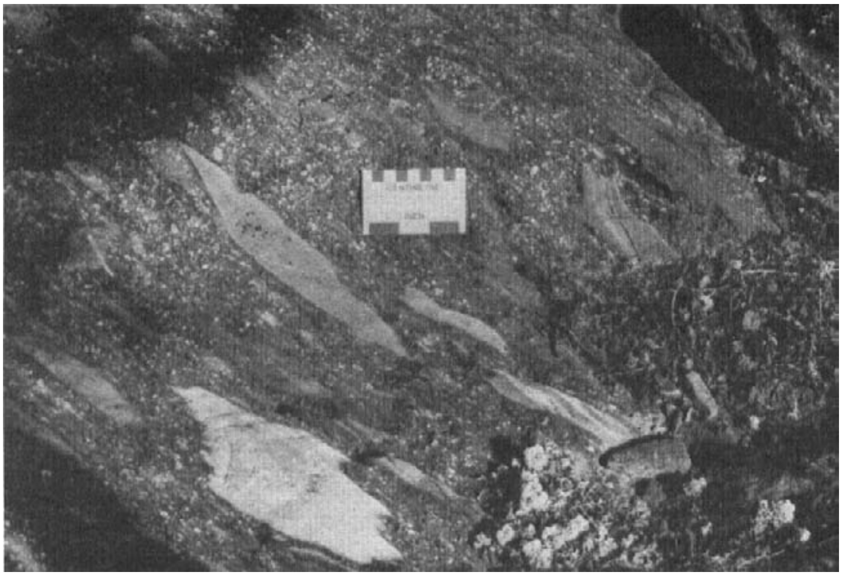


Figure 43: Intermediate pyroclastic breccia (unit 1g) that contains angular cobbles (mafic to intermediate, with subordinate felsic types) within a mafic crystal tuff matrix. Located north of the west end of MacBride Lake.

Au; the ground is presently held by Knobby Lake Mines Ltd. Petrographic details of the volcanic rocks north of the MacBride Lake area are given in Table 11.

Amphibolite enclaves, locally associated with paragneiss, occur within the granitoid terrane west of Hollingworth Lake (4-5 km east of the volcanic belt north of MacBride Lake). Primary volcanic structures occur sporadically in the amphibolite units, which range from small xenoliths to units at least 5 m thick. Some amphibolites contain andesine phenocrysts and hornblende pseudomorphs after pyroxene. Quartz amygdales and epidotic pillow selvage remnants occur at one locality. A volcaniclastic origin is indicated elsewhere in several amphibolite units that contain mineral fragments of plagioclase and quartz, and felsic volcanic granules and lapilli. Alternating hornblende-rich and plagioclase-rich laminae (1-20 mm) in some enclaves may represent primary layering. The mafic rocks are variously altered and assimilated by the surrounding granitoid rocks; the localized development of biotite (up to 10% of some amphibolites) and sporadic clinopyroxene and scapolite are attributed to metamorphism and metasomatism.

Mafic crystal tuff and lapilli tuff (1e, f), and basaltic flows and/or sills (1a) form a 100 m thick sequence at a chain of islets in the southeast part of Magrath Lake. The tuff contains plagioclase (andesine) and hornblende crystals (both are 0.5-2 mm, up to 15% of the rock) and minor felsic lapilli. The basaltic flows contain plagioclase phenocrysts (0.5-2 mm, up to 15% of the rock) and hornblende pseudomorphs with sporadic clinopyroxene relicts (0.5-1 cm, up to 25% of the rock). The volcanic rocks are intruded by porphyritic diabase and biotite-gabbro (1h), and are associated with coarse grained, layered mafic gneiss (hornblende-clinopyroxene-labradorite-clinozoisite) of probable igneous origin.

Table 11: Mineralogy and petrography of mafic to intermediate volcanic rocks (1) in the area north of MacBride Lake

Lithology	Assemblage	Notes
Mafic to intermediate volcanic breccia and tuff	Quartz-plagioclase-hornblende-magnetite-biotite ± garnet ± cummingtonite ± pyrite	Variable grain size and composition is related to the original fragmental structure. Felsic clasts consist of quartz-plagioclase-clinozoisite ± biotite ± hornblende; mafic clasts are hornblendic (± biotite). Biotite is variable, up to 35% of some zones (clasts?); biotite is partly altered to chlorite. Plagioclase phenocrysts (An_{60-65}) are partly altered to sericite and epidote (generally 10%). Magnetite is locally concentrated in ovoid aggregates (up to 1 mm across). Cummingtonite (locally accompanied by green hornblende) results in pale green weathered surfaces.
Basalt	Plagioclase-hornblende-magnetite-quartz-biotite ± cummingtonite ± pyrite	Plagioclase phenocrysts (An_{60-65}) are 1-3 mm, 5-35% of the rock. Hornblende pseudomorphs (after pyroxene) are 1-2 mm, up to 10% of the rock. Quartz amygdales are rare and subordinate (1-3 mm, up to 10% of the rock).

A distinctive flow breccia (1a3) underlies an islet close to the west shore of Magrath Lake; the rock contains ovoid, quartz amygdaloidal, epidotic fragments up to 40 cm long in a hornblende- and plagioclase-phyric basalt matrix (Fig. 44). The rock is partially altered to mafic gneiss with minor micaceous stringers and aggregates, and incipient hornblendic and feldspathic lamination.

Mafic to intermediate volcanic rocks compose an inlier (at least 175 m wide) 1 km north of Soltowski Lake. Porphyritic basalt, tuff and lapilli tuff (Ia, b, e and f) occur as 1 to 5 m thick layers, and are similar to equivalent lithologies at southern Magrath Lake. Felsic and minor mafic lapilli occur sporadically in the tuff; the fragments are locally angular, but generally they are tectonically attenuated. Andesine phenocrysts are partly recrystallized to quartzofeldspathic aggregates. Hornblende pseudomorphs (after pyroxene) are commonly flattened and recrystallized to lenticular aggregates that are partly altered to biotite. Some tuff layers display traces of primary lamination that is defined by variable composition and grain size. Elsewhere in the Soltowski Lake area, mafic xenoliths and skialithic units (up to 5 m thick) that have detrital texture and are heterolithic are interpreted to be tuffaceous, but primary textures are generally not preserved. Hornblende and/or biotite poikiloblasts locally overprint the earlier fabric.

Supracrustal enclaves in the eastern extension of the southern belt (a 4 km wide zone immediately north of Barrington River) are less varied and generally smaller than in the eastern end of the northern belt. Amphibolite units constitute 10 to 15% of this zone and are generally 1 to 10 m thick; except for porphyritic textures, these units are devoid of primary features. The largest mafic volcanic enclave (1 km wide), which occurs at Nose Lake, comprises predominantly plagioclase phyric basalt (plagioclase 1-2 mm, 10-20% of the rock) and subordinate aphyric basalt (Ia). Hornblende poikiloblasts, clinopyroxenes with skeletal hornblende inclusions, and sporadic garnets occur in some units; magnetite and subordinate pyrite compose 5 to 10% of the basalt.

Minor gabbro and diabase intrusions (1h) occur within supracrustal sections in the MacBride, Magrath and Soltowski lakes areas; these are generally too small (<5 m thick) to be delineated on the map (GR87-3-3). At islands in the south part of Magrath Lake, hornblende phyric diabase intrusions (>5 m) occur within mafic volcanic rocks. Clinopyroxene (up to 5 mm) constitutes up to 35% of the diabase (Fig. 45); related gabbro locally contains irregular aggregates of biotite up to 2 cm across. These rocks are variously altered to amphibolite and epidote-bearing hornblende gneiss.

Intermediate to felsic volcanic extrusive, intruslve and fragmental rocks (2)

Aphyric rhyolite and dacite (2a)
Porphyritic rhyolite and dacite (2b)
Intermediate to felsic volcanic breccia and lapilli tuff (2c)

Intermediate to felsic volcanic rocks constitute 5 to 10% of the supracrustal belt south and southwest of MacBride Lake, and occur sporadically north of MacBride Lake and north, east and south of Soltowski Lake. These intermediate to felsic units (typically 1-5 m thick, up to 40 m), are interlayered with mafic to intermediate flows and volcanic breccia. Massive intermediate to felsic units (2a, b) probably include both flows and sills, but definitive evidence for extrusion is not preserved. Rare occurrences of intermediate to felsic fragmental rocks (2c) occur southwest and north of MacBride Lake.

Porphyritic rhyolite and dacite (2b) are white to pale grey, and locally contain darker grey, streaky zones that are attributed to flow layering and/or contamination. Subhedral plagioclase phenocrysts (oligoclase-andesine) generally constitute 10 to 20% of the rocks. Quartz phenocrysts, which constitute 5 to 10% of many units, are commonly flattened and recrystallized to finer grained aggregates. Biotite is the main mafic mineral, but muscovite, green hornblende

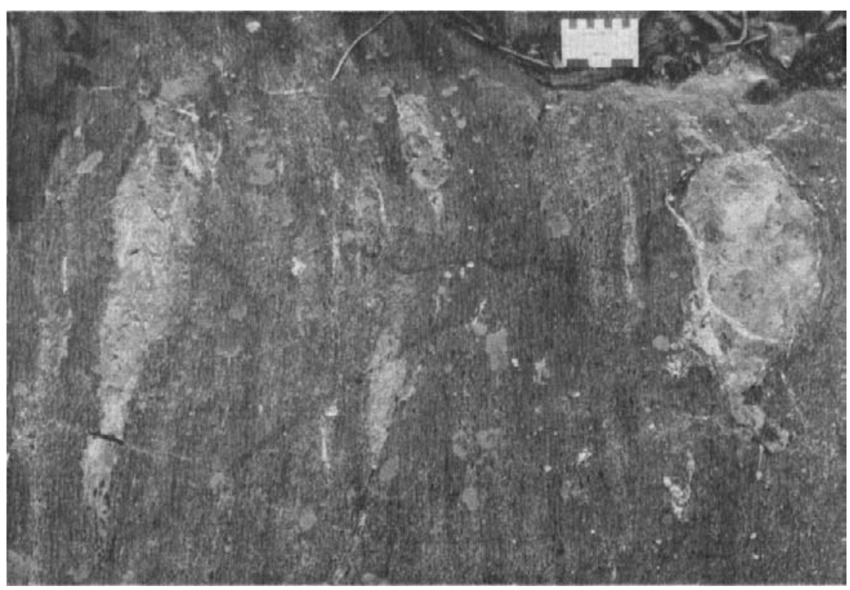


Figure 44: Mafic flow breccia (unit 1a3) at Magrath Lake that contains ovoid clasts of quartz amygdaloidal basalt (largely altered to epidote) in a hornblende- and plagioclase-phyric basalt matrix.

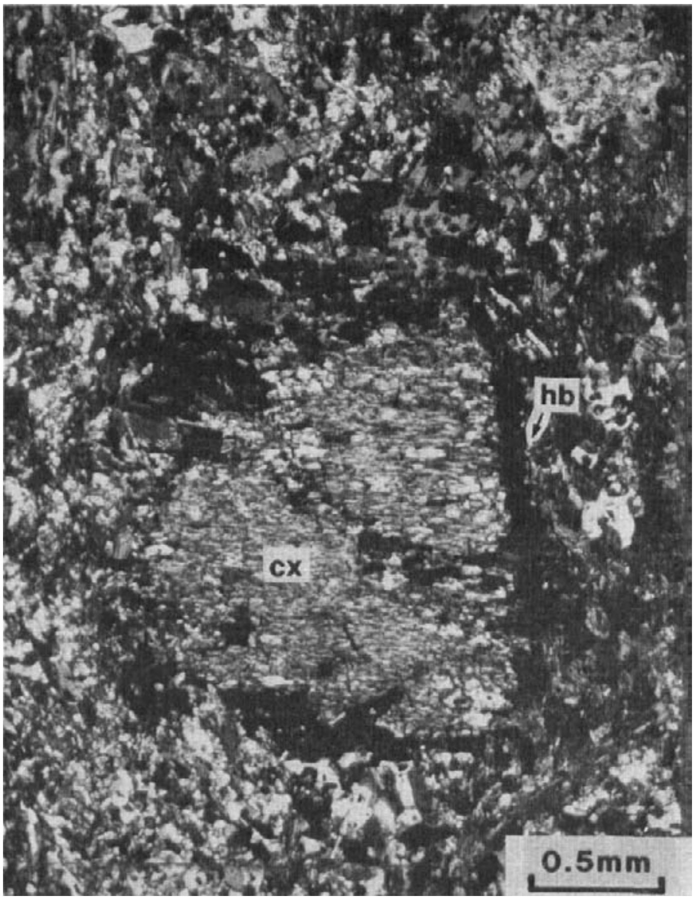


Figure 45: Clinopyroxene (cx) phenocryst in diabase (unit 1h) with a mantle of secondary green hornblende (hb). Sample 397-4, crossed polarizers.

and/or cummingtonite are present in some rocks; these minerals are locally poikiloblastic. Lenticular, micaceous aggregates are characteristic of rhyolite in the vicinity of Soltowski Lake. Accessories include magnetite (up to 7% of some units), microcline, chlorite, epidote, sphene, zircon, pyrite and sporadic porphyroblastic garnet.

Intermediate to felsic volcanic breccia (2c) is associated with mafic to intermediate flows and fragmental rocks north of MacBride Lake, just east of North MacBride River. Felsic, aphyric fragments (up to 1 x 10 cm) occur in a micaceous, garnetiferous matrix. A similar unit (5-10 m thick) west of North MacBride River has been metamorphosed to gneiss with alternating white and green laminae that are derived from breccia fragments and matrix respectively.

Sedimentary rocks (3)

Greywacke, siltstone (3a)
Conglomerate (3b)

Greywacke and siltstone interlayers are a minor part of the mainly basaltic northern belt southwest of MacBride Lake; further west, at Barrington Lake, sedimentary interlayers are very rare. Minor conglomerate occurs close to the east end of MacBride Lake. Metasedimentary rocks north and northeast of MacBride Lake and at Magrath and Soltowski lakes have been largely altered to paragneiss and schist (5). Several well preserved greywacke, siltstone and minor conglomerate units occur west of the north end of Hollingworth Lake.

Feldspathic greywacke and/or siltstone units (3a) up to 12 m thick are interlayered with mafic to intermediate and minor felsic volcanic rocks southwest of MacBride Lake. The greywacke is medium grey, and contains detrital plagioclase grains and hornblende that are generally predominant over biotite. Siltstones include medium grey, micaceous and green, hornblendic types. Bedding is locally indicated by fine trails of biotite or thin laminae (0.1-3 cm) that are defined by variable mafic mineral content. Grey siltstone and green mafic mudstone are locally thinly interlayered (at 2-10 mm) in the same sedimentary unit. Hornblende porphyroblasts and lenticular aggregates, sporadic garnets (Fig. 46) and rare biotite poikiloblasts occur in some beds.

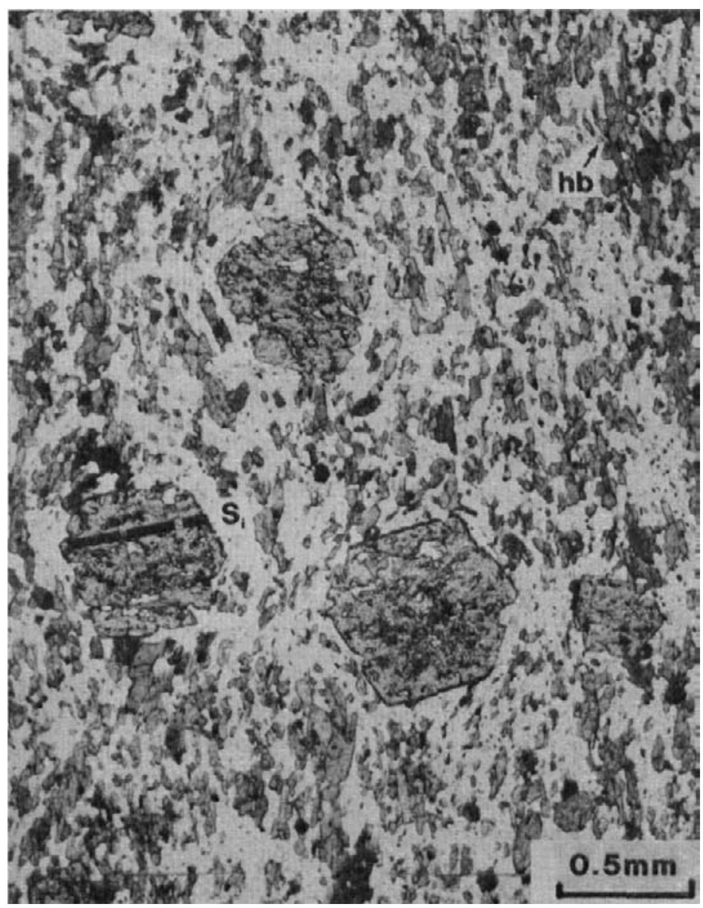


Figure 46: Hornblende (hb) greywacke (unit 3a) that contains rotated garnet poikiloblasts that display an internal quartzofeldspathic foliation (Si). Sample 228-3, plane polarized light.

These rocks contain essential quartz and plagioclase (andesine to labradorite), up to 40% green hornblende and 20% biotite, and accessory epidote, sphene, magnetite, pyrite and hematite.

A 15 m conglomerate unit between MacBride and Hollingworth lakes contains mafic, intermediate and felsic pebbles that constitute 20 to 30% of the rock. Magnetite makes up 5 to 8% of the intermediate greywacke matrix and up to 15% of some amphibolite clasts. The conglomerate (3b) is characterized by poorly defined fragmental structure and gneissic texture, and contains poikiloblasts of clinopyroxene (with altered, hornblendic rims), green hornblende, cummingtonite, garnet, biotite and magnetite. The conspicuous gneissic texture of the conglomerate is attributed to contact metamorphism by the surrounding granitoid rocks.

Greywacke, siltstone and rare conglomerate units are interlayered with mafic to intermediate and minor felsic volcanic rocks northwest of Hollingworth Lake. The conglomerate beds are up to 3 m thick and contain amphibolite and felsite pebbles that constitute 30% of the rock, in an intermediate hornblende greywacke matrix. Greywacke-siltstone units (up to 15 m) are mainly hornblendic and contain minor biotite, but intermediate and felsic biotite greywacke that contains 50 to 90% quartz and plagioclase are also present. Localized compositional layering at 0.1 to 2 cm (dark to pale grey/beige/cream) is interpreted to be metamorphic lamination that probably parallels original bedding. Detrital quartz and plagioclase, felsic granules and sporadic garnets occur in some beds. The rocks locally contain poikiloblastic hornblende or clinopyroxene (less common) and up to 8% opaque minerals.

ROCKS OF PROBABLE WASEKWAN GROUP AGE

Paragneiss, schist and related migmatite (4)

Psammitic gneiss (4a)
Semipelitic gneiss (4b)
Pelitic gneiss (4c)
Hornblende-plagioclase-biotite gneiss (4e)
Migmatite (4f)

Paragneiss, schist, migmatite and granitoid rocks occur in a 2 km wide zone that extends through Hollingworth Lake to northern Magrath Lake. Related gneisses also occur in the south part of Magrath Lake and sporadically in the largely granitoid terrane between MacBride, Hollingworth and Soltowski lakes. Paragneiss also occurs locally along the south shore of Barrington River. Rare detrital textures, including pebbles, are preserved in these rocks, which are interpreted to be metamorphic equivalents of unit 3. The paragneiss comprises semipelitic (4b), psammitic (4a), pelitic (4c), and calcium-rich (4e) lithologies. Gneiss and schist are intimately associated with volcanic-derived hornblendic rocks (5). Pervasive granitoid intrusions have led to the development of migmatites. Younger, posttectonic granitoid intrusions are locally abundant.

Semipelitic gneiss ranges from fine grained, medium grey rock that contains rare traces of bedding and detrital texture, to coarser grained, speckled biotite-plagioclase gneiss that is devoid of primary structures. Gneissic layering is locally defined by variable biotite, amphibole, felsic minerals, magnetite, garnet, or rare pyroxene; the layering is locally reinforced by variations in grain size. At Hollingworth Lake, paragneiss displays alternating semipelitic and calc-silicate laminae (1-5 mm thick) that are pale to dark grey (micaceous), green (hornblendic) and yellow-green (pyroxenitic); some laminae contain garnets up to 2 mm across. The mafic minerals define the regional foliation, and they are also commonly poikiloblastic. Concordant, disrupted tonalitic *lits* and irregular intrusions are widespread. Reaction between granitoid rocks and paragneiss resulted in the development of migmatite (4f) that contains younger granitoid dykes and veins. In the southwest part of Hollingworth Lake, a 20 m thick unit of fault breccia contains angular semipelitic and psammitic gneiss clasts (up to 50 cm) within tonalite (Fig. 47). At northern Magrath Lake, paragneiss contains cordierite, garnet, muscovite, biotite, sillimanite, green hornblende, cummingtonite, clinopyroxene and magnetite (Table 12; see Metamorphic History).

Porphyroblastic semipelitic gneiss (4b) occurs at the south shore of Barrington River close to the southwest corner of the Fraser Lake map area. Stratabound anthophyllite (up to 1.5 cm) occurs locally within well layered pale to dark grey paragneiss. The amphibole is associated with biotite, cordierite, magnetite, and rare fibrolitic sillimanite (see Metamorphic History). The origin of minor amphibolite interlayers in the paragneiss is uncertain.

Minor pelitic units (4c), up to 30 cm thick, occur within the paragneiss at northern Magrath Lake. These units consist of biotite (50%), cummingtonite (25%) and subordinate labradorite (15%), magnetite (5%) and quartz. Medium grained, biotite (± garnet) schist is locally associated with the anthophyllite-cordierite gneiss at Barrington River.

Pale grey to cream weathering, fine grained psammitic gneiss layers (4a), that range from 30 cm to 3 m thick, occur at Hollingworth Lake, northern Magrath Lake and the south shore of Barrington River. The rocks are locally interlayered with semipelitic gneiss (at a scale of 2 cm - 1 m) and are interpreted to be sedimentary; however, a volcanic or intrusive origin cannot be ruled out for some units. Psammitic gneiss contains quartz and feldspar (80-90%), biotite (3-10%), magnetite (2-10%) and minor muscovite. Locally stratabound garnet porphyroblasts are common; green hornblende (± cummingtonite) poikiloblasts occur in several units. Some rocks contain thin, mafic laminae or diffuse zones. At Hollingworth Lake, 2 to 5 mm laminae with up to 20% magnetite occur in one psammitic unit that also contains ovoid aggregates (up to 2 mm across) that consist of corundum + sericite + epidote + magnetite + hercynite, which locally mantle prismatic sillimanite (Fig. 48). The sillimanite + corundum assemblage is attributed to an early high grade metamorphic event (see Metamorphic History).

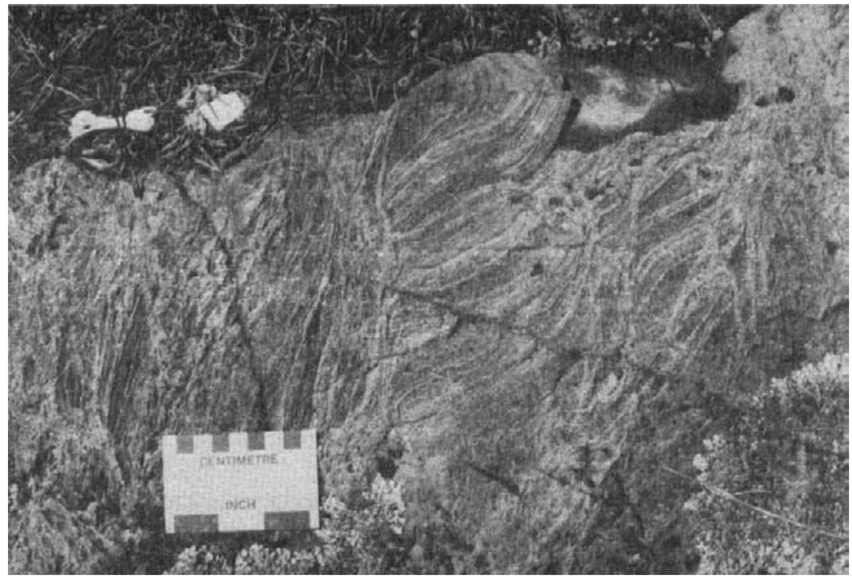


Figure 47: Fault breccia within paragneiss (unit 4) at Hollingworth Lake that contains dislocated blocks and angular fragments of gneiss, variously intruded by tonalite.

Table 12: Mineralogy and petrography of paragneisses (4a, b, c, e, f) in the Fraser Lake area

Mineral	Notes
QUARTZ	
PLAGIOCLASE	Andesine to labradorite.
MICROCLINE	
BIOTITE	Subparallel to randomly oriented; locally poikiloblastic, up to 5 mm blades. Generally brown, locally brown-green in cordierite-bearing gneiss at Magrath Lake. Minor alteration to chlorite.
GREEN HORNBLENDE	Subparallel to randomly oriented; commonly as porphyroblasts or blastic aggregates.
CUMMINGTONITE	Sporadic occurrences in semipelitic to psammitic gneisses (*e.g.* subhedral prisms up to 1 cm at Barrington River). Commonly associated with green hornblende.
ORTHOPYROXENE	As relict poikiloblasts, partly altered to cummingtonite, green hornblende and biotite; occurs in diffuse leucocratic zones in hornblendic gneiss.
CLINOPYROXENE	Locally poikiloblastic; generally associated with green hornblende.
GARNET	Common in semipelitic and psammitic gneisses. Locally overprints quartzofeldspathic foliation. Porphyroblasts up to 1.5 cm at Hollingworth Lake adjacent to fault breccia veined by tonalite.
CORDIERITE	Occurs at northern Magrath Lake and at Barrington River as large (1 cm) porphyroblasts; locally contains magnetite as fine grained inclusions or very fine grained dusting. Variously altered to pinite or sericite.
MUSCOVITE	Common accessory; locally as poikiloblasts (*e.g.* up to 1 cm in cordierite-bearing gneiss at northern Magrath Lake).
ANTHOPHYLLITE	Subhedral prisms up to 8 mm in biotite gneiss at Barrington Lake.
SILLIMANITE	Fibrolitic aggregates associated with biotite and magnetite in cordierite-biotite-muscovite-garnet-sillimanite gneiss at northern Magrath Lake; rare porphyroblasts associated with corundum at Hollingworth Lake in cores of secondary aggregates of sericite, epidote, magnetite and hercynite.
SCAPOLITE	Poikiloblasts (up to 5 mm) in layered clinopyroxene-hornblende-epidote-biotite-carbonate-plagioclase gneiss at southeast Magrath Lake.
MAGNETITE	Commonly constitutes 2-5% of paragneisses, up to 10% of cordierite-bearing gneisses and some psammitic units. Generally disseminated, locally defines laminae or (rarely) an early, deformed foliation.
PYRITE PYRRHOTITE	Occasional accessories, disseminated or locally in lenticular aggregates or stringers. Hematite is locally associated with sulphides or magnetite.
APATITE, SPHENE	Minor accessories.
CARBONATE, SERICITE	Minor secondary minerals, locally in zones parallel to the foliation. Sericite associated with alteration of plagioclase, cordierite and anthophyllite.

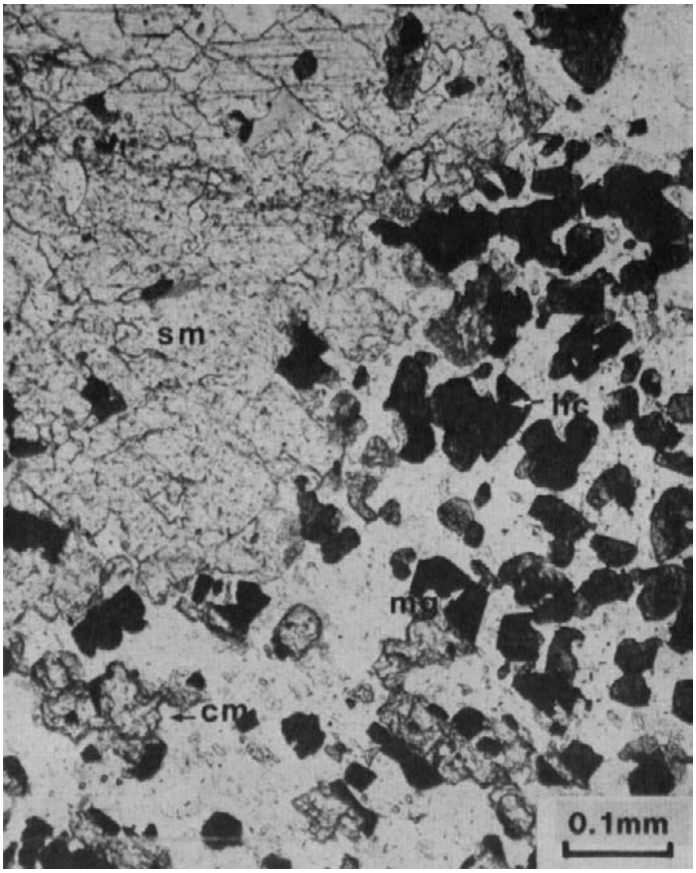


Figure 48: *Psammitic gneiss (unit 4a) that contains a sillimanite porphyroblast (sm) surrounded by an aggregate of corundum (cm) + sericite + epidote + magnetite (mg) + hercynite (hc). Sample 329-1, plane polarized light.*

Hornblende-plagioclase-biotite gneiss (4e) at the south shore of Magrath Lake contains green hornblende (20-65%), andesine (20-55%), biotite (4-15%) and minor microcline, quartz, sphene and magnetite; clinopyroxene (up to 10%) occurs locally. Green hornblende poikiloblasts occur sporadically; biotite occurs as random porphyroblasts and locally defines fine (1-4 mm) laminae. Gneissic lamination at one locality is defined by magnetiferous stringers and variable hornblende content. Several units of semipelitic gneiss (4b) are interlayered with the hornblendic gneiss. Tonalitic *lits* and discordant minor intrusions occur sporadically. Scapolite poikiloblasts (up to 5 mm) occur in laminated biotite-pyroxene-hornblende-epidote gneiss (over 4 m thick) close to the southeast corner of Magrath Lake. Epidotic laminae are characteristic of hornblendic gneiss at the southwest corner of the lake. Hornblende-plagioclase-biotite gneiss at southern Magrath Lake is interpreted to be altered calcareous sedimentary rock.

Migmatitic hornblende-hypersthene-biotite gneiss (4f), 2 km east of Hollingworth Lake, contains tonalitic *lits* (1-20 mm thick) and diffuse amphibolitic stringers partly altered to biotite; similar gneiss, with clinopyroxene, occurs at a locality 2 km west of Hollingworth Lake. Hypersthene occurs in diffuse leucocratic zones interpreted to be incipient anatectic segregations. The orthopyroxene occurs as anhedral to subhedral relict poikiloblasts up to 1.5 mm long, that are partly altered to cummingtonite, green hornblende, biotite and bastite (Fig. 49). The occurrence of orthopyroxene is interpreted as evidence for an early granulite facies metamorphic event, although the grain size of the gneiss is relatively fine compared to typical granulites (J. Macek, pers. comm.). The hypersthene-bearing gneisses near Hollingworth Lake and the sillimanite + corundum assemblage (described previously) are the only known occurrences of granulite facies assemblages in the project area, but it is probable that other hypersthene-bearing gneisses exist in the gneiss terrane that encompasses Hollingworth and Magrath lakes.

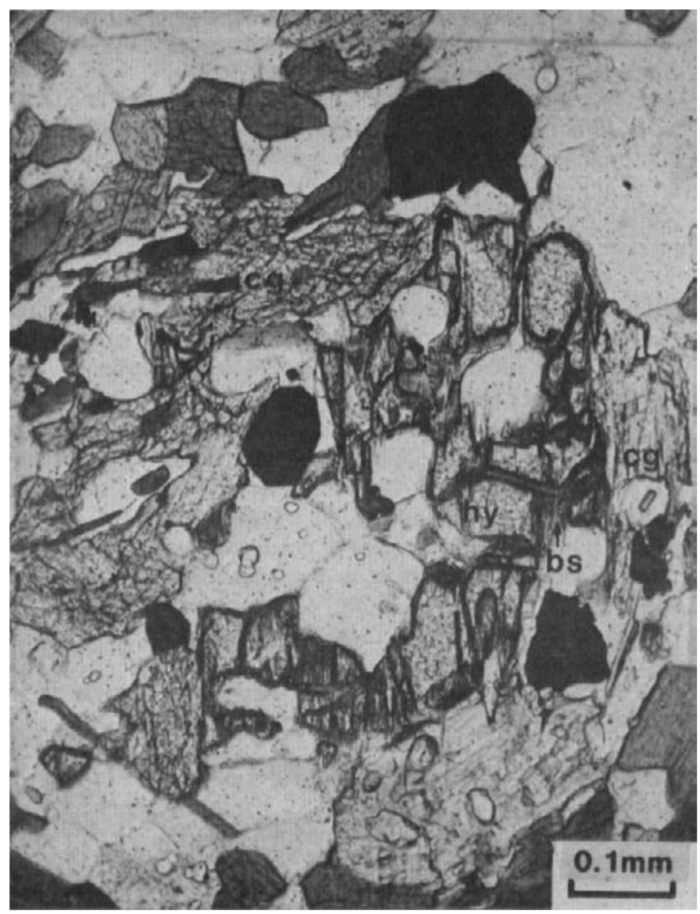


Figure 49: *Migmatitic gneiss (unit 4f) that contains a hypersthene porphyroblast (hy) partly altered to cummingtonite (cg) and bastite (bs). Sample 270-2, plane polarized light.*

Amphibolite, schist, gneiss and related migmatite (5)

Amphibolite, hornblende-plagioclase gneiss and migmatite (5a)
Mafic to intermediate schist and gneiss (5b)
Intermediate to felsic schist and gneiss (5c)

Amphibolite, related gneiss and migmatite (5a) are closely associated with paragneiss and schist (4) in the Hollingworth Lake-Soltowski Lake area. Rare traces of plagioclase phyric texture, pillow selvages and quartz amygdales were observed in some fine- to medium-grained amphibolite and indicate a volcanic origin. A sedimentary or tuffaceous origin is locally inferred for minor laminated amphibolites, and for rare occurrences of mafic rocks with traces of felsic fragments. Units 5a and 4 are approximately equal in abundance in the Hollingworth-Soltowski lakes area; thus sedimentary rocks (4) are significantly more common in this part of the northern belt, compared with the same belt further west at Barrington Lake, which is largely basaltic.

Amphibolite and related gneiss in the Hollingworth Lake-Soltowski Lake area are pervasively intruded by tonalite and minor pegmatite with development of layered hornblende-plagioclase gneiss. hornblende quartz diorite, and agmatitic to nebulitic migmatite with irregular mafic schlieren. The gneiss locally displays compositional layering (0.1-2 cm) that is defined by variable amphibole/plagioclase ratio (Fig. 50) and locally variable biotite or clinopyroxene contents. Green hornblende and plagioclase are the most abundant minerals, and they are generally accompanied by cummingtonite and subordinate microcline and biotite (Table 13). Minor clinopyroxene is commonly partly altered to amphibole.

Amphibolite, related gneiss and migmatite immediately north of Barrington River compose the eastern extension of the southern belt of volcanic rocks, where it is extensively intruded by granitoid rocks of unit 9 (see description of unit 5a, Barrington Lake area).

Garnet-chlorite schist (5b) occurs locally within the mafic to intermediate volcanic section north of MacBride Lake. The volcanic-derived schist units (up to 50 cm thick) are gradational with volcanic fragmental units that contain diffuse garnetiferous zones with porphyroblasts up to 5 mm. Mafic to intermediate schist and gneiss (5b) and rare intermediate to felsic gneiss (5c) occur sporadically in the MacBride Lake-Soltowski Lake area, generally in association with amphibolite (5a).

SICKLE OR WASEKWAN GROUP

Conglomerate, feldspathic greywacke and siltstone (6)

Polymictic conglomerate with minor feldspathic greywacke interlayers (6a)

Polymictic conglomerate extends from the area east of southern Magrath Lake to the south part of Soltowski Lake, forming a pear-shaped unit up to 1.7 km wide and at least 5.2 km long. The conglomerate is lithologically similar to the Zed Lake-Hughes River conglomerate (late Wasekwan Group or Sickle Group) that extends along the north margin of the Lynn Lake greenstone belt as far east as northern Barrington Lake, 33 km northwest of Soltowski Lake (Gilbert *et al.,* 1980). The Soltowski Lake conglomerate is flanked to the north and south by basalt, mafic tuff, greywacke and related paragneiss with felsitic and felsic porphyry interlayers. The east end of the conglomerate is terminated in a younger granitoid terrane that extends east to Southern Indian Lake; the western termination is interpreted to be fault bounded. At least two periods of deformation affected the Soltowski Lake conglomerate. D_1 resulted in regional foliation (vertical to subvertical) that is deformed by tight, west-plunging D_2 folds with amplitudes of 1 to 25 cm. Limited data suggest a synformal structure for the conglomerate. Granite, granodiorite and pegmatite intrusions (9) pervade the Soltowski Lake conglomerate and constitute 5 to 10% of the unit.

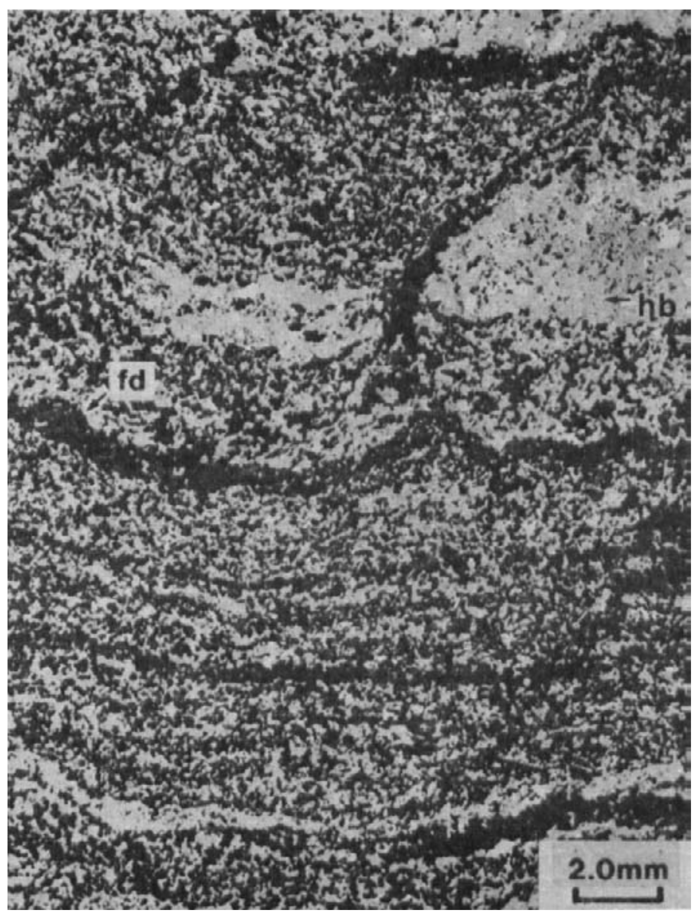


Figure 50: Amphibole-plagioclase gneiss (unit 5a) showing fine lamination defined by alternating green hornblende (hb) and feldspar (fd) units. Feldspar-filled microfractures intersect the lamination. Sample 550-1. Negative image photomicrograph, plane polarized light.

Table 13: Mineralogy and petrography of amphibollte and hornblende-plagloclase gneiss (5a) inthe Fraser Lake area

Mineral	Notes	Abundance (approx. %)
GREEN HORNBLENDE	Subparallel to randomly oriented, commonly poikiloblastic; locally contains fine opaque inclusions interpreted as evidence for possible pyroxene precursor.	20 - 65
CUMMINGTONITE	Subparallel to randomly oriented, commonly poikiloblastic; locally in optical continuity with green hornblende.	0 - 25
PLAGIOCLASE	Andesine to labradorite; commonly zoned.	20 - 50
BIOTITE	Subparallel to randomly oriented, locally poikiloblastic or in lenticular aggregates or irregular stringers.	0 - 15
CLINOPYROXENE	Commonly poikiloblastic, locally partly altered to green hornblende or cummingtonite (*e.g.* at margins).	0 - 10
GARNET	Sporadic.	0 - 10
MICROCLINE		0 - 10
QUARTZ		0 - 10
MAGNETITE	Disseminated, locally euhedral.	2 - 6
APATITE, SPHENE	Minor accessories.	Generally less than 5% each
PYRITE, EPIDOTE	Sporadic accessories.	
CARBONATE	Rare accessory	
SERICITE, CLINOZOISITE, CHLORITE, STILPNOMELANE	Minor secondary minerals; stilpnomelane locally associated with alteration of cummingtonite or orthopyroxene.	

The conglomerate is composed of plutonic, volcanic and sedimentary cobbles and pebbles, and is characterized by a prominent foliation and local gneissic texture (Table 14; Fig. 51). The matrix is generally hornblende greywacke (with 20-50% green hornblende) or locally biotite greywacke. Feldspathic greywacke interbeds occur sporadically in the conglomerate. In the central part of the conglomerate unit, rare graded bedding, in pebble conglomerate and associated greywacke interbeds, faces north-northeast (Fig. 52).

Felsic to intermediate lithologies typically constitute 50 to 75% of the total clast volume, but amphibolite fragments are locally prominent. The clasts are generally unsorted, ovoid to highly attenuated and locally crenulated (Fig. 53). Tonalitic and quartz clasts locally display subrounded to subangular shapes; mafic clasts are strongly flattened and transformed into hornblendic stringers where the conglomerate is altered to gneiss. Lamination in the gneiss (0.5 to 10 mm) is defined by grain size and compositional variation (hornblendic, epidotic, quartzofeldspathic and minor pyroxenic and micaceous units) that resulted from strong flattening and attenuation of the original fragmental structure. The rock is locally altered to micaceous amphibolite that contains biotite and clinopyroxene (up to 15% each), and magnetite (up to 7%). Accessory microcline and sphene, and secondary chlorite, carbonate and sericite are widespread. Epidote and microcline occur in fine concordant stringers and irregular zones. Boudinaged quartz veinlets are ubiquitous, and amphibolitic veins occur sporadically.

Quartz-rich conglomerate occurs in a 20 to 50 m wide zone close to the north margin of the central part of the Soltowski Lake conglomerate. Chert, magnetiferous chert, tonalite and felsic volcanic clasts are predominant in a biotite-bearing, quartzitic matrix. Ovoid calc-silicate clasts (epidotic cores, hornblendic rims) up to 15 cm across occur sporadically in this unit.

Feldspathic greywacke, siltstone, minor amphibolite (6b)

Minor feldspathic greywacke and siltstone lenses and interbeds (10 cm - 5 m thick) occur sporadically in the Soltowski Lake conglomerate; only the thicker interlayers have been identified (6b) on the map (Fraser Lake area, Map GR87-3-3). A 30 m thick greywacke unit occurs at the north side of the conglomerate at Soltowski Lake and a major (400 m) greywacke section occurs at the south side, just south of Soltowski Lake; this section, together with the minor greywacke units, constitutes approximately 10% of the Soltowski Lake conglomerate.

Table 14: Clast types in the Soltowski Lake conglomerate (6a)

Clast type	Notes	Relative abundance
Tonalite, quartz-eye tonalite (pre-conglomerate).	Fine- to medium-grained, massive to gneissoid; with biotite and/or hornblende ± quartz eyes (1-3 mm, <30%) ± rare hornblende porphyro- blasts ± rare biotite aggregates; ± quartz veins	
Granodiorite, granite	Fine grained, microcline-rich.	Generally predominant, up to 90% total clast volume.
Felsic volcanic	Very fine grained to aphanitic; ± quartz ± plagioclase phenocrysts (0.5-3 mm, 5-15% each) ± hornblende porphyroblasts.	
Intermediate	Fine grained, micaceous. Sedimentary or volcanic origin.	
Amphibolite, hornblendite	Amphibolite is fine grained to medium grained; mesocratic to melanocratic (hornblende content = 20-65%); ± rare quartz amygdales ± rare hornblende porphyroblasts. Hornblendite (less common) is probably related to amphibolite.	Generally subordinate (10-15% locally up to 50% total clast volume)
Mafic, micaceous	Dark gray, fine grained.	Subordinate.
Chert, magnetiferous chert	Aphanitic, white to gray.	Subordinate, sporadic occurrences.
Quartz	Translucent; granules and small pebbles.	Subordinate but widely distributed.
Epidosite, altered rocks	Altered, mafic and possible felsic, fine grained lithologies. Assemblages include (1) epidote; (2) epidote-quartz-carbonate-garnet; (3) epidote-hornblende-plagioclase ± clinopyroxene.	

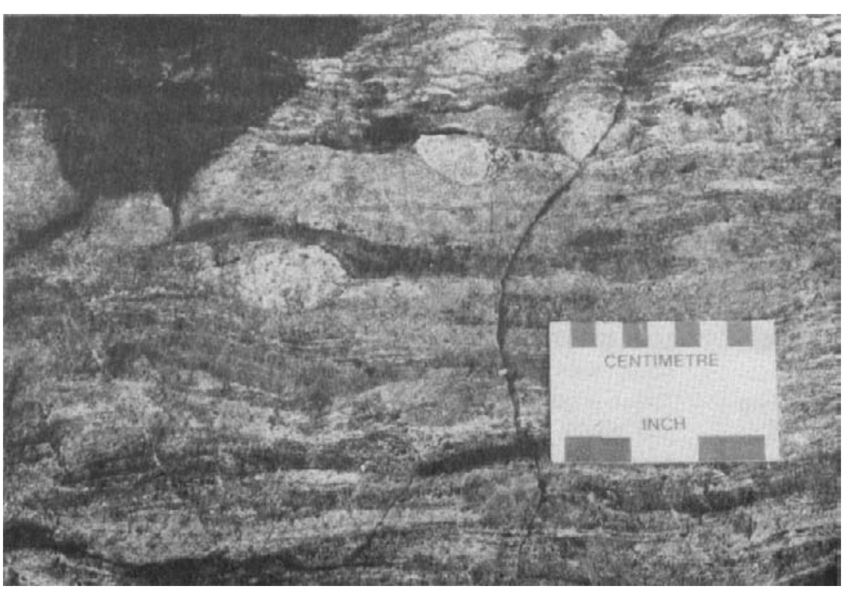


Figure 51: Soltowski Lake conglomerate (unit 6a) showing several rounded, undeformed granitoid fragments and strongly flattened mafic clasts in a hornblende greywacke matrix. Located close to the west shore of Soltowski Lake.

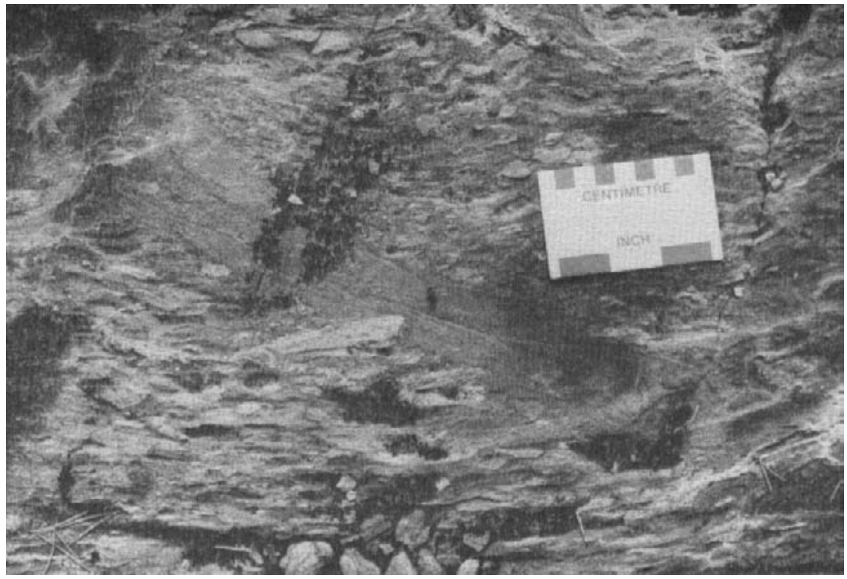


Figure 52: Lens of feldspathic greywacke within Soltowski Lake conglomerate (unit 6a). The foliation and plane of flattening of the clasts are discordant to bedding. Grading in the conglomerate is evident on both sides of the greywacke lens (fining toward the lower left corner of the photograph). Located west of Soltowski Lake.

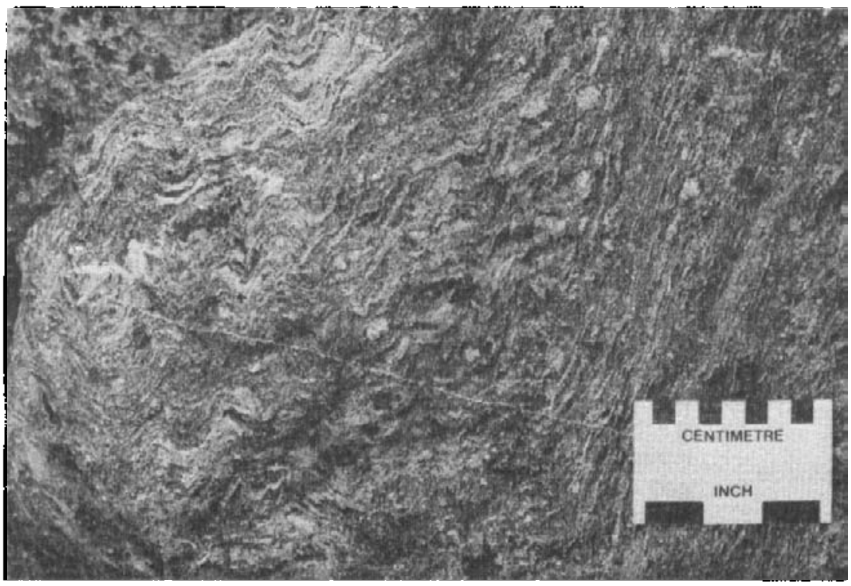


Figure 53: *Conglomerate (unit 6a) at Soltowski Lake showing crenulation of highly attenuated fragments and incipient development of gneissic lamination.*

The feldspathic greywacke and siltstone (6b) are similar to the conglomerate matrix in texture and composition. They are mainly massive, intermediate and grey weathering, with localized darker grey, mafic laminae (1-5 mm) or interlayers up to 10 cm thick. Rare felsic wacke units (0.5-1 m thick) contain up to 85% quartz and feldspar (Table 15). Biotite (and locally hornblende) define the foliation. Detrital quartz and/or plagioclase grains are rarely preserved. Conglomerate-greywacke contacts are sharp or gradational, and locally there is an intervening pebbly wacke zone.

Stringers of epidote or hornblende, and hornblende + plagioclase aggregates occur in some greywacke units, with local rare hornblende porphyroblasts in 5 to 10 cm wide concordant zones. A significant calcareous component (probably mafic volcanic) in the source terrane of unit 6 is indicated by the common abundance of green hornblende in greywacke (6b). in the conglomerate matrix (6a), and in sporadic units of quartz-bearing sedimentary amphibolite.

Table 15: Mineralogy and petrography of feldspathic greywacke and amphibolite (6b) in the Fraser Lake area

Mineral	FELDSPATHIC GREYWACKE Notes	Abundance (approx. %) Greywacke	Abundance (approx. %) Amphibolite	AMPHIBOLITE Notes
QUARTZ, PLAGIOCLASE		65-85	45-65	Quartz content exceeds 10% in some units. Relict plagioclase phyric texture locally preserved.
GREEN HORNBLENDE	Subparallel to randomly oriented; localized incipient blastesis; rare stratabound porphyroblasts.	0-10 (rarely, up to 20)	20-45	Commonly poikiloblastic, locally with twin lamellae. Sporadic subhedral grains (possibly after pyroxene) occur in one unit.
BIOTITE	Defines foliation; locally variable content defines fine lamination. Dark brown, locally red-brown or green-brown.	5-15 (rarely, up to 30)	0-15	Red-brown, randomly-oriented blades.
MICROCLINE		0-10	0-10	
MAGNETITE/ILMENITE	Generally fine grained, disseminated; locally as 0.5 mm subhedral grains.	0-8	0-5	
MUSCOVITE	Sporadic flakes parallel and locally discordant to biotite.	0-8	0	
CLINOPYROXENE		0	0-20	Sporadic grains, irregular aggregates, or in thin, diffuse laminae.
SPHENE, EPIDOTE, APATITE, PYRITE	Disseminated grains or in stringers.	Generally <5% each	Generally <5% each	Disseminated grains or in stringers.
CHLORITE, SERICITE	Moderate alteration of biotite and plagioclase; locally pervasive alteration adjacent to discordant microfractures.			Minor alteration products.

INTRUSIVE ROCKS

Gabbro, norite, amphibolite and related gneiss; hornblendite, diabase and minor diorite (10)

Norite, gabbronorite, minor gabbro; hornblende gabbro, biotite-hornblende gabbro (10a)
Pegmatitic hornblende gabbro (10b)
Amphibolite, garnet amphibolite and hornblende gneiss (10c)
Hornblendite; biotite hornblendite (10d)
Diabase, related amphibolite and schist (10e)
Diorite, biotite diorite (10f)

Small gabbroic intrusions occur 1.5 km south of Hollingworth Lake, in the north part of Magrath Lake, east of Soltowski Lake and sporadically in the vicinity of Barrington River. These intrusions were generally emplaced within older granitoid rocks (9). Diorite and hornblendite units east of Soltowski Lake are older than the surrounding tonalite and white pegmatite (11). The relative ages of the various mafic intrusive units, and similar intrusions in the Barrington Lake and Melvin Lake areas, are not known. Unit 10 probably includes intrusions of several ages.

The intrusive rocks of unit 10 in the Fraser Lake area include gabbro, norite, hornblendite and diorite, with minor related pegmatitic gabbro, amphibolite and gneiss (Table 16). Diorite is distinguished from gabbro by relatively more sodic plagioclase and primary green hornblende; in gabbro, a secondary origin of hornblende after pyroxene is indicated by fine opaque inclusions and/or patchy birefringence. Biotite (up to 15%) is typically poikilitic, and occurs in most intrusions. Common accessories include quartz, microcline and sphene (up to 5%, locally 10% each), magnetite and ilmenite (4-12%) and apatite (1-5%); perovskite and zircon are rare accessories (Table 16).

A 350 m wide biotite-hornblende gabbro and pegmatitic gabbro intrusion (10a, b) is emplaced in the granitoid rocks 1.5 km south of Hollingworth Lake. Thin (0.2-1 cm) hornblendic and feldspathic laminae are interpreted to be primary layering at one locality. The gabbros contain prominent biotite poikilocrysts or irregular aggregates (up to 1.5 cm across) and up to 5% apatite, commonly as inclusions in biotite. Incipient plagioclase phyric texture occurs locally. A related, coarse grained, mafic dyke at least 5 m wide just north of the main intrusion consists largely of poikilitic brown biotite (35%), green hornblende with remnants of clinopyroxene (35%), plagioclase and minor microcline with up to 8% interstitial quartz, 5% apatite and 2% zircon.

Biotite-hornblende gabbro, hornblende norite and garnet amphibolite (10a, c) form a 75 m thick sill in the north part of Magrath Lake. The sill is intruded by several quartz diorite and felsic granophyre dykes, but the age relationship with adjacent granitoid rocks is unknown. The gabbro and

Table 16: Mineralogical compositions of mafic and minor ultramafic rocks (10a-f) in the Fraser Lake area

	LITHOLOGIES							
	BIOTITE-HORNBLENDE GABBRO, MINOR PEGMATITIC GABBRO (10a,b)	BIOTITE-HORNBLENDE GABBRO. HORNBLENDE NORITE, GARNET AMPHIBOLITE (10a.c)	HORNBLENDE PLAGIOCLASE-CLINOPYROXENE GNEISS (10c)	HORNBLENDITE (10d)	HORNBLENDITE, BIOTITE HORNBLENDITE (10d)	BIOTITE HORNBLENDITE (10d)	BIOTITE DIORITE (10f)	BIOTITE AMPHIBOLITE, HORNBLENDE-BIOTITE SCHIST (10e)
HYPERSTHENE		•						
CLINOPYROXENE	•		•					
GREEN HORNBLENDE	•	•	•		•	•	•	•
TREMOLITE-ACTINOLITE				•				
CUMMINGTONITE		•						
BIOTITE	•	•			•	•	•	•
GARNET		•						
PLAGIOCLASE	•	•	•			•	•	•
MICROCLINE	•	•					•	
QUARTZ	•	•					•	
APATITE	•	•			•		•	•
PEROVSKITE						•		
SPHENE	•	•	•			•	•	•
ZIRCON	•						•	
MAGNETITE/ILMENITE	•	•		•				
PYRITE	•						•	
HEMATITE	•			•			•	
CARBONATE	•	•		•				
EPIDOTE	•	•		•				
CHLORITE	•							
SERICITE				•				
SECONDARY BIOTITE				•				
PREHNITE	•						•	
LOCALITIES	SOUTH OF HOLLINGWORTH LAKE	MAGRATH LAKE (NORTH PART)	MAGRATH LAKE (NARROWS)		BARRINGTON RIVER (CLOSE TO NORTH SHORE)	EAST OF SOLTOWSKI LAKE	SOUTH END OF SOLTOWSKI LAKE	BARRINGTON RIVER (SOUTH SHORE)

amphibolite are medium grained, meso- to melano-cratic and contain up to 15% pink garnet porphyroblasts and aggregates, poikiloblastic green hornblende and plagioclase. Norite is distinguished by up to 20% fresh hypersthene. Mafic, garnetiferous laminae at the west end of the sill are attributed to contamination during emplacement. Clinopyroxene locally contains corroded biotite xenocrysts and is variously altered to green hornblende; biotite, in turn, contains corroded plagioclase xenocrysts. Fascicular secondary prehnite occurs within biotite and green hornblende commonly contains very fine grained magnetite inclusions.

At the narrows of Magrath Lake a unit of hornblende-plagioclase-clinopyroxene gneiss (unit 10c, 3 m thick) and a unit of hornblendite (unit 10d, 1.5 m) are emplaced within paragneiss (4a, b). Amphiboles within the gneiss and hornblendite display dusty, opaque inclusions and/or darker pleochroic cores that indicate pyroxene precursors; vermicular hematite is characteristic of the hornblendite. A related dyke contains approximately 10% magnetite in place of hematite. These dykes (samples 19 and 5 in the Appendix) have unusually high MgO contents (see Geochemistry of the Wasekwan Group).

A small hornblendite stock (10d) 3 km north-northeast of Nose Lake, mapped by Hinds (1972), is outlined by an aeromagnetic anomaly (Fraser Lake area, Geophysics Map 2390G, Federal-Provincial Aeromagnetic Series). Several minor hornblendite units (10d) occur close to the north shore of Barrington River. Minor ultramafic units also occur 2 km east of Soltowski Lake, where relict intrusions of coarse grained biotite hornblendite up to 5 m across are intruded by the surrounding tonalite and white pegmatite (11); the ultramafic rocks consist largely of poikilitic hornblende with up to 20% biotite and 4% perovskite. The biotite hornblendite is associated with a 5 m wide unit of plagioclase phyric biotite diorite (10f) that is gradational to biotite schist. The coarse grained, massive diorite is also intruded by adjacent granitoid rocks and contains calcic oligoclase (55%) and accessory quartz (5%) together with green hornblende and biotite.

Biotite diorite also occurs in a large lensoid unit close to the south end of Soltowski Lake. The diorite, together with associated biotite-hornblende quartz diorite, is over 150 m thick and is interpreted to be intrusive into the adjacent conglomerate and greywacke (6a, b). The diorite (10f) is massive, medium- to coarse-grained, and consists of albite-oligoclase and poikilitic green hornblende (interpreted to be primary). The rock contains ovoid to irregular feldspathic and micaceous aggregates (0.5-1 cm across) and prominent red sphene (1.5 mm, up to 10% of the rock). Veins and minor dykes of well foliated, micaceous amphibolite, which occur sporadically in the Soltowski Lake conglomerate, are possibly related to the biotite diorite. Biotite in the dykes occurs in lenticular aggregates or as regular, fine laminae that alternate with green hornblende.

A dyke that consists of coarse grained biotite amphibolite and related schist (10e) was emplaced in granite at the south shore of Barrington River. The schist contains biotite (35%) and green hornblende (20%) and is strongly microcrenulated (Fig. 54); garnets (up to 1.5 cm) occur in a similar amphibolite unit close to the southwest corner of the Fraser Lake area.

The mafic intrusive rocks of unit 10 commonly display alteration of pyroxene to green hornblende and locally contain almandine garnet, which is interpreted to be the result of contamination during intrusion. Subsequent alteration resulted in sericite, saussurite, chlorite and epidote. Sporadic carbonatization and fine grained lenticular aggregates of prehnite or yellow epidote within biotite cleavages are less common. The secondary minerals are both disseminated and concentrated in late microfractures; a minor vein of zoisite and carbonate was observed in the noritic sill at north Magrath Lake. The setting and petrographic features of the mafic intrusions of unit 10 in the Fraser Lake area indicate most of these intrusions are relatively late; some are possibly contemporaneous with the Melvin Lake norite, which has been interpreted to be younger than granitoid rocks (9) in the Melvin Lake area.

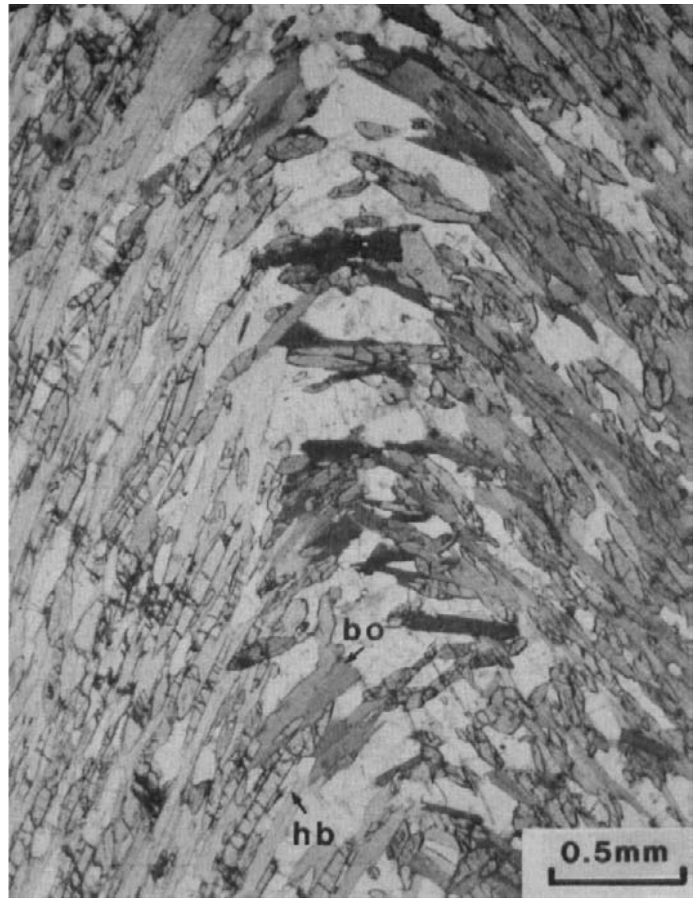


Figure 54: Microcrenulation in strongly foliated micaceous amphibolite (unit 10e); bo = biotite; hb = green hornblende. Sample 918-2, plane polarized light.

INTRUSIVE ROCKS

Quartz-plagioclase porphyry, felsite, tonalite (8)

Quartz-plagioclase porphyry (8a)
Felsite (8b)
Fine grained tonalite and porphyritic tonalite (8c)

Felsic porphyries and related tonalitic intrusions (8) are widely distributed in the Barrington Lake-Fraser Lake area (Maps GR87-3-1 and GR87-3-3), but are absent in the Melvin Lake area (Map GR87-3-2). These rocks occur as generally concordant units, typically 0.5 to 3 m wide, within rocks of all ages, but most commonly in mafic volcanic rocks (1). Some felsic lithologies in unit 8 are indistinguishable from felsic volcanic rocks (2) and classification of some intrusions is therefore uncertain. Minor felsic stocks (8) occur within the northern belt northwest of Gordon Lake and at the margins of the belt west of Brooks Island and at the southeast shore of Barrington Lake. The felsic porphyry and tonalitic dykes are generally foliated and recrystallized; alteration of felsic porphyries to garnet-bearing gneisses is common in the Camp Bay-Star Lake basaltic section, and in laterally equivalent sections northwest of Camp Bay and south of Star Lake. The common spatial association and lithologic gradation of porphyries (8) with granitoid rocks (9) suggest a part of unit 8 was penecontemporaneous with granitoid intrusion; however, unit 8 probably includes several ages of intrusions.

In the Barrington Lake area, quartz-feldspar porphyries and related fine grained tonalite (8) occur at the margin of the tonalite-granodiorite terrane 3 km west of Brooks Island. Quartz-plagioclase porphyries are also abundant at the east shore of Barrington Lake within, and at the margins of, the basaltic section south of Star Lake; a zone of felsic porphyry over 100 m wide occurs at the margin of the porphyritic tonalite intrusion northwest of Spider Lake. In the southern belt, felsic intrusions (8) occur at the south margin of the basaltic section south of Marsh Lake.

In the Fraser Lake area, porphyritic tonalite (8c, 9b) and derived intermediate garnet-hornblende gneiss units (1-20 m thick) are emplaced at the east end of the basaltic enclave at Nose Lake. Several occurrences of felsic porphyry occur within paragneiss (4) at Magrath Lake, within the Soltowski Lake conglomerate (6) and within granitoid rocks (9) in contiguous areas. Felsic intrusions and quartz veins 1 km north of Webb Lake contain chalcopyrite and molybdenite[4]; these intrusions have been mapped as unit 2a, but might equally well be assigned to unit 8.

Felsic porphyries include types with roughly equal amounts of plagioclase and quartz, and plagioclase porphyries that are devoid of quartz phenocrysts; dykes can be subdivided into coarse types (2-8 mm phenocrysts) and fine types (1-4 mm). Plagioclase phenocrysts (albite to andesine) locally display normal to fine oscillatory zoning. The phenocrysts (up to 60% of the rocks) are commonly corroded, and locally occur in clusters. The felsitic matrix generally contains minor biotite (± green hornblende), pyrite and up to 7% magnetite. Localized brittle deformation resulted in plagioclase deformation twinning, straining and granulation; quartz phenocrysts are generally recrystallized to fine grained mosaics. Porphyroblasts of muscovite, biotite, chlorite, amphibole and garnet occur locally in porphyry dykes.

Massive to gneissoid tonalite, quartz diorite, diorite and related gneiss; granodiorite, granite, pegmatite and aplite (9)
Granite and granodiorite, medium grained to pegmatitic; related cataclasite (11)

Tonalitic to granitic intrusive rocks (9) have not been mapped systematically. Details of these units on the maps accompanying this report are based partly on the maps of Stanton (1948), Crombie (1948), Hunter (1952), Kilburn, (1956) and Milligan (1960). and partly on field work by the author.

Late granitoid rocks lithologically equivalent to unit 11 (as defined at Melvin Lake) occur within the extensive granitoid terrane (9) in the Fraser Lake area (Map GR87-3-3). The ages of granodioritic and granitic phases of unit 9 (9e to 9i), relative to tonalitic to quartz dioritic phases (9a to 9d), are unknown. Some young, K-rich granitoid phases have been mapped as unit 11, where they intrude biotite hornblendite and diorite (10d, f) 2 km east of Soltowski Lake.

4 Assays of quartz veins gave up to 0.56% Cu, 1.94% Mo and 0.03% Zn.

STRUCTURAL HISTORY

Three deformation events have been recognized in the supracrustal rocks of the project area (Table 17). Major D_1 folds have been mapped at southern Barrington Lake where facing directions are locally evident, but elsewhere primary structures are not well preserved and the investigation has focussed largely on deformational features. Granitoid plutons have significantly influenced the regional structural pattern of supracrustal rocks.

Three areas have been defined for the purpose of this description: Melvin Lake-northern Barrington Lake; southern Barrington Lake; and MacBride Lake-Soltowski Lake. Structural data related to folding are largely confined to these areas. Continuity of structures between these areas has been interpreted from sporadic outcrops and aeromagnetic data (Barrington Lake area, Questor Surveys Ltd.; Manitoba Energy and Mines, 1977).

Table 17: Structural history of the Barrington Lake-Melvin Lake-Fraser Lake area

D_1	Major folding (west to northwest trend, with steeply dipping axial planes). Regional foliation (S_1).
D_2	Major folding and associated minor folds and linear structures; folds plunge at medium to steep angles generally subparallel to S_1. Synforms at Soltowski and Hollingworth lakes (possibly initiated during D_1.) Localized fracture cleavage oblique to S_1.
GRANITOID PLUTONISM (syn- to post-D_2).	Deformation of older structures (*e.g.* at southern Barrington Lake) and warping of regional foliation trends.
D_3	Faulting (mainly north to northeast, also northwest trends); locally inferred major vertical displacement (*e.g.* east of Magrath Lake). Shearing parallel to S_1 of uncertain age.

MELVIN LAKE - NORTHERN BARRINGTON LAKE AREA

The Melvin Lake area contains part of an extensive greywacke-paragneiss terrane that is intruded by granitoid units that range from small veins to plutons. Foliation trends in the paragneiss (and granitoid rocks, where these are foliated) are largely east, but the foliations are locally parallel to the southeast-trending pluton margin that extends across the central part of Melvin Lake (Fig. 55). Sparse data indicate a syncline in the paragneiss (4) northeast of the conglomerate at the east shore of Melvin Lake, and additional folds may exist in the unit. The Melvin Lake norite (10) truncates the granitoid rock-paragneiss contact in the central part of the lake, and foliations in host rocks adjacent to the norite are subparallel to the margins of the intrusion. A northeast- to north-trending synformal structure in the norite is indicated by primary layering. Greywacke at northern Melvin Lake trends northeast, parallel to the linear trend of the shoreline that may result from a major shear along this arm of the lake as postulated by Hunter (1952). The emplacement of the Melvin Lake norite may have been controlled by a related northeast-trending fault. The synformal structure of the Melvin Lake norite may in part reflect an original funnel-shaped or lopolithic structure, but the localized development of foliation indicates the intrusion was subjected to tectonism.

An east-southeast-trending zone (0.5-1 km wide) at the north end of Barrington Lake contains remnants of paragneiss (4b), amphibolitic supracrustal rocks (5a, b) and conglomerate (6a) within well foliated granitoid rocks (9). This zone can be traced on the aeromagnetic map (Barrington Lake area, Questor Surveys Ltd.; Manitoba Energy and Mines, 1977) directly into the conglomerate that extends along the north margin of the Lynn Lake greenstone belt between Zed Lake and Hughes River, 30 km west of Barrington Lake (Gilbert *et al.,* 1980). The supracrustal remnants at northern Barrington Lake are highly attenuated and gneissic, which indicates intense shearing along this zone that represents the contact between the Lynn Lake greenstone belt and the Southern Indian gneiss belt to the north (Fig. 1).

Minor fold plunges in the paragneiss and conglomerate at northern Barrington Lake and Melvin Lake range generally from northwest to east at moderate to high angles; axial planes are steeply dipping to vertical (Fig. 56). The folds affect both the bedding and (parallel) regional foliation (S_1) and are therefore attributed to a younger deformation event (D_2); inferred (D_1) folds have not been recognized at mesoscopic scale. The stereographic projections of the D_2 folds indicate dispersion of the axes in a plane dipping approximately north at 65° (Fig. 56); this is probably due to later deformation, possibly related to granitoid plutonism.

SOUTHERN BARRINGTON LAKE AREA

A major D_1 southeast- to east-trending anticline extends through the northern belt parallel to the north margin of the belt where it is in contact with granitoid rocks of unit 9 (Fig. 57). A complementary syncline occurs north of White Owl Lake, and another anticlinal fold, west of Gordon Lake, has been mapped close to the south margin of the belt. The latter fold has resulted in apparent thickening of the iron formation at Gordon and Farley lakes. These major folds are defined by facing indicators such as graded bedding, pillows, and flow-top structures in mafic extrusive rocks. Primary layering and the regional foliation (S_1) are parallel or subparallel to the axial planes of D_1 folds, which are interpreted to be tight to isoclinal.

The regional foliation in the northern belt is deformed by minor D_2 folds that plunge moderately to steeply northwest and southeast, with sporadic subvertical axes (Fig. 58). The trends of these folds are generally subparallel to the major D_1 structures (Fig. 57) and their bimodal distribution may be due to the obliquity of the D_1 and D_2 axial planes.

The south margin of the northern belt east of Nickel Lake is characterized by strongly foliated and attenuated rocks that are deformed by D_2 minor folds; this zone apparently represents an area of increased stress at the margin of the supracrustal belt during D_1. A major shear occurs at

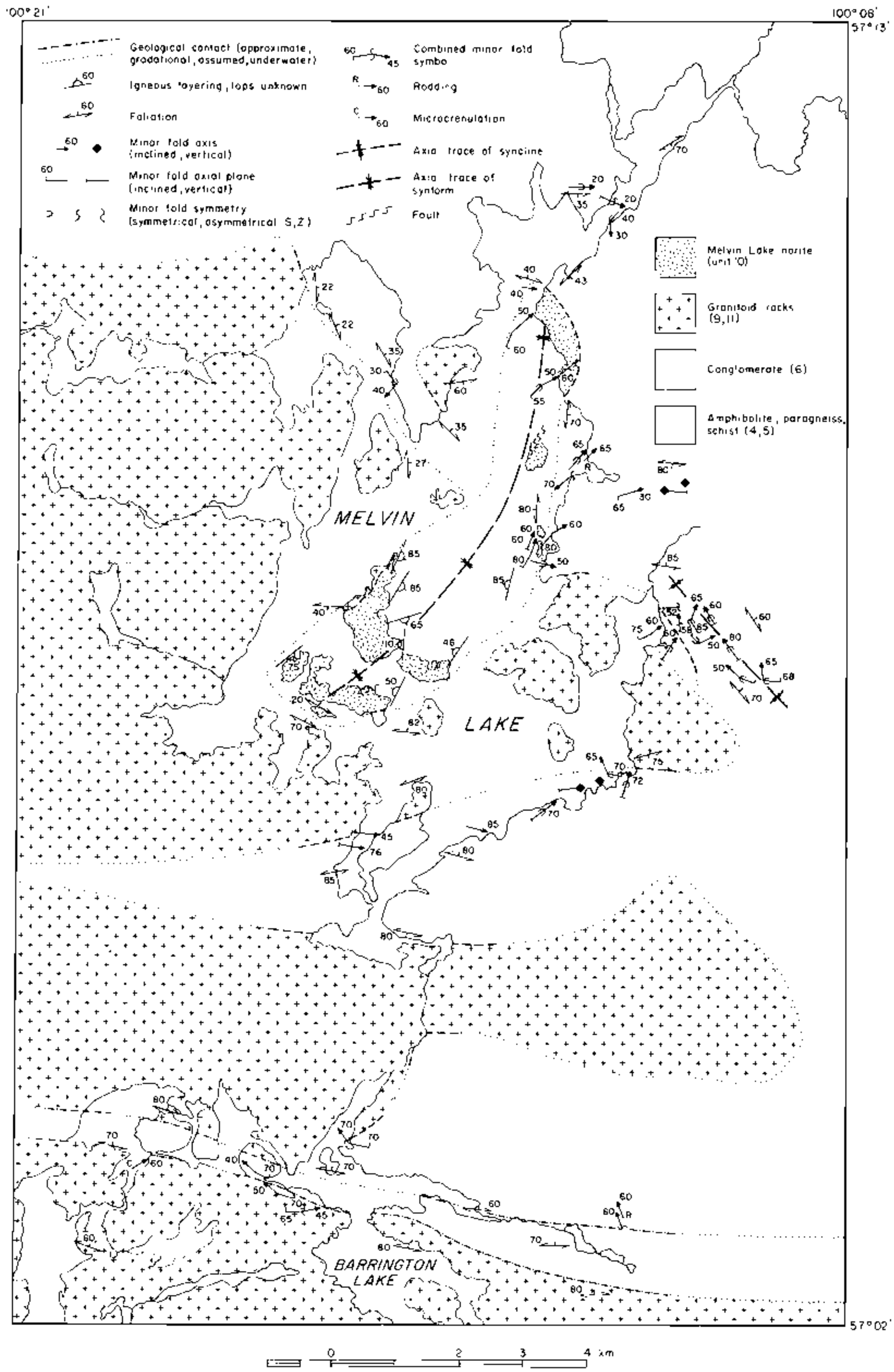


Figure 55: Structural geology of the Melvin Lake-northern Barrington Lake area.

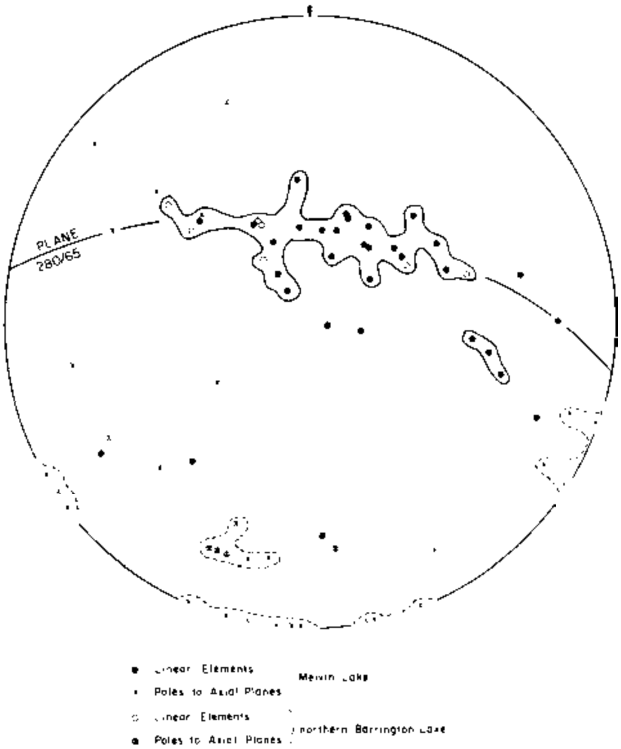


Figure 56: Lower hemisphere stereographic plots of D_2 folds in the Melvin Lake-northern Barrington Lake area.

the east end of Nickel Lake (Stanton, 1948). This shearing represents a more brittle style of deformation than the preceding deformation events, and is probably post D_2 in age. Late, steeply-dipping shears and faults with up to several metres displacement cut the foliation at high angles.

The Webb Lake-Star Lake belt branches north from the northern belt around a granitoid pluton to the east and extends northwest from Star Lake to Camp Bay (Fig. 57). Sporadic stratigraphic top indicators suggest a west-facing monoclinal structure. Faulting or folding may have occurred between this belt and the northern part of the northern belt, which faces north or northeast. The regional foliation (S_1) is deformed by minor folds (D_2) that plunge from south through west to north, at moderate to high angles with mostly vertical axial planes (Fig. 59). Dispersion of D_2 fold axes may, in part, be due to emplacement of the granitoid pluton to the east. Linear structures related to D_2 folds include deformed clasts, rodding, microcrenulation and mineral lineation. South of Star Lake, sporadic occurrences of northeast-trending fracture cleavage discordant to the northwest-trending S_1 are attributed to D_2.

MacBRIDE LAKE-SOLTOWSKI LAKE AREA

Volcanic and sedimentary rocks and related gneisses and schists (units 1 to 5) at Hollingworth Lake, and conglomerate (6) at Soltowski Lake make up major supracrustal enclaves in the granitoid terrane east of MacBride Lake. Foliation is strongly developed in these rocks and conglomerate clasts are highly attenuated. The structure of the Soltowski Lake conglomerate is interpreted to be synformal, consistent with the interpretation of a synclinal axis through the south part of Magrath Lake (Kilburn, 1956). The symme-

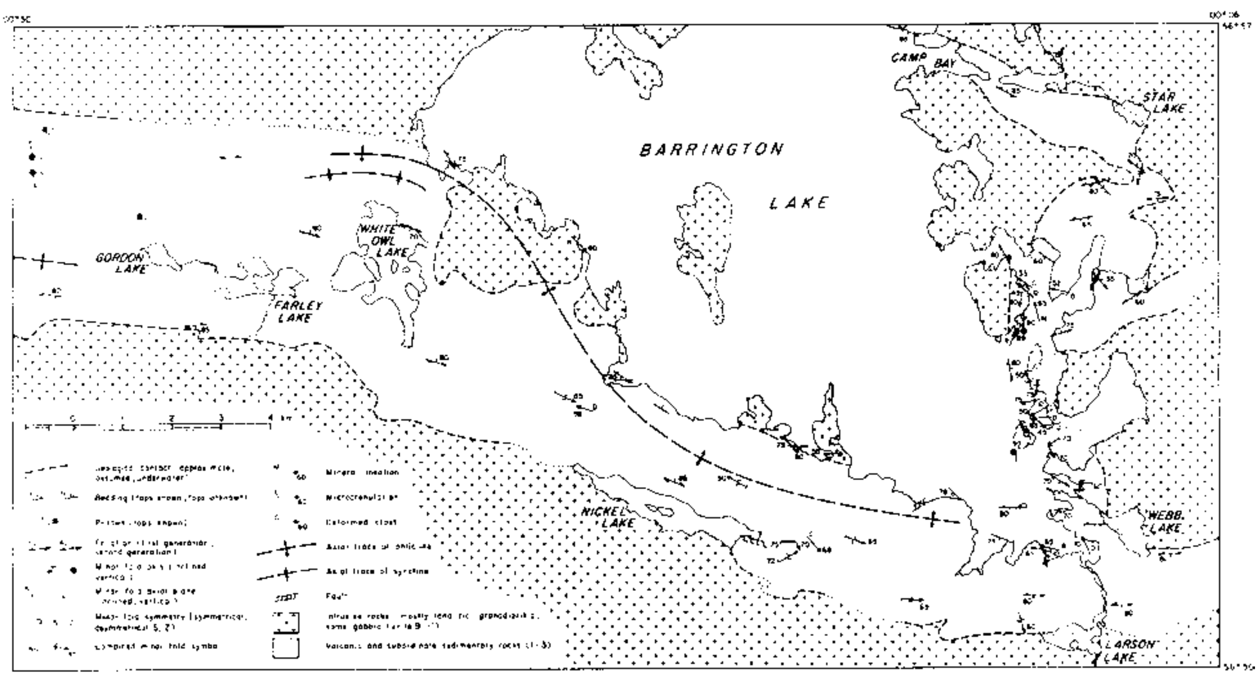


Figure 57: Structural geology of the southern Barrington Lake area.

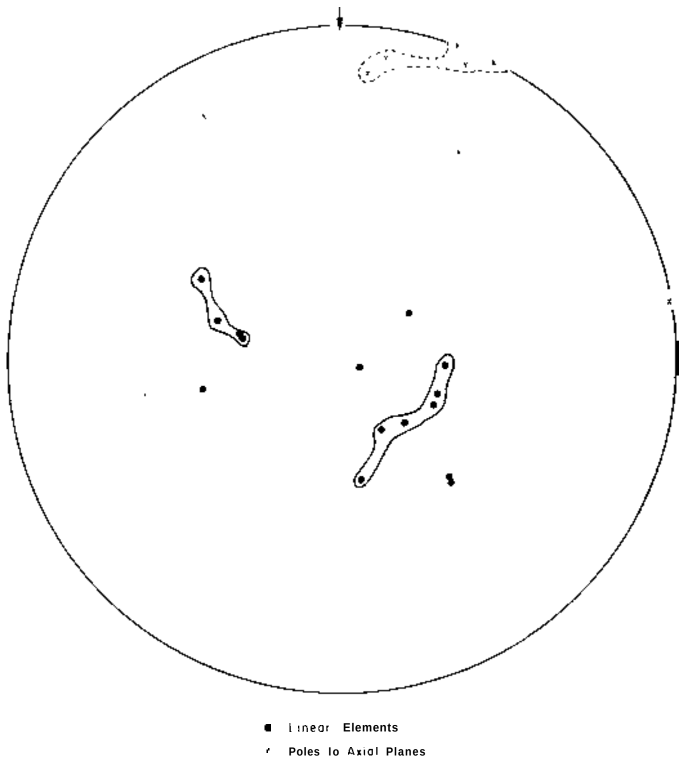


Figure 58: Lower hemisphere stereographic plots of D_2 folds in the northern belt, southern Barrington Lake area.

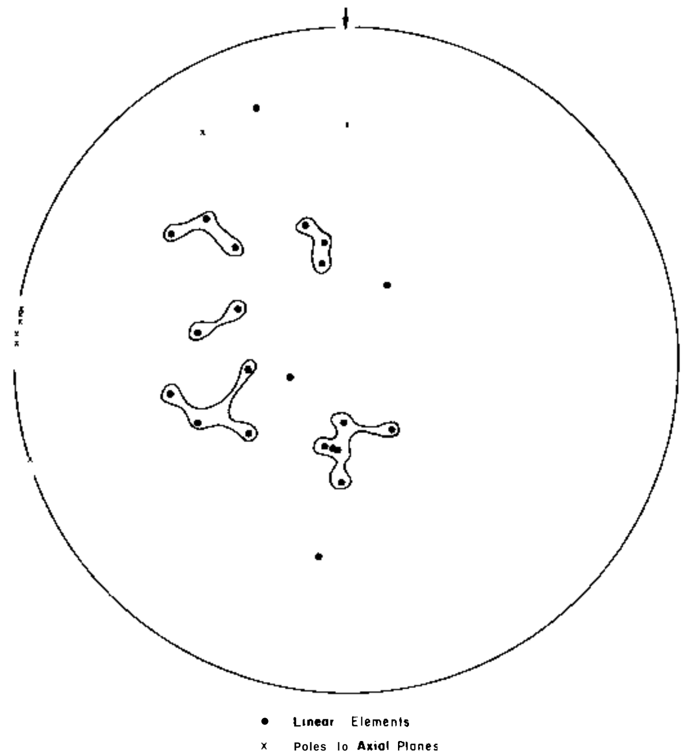


Figure 59: Lower hemisphere stereographic plots of D_2 folds in the Webb Lake-Star Lake belt, southern Barrington Lake area.

try and distribution of predominantly west-plunging D_2 minor folds, which deform the foliation, are generally consistent with this structure (Fig. 60). Down-folding may have originated during D_1 and continued through D_2. The relatively steep plunge (60°) of D_2 fold axes (Fig. 61) suggests the dip of the foliation that was developed during D_1 was also steep; the axial planes of D_2 folds are steeply dipping to vertical. Sporadic east-northeast-plunging folds are attributed to local irregularities in the foliation prior to D_2.

A major north-northeast-trending fault (D_3) is inferred west of the Soltowski Lake conglomerate to account for the occurrence of older volcanic rocks (unit 1) in the southern part of Magrath Lake, in the hinge zone of the proposed west-plunging synform (Fig. 60). A parallel fault is interpreted south of Soltowski Lake, where there are stratigraphic discontinuities across a very prominent topographic lineament.

Minor folding in the Hollingworth Lake supracrustal enclave is rare, possibly because of the relatively greater extent of granitoid intrusion within this body compared to the Soltowski Lake conglomerate. The Hollingworth Lake enclave has a similar form to that at Soltowski Lake, with a tapering terminatios to the east, consistent with a west-plunging synformal structure. The Hollingworth Lake enclave is apparently continuous with the volcanic and sedimentary rock section north of MacBride Lake; the positive aeromagnetic anomaly associated with these rocks is continuous and shows a marked southward flexure across the drift-covered terrane between these areas (Barrington Lake area, Questor Surveys Ltd.; Manitoba Energy and Mines, 1977). Smaller supracrustal enclaves east of Magrath Lake are probably also synformal keels within the granitoid terrane.

Minor amphibolitic enclaves and paragneisses in the granitoid terrane north and south of Barrington River are virtually devoid of primary features, but contain the regional S_1 foliation that generally trends west, and locally northwest or northeast (Fraser Lake area, Map GR87-3-3). Sporadic D_2 linear structures plunge north, east and west at low to high angles. A northeast-trending fault (D_3) between the east end of Barrington River and Nose Lake is inferred from a prominent topographic lineament. Similar lineaments trend northeast and northwest in the granitoid terrane north and east of Fraser Lake. Diabase dykes were reported within one northwest lineament by Hinds (1972), who interpreted the lineaments as late faults that postdate the main granitoid plutonism.

SUMMARY

The history of deformation is summarized in Table 17. The nature of the D_1 folds is based on the major structures mapped in the northern belt in the Barrington Lake area, and in the Hollingworth Lake and Soltowski Lake areas. No minor D_1 folds have been recognized, and bedding is rarely

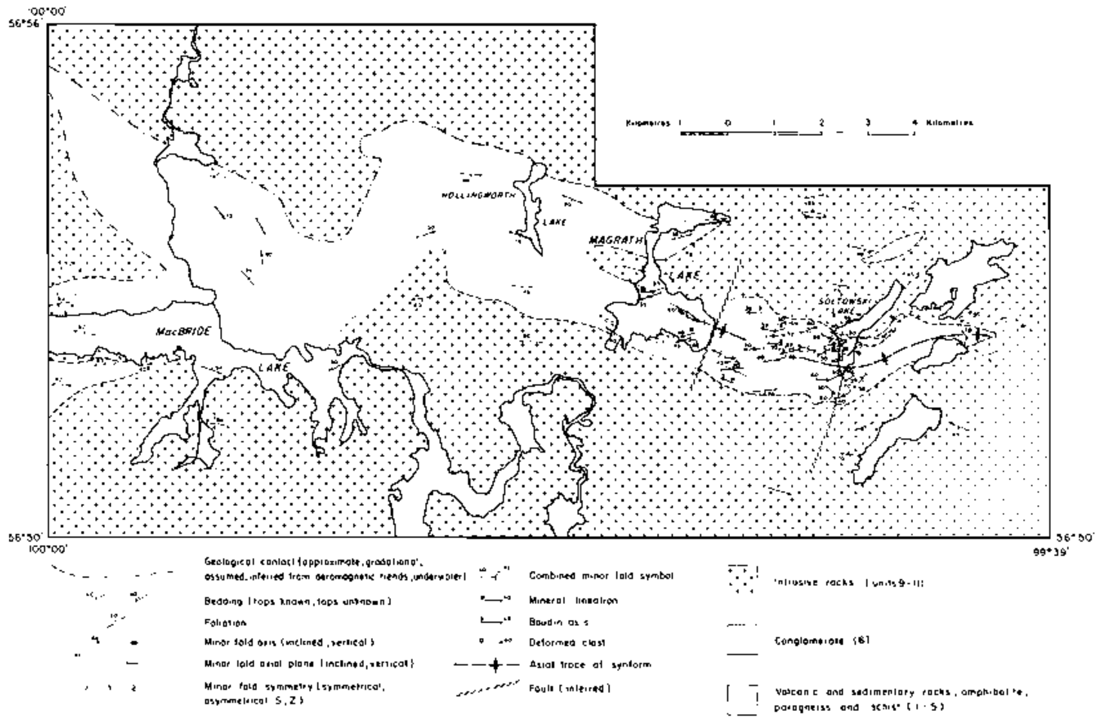


Figure 60: Structural geology of the MacBride Lake-Soltowski Lake area.

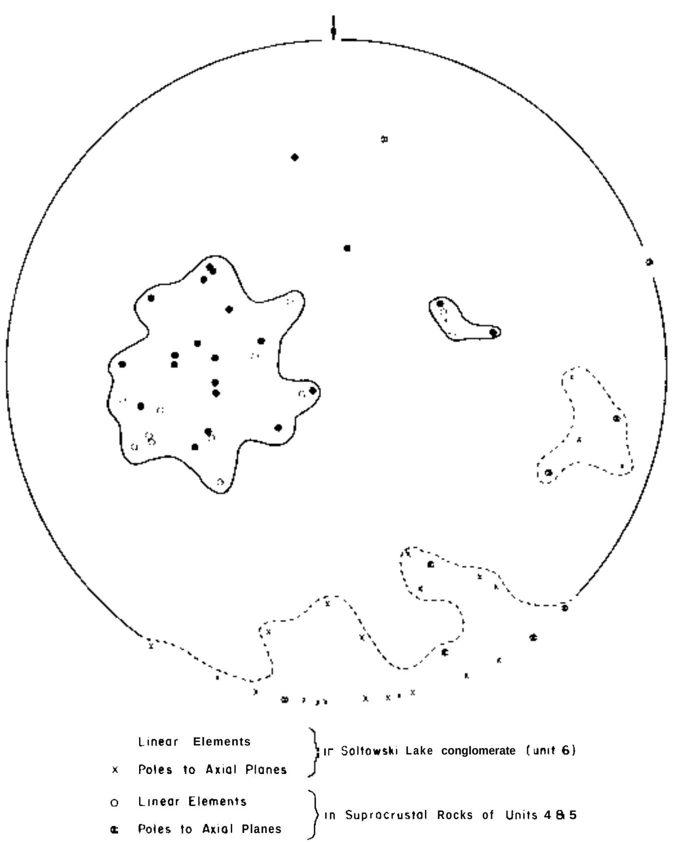


Figure 61: Lower hemisphere stereographic plots of D_2 folds in the MacBride Lake-Soltowski Lake area.

found discordant to the foliation, suggesting that D_1 structures were originally very tight to isoclinal and/or were further deformed during D_2. The distribution of D_2 linear structures is probably partly a result of the obliquity between the D_1 and D_2 axial surfaces, but some dispersion is attributed to the localized influence of granitoid plutons acting as buttresses; whether this influence was active or passive is conjectural. At Melvin Lake, the east trend of S_1 foliation in paragneiss (4) has locally been reoriented parallel to the southeast-trending margin of the granitoid terrane that extends across the central part of Melvin Lake, possibly due to the emplacement of the granitoid rocks.

The timing of the three deformation events relative to the Sickle Group is not clearly defined because of the absence of structural data in the few outcrops of known Sickle Group rocks (7), which are confined to the southwest part of the Barrington Lake area. Deposition of the Soltowski Lake conglomerate (unit 6, late Wasekwan Group or Sickle Group age) is considered to be pre D_1, because the deformational structures in the conglomerate are concordant, and apparently contemporaneous, with those in the adjacent Wasekwan Group rocks that are deformed by D_1. If this conglomerate is part of the Sickle Group, the history of deformation described in the foregoing section postdates the Sickle Group. In the Lynn Lake area, two deformation events (D1, D2; Gilbert *et al.,* 1980, p. 10) have been recognized in Wasekwan Group rocks prior to deposition of the Sickle Group. Thus "D1 and D2" defined in the Lynn Lake area are not equivalent to D_1 and D_2 described in this report (based on the evidence of structural data in the Soltowski Lake conglomerate, if the conglomerate is considered to be part of the Sickle Group).

METAMORPHIC HISTORY

INTRODUCTION

Three regional metamorphic events affected supracrustal rocks throughout the project area (M_1 to M_3). In the Fraser Lake area, several localities of hypersthene-bearing gneiss are interpreted to be remnants of an early pre M_1 granulite event. Localized post M_3 thermal metamorphism is recognized in the Barrington Lake area.

Metamorphic rocks produced by regional M_1 greenschist to middle amphibolite facies metamorphism have generally been recrystallized during M_2 to middle or upper amphibolite facies grade. M_2 metamorphism is marked by assemblages that contain biotite ± muscovite, in rocks of appropriate composition, locally accompanied by diagnostic porphyroblasts (*e.g.* garnet, cordierite, andalusite, anthophyllite, sillimanite). The porphyroblasts generally developed during late- to post-kinematic stages of D_2 deformation, except for fibrolitic sillimanite (pre- to syn-kinematic) and garnet (pre-, syn- and post-kinematic). M_3 metamorphism was retrogressive, and produced ubiquitous chlorite and sericite.

Some of the pervasive granitoid intrusions in the gneissic terranes of the Melvin Lake and Fraser Lake areas may be contemporaneous with, and in part related to, M_2. Quartzofeldspathic veining in paragneisses of these areas may be derived from anatectic melting at the peak of M_2 metamorphism, with subsequent injection at higher levels (exposed at the present erosional surface). The relative paucity of granitoid veining in supracrustal rocks in the Barrington Lake area is consistent with the lower grade of metamorphism (lower to middle amphibolite facies) in that area.

MELVIN LAKE AREA

Three metamorphic events have been recognised in the paragneiss terrane in the Melvin Lake area. M_1 at medium grade resulted in regional foliation and localized porphyroblasts. The foliation is overprinted by M_2 porphyroblasts that range from pre- to post-kinematic types (relative to D_2). Moderate M_3 retrogression affected most rocks in the Melvin Lake area.

M_1

The earliest metamorphic assemblage (M_1), which defines the internal foliation of M_2 garnet porphyroblasts, is given in Table 18 (assemblage 1). The regional foliation, defined by biotite and/or muscovite and/or green hornblende is also attributed to M_1. Muscovite porphyroblasts formed during M_1 include both aligned and randomly oriented types that are syn- to post-kinematic, respectively, with respect to D_1.

Table 18: Metamorphic mineral assemblages identified In Wasekwan Group rocks in the Melvin Lake and Fraser Lake areas. Assemblages are attributed to metamorphic phases shown In brackets

1 (M_1)	Quartz-plagioclase-biotite-magnetite
2 (M_2)	Quartz-plagioclase-K-feldspar-biotite-muscovite -sillimanite (fibrolite)
3 (M_2)	Quartz-plagioclase-K-feldspar-biotite-garnet -sillimanite (fibrolite and prisms) ± muscovite
4 (M_2)	Quartz-plagioclase(An_{45})-cordierite-garnet -biotite (magnetite and ilmenite are also present; quartz, staurolite, biotite and sillimanite occur as relict phases within plagioclase)
5 (M_1)	Quartz-plagioclase ± green hornblende ± biotite ± chlorite
6 (M_1/M_2)	Quartz-plagioclase-green hornblende -cummingtonite-biotite (+ pre M_1 hypersthene)
7 (M_1/M_2)	Quartz-plagioclase-(An_{35})-biotite-cummingtonite-green hornblende (+ pre M_1 clinopyroxene + hypersthene)
8 (M_1/M_2)	Quartz-plagioclase(An_{56})-biotite-garnet -cummingtonite-hercynite (+ pre M_1 sillimanite + corundum)
9 (M_1)	Quartz-plagioclase-biotite ± green hornblende
10 (M_2)	Quartz-plagioclase-biotite-garnet
11 (M_2)	Quartz-plagioclase-biotite-muscovite-cordierite ± garnet
12 (M_2)	Quartz-plagioclase-biotite-muscovite-cordierite -garnet-sillimanite
13 (M_2)	Quartz-plagioclase-biotite-green hornblende ± garnet
14 (M_2)	Quartz-plagioclase-biotite-green hornblende ± cummingtonite
15 (M_2)	Green hornblende-clinopyroxene-scapolite-epidote-calcite-biotite-muscovite
16 (M_2)	Green hornblende-clinopyroxene-plagioclase -calcite-biotite-quartz
17 (M_2)	Quartz-plagioclase-biotite-cordierite ± anthophyllite
18 (M_2)	Quartz-plagioclase(An_{40})-biotite-anthophyllite ± sillimanite
19 (M_2)	Quartz-plagioclase-biotite-garnet
20 (M_1/M_2)	Plagioclase(An_{41-52})-green hornblende -clinopyroxene ± epidote ± quartz ± biotite ± garnet
21 (M_1/M_2)	Plagioclase-biotite-cummingtonite-quartz
22 (M_1/M_2)	Plagioclase-green hornblende-cummingtonite-biotite ± clinopyroxene ± quartz

Garnet, sillimanite and sporadic cordierite are the characteristic M_2 porphyroblasts in part of the paragneiss terrane east of central Melvin Lake (Fig. 62). Garnet (pink-red almandine) locally displays a deformed internal fabric continuous with the external foliation due to synkinematic growth ("rotational" type of Spry, 1969). Some schists con-

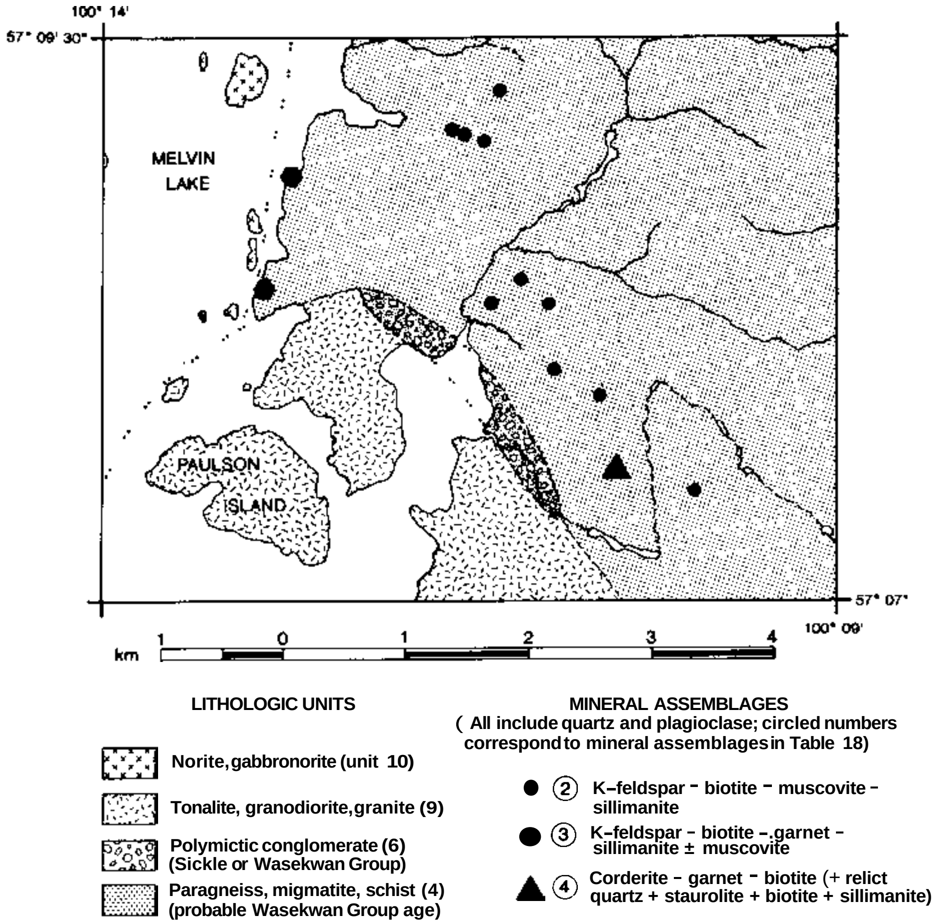


Figure 62: Map showing the distribution of metamorphic mineral assemblages east of the central part of Melvin Lake.

tain rotated garnets (internal foliation discordant to external foliation due to prekinematic development with respect to D_2). Fibrolitic sillimanite knots (*faserkiesel*) are commonly aligned parallel to S_1 and locally show tight mesoscopic folding and microfolding of the fibrous elements within the knots; this suggests early- to syn-kinematic development (Fig. 63). Randomly oriented, sporadic subhedral prisms of sillimanite up to 1.5 mm that coexist with fibrolite suggest postkinematic development. Assemblages 2 and 3 (Table 18) are typical for sillimanite gneiss and schist (unit 4d).

In rocks with assemblage 2, muscovite breaks down with development of fibrolitic knots and adjacent K-feldspar (Fig. 64) according to the reaction:

(a) muscovite + quartz = sillimanite + K-feldspar + H_2O,

which marks the onset of high grade metamorphism and is associated with anatexis at pH_2O >3.5 Kb (Winkler, 1976; Table 19).

In some cases the development of sillimanite is accompanied by quartz, which may be due to the following reaction, cited by Carmichael (1969):

(b) 2 muscovite + $2H^+$ = 3 sillimanite + 3 quartz + $2K^+$ + $3H_2O$

Assemblage 3, which also occurs above the sillimanite-K-feldspar isograd, was recorded at several shoreline outcrops 1 to 2 km north of Paulson Island. In these rocks, sillimanite generally occurs within biotite or in biotite-rich zones of the paragneiss. In one unit, sillimanite is associated with the development of biotite-quartz intergrowths, and associated feldspars are recrystallized with development of myrmekitic plagioclase and albitized rims round microcline; this texture may be due to the following reaction:

(c) 2 muscovite + albite = 3 sillimanite + biotite + 3 quartz + (K^+, Na^+, $4H^+$)

(Carmichael, 1969).

Garnet may have originated according to the isograd reaction:

(d) staurolite + muscovite + quartz = sillimanite + garnet + biotite + vapour

(Carmichael *et al.,* 1987).

Relict muscovite porphyroblasts occur locally in assemblage 3, but the above reactions (c) and (d) would necessarily have gone to completion in rocks devoid of both staurolite and muscovite (Fig. 65). Staurolite has been observed at only one locality within the paragneisses (4d) east of Melvin Lake, where it occurs as relicts within plagioclase (assemblage 4, Table 18).

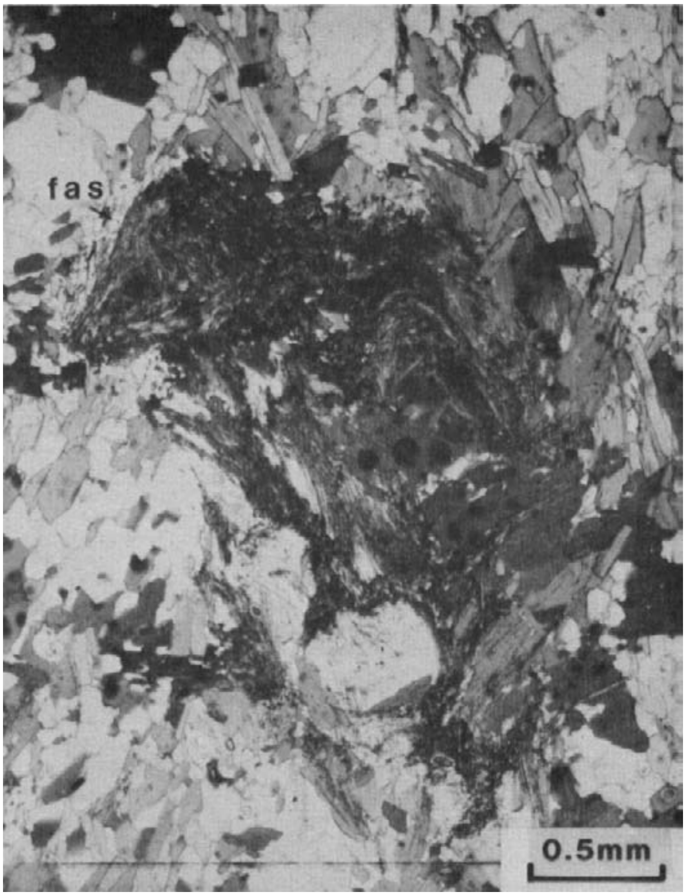


Figure 63: Microfolded faserkiesel (fas) in paragneiss (unit 4d) that contain quartz, plagioclase and biotite. Sample 165-1, plane polarized light.

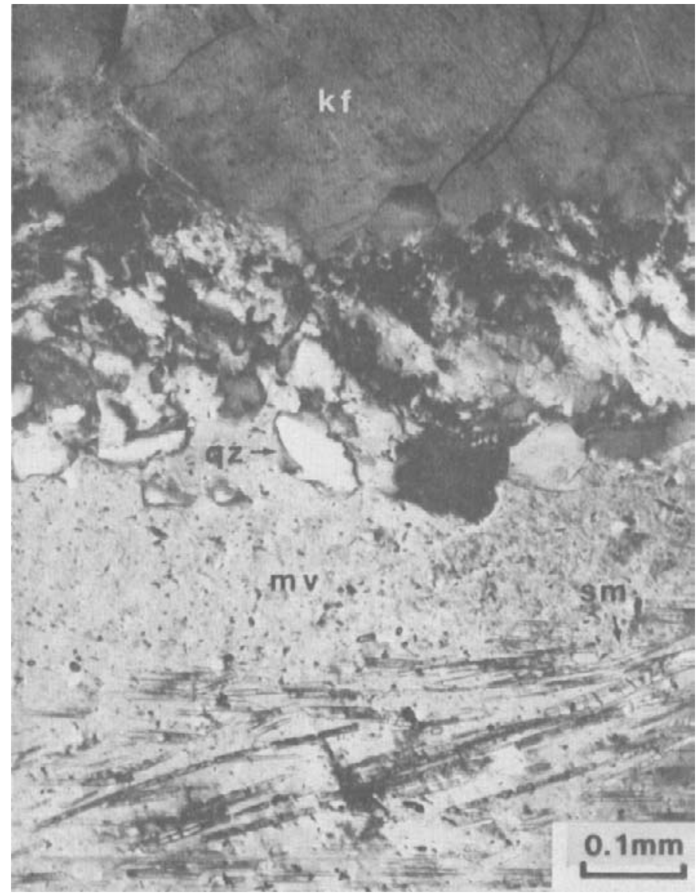


Figure 64: Paragneiss (unit 4d) that contains fine sillimanite (sm) needles within muscovite (mv), associated with quartz (qz) and K-feldspar (kf), interpreted as reactants in reaction (a). Sample 5-1, crossed polarizers.

Sillimanite in assemblage 3 includes both fibrolite and sporadic larger prisms. Although sillimanite is generally associated with muscovite-consuming reactions, secondary white mica appears locally to be associated with the development of fibrolite at Melvin Lake; in this connection, secondary muscovite has been identified as a product of one of a series of complex ion-exchange reactions that describe the breakdown of muscovite, staurolite and albite at the sillimanite-garnet-biotite isograd (Carmichael, 1969).

The muscovite-free association cordierite + garnet + biotite (assemblage 4, Table 18) occurs in semipelitic gneiss 2.3 km east of Paulson island (Fig. 62). The cordierite and garnet may be derived from the following reaction:

e) staurolite + quartz = cordierite + garnet + H_2O

The occurrence of quartz and staurolite remnants in plagioclase (Fig. 66) is consistent with this reaction; co-existing relicts of biotite and sillimanite in the plagioclase may be derived from an earlier reaction in the prograde metamorphic sequence such as the breakdown of muscovite + chlorite (Hirschberg and Winkler, 1968).

Table 19: Breakdown of muscovite in the presence of quartz (temperatures ± 10°C). Data after Althaus *et al.* (1970).

pH_2O, kb	Temperature (°C) for the reaction: muscovite + quartz = sillimanite + K-feldspar + H_2O
1	580
2	622
3	654
4	682

The distribution of mineral assemblages 2, 3, and 4 in paragneisses east of central Melvin Lake is shown in Figure 62. The muscovite-free assemblage (4) is attributed to a variation in lithologic composition rather than metamorphic grade. The lack of muscovite may be due to a possible deficiency of potassium in the rock; compositional variation in this vicinity is indicated by the occurrence of up to 20% amphibole in related muscovite-free paragneisses. Sillimanite-garnet-biotite gneisses north of Paulson Island (assemblage

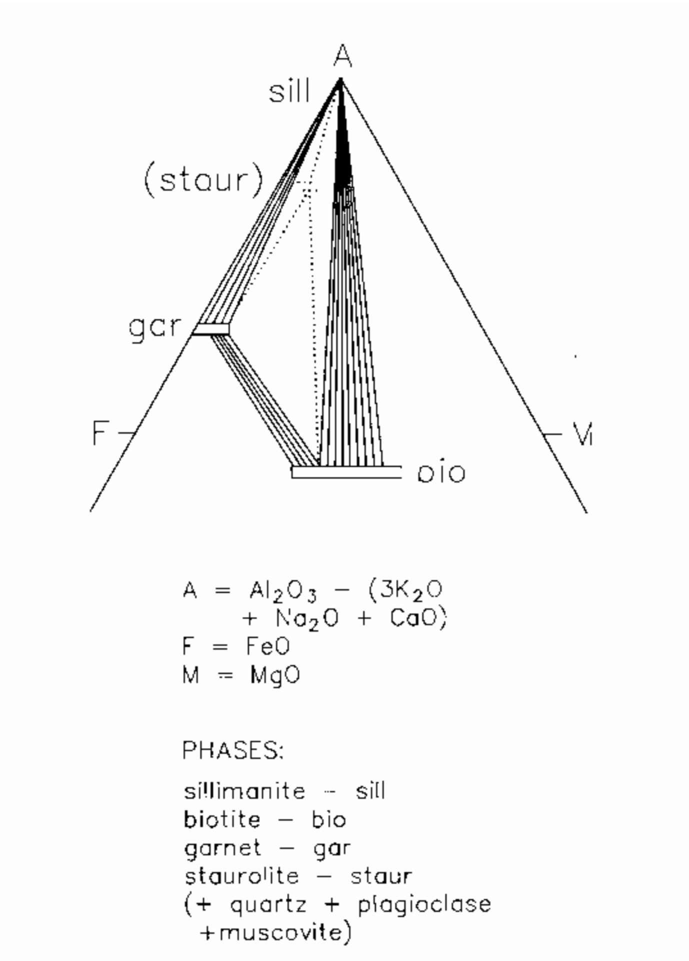


Figure 65: AFM diagram showing the discontinuous reaction at the sillimanite-garnet-biotite isograd (Carmichael, 1970). The dotted tie lines are broken by the isograd reaction (d).

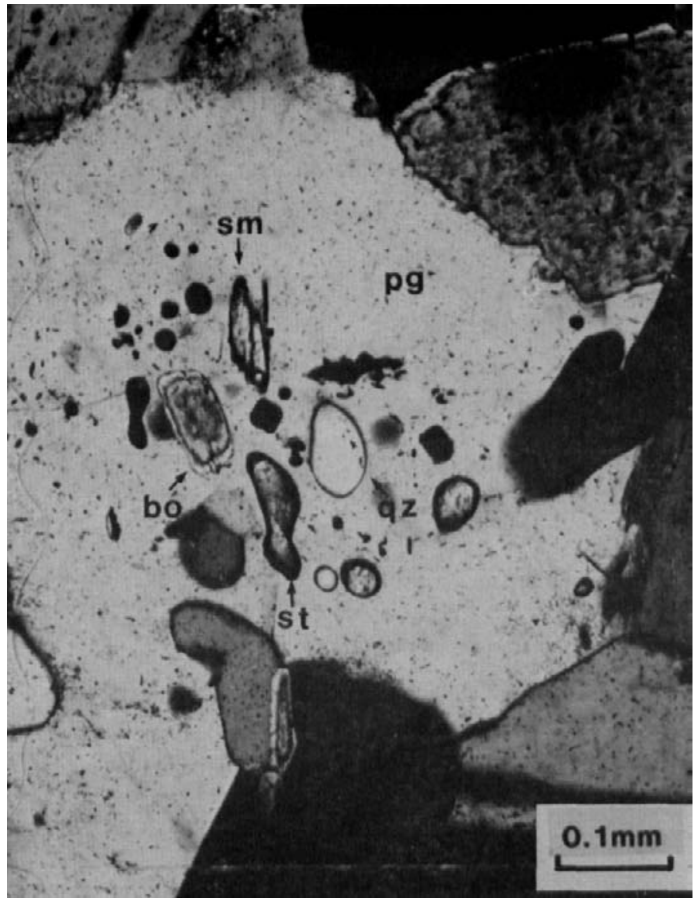


Figure 66: Inclusions of quartz (qz), staurolite (st), biotite (bo), and sillimanite (sm) occur within plagioclase (pg) in paragneiss (unit 4d). Sample 27-1, crossed polarizers.

3) contain relatively coarser fibrolite and sporadic sillimanite prisms, consistent with a slightly higher metamorphic grade than fibrolite-bearing gneisses (assemblage 2) to the east (Hollister, 1969; Naggar and Atherton, 1970).

M_3

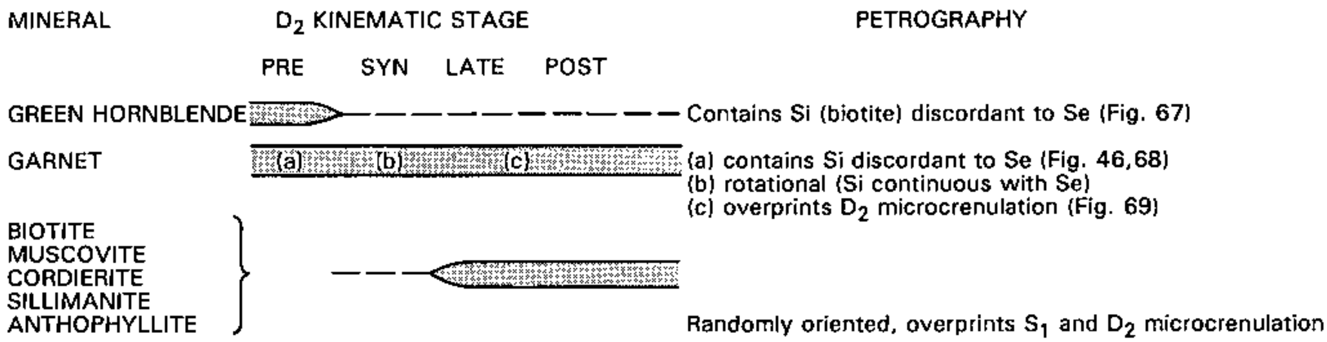
The products of M_3 retrograde metamorphism include chlorite, sericite, clinozoisite, pinite (after cordierite) and prehnite (after biotite); microcline is locally replaced by myrmekitic albite. Minor kinking of mica cleavages and straining of felsic minerals and hornblende are attributed to late stresses (D_3) that may, in part, be contemporaneous with M_3. The age of the greenschist facies M_3 alteration is uncertain. It is considered to be either contemporaneous with the waning stages of the major granitoid plutonism (unit 9) or, possibly, a result of later regional metamorphism.

FRASER LAKE AREA

Paragneiss and intermediate to mafic metavolcanic rocks in the Fraser Lake area record polyphase metamorphism that is broadly similar to the metamorphic history in the Melvin Lake area. The earliest regional metamorphism (M_1) is low to medium grade, and is represented by assemblage 5 (Table 18). The regional S_1 foliation is overprinted by M_2 biotite, garnet, green hornblende, muscovite, cordierite, and anthophyllite porphyroblasts, and rare sillimanite. These are commonly poikiloblastic, generally randomly oriented, and locally overprint D_2 microcrenulation. Locally, the S_1 foliation was deflected around prekinematic M_2 green hornblende or garnet porphyroblasts by D_2. In addition, some garnets were rotated during synkinematic (D_2) growth (Table 20). Retrograde metamorphism (M_3) is represented mainly by alteration of plagioclase to sericite and saussurite, and by chlorite. Chlorite is a common minor accessory, and locally occurs as randomly oriented porphyroblasts or irregular aggregates causing spotted texture. M_3 minerals typically occur as disseminations and are locally developed along microfractures, commonly with carbonate.

TABLE 20

KINEMATIC STAGES OF M_2 PORPHYROBLAST GROWTH RELATIVE TO D_2 IN PARAGNEISSES (UNIT 4) IN THE FRASER LAKE AREA



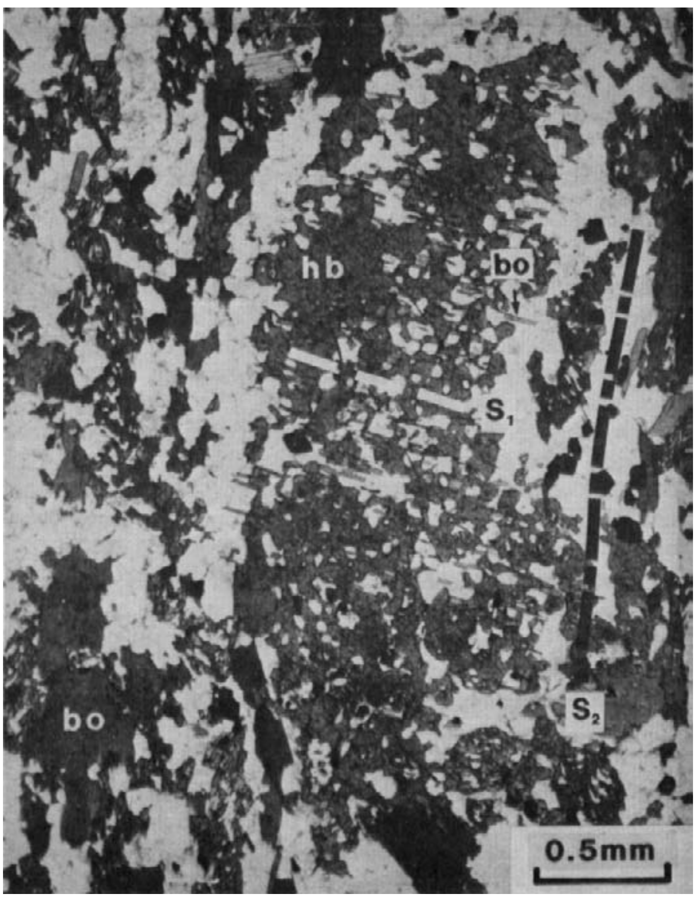


Figure 67: Hornblende-plagioclase gneiss (unit 5a) with rotated green hornblende porphyroblast that displays discordance between the internal foliation (S_1) and external foliation (S_2). Biotite = bo; green hornblende = hb. Sample 464-2, plane polarized light.

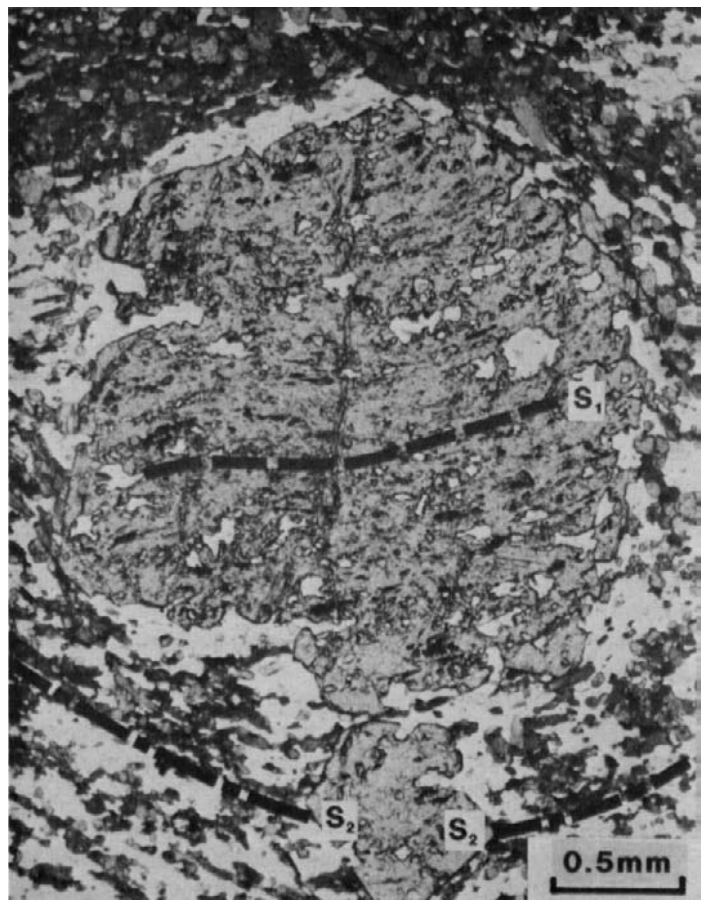


Figure 68: Rotated garnet poikiloblast in gneiss (unit 5b) showing discordance between internal (S_1) and external (S_2) foliations. Sample 173-1, plane polarized light.

Additional evidence for an early high grade metamorphic event occurs in gneiss at the west shore of Hollingworth Lake, which contains the association sillimanite + corundum (Fig. 48); these minerals occur as relicts in gneiss that has been recrystallized by subsequent metamorphism (M_1, M_2) (assemblage 8, Table 18). Corundum occurs as corroded remnants in coronas around sillimanite (>l mm prisms); the coronas contain sericite (M_3), hercynite and minor magnetite. The inferred pre M_1 assemblage may be derived from the breakdown of muscovite as follows:

(a) muscovite + quartz = sillimanite + K-feldspar + H_2O
(see Metamorphic History, Melvin Lake area)

(g) muscovite = corundum + K-feldspar + H_2O (Evans, 1965)

The prismatic sillimanite + corundum assemblage also occurs in metasedimentary enclaves within the Donegal granite, and records the highest grade of thermal metamorphism attained in the Donegal area (Naggar and Atherton, 1970).

The localities of granulite facies metamorphism in the vicinity of Hollingworth Lake are interpreted to be remnants of a former granulite terrane; the early granulite assemblages are assumed to have been largely altered by subsequent granitoid plutonism (unit 9) and metamorphism (M_1, M_2).

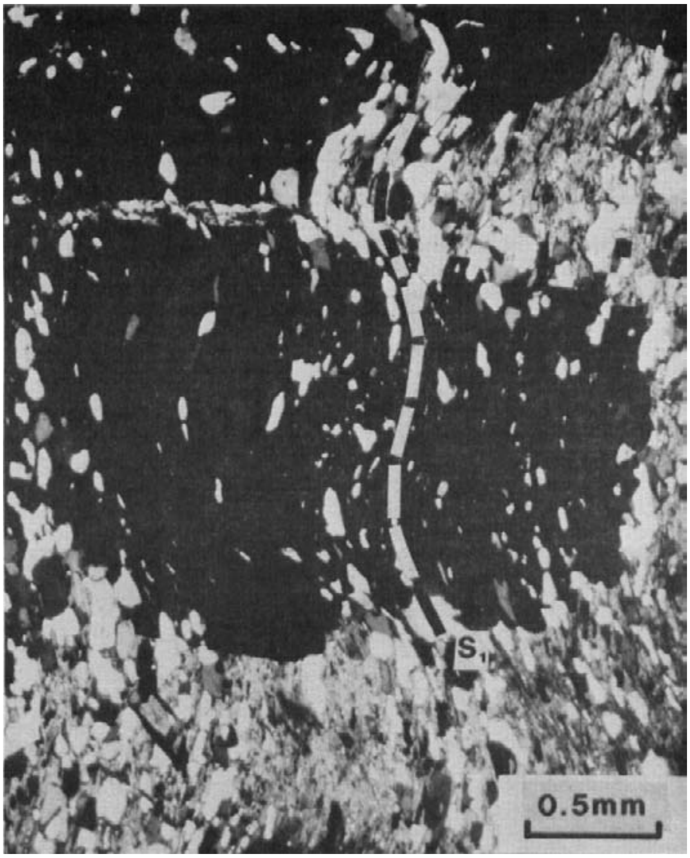


Figure 69: Postkinematic garnet porphyroblast in gneiss (unit 5b) that has overprinted D_2 microcrenulations of S_1 foliation. Sample 172-4, crossed polarizers.

Pre M_1

Evidence for a pre M_1 granulite facies metamorphism is contained in hypersthene-bearing stromatic gneisses within migmatites (4f) near Hollingworth Lake. Granulite gneisses 2 km east of Hollingworth Lake contain concordant amphibolitic palaeosome zones and diffuse leucocratic zones characterized by assemblage 6 (Table 18).

The hypersthene may be derived from the following reaction (Hess, 1969) that marks the onset of granulite facies metamorphism:

(f) biotite + quartz = hypersthene + K-feldspar + H_2O.

The hypersthene is variously altered to amphibolite facies minerals (M_1 and/or M_2), including cummingtonite, green hornblende, biotite and later bastite (M_3) in microveins (Fig. 49). Intermediate to mafic hypersthene-bearing gneiss west of Hollingworth Lake (assemblage 7, Table 18) displays partial alteration of early clinopyroxene porphyroblasts (interpreted as pre M_1) to highly poikiloblastic cummingtonite and/or green hornblende.

M_1 and M_2 in semipelitic and calcareous paragneisses (unit 4)

Regional M_1 metamorphism was followed by M_2 that was of equal or higher metamorphic grade. The earlier M_1 assemblages have therefore been widely recrystallized and can only be identified where S_1 is deformed by D_2 structures (generally microcrenulation) or where an age relationship can be recognized between M_1 (S_1) minerals and M_2 porphyroblasts. For example, at the west shore of south Magrath Lake an amphibolite displays remnants of S_1 foliation that consists of microcrenulated stringers of magnetite and traces of gneissic lamination; however, green hornblende and plagioclase have been recrystallized by M_2.

At the west shore of the narrows of Magrath Lake, metasedimentary gneisses and schists display S_1 foliation, defined by the greenschist or lower amphibolite assemblage 9 (Table 18). M_2 middle amphibolite facies metamorphism resulted in assemblages 10 to 14 at Magrath Lake narrows (Table 18).

The association of biotite + muscovite + cordierite + garnet + sillimanite in assemblage 12 (Table 18) is enigmatic, because only four mineral phases would be expected in the pelitic system Al_2O_3-FeO-MgO-K_2O-SiO_2-H_2O within which these minerals occur. It is possible that the garnet exists due to stabilisation by manganese (E.Froese, pers. comm., 1992); the other minerals in assemblage 12 could be due to the following reaction:

(h) chlorite + muscovite = cordierite + biotite + Al_2SiO_5
+ quartz + H_2O

(Hirschberg and Winkler, 1968)

In this interpretation, muscovite would occur together with the products'of reaction (h) due to the consumption of all chlorite. Garnet in assemblage 12 could be due to an earlier reaction *(e.g.* breakdown of chlorite) in which it was stabilised by manganese. The garnet composition in assemblage 12 is unknown, but in this connection the relatively high magnetite content of this sample (approximately 10%) is notable. High manganese contents have been reported in oxide facies iron formation in the Ospwagan Group at Pipe Pit Mine, Thompson (Macek and Bleeker, 1989); the manganese is inferred to be incorporated in garnet (Macek, pers. comm., 1992).

At the southeast corner of Magrath Lake a calcareous zone within metasedimentary rocks (unit 4) locally contains poikiloblastic scapolite, a medium to high temperature mineral attributed to M_2 (assemblages 15, 16, Table 18). Assemblage 16 is also common in the Soltowski Lake conglomerate (unit 6a).

Supracrustal paragneiss enclaves at the south shore of Barrington River display prominent M_2 porphyroblasts including anthophyllite (up to 1.5 cm), cordierite (up to 1 cm) and garnet. Fibrolitic sillimanite was identified at one locality; however, muscovite was not observed in these paragneisses. Assemblages 17 to 19 (Table 18) are representative of paragneiss at the south shore of Barrington River. The occurrence of anthophyllite and the local abundance of pyrite (average 5-10%, up to 20%) indicate these paragneisses have probably been altered by sulphide-bearing hydrothermal solutions.

M_1 and M_2 in metabasites of units 5 and 10

Mafic intrusive rocks (5a) within paragneiss at Magrath Lake are recrystallized to assemblages 20 and 21 (Table 18). Amphibolite and hornblende gneiss (5a) derived from metavolcanic rocks are represented by a similar assemblage (22, Table 18). Gabbro and norite (unit 10) are characterized by assemblages 21 and 22.

Two generations of clinopyroxene are recognized in these metabasites (units 5 and 10). Magmatic clinopyroxene is locally preserved in the cores of M_1 amphibole pseudomorphs. Subsequent metamorphism (M_2) resulted in alteration of green hornblende to clinopyroxene that occurs as mantles on the hornblende (Fig. 70). M_2 clinopyroxene, of restricted occurrence, has been identified at Magrath Lake and within the mafic volcanic inlier at Nose Lake.

BARRINGTON LAKE AREA

In the Barrington Lake area, an early greenschist to a amphibolite facies metamorphism (M_1) was followed by amphibolite facies (M_2), and subsequent greenschist facies (M_3) metamorphism, as in the foregoing descriptions of the Melvin Lake and Fraser Lake areas. The volcanic section extending from White Owl Lake to Spider Lake consists largely of amphibolites that contain green hornblende and plagioclase, locally with cummingtonite. Green or blue-green hornblende (locally chlorite) defines the regional foliation. Hornblende occurs as porphyroblasts and as pseudomorphs (M_1) after primary pyroxene; the latter was observed locally as relict cores. Green hornblende pseudomorphs are partly altered to actinolite ± biotite (M_2).

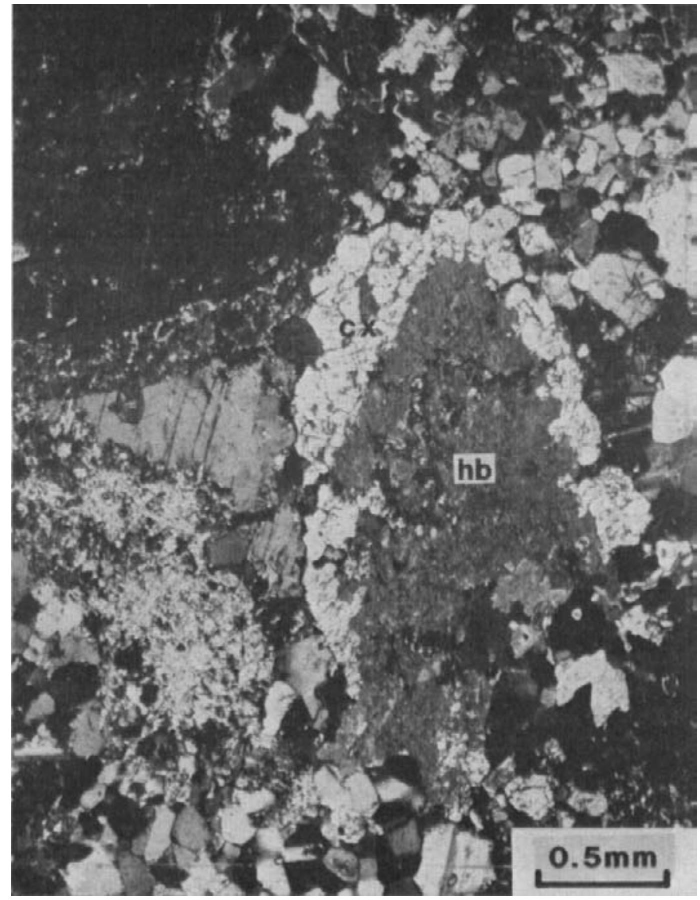


Figure 70: Amphibolite (unit 10c) that contains green hornblende (hb) partly altered to clinopyroxene (cx) as mantles on the amphibole. Some hornblende crystals (not shown) exhibit patchy pleochroism and zones of opaque inclusions consistent with a pyroxene precursor. Green hornblende and clinopyroxene are attributed to M_1 and M_2 respectively. Sample 466-3, crossed polarizers.

M_1

M_1 metamorphism, interpreted to be related to the major D_1 deformation, produced a regional S_1 foliation defined by chlorite, biotite or green hornblende ± cummingtonite. In the vicinity of Farley Lake, and in the section south of Barrington Lake between Nickel and Larson lakes, an early chlorite foliation (S_1) is locally overprinted by randomly distributed M_2 green hornblende and biotite poikiloblasts (Fig. 71). Elsewhere, the regional S_1 foliation is defined by green

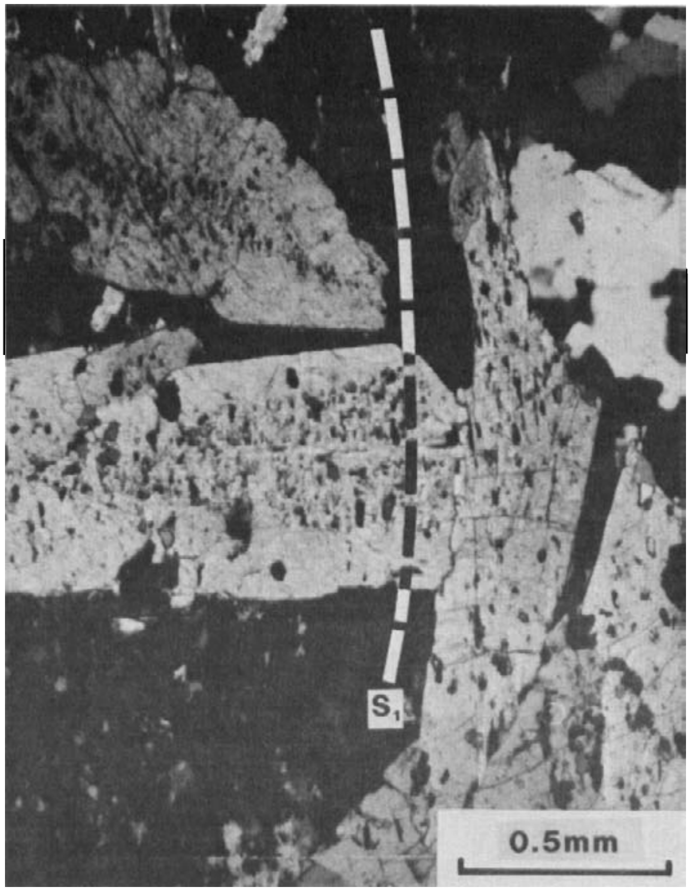


Figure 71: Randomly oriented green hornblende poikiloblasts (M_2) overprint the chloritic S_1 foliation in schistose basalt (unit 1a). Sample 225-2, crossed polarizers.

hornblende (+ cummingtonite) and/or biotite. In the absence of M_2 porphyroblasts, it is not possible to distinguish between an M_1 or M_2 age for the regional foliation because of widespread recrystallization of the S_1 fabric during M_2.

M_2

Regional M_2 metamorphism is characterized by locally extensive porphyroblast development. Porphyroblasts are generally poikiloblastic and locally display internal foliations. Rotated garnets with an early (M_1) internal quartz-magnetite foliation are attributed to early M_2 development (subsequently rotated by D_2). Rotational fabrics in other garnets indicate synkinematic D_2 growth (Fig. 22). Randomly oriented, postkinematic garnet porphyroblasts locally overprint microcrenulations (D_2) in the regional S_1 foliation. Green hornblende, epidote, cummingtonite and biotite also show evidence of pre- and post-kinematic phases of M_2 development (Fig. 72). The peak of metamorphism was probably late- or post-kinematic, when porphyroblasts of anthophyllite, cordierite, muscovite and andalusite were developed in rocks of appropriate composition. Hydrothermally altered volcanic rocks at the west shore of Barrington Lake are conspicuously porphyroblastic (see below). Iron formation (unit 3d) at Farley Lake contains subparallel grunerite prisms (M_2) that overprint actinolitic amphibole (M_1). Recrystallization of the regional biotite or green hornblende S_1 foliation was probably widespread during M_2, together with the local development of metamorphic lamination defined by variable green hornblende, biotite, plagioclase ± epidote (*e.g.* in **mafic tuff**).

M_3

Chlorite, epidote and muscovite are the main products of the ubiquitous M_3 retrograde metamorphism; the extent of M_3 alteration is generally moderate, except close to sheared zones and minor felsic intrusions. In one unit, plagioclase phenocrysts have been metasomatically replaced by chlorite

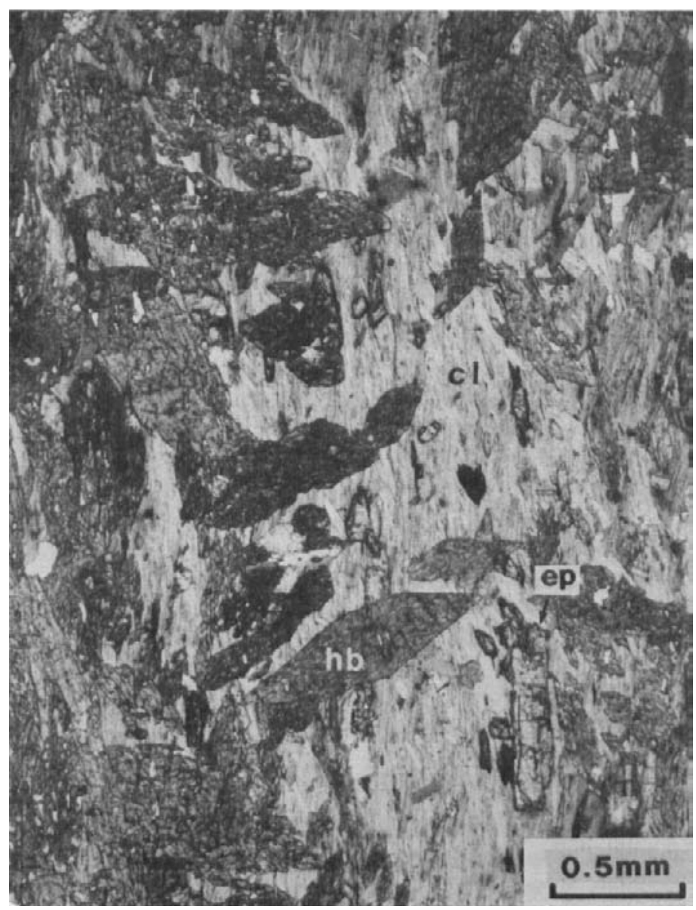


Figure 72: Green hornblende (hb) and epidote (ep) porphyroblasts, which overprint the foliation of chloritic schist (unit 5b), are randomly oriented and undeformed, indicating postkinematic growth. Sample 1002-4, plane polarized light.

pseudomorphs in which details of fine lamellar twinning have been preserved. Amphibole, biotite and garnet are variably altered to fine grained chlorite that also occurs as random porphyroblasts (Fig. 73) or irregular ovoid aggregates that produce a spotty texture. Muscovite also occurs as random porphyroblasts, but more commonly as sericite, which, like saussurite, is widespread. Sporadic occurrences of epidote porphyroblasts, clinozoisite and rare zoisite are also attributed to M_3. Carbonate porphyroblasts, fine grained pervasive carbonatization and microveins of carbonate, chlorite or epidote are attributed to metasomatism and mobilization along late fractures; they could be M_3 or even later in age. Late deformation effects include localized kinking of chlorite cleavages, mortaring of quartz and recrystallization of M_2 hornblende porphyroblasts; the latter have been converted to fine grained fibrous aggregates that are locally microcrenulated, together with chloritic laminae that display strain-slip cleavage (Fig. 74). These deformation features, together with the localized development of chloritic schist in D_3 shear zones, may also be penecontemporaneous with or later than M_3.

Figure 73: ***Chlorite porphyroblasts (M_3) in schist (unit 5b) are randomly oriented and partly dislocated by late brittle deformation. Chlorite = cl; biotite = bo. Sample 1158-1, crossed polarizers.***

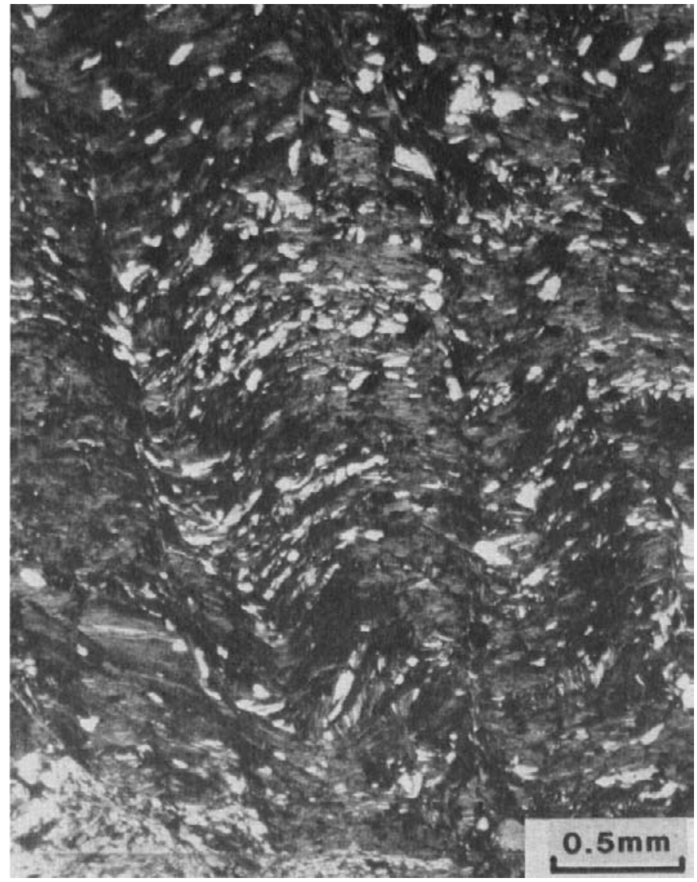


Figure 74: Strain-slip cleavage in chlorite-quartz schist (unit 5b). Sample 1085-5, plane polarized light.

Metamorphism of altered volcanic rocks (unit 5) at the west shore of Barrington lake

An alteration zone at least 60 m wide is associated with a subeconomic Cu-bearing sulphide deposit located on an east-trending fault east of Brooks Bay, Barrington Lake. The zone contains remnants of the intermediate to mafic volcanic fragmental host rocks, but generally these are converted to porphyroblastic schists and gneisses. Mineral assemblages within the porphyroblastic zone are listed on page 25 (assemblages (i) to (xi), units 5b, 5c). The most significant assemblages are:

(ii) Quartz-biotite-muscovite-andalusite-kyanite-staurolite

(vii) Quartz-biotite-garnet-anthophyllite-cordierite-staurolite

These assemblages are attributed to M_2 regional metamorphism, except for kyanite and staurolite, which are apparently later (see below). The common occurrence of andalusite (M_2) in the alteration zone indicates relatively lower grade conditions than at the localities previously described in the Melvin Lake and Fraser Lake areas, where the alumino-silicate (if present) is sillimanite. Garnet and cordierite (assemblage (vii)) may be due to the following reaction:

(i) chlorite + andalusite + quartz = garnet + cordierite + H_2O

(Hess, 1969)

The occurrences of anthophyllite and kyanite are considered to reflect the distinctive compositional characteristics of the alteration zone. Anthophyllite is widely developed in metamorphosed alteration zones characterized by Mg-metasomatism and/or removal of Ca ("dalmatianite", Cooke, 1927, p. 41). The association of kyanite with MgO-rich rocks has been described in the aureoles of the Donegal granites where the mineral is controlled by the MgO/FeO ratio of the host rock (Naggar and Atherton, 1970).

Andalusite in assemblage (ii) occurs as large poikiloblasts that predate smaller kyanite grains; the kyanite occurs sporadically both within and external to the andalusite, and crystallized as a separate growth phase rather than by inversion from andalusite (Fig. 75, 76, 77). Andalusite has apparently resisted inversion and persisted metastably during the development of kyanite. Kyanite is unaltered in contrast to andalusite, which is affected by retrograde metamorphism.

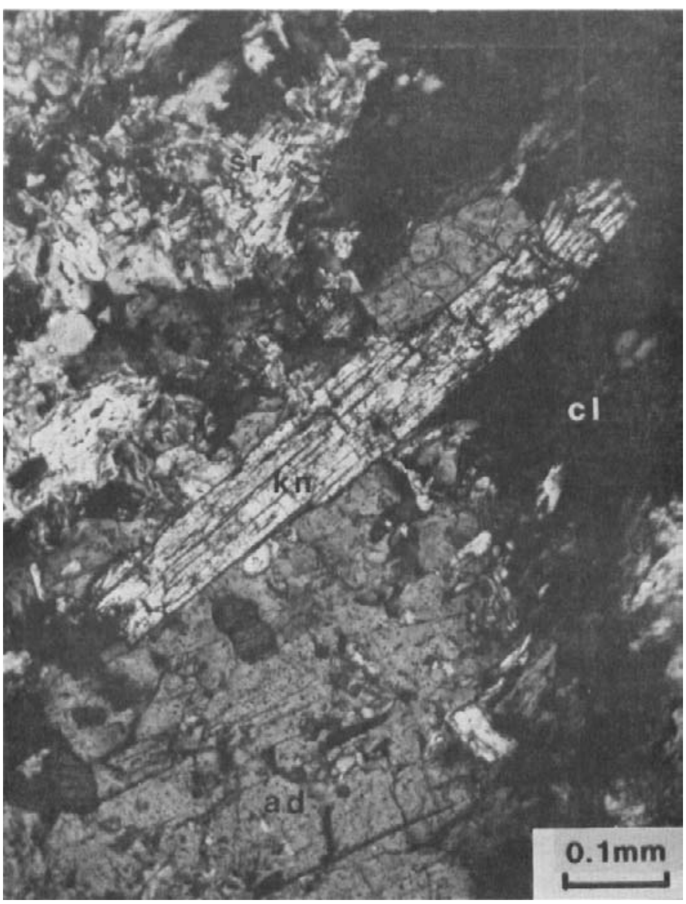


Figure 75: Intermediate gneiss (unit 5b) that contains a kyanite (kn) crystal that overprints the margin of an andalusite porphyroblast (ad), where it is altered to chlorite (cl) and sericite (sr). Sample 1112-4, crossed polarizers.

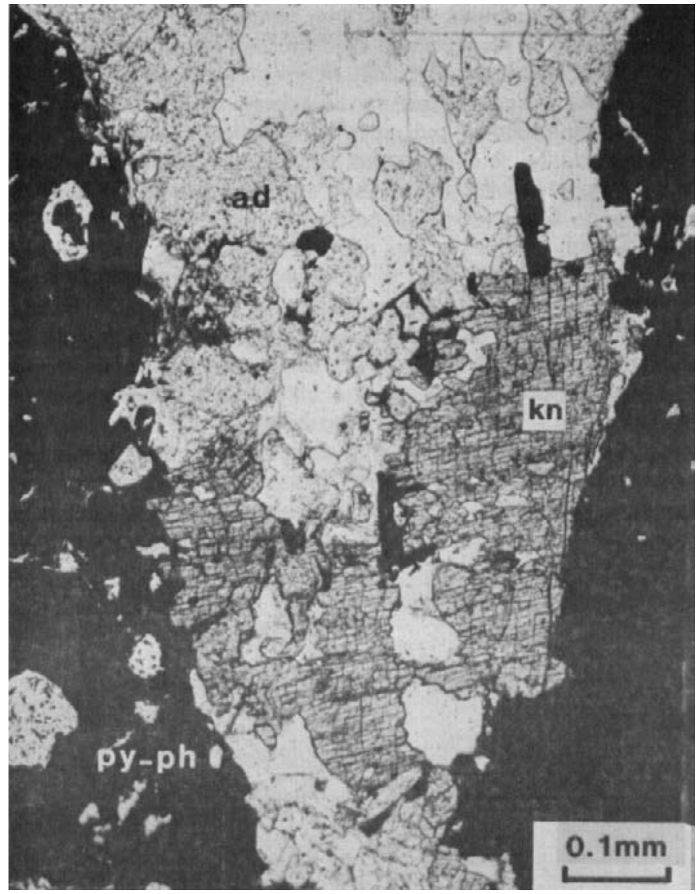


Figure 76: Kyanite (kn) in intermediate gneiss (unit 5b). associated with pyrite-pyrrhotite (py-ph) and andalusite (ad). Sample 1112-6, plane polarized light.

Kyanite represents increased pressure and/or decreased temperature conditions relative to the pT conditions of andalusite (Chinner, 1966). This distinction, together with petrographic evidence, suggests kyanite is due to a younger metamorphic event than andalusite. The kyanite occurrence east of Brooks Bay is unique in the project area. Other localities of alumino-silicate minerals yield only sillimanite, and sporadic occurrences of cordierite indicate regional metamorphic pressures were generally below the minimum required for kyanite development.

In the alteration zone, chloritization of biotite (porphyroblasts and matrix) is generally advanced, together with minor chloritic alteration of garnet. The chloritized minerals are overprinted by younger fine grained staurolite (Fig. 78) that is apparently contemporaneous with kyanite; both staurolite and kyanite are randomly distributed and free of alteration.

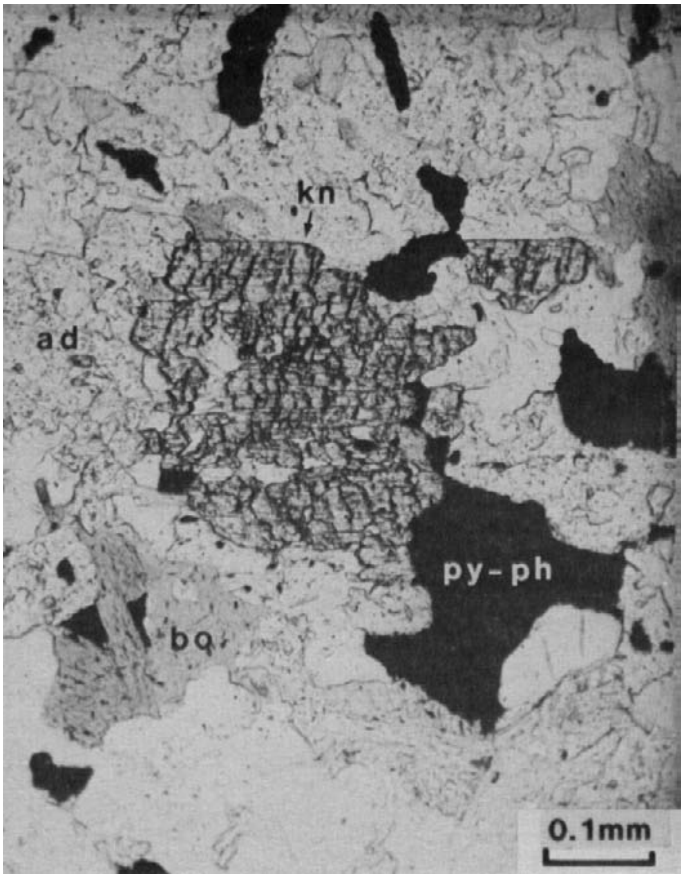


Figure 77: Kyanite (kn) within an andalusite porphyroblast (ad) associated with pyrite-pyrrhotite (py-ph) and biotite (bo). The intermediate gneiss (unit 5b) also contains garnet and staurolite. Kyanite is free of alteration, in contrast to andalusite that contains subordinate sericite. Sample 993-12, plane polarized light.

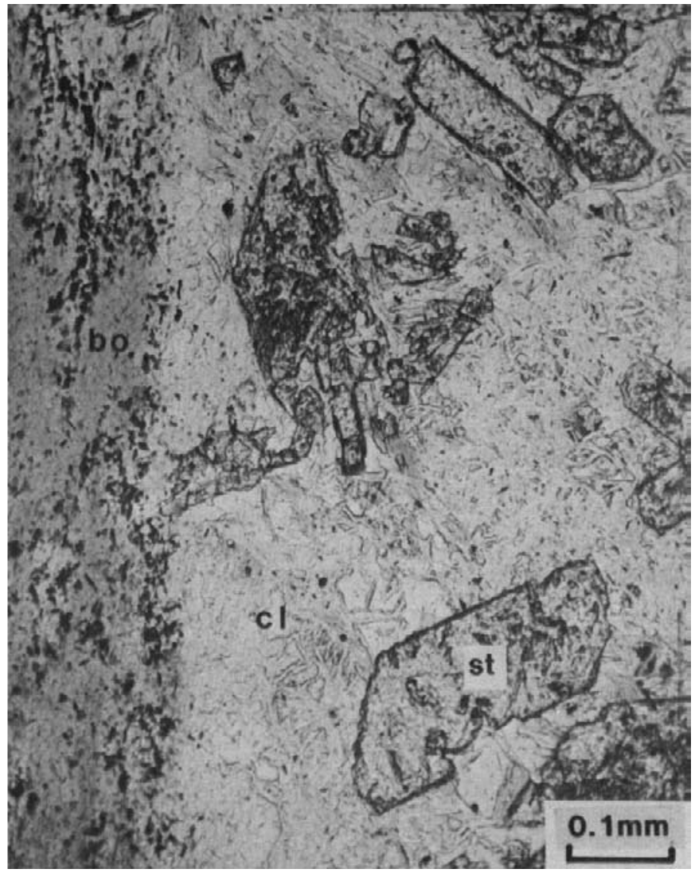


Figure 78: Intermediate gneiss (unit 5b) that contains randomly oriented staurolite porphyroblasts (st) that overprint chlorite (cl) derived from biotite (bo). Sample 1112-5, plane polarized light.

It is not clear whether the staurolite and kyanite in the alteration zone east of Brooks Bay are products of regional or localized thermal metamorphism. Contact metamorphism associated with granitoid intrusions has locally been recognised in the southeast part of the Barrington Lake area (see below), and it is conceivable that the staurolite + kyanite association east of Brooks Bay is similarly due to thermal metamorphism, caused by a possible unexposed intrusion related to the adjacent granitoid terrane. This mineral association also occurs in the zoned aureoles of the Donegal granites, where staurolite + kyanite occur near the outer limit of thermal metamorphism (Naggar and Atherton, 1970). The age of the staurolite + kyanite association is also uncertain; textural evidence indicates these minerals are late (possibly post M_3), but more data are required to clearly establish their age.

Contact Metamorphism related to granitoid intrusions

Porphyroblastic schist and gneiss occur in the contact zone between mafic volcanic rocks and the felsic plug (8a, c; 9a, e) 2 km south-southwest of Star Lake. These rocks contain garnet, biotite, green hornblende, cummingtonite and chloritoid; assemblages are listed on page 25 (xiv) to (xvi), units 5b, 5c). The schist and gneiss are interpreted to be altered metavolcanic rocks (and possible metasedimentary interlayers) in the aureole of the tonalite. In addition, the marginal zone of the plug contains gneiss apparently derived from tonalite contaminated by the host rocks. It is not clear whether the porphyroblastic rocks in the aureole of the tonalite plug are due to contact or regional metamorphism. Chloritic alteration of the porphyroblasts indicates they predate M_3 retrograde metamorphism, and may be coincident with M_2, consistent with a possible link between M_2 regional metamorphism and granitoid plutonism (unit 9).

Randomly distributed biotite porphyroblasts that overprint M_3 chlorite and sericite occur in garnetiferous schist in the vicinity of the tonalite south-southwest of Star Lake. The biotite is attributed to late thermal metamorphism, possibly due to post M_3 minor granitoid intrusions (Fig. 79). Random cummingtonite prisms that overprint M_3 chlorite in felsite south of Camp Bay are also attributed to late thermal metamorphism (Fig. 80).

The metamorphic effects of the major granitoid intrusions (unit 9) are well displayed in the southern belt where the mafic volcanic section is gradational eastward into a tonalitic terrane with enclaves of volcanic-derived amphibolite, mafic gneiss and related hybrid rocks. Assimilation of the metabasites, which resulted variously in agmatite, schlieren, and hornblende-feldpsar gneissic lamination, led to the amphibolite facies mineral assemblage green hornblende + andesine, with variable quartz and subordinate biotite. The migmatization is interpreted to be contemporaneous with M_2 metamorphism recognized in the porphyroblastic rocks of the northern belt, but the two events cannot be directly correlated.

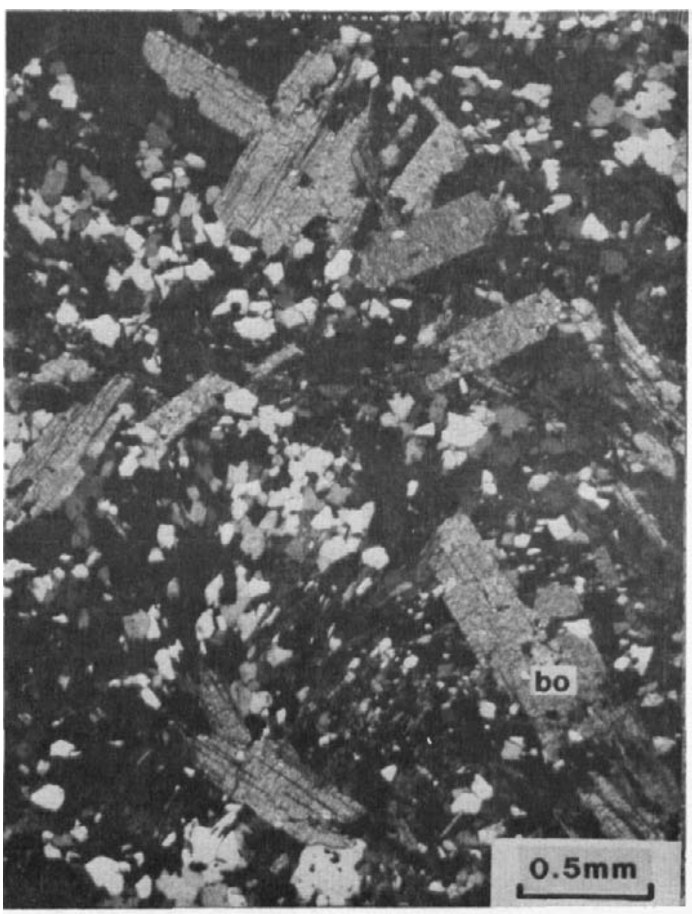


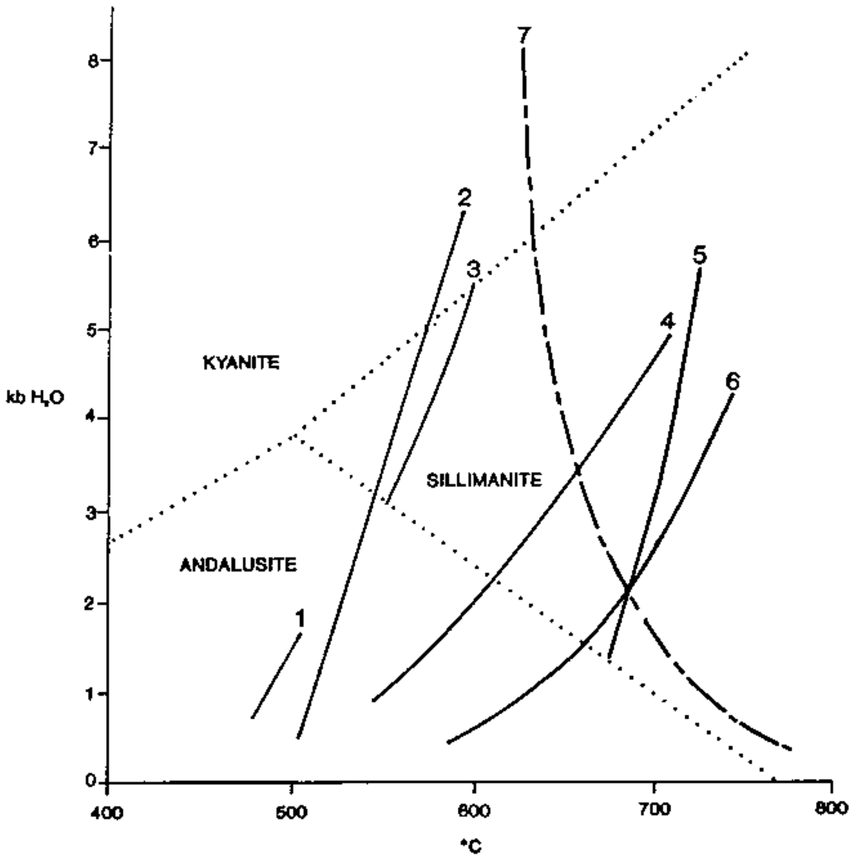
Figure 79: Biotite porphyroblasts (bo) in garnetiferous schist (unit 5b), which overprint M_3 chlorite and sericite, are attributed to late thermal metamorphism. Sample 1138-7, crossed polarizers.

Figure 80: Felsite (unit 8b) that contains randomly oriented cummingtonite (cg) attributed to post M_3 thermal metamorphism. Sample 582-1, plane polarized light.

REGIONAL VARIATIONS IN THE CONDITIONS OF METAMORPHISM

Figure 81 shows lines defining the approximate pT conditions for various reactions postulated to explain the observed mineral assemblages. The conditions of inferred pre M_1 granulite metamorphism in the vicinity of Hollingworth Lake (Fraser Lake area) are shown by lines 5 and 6, which represent reactions (f) and (g) respectively. Greenschist to amphibolite facies M_1 conditions cannot be clearly defined due to widespread M_2 recrystallization.

M_2 metamorphic conditions varied from medium to high grade. Line 1 (reaction i) indicates the pT conditions inferred for M_2 metamorphism in the alteration zone at the west shore of Barrington Lake. Line 2 (reaction h) defines the M_2 conditions interpreted in paragneiss at Magrath Lake narrows (Fraser Lake area). A relatively higher metamorphic grade is indicated by assemblages in paragneiss (4) east of Melvin Lake that show pT conditions exceeded line 3 (reaction d) and line 4 (reaction a) that defines the onset of high grade metamorphism (Table 19). The intersection of line 7,



Note: Al_2SiO_5 mineral phase boundaries after Holdaway (1971).

Reaction Lines:

1. Chlorite + andalusite + quartz ⇌ garnet + cordierite + H_2O
   (Hess, 1969)
2. Chlorite + muscovite + quartz ⇌ cordierite + biotite + Al_2SiO_5 + H_2O
   (Hirschberg and Winkler, 1968)
3. Staurolite + muscovite + quartz ⇌ sillimanite + garnet + biotite + vapour
   (Carmichael et al., 1987)
4. Muscovite + quartz ⇌ sillimanite + K-feldspar + H_2O
   (Evans, 1965)
5. Biotite + quartz ⇌ hypersthene + K-feldspar + H_2O
   (Hess, 1969)
6. Muscovite ⇌ corundum + K-feldspar + H_2O
   (Evans, 1965)
7. Beginning of melting of granite (Miyashiro, 1973)

Figure 81: P-T diagram showing lines of selected metamorphic reactions and phase boundaries of the alumino-silicate minerals (after Holdaway, 1971), and the beginning of anatexis. Lines 1 to 6 represent reactions i, h, d, a, f, and g discussed in the text.

which marks the beginning of melting of granite, with line 4 shows that granitoid *lits* within the Melvin Lake paragneiss could have an anatectic origin related to M_2 metamorphism.

The M_2 middle to upper amphibolite facies conditions in the Fraser Lake and Melvin Lake areas contrast with the lower to middle amphibolite facies M_2 grade in the Barrington Lake area. This variation is consistent with the relatively more extensive granitoid plutonism, localized migmatization and deeper erosional levels inferred in the Fraser Lake and Melvin Lake areas, where the metamorphic grade locally exceeded the pT conditions of the beginning of anatexis.

Geochemical sampling was undertaken during field mapping in 1979 and 1980 in order to investigate the origin of the volcanic rocks, and compare these with the Wasekwan Group in the Lynn Lake area (Syme, 1985, 1990). Twenty-four samples were selected from areas free of conspicuous alteration or deformation; 15 samples from the mapping of H.V. Zwanzig in 1974 were also utilized for this study. Major and minor element analyses were carried out on all 39 samples; selected trace and rare-earth element (REE) data were obtained for 15 samples (see Appendix). Thirty-four volcanic rock samples are from the Barrington Lake area; three basaltic flows and two mafic dykes are from the Fraser Lake area. For the purpose of this description, the term "Barrington volcanics" refers to all analyzed volcanic rocks in the Barrington Lake and Fraser Lake areas.

ALTERATION

The effects of sea-floor and metamorphic alteration of volcanic rocks have been widely investigated, especially for alkali elements, calcium and related trace elements (Hughes, 1972; Hart, 1970, 1973; Reed and Morgan, 1971; Ludden *et al.,* 1982). Increase in K/Na is characteristic of sea-floor alteration, and Ca is depleted during weathering and low grade metamorphism (Pearce, 1975). Almost half the Barrington volcanics plot outside the "igneous spectrum" of Hughes (1972), which indicates extensive alkali metasomatism (Fig. 82). Those elements that are characteristically mobile during alteration have therefore been largely excluded from this investigation.

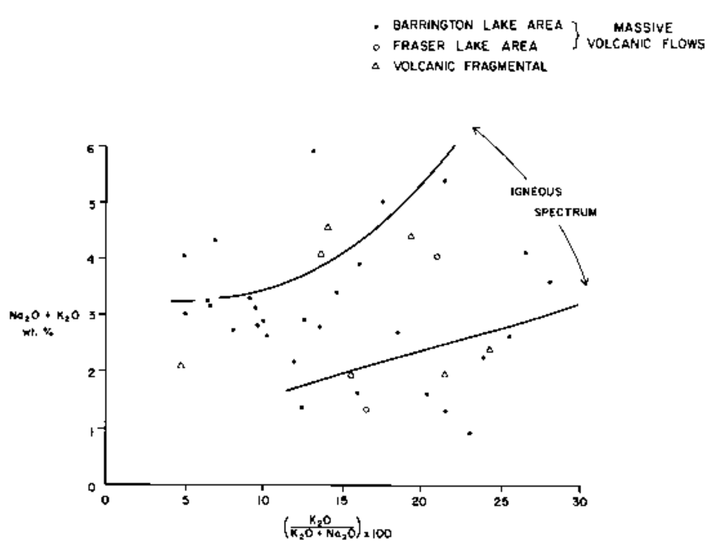


Figure 82: (Na_2O + K_2O) vs. 100 x K_2O/(Na_2O + K_2O) for volcanic rocks in the Barrington Lake and Fraser Lake areas, showing the "igneous spectrum" (Hughes, 1972).

Oxidation of Fe during alteration is a common feature for which Irvine and Baragar (1971) suggest adjustment of analytical data to produce a more accurate "original" composition. Half of the intermediate to mafic rocks analyzed contain excess Fe_2O_3 in a range considered to be due to secondary oxidation by Irvine and Baragar; accordingly, only total Fe (FeO*) has been used in the present study. Volatile constituents (H_2O, CO_2, S, etc.) are generally minor (see Appendix) and the analyses have not been recast on a volatile-free basis, as suggested by Irvine and Baragar.

COMPOSITION AND PETROGENESIS OF BARRINGTON LAKE-FRASER LAKE AREA VOLCANIC ROCKS AND COMPARISON WITH THE WASEKWAN GROUP IN THE NORTHERN BELT OF THE LYNN LAKE AREA

The histogram of volcanic rock composition (Fig. 83) is approximately representative of the Wasekwan Group in the Barrington Lake-Fraser Lake area; the majority of the sample population is basaltic, and felsic volcanic rocks constitute 5 to 10% of the volcanic section. Half the rocks of andesitic composition are fragmental and contain mixed mafic to felsic fragments (samples 24 to 34 in Appendix); true andesites are relatively uncommon.

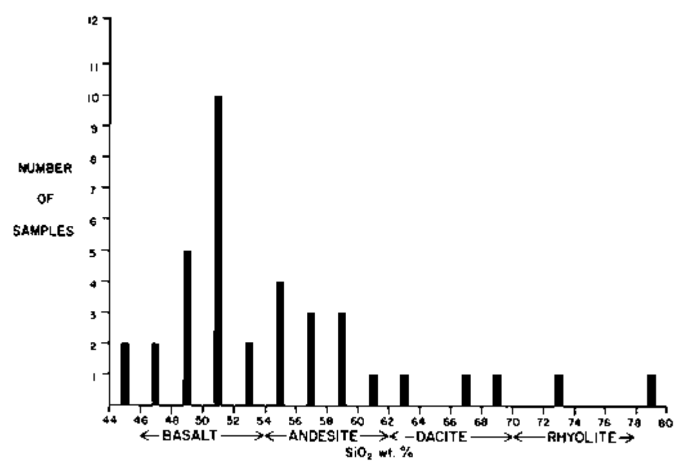


Figure 83: SiO_2 histogram of 37 volcanic rocks in the Barrington Lake-Fraser Lake area.

Three distinct compositional types are distinguished in Wasekwan Group mafic volcanic rocks: high-Al basalts, normal-Al basalts, and high-Mg mafic rocks (discussed later). One third of Barrington volcanics contain more than 17 weight per cent Al_2O_3 and constitute a group of high-Al basalt, associated with basalt in the normal-Al range (14-17 weight per cent Al_2O_3). The presence of high-Al and normal-Al basalts was also recognized in the northern belt in the Lynn Lake area (Gilbert *et al.,* 1980), where these two types have been interpreted to be genetically related (Syme, 1985). High-Al basalt in the project area is widely distributed throughout the northern belt, and interspersed with normal-

Al basalt. All high-Al basalt flows contain subordinate to abundant plagioclase phenocrysts (15-55%), which result in higher Al_2O_3 contents since the weight percentage of Al_2O_3 in the plagioclase molecule is approximately 35, well above the range of Al_2O_3 in basalts. Basalts in the "normal" Al range include both aphyric and plagioclase phyric types (Fig. 84). This suggests that the high-Al basalts are not simply due to the presence of plagioclase phenocrysts, but constitute a geochemically distinct magma type.

The Jensen diagram (Fig. 85) shows Barrington volcanics define an overall tholeiitic (TH) trend; high-Mg mafic to ultramafic rocks occur in the komatiitic fields and high-Al basalt is mostly within, or at the margins of, the calc-alkaline (CA) field. On the discriminant diagrams of Miyashiro (1974), high-Al basalt is exclusively TH (Fig. 86, 87). The AFM diagram (Irvine and Baragar, 1971; Fig. 88) confirms the TH trend. In the discriminant diagram of Mullen (1983), Barrington volcanics extend across the island arc tholeiite (IAT) and CA fields (Fig. 89). Comparison of minor element, trace element and REE abundances in Barrington volcanics with averages for modern volcanic arc, within-plate and mid-ocean ridge (MOR) rock suites (Table 21) indicates a volcanic arc association for Barrington rocks.

The majority of Barrington volcanics are from the northern belt in the Barrington Lake area (Map GR87-3-4), which is continuous west with the northern belt of the Lynn

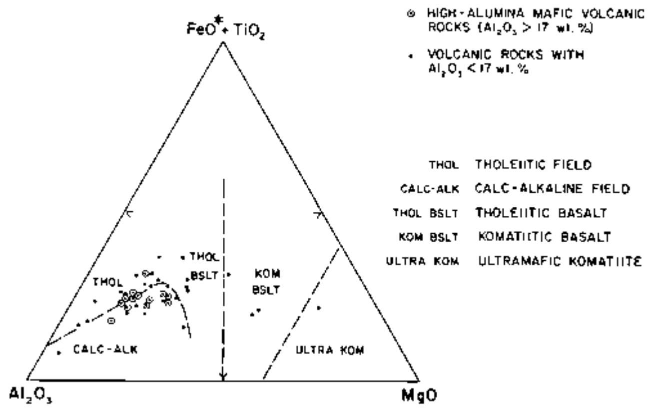


Figure 85: *Al_2O_3-(FeO^*+ TiO_2)-MgO cation diagram of Jensen (1976) for high-alumina and normal-alumina rocks in the Barrington Lake-Fraser Lake area.*

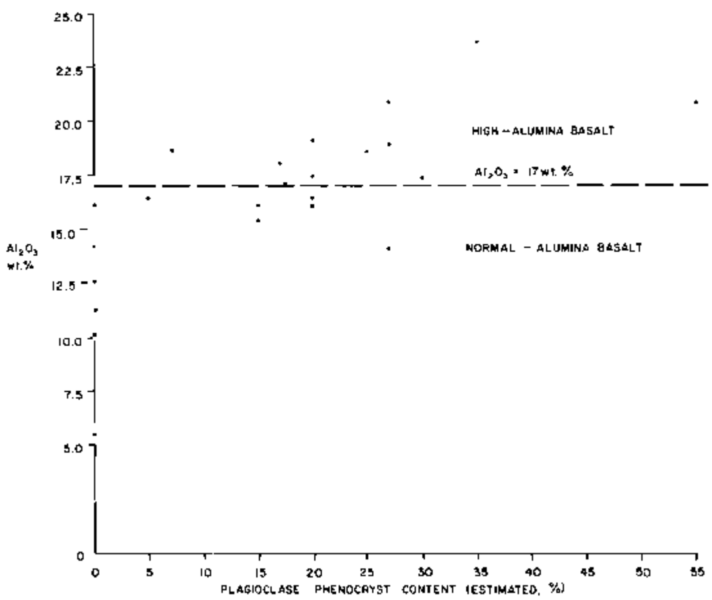


Figure 84: *Al_2O_3 vs. plagioclase phenocryst content of basalts in the Barrington Lake-Fraser Lake area, showing the occurrence of plagioclase phyric rocks in both the high- and normal-alumina fields.*

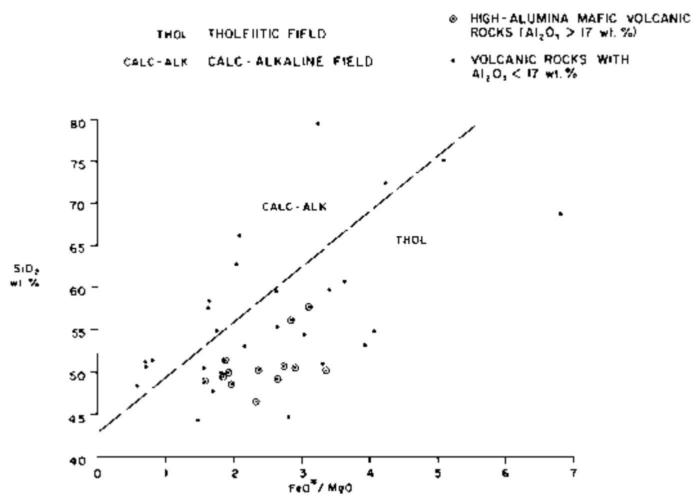


Figure 86: *SiO_2 vs. FeO^*/MgO discriminant diagram (Miyashiro, 1974) for high-alumina and normal-alumina rocks in the Barrington Lake-Fraser Lake area.*

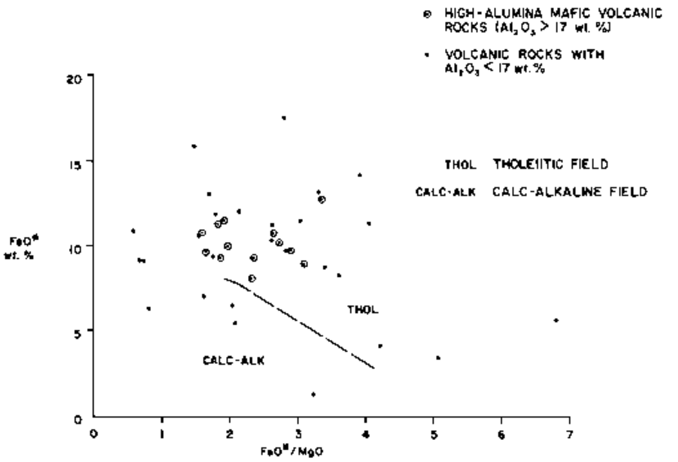


Figure 87: *FeO* vs. FeO*/MgO discriminant diagram (Miyashiro, 1974) for high-alumina and normal-alumina rocks in the Barrington Lake-Fraser Lake area.*

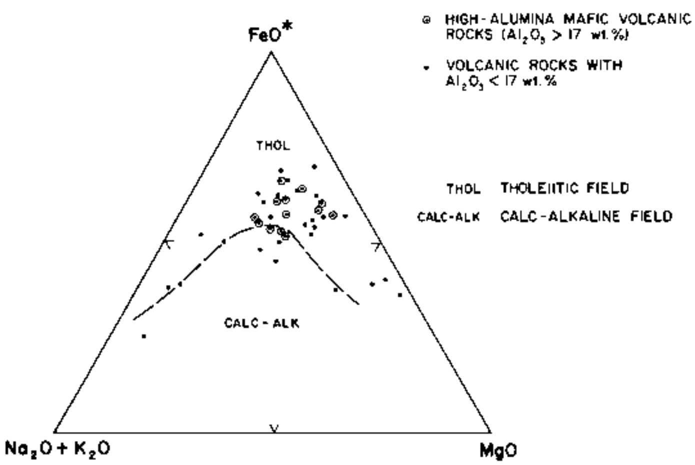


Figure 88: *(Na_2O + K_2O)-FeO*-MgO (AFM) ternary diagram (Irvine and Baragar, 1971) for high-alumina and normal-alumina rocks in the Barrington Lake-Fraser Lake area.*

Lake area (Gilbert *et al.,* 1980). The Wasekwan Group rocks of both areas of this belt are broadly similar and comprise high-Al and normal-Al basalts with intercalated high-Mg mafic units; however, significant differences (discussed below) occur between these two areas in the degree of depletion of trace elements and REE that indicate the Barrington volcanics are derived from a magma source that was relatively more primitive, and/or influenced by a higher degree of partial melting, than the source of the Lynn Lake area rocks.

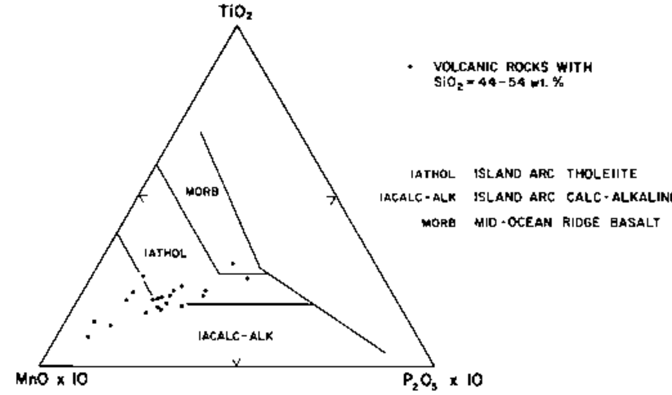


Figure 89: *MnO-TiO_2-P_2O_5 ternary diagram (Mullen, 1983) for basalts in the Barrington Lake-Fraser Lake area.*

The low Ni and Cr contents of Wasekwan Group rocks (excluding high-Mg types) in both Barrington Lake and Lynn Lake areas (Syme, 1985) are in the range of modern IAT (Table 21), and are also distinctive for island arc as opposed to marginal basin basalts (Tarney *et al.,* 1981). TiO_2 contents are also low and comparable with modern arc basalts. Compared with Lynn Lake area rocks, Barrington Lake high-Al basalts and andesites have lower TiO_2 and higher Ni and Cr contents, which suggests a relatively less fractionated source for the Barrington volcanics (Table 22). At Lynn Lake, Division D volcanic rocks are relatively more primitive than underlying Division B rocks (Syme, 1985); Table 22 shows increasing TiO_2 and decreasing Ni and Cr contents from Barrington volcanics to Lynn Lake Division D to Division B rocks, which corresponds to a trend of increasingly more fractionated magma sources. During fractionation, Ni and Cr decrease due to incorporation in olivine and pyroxene crystallizing phases, whereas TiO_2 increases until the appearance of magnetite, when TiO_2 begins to decline (Fig. 90).

Figure 91 illustrates the low TiO_2 contents of Barrington Lake high-Al basalts, and the increase through Lynn Lake Division D to *Division B more evolved rocks (with higher values of FeO*/MgO).

Fractionation is a major control on the contents of compatible elements such as Ni and Cr, but it is only one of several factors involved in magma genesis, which include partial melting, remelting, magma mixing, addition of components from oceanic crust, and the influence of rising hydrothermal fluids from the subducted lithosphere (Pearce, 1982). Depletion of high field strength (HFS) incompatible elements (P, Hf, Zr, Ti, Y), which is characteristic of Barrington volcanics, may be attributed to various factors, of which the most significant are: high degrees of partial melting (Pearce and Norry, 1979); selective retention of elements in residual minor oxide phases such as rutile, sphene and zircon (Saunders *et al.,* 1980); and remelting of already de-

Table 21: Chemical characteristics of Barrington Lake-Fraser Lake area basalts, compared with modern volcanic arc, within-plate and mid-ocean ridge basalts (after Pearce, 1982)

Element	Barrington Lake-Fraser Lake		Volcanic arc			Within-plate		Mid-ocean ridge		Element
	Average	Range	Tholeiitic	Calc-alkaline	Shoshonitic	Tholeiitic	Alkaline	Tholeiitic	Transitional	
Ce	3.6	2 - 6	6.94	29.3	50.2	31.3	96.8	11.0	23.3	Ce
Sm	0.85	0.48 - 1.4	1.89	3.78	4.88	5.35	8.87	3.26	3.83	Sm
P_2O_5	0.08	0.03 -0.23	0.08	0.19	0.44	0.25	0.64	0.12	0.18	P_2O_5
Hf	0.34	0.2 - 0.8	1.17	2.23	2.24	3.44	6.36	2.44	2.93	Hf
Zr	24.9	10 - 47	40	71	87	149	213	90	96	Zr
TiO_2	0.64	0.3 - 1.48	0.84	0.98	0.94	2.23	2.90	1.40	1.39	TiO_2
Y	6	2 - 12	17	22	22	26	25	33	25	Y
Yb	0.86	0.49 - 1.31	1.95	2.31	2.55	2.12	0.89	3.22	2.63	Yb
Rb	8	32 - 2	4.7	23	51	(7.5)	(40)	(2)	(6)	Rb
Ba	140.8	30 - 440	60	260	609	(100)	(600)	(20)	(60)	Ba
K_2O	0.37	0.17 - 1.17	0.43	0.94	2.51	(0.5)	(1.5)	0.20	(0.51)	K_2O
Th	0.23	0.1 - 0.3	0.37	1.26	3.6	0.77	4.5	0.26	0.80	Th
Sr	195.6	10 - 420	231	428	934	290	842	121	196	Sr
Ni	17	6 - 43	18	50	14	(70)	(90)	(90)	(130)	Ni
Cr	45.8	12 - 139	111	160	100	352	536	251	411	Cr

NOTE: Values are in ppm, except for P_2O_5, TiO_2, K_2O (%). Brackets () denote estimated values (no compilation available). Volcanic arc, within-plate and MOR basalt data are from Pearce (1982). The most diagnostic elements that indicate a modern IAT association of Barrington Lake-Fraser Lake area basalts are the HFS elements and REE (listed first). LIL-element and transitional metal contents of these basalts are less distinctive, but comparable with modern IAT.

pleted mantle (Green, 1973). Repeated remelting of a magma source results in strong depletion of incompatible elements (Saunders and Tarney, 1984).

Table 22: TiO_2, Ni and Cr average contents (and ranges) in high-Al basalt and andesite in the Barrington Lake-Fraser Lake area and in the Lynn Lake area

	Barrington Lake (N = 13)	Lynn Lake Div. D (N = 6)	Lynn Lake Div. B (N = 9)
TiO_2	0.64	0.78	0.91
(wt.%)	(0.30 - 1.48)	(0.57 - 0.89)	(0.65 - 1.04)
Ni	17	12.7	4.7
(ppm)	(6 - 43)	(1 - 30)	(1 - 10)
Cr	45.8	36	16
(ppm)	(12 - 139)	(10 - 90)	(8 - 40)

The degree of partial melting is an important control on the abundance of incompatible elements, and may explain the relative depletion of HFS elements in Barrington basalts compared to Lynn Lake Division D and Division B basalts. Figures 92 and 93 illustrate the progressive increase in the contents of Y and Zr in the three suites from Barrington Lake, Lynn Lake Division D and Division B. The regional variation in Zr content is also shown in Fig. 98. The Cr/Y diagram was devised by Pearce (1982) to demonstrate variations due to fractionation and partial melting, without the influence of any prior events leading to mantle heterogeneity. Figure 92 shows the variation of Y between the three suites, which reflects variable degrees of partial melting of the source magma, whereas variation within suites follows trends subparallel to the Cr axis, which is an index of fractionation. MgO is the fractionation index in Figure 93, which shows that Lynn Lake Division B basalts and andesites are, in part, lower in Mg (more fractionated) than Division D and Barrington Lake rocks. MORB-normalized trace element abundances of high-Al basalts in these three rock suites are

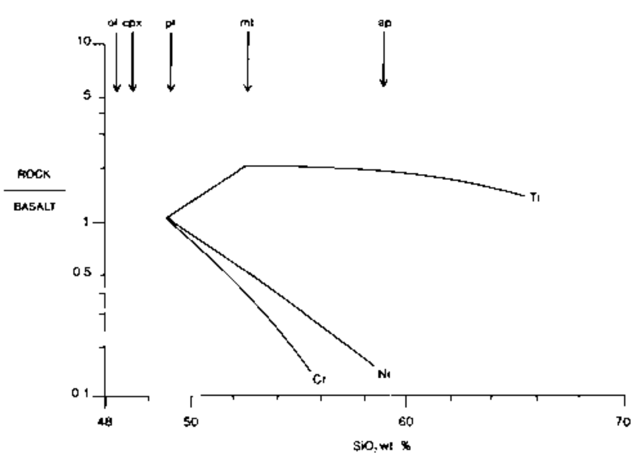


Figure 90: Variations of Ti, Ni and Cr with SiO_2 content in a typical tholeiitic suite. Arrows mark approximate points at which indicated minerals become crystallizing phases (from Pearce, 1982, Fig. 10).

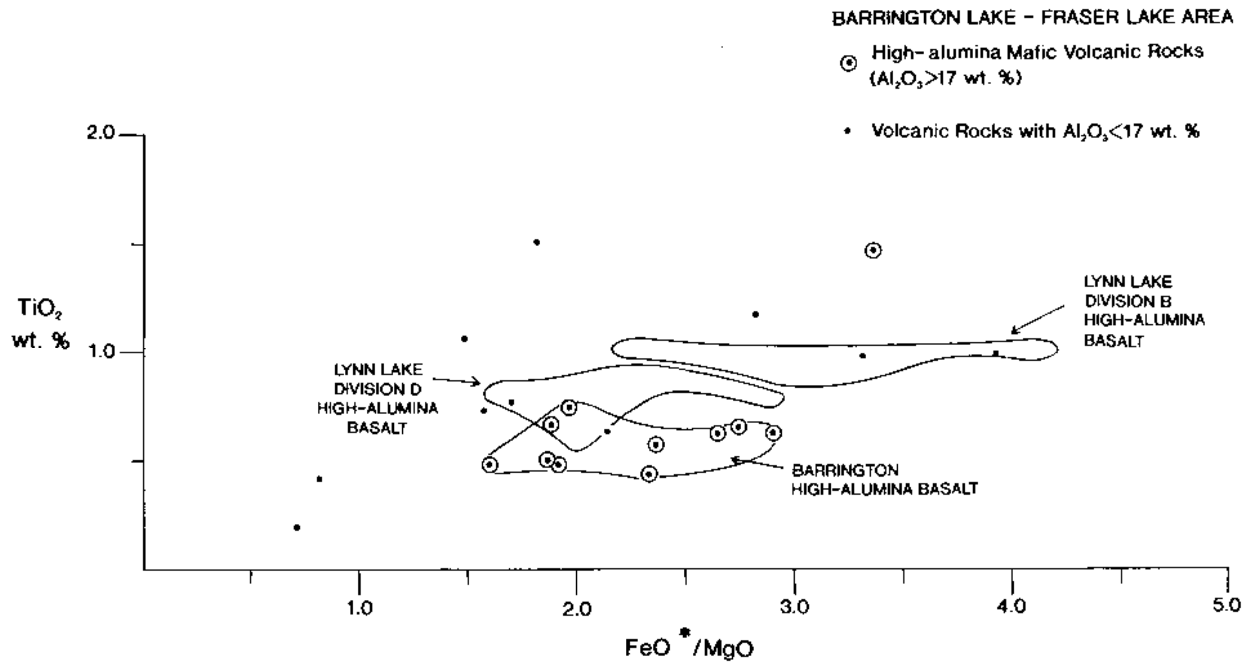


Figure 91: TiO_2 vs FeO/MgO for mafic volcanic rocks in the Barrington Lake-Fraser Lake area (subdivided according to Al_2O_3 content) and the fields of Lynn Lake high-Al basalts (Syme, 1985).*

plotted in Figure 94[5], which shows increasing values of HFS elements from Barrington Lake rocks through Lynn Lake Division D to Division B rocks; the variation may be due to differences in the degrees of partial melting and/or subsequent fractionation in the source magmas (lower fractionation for Barrington Lake rocks).

Superimposed on a pattern of depleted HFS elements, Barrington volcanics display increased contents of P and Ti relative to other HFS-element levels (Fig. 94, 95). The P and Ti anomalies are possibly due to accumulations of apatite and titaniferous magnetite (respectively), in amounts above the stoichiometric proportions due to fractional crystallization. These anomalies are not observed in Wasekwan Group volcanic rocks further west in the Lynn Lake area (Syme, 1985).

REE contents of Barrington volcanics are generally lower than for Lynn Lake area rocks, consistent with a relatively lower degree of fractionation in the source magma. Barrington basalts have REE contents <8 x chondrite whereas Lynn Lake northern belt basalts are almost all >8 x chondrite (Fig. 96a, b, 97)[6].

Progressive increase in REE abundances from Barrington basalts, through Lynn Lake Division D to Division B basalts is comparable with the trend of increasing trace element contents (Fig. 94). Barrington high-Al basalts have generally lower REE contents than associated normal-Al basalts (Fig. 96a, b) (Ni and Cr are also lower in the high-Al suite). In contrast, Lynn Lake area high-Al basalts are moderately light REE-enriched compared to associated normal-Al basalts (Fig. 97b). Barrington mafic rocks are characterized by relatively flat REE patterns, although four samples (1, 4, 7 and 10) show slight light-REE depletion (samples depicted by cross symbols in Figures 96a, b).

Comparison of felsic volcanic rocks shows the Lynn Lake rhyolite (Fig. 97b) is notably higher in REE than the two rhyolites at Barrington Lake (samples 38, 39, Fig. 96c); all rhyolites show slight negative Eu anomalies and light REE enrichment (relatively more pronounced in the Lynn Lake rhyolite). The Eu anomalies of the felsic rocks reflect plagioclase loss by fractional crystallization. In contrast, several mafic rocks display moderate positive Eu anomalies that resulted from the accumulation of plagioclase phenocrysts (samples 1, 2, 3, 4, 6, Fig. 96a, b).

In summary, Barrington volcanics are significantly more depleted in HFS incompatible elements and REE than rocks in the northern belt in the Lynn Lake area, which are considered to be roughly time equivalent. The Barrington volcanics are probably derived from a different source magma than Lynn Lake area rocks, characterized by less fractionation and/or higher degrees of partial melting. More evolved volcanic rocks in the Lynn Lake greenstone belt (*e.g.* enriched tholeiitic and/or calc-alkaline suites) are confined to the west and central parts of the belt (Fox Lake, Lynn Lake and Hughes Lake areas; Gilbert *et al.,* 1980).

5 MORB-normalizing values are from Saunders and Tarney, 1984.

6 Chondrite-normalizing values are from Masuda *et al.*, 1973.

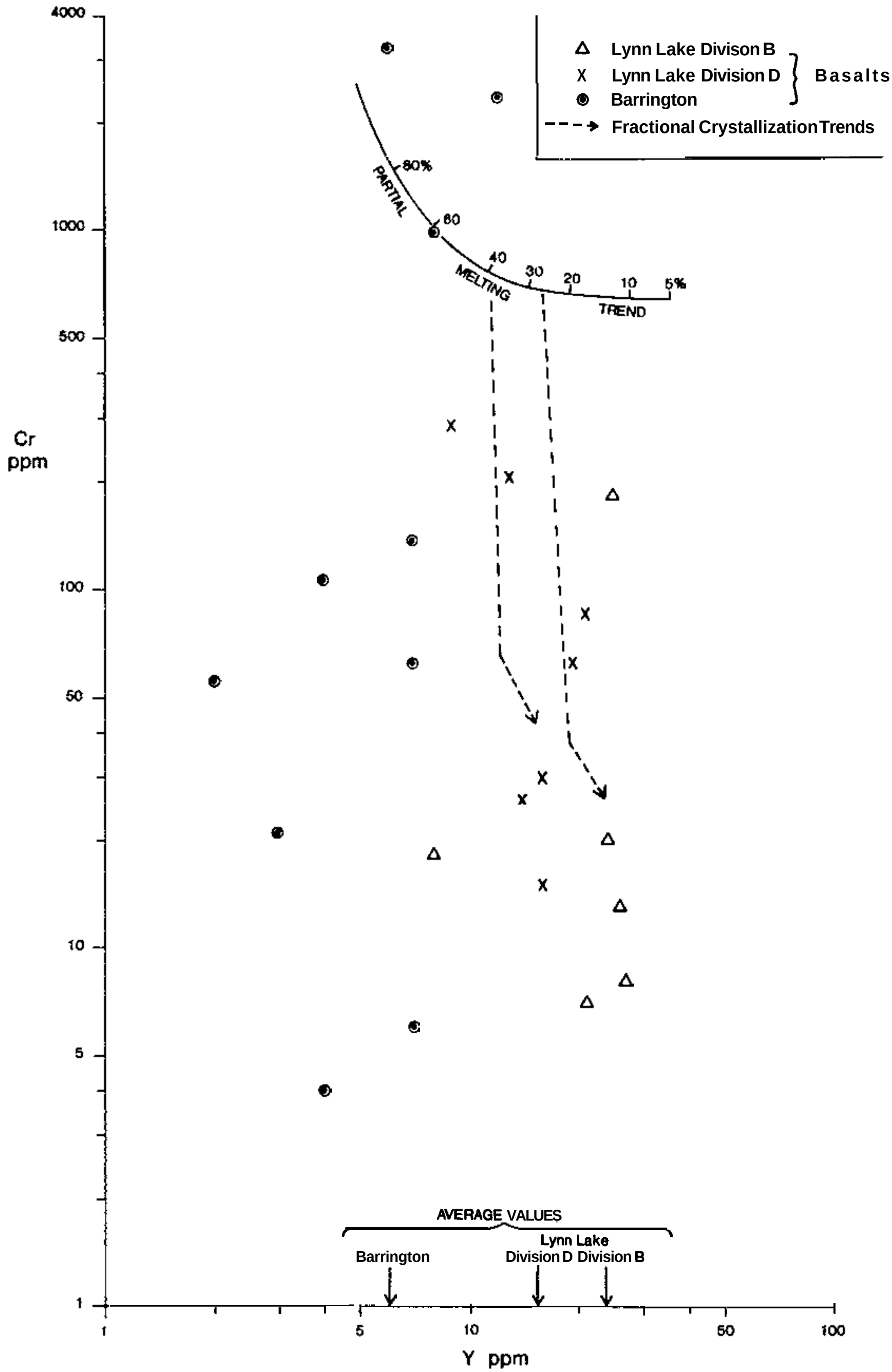


Figure 92: *Cr vs. Y for Barrington Lake-Fraser Lake area basalts; Lynn Lake area basalt analyses are from Syme (1985, Table A2); petrogenetic trends are from Pearce (1982).*

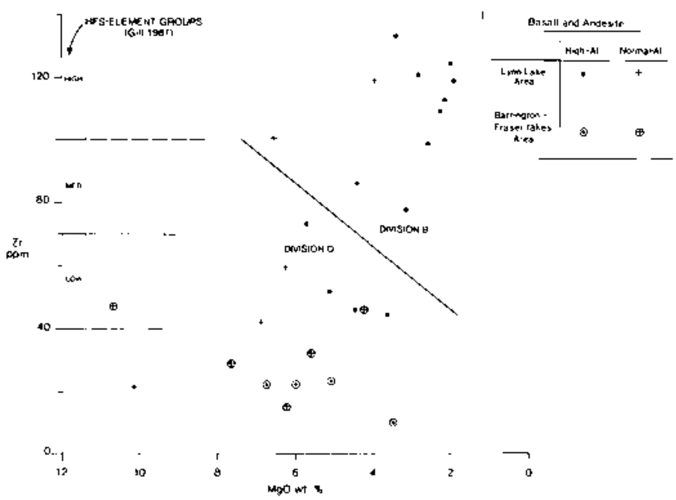


Figure 93: *Zr vs. MgO for high-Al and normal-Al basalts and andesites in the Barrington Lake-Fraser Lake area compared with Lynn Lake area northern belt rocks of Divisions B and D (from Syme, 1985). Ranges of HFS-element rock groups of Gill (1987) are indicated on the Zr axis.*

TECTONIC SETTING

The minor and trace element contents (Table 21) indicate Barrington Lake-Fraser Lake area basalts are geochemically similar to modern island arc tholeiites (Jakes and Gill, 1970). This association is also indicated by the Ti/Zr discriminant diagram of Pearce *et al.* (1981), reproduced in Figure 98; (Lynn Lake area Wasekwan Group rocks are also plotted to illustrate the relative Zr depletion of Barrington volcanics). Extreme depletion of Y in Barrington basalts is shown in Figure 99, where the rocks plot beyond the field of (Y-depleted) modern arc magmas. Figure 100 illustrates the strong depletion of Ce (relative to Sr) in Barrington volcanics, which compare with modern arc magmas with the lowest Ce/Sr values (Pearce, 1982).

Subdivision of low-K arc tholeiites on the basis of HFS-element content is shown to have stratigraphic and tectonic significance in the modern Fiji arc (Gill, 1987). The arc basement contains high HFS-element volcanic rocks with intercalated high-Mg andesite; the extremely depleted low HFS-element group probably postdates the early high HFS-element group and the development of back arc basins. Barrington volcanics are similar to the low HFS-element group in having very low Zr and REE contents, high Ti/Zr (Barrington volcanics average = 320), low Th and Th/U (<2), and very low Ni and Cr relative to MgO (Fig. 93, 101;

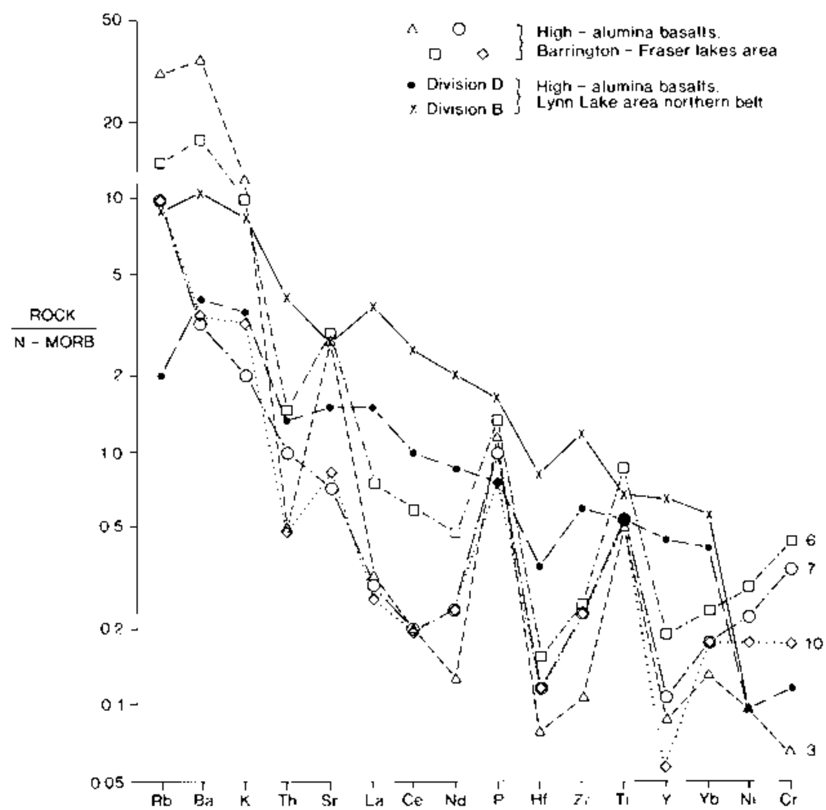


Figure 94: *MORB-normalized trace element plot of high-Al basalts in the Barrington Lake-Fraser Lake area and the Lynn Lake area northern belt (Syme, 1990). Sample numbers appear in the column at right (see Appendix).*

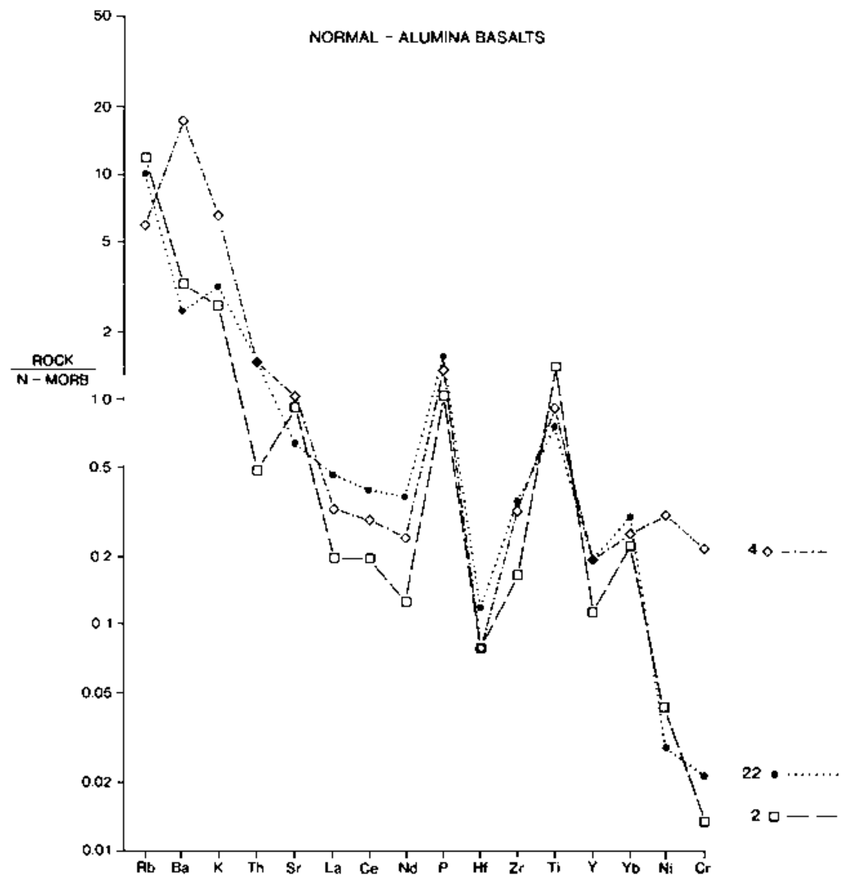


Figure 95: MORB-normalized trace element plot of normal-Al basalts in the Barrington Lake-Fraser Lake area. Sample numbers appear in the column at right (see Appendix).

Gill, 1987). However, some factors suggest correlation of Barrington volcanics with the medium HFS-element group, which occurs locally in or above the basement of early arc volcanic rocks in some parts of Fiji (Gill, 1987); these factors include the generally flat REE pattern (Fig. 96, 102) and the predominance of porphyritic basalt and basic andesite, in contrast to the low HFS-element group that consists largely of basic andesite. The available evidence suggests Barrington volcanics compare most closely with the strongly depleted low HFS-element group in Fiji, which was apparently developed on back-arc basin crust 20 to 30 Ma after inception of the Fiji volcanic arc (Gill, 1987).

Decoupling of incompatible elements defined by high large ion lithophile (LIL) element and low HFS-element contents is characteristic of IAT and also back-arc basin basalts (Gill, 1981; Tarney *et al.,* 1981; Saunders and Tarney, 1984). This pattern is also conspicuous in Barrington volcanics (Fig. 94, 95). In the case of modern island arcs, this pattern is generally attributed to initial depletion of incompatible elements followed by enrichment of LIL elements due to metasomatism by aqueous fluids. The LIL-rich aqueous fluids result from dehydration of the subducted oceanic crustal slab, and rise through the mantle wedge where the arc magmas originate. LIL elements are derived from the upper part of the crustal slab, where they are concentrated by sea-floor weathering (Pearce, 1982).

HIGH-Mg ROCKS

A fine grained Mg-rich mafic rock (sample 17, Appendix) occurs close to the southeast corner of Barrington Lake (Map GR87-3-4), at the north margin of the magnetic anomaly associated with the Agassiz Metallotect (Fedikow, 1983, 1984, 1986b). The Metallotect extends 65 km through the northern belt of the Lynn Lake greenstone belt and is characterized by high-Mg picritic basalt and tuff, and contains the 2.9 million tonne Agassiz Au-Ag ore deposit (Fedikow, 1986b). Sample 17 is interpreted to be a komatiite within the stratigraphic section of the Agassiz Metallotect. Diagnostic features include low K and Ti, high Mg, Ni and Cr, and Ca/Al>1, characteristic of a basaltic to pyroxenitic komatiite (Brooks and Hart, 1974; Arndt *et al.,* 1977). The low FeO*/(FeO* + MgO) ratio relative to Al_2O_3, and low TiO_2/MgO of sample 17 distinguish the rock as komatiitic (KOM) rather than tholeiitic (TH) (Fig. 103, 104).

Two minor intrusive units at the west shore of Magrath Lake narrows (samples 19 and 5) are characterized by high MgO content. Sample 19 is compositionally very similar to sample 17 (above); both rocks are within the field of KOM lavas of Munro township (Fig. 103) and plot close to the dividing line between KOM basalt and KOM pyroxenite (Fig. 105). Sample 5 has the composition of a KOM pyroxenite, with the highest Ca/Al and MgO values recorded in the project area. This rock is distinguished by very low Al_2O_3 con-

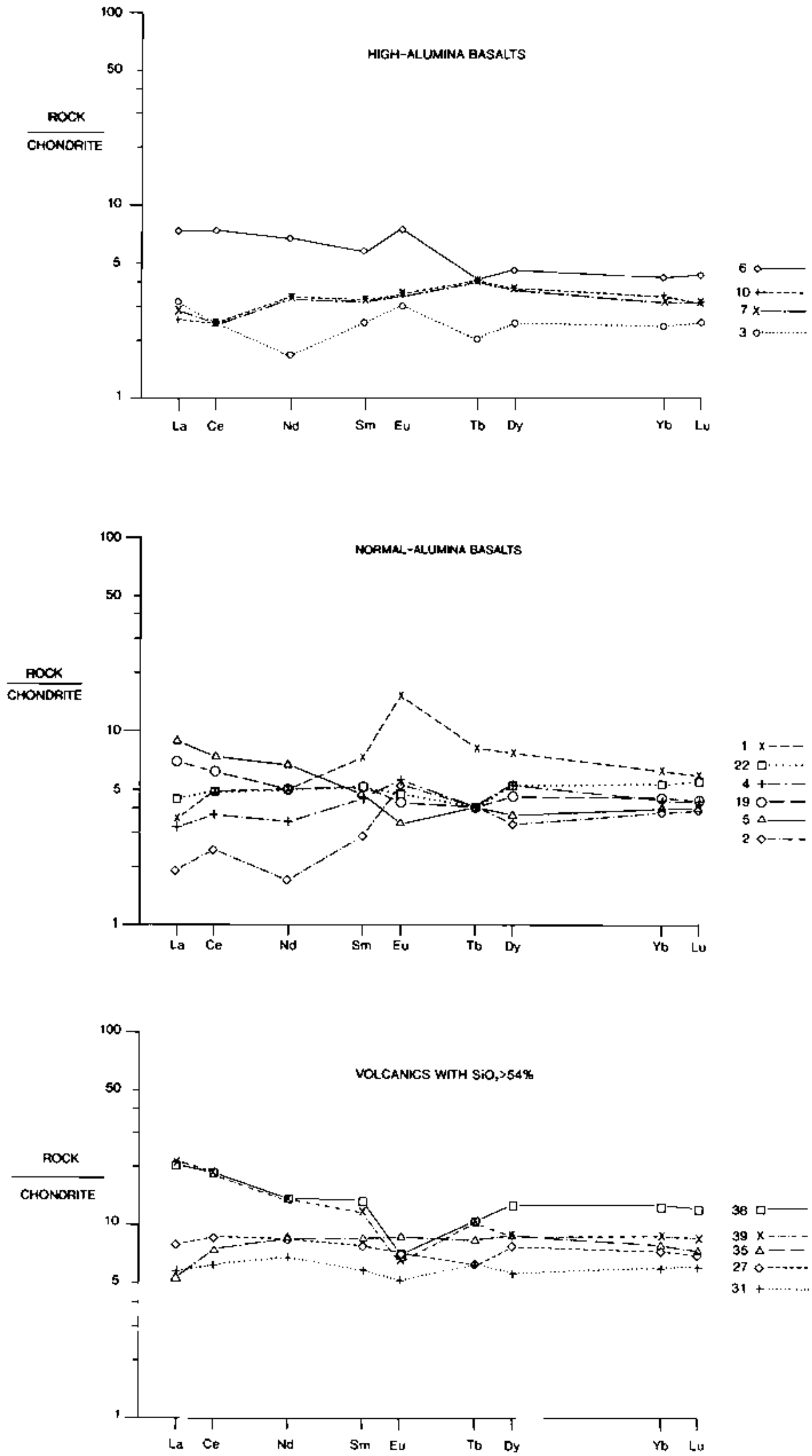


Figure 96: Chondrite-normalized REE plots, Barrington Lake-Fraser Lake area: (a) high-Al basalts, (b) normal-Al basalts, and (c) volcanic rocks with SiO_2 >54%. Sample numbers appear in the columns at right (see Appendix).

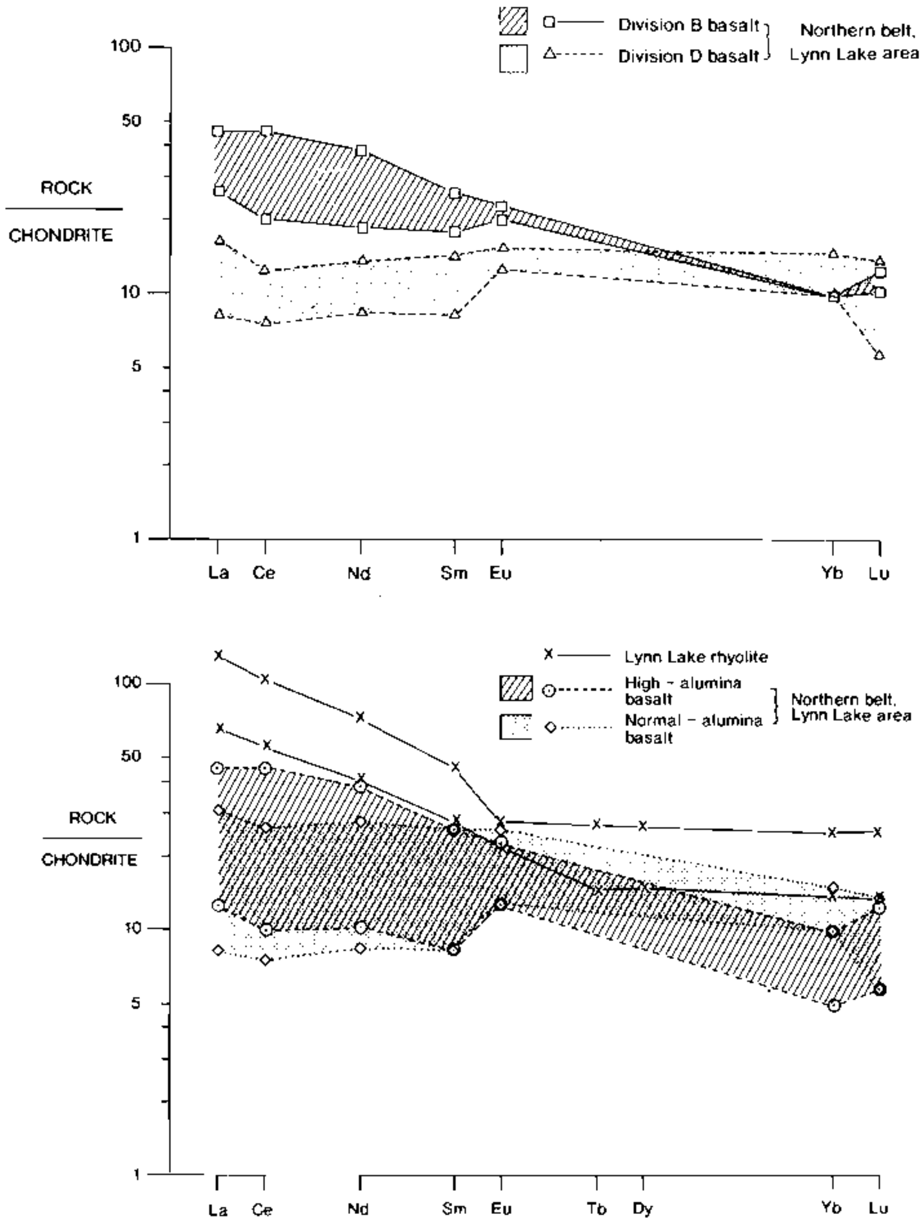


Figure 97: Chondrite-normalized REE plots, Lynn lake area northern belt: (a) Divisions B and D basalts, (b) high-Al and normal-Al basalts and Lynn Lake rhyolite.

tent, and plots within the field of komatiites of the Barberton Mountain Land (Fig. 103) on the TH side of the TH/KOM dividing line; however, the high Ca/Al ratio (>2) of sample 5 identifies it as KOM.

The compositional similarities of the three KOM rocks do not necessarily imply a common origin since these compositions may reflect either a primary magma type (as in the case of "true" komatiites) or be due to differentiation and development of cumulate fractions within a magma chamber. The field evidence indicates sample 17 is a komatiite within the Wasekwan Group (unit 1a1). However, samples 19 and 5 are from intrusive units within paragneisses of inferred Wasekwan Group age. The age of the intrusions (assigned to units 10c and 10d respectively) is uncertain; the setting and petrography of the units is consistent with either a syn- or post-Wasekwan Group age of emplacement (Table 23). Although it is not clear what role igneous differentiation may have played in the genesis of the intrusive units, interpretation of the intrusions as related to KOM volcanism cannot be ruled out.

Komatiites, "boninites", high-Mg volcanic rocks and related minor intrusions compose approximately 5% of the volcanic section in the central La Ronge belt in Saskatchewan, which is, in part, stratigraphically comparable with the Lynn Lake greenstone belt (Fox and Johnston, 1980). The magnesian volcanic rocks generally occupy the basal part of the

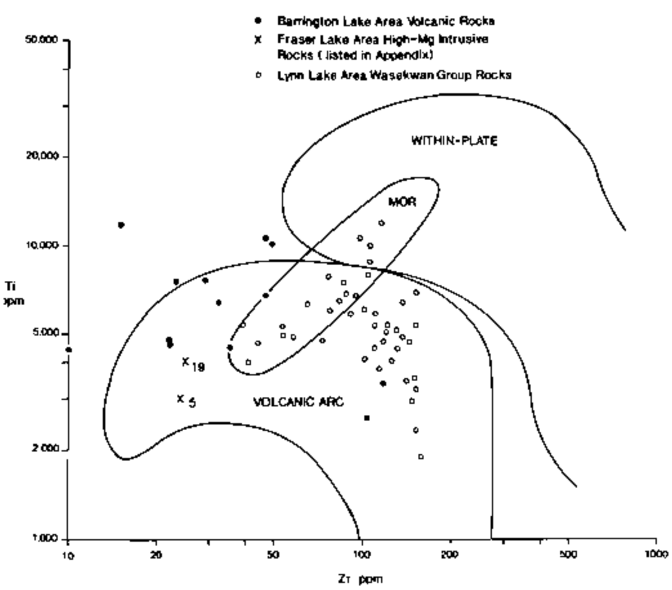


Figure 98: *Ti vs. Zr for Barrington Lake-Fraser Lake area rocks. Compositional fields of modern volcanic rocks are from Pearce et al., 1981; Lynn Lake data from Syme (1985).*

La Ronge metavolcanic section, in contrast to the high-Mg picritic rocks of the Agassiz Metallotect, which are considered to be in the upper part of the (equivalent) Wasekwan Group.

Barrington and Magrath lakes magnesian rocks (samples 17, 19, 5) are geochemically more akin to the high Mg-rocks of the La Ronge belt than the TH picrites in the vicinity of Agassiz Mine. Depletion of the incompatible elements Ti and Zr is diagnostic of La Ronge high-Mg rocks (Fox and Johnston, 1980); Ti and (to a lesser extent) Zr contents are also very low in samples 17, 19 and 5 (Fig. 98, 106). In contrast, the Agassiz picrites contain over 1% TiO_2 and (according to the one available analysis) lack Zr depletion. These data, together with slightly greater Fe-enrichment in the picrites, indicate a TH rather than KOM association for the Agassiz Mine picrites (Fox and Johnston, 1980).

In summary, a komatiite flow at Barrington Lake is considered part of the stratigraphic unit defined as the Agassiz Metallotect in the northern belt of the Lynn Lake greenstone belt. Compositionally similar intrusions at Magrath Lake are possibly related to the high-Mg volcanic rocks of the metallotect. The komatiite flow is equivalent stratigraphically to picrites in the Agassiz Mine area, but is geochemically more comparable with high-Mg rocks at the base of the section in the central part of the La Ronge metavolcanic belt in Saskatchewan.

The geochemical similarity between the komatiite flow (sample 17) and one of the Magrath Lake dykes (sample 19) is demonstrated by low TiO_2; high Mg, Ni and Cr; and LIL-element and SiO_2 contents well above those of typical magnesium-rich ultramafic rocks. These features, and notably low Zr and Ta contents (shown by the Magrath Lake intrusions (data is not available for the komatiite flow) are distinctive for high-Mg rocks intercalated with tholeiites in the lower parts of modern island arc sequences (Wood *et al.,* 1979). Distinctive trace element contents and ratios *(e.g.* Ni, Cr; Fig. 101) suggest the high-Mg rocks are not comagmatic with associated tholeiites, but are derived from a separate source. Tarney *et al.* (1981) suggest derivation by partial melting of a mantle source already depleted by prior melt extraction, and variably re-enriched, possibly by aqueous fluids rising from the dehydrated subducted slab of oceanic lithosphere in an island arc setting (Sun and Nesbitt, 1978. Tarney *et al.,* 1981).

SUMMARY

The Barrington Lake-Fraser Lake area contains the eastern extension of the northern belt of the Lynn Lake area. Northern belt volcanic rocks consist largely of intercalated high-Al and normal-Al mafic volcanic flows, with minor high-Mg units. The geochemical signature of the Wasekwan Group metavolcanic rocks is similar to that of modern IAT;

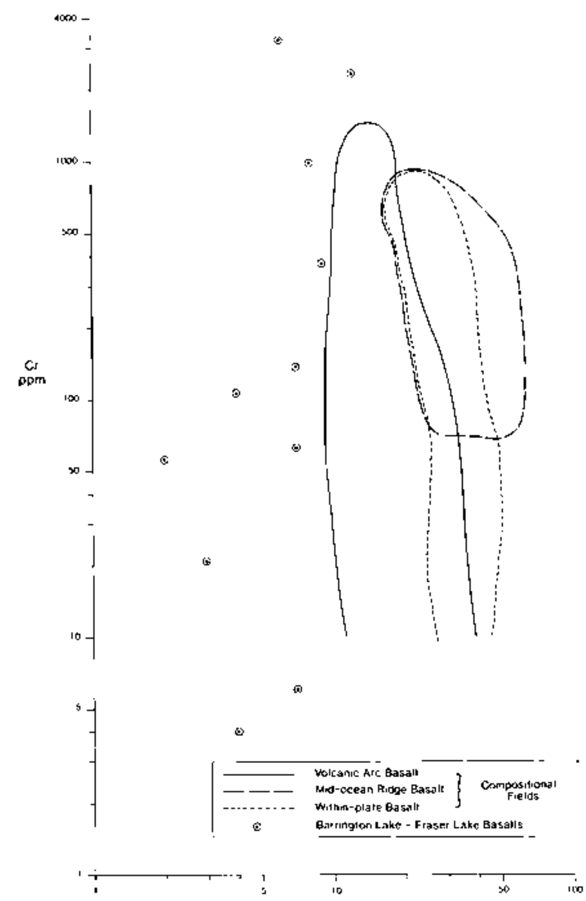


Figure 99: *Cr vs. Y for Barrington Lake-Fraser Lake area basalts. Compositional fields of modern basalts are from Pearce (1982).*

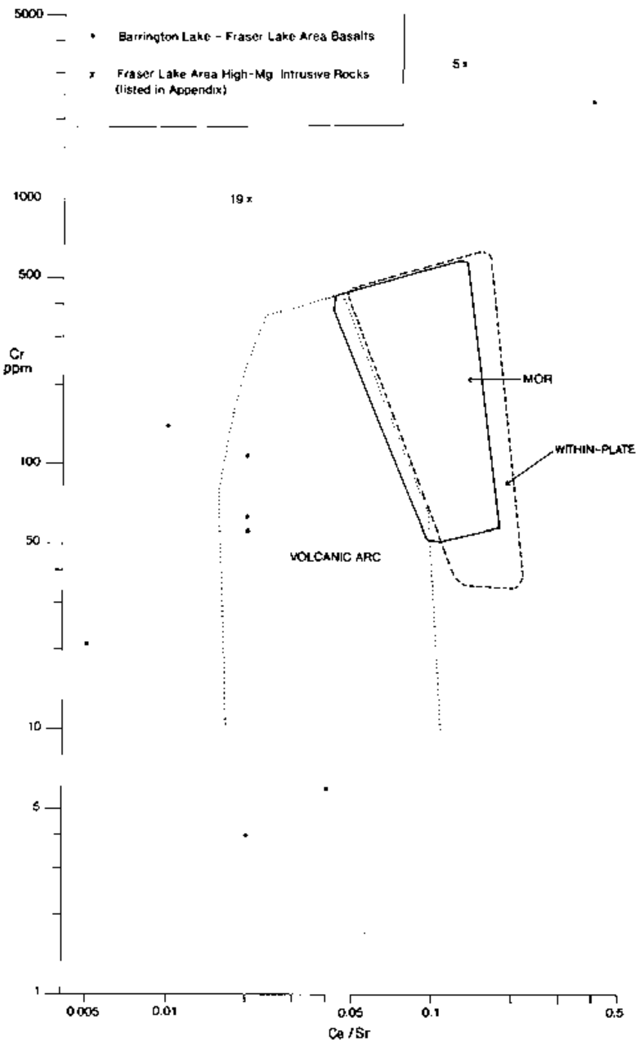


Figure 100: Cr vs. Ce/Sr for Barrington Lake-Fraser Lake area basalts. Compositional fields of modern basalts are from Pearce (1982).

this correlation is established by major, minor and trace element levels and distinctive element ratios.

Strongly depleted REE and transition metals, and decoupling of LIL- and HFS-element groups are also comparable to the patterns of modern arc volcanic rocks. Low Ni and Cr contents indicate olivine and pyroxene fractionation were important in the evolution of the source magma; Ti and P anomalies are characteristic of all Barrington volcanics and possibly reflect accumulations of magnetite and apatite respectively; Eu anomalies, which occur in a minority of the sample population, reflect variations in plagioclase phenocryst content. Significantly greater depletion of HFS elements in Barrington volcanics compared with rocks in the northern belt in the Lynn Lake area probably reflects less fractionation and/or a higher degree of partial melting in the development of the source magma, assumed to have originated in the ancient equivalent of the mantle wedge of the modern island arc setting.

Investigation of trace element depletion in the Barrington volcanics reveals similarities with the low HFS-element group of rocks in the modern Fiji arc, which is probably considerably younger than the basal part of the Fiji volcanic sequence (Gill, 1987). The inference for Barrington volcanics to have an equivalent relative position in the regional stratigraphy is consistent with the interpretation that the northern belt in the Lynn Lake area, considered to be roughly time equivalent to the Barrington volcanics, is younger than the volcanic and sedimentary rocks that compose the southern belt (Gilbert *et al.,* 1980).

A komatiite flow near the southeast corner of Barrington Lake is considered to be part of the eastern extension of the Agassiz Metallotect (Fedikow, 1984); minor high-Mg intrusive units further east at Magrath Lake are possibly related to the komatiite flow.

The major part of the Lynn Lake greenstone belt is tholeiitic, with localized development of calc-alkaline volcanic sections in the west and central parts of the belt (Gilbert *et al.,* 1980). This pattern is similar to some modern island arcs, where TH plus CA volcanic sections are laterally gradational with TH-only sections (Miyashiro, 1974).

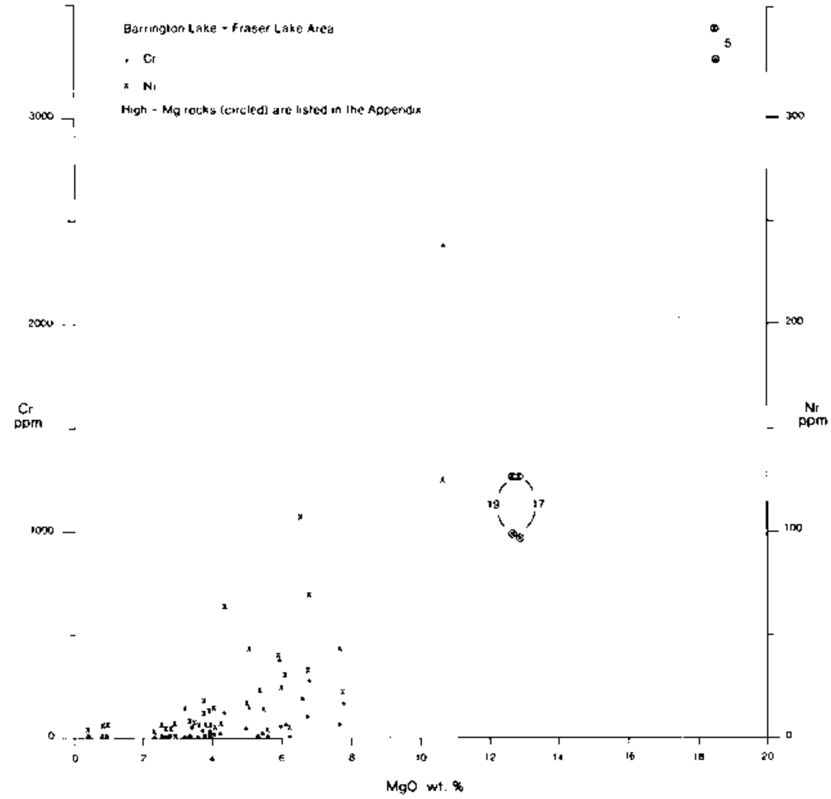


Figure 101: MgO vs. Ni, Cr for Barrington Lake-Fraser Lake area rocks.

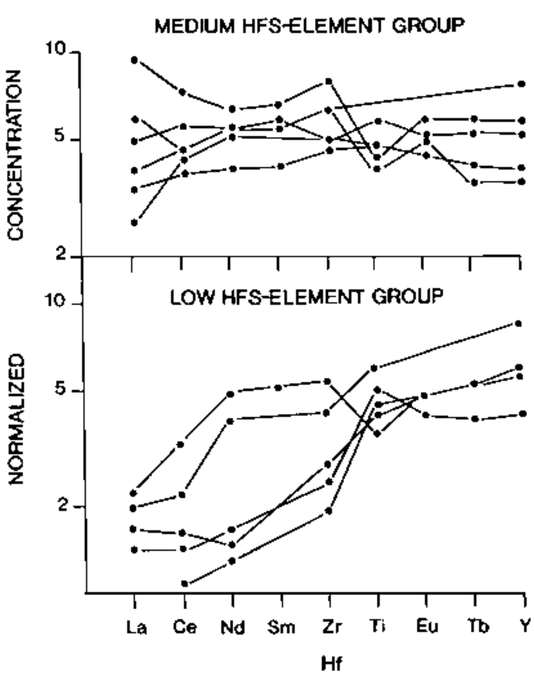


Figure 102: Normalized trace element concentrations of the medium HFS-element and low HFS-element rock groups (Gill, 1987, p. 600).

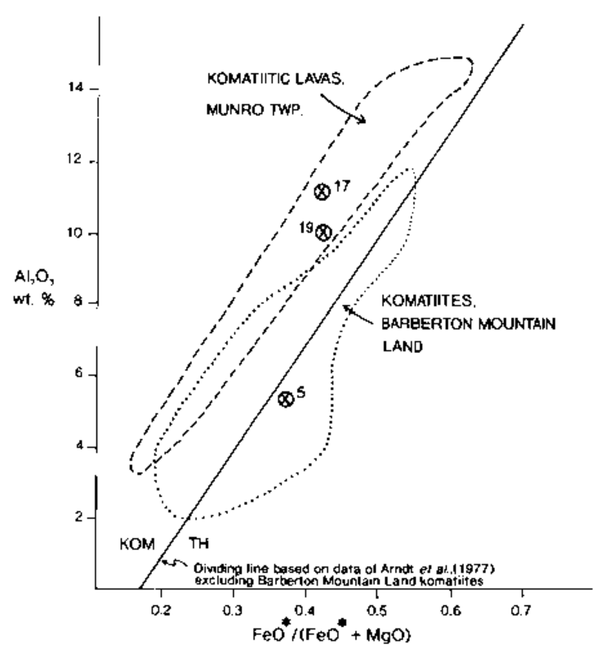


Figure 103: Al_2O_3 vs. FeO/(FeO* + MgO) for Barrington Lake-Fraser Lake area high-Mg rocks (crosses), listed in the Appendix. Komatiitic fields based on data in Arndt et al. (1977).*

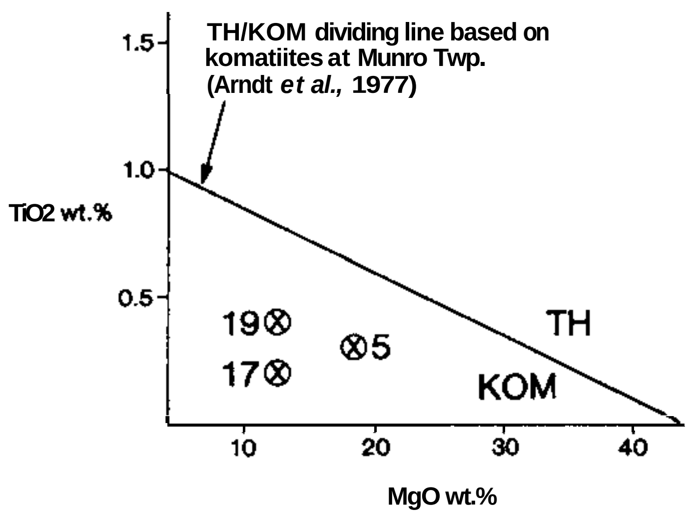


Figure 104: *TiO_2 vs. MgO for Barrington Lake-Fraser Lake area high-Mg rocks (listed in the Appendix).*

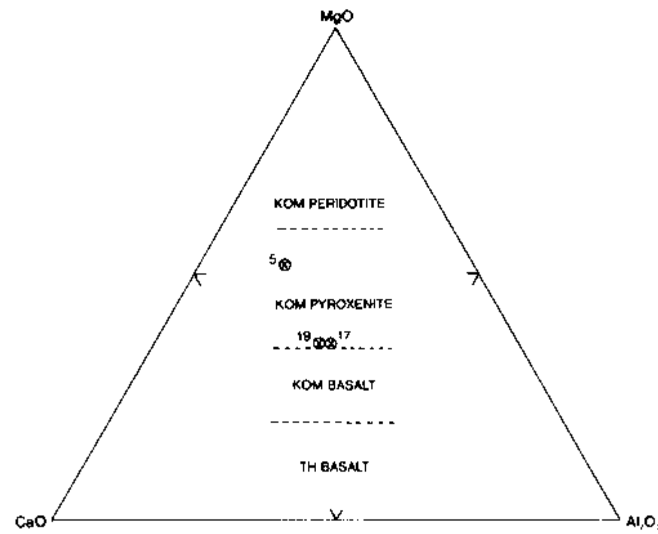


Figure 105: *CaO-MgO-Al_2O_3 ternary plot of Barrington Lake-Fraser Lake area high-Mg rocks (listed in the Appendix). Komatiitic (KOM) and tholeiitic (TH) fields are based on compositions of Munro township extrusive rocks (Arndt et al., 1977).*

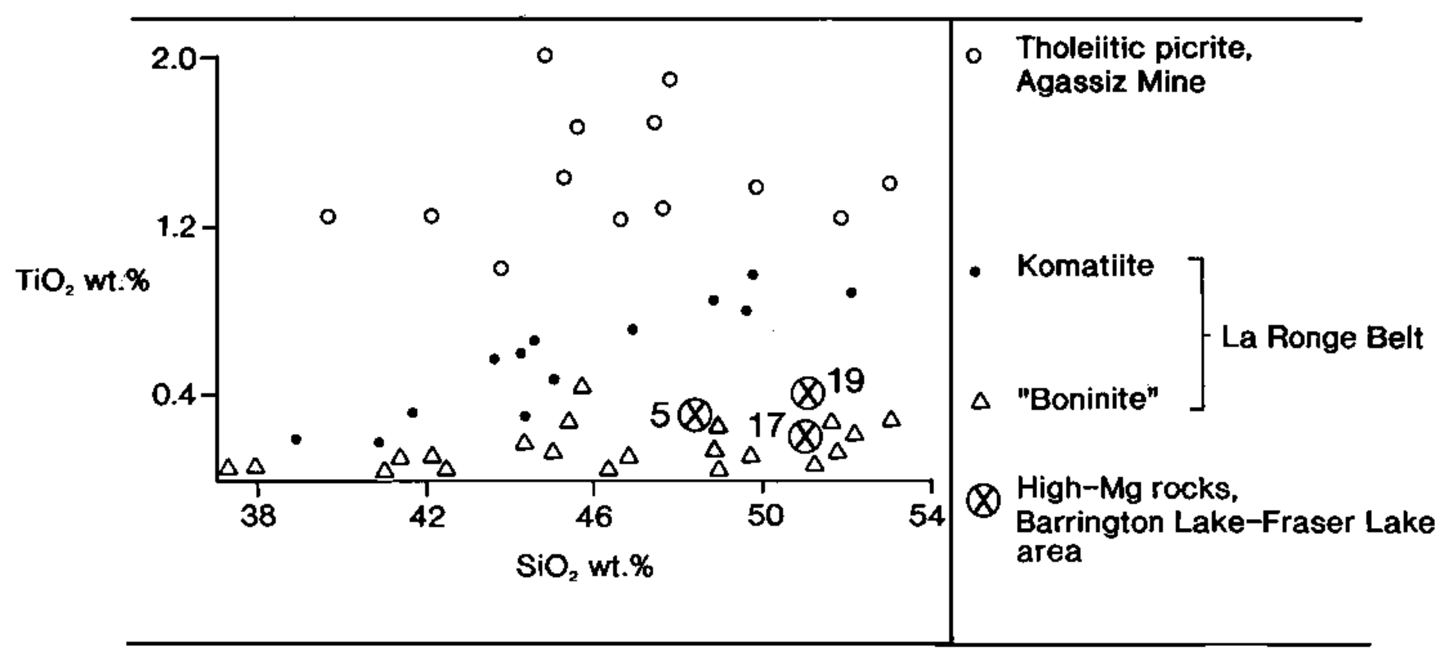


Figure 106: *TiO_2 vs. SiO_2 plot of high-Mg rocks in the La Ronge and Lynn Lake metavolcanic belts. Data are from Fox and Johnston (1980), except Barrington Lake-Fraser Lake area high-Mg rocks (listed in the Appendix).*

Table 23: Hlgh-Mg intrusive rocks at the west shore of Magrath Lake narrows

Sample number	Map-unit number	Thickness (m)	Host rocks	Petrography
5	10d	1.5	Intermediate to felsic paragneiss with subordinate intercalated units of amphibolite and porphyritic granodiorite.	Fine- to medium-grained hornblendite with tremolitic amphibole, minor magnetite, and vermicular aggregates of secondary hematite. Fine opaque inclusions outline pyroxene precursors within amphiboles.
19	10c	3	Same as sample 5.	Fine- to medium-grained hornblende-plagioclase-clinopyroxene gneiss.

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APPENDIX

The Appendix lists 39 whole rock chemical analyses of Wasekwan Group volcanic rocks in the Barrington Lake-Fraser Lake area. Twenty four samples were collected by the author in 1979 and 1980, and fifteen by H.V. Zwanzig in 1974. Samples are listed in order of increasing quartz content. Samples are identified by a column number (1 to 39) and a field sample number (*e.g.* 616-8). Brief descriptive notes are provided for each sample under the analytical data. Locations of samples are shown on Map GR87-3-4.

Major and minor element analyses (SiO_2 to Ba) were undertaken by the Manitoba Energy and Mines Analytical Laboratory; trace elements and rare-earth elements (Th to Lu) were analyzed by Activation Laboratories Ltd. Atomic absorption spectroscopy was employed for the following elements: Mn, Mg, Ca, Na, K, Ni, Cr, Cu, Zn, Rb, Sr and Ba. FeO was measured by titration, and SiO_2, TiO_2, Al_2O_3, FeO* (total iron) and P_2O_5 were determined by colorimetry. H_2O was determined by the Penfield moisture method; S and CO_2 were measured in an induction furnace. The following elements were determined by induced neutron activation analysis: Th, U, Ta, Hf, La, Ce, Nd, Sm, Eu, Tb, Yb and Lu. X-ray fluorescence was used to measure Zr and Y.

The value listed as "OTHER" was calculated by the Manitoba Energy and Mines Analytical Laboratory as the sum of the analyzed trace elements in oxide form. Analytical precision and detection limits for the various oxides and elements are given in the following tables.

Table of analytical precision and detection limits for Manitoba Energy and Mines Analytical Laboratory

Oxide or element	Concentration range (%)	Absolute precision (%)	Detection limit (%)
SiO_2	30.00 - 80.00	±0.50	not det.
TiO_2	0.01 - 2.50	±0.05	0.02%
Al_2O_3	3.00 - 25.00	±0.30	not det.
FeO^*	0.10 - 20.00	±0.10	0.05%
FeO	0.05 - 20.00	±0.05	0.15%
MnO	0.01 - 1.50	±0.02	0.01%
MgO	0.40 - 40.00	±0.30	0.02%
CaO	0.40 - 20.00	±0.20	0.02%
Na_2O	0.10 - 10.00	±0.20	0.01%
K_2O	0.10 - 10.00	±0.20	0.01%
P_2O_5	0.01 - 1.00	±0.03	0.01%
H_2O	0.01 - 7.00	±0.10	0.02%
S	0.01 - 0.40	±0.02	0.004%
CO_2	0.00 - 6.00	±0.10	0.01%

Element	Detection limit (ppm)
Ni	3
Cr	4
Cu	1
Zn	1
Rb	2
Sr	3
Ba	10

Table of detection limits of trace and rare earth elements for Activation Laboratories Ltd.

Element	Detection limit (ppm)
Th	0.10
U	0.10
Ta	0.30
Hf	0.20
Zr	5.00
Y	2.00
La	0.10
Ce	1.00
Nd	3.00
Sm	0.01
Eu	0.05
Tb	0.10
Dy	0.50
Yb	0.05
Lu	0.01

Table of whole rock chemical analyses

	1 616-8	2 906-4	3 1121-2	4 1118-1	5 466-2	6 437-1	7 55-3	8 215-1
SiO_2	44.40	44.70	46.55	47.85	48.40	48.60	48.90	49.25
TiO_2	1.07	1.18	0.44	0.77	0.30	0.75	0.48	0.62
Al_2O_3	12.51	15.31	23.66	16.06	5.48	18.65	18.00	18.94
Fe_2O_3	2.86	4.58	1.88	1.45	6.74	3.17	1.74	3.38
FeO	13.24	13.35	6.36	11.70	4.79	7.12	9.15	7.65
MnO	0.38	0.27	0.14	0.24	0.19	0.17	0.17	0.20
MgO	10.66	6.22	3.45	7.64	18.53	5.08	6.75	4.04
CaO	10.71	11.38	11.43	9.78	11.92	10.28	11.24	12.50
Na_2O	1.02	1.11	2.59	1.72	0.70	3.20	1.20	1.63
K_2O	0.28	0.22	1.01	0.54	0.15	0.85	0.17	0.30
P_2O_5	0.07	0.06	0.07	0.08	0.09	0.08	0.06	0.08
H_2O	2.38	1.67	1.78	2.21	2.35	1.42	1.78	1.16
S	<0.003	0.14	<0.003	0.02	<0.003	0.01	0.01	<0.003
CO_2	0.13	0.07	0.07	0.08	0.25	0.17	0.05	0.12
OTHER	0.41	0.06	0.12	0.08	0.55	0.13		0.06
O = S		0.06		0.01				
TOTAL	100.12	100.26	99.55	100.21	100.44	99.68	99.70	99.03
Ni	125	6	14	43	342	43	33	6
Cr	2370	4	21	63	3280	139	107	17
Cu	6	170	13	162	38	118	100	21
Zn	273	149	70	104	97	101	100	97
Rb	<10	12	32	6	<2	14	<10	4
Sr	10	125	400	140	45	420	<100	225
Ba	70	70	440	130	50	210	49	160
Th	0.3	<0.1	<0.1	0.3	0.3	0.3	0.2	
U	<0.1	<0.1	<0.1	0.2	0.4	<0.1	<0.1	
Ta	0.5	0.6	0.6	0.5	<0.3	0.6	0.7	
Hf	0.8	<0.2	<0.2	<0.2	0.5	0.4	0.3	
Zr	47	15	10	29	24	23	22	
Y	12	4	3	7	6	7	4	
La	1.1	0.6	1.0	1.0	2.8	2.3	0.9	
Ce	4	2	2	3	6	6	2	
Nd	3	1	1	2	4	4	2	
Sm	1.4	0.55	0.48	0.85	0.92	1.1	0.6	
Eu	1.1	0.39	0.22	0.4	0.24	0.54	0.26	
Tb	0.4	0.2	0.1	0.2	0.2	0.2	0.2	
Dy	2.5	1.1	0.8	1.7	1.2	1.5	1.2	
Yb	1.31	0.82	0.49	0.9	0.82	0.87	0.65	
Lu	0.19	0.13	0.08	0.14	0.13	0.14	0.1	
FeO^*	15.81	17.47	8.05	13.00	10.85	9.97	10.72	10.69

1 618-8 Fine grained hornblendite (1a), 3 m thick, interlayered with basalt and intermediate to mafic tuff.

2 906-4 Porphyritic, hornblende-rich basalt (1a2) with plagioclase phenocrysts (15%), interlayered with aphyric basalt.

3 1121-2 Porphyritic basalt (1a2) with plagioclase phenocrysts (35%), interlayered with aphyric basalt.

4 1118-1 Porphyritic basalt (1a2) with plagioclase phenocrysts (15%) and pseudomorphs after pyroxene phenocrysts (15%), associated with aphyric basalt.

5 466-2 Hornblendite (pyroxenite-derived) dyke (10d), 1.5 m wide, within paragneiss.

6 437-1 Porphyritic basalt (1a2) with plagioclase phenocrysts (25%) and pseudomorphs after pyroxene phenocrysts (10%).

7 55-3 Porphyritic basalt (1a2) with plagioclase phenocrysts (20%).

8 215-1 Porphyritic basalt (1a2) with plagioclase phenocrysts (25%).

	9 **76-1**	**10** **226-3**	**11** **89-1**	**12** **802-5**	**13** **227-3**	**14** **65-1**	**15** **55-1**	**16** **1057-2**
SiO_2	49.55	49.90	50.00	50.20	50.25	50.50	50.65	50.90
TiO_2	0.50	0.48	1.51	1.48	0.57	0.74	0.63	0.65
Al_2O_3	17.40	17.46	14.15	17.07	20.80	16.45	20.85	19.02
Fe_2O_3	2.00	1.58	2.59	4.09	1.78	2.12	2.16	2.66
FeO	9.51	10.02	9.54	9.03	7.76	8.72	7.78	7.82
MnO	0.31	0.31	0.18	0.20	0.17	0.19	0.17	0.27
MgO	6.09	5.98	6.56	3.79	3.95	6.78	3.35	3.73
CaO	10.64	10.84	10.60	9.30	11.06	9.44	10.00	10.55
Na_2O	1.54	1.29	3.00	2.51	2.62	2.87	2.57	1.98
K_2O	0.42	0.33	0.30	0.22	0.29	0.15	0.37	0.68
P_2O_5	0.03	0.05	0.17	0.23	0.06	0.08	0.07	0.08
H_2O	1.56	1.64	1.48	2.18	0.98	1.59	1.39	1.47
S	<0.003	<0.003	0.05	<0.007	<0.007	<0.007	<0.007	0.02
CO_2	0.36	0.22	0.22	0.08	0.13	0.07	0.05	0.26
OTHER		0.05	0.10	0.07	0.04			0.11
O = S			0.02		0.01			
TOTAL	99.75	100.15	100.43	100.45	100.46	99.70	100.05	100.19
Ni	31	26	107	12	14	69	8	181
Cr	65	56	189	13	29	276	12	37
Cu	<40	6	105	83	8	100	100	236
Zn	200	172	102	120	67	100	100	160
Rb		<10	2	2				8
Sr		120	210	315	190			230
Ba		50	105	70	60			180
Th		<0.1						
U		<0.1						
Ta		0.8						
Hf		0.3						
Zr		22						
Y		2						
La		0.8						
Ce		2						
Nd		2						
Sm		0.62						
Eu		0.25						
Tb		0.2						
Dy		1.2						
Yb		0.7						
Lu		0.1						
FeO^*	11.31	11.44	11.87	12.71	9.36	10.63	9.72	10.21

9 76-1 Porphyritic basalt with plagioclase phenocrysts (20%); sample is a clast from mafic to intermediate breccia (1g).

10 226-3 Porphyritic basalt (1a2) with plagioclase phenocrysts (15%) from a massive flow interlayered with flow breccia.

11 89-1 Aphyric basalt (1a1) within a section of interlayered porphyritic and aphyric mafic flows.

12 802-5 Porphyritic basalt (1a2) with plagioclase phenocrysts (20%) associated with aphyric flows and intermediate volcanic breccia.

13 227-3 Porphyritic basalt (1a2) with plagioclase phenocrysts and phenocryst aggregates (30%) and minor (<5%) quartz amygdales, pseudomorphs after pyroxene, and lithic granules.

14 65-1 Sparsely porphyritic basalt (1a2) with plagioclase phenocrysts (<5%).

15 55-1 Porphyritic basalt (1a2) with abundant plagioclase phenocrysts (50%)

16 1057-2 Porphyritic basalt (1a2) with plagioclase phenocrysts (20%).

	17	18	19	20	21	22	23	24
	70-6	**1137-1**	**466-3**	**1099-1**	**73-1**	**595-1**	**964-1**	**230-X**
SiO_2	50.95	51.05	51.15	51.45	51.45	53.00	53.20	54.40
TiO_2	0.20	0.99	0.40	0.41	0.66	0.64	0.99	0.65
Al_2O_3	11.15	16.39	10.11	16.02	18.70	16.10	14.11	16.75
Fe_2O_3	0.97	3.10	2.10	0.86	1.65	1.75	3.63	2.82
FeO	8.27	10.30	7.29	5.55	7.86	10.41	10.87	8.96
MnO	0.20	0.21	0.20	0.13	0.20	0.24	0.23	0.17
MgO	12.85	3.96	12.67	7.76	4.98	5.59	3.61	3.79
CaO	11.67	9.69	12.55	12.68	8.95	9.13	9.15	8.46
Na_2O	0.70	2.20	1.51	2.54	4.04	1.37	2.42	2.99
K_2O	0.21	0.50	0.25	0.27	0.30	0.26	0.38	0.21
P_2O_5	0.02	0.14	0.09	0.04	0.04	0.09	0.15	0.09
H_2O	2.25	1.20	1.82	1.26	0.92	1.55	1.18	1.12
S	0.04	<0.003	<0.003	<0.003	<0.003	0.03	<0.003	0.01
CO_2	0.32	0.07	0.12	1.04	0.05	0.07	0.07	0.08
OTHER		0.12	0.22	0.08		0.03	0.07	0.03
O = S	0.02					0.01		
TOTAL	99.80	99.92	100.48	100.09	99.80	100.25	100.06	100.53
Ni	127	12	126	23	16	4	6	6
Cr	969	25	990	165	43	6	4	6
Cu	<50	220	45	17	<40	33	36	3
Zn	<50	117	120	82	<50	67	103	52
Rb		6	4	2		<10	2	
Sr		230	255	220		90	195	155
Ba		390	110	90		30	270	40
Th			0.3			0.3		
U			<0.1			0.4		
Ta			0.4			0.9		
Hf			<0.2			0.3		
Zr			25			32		
Y			8			7		
La			2.2			1.4		
Ce			5			4		
Nd			3			3		
Sm			1.0			0.98		
Eu			0.31			0.34		
Tb			0.2			0.2		
Dy			1.5			1.7		
Yb			0.94			1.10		
Lu			0.14			0.18		
FeO^*	9.14	13.09	9.18	6.32	9.34	11.98	14.14	11.50

17 70-6 Aphyric basalt (1a1).
18 1137-1 Porphyritic basalt (1a2) with plagioclase phenocrysts (up to 30%), associated with mafic tuff.
19 466-3 Hornblende-plagioclase-clinopyroxene gneiss (10c); 3 m wide dyke within paragneiss.
20 1099-1 Porphyritic basalt (1a2) with plagioclase phenocrysts and phenocryst aggregates (20%) and pseudormorphs after pyroxene (10%).
21 73-1 Sparsely porphyritic basalt (1a2) with plagioclase phenocrysts (<5%).
22 595-1 Aphyric basalt (1a1).
23 964-1 Porphyritic basalt (1a2) with plagioclase phenocrysts (25%).
24 230-X Synvolcanic diabase dyke (1h), 60 cm wide, within mafic volcanic flows and fragmental rocks.

	25 526-1	26 71-1	27 74-1	28 68-2	29 62-1	30 996-1	31 69-1	32 72-1
SiO_2	54.80	54.90	55.20	56.10	57.60	57.70	58.35	59.50
TiO_2	0.95	0.31	0.68	0.36	0.64	0.69	0.45	0.69
Al_2O_3	15.67	15.45	16.45	17.45	17.70	16.49	12.20	13.75
Fe_2O_3	2.52	1.75	2.45	2.52	1.55	2.04	1.55	2.71
FeO	9.04	7.80	8.99	7.46	7.58	5.26	8.24	7.92
MnO	0.19	0.19	0.20	0.18	0.13	0.13	0.18	0.23
MgO	2.79	5.33	4.25	3.43	2.90	4.38	5.88	3.94
CaO	8.64	10.41	7.17	6.67	5.76	7.59	8.76	6.24
Na_2O	3.30	1.92	1.99	3.92	3.54	3.04	1.81	3.86
K_2O	0.63	0.26	0.10	0.64	0.56	1.10	0.58	0.20
P_2O_5	0.10	0.06	0.07	0.06	0.11	0.20	0.08	0.07
H_2O	1.20	1.34	2.19	1.33	1.91	1.37	1.46	0.93
S	0.15	0.03	0.11	0.01	0.16	<0.003	0.01	
CO_2	0.39	0.57	0.19	0.07	0.07	0.05	0.89	0.12
OTHER	0.07					0.14		
O = S	0.06	0.01	0.04		0.06			
TOTAL	100.38	100.35	100.00	100.20	100.17	100.18	100.45	100.16
Ni	4	23	7	6	<6	63	40	<6
Cr	10	8	24	45	12	124	372	<8
Cu	124	100	<50	100	100	36	100	<50
Zn	136	100	200	100	100	110	100	<50
Rb			11			20	17	
Sr	160		<100			365	100	
Ba	130		75			470	180	
Th			0.3				0.3	
U			0.3				<0.1	
Ta			0.8				0.6	
Hf			0.9				0.6	
Zr			46				35	
Y			13				9	
La			2.5				1.8	
Ce			7				5	
Nd			5				4	
Sm			1.5				1.1	
Eu			0.51				0.37	
Tb			0.3				0.3	
Dy			2.5				1.8	
Yb			1.5				1.22	
Lu			0.22				0.19	
FeO^*	11.31	9.37	11.19	9.73	8.97	7.10	9.63	10.36

25 526-1 Porphyritic basalt (1a2) with plagioclase phenocrysts (15%), associated with mafic flow breccia and tuff.
26 71-1 Aphyric andesite (1d).
27 74-1 Andesite : intermediate breccia (1g).
28 68-2 Andesite : intermediate breccia (1g).
29 62-1 Andesite : intermediate breccia (1g).
30 996-1 Porphyritic basalt (1a2) with plagioclase phenocrysts (30%).
31 69-1 Plagioclase phyric andesite : intermediate breccia (1g).
32 72-1 Andesite : intermediate breccia (1g).

	33 75-1	34 801-1	35 515-1	36 1099-2	37 68-3	38 51-1	39 471-1
SiO_2	59.70	60.65	62.70	66.10	68.7	72.35	79.4
TiO_2	0.64	0.99	1.02	0.46	0.49	0.34	0.26
Al_2O_3	16.45	15.96	14.60	13.57	13.20	13.45	11.20
Fe_2O_3	2.90	4.01	1.86	1.13	1.71	1.55	0.16
FeO	6.17	4.68	4.88	4.47	4.10	2.70	1.15
MnO	0.14	0.12	0.15	0.10	0.14	0.05	0.03
MgO	2.58	2.29	3.21	2.63	0.83	0.97	0.40
CaO	7.55	3.20	7.33	6.97	4.37	2.47	3.10
Na_2O	2.85	5.14	2.37	3.05	3.55	4.24	2.91
K_2O	0.30	0.78	0.27	0.21	0.85	1.16	0.50
P_2O_5	0.07	0.24	0.15	0.16	0.13	0.07	0.06
H_2O	0.91	1.61	1.00	0.75	1.08	0.62	0.24
S	<0.003	<0.003	0.007	0.01	0.12	0.02	0.03
CO_2	0.08	0.25	0.20	0.48	1.13	0.07	0.16
OTHER		0.07	0.03	0.04			0.05
O = S							0.01
TOTAL	100.35	99.99	99.77	100.13	100.35	100.05	99.64
Ni	<6	<2	14	4	<6	<6	4
Cr	10	4	<3	<4	<8	<8	6
Cu	<40	21	18	21	100	<40	180
Zn	<50	100	58	48	100	<50	32
Rb		14	<10	2		22	14
Sr		250	160	190		<100	130
Ba		230	40	100		340	100
Th			0.4			0.9	1.2
U			0.5			0.5	0.8
Ta			1.0			1.5	2.0
Hf			1.0			2.3	0.6
Zr			49			117	103
Y			13			23	16
La			1.7			6.4	6.7
Ce			6			15	15
Nd			5			8	8
Sm			1.6			2.5	2.2
Eu			0.62			0.5	0.46
Tb			0.4			0.5	0.5
Dy			2.8			4.0	2.8
Yb			1.59			2.53	1.85
Lu			0.23			0.38	0.28
FeO^*	8.78	8.29	6.55	5.49	5.64	4.09	1.29

33 75-1 Plagioclase phyric andesite (1d).

34 801-1 Porphyritic andesite (1d) with plagioclase phenocrysts (30%) within a section of mafic to intermediate flows and fragmental rocks that are locally highly altered.

35 515-1 Dacite (2a) that contains green hornblende porphyroblasts (15%), interlayered with plagioclase phyric basalt.

36 1099-2 Dacite (2a) associated with porphyritic basalt.

37 68-3 Felsic volcanic breccia (2c).

38 51-1 Rhyolite (2); unit is overlain by intermediate to felsic volcanic breccia.

39 471-1 Porphyritic rhyolite (2b1) with plagioclase phenocrysts (10%) and quartz microphenocrysts (15%), associated with mafic volcanic breccia.