THE GEOCHEMISTRY, MINERALOGY AND PETROLOGY OF THE CROSS LAKE PEGMATITE FIELD, CENTRAL MANITOBA.

by

Alan Anderson

A thesis
presented to the University of Manitoba
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Master of Science
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Dedicated to Deborah Anderson

ABSTRACT

The Cross Lake pegmatite field extends over an area of about 200 km^2 at the western margin of the Sachigo subprovince in central Manitoba. The pegmatites penetrate amphibolite-facies supracrustal rocks that are bordered by granulite-facies rocks to the northwest and upper greenschist-facies terrain to the southeast. The pegmatites and pegmatitic granites comprise narrow linear zones that extend for several kilometres and are parallel to the axial trend of the host greenstone belt. Late granites are rare and occur as small elongated stocks and dikes. Geochemical, paragenetic and textural variations in the pegmatites and pegmatitic granites indicate that they are progressively more fractionated in an easterly direction parallel to decreasing metamorphic grade of the host rocks. The fractionation trend is locally disrupted by vertical dislocations of greenstone belt segments hosting the pegmatites. The field is subdivided into four major series based on paragenetic variations: the Nelson, Minago, Northern and Southern. Geochemical data indicate that the Minago and Southern series are genetically related; probably to a common source at depth. The Northern series is geochemically distinct and was derived from a seperate source. The Nelson series con-

sists mainly of allochthonous anatectic bodies as indicated by the Ba-rich K-feldspars and Ca-Mg-Fe-rich garnets. Highly fractionated granite stocks appear to be offshoots from deep-seated intrusions that are most likely parental to the pegmatitic granites and rare-element pegmatites.

Two types of pegmatite mineralization are recognized: Be-Nb-Ta pegmatites in the Northern series, and Li-Be-Nb-Ta-Sn pegmatites in the Southern series. The pegmatites do not contain sufficient concentrations of rare elements and are to small to be of economic interest at the present time.

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Chapter I

INTRODUCTION

The following study began under the auspices of the Tantalum Mining Corporation of Canada Ltd., and was later funded by the Manitoba Department of Energy and Mines under the Federal-Provincial Interim Mineral Agreement (1983-85).

The discovery of Ta-Nb-Sn oxide mineralization in the spodumene-bearing pegmatites at Cross Lake by TANCO in 1979 indicated the need for a detailed investigation of the pegmatites. A field and laboratory study was conducted by the writer to determine the extent and distribution of the pegmatites and related granitic intrusions, and to document their geochemistry, mineralogy, and petrology.

The primary goals of this study are to define and evaluate pegmatites of potential economic significance and to offer a petrogenetic model for the Cross Lake pegmatites.

1.1 LOCATION AND ACCESS

The granitic pegmatites examined in this study occur within an area of about 200 km^2 in central Manitoba. It extends from the Minago River at latitude 54° 33′ north and longitude 98° 12′ west to the islands north and south of the Cross Lake settlement which lies 72 km north of the north

end of Lake Winnipeg and 120 km south of Thompson (Figure 1).

Regular air flights and a gravel road provide good access to the Cross Lake community from where the pegmatites are accessible to within 20 km by boat.

1.2 PREVIOUS WORK

The first geological investigations in the Cross Lake area were conducted by the Geological Survey of Canada (R. Bell 1879, 1881 and Tyrrell 1900). These early observations were compiled by McInnes (1913). The first geological map of the area was produced by Alcock (1920) at a scale of 2 miles to 1 inch. Reconnaissance mapping at a scale of 4 miles to 1 inch was done by Horwood (1934). Horwood's map includes much of the area examined in this study. The area was remapped by C.K. Bell (1962,1978) at 4 miles to 1 inch and Rousell (1965) at 1 mile to 1 inch.

The late granitoid and pegmatitic intrusions have been briefly described in several previous geological reports (Alcock 1921, Horwood 1934, C.K. Bell 1962, Rousell 1965 and Bannatyne 1973). The rocks containing numerous pegmatite dykes and veins have been collectively referred to as hybrids (Alcock 1921), agmatite (C.K. Bell 1962), and migmatite (Rousell 1965).

Horwood (1935) recognized that the pegmatites are most abundant within, and in the vicinity of, the late granite intrusions. He suggested that the pegmatites crystalized

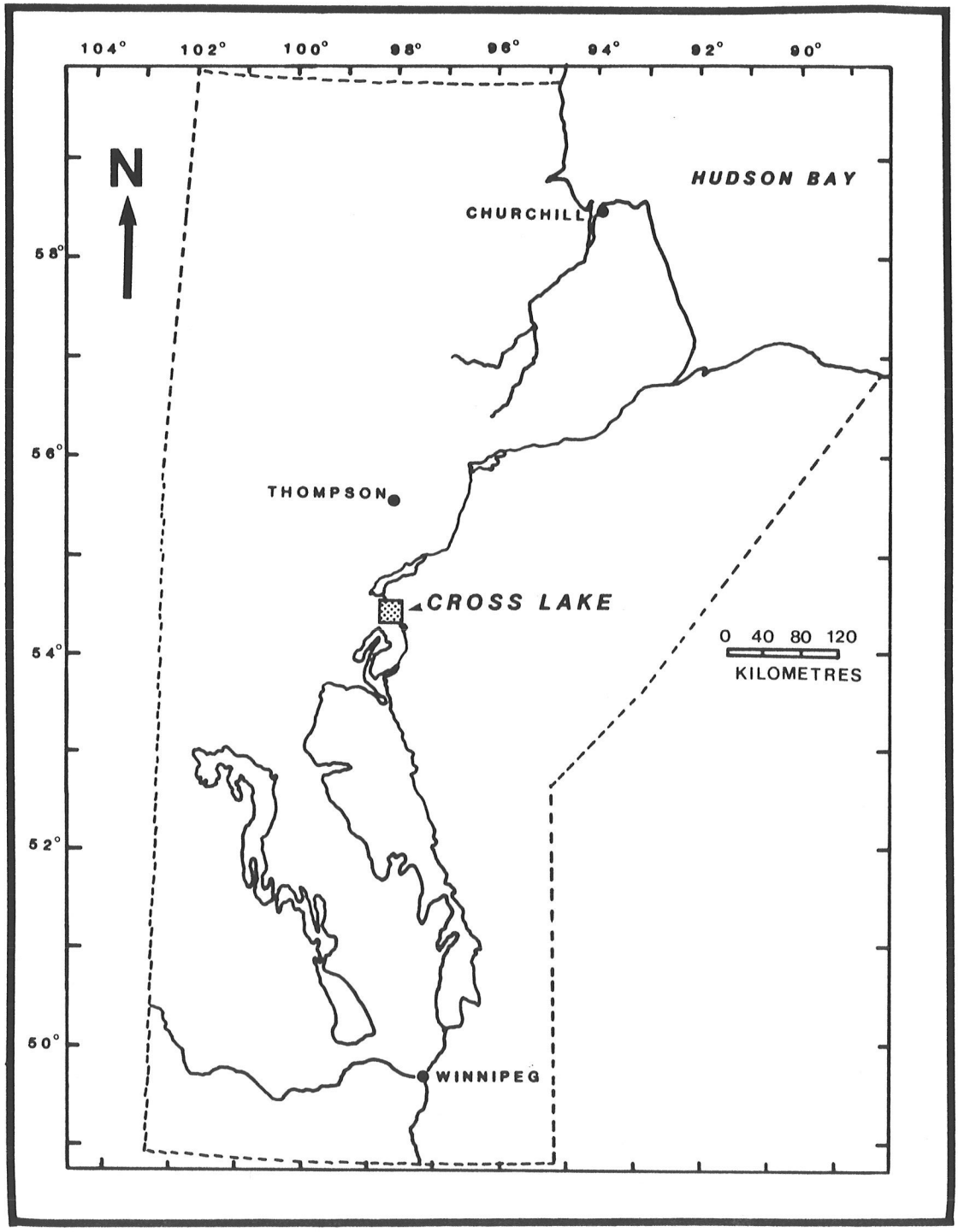

Figure 1: Location map of the study area in central Manitoba.

from a late stage solution enriched in "pegmatitic constituents" that emanated from a granitic mass at depths greater than 4 km. Furthermore, Horwood claimed that the pegmatites intruded rocks that had been previously granitized by an earlier more dilute solution emanated from higher levels of the same granitic body.

Other than minor trenching and prospecting, no exploration of the pegmatites was conducted prior to TANCO's geochemical and drilling program started in 1979.

Chapter II

FIELD AND LABORATORY PROCEDURES

2.1 FIELD WORK

2.1.1 Introduction

The field work was conducted during the months of June and July 1982 and continued during the month of June 1983. Additional sampling of the pegmatites with the aid of explosives was done in September 1983. A total of 3 months was spent mapping, sampling and prospecting 115 pegmatites and 8 spatially related granitoid intrusions. Samples were obtained from drill core and outcrop.

Pegmatites and granitoids were sampled with the aim of collecting those minerals and rocks that would, by their chemistry, mineralogy, and physical characteristics provide information useful for a petrogenetic interpretation and a semi-quantitative economic evaluation of the pegmatite dykes. Rocks and pegmatite minerals that could not be identified in the field were collected for identification in the laboratory.

2.1.2 Mapping of the Granitoids and Pegmatites

The primary concerns in mapping was to establish the distribution and extent of the pegmatite field and neighboring granitoids and to obtain the following data:

(1) Size, shape, attitude, and contact relationships of the individual granite-pegmatite intrusions.

(2) Description of the internal structure of the pegmatites.

(3) Description of tectonic-structural features in the pegmatites.

(4) Identification of the host rocks.

More detailed investigations of the structure and mode of emplacement of the pegmatites and the documentation of the neighboring gneissic terrain is presently being undertaken by the Manitoba Department of Energy and Mines.

2.1.3 Sampling of the Pegmatites

A total of 830 mineral samples was collected from the pegmatites . Minerals sought for chemical analysis were sampled only if they appeared pure, unaltered, and obtainable in sufficient quantity. Common phases such as feldspar and book-type muscovite were sampled evenly over the entire exposed section of any given pegmatite. Accessory minerals such as garnet, apatite and columbite-tantalite were sampled wherever found.

Rock samples were collected from six pegmatitic granites for whole-rock chemical analyses. These samples were obtained only from texturally relatively homogeneous dykes that would yield sufficient (160 kg) fresh and modally representative sample with the aid of a sledge hammer. Rock samples of fine-grained metasomatic assemblages were obtained for thin section observation. One rock sample from a pegmatitic leucosome in the high grade migmatized metasedimentary rock near Hill Lake (54°28′ latitude 98°40′ and longitude) was obtained for geochemical comparison with the pegmatitic granite sample taken near the mouth of the Minago river.

2.1.4 Sampling of the Granitoids and Pegmatitic Granites

A total of 43 samples was collected from the granitoids in the Cross Lake area. Each sample consisted of about 6.0 kg of rock fragments that showed the least degree of visible secondary alteration and inhomogeneties. Samples were collected evenly over the entire exposed section of the body at intervals that varied according to the intrusion's size and rock type. For example, a small seemingly well fractionated granite body containing muscovite, garnet, and abundant K-feldspar was sampled at intervals of <50 metres whereas a large mafic-rich granitoid was sampled at intervals up to 200 metres.

2.2 LABORATORY PROCEDURES

2.2.1 Sample Preparation

2.2.1.1 Minerals

Minerals selected for chemical analyses required seperation of about 2.5 g of unaltered and inclusion-free mineral. Separation of most minerals was done manually with the aid of a binocular microscope. The samples were pulverized in an agate ball and mortar except for the micaceous minerals which were powdered in a tungsten carbide disk mill. The pulverized sample was submitted for chemical analysis after a small portion was retained for X-ray diffraction studies and storage. Garnets and opaque minerals were mounted in epoxy and polished for electron microprobe analyses. Unknown minerals, natural columbites-tantalites, and columbites-tantalites heated for 16 hours at 1000 C° were powdered manually with a mortar and pestle for powder X-ray diffraction studies.

2.2.1.2 Rocks

Preparation of the granitoid rocks for whole-rock chemical analyses involved the following steps,

(1) The removal of weathered and altered edges.

(2) Crushing of the sample down to 1 cm size fragments.

(3) Reduction of the crushed rock, by splitting, to about 500 g.

(4) Pulverizing of the reduced portion in a tungsten carbide disk mill.

(5) Splitting of the finely ground rock material into three 10 g portions.

Slabs were cut from each rock sample for thin sectioning and storage. Thin sections were also made from samples collected from aplite dykes and metasomatic units in complex pegmatites.

2.2.2 Mineral Analyses

2.2.2.1 AAS

Partial analyses of 325 K-feldspars, 104 muscovites, 46 beryls, and 16 spodumenes by atomic absorption spectrophotometry was done in the Manitoba Department of Energy and Mines laboratory, and in the geochemical laboratory of Ecole Polytechnique in Montreal. The elements analysed for in different species are given in (Table 1).

TABLE 1

Elements determined for different mineral species analysed by atomic absorption spectrophotometry.

	Na	K	Ca	Mg	Mn	Fe	Be	Li	Cs	Rb	Sr	Pb	Ba
K-feldspar	*	*	*			*		*	*	*	*	*	*
Muscovite	*	*	*	*	*	*	*	*	*	*			
Beryl	*	*	*		*	*		*	*	*			
Spodumene		*	*		*	*		*					

A 0.5 g portion of powdered mineral sample was weighed into a teflon beaker then 15 ml of HF and 2 ml of $HClO_4$ were added. The solution was heated over a steam bath for about 16 hours then was reduced to less than 2 ml on a hot plate and 1 ml of HNO_3 was added. After 15 minutes, 2 ml of HCL was added and the beaker was placed on a steam bath for 90 minutes. The sample was made up to 100 ml and stored in a nalgene bottle.

Solutions were also made by disolving beads of fused K-feldspar+lithium metaborate-tetraborate in an acid solution.

All solutions analysed by the Manitoba Department of Energy and Mines laboratory were done on a Varian AA975 instrument. National Bureau of Standards rock samples and previously analysed K-feldspars, micas, beryls, and spodumene were run as standards with each batch.

At the Geochimie Analytique, Ecole Polytechnique in Montreal, micas, K-feldspars and spodumenes were dissolved in a mixture of HF, $HClO_4$ and HNO_3 and analyzed by atomic absorption flame spectrophotometry. Beryls were dissolved in a mixture of HF and HCl at high temperature and pressure in a teflon bomb and then were treated and analyzed in the same manner as the other mineral species. Standards SY2 and MRG1 supplied by the Canadian Reference Material Commitee, and DRN supplied by CRPG in Marseilles, France were used.

2.2.2.2 Electron Microprobe Analysis

Chemical analyses of 72 Nb-Ta oxide mineral grains, 57 garnets, 4 cassiterites, and 4 unknown metamict minerals were done by the writer at the University of Manitoba by energy dispersive electron microprobe analysis on a MAC 5 instrument. One to four spots from the center to the edge of the mineral grains were analysed by collecting 200 second-counts at a specimen current of .005 mA at 15 kv.

Garnet and Ta-Nb-Sn oxide mineral standards used for analyses are listed in Table 2.

TABLE 2

University of Manitoba, Department of Earth Sciences electron microprobe standards used for garnet and Ta-Nb-Sn oxide mineral analyses.

	Garnet Standards	Nb-Ta-Sn Oxide Mineral Standards
Mg	Pyrope	-
Al	Spessartine	-
Si	Pyrope	-
Ca	Pyrope	-
Ti	-	Ilmenite
Mn	Spessartine	Manganotantalite
Fe	Chromite	Ilmenite
Sn	-	Cassiterite
Ta	-	Manganotalite

Ilmenite from Ilmenite Mtns. Miask, U.S.S.R.
Manganotantalite from U.S.G.S.
All other standards from the Charles M. Taylor Co., Stanford Cal.

2.2.2.3 Optical determination of Plagioclase

Refractive indices of 65 plagioclase feldspars were measured by the immersion method. Plagioclase grains were immersed in standard Cargille liquids starting at refractive indices of 1.528 and continuing at an interval of +0.002 until the liquid matched the lower value of the (010) or (001) cleavage flake. Plagioclase compositions (An) were derived using the determinative curves of Morse (1968).

2.2.2.4 X-ray Diffraction Studies

Diffractograms obtained from glass-slide powder mounts using a Philips PW 1050/81 goniometer and PW 1729 generator were used for; identification of unknown minerals, determination of unit cell dimensions, and determination of K-feldspar triclinicities. In all work Cu radiation filtered by a Ni monochromator was used.

The values of 2θ were measured from diffractograms run over a range of 10-65° 2θ at a goniometer speed of 6° per minute. Fast scans, used for identification of unknown minerals were ran at a goniometer speed of 30° per minute. Minerals intended for unit cell refinements were powdered and mixed with small portions of annealed CaF_2 (a=5.4620 Å) serving as an internal standard.

Unit cell parameters for 21 K-feldspars, 44 natural columbite-tantalites, and 32 heated columbite-tantalites were refined from the measured 2θ values using the least squares self-indexing computer program of Appleman and Evans (1973).

The peak positions of the 131 and $1\bar{3}1$ were measured from slow X-ray scans between 29-31° 2θ for 265 K-feldspars. Triclinicities were calculated from both computer and manually measured 2θ values using the formula of Goldsmith and Laves (1954)

$$\Delta = 12.5(d_{131} - d_{1\bar{3}1})$$

Where $\Delta = 1$ corresponds to ordered maximum microcline, and monoclinic alkali feldspar has $\Delta = 0$.

2.2.3 Rock Analyses

Modal estimates of the granitic rocks were done by the writer by averaging of 100 point counts for thin sections obtained from each sample.

Whole-rock analyses were done at the University of Ottawa, Department of Geology labroratory; the University of Manitoba, Department of Earth Sciences laboratory; and by the Bondar-Clegg & Co Ltd., Ottawa. All determinations were done by X-ray fluorescence spectrometry except for F, CO_2, H_2O, Be, Cs, Li and Fe^{2+}. A total of 50 whole-rock analyses were done. Table 3 lists the laboratories and their methods of determination for the required major and trace elements in all granitoid rocks submitted.

TABLE 3

Analytical laboratories, methods of analyses, and elements determined for whole-rock analyses of Cross Lake granitic rocks.

Element	XRF	AAS	Titration	Specific electrode	Other
SiO_2	O				
Al_2O_3	O				
ΣFe_2O_3	O				
FeO			M		
MgO	O				
CaO	O				
Na_2O	O				
K_2O	O				
TiO	O				
P_2O_5	O				
MnO	O				
CO_2					M
H_2O					M
S	O				
Ba	O				
Sr	O				
Rb	O				
Y	O				
Nb	O				
Zn	O				
Ni	O				
Cs		M			
Li		M			
Be		M			
Sn	B				
Ga	B				
U	B				
Th	B				
F				B	

B = Bondar-Clegg & Co. Ltd., Ottawa
M = University of Manitoba, Department of Earth Sciences Laboratory
O = University of Ottawa, Department of Geology Laboratory

Chapter III

REGIONAL AND LOCAL GEOLOGY

3.1 THE SACHIGO SUBPROVINCE

The Cross Lake pegmatite field is located at the westernmost margin of the Sachigo subprovince of the Superior province (Figure 2).

Supracrustal rocks of the subprovince occur as thin east-trending bifurcating belts and comprise about 10-15% of the region (Ermanovics et al. 1979). The greenstone belts typically consist of a lower succession of volcanogenic rocks that are overlain mainly by metasedimentary rocks.

About 75% of the subprovince consists of oval shaped masses of plutonic rocks. Of these, two main suites have been recognized (Ermanovics et al. 1979). The first is a layered and foliated augen gneiss of tonalitic, trondhjemitic, and granodioritic composition. These gneisses are considered to be the earliest plutonic rocks in the region. The later suite of plutonic rocks range in composition from quartz diorite to granite and comprise about 25 % of all rocks in the subprovince. The late granitoids vary texturally from massive to weakly foliated (Ermanovics et al. 1979). Migmatitic rocks generally occur between areas of supracrustal and batholithic terranes and comprise about 10% of the subprovince lithologies (Ermanovics et al. 1979).

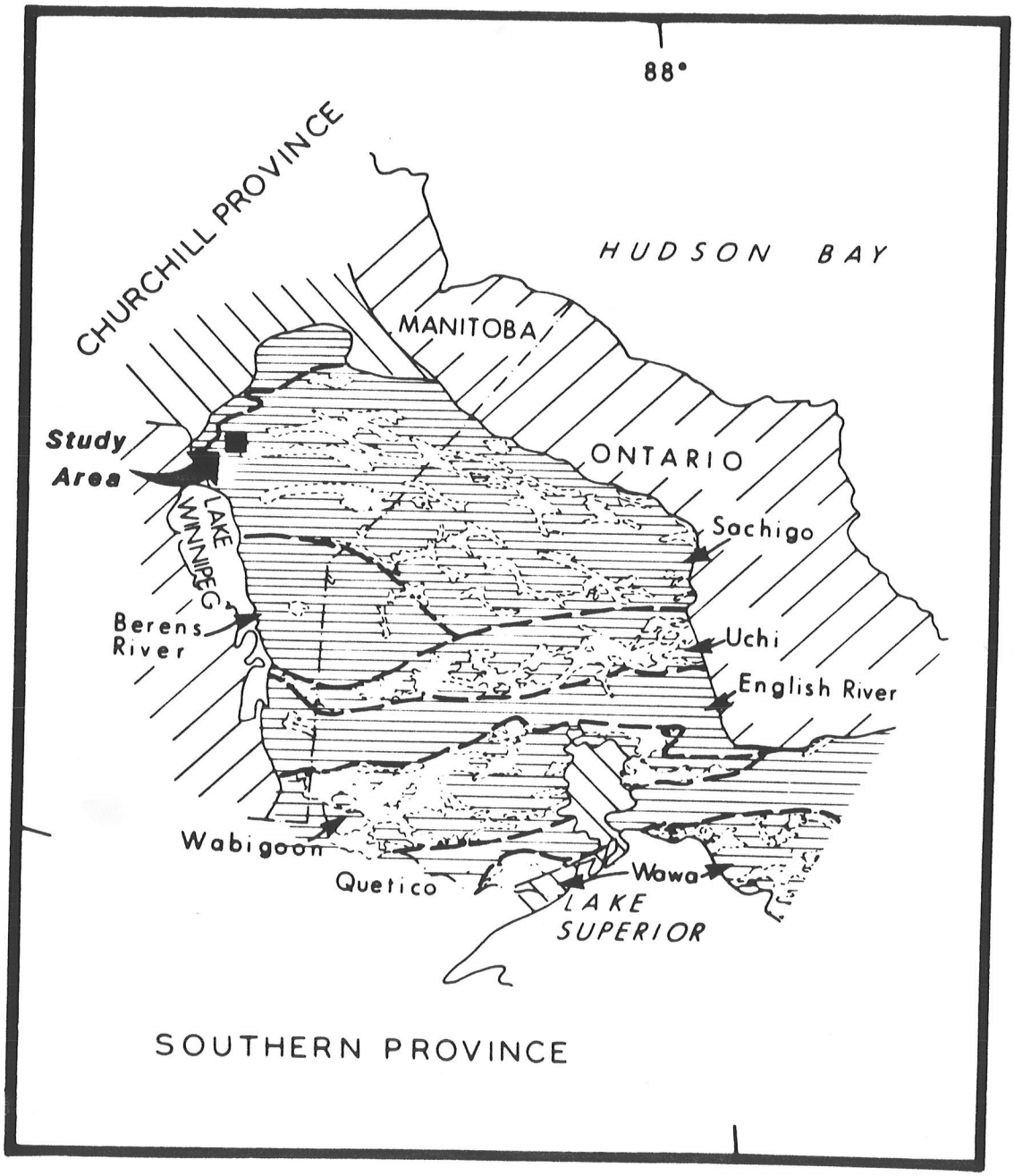

Figure 2: The position of the Cross Lake pegmatite field in the Western Superior province of the Canadian Shield. The horizontal hatching represents granitoid rocks, including plutons, old sialic crust and unspecified gneisses. The blank areas within the Superior province represents metavolcanic-metasedimentary greenstone belts. The heavy dashed boundaries seperate the subprovinces (modified from Douglas 1969).

Whole rock Rb/Sr and U/Pb zircon dates range between 2.7 and 2.8 Ga for both supracrustals and early intrusive rocks of the northwestern Sachigo subprovince (Hubregtse 1980). A late tectonic granite that intrudes the Oxford Lake Group metasedimentary rocks, which are situated about 135 km east of Cross Lake, gave a whole-rock Rb/Sr age of 2455 Ma (±37 Ma) (Cheung 1978).

Available K-Ar dates, however, for the Sachigo subprovince are characteristically younger than the typical Kenoran ages of the Main Superior province to the south (C.K. Bell 1971a, Wanless et al. 1968).

3.2 LOCAL GEOLOGY

The geology of the Cross Lake area is dominated by a greenstone belt in the form of a syncline whose axial trace trends E.N.E. and bifurcates in the vicinity of Cross Island. One limb extends in a northeast direction and the other in an east-southeast direction. The supracrustal rocks of the greenstone belt are flanked by granodioritic and tonalitic gneisses which have been intruded by acidic and ultramafic bodies. All rocks except the Molson dykes, which are considered to be early Aphebian (Ermanovics and Fahrig 1975), are Archean in age.

Figure 3: Simplified geological map of the Cross Lake area, modified after Rousell (1965). 1. Mafic metavolcanic rocks, 2. Metaconglommerate, 3. Metasandstone, metaarkose and metagreywacke, 4. Gneiss complex of tonalitic, granodioritic and granitic affinity, 5. Two-mica garnetiferous granite, 6. Structural lineament, typically associated with areas of deformation, faulting and minor intrusions, 7. Granitic pegmatite and pegmatitic leucogranite dykes.

LEGEND

7

6

5

4

3

2

1

N

0km 1 2 3 4km

CROSS LAKE

CROSS LAKE

CROSS ISLAND

3.2.1 Metavolcanic Rocks

Metavolcanic rocks are exposed in the southern and eastern margins of the study area (Figure 3). Well preserved exposures indicate that the volcanic sequence consists mainly of massive and pillowed mafic flows in the order of a few metres in thickness (Corkery 1983). Primary structures such as flow tops and pillows are generally well preserved in areas of minimal deformation and recrystallization.

The rocks are basaltic in composition and are typically dark grey to green grey in colour. The major minerals are plagioclase and hornblende with lesser and varying amounts of quartz, garnet, pyroxene, biotite, magnetite, and sphene (Rousell 1965). Disseminated pyrite and arsenopyrite occur sporadically in the metavolcanic unit. Oxidation of the sulphides yields gossans that range up to 30 metres in thickness.

3.2.2 Metaconglomerate

Polymictic conglomerates comprise the lower unit of the metasedimentary sequence. They overlie metavolcanic rocks and unconformably overlie granodioritic gneiss at the north end of Cross Island (Figure 4). The basal section of the conglomeratic unit is dominated by a thickly bedded, poorly sorted, matrix-supported conglomerate. The conglomerates are typically bedded on a scale of 1 to 3 metres (Corkery 1983). It is typically composed of a mafic-rich matrix and a highly variable clast composition (Corkery 1983). Con-

glomerates in the upper part of the unit are characterized by a more quartz-rich matrix and bedding in the order of 1 to 4 metres in thickness. Clasts have been locally deformed into ellipsoidal and pancake-like shapes due to varying degrees of tectonic stress.

3.2.3 Metapsammitic and Metapelitic Rocks

A thick sequence of metapsammitic and minor metapelitic rocks overlie the metaconglomerates and comprise about 40% of the rocks in the study area. They are buff-brown to grey in colour and are thickly to thinly bedded. Mapping by Corkery (1983) in the vicinity of the eastern outlet of the Nelson river indicate that metapsammitic rocks range up to 10 metres in thickness. Siltstones are finely laminated to thinly bedded.

The meta-sandstone, arkose, and greywacke are composed mainly of quartz, plagioclase, biotite, and muscovite. The grain sizes range from 0.2 to 2 mm (Rousell 1965). Despite folding and metamorphism, primary sedimentary structures are well perserved (Figure 5).

3.2.4 Ultramafic Intrusions

Small bodies (up to 10 m^2) of layered anorthositic gabbro intrude the metavolcanic rocks in the Islands south of Cross Island. The rock is black to dark green-black and weathers to a dark brown colour. It consists of a fine grained am-

phibole and plagioclase matrix with cumulate layers of plagioclase phenocrysts. The phenocrysts are generally less than 2 cm in size, however, one small exposure in the study area contains ovoid plagioclase megacrysts up to 7 cm in diameter.

The small ultramafic intrusions are possibly related to the Pipestone Lake sill that intrudes the mafic metavolcanics on the south shore of Pipestone Lake (Rousell 1965).

3.2.5 The Gneiss Complex

The gneiss complex surrounds the supracrustal rocks and comprises 30% of the study area. Contacts between the greenstone belt and the gneissic granitoids are both sharp and gradational. The gneissic bodies appear, for the most part, to intrude the supracrustal rocks. However, an unconformity exists between a boulder conglomerate and a biotite granodiorite on the north shore of Cross Island (Figure 4). The boulders are granodioritic and appear to be locally derived.

The gneisses consist of a complex, strongly foliated to massive granitoid complex composed mainly of biotite granodiorite or tonalite. Exposures are typically highly contorted.

The tonalite gneiss is typically grey to pink, medium-grained and equigranular. Its major mineral constituents are oligoclase (average 60 modal %), quartz (average 30 modal %) and biotite (average 10 modal %) (C.K. Bell 1978).

Accessory minerals include apatite, K-feldspar, hornblende, muscovite, zircon, and sphene. Biotite granodiorite gneiss is grey to grey-pink, medium-grained and equigranular. Texturally it ranges from having a gneissic foliation to massive. The major mineral constituents are on average, oligoclase (47% modal) quartz (33% modal), biotite-muscovite (10% modal), and microcline (12% modal) (C.K. Bell 1978). The accessory phases are magnetite, apatite, sphene, epidote, calcite, chlorite, and allanite (Rousell 1965).

Rafts of deformed supracrustal rocks occur sporadically within the gneisses. They are commonly composed entirely of mafic metavolcanic rock.

3.2.6 Mafic dykes

Numerous mafic dykes of the Molson dyke swarm (Scoates and Macek 1978) cross-cut all rocks types in the study area. They are generally less than 2 metres in thickness but range up to 15 meters . The two major trends observed for the mafic dykes in the Cross Lake area are N40°E and N60°W (Rousell 1965). The dykes are ultramafic to mafic in composition and typically contain olivine, clinopyroxene, plagioclase, hornblende, and opaque minerals (Scoates and Macek 1978). The undeformed and unmetamorphosed character of the dykes suggests that their emplacement postdates the major metamorphic and tectonic events in the region. The emplacement of the Molson dykes also postdates the pegmatite dykes as indicated by cross-cutting relationships (Figure 27).

The Molson dyke swarm is considered to represent a major period of Aphebian continental volcanism and magmatism (Scoates and Macek 1978).

3.2.7 Metamorphism

Metamorphic grade increases progressively over a distance of about 40 km from upper greenschist in the vicinity of Pipestone Lake through to granulite facies in the Pikwitonei gneisses adjacent to the western margin of the study area.

Pegmatite dykes of the Cross Lake field are confined to amphibolite grade supracrustal rocks. Within the study area there is an increase in metamorphic grade in a northwesterly direction which is generally parallel to the decreasing textural and mineralogical complexity of the pegmatites. The dashed line shown in Figure 24 indicates the approximate easterly and southeasterly limit of the sillimanite bearing metapsammitic rocks in the study area (see chapter 5 section 6). Sillimanite knots are concentrated along specific lithological horizons and may locally comprise 50% of the rock by volume (Rousell 1965). Farther east, beyond the sillimanite boundary, staurolite occurs locally in the garnetiferous metapelites (Horwood 1935).

3.2.8 Structure

The dominant structural feature in the poly-deformed rocks of the Cross Lake area is a major northeast-trending syncline. The syncline is bifurcated near the western shore of Cross Island where one limb trends in a northeast direction and the southern limb trends east-southeast (Rousell 1965). The supracrustal rocks are tightly folded. Their fold hinges are typically steeply plunging. The major antiformal structures are situated between the northern and southern extensions of the greenstone belt and is occupied by the gneiss complex (Rousell 1965). The mean fold axial plane strikes N70°E and dips 84° (Rousell 1965).

Large scale linear features transect the study area and are interpreted as block boudaries that are typically associated with areas of extreme deformation and faulting (Figure 3).

Numerous joints occur in the greenstones in the southeast third of the study area and have a consistent orientation of N35°W and dips between 80° and vertical (Rousell 1965).

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Figure 4: Unconformity between metaconglomerate and basement biotite granodiorite, on the north shore of Cross Island. The location of the outcrop in this photograph is designated by a triangle in figure 3.

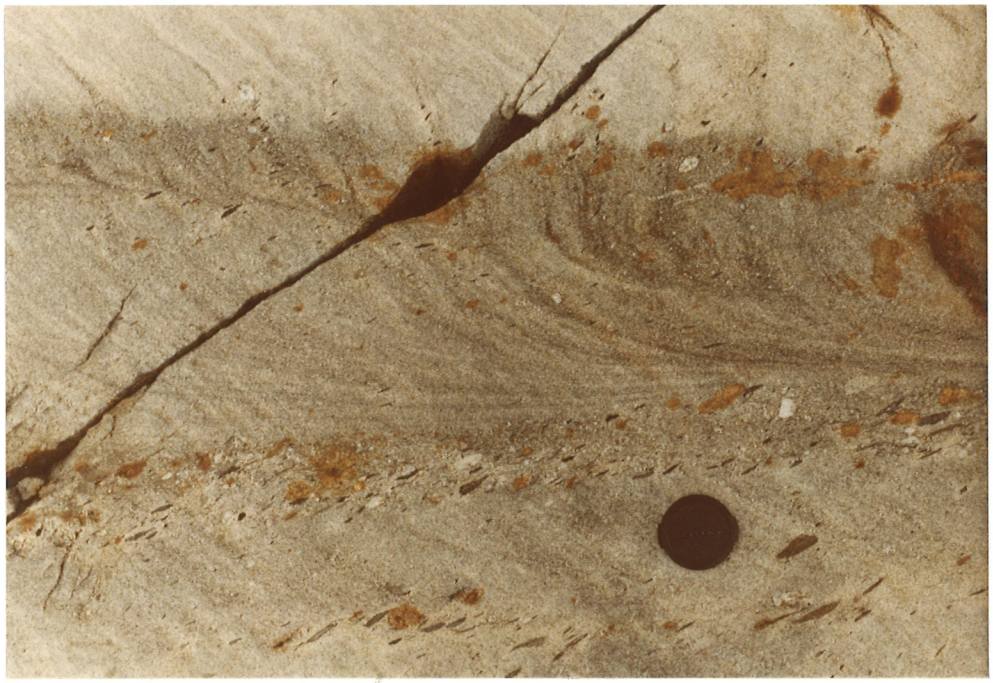

Figure 5: Large scale cross-bedding in metasandstone, south shore of Cross Island.

Chapter IV

GRANITIC ROCKS

Late leucogranites are rare and occur sporadically in the Cross Lake area. They intrude the rocks of the greenstone belt and the gneiss complex in the form of small concordant elliptical stocks and dykes. Several of the granitoids that were mapped as adamelite by Rousell (1965) are indistinguishable from the rocks of the gneiss complex and are clearly unrelated to the late granites. Of the granitic intrusions examined by the writer, only three appear to be characteristic of granites capable of generating rare-element pegmatites (Beus and Stinin 1968). Nevertheless, all granites examined by the writer are described below for comparative purposes.

The individual granite bodies are geochemically dissimilar and have equally diverse textures ranging from massive to strongly schistose. Figure 6 gives the locations of the granites examined in this study. Whole rock sample localities for granites and pegmatitic granites are shown in Figure 7.

The colour assignments used in the rock description below are from the U.S.G.S. rock-colour chart.

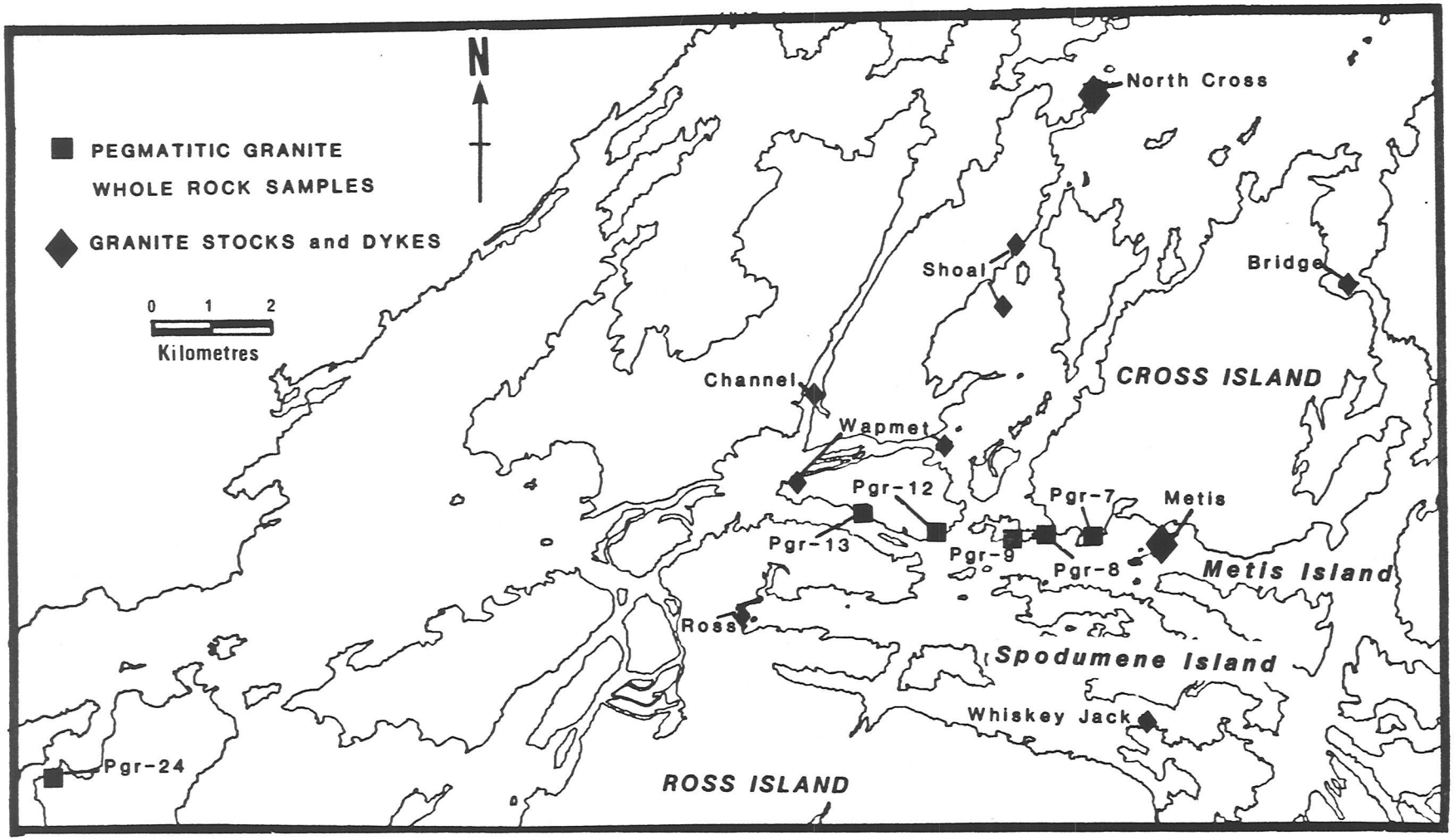

Figure 6: Distribution of granitic stocks and dykes examined, and whole-rock sample localities of pegmatitic granites.

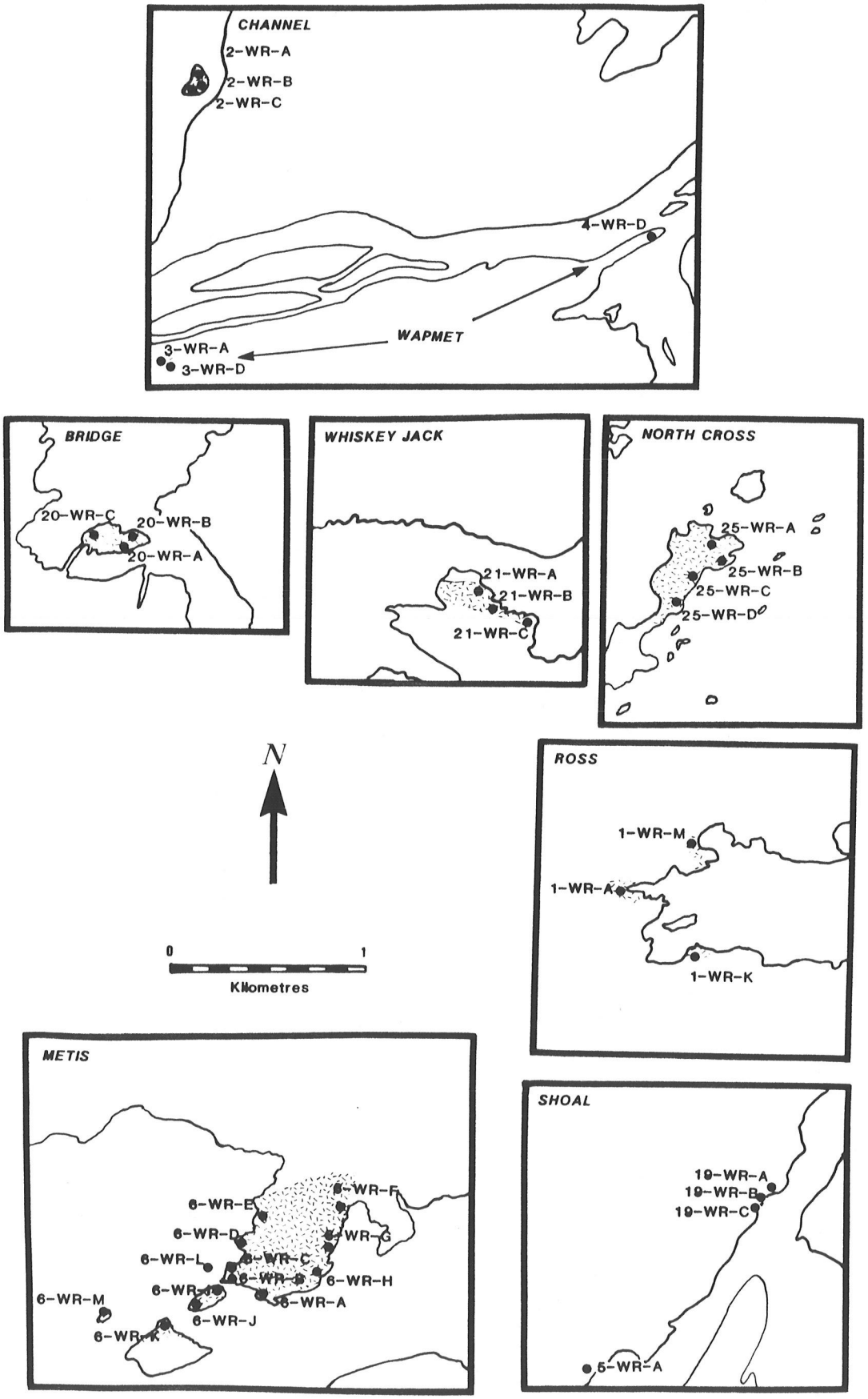

Figure 7: Whole-rock sample locations of granites from Cross Lake intrusions. The location of the granites are given in Figure 6. The scale for the Metis granite map is 1:50,000.

4.1 PETROGRAPHY

4.1.1 The Ross Granite

This granite is in intrusive contact with the metasedimentary-volcanic and gneissic rocks. The size and shape of the body is unknown due to its limited exposure along lake shore-line.

The rock is strongly foliated and grades into biotite-peristerite pegmatite of the Southern series(see p.60 for definition). It is very light grey to white in colour, hypidiomorphic, inequigranular and medium-grained (1.0-3.5 mm).

The major minerals constituents are quartz (32%), plagioclase (22%), K-feldspar (38%), and biotite (8%). Accessory minerals include garnet, tourmaline, chlorite, sericite and epidote.

Quartz is present as clear to cloudy anhedral grains and is commonly interstitial to feldspar. Plagioclase (An 9-14) occurs as subhedral lath-like crystals. Albite and Carlsbad twinning is generally well developed.

K-feldspar occurs as anhedral and subhedral grains. It is locally perthitic and cross-hatched twinning is common. Biotite occurs as subhedral prismatic crystals and is almost always partially replaced by muscovite. Biotite flakes exhibit green to brown pleochroism. Garnet is the most common accessory phase in the granite. Subhedral to euhedral crystals between 0.5 and 1.5 mm in size occur in rows that are

parallel to the schistosity. Sericite is common in microfractures and between the contacts of individual grains.

4.1.2 The Metis Granite

The Metis granite is elliptical in plan and is about 900 metres in its maximum exposed dimension. The major axis is subparallel to the strike of the pegmatitic granite sheets that form a narrow west trending zone of en echelon dykes. It is in sharp intrusive contact with the metapsammitic rocks on the southwest shore of Cross Island. The outer margin of the body is coarser grained and strongly foliated to gneissic in texture. Subtle igneous layering is visible in the outcrop by its slightly more mafic bands that strike at about 170°. The body is cross-cut by simple muscovite +biotite +almandine +tourmaline-bearing pegmatites that range in width between 1.0 and 1.5 metres.

In hand specimen the rock is very light grey to pink in colour. It is moderately foliated and medium-grained (1-3 mm) with a typical hypidiomorphic, inequigranular texture.

The principal minerals are K-feldspar (35%), quartz (25%), plagioclase (27%), muscovite (8%) and biotite (5%). Garnet, tourmaline (Figure 8), apatite, sericite and zircon are present as accessory minerals. K-feldspar occurs as anhedral and subhedral laths that are commonly cross-hatch twinned. Perthitic exsolution is weak to absent. Plagioclase (An 12-16) occurs as elongate anhedral and subhedral

laths. Carlsbad and albite twinning was observed. Quartz occurs as anhedral grains that show slight strain extinction. Inclusions of mica and rounded quartz occur in the plagioclase. Muscovite is the dominant mica in the granite. It occurs as thin prismatic, subhedral crystals which cross-cut the other phases present, indicating a late origin. Muscovite flakes are oriented in two main directions (Figure 9). Biotite occurs as prismatic subhedral laths and is locally partially replaced by muscovite. Zircon inclusions within biotite are common and typically give rise to pleochroic haloes. Garnet is a common accessory phase in the granite (Figure 10). Crystals are subhedral to euhedral and may contain tiny inclusions of muscovite within microfractures. Sericitization is present between grain boundaries but not extensively developed.

4.1.3 The Whiskey Jack Granite

This granite occurs at the contact of the greenstones and the gneiss complex in the form of elongate lit-par-lit sheets. The Whiskey Jack granite is in sharp intrusive contact with a well foliated porphyritic granite and is easily recognizable by its leucocratic and K-feldspar-rich nature. The granite is cross-cut by quartz veins.

The rock is greyish pink in colour. Texturally it is medium-grained (0.5-3.0 mm) weakly porphyritic and hypidiomorphic inequigranular.

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Figure 8: Photomicrograph of accessory tourmaline crystal in the Metis granite. Plane polarized light, (50X).

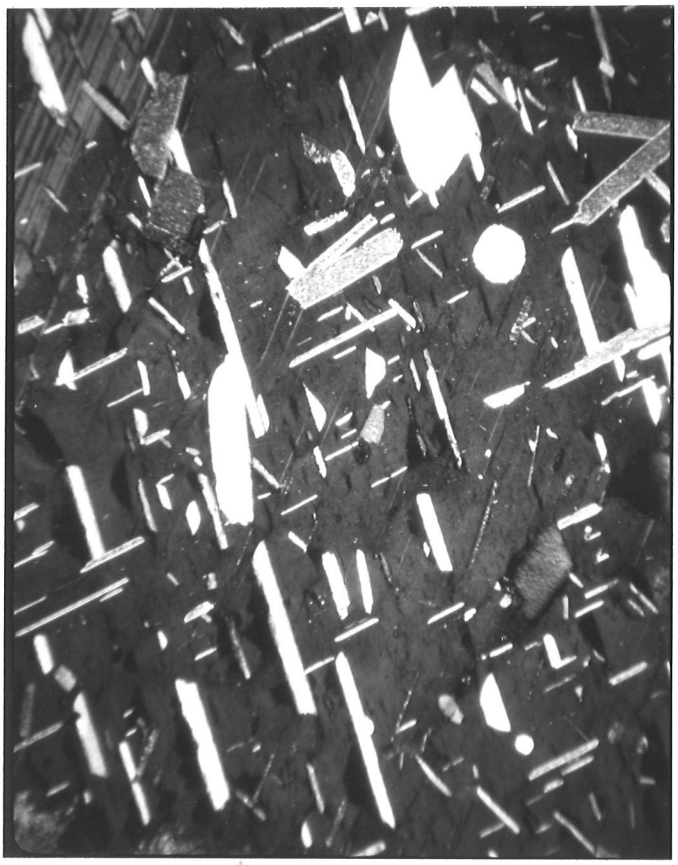

Figure 9: Photomicrograph of oriented muscovite laths in plagioclase from the Metis granite. Crossed nicols, (30X).

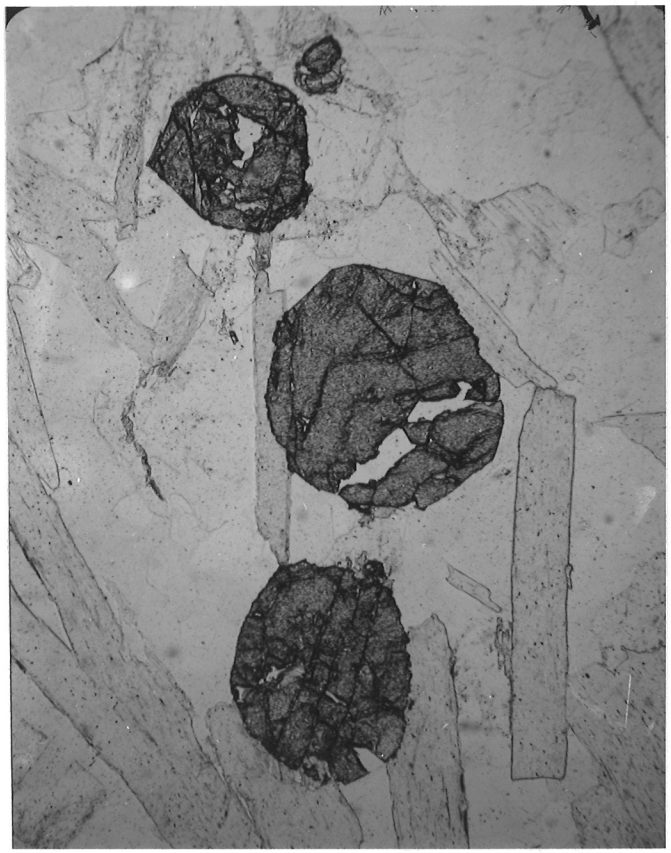

Figure 10: Photomicrograph of garnetiferous, muscovite-rich Metis granite. Plane polarized light, (50X).

The essential mineral constituents are K-feldspar (38%), quartz (28%), muscovite (6%), biotite (4%) and plagioclase (24%). Accessory minerals are garnet, chlorite and opaques. K-feldspar occurs as anhedral and subhedral laths. They are typically cross-hatch twinned and contain rounded quartz inclusions. Subhedral laths of plagioclase (An 9-14) are twinned according to the albite, Carlsbad and pericline laws. Quartz is anhedral, has undulatory extinction and occurs as distinct grains or as rounded inclusions in feldspar. Biotite is red-brown to green. Crystals are anhedral to subhedral and prismatic. Muscovite occurs as subhedral, prismatic crystals up to 3 mm in length. Smaller crystals are often interstitial and occur in cracks cutting the quartz and feldspar. All micas are well foliated parallel to the contacts of the granite and the foliation of the host gneisses indicating that emplacement of the granite predates a major phase of tectonism.

Large subhedral garnets occur in this granite but are relatively rare in comparison to the Metis granite.

4.1.4 The Channel Granite

This granite forms a subcircular stock about 80 metres in diameter. It intrudes the metapsammitic rocks within a northeast-trending zone of deformatiton west of Cross Island. The outer margin of the body is locally pegmatitic.

The rock is greyish pink in colour and is moderately foliated. It is medium to coarse grained (1-5 mm) hypidiomorphic and granular in texture.

The major minerals are K-feldspar (36%), quartz (32%), plagioclase (17%), and minor biotite (5%). Garnets are a relatively abundant accessory phase. Their size ranges up to 2.5 cm in diameter, and are commonly rimmed by biotite (Figure 11). Quartz occurs as rounded grains and as small anhedral inclusions in feldspar (Figure 12). Quartz grains are clear to light grey in colour and show undulatory extinction. K-feldspar occurs as anhedral and subhedral grains. It is locally perthitic and poikilitic. Cross hatch twinning is present. Plagioclase occurs as subhedral laths and shows albite and Carlsbad twinning. Plagioclase is, like K-feldspar, locally poikilitic. Biotite occurs in the form of prismatic flakes or as crystal clots up to 3 cm in diameter.

Sericite replaces plagioclase and is present along grain boundaries.

4.1.5 The Wapmet Granite

This granite consists of small (<4 metres long) tabular bodies within the metapsammitic rocks west of Cross Island (Figure 6). The dykes strike at 100° and 95° and are parallel to the trend of the pegmatitic granite neighboring to the south. Some granites grade into a pegmatitic component.

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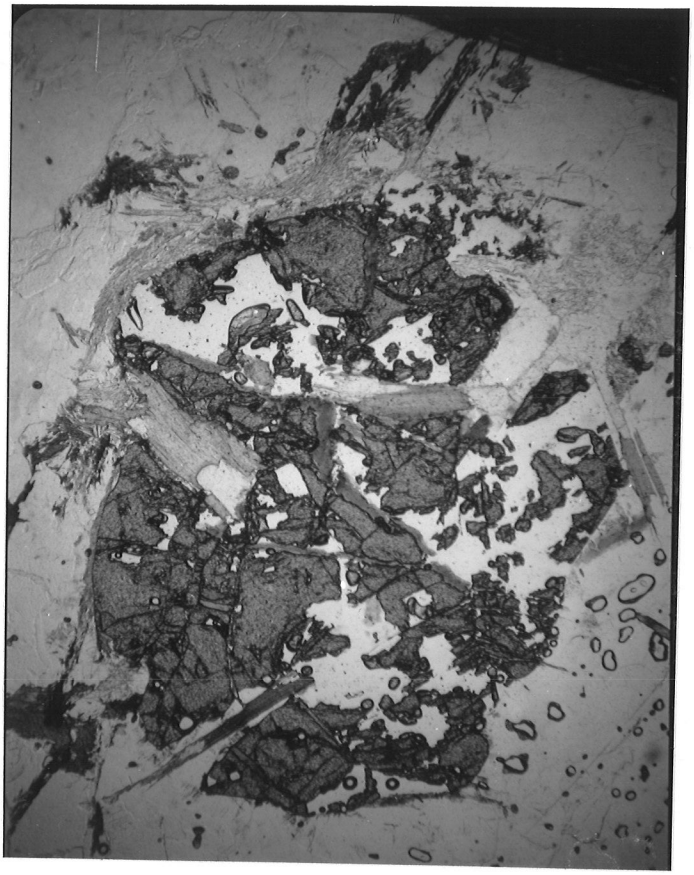

Figure 11: Photomicrograph of almandine in the Channel granite. Note the biotite and muscovite laths surrounding and penetrating the garnet. Plane polarized light, (50X).

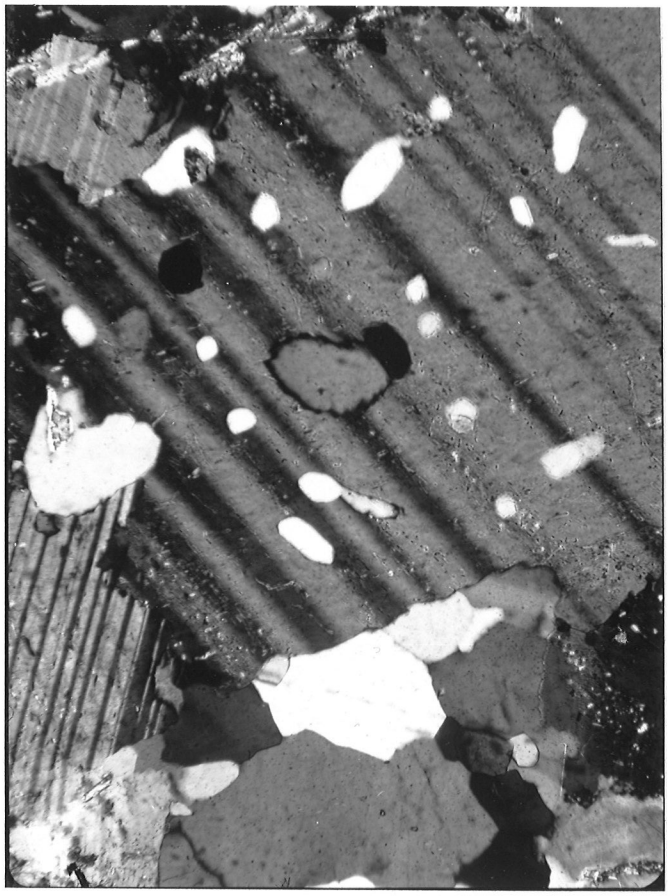

Figure 12: Photomicrograph of poikilitic plagioclase from the Metis granite. Crossed nicols, (40X).

In hand specimen the rock is very light grey to white in colour. Texturally it is medium-grained with minor coarser variants (2-7 mm), hypidiomorphic granular and weakly foliated. The primary minerals are K-feldspar (33%), quartz (32%), plagioclase (25%), and biotite (10%). Garnet, magnetite, epidote and secondary muscovite are the accessory minerals.

The quartz occurs as anhedral grains showing undulatory extinction, and as rounded inclusions in the feldspars. K-feldspar is dominantly microcline and weakly perthitic. It occurs as anhedral and subhedral grains that are typically cross-hatch twinned. Plagioclase occurs as subhedral pokilitic laths. Both Carlsbad and albite twins are present. Biotite is red-brown. It occurs as subhedral prismatic grains that are typically interstitial. Biotite is replaced by muscovite and is associated with epidote.

Garnets occur as anhedral and subhedral crystals. Fractures in the garnets contain chlorite and secondary muscovite. Secondary muscovite is interstitial and occurs as fracture fillings. Individual grains are prismatic and locally form radial clusters.

4.1.6 The Shoal Granite

The rock is light pink in colour. Texturally it is coarse grained to pegmatitic, massive, hypidiomorphic and inequigranular. The major mineral constituents are K-feldspar (35%), plagioclase (29%), quartz (28%) and biotite (7%).

Schorl, almandine, muscovite, zircon and opaques are the accessory minerals.

Quartz is interstitial and occurs as clear to light grey anhedral grains and has undulatory extinction. Rose pink coloured quartz is locally present. Subhedral to anhedral laths of K-feldspar are commonly perthitic and contain rounded inclusions of quartz. Plagioclase (An 12-16) is subhedral to anhedral and is twinned according to the Carlsbad and albite laws. Replacement of plagioclase by muscovite occurs mainly in the calcic rich zones.

The biotite flakes are subhedral and exhibit light brown to dark brown and pleochroism. Zircon inclusions with pleochroic haloes are locally present. Muscovite is secondary in origin, it replaces biotite and is present as fine flakes along grain boundaries; magnetite appears to form at the expense of biotite.

4.1.7 The Bridge Granite

The rock comprising a small island in the channel east of Cross Island was mapped as adamelite by Rousell (1965). In the field it is indistinguishable from the rocks of the gneiss complex and has no observable contact. This granite is most likely part of the older gneiss complex and is unrelated to the garnet, two mica granites described above.

The rock is very light grey in colour, fine to medium-grained (0.1 to 5 mm) hypidiomorphic, inequigranular and well foliated.

The essential mineral constituents are quartz (35%), K-feldspar (27%), plagioclase (22%), muscovite (9%) and minor biotite (4%). Epidote, monazite, zircon, and magnetite are the accessory minerals.

Quartz occurs in granular clusters. The grains are anhedral and have undulatory extinction. Microcline and plagioclase are anhedral and show cross-hatch and Carlsbad twinning respectively. Muscovite is the prominent mica in this rock. It occurs as subhedral prismatic interstitial grains or replacing feldspar and biotite. Biotite occurs as dark green prismatic laths. Epidote occurs in association with muscovite. Magnetite appears to have formed at the expense of biotite.

4.1.8 The North Cross Granite

This granite outcrops northwest of Cross Island (Figure 6). It is one of several exposures of the gneissic complex that occurs between extensions of the northeast arm of the greenstone belt.

In hand specimen the rock is medium grey in colour and has a well defined schistosity. It is porphyritic with a fine grained (0.1-1.0 mm) matrix. The phenocrysts consist of white maximum microcline (Δ =0.92) and seldom exceeds 1.0 cm in maximum dimension. The matrix has a seriate texture and is composed of quartz (35%), K-feldspar (26%), plagioclase (24%), biotite (8%) and muscovite (5%). Magnetite and zircon are the accessory minerals.

Quartz is anhedral with angular edges and shows undulatory extinction. The anhedral K-feldspar is locally perthitic and contains numerous microfractures. Microcline twinning is rare to absent. Anhedral plagioclase is poorly twinned. Biotite is anhedral to subhedral and occurs as laths. It is pleochroic light green to dark brown in colour. Biotite flakes locally contain trace amounts of zircon with pleochroic haloes. Muscovite appears to have formed at the expense of feldspar and biotite. It occurs as subhedral laths with no apparent orientation. Magnetite is a common accesssory and appears to have formed at the expense of biotite (Figure 13).

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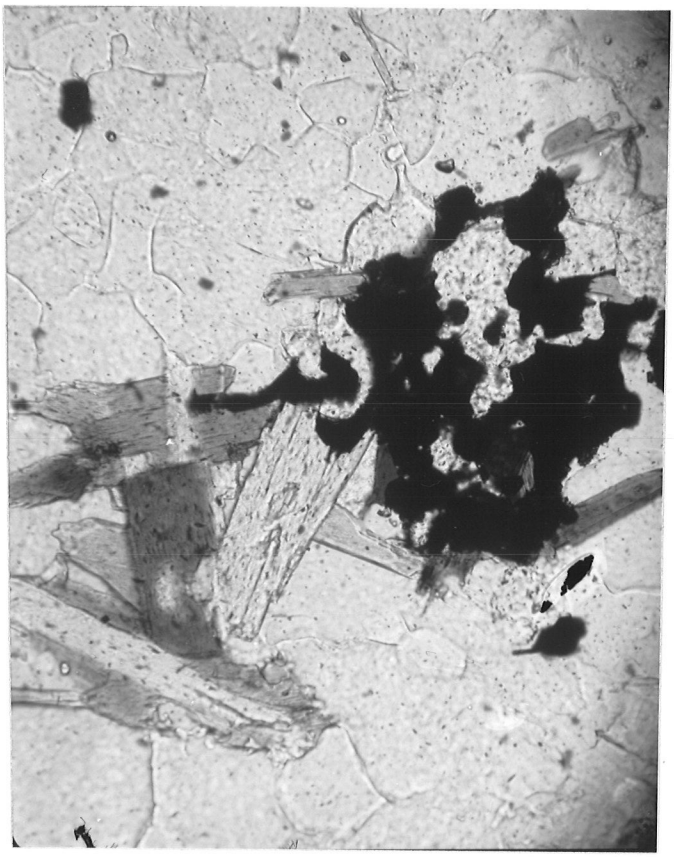

Figure 13: Photomicrograph of the North Cross granite showing biotite and associated magnetite. Plane polarized light, (50X).

4.2 PETROCHEMISTRY

The chemical analyses, C.I.P.W. norms and differentiation indices (D.I.) for the granites, pegmatitic granites, granitoid gneisses and migmatite leucosome are given in Table 24. All of the granites sampled are silicic and peraluminous but otherwise have contrasting chemical compositions.

Figure 72 gives the mesonormatitve compositions of the granites, pegmatitic granites and leucosome in the Ab-Or-Qtz and Ab-Or-An diagrams. Most granites lie on the Or-rich side of the eutectics in the Ab-Or-Qtz diagram.

Two compositional fields are distinguished in the K/Rb vs Rb plot (Figure 14): a field of highly fractionated granites characterised by low K/Rb ratios; and a field of less fractionated granites with K/Rb ratios >200. Although two seperate compositional fields are well defined in the K/Rb vs Rb graph some granites plot within or between both fields. This shows the compositional heterogeneity of some of the granite intrusions examined.

K/Rb ratios of less than 160 indicate advanced fractionation (Shaw 1968). The granites comprising the well fractionated pegmatite field include the Metis, Ross, and Whiskey Jack. These granites have an average K/Rb of about 100 whereas the K/Rb's for the group of less differentiated granites lies between 220 and 400. The Rb values for the pegmatitic granites plot within and between the two fields. The wide range in Rb values in the pegmatitic granites may

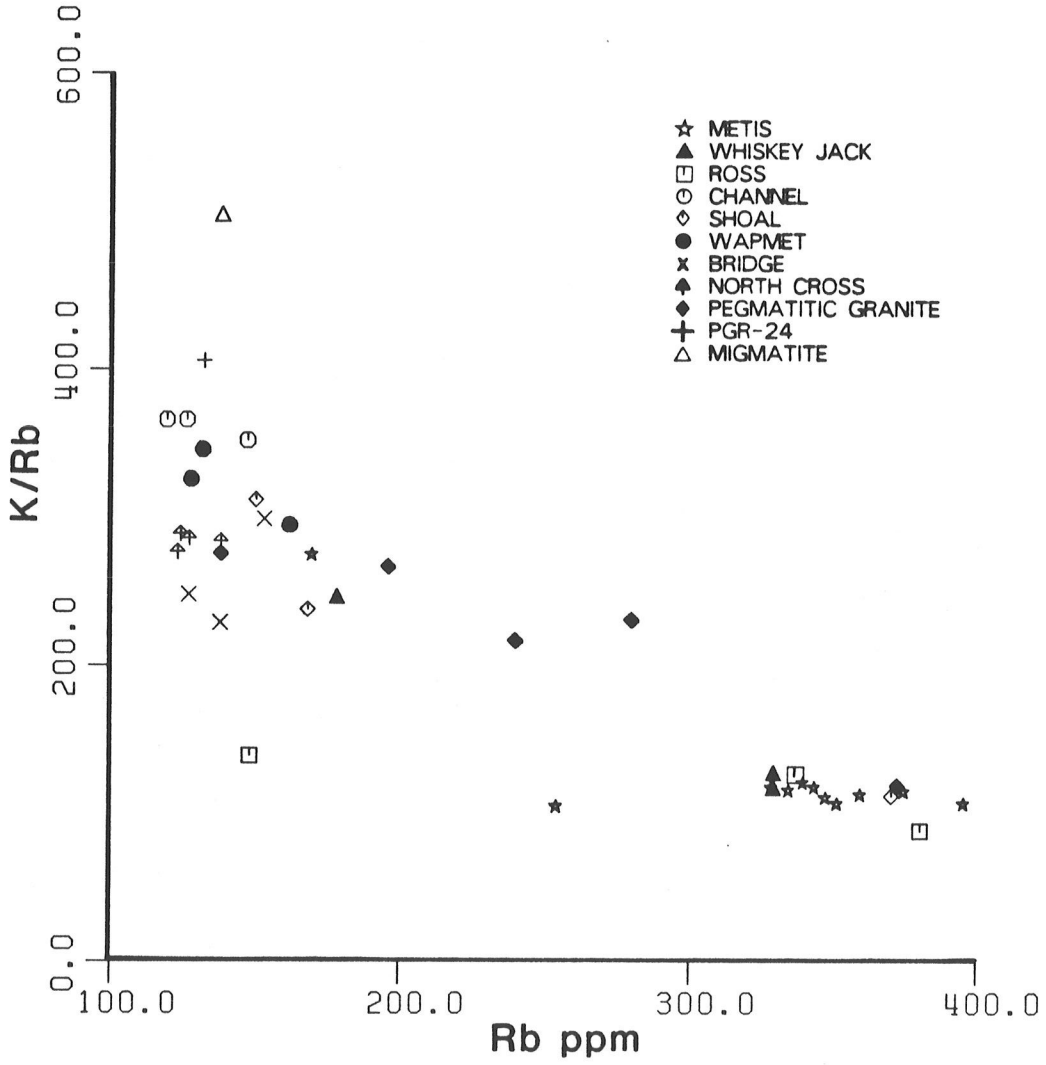

Figure 14: K/Rb vs Rb plot of Cross Lake granites, pegmatitic granites and migmatite leucosome. This plot shows two distinct granite groups: one highly fractionated group with K/Rb <200 and the another less fractionated group with K/Rb >200. The pegmatitic granites plot within and between the two groupings.

be due to the error in estimating and extracting a modally representative sample from the coarse grained rock. Nevertheless, some analyses indicate that the pegmatitic granites near the southwestern shore of Cross Island have attained a high level of fractionation. Whole-rock sample Pgr-24 from pegmatitic granite P-24 at the mouth of the Minago river (Figure 24) has similar Ba and Sr contents and Mg/Li ratio (Figure 21) to the pegmatitic granites at the eastern end of the Minago series, but is clearly less differentiated as indicated by its high K/Rb ratio (Figure 14).

The well differentiated granites have characteristically high Li, Rb, Cs, Ga, Y, Nb, F and Sn, and low Ti, Fe, Mg, Sr, Ca and Ba contents. However, the concentrations of the above elements varies considerably between the different well fractionated bodies. Figure 16 shows K/Rb vs Li ppm for the Cross Lake granites. The plot indicates that the Metis granite has the highest Li values ranging between 90 and 160 ppm. Although it is the most Li-rich granite it is not as enriched in Sn (Figure 20), Nb (Figure 17), F (Figure 18) and Y (Figure 19) or as depleted in Ba and Sr as the Whiskey Jack granite.

The texturally and mineralogically similar Ross and Whiskey Jack granites also have similar compositions, however, the Whiskey Jack granite is more differentiated as evidenced by its Sn, F and Nb enrichment. Figure 15 shows that the Ross and Whiskey Jack granites have the lowest Ba and Sr values. The greater abundance of mica in the Whiskey Jack

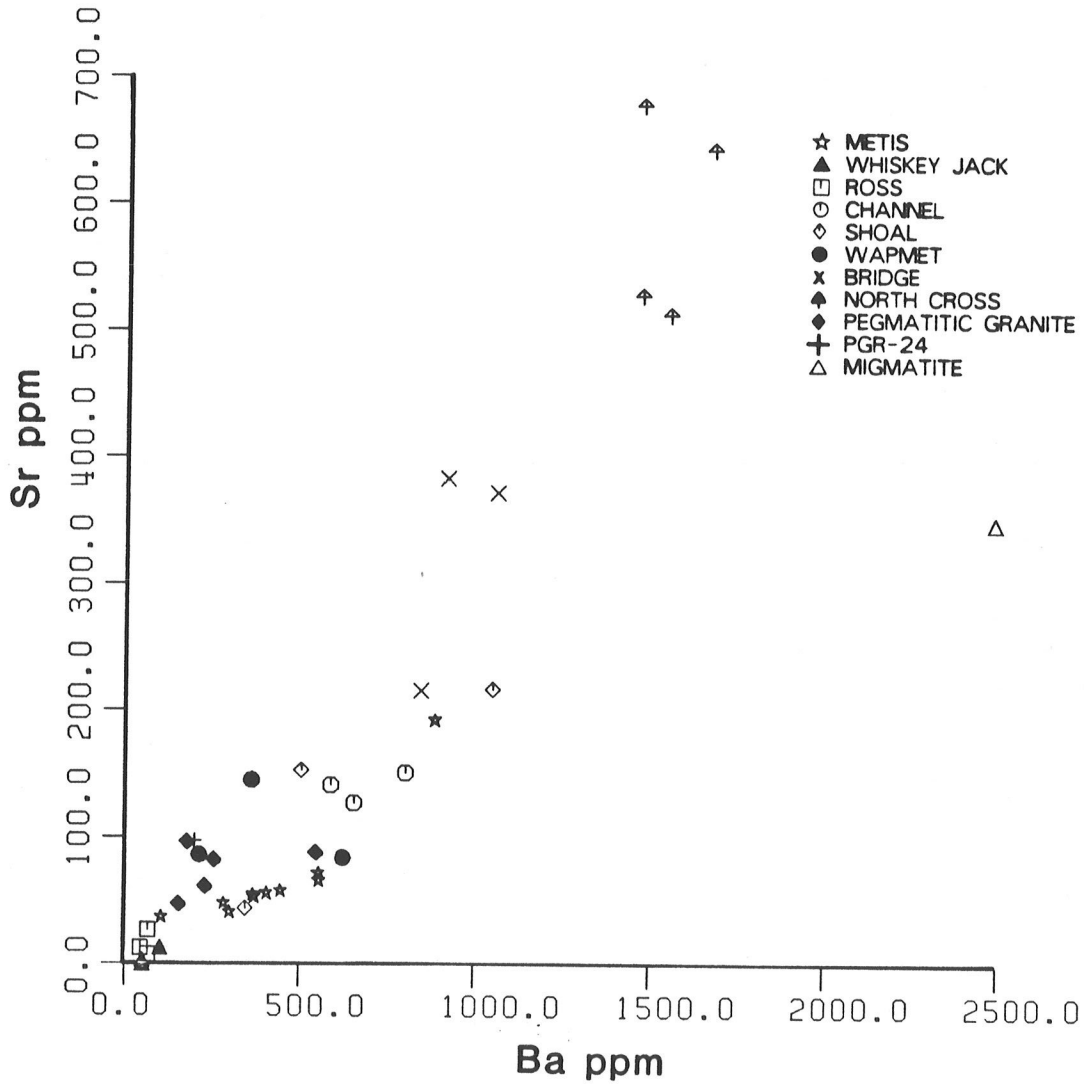

Figure 15: Sr vs Ba plot of samples from the granites, pegmatitic granites and migmatite leucosome. Note that the highly fractionated Whiskey Jack and Ross granites are depleted in Sr and Ba whereas the North Cross and Bridge granites are relatively Ba- and Sr-rich. Note also that PGR-24 of the Minago series (designated as P-24 in Figure 24) plots within the range of the other pegmatitic granites in the eastern half of the study area.

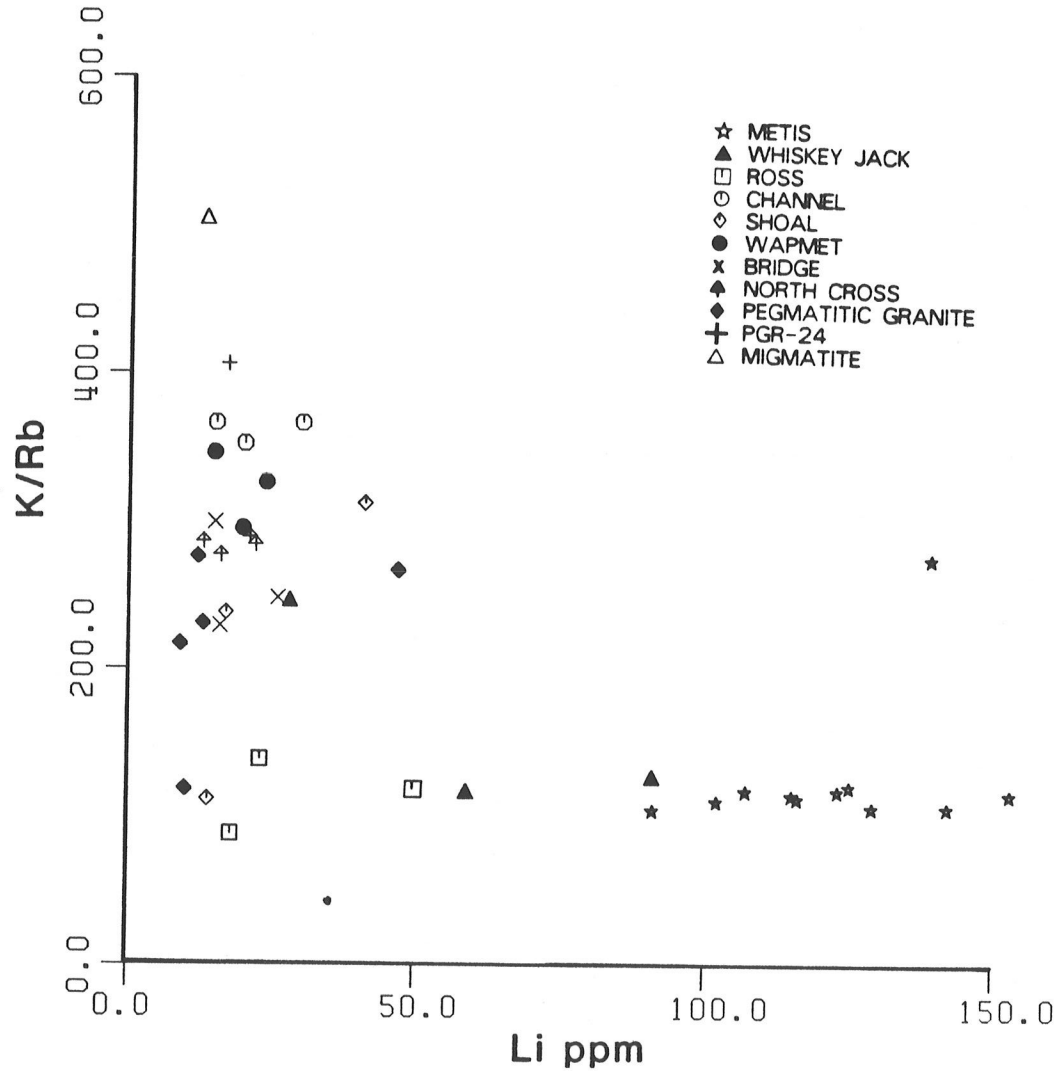

Figure 16: K/Rb vs Li plot of granites, pegmatitic granites and migmatite leucosome. Note that the Metis granite is extremely Li-rich followed by the Whiskey Jack granite.

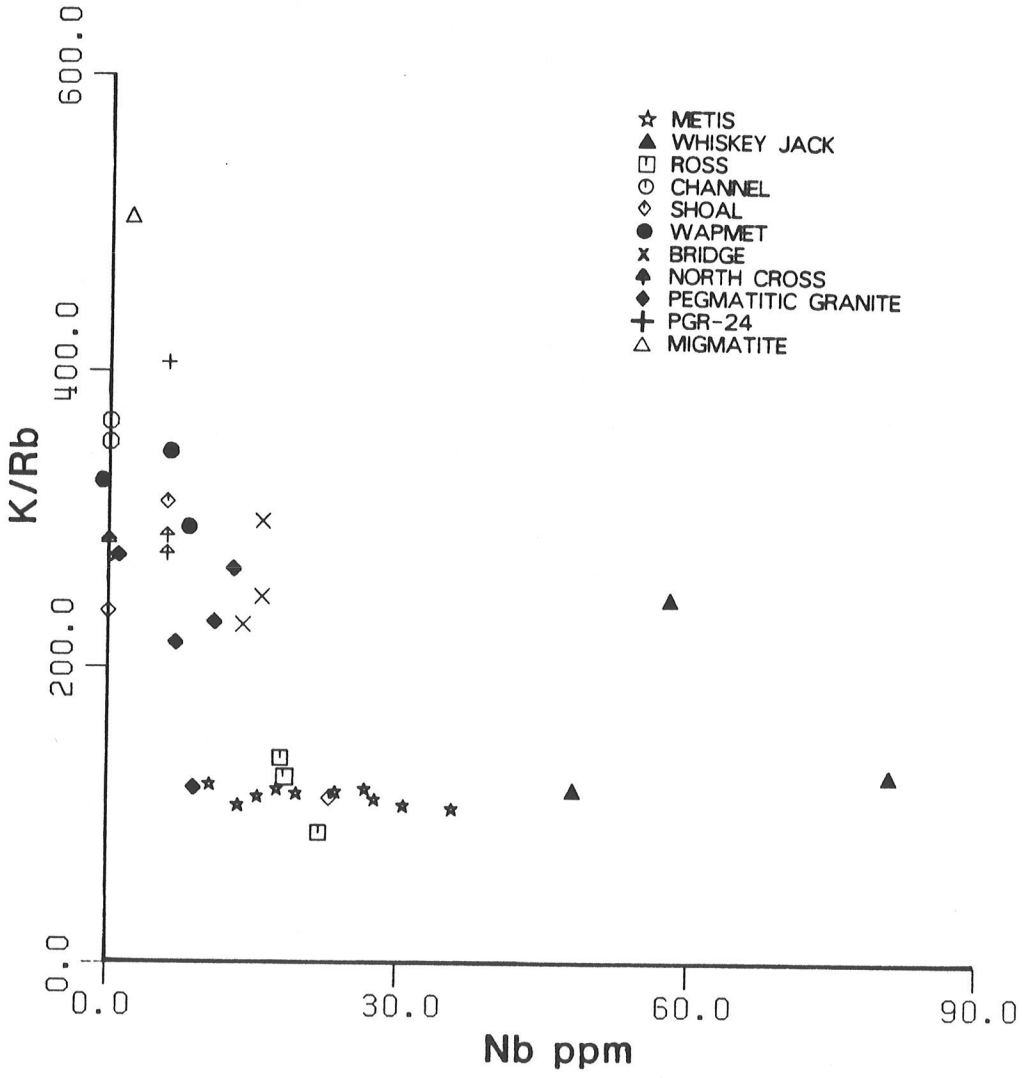

Figure 17: K/Rb vs Nb plot for Cross Lake granites, pegmatitic granites and migmatite leucosome samples. Nb is most abundant in the Whiskey Jack granite followed by the Metis granite, Shoal granite and Ross granite.

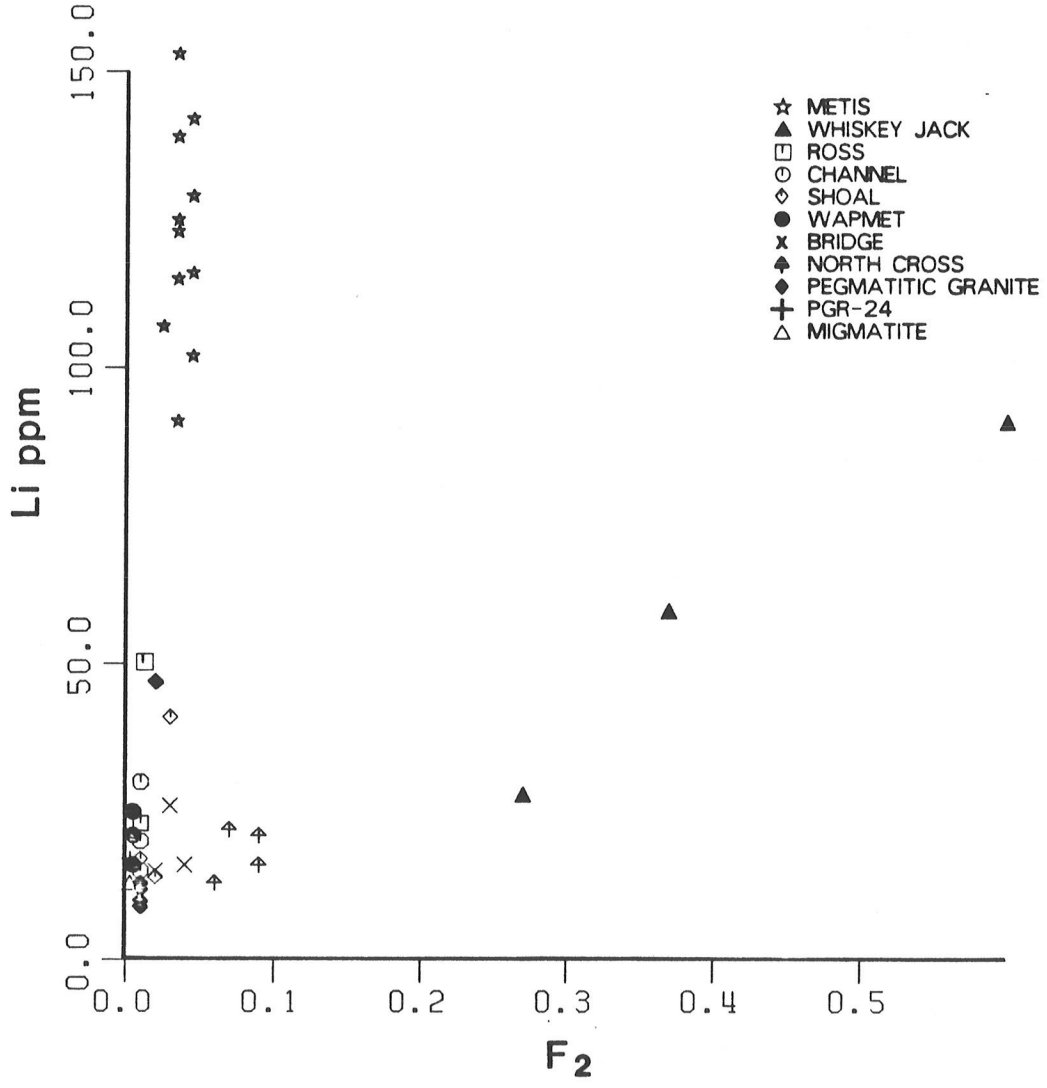

Figure 18: Li ppm vs F_2 plot of samples from granites, pegmatitic granites and migmatite leucosome. Note that the Li-rich Metis granite is relatively F-poor, whereas the highly fractionated Whiskey Jack granite is extremely fluorine rich.

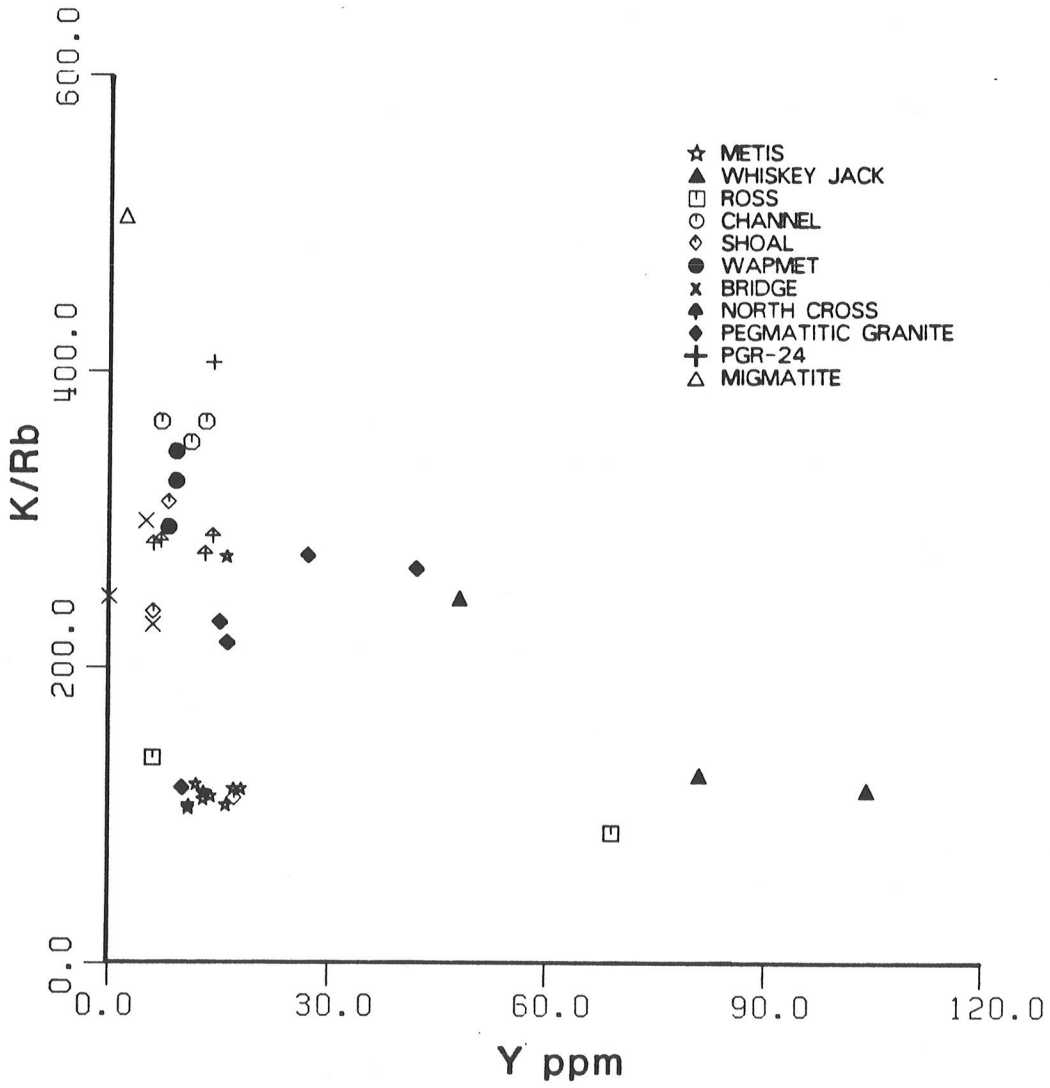

Figure 19: K/Rb vs Y plot of granites, pegmatitic granites and migmatite leucosome. Note the high Y content of the Whiskey Jack granite and one sample from the Ross granite.

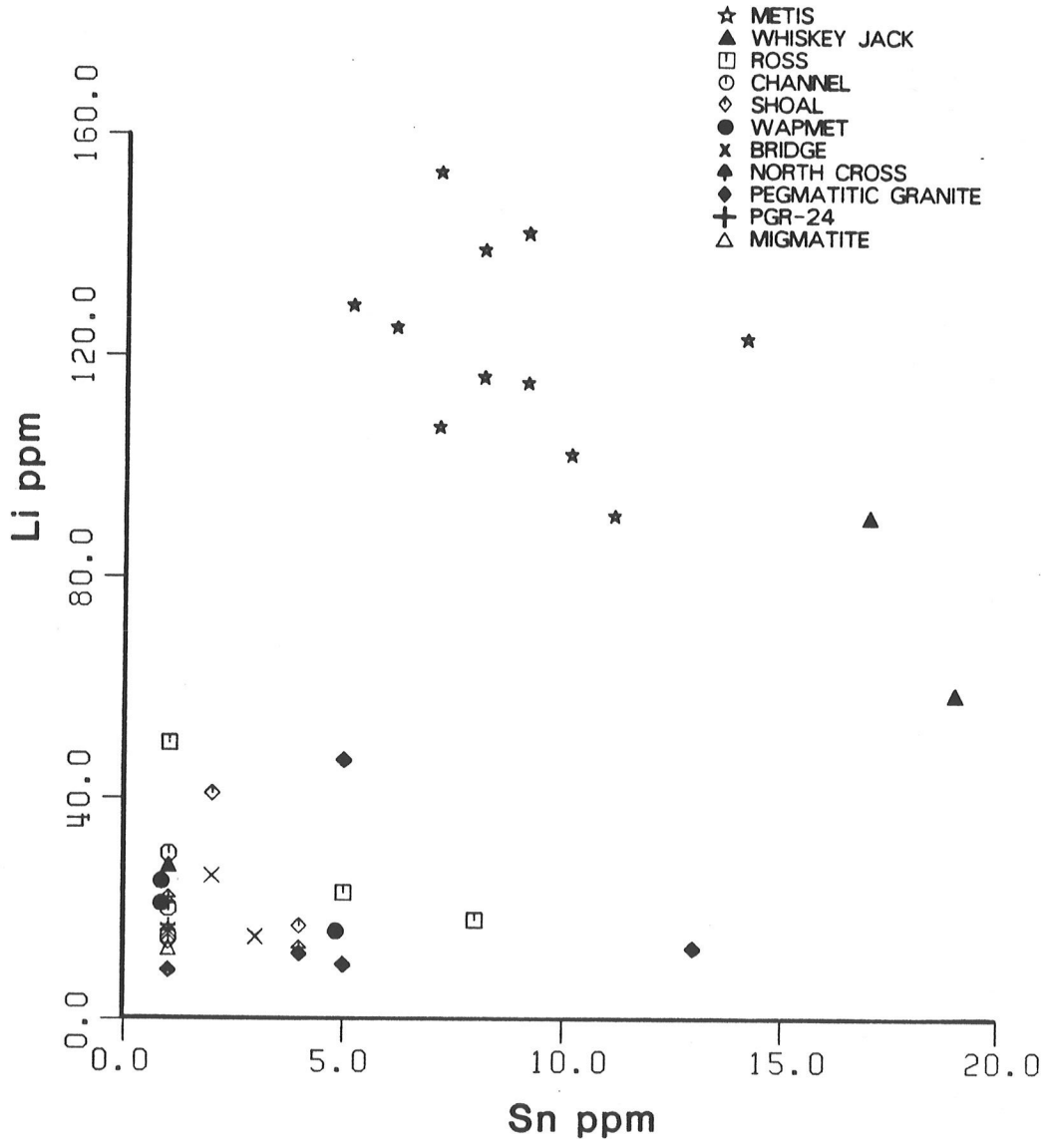

Figure 20: Li ppm vs Sn plot of samples from the granites, pegmatitic granites and migmatite leucosome. Note that the Whiskey Jack granite is the most Sn-rich body followed by the pegmatitic granites, and the Ross and Metis granite.

granite as compared to the Ross granite is probably why the latter has relatively low F, Sn and Nb values.

The compositional dissimilarities between the highly fractionated Metis and Whiskey Jack granites suggests that they are not directly related, genetically as well as temporaly.

The North Cross and the Bridge intrusions are the least fractionated granites of the group that is characterised by high K/Rb ratios and low Rb contents in (Figure 14). In accordance with their textural dissimilarities the North Cross and the Bridge granites are geochemically seperate from the Channel, Wapmet and Shoal granites. The Bridge and North Cross granites have the highest Mg/Li ratios (Figure 21) and Ba, Mg, Ti, Fe, Ca, and Sr contents .

The Ba and Sr contents of the Channel and Wapmet granites are intermediate between the Bridge and the Metis granites ranging between 90 and 160 ppm Sr, and 230 and 800 ppm Ba (Figure 15). The Mg/Li ratios for these granites are low ranging between 6 and 60 ppm. In contrast, their K/Rb ratio is slightly higher than the K/Rb ratios in the Bridge and North Cross granites (Figure 14).

One of three samples obtained from the Shoal granite has Sr, Ba, Y, Nb contents and K/Rb and Rb/Sr values comparable to the highly fractionated Metis granite. However, it has a high Al/Ga ratio (Figure 22) and relatively low Li and F contents. The other two analyses from the Shoal granite

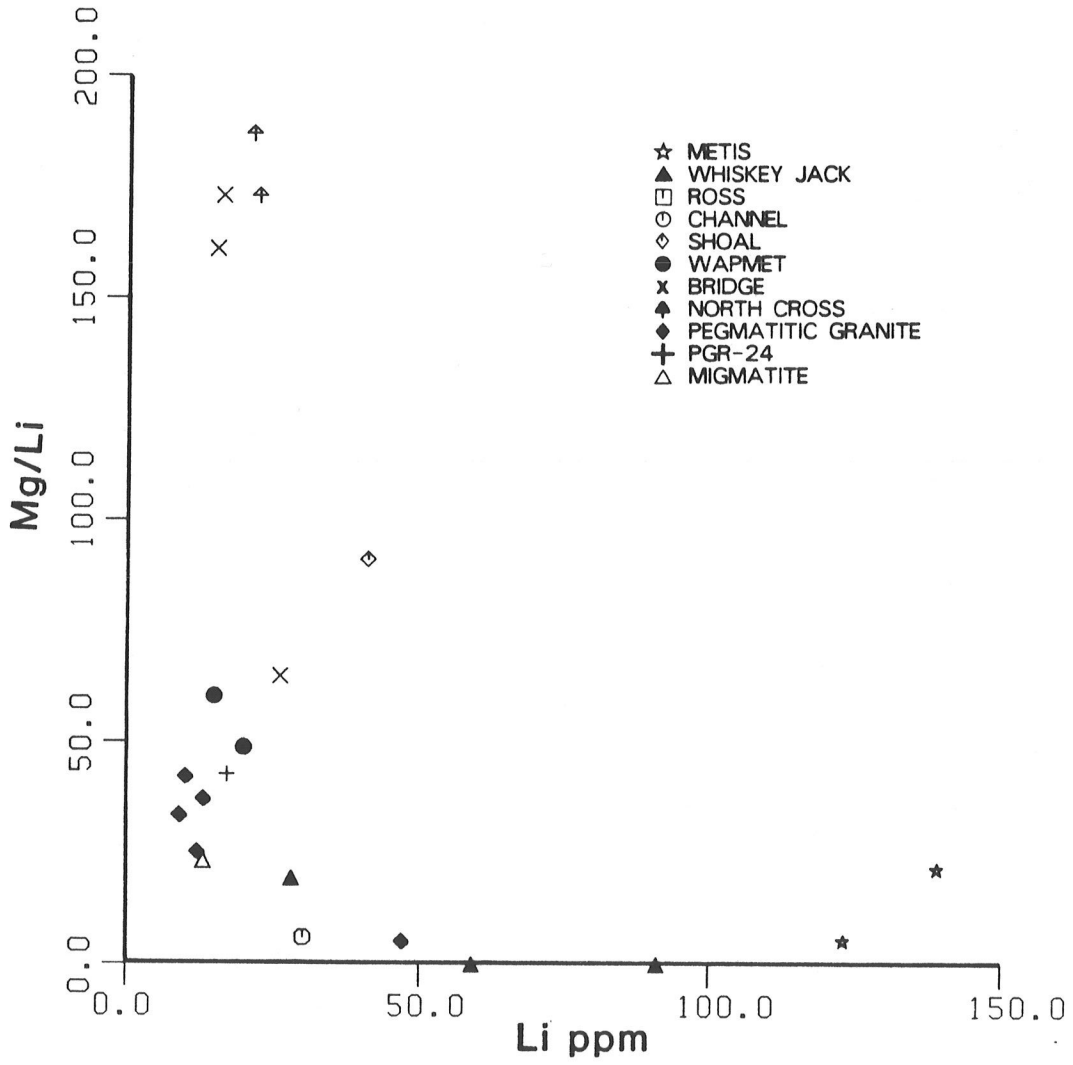

Figure 21: Mg/Li vs Li plot of samples from the granites, pegmatitic granites and migmatite leucosome. Note the Li-rich but Mg-poor character of the Metis and Whiskey Jack granites and the Mg-rich but Li-poor nature of the Bridge and North Cross granites.

have compositions that are similar to the Channel and Wapmet bodies. The Shoal granite may represent a link between the more primitive granites west of Cross Island and the highly fractionated granites.

In an effort to elucidate the petrogenesis of the pegmatitic granites, whole-rock analysis of a nearby migmatite leucosome is presented for comparative purposes. The leucosome is extremely Ba- and Sr-rich (Figure 15) and is depleted in Rb (Figure 14), Cs, Li, Sn and Y (Table 24) in comparison to the primitive pegmatitic granites near the mouth of the Minago river. Their contrasting geochemical character disputes derivation of the pegmatitic granites from a source similar to that of the migmatite.

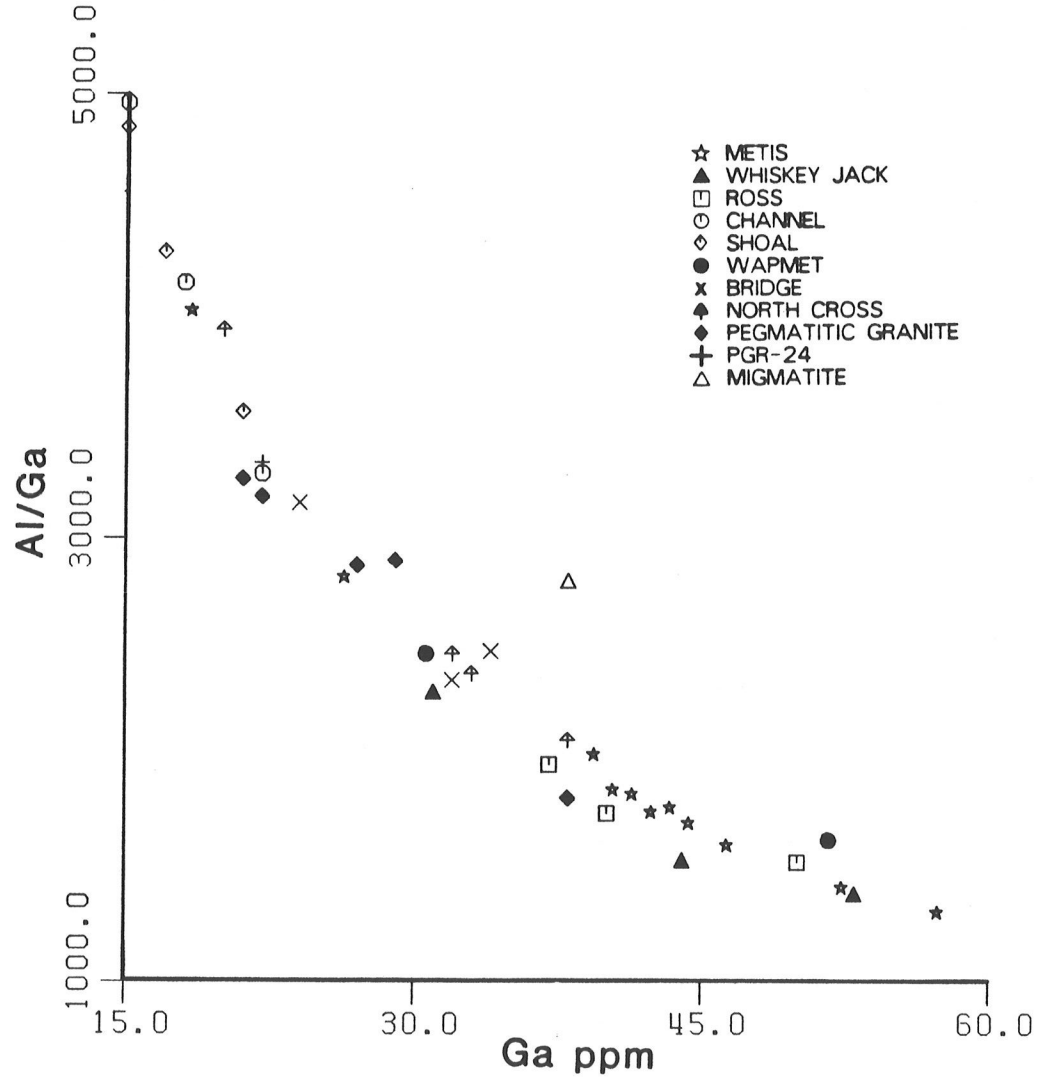

Figure 22: Al/Ga vs Ga plot of samples from granites, pegmatitic granites and migmatite leucosome. The highly fractionated Metis, Ross and Whiskey Jack granites have low Al/Ga ratios and high Ga contents. However, samples from the less fractionated Wapmet granite and pegmatitic granite are also Ga-rich. Note that the migmatite leucosome plots above the granite trend.

Chapter V

THE PEGMATITES

5.1 DISTRIBUTION AND SUBDIVISION OF THE PEGMATITE FIELD

The Cross Lake pegmatite field extends from the Minago River to north and south of Cross Island. It is confined to amphibolite grade metavolcanic-sedimentary rocks in a bifurcated greenstone belt. The pegmatites are en echelon and comprise narrow linear east and northeast-trending zones that are parallel to the axial trend of the greenstone belt. The pegmatites exploited zones of weakness characterized by extreme deformatiton and faulting.

The pegmatite field has been subdivided into four seperate series, some of which may show mutual transition and may or may not be sharply seperated in the geochemical sense.

A pegmatite series consists of spatially and structurally related pegmatite bodies that share similar gross geochemical, paragenetic, and textural characteristics. As a unit subordinate to pegmatite field, a series is analogous to a pegmatite group but differs by the absence of a recognizable parental granitoid intrusion (Černý 1982a). The possible genetic affliation between the pegmatite series shall be discussed in the final sections. The pegmatite field has been divided into the Minago, Nelson, Northern, and Southern

series. The fundamental characteristics of each series are given below.

5.1.1 Nelson Series

The Nelson series consists of barren biotite +oligoclase +microcline +quartz +garnet pegmatite. The dykes belonging to this series occur in the metapsammitic-pelitic rocks west of Cross Island (Figure 24). Additional minerals in these pegmatites include accessory pale blue apatite and rare schorl.

5.1.2 Minago Series

The Minago series consists of a narrow linear zone of pegmatitic granite bodies and barren pegmatite dykes which outcrop intermittently from the Minago River to the western rim of Cross Island (Figure 24).

The pegmatitic granites and related pegmatites are typically composed of microcline perthite, quartz, albite-oligoclase, biotite and muscovite. Graphic microcline perthite is most prevalent in the pegmatites and pegmatitic granites that comprise the eastern end of the Minago series but is absent or weakly developed in the bodies that lie further west. Garnet and schorl are locally abundant accessory phases. Apatite, arsenopyrite and beryl are rare or absent.

5.1.3 Northern Series

The Northern Series consists of muscovite-bearing pegmatites that intrude the metasedimentary rocks north of Cross Island (Figure 24). The series has been sudivided into a barren muscovite pegmatite zone and a beryl-columbite pegmatite zone.

5.1.4 Southern Series

The pegmatites of the Southern Series form an 8 km long belt south of Cross Island (Figure 24). They intrude the metavolcanic rocks and metasedimentary rocks south and east of the sillimanite zone of metamorphism. The series has been subdivided into two zones which are texturally and paragenetically distinct but are spatially, structurally and geochemically related. These are the biotite-peristerite zone and the spodumene pegmatite zone.

The biotite-peristerite pegmatite zone comprises the western third of the Southern series (Figure 24). Albitization and internal zonation are absent or weakly developed in the pegmatites of this zone. Its diagnostic minerals are biotite, peristerite, pale green apatite and rare ferrocolumbite.

In contrast, the spodumene-bearing pegmatites are texturally complex, extensively albitized and paragenetically diverse. Spodumene is the most conspicuous typomorphic mineral in this zone.

5.2 SIZE, SHAPE AND ATTITUDE

Most of the pegmatites in the Cross Lake field are elongate tabular, or podiform bodies. However, more irregular-shaped pegmatites with complex apophyses occur in the spodumene pegmatite zone of the Southern series.

In plan, the major axis of elongation of the pegmatites and pegmatitic granite bodies is consistently parallel to the axial surface of the major isoclinal folds in the region, which strike east and east-north-east. Almost all of the pegmatites appear to be vertical or steeply dipping, except those of the Southern series which dip between 40° and 80° north (Figure 23).

Sheet-like intrusions of pegmatitic granite attain lengths of about 200 metres and range up to about 15 metres in width. The size of the pegmatite dykes varies widely for all pegmatite types, from 1 metre long veins and pods to 200 metre long dykes. The mineralized pegmatites of the Northern and Southern series seldom exceed 8 metres in width and are generally less than 3 metres wide.

Boudinage is ubiquitous in the pegmatites of the Cross Lake field (Figure 25) and is typically well developed in the pegmatites of the Minago, Nelson and Northern series.

The spodumene-bearing pegmatites shown in Figure 26 has been fractured and boudinaged due to tensional stresses. The fractures within the pegmatite do not continue into the less competent host rocks. Minor faulting is most prevalent

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Figure 23: Moderately dipping spodumene-bearing pegmatite dyke, Southern Series.

INDEX MAP OF CROSS LAKE PEGMATITES

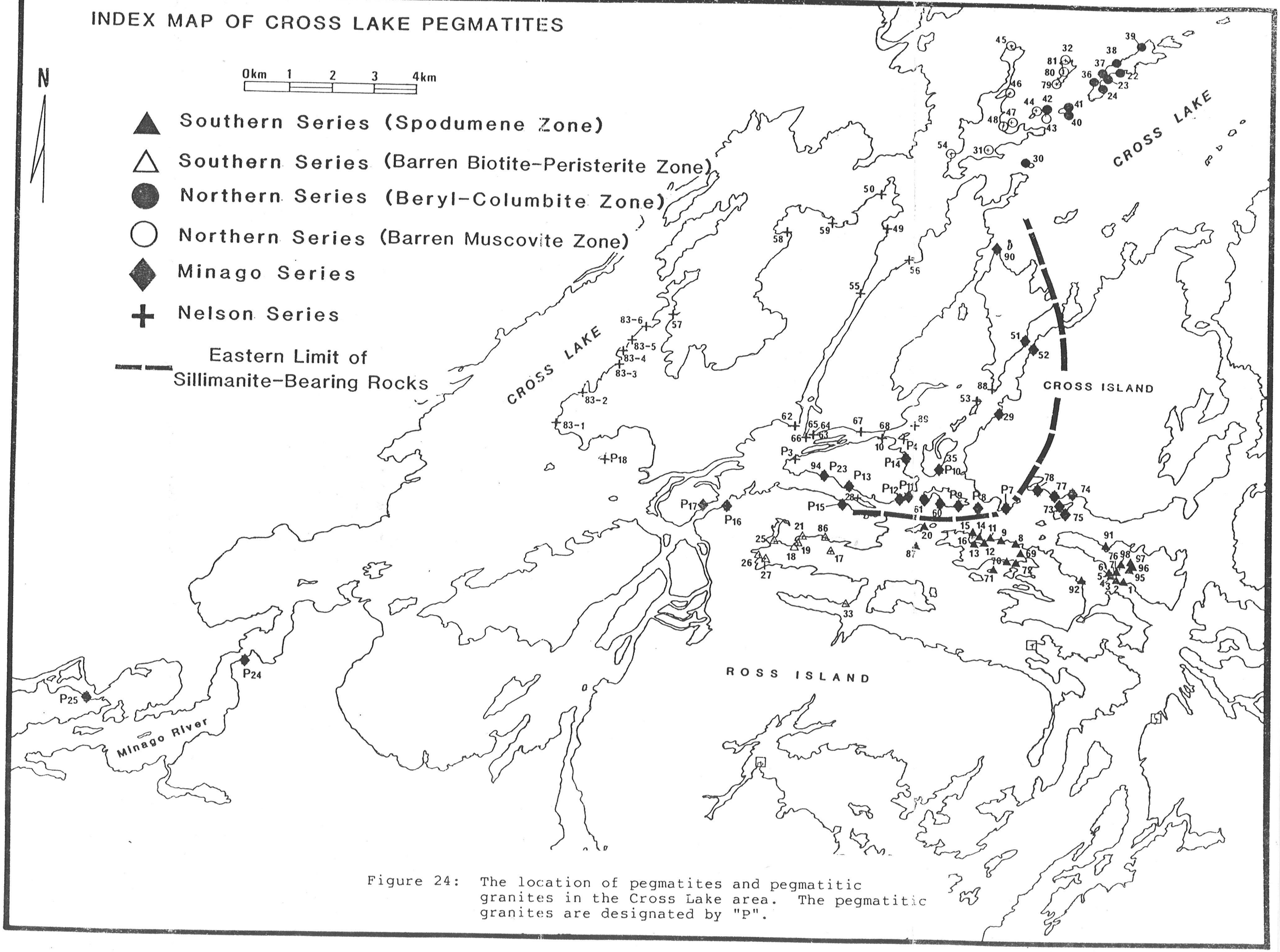

Figure 24: The location of pegmatites and pegmatitic granites in the Cross Lake area. The pegmatitic granites are designated by "P".

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Figure 25: Incipient boudinage of pegmatite 22 of the Northern series.

in the pegmatites of the spodumene pegmatite zone of the Southern series.

The barren pegmatites in the field generally show a more conformable relationship to the foliation of the host rock whereas the more complex pegmatites are generally discordant to the bedding and schistosity of the host. Concordant, folded pegmatite in the folded metapsammitic rocks west of Cross Island display crystal growth normal to subnormal to the contacts which suggest that the solidification of the pegmatite is penecontemporaneous or occurred subsequent to the folding of the host rocks. Apophyses given of by the main bodies are typically ptygmatically folded (Figure 28).

Pegmatites of the field are locally cross-cut by mafic dykes of the Molson dyke swarm indicating that the pegmatites predate the emplacement of the Molson dykes (Figure 27).

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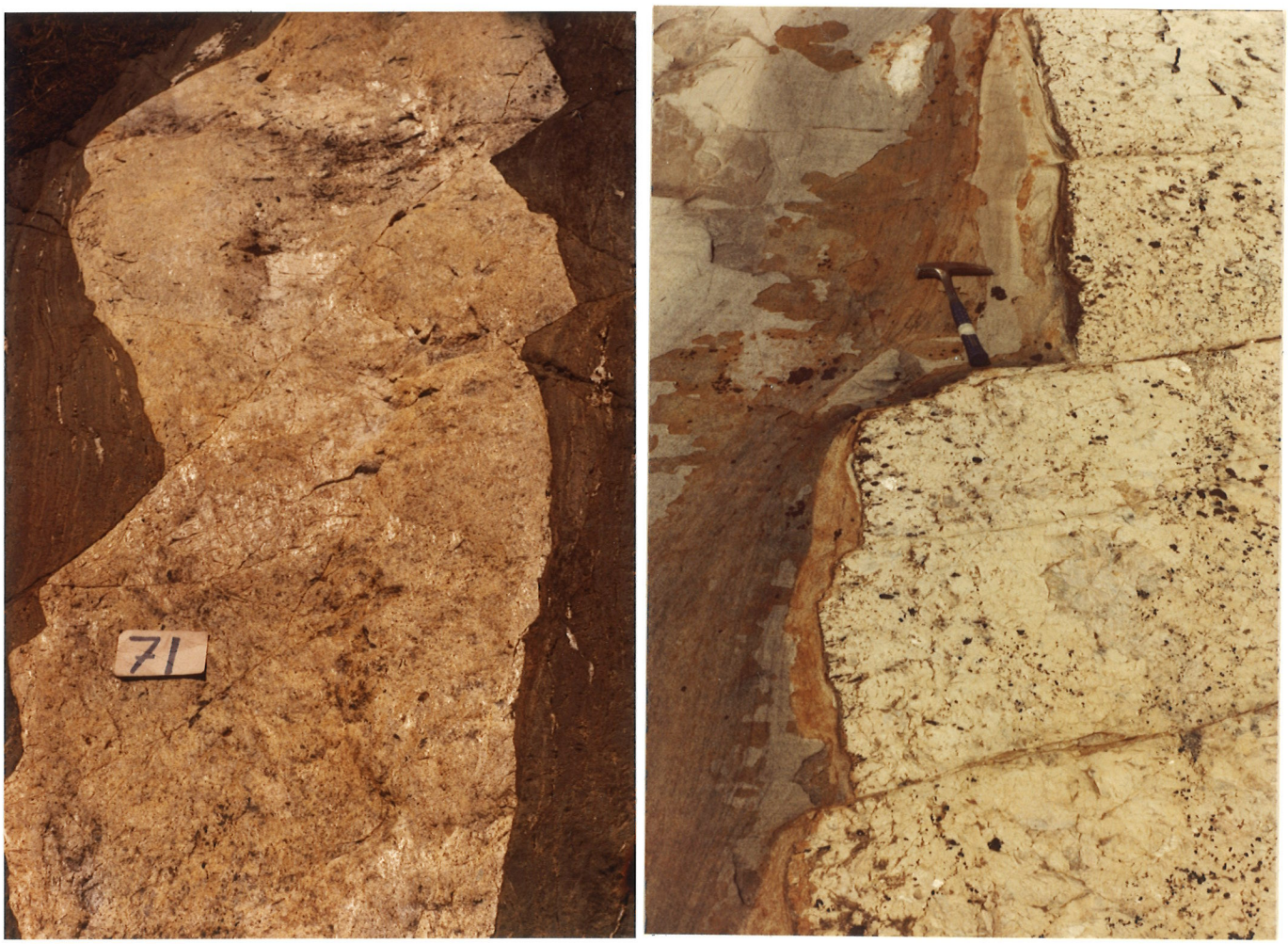

Figure 26: Brittle fracturing and offsetting of pegmatites 71 and 54. Note that the less competent host rock to the pegmatites deforms in a ductile manner.



Figure 27: Mafic dyke of the Molson dyke swarm cross-cutting pegmatite dyke of the Northern series. The red flagging tape marks the contacts of the mafic and pegmatite dykes. The boot is size 8 $^{1}/_{2}$ men's.



Figure 28: Ptygmatically folded pegmatite adjacent to the Metis granite, south shore of Cross Island.

5.3 INTERNAL STRUCTURE

The following section describes the internal structural characteristics of the major pegmatite types in the Cross Lake field. Detailed documentation of the internal structure of all pegmatites was impossible due to the lack of three dimensional exposure of the bodies. Cross section maps were made of well exposed pegmatites that show a particular stage in the textural evolution of the Northern and Southern pegmatite series.

5.3.1 Minago Series Internal Structure

The pegmatitic granites of the Minago series are in sharp contact with the host metasedimentary rocks. They are typically texturally homogeneous with a slight increase in the grain size towards the inner regions of the body. The average grain size is about 20-30 cm however, K-feldspar megacrysts attain sizes up to 1.5 metres (Figure 29).

The essential mineral constituents in the pegmatitic granite are quartz (average 20-25%) potassium feldspar (35-40%), oligoclase (30-35%) biotite and muscovite (10-20%). Tourmaline, garnet, arsenopyrite, secondary muscovite and rare beryl comprise the accessory phases.

White and light grey quartz is interstitial to the alkali feldspar crystals and has a cloudy white appearance when weathered. Small late-stage quartz veins cut the pegmatitic granite locally.

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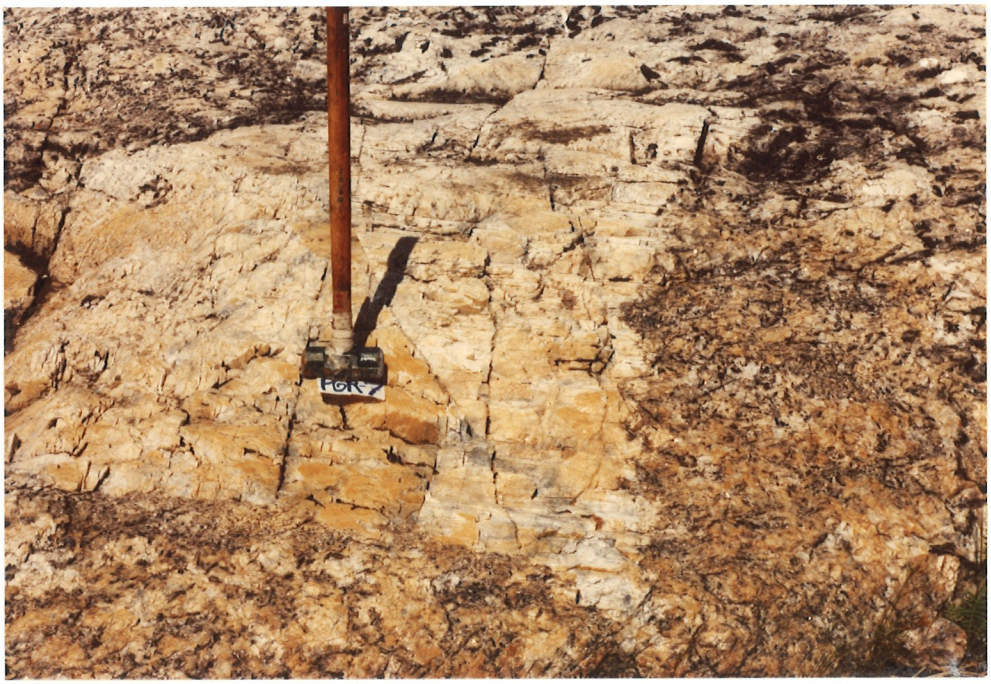


Figure 29: K-feldspar megacryst in pegmatitic granite (P-7) on the southwest shore of Cross Island. The K-feldspar is 1.5 metres in its maximum dimension.

K-feldspars are subhedral to euhedral and are white in colour. Graphic K-feldspar is locally abundant. The average size of the K-feldspar crystals is about 40 cm in their maximum dimension. Oligoclase occurs as coarse xenomorphic crystals which commonly show well developed polysynthetic twinning. Fresh unaltered plagioclase is white whereas altered samples are cloudy grey to brown in colour.

Book type biotite and lesser amounts of muscovite range up to 50 cm in length. The sheets are commonly oriented parallel relative to the contacts of the dyke between 077° and 100°.

Tourmaline (schorl) is the most abundant accessory phase in the pegmatitic granites, despite its sporadic occurrence. Some schorl crystals are broken and are seperated subnormal to the c-axis and healed by quartz or plagioclase.

Almandine varies in size up to 7 cm in diameter and occurs in clusters throughout the dyke.

Xenoliths of locally derived metasedmentary rocks are common in the pegmatitic granite. The xenoliths occur as thin sheets and angular rafts with secondary muscovite and minor tourmaline along their contacts. Contorted xenoliths appear to be folded similar to the folded host rocks suggesting that the intrusion of the pegmatitic granite postdated deformatiton.

5.3.2 Northern Series Internal Structure

The internal zoning in the pegmatites of the Northern series is, in general, weakly developed. The internal structure of the pegmatites within the barren muscovite-pegmatite zone evolves from a near texturally homogeneous muscovite + K-feldspar + quartz + plagioclase pegmatite, to concentrically zoned bodies containing quartz cores. Figure 30 is a cross-section diagram showing the internal structure of a well zoned pegmatite of the barren muscovite-pegmatite zone of the Northern series. A generalized zonal arrangement representative of an intermediate stage in the textural evolution of the Northern series pegmatites is as follows:

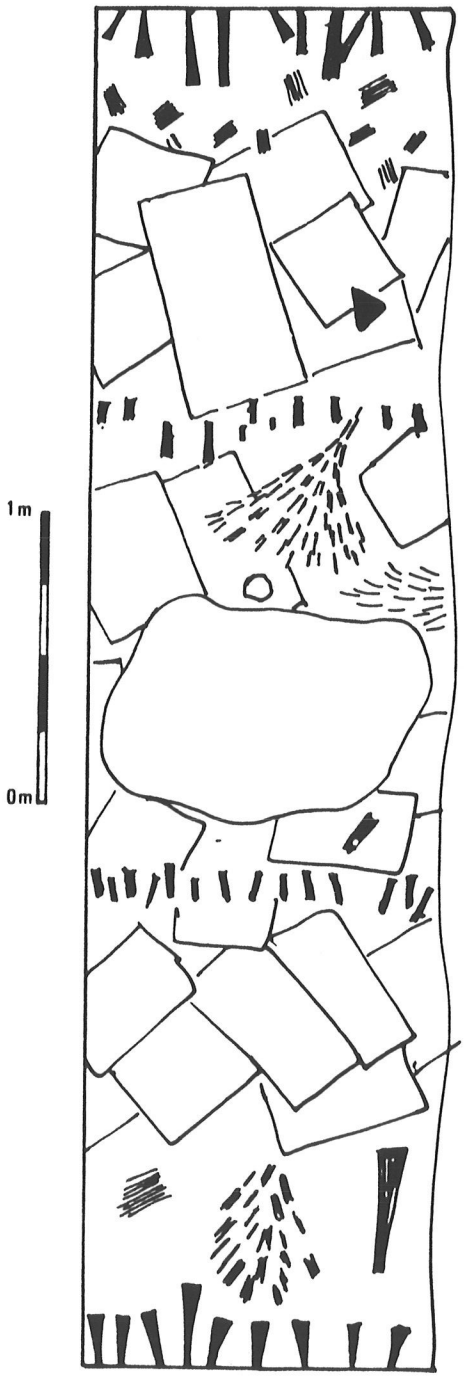
1) A border zone consists of subparallel oriented tourmaline crystals up to 16 cm in length in xenomorphic plagioclase with accessory apatite.

2) The wall zone consists of plagioclase with book-type muscovite +interstitial quartz +accessory tourmaline and garnet.

3) The core-margin is composed primarily of large blocky K-feldspar crystals +book-type muscovite +quartz +plagioclase and accessory almandine and schorl.

4) Monomineralic quartz core.

The pegmatites of the beryl-columbite zone are texturally more diverse, and have been albitized to varying degrees. Schorl is abundant in the border and wall zones and is locally associated with almandine and dark green apatite. In some pegmatites it occurs in a plagioclase +quartz matrix as



ALBITE + TOURMALINE (CRYSTALS NORMAL TO CONTACT) + APATITE

PLAGIOCLASE + MUSCOVITE(BOOKS)

BLOCKY MICROCLINE-PERTHITE + QUARTZ + MINOR ALMANDINE AND SCHORL

SCHORL CRYSTALS (NORMAL TO CONTACT)

PLUMOSE MUSCOVITE + QUARTZ + BLOCKY MICROCLINE-PERTHITE + ACCESSORY ALMANDINE

QUARTZ CORE

BLOCKY MICROCLINE-PERTHITE + BOOK MUSCOVITE

SCHORL CRYSTALS (NORMAL TO CONTACT)

BLOCKY MICROCLINE-PERTHITE + PLAGIOCLASE + QUARTZ

PLUMOSE MUSCOVITE + QUARTZ + ALMANDINE + SCHORL (22 cm in length)

SCHORL CRYSTALS (NORMAL TO CONTACT) + PLAGIOCLASE

Figure 30: Cross section of pegmatite 44 of the barren-muscovite pegmatite zone of the Northern series. The internal structure is representative of the intermediate stage in the textural evolution of the Northern series. The azimuth of the section illustrated is normal to the strike of the dyke which is 115°.

large columnar crystals which are oriented subparallel relative to the contacts of the body. In others, small stubby crystals of schorl are concentrated in dark layers throughout the outer zones. The discontinuous shorl-enriched layers may attain a dendritic appearance in some cases (Figure 31). Columnar beryl is a relatively abundant accessory phase and is most common in the wall zones of the pegmatites.

The wall zone consists primarily of quartz, muscovite and xenomorphic albite.

The core-margin zone typically consists of large blocky K-feldspar, book-type muscovite, and quartz. A single generalized cross-section cannot adequately describe the internal structure of all the pegmatites involved despite the minor textural similarities between the pegmatites.

The most advanced stage in the textural evolution of the Northern pegmatite series is represented in a cross-section of pegmatite 22 (Figure 32).

5.3.3 Southern Series Internal Structure

Internal zonation is absent or poorly developed in the pegmatites of the biotite-peristerite zone in the Southern series. The simplest pegmatites have a homogeneous texture and consist of coarse (up to 30 cm) K-feldspar crystals with xenomorphic plagioclase and interstitial quartz. Biotite occurs throughout the pegmatite as coarse sheets up to 5 cm

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Figure 31: Schorl + almandine + dark green apatite bands within pegmatite 36 of the Northern series.

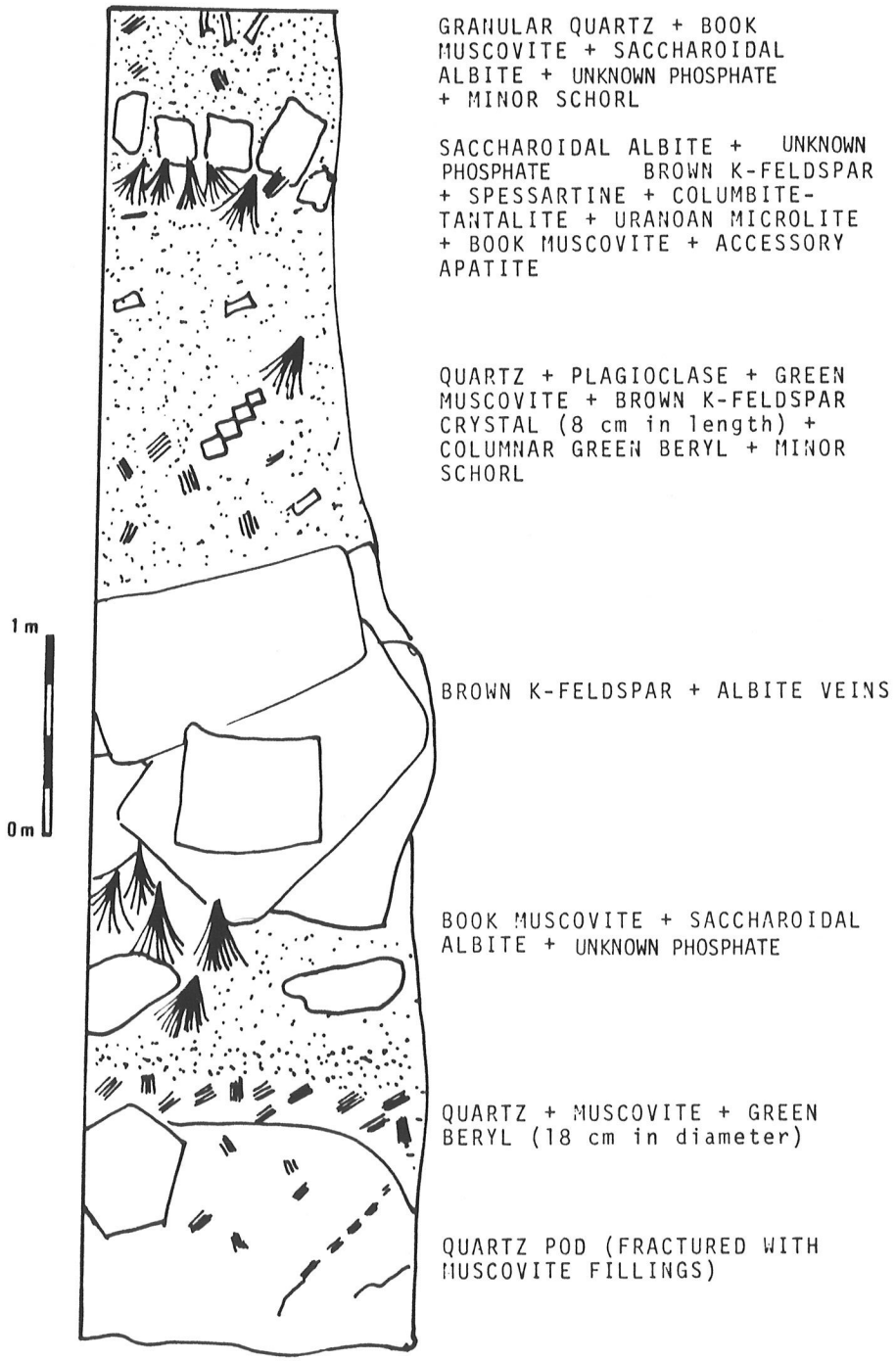

Figure 32: Cross section of pegmatite 22 of the beryl-columbite zone illustrating the textural character of the most fractionated member exposed in the Northern series. The azimuth of the section illustrated is normal to the strike of the dyke which is 70°.

in length. It is locally replaced by silver-white muscovite.

The internal structure of the most evolved pegmatites in the biotite-peristerite pegmatite zone is given in the following generalized sequence:

1) The exocontact consists of a thin coating of flaky biotite.

2) The border zone consists mainly of tourmaline and plagioclase and is typically poorly developed or absent.

3) The wall zone is made up primarily of plagioclase, quartz, with accessory tourmaline, locally having a subnormal orientation relative to the contacts of the pegmatite. Fine grained albite in the wall zone shows a gradual coarsening in grain size towards the core of the pegmatite. The albite contains biotite, garnet, pale green apatite and rare ferrocolumbite.

4) The inner zone of the pegmatite is composed of coarse K-feldspar +quartz + plagioclase. Figure 33 is a cross-section diagram of a pegmatite representative of an intermediate stage in the textural evolution of the Southern series pegmatites.

The pegmatites of the spodumene pegmatite zone in the Southern series are the most mineralogically diverse and texturally complex in the Cross Lake field.

Tectonic effects have severely influenced the internal structure of many of the spodumene-bearing pegmatites. On Spodumene Island the pegmatites typically show a directional

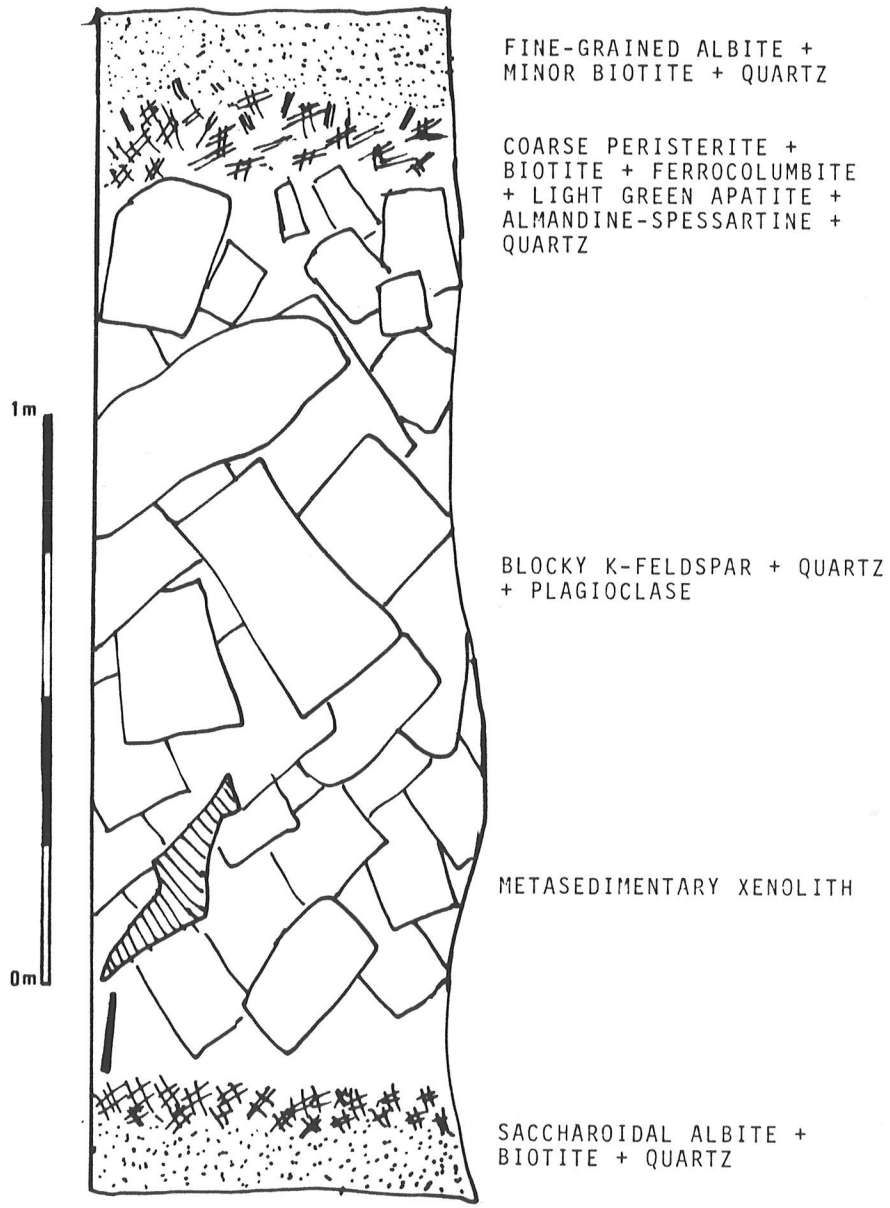

Figure 33: Cross section of pegmatite 21 of the biotite-peristerite zone of the Southern series. The internal structure of pegmatite 21 typifies the simple textural character of the most evolved pegmatites in the biotite-peristerite zone of the Southern series. The azimuth of the section illustrated is normal to the strike of the dyke which is 105°.

fabric which is characterised by the elongation and subparallel orientation of the crystals relative to the contacts of the bodies (Figure 34). The intensity of deformation observed in the pegmatites varies locally. Internal structure is generally poorly developed in those pegmatites which have a strong directional fabric, consisting of lenticular K-feldspars and needle-like tourmaline and spodumene crystals in a fine grain albite-quartz-muscovite matrix. Rare cassiterite, columbite-tantalite, white beryl, and triphylite-lithiophilite occur in the fine-grained albite. The possible origin of the directional fabric shall be discussed in chapter VI.

Spodumene pegmatites, such as those on Metis Island that do not have a strong parallel alignment of minerals generally have a well developed zonal structure. Internal zoning of the pegmatites is concentric and asymmetric. Figure 35 is a cross-section diagram of a well zone pegmatite representative of the highly fractionated pegmatites of the spodumene pegmatite zone. A generalized sequence of the internal structure from the outer margin to the core is as follows:

1) The exocontact consists of tourmalinized host rock and ranges up to 6 cm in thickness.

2) The border zone is thin or absent and consists of tourmaline +albite +muscovite +apatite.

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Figure 34: Intensely sheared spodumene-bearing pegmatite (16) on Spodumene Island. The minerals are elongated and parallel with respect to the contact of the pegmatite. Note the lack of internal zonation.

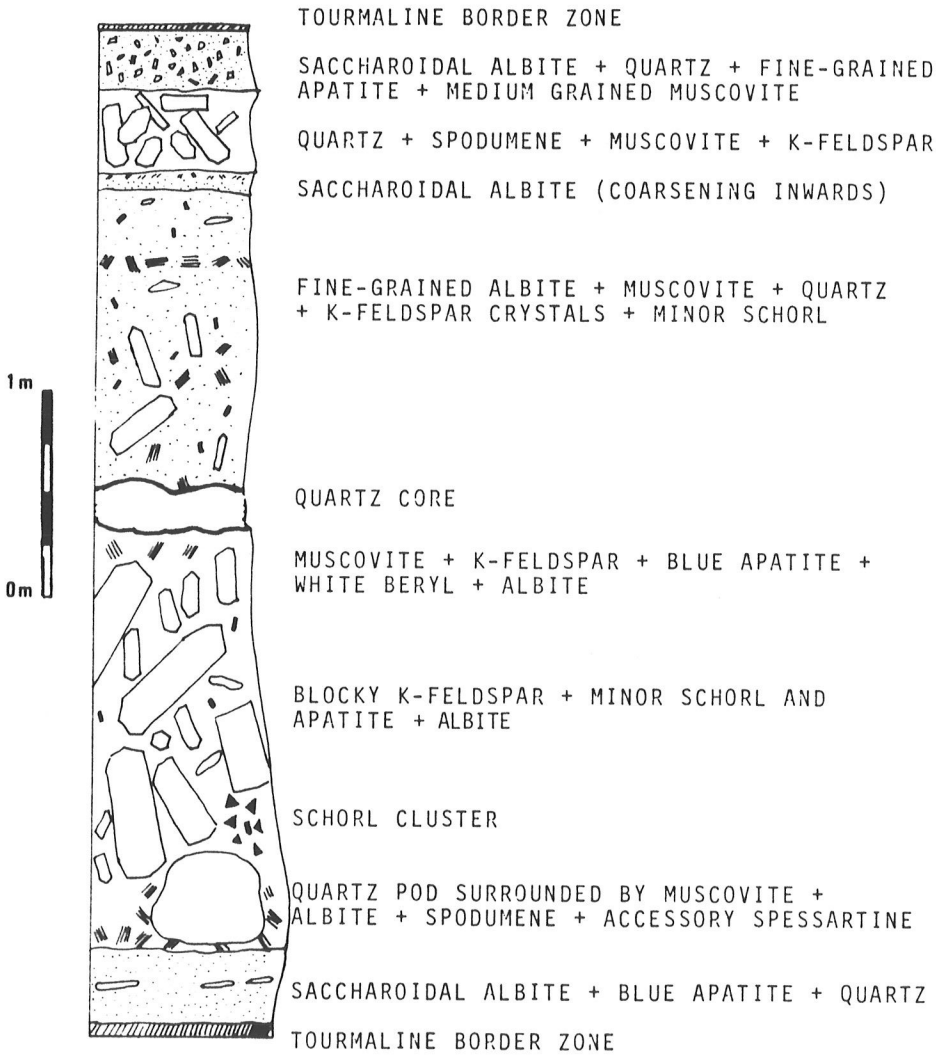

Figure 35: Cross section of pegmatite 6 of the spodumene zone of the Southern series. The cross section illustrates the internal structure of a highly fractionated pegmatite representative of an advanced stage in the textural evolution of the Southern pegmatite series. The azimuth of the section illustrated is normal to the strike of the dyke which is 100°.

3) The wall zone consists of fine grained albite or clevelandite +quartz +muscovite +tourmaline +apatite.

4) The intermediate zone is composed of quartz +spodumene book muscovite +clevelandite +spodumene +white beryl +K-feldspar.

5) The core-margin zone consists mainly of blocky K-feldspar +spodumene +book-type muscovite +albite.

6) The core zone is compose entirely of quartz with minor muscovite and tourmaline.

Metasomatic units consist of albite, minor quartz and muscovite and appear to conform to the zonal arrangement of the primary phases and are preferably located along the margins of the pegmatite. Saccharoidal albite locally replaces large portions of the pegmatite.

A cross-section of a highly fractionated pegmatite from the spodumene pegmatite zone is shown in Figure 35.

5.4 PARAGENESIS

The paragenesis of the pegmatites of the Nelson (Table 4), Minago (Table 6), Northern (Table 5), and Southern series (Table 7 and 8) is given in uniform paragenetic tables for ease of mutual comparison.

The relative abundance of the minerals in a particular pegmatite is based on visual estimates made by the writer while in the field and do not represent measured modal percentages. The locations of the pegmatites are given on the

TABLE 4

Paragenesis of the Nelson series.

Pegmatite Number	10	35	49	50	53	55	56	57	58	59	62	63	64	65	66	67	68	83	88	89	P18
MICROCLINE	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ORTHOCLASE																					
OLIGOCLASE	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ALBITE																					
QUARTZ	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
BIOTITE	X	X	X		X	X	X	X	X		X	X	X			*	X	X		X	X
MUSCOVITE																					
SPODUMENE																					
BERYL																					
ALMANDINE	X	X		X							X	X	X	X		X	X	*			
SPESSARTINE																					
ZIRCON																					
SCHORL										X	X	X		X				*			
ELBAITE																					
CASSITERITE																					
COLUMBITE-TANTALITE																					
IXIOLITE																					
WODGINITE																					
TAPIOLITE																					
URANIAN MICROLITE																					
TANTALIAN RUTILE																					
ILMENITE																					
APATITE			*	*		*	*	*	*		*							*			
MONAZITE																					
TRIPHYLITE-LITHIOPHILITE																					
UNKNOWN PHOSPHATE																					
SICKLERITE																					
ARSENOPYRITE																					
LOELLINGITE																					

● - abundant, O - subordinate, X - accessory, * - rare

The locations of the pegmatites are given in figure (24).

TABLE 5

Paragenesis of the Northern series.

	NORTHERN SERIES (BERYL-COLUMBITE PEGMATITE ZONE)											(MUSCOVITE PEGMATITE ZONE)											
Pegmatite Number	22	23	24	30	36	37	38	39	40	41	42	31	32	43	44	45	46	47	48	54	79	80	81
MICROCLINE	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ORTHOCLASE	*																						
OLIGOCLASE											●	●	●	●	●	●	●	●	●	●	●	●	●
ALBITE	●	●	●	●	●	●	●	●	●	●													
QUARTZ	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
BIOTITE																			*				
MUSCOVITE	O	X	X		O	O	X	X	X	X	X	X		X	X	X	*	X	X	X	X		X
SPODUMENE																							
BERYL	X	X	X	*	X	X	X		X	X	*												
ALMANDINE		X	*		X	X			*	*	X		X	X	*	X		X	X	X	X		*
SPESSARTINE	X			X			X	X															
ZIRCON																							
SCHORL	X	*	*	X	X	X	X	X	X	X	X	*		X	X	X	*	X	X	X	X		X
ELBAITE																							
CASSITERITE																							
COLUMBITE-TANTALITE	X			*	*	*	X		*	*													
IXIOLITE																							
WODGINITE																							
TAPIOLITE									*	?													
URANIAN MICROLITE	X																						
TANTALIAN RUTILE									*	*													
ILMENITE												*											
APATITE	X	*	*	*	X	X		*	*		X	*	X	X	X	*	*	*	X	*	X		X
MONAZITE																							
TRIPHYLITE-LITHIOPHILITE																							
UNKNOWN PHOSPHATE	X																						
SICKLERITE																							
	*																						
ARSENOPYRITE				*																			
LOELLINGITE																							

● - abundant, O - subordinate, X - accessory, * - rare

The locations of the pegmatites are given in figure (24).

TABLE 6

Paragenesis of the Minago series.

MINAGO SERIES

Pegmatite Number	29	51	52	60	61	73	74	75	77	78	90	94	P7	P8	P10	P11	P12	P13	P14	P15	P16	P17	P23	P24	P25
MICROCLINE	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ORTHOCLASE																									
OLIGOCLASE	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ALBITE																									
QUARTZ	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
BIOTITE	O			X	X	X	*	X					X	O	O	O	O	X	X	X	O	*	*	*	*
MUSCOVITE		X	X	X		X	*	X	X	X	X	X	X	*			*	X					*		
SPODUMENE																									
BERYL																				*					
ALMANDINE	X	X	X		X	*	X		X	X	X	X	X	X			*	X		X	X		*	X	
SPESSARTINE																									
ZIRCON																									
SCHORL	X	X	X			X	X		X	X	X	X	X	X		*		X		X	X		X		
ELBAITE																									
CASSITERITE																									
COLUMBITE-TANTALITE																									
IXIOLITE																									
WODGINITE																									
TAPIOLITE																									
URANIAN MICROLITE																									
TANTALIAN RUTILE																									
ILMENITE																									
APATITE	*	*	*			*											*								
MONAZITE																									
TRIPHYLITE-LITHIOPHILITE																									
UNKNOWN PHOSPHATE																									
SICKLERITE																									
ARSENOPYRITE									*	*										*	*				
LOELLINGITE																									

.● - abundant, O - subordinate, X - accessory, * - rare

The locations of the pegmatites are given in figure (24).

TABLE 7

Paragenesis of the biotite-peristerite zone of the Southern series.

SOUTHERN SERIES
(BIOTITE-PERISTERITE PEGMATITE ZONE)

Pegmatite Number	17	18	19	21	25	26	27	33	86
MICROCLINE	●	●	●	●	●	●	●	●	O
ORTHOCLASE									
OLIGOCLASE		●	●		●	●	●		●
ALBITE	●			●				●	
QUARTZ	●	●	●	●	●	●	●	●	●
BIOTITE	*	X	X	X		X	X		*
MUSCOVITE						*			
SPODUMENE									
BERYL									
ALMANDINE	*	X	*	X	*	*	X		
SPESSARTINE	*			X					
ZIRCON									
SCHORL	X	X	*	*	*	X	X	*	*
ELBAITE									
CASSITERITE									
COLUMBITE-TANTALITE			*	X					
IXIOLITE									
WODGINITE									
TAPIOLITE									
URANIAN MICROLITE									
TANTALIAN RUTILE									
ILMENITE									
APATITE	X	X	X	X					X
MONAZITE									
TRIPHYLITE-LITHIOPHILITE									
UNKNOWN PHOSPHATE									
SICKLERITE									
ARSENOPYRITE				*					
LOELLINGITE									

● - abundant, O - subordinate, X - accessory, * - rare

The locations of the pegmatites are given in figure (24).

TABLE 8

Paragenesis of the spodumene pegmatite zone of the Southern series.

SOUTHERN SERIES (SPODUMENE PEGMATITE ZONE)

Pegmatite Number	1	2	3	4	5	6	7	8	9	11	12	13	14	15	16	20	69	70	71	72	76	87	91	92	95	96	97	98	DH*
MICROCLINE	●	●	●	●		●	●	●	●	●				●	●	●	●	●	●	●	*	●	X	●	●	●	●	●	●
ORTHOCLASE																													
OLIGOCLASE																													
ALBITE	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
QUARTZ	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
BIOTITE																													
MUSCOVITE	X	X	X	X	X	X	X	X	X	*	*	*	*	*	*	X	X	X	X	*	X		*	X	X	X	X	X	X
SPODUMENE	O	X	O	*	X	O	X	X	X	X			X	X	X	O	O	X	X	*				O	X	X	X	X	O
BERYL	X	*	*	X		X	X	X	X	*						*		X	*		X			*	*	*			*
ALMANDINE																				*									
SPESSARTINE						X										X													
ZIRCON																													*
SCHORL	X	X	X	X	X	X	X	X	X	X		*	*	X	X	*	*	X	X	*		*		*	X	X	X	X	X
ELBAITE						*																							
CASSITERITE				*					*															*					*
COLUMBITE-TANTALITE	X	*		X		X			*							*					*		*	*	*	*	*	*	*
IXIOLITE		*		*																			?						*
WODGINITE				*																				*					
TAPIOLITE																													
URANIAN MICROLITE																													
TANTALIAN RUTILE																													
ILMENITE																													
APATITE	*	*	*	*	*	*			*	*						*		*				*			*				*
MONAZITE				*																									
TRIPHYLITE-LITHIOPHILITE				*		*													*					*					*
UNKNOWN PHOSPHATE																													
SICKLERITE																													
ARSENOPYRITE				*										*	*														
LOELLINGITE																													*

● - abundant, O - subordinate, X - accessory, * - rare

The locations of the pegmatites are given in figure (24).

index map of pegmatite localities in the Cross Lake field (Figure 24).

The tables indicate that the most paragenetically diverse pegmatites occur in the spodumene zone of the Southern series and the beryl-columbite zone of the Northern series.

The distinctive geochemical character of the two series is reflected, inpart, by their mineralogy. The Southern series contains minerals of Li, Be, Nb, Ta and Sn and is relatively P- and F-poor as indicated by the absence of amblygonite, lepidolite and microlite and the rarity of triphylite-lithiophilite. Loellingite rather than arsenopyrite in the spodumene-bearing pegmatites indicates a S-deficient environment.

In contrast, the beryl-columbite zone of the Northern series contains minerals of Be, Nb and Ta but is comparatively F- and P-rich, as evidenced by the presence of a wyllieite-like phosphate mineral, uranian microlite and abundant apatite. The pegmatites of the beryl-columbite zone are also Li deficient as indicated by the absence of spodumene and Li-bearing phosphates.

5.5 MINERALOGY

5.5.1 Quartz

Quartz occurs in massive form and as granular aggregates (Figure 36). It is interstitial to other primary phases and also occurs as discrete massive pods comprising the core

zone of the well zoned pegmatites. Quartz also occurs as blebs and as graphic intergrowths within blocky K-feldspars.

The colour ranges from predominant white and grey to rare black. Alternating bands of white and grey quartz grains give some quartz a "wispy" appearance.

5.5.2 Plagioclase

Plagioclase is ubiquitous in the Cross Lake pegmatites. The grainsize, composititon, colour and crystal habit varies from white xenomorphic oligoclase in the barren pegmatites to highly sodic pink, grey, red or white saccharoidal albite and clevelandite in the rare-element bearing pegmatite series. Table 9 gives the An mol% for 65 plagioclases from the Cross Lake pegmatite field. In general the pegmatites of the Minago and Nelson series contain white equant laths of oligoclase. Oligoclase also occurs in the barren pegmatites of the Northern and Southern series.

Plagioclase in the complex pegmatites of the Northern and Southern series is highly sodic albite (An 1-4). It occurs as either coarse blades or fine-grained laths, and displays a greater colour diversity. Divergent blades of albite (clevelandite) are grey, white, or mottled grey-pink-white in colour. Crystals range up to 6 cm in length. Clevelandite is a major constituent of the wall and intermediate zones of the spodumene-bearing pegmatites of the Southern series and is associated with quartz, K-feldspar, pale green

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Figure 36: Granular quartz aggregate from pegmatite 17 of the Southern series. (1.5X) actual size.

TABLE 9

An (mol %) of plagioclase samples from pegmatites and pegmatitic granites in the Cross Lake field.

SAMPLE	DESCRIPTION	AN%
PLG-1-F	GREY, CLEVELANDITE	2.5
PLG-1-I	GREY-BROWN SACCHAROIDAL ALBITE	4.0
PLG-3-A	GREY-WHITE SACCHAROIDAL ALBITE	2.5
PLG-4-B	GREY CLEVELANDITE	2.5
PLG-5-A	GREY SACCHAROIDAL ALBITE	4.0
PLG-6-H	WHITE SACCHAROIDAL ALBITE	4.0
PLG-9-B	GREY CLEVELANDITE	2.5
PLG-9-F	" "	1.0
PLG-10-D	WHITE, COARSE XENOMORPHIC	16.0
PLG-11-I	GREY-BROWN SACCHAROIDAL ALBITE	6.5
PLG-13-C	GREY SACCHAROIDAL ALBITE	23.0
PLG-14-C	PINK SACCHAROIDAL ALBITE	2.5
PLG-16-F	RED SACCHAROIDAL ALBITE	3.0
PLG-16-H	WHITE SACCHAROIDAL ALBITE	1.0
PLG-17-B	PINK COARSE PERISTERITE	11.0
PLG-17-E	" "	7.0
PLG-19-F	" "	16.0
PLG-20-J	LIGHT BROWN SACCHAROIDAL ALBITE	1.0
PLG-21-X	PINK COARSE PERISTERITE	14.0
PLG-22-M	PINK SACCHAROIDAL ALBITE	2.5
PLG-24-A	WHITE SACCHAROIDAL ALBITE	14.0
PLG-25-D	WHITE, COARSE XENOMORPHIC	14.0
PLG-27-D	" "	14.0
PLG-28-B	" "	14.0
PLG-28-C	" "	16.0
PLG-29-D	" "	14.0
PLG-29-G	" "	14.0
PLG-30-K	" "	11.0
PLG-31-E	" "	29.0
PLG-32-F	" "	14.0
PLG-32-B	" "	14.0
PLG-33-C	RED-PINK SACCHAROIDAL ALBITE	4.0
PLG-35-E	WHITE, COARSE XENOMORPHIC	22.0
PLG-37-J	BEIGE-GREY, COARSE LATHS	2.5
PLG-39-E	RED-PINK, FINE GRAIN LATHS	14.0
PLG-40-K	RED-PINK, COARSE XENOMORPHIC	4.0
PLG-43-A	WHITE, COARSE XENOMORPHIC	11.0
PLG-44-G	" "	14.0
PLG-45-B	" "	14.0
PLG-48-D	" "	14.0
PLG-49-C	" "	30.0
PLG-53-D	" "	14.0
PLG-55-D	" "	25.0
PLG-56-B	" "	25.0
PLG-56-C	" "	25.0
PLG-61-D	" "	22.0
PLG-68-B	" "	25.0
PLG-70-J	RED SACCHAROIDAL ALBITE	1.0
PLG-70-D	GREY-BROWN SACCHAROIDAL ALBITE	6.0
PLG-71-D	WHITE, FINE GRAIN LATHS	6.0
PLG-76-I	GREY-WHITE SACCHAROIDAL ALBITE	2.5
PLG-79-G	LIGHT BROWN, COARSE XENOMORPHIC	13.0
PLG-80-B	WHITE, COARSE XENOMORPHIC	16.0
PLG-81-E	" "	24.0
PLG-81-F	" "	24.0
PLG-89-C	WHITE-BROWN COARSE XENOMORPHIC	22.0
PLG-95-C	GREY CLEVELANDITE	3.0
P-PLG-15-A	WHITE, COARSE XENOMORPHIC	8.0
P-PLG-10-9-1B	" "	16.0
11-9-4A	WHITE SACCHAROIDAL ALBITE	2.0
11-9-4B	" "	1.0
11-9-5E	" "	3.0
12-9-1B	" "	3.0
11-9-5A	" "	3.0
P-PLG-24	BEIGE, COARSE XENOMORPHIC	16.0

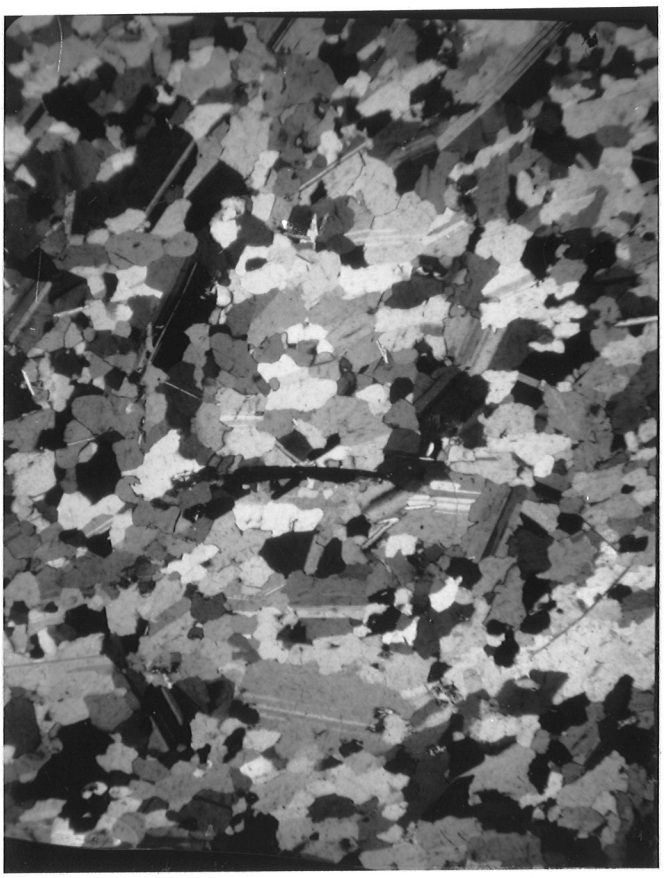

Figure 37: Photomicrograph of saccharoidal albite +quartz and columbite-tantalite. Crossed nicols, (50X).

Plagioclase in the Minago and Nelson series is typically white oligoclase (An 14-29). Sericitized oligoclase is cloudy light grey or light green in colour, and weathers to colours between white and light brown.

5.5.3 K-feldspar

Microcline-perthite is the dominant, primary K-feldspar in the Cross Lake pegmatites and pegmatitic granites. Almost all of the pegmatites sampled contain maximum microcline. The average obliquity for 265 samples is 0.93 with a standard deviation of 0.08. Intermediate microcline was found in two rare element pegmatites of the Northern series, 22 and 38. Orthoclase was found in only one of the two pegmatites that contain intermediate microcline. A single hand specimen of brown K-feldspar from pegmatite 22 has a wide range in structural states ranging between Δ = 0.0 to 0.60.

The K-feldspars from all pegmatite types in the field cluster in the low microcline region in the plot of the $\underline{b}$ versus $\underline{c}$ cell dimensions, except for the orthoclase from pegmatite 22 which falls approximately midway between low microcline an high sanidine (Figure 38).

The colour of the K-feldspar is white in the pegmatitic granites and barren pegmatites but is pink or white in the more fractionated pegmatites in the field. A mottled pink-grey-white K-feldspar occurs locally in the spodumene pegmatite zone of the Southern series. Brown K-feldspar is found in pegmatites 22 and 37 of the Northern series. Microscopic

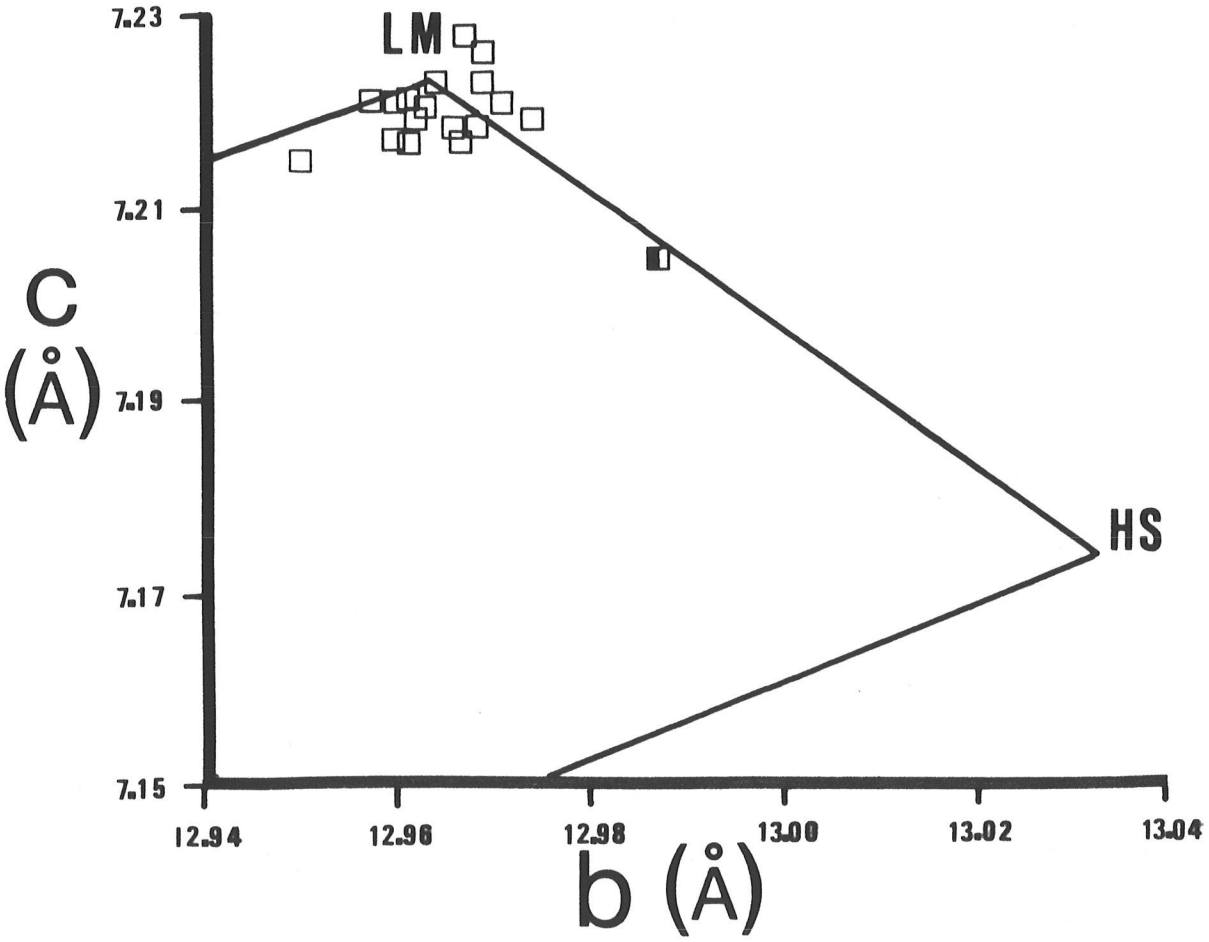

Figure 38: Portion of a b -c plot for selected K-feldspars from all pegmatite types in the Cross Lake pegmatite field. Orthoclase from pegmatite 22 of the Northern series (designated by the half-shaded square) falls almost midway between low microcline and high sanidine. Open squares designate microcline.

inclusions in the K-feldspar is the probable cause of the colour variation (Černý and Macek 1972).

Dimensions of the albite exsolution lamellae in the microcline-perthite decreases with increasing complexity of the pegmatite type. Coarse perthite, with lamellae between 1 and 2 mm is common in the pegmatitic granite and barren pegmatites in the field. In contrast, the sodic phase is barely visible in the K-feldspars in the spodumene-bearing pegmatites of the Southern series. The total Na_2O wt% content is representative of the exsolved perthitic albite plus the albitic component still in solid solution (Černý et al. 1981).

Graphic K-feldspar occurs in the pegmatites and pegmatitic granites of the Minago series and the Nelson series.

Blocky K-feldspar crystals range up to 2.5 m in their maximum dimension. In some pegmatites, tectonic stresses have deformed the K-feldspar crystals into lenticular forms.

In the pegmatites of the Minago and Nelson series, K-feldspar occurs with quartz, biotite-muscovite and plagioclase and is dispersed evenly over the entire body. In the complex pegmatites K-feldspar occurs in the intermediate and core-margin zones and is associated with muscovite, quartz, spodumene and minor tourmaline.

The results of the partial analysis of 321 K-feldspars sampled is given in Table 25 and the compositional characteristics of the K-feldspars is summarised in Table 10. The concentrations of the elements Li, Rb, Sr, Cs, Ba, Pb and Na

in the K-feldspar vary markedly between pegmatites and especially between the different pegmatite series. In concordance with the findings of Heier (1962) and Smith (1974) the values for Ba, Sr and Pb are indirectly proportional to Rb, Cs and Li contents. In order to compare the variations in the concentrations of these elements from the different pegmatite series they are plotted against the K/Rb ratios. The K/Rb ratios are used because they best discriminate the different pegmatite series, and is widely used as a measure of fractionation.

K-feldspar rubidium contents range from 69 to 26470 ppm. The Nelson series and the barren pegmatites of the Northern series have the K-feldspars with the lowest Rb values (average 390 ppm). On average, the absolute Rb content is about twice as high in the K-feldspars from the pegmatites and pegmatitic granites of the Minago series. The biotite-peristerite pegmatite zone of the Southern series has an average Rb content of 2077 ppm; this is slightly greater than the average Rb values for the K-feldspars from the beryl-columbite zone of the Northern series.

The most Rb-rich K-feldspars occur in the spodumene-bearing pegmatites of the Southern series (average 15833 ppm), which is about 8 times greater than that of the K-feldspars from the mineralized pegmatites from the Northern series.

The cesium content in the K-feldspars ranges between 2 and 4472 ppm. Unlike rubidium, there is considerable over-

lap in the range of Cs contents between the different pegmatite series. Figure 39 shows K/Rb vs Cs ppm. Cesium is in general directly proportional to the rubidium content, however, their relative proportions vary among the pegmatite series. The K-feldspars of the Minago series and the barren pegmatite zone of the Northern and Southern series have slightly greater average Cs contents than the K-feldspars from the Nelson series (Table 10).

The highest Cs in the K-feldspars occurs in the mineralized pegmatites of the Northern and Southern series. Although the average Cs value for the K-feldspars from the spodumene-bearing pegmatites of the Southern series is about twice that of the K-feldspars from the beryl-columbite zone of the Northern series, the range in the concentrations is very similar.

The average lithium content for the K-feldspars from the Northern, Minago and Nelson series is less than 7 ppm. However, the more evolved pegmatites of the beryl-columbite zone and the Minago series contain K-feldspars with lithium contents as high as 56 ppm.

The K-feldspars of the Southern pegmatite series have the highest Li values. Figure 40 shows the K/Rb vs Li ppm plot for the K-feldspars. The graph indicates that Li increases directly with Rb. Symbols as in Figure 24. Furthermore, the Minago and Southern pegmatite series show the greatest range of Li in the K-feldspars.

TABLE 10

Compositional characteristics of the K-feldspars from the pegmatites and pegmatitic granites.

	NELSON SERIES	MINAGO SERIES	SOUTHERN SERIES		NORTHERN SERIES	
			BIOTITE-PERISTERITE ZONE	SPODUMENE ZONE	BARREN ZONE	BERYL ZONE
	N = 61 *N = 29	N = 89 *N = 40	N = 26 *N = 12	N = 77 *N = 35	N = 29 *N = 12	N = 32 *N = 10
NA20 WT%	1.93 ±0.44 (0.85-2.78)	2.36 ±0.45 (1.18-5.28)	2.24 ±0.53 (1.29-3.26)	1.57 ±0.42 (0.74-2.70)	2.74 ±0.56 (1.50-3.60)	2.65 ±0.62 (1.32-4.24)
LI PPM	5.6 ±5.6 (0-21)	6.8 ±10.8 (1-59)	24.6 ±18.1 (2-64)	94.4 ±140.4 (3-1233)	2.4 ±1.0 (1-5)	6.6 ±12.0 (1-65)
RB PPM	370 ±114 (222-860)	798 ±959 (181-8092)	2077 ±1564 (297-5810)	15833 ±4665 (2465-26470)	414 ±189 (69-710)	1805 ±1219 (620-5390)
CS PPM	19 ±9 (3-50)	56 ±109 (2-905)	84 ±104 (7-478)	1201 ±772 (79-4472)	56 ±49 (4-178)	581 ±742 (21-2881)
SR PPM*	136 ±81 (41-323)	50 ±32 (8-172)	63 ±50 (22-162)	79 ±27 (24-166)	69 ±84 (8-293)	34 ±31 (8-103)
BA PPM*	1505 ±1464 (81-5168)	344 ±323 (76-1212)	628 ±854 (80-2239)	156 ±271 (51-10541)	659 ±826 (86-2643)	158 ±198 (53-691)
PB PPM*	60 ±26 (14-125)	59 ±21 (18-117)	44 ±22 (14-98)	20 ±11 (4-43)	50 ±42 (10-147)	48 ±26 (14-89)
K/RB	328 ±89 (176-547)	198 ±92 (14-459)	102 ±105 (18-374)	7.9 ±4.8 (3.6-44.4)	364 ±314 (139-1597)	83 ±45 (20-169)
K/CS	7780 ±5812 (2220-33510)	6373 ±8215 (128-51800)	3015 ±2836 (232-14140)	146 ±167 (23-1387)	4116 ±5198 (631-28350)	787 ±1087 (39-4906)
RB/CS	27.3 ±37.1 (8.7-286.7)	30.4 ±34.0 (5.4-220.0)	36.2 ±25.3 (8.5-125.7)	17.7 ±10.0 (4.2-51.2)	11.8 ±9.2 (3.1-40.0)	7.8 ±8.4 (1.6-31.7)

T = TOTAL , * = NUMBER OF K-FELDSPARS ANALYSED FOR PB, BA, SR

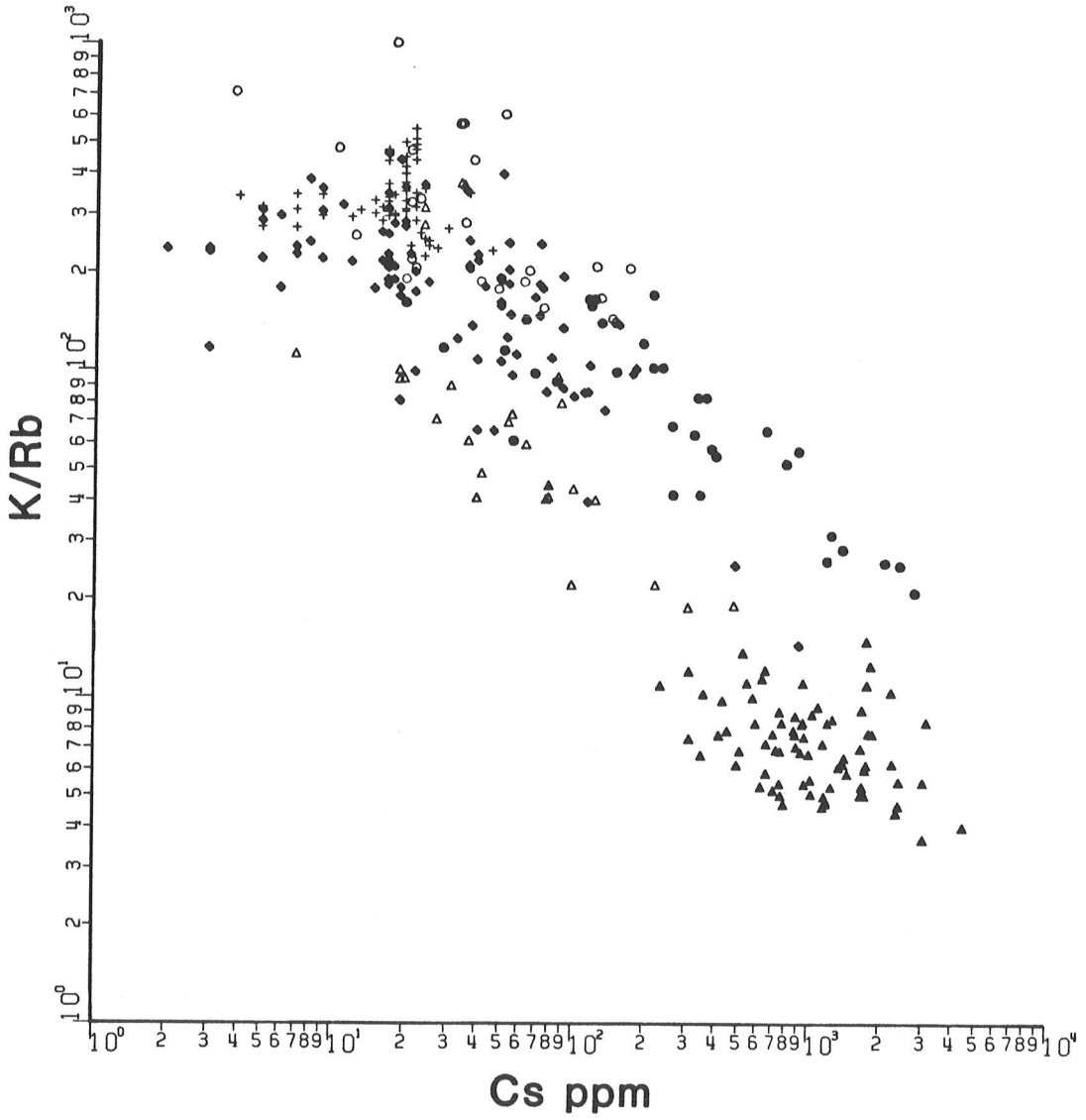

Figure 39: K/Rb vs Cs plot of K-feldspars from the Cross Lake pegmatites. As fractionation progresses, the K/Rb ratio decreases with increasing Cs. Note that the Northern and Southern series form two distinct but parallel trends. The feldspars of the Northern series have lower Rb/Cs ratios. Symbols as in Figure 24.

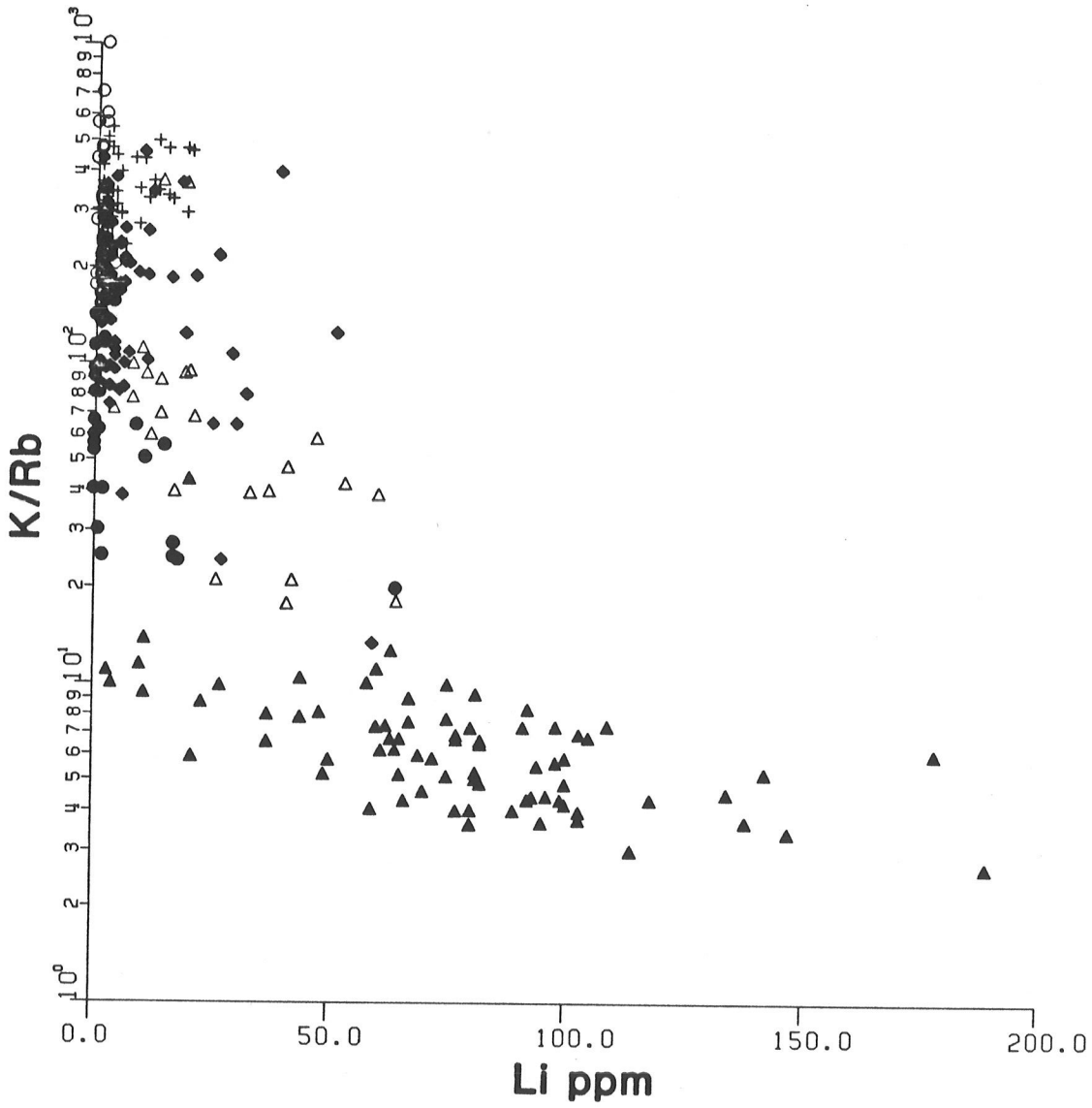

Figure 40: K/Rb vs Li plot of K-feldspars from the Cross Lake pegmatites. Note that the K-feldspars from the Minago series and the Southern series are Li-rich compared to the Northern series K-feldspars.

K-feldspars from the simple barren pegmatites show a wide range in Ba contents. This is shown on Figure 41 which shows K/Rb vs Ba ppm. The Rb rich K-feldspars of the Southern series have the lowest Ba contents, generally less than 100 ppm.

The K-feldspars from the Nelson pegmatite series, particulary the pegmatites in the northwestern margin of the study area have the highest Ba contents which range up to 5168 ppm. Two pegmatites of the Southern series have anomalous Ba contents in the K-feldspars (up to 1054 ppm).

Figure 42 is a plot of K/Rb vs Sr. The Sr values decrease with decreasing K/Rb to about K/Rb = 70. There is an increase in Sr contents in the K-feldspars with increasing K/Rb fractionation below this level. Possible explanations for the reversal in the expected behavior of Sr are discussed in chapter VI.

Lead ranges from 4 to 147 ppm in the K-feldspars. There is a slight decrease in the average Pb contents in the K-feldspars in the more evolved pegmatite series. The K/Rb vs Pb plot for the K-feldspars (Figure 43) indicates that all of the pegmatite series except the spodumene-bearing pegmatites of the Southern series show a wide range in Pb values. The spodumene-bearing pegmatites of the Southern series, however, have K-feldspar Pb contents that range only between 4 and 43 ppm.

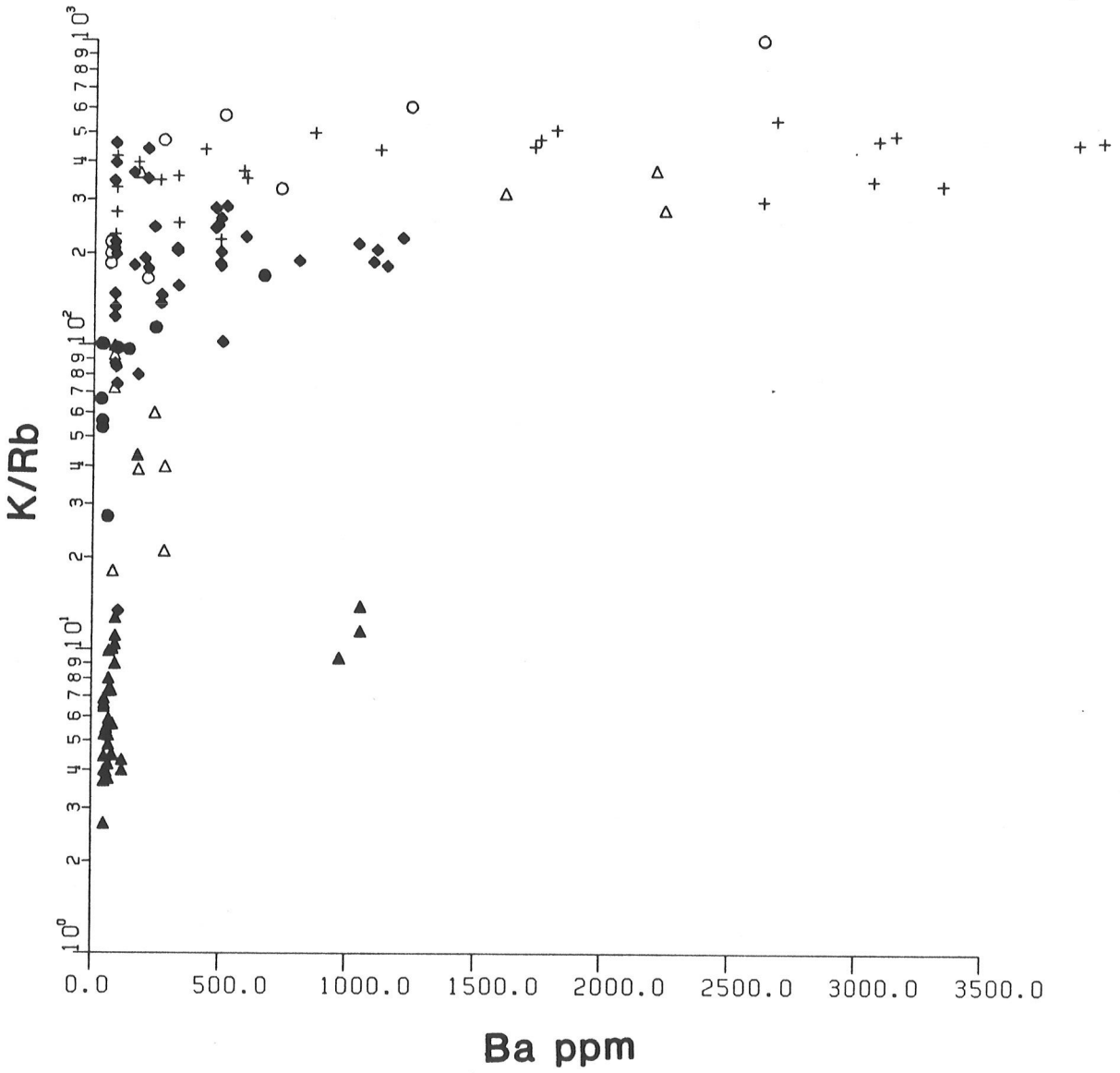

Figure 41: K/Rb vs Ba plot of K-feldspars from the Cross Lake pegmatites. K-feldspars from the barren pegmatites of the Nelson series are Ba-rich whereas the rare-element pegmatite K-feldspars are Ba depleted. The high Ba content in the K-feldspars from two pegmatites in the Southern series is probably due to contamination from the host rocks. Symbols as in Figure 24.

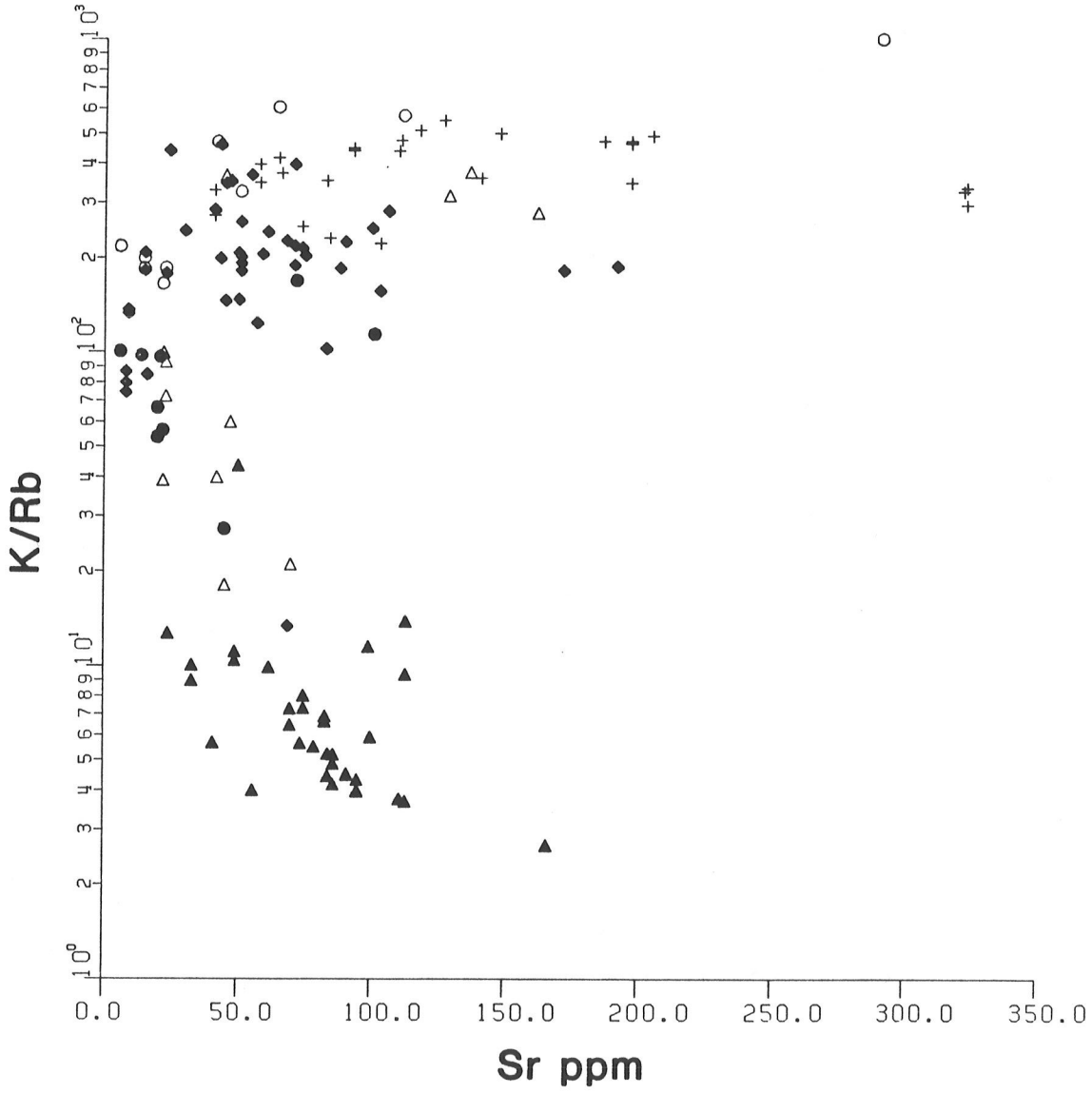

Figure 42: K/Rb vs Sr plot of K-feldspars from the Cross Lake pegmatite field. Note that Sr decreases with the decreasing K/Rb ratio to about K/Rb = 100, at which point Sr increases with decreasing K/Rb. Symbols as in Figure 24.

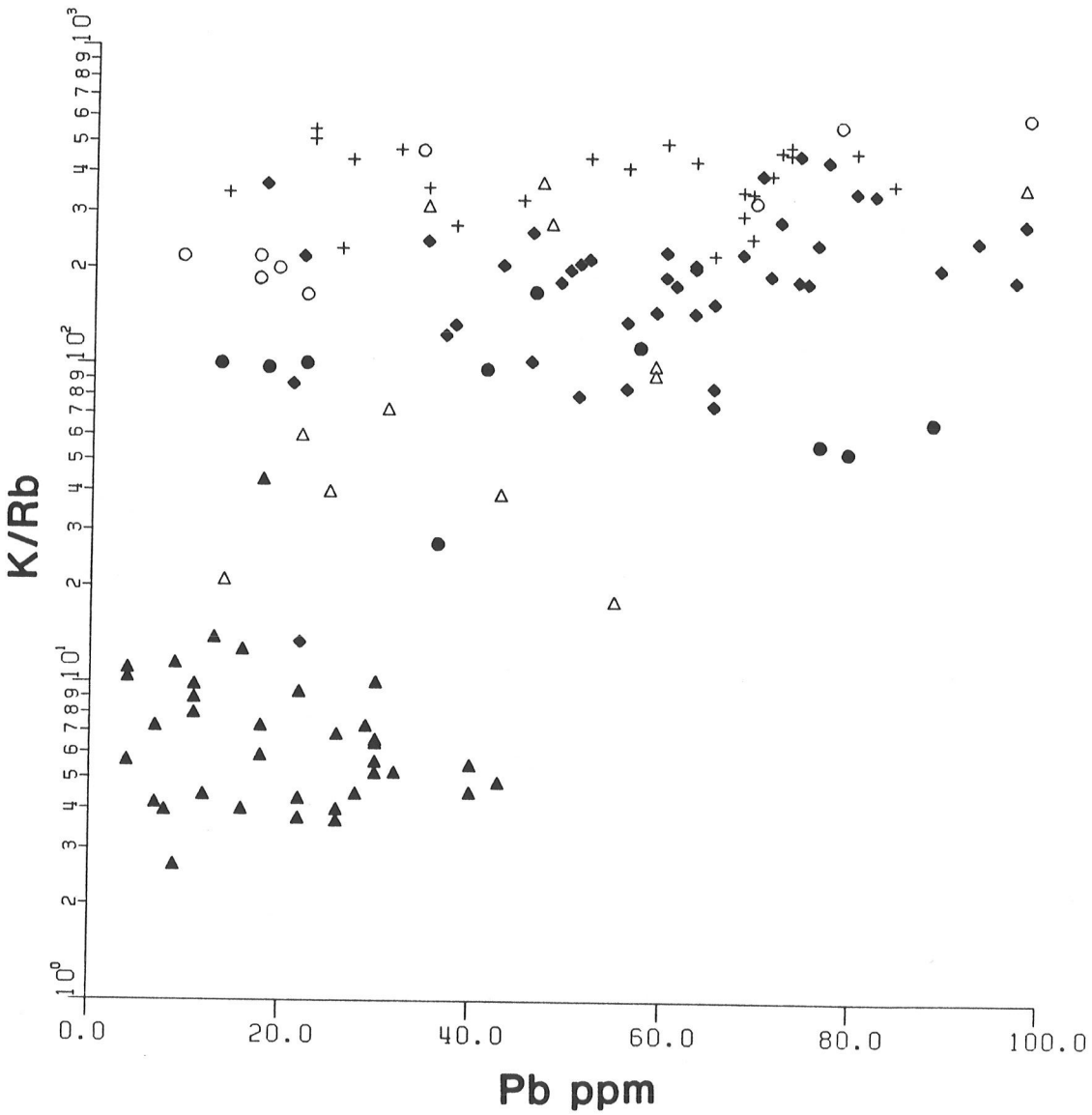

Figure 43: K/Rb vs Pb plot of K-feldspars from the Cross Lake pegmatites. Note that the spodumene-bearing pegmatites of the Southern series have relatively low Pb contents (<40 ppm) whereas the Pb content in the K-feldspars from the other pegmatites range up to 80 ppm. Symbols as in Figure 24.

5.5.4 Muscovite

Muscovite occurs in almost all of the pegmatites of the spodumene pegmatite zone of the Southern series and the Minago and Northern series. Only two samples were obtained from the pegmatites of the biotite-peristerite zone of the Southern series. Two paragenetic types of muscovite occur in the pegmatites. These are; primary book type and late fine-grained muscovite. The colour, size, habit and chemistry of the primary muscovites varies within and among pegmatite series in the Cross Lake field.

Muscovite in the pegmatites of the spodumene zone of the Southern series is characterized by its pale green colour. It occurs in the wall, intermediate, and core-margin zones of the pegmatite and is associated with quartz, albite, and K-feldspar. Muscovite is rare in the biotite-peristerite pegmatites of the Southern series, where it appears to replace biotite.

In the Minago series muscovite occurs as bronze to silver-white sheets up to 10 cm in length. It is associated with quartz, K-feldspar, oligoclase, and biotite.

The Northern pegmatite series contains muscovite which ranges in colour from silver-white in the barren pegmatite zone to pale and deep green in the well fractionated pegmatites of the beryl-columbite zone. Muscovite is comparatively more abundant, and individual crystals are larger in the Northern series. Large wedge-shaped crystals (up to 45

cm in their maximum dimension) and plumose aggregates of muscovite and quartz are found only in the Northern series (Figure 44).

The partial chemical analyses of the muscovites are given in Table 26, and the compositional characteristics of the muscovites for the different pegmatite series are summarised in Table 11.

The geochemical trends shown by the K-feldspars for the different pegmatite series are simulated by the muscovites. In general, the muscovites from the mineralogically and texturally complex pegmatites typically contain more Rb, Cs, Be, Mn and less Fe and Mg than the muscovites from the simple barren pegmatites. However, the relative contents of Li in the muscovites between the different pegmatite series does not simulate the Li trend observed for the K-feldspars. For example, the muscovites in the Southern and Minago series have almost equal average Li values whereas for K-feldspars, the Li contents in the Southern series is several times greater than that of the Minago series.

The average ΣFe_2O_3 content for the muscovites of the Minago series ranges between 2.26 and 2.78 wt% (Table 11). There is a sharp decrease in the iron contents in the muscovites in the spodumene-bearing pegmatites of the Southern series which have an average of 0.76 wt%.

Figure 45 gives the total Fe_2O_3 against MgO wt% for the muscovites. Magnesium shows a positive correlation to iron.

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Figure 44: Wedge-shaped quartz + muscovite cluster in a barren pegmatite (79) of the Northern series.

TABLE 11

Compositional characteristics of the muscovites from the pegmatites and pegmatitic granites.

	MINAGO SERIES	SOUTHERN SERIES	NORTHERN SERIES	
			BARREN ZONE	BERYL-COLUMBITE ZONE
	N = 27	N = 29	N = 20	N = 25
TFE2O3 WT%	2.259 ±0.432 (1.17-3.16)	0.756 ±0.534 (0.33-2.61)	2.660 ±0.654 (1.54-3.87)	2.780 ±0.733 (1.65-4.27)
MGO WT%	0.52 ±0.21 (0.15-0.80)	0.06 ±0.14 (0.01-0.75)	0.45 ±0.14 (0.28-0.73)	0.38 ±0.22 (0.10-0.86)
LI2O WT%	0.044 ±0.043 (0.01-0.15)	0.044 ±0.017 (0.01-0.11)	0.009 ±0.005 (0.00-0.02)	0.014 ±0.013 (0.00-0.05)
RB PPM	1218 ±612 (418-2528)	19651 ±7343 (1374-32820)	658 ±451 (158-1494)	2544 ±909 (1174-4420)
CS PPM	70 ±80 (10-249)	932 ±669 (190-2234)	103 ±169 (9-741)	502 ±566 (31-2660)
BE PPM	12.8 ±6.9 (4-27)	23.3 ±6.4 (8-49)	12.7 ±8.0 (2-26)	26.6 ±5.2 (11-36)
K/RB	88.0 ±44.3 (33.9-205.4)	6.6 ±11.4 (2.2-62.2)	220.0 ±57.6 (57.6-508.1)	38.3 ±16.7 (19.1-74.5)
K/CS	3550.2 ±2989.9 (342-8675)	154.4 ±125.6 (35-411)	3774.4 ±3492.6 (116-9796)	486.7 ±721.1 (32-2820)
RB/CS	35.3 ±21.6 (6.5-75.8)	33.4 ±23.0 (1.6-80.9)	15.8 ±14.3 (2.0-69.3)	10.9 ±9.7 (1.1-37.9)

T = TOTAL

However, some pegmatitic granites and barren pegmatites of the Southern and Northern series deviate from the major trend.

Rb and Cs range between 158 and 32820 ppm and 9 and 2660 ppm, respectively. Figure 46 shows K/Rb against Cs ppm for the muscovites. The plot indicates, as in the K-feldspars, that the relative proportions of Rb and Cs differs between the pegmatites series in the same manner and that K/Rb and Cs are inversely related. The difference in the K/Rb values and the overlap in the Cs values for the muscovites from the mineralized pegmatites of the Northern and Southern series is more pronounced than in the K-feldspars.

The muscovites from the Minago and Southern pegmatite series have equal Rb/Cs ratios that are more than two times as high as the Rb/Cs ratios for the muscovites in the barren muscovite and beryl-columbite zone of the Northern series (Table 11).

Figure 47 shows K/Rb versus Be ppm for the muscovites. Beryllium in the muscovites ranges from 2 to 49 ppm and increases directly with the Cs content. The relative abundance of beryl in the mineralized pegmatites of the Northern and Southern series is reflected in the Be contents of the muscovites. This relationship has been previously documented for other pegmatites by Heinrich (1962), Odikadze (1956) and Beus (1956). Beryl is conspicuously more abundant in the mineralized pegmatites of the Northern series and the muscovites have an average 3.3 ppm more Be than the muscov-

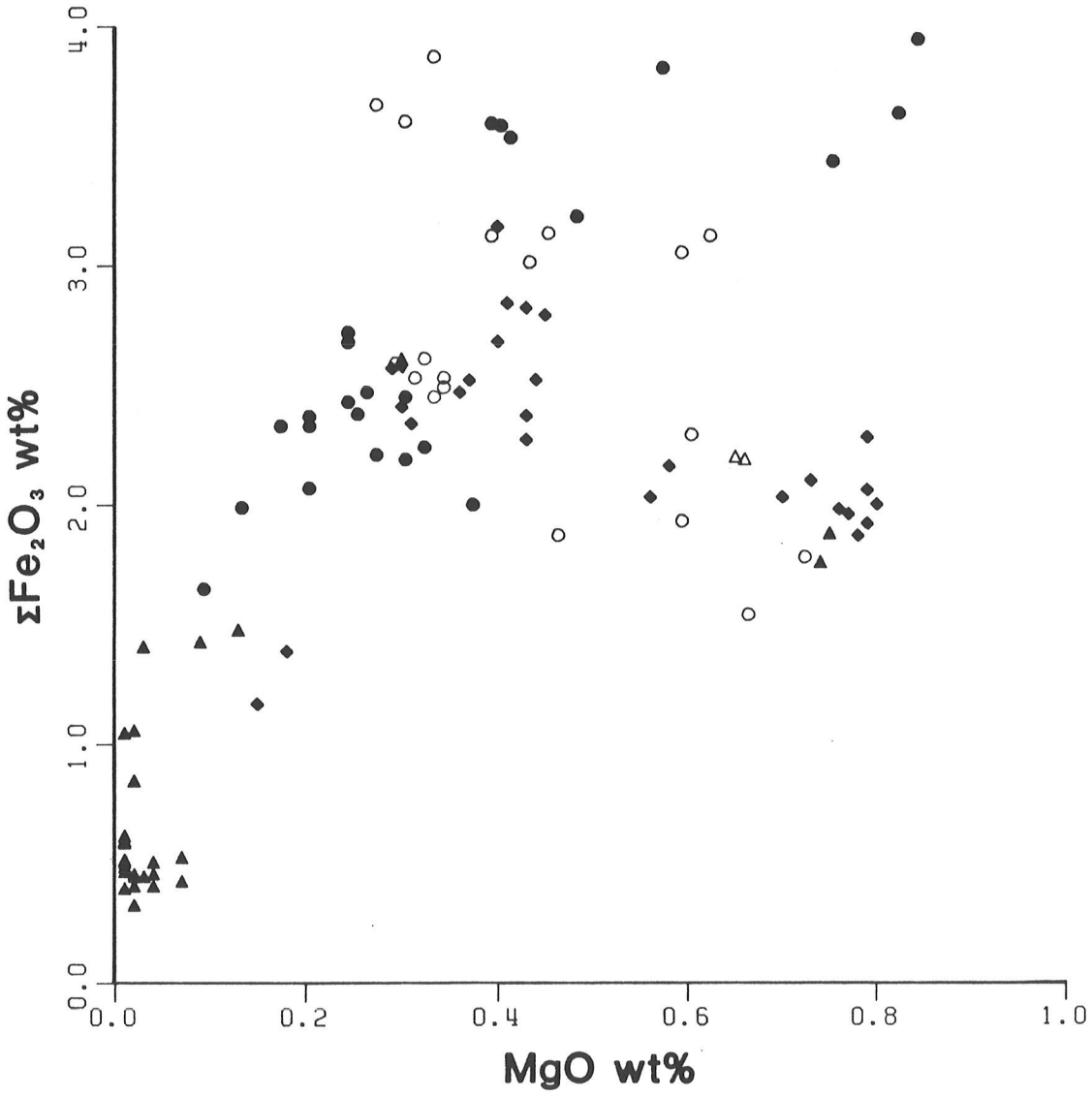

Figure 45: ΣFe_2O_3 vs MgO plot of muscovites from the Cross Lake pegmatites. Note that the muscovite from the highly fractionated spodumene-bearing pegmatites of the Southern series have low Fe and Mg contents. However, the less fractionated pegmatites contain muscovites which have higher and varying amounts of Fe and Mg. Symbols as in Figure 24.

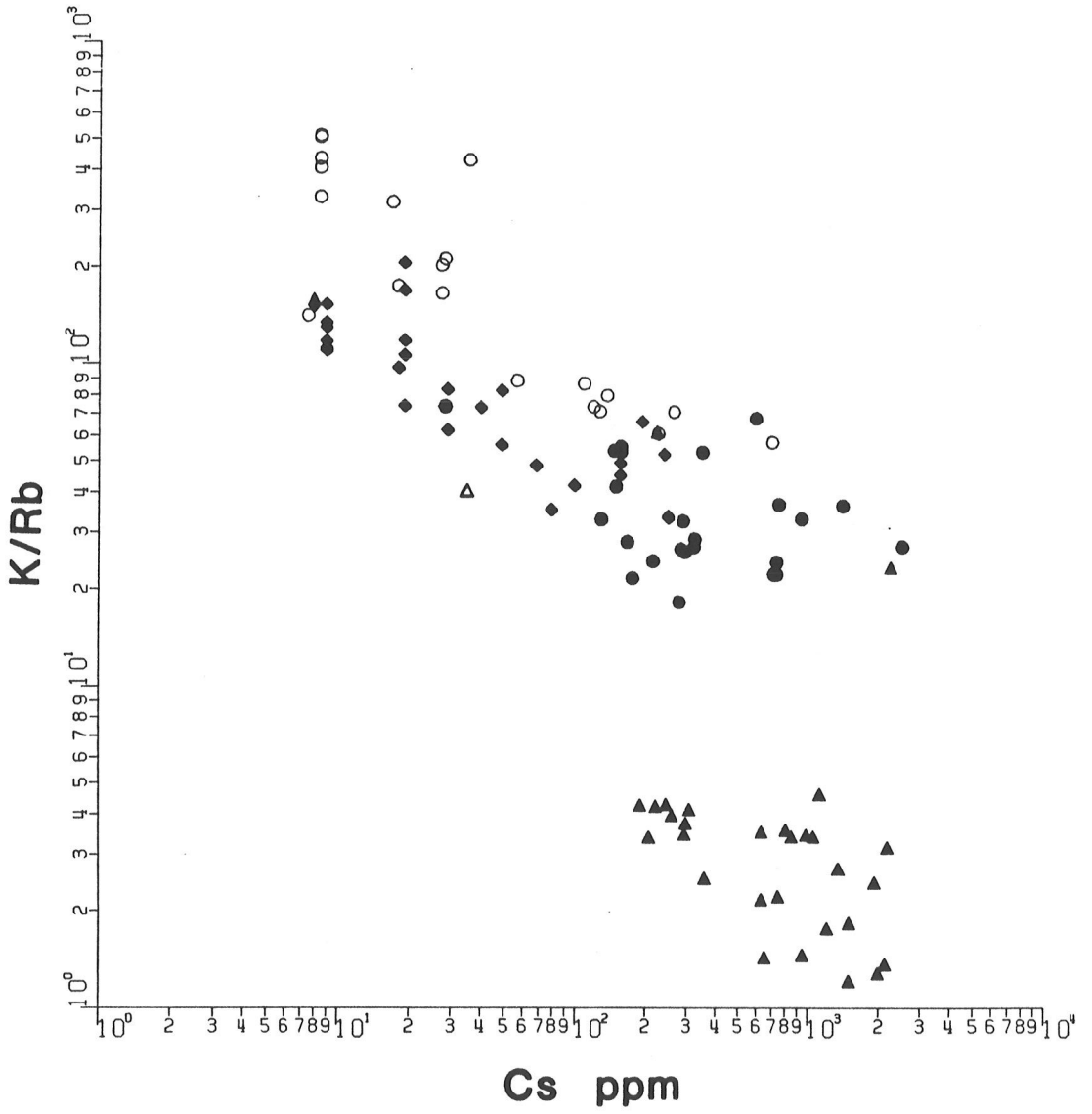

Figure 46: K/Rb vs Cs plot of muscovites from the Cross Lake pegmatite field. Note that the muscovites from the beryl-columbite zone of the Northern series and the spodumene zone of the Southern series have similar ranges in Cs content but have extremely different K/Rb ratios. The same relationship is true for the muscovites from the Northern and Minago series however the difference in K/Rb is not as great. Symbols as in Figure 24.

ites from the spodumene-bearing pegmatites of the Southern series (Table 11).

Lithium in the muscovites ranges between 0 and 700 ppm. In contrast to the K-feldspars, the most lithium-rich muscovites occur in the pegmatites of the Minago series that intrude the Metis granite. The average Li_2O wt% content for the muscovites from the spodumene-bearing pegmatites of the Southern series and the Minago series is only 0.044 wt%.

Figure 48 shows K/Rb against Li for the muscovites. As in the K-feldspars, muscovite from the Northern series has comparatively low Li contents. Within the Northern series there is a slight increase in Li in the muscovites in the more complex pegmatites. Figure 49 gives Li_2O against MgO for the muscovites. Excluding the Mg-poor muscovites from the spodumene pegmatite zone, the Mg-rich muscovites are also relatively rich in Li.

5.5.5 Biotite

Biotite occurs in the pegmatites of the Nelson and Minago series and in the biotite-peristerite zone of the Southern series. It is dark brown to black in colour and varies in size up to 50 cm. Small (4 cm) flakes of biotite locally occur along the contacts of host rocks and xenoliths. Biotite books commonly are oriented parallel to the contacts of the body. No chemical analysis of the biotites was performed.

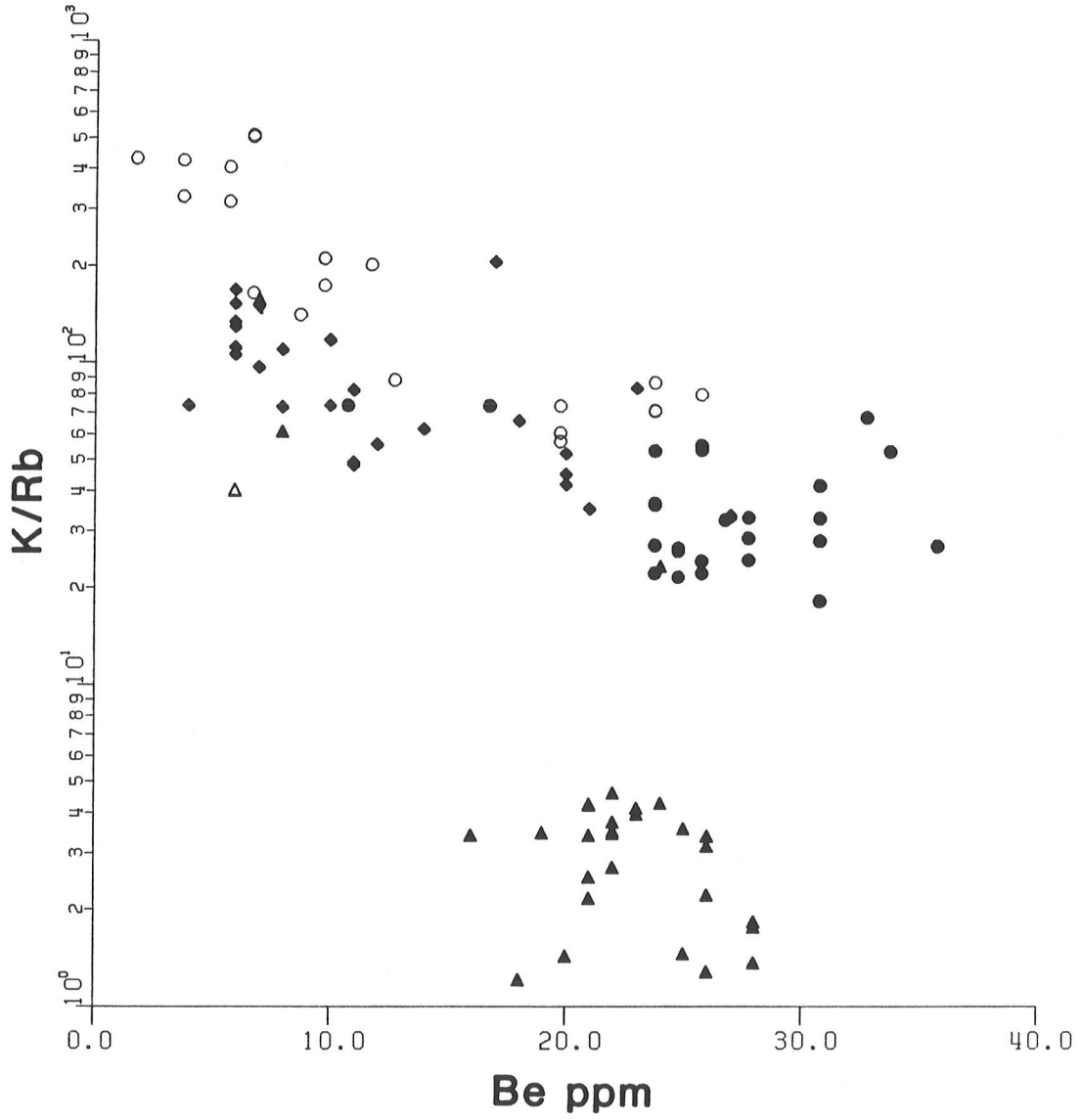

Figure 47: K/Rb vs Be plot of muscovites from the Cross Lake pegmatite field. Note that the muscovites from the beryl-columbite zone of the Northern series are generally more Be-rich than the muscovites from the more fractionated spodumene-bearing pegmatites of the Southern series. Symbols as in Figure 24.

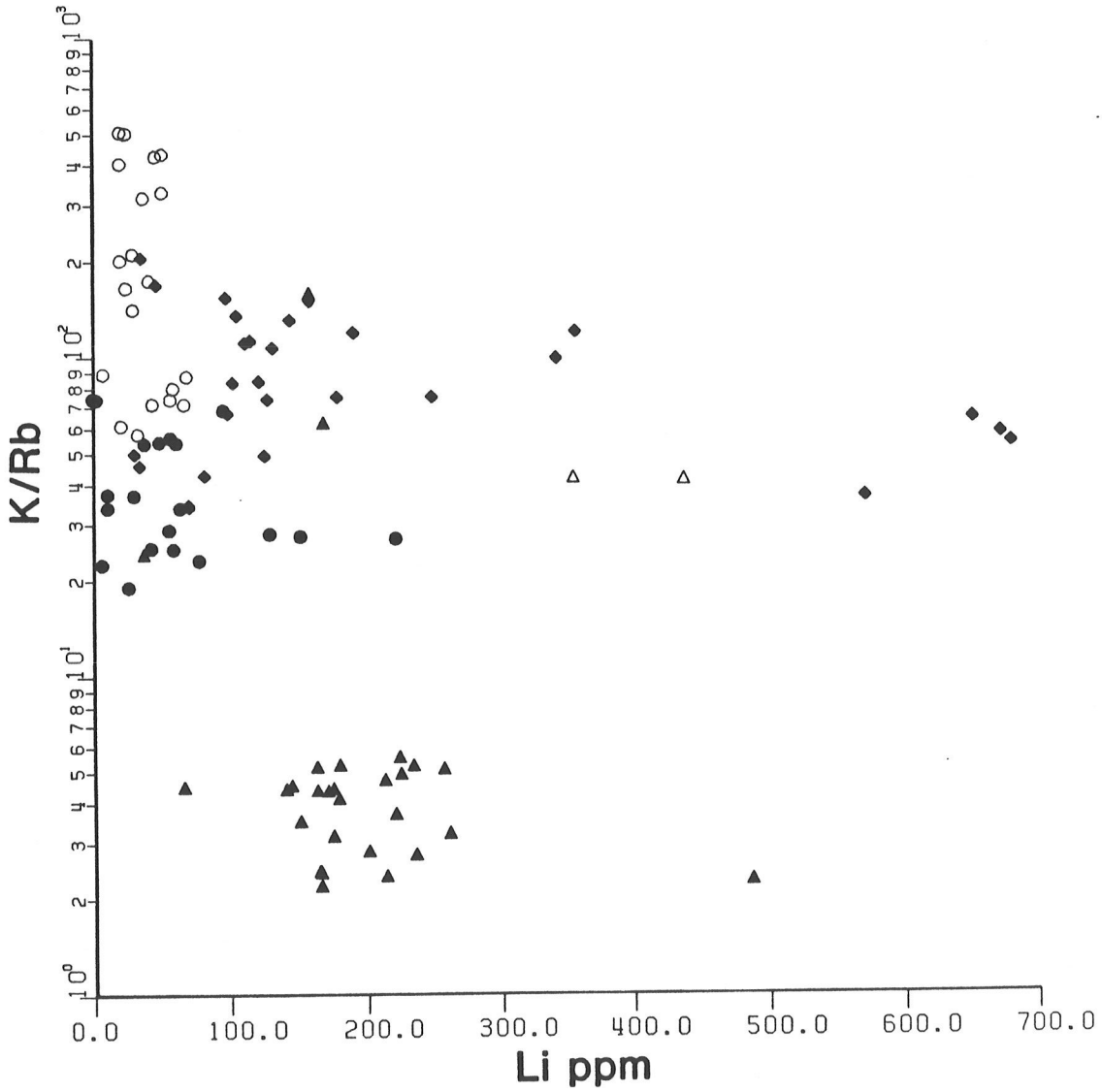

Figure 48: K/Rb vs Li plot of muscovites from the Cross Lake pegmatite field. Note that the muscovites from the pegmatites of the Northern and Southern series are relatively Li-poor and the most Li-rich muscovites occur in the pegmatites and pegmatitic granites of the Minago series. Symbols as in Figure 24.

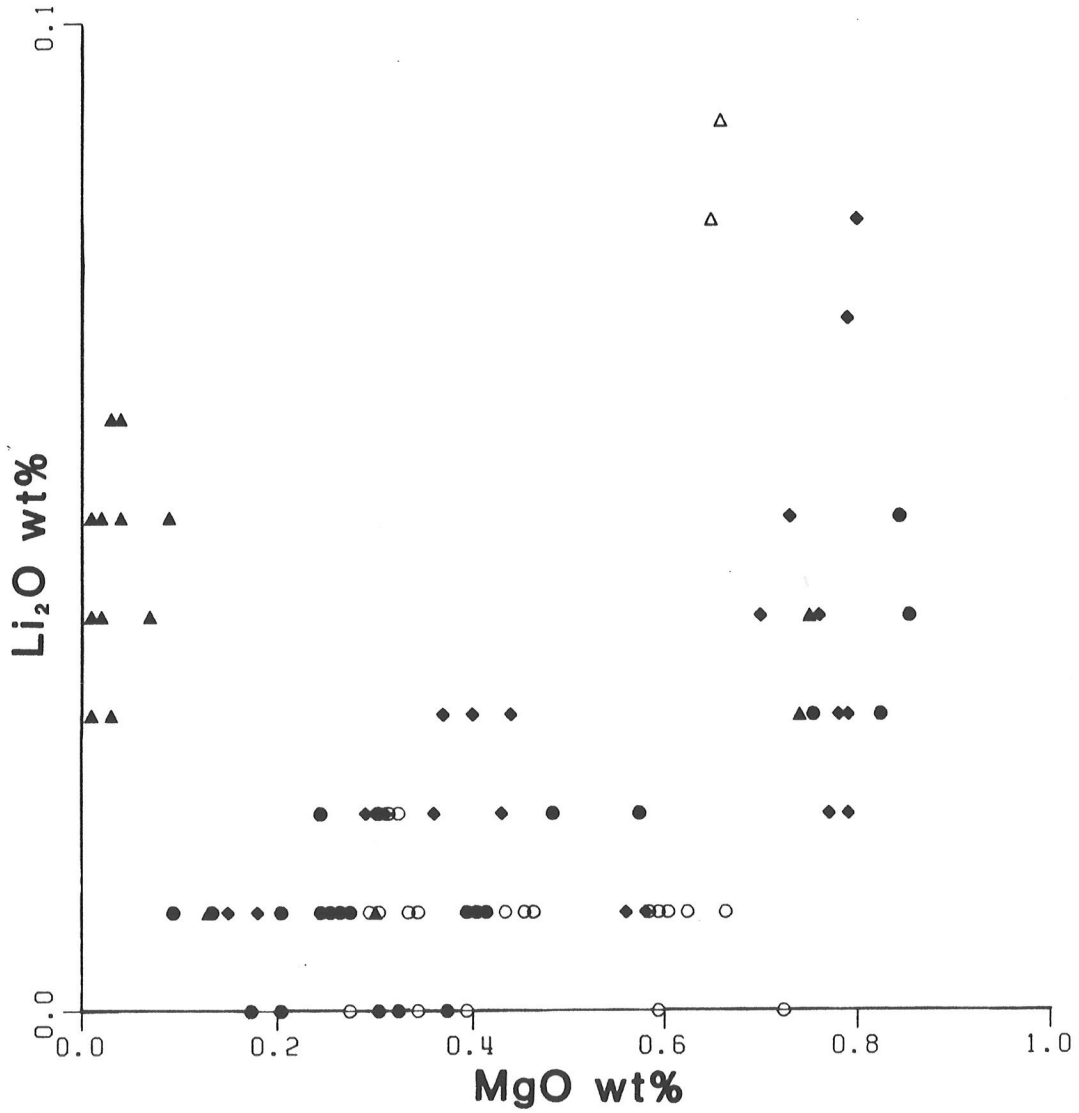

Figure 49: Li_2O vs MgO plot of the muscovites from the Cross Lake pegmatite field. Note that with the exception of the spodumene-bearing pegmatites of the Southern series, the relatively Li-rich muscovites are also relatively Mg-rich. Symbols as in Figure 24.

5.5.6 Spodumene

Spodumene-bearing pegmatites comprise a 5 km long east-trending zone south of Cross Island, amounting to about two thirds of the Southern pegmatite series.

Unaltered spodumene ranges in colour from white to light grey green, to pale green; altered samples are dark green to brown in colour.

The crystals are mostly tabular, elongated along the c axis and flattened along the a axis. Spodumene crystals up to 70 cm in length occur in the intensively sheared pegmatites on Spodumene Island (Figure 34). In the comparatively undeformed pegmatites, blocky euhedral crystals range up to 50 cm in their maximum dimension (Figure 50).

Spodumene is most abundant in the intermediate zones of the well zoned pegmatites in association with quartz, muscovite, and albite.

The partial chemical analyses of spodumene specimens are given in Table 27 and the compositional characteristics are summarized in Table 12. Other than a slight decrease in the total Fe_2O_3 in the well fractionated pegmatites no systematic variation of the determined elements was observed.

5.5.7 Beryl

Beryl occurs in the complex pegmatites of the Northern and Southern series. It is also a rare accessory phase in the pegmatitic granites of the Minago series.

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Figure 50: Blocky spodumene crystal in quartz + albite in pegmatite 9 of the Southern series.

TABLE 12

Compositional characteristics of the spodumenes from the pegmatites of the Southern series.

	N = 16
TFe203 wt%	0.476 ±0.282 (0.16-1.16)
MnO wt%	0.13 ±0.06 (0.02-0.29)
CaO wt%	0.024 ±0.018 (0.00-0.07)
Na20 wt%	0.313 ±0.326 (0.10-1.14)
Li20 wt%	7.792 ±0.633 (6.00-8.50)

Beryls from the Northern and Southern series have contrasting colour, morphology and chemistry. Furthermore, beryl is relatively more abundant in the Northern series.

Beryls in the Southern series are dull to vitreous white and rarely green in colour. Vitreous varieties are difficult to distinguish from quartz when the crystal faces are hidden or absent. The crystals are stubby columnar, anhedral to euhedral and vary in size from a few millimeters to 15 cm in diameter (Figure 51).

Beryl in the Southern series is associated with clevelandite, quartz and muscovite in the inner zones of the pegmatites. Crystals were also found within and fringing the saccharoidal albite units in contact with quartz.

In contrast, the beryl of the Northern series is euhedral, columnar and occurs in diverse colours of pale green, yellow and white. Most crystals are turbid and fractured and are not of gem quality. Individual crystals range in size up to 30 cm in length (Figure 52) and 18 cm in diameter. Scabbard or "stuffed" beryls occur locally and appear to be skeletal growths surrounding prexisting plagioclase +quartz +garnet, +muscovite (Figure 53). Tiny tourmaline inclusions are also common in the green beryls.

Beryl in the Northern series pegmatites occurs in coarse albite +quartz +muscovite +garnet +schorl +apatite +saccharoidal albite.

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Figure 51: White, stubby-columnar beryl in pegmatite 9 of the spodumene zone, Southern series.



Figure 52: Green columnar beryl in pegmatite 36 of the beryl-columbite zone of the Northern series.



Figure 53: "Stuffed" or "scabbard" beryl from pegmatite 37, Northern series. The core is occupied by quartz, albite, apatite and garnet.

Table 28, gives the partial analyses of the Cross Lake beryls. The chemical characteristics of the beryls are summarised in Table 13. Variations in the alkali contents of beryl can be used for gauging the fractionation level of the granitic pegmatites (Trueman and Černý 1982). In general, the Southern series beryls are enriched in Na, Li, Rb and Cs and depleted in total Fe_2O_3 relative to the beryls of the Northern series (Figure 54). The compositional fields for the beryls are clearly seperated in the Na/Li vs Cs ppm plot (Figure 55). With progressive fractionation the Na/Li ratio decreases due to Li substitution for Be. With further rare alkali enrichment the Cs content starts to increase just when the change in the Na/Li ratio becomes less informative (Beus 1960, Černý 1975). The concentration of rare alkalis in the beryls of the Southern series is comparable to the Bernic Lake group of southeast Manitoba (Černý et. al. 1981).

5.5.8 Garnet

Garnets are a widespread accessory phase in the Cross Lake pegmatite field. They are generally less than 2 cm in diameter; however, crystals up to 7 cm were found in the pegmatitic granites of the Minago series. Almandine is the dominant species in the pegmatites. It occurs as subhedral to euhedral trapezohedral crystals that are deep red-brown in colour. Almandine is associated with plagioclase and

TABLE 13

Compositional characteristics of the beryls from the pegmatites of the Cross Lake field.

	NORTHERN SERIES N = 23	SOUTHERN SERIES N = 21
TFE203 WT%	0.52 ±0.25 (0.08-0.99)	0.32 ±0.13 (0.04-0.66)
NA20 WT%	0.58 ±0.33 (0.15-1.56)	1.60 ±0.44 (0.61-2.41)
LI PPM	340.52 ±106.71 (158-544)	3933.26 ±849.88 (2007-5480)
RB PPM	48.3 ±25.3 (18-107)	1030.5 ±257.1 (464-1519)
CS PPM	1322 ±677 (347-2871)	10204 ±257 (2684-22590)
NA/LI	13.05 ±6.94 (4.5-28.7)	3.03 ±0.66 (2.1-4.5)

T = Total

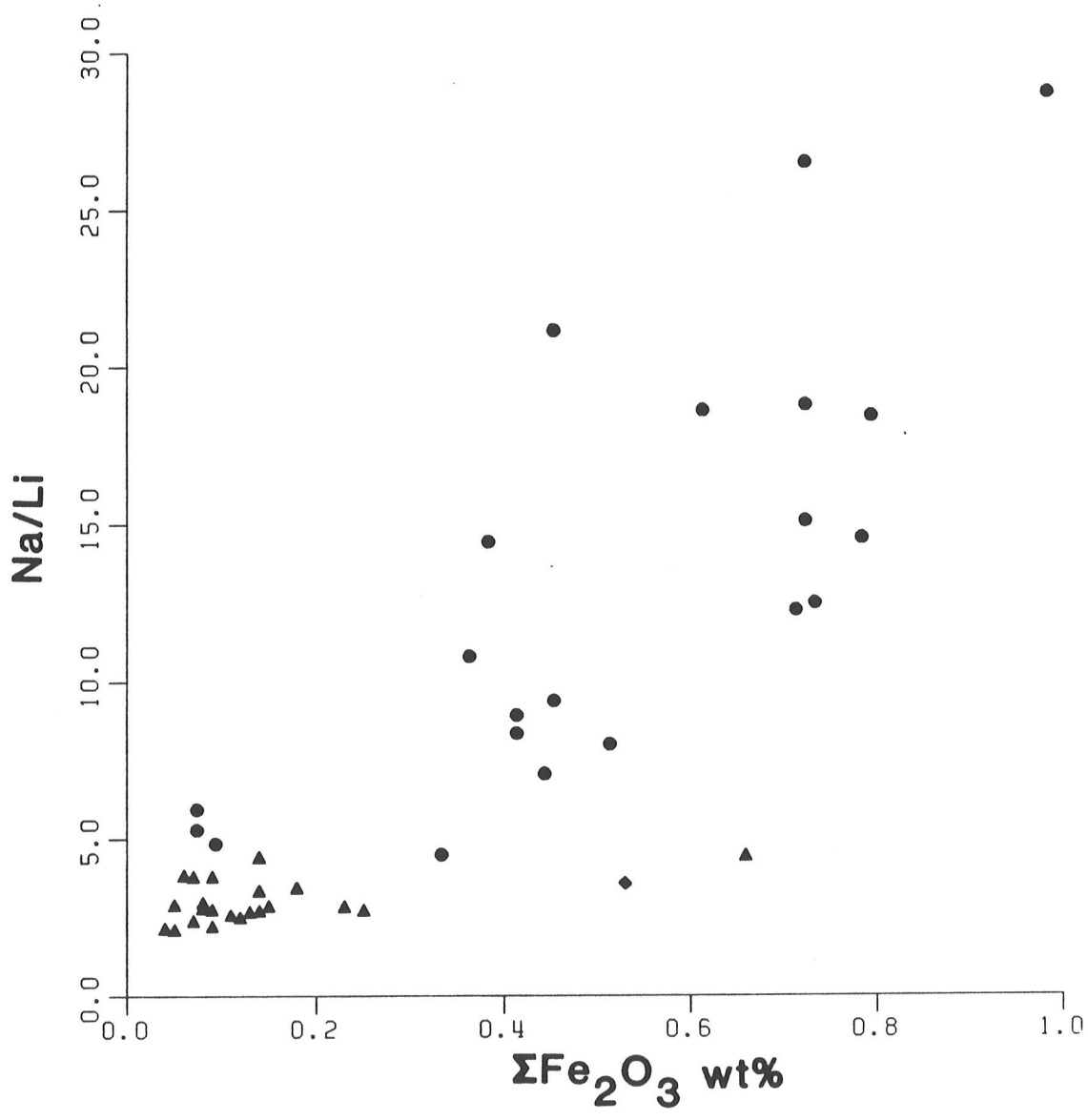

Figure 54: Na/Li vs ΣFe_2O_3 plot of beryls from the Cross Lake pegmatite field. Note that the Na/Li ratio decreases with decreasing Fe. Furthermore, the white beryls from the highly fractionated spodumene-bearing pegmatites of the Southern series and pegmatite 30 of the Northern series have low Na/Li ratios and low Fe contents where as the green beryls from the less evolved Northern series contain higher amounts of Fe and higher Na/Li. Symbols as in Figure 24.

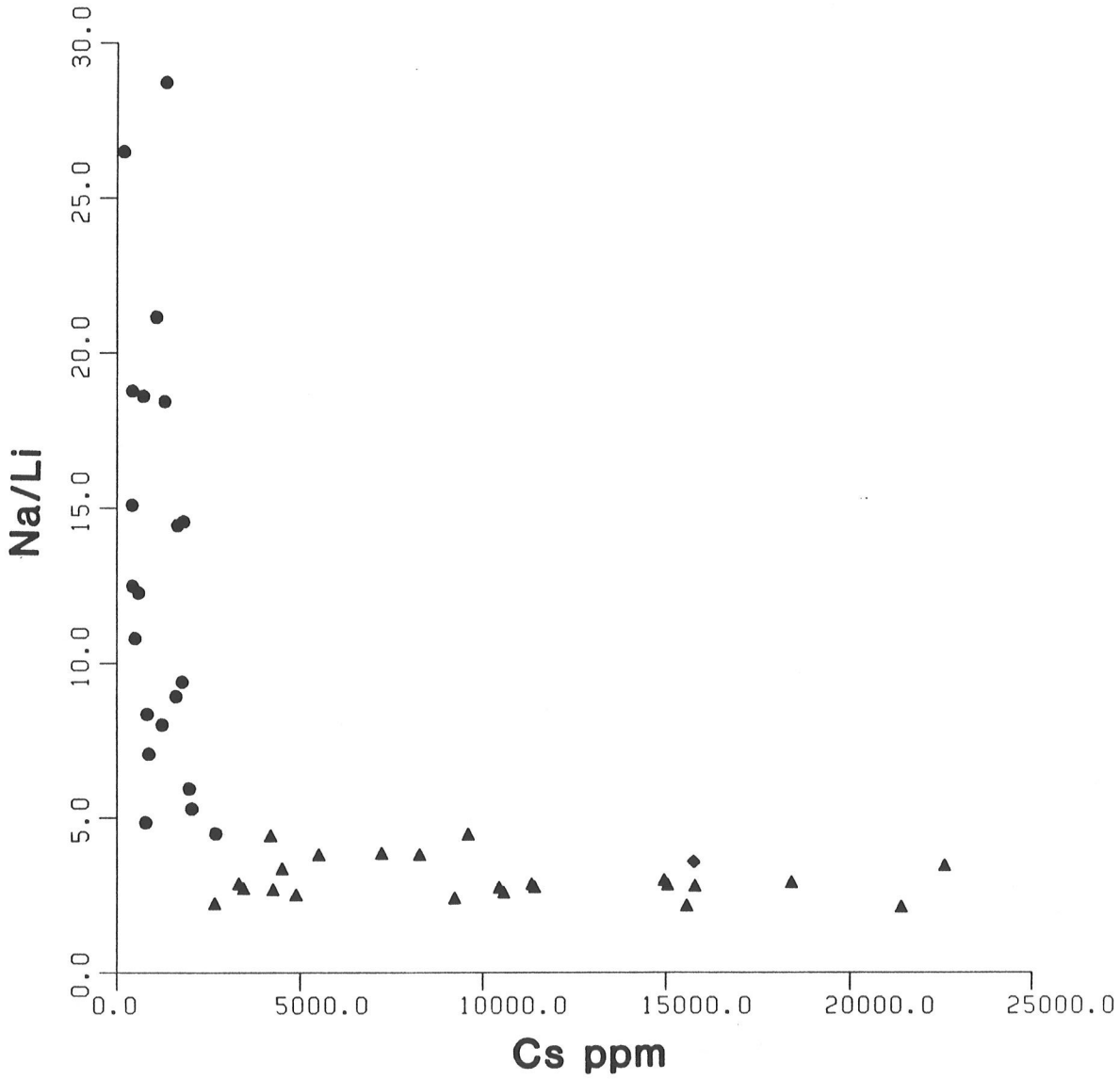

Figure 55: Na/Li vs Cs plot of beryls from the Cross Lake pegmatite field. With progressing fractionation Li starts substituting for Be and the Na/Li ratio rapidly decreases. At more advanced stages of fractionation the Cs content increases and the Na/Li ratio becomes less informative. Note that the Northern series beryls have a wide range of Na/Li ratios and a narrow range of Cs contents, whereas the beryls from the Southern pegmatite series show a wide range in Cs content but little variation in the Na/Li ratio. Symbols as in Figure 24.

quartz in the wall and border zone and occurs in clusters and bands that are parallel to the contact of the pegmatite (Figure 56). In some pegmatites almandine is closely associated with biotite, apatite or schorl.

Spessartine occurs only in the highly fractionated pegmatites of the Northern and Southern series. Crystals are subhedral and range in colour from red to pale pink (Figure 57). Spessartine occurs in all textural varieties of albite in the complex pegmatites. In the spodumene pegmatite zone of the Southern series it occurs in saccharoidal albite with quartz and spodumene in the intermediate zones of the pegmatite. Garnets were found in only three pegmatites of the spodumene pegmatite zone.

Both unzoned and compositionally zoned garnets occur in the Cross Lake pegmatites. The nature of zoning in the garnets is beyond the scope of this study. Nevertheless, two- and three-spot microprobe analyses of single crystals indicate that the core of the zoned garnets is generally enriched in Mn relative to the edges.

Table 29 gives the composition of the garnets from the different pegmatite series in the Cross Lake field. The compositional characteristics are summarised in Table 14. The Fe-rich almandines have comparatively high concentrations of Ca and Mg which progressively decreases with increasing Mn (Figure 58).

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Figure 56: Band of almandine crystals in the wall zone of pegmatite 36 of the Northern series. Note that the garnet band conforms to the contact of the pegmatite.



Figure 57: Pink Mn-rich spessartine in spodumene + quartz assemblage, pegmatite 6 of the Southern series. The crystal is 7mm in diameter.

TABLE 14

Compositional characteristics of the garnets from the pegmatites and pegmatitic granites.

	NELSON SERIES	MINAGO SERIES	SOUTHERN SERIES		NORTHERN SERIES	
			BIOTITE-PERISTERITE ZONE	SPODUMENE ZONE	BARREN ZONE	BERYL ZONE
	N = 10	N = 19	N = 7	N = 4	N = 11	N = 19
CaO wt%	1.0 ±0.27 (0.8-1.7)	1.2 ±1.20 (0.3-4.8)	0.62 ±0.20 (0.3-0.9)	0.38 ±0.13 (0.2-0.6)	0.56 ±0.23 (0.3-0.9)	0.29 ±0.11 (0.1-0.5)
MgO wt%	3.1 ±0.49 (2.5-3.8)	1.1 ±0.8 (0.0-2.3)	0.87 ±0.80 (0.0-2.4)	0.26 ±0.31 (0.0-0.6)	1.16 ±0.86 (0.3-2.8)	0.76 ±0.60 (0.0-2.3)
MnO wt%	4.0 ±0.69 (2.4-4.8)	12.2 ±6.9 (4.3-31.8)	13.9 ±5.3 (7.5-21.7)	28.3 ±11.5 (14.7-37.8)	9.9 ±2.4 (6.7-13.3)	22.7 ±6.4 (14.5-34.0)
FeO wt%	34.0 ±0.9 (32.5-35.5)	28.3 ±5.8 (11.3-34.8)	27.6 ±4.7 (21.0-32.8)	14.3 ±11.4 (4.6-27.9)	31.0 ±2.0 (28.2-33.9)	19.2 ±5.9 (8.9-27.9)

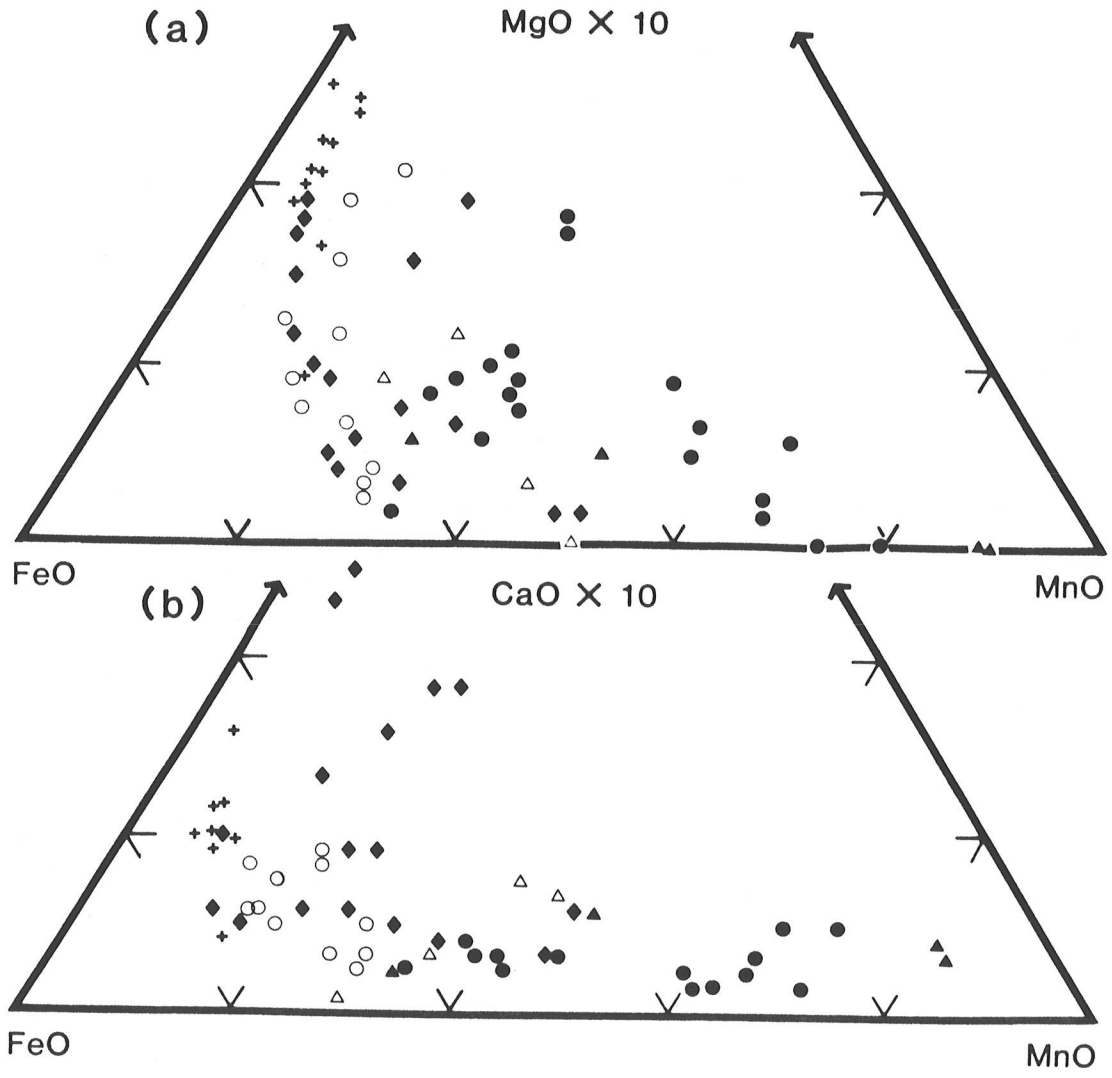

Figure 58: Composition of garnets from the Cross Lake field in the FeO-MnO-MgO x 10 (a), and FeO-MnO-MgO x 10 (b) triangles. With progressing fractionation Ca, Mg and Fe decreases with increasing Mn. Note that the garnets from the spodumene-bearing pegmatites of the Southern series and the beryl-columbite zone of the Northern series are relatively Mn-rich. The most Mg-rich garnets occur in the Nelson series whereas the most Ca-rich garnets occur in the pegmatitic granites. Symbols as in Figure 24.

5.5.9 Tourmaline

Black tourmaline (variety schorl) is found in almost every pegmatite in the Cross Lake field. It occurs in trace amounts in the simple microcline +oligoclase +biotite pegmatites and is a prominent phase in the wall and border zones of the more evolved dykes. The crystals are dominantly euhedral and range in size up to 30 cm in length. Crystal habits, however, are highly diverse varying from thin prismatic to short and stubby. Tourmalines from the spodumene zone of the Southern series rarely contain inclusions parallel to their c axis.

Tourmalines often show a perferred orientation within a pegmatite. Crystals oriented subnormal in to the contacts occur in continuous bands that are parallel to the contacts (Figure 59). In many of the pegmatites in the spodumene pegmatite zone of the Southern series the tourmalines are elongated with their c-axis parallel to the contacts of the pegmatite. Broken and healed tourmaline crystals were found in all pegmatite types in the field.

Schorl is typically associated with albite, muscovite and quartz. Almandine and dark green apatite is closely associated with tourmaline in the Northern pegmatite series.

Elbaite (verdelite) was found in only one pegmatite. It occurs as dark green euhedral crystals (Figure 60) in the quartz core of pegmatite 6 in the spodumene pegmatite zone of the Southern series.

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Figure 59: Schorl crystals oriented subnormal relative to the contact in pegmatite 30 of the Northern series.

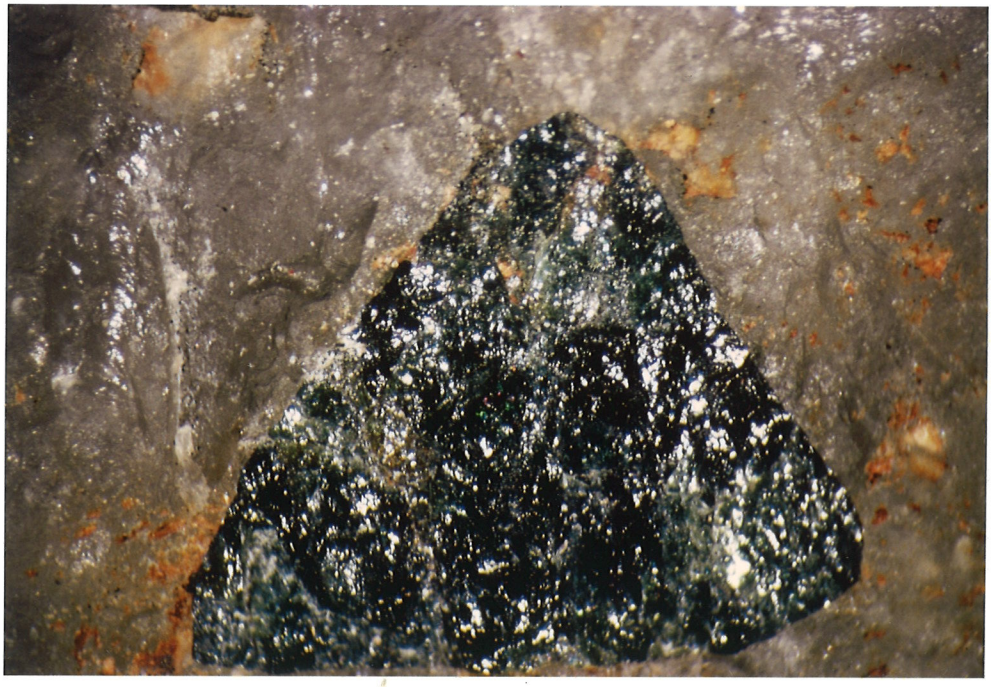

Figure 60: Green elbaite (var. verdelite) from pegmatite 6 of the Southern series. The crystal is 8 mm in diameter.

No X-ray diffraction studies or chemical analyses were performed on the tourmalines.

5.5.10 Zircon

Two zircons between 2 and 3 mm in diameter were found within the pale green muscovite in the spodumene-bearing pegmatites of the Southern series. Zircon was identified by electron microprobe analyses and by x-ray diffraction after heating. The crystals are bipyramidal, euhedral and are dull black in colour. X-ray powder diffraction patterns indicate that they are strongly metamict.

5.5.11 Columbite-Tantalite

Columbite-tantalite is an accessory phase which occurs in clevelandite and the saccharoidal albite units of the complex pegmatites of the Northern and Southern series. Grains are dull metallic black, tabular and wedge shaped, and are between 0.1 and 5.0 cm in size. Crystals occur in both coarse and fine grain albite, locally in fan-like divergent clusters (Figure 61).

Figures 62, 63 and 64 are a-c unit cell dimension diagrams for columbite-tantalites from the Cross Lake pegmatite field. The a and c parameters are sensitive to the changes in the structural state and also can be used to indirectly estimate the Mn/Fe ratio of the ordered phases (Komkov 1970, Černý and Turnock 1971a). Both the a and c dimensions increase with increasing Mn/Fe ratios. Ordering of the natu-

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Figure 61: Columbite-tantalite from pegmatite 22 of the Northern series showing typical divergent habit of tabular crystals.

ral columbites in response to heating causes the a dimension to increase and the c dimensions to decrease. The dashed tie lines in Figure 62 join the heated and natural a-c coordinates for columbite-tantalite samples. The symbols used in Figure 62 designate the pegmatite series as in Figure 24

Columbite-tantalite from the Northern and Southern series show a wide range in Mn/Fe ratios. The structural state varies from intermediate to disordered.

The symbols used in Figure 63 seperate the columite-tantalites on the basis of their chemical composition on the a-c plot. There is no aparent correlation between the structural state and the chemical composition of the columbite-tantalites. The plot does indicate that the most Mn rich samples are also relatively enriched in Ta.

Figure 64 gives the field of unit cell dimensions for columbite-tantalites from individual pegmatites from the Cross Lake field. The structural state and Mn/Fe ratios for columbite-tantalites from a single pegmatite generally does not show a wide variation. An exception to this are the columbites-tantalites of pegmatite 22. In the Southern series the Mn/Fe ratio for the columbite-tantalites from individual pegmatites shows a progressive increase in an easterly direction. The Mn/Fe ratio in the columbite-tantalites in the pegmatites of the Northern series increases in a direction that is consistent with the fractionation trend shown by the garnets.

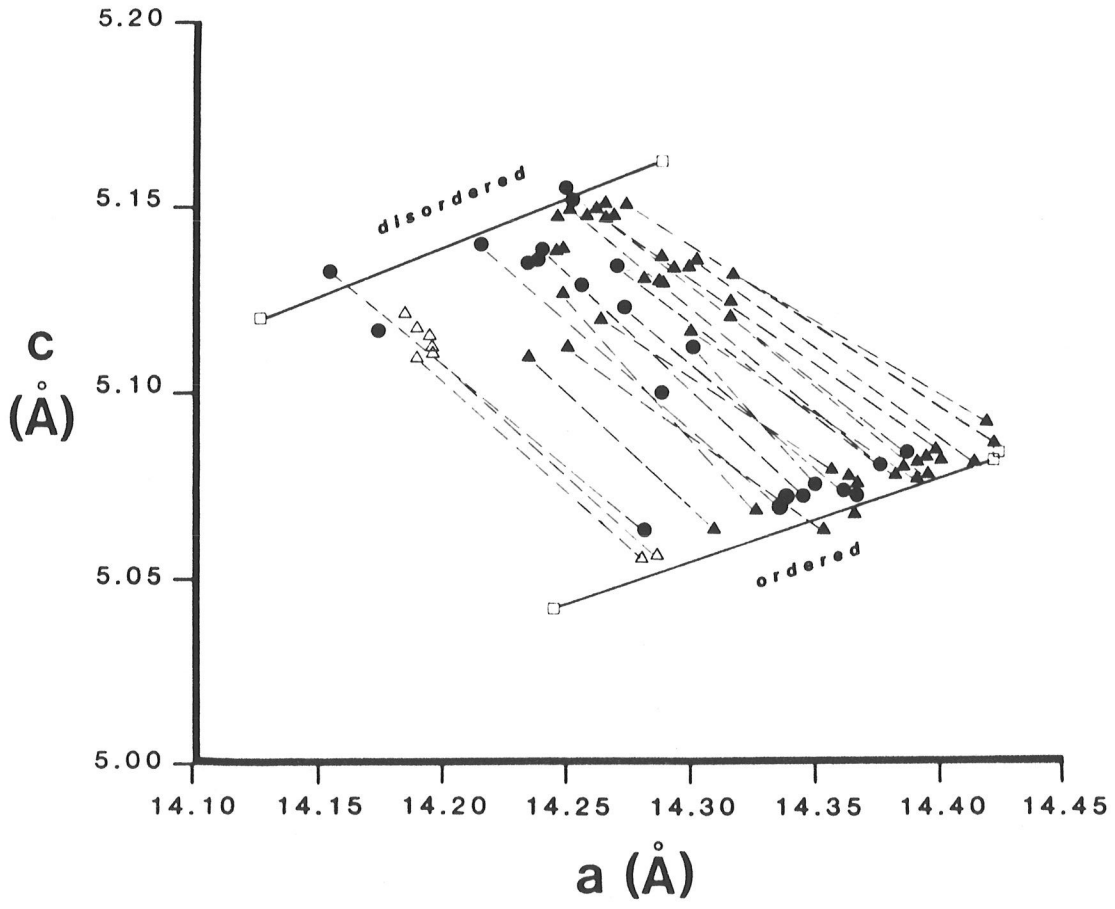

Figure 62: Natural and heated columbite-tantalite minerals of the Cross Lake pegmatite field in the a-c unit cell dimension diagram. The a dimension increases and the c dimension decreases with ordering. The dashed lines join the a-c coordinates of the heated and natural specimen. The graph indicates that the structural state of the Cross Lake columbite-tantalites range between intermediate and disordered. The open squares designate synthetic ordered phases of Weitzel (1976). IRA-16 is disordered columbite from the Irgon Claim, S.E. Manitoba and TSE-42 is disordered manganotantalite from the Tanco pegmatite. Symbols as in Figure 24.

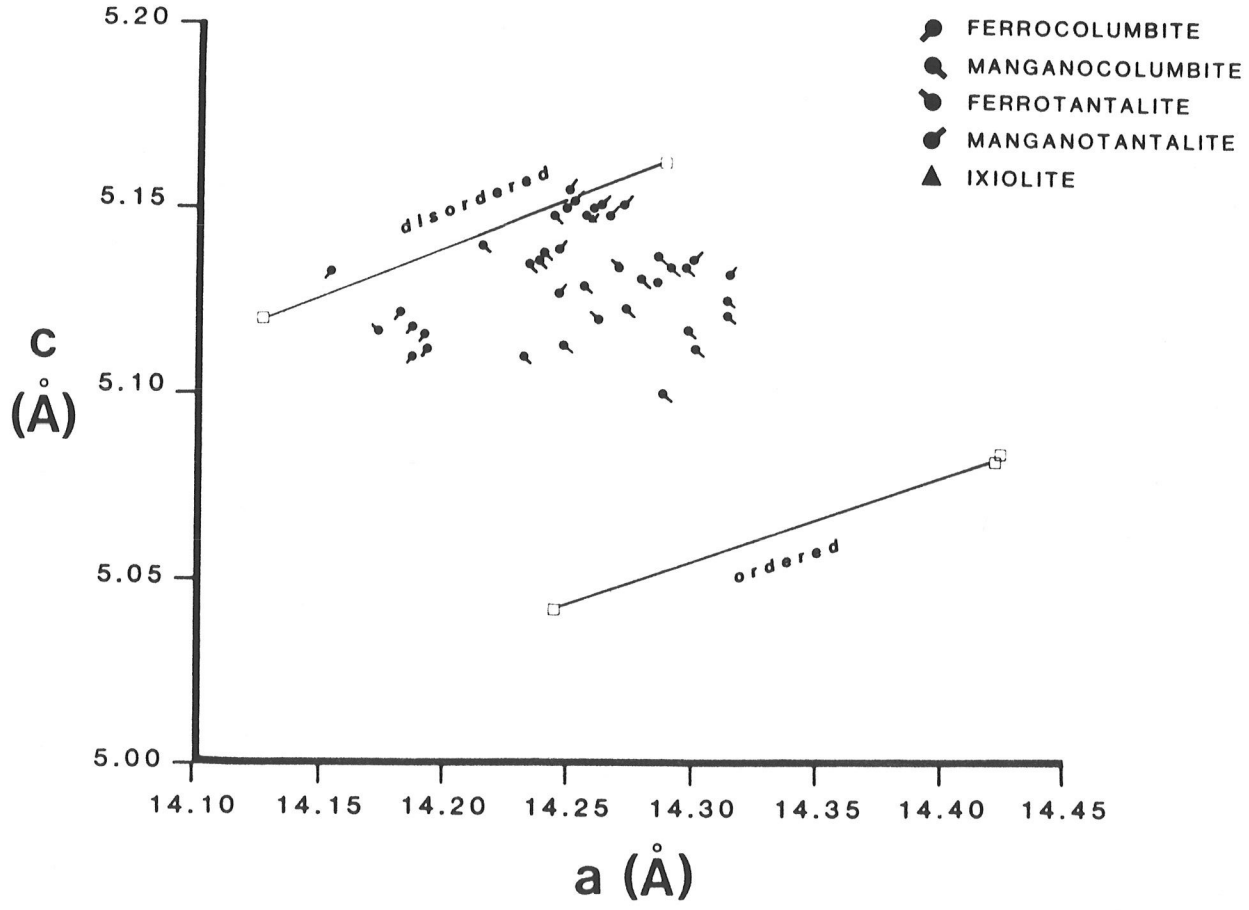

Figure 63: Columbite-Tantalite minerals from the Cross Lake field in the a-c unit cell dimension diagram. The symbols designate the general composition of the columbite-tantalite minerals determined by electron microprobe analyses. The a and c cell edge increases with increasing Mn/Fe ratio (Komkov 1970). Note that the samples with the highest Mn/Fe ratio, as determined by their position on the a-c plot, are typically mangonotantalites.

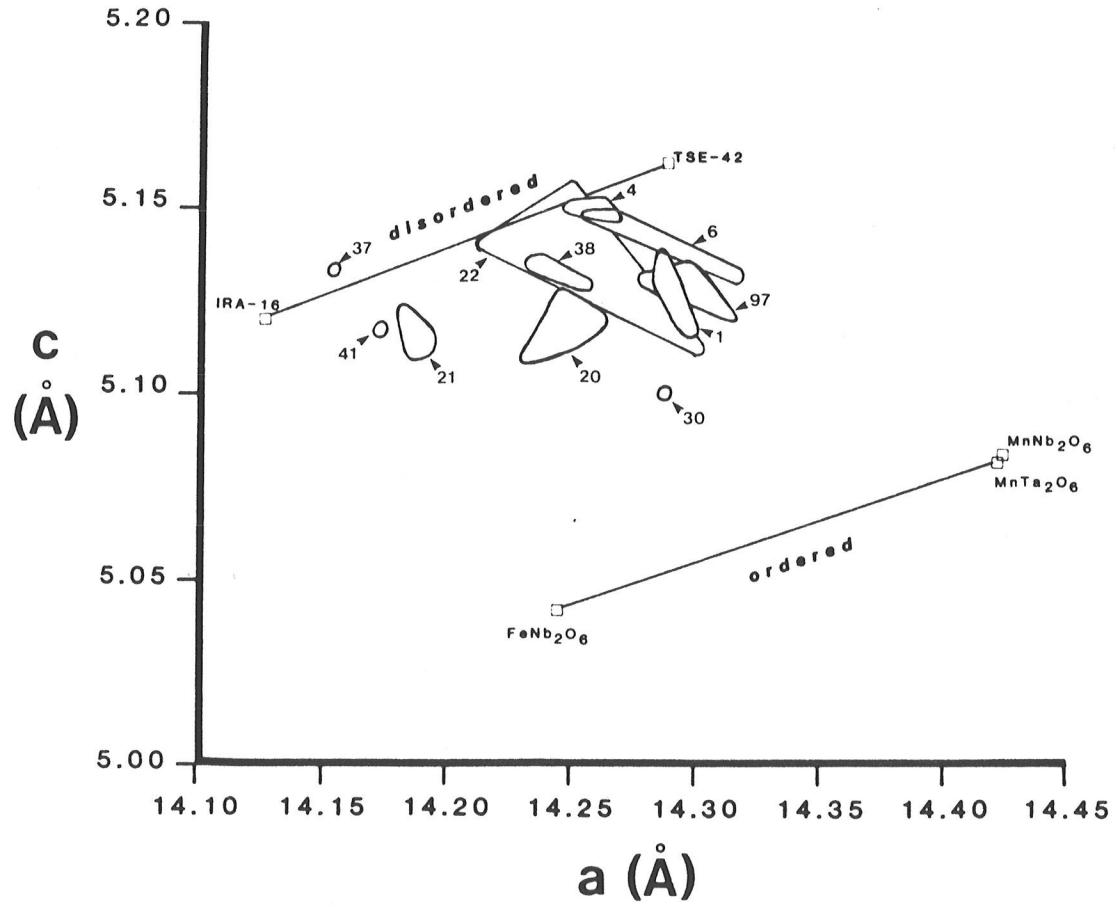

Figure 64: A plot showing the fields of a-c unit cell dimensions for columbite-tantalite minerals from individual pegmatites in the Cross Lake field. With the exception of pegmatite 22 of the Northern series, columbite-tantalite minerals from a single pegmatite typically have similar unit cell dimensions.

TABLE 15

Unit cell parameters of columbite-tantalite minerals from the Cross Lake field, in natural state and after heating to 1000°C for 16 hours in air.

	NATURAL				HEATED			
SAMPLE NO.	A X 3	B	C	V	A	B	C	V
TA-1-AA	14.300(6)	5.748(2)	5.117(2)	420.6(1)	14.3937(8)	5.7549(3)	5.0769(4)	420.54(4)
TA-1-?	14.289(3)	5.751(1)	5.137(1)	422.1(1)	14.366(4)	5.751(1)	5.077(2)	419.5(2)
TA-1-XX	14.288(3)	5.746((1)	5.1303(7)	421.22(6)	.	.	.	
TA-4-AA	14.252(6)	5.745(1)	5.150(1)	421.6(1)	14.384(1)	5.7520(7)	5.0785(7)	420.20(7)
TA-4-YY	14.266(2)	5.7474(8)	5.1508(7)	422.34(6)	14.3887(8)	5.7535(3)	5.0804(4)	420.58(3)
TA-4-XX	14.269(2)	5.7427(9)	5.148(1)	421.8(1)	14.394(3)	5.753(1)	5.082(2)	420.9(2)
TA-4-ZZ	14.263(1)	5.7457(5)	5.1497(4)	422.0(6)	14.394(1)	5.7555(7)	5.0830(8)	421.11(6)
TA-6-AA	14.303(3)	5.743(1)	5.135(1)	421.9(1)	14.416(3)	5.756(1)	5.080(1)	421.6(1)
TA-6-CX	14.260(3)	5.7411(9)	5.147(1)	421.4(1)	14.399(1)	5.7550(5)	5.0823(5)	421.17(5)
TA-6-EE	14.266(1)	5.7444(6)	5.1479(8)	421.89(7)	.	.	.	
TA-6-**	14.317(3)	5.749(2)	5.131(1)	422.4(1)	14.421(1)	5.7635(8)	5.092(3)	423.3(2)
TA-9-L	14.246(1)	5.738(2)	5.139(1)	420.1(1)	14.368(2)	5.7496(7)	5.072(1)	419.08(8)
TA-20-O-A	14.249(6)	5.735(1)	5.126(1)	418.9(1)	14.327(5)	5.743(1)	5.067(2)	417.0(1)
TA-20-Q	14.234(3)	5.7367(9)	5.1098(9)	417.2(1)	14.312(5)	5.739(1)	5.062(2)	415.8(2)
TA-20-R	14.250(3)	5.749(1)	5.113(6)	418.2(5)	14.3559(8)	5.7437(2)	5.0630(2)	417.48(3)
TA-20-S	14.264(4)	5.740(1)	5.1202(9)	419.2(1)	14.359(4)	5.754(1)	5.079(2)	419.6(1)
TA-21-A-S	14.184(4)	5.720(1)	5.122(1)	415.62(9)	14.288(3)	5.735(1)	5.056(1)	414.3(1)
TA-21-AA+	14.188(3)	5.719(1)	5.109(1)	414.6(1)	14.283(1)	5.7314(9)	5.055(1)	413.84(9)
TA-21-B-S	14.190(4)	5.721(1)	5.118(2)	415.5(1)	.	.	.	
TA-21-I-C	14.196(6)	5.721(2)	5.112(2)	415.2(1)	.	.	.	
TA-21-N-S	14.195(5)	5.719(2)	5.116(1)	415.4(1)	.	.	.	
TA-22-I	14.218(5)	5.734(2)	5.139(2)	419.1(1)	14.329(4)	5.7408(9)	5.068(1)	416.9(1)
TA-22-II	14.303(6)	5.740(1)	5.112(2)	419.7(1)	14.341(2)	5.7427(7)	5.0711(9)	417.64(8)
TA-22-III	14.272(4)	5.741(1)	5.134(2)	420.7(1)	14.378(2)	5.7464(7)	5.0804(8)	419.77(8)
TA-22-J	14.255(3)	5.7414(9)	5.151(1)	421.65(9)	14.377(2)	5.7462(8)	5.0812(8)	419.80(9)
TA-22-N	14.258(5)	5.743(1)	5.155(2)	422.1(1)	14.388(1)	5.7516(6)	5.0828(7)	420.65(7)
TA-22-H-A	14.275(3)	5.740(1)	5.122(1)	419.7(1)	14.363(5)	5.742(2)	5.073(2)	418.5(2)
TA-22-Z-A	14.241(3)	5.735(2)	5.136(1)	419.5(1)	14.339(3)	5.7402(7)	5.0699(7)	417.31(8)
TA-30-J	14.290(1)	5.7369(5)	5.1001(8)	418.14(6)	.	.	.	
TA-37-M	14.157(2)	5.7271(8)	5.1327(8)	416.1(8)	14.282(3)	5.727(1)	5.062(2)	414.1(1)
TA-38-I	14.243(5)	5.738(1)	5.134(1)	419.6(1)	14.352(4)	5.744(2)	5.075(1)	418.5(1)
TA-38-N	14.237(3)	5.740(5)	5.1348(8)	419.63(9)	14.368(4)	5.751(1)	5.074(1)	419.3(1)
TA-38-O-A	14.259(1)	5.744(1)	5.1288(7)	420.09(6)	14.347(3)	5.745(1)	5.071(1)	418.0(1)
TA-41-ZZ	14.176(2)	5.7222(5)	5.1171(6)	415.09(6)	.	.	.	
TA-97-BB	14.299(3)	5.7462(8)	5.1340(7)	421.8(7)	.	.	.	
TA-97-CC	14.282(4)	5.743(3)	5.131(1)	420.8(1)	.	.	.	
TA-97-EE	14.317(3)	5.746(1)	5.121(1)	421.3(1)	14.397(1)	5.7554(5)	5.0779(6)	420.78(6)
TA-DH-7	14.248(6)	5.731(1)	5.138(2)	419.6(1)	.	.	.	
TA-DH-13	14.316(7)	5.750(1)	5.125(1)	421.9(1)	.	.	.	
TA-DH-17	14.274(5)	5.745(1)	5.151(1)	422.4(1)	14.4325(2)	5.7627(6)	5.0861(7)	422.81(7)
TA-DH-18	14.293(4)	5.753(2)	5.134(1)	422.1(1)	.	.	.	
TA-DH-24	14.247(3)	5.744(1)	5.148(1)	421.3(1)	.	.	.	

The chemical composition of columbite-tantalite determined by energy dispersive electron microprobe analyses is given in Table 30. The average Mn/Mn+Fe and Ta/Ta+Nb for the columbite-tantalite from the Northern and Southern series is given in Table 16. The chemical composition may vary considerably between columbite-tantalite from different pegmatite types. The tendency is for Ta/Ta+Nb and Mn/Mn+Fe ratios to increase from the simple pegmatites to the complex well zoned pegmatites.

Figure 65 gives the columbite-tantalite in the $FeNb_2O_6$-$FeTa_2O_6$-$MnNb_2O_6$-$MnTa_2O_6$ (mol%) diagram. With the exception of some Ti rich ferrocolumbite-tantalites the Northern series columbite-tantalite minerals are Mn-rich and show a wide range in Ta content. The majority of the samples are manganocolumbite with manganotantalite occurring only in the most fractionated pegmatite (22).

Ferrocolumbite is the only Ta-Nb oxide found in the biotite-peristerite pegmatites of the Southern series. Farther east in the spodumene pegmatite zone of the Southern series the dominant species is manganocolumbite. In the spodumene zone, Fe-rich columbite-tantalite occurs in the westernmost spodumene-bearing pegmatite whereas manganotantalite typically occurs in the most fractionated pegmatites on Metis Island.

Figure 66 (a) and (b) gives Ta vs Ti wt% and Mn vs Ti wt% for columbite-tantalites from the Northern and Southern se-

TABLE 16

Compositional characteristics of columbite-tantalite from the Northern and Southern series.

	NORTHERN SERIES	SOUTHERN SERIES	
		SPODUMENE ZONE	BIOTITE-PERISTERITE ZONE
	N = 25	N = 58	N = 7
Mn/Mn+Fe	0.652 ±0.064 (0.507-0.780)	0.797 ±0.129 (0.386-0.940)	0.254 ±0.055 (0.183-0.339)
Ta/Ta+Nb	0.366 ±0.184 (0.102-0.821)	0.422 ±0.159 (0.208-0.697)	0.179 ±0.081 (0.108-0.299)

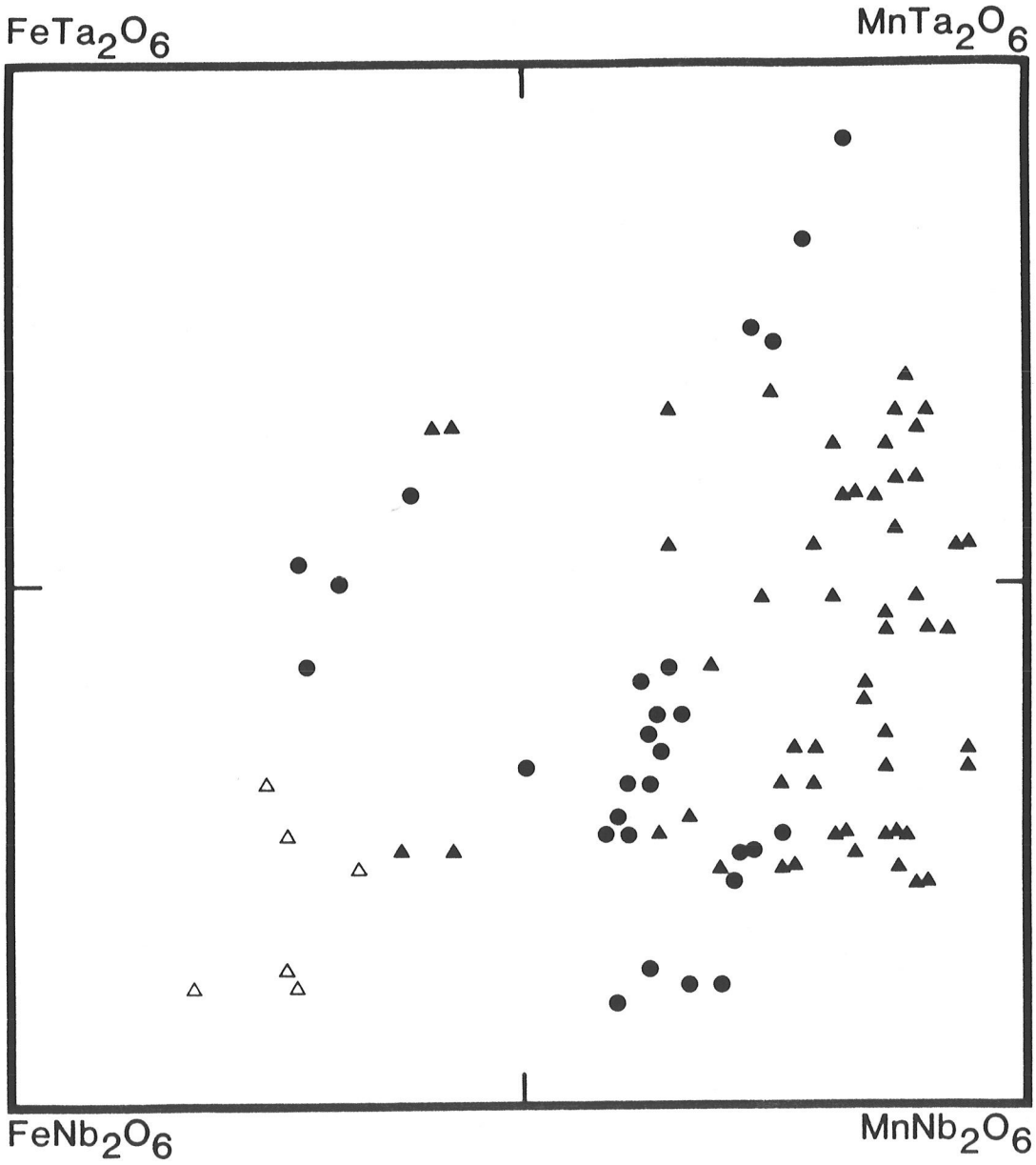

Figure 65: Columbite-tantalite minerals of the Cross Lake pegmatite field in the $FeNb_2O_6$-$FeTa_2O_6$-$MnNb_2O_6$-$MnTa_2O_6$ (mol %) diagram. Note that columbite-tantalite from the Southern series is the most Mn-rich but the most Ta-rich specimens occur in the Northern series. Symbols as in Figure 24.

ries respectively. There is a slight decrease in Ti with increasing Mn but there is no apparent correlation between Ta and Ti. The columbite-tantalites from the Northern pegmatite series locally have a significantly greater Ti content than the Southern series columbite-tantalites.

Figure 67 (a) and (b) show Ta vs Sn and Mn vs Sn for columbite-tantalites, respectively. The Northern series columbite-tantalites are Sn deficient except for one manganotantalite. In contrast, the spodumene-bearing pegmatites of the Southern series have columbite-tantalites that are comparatively rich in Sn. There is a slight increase in Sn with increasing Mn and Ta values.

5.5.12 Ixiolite and Wodginite

Trace amounts of ixiolite and wodginite occur as anhedral and subhedral grains. The grains are less than 0.5 cm in their maximum dimension. They occur in the saccharoidal albite units of the highly fractionated spodumene-bearing pegmatites of the Southern series and are closely associated with columbite-tantalite, and cassiterite. Table 17 shows the chemical composition of ixiolites and wodginite from the Cross Lake pegmatites. The cell parameters for wodginite refined from powder data are $\underline{a}$ 9.502 (±0.003), $\underline{b}$ 11.491 (±0.003), $\underline{c}$ 5.145 (±0.002), V = 561.8 Å^3 in its natural state, and $\underline{a}$ 9.490 (±0.002), $\underline{b}$ 11.449 (±0.002), $\underline{c}$ 5.108 (±0.002), V = 554.95 (±0.14) Å^3 after heating to 1000°C for

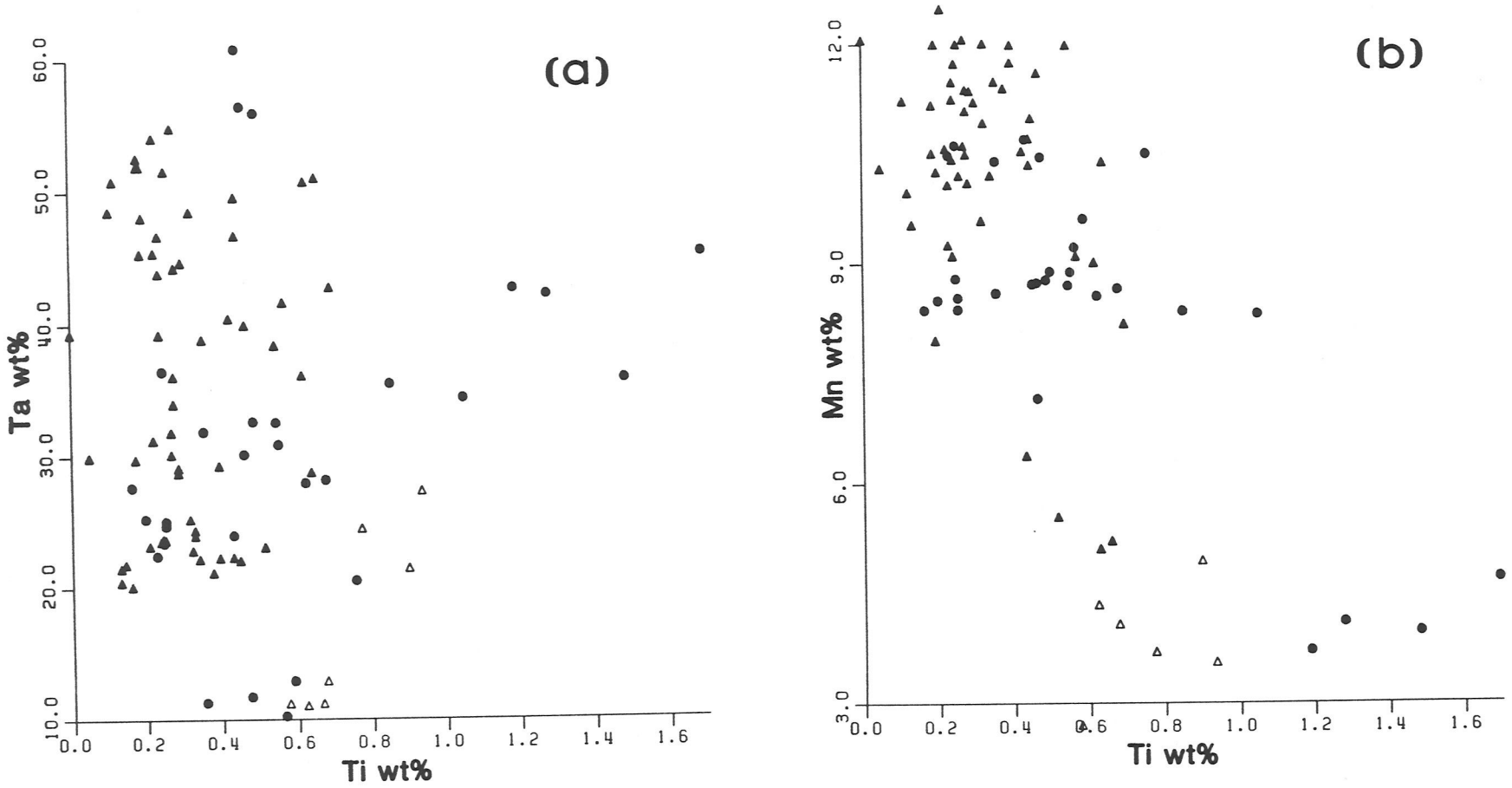

Figure 66: (a) Ta vs Ti plot of columbite-tantalites and (b) Mn vs Ti plot of columbite-tantalites from the Cross Lake field. Note that there is a slight decrease in Ti with decreasing Mn. No apparent correlation exists between Ta and Ti. Symbols as in Figure 24.

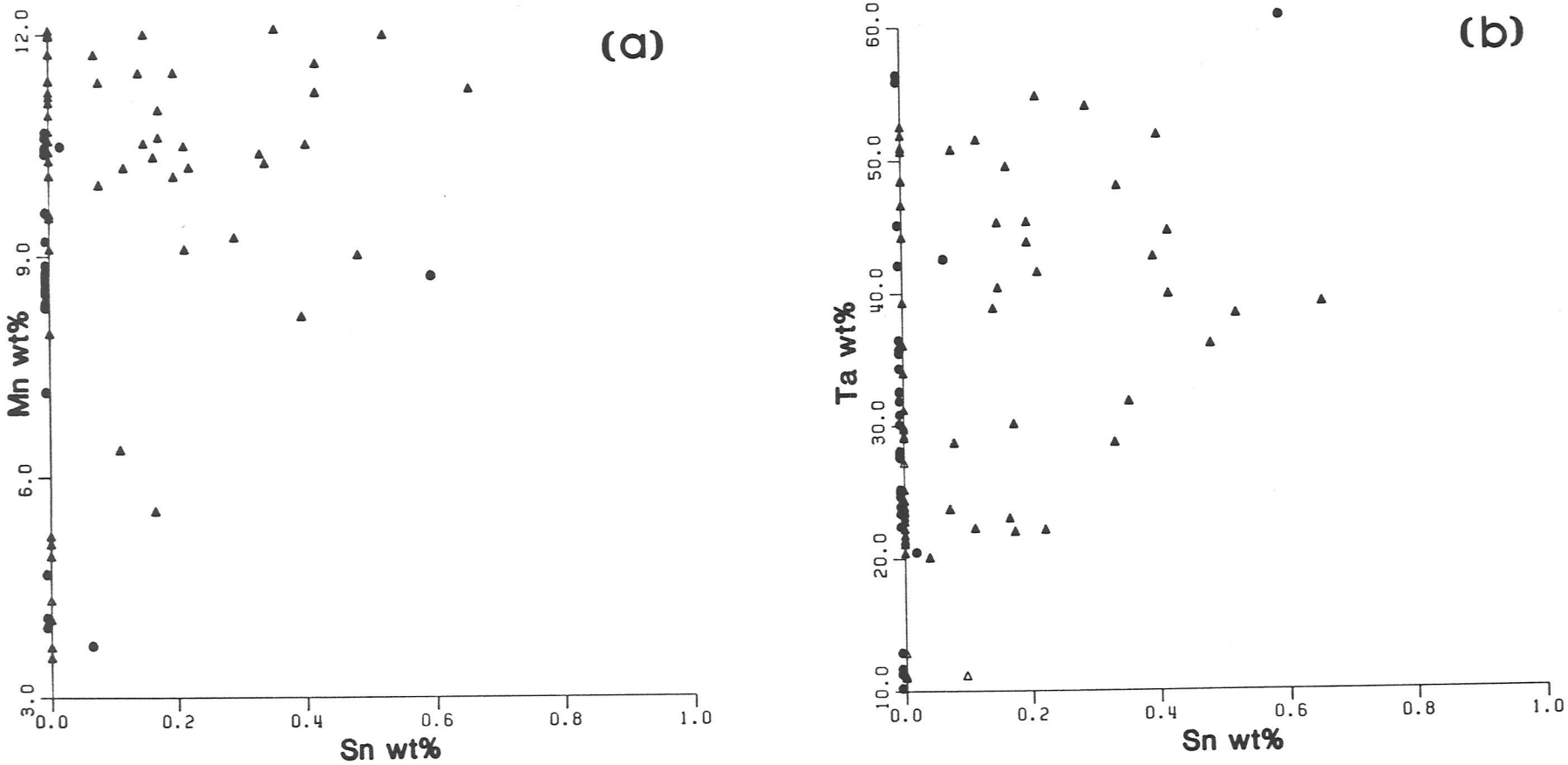

Figure 67: (a) Mn vs Sn plot of columbite-tantalite minerals and (b) Ta vs Sn plot of columbite-tantalites from the Cross Lake pegmatite field. The relatively Sn-rich columbite-tantalite minerals are also typically Mn- and Ta-rich. Symbols as in Figure 24.

16 hours in air. Figure 68 gives the ixiolite and/or wodginite phases in the $FeNb_2O_6$-$FeTa_2O_6$-$MnNb_2O_6$-$MnTa_2O_6$ (mol%) diagram.

TABLE 17

Electron microprobe analyses of ixiolite and/or wodginite from the Southern series.

Sample No.	(†)Ta-DH-Sn-7	Ta-DH-2-1	Ta-4-XX	Ta-91-CC
FeO	1.16	2.73	2.26	3.08
MnO	8.54	8.43	9.97	8.99
Nb_2O_5	5.97	1.99	7.94	6.03
Ta_2O_5	63.18	69.00	63.87	66.66
TiO_2	1.16	0.63	0.25	0.39
SnO_2	16.60	16.01	14.92	14.81
Total	98.38	98.79	99.21	99.96

(†) wodginite

5.5.13 Tapiolite and Tantalian Rutile

Rare tapiolite intergrown with tantalian rutile occurs as small (3-7 mm) black grains in pegmatites 40 and 41 of the Northern series. The grains occur in saccharoidal albite with quartz, yellow beryl and Ti-enriched columbite-tantalite.

The cell parameters for tapiolite refined from the powder data are a 4.749 (±0.0007), b 4.749 (±0.0007), c 9.241 (±0.0064) Å, V = 208.466 (±0.154) $Å^3$. Table 18 gives the chemical composition of tantalian rutile from pegmatite 40. The Ti and Nb content between the different intergrown phases within a grain is extremely variable.

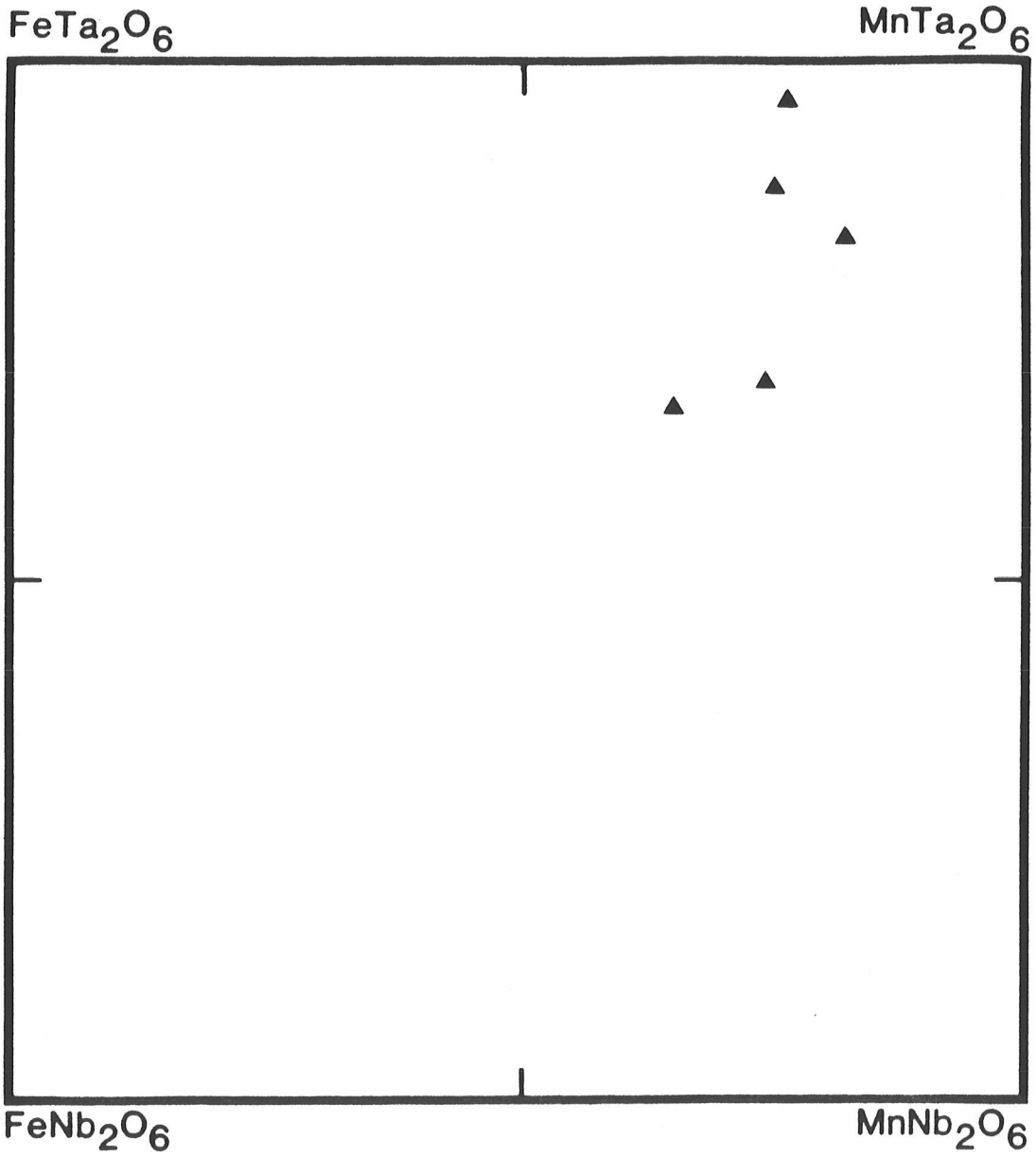

Figure 68: Ixiolite and/or wodginite phases in the $FeNb_2O_6$-$FeTa_2O_6$-$MnNb_2O_6$-$MnTa_2O_6$ (mol%) diagram. Symbols as in Figure 24.

TABLE 18

Electron microprobe analyses of tantalian rutile from pegmatite 40 of the Northern series.

	Ta-40-D-D
TiO_2	30.69
FeO	8.93
Nb_2O_5	8.57
SnO_2	0.57
Ta_2O_5	50.06
Total	98.83

5.5.14 Uranian microlite

Uranian microlite occurs as small (1-4 mm) sub to anhedral grains in pegmatite 22 of the Northern series. The grains are shiny dark grey to black in colour and are easily distiguished from columbite-tantalite by their vitreous lustre and equant dimensions (Figure 69). Individual grains are often surrounded by a thin brown altered rim of saccharoidal albite. Uranian microlite is confined to the saccharoidal albite of the wall and intermediate zones in association with a wyllieite-like phosphate mineral, quartz, book muscovite, and columbite-tantalite.

Table 19 gives the chemical composition of a Uranian microlite sample from pegmatite 22. Undetermined F and OH and the metamict nature of the microlite account for the low total. The low oxide total may be attributed to metamictization and the missing F and OH analyses.

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Figure 69: Uranian microlite (3 mm in maximum dimension) in albite and quartz from pegmatite 22 of the Northern series.

TABLE 19

Electron microprobe analyses of uranian microlite from pegmatite 22 of the Northern series.

	Ta-22MT3
CaO	5.53
TiO_2	0.73
FeO	2.13
Nb_2O_5	0.25
Ta_2O_5	65.28
PbO	1.65
UO_2	10.99
Total	86.57

Undetermined F and OH and the metamict nature of the mineral account for the low total.

5.5.15 Cassiterite

Cassiterite is a rare accessory phase found only in the spodumene pegmatite zone of the Southern series. The grains are dark red-black in colour, subhedral to anhedral, and are on average less than 1 cm in diameter. Cassiterite grains occur in albite and is associated with quartz, scaly muscovite and columbite-tantalite.

Electron microprobe analyses representative of cassiterite in the Cross Lake pegmatites is given in Table 20. In general, the cassiterites are Ta enriched. Chemical compositions obtained from different spots on individual grains indicate that they are compositionally heterogeneous having zones of varying Ta/Sn ratios.

TABLE 20

Electron microprobe analyses of cassiterite from the spodumene-pegmatite zone of the Southern series.

	Sn-92-HH	Sn-DH-10	Sn-DH-10-1
TiO_2	-	0.37	0.36
MnO	0.26	0.49	0.74
FeO	0.43	1.10	0.68
Nb_2O_5	0.69	0.31	0.72
Ta_2O_5	2.82	5.13	7.42
SnO_2	96.98	92.30	88.27
Total	101.18	99.68	98.21

5.5.16 Ilmenite

One 4 cm long tabular ilmenite crystal was found in a small quartzo-feldspathic pod adjacent to pegmatite 31 in the Northern series. It is dark metallic grey and is distinguished from columbite-tantalite by its shiny lustre. The ilmenite is associated with oligoclase and quartz.

Electron microprobe analyses indicate that it contains trace amounts of manganese and tantalum (Table 21).

5.5.17 Apatite

Apatite is an accessory mineral found in every type of pegmatite in the Cross Lake pegmatite field. The simple pegmatites of the Nelson series contain medium to light green, or aqua-blue coloured apatites whereas rare-element bearing bodies yield dark green, dark green-maroon, blue and blood-red coloured apatites. Iron rich apatites tend to be

TABLE 21

Electron microprobe analyses of ilmenite from pegmatite 31 of the Northern series.

	Ta-31-I
TiO_2	50.65
MnO	1.40
FeO	46.65
Ta_2O_5	0.34
Total	99.04

green in colour whereas Mn^{+2} in apatite produces pink and blue tones, and Mn^{+3} produces a blue colour. The intensity of colour increases with the Mn content (Deer et al. 1966).

The crystals are anhedral to euhedral (tabular and prismatitic) and range in size from 0.1 cm to 15 cm in length in their maximum dimension.

In the simple pegmatites trace amounts of apatite occurs with biotite +oligoclase +quartz assemblages. However, it is comparatively more abundant in the complex pegmatites of the Northern and Southern series where it occurs in association with albite, quartz, muscovite, garnet and tourmaline in the border and wall zones, and in the metasomatic unit.

Saccharoidal albite in the outer zones of the spodumene-bearing pegmatites locally contains numerous microscopic apatites giving the rock a bluish tinge.

5.5.18 Triphylite-Lithiophilite

Minor amounts of triphylite-lithiophilite occur in the intermediate zones in the spodumene-bearing pegmatites of the Southern series. It forms small dark brown masses less than 3 cm in diameter within albite and is associated with quartz, muscovite and tourmaline.

The composition of a relatively fresh looking triphylite-lithiophilite sample from pegmatite 6 was estimated from its unit cell dimensions using the graphs of Antenucci (1981). The average $Fe^{2+}/(Fe^{2+}+Mn^{2+}) = 0.60$.

5.5.19 Unknown Phosphate

Nodules of an unknown Ca, Na, Mn, Fe, Al phosphate occur in pegmatites 22 and 37 of the Northern series. Altered masses up to 25 cm across are dull brown black to dark green in colour and have a cinder-like texture. The fresh looking material in the core of the nodules varies from red-brown to green in colour. One cleavage plane gives a bronze metallic lustre in reflected light. The mineral has one well defined cleavage.

It is confined to the intermediate zones of pegmatite 22 and is in direct contact with pink saccharoidal albite and is associated with blocky brown intermediate microcline, granular quartz and muscovite.

The unit cell parameters refined from single crystal data are: a 11.982 (±0.002), b 12.479 (±0.002), c 6.399 (±0.001),

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Figure 70: Unaltered red-brown unknown Ca, Na, Mn, Fe, Al phosphate mineral from pegmatite 22 of the Northern series.

β 114.50 (0.01), V = 870.50 (±0.03) $Å_3$ (T.S. Ercit pers. com.). The space group is $P2_1/n$.

5.5.20 Monazite

This mineral occurs as shiny black, tabular grains on the order of 5 mm in length in the spodumene-bearing pegmatites in the Southern series. It was found in only one pegmatite in a clevelandite +quartz +muscovite +apatite +beryl assemblage. It is distinguished from schorl by its greasy lustre and by the presence of a thin alteration halo. Qualitative microprobe analyses indicates that this monazite is enrich in Ca and may infact be brabantite $CaTh(PO_4)_2$ (Rose 1980).

5.5.21 Sicklerite

Sicklerite is a secondary phosphate after triphylite-lithiophilite and occurs in the pegmatites of the spodumene-pegmatite zone in the Southern series. It forms light brown to amber masses and is associated with white-blue grey clevelandite and white K-feldspar. The occurrence of sicklerite rather than ferrisicklerite indicates Mn predominates over Fe in the primary phase, or it may be a product of oxidation and alkali leaching in Fe rich lithiophilite and triphylite (Shigley and Brown 1980). The d values and their intensities are given in Table 22.

TABLE 22

Sicklerite X-ray diffraction data.

d Å	I/I_{100}
5.167	25.6
4.292	60.4
3.489	41.9
3.036	87.2
2.800	29.1
2.534	100.0
2.480	17.4
2.282	24.4
1.754	33.7

5.5.22 Arsenopyrite and Loellingite

Arsenopyrite is a rare accessory phase found in the pegmatites of the Northern, Southern, and Minago series. It is silver white in colour and weathers to dark rusty brown. Loellingite ($FeAs_2$) occurs only in the most fractionated pegmatites of the Southern series. Most specimens are indistinguishable from arsenopyrite and were identified by x-ray diffraction. Some loellingite samples have a bluish cast.

Both loellingite and arsenopyrite occur in quartz, and to a lesser extent in spodumene, as subhedral to anhedral crystals up to 1.5 cm across. Both minerals are closely associated with schorl and plagioclase (Figure 71).

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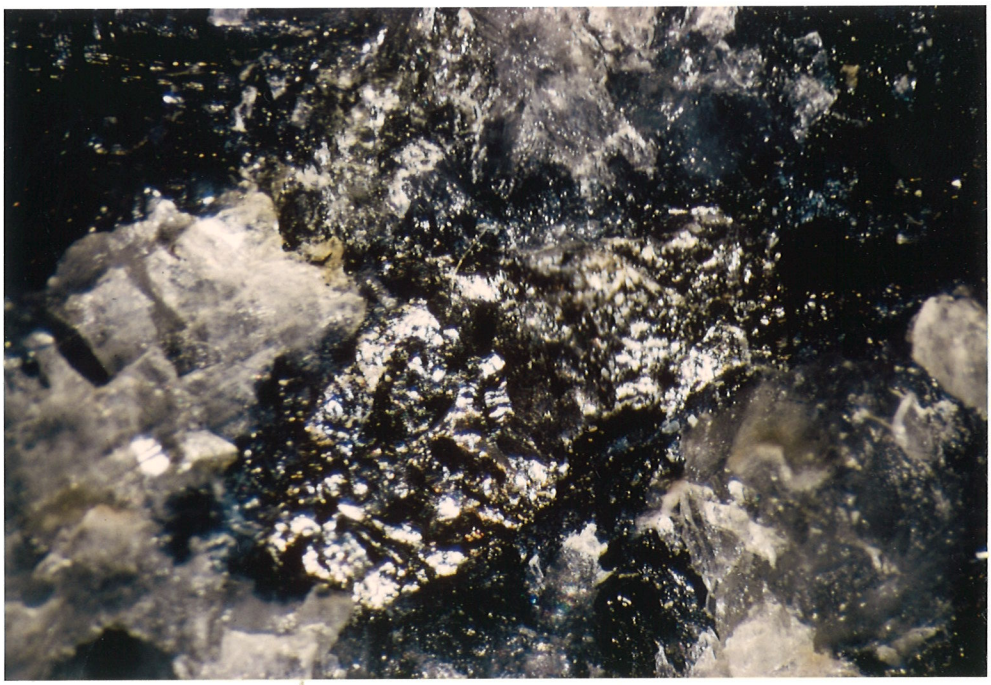

Figure 71: Loellingite surrounded by schorl and quartz from highly fractionated spodumene-bearing pegmatite on Metis Island. The loellingite is 1 cm in its maximum dimension. The sample was obtained from drill core provided by Tanco exploration.

5.6 REGIONAL ZONING

Regional zoning of pegmatite types is observed in all pegmatite series. The pegmatites of a series appear to be emplaced within their respective fracture systems that strike parallel to the axial trend of the greenstone belt. Tectonic tilting, dislocation of block structures and subsequent erosion has exposed pegmatites of diverse textural and mineralogical characteristics that were emplaced at different depths. The evidence for this is suggested by the relationship between the regional metamorphic gradient and the distribution of pegmatite types. Irregularities in the erosional plane coupled with local vertical displacements are responsible for minor deviations and discontinuities in the regional horizontal zonal pattern.

5.6.1 Regional Zoning of the Nelson Series

The pegmatites of the Nelson series have essentially the same texture and paragenesis. However, a regional geochemical zonation is observed which is most clearly expressed by the variations in the Ba contents in the K-feldspars. The average Ba content in the K-feldspars tends to decrease in an easterly direction (Figure 84 appendix) parallel to decreasing metamorphic grade of the host rocks.

5.6.2 Regional Zoning of the Minago Series

The pegmatitic granites and pegmatites of the Minago Series show a gradual change to more paragenetically diverse bodies in an easterly direction. Significant paragenetic variations in the series are outlined below in order of increasing complexity.

(i) The simplest pegmatites and pegmatitic granites in this series occur near the mouth of the Minago River. They are characterised by the presence of megacrystic K-feldspar +oligoclase +almandine +garnet +minor biotite and schorl.

The almandine is characteristically Ca-rich (up to 3.70 wt% CaO) and Mn-poor.

(ii) A more advanced but intermediated stage in the evolution of the Minago Series is represented by two mica (biotite > muscovite) pegmatite that contains larger and more abundant almandine and schorl crystals. Additional typomorphic minerals include yellow-green beryl and arsenopyrite.

(iii) The most evolved pegmatites and pegmatitic granites of the series occur at the southwest and western shore of Cross Island. This zone is characterized by the presences of two mica (muscovite > biotite), spessartine, and Mn-rich almandine. The muscovites are notably Li rich and locally have high Be contents.

5.6.3 Regional Zoning of the Northern Series

A gradual increase in the textural complexity and paragenetic diversity of the Northern pegmatite series is observed in an east and southeasterly direction. Characteristic features of the pegmatites from the various zones is outlined below.

(i) The most primitive pegmatites consist mainly of microcline +oligoclase +quartz with minor muscovite, schorl and almandine. These pegmatites are generally texturally homogeneous and have both sharp and gradational contacts.

(ii) The barren muscovite pegmatites evolve into bodies that have a better developed internal structure such as pegmatite 44 (Figure 30). Muscovite, tourmaline, apatite and almandine increase in size and abundance and display more diverse and complex crystal habits. For example, muscovite occurs as large curved books or with quartz in plumose aggregate (Figure 44). Tourmaline crystals may occur in divergent clusters. This intermediated pegmatite zone is also characterized by the appearance of minor yellow-green beryl and pale blue and medium green coloured apatite.

(iii) The beryl-columbite zone comprises the most complex pegmatites in the Northern series. Their internal structure is extremely diverse, varying from poor to well zoned. Nevertheless, internal zoning is conspicuous in all of the pegmatites. Albitization is developed locally.

The pegmatites of this zone are relatively enriched in green beryl and contain dark green-blue apatite, Mn-rich almandine, spessartine, highly sodic albite and minor amounts of columbite-tantalite, tapiolite and arsenopyrite. In addition to these minerals, the most fractionated pegmatite contains uranian microlite and a wyllieite-like phosphate mineral. The size of the accessory phases is generally larger in this zone, particularly beryl.

5.6.4 Regional Zoning of the Southern Series

Two major zones can be distinguished in the Southern series; a biotite-peristerite pegmatite zone, that occupies the western third of the belt, and a spodumene pegmatite zone which comprises the eastern two thirds. There is an abrupt hiatus in the degree of fractionation between the two zones, which is in contrast to the gradual transition of pegmatite types observed in the Northern series. However, the complexity of the pegmatites within both the biotite-peristerite and spodumene zones increases in an easterly direction.

(i) Internal zoning and albitization in the biotite-peristerite pegmatites is poor to absent. At the western end of the series, simple, unzoned pegmatites consisting mainly of quartz +plagioclase (peristerite) +biotite +microcline-perthite and accessory schorl and almandine are in gradational contact with a foliated leucogranite.

Farther east in the biotite-peristerite zone the pegmatites are texturally and paragenetically more complex (Figure 33). In addition to the appearance of spessartine and ferrocolumbite, accessory phases such as schorl, almandine and pale green apatite are generally larger and more abundant.

(ii) In contrast, the pegmatites of the spodumene pegmatite zone are extensively albitized and contain abundant primary spodumene. Typomorphic minerals characteristic of this zone include clevelandite, pale green muscovite, dark green-blue apatite, rare triphylite-lithiophilite, beryl, cassiterite and manganoan columbite-tantalite. This zone is also marked by the rarity of garnet and the disappearance of biotite.

Minor paragenetic variations within the spodumene pegmatite zone, such as the occurrence of green beryl, ferrocolumbite-tantalite and almandine garnet in the western half of the zone, and elbaite, wodginite, ixiolite, mangano-tantalite, loellingite and near-end-member spessartine in the eastern extremity of the spodumene pegmatite zone indicate that the pegmatites are more fractionated in an easterly direction.

The internal structure of many of the spodumene pegmatites has been obscured by tectonic processes during their formation. Therefore, variation in the internal structure of the pegmatites within the spodumene pegmatite zone could

not be discerned. Nevertheless, the relatively undeformed pegmatites generally show well developed internal zonation.

Numerous quartz veins intrude the rocks beyond the eastern limit of the Southern pegmatite series at attitude similar to the pegmatites. They may represent the final and outer zone in the regional zoning scheme of the Southern series. However, several "normal" aplite dykes of similar dimension and structural position to the rare metal pegmatites occur on the north shore of Pipestone Lake. No analyses of the aplite dykes was made therefore their relation to the pegmatite field is uncertain.

The direction of increasing complexity of the pegmatite types in the Minago, Southern and Northern Series is consistent with the fractionation trend shown by the geochemical data for the K-feldspars, muscovites, garnets, tantalites-columbites and beryls. Figures 82-91 (appendix) are combination bar-graph maps which give the average concentration of an element for a given mineral from a pegmatite locality in the Cross Lake area. Increasing fractionation is marked by enrichment in Li, Mn, Be, Cs, Rb, Na, Ta, Nb, Sn, P and F and a depletion of Ba, Ca, Pb, Fe and S in the pegmatites.

Chapter VI

DISCUSSION

In this chapter the distribution, derivation, emplacement and evolution of the pegmatites in the Cross Lake field are discussed with respect to the laboratory and field data.

6.1 STRUCTURAL POSITION OF THE PEGMATITE FIELD

The northwestern margin of the Superior province has recently been interpreted in terms of plate tectonic processes and relationships (Fountain and Salisbury 1982, Scoates 1980, Hubregtse 1980). The lithologic and metamorphic zonation observed at the western margin of the Superior province is believed to represent continental crust exposed in cross section, possibly due to obduction of the Superior province during an ancient continent-continent collision between the Churchill and Superior provinces (Fountain and Salisbury 1982). The lower crust consists of granulite facies rocks of the Pikwitonei domain while intermediate and shallow levels consist predominantly of amphibolite facies and greenschist facies rocks respectively (Fountain and Salisbury 1982). Post-metamorphic granitic intrusions occur in the intermediate and shallow levels.

The above lithospheric model provides a working hypothesis with which to examine the Cross Lake pegmatite field in terms of its position within the crust and of the distribution of different geochemical types of granites and pegmatites across the metamorphic gradient. Hubregtse (1978) suggested that the extraction and subsequent ascent of volatile and potassium-rich components during M_2 granulite facies metamorphism, led to the formation of "dry" and K-depleted granulite facies rocks overlain by an amphibolite facies complex enriched in volatile and K-rich granitic components.

6.2 GRANITIC ROCKS AND THEIR RELATION TO THE PEGMATITE FIELD

Figure 72 gives the mesonormative compositions of the granites and pegmatitic leucogranites in the Ab-Or-Qtz and the Ab-Or-An systems. The wide scatter of compositions in the ternary feldspar plots largely reflects the inhomogeneous nature of the intrusions. In general, the majority of the granites lie on the Or-rich side of the Ab-Or-Qtz minima and eutectics and some are shifted towards the Qtz-Or edge. In the Ab-Or-An mesonorm diagram most of the granites fall into the low temperature trough (Figure 72) which covers the range of 1 to 10 kb (after Kleeman 1965).

The geochemical diversity of the granitic intrusions (Figures 14, 15, 16, 17, 18, 19, 20, 21, 22) coupled with textural and mineralogical dissimilarities indicate that

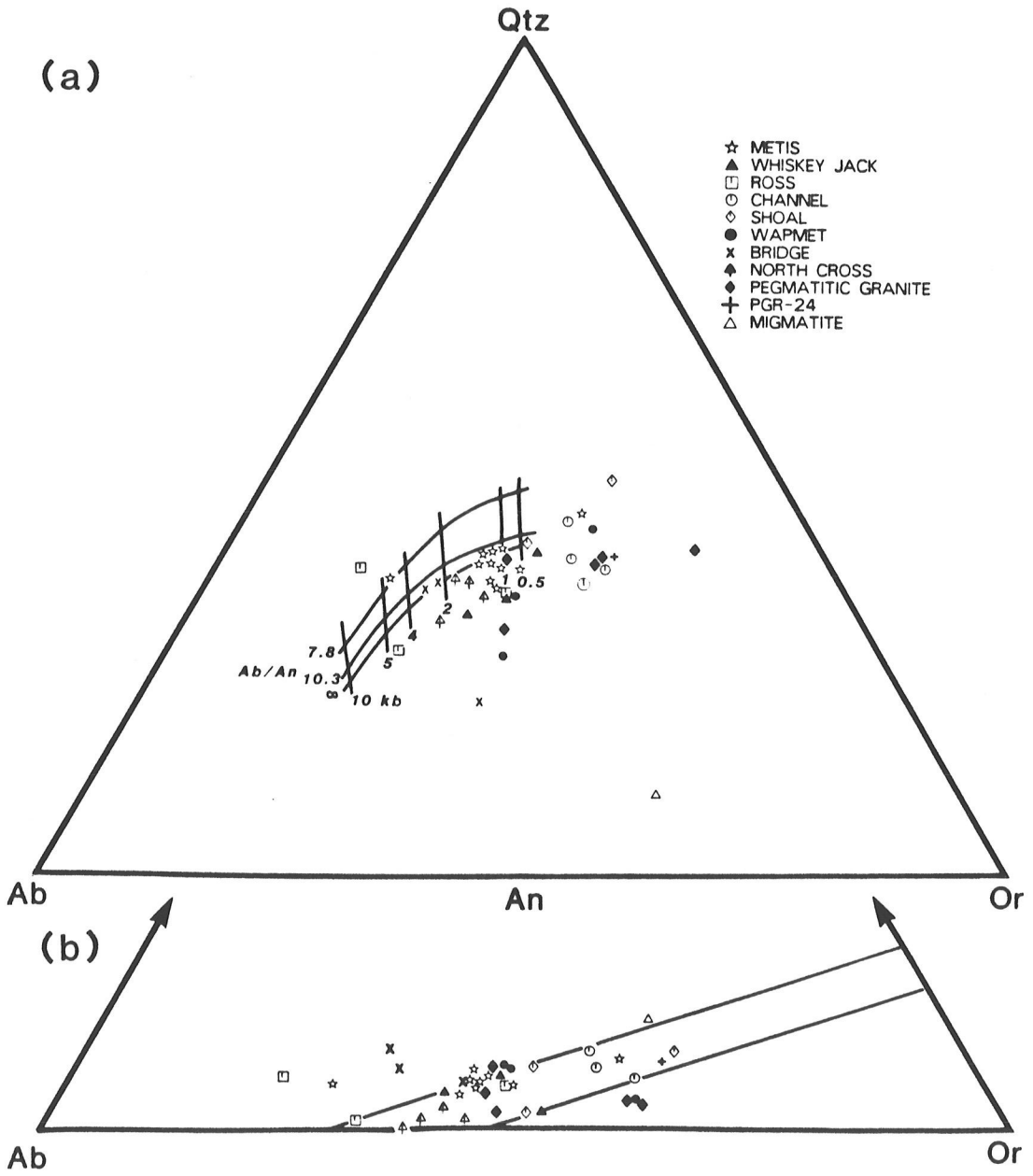

Figure 72: (a) Ab-Or-Qtz mesonormative composition for Cross Lake granitoids in the Anderson and Cullers (1978) grids, and (b) Ab-Or-An mesonormative composition of Cross Lake granitoids. The Ab-Or-An mesonormative plot includes the low temperature trough of Kleeman (1965) which covers a range of 1 to 10 kb.

many of the granites examined are genetically and spacially unrelated. For example the Bridge and North Cross granites are relatively primitive granites characterized by high Mg (Figure 21), Ba (Figure 15), Sr (Figure 15) and Cr (Table 24) contents and lower differentiation indices (Table 24). Mineralogically, they are biotite and magnetite rich and are void of garnet and tourmaline. Texturally they are as well foliated as the surrounding granitic-granodioritic gneisses for which no contact was observed. The geochemical data and observations above suggest that the North Cross and Bridge intrusions are early granitic phases related to the gneiss complex that predate a major tectonic event which preceded the emplacement of the highly fractionated granites and pegmatites.

The pegmatitic granites and the Metis, Whiskey Jack, Ross, Channel, Shoal and Wapmet granites are generally more leucocratic, less foliated (except for the Whiskey Jack granite), more peraluminous and more differentiated (Table 24) than the North Cross and Bridge granites. An interpretation of the origin of the individual intrusions cannot be derived from the available data. However, the geochemical data does serve to identify a possible relation between some granites and specific pegmatite groups.

Granites parental to rare-element pegmatites are typically highly silicic, meta-aluminous to peraluminous and have low Ti, Fe, Mg, Ca and Sr and high Na and K content and low K/Rb, K/Cs and Mg/Li ratios (Beus 1968, Černý 1982b). Table

TABLE 23

Geochemical indicators of Beus and Sitnin (1968) and Beus et al. (1968) for barren vs. fertile granites.

	Li		Rb	Sn	V	Mg/Li		Zr/Sn	
Intrusion type	< 25ppm	> 100ppm	< 150ppm	> 20ppm	> 4ppm	<30	>100	<30	>100
Parental to Ta-bearing apogranites	<1%	64%	<1%	28%	1%	100%	<0.1%	83%	<0.1%
Parental to Ta-bearing pegmatites	<1	41	5	26	1	39	0.4	93	14
Parental to Ta-poor pegmatites	26	27	24	16	1	27	30	87	5
Parental to Ta-free greisens	26	23	30	21	14	44	12	46	70
Barren granites	54	2	43	1	30	<<0.1	98	7	48

(23) gives the geochemical indicators of Beus and Sitnin (1968) for various fertile and barren granites. Of the granites examined in the Cross Lake area, only the Metis, Ross and Whiskey Jack granites appear to be characteristic of fertile granites. The pegmatitic granites are structurally, spatially and paragenetically related to the Metis granite but are depleted in Zr, Cs and Li and enriched in Cr and Mg in comparison.

The Metis granite is intruded and surrounded by pegmatites of the Minago series that are less fractionated than the granite itself, suggesting that they probably belong to an unrelated fractionation and intrusive event. The close spatial relationship between the Li-rich Metis granite and Southern series suggests a genetic link. The structural position of the Metis granite and the level of emplacement make it difficult to consider it a direct parent to the Southern pegmatite series; it may, however, represent a relatively shallow offshoot of the same granitic body that generated the Southern and Minago series, emplaced at a high level in a structural environment different from that hosting the pegmatites.

The Ross and Whiskey Jack granites are also enriched in incompatible elements but are distinguished from the Metis granite by more intense shearing, lesser amounts of plagioclase, accessory garnet and tourmaline, and lower Ba, Sr and Li contents. The Whiskey Jack granite is also significantly more F-, Sn-, Nb- and Y-rich.

The Ross granite grades into pegmatites of the biotite-peristerite zone indicating a direct relationship to the Southern series. The Whiskey Jack granite is extremely F-rich and is therefore not considered to be a direct parent to the F-poor rare-element pegmatites of the Southern series.

Despite the absence of a large parental granite in the Cross Lake area, an igneous origin involving the injection of a highly differentiated rest-liquid derived from granitic magma (Jahns 1969), rather than a metasomatic or metamorphic derivation of the pegmatites, is preffered for the following reasons:

1) Many of the pegmatites are sharply discordant, and tourmalinization is extensively developed along foliation planes within the host rock; both features indicate allochthonous origin and exomorphism.

2) Evidence of forceful injection of the pegmatite into a host structure (Figure 73), indicative of allochthonous origin of the pegmatite melt and intrusion at P(melt) > P(load).

3) The compositional dissimilarities between the host rock and the pegmatites; they are very close to those analyzed by Kretz (1968) who demonstrated their material independence.

4) The abundance of minerals containing (Li, Be, Mn, Nb, Ta) at high concentration levels that are more compatible with an igneous derivation (Jahns 1955, Černý 1982b).

5) Existing views on the anatectic orgin of rare-element granitic pegmatites (Norton 1981, Stewart 1978) are highly speculative and not supported by geochemical or petrogenetic evidence.

6.3 DISTRIBUTION OF PEGMATITE TYPES IN THE CROSS LAKE FIELD.

Geochemical, paragenetic and textural variations of the pegmatites indicate that a wide range of pegmatite types occur in the Cross Lake area. The paragenetic type of pegmatite is a function of the geochemical character of the source magma (Černý 1982b), the depth of formation of the pegmatite body (Makrygina 1979, Shmakin 1971) and the distance of the pegmatite from its source (Heinrich 1953, Hutchinson 1955, Jahns 1955, Temnikov 1970, Varlamoff 1978).

The configuration of the pegmatite field is controlled by the host structures, and in some cases subsequent tectonic activity which may affect the relative positon of the pegmatites in the field (Arkhangel'skaya and Ginsburg 1982).

Pegmatites of the Cross Lake field were emplaced within fracture zones that extend for several kilometres, generally parallel to, and near the axial parts of the greenstone belt. The dykes are long, thin, tabular and are locally arranged en echelon. Ginsburg (1960) and Nedumov (1964) noted that thin tabular bodies of this type are typical of narrow elongated pegmatite fields where emplacement occurred within regional, tectonically active faults.

Intrusion of the late granites, pegmatitic granites and pegmatites is one of the latest events in the Cross Lake area. It is post-dated by a period(s) of deformation which was followed by the emplacement of the mafic dykes of the Molson dyke swarm (Figure 27).

The pegmatites are generally steeply dipping and concordant to the schistosity of the host rock, however, discordant and moderately dipping bodies occur, particularly in the Southern pegmatite series. Pegmatites that were emplaced at relatively great depths (within the sillimanite and near the pyroxene zone) typically show a conformable relationship with the enclosing plastically deformed metasedimentary rocks; such intrusive relationships are prevalent in the Northern, Nelson and Minago series.

Evidence for brittle behavior of the rocks hosting the spodumene-bearing pegmatites numerous small-scale faults and extensive development of joints. These are the structures hosting the spodumene-bearing pegmatites, suggesting that their emplacement occurred at higher crustal levels into fractures which commonly cross-cut the foliation in the more rigidly behaving host rocks.

Forcible emplacement of the pegmatites accompanied by movement of the host structure is suggested in several pegmatites. Deformation of the host rock along the intrusive contacts is indicated by bending of conglommerate clasts and folding of bedding and foliation planes (Figure 73). Continuous or broken schist bridging is also observed. Evi-

dence of forcible intrusion is most prevalent in the pegmatites of the Minago and Southern series, but it is also shown by some pegmatites of the Northern series.

Parallel and perpendicular orientations of minerals with respect to the pegmatite contacts, notably spodumene, tourmaline, mica and microcline occur in the pegmatitic granites and complex pegmatites of the field. The internal structures of pegmatite bodies formed in zones of compression and tension are distinguished by the nature of mineral orientation relative to the contacts of the pegmatite (Rossovskyi and Konovalenko 1979).

A parallel orientation of crystals relative to the contacts, in the spodumene-bearing pegmatites on Spodumene Island (Figure 34) suggests that these pegmatites formed or recrystallized under conditions of compression. The interpretation of the parallel directional fabric is supported by the recognition of linear zones of compression parallel to, and possibly hosting, the pegmatitic granites and rare-element pegmatites (Lenton and Anderson 1983). The effects of compression during the emplacement of the pegmatites is also expressed in the development of cataclastic texture in some of the pegmatites on Spodumene Island (Figure 34) (Rossovskyi and Bovin 1971). The degree of cataclasis in the bodies varies locally, suggesting varible intensity of deformation across the field. Fracturing of minerals, most conspicuously of beryl and schorl crystals, subsequently healed by crystallization of later minerals is also widespread.

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Figure 73: Rare-element pegmatite intruding deformed metaconglomerate on Spodumene Island. Bending of the host rock at the contacts suggests that the pegmatite was forcecibly emplaced and accompanied by movement of the host structure in a sinistral sense (Chadwick 1958).

Normal or oblique orientations of minerals relative to the major axis of the pegmatites that hold across the full width of pegmatite bodies (such as that documented in the Violet-Thompson pegmatite in the Wekusko Lake field; Černý et al.(1981)), was not encountered in the Cross Lake field. This directional fabric is suggestive of pegmatite crystallization in a tensional field in a dilating structure.

Many of the spodumene-bearing pegmatites, as well as the other pegmatites in the field, display a random orientation of crystals, with the exception of some border and wall zone minerals that are normal or subnormal to contacts. This type of texture is typical of pegmatites which form in a static (or near static) regime, and the crystal growth along the margins is controlled by geometric selection.

Due to regional, large scale tectonic tilting a wide range of pegmatite types that formed at various depths are seen throughout the exposed amphibolite facies complex. Tectonic activity responsible for the exposure affecting the crustal section may have also contributed to more local structural modifications in the distribution of pegmatites in the field.

The spodumene-bearing pegmatites outcrop within an area that is bounded by structural lineaments in the southeastern part of the study area (Figure 3). The lineaments seperate areas of staurolite-bearing rocks which host the highly fractionated rare-element enriched pegmatites on Metis and

Spodumene Island, and sillimanite-bearing rocks hosting barren pegmatites of the Minago series. It is suggested that the lineaments are faults seperating block structures that are vertically displaced with respect to one another. The block hosting the barren pegmatites of the biotite-peristerite zone of the Southern series and the Minago series is uplifted relative to the block hosting the spodumene-bearing pegmatites of the Southern series. Arkhangel'skaya and Ginsburg (1976) have reported similar block faulting in the pegmatite fields of the Soviet Union, noting that local zones of either uplift or subsidence greatly affect the distribution of pegmatite bodies. The continuity in the fractionation trend observed in the Northern series suggests that structural dislocations have not affected their distribution to a great degree.

Regional zoning in pegmatite fields has been addressed in numerous papers (Heinrich 1953, Jahns 1955, Nedumov 1964, Solodov 1971 and Černý 1982b). Rare-element pegmatites typically intrude the country rocks around the upper parts of the parental granite with the most fractionated pegmatites enriched in rare elements and volatile components emplaced progressively farther from the parent body (Černý 1982b). Differentiation of the pegmatites increases, and is best expressed, in a vertical direction towards levels of lower pressure and temperature.

The Minago, Southern and Northern series show a regional zoning pattern. The direction of increasing fractionation within each series is generally consistent with decreasing metamorphic grade of the host rocks, suggesting that more evolved pegmatites were emplaced at progressively shallower levels. Barren pegmatites occur in the sillimanite-bearing rocks west of Cross Island. Rare-element pegmatites occur at the edge of the sillimanite isograd and within the staurolite-almandine bearing rocks (Figure 24).

6.4 GENETIC CONSIDERATIONS

The pegmatites of the Nelson series are the most primitive in the pegmatite field and are uniform in appearance and composition. The Ba and Sr contents of the K-feldspars show the greatest variability within the series, generally decreasing in a southeasterly direction. The pegmatites in the northwestern part of the study area contain Ba-rich K-feldspar (>1000 ppm) (Figure 84) and Ca, Mg, Fe-rich garnet. They are considered to represent allochthonous melts derived by direct anatexis from the adjacent amphibolite-granulite facies transition in metasediments. However, pegmatites of the Nelson series that are in the vicinity of the Minago series pegmatitic granites have lower Ba contents similar to the K-feldspars of the Minago series (Figure 84). The close spatial and geochemical relationship suggests that some of the pegmatites which comprise the Nelson series (as defined

in chapter V) are genetically related to the pegmatitic granites.

The geochemical character of the parent is inherited by the related pegmatite bodies. In the Cross Lake field the geochemical, textural and mineralogical diversity of some of the pegmatites can be attributed to their affliation to geochemically different granite sources.

The Southern (Li, Be, Nb, Ta, Sn) series is Li-rich, P- and F-poor and contains minor amounts of Sn. The muscovites and K-feldspars of the Southern pegmatite series have high Rb/Cs ratios. In contrast, the Northern (Be, Nb, Ta) series is Li and Sn deficient and is comparatively Be-,P- and F-rich and the muscovites and K-feldspars are characterised by low Rb/Cs ratios (Figure 74).

The inherent geochemical differences between the Northern and Southern series can be traced back to the most primitive pegmatites of these two series, and probably to the granites from which they were derived. The geochemical incompatibility between the two groups is best shown on the K/Rb vs Cs ppm plot for K-feldspars (Figure 39) and muscovites (Figure 46). The Northern and Southern series form seperate compositional fields which have subparallel non-sequential fractionation trends due to the proportional increases in both Rb and Cs with differentiation. Different igneous sources can be assummed for the two series, with different intial Rb/Cs ratio. Divergent geochemical evolution from a common source is highly improbable. The Rb/Cs ratio is a useful

petrogenetic indicator in the Cross Lake pegmatite field for determining the genetic affliation of a pegmatite body, particularly in the case of barren pegmatites that lack the accessory minerals diagnostic for a particular group, and may be formed well inside the apparent spatial gap separating the series.

The Li-deficient nature of the minerals in even the most fractionated pegmatites of the Northern series indicates that the group was derived from a Li-poor source. However, the K-feldspars and muscovites of the Southern and Minago series are considerably more Li-rich (Figure 40 and 48) suggesting a geochemical link between the two pegmatite series and the nearby highly fractionated, and Li-rich (90 Metis granite.

In contrast to the expected trend, the Li content of the muscovites from some of the pegmatites of the Minago series is greater than the Li values in the muscovites of the Southern series. It is suggested that most of the available Li in the pegmatites of the Southern series was incorporated into spodumene, and only minor remaining Li was incorporated into the late forming muscovites. Because there are no major Li minerals in the Minago series most of the Li in the pegmatites occurs in the muscovites.

Also in contrast to the expected trend is the increase in Sr content in the K-feldspars of the Southern series, which is greater than that in the less evolved pegmatites of the Minago series (Figure 42). It is suggested that the in-

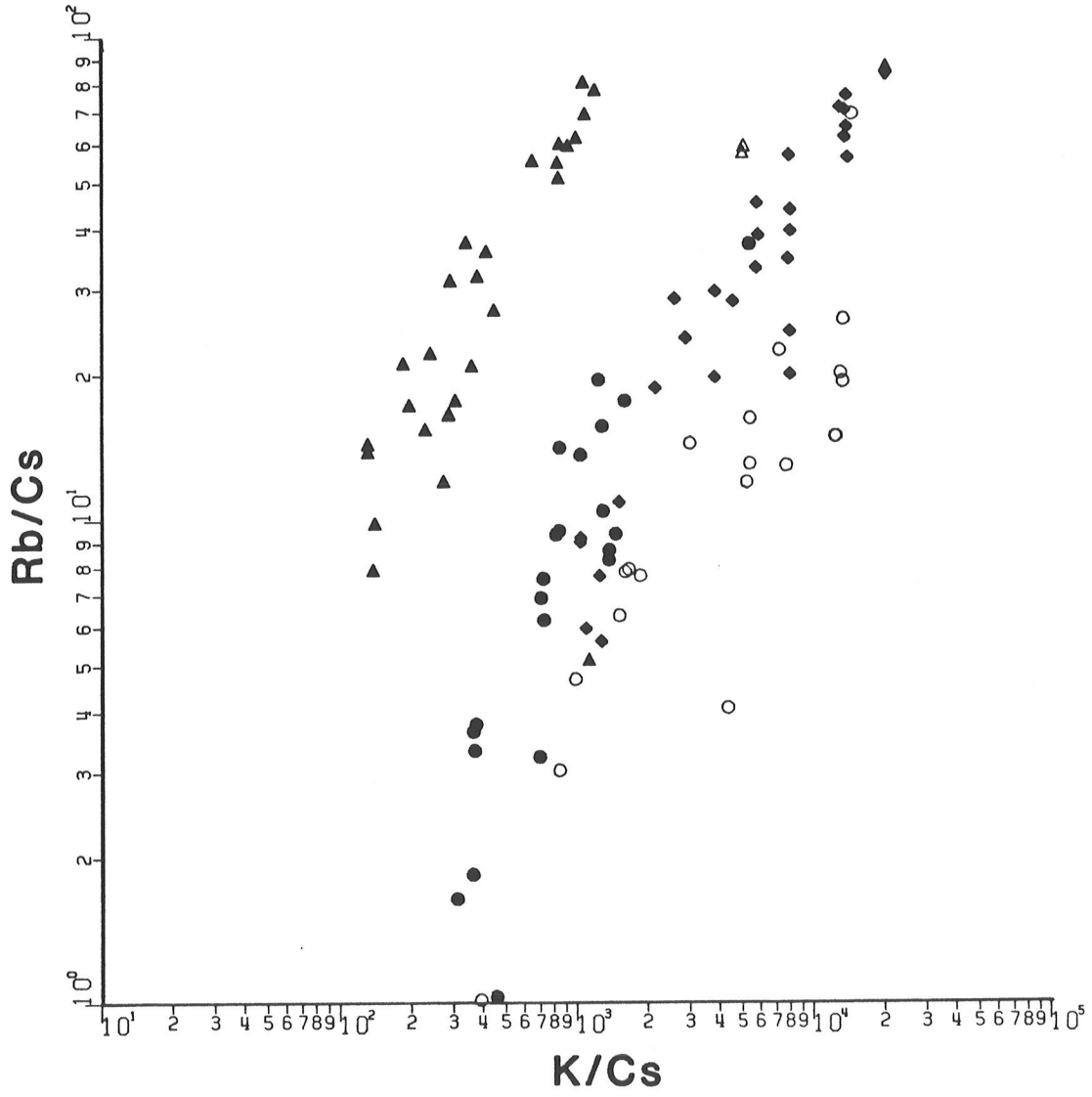


Figure 74: Rb/Cs vs K/Cs plot of muscovites from the Cross Lake pegmatite field. Note that the muscovite of the Northern series have a lower Rb/Cs ratio than the Southern series muscovites suggesting that the source of Northern series has a low intial Rb/Cs ratio. Symbols as in Figure 24.

crease is due, at least inpart, to the high radiogenic Sr content in the Rb-rich K-feldspars.

Chapter VII

ECONOMIC ASPECTS

Granite pegmatites are an important source of commercial feldspar, mica, amblygonite, beryllium, tantalum, niobium, cesium and lithium. Pegmatites have also yielded significant amounts of tin, uranium, thorium, rare earth minerals and gem materials. Precambrian pegmatites of intermediate levels such as those in the Cross Lake field are known to contain commercial quantities of Ta, Li, Be, Cs, Rb and industrial minerals but generally do not have economic concentrations of U, Th or rare earth elements (Černý 1982a).

The economic viability of a pegmatite is dependent on the absolute concentration of rare elements in it, the extractability of the rare element-bearing minerals, and the size and accessibility of the pegmatite. These characteristics are largely obtainable only through detailed exploration. However, the type and extent of rare-element mineralization in a pegmatite is also a function of the general level of fractionation attained by the pegmatite melt. Therefore, a measure of the overall degree of fractionation may be used for indirect estimates of the economic potential.

In an attempt to estimate the pegmatite mineralization potential of the area, the writer used various diagrams for the prediction and evaluation of rare metal mineralization

constructed by Gordiyenko (1971, 1976), Černý (1975), and Trueman and Černý (1982).

The graphs of Gordiyenko (Figure 75, 76, and 77) (1971) characterise several pegmatite types based on the variations of Rb, Cs and Li in the K-feldspars and muscovites from a diversity of pegmatite fields and provinces. The diagrams distinguish four pegmatite types based on the commercial classification of Ginsburg (1957). They are: (I) feldspathic (barren) (II) muscovite-feldspathic (Be-Nb-Ta mineralization) (III) spodumenic (Li-Be-Ta-Nb-Sn mineralization) (IV) spodumene-lepidolitic (Li-Cs-Ta-Be-Nb-Sn mineralization). The average content of Rb, Cs and Li in the K-feldspars and muscovites from the most highly fractionated pegmatites in the Northern and Southern group are plotted on their respective graphs.

According to Gordiyenko, the mineralization potential of the highly fractionated pegmatite types are most reliably distinguished by the Cs content of the K-feldspars. The Cs graph (Figure 77) indicates that the pegmatites from both groups plot within the range of type IV. In the Rb plot (Figure 75), pegmatite 6 of the Southern series falls into the range of type IV, whereas pegmatite 22 of the Northern series plots in the range of types I, II, and III. The average Li content in the muscovite from pegmatite 6 plot in the range of types III and IV. But the average Li content in the muscovite for pegmatite 22 falls in the range of type

I. Barren pegmatites from both the Northern and Southern series plot in the range of type I in Gordiyenko's diagrams.

Variations in the K/Cs vs Na_2O wt% in the K-feldspars (Figure 78) was also proposed by Gordiyenko (1976) to distinguish several different types of Precambrian rare-element pegmatites from non-mineralized ceramic and muscovite provinces (Gordiyenko 1976).

The compositions of the K-feldspars from the Nelson series correspond to the mica-bearing pegmatites of Barrovian metamorphic facies. The primitive composition of the Nelson series is consistent with the geochemical signature of the mica-bearing pegmatites despite their different metamorphic environment. The similarity of the Nelson series with the anatectic mica-bearing pegmatites supports the contention that some of the Nelson series pegmatites formed from allochthonous anatectic melts.

The Minago series K-feldspars occupy the compositional fields of barren pegmatites for both rare-element and mica-bearing provinces. A number of Minago series K-feldspars also fall into the beryl-bearing field. This is in agreement with the generally barren character of this series, with only rare beryl occurrences.

The biotite-peristerite pegmatites of the Southern series fall mainly into the beryl-bearing and barren pegmatite fields of the rare-element provinces. As expected, the K-feldspars of the spodumene-bearing pegmatites fall into the

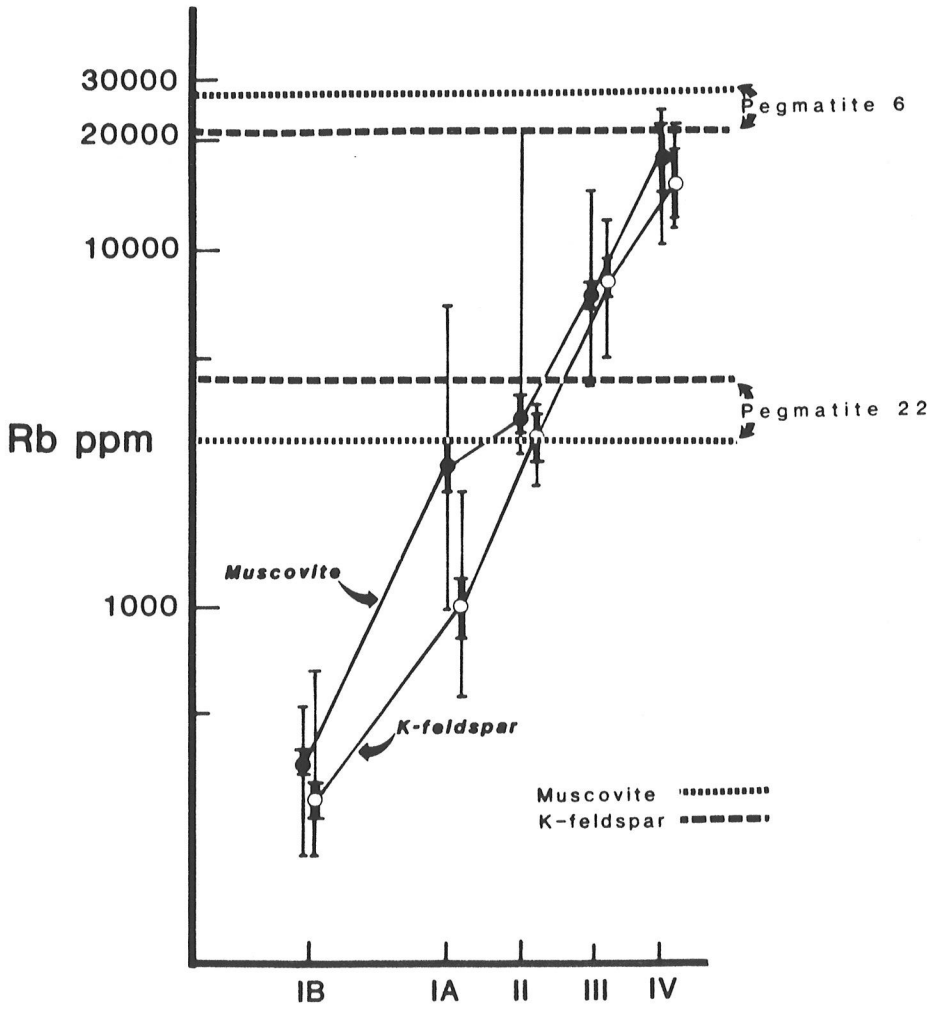


Figure 75: Plot of the average Rb contents of muscovite and K-feldspar from pegmatite 22 and 6 of the Northern and Southern series, respectively, on the graph of Gordiyenko (1971). The mean Rb content of muscovite and K-feldspar from different pegmatite types is designated by an open circle. The pegmatite types are: IB - barren feldspathic pegmatites, IA - feldspathic pegmatites of rare-metal provinces, II - muscovite-feldspathic pegmatites with Be and Nb-Ta mineralization, III - spodumene-bearing pegmatites with Li, Be, Ta-Nb, Sn mineralization, IV - spodumene-lepidolite-bearing pegmatites with Li, Cs, Ta-Nb, Be and Sn mineralization. The solid and vertical lines indicate the 95% interval of the mean content of Rb, the thin lines denote the range of the arithmetic means with 95% confidence level.

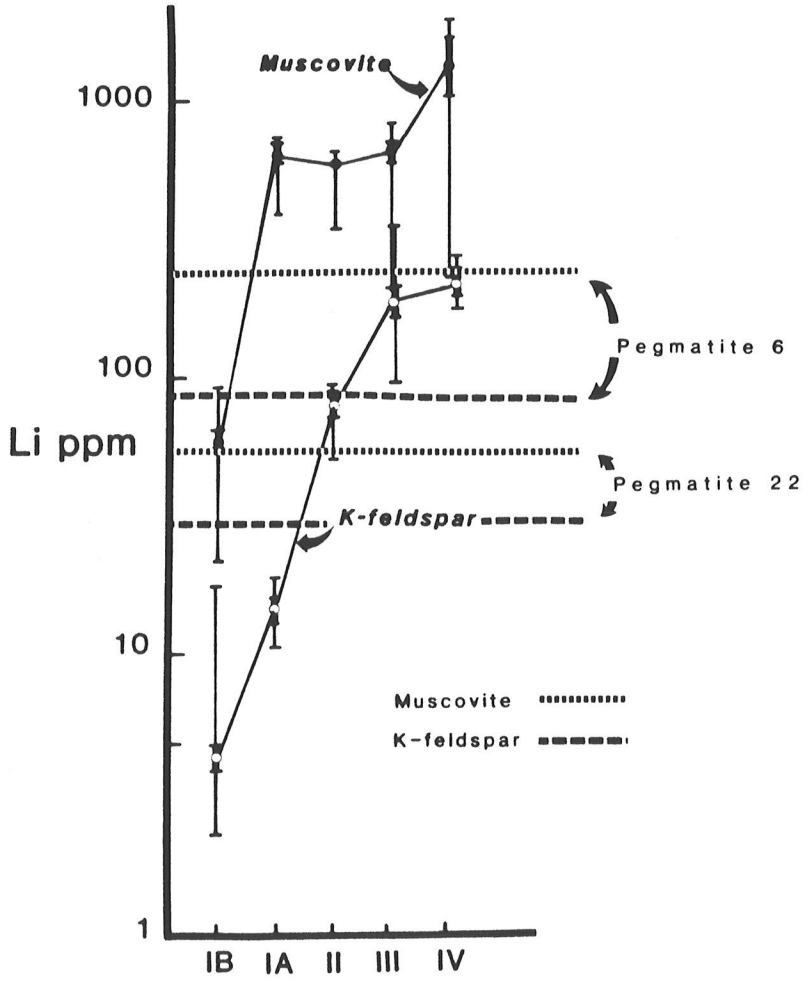


Figure 76: Plot of the average Li contents of muscovite and K-feldspar from pegmatite 22 and 6 of the Northern and Southern series, respectively, on the graph of Gordiyenko (1971). The mean Li content of muscovite and K-feldspar from different pegmatite types is designated by an open circle. The pegmatite types are: IB - barren feldspathic pegmatites, IA - feldspathic pegmatites of rare-metal provinces, II - muscovite-feldspathic pegmatites with Be and Nb-Ta mineralization, III - spodumene-bearing pegmatites with Li, Be, Ta-Nb, Sn mineralization, IV - spodumene-lepidolite-bearing pegmatites with Li, Cs, Ta-Nb, Be and Sn mineralization. The solid and vertical lines indicate the 95% interval of the mean content of Li, the thin lines denote the range of the arithmetic means with 95% confidence level.

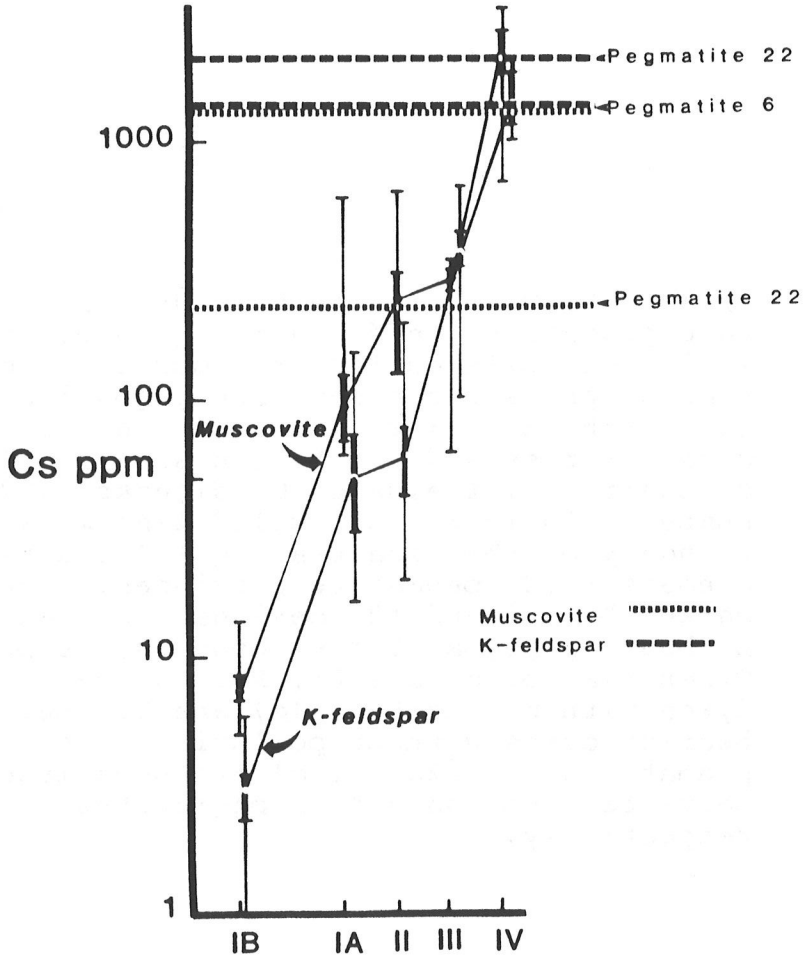
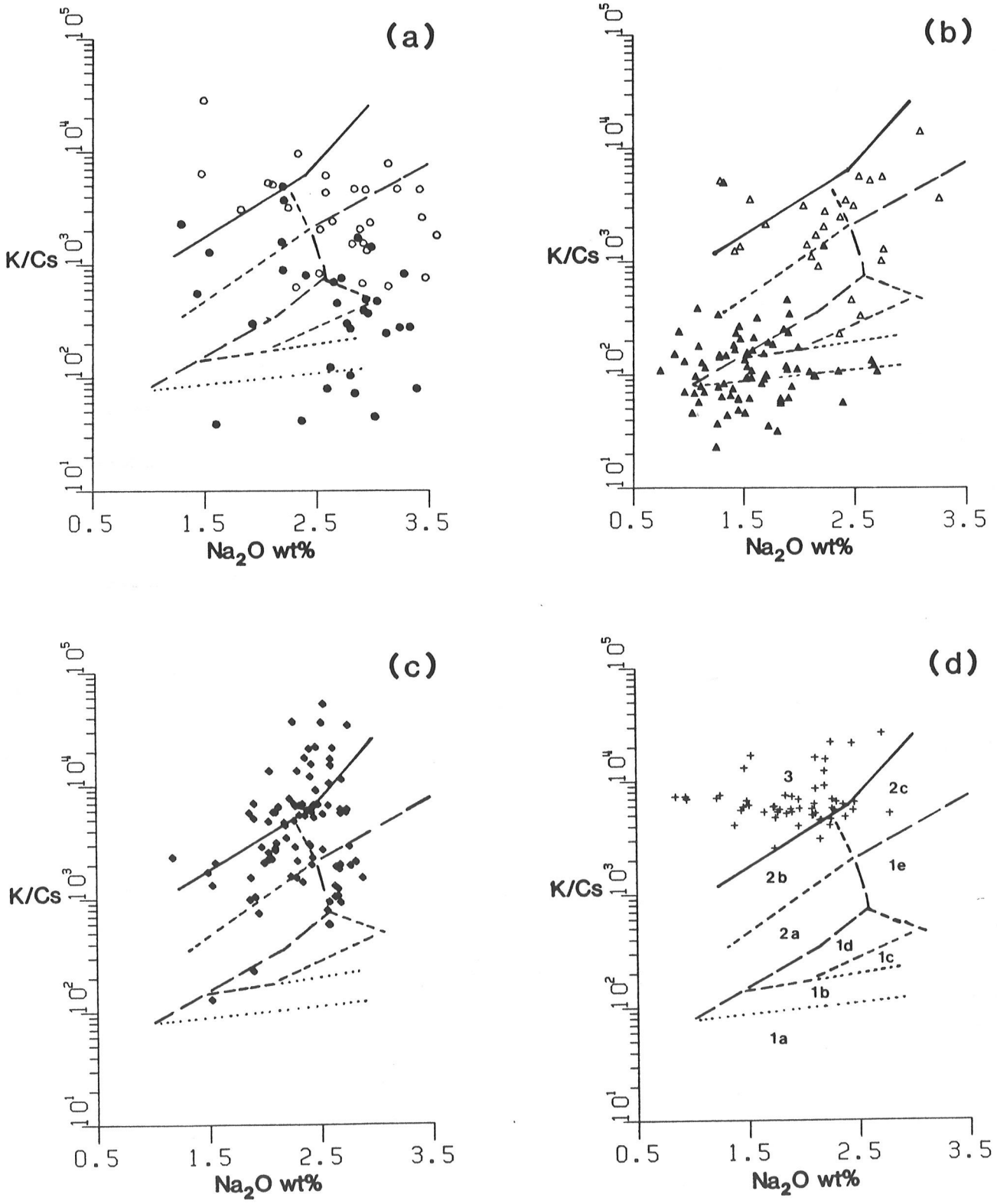


Figure 77: Plot of the average Cs contents of muscovite and K-feldspar from pegmatite 22 and 6 of the Northern and Southern series, respectively, on the graph of Gordiyenko (1971). The mean content of Cs of muscovite and K-feldspar from different pegmatite types is designated by an open circle. The pegmatite types are: IB - barren feldspathic pegmatites, IA - feldspathic pegmatites of rare-metal provinces, II - muscovite-feldspathic pegmatites with Be and Nb-Ta mineralization, III - spodumene-bearing pegmatites with Li, Be, Ta-Nb, Sn mineralization, IV - spodumene-lepidolite-bearing pegmatites with Li, Cs, Ta-Nb, Be and Sn mineralization. The solid and vertical lines indicate the 95% interval of the mean content of Cs, the thin lines denote the range of the arithmetic means with 95% confidence level.


(a)
(b)
(c)
(d)
K/Cs
10^1
10^2
10^3
10^4
10^5
0.5
1.5
2.5
3.5
Na_2O wt%
3
2c
2b
1e
2a
1d
1c
1b
1a

spodumene-bearing pegmatite field, but also fall into the fields characterised by Cs mineralization. In fact, the geochemical signature of the most fractionated members of the series approaches that of pollucite-bearing pegmatites such as Tanco (Černý 1981).

The K-feldspars of the Northern series are dispersed throughout the whole diagram. This "anomalous" behavior is in agreement with the unusual mineralogy and geochemistry of these pegmatites, and with the fact that this pegmatite type was not used in the construction of Gordiyenko's graph in the first place.

Figure (79) shows the K/Rb vs Cs ppm plot for the blocky K-feldspars in the Northern and Southern series of the Cross Lake field. The dashed lines indicate the approximate appearance of significant mineralization in the Winnipeg River pegmatite district of southeastern Manitoba (Trueman and Černý 1982). Because the Northern series pegmatites are unlike any of the pegmatite types found in southeastern Manitoba they cannot be effectively compared to the mineralization boundaries in figure (79), and the wide scatter of their data plots is meaningless. The Southern series , however, is paragenetically analogous to pegmatites in the Winnipeg River district (Černý et al. 1981). Therefore, the K/Rb vs Cs ppm fields that characterize the appearance of particular types of mineralization in the Winnipeg River district should reflect more reliably the mineralization potential of the Southern series. This is shown by the good

match of the onset of Li mineralization indicated by the graph with the appearance of spodumene in the Southern series.

Černý (1975) quantified the alkali contents of beryl and correlated the Na/Li vs Cs ppm values of the latest most fractionated beryl generations with several types of rare element pegmatites (Figure 80). The pegmatite types are as follows:

(A) Barren and Be, Nb, Ta-bearing pegmatites poor in rare-alkalis.

(B) Be, Nb, Ta pegmatites of rare-alkali enriched groups, up to spodumene-bearing.

(C) Spodumene pegmatites.

(D) Pegmatites with Li, Rb, Cs, Be, Ta-mineralization.

The beryls of the spodumene pegmatite zone of the Southern series fall into the field of types D, C and B whereas the beryl of the Northern series fall mostly into the A-type field.

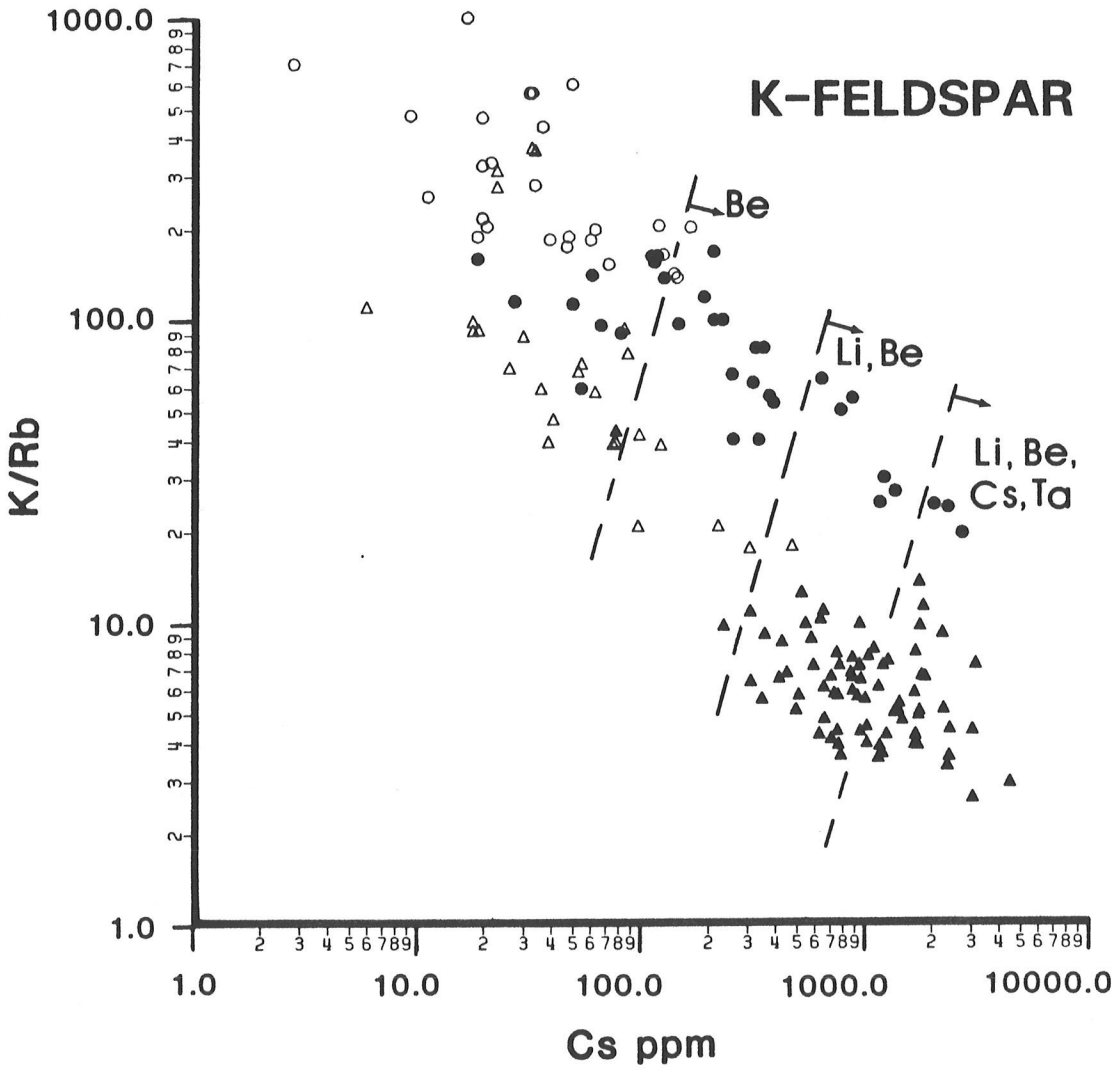


Figure 79: K/Rb vs Cs plot of the K-feldspar from the Northern and Southern series showing the compositional fields which designate the appearance of significant mineralization in the Winnipeg River district (Trueman and Černý 1982). Note that the first occurrence of Li mineralization in the Southern series closely corresponds to the Li, Be, boundary of the Winnipeg River pegmatite district southeastern Manitoba. Symbols as in Figure 24.

7.1 OBSERVED MINERALIZATION AND ECONOMIC POTENTIAL

Several pegmatites in the Northern series contain minerals of Be, Nb and Ta in variable quantities. The mineralized dykes are small, widely distributed and do not contain sufficient quantities of rare elements to be economically viable. A grab sample of saccharoidal albite from pegmatite 22 assayed 0.10 % Ta_2O_5. The elevated Ta content of pegmatite 22 indicates that further exploration for subsurface Ta-bearing pegmatites in the northeastern extension of the greenstone belt may be rewarding.

Mineralized pegmatites of the Southern series contain minerals of Li, Be, Nb, Ta and Sn. No pollucite was observed, despite its prediction by the various geochemical indicators. Ta, Nb, Sn and Be do not appear to be present in quantities sufficient for commericial exploitation. However, the Li mineral spodumene is relatively abundant in almost all of the pegmatites in the spodumene zone. The spodumene dykes locally occur as closely spaced moderately dipping sheets which range up to 10 metres in thickness. Individual swarms may contain significant Li reserves that could be exploited by an open pit operation, with Ta as a possible byproduct. The iron-rich nature of the spodumene (ΣFe_2O_3 0.16-1.16 wt%) make it poorly suited for glass and ceramic applications, unless Fe-leaching by chlorination is applied (Gyongyossy and Spooner 1979). Phosphorous was not found in sufficient quantity in any of the exposed pegma-

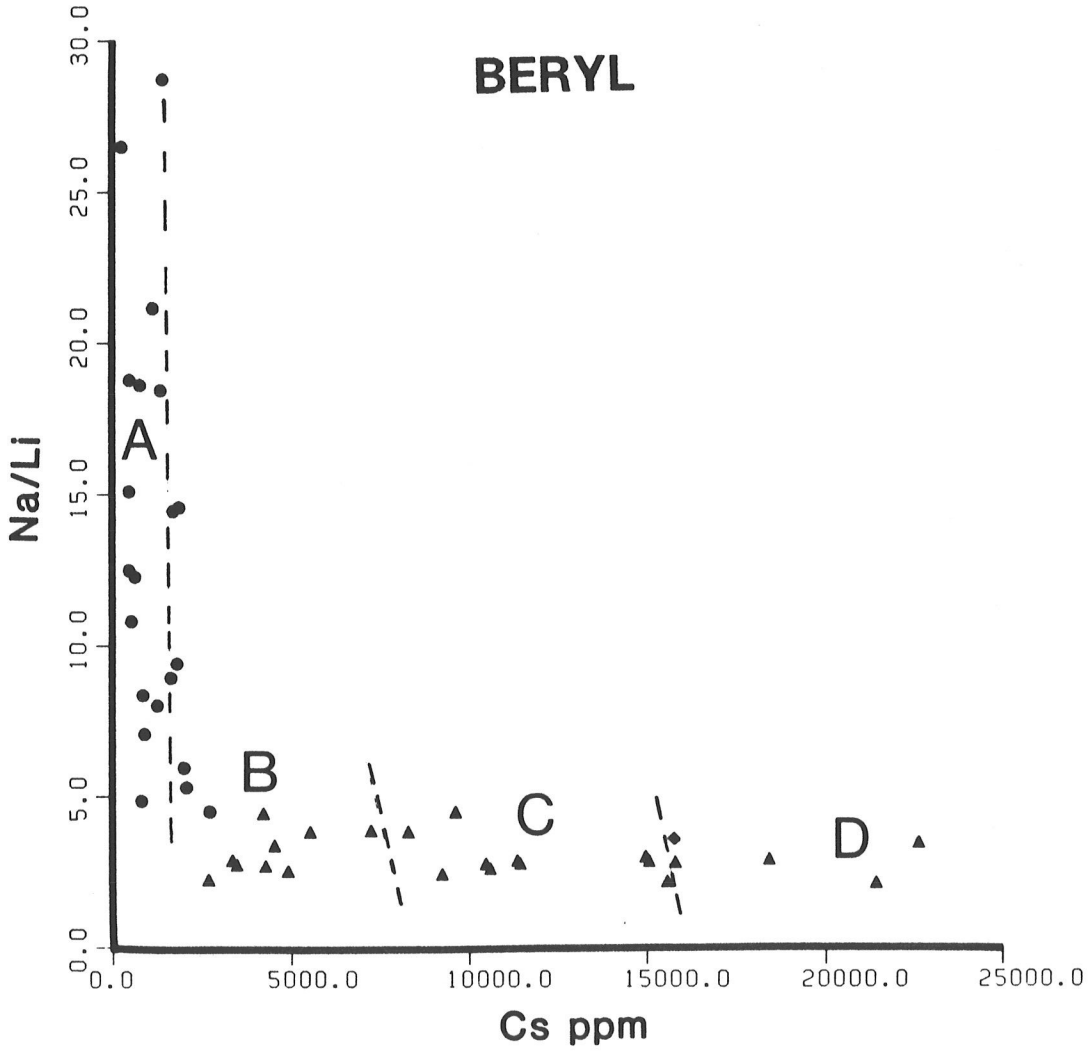


Figure 80: Na/Li vs Cs plot for Cross Lake beryls showing the compositional fields for four different rare-element pegmatite types (Černý 1975). A - barren and Be, Nb, Ta pegmatites poor in rare alkalis; B - Be, Nb, Ta pegmatites of rare-alkali enriched groups up to spodumene-bearing; C - spodumene pegmatites; D - pegmatites with Li, Rb, Cs, Be, Ta mineralization. Symbols as in Figure 24.

tites to consider the field as a potential phosphorous prospect. Furthermore, the P-poor character of the Southern series indicates that it is very unlikely that even extremely fractionated, hidden pegmatites in the Southern series would contain significant amounts of phosphorous.

The most promising area for undiscovered mineralized pegmatites lies on strike and east of the spodumene pegmatite zone of the Southern series, east of the eastern outlet of the Nelson River outlet into Cross Lake. It is suggested that if the aplite dykes on the north shore of Pipestone Lake are related to the Southern pegmatite series, more undiscovered pegmatites exist between the known eastern limit of the spodumene-bearing pegmatites and Pipestone Lake. Furthermore, extrapolation of the easterly fractionation trend of the Southern pegmatite series indicates that any additional pegmatites in the proposed target area will be highly differentiated. However, this mineralization potential would be realized only at depth, because no pegmatites are exposed on the surface, and the metamorphic grade at the erosion surface level is distinctly lower than that typical of the pegmatite-bearing terrain of the Southern series and of the environments hosting complex rare-element pegmatites in general.

7.2 CONCLUDING REMARKS

The paragenetic and geochemical observations made in this study have also been used to further quantify the relations between Ta fractionation and the value of various petrogenetic indicator elements and ratios. The writer has observed that the average K/Cs ratio for the K-feldspars decreases as the average Ta/Ta+Nb ratio for the columbite-tantalites plus ixiolite increases in the different pegmatite dykes (Figure 81). Despite the geochemical differences between the Northern and Southern series both follow the same basic trend in the K/Cs vs Ta/Ta+Nb plot. Therefore, the K/Cs ratio in the K-feldspars and muscovites should be investigated further as a potential indicator of Nb-Ta fractionation in regions where several genetically distinct pegmatite series may be explored.

The dominant Ta-Nb oxide mineral in the highly fractionated but relatively F- and P-poor spodumene-bearing pegmatites is manganocolumbite. Manganotantalite occurs in the spodumene-bearing pegmatites, but has a Ta/Ta+Nb ratio of less than 7.0 (Figure 81). Pegmatite 22 of the less evolved but comparatively P- and F-rich Northern series is also relatively Ta-rich as indicated by the presence of uranian microlite and manganotantalite (with Ta/Ta+Nb up to 0.93). It is suggested that the increasing activity of F is accompanied by an increase in Ta fractionation. The apparent relationship between Ta and F in the Cross Lake pegmatites exemplifies the importance of the recognition of F-bearing

phases as favorable criteria in the initial assessment of the Ta mineralization potential in a given pegmatite or pegmatite series.

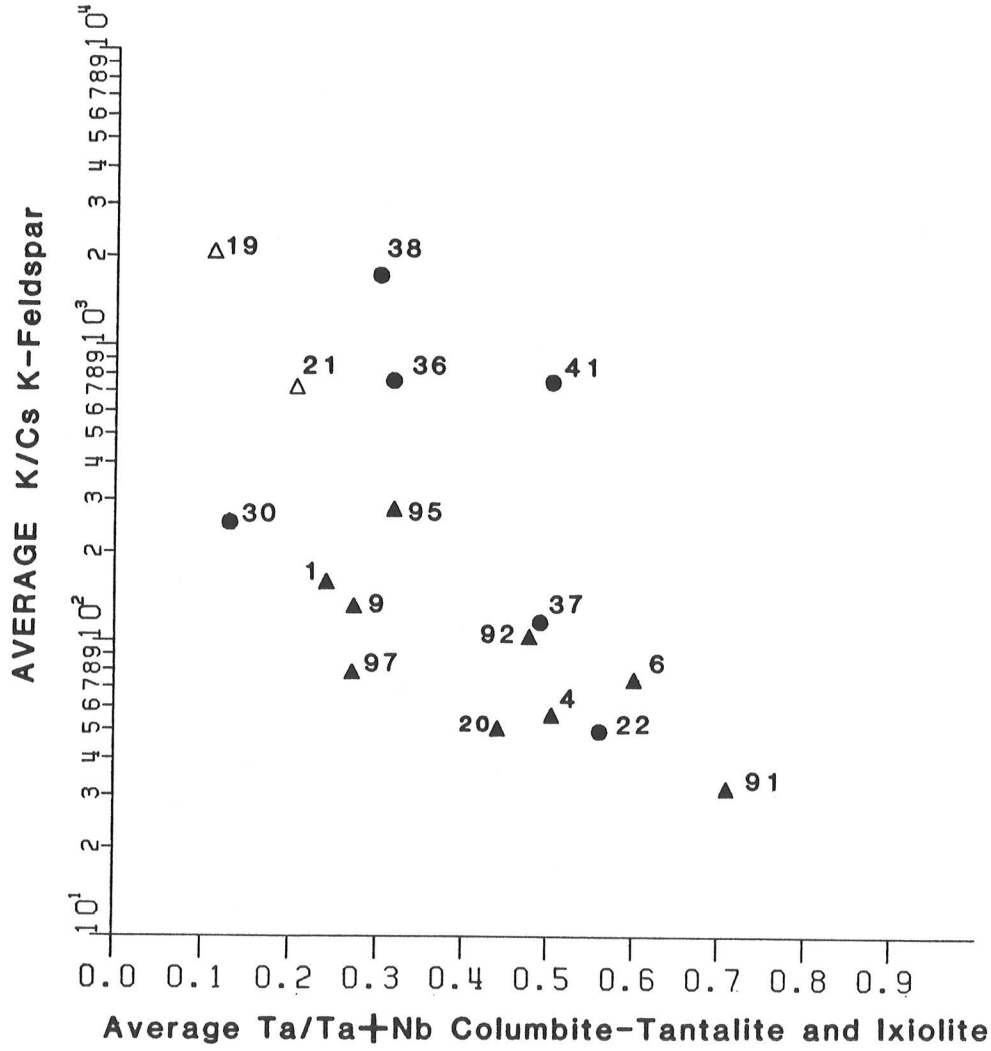


Figure 81: A plot of the average K/Cs ratio of the K-feldspar vs the average Ta/Ta+Nb ratio for the columbite-tantalites and ixiolites from individual pegmatites in the Cross Lake field. Note that the average K/Cs ratio of the K-feldspars decreases as the average Ta/Ta+Nb for the columbite-tantalite and ixiolite increases. Symbols as in Figure 24.

Chapter VIII

SUMMARY AND CONCLUSIONS

The pegmatites of the Cross Lake field outcrop within an area of about 200 km^2 at the westernmost margin of the Sachigo subprovince in central Manitoba. The pegmatite dykes and pegmatitic granites occur in narrow elongate linear zones that are parallel to the axial trend of the greenstone belt. All pegmatites are confined to amphibolite facies supracrustal rocks which range from sillimanite to staurolite subfacies.

Late stage granite intrusions are small, rare and texturally and geochemically diverse. The highly fractionated character of the Whiskey Jack, Metis and Ross granites is characteristic of pegmatite-generating granites. However a direct relationship between the granites and the pegmatites is only observed for the Ross granite and the biotite-peristerite pegmatites of the Southern series, and for the Metis granite and the pegmatites of the Minago series.

The pegmatite field is subdivided into four series, some of which appear to be genetically related. The series are: the Nelson, Minago, Northern and Southern. The majority of the pegmatites of the Nelson series are mobilizates derived by partial melting below the level of erosion. The Northern pegmatite series is paragenetically and geochemically dis-

tinct (typified by a Be, Nb-Ta, F, P association) and was derived from a parent magma unrelated to the other pegmatites in the field. The Metis granite, and the pegmatitic granites and pegmatites of the Minago series were derived from a magmatitc source which is also parental to the Southern pegmatite series (typified by a Li, Rb, Cs, Be, Sn, Nb-Ta association).

Individual series are confined to seperate host structures. The east-trending regional distribution of simple to complex paragenetic types of pegmatites within a series is parallel to the decrease in regional metamorphic grade. The extent of fractionation of a pegmatite increases with the reduction of its depth of formation.

The pegmatites were emplaced in a tectonically active environment; some show textures indicative of crystallization after emplacement, others crystallized during their emplacement which was connected with the dilation of host structures. Post-emplacement tectonism such as vertical dislocations of block structures severly affected the distribution of the pegmatite types, causing discontinuities in the fractionation trends exposed on the surface.

Pegmatites with Be, Nb and Ta mineralization occur in the beryl-columbite zone of the Northern series, and pegmatites with Li, Be, Nb, Ta and Sn mineralization occur in the spodumene pegmatite zone of the Southern series. Neither group is presently economically viable; however, there are signif-

icant amounts of Li in the spodumene zone of the Southern pegmatite series which may be of potential economic value.

The most reliable indicator of Ta fractionation used in this study is the K/Cs ratio in the K-feldspars and muscovites. The correlation between Ta-enrichment and the presence of F-bearing phases in the Northern series shows that F-bearing minerals are favorable indicators of Ta-mineralization potential.

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Appendix A

WHOLE-ROCK AND MINERAL ANALYSES

TABLE 24

Major and trace element analyses, C.I.P.W. norms and differentiation index (of Thorton and Tuttle 1960) for granitic rocks in the Cross Lake area.

	Ross Granite			Whiskey Jack Granite			Metis Granite	
	1-WR-A	1-WR-K	1-WR-M	21-WR-A	21-WR-B	21-WR-C	6-WR-B	6-WR-C
SiO_2	74.30	74.22	76.76	73.54	72.89	75.26	74.29	74.55
TiO_2	0.05	-	-	0.01	0.01	0.02	0.04	0.05
Al_2O_3	13.87	145.54	13.32	13.97	13.52	12.87	13.82	13.85
Fe_2O_3	0.59	0.57	0.26	0.79	0.72	0.49	0.69	0.57
FeO	0.28	0.44	-	0.28	0.64	0.32	0.28	0.40
MnO	0.04	0.34	0.01	0.04	0.02	0.01	0.04	0.03
MgO	-	-	-	0.00	0.00	0.09	-	-
CaO	0.81	0.32	0.87	0.70	0.88	0.67	0.77	0.89
Na_2O	3.85	5.66	5.42	4.47	3.85	3.31	3.56	3.80
K_2O	5.10	4.04	2.48	4.68	5.07	5.29	4.98	4.31
P_2O_5	-	0.02	-	0.00	0.00	0.00	0.04	0.06
CO_2	0.06	0.05	0.07	0.06	0.05	0.29	0.06	0.05
H_2O^+	0.23	0.23	0.39	0.64	0.50	0.62	0.55	0.54
S	-	-	-	0.99	0.99	0.99	-	-
F_2	0.16	0.11	0.01	0.37	0.60	0.27	0.03	0.04
$-O=F_2, S$	0.07	0.05	0.00	0.65	0.75	0.61	0.01	0.02
Total	99.27	100.49	99.59	99.89	98.99	99.89	99.14	99.12
TRACE ELEMENTS (ppm)								
Li	50	18	23	59	91	28	114	128
Rb	336	380	148	329	329	178	372	349
Cs	3	7	12	5	5	4	14	19
Be	1	2	1	1	2	2	2	3
Sr	26	7	12	3	0	13	48	53
Ba	67	66	45	53	53	102	353	429
Ga	37	50	40	53	31	44	42	46
U	9	12	5	2	1	8	6	1
Th	23	14	9	31	33	48	21	24
Zr	97	89	73	45	61	96	95	103
Sn	1	8	5	19	17	1	9	5
Ni	6	8	8	5	26	4	8	7
Cr				21	22	27		
Zn	23	23	23	52	73	14	56	77
Nb	18	22	18	48	81	58	19	13
Y	17	69	6	104	81	48	12	10
C.I.P.W. NORMS								
Q	30.89	24.63	34.07	28.43	29.29	34.59	33.38	34.51
Cor	0.54	0.31	0.13	0.27	0.09	0.48	1.28	1.47
Or	30.43	23.80	14.75	28.00	30.52	31.68	29.82	25.81
Ab	32.86	47.69	46.13	38.26	33.15	28.35	30.50	32.55
An	4.05	1.45	4.34	3.51	4.44	3.36	3.60	4.07
En	-	-	-	-	-	0.22	-	-
Fs	0.03	1.01	-	-	0.92	-	-	0.26
Ru	-	-	-	-	-	-	-	-
Mt	0.86	0.82	0.05	0.72	1.06	0.57	1.01	0.83
Il	0.09	-	-	0.01	0.01	0.03	0.07	0.09
Cr	0.22	0.22	0.28	0.46	0.48	0.58	0.22	0.23
Hm	-	-	0.22	0.29	-	0.10	0.00	-
Ap	-	0.04	-	-	-	-	0.09	0.14
Po	-	-	-	-	-	-	-	-
RATIOS AND D.I.								
K/Rb	126.0	88.3	139.0	118.0	128.0	247.0	111.0	103.0
K/Ba	632.0	508.0	458.0	733.0	794.0	431.0	117.0	83.4
Ba/Rb	0.19	0.11	0.30	0.16	0.16	0.57	0.94	1.23
Ba/Sr	2.58	9.43	3.75	17.7	-	7.85	7.35	8.09
Rb/Sr	12.9	54.3	12.3	110.0	65.8	13.7	26.6	18.4
Ca/Sr	223.0	327.0	518.0	1670.0	-	368.0	115.0	120.0
Ca/Y	341.0	33.1	1040.0	48.1	77.6	99.8	459.0	636.0
Mg/Li	-	-	-	0.0	0.0	19.4	-	-
Zr/Sn	97.0	11.1	14.6	2.37	3.59	96.0	10.6	20.6
U/Th	0.39	0.85	0.55	0.06	0.03	0.16	0.28	0.04
Al/Ga	1980.0	1540.0	1760.0	1400.0	2310.0	1550.0	0.17	1590.0
D.I.	94.19	96.13	94.96	94.70	92.98	94.63	93.71	92.88

Table 24 continued.

	Metis Granite						
	6-WR-D	6-WR-E	6-WR-F	6-WR-G	6-WR-I	6-WR-J	6-WR-K
SiO_2	74.11	74.33	75.31	74.42	74.25	74.77	74.57
TiO_2	0.06	0.05	0.01	0.02	0.03	0.01	0.03
Al_2O_3	13.60	13.85	14.76	13.94	13.76	14.10	14.30
Fe_2O_3	0.45	0.63	0.16	0.03	0.47	0.47	0.43
FeO	0.82	0.40	0.38	0.72	0.90	0.20	0.36
MnO	0.04	0.03	0.02	0.05	0.04	0.03	0.04
MgO	-	-	-	-	0.08	-	-
CaO	0.97	0.83	0.87	0.63	0.85	0.82	0.75
Na_2O	3.64	3.59	5.10	3.95	3.77	4.02	3.95
K_2O	4.46	4.46	3.06	4.44	4.70	4.70	4.89
P_2O_5	0.01	-	0.07	0.03	0.04	0.03	0.02
CO_2	0.07	0.06	0.03	0.06	0.09	0.07	0.06
H_2O^+	0.38	0.61	0.56	1.56	0.49	0.47	0.53
S	-	-	-	-	-	-	-
F_2	0.02	0.03	0.03	0.04	0.03	0.04	0.04
$-O=F_2,S$	0.01	0.01	0.01	0.02	0.01	0.02	0.02
Total	98.62	98.86	100.35	99.87	99.49	99.71	99.95
TRACE ELEMENTS (ppm)							
Li	106	152	90	101	122	115	141
Rb	326	332	252	345	341	357	393
Cs	17	14	13	19	17	12	14
Be	2	5	4	2	2	3	2
Sr	67	51	32	36	48	50	43
Ba	536	388	87	283	353	349	266
Ga	18	57	39	40	26	41	43
U	12	8	8	8	11	6	17
Th	24	26	39	40	26	41	43
Zr	113	106	87	91	122	90	90
Sn	7	7	11	10	14	8	9
Ni	6	4	8	8	11	10	9
Cr							
Zn	55	57	23	39	48	29	35
Nb	7	23	35	27	26	15	30
Y	16	12	10	12	17	13	15
C.I.P.W. NORMS							
Q	33.01	35.05	31.97	33.03	30.55	31.84	31.25
Cor	1.01	1.62	1.64	1.58	0.95	0.98	1.19
Or	25.76	26.80	18.10	26.66	26.14	27.95	29.04
Ab	30.07	30.86	43.16	33.93	30.00	34.19	33.55
An	4.63	4.18	3.86	2.97	3.72	3.89	3.60
En	-	-	-	-	0.18	-	-
Fs	-	0.18	0.65	1.41	-	0.09	0.39
Ru	1.21	-	-	-	-	-	-
Mt	-	0.92	0.23	0.04	-	0.68	0.62
Il	-2.20	0.09	0.01	0.03	-4.70	0.01	0.05
Cr	6.01	0.25	0.17	0.23	10.09	0.26	0.22
Hm	0.44	-	-	-	0.44	-	-
Ap	0.02	-	0.16	0.07	0.08	0.07	0.04
Po	-	-	-	-	-	-	-
RATIOS AND D.I.							
K/Rb	114.0	112.0	101.0	107.0	114.0	109.0	103.0
K/Ba	69.1	95.4	292.0	130.0	111.0	112.0	153.0
Ba/Rb	1.64	1.17	0.34	0.82	1.04	0.97	0.67
Ba/Sr	8.00	7.61	2.72	7.86	7.35	6.98	6.19
Rb/Sr	4.87	6.51	7.88	18.2	7.10	7.14	9.14
Ca/Sr	103.0	116.0	194.0	125.0	127.0	117.0	125.0
Ca/Y	433.0	494.0	622.0	375.0	357.0	451.0	357.0
Mg/Li	-	-	-	-	3.95	-	-
Zr/Sn	16.1	15.1	7.91	9.10	8.71	11.3	10.0
U/Th	0.50	0.30	0.20	0.20	0.42	0.14	0.39
Al/Ga	4000.0	1290.0	2000.0	1840.0	2800.0	1820.0	1760.0
D.I.	88.86	92.72	93.25	93.63	86.71	93.99	93.85

Table 24 continued.

	Metis Granite		Pegmatitic Granite					
	6-WR-L	6-WR-M	PGR-7	PGR-8	PGR-9	PGR-12	PGR-13	PGR-24
SiO_2	74.53	73.61	75.16	74.62	73.77	74.97	71.21	73.62
TiO_2	0.05	0.09	0.02	0.01	0.02	0.03	0.02	0.02
Al_2O_3	14.09	13.78	13.13	12.97	14.68	13.24	15.87	13.90
Fe_2O_3	0.67	0.82	0.46	0.20	0.44	0.41	0.34	0.36
FeO	0.44	0.30	0.12	0.12	0.08	0.04	0.14	0.44
MnO	0.05	0.01	0.01	0.01	0.02	0.01	0.06	0.07
MgO	-	0.46	0.04	0.05	0.05	0.08	0.07	0.12
CaO	0.92	1.14	0.59	0.58	1.06	0.23	0.81	1.19
Na_2O	3.73	2.34	2.72	2.59	3.61	1.53	4.10	2.35
K_2O	4.73	5.46	6.30	6.28	4.59	7.79	5.33	6.46
P_2O_5	0.01	0.04	0.08	0.10	0.04	0.07	0.21	0.00
CO_2	0.07	0.11	0.06	0.03	0.09	0.04	0.20	0.13
H_2O^+	0.53	0.71	0.46	0.31	0.38	0.55	0.37	0.31
S	-	-	0.99	0.99	0.01	0.99	0.01	0.01
F_2	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.00
$-O=F_2, S$	0.01	0.01	0.50	0.50	0.01	0.50	0.01	0.01
Total	99.84	98.89	99.66	98.37	98.84	99.49	98.74	98.98
TRACE ELEMENTS (ppm)								
Li	124	138	47	9	12	13	10	17
Rb	337	167	196	240	138	280	372	132
Cs	17	9	6	2	2	3	25	5
Be	1	2	1	0	1	0	2	1
Sr	61	188	47	61	82	88	96	97
Ba	537	868	155	230	255	545	178	198
Ga	44	52	38	21	27	22	29	22
U	8	11	8	1	4	1	13	1
Th	44	52	18	6	10	9	7	23
Zr	105	124	16	7	11	2	18	19
Sn	6	8	5	1	4	13	5	1
Ni	26	9	9	28	12	0	0	0
Cr			24	28	23	21	20	37
Zn	50	25	14	9	17	11	18	71
Nb	10	0	13	7	1	11	9	6
Y	11	15	42	16	27	15	10	14
C.I.P.W. NORMS								
Q	32.40	36.66	34.41	34.90	33.33	36.27	26.09	32.73
Cor	1.30	2.07	0.95	1.11	1.96	2.05	2.42	0.88
Or	28.28	32.82	37.60	37.79	27.46	46.68	32.02	38.56
Ab	33.86	20.12	23.22	22.29	30.89	13.11	35.23	20.06
An	4.55	5.48	2.42	2.26	5.05	0.69	2.68	5.95
En	-	1.16	0.10	0.12	0.12	0.20	0.17	0.30
Fs	0.67	-	-	0.34	-	-	-	0.09
Ru	-	-	-	-	-	0.13	-	-
Mt	0.97	0.75	0.17	0.29	0.14	-	0.07	0.52
Il	0.09	0.17	0.03	0.01	0.03	-0.20	0.03	0.03
Cr	0.29	0.32	0.52	0.61	0.50	0.46	0.43	0.80
Hm	-	0.31	0.34	-	0.34	0.41	0.29	-
Ap	0.02	0.09	0.18	0.23	0.09	0.16	0.49	-
Po	-	-	-	-	0.02	-	0.02	0.02
RATIOS AND D.I.								
K/Rb	117.0	271.0	267.0	217.0	276.0	231.0	119.0	406.0
K/Ba	73.1	52.2	337.0	227.0	149.0	119.0	249.0	271.0
Ba/Rb	1.59	5.20	0.79	0.95	1.85	1.95	0.47	1.50
Ba/Sr	8.80	4.62	3.30	3.77	3.11	6.19	1.85	2.04
Rb/Sr	5.52	18.6	4.17	3.93	1.68	3.18	3.88	26.4
Ca/Sr	108.0	43.3	89.7	68.0	92.4	18.7	60.3	87.7
Ca/Y	598.0	543.0	100.0	259.0	281.0	110.0	579.0	607.0
Mg/Li	-	20.1	5.13	33.5	25.1	37.1	42.2	42.6
Zr/Sn	17.5	15.5	3.20	7.00	2.75	0.15	3.60	19.0
U/Th	0.18	0.21	0.44	0.16	0.40	0.11	1.86	0.043
Al/Ga	1690.0	1400.0	1830.0	3270.0	2880.0	3190.0	2900.0	3340.0
D.I.	92.24	89.91	95.25	94.99	91.70	96.07	93.35	91.37

Table 24 continued.

	Shoal Granite			Wapmet Granite		
	5-WR-A	19-WR-B	19-WR-C	3-WR-A	3-WR-D	4-WR-D
SiO_2	73.08	74.43	74.61	74.83	73.92	70.52
TiO_2	0.15	0.04	0.06	0.07	0.01	0.06
Al_2O_3	13.75	14.18	13.77	13.02	14.54	16.16
Fe_2O_3	0.39	0.09	0.68	0.52	0.36	0.44
FeO	1.04	0.82	-	0.46	0.12	0.56
MnO	0.01	0.05	-	0.03	0.03	0.04
MgO	0.62	-	-	0.17	-	0.16
CaO	1.09	0.67	1.11	0.61	1.21	1.35
Na_2O	1.74	3.26	3.19	2.46	3.79	4.15
K_2O	5.64	5.00	4.82	5.83	5.10	5.59
P_2O_5	0.01	0.04	-	0.03	0.04	-
CO_2	0.11	0.28	0.13	0.18	0.12	0.19
H_2O^+	0.93	0.68	0.54	0.65	0.31	0.55
S	-	-	-	-	-	-
F_2	0.03	0.02	0.01	0.01	0.01	0.01
$-O=F_2, S$	0.01	0.01	0.00	0.00	0.00	0.00
Total	98.58	99.55	98.92	98.87	99.56	99.78
TRACE ELEMENTS (ppm)						
Li	41	14	17	21	25	16
Rb	150	370	168	164	130	134
Cs	8	5	4	2	3	3
Be	2	1	1	1	0	0
Sr	217	44	153	84	86	145
Ba	1050	345	505	643	233	382
Ga	15	21	17	15	31	52
U	14	22	19	6	14	9
Th	22	21	17	25	23	29
Zr	113	100	166	118	88	83
Sn	2	1	4	1	1	5
Ni	10	8	7	6	7	8
Cr						
Zn	48	45	11	21	0	13
Nb	1	23	0	9	0	7
Y	8	17	6	9	10	10
C.I.P.W. NORMS						
Q	37.22	34.71	35.74	37.19	30.05	1.67
Cor	2.75	2.30	1.30	1.64	0.68	0.82
Or	32.57	29.92	28.94	35.09	30.36	3.31
Ab	14.37	27.90	27.39	21.18	32.27	5.37
An	5.21	3.09	5.59	2.88	5.77	6.74
En	1.50	-	-	0.43	-	0.40
Fs	-	1.51	-	0.37	-	0.70
Ru	1.31	-	0.05	-	-	-
Mt	-	0.13	-	0.76	0.50	0.64
Il	-2.21	0.07	0.00	0.13	0.01	0.11
Cr	6.84	0.23	0.26	0.22	0.22	0.19
Hm	0.38	-	0.69	-	0.01	-
Ap	0.02	0.09	-	0.07	0.09	-
Po	-	-	-	-	-	-
RATIOS AND D.I.						
K/Rb	312.0	112.0	238.0	295.0	326.0	346.0
K/Ba	44.6	120.0	79.2	75.3	182.0	121.0
Ba/Rb	7.00	0.93	3.01	3.92	1.79	2.85
Ba/Sr	4.84	7.84	3.30	7.65	2.71	2.63
Rb/Sr	0.69	8.41	1.10	1.95	1.51	0.92
Ca/Sr	35.9	109.0	51.9	51.9	101.0	66.5
Ca/Y	974.0	282.0	1320.0	484.0	865.0	965.0
Mg/Li	91.2	-	-	48.8	-	60.3
Zr/Sn	56.5	100.0	41.5	118.0	88.0	16.6
U/Th	0.63	1.05	1.12	0.24	0.60	0.31
Al/Ga	4850.0	3570.0	4290.0	4590.0	2480.0	1640.0
D.I.	84.16	92.54	92.09	93.47	92.69	90.36

Table 24 continued.

	Channel Granite			Bridge Granite		
	2-WR-A	2-WR-B	2-WR-C	20-WR-A	20-WR-B	20-WR-C
SiO_2	73.89	73.37	73.85	69.32	72.07	71.50
TiO_2	-	0.04	0.05	0.20	0.17	0.16
Al_2O_3	14.05	14.11	13.68	16.02	14.35	14.28
Fe_2O_3	0.32	0.40	0.52	0.72	0.98	0.88
FeO	-	0.40	0.84	0.74	0.50	0.42
MnO	0.01	0.03	0.06	0.03	0.03	0.02
MgO	-	-	0.03	0.40	0.46	0.28
CaO	1.30	0.94	1.18	1.10	1.53	1.46
Na_2O	2.83	2.58	2.56	4.72	4.45	4.33
K_2O	5.56	6.23	5.24	5.51	3.80	3.79
P_2O_5	-	-	-	0.08	0.06	0.03
CO_2	0.08	0.14	0.25	0.10	0.14	0.41
H_2O^+	0.32	0.51	0.46	0.54	0.61	0.81
S	-	-	-	0.99	0.01	0.99
F_2	0.01	0.01	0.01	0.02	0.04	0.03
$-O=F_2, S$	0.00	0.00	0.00	0.50	0.02	0.51
Total	98.37	98.76	98.73	99.99	99.18	98.88
TRACE ELEMENTS (ppm)						
Li	15	20	30	15	16	26
Rb	126	147	119	153	138	127
Cs	2	1	2	3	3	3
Be	0	0	0	1	1	1
Sr	127	151	141	216	383	372
Ba	654	802	588	846	918	1063
Ga	15	18	22	34	24	32
U	6	10	4	1	1	2
Th	8	38	11	15	6	7
Zr	91	102	109	91	86	89
Sn	1	1	1	3	1	2
Ni	7	8	8	3	0	0
Cr				20	23	23
Zn	0	3	11	50	40	46
Nb	0	0	0	16	14	16
Y	7	11	13	5	6	0
C.I.P.W. NORMS						
Q	33.94	38.82	36.40	18.03	28.18	29.06
Cor	1.02	1.43	1.67	0.48	0.27	0.48
Or	33.48	37.47	31.55	32.86	22.76	22.99
Ab	24.37	22.20	22.04	40.27	38.12	37.57
An	6.56	4.74	5.95	4.97	7.28	7.22
En	-	-	0.07	1.00	1.16	0.71
Fs	-	0.46	1.22	0.31	-	-
Ru	-	-	-	-	-	-
Mt	0.03	0.59	0.76	1.05	0.63	0.44
Il	-	0.07	0.09	0.38	0.32	0.31
Cr	0.27	0.19	0.19	0.43	0.50	0.51
Hm	0.30	-	-	-	0.55	0.59
Ap	-	-	-	0.18	0.14	0.07
Po	-	-	-	-	0.02	-
RATIOS AND D.I.						
K/Rb	366.0	352.0	366.0	299.0	229.0	248.0
K/Ba	70.6	64.5	74.0	54.1	34.4	29.6
Ba/Rb	5.19	5.46	4.94	5.53	6.65	8.37
Ba/Sr	5.15	5.31	4.17	3.92	2.40	2.86
Rb/Sr	0.99	0.97	0.84	0.70	0.36	0.34
Ca/Sr	73.2	44.5	59.8	36.4	28.6	28.1
Ca/Y	1330.0	611.0	649.0	1570.0	1820.0	-
Mg/Li	-	-	6.03	161.0	173.0	64.9
Zr/Sn	91.0	102.0	109.0	30.3	86.0	44.5
U/Th	0.75	0.26	0.36	0.066	0.16	0.26
Al/Ga	4960.0	4150.0	3290.0	2490.0	3160.0	2360.0
D.I.	91.80	92.50	90.00	91.17	89.08	89.64

Table 24 continued.

	North Cross Granite				Migmatite
	25-WR-A	25-WR-B	25-WR-C	25-WR-D	MIN-A
SiO_2	68.74	68.94	67.51	68.15	63.07
TiO_2	0.20	0.20	0.21	0.21	0.03
Al_2O_3	15.01	15.04	14.88	14.89	20.18
Fe_2O_3	1.62	1.60	1.87	1.59	0.00
FeO	0.58	0.62	0.54	0.68	0.24
MnO	0.06	0.05	0.06	0.06	0.01
MgO	0.63	0.69	0.72	0.65	0.05
CaO	1.83	1.11	2.36	2.15	2.54
Na_2O	3.84	4.54	3.92	3.80	3.14
K_2O	4.72	4.37	4.10	4.31	8.39
P_2O_5	0.21	0.21	0.16	0.17	0.00
CO_2	1.04	0.93	1.59	1.25	0.11
H_2O^+	0.63	0.56	0.81	0.71	0.39
S	0.00	0.00	0.00	0.99	0.01
F_2	0.07	0.06	0.09	0.09	0.00
$-O=F_2, S$	0.03	0.03	0.04	0.53	0.01
Total	99.15	98.89	98.78	99.17	98.16
TRACE ELEMENTS (ppm)					
Li	22	13	16	21	13
Rb	138	127	123	124	138
Cs	5	8	0	8	3
Be	1	1	2	1	0
Sr	643	513	528	678	349
Ba	1671	1548	1473	1465	2486
Ga	32	38	20	33	38
U	5	7	5	1	1
Th	26	31	24	23	6
Zr	150	146	140	150	51
Sn	1	4	1	1	1
Ni	5	1	3	0	0
Cr	92	79	100	90	29
Zn	39	40	39	37	46
Nb	0	0	6	6	2
Y	6	7	13	14	2
C.I.P.W. NORMS					
Q	24.33	23.32	23.84	24.94	7.28
Cor	0.76	1.34	0.08	0.47	1.33
Or	28.24	26.23	24.79	26.02	50.60
Ab	32.86	38.98	33.90	32.81	27.08
An	7.79	4.19	10.89	9.75	12.84
En	1.58	-	1.83	1.65	0.12
Fs	-	1.74	-	-	0.00
Ru	0.13	-	0.27	0.07	-
Mt	-	-	-	-	-
Il	0.12	0.29	-0.11	0.26	0.05
Cr	2.01	1.71	2.19	1.96	0.63
Hm	1.63	1.62	1.91	1.62	-
Ap	0.49	0.49	0.37	0.40	-
Po	-	-	-	-	0.02
RATIOS AND D.I.					
K/Rb	284.0	286.0	277.0	289.0	505.0
K/Ba	23.4	23.4	23.1	24.4	28.0
Ba/Rb	12.1	12.2	12.0	11.8	18.0
Ba/Sr	2.60	3.02	2.79	2.16	7.12
Rb/Sr	0.21	0.24	0.23	-	0.39
Ca/Sr	20.3	15.5	31.9	22.7	52.0
Ca/Y	2180.0	1130.0	1300.0	1100.0	9080.0
Mg/Li	173.0	320.0	271.0	0.18	23.2
Zr/Sn	150.0	36.5	140.0	187.0	51.0
U/Th	0.19	0.22	0.20	0.04	0.16
Al/Ga	2480.0	2090.0	3940.0	2390.0	2810.0
D.I.	85.45	88.54	82.53	83.78	84.97

TABLE 25

Partial chemical analysis and obliquity Δ for K-feldspars from pegmatites and pegmatitic granites.

	wt. %				ppm									
Sample	ΣFe_2O_3	CaO	Na_2O	K_2O	Li	Rb	Cs	Sr	Ba	Pb	K/Rb	K/Cs	K/Ba	Rb/Cs	Δ
Nelson Series															
KF-49-A	0.03	0.19	1.90	13.08	2	330	15	-	-	-	329.04	7238.99	-	22.00	.99
KF-49-B	0.03	0.22	1.73	14.18	2	380	20	-	-	-	309.78	5885.83	-	19.00	.95
KF-49-D	0.06	0.11	1.49	14.47	3	350	18	-	-	-	343.21	6673.56	-	19.44	.96
KF-50-A	0.03	0.12	1.38	14.65	2	450	30	-	-	-	270.26	4053.95	-	15.00	.98
KF-50-B	0.05	0.10	1.37	14.21	2	280	68	114	97	15	421.31	1734.79	-	4.12	.98
KF-50-C	0.03	0.15	1.85	14.23	2	450	23	-	-	-	262.51	5136.16	-	19.57	.95
11-9-3A	0.04	0.10	1.96	13.02	6	460	27	-	-	-	234.97	4003.22	-	17.04	-
11-9-3B	0.04	0.12	2.19	13.08	5	370	12	-	-	-	293.47	9048.74	-	30.83	.94
11-9-3C	0.04	0.10	1.84	13.42	3	370	15	-	-	-	301.10	7427.16	-	24.67	.94
11-9-3D	0.04	0.10	1.89	13.58	0	370	20	-	-	-	304.69	5636.78	-	18.50	.94
KF-51-B	0.03	0.12	2.57	13.00	6	1070	183	-	-	-	100.86	589.73	-	5.85	.93
KF-51-H	0.03	0.17	2.58	12.55	2	1070	177	-	-	-	97.37	588.62	-	6.05	.92
KF-52-A	0.00	0.11	1.90	13.48	2	560	22	43	86	50	199.83	5086.61	6.51	25.45	.99
KF-52-C	0.03	0.10	2.68	12.01	1	620	50	-	-	-	160.81	1994.04	-	12.40	.94
KF-52-G	0.03	0.17	2.28	12.67	2	630	69	-	-	-	166.95	1524.37	-	9.13	-
KF-53-A	0.02	0.08	2.78	12.99	1	450	21	-	-	-	239.64	5135.13	-	21.43	.93
KF-53-E	0.02	0.08	2.15	13.46	1	450	25	-	-	-	248.31	4469.58	-	18.00	.93
KF-55-A	0.03	0.11	2.08	13.12	2	314	22	197	3058	14	346.87	4950.77	35.62	14.27	.93
KF-55-B	0.00	0.19	2.09	13.19	2	224	22	205	3145	73	488.83	4977.18	34.82	10.18	.975
KF-55-C	0.04	0.18	2.20	13.03	3	350	7	-	-	-	309.06	15432.83	-	50.00	.97
KF-55-G	0.03	0.15	2.26	13.25	1	350	16	-	-	-	314.27	6874.76	-	21.88	.97
KF-56-A	0.30	0.10	2.38	12.74	3	224	22	111	1747	32	472.15	4807.38	60.54	10.18	.95
KF-56-F	0.30	0.14	2.71	12.68	2	310	4	-	-	-	339.56	26316.06	-	77.50	.95
KF-56-G	0.02	0.17	2.30	13.36	1	300	17	-	-	-	369.70	6524.07	-	17.65	.99
KF-56-H	0.01	0.12	2.11	13.59	2	222	22	118	1812	23	508.19	5128.12	62.26	10.09	.96
KF-58-A	0.00	0.12	1.44	14.63	3	222	22	127	2675	23	547.08	5520.56	45.40	10.09	.94
KF-58-B	0.04	0.19	1.53	14.11	3	340	7	-	-	-	344.52	16733.65	-	48.57	.93
KF-58-C	0.04	0.19	1.47	14.05	4	340	9	-	-	-	343.05	12959.71	-	37.78	-
KF-58-D	0.00	0.14	1.65	14.05	8	266	22	93	431	27	438.49	5301.70	270.62	12.09	.95
KF-58-E	0.01	0.15	1.96	14.00	10	266	17	110	1122	63	436.93	6836.61	103.58	15.65	.98
KF-59-A	0.03	0.13	1.90	14.01	4	370	22	-	-	-	314.34	5286.61	-	16.82	.91
KF-59-B	0.02	0.09	1.74	14.33	4	266	20	93	1726	52	447.22	5948.09	68.92	13.30	.98
KF-59-C	0.03	0.12	2.19	13.22	5	370	9	-	-	-	296.61	12194.12	-	41.11	.94

Table 25 continued.

	wt. %				ppm									
Sample	ΣFe_2O_3	CaO	Na_2O	K_2O	Li	Rb	Cs	Sr	Ba	Pb	K/Rb	K/Cs	K/Ba	Rb/Cs	△
KF-62-A	0.02	0.02	2.10	13.57	3	380	18	-	-	-	296.45	6258.48	-	21.11	.93
KF-62-B	0.01	0.16	2.08	13.58	1	270	20	65	86	56	471.54	5636.78	1310.88	13.50	.97
KF-62-F	0.03	0.17	1.79	13.46	13	225	20	148	866	60	496.62	5586.97	129.03	11.25	-
KF-62-G	0.03	0.14	1.46	11.36	2	330	16	-	-	-	285.78	5894.13	-	20.63	.92
KF-63-A	0.03	0.17	2.16	13.59	3	470	25	-	-	-	240.04	4512.75	-	18.80	.93
KF-63-B	0.03	0.17	2.26	13.70	9	416	20	41	85	38	273.39	5686.59	1338.02	20.80	.50
KF-63-C	0.00	0.16	1.97	13.74	9	324	20	83	598	68	352.05	5703.20	190.74	16.20	.955
KF-63-D	0.01	0.17	1.51	14.64	11	370	20	41	85	45	328.47	6076.77	1429.83	18.50	.930
KF-64-A	0.03	0.14	2.46	13.22	2	360	17	-	-	-	304.85	6455.71	-	21.18	.94
KF-64-B	0.01	0.15	2.28	13.28	5	277	20	58	170	71	398.00	5512.26	648.50	13.85	-
KF-64-C	0.01	0.19	2.15	13.57	13	324	37	58	256	69	347.69	3044.67	440.05	8.76	.95
KF-64-D	0.02	0.19	2.11	13.49	2	410	7	-	-	-	273.14	15998.36	-	58.57	.94
KF-65-B	0.03	0.16	1.77	14.10	3	410	22	-	-	-	285.49	5320.57	-	18.64	.94
KF-66-A	0.03	0.16	2.44	12.88	2	340	5	-	-	-	314.48	21384.91	-	68.00	.95
KF-66-B	0.02	0.15	2.36	13.36	2	370	18	-	-	-	299.75	6161.62	-	20.56	.92
KF-67-A	0.02	0.16	2.25	13.21	3	400	5	-	-	-	274.16	21932.82	-	80.00	.97
KF-67-B	0.02	0.15	2.11	13.32	1	360	13	-	-	-	307.16	8505.94	-	27.69	.96
KF-67-C	0.00	0.20	2.45	13.31	12	296	20	66	585	84	373.29	5524.71	188.88	14.80	.955
KF-83-1-A	0.00	0.15	1.25	15.39	19	431	17	323	2626	68	296.43	7515.38	48.65	25.35	-
KF-83-3-A	0.02	0.14	0.94	15.01	15	370	17	323	3333	118	336.78	7329.82	37.39	21.76	-
KF-83-3-B	0.04	0.16	0.85	15.02	16	381	17	322	5168	125	327.27	7334.70	24.13	22.41	-
KF-83-5-A	0.04	0.15	1.22	14.42	15	254	17	187	3081	72	471.30	7041.71	38.85	14.94	-
KF-83-6-B	0.03	0.11	0.95	14.40	19	254	17	197	3975	80	470.64	7031.94	30.07	14.94	-
KF-83-6-C	0.04	0.09	0.95	14.16	20	254	17	197	3876	73	462.80	6914.74	30.33	14.94	-
KF-88-AA	0.02	0.11	1.74	14.14	2	508	46	84	81	26	231.07	2551.84	1449.19	11.04	-
KF-88-BB	0.02	0.06	1.75	13.67	2	317	24	141	324	35	357.99	4728.45	350.26	13.21	-
KF-89-A	0.04	0.11	2.24	11.63	2	434	24	103	494	65	222.46	4022.81	195.44	18.08	-
KF-89-B	0.01	0.13	2.25	13.15	2	434	24	74	329	69	251.53	4548.58	331.81	18.08	-
Minago Series															
KF-29-F	0.04	0.18	2.41	12.69	1	299	36	47	207	80	352.33	2926.31	508.92	8.31	.95
KF-29-K	0.02	0.11	2.46	12.97	2	500	12	-	-	-	215.34	8972.64	-	41.67	.96
KF-29-L	0.00	0.70	2.52	12.67	1	239	19	24	207	77	440.09	5535.85	508.12	12.58	.98
KF-29-N	0.02	0.10	2.36	12.51	1	350	6	-	-	-	296.72	17308.83	-	58.33	.93
KF-35-A	0.00	0.58	2.42	13.29	1	616	19	23	212	61	179.10	5806.75	520.42	32.42	.94
KF-35-B	0.02	0.15	2.44	12.01	1	560	15	-	-	-	178.04	6646.81	-	37.33	.93
KF-35-G	0.02	0.13	2.31	12.75	3	490	16	-	-	-	216.01	6615.34	-	30.63	.97
KF-60-A	0.02	0.07	2.17	12.36	3	590	22	-	-	-	173.91	4663.99	-	26.82	.95

Table 25 continued.

Sample	wt. %				ppm						K/Rb	K/Cs	K/Ba	Rb/Cs	△
	ΣFe_2O_3	CaO	Na_2O	K_2O	Li	Rb	Cs	Sr	Ba	Pb					
KF-60-B	0.01	0.03	2.09	12.85	1	495	40	74	1039	52	215.51	2666.89	102.67	12.38	.95
KF-60-D	0.03	0.05	2.09	13.44	1	495	40	90	1212	68	225.40	2789.34	92.06	12.38	.955
KF-61-A	0.04	0.10	2.51	12.77	1	450	3	-	-	-	235.58	35337.14	-	150.00	.95
KF-61-B	0.03	0.10	2.44	13.10	1	480	21	-	-	-	226.56	5178.61	-	22.86	.99
KF-61-C	0.01	0.09	2.07	13.90	1	405	20	41	519	72	284.92	5769.61	222.34	20.25	.96
KF-73-A	0.02	0.08	1.97	13.80	29	1065	40	-	-	-	107.57	2864.05	-	26.63	.94
KF-73-E	0.04	0.06	2.56	12.78	3	1406	135	8	91	65	75.46	785.88	1165.87	10.41	.90
KF-74-A	0.00	0.07	2.34	13.01	3	1261	77	16	87	56	85.65	1042.65	1241.42	16.38	.95
KF-74-B	0.03	0.12	2.63	12.50	5	1250	100	-	-	-	83.02	1037.70	-	12.50	.93
KF-74-C	0.11	0.07	1.86	13.53	3	1309	115	16	87	65	85.81	976.70	1291.04	11.38	.93
KF-74-D	0.02	0.07	2.68	12.75	6	2670	115	-	-	-	39.64	920.39	-	23.22	.91
KF-75-A	0.01	0.05	2.52	13.02	25	1650	40	-	-	-	65.51	2702.17	-	41.25	.91
KF-75-A	0.00	0.02	2.38	13.68	32	1404	19	8	175	51	80.89	5977.15	648.95	73.89	.94
KF-77-A	0.02	0.08	1.99	14.36	4	1070	58	-	-	-	111.41	2055.36	-	18.45	.97
KF-77-B	0.00	0.06	1.94	13.80	1	832	154	9	263	56	137.69	743.91	435.60	5.40	.93
KF-77-C	0.00	1.82	9.81	1.66	3	52	18	9	83	13	265.01	765.59	166.03	2.89	-
KF-77-D	0.00	0.06	1.53	14.30	1	884	90	9	83	38	134.29	1319.03	1430.28	9.82	.95
KF-77-I	0.00	0.04	2.66	11.55	1	1092	90	8	83	21	87.81	1065.37	1155.22	12.13	.95
KF-77-J	0.02	0.08	2.64	12.79	4	1100	56	-	-	-	96.52	1896.03	-	19.64	.93
KF-78-C	0.00	0.07	2.88	13.12	1	743	73	45	265	63	146.59	1512.74	-	10.32	.93
KF-78-D	0.00	0.05	1.49	14.85	1	675	72	172	1150	117	182.64	1712.20	107.20	9.38	.92
KF-78-F	0.04	0.09	1.87	13.71	5	640	74	-	-	-	177.84	1538.04	-	8.65	.95
KF-78-E	0.02	0.08	2.12	13.18	6	510	17	-	-	-	214.54	6436.18	-	30.00	.96
KF-90-A	0.00	0.12	2.06	13.51	21	597	50	192	1098	97	187.86	2243.09	102.14	11.91	-
KF-90-BB	0.01	0.09	2.03	13.37	2	706	50	103	329	65	157.21	2219.85	337.36	14.12	-
KF-90-E	0.04	0.09	2.18	13.37	16	597	25	88	494	74	185.92	4439.69	224.68	23.88	-
KF-94-BB	0.08	0.16	2.03	13.80	18	311	24	55	154	18	368.37	4773.42	743.91	12.96	-
KF-94-CC	0.02	0.10	1.52	14.04	59	8092	905	69	102	22	14.40	128.79	1142.69	8.94	-
P-KF-3-B	0.02	0.15	2.57	12.76	6	400	16	-	-	-	264.82	6620.52	-	25.00	.98
P-KF-3-C	0.03	0.13	2.36	12.94	3	390	20	-	-	-	275.44	5371.13	-	19.50	.92
P-KF-4-B	0.02	0.11	2.31	13.11	2	300	20	-	-	-	362.78	5441.70	-	15.00	.95
P-KF-7-A	0.00	0.03	2.68	13.18	1	526	18	50	324	63	208.01	6078.61	337.70	29.22	1.00
P-KF-7-B	0.02	0.08	2.73	12.55	11	550	18	-	-	-	189.43	5788.06	-	30.56	.96
P-KF-7-D	0.03	0.06	2.68	12.24	6	490	18	-	-	-	207.37	5645.09	-	27.22	.96
P-KF-7-L	0.02	0.09	2.03	13.23	6	610	43	-	-	-	180.05	2554.19	-	14.19	.96
P-KF-7-M	0.00	0.04	2.77	12.87	1	723	55	50	81	59	147.78	1942.57	1319.03	13.15	.95
P-KF-7-S	0.00	0.04	2.76	12.92	1	526	37	75	324	89	203.91	2898.83	331.04	14.22	.96
P-KF-7-R	0.02	0.06	2.42	12.73	51	840	53	-	-	-	125.81	1993.95	-	15.85	.92

Table 25 continued.

	wt. %				ppm									
Sample	ΣFe_2O_3	CaO	Na_2O	K_2O	Li	Rb	Cs	Sr	Ba	Pb	K/Rb	K/Cs	K/Ba	Rb/Cs	△
P-KF-7-T	0.02	0.06	2.09	13.25	5	650	19	-	-	-	169.22	5789.27	-	34.21	.93
P-KF-8-A	0.02	0.11	2.69	12.16	3	460	9	-	-	-	219.45	11216.38	-	51.11	.925
P-KF-8-B	0.02	0.10	2.59	12.55	3	460	7	-	-	-	226.49	14883.58	-	65.71	.96
P-KF-8-C	0.00	0.06	2.10	13.77	1	460	37	100	486	93	248.51	3089.54	235.21	12.43	.963
P-10-9-1A	0.04	0.10	2.74	12.53	2	550	17	-	-	-	189.13	6118.76	-	32.35	-
P-KF-9-A	0.02	0.08	2.42	12.95	5	450	7	-	-	-	238.90	15357.95	-	64.29	.93
P-KF-9-B	0.03	0.07	2.53	12.48	5	440	2	-	-	-	235.46	51801.97	-	220.00	.93
P-KF-9-C	0.00	0.06	2.40	13.53	1	538	37	15	79	51	208.77	3035.69	1421.78	14.54	.925
P-KF-9-E	0.00	0.07	2.23	13.77	1	471	73	61	475	76	242.70	1565.93	240.66	6.54	.95
P-KF-10-A	0.03	0.07	2.22	10.03	2	260	11	-	-	-	320.25	7565.54	-	23.64	.97
P-KF-10-B	0.03	0.08	2.58	11.26	2	260	9	-	-	-	359.52	10386.22	-	28.89	.96
P-KF-10-C	0.01	0.09	2.67	11.89	1	403	54	30	237	35	244.93	1827.89	416.48	7.46	.97
P-KF-11-A	0.03	0.07	2.41	12.94	2	350	9	-	-	-	306.92	11935.85	-	38.89	.95
P-KF-11-B	0.04	0.06	2.61	12.80	2	370	5	-	-	-	287.19	21252.09	-	74.00	.96
P-KF-11-C	0.01	0.01	2.42	13.66	1	403	18	106	475	98	281.39	6299.99	238.74	22.39	.97
P-KF-11-F	0.04	0.04	1.56	13.37	1	605	54	15	158	75	183.46	2055.41	702.48	11.20	.96
P-KF-11-G	0.00	0.07	2.66	13.24	9	570	90	51	198	71	192.83	1221.26	555.12	6.33	.95
P-KF-11-H	0.00	0.07	2.29	13.91	1	570	54	51	496	63	202.59	2138.43	232.81	10.56	.96
P-KF-11-I	0.00	0.06	2.26	13.94	3	633	17	51	496	49	183.82	6807.31	233.32	37.24	.97
P-KF-11-K	0.00	0.07	2.48	13.86	1	507	17	68	596	60	226.94	6768.24	193.05	29.82	.925
P-KF-11-L	0.01	0.07	2.34	13.94	11	443	17	51	496	46	261.23	6807.31	233.32	26.06	.97
P-KF-12-A	0.03	0.07	2.46	12.99	3	490	5	-	-	-	220.08	21567.55	-	98.00	.92
P-KF-12-B	0.02	0.09	2.25	13.07	3	470	3	-	-	-	230.86	36167.29	-	156.67	.98
P-KF-12-C	0.02	0.05	1.90	14.09	3	616	17	71	808	60	189.89	6880.56	144.76	36.24	.95
P-KF-13-A	0.02	0.10	2.82	12.66	4	990	50	-	-	-	106.16	2101.96	-	19.80	.954
P-KF-13-B	0.03	0.07	2.63	12.57	7	960	81	-	-	-	108.70	1288.28	-	11.85	.99
P-KF-13-C	0.04	0.08	2.58	12.42	6	1210	110	-	-	-	85.21	937.33	-	11.00	.95
P-KF-13-D	0.01	0.15	1.91	14.55	11	1172	117	83	505	46	103.06	1032.38	239.18	10.02	.90
P-KF-14-A	0.04	0.04	2.59	12.28	2	570	6	-	-	-	178.85	16990.60	-	95.00	.925
P-KF-14-B	0.02	0.07	2.47	13.79	7	555	17	59	1111	43	206.27	6734.06	103.04	32.65	.94
P-KF-14-C	0.04	0.07	2.40	12.64	2	340	5	-	-	-	308.62	20986.44	-	68.00	.97
P-KF-14-D	0.03	0.05	2.29	12.81	2	430	8	-	-	-	247.31	13292.93	-	53.75	.96
P-KF-15-A	0.02	0.12	1.89	13.36	27	4390	483	-	-	-	25.26	229.63	-	9.09	.97
P-KF-16-A	0.02	0.09	2.26	12.89	3	1080	22	-	-	-	99.08	4863.98	-	49.09	.93
P-KF-16-B	0.02	0.09	1.86	11.68	2	310	17	-	-	-	312.78	5703.69	-	18.24	.97
P-KF-16-C	0.03	0.12	2.27	13.03	3	790	38	-	-	-	136.92	2846.57	-	20.79	.94
P-KF-17-B	0.04	0.14	2.75	12.11	4	860	3	-	-	-	116.90	33510.77	-	286.67	.96
P-KF-18-A	0.03	0.19	2.04	12.92	4	280	8	-	-	-	383.06	13407.08	-	35.00	.915

Table 25 continued.

	wt. %				ppm										
Sample	ΣFe_2O_3	CaO	Na_2O	K_2O	Li	Rb	Cs	Sr	Ba	Pb	K/Rb	K/Cs	K/Ba	Rb/Cs	Δ
P-KF-23-AA	0.00	0.15	2.19	13.61	19	906	33	57	81	37	124.71	3423.78	1394.87	27.45	-
P-KF-23-BB	0.00	1.59	5.28	4.76	26	181	17	71	81	22	218.32	2324.45	487.85	10.65	-
P-KF-24-AA	0.02	0.18	1.18	14.45	39	302	51	71	81	70	397.21	2352.12	1480.96	5.92	-
P-KF-25-AA	0.07	0.16	2.27	13.34	10	241	17	43	81	74	459.52	6514.31	1367.20	14.18	-
P-KF-25-BB	0.03	0.21	2.33	13.45	12	322	17	45	76	82	346.76	6568.03	1469.16	18.94	-
Northern Series (Barren Muscovite-Pegmatite Zone)															
KF-31-C	0.04	0.08	1.85	12.95	3	190	35	-	-	-	585.82	3071.59	-	5.43	.95
KF-31-D	0.03	0.11	1.52	13.66	2	160	4	-	-	-	708.75	28349.95	-	40.00	.97
KF-31-F	0.00	0.46	1.50	14.62	3	121	19	293	2643	147	1003.05	6387.86	45.92	6.37	.93
KF-31-I	0.00	0.58	2.56	13.26	3	182	54	67	1264	99	604.83	2038.50	87.09	3.37	-
KF-32-A	0.04	0.07	2.67	11.60	1	220	40	-	-	-	437.72	2407.46	-	5.50	.93
KF-32-C	0.03	0.14	2.36	12.65	2	220	11	-	-	-	477.34	9546.83	-	20.00	.95
KF-43-H	0.02	0.12	2.94	12.27	2	710	150	-	-	-	143.47	679.07	-	4.73	.96
KF-43-K	0.02	0.12	3.17	11.93	3	710	155	-	-	-	139.49	638.96	-	4.58	-
KF-44-B	0.00	0.23	3.50	12.34	2	617	135	24	232	23	166.03	758.83	441.56	4.57	.94
KF-44-D	0.02	0.02	3.31	11.89	4	600	120	-	-	-	164.51	822.55	-	5.00	.95
KF-44-H	0.02	0.08	2.98	12.46	2	670	78	-	-	-	154.38	1326.13	-	8.59	.93
KF-45-A	0.03	0.14	2.92	12.56	1	590	51	-	-	-	176.73	2044.47	-	11.57	.90
KF-45-D	0.00	0.35	3.45	12.09	2	308	22	53	756	70	325.86	4562.10	132.76	14.00	.935
KF-45-G	0.03	0.08	3.47	11.51	1	340	37	-	-	-	281.03	2582.47	-	9.19	.95
KF-46-D	0.04	0.08	2.61	12.46	2	310	24	-	-	-	333.67	4309.91	-	12.92	.95
KF-46-E	0.03	0.23	2.09	13.97	2	247	22	44	291	35	469.53	5271.51	398.53	11.23	.95
KF-47-F	0.03	0.09	3.17	12.11	3	390	13	-	-	-	257.78	7733.25	-	30.00	.91
KF-47-A	0.05	0.31	2.55	12.96	2	520	129	-	-	-	206.90	834.02	-	4.03	.93
KF-47-D	0.03	0.21	2.85	12.42	2	514	68	17	86	20	200.59	1516.26	1198.60	7.56	.935
KF-47-G	0.04	0.15	2.34	13.53	2	550	178	-	-	-	204.22	631.01	-	3.09	.94
KF-48-A	0.03	0.16	2.13	13.50	2	514	22	8	86	10	218.04	5094.16	1303.16	23.36	.92
KF-48-B	0.05	0.23	3.60	11.23	1	490	52	-	-	-	190.26	1792.83	-	9.42	.95
KF-54-A	0.00	0.15	2.87	12.30	4	467	22	8	86	18	218.65	4641.34	1187.32	21.23	-
KF-54-B	0.04	0.09	3.01	12.09	4	539	43	25	86	18	186.21	2334.10	1167.05	12.53	.95
KF-54-D	0.01	0.10	2.95	12.05	4	539	65	17	86	18	185.59	1538.99	1163.19	8.29	.965
KF-54-F	0.03	0.11	3.25	11.68	2	510	21	-	-	-	190.12	4617.27	-	24.29	.94
KF-54-C	0.03	0.17	2.97	12.61	5	510	23	-	-	-	205.26	4551.44	-	22.17	.99
KF-79-A	0.00	0.02	2.61	13.27	4	69	18	160	1769	71	1596.55	6120.12	62.27	3.83	.94
KF-79-E	0.04	0.02	2.27	13.79	1	202	36	114	530	79	566.73	3179.97	216.00	5.61	.945

Table 25 continued.

Sample	wt. % ΣFe_2O_3	CaO	Na_2O	K_2O	ppm Li	Rb	Cs	Sr	Ba	Pb	K/Rb	K/Cs	K/Ba	Rb/Cs	Δ
Northern Series (Beryl-Columbite Pegmatite Zone)															
KF-22-B	0.01	0.07	2.39	12.56	19	4130	2496	-	-	-	25.25	41.77	-	1.65	.41
KF-22-J	0.02	0.07	1.63	13.57	65	5390	2881	-	-	-	20.90	39.10	-	1.87	.60
KF-22-K	0.00	0.70	2.87	12.72	18	3731	1452	47	80	37	28.30	72.72	1319.95	2.57	.60
11-9-4C	0.16	0.08	3.05	11.79	18	3800	2168	-	-	-	25.76	45.15	-	1.75	.231
KF-30-A	0.00	0.11	3.15	12.38	1	1885	417	22	57	80	54.52	246.46	1803.05	4.52	.966
KF-30-B	0.02	0.02	2.62	12.55	2	3330	1299	-	-	-	31.29	80.20	-	2.56	.95
KF-30-C	0.01	0.06	2.99	12.21	1	2440	275	-	-	-	41.54	368.59	-	8.87	-
KF-30-D	0.00	0.34	2.83	13.03	1	1885	399	24	57	77	57.38	271.10	1897.72	4.72	.935
KF-30-I	0.00	0.58	2.95	12.84	1	1581	272	22	53	89	67.42	391.88	2011.18	5.81	.97
11-9-6A	0.06	0.08	2.80	12.21	2	1600	337	-	-	-	63.35	300.78	-	4.75	.95
11-9-6B	0.06	0.08	3.36	11.98	3	2400	357	-	-	-	41.44	278.58	-	6.72	.97
11-9-6C	0.06	0.05	3.42	11.94	3	3800	1245	-	-	-	26.08	79.62	-	3.05	.96
KF-36-A	0.05	0.12	2.75	12.42	3	740	136	-	-	-	139.33	758.13	-	5.44	.99
KF-37-F	0.06	0.05	4.24	9.80	10	1250	680	-	-	-	65.08	119.64	-	1.84	.89
KF-37-M	0.05	0.12	2.65	12.32	12	1980	828	-	-	-	51.65	123.52	-	2.39	.92
KF-37-QQ	0.04	0.11	2.83	11.76	16	1730	932	-	-	-	56.43	104.75	-	1.86	.92
KF-38-D	0.02	0.10	2.90	12.22	1	1670	59	-	-	-	60.75	1719.42	-	28.31	.41
KF-38-G	0.01	0.46	2.21	13.74	1	1170	72	23	159	42	97.49	1584.22	717.38	16.25	.86
KF-38-J	0.02	0.10	1.57	13.64	1	1230	88	-	-	-	92.06	1286.75	-	13.98	.89
KF-38-K	0.00	0.09	1.32	14.93	1	1081	54	103	265	58	114.66	2295.24	467.71	20.02	.90
12-9-3B	0.11	0.07	2.22	12.41	3	640	21	-	-	-	160.97	4905.85	-	30.48	.92
KF-39-B	0.03	0.09	2.23	13.38	3	950	30	-	-	-	116.92	3702.51	-	31.67	.91
KF-39-C	0.03	0.05	3.02	11.33	1	660	66	-	-	-	142.51	1452.11	-	10.00	.90
KF-41-A	0.00	0.46	1.46	15.11	6	739	225	74	691	47	169.74	557.50	181.53	3.28	.96
KF-41-B	0.03	0.08	2.43	12.30	5	620	127	-	-	-	164.69	804.01	-	4.88	.92
KF-41-C	0.04	0.14	2.22	13.24	5	700	123	-	-	-	157.02	893.60	-	5.69	.91
KF-42-C	0.03	0.10	1.95	13.67	1	1380	377	-	-	-	82.23	301.02	-	3.66	.89
KF-42-D	0.00	0.46	2.71	13.57	2	1109	247	8	53	23	101.58	456.08	2125.52	4.49	.935
KF-42-F	0.03	0.09	3.27	11.58	2	1170	348	-	-	-	82.16	276.24	-	3.36	.91
KF-42-L	0.00	0.23	3.07	12.82	2	1050	225	8	58	14	101.36	473.01	1834.94	4.67	.96
KF-42-N	0.01	0.11	2.68	13.20	2	1112	157	16	116	19	98.54	697.97	944.66	7.08	-
Southern Series (Biotite-Peristerite Pegmatite Zone)															
KF-17-G	0.00	0.23	2.11	13.30	26	4998	99	70	283	14	22.09	1115.27	390.15	50.48	.96
KF-17-I	0.02	0.04	2.55	12.37	41	5460	308	-	-	-	18.81	333.41	-	17.73	.93
KF-17-J	0.02	0.07	2.47	12.39	42	4660	222	-	-	-	22.07	463.32	-	20.99	.95
KF-18-E	0.03	0.09	1.47	14.18	20	1230	86	-	-	-	95.70	1368.80	-	14.30	.96

Table 25 continued.

	wt. %				ppm									
Sample	ΣFe_2O_3	CaO	Na_2O	K_2O	Li	Rb	Cs	Sr	Ba	Pb	K/Rb	K/Cs	K/Ba	Rb/Cs	Δ
KF-18-F	0.00	0.35	2.23	13.46	37	2737	40	42	283	25	40.83	2793.49	394.84	68.42	.99
KF-18-Z	0.03	0.07	2.37	12.50	41	2140	42	-	-	-	48.49	2470.71	-	50.95	.96
KF-19-B	0.04	0.07	2.15	13.22	47	1850	64	-	-	-	59.32	1714.80	-	28.91	.97
KF-19-C	0.03	0.07	2.07	13.04	33	2680	77	-	-	-	40.39	1405.88	-	34.81	.96
KF-19-J	0.00	0.58	2.49	13.18	19	297	35	45	180	98	368.40	3126.14	607.86	8.49	.96
KF-21-C	0.00	0.35	2.36	13.36	64	5810	478	45	80	55	19.09	232.03	1386.37	12.15	.93
KF-21-H	0.00	0.23	2.17	13.58	60	2813	124	22	180	43	40.08	909.16	626.31	22.69	.97
KF-21-J	0.03	0.03	2.74	12.36	53	2370	100	-	-	-	43.29	1026.08	-	23.70	.98
KF-25-B	0.02	0.10	1.70	13.93	21	1670	54	-	-	-	69.25	2141.50	-	30.93	.97
KF-25-F	0.00	1.06	2.04	13.92	12	1896	37	47	240	22	60.95	3123.20	481.49	51.24	.97
KF-25-G	0.03	0.09	2.76	12.32	17	2500	79	-	-	-	40.91	1294.63	-	31.65	.95
KF-26-A	0.00	0.46	2.75	12.90	11	1137	19	23	80	59	94.19	5636.35	1338.63	59.84	.964
KF-26-B	0.03	0.10	3.09	11.92	10	880	7	-	-	-	112.45	14136.44	-	125.71	.96
KF-26-E	0.00	0.81	2.54	13.04	8	1077	19	22	80	59	100.51	5697.52	1353.16	56.68	1.00
KF-26-G	0.03	0.10	2.64	12.64	19	1110	20	-	-	-	94.53	5246.61	-	55.50	.98
KF-27-A	0.03	0.09	3.26	11.78	14	1380	27	-	-	-	70.86	3621.96	-	51.11	.94
KF-27-E	0.01	0.35	2.22	13.76	4	1556	56	23	80	31	73.41	2039.82	1427.87	27.79	.99
KF-27-G	0.03	0.11	2.42	13.12	14	1210	31	-	-	-	90.01	3513.45	-	39.03	.91
KF-33-A	0.06	0.05	1.42	13.26	8	1390	89	-	-	-	79.31	1238.71	-	15.62	.97
KF-86-A	0.01	0.19	1.56	14.52	14	322	34	137	2204	47	374.35	3545.27	54.69	9.47	-
KF-86-BB	0.00	0.10	1.29	15.00	2	447	24	162	2239	48	278.58	5188.50	55.62	18.63	-
KF-86-CC	0.00	0.15	1.32	14.51	2	383	24	129	1612	35	314.51	5019.01	74.72	15.96	-
Southern Series (Spodumene Pegmatite Zone)															
KF-1-A	0.02	0.06	1.93	13.05	75	17680	1356	-	-	-	6.13	79.89	-	13.04	.89
KF-1-B	0.02	0.04	1.58	12.61	118	19590	629	-	-	-	5.34	166.43	-	31.14	.89
KF-1-C	0.04	0.12	1.43	13.98	49	18670	495	86	67	30	6.22	234.46	1732.18	37.72	.93
13-8-4B	0.04	0.04	1.59	13.13	72	15900	510	-	-	-	6.86	213.73	-	31.18	.95
13-8-4C	0.04	0.04	1.57	13.08	64	15000	1154	-	-	-	7.24	94.09	-	13.00	.63
13-8-4D	0.04	0.04	1.42	13.30	61	15300	659	-	-	-	7.22	167.54	-	23.22	.954
KF-2-A	0.02	0.06	2.14	13.00	92	11550	1104	-	-	-	9.34	97.75	-	10.46	.89
KF-2-F	0.02	0.03	1.70	12.42	70	18380	1024	-	-	-	5.61	100.69	-	17.95	.93
13-8-2C	0.06	0.09	1.35	12.62	95	22400	2381	-	-	-	4.68	44.00	-	9.41	.89
13-8-2F	0.04	0.05	1.98	12.68	50	15500	927	-	-	-	6.79	113.55	-	16.72	.94
KF-3-B	0.03	0.06	1.03	13.06	147	24490	2345	-	-	-	4.43	46.23	-	10.44	.89
KF-3-G	0.03	0.05	1.25	12.42	114	25710	4472	-	-	-	4.01	23.06	-	5.75	.90
KF-4-A	0.02	0.06	0.74	13.60	59	22260	1027	-	-	-	5.07	109.93	-	21.67	.93
KF-4-B	0.00	0.24	1.27	14.38	98	17920	350	74	67	30	6.66	341.08	1781.75	51.20	.94

Table 25 continued.

	wt. %				ppm										
Sample	ΣFe_2O_3	CaO	Na_2O	K_2O	Li	Rb	Cs	Sr	Ba	Pb	K/Rb	K/Cs	K/Ba	Rb/Cs	△
KF-4-F	0.56	0.24	1.09	14.33	82	20230	660	86	67	43	5.88	180.25	1775.55	30.65	.92
KF-4-G	0.03	0.05	1.15	13.47	93	20560	958	-	-	-	5.44	116.72	-	21.46	.93
KF-6-C	0.02	0.04	1.83	12.49	80	20590	1668	-	-	-	5.04	62.16	-	12.34	.93
KF-6-G	0.00	0.36	1.06	14.13	103	24640	1200	111	67	22	4.76	97.75	1750.77	20.53	.94
KF-8-3E	0.04	0.06	1.66	12.65	92	19700	1251	-	-	-	5.33	83.94	-	15.75	.93
13-8-3F	0.04	0.03	1.38	13.35	66	20800	1684	-	-	-	5.33	65.81	-	12.35	.92
13-8-3G	0.04	0.04	1.55	13.09	81	18000	1736	-	-	-	6.04	62.60	-	10.37	.92
KF-7-A	0.01	0.02	1.68	13.22	63	14180	707	-	-	-	7.74	155.23	-	20.06	.93
KF-7-B	0.01	0.02	1.45	13.33	81	17680	2254	-	-	-	6.26	49.10	-	7.84	.94
KF-7-C	0.00	0.48	1.53	13.56	100	21683	708	86	67	7	5.19	159.00	1680.14	30.63	.917
KF-8-A	0.02	0.06	1.45	13.33	75	10130	1769	-	-	-	10.92	62.56	-	5.73	.93
KF-8-B	0.03	0.04	1.40	13.38	100	19000	1468	-	-	-	5.85	75.66	-	12.94	.94
KF-8-E	0.00	0.00	1.89	13.10	27	9976	236	62	67	11	10.90	460.81	1623.15	42.27	.94
KF-9-C	0.03	0.11	2.70	11.61	178	13660	884	-	-	-	7.06	109.03	-	15.45	.93
KF-9-E	0.00	0.47	2.22	13.20	20	2465	79	50	176	18	44.45	1387.10	622.62	31.20	.98
KF-9-G	0.00	0.23	1.28	13.31	21	15980	728	100	67	18	6.91	151.78	1649.17	21.95	.94
KF-9-I	0.02	0.06	2.65	12.26	100	14850	758	-	-	-	6.85	134.27	-	19.59	.91
KF-11-A	0.02	0.05	2.09	12.37	37	13530	959	-	-	-	7.59	107.08	-	14.11	.94
KF-11-F	0.00	0.23	0.87	14.27	98	14180	772	75	67	18	8.35	153.45	1768.12	18.37	.95
KF-11-H	0.04	0.05	0.96	13.78	103	14380	865	-	-	-	7.96	132.25	-	16.62	.93
KF-15-A	0.01	0.06	1.45	13.25	105	14120	1801	-	-	-	7.79	61.08	-	7.84	.92
KF-15-G	0.00	0.23	1.34	13.64	37	12500	753	75	67	11	9.06	150.38	1690.06	16.60	.96
KF-16-A	0.03	0.09	1.83	12.72	65	13640	1864	-	-	-	7.74	56.65	-	7.32	.91
KF-16-F	0.00	0.35	1.76	13.30	91	13270	594	70	70	7	8.32	185.88	1577.30	22.34	.945
KF-16-G	0.02	0.07	1.89	12.66	80	12680	938	-	-	-	8.29	112.05	-	13.52	.93
KF-20-C	0.00	1.17	1.26	13.49	284	20360	3020	91	80	28	5.50	37.08	1399.86	6.74	.685
KF-20-E	0.02	0.09	2.39	12.24	65	16360	1760	-	-	-	6.21	57.73	-	9.30	.93
KF-20-G	0.00	1.17	1.51	13.39	134	20110	2402	91	80	40	5.53	46.28	1389.48	8.37	.91
KF-20-K	0.04	0.06	1.90	12.67	69	15100	1670	-	-	-	6.97	62.98	-	9.04	.93
KF-69-A	0.02	0.01	1.05	14.04	48	12730	1692	-	-	-	9.16	68.89	-	7.52	.94
KF-69-B	0.02	0.01	1.57	13.74	44	12840	1044	-	-	-	8.88	109.26	-	12.30	.96
KF-69-D	0.04	0.01	2.13	12.06	1253	14930	1088	46	83	4	6.71	99.32	1206.23	14.81	.94
KF-70-B	0.01	0.05	1.12	14.82	58	11120	952	33	83	30	11.06	129.23	1482.29	11.68	.96
KF-70-H	0.00	0.05	1.72	13.62	67	11310	579	33	91	11	10.00	195.28	1242.50	19.53	.95
KF-70-E	0.03	0.01	1.53	13.94	60	13850	1212	75	79	29	8.36	95.48	1464.86	11.43	.92
KF-70-F	0.02	0.05	1.53	13.60	109	13460	951	-	-	-	8.39	118.72	-	14.15	.92
KF-70-G	0.06	0.03	1.46	13.91	23	11820	431	-	-	-	9.77	267.92	-	27.42	.90
KF-71-A	0.01	0.01	0.91	15.39	63	9335	526	24	91	16	13.69	242.89	1403.97	17.75	.93

Table 25 continued.

	wt. %				ppm										
Sample	ΣFe_2O_3	CaO	Na_2O	K_2O	Li	Rb	Cs	Sr	Ba	Pb	K/Rb	K/Cs	K/Ba	Rb/Cs	△
KF-71-B	0.00	0.02	1.99	13.41	44	9749	635	49	91	4	11.42	175.31	1223.35	15.35	.92
KF-71-C	0.07	0.02	1.41	14.45	60	9894	653	49	91	4	12.12	183.70	1318.22	15.15	.92
KF-71-E	0.02	0.06	1.62	13.87	81	11220	359	-	-	-	10.26	320.70	-	31.25	.91
KF-71-H	0.02	0.02	1.72	13.35	62	13200	3130	-	-	-	8.40	35.41	-	4.22	.91
KF-72-A	0.04	0.07	1.47	13.73	4	10280	547	-	-	-	11.09	208.37	-	18.79	.91
KF-72-B	0.04	0.05	1.08	14.58	3	10050	310	-	-	-	12.04	390.44	-	32.42	.91
KF-87-AA	0.02	0.12	1.09	15.42	11	12330	2222	113	973	22	10.38	57.61	131.56	5.55	-
KF-87-BB	0.02	0.07	0.96	15.56	10	10340	1826	99	1054	9	12.49	70.74	122.55	5.66	-
KF-87-CC	0.00	0.12	1.14	14.92	11	8329	1757	113	1054	13	14.87	70.50	117.51	4.74	-
KF-91-AA	0.04	0.09	1.80	11.73	189	26470	3038	166	51	9	3.68	32.05	1909.37	8.71	-
KF-92-AA	0.03	0.16	2.35	11.48	75	10870	882	-	-	-	8.77	180.05	-	12.32	-
KF-92-BB	0.02	0.08	1.88	12.68	77	13640	876	-	-	-	7.72	120.16	-	15.57	-
KF-92-CC	0.02	0.10	1.32	12.94	67	12490	1273	-	-	-	8.60	84.39	-	9.81	-
KF-95-KK	0.02	0.01	1.90	12.97	77	13600	452	83	51	26	7.92	238.21	2111.21	30.09	-
KF-95-LL	0.00	0.01	1.86	12.82	82	13890	417	83	51	30	7.66	255.22	2086.79	33.31	-
KF-95-JJ	0.03	0.01	1.91	12.98	82	14390	312	70	51	30	7.49	345.37	211.84	46.12	-
KF-96-CC	0.02	0.01	1.51	12.91	138	22780	783	113	51	26	4.70	136.88	2101.44	29.09	-
KF-96-DD	0.00	0.02	2.67	11.31	89	18710	765	56	51	26	5.02	122.73	1841.00	24.46	-
KF-96-EE	0.02	0.02	1.28	13.13	96	19980	756	84	51	12	5.46	144.18	2137.25	26.43	-
KF-97-AA	0.00	0.04	1.11	13.48	142	17900	1413	84	51	32	6.25	79.20	2194.23	12.67	-
KF-97-II	0.03	0.07	1.27	13.57	94	17230	1430	79	60	40	6.53	78.72	1876.16	12.05	-
KF-98-AA	0.02	0.04	1.68	12.91	103	21550	1167	95	60	8	4.97	91.84	1786.23	18.47	-
KF-98-BB	0.05	0.02	1.83	12.36	77	20450	1726	95	120	16	5.02	59.45	855.06	11.85	-
KF-98-EE	0.02	0.02	1.30	13.20	99	20500	1688	95	120	22	5.35	64.92	913.18	12.14	-

TABLE 26

Partial analyses of the Cross Lake muscovites from the pegmatites and pegmatitic granites.

	wt. %							ppm					
Sample	ΣFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Li_2O	Rb	Cs	Be	K/Rb	K/Cs	Rb/Cs
Minago Series													
Musc-51-E	2.570	0.020	0.290	0.050	0.800	10.090	0.018	1966	100	20	42.61	837.63	19.66
Musc-51-F	2.340	0.010	0.310	0.040	0.670	10.280	0.015	2480	249	27	34.41	342.73	9.96
Musc-51-I	2.410	0.020	0.300	0.040	0.680	10.350	0.015	2528	249	27	33.99	345.07	10.15
Musc-52-B	2.270	0.010	0.430	0.040	0.710	10.300	0.022	1030	50	11	83.02	1710.13	20.60
Musc-52-D	2.370	0.020	0.430	0.040	0.830	10.280	0.021	1280	194	18	66.67	439.90	6.60
Musc-60-E	1.960	0.020	0.770	0.040	0.850	10.260	0.025	758	10	6	112.37	8517.44	75.80
Musc-60-F	2.060	0.020	0.790	0.040	0.820	10.370	0.028	806	20	6	106.81	4304.37	40.30
Musc-73-C	2.790	0.010	0.450	0.050	0.830	10.440	0.140	1376	30	14	62.99	2888.96	45.87
Musc-73-D	2.820	0.010	0.430	0.050	0.840	10.370	0.144	1522	50	12	56.56	1721.75	30.44
Musc-73-G	2.840	0.010	0.410	0.050	0.860	10.650	0.146	1670	240	20	52.94	368.38	6.96
Musc-75-D	3.160	0.020	0.400	0.050	0.890	10.230	0.123	2358	80	21	36.02	1061.57	29.47
Musc-77-E	1.390	0.010	0.180	0.040	0.960	10.210	0.007	1848	156	20	45.87	543.33	11.85
Musc-77-11	1.170	0.010	0.150	0.040	0.770	8.110	0.006	1348	156	11	49.95	431.58	8.64
Musc-90-CC	2.520	0.010	0.370	0.150	0.780	10.600	0.028	1194	41	8	73.70	2146.27	29.12
Musc-90-DD	2.470	0.010	0.360	0.050	1.270	9.520	0.024	716	10	8	110.38	7903.12	71.60
Musc-94-DD	2.030	0.010	0.560	0.050	0.890	10.340	0.008	418	20	17	205.36	4291.92	20.90
P-Musc-7-F	1.920	0.010	0.790	0.030	0.910	9.920	0.074	844	19	7	97.57	4334.30	44.42
P-Musc-7-G	2.100	0.010	0.730	0.030	0.800	10.260	0.054	1144	29	10	74.45	2937.05	39.45
P-Musc-7-H	2.000	0.020	0.800	0.040	0.850	10.070	0.077	708	10	10	118.07	8359.70	70.80
P-Musc-7-O	2.030	0.010	0.700	0.050	0.850	10.090	0.041	708	20	10	118.31	4188.16	35.40
P-Musc-7-Q	1.980	0.010	0.760	0.050	0.870	10.280	0.039	1144	20	4	74.60	4267.02	57.20
P-Musc-7-P	1.760	0.010	0.740	0.050	0.760	14.890	0.034	780	9	7	158.48	13734.53	86.67
P-Musc-8-H	1.870	0.010	0.780	0.080	0.860	10.260	0.031	654	10	6	130.24	8517.44	65.40
P-Musc-11-D	2.160	0.010	0.580	0.050	0.900	10.330	0.010	508	20	6	168.81	4287.77	25.40
P-Musc-12-E	2.280	0.010	0.790	0.050	0.900	10.100	0.023	622	10	6	134.80	8384.61	62.20
P-Musc-12-G	2.280	0.020	0.790	0.040	0.760	10.450	0.021	566	10	6	153.27	8675.17	56.60
P-Musc-13-E	2.680	0.010	0.400	0.050	0.010	10.030	0.027	1698	69	11	49.04	1206.74	24.61
P-Musc-13-G	2.520	0.010	0.440	0.050	0.880	10.280	0.026	1018	30	23	83.83	2844.68	33.93
Northern Series (Barren Muscovite Pegmatite Zone)													
Musc-31-A	3.050	0.010	0.600	0.050	0.600	10.510	0.012	202	10	2	431.93	8724.99	20.20
Musc-31-B	3.120	0.010	0.630	0.030	0.670	10.590	0.012	268	10	4	328.04	8791.39	26.80
Musc-31-G	2.290	0.000	0.610	0.040	0.700	10.150	0.007	400	31	10	210.65	2718.10	12.90

Table 26 continued.

	wt. %							ppm					
Sample	ΣFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Li_2O	Rb	Cs	Be	K/Rb	K/Cs	Rb/Cs
Musc-43-C	2.590	0.010	0.300	0.050	0.930	10.040	0.013	1128	127	20	73.89	656.28	8.88
Musc-43-G	2.610	0.020	0.330	0.050	0.940	10.510	0.016	1002	116	24	87.08	752.15	8.64
Musc-44-F	2.530	0.010	0.320	0.060	0.980	9.650	0.015	1124	279	24	71.27	287.13	4.03
Musc-44-J	2.450	0.010	0.340	0.050	0.860	10.220	0.010	1186	135	24	71.54	628.46	8.79
Musc-44-K	2.490	0.010	0.350	0.050	0.910	10.240	0.014	1062	145	26	80.05	586.26	7.32
Musc-46-A	3.010	0.010	0.440	0.110	0.830	10.620	0.007	624	9	9	141.29	9795.88	69.33
Musc-46-B	3.120	0.010	0.400	0.050	0.820	10.190	0.005	420	30	12	201.41	2819.77	14.00
Musc-46-C	3.130	0.010	0.460	0.050	0.790	10.230	0.006	514	30	7	165.22	2830.84	17.13
Musc-46-I	2.530	0.010	0.350	0.050	0.890	10.000	0.003	934	61	13	88.88	1360.92	15.31
Musc-47-B	3.600	0.020	0.310	0.040	0.690	10.370	0.008	1494	741	20	57.62	116.18	2.02
Musc-47-C	3.870	0.020	0.340	0.050	0.760	9.760	0.009	466	20	10	173.87	4051.18	23.30
Musc-47-F	3.670	0.020	0.280	0.040	0.770	10.000	0.005	1356	239	20	61.22	347.35	5.67
Musc-79-H	2.020	0.010	0.590	0.050	0.890	10.140	0.011	198	39	4	425.14	2158.42	5.08
Musc-79-I	1.870	0.010	0.470	0.040	0.950	10.050	0.009	264	19	6	316.03	4391.11	13.89
Musc-80-A	1.930	0.010	0.600	0.040	0.980	10.230	0.005	210	10	6	404.41	8492.53	21.00
Musc-81-A	1.540	0.010	0.670	0.040	1.170	9.580	0.006	158	10	7	503.35	7952.93	15.80
Musc-81-B	1.780	0.010	0.730	0.040	1.040	9.670	0.005	158	10	7	508.08	8027.64	15.80
Northern Series (Beryl-Columbite Pegmatite Zone)													
Musc-22-A	2.450	0.030	0.310	0.040	0.910	10.310	0.015	2540	137	31	33.70	624.74	18.54
Musc-22-E	2.210	0.050	0.280	0.040	0.870	10.180	0.013	2930	177	31	28.84	477.46	16.55
Musc-22-G	1.650	0.050	0.100	0.040	0.910	10.180	0.006	4420	294	31	19.12	287.45	15.03
Musc-22-I	2.070	0.040	0.210	0.040	0.920	10.060	0.010	3306	227	28	25.26	367.95	14.56
11-9-4E	2.470	0.033	0.270	0.010	0.870	9.170	0.012	1800	158	31	42.29	481.81	11.39
11-9-4F	1.990	0.045	0.140	0.010	0.860	9.730	0.010	2900	340	36	27.85	237.57	8.53
Musc-36-H	3.530	0.030	0.420	0.030	0.750	10.470	0.011	1600	155	26	54.76	560.76	10.32
Musc-36-J	3.580	0.040	0.410	0.050	0.770	10.340	0.013	1534	166	26	55.96	517.10	9.24
Musc-36-L	3.590	0.050	0.400	0.040	0.730	10.390	0.014	1600	166	24	53.91	519.60	9.64
Musc-37-C	3.630	0.040	0.830	0.030	0.610	10.390	0.029	3086	2660	24	27.95	32.43	1.16
Musc-37-E	3.430	0.020	0.760	0.030	0.730	10.360	0.034	3134	300	25	27.44	286.68	10.45
Musc-37-L	3.940	0.030	0.850	0.020	0.750	10.360	0.049	3200	311	25	26.88	276.54	10.29
11-9-5B	4.270	0.028	0.860	0.010	0.750	8.820	0.035	2200	306	27	33.28	239.28	7.19
11-9-5F	3.820	0.024	0.580	0.010	0.820	9.560	0.019	2700	343	28	29.39	231.38	7.87
Musc-38-E	2.000	0.020	0.380	0.030	0.720	10.260	0.002	3786	186	25	22.50	457.93	20.35
Musc-39-A	2.240	0.020	0.330	0.030	0.890	10.470	0.001	1174	31	17	74.04	2803.80	37.87
Musc-39-F	2.190	0.050	0.310	0.040	0.750	10.530	0.001	1174	31	11	74.46	2819.86	37.87
Musc-40-G	2.680	0.010	0.250	0.040	1.040	10.010	0.017	3596	753	24	23.11	110.36	4.78
Musc-40-I	2.430	0.010	0.250	0.030	1.060	10.010	0.017	3596	774	26	23.11	107.36	4.65

Table 26 continued.

Sample	wt. %							ppm					
	ΣFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Li_2O	Rb	Cs	Be	K/Rb	K/Cs	Rb/Cs
Musc-40-M	2.720	0.010	0.250	0.040	1.060	10.130	0.014	3352	774	26	25.09	108.65	4.33
Musc-41-E	3.200	0.020	0.490	0.110	0.680	10.490	0.022	1278	629	33	68.14	138.45	2.03
Musc-42-A	2.370	0.030	0.210	0.060	0.840	10.680	0.003	2620	990	28	33.84	89.56	2.65
Musc-42-I	2.330	0.020	0.210	0.050	0.940	10.060	0.007	2256	1479	24	37.02	56.47	1.53
Musc-42-J	2.330	0.010	0.180	0.040	0.850	10.150	0.003	2256	792	24	37.35	106.39	2.85
Musc-42-M	2.380	0.020	0.260	0.050	0.960	10.130	0.009	1566	370	34	53.70	227.28	4.23
Southern Series (Biotite-Peristerite Pegmatite Zone)													
Musc-26-C	2.190	0.010	0.660	0.040	0.760	10.660	0.094	2158	36	6	41.01	2458.19	59.94
Musc-26-F	2.200	0.070	0.650	0.060	0.830	10.440	0.076	2092	36	6	41.43	2407.46	58.11
Southern Series (Spodumene Pegmatite Zone)													
Musc-3-F	0.430	0.050	0.070	0.100	0.690	8.360	0.105	30360	1980	26	2.26	35.05	15.33
Musc-4-C	0.530	0.070	0.070	0.090	0.700	8.920	0.037	16828	208	26	4.40	356.01	80.90
13-8-2G	0.460	0.067	0.040	0.060	0.580	8.660	0.056	20800	1920	49	3.46	37.44	10.83
Musc-6-B	0.450	0.080	0.030	0.030	0.590	9.490	0.056	24440	746	26	3.22	105.61	32.76
Musc-6-E	0.470	0.070	0.010	0.040	0.620	9.300	0.051	27860	1206	28	2.77	63.86	23.04
Musc-6-F	0.410	0.060	0.040	0.040	0.570	9.000	0.046	31540	2132	28	2.37	35.04	14.79
13-8-3J	0.460	0.059	0.020	0.010	0.710	7.910	0.051	14900	850	21	4.41	77.25	17.53
Musc-7-F	0.590	0.060	0.010	0.040	0.540	9.300	0.043	27180	1493	28	2.84	51.71	18.20
Musc-8-D	1.403	0.040	0.090	0.080	0.660	9.840	0.048	14576	1121	22	5.60	72.87	13.00
Musc-15-B	0.850	0.050	0.021	0.040	0.530	9.660	0.039	19322	2174	26	4.15	36.89	8.89
Musc-15-C	2.610	0.040	0.300	0.040	0.710	10.500	0.008	3586	2234	24	24.31	39.02	1.61
Musc-20-B	1.060	0.020	0.020	0.060	0.650	9.770	0.035	18386	1054	16	4.41	76.95	17.44
Musc-20-D	1.050	0.030	0.010	0.040	0.690	9.790	0.030	18286	981	22	4.44	82.85	18.64
Musc-20-P	1.410	0.020	0.030	0.080	0.760	9.640	0.031	17518	805	25	4.57	99.41	21.76
Musc-71-N	1.880	0.020	0.750	0.050	0.760	10.300	0.036	1374	224	8	62.23	381.73	6.13
Musc-72-D	1.480	0.010	0.130	0.050	0.720	9.670	0.014	17738	632	22	4.53	127.02	28.07
Musc-76-A	0.410	0.020	0.020	0.050	1.020	9.060	0.036	30560	952	25	2.46	79.00	32.10
Musc-76-J	0.450	0.020	0.020	0.040	1.420	7.350	0.036	25060	654	20	2.43	93.30	38.32
Musc-76-K	0.330	0.010	0.020	0.040	1.070	8.750	0.036	32820	1494	18	2.21	48.62	21.97
Musc-95-BB	0.510	0.060	0.010	0.050	0.810	9.860	0.055	15936	308	23	5.14	265.76	51.74
Musc-95-CC	0.400	0.060	0.010	0.040	0.800	9.320	0.048	15572	259	23	4.79	298.73	60.12
Musc-95-DD	0.620	0.070	0.010	0.040	0.870	9.410	0.050	14814	190	21	5.27	411.15	77.97
Musc-95-GG	0.520	0.060	0.010	0.040	0.920	8.540	0.033	20100	359	21	3.53	197.48	55.99
Musc-96-HH	0.520	0.070	0.010	0.040	0.770	8.880	0.038	23200	633	21	3.17	116.46	36.71
Musc-97-HH	0.400	0.050	0.010	0.040	0.930	9.620	0.038	17880	295	19	4.47	270.72	60.61
Musc-97-KK	0.600	0.050	0.010	0.040	0.880	9.690	0.035	15364	221	21	5.24	363.99	69.52

Table 26 continued.

	wt. %							ppm					
Sample	ΣFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Li_2O	Rb	Cs	Be	K/Rb	K/Cs	Rb/Cs
Musc-97-LL	0.590	0.050	0.010	0.040	0.810	9.720	0.039	15274	245	24	5.28	329.35	62.34
Musc-97-MM	0.490	0.040	0.010	0.040	0.710	9.450	0.046	16508	298	22	4.75	263.26	55.40
Musc-98-GG	0.510	0.040	0.040	0.040	0.710	9.870	0.048	22080	1351	22	3.71	60.65	16.34

TABLE 27

Partial analysis of spodumene from the pegmatites of the Southern series.

Sample	ΣFe_2O_3	MnO	CaO	Na_2O	K_2O	Li_2O
Southern Series (Spodumene Pegmatite Zone)						
Sp-1-D	0.470	0.150	0.030	0.160	0.150	8.500
Sp-3-H	0.280	0.140	0.030	0.200	0.040	8.400
13-8-2H	0.360	0.017	-	0.100	0.010	-
Sp-6-A	0.200	0.120	0.030	0.160	0.060	7.900
13-8-3K	0.260	0.016	-	0.100	0.100	-
Sp-7-D	0.320	0.120	0.010	0.220	0.090	7.600
Sp-8-C	0.860	0.080	0.030	0.210	0.150	8.200
Sp-9-A	0.470	0.130	0.010	0.140	0.120	8.200
Sp-9-E	0.410	0.150	0.020	0.170	0.050	7.800
Sp-11-D	0.660	0.140	0.020	0.390	0.160	7.700
Sp-16-E	0.710	0.200	0.070	0.330	0.420	7.400
Sp-16-S	0.780	0.120	0.050	1.140	0.460	6.000
Sp-20-H	0.280	0.120	0.020	0.220	0.070	8.200
Sp-71-F	1.160	0.140	0.020	1.110	0.780	7.300
Sp-97-NN	0.230	0.290	0.000	0.170	0.060	8.200
Sp-98-FF	0.160	0.140	0.000	0.190	0.060	7.700

TABLE 28

Partial analysis of Cross Lake beryl from the Minago, Northern and Southern series.

Sample	ΣFe_2O_3	MnO	CaO	Na_2O	K_2O	Li	Rb	Cs	Na/Li
Minago Series									
P-BE-15-A	0.53	0.02	0.69	2.14	0.22	4435	502	15750	3.58
Northern Series (Beryl-Columbite Pegmatite Zone)									
Be-22-C	0.52	0.01	0.03	0.38	0.07	352	82	1397	8.00
Be-22-L	0.34	0.02	0.17	0.33	0.02	544	35	2871	4.50
Be-22-Y	0.42	0.01	0.03	0.42	0.02	349	26	1787	8.92
Be-83-22-R	0.46	0.01	0.04	0.61	0.09	482	50	1955	9.38
11-9-4D	0.39	0.01	0.06	0.81	0.05	416	42	1830	14.44
11-9-5H	0.99	0.01	0.03	1.56	0.05	403	85	1500	28.71
Be-30-F	0.08	0.01	0.01	0.21	0.05	262	18	2149	5.94
Be-30-F-I	0.08	0.01	0.03	0.23	0.05	322	21	2224	5.29
Be-83-30-I	0.10	0.01	0.05	0.15	0.03	229	18	949	4.85
Be-36-I	0.72	0.01	0.09	0.68	0.11	411	41	756	12.27
Be-36-J	0.73	0.01	0.03	0.60	0.10	237	60	581	18.78
Be-36-K	0.73	0.00	0.01	0.60	0.03	168	36	347	26.49
Be-37-G	0.80	0.01	0.01	0.87	0.03	350	107	1461	18.44
Be-37-K	0.62	0.01	0.01	0.68	0.04	271	74	881	18.61
Be-37-O	0.79	0.03	0.06	1.05	0.15	535	91	1994	14.56
Be-38-B	0.37	0.01	0.00	0.23	0.02	158	37	657	10.79
Be-40-J	0.45	0.00	0.01	0.34	0.05	357	36	1030	7.06
Be-40-O	0.42	0.00	0.02	0.42	0.05	373	34	991	8.35
Be-42-B	0.46	0.01	0.03	0.71	0.17	249	36	1241	21.15
Be-83-41-Y	0.74	0.01	0.04	0.67	0.43	398	36	589	12.48
Be-41-F	0.73	0.01	0.03	0.58	0.18	285	50	573	15.09
Southern Series (Spodumene Pegmatite Zone)									
DH-Be-3	0.09	0.01	0.01	0.61	0.06	2007	464	2684	2.25
Be-1-G	0.11	0.01	0.02	1.58	0.08	4486	1051	10580	2.61
Be-1-J	0.18	0.01	0.05	1.81	0.33	3861	1231	22590	3.47
Be-1-Z	0.14	0.00	0.01	1.70	0.05	4622	795	3461	2.72
Be-2-Z	0.05	0.00	0.02	1.58	0.08	5480	1519	21390	2.13
Be-3-D	0.04	0.00	0.02	1.60	0.08	5461	1398	15555	2.17
Be-3-Z	0.12	0.01	0.02	1.32	0.08	3872	1221	4891	2.52
Be-5	0.13	0.01	0.02	1.52	0.19	4190	994	4267	2.69

Table 28 continued.

Sample	ΣFe_2O_3	MnO	CaO	Na_2O	K_2O	Li	Rb	Cs	Na/Li
Be-6-J	0.09	0.01	0.00	1.53	0.07	4102	1281	11420	2.76
Be-83-6-F	0.05	0.00	0.04	1.67	0.07	4222	1358	18390	2.93
13-8-2I	0.06	0.00	0.02	2.27	0.07	4370	866	7230	3.85
13-8-3H	0.09	0.01	0.02	2.31	0.05	4476	987	5508	3.82
13-8-3I	0.07	0.01	0.03	2.31	0.05	4475	1264	8260	3.82
Be-9-J	0.15	0.01	0.01	1.30	0.05	3334	1127	3351	2.89
Be-83-9-Z	0.14	0.01	0.02	1.69	0.05	3706	1081	4513	3.38
Be-11-G	0.23	0.01	0.03	1.35	0.25	3482	907	11350	2.87
Be-70-K	0.25	0.00	0.01	1.08	0.19	2904	913	10450	2.75
Be-83-71-A	0.66	0.01	0.06	1.85	0.30	3063	824	9600	4.48
Be-76-E	0.08	0.00	0.01	1.24	0.09	3234	690	15050	2.84
Be-76-G	0.08	0.00	0.01	1.30	0.07	3219	649	14960	2.99
Be-76-L	0.08	0.01	0.01	1.09	0.11	2874	902	15780	2.81
Be-95-II	0.07	0.00	0.01	1.63	0.06	5005	1044	9220	2.41
Be-96-BB	0.14	0.00	0.04	2.41	0.16	4020	1135	4198	4.44

TABLE 29

Electron microprobe analyses of garnets from the Cross Lake pegmatite field.

	wt. %							Number of cations per 12 oxygens							
Sample	SiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Total	Si	Al	Fe^{2+}	Mn	Mg	Ca	Total	MnOx100/MnO+FeO
Nelson Series															
Gar-10-A	36.80	20.55	33.82	4.61	2.82	0.90	99.50	2.99	1.97	2.30	0.31	0.34	0.07	8.01	11.99
Gar-10-A1	37.74	20.83	32.54	4.79	3.54	1.04	100.48	3.02	1.96	2.17	0.32	0.42	0.08	7.99	12.83
Gar-62-D	37.26	21.12	34.26	4.25	3.13	0.94	100.96	2.98	1.99	2.29	0.28	0.37	0.08	8.01	11.03
Gar-62-D1	37.43	21.32	32.83	4.16	3.82	0.86	100.42	2.99	2.00	2.19	0.28	0.45	0.07	8.00	11.24
Gar-63-F-1	37.04	20.54	34.16	4.01	2.72	1.19	99.66	3.01	1.96	2.32	0.27	0.32	0.10	8.00	10.50
Gar-65-C	37.06	20.59	34.81	3.85	2.58	1.16	100.05	3.00	1.96	2.36	0.26	0.31	0.10	8.01	9.95
Gar-67-D	37.26	20.86	35.47	3.76	2.48	0.95	100.78	3.00	1.98	2.39	0.25	0.29	0.08	8.00	9.58
Gar-68-A	36.83	20.99	33.74	4.61	3.04	0.82	100.03	2.98	2.00	2.28	0.31	0.36	0.07	8.01	12.02
Gar-83-1	36.50	21.18	34.63	3.68	3.19	0.92	100.10	2.95	2.02	2.34	0.25	0.38	0.08	8.03	9.60
Gar-83-6-A	37.52	21.64	33.82	2.37	3.86	1.73	100.94	2.97	2.02	2.24	0.15	0.45	0.14	8.01	6.54
Minago Series															
Gar-29-B	36.54	20.18	32.18	8.67	1.00	1.43	100.00	3.00	1.95	2.21	0.60	0.12	0.12	8.02	21.22
Gar-29-I	36.82	20.12	29.68	11.38	0.38	1.84	100.22	3.02	1.94	2.03	0.79	0.04	0.16	8.00	27.71
Gar-35-F	37.35	20.87	32.35	6.61	1.97	0.36	99.51	3.03	2.00	2.20	0.45	0.23	0.03	7.96	16.96
Gar-52-E	36.74	20.49	30.57	11.34	0.43	0.89	100.46	3.01	1.97	2.09	0.78	0.05	0.07	8.00	27.05
Gar-60-H	36.65	20.83	27.46	11.77	1.78	0.91	99.40	2.99	2.00	1.87	0.81	0.21	0.08	7.99	30.00
Gar-73-F	36.24	20.32	25.91	16.36	0.63	0.39	99.85	2.99	1.97	1.79	1.14	0.07	0.03	8.01	38.70
Gar-77-G	36.24	20.16	20.18	22.04	0.16	0.55	99.33	3.01	1.97	1.40	1.55	0.02	0.04	8.00	52.20
Gar-77-K	36.34	20.10	21.63	20.89	0.15	0.34	99.45	3.01	1.96	1.50	1.46	0.01	0.03	8.00	49.13
Gar-78-B	36.32	20.16	27.93	14.58	0.34	0.44	99.77	3.00	1.96	1.93	1.02	0.04	0.03	8.01	34.29
Gar-78-G	36.28	20.22	29.95	12.22	0.56	0.56	99.79	3.00	1.97	2.07	0.85	0.06	0.05	8.01	28.97
Gar-78-Z	36.07	20.39	30.91	9.68	0.92	0.55	98.52	3.00	2.00	2.15	0.68	0.11	0.04	7.99	23.84
P-Gar-7-K	36.60	20.12	27.04	13.20	0.72	2.27	99.95	3.00	1.94	1.85	0.91	0.08	0.20	8.01	32.80
P-Gar-13-F	36.43	19.98	33.69	7.49	1.21	0.47	99.27	3.01	1.94	2.33	0.52	0.14	0.04	8.01	18.18
P-Gar-15-H	36.92	20.56	23.92	13.42	2.31	2.18	99.31	3.00	1.97	1.62	0.92	0.28	0.19	8.00	35.94
P-Gar-16-D	36.26	20.41	34.77	6.09	1.82	0.52	99.87	2.97	1.97	2.38	0.42	0.22	0.04	8.03	14.90
P-Gar-17-D	36.78	20.72	34.52	5.04	2.33	0.98	100.37	2.98	1.98	2.34	0.34	0.28	0.08	8.02	12.74
P-Gar-24	37.44	21.62	31.94	4.32	2.22	3.11	100.65	2.99	2.03	2.13	0.29	0.26	0.26	7.98	11.91
P-Gar-24-1	37.25	21.28	32.16	4.80	1.97	4.80	102.26	2.95	1.99	2.13	0.32	0.23	0.40	8.04	12.98

Table 29 continued.

Sample	wt. % SiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Total	Number of cations per 12 oxygens Si	Al	Fe^{2+}	Mn	Mg	Ca	Total	MnOx100/MnO+FeO
Northern Series (Barren-Muscovite Pegmatite Zone)															
Gar-32-B	36.59	20.15	30.67	9.57	1.24	0.92	99.14	3.02	1.96	2.11	0.66	0.15	0.08	8.00	23.78
Gar-32-G	37.28	20.79	28.25	9.35	2.77	0.78	99.22	3.02	1.98	1.91	0.64	0.33	0.06	7.97	24.86
Gar-43-B	36.49	20.03	28.69	13.30	0.36	0.29	99.16	3.03	1.96	1.99	0.93	0.04	0.02	7.98	31.67
Gar-44-C	36.53	20.31	28.44	12.76	0.31	0.43	98.78	3.03	1.98	1.97	0.89	0.03	0.03	7.97	30.97
Gar-44-I	36.06	20.23	29.94	13.31	0.25	0.26	100.05	2.98	1.97	2.07	0.93	0.03	0.02	8.02	30.77
Gar-45-E	35.86	20.39	32.80	9.12	0.77	0.46	99.40	2.97	1.99	2.27	0.64	0.09	0.04	8.02	21.75
Gar-45-E1	36.94	20.55	32.07	7.46	2.41	0.49	99.92	3.00	1.97	2.18	0.51	0.29	0.04	8.00	18.87
Gar-46-G	36.71	20.85	33.60	8.28	0.91	0.58	100.93	2.98	2.00	2.28	0.57	0.11	0.05	8.01	19.77
Gar-48-C	36.59	20.40	30.57	11.72	0.62	0.33	100.23	3.00	1.97	2.10	0.81	0.07	0.02	8.00	27.71
Gar-54-G	36.38	20.39	33.99	6.74	1.34	0.85	99.69	2.99	1.97	2.33	0.47	0.16	0.07	8.01	16.54
Gar-79-L	36.42	20.77	31.61	8.11	1.85	0.74	99.50	2.98	2.00	2.16	0.56	0.22	0.06	8.01	20.41
Northern Series (Beryl-Columbite Pegmatite Zone)															
Gar-22-U	36.45	20.68	14.95	27.56	0.63	0.17	100.44	2.98	1.99	1.02	1.91	0.07	0.01	8.01	64.83
Gar-23-B	37.11	20.51	20.07	20.12	2.30	0.31	100.42	3.00	1.95	1.36	1.38	0.27	0.02	8.01	50.06
Gar-23-B1	36.61	20.14	19.46	20.07	2.11	0.26	98.65	3.01	1.95	1.34	1.40	0.25	0.02	8.00	50.77
Gar-30-L	36.49	20.83	8.97	34.03	-	0.49	100.81	2.98	2.00	0.61	2.35	-	0.04	8.01	79.14
Gar-30-X	37.09	20.79	11.32	31.83	-	0.52	101.55	3.00	1.98	0.76	2.18	-	0.04	7.99	73.76
Gar-36-G	36.31	20.46	25.94	16.17	0.93	0.39	100.20	2.98	1.98	1.78	1.12	0.11	0.03	8.02	38.39
Gar-37-A	36.44	20.43	22.91	18.08	1.14	0.26	99.26	3.00	1.98	1.58	1.26	0.14	0.02	8.00	44.10
Gar-37-VV	36.47	20.36	23.02	19.06	0.93	0.25	100.09	2.99	1.98	1.58	1.32	0.11	0.02	8.01	45.29
Gar-37-V1	35.88	20.56	22.83	19.01	0.70	0.29	99.27	2.97	2.01	1.58	1.33	0.08	0.02	8.01	45.43
Gar-37-V2	35.82	20.31	22.75	18.56	0.83	0.23	98.50	2.99	1.99	1.58	1.31	0.10	0.02	8.01	44.92
Gar-38-F	36.10	19.77	15.46	26.23	0.95	0.24	98.75	3.00	1.94	1.07	1.85	0.11	0.02	8.02	62.91
Gar-38-F1	36.95	20.23	15.85	27.07	0.51	0.16	100.77	3.02	1.94	1.08	1.87	0.06	0.01	8.00	63.07
Gar-38-M	36.38	20.29	11.12	31.46	0.54	0.14	99.93	3.00	1.97	0.76	2.19	0.06	0.01	8.01	73.88
Gar-39-H	36.79	20.20	13.02	29.75	0.20	0.27	100.23	3.02	1.95	0.86	2.07	0.02	0.02	7.99	69.55
Gar-39-H1	36.70	20.12	13.32	29.50	0.15	0.26	100.05	3.02	1.95	0.91	2.05	0.01	0.02	7.99	68.89
Gar-40-B	36.39	20.20	27.97	14.61	0.34	0.44	99.76	3.01	1.97	1.93	1.02	0.01	0.03	8.00	34.31
Gar-40-B1	36.89	20.19	26.64	14.47	0.79	0.22	99.20	3.04	1.96	1.83	1.01	0.09	0.01	7.97	35.19
Gar-41-U	35.19	20.50	23.87	17.45	1.00	0.26	98.27	2.95	2.02	1.67	1.23	0.12	0.02	8.03	42.23
Gar-42-K	36.10	19.97	24.57	17.49	0.57	0.37	99.07	3.00	1.96	1.71	1.23	0.07	0.03	8.01	41.58
Southern Series (Biotite-Peristerite Pegmatite Zone)															
Gar-18-D-1	37.20	20.53	28.80	12.30	0.95	0.74	100.52	3.02	1.97	1.96	0.84	0.11	0.06	7.98	29.92
Gar-21-AA	35.95	20.74	22.23	19.67	0.27	0.71	99.57	2.97	2.02	1.53	1.37	0.03	0.06	8.01	46.94
Gar-21-A2	37.04	20.46	21.01	21.72	-	0.70	100.93	3.02	1.96	1.43	1.50	-	0.06	7.99	50.83

Table 29 continued.

	wt. %							Number of cations per 12 oxygens							
Sample	SiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Total	Si	Al	Fe^{2+}	Mn	Mg	Ca	Total	MnOx100/MnO+FeO
Gar-25-A	36.79	20.94	25.86	15.50	1.25	0.33	100.67	2.99	2.00	1.75	1.06	0.15	0.02	8.00	37.47
Southern Series (Spodumene Pegmatite Zone)															
Gar-6-**	36.91	20.60	5.03	37.71	-	0.42	100.67	3.01	1.98	0.34	2.61	-	0.03	7.99	88.23
Gar-6-DD	36.44	20.26	4.67	37.84	-	0.33	99.54	3.01	1.97	0.32	2.65	-	0.02	7.99	89.01
Gar-20-N	36.15	20.26	19.48	22.72	0.50	0.56	99.67	2.99	1.97	1.34	1.59	0.06	0.05	8.02	53.83
Gar-72-F	36.27	20.18	27.92	14.76	0.56	0.24	99.93	2.99	1.96	1.93	1.03	0.06	0.02	8.01	34.58

TABLE 30

Electron microprobe analyses of columbite-tantalite, ixiolite and/or wodginite (*) and tantalian rutile (†) from the Cross Lake pegmatite field.

	wt. %							Element ratios based on 6 oxygens								
Sample	MnO	FeO	Nb_2O_5	Ta_2O_5	TiO_2	SnO_2	Total	Mn	Fe^{2+}	Nb	Ta	Ti	Sn	Total	Mn/Mn+Fe	Ta/Ta+Nb
Northern Series																
Ta-22-AA	10.97	2.44	3.82	77.82	5.52	0.10	100.67	0.72	0.15	0.13	1.65	0.32	0.00	2.99	0.82	0.92
Ta-22-I	13.80	4.46	51.76	29.26	0.74	0.00	100.02	0.73	0.23	1.47	0.50	0.03	0.00	2.99	0.75	0.25
Ta-22-II	11.47	6.73	44.16	37.69	0.94	0.00	100.99	0.63	0.36	1.29	0.66	0.04	0.00	3.00	0.63	0.33
Ta-22-III	11.48	3.99	16.15	68.30	0.85	0.00	100.77	0.73	0.25	0.55	1.41	0.04	0.00	3.00	0.74	0.71
Ta-22-J	11.28	4.36	14.67	68.92	0.79	0.00	100.02	0.73	0.28	0.51	1.44	0.04	0.00	3.02	0.72	0.73
Ta-22-N	11.26	3.21	9.76	74.25	0.77	0.76	100.01	8.72	2.49	6.82	60.80	0.46	0.59	2.99	0.78	0.82
Ta-22-H-A	11.10	6.84	41.61	38.93	0.61	0.00	99.09	0.63	0.38	1.26	0.70	0.03	0.00	3.01	0.62	0.36
Ta-22-H-B	11.36	6.26	37.51	44.54	0.43	0.00	100.10	0.65	0.35	1.15	0.82	0.02	0.00	3.01	0.64	0.41
Ta-22-Z-A	11.24	6.47	40.75	39.75	0.93	0.00	99.14	0.63	0.36	1.23	0.72	0.04	0.00	3.01	0.63	0.37
Ta-22-Z-B	11.33	6.12	39.90	39.84	0.83	0.00	98.02	0.65	0.34	1.22	0.73	0.04	0.00	3.00	0.65	0.37
Ta-30-K	13.49	6.08	65.99	14.34	0.81	0.00	100.71	0.67	0.29	1.75	0.22	0.03	0.00	2.99	0.69	0.11
Ta-30-KK	13.55	5.78	56.43	25.02	1.21	0.03	102.09	0.69	0.29	1.54	0.41	0.05	0.00	3.00	0.70	0.21
Ta-30-WA	12.40	7.58	63.86	15.80	1.00	0.00	100.64	0.62	0.37	1.71	0.25	0.04	0.00	3.00	0.62	0.13
Ta-30-Wt	13.42	6.77	66.58	13.25	0.61	0.00	101.21	0.66	0.33	1.76	0.22	0.02	0.00	3.00	0.66	0.11
Ta-30-W	11.90	8.12	66.37	12.53	0.96	0.00	99.88	0.59	0.40	1.76	0.20	0.04	0.00	3.00	0.59	0.10
Ta-36-Bt	9.25	9.12	46.04	36.80	0.79	0.00	102.00	0.50	0.48	1.33	0.64	0.03	0.00	3.00	0.50	0.32
Ta-37-1X	6.06	9.61	24.28	55.15	2.84	0.00	97.94	0.37	0.58	0.80	1.09	0.15	0.00	3.00	0.39	0.57
Ta-37-M	5.13	12.34	35.96	43.65	2.49	0.00	99.57	0.29	0.69	1.09	0.80	0.12	0.00	3.02	0.29	0.42
Ta-38-A-1	11.05	7.20	45.83	34.11	1.06	0.00	99.25	0.61	0.39	1.35	0.60	0.05	0.00	3.01	0.60	0.30
Ta-38-A-2	11.18	6.87	45.88	34.38	1.15	0.00	99.46	0.61	0.37	1.35	0.60	0.05	0.00	3.00	0.62	0.31
Ta-38-I	10.78	6.80	37.49	43.31	1.44	0.00	99.82	0.61	0.38	1.14	0.79	0.07	0.00	3.01	0.61	0.41
Ta-38-I-A	10.73	6.73	37.40	41.95	1.77	0.00	98.58	0.61	0.38	1.15	0.77	0.09	0.00	3.01	0.61	0.40
Ta-38-N-A	10.98	7.52	49.82	30.83	0.35	0.00	99.50	0.59	0.40	1.44	0.53	0.01	0.00	3.00	0.59	0.27
Ta-38-N	11.02	7.37	50.84	30.60	0.44	0.00	100.27	0.59	0.39	1.46	0.52	0.02	0.00	2.99	0.60	0.26
Ta-38-N-X	10.81	7.17	46.70	33.78	0.29	0.00	98.75	0.60	0.39	1.38	0.60	0.01	0.00	3.00	0.60	0.30
Ta-38-N-Y	10.82	7.66	50.49	30.15	0.44	0.00	99.56	0.58	0.41	1.46	0.52	0.02	0.00	3.00	0.58	0.26
Ta-38-O-A	13.70	5.08	51.84	28.58	0.43	0.00	99.63	0.73	0.27	1.48	0.49	0.02	0.00	3.00	0.73	0.24
Ta-38-O-B	13.53	5.33	52.83	27.41	0.40	0.00	99.50	0.72	0.28	1.51	0.47	0.01	0.00	3.00	0.72	0.23
† Ta-40-D-D	0.00	8.93	8.57	50.06	30.69	0.57	98.82	0.00	0.45	0.23	0.83	1.41	0.01	2.96	0.00	0.77
Ta-41-Z-Z	5.30	11.18	30.00	51.45	2.15	0.00	100.08	0.31	0.65	0.94	0.97	0.11	0.00	3.00	0.32	0.50
Ta-41-ZXA	4.80	12.18	29.38	52.00	2.00	0.09	100.45	0.28	0.71	0.92	0.98	0.10	0.00	3.01	0.28	0.51

Table 30 continued.

	wt. %							Element ratios based on 6 oxygens								
Sample	MnO	FeO	Nb_2O_5	Ta_2O_5	TiO_2	SnO_2	Total	Mn	Fe^{2+}	Nb	Ta	Ti	Sn	Total	Mn/Mn+Fe	Ta/Ta+Nb
Southern Series																
Ta-1-AA	16.67	2.58	54.04	26.63	0.24	0.00	100.16	0.88	0.13	1.53	0.45	0.01	0.00	3.01	0.86	0.22
Ta-1-?	15.48	3.33	51.72	27.22	0.66	0.00	98.41	0.83	0.17	1.49	0.47	0.03	0.00	3.01	0.82	0.24
Ta-1-?-B	15.51	3.22	51.47	27.89	0.54	0.00	98.63	0.84	0.17	1.48	0.48	0.02	0.00	3.01	0.83	0.24
Ta-1-?-A	15.50	3.38	51.39	28.87	0.42	0.00	99.56	0.83	0.18	1.47	0.50	0.02	0.00	3.01	0.82	0.25
Ta-1-?-BB	15.15	3.70	51.40	28.99	0.41	0.09	99.74	0.81	0.19	1.47	0.50	0.02	0.00	3.01	0.80	0.25
Ta-1-?-C	16.43	2.56	51.14	29.24	0.55	0.00	99.92	0.88	0.13	1.46	0.50	0.02	0.00	3.01	0.86	0.25
Ta-4-AA	13.05	3.54	29.11	54.08	0.47	0.00	100.25	0.78	0.21	0.93	1.04	0.02	0.00	3.00	0.78	0.52
Ta-4-AA1	13.02	3.59	28.80	55.45	0.38	0.25	101.49	0.77	0.21	0.91	1.06	0.02	0.00	2.99	0.78	0.53
Ta-4-G	13.70	4.09	43.85	36.83	0.45	0.22	99.14	0.77	0.22	1.31	0.66	0.02	0.00	3.00	0.77	0.33
Ta-4-G-1	13.31	0.88	42.81	36.59	0.08	0.00	93.67	0.79	0.05	1.36	0.69	0.00	0.00	2.90	0.93	0.34
Ta-4-G-2	13.65	3.77	44.08	38.17	0.37	0.00	100.04	0.76	0.20	1.31	0.68	0.01	0.00	2.98	0.78	0.34
Ta-4-YY	14.83	2.38	35.36	47.45	0.59	0.18	100.79	0.85	0.13	1.09	0.88	0.03	0.00	3.00	0.86	0.44
* Ta-4-XX	9.97	2.26	7.94	63.87	0.25	14.92	99.21	0.67	0.15	0.28	1.38	0.01	0.47	2.99	0.81	0.82
Ta-4-ZZ	14.32	2.73	38.88	44.09	0.46	0.00	100.48	0.81	0.15	1.18	0.80	0.02	0.00	2.98	0.84	0.40
Ta-6-AA	15.50	1.18	28.64	55.36	0.32	0.19	101.19	0.92	0.07	0.91	1.06	0.01	0.00	3.00	0.93	0.53
Ta-6-BB	13.36	2.21	21.06	60.52	0.74	0.21	98.10	0.85	0.14	0.72	1.24	0.04	0.00	3.00	0.86	0.63
Ta-6-CX	14.50	1.85	24.68	59.30	0.18	0.00	100.51	0.89	0.11	0.81	1.17	0.01	0.00	3.00	0.88	0.59
Ta-6-EE	14.10	2.16	24.46	59.23	0.54	0.00	100.49	0.86	0.13	0.80	1.17	0.03	0.00	3.00	0.86	0.59
Ta-6-GG	13.18	1.63	20.41	62.99	0.43	0.15	98.79	0.86	0.10	0.69	1.29	0.02	0.00	2.97	0.89	0.65
Ta-9-K	14.67	4.05	46.24	35.12	0.48	0.10	100.66	0.80	0.21	1.35	0.61	0.02	0.00	3.01	0.78	0.31
Ta-9-L	13.18	5.80	53.96	27.11	0.57	0.28	100.90	0.69	0.30	1.51	0.45	0.02	0.00	3.00	0.69	0.23
Ta-9-L-1	14.18	4.68	53.49	26.93	0.75	0.22	100.25	0.75	0.24	1.51	0.45	0.03	0.00	3.00	0.75	0.23
Ta-19-G	3.53	15.99	66.36	13.68	0.11	0.00	100.67	0.17	0.78	1.75	0.21	0.04	0.00	2.98	0.18	0.11
Ta-19-G-1	3.49	15.60	65.17	13.68	0.96	0.12	99.02	0.17	0.77	1.75	0.22	0.04	0.00	2.98	0.18	0.11
Ta-20-O-A	12.88	3.10	22.08	62.09	0.20	0.10	100.45	0.80	0.19	0.73	1.25	0.01	0.00	3.00	0.80	0.62
Ta-20-Q	12.31	5.52	53.68	26.27	0.22	0.00	98.00	0.66	0.29	1.55	0.45	0.01	0.00	2.97	0.69	0.22
Ta-20-Q-B	7.16	11.52	50.87	28.17	0.86	0.21	98.79	0.38	0.61	1.47	0.49	0.04	0.00	3.01	0.38	0.25
Ta-20-Q-C	8.24	10.68	51.02	27.23	0.72	0.14	98.03	0.44	0.57	1.48	0.47	0.03	0.00	3.02	0.43	0.24
Ta-20-R	11.76	6.93	51.04	28.68	0.40	0.00	98.81	0.63	0.37	1.48	0.50	0.01	0.00	3.01	0.63	0.25
Ta-20-S	6.59	9.26	20.08	61.92	1.05	0.00	98.90	0.42	0.58	0.68	1.26	0.05	0.00	3.01	0.41	0.65
Ta-20-S-B	6.73	8.81	20.79	62.29	1.10	0.00	99.72	0.42	0.54	0.70	1.26	0.06	0.00	2.99	0.43	0.64
Ta-21-AAt	5.61	14.49	66.84	13.49	1.04	0.00	101.47	0.27	0.70	1.75	0.21	0.04	0.00	2.99	0.28	0.10
Ta-21-A-S	6.38	12.58	53.30	26.14	1.50	0.00	99.90	0.33	0.65	1.50	0.44	0.07	0.00	3.01	0.33	0.22
Ta-21-B-S	4.78	13.18	50.90	29.83	1.29	0.00	99.98	0.25	0.69	1.45	0.51	0.06	0.00	2.98	0.26	0.26
Ta-21-1-C	4.60	13.84	47.03	33.32	1.56	0.00	100.35	0.25	0.74	1.36	0.58	0.07	0.00	3.01	0.25	0.29
Ta-21-N-S	5.27	14.33	61.78	15.81	1.13	0.00	98.32	0.27	0.72	1.69	0.26	0.05	0.00	3.01	0.27	0.13
Ta-91-AA	13.24	2.77	25.33	58.73	0.33	0.43	100.83	0.81	0.16	0.82	1.15	0.01	0.01	2.99	0.82	0.58

Table 30 continued.

	wt. %							Element ratios based on 6 oxygens								
Sample	MnO	FeO	Nb_2O_5	Ta_2O_5	TiO_2	SnO_2	Total	Mn	Fe^{2+}	Nb	Ta	Ti	Sn	Total	Mn/Mn+Fe	Ta/Ta+Nb
Ta-91-BB	11.95	3.98	18.79	66.04	0.38	0.37	101.51	0.75	0.24	0.63	1.33	0.02	0.01	3.00	0.75	0.67
Ta-91-CC	8.99	3.08	6.03	66.66	0.39	14.81	99.96	0.61	0.20	0.21	1.45	0.02	0.47	2.99	0.74	0.86
Ta-92-T1	11.64	5.30	35.97	44.11	1.03	0.61	98.66	0.68	0.30	1.12	0.82	0.05	0.01	3.00	0.69	0.42
Ta-92-TT	10.56	5.86	27.75	52.20	1.16	0.50	98.03	0.64	0.35	0.90	1.02	0.06	0.01	3.01	0.64	0.53
Ta-95-EE	15.17	2.57	46.09	35.76	0.66	0.00	100.25	0.83	0.14	1.35	0.63	0.03	0.00	2.99	0.85	0.31
Ta-97-BB	15.58	1.72	35.06	48.05	0.00	0.00	100.41	0.91	0.09	1.09	0.90	0.00	0.00	3.00	0.90	0.45
Ta-97-CC	14.71	4.51	55.49	25.84	0.63	0.00	101.18	0.76	0.23	1.54	0.43	0.02	0.00	3.00	0.76	0.21
Ta-97-EE	17.11	2.09	56.24	25.01	0.22	0.00	100.67	0.89	0.10	1.57	0.42	0.01	0.00	3.00	0.89	0.21
Ta-97-GG	17.27	1.97	56.34	24.58	0.27	0.05	100.48	0.90	0.10	1.57	0.41	0.01	0.00	3.00	0.89	0.20
DH-Ta-1-A	13.60	3.20	32.17	49.38	0.71	0.19	99.25	0.81	0.18	1.02	0.94	0.03	0.00	3.00	0.81	0.48
* DH-Ta-2-1	8.43	2.73	69.00	1.99	0.63	16.01	98.79	0.59	0.18	0.01	1.55	0.03	0.53	2.98	0.75	0.95
DH-Ta-3	14.52	2.52	33.59	47.93	0.40	0.83	99.79	11.24	1.95	23.48	39.25	0.24	0.65	3.01	0.85	0.46
DH-Ta-6-A	14.47	2.16	27.77	54.57	0.50	0.53	100.00	0.87	0.12	0.90	1.06	0.02	0.01	3.01	0.87	0.54
DH-Ta-7-A	10.29	5.75	20.05	63.40	0.32	0.00	99.81	0.65	0.36	0.68	1.29	0.01	0.00	3.01	0.64	0.65
* DH-Ta-7-B	8.75	3.21	7.07	64.22	1.36	15.13	99.74	0.58	0.21	0.25	1.38	0.08	0.47	2.99	0.73	0.84
* DH-Ta-7-1	8.54	2.93	5.97	63.18	1.16	8.54	90.32	0.63	0.21	0.23	1.51	0.07	0.30	2.98	0.74	0.86
DH-Ta-8-A	13.57	2.08	19.35	63.40	0.31	0.51	99.22	0.87	0.13	0.66	1.30	0.01	0.01	3.00	0.86	0.66
DH-Ta-8-B	13.55	1.89	17.38	66.98	0.46	0.27	100.53	0.87	0.12	0.59	1.38	0.02	0.00	3.00	0.87	0.69
DH-Ta-12-1	13.82	2.55	24.24	57.00	0.74	0.00	98.35	0.86	0.15	0.81	1.14	0.04	0.00	3.02	0.84	0.58
DH-Ta-12-2	14.98	1.88	31.92	48.78	0.78	0.53	98.87	0.89	0.11	1.01	0.93	0.04	0.01	3.01	0.89	0.47
DH-Ta-13-1	15.58	2.61	42.60	38.87	0.45	0.45	100.56	0.87	0.14	1.27	0.69	0.02	0.01	3.01	0.85	0.35
DH-Ta-16-1	14.42	1.56	19.89	64.89	0.31	0.00	100.41	0.91	0.09	0.67	1.30	0.01	0.00	3.01	0.90	0.66
DH-Ta-17-B	14.83	0.96	29.02	53.59	0.40	0.25	99.05	0.90	0.05	0.94	1.04	0.02	0.00	2.98	0.94	0.52
DH-Ta-18-A	17.18	1.20	45.04	35.57	0.48	0.00	99.47	0.95	0.06	1.33	0.63	0.02	0.00	3.01	0.93	0.32
DH-Ta-18-B	17.08	1.13	43.57	36.38	0.29	0.00	98.45	0.96	0.06	1.31	0.66	0.01	0.00	3.02	0.93	0.33
DH-Ta-18-C	16.13	2.78	51.06	28.33	0.35	0.00	98.65	0.87	0.14	1.48	0.49	0.01	0.00	3.01	0.85	0.25
DH-Ta-20-1	13.46	2.96	25.46	57.00	0.40	0.00	99.28	0.83	0.18	0.84	1.13	0.02	0.00	3.01	0.82	0.57
DH-Ta-20-2	16.90	2.30	51.74	29.77	0.55	0.00	101.26	0.89	0.12	1.46	0.50	0.02	0.00	3.01	0.88	0.25
DH-Ta-22	14.69	2.92	40.12	41.50	0.46	0.00	99.69	0.83	0.16	1.22	0.76	0.02	0.00	3.00	0.83	0.38
DH-Ta-23	11.75	4.26	32.02	50.83	0.95	0.27	100.08	0.69	0.24	1.01	0.96	0.05	0.00	2.97	0.73	0.48
DH-Ta-24	12.38	6.36	50.12	30.79	0.53	0.00	100.18	0.66	0.33	1.44	0.53	0.02	0.00	3.00	0.66	0.27
DH-Ta-24X	13.41	4.37	46.07	35.09	1.07	0.42	100.43	0.73	0.23	1.34	0.61	0.05	0.01	2.99	0.75	0.31
DH-Ta-25	15.47	1.32	35.34	46.89	0.91	0.66	100.59	0.89	0.07	1.09	0.87	0.04	0.01	2.99	0.92	0.44

Appendix B

MINERAL GEOCHEMICAL MAPS

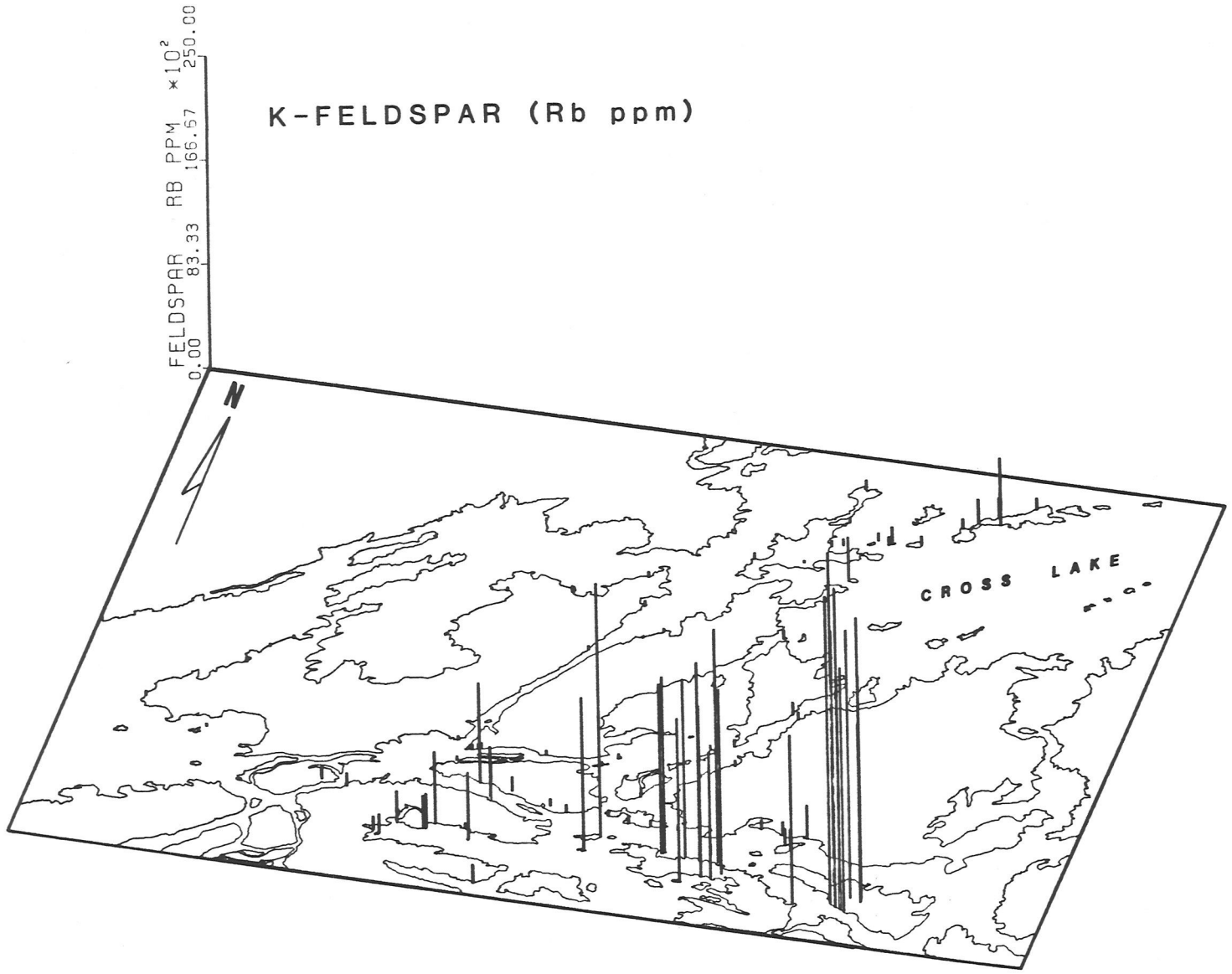

Figure 82: Map of the Cross Lake area showing the average Rb content of K-feldspars from individual pegmatites and pegmatitic granites.

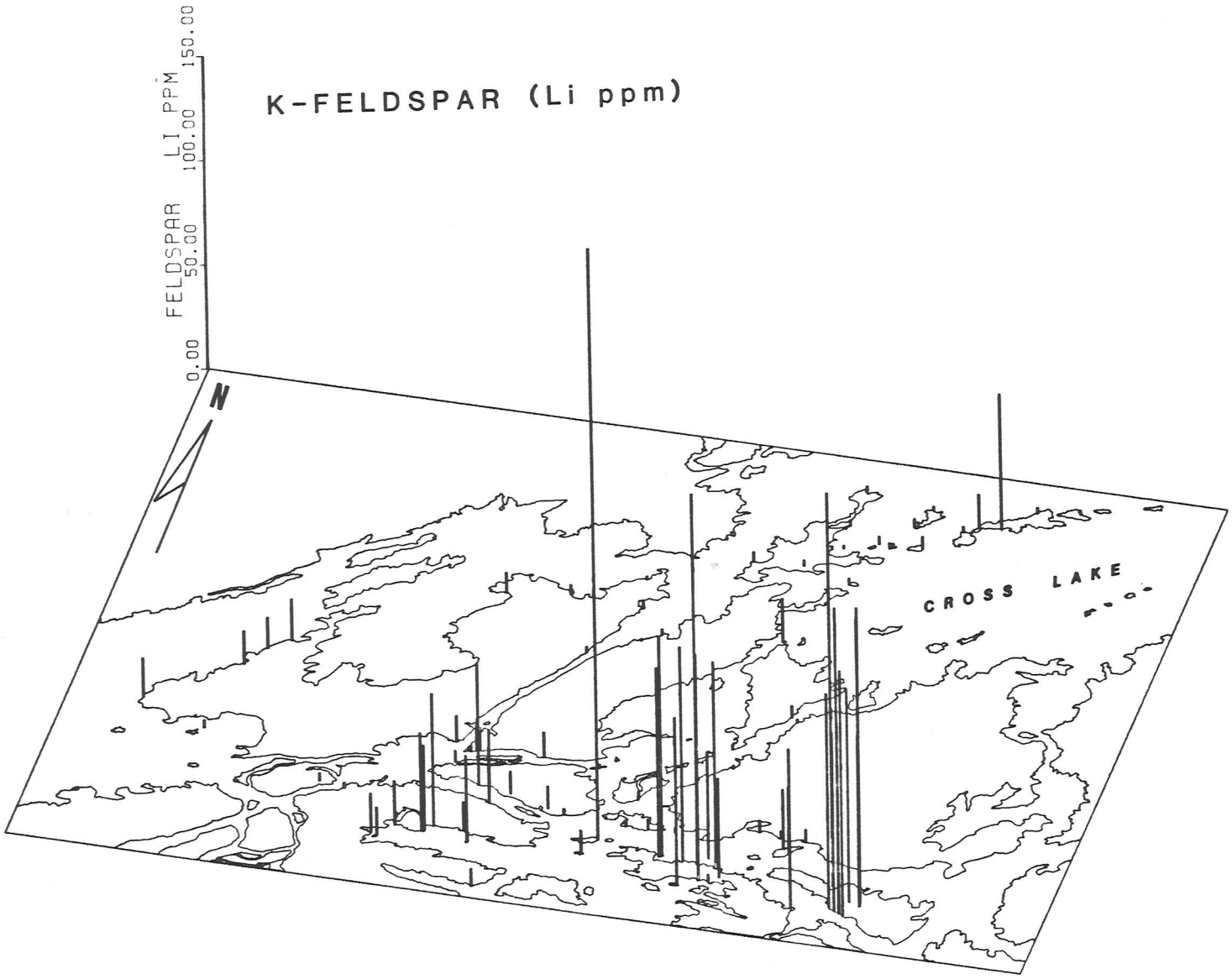

Figure 83: Map of the Cross Lake area showing the average Li content of K-feldspars from individual pegmatites and pegmatitic granites.

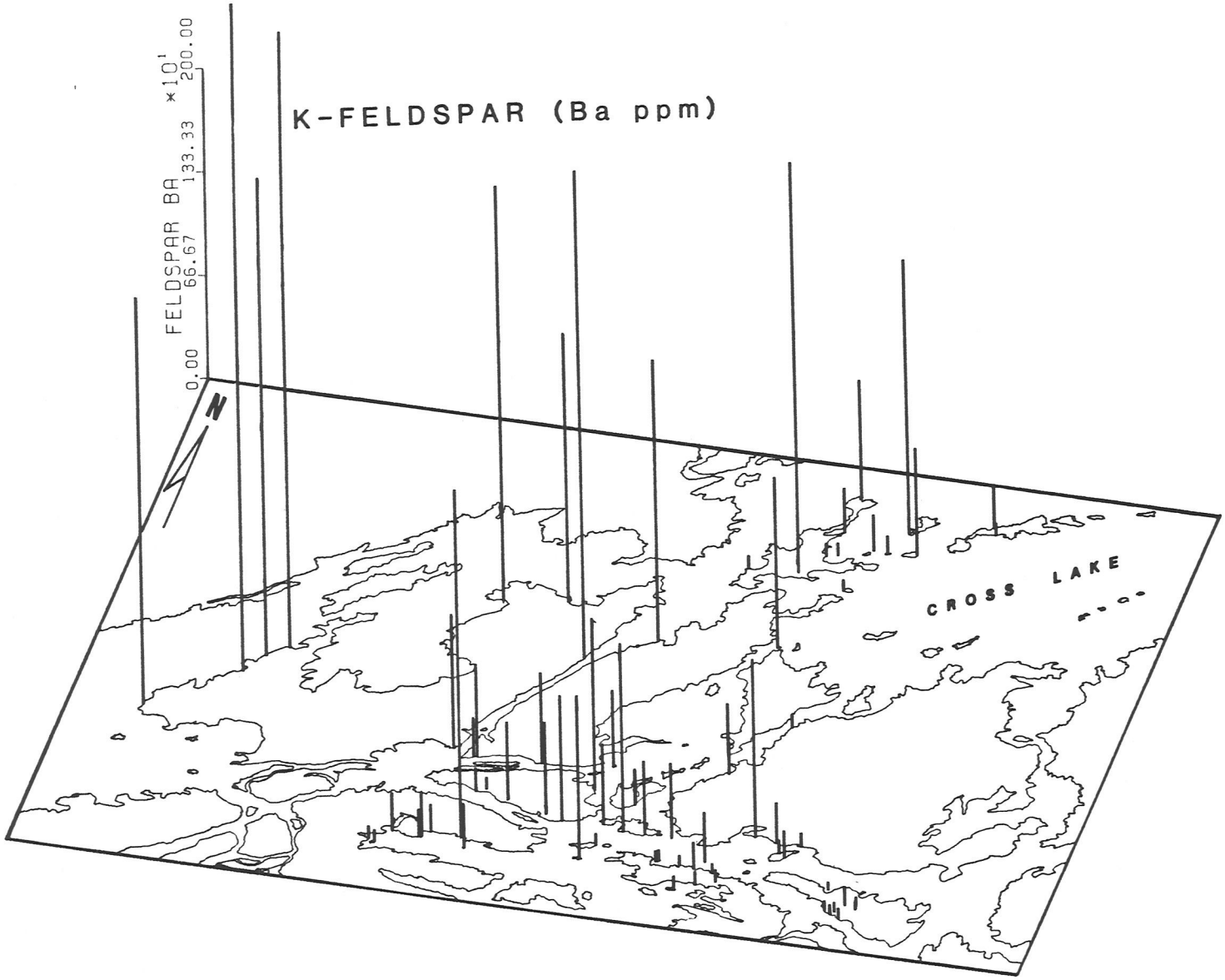

Figure 84: Map of the Cross Lake area showing the average Ba content of K-feldspars from individual pegmatites and pegmatitic granites.

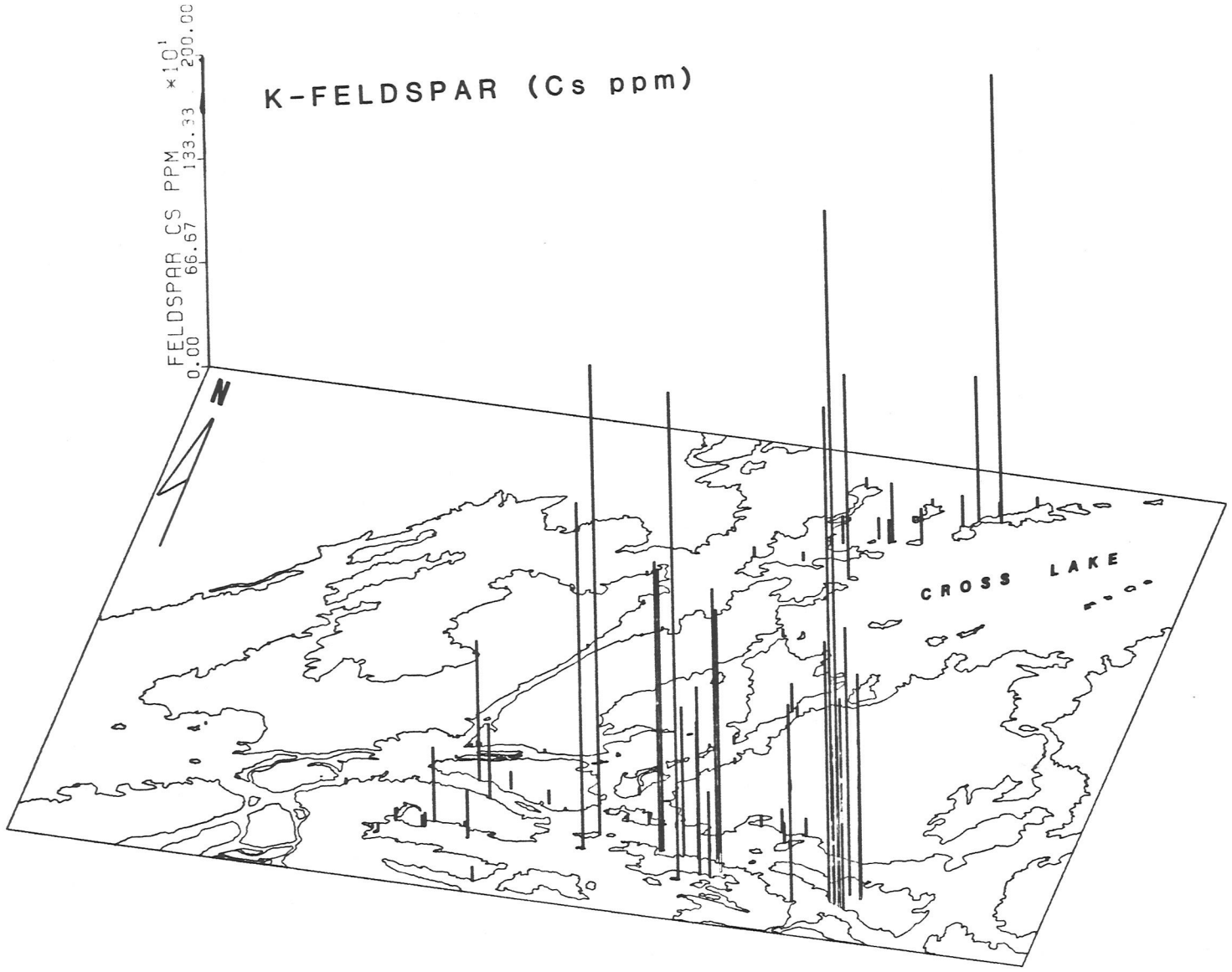

Figure 85: Map of the Cross Lake area showing the average Cs content of K-feldspars from individual pegmatites and pegmatitic granites.

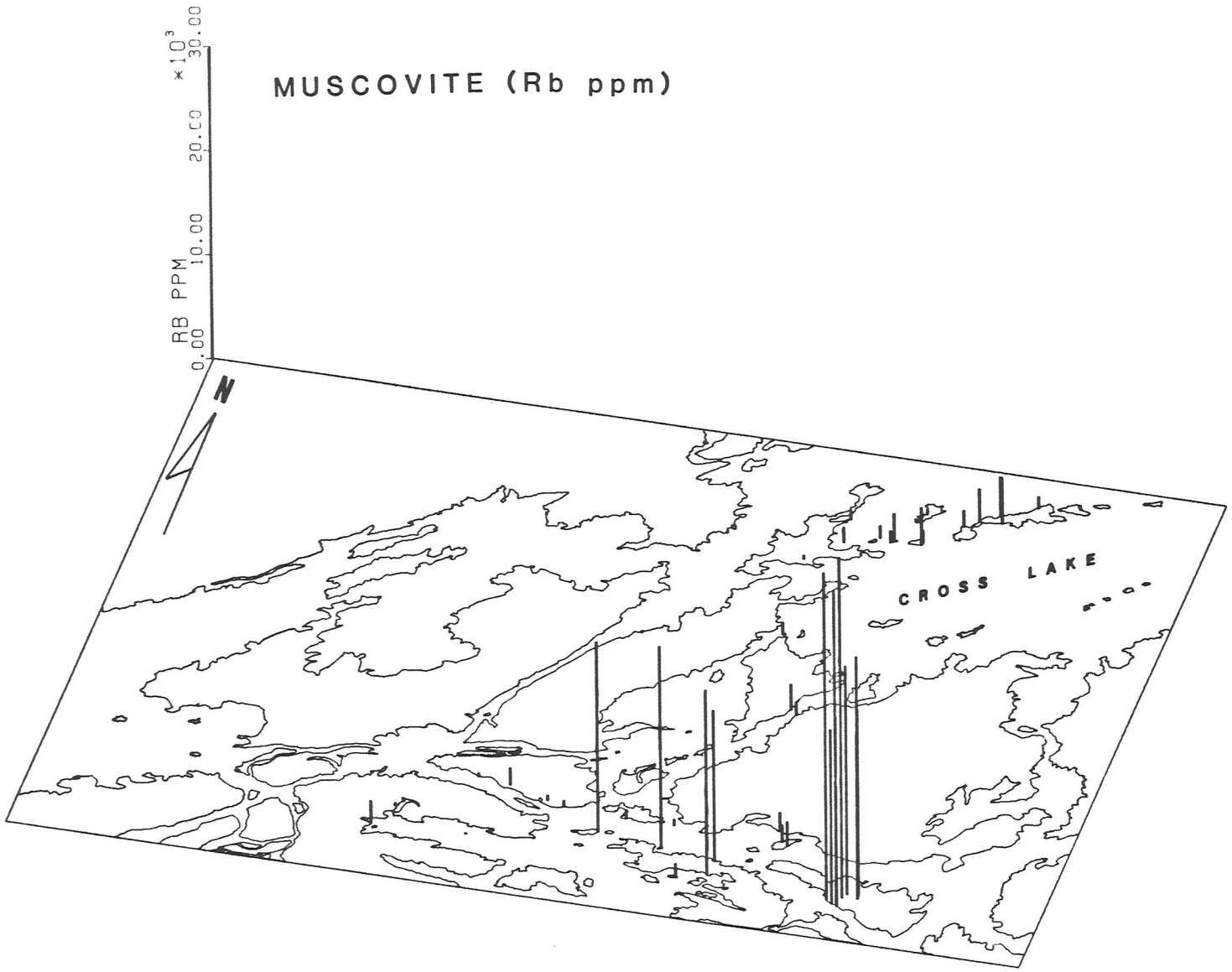

Figure 86: Map of the Cross Lake area showing the average Rb content of muscovites from individual pegmatites and pegmatitic granites.

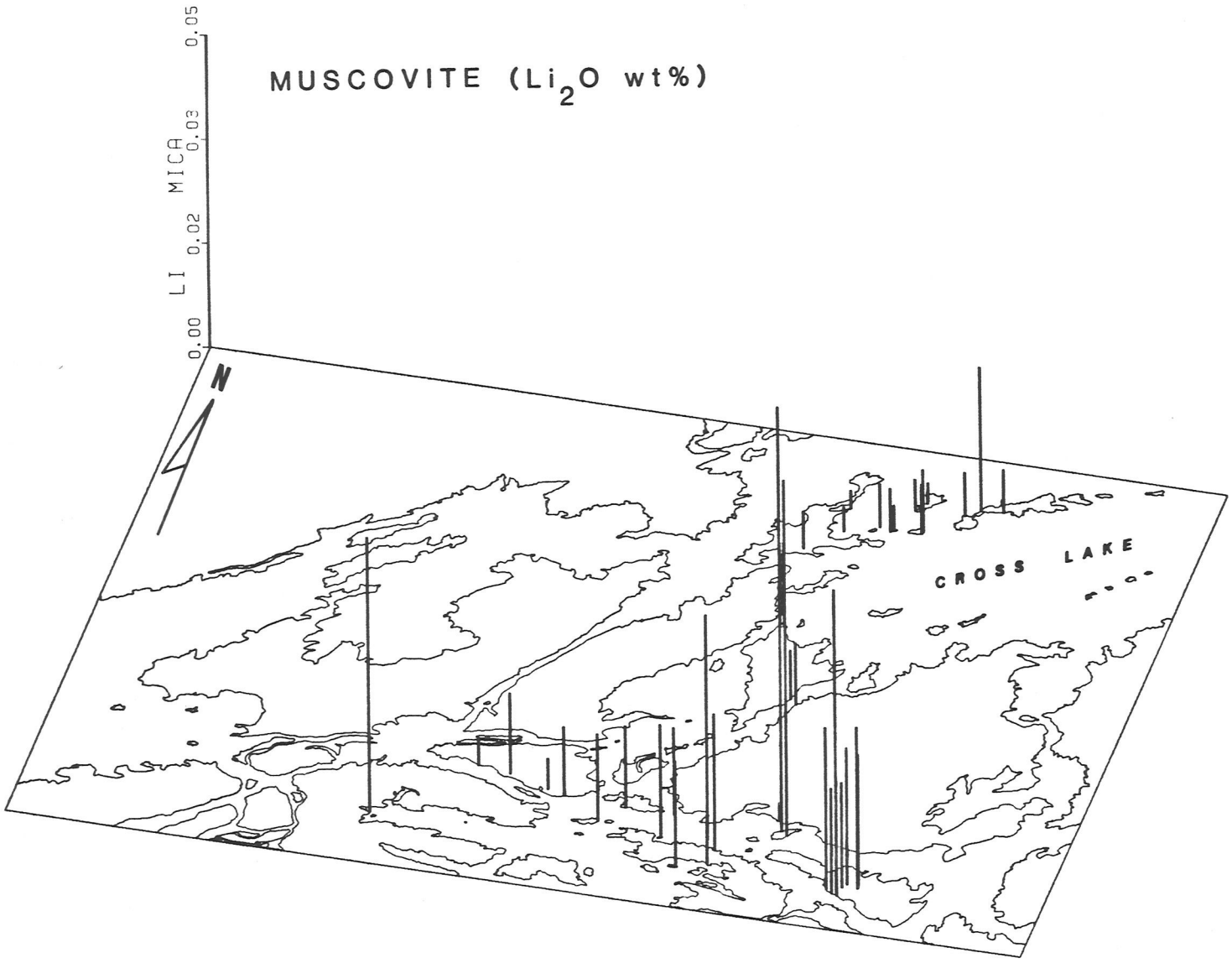

Figure 87: Map of the Cross Lake area showing the average Li content of muscovites from individual pegmatites and pegmatitic granites.

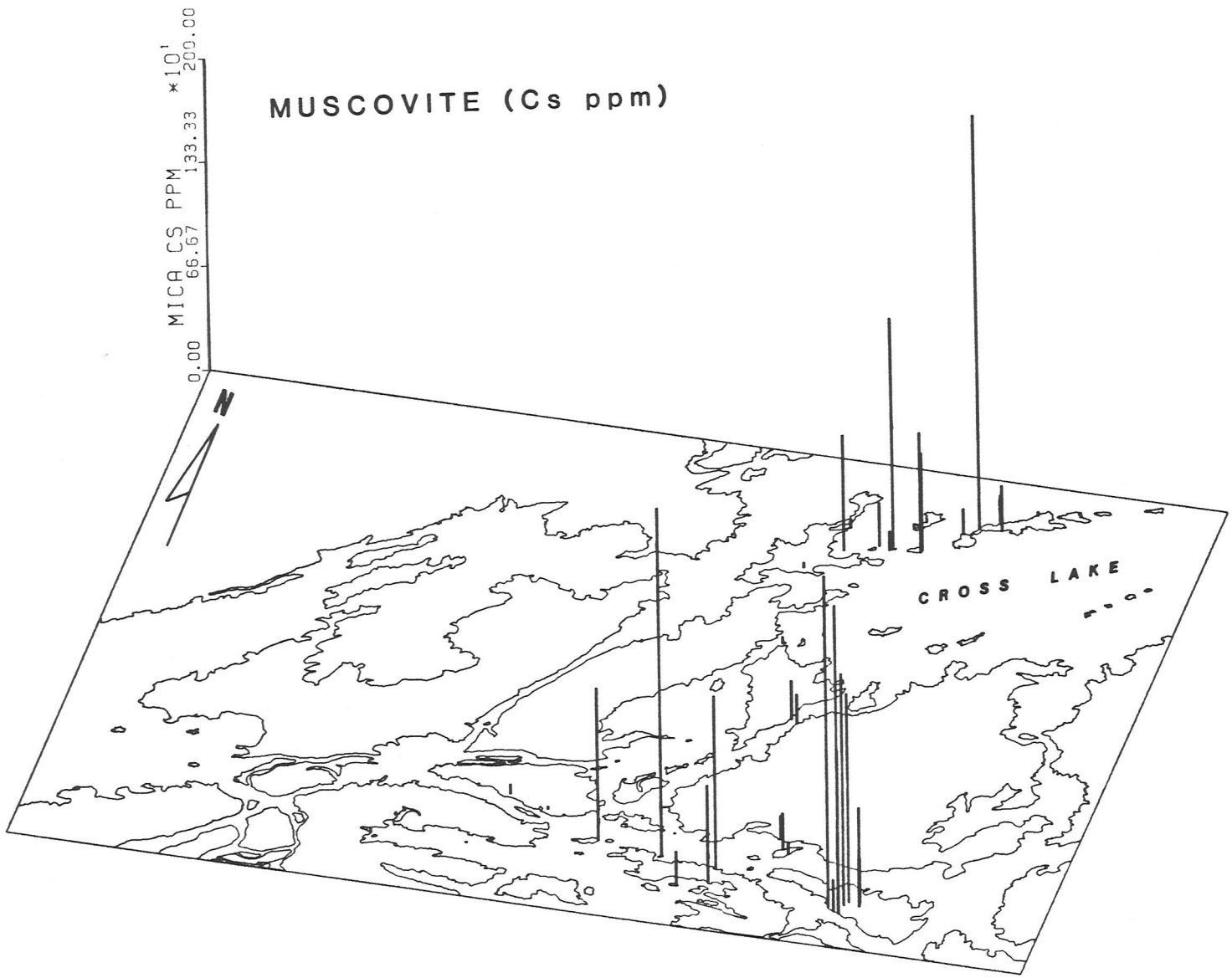

Figure 88: Map of the Cross Lake area showing the average Cs content of muscovites from individual pegmatites and pegmatitic granites.

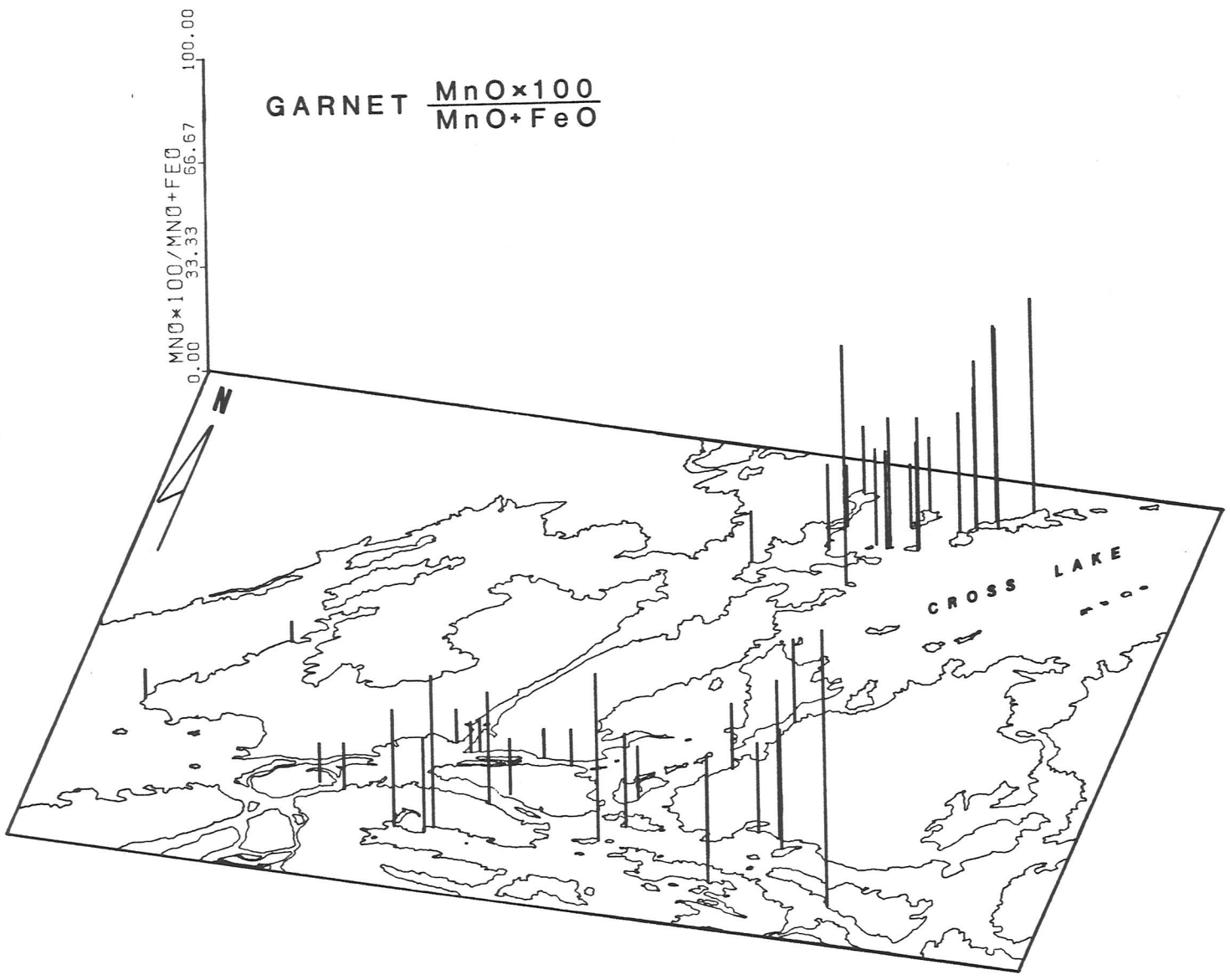

Figure 89: Map of the Cross Lake area showing the average MnO X 100/MnO + FeO content of garnets from individual pegmatites and pegmatitic granites.

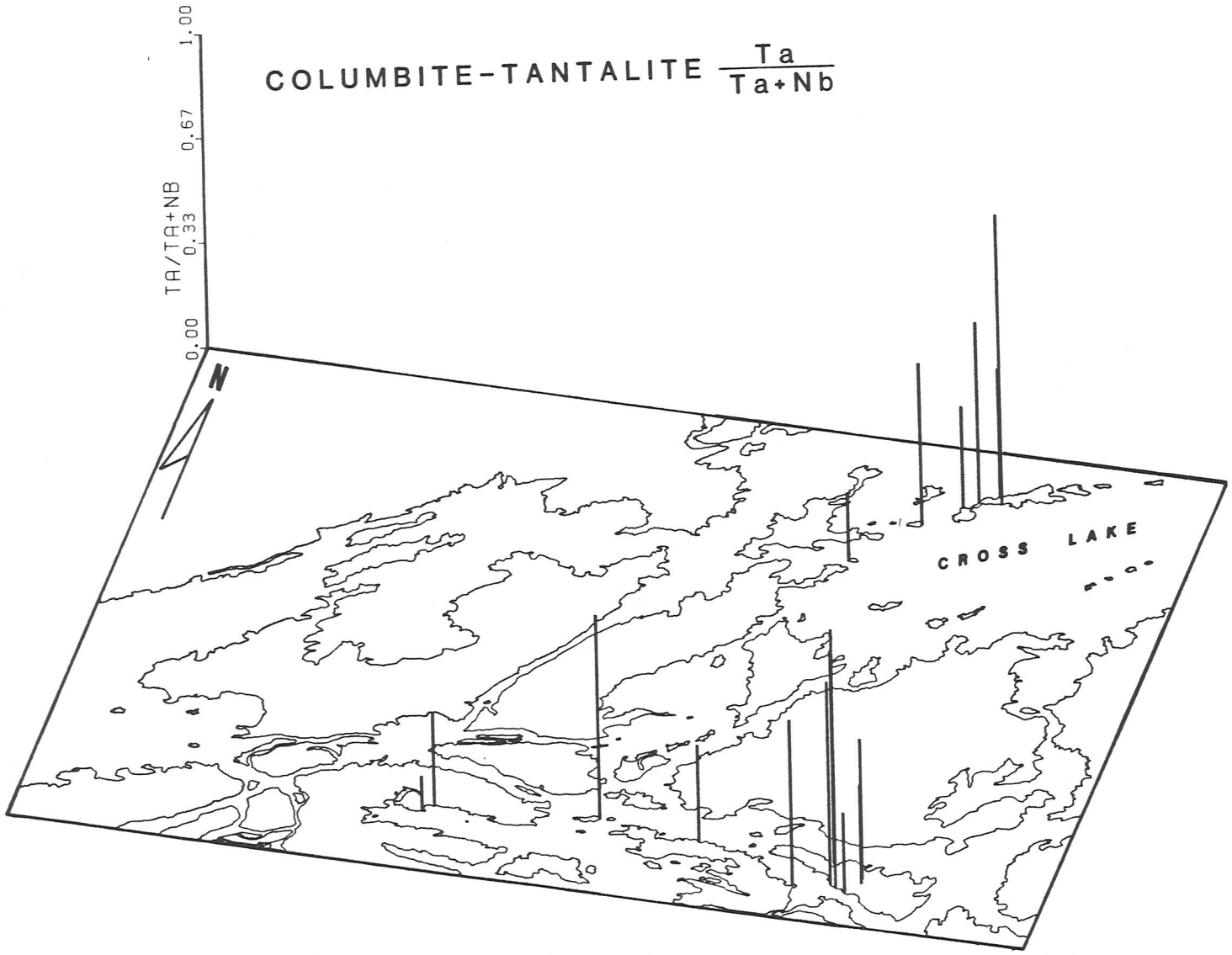

Figure 90: Map of the Cross Lake area showing the average Ta/Ta + Nb content of muscovites from individual pegmatites.

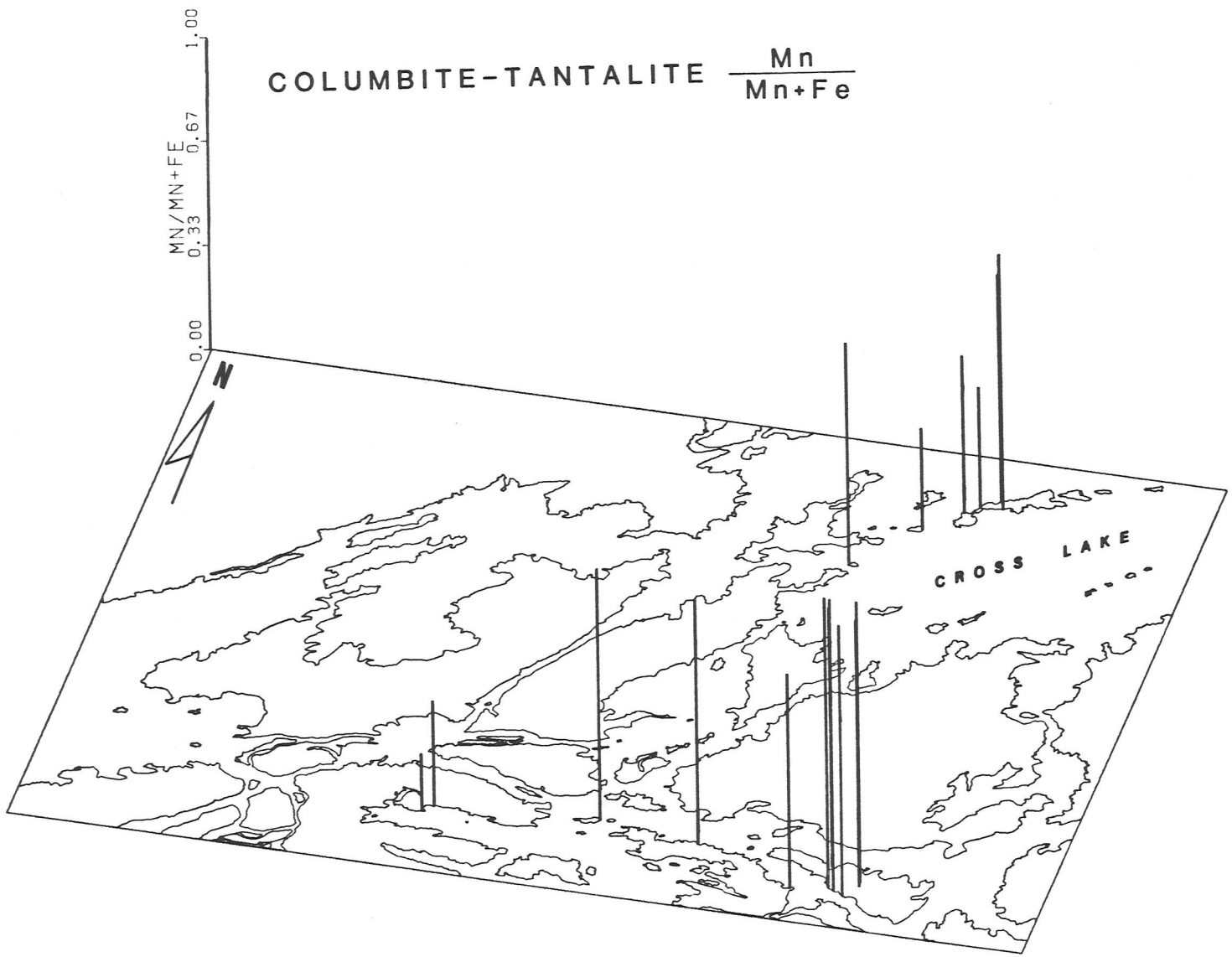

Figure 91: Map of the Cross Lake area showing the average Mn/Mn + Fe content of columbite-tantalite minerals from individual pegmatites.

Appendix C

SYMBOL LEGEND

PEGMATITE SERIES SYMBOLS

- NELSON SERIES
- MINAGO SERIES
- NORTHERN SERIES (BARREN MUSCOVITE ZONE)
- NORTHERN SERIES (BERYL-COLUMBITE ZONE)
- SOUTHERN SERIES (BIOTITE-PERISTERITE ZONE)
- SOUTHERN SERIES (SPODUMENE ZONE)

GRANITE, PEGMATITIC GRANITE AND MIGMATITE SYMBOLS

- METIS
- WHISKEY JACK
- ROSS
- CHANNEL
- SHOAL
- WAPMET
- BRIDGE
- NORTH CROSS
- PEGMATITIC GRANITE
- PGR-24
- MIGMATITE