THE PETROLOGY OF THE
METAVOLCANIC ROCKS OF THE
RUSTY LAKE AREA, MANITOBA

A Thesis
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by
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ABSTRACT

A study of the mineralogical and chemical properties of the metavolcanic rocks of the Rusty Lake greenstone belt was accomplished by means of sampling on a 1000 foot grid. In total, this greenstone belt is exposed over more than 250 square miles. Metavolcanic rocks constitute about 40 per cent of this belt with the remainder being made up of pyroclastic rocks, volcanic wackes and volcanic siltstones. Of the samples collected, 44 were submitted for chemical (major element) analyses.

Based on field observations and the mineralogical and chemical composition of these metavolcanic rocks, the following conclusions were drawn:

1) The order of decreasing abundance in the volcanic pile, which consists of two separate volcanic sequences, is basalt - andesite - picrite - dacite - rhyodacite - rhyolite.

2) There is no chemical difference between the two separate volcanic sequences except that there are no acid volcanic rocks associated with the upper volcanic sequence.

3) The metavolcanic rocks are chemically similar across the whole of the Rusty Lake greenstone belt and, in general, exhibit a high-alumina to tholeiitic character.

4) Field observations of preserved primary structures suggest that the major part of the volcanic pile was extruded in a shallow marine or subaerial environment.

5) The metavolcanic rocks of the Rusty Lake greenstone

belt show six distinctive chemical characteristics: (a) a high and extremely variable Al_2O_3 content, (b) a low TiO_2 content, (c) high FeO/Fe_2O_3 ratios, (d) a high CaO content with a corresponding low MgO content, (e) a low alkali content, especially K_2O and (f) a high volatile (CO_2 and H_2O) content.

6) The intrusive rocks in the Rusty Lake area show only minor differences in chemical and mineralogical composition to their respective extrusive equivalents.

INTRODUCTION

During the field seasons of 1969 and 1970 the writer and C.F. Lamb re-examined the Rusty Lake greenstone belt in conjunction with the Southern Indian Lake project of the Geological Survey of Manitoba. The purpose of this study was to determine the chemical nature and, if possible, the tectonic setting of this greenstone belt. The area mapped (by the writer and C.F. Lamb) is outlined in Figure 1.

A complete differentiation trend of extrusive rocks (from picrites to rhyolites) exists in the volcanic pile and at least one analysis of each rock type is presented in Table 3 (chemical analyses and C.I.P.W. norms). Some analyses of gabbros and diorites are also included in this table. Although the rocks of the Rusty Lake greenstone belt have been regionally metamorphosed to the lower amphibolite facies, only 3 or 4 samples contain anomalous amounts of alkalies and/or volatiles. This would indicate that metasomatic processes played a very minor role in the alteration of these rocks. The chemical analyses were plotted on a set of variation diagrams introduced by Kuno (1960) in his study of Japanese basalts. The only modification of these diagrams made by the writer was the plotting of a tholeiitic-alkalic division line in the alkali-SiO_2 diagram (Fig.4). This division line was taken from MacDonald and Katsura (1964) in their study of Hawaiian basalts.

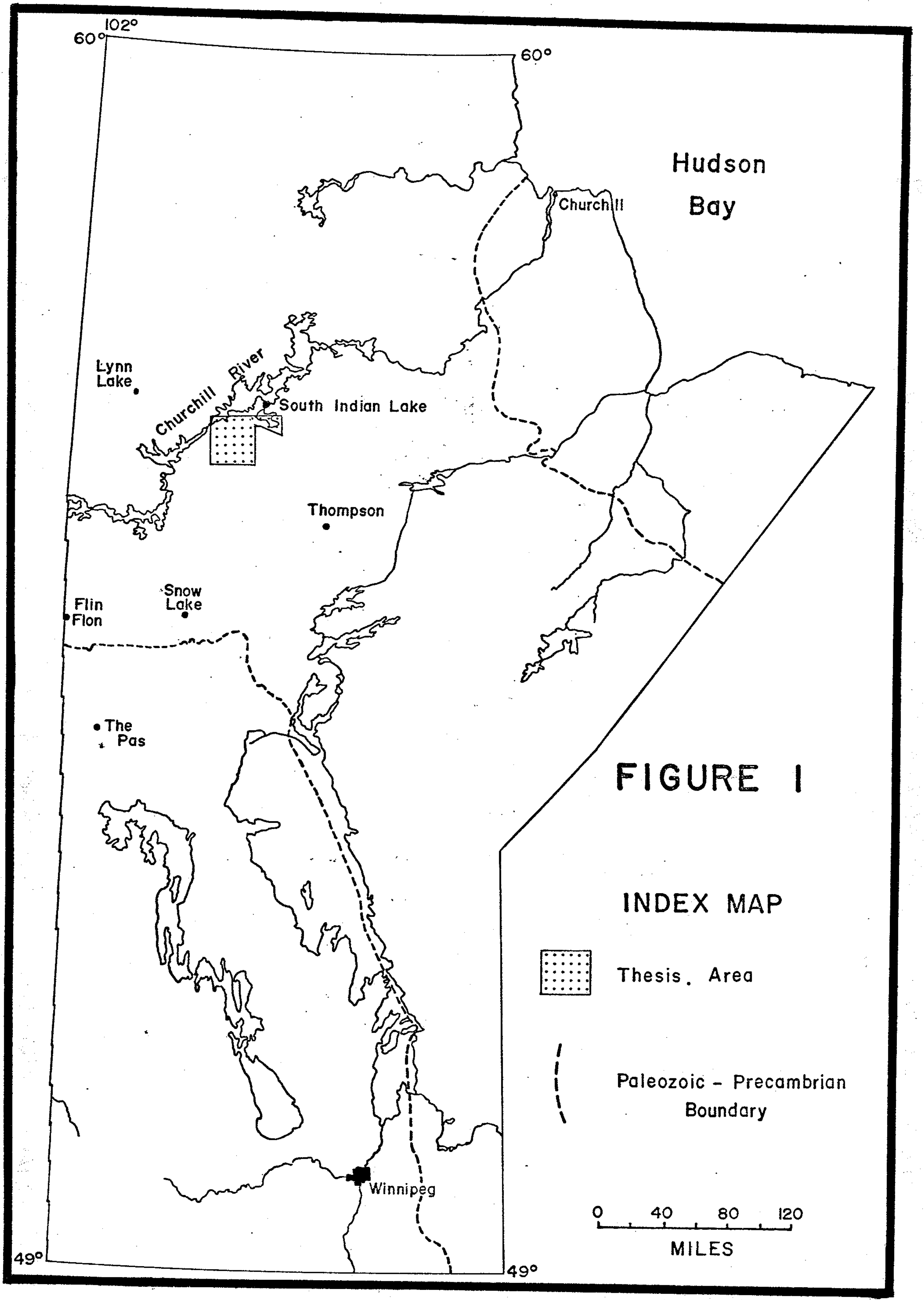

FIGURE I

INDEX MAP

Very little work has been done previously on the greenstone belts of the Churchill Province and, as a result, the metavolcanic rocks of the Rusty Lake area are compared with metavolcanic rocks of the Superior Province (Wilson et al. (1965); Goodwin (1968)).

GENERAL GEOLOGY

Reconnaissance geologic mapping by Henderson et al. (1936) in the Granville Lake area established the presence of a group of medium to coarse-grained clastic metasedimentary rocks lying unconformably on a more highly metamorphosed complex of volcanic and derived volcaniclastic rocks. This group of clastic metasedimentary rocks was called the Sickle Series. Bateman (1945) named the pre-Sickle metavolcanic and derived metamorphosed volcaniclastic rocks the Wasekwan Series. Bateman also subdivided the intrusive rocks of the Granville Lake area into pre-Sickle and post-Sickle intrusions. Milligan (1960), in compiling the geology of the Lynn Lake district, used this division of the Precambrian rock units but added a fifth group; Kisseynew-type gneisses. In the Table of Formations (Table 1), the thirteen map-units have been divided into five major headings: Wasekwan Group, Pre-Sickle Intrusives, Sickle Group, Opachuanau Gneisses and Post-Sickle Intrusives. Map-units within each group conform to an inferred time sequence although the age relationships between some of the intrusive rock units are not clear.

TABLE OF FORMATIONS

PLEISTOCENE and RECENT		Till; lacustrine clays and silts; outwash deposits; minor sand and gravel deposits	
	Map-Unit	MAJOR UNCONFORMITY	
PRECAMBRIAN		POST-SICKLE INTRUSIONS	
	13	Diabase	
	12	Pegmatite	
	11 c)	Quartz-eye granite	
	11 b)	Pink biotite quartz monzonite	
	11 a)	Biotite-hornblende granodiorite	
	10 b)	Biotite-hornblende granodiorite and quartz monzonite	
	10 a)	Biotite-hornblende tonalite and diorite	
		INTRUSIVE CONTACT	
		OPACHUANAU GNEISSES	
	9	Biotite-plagioclase-quartz paragneisses	Derived mainly from rocks of the Sickle Group
		SICKLE GROUP	
	8	Biotite-muscovite schist	
	7	Arkosic conglomerate, arkose	
		UNCONFORMITY	
		PRE-SICKLE INTRUSIONS	
	6 b)	Diorite and quartz diorite	
	6 a)	Gabbro	
		INTRUSIVE CONTACT	
		WASEKWAN GROUP	
	5	Sulphide horizon	
	4	Meta-basalt; meta-andesite	
	3	Metamorphosed volcanic wackes and siltstones; greywacke; meta-argillite; intermediate pyroclastic rocks; medium to coarse-grained plagioclase amphibolite	
	2	Dacite; minor rhyodacite and rhyolite; acid tuff; agglomerate; volcanic breccia	
	1	Meta-basalt; meta-andesite; minor meta-picrite; fine-grained amphibolite	

WASEKWAN GROUP
(THE RUSTY LAKE GREENSTONE BELT)

The oldest rocks in the thesis area appear to be a group of metavolcanic and derived metamorphosed volcaniclastic rocks. Extended limbs and isolated patches exist apart from the main belt, but generally the greenstone belt trends in an easterly to northeasterly direction.

The rocks of the Rusty Lake greenstone belt have been correlated with the Wasekwan Group of the Lynn Lake district by Burwash (1962). This classification was adopted by Pearce (1964), Milligan (1964) and Bristol (1966) who also have carried out geologic mapping in the Rusty Lake area. This classification was made on the basis of lithologic similarity between the rocks of the Rusty Lake greenstone belt and type Wasekwan metasedimentary rocks of the Lynn Lake district. Also, there is an imperfect continuity of scattered outcrop (in a mainly drift covered area), and continuity of aeromagnetic data between the thesis area and known occurrences of Wasekwan rocks in the Granville Lake area. Similar correlation applies to the use of the term Sickle Group for a younger, less deformed series of arkosic and pelitic rocks that unconformably overlie the rocks of the Rusty Lake greenstone belt.

The Wasekwan Group as exposed in the thesis area, consists of up to 80,000 feet of metamorphosed basic, intermediate and acid volcanic rocks and derived metasedimentary rocks. The lower 50,000 feet is made up of massive flows of picrite, basalt and andesite with a number of small lenses of acid volcanic rocks and thin intercalated sedimentary horizons. The upper 30,000 feet consists mainly of volcaniclastic rocks, metagreywacke, meta-argillite and sedimentary amphibolite with minor flows of basic and intermediate volcanic rocks.

Meta-Picrite, Meta-Basalt, Meta-Andesite, Fine-Grained Amphibolite (1)[1]

The basic and intermediate extrusive rocks of the lower volcanic sequence vary in fabric from highly schistose to almost massive. They are black to greenish-black in color and tend to be very fine-grained except for porphyries and in local areas of recrystallization. Metamorphism has destroyed or distorted most of the primary features, but pillow structures and amygdales are recognizable in a few localities. The most common rock type in the sequence is meta-basalt. The mineralogy of the meta-basalt is hornblende (50 to 65 %), plagioclase (30%), biotite (5%) and magnetite (5 to 10 %). Trace amounts of quartz, potash feldspar, sphene, ilmenite, apatite, actinolite, epidote, pyrite and

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[1] Numbers in parenthesis refer to map-units in the Opachuanau Lake-Issett Lake-Pemichigamau Lake area; see geologic map (Fig.8).

other sulphides are also present. In more altered samples, actinolite and epidote become more abundant. None of the thin sections examined contained olivine, serpentine, orthopyroxene or clinopyroxene. The hornblende occurs as subhedral, prismatic crystals, many of which are aligned in the plane of schistosity but oriented randomly within that plane. Most of the hornblende is neither poikilitic nor zoned, and the shape of some crystals together with rare zoning suggests that they are pseudomorphic after pyroxene. This is further substantiated by a relict "hour glass" pattern made up of small anhedral magnetite inclusions in some of the zoned hornblende crystals. The plagioclase, like the hornblende, is usually subhedral. It is often sparsely twinned and ranges in composition from An_{32} to An_{44}. In some cases, relict (unaltered) cores of labradorite (i.e. of composition greater than An_{50}) were observed. These more calcic cores are generally confined to plagioclase phenocrysts in porphyritic rocks. The biotite occurs as subhedral blades in thin lenticular zones or as anhedral grains around the edges of the hornblende crystals. The magnetite is anhedral and its content ranges from 5 to 15%. The trace minerals are generally interstitial with the exception of the epidote and actinolite which in some cases become major constituents of the rock.

Picrite is less abundant in the lower volcanic sequence than either basalt or andesite; it was not distinguished in field mapping but defined by chemical analysis. It is practically indistinguishable from basalt in the field although it appears to be confined, for the most part, to porphyritic flows. The mineralogy of the average picrite is hornblende (50 to 65%), plagioclase (15 to 25%) and magnetite (5 to 15%). Trace amounts of biotite, sphene, ilmenite, actinolite, epidote and minor sulphides are present as well. Biotite occurs only as an alteration product of hornblende. The textural relationships are the same as in the basalts and again it is probable that the hornblende is pseudomorphic after pyroxene. The composition of the plagioclase seldom exceeds An_{40} except in relict cores of phenocrysts.

As in the case of the picrites, rocks of andesitic composition are almost impossible to distinguish from the basalts by field techniques. Some success was achieved with the use of color index in the rocks of the upper volcanic sequence but was found to be totally unreliable in those of the lower volcanic sequence. The andesites are made up of hornblende (35 to 50%), plagioclase (40 to 45%), biotite (10%), quartz (3%) and potash feldspar (2 to 5%). Common accessory minerals are magnetite, actinolite, epidote, apatite, zircon, minor sulphides and occasionally chlorite. The hornblende is subhedral and free of zonations or poikiloblasts. The plagioclase is usually subhedral but occasionally it is present in the form of euhedral laths.

The composition of the plagioclase is generally An_{30} to An_{35} (andesine) but a few determinations revealed a composition below An_{30} (oligoclase). The oligoclase occurs as fresh rims around the more altered laths of andesine. The biotite is subhedral to anhedral and appears to be primary rather than an alteration product of hornblende. Chlorite is not a common constituent in the andesites but does occur in certain restricted areas where it possibly indicates a lowering in regional metamorphic grade.

Within the basic volcanic flows, thin beds of acid volcanic (and pyroclastic) material, volcaniclastic rocks and meta-argillites were often encountered. These are petrographically similar to the acid volcanic rocks (2) and the metasedimentary rocks of the Upper Wasekwan Group. In most cases, they lack the thickness and stratigraphic continuity to constitute mappable units.

Dacite, Rhyodacite, Rhyolite, Acid Tuff, Agglomerate and Volcanic Breccia (2)

Most of the acid rocks of the volcanic pile are confined to two major areas; the first occurs just north of Karsakuwigamak Lake while the second, a series of small lenses around the major volcanic-sedimentary contact, is found south of Rusty Lake. A number of small lenses of these rocks exist apart from the two main areas but, in most cases, they are not mappable. In the field, acidic rocks differ from more basic varieties by their lighter color and conchoidal to sub-conchoidal fracture. Many of the fine-grained acid volcanic rocks display a very thin lamillar bedding (from less than 1 millimeter to approximately 3 centimeters in thickness) that probably reflects primary flow structure as it tends to flow around fragments. Phenocrysts are almost perfectly aligned parallel to the bedding which in some cases is cross-cut at a low angle by the regional foliation. The lamillar bedding itself is composed of alternating light-colored quartzo-feldspathic, and darker, more mafic layers. In areas of intense recrystallization, this flow banding is either poorly defined or destroyed.

The majority of the acid volcanic rocks were found to be dacitic in composition. Commonly they are fine-grained and medium to light-grey in color. The average dacite is composed of quartz (25 to 30%), plagioclase (40%), hornblende (15%), potash feldspar (10%) and biotite (10%). Accessory minerals are magnetite, chlorite, sericite, apatite, zircon and epidote. Often the dacite is porphyritic and phenocrysts of sodic plagioclase, biotite, hornblende, quartz and potash feldspar may constitute as much as 30% of the rock.

The rhyolites and rhyodacites are greyish-white to pink in color and exhibit a more perfect conchoidal fracture than the dacites. They are usually fine-grained to aphanitic (except when recrystallized) but may also be porphyritic. In general, they are texturally and mineralogically similar to the dacites but are richer in quartz and potash feldspar and poorer in mafic minerals and plagioclase. Some of the greyish-white rhyolites south of Rusty Lake consist of quartz (35 to 40%), potash feldspar (40 to 45%), sodic plagioclase (15%), biotite (5%) and hornblende (1 to 2%) with trace amounts of sericite, chlorite, epidote and pyrite. The rhyodacites contain less quartz and potash feldspar and more sodic plagioclase. Phenocrysts of quartz (in bluish-white quartz "eyes"), potash feldspar and sodic plagioclase are common.

The acid tuffaceous rocks are lithologically and mineralogically similar to the rhyolites and rhyodacites. They can be distinguished from the acid extrusives by their coarser grain size. In addition to this, they lack flow structures and are more commonly fragmental. Crystal tuffs are rare. Two occurrences of acid tuffaceous rocks are of particular interest. One is found on an island in the Churchill River about 6 miles east of the western boundary of the map-area while the other is situated southwest of Grass Lake. In both of these localities, the clasts display a pronounced flattening parallel to the bedding. As the regional foliation is not well defined in these areas, they probably represent ignimbritic deposits.

Agglomerates are usually found interbedded with the acid extrusive and tuffaceous rocks. They consist of white to greyish-white, well rounded rhyolitic clasts in a fine-grained more mafic groundmass. Less commonly, agglomerates were encountered in the Upper Wasekwan where they contain basaltic clasts. They are seldom large enough to constitute mappable units as they are rarely thicker than 50 feet and a stratigraphic continuity of more than 250 feet is exceptional.

Volcanic breccias are usually found interbedded with basic volcanic rocks of the lower volcanic sequence and tuffaceous rocks of the Upper Wasekwan. The angular fragments are generally basaltic and in a few localities have retained a "spiral" shape. The groundmass varies from dacitic to andesitic in composition. Two occurrences of volcanic breccia are noteworthy. One is located on the northeast shore of Eagle Lake where the basaltic clasts display a remarkable spiraling and a remnant "bread crust" bomb was identified. In the other locality, on the southwest shore of Opachuanau Lake, the basaltic clasts also exhibit a well defined spiraling. One unusual feature is common to both localities; some of the clasts appear to have been torn apart and the interstices between the fragments are filled with the tuffaceous groundmass. The writer attributes this feature to pressure exerted by escaping gases upon rapid cooling of these deposits.

Some of the volcanic breccias interbedded with the basic and intermediate volcanic rocks contain a number of lithologically dissimilar clasts of varying sizes and shapes. The lack of bedding, definite contact relationships with the surrounding rocks and even rudimentary sorting suggests that these may represent laharic deposits (volcanic mudflows). This has also been suggested by Milligan (1964) who noted similar deposits in the Earp Lake area.

Metamorphosed Volcaniclastic and Pyroclastic Rocks, Metagreywacke, Meta-Argillite, Amphibolite (3)

The greatest stratigraphic thickness of metasedimentary rocks rests unconformably on the metavolcanic rocks and constitutes the major part of the 30,000 feet of the Upper Wasekwan. A number of horizons of metasedimentary rocks were also encountered in the Lower Wasekwan (1) but many of these were too small to be mapped separately. Almost no primary structures other than compositional layering (which probably reflects original bedding) were observed. The pyroclastic rocks which contain a large number of fragments (from lapilli-sized particles to bombs and blocks) display no graded bedding or sorting of the larger clasts. The writer observed a feature in three or four localities that appears to be cross bedding but could be due also to the regional foliation cutting the bedding at a low angle.

The volcaniclastic rocks are made up of volcanic wackes and volcanic siltstones. Both are black to dark-grey and in many instances are extremely difficult to separate from the basic and intermediate volcanic rocks (1). However, the volcaniclastic rocks tend to be more granular in appearance. The mineralogy of these rocks is similar to that of the intermediate volcanic rocks except that they are more siliceous. An average mineralogical composition of the volcaniclastic rocks is plagioclase (40%), quartz (10 to 25%), hornblende (20 to 25%), biotite (15%) and potash feldspar (5%). Common accessory minerals are diopside, epidote, sericite, magnetite, zircon, apatite and rarely, chlorite. The majority of the grains are anhedral.

In the field, lithic greywackes may be distinguished from the volcaniclastic rocks by their lighter color and the fact that they often contain visible quartz. They do, however, have the same granular appearance. The medium to light-grey greywackes are usually bedded with alternating thick quartzo-feldspathic and thin biotite-rich layers. Occasionally the greywackes are conglomeratic containing well rounded clasts of mafic and acid material that vary considerably in size. The composition of these rocks is sodic plagioclase (40%), quartz (30 to 35%), biotite (25%) and hornblende (5%) with trace amounts of chlorite, sericite, magnetite, carbonate and apatite. A chemical analysis was made of one of the typical greywackes and is presented below:

Sample Number: 28-0-262

Laboratory Number: R-688

Oxide	Per Cent
SiO_2	68.15

Oxide	Per Cent
Al_2O_3	16.0
TiO_2	0.50
Fe_2O_3	0.88
FeO	3.06
MnO	0.04
CaO	1.22
MgO	1.71
Na_2O	2.12
K_2O	3.95
P_2O_5	0.20
H_2O	1.53
CO_2	0.48
Total	99.85

Intermediate pyroclastic rocks constitute almost one half of the Upper Wasekwan, although they seldom occur in stratigraphic thicknesses of over 500 feet. In general, they occur as horizons varying in thickness from 50 to 200 feet that are only rarely continuous for more than a few thousand feet. In the northwestern portion of the Upper Wasekwan, however, intermediate tuffaceous rocks make up a vast stratigraphic thickness that is interrupted only by thin seams of basic and intermediate metavolcanic rocks. The pyroclastics in this area are generally non-fragmental. The tuffaceous rocks of the Upper Wasekwan range from andesitic to dacitic in composition and are commonly grey to greyishgreen in color. The grain size of these rocks is variable due to widespread recrystallization.

Meta-argillites occur only as thin seams in the metavolcanic and metasedimentary rocks of the Wasekwan Group. They are rarely more than 50 feet thick in the southern half of the map-area but may reach thicknesses of more than 200 feet north and east of Rusty Lake. The meta-argillites in the southern half of the map-area are very fine-grained, light-grey and extremely difficult to distinguish from acid metavolcanic rocks. They consist of quartz (55%), plagioclase (15%) and biotite (30 to 35%) with trace amounts of sericite, apatite, magnetite and garnet. In northern sections of the Wasekwan Group, the meta-argillites are richer in biotite and often recrystallized to such an extent that they are now quartz-biotite schists. The meta-argillites are the only rocks of the Rusty Lake greenstone belt that commonly contain garnet.

The medium to coarse-grained plagioclase amphibolites have a dual paragenesis. In general, they result from intense local recrystallization of the volcaniclastic rocks. Less commonly, the amphibolites appear to represent metamorphosed marls or impure dolomites. The average mineral content of the plagioclase amphibolite is hornblende (40 to 50%), plagioclase (40%), quartz (5 to 10%) and epidote (5%) Common accessory minerals are magnetite, potash feldspar, sericite and sulphides.

Meta-Basalt, Meta-Andesite (4)

The meta-basalts and meta-andesites of the second basic extrusion are younger than the majority of the meta-sedimentary rocks of the Upper Wasekwan. They are not nearly so widespread as those of the lower volcanic sequence (1) as they are present only as sills and isolated lensoid bodies. These rocks are fairly fresh in appearance and primary features, especially amygdaloidal and vesicular lavas, are more readily recognizable. Commonly, these volcanic rocks are aphanitic with porphyritic varieties being restricted to the western portion of the map-area along the Churchill River.

Amygdaloidal and vesicular lavas are most prevalent in the northwestern portion of the map-area. Neither the amygdales nor the vesicles display intensive deformation. The amygdales are now composed of quartz and carbonate. Pillow structures were observed in only one locality; these occur about 3,000 feet south of the narrows of Rusty Lake. A well preserved flow top breccia, a feature not encountered in the lower volcanic sequence, was observed about 2 miles west of Rusty Lake.

Basaltic rocks appear to be more abundant than those of andesitic composition. No rocks of a picritic composition were observed. Texturally and mineralogically, the meta-basalts and meta-andesites are identical to those of the Lower Wasekwan (1). The only significant difference is that the hornblende and plagioclase crystals are more frequently zoned and the hornblende is occasionally poikilitic. Pyroxene, olivine and serpentine were not observed in the thin sections examined.

Sulphide Horizons (5)

Three separate sulphide horizons are found north and east of Rusty Lake where they define major fold structures.

Burwash (1962) states that this rock type consists mainly of quartz and pyrrhotite with varying amounts of plagioclase, microcline, hornblende, tremolite-actinolite, diopside, epidote, carbonate, biotite and sphene. Samples examined by the writer contained at least 50% quartz and up to 30% sulphides (mainly pyrrhotite and pyrite).

Burwash (1962) concluded that these horizons are pyrrhotite-bearing tuffs. The writer does not concur with this statement but instead interpretes them as being tectonically controlled, silicified and mineralized horizons. The great variation in mineralogy of these rocks suggests that this unit is derived from more than one rock type and not merely a more porous tuffaceous rock.

PRE-SICKLE INTRUSIVE ROCKS

Hornblende gabbros and hornblendites (6a), and the hornblende diorites and quartz diorites (6b) have been classified as Pre-Sickle in age. These rocks intrude those of the Wasekwan Group but their relationships with Sickle Group rocks are not known. However, these rocks are the only intrusions that display a well defined secondary foliation which suggests that they are the oldest intrusive rocks in the map-area.

The gabbro and hornblendite (6a) form a number of small lensoid bodies that are scattered throughout the map-area with the largest occurring in the southwestern portion, west of Karsakuwigamak Lake. The diorite and quartz diorite (6b) are more abundant than the mafic rocks and occur as irregular stocks in the southern half of the map-area and north of Rusty Lake. One sill of mappable proportions is situated just north of Ruttan Lake.

Both gabbros and diorites, units 6a and 6b respectively, were chemically analyzed and were found to be similar to their extrusive equivalents in the main volcanic sequence (1). This would indicate that they may have been derived from the same magma source.

Hornblende Gabbro, Minor Hornblendite (6a)

The hornblende gabbros and hornblendites are greenish-black, coarse-grained and, for the most part, well exposed. Hornblendite is not as common as gabbro and usually occurs only as central core zones of predominantly gabbroic plugs. The hornblendite is composed of hornblende (80 to 90%), plagioclase (5 to 10%, An_{38} to An_{46}) and epidote (5%) with accessory magnetite, uralite, actinolite, sphene and sulphides. The mineralogy of the gabbro is hornblende (60 to 75%), epidotized plagioclase (20 to 35%), magnetite (3%) and biotite (2%) with the same accessory minerals that are found in the hornblendite. As in the metavolcanic rocks, much of the hornblende is probably pseudomorphic after pyroxene. This is substantiated somewhat by the presence of uralite.

Hornblende Diorite, Quartz Diorite (6b)

Hornblende diorite and quartz diorite (6b) are medium to coarse-grained mesocratic rocks and the quartz diorite may have been formed by local silica enrichment rather than as a separate differentiate. The average mineralogical composition of the hornblende diorite is hornblende (35%), plagioclase (40 to 45%, An_{28} to An_{42}), quartz (5 to 10%), biotite (5 to 10%) and potash feldspar (5%). Common accessory minerals are magnetite, epidote, chlorite, sphene, apatite, zircon, sericite and sulphides. Dioritic rocks with over 10% quartz were classified as quartz diorites. The only intrusive body that is composed entirely of quartz diorite is the small stock on the west shore of Rusty Lake.

SICKLE GROUP

Rocks of the Sickle Group outcrop to the northwest of Rusty Lake, along the south shore of the Churchill River, and immediately south of the Opachuanau Gneisses (9) in the eastern half of the map-area. A slight angular unconformity was observed between the Sickle rocks and those of the Wasekwan Group where sufficient outcrop was present to determine stratigraphic relationships between the two. There also appears to have been a long period of erosion between the deposition of Wasekwan rocks and the deposition of the basal units (arkose and arkosic conglomerate) of the Sickle Group. Evidence of this is the large number of clasts (mainly of pebble and cobble size) of Wasekwan and Pre-Sickle intrusive material found in the arkosic conglomerate northwest of Rusty Lake.

Although the Sickle Group in the map-area does not strike into the type locality at Granville Lake, similarities in lithology and age relations suggest that they are equivalent. The Sickle Group in the map-area was originally made up of conglomerate, arkose, shale and siltstone. A few hornblende rich horizons also occur in the Sickle Group which probably represent thin calcareous lenses but could also be thin layers of metavolcanic rocks.

Primary structural features such as graded bedding, cross bedding, ripple marks and sole markings were not observed in the rocks of the Sickle Group.

Arkosic Conglomerate, Minor Arkose (7)

The arkosic conglomerate shows less deformation than any other rock unit of the Sickle Group. Clasts are commonly round and display only a minor elongation parallel to the foliation but they are rotated into the plane of the foliation. In areas of intense recrystallization and deformation, near the contact with the Opachuanau Gneisses (9), the pebbles and cobbles are often severely deformed and siliceous clasts are no longer recognizable.

The matrix of the conglomerate is light-grey and fine to medium-grained. The average mineralogical composition of the matrix is quartz (65 to70%), sodic plagioclase (13%), microcline (7%) and biotite (10%) with trace amounts of magnetite, epidote and disseminated sulphides. The most frequent types of clasts found in the conglomerate are those of Pre-Sickle intrusive and Wasekwan metasedimentary material. However, clasts of acid and basic metavolcanic material are also present. This conglomerate lacks even rudimentary sorting.

Arkose occurs as thin wedges within the conglomerate and is identical, both texturally and mineralogically, to the arkosic matrix of the conglomerate.

Biotite-Muscovite Schist (8)

The biotite-muscovite schists are up to 10,000 feet thick in the northwestern portion of the map-area (east of Opachuanau Lake). These brownish-black schistose rocks were probably derived from very fine-grained pelitic sediments such as shales and siltstones but recrystallization has increased the average grain size which now varies between 1 and 3 millimeters. Relatively narrow horizons of hornblende rich schists also occur and these are thought to have been derived from more calcareous shales in this generally pelitic unit. The biotite-muscovite schists (8) do not overlie the more arkosic rocks of the Sickle Group but are found at approximately the same stratigraphic level to the east. It is possible, therefore, that a transgressive (i.e. facies) relationship exists between these two units.

The mineralogy of these schists is variable; generally it is biotite (30%), muscovite (25%), quartz (25 to 30%), sodic plagioclase (15 to 20%) and potash feldspar (5%) with accessory apatite, amphibole, magnetite, graphite, epidote, zircon and sphene. In more calcareous zones, hornblende and actinolite may constitute as much as 50% of the schist at the expense of the biotite, muscovite and quartz. The plagioclase content also increases in these calcareous horizons.

The biotite-muscovite schist is very susceptible to weathering and for this reason is poorly exposed.

THE OPACHUANAU GNEISSES

The Opachuanau paragneisses outcrop along the entire northern boundary of the map-area in stratigraphic thicknesses in excess of 10,000 feet. They are generally arkosic to calcareous in nature and display a marked lithologic similarity throughout their extent. Occasionally lenses of more mafic and siliceous gneissic rocks were encountered but these were not found in sufficient proportions to constitute mappable units and will not be discussed in detail.

The Opachuanau gneisses are derived mainly from rocks of the Sickle Group but it is possible that some rocks of the Wasekwan Group have also been incorporated into the gneissic belt. Two possible mechanisms for the formation of these paragneisses have been postulated by C.F. Lamb (1971). Firstly, they may be the result of deeper burial in a sedimentary basin than other less deformed rocks of the Sickle Group or secondly, the result of intensive recrystallization of Sickle and Wasekwan rocks during the formation of a mobile gneissic belt caused by large scale granitic intrusions to the north and south of the biotite-plagioclase-quartz gneisses.

Biotite-Plagioclase-Quartz Gneisses (9)

The biotite-plagioclase-quartz gneisses are well foliated and medium to coarse-grained. They are light to medium-grey on a fresh surface but commonly weather to a darker or more reddish-grey. Occasionally these rocks contain whitish quartzo-feldspathic lits. The paragneisses have a very consistent mineral composition; this is approximately plagioclase (45%), quartz (30%), biotite (15%), potash feldspar (5%) and hornblende (5%). Accessory minerals include epidote, apatite, sphene, zircon and magnetite. The magnetite partially alters to hematite which imparts a reddish stain to the rock. The sericitized plagioclase grains range in composition from An_{30} to An_{40}. Occasionally, myrmekitic intergrowths of quartz and plagioclase were observed. Near granitic contacts, the paragneiss was found to contain as much as 10% potash feldspar.

POST-SICKLE INTRUSIVE ROCKS

Two major intrusions of batholithic proportion were classified as Post-Sickle in age; the biotite-hornblende tonalite and diorite batholith (10a) with granodioritic and quartz monzonitic differentiation phases (10b), and the biotite-hornblende granodiorite batholith (11a) with related stocks of quartz monzonite (11b) and quartz-eye granite (11c). Pegmatite (12) and diabase (13) are also grouped with the Post-Sickle intrusive rocks.

Biotite-Hornblende Tonalite and Diorite (10a) with minor Differentiation Phases of Granodiorite and Quartz Monzonite (10b)

The batholithic complex of tonalite and related rocks occupies approximately 120 square miles in the northeastern portion of the map-area. The batholith is heterogeneous in composition but is predominantly biotite-hornblende tonalite and diorite (10a) which grades into more leucocratic phases of granodiorite and quartz monzonite (10b). The rocks are generally massive in the central portions of the batholith but become increasingly foliated towards the outer margins. On weathered surfaces the coarse-grained tonalite and diorite vary from dark-grey to pinkish-grey depending on the potash feldspar content and the amount of hematite alteration in the rock; on fresh surfaces these rocks are medium to light-grey. The biotite-hornblende tonalite is composed of plagioclase (50 to 55%), quartz (20%), biotite (15%), hornblende (5%) and microcline (5%) with accessory zircon, magnetite, sphene and epidote. The plagioclase varies in composition from An_{27} to An_{44} and locally shows oscillatory zoning. Sericitization has obliterated some of the microcline grains but has had little or no effect on the plagioclase. The diorite is made up of mafic minerals (35 to 40%), plagioclase (50 to 60%, An_{38} to An_{60}) and quartz (5 to 10%).

The biotite-hornblende granodiorite and quartz monzonite (10b) are medium to coarse-grained and vary from light-pink to light-grey. These rocks are generally massive. The only difference between the granodiorite and the quartz monzonite is the ratio of potash feldspar to plagioclase. Rocks with one-third or more potash feldspar were classified as quartz monzonites and those with less than one-third potash feldspar as granodiorites.

Biotite-Hornblende Granodiorite (11a) and Related Quartz Monzonite (11b) and Granite (11c)

The biotite-hornblende granodiorite (11a), which occupies almost one-fifth of the total area mapped, outcrops in the southern and western portions of the map-area. It is younger than the regional tectonic foliation but displays a primary flow foliation around its contact margins and is well jointed. The granodiorite is composed of oligoclase (50 to 55%), microcline (15 to 20%), quartz (20%) and mafic minerals (5 to 10%)

with trace amounts of sphene, apatite, zircon, magnetite, sericite and chlorite. Macroscopically, it is pinkish-white, medium to coarse-grained and massive.

Pink biotite quartz monzonite (11b) occurs as a number of small stocks to the east and north of the granodiorite (11a). Texturally and mineralogically it is similar to the granodiorite but contains slightly more quartz, 10 to 15% more microcline and approximately one-half as much oligoclase. Except for areas near contacts with more mafic rocks, the quartz monzonite seldom contains more than 5% mafic minerals. Contacts between the granodiorite (11a) and the quartz monzonite (11b) are gradational and no cross-cutting relationships were observed. Therefore, it is probable that the quartz monzonite stocks are a related, more leucocratic differentiate of the biotite-hornblende granodiorite.

One stock of quartz-eye granite (11c) outcrops in the map-area; it is situated in the north central portion around Opachuanau Lake. As this granite does not come in contact with either the granodiorite (11a) or the quartz monzonite (11b), age relationships between them are indeterminable. However, the quartz-eye granite appears to have suffered almost no alteration and is, therefore, tentatively classified as the youngest intrusive rock of unit 11. It may be readily distinguished from other leucocratic rocks by its salmon-pink color and peculiar quartz "eye-shaped" phenocrysts. A representative sample collected from the western shore of Opachuanau Lake was found to contain perthitic microcline (55%), zoned sodic plagioclase (15%), quartz (25 to 30%) and biotite (3%) with accessory muscovite, apatite, sericite and magnetite.

Pegmatite (12)

Pegmatite occurs mostly as small dykes although a fairly large sill-like body outcrops in the northeastern part of the map-area. Two distinct varieties of pegmatite occur; a pink perthite pegmatite and a white albite pegmatite. Both types may contain muscovite or biotite but seldom both. At least two ages of perthite pegmatite occur but age relationships between it and the albite-bearing variety are unknown. The mineralogy of the pegmatites is very simple and none of those observed contained any minerals other than quartz, feldspar and micas.

Diabase (13)

The diabase occurs in dykes and sills which range in width from less than one foot to greater than 200 feet. Most of these dykes and sills exhibit an ophitic texture with an aphanitic groundmass. However, the two large dykes east of Ruttan Lake are coarse-grained and hypidiomorphic granular in texture. The greenish-black diabases are remarkably fresh in character and have suffered very little alteration. The average composition of these rocks is augite (35%), hypersthene (5%), labradorite (45%) and magnetite-ilmenite (15%) with accessory sphene, leucoxene, hematite and hornblende.

DISCUSSION OF CHEMICAL ANALYSES, C.I.P.W. NORMS AND VARIATION DIAGRAMS

General Statement

The chemical analyses were performed by the staff of the Manitoba Mines Branch Analytical Laboratory who used wet chemical methods. At least one sample of each extrusive rock type found in the Rusty Lake greenstone belt has been chemically analyzed. Analyses of two Pre-Sickle gabbros and three Pre-Sickle diorites have been included also in order to determine whether or not they differ chemically from their older extrusive equivalents. Different symbols have been used in the variation diagrams (Fig.2 - Fig.7) for basalt, andesite, dacite, rhyodacite, rhyolite, gabbro and diorite, but no plot distinction has been made between picrites and basalts. The various types of extrusive and intrusive rocks were delineated according to a classification put forward by Goodwin (1968). This classification is based on the SiO_2 content:

TABLE 2: Classification of Extrusive and Intrusive Rock Types

Extrusive Rock Types	%SiO_2	Plot Symbol
picrite	<45	●
basalt	45-52	●
andesite	52-58	○
dacite	58-64	■
rhyodacite	64-71	◩

rhyolite	>71	□

Intrusive Rock Types	%SiO_2	Plot Symbol
gabbro	45-52	▲
diorite	52-58	△

The variation diagrams used in this study have been adapted from Kuno (1968). Most of these attempt to separate the volcanic rocks into three igneous rock series; the pigeonitic (tholeiitic) rock series, the high-alumina rock series and the alkalic (alkali-olivine) rock series. High-alumina basalts are defined by Kuno (1968) as those containing greater than 16.5% Al_2O_3 in aphyric rocks with an alkali ($Na_2O + K_2O$) content intermediate between tholeiitic and alkali-olivine basalts for a given SiO_2 content.

Mineralogically, high-alumina basalts are transitional between tholeiites and alkali-olivine basalts and may display features of both. Characteristic mineralogical features of tholeiites are the presence of a reaction relation between Mg-rich olivine (forsterite) and Ca-poor pyroxenes (orthopyroxene and pigeonite) resulting in a general absence of forsterite, and the presence of silica minerals or siliceous glass in the groundmass. Alkali-olivine basalts are characterized by the presence of Mg-rich olivine (i.e. no reaction between forsterite and Ca-poor pyroxenes) and Ca-rich clinopyroxene while alkali feldspar, zeolites and occasionally, feldspathoids take the place of silica in the groundmass.

The metavolcanic rocks of the Rusty Lake greenstone belt are composed mainly of secondary minerals, as much of the original mineralogy has been destroyed by metamorphism. Many of the basic metavolcanic rocks do contain minute amounts of both quartz and alkali feldspar in the groundmass, but the possibility exists that this is of secondary origin. Therefore, the distinction between the three igneous rock series has been based almost exclusively on the variation diagrams and the chemical analyses.

Discussion of Chemical Analyses

Chemical analyses revealed that the metavolcanic rocks of the Rusty Lake greenstone belt show six distinctive chemical characteristics: a) a high and extremely variable Al_2O_3 content, b) a low TiO_2 content, c) high FeO/Fe_2O_3 ratios, d) a high CaO content with a corresponding low MgO content, e) a low alkali content, especially K_2O and f) a high volatile (CO_2 and H_2O) content.

The Al_2O_3 content in the metavolcanic rocks is extremely variable as it ranges from less than 12% to more than 20%. Most of the basalts and all of the picrites contain at least 16.5% Al_2O_3. That is to say, most of the basic extrusive rocks of the Rusty Lake area are very definitely high-alumina in character. High-alumina basalts appear to be uncommon in the Precambrian shield but this is due, at least in part, to the fact that most previous studies differentiate only between tholeiites and alkali-olivine basalts.

Low TiO_2 contents are characteristic of basic extrusive rocks of the Precambrian shield (Goodwin, 1968). In this particular study, TiO_2 contents are also low and rarely exceed 1%. This feature, however, is not a critera for differentiating between the various types of basaltic rocks.

High FeO/Fe_2O_3 ratios (usually in the order of 3/1 to greater than 5/1) are prevalent in the basic volcanic rocks of the Rusty Lake greenstone belt. A ratio of this order is common not only to other Precambrian basaltic rocks (Goodwin, 1968) but also to Tertiary volcanic suites (Kuno, 1960). High FeO/Fe_2O_3 ratios, however, do not seem to be a diagnostic feature of either tholeiites or alkali-olivine basalts.

The relatively high CaO content and corresponding low MgO content is a unique feature that is common to neither recent basic volcanic rocks nor others in the Precambrian. This feature does not appear to be due to metamorphism as CaO would be removed preferentially to MgO in mafic rocks of the proposed metamorphic grade (lower Amphibolite facies), especially with the presence of high concentrations of H_2O and CO_2 (Vogt, 1927). Also, the lack of carbonate minerals in these rocks would suggest that very little CaO has been introduced. It is assumed, therefore, that the metavolcanic rocks of the Rusty Lake area were originally Ca-rich and that Ca-rich clinopyroxene was the most abundant mafic mineral (i.e. an alkali-olivine association). The variation diagrams, however, suggest that orthopyroxene and pigeonite were the predominant mafic minerals (i.e. a tholeiitic association).

The low alkali content (particularly K_2O) in the metavolcanic rocks of the map-area is a characteristic feature of tholeiitic magma types as contrasted to much higher alkali values in alkali-olivine rocks. Despite the high Al_2O_3 values, alkali values are often so low that many of the basalts plot as tholeiites on the variation diagrams. This results in an apparent transitional volcanic suite between a tholeiitic and a high-alumina association in basic volcanic rocks containing at least 16.5% Al_2O_3. Both Wilson et al. (1965) and Goodwin (1968) conclude that most of the volcanic suites examined in the Superior Province are also low in Na_2O and K_2O and that alkali-olivine basalts are rare.

Another chemical characteristic of the basaltic rocks of the Rusty Lake greenstone belt is the high volatile (H_2O + CO_2) content. Goodwin (1968) states that this is a common feature of Precambrian metavolcanic rocks. The high CO_2 content is probably an original chemical characteristic of these rocks. If it was hydrothermally introduced, the CaO content would be lower due to the probable formation and removal of calcium carbonate material. The H_2O could be either primary or secondary in origin. In any case, it has allowed the formation of hydrous minerals such as hornblende and biotite.

Discussion of C.I.P.W. Norms

C.I.P.W. norms were calculated for all of the chemically analyzed metavolcanic and intrusive rocks.

Every intrusive and volcanic rock in the map-area contains at least trace amounts of normative orthoclase but only about one in five of the more basic varieties contains normative quartz. However, normative quartz is present in all of the intermediate and acid extrusive rocks (as well as the diorites). Rocks containing normative quartz do not contain normative forsterite or fayalite. The absence of olivine minerals is accompanied by a sharp increase in normative orthopyroxene (enstatite and ferrosilite) and a corresponding decrease in normative clinopyroxene (diopside and hedenbergite).

Approximately one-quarter of the basic rocks were found to contain normative nepheline. Where nepheline is present, the normative analysis was found to be void of both ferrosilite and enstatite as well as quartz, which is to be expected. The presence of normative nepheline is accompanied by a marked rise in clinopyroxene and olivine (especially forsterite).

Two major conclusions can be drawn from the normative analysis. Firstly, the normative mineralogy suggests that the volcanic rocks of the Rusty Lake greenstone belt display mineralogical characteristics of both tholeiitic and alkali-olivine basalts. That is to say, the normative mineralogy suggests that these rocks are an intermediate group between tholeiites and alkali-olivine basalts. This concurs with observations made by Kuno (1960) in his work on high-alumina basalts. Secondly, the normative mineralogy of the intermediate and acid extrusive rocks (and the diorites to some extent) indicates that they tend to be more strongly tholeiitic than the basic rocks of the map-area. They all contain normative quartz and orthopyroxene but no normative olivine or nepheline and, with the exception of the diorites, only small amounts of clinopyroxene with respect to orthopyroxene. This second observation is further substantiated by the variation diagrams.

TABLE 3: Chemical Analyses and C.I.P.W. Norms

Sample No. Lab. No. Rock Type	23-1039-2 R-631 Basalt	23-1023-2 R-632 Basalt	23-1029-1 R-633 Basalt	23-1031-1 R-634 Basalt	23-59-1 R-635 Basalt
SiO_2 %	50.00	46.65	47.25	47.25	47.95
Al_2O_3	16.20	17.70	19.90	20.00	16.70
TiO_2	1.36	0.46	0.65	0.61	0.72
Fe_2O_3	2.27	2.53	1.74	2.71	1.97
FeO	7.80	8.34	9.03	7.90	9.19
MnO	0.17	0.23	0.20	0.19	0.21
MgO	5.12	6.95	4.45	4.50	8.45
CaO	10.00	11.40	12.20	13.15	9.90
Na_2O	4.13	2.53	1.78	1.66	1.94
K_2O	0.99	1.24	0.93	0.50	0.58
P_2O_5	0.62	0.08	0.09	0.26	0.19
H_2O	1.47	1.91	1.79	1.42	1.98
CO_2	0.28	0.07	0.12	0.13	0.11
Total	100.40 %	100.10 %	100.15 %	100.30 %	99.90 %

C.I.P.W. Norms

Quartz	-	-	-	0.11	-
Orthoclase	5.99	7.46	5.60	2.99	3.51
Albite	27.12	15.86	15.33	14.22	16.78
Anorthite	27.88	33.92	44.35	46.23	35.94
Nepheline	-	3.23	-	-	-
Diopside	8.97	11.52	6.52	7.89	6.65
Ferrosilite	7.10	-	5.80	7.97	8.56
Enstatite	8.61	-	4.45	7.69	12.46
Hedenbergite	6.45	7.48	7.40	7.13	3.98
Forsterite	0.20	8.62	2.67	-	4.18
Fayalite	0.19	7.08	3.83	-	3.17
Magnetite	3.37	3.74	2.57	3.98	2.92
Ilmenite	2.65	0.89	1.26	1.17	1.40
Corundum	-	-	-	-	-
Apatite	1.47	0.19	0.21	0.61	0.45

Sample No. Lab. No. Rock Type	23-273-1 R-636 Basalt	23-291-1 R-637 Basalt	23-290-1 R-638 Andesite	23-262-1 R-639 Basalt	23-66-2 R-640 Basalt
SiO_2 %	51.65	46.60	53.35	48.00	45.60
Al_2O_3	16.40	11.90	16.95	14.90	12.85
TiO_2	0.75	0.70	0.76	0.72	0.60
Fe_2O_3	2.38	3.49	2.66	4.25	1.73
FeO	7.29	7.35	8.82	6.84	9.15
MnO	0.19	0.21	0.21	0.20	0.22
MgO	5.45	11.35	3.65	8.00	12.15
CaO	9.60	12.65	8.55	12.00	12.00
Na_2O	3.37	2.14	3.06	2.46	1.67
K_2O	1.31	0.52	0.55	0.68	0.67
P_2O_5	0.23	0.34	0.15	0.23	0.38
H_2O	1.54	2.02	1.35	1.81	2.51
CO_2	0.29	0.95	0.22	0.18	0.49
Total	100.45 %	100.22 %	100.28 %	100.25 %	100.00 %

C.I.P.W. Norms

Quartz	-	-	6.48	-	-
Orthoclase	7.86	3.16	3.30	4.10	4.09
Albite	28.90	17.60	26.23	21.18	13.78
Anorthite	26.11	21.93	31.30	28.09	26.37
Nepheline	-	0.55	-	-	0.42
Diopside	10.11	24.80	3.96	18.33	18.40
Ferrosilite	4.71	-	10.65	1.57	-
Enstatite	6.07	-	7.37	3.80	-
Hedenbergite	6.84	7.54	4.99	6.60	7.84
Forsterite	2.11	12.31	-	5.58	15.88
Fayalite	1.81	4.73	-	2.54	8.55
Magnetite	3.50	5.20	3.91	6.27	2.59
Ilmenite	1.44	1.37	1.46	1.40	1.18
Corundum	-	-	-	-	-
Apatite	0.54	0.81	0.35	0.54	0.91

Sample No.	23-236-1	23-1166-1	23-1232-1	23-248-1	23-1179-1
Lab. No.	R-641	R-642	R-643	R-644	R-645
Rock Type	Dacite	Gabbro	Basalt	Basalt	Basalt
SiO_2 %	58.65	44.90	51.00	46.60	51.35
Al_2O_3	16.70	13.90	19.10	15.55	14.70
TiO_2	0.75	0.73	0.66	1.45	1.81
Fe_2O_3	1.70	3.43	3.26	3.27	3.65
FeO	7.21	7.49	7.14	9.49	8.26
MnO	0.15	0.21	0.21	0.26	0.27
MgO	2.82	11.30	3.12	7.15	4.80
CaO	6.27	11.70	9.35	11.95	8.50
Na_2O	2.40	1.90	3.42	1.98	2.87
K_2O	1.80	0.83	1.07	0.25	1.51
P_2O_5	0.11	0.10	0.25	0.37	0.63
H_2O	1.26	2.60	1.33	1.81	1.84
CO_2	0.21	0.76	0.18	0.25	0.26
Total	100.05 %	99.85 %	100.10 %	100.40 %	100.45 %

C.I.P.W. Norms

Quartz	15.94	-	1.03	-	4.25
Orthoclase	10.80	5.09	6.42	1.50	9.08
Albite	20.60	13.14	29.35	17.04	24.69
Anorthite	29.91	27.93	34.09	33.37	23.15
Nepheline	-	1.91	-	-	-
Diopside	0.33	19.29	4.51	12.31	7.49
Ferrosilite	10.80	-	7.24	6.19	7.02
Enstatite	6.97	-	5.79	8.60	8.68
Hedenbergite	0.45	6.40	4.92	7.72	5.28
Forsterite	-	14.17	-	2.67	-
Fayalite	-	5.61	-	2.12	-
Magnetite	2.50	5.15	4.80	4.82	5.38
Ilmenite	1.45	1.44	1.27	2.80	3.50
Corundum	-	-	-	-	-
Apatite	0.26	0.24	0.59	0.87	1.49

Sample No. Lab. No. Rock Type	23-1068-1 R-646 Andesite	23-1084-1 R-647 Basalt	23-122-1 R-648 Basalt	23-1086-1 R-649 Basalt	23-79-1 R-650 Diorite
SiO_2 %	54.70	46.60	48.30	47.65	54.80
Al_2O_3	15.80	14.30	13.45	19.20	17.70
TiO_2	0.53	0.62	2.47	0.54	0.62
Fe_2O_3	2.73	3.64	1.34	1.73	2.31
FeO	5.87	7.91	11.66	8.63	5.26
MnO	0.19	0.21	0.27	0.21	0.16
MgO	4.80	7.00	7.10	5.20	4.70
CaO	8.45	14.80	10.45	12.50	8.80
Na_2O	2.64	1.53	2.99	1.70	3.45
K_2O	1.21	0.95	0.11	0.47	0.45
P_2O_5	0.19	0.24	0.25	0.72	0.14
H_2O	1.26	1.66	1.55	1.26	1.28
CO_2	0.16	0.15	0.49	0.09	0.20
Total	99.50 %	99.60 %	100.45 %	99.90 %	99.90 %

C.I.P.W. Norms

Quartz	9.42	-	-	0.13	6.89
Orthoclase	7.37	5.77	0.66	2.82	2.71
Albite	23.00	8.50	25.71	14.59	29.67
Anorthite	28.51	30.12	23.33	44.01	32.00
Nepheline	-	2.60	-	-	-
Diopside	6.90	18.17	12.54	6.05	6.11
Ferrosilite	6.10	-	4.94	11.11	5.44
Enstatite	9.11	-	5.22	10.33	9.06
Hedenbergite	4.03	18.09	10.34	5.67	3.20
Forsterite	-	6.63	4.86	-	-
Fayalite	-	8.35	5.07	-	-
Magnetite	4.08	-	1.98	2.55	3.40
Ilmenite	1.04	1.21	4.77	1.04	1.20
Corundum	-	-	-	-	-
Apatite	0.45	0.57	0.59	1.70	0.33

Sample No. Lab. No. Rock Type	23-1219-1 R-651 Diorite	23-57-1 R-652 Picrite	23-226-1 R-653 Andesite	23-58-1 R-654 Gabbro	28-142-1 R-686 Basalt
SiO_2 %	52.30	44.45	55.65	46.55	49.10
Al_2O_3	18.35	17.70	12.00	19.55	16.60
TiO_2	1.09	0.82	1.26	0.62	1.00
Fe_2O_3	4.75	4.08	2.88	2.05	2.83
FeO	5.44	7.35	7.55	8.77	9.21
MnO	0.15	0.22	0.20	0.21	0.21
MgO	3.30	4.95	3.70	6.20	6.90
CaO	8.00	15.15	11.25	12.30	9.85
Na_2O	3.95	1.60	2.70	1.80	1.95
K_2O	0.84	0.60	0.17	0.30	0.13
P_2O_5	0.42	0.15	0.14	0.08	0.14
H_2O	1.17	1.69	1.24	1.43	1.72
CO_2	0.18	1.04	1.65	0.19	0.46
Total	99.95 %	99.80 %	100.40 %	100.05 %	100.15 %

C.I.P.W. Norms

Quartz	4.76	-	13.46	-	2.81
Orthoclase	5.04	3.66	1.03	1.80	0.79
Albite	33.90	11.22	23.43	15.47	16.85
Anorthite	30.29	40.53	20.64	45.09	36.93
Nepheline	-	1.48	-	-	-
Diopside	3.93	17.83	15.36	7.59	5.90
Ferrosilite	3.60	-	2.47	5.02	11.48
Enstatite	6.51	-	2.33	5.63	14.81
Hedenbergite	1.91	11.58	14.21	5.91	3.98
Forsterite	-	3.11	-	4.58	-
Fayalite	-	2.55	-	4.51	-
Magnetite	6.99	6.09	4.28	3.02	4.19
Ilmenite	2.10	1.60	2.45	1.12	1.94
Corundum	-	-	-	-	-
Apatite	0.99	0.36	0.33	0.19	0.33

Sample No.	28-276-1	28-300-1	28-1192-1	28-1269-1	28-144-1
Lab. No.	R-689	R-690	R-691	R-692	R-706
Rock Type	Rhyodacite	Rhyodacite	Basalt	Rhyolite	Andesite
SiO_2 %	70.10	64.75	48.75	72.20	53.75
Al_2O_3	14.20	17.40	16.95	13.90	15.75
TiO_2	0.36	0.65	0.54	0.19	0.86
Fe_2O_3	2.06	3.62	1.27	1.66	1.41
FeO	3.26	2.56	7.97	2.66	8.97
MnO	0.07	0.11	0.21	0.12	0.22
MgO	0.80	0.90	4.90	0.75	5.75
CaO	1.10	1.75	14.80	1.60	6.50
Na_2O	3.65	4.75	1.85	3.45	4.55
K_2O	2.70	1.45	0.45	1.95	0.11
P_2O_5	0.02	0.27	0.18	0.01	0.27
H_2O	0.96	0.70	0.86	0.99	1.13
CO_2	0.55	0.95	0.76	0.41	0.46
Total	99.85 %	99.85 %	99.50 %	99.90 %	99.75 %

C.I.P.W. Norms

Quartz	33.86	27.35	-	39.18	0.41
Orthoclase	16.24	8.73	2.72	11.71	0.66
Albite	31.41	40.92	15.99	29.64	39.23
Anorthite	5.42	7.04	37.41	7.99	22.65
Nepheline	-	-	-	-	-
Diopside	-	-	15.60	-	3.72
Ferrosilite	3.89	0.86	4.59	3.48	12.85
Enstatite	2.03	2.28	4.28	1.90	12.87
Hedenbergite	-	-	14.59	-	3.24
Forsterite	-	-	0.67	-	-
Fayalite	-	-	0.79	-	-
Magnetite	3.04	5.34	1.88	2.44	2.08
Ilmenite	0.70	1.26	1.05	0.37	1.66
Corundum	3.38	5.58	-	3.28	-
Apatite	0.05	0.64	0.43	0.02	0.64

Sample No. Lab. No. Rock Type	28-158-1 R-707 Basalt	28-229-1 R-708 Andesite	28-1247-1 R-709 Andesite	23-116-1 R-758 Quartz Diorite	23-768-1 R-759 Basalt
SiO_2 %	49.50	55.00	56.00	60.40	47.60
Al_2O_3	17.30	15.40	17.85	19.05	16.10
TiO_2	0.67	1.71	0.72	0.28	0.64
Fe_2O_3	2.19	1.85	1.88	1.20	3.88
FeO	8.45	9.49	6.51	2.31	7.25
MnO	0.21	0.22	0.17	0.05	0.20
MgO	6.37	2.88	3.47	1.45	7.86
CaO	10.40	6.45	6.75	3.36	11.12
Na_2O	2.60	4.75	3.15	2.62	2.40
K_2O	0.22	0.30	1.35	3.17	0.66
P_2O_5	0.20	0.35	0.24	0.08	0.18
H_2O	1.59	1.05	1.37	0.82	1.63
CO_2	0.19	0.05	0.41	0.57	0.08
Total	99.95 %	99.50 %	99.85 %	100.40 %	99.60 %

C.I.P.W. Norms

Quartz	-	5.18	9.68	24.02	-
Orthoclase	1.33	1.80	8.14	19.95	3.99
Albite	22.42	40.84	27.17	23.59	20.74
Anorthite	35.56	20.14	31.17	17.18	31.88
Nepheline	-	-	-	-	-
Diopside	7.37	3.22	0.58	-	13.26
Ferrosilite	9.92	10.90	9.42	3.07	2.71
Enstatite	12.11	5.80	8.54	3.84	5.62
Hedenbergite	5.38	5.28	0.56	-	5.57
Forsterite	0.40	-	-	-	5.77
Fayalite	0.36	-	-	-	3.06
Magnetite	3.24	2.73	2.80	1.85	5.75
Ilmenite	1.30	3.30	1.40	0.57	1.24
Corundum	-	-	-	5.74	-
Apatite	0.47	0.83	0.57	0.20	0.43

Sample No.	23-773-1	23-2317-1	23-2407-1	23-767-1
Lab. No.	R-760	R-782	R-783	R-784
Rock Type	Basalt	Picrite	Basalt	Basalt
SiO_2 %	49.85	44.45	49.85	48.65
Al_2O_3	17.45	17.20	20.40	16.45
TiO_2	0.69	0.64	0.48	0.65
Fe_2O_3	5.28	5.07	1.41	2.94
FeO	5.18	6.27	5.67	8.59
MnO	0.19	0.19	0.13	0.21
MgO	5.97	8.23	4.76	7.05
CaO	8.00	12.10	11.90	10.60
Na_2O	2.61	1.83	2.34	2.82
K_2O	2.34	1.57	0.87	0.96
P_2O_5	0.36	0.24	0.10	0.19
H_2O	1.75	2.16	1.35	1.62
CO_2	0.13	0.24	0.47	0.19
Total	99.80 %	100.20 %	99.75 %	100.90 %

C.I.P.W. Norms

Quartz	0.51	-	0.05	-
Orthoclase	14.14	9.51	5.26	5.73
Albite	22.56	3.96	20.22	24.07
Anorthite	29.60	35.05	43.50	29.66
Nepheline	-	6.48	-	-
Diopside	5.43	11.39	8.06	11.13
Ferrosilite	3.72	-	6.14	0.98
Enstatite	12.67	-	8.37	1.36
Hedenbergite	1.39	9.30	5.15	7.00
Forsterite	-	11.06	-	7.84
Fayalite	-	11.41	-	6.23
Magnetite	7.82	-	2.09	4.30
Ilmenite	1.34	1.25	0.93	1.25
Corundum	-	-	-	-
Apatite	0.85	0.57	0.24	0.45

Discussion of Variation Diagrams

MFA Ternary Oxide Diagram

Variations in the ratio MgO : FeO(+.8998 Fe_2O_3) : $Na_2O + K_2O$ of the igneous rocks of the Rusty Lake greenstone belt are plotted on an MFA ternary oxide diagram (Fig.2). Samples with a solidification index (SI) greater than 40 were not plotted on this diagram as they probably represent cumulate rocks. The fractionation trend line almost parallels the MgO-FeO edge of the triangle for the early and intermediate stages but breaks sharply towards the alkali (Na_2O + K_2O) corner in later stages. Kuno (1968) states that this trend is characteristic of a high-iron concentration type of fractionation.

In Figure 2, the pigeonitic (P), hypersthenic (H) and alkalic (A) fields have been delineated as well as the fractionation trend line of the Skaergaard intrusion (S). The trend line of the rocks of the thesis area does not plot exclusively in one field but is transcendent between the pigeonitic and hypersthenic fields. It is interesting to note that the 4 acid volcanic samples plot as the most strongly pigeonitic of all rock types.

In general, a high-iron concentration type of fractionation is characteristic of a tholeiitic volcanic suite. The metavolcanic rocks of the Rusty Lake greenstone belt do display this type of fractionation although not as strongly as the intrusive rocks of the Skaergaard.

Alumina-Alkali Diagrams

Four separate alumina-alkali variation diagrams (Fig.3) have been plotted for different ranges in per cent SiO_2. These ranges are as follows: a) 45.00 to 47.50%, b) 47.51 to 50.00%, c) 50.01 to 52.50%, d) 52.51 to 55.00%. Tholeiitic (Thol.), high-alumina (H. Al.) and alkali-olivine (Alk.) fields have been delineated in each diagram.

In diagrams a) and b), the samples plot mainly as tholeiitic basalts although many are very close to the division line between the tholeiitic and high-alumina fields. While most of the samples contain at least 16.5% Al_2O_3, the alkali (Na_2O + K_2O) content is sufficiently low that they plot as tholeiites rather than high-alumina basalts. A total of 4 basalt samples plot in the alkali-olivine field but only one is far removed from the high-alumina/alkali-olivine division line. It is probable that this sample has suffered some alkali metasomatism as it is abnormally high in Na_2O.

In diagrams c) and d), there is a shift of points towards the high-alumina and alkali-olivine fields. Every sample in diagram c) of Figure 3 falls on or near the division line between the high-alumina and alkali-olivine fields. In diagram d), 5 of the 7 samples (6 andesites and 1 diorite) plot in the high-alumina field. One andesite plots in the alkali-olivine field (close to the high-alumina/alkali-olivine division line) while the other plots as one of the most strongly tholeiitic rocks of the entire volcanic suite.

Figure 3 indicates that most of the metavolcanic and intrusive rocks of the Rusty Lake greenstone belt are transitional between a tholeiitic and a high-alumina trend. Those rocks with silica values between 45.00 and 50.00% tend to be tholeiitic while those with silica values between 50.01 and 55.00% fall mainly in the high-alumina field.

Alkali-Silica Diagram

The alkali-silica variation diagram (Fig.4) is a combination of two such diagrams taken from Kuno (1968) and MacDonald and Katsura (1964). Kuno's alkali-silica diagram depicts the alkali-olivine (Alk.), high-alumina (High Al.) and tholeiite (Thol.) fields while that of MacDonald and Katsura differentiates only between tholeiitic and alkali-olivine magma types.

The fields of Kuno's alkali-silica diagram are delineated by the solid lines. In this variation diagram, almost three-quarters of the samples plot in the high-alumina field with roughly equal numbers falling in the tholeiitic field below and the alkali-olivine field above. Those samples that fall in the alkali-olivine field are basaltic and those that fall in the tholeiitic field are more acidic (i.e. 2 andesites and 3 acid volcanic samples) of the volcanic sequence. This alkali-silica variation diagram depicts the high-alumina nature of the rocks of the map-area more effectively than the alumina-alkali diagrams (Fig.3).

The dashed line on Figure 4 represents a division between tholeiitic and alkali-olivine magma types proposed by MacDonald and Katsura (1964) in their study of Hawaiian basalts. Using this classification, only 5 basalts and 1 gabbro plot in the alkali-olivine field (all of which fall fairly close to the tholeiite/alkali-olivine division line). In the alkali-silica variation diagram of MacDonald and Katsura, the acid volcanic rocks again plot as the most strongly tholeiitic of all rock types. Also, many of the samples plot in the vicinity of the tholeiite/alkali-olivine division line which would indicate that the volcanic and intrusive rocks of the Rusty Lake greenstone belt are transitional between tholeiitic and alkali-olivine rocks.

Silica vs. SI Diagram

Figure 5 is a plot of the SiO_2 content against the solidification index ($SI= MgO \times 100/MgO + FeO + Fe_2O_3 + Na_2O + K_2O$). The upper field, delineated by the dashed lines, is the hypersthenic field (Hyp.) while the lower field, delineated by the solid lines, is the pigeonitic field (Pig.). Silica values of the rocks of the thesis area rise very gradually until a solidification index value of approximately 20 is reached; thereafter it rises very rapidly. That is, there appears to be very little silica differentiation with respect to the solidification index before an SI value of 20. This value (SI=20) roughly corresponds to those rocks that contain at least

50 per cent SiO_2. Kuno (1968) states that the trend depicted in Figure 5 is characteristic of a pigeonitic rock series. In other rock series, the SiO_2 values (when plotted against SI) rise steadily throughout.

Iron Oxide vs. SI Diagram

The iron oxide versus SI variation diagram (Fig.6) also displays a pigeonitic (Pig.) and a hypersthenic (Hyp.) field. However, in this particular diagram the pigeonitic field (outlined by solid lines) is much larger than the hypersthenic one (outlined by dashed lines). Despite the wide scatter of points between SI values of 30 and 35, the $FeO + Fe_2O_3$ variation trend approaches a maximum at approximately SI=20. Kuno (1968) states that a general variation trend (for $FeO + Fe_2O_3$) of this type is characteristic of a pigeonitic rock series and that the $FeO + Fe_2O_3$ trend line of other rock series plots within a narrow zone below the pigeonitic field being nearly constant in the early stage and decreasing in the middle to late stages.

Single Oxide vs. SI Diagrams

All of the major oxides appear to show at least a rudimentary variation trend when plotted against the solidification index (Fig.7) with the possible exception of Al_2O_3. The MgO versus SI plot shows the most profound variation trend but this is not indicative of any particular magma type. The SiO_2 versus SI and the $FeO + Fe_2O_3$ versus SI plots indicate that the volcanic and basic intrusive rocks of the Rusty Lake greenstone belt represent a pigeonitic rock series (for reasons discussed previously). The TiO_2 versus SI trend (Fig.7) is also fairly typical of a pigeonitic rock series as it reaches a maximum at approximately SI=23 and does not steadily decrease thereafter as in other rock series. Other oxide trend lines such as that of CaO, Na_2O and K_2O are also similar to those of a pigeonitic rock series.

The Al_2O_3 versus SI plot (Fig.7) displays a variation trend that is typical of neither a pigeonitic nor an alkalic rock series. In a classical pigeonitic series, the Al_2O_3 trend line steadily decreases and remains almost constant in a classical alkalic one. In Figure 7, the Al_2O_3 variation trend rises quickly to reach a maximum at an SI value of about 30 then very gradually decreases. This type of trend is characteristic of a high-alumina rock series

STRUCTURAL GEOLOGY

Introduction

The lack of exposure in parts of the map-area necessitated the extended use of aerial photographs, aeromagnetic maps and electromagnetic trend maps for the structural analysis, particularly in the delineation of faults and folds.

Primary Structures

A) Volcanic Structures

In the basic and intermediate volcanic rocks of the Wasekwan Group, fewer than a dozen occurrences of ellipsoidal lavas were observed. Top determinations were possible at approximately half of these localities. Many of the relatively undeformed pillow structures are almost perfectly spherical. This would suggest that the pillows were formed as the result of a subaerial extrusion flowing into shallow water rather than a submarine extrusion. Pillow structures formed during submarine extrusions of volcanic material do not, as a rule, form near perfect spherical shapes and commonly display at least minor brecciation (Jones, 1969).

Amygdaloidal and vesicular lavas are rare in the southern and eastern portions of the metavolcanic suite but are very common in the western extremity of the greenstone belt along the shore of the Churchill River. These structures are remarkably well preserved and show very little deformation. The amygdales are now composed of quartz and carbonate material. Occurrences of amygdaloidal and vesicular lavas are useful for local top determinations but are not sufficiently widespread to permit a detailed stratigraphic analysis.

Columnar jointing is a relatively rare primary feature and occurs only in two or three places in the eastern portion of the metavolcanic suite.

Flow structures were frequently observed in the acid volcanic rocks (2) that have not undergone extensive recrystallization. These have been discussed in detail in the section dealing with the acid volcanic and pyroclastic rocks (2). Pearse (1964) states that flow structures occur in the basic volcanic porphyries (i.e. alignment of phenocrysts) but the writer believes this to be related to the development of the regional tectonic foliation as some of the phenocrysts display a distinct "rolled" appearance.

Volcanic breccias, agglomerates and features indicating possible ignimbrites and lahars have been discussed formally in a previous section (unit 2). The occurrence of a flow top breccia is discussed in connection with map-unit 4. The presence of ignimbrites and lahars is indicative of subaerial volcanic activity. A subaerial to shallow water environment is also suggested by the shape of some relatively undeformed pillow structures, the lack of graded bedding or rudimentary sorting of the larger clasts in the pyroclastic rocks and possible cross bedding in the acid to intermediate tuffs.

B) Sedimentary Structures

Relict bedding is the only primary feature preserved in the metasedimentary rocks (3) of the Wasekwan Group (with the exception of possible cross bedding in the tuffaceous rocks). This is true also for the rocks of the Sickle Group although the clasts of the arkosic conglomerate (7) are still readily recognizable.

The proposed transgressive relationship between the two units of the Sickle Group was not based on primary structures but on the fact that the spatial relationship between the arkosic conglomerate and arkose (7) and the biotite-muscovite schist (8) suggests a lateral gradation rather than a vertical succession. If this interpretation is correct, the sedimentary rocks of the Sickle Group were deposited in a shallow water environment that deepened somewhat towards the pelitic unit to the east.

C) Intrusive Structures

Tonalite, diorite (10) and granodiorite (11) and their associated, more acid differentiates exhibit primary igneous foliations. Foliation is generally absent in the center of the intrusions but increases towards the outer margins. This primary flow foliation is concordant to the contacts between the intrusive bodies and the country rocks.

A number of joint systems are present in all of the intrusive rocks but are best developed in the two batholithic complexes (units 10 and 11). While many are the result of regional tectonism, those that form a "ring-type" pattern parallel to the periphyries of the intrusive bodies are most likely cooling joints.

Many of the intrusive rocks display a primary magmatic differentiation. This feature is best illustrated by the small, circular to ellipsoidal mafic plugs and the zoned gabbroic dyke on the west shore of Rusty Lake.

Secondary Structures

A) Foliation

A general east-west trending tectonic foliation has been superimposed on all rocks in the map-area which are older than the Post-Sickle intrusives. This foliation has resulted from a north-south compressive force. It is, for the most part, parallel to bedding and layering in the metavolcanic and metasedimentary rocks. The regional foliation has been deformed by two periods of folding and by the intrusion of the Post-Sickle intrusive rocks.

B) Folding

Two periods of folding have been recognized within the map-area. The first period was produced by an apparent north-south compression and resulted in a series of easterly plunging, almost isoclinal folds. During this period, the east-west tectonic foliation was imposed on all rocks pre-dating the Post-Sickle intrusives.

A second period of folding was caused by compression produced during the intrusion of the tonalite, diorite (10) and granodiorite (11) batholiths. The axial traces of these open, more concentric folds trend to the northeast and in a few instances refold those of the first period of folding.

C) Faulting

Faults within the map-area occur in three preferred directions. The majority of the faults trend in either a northeasterly or a northwesterly direction. Some of these faults show evidence of apparent right lateral strike-slip movement, while others display apparent left lateral movement.

The third preferred direction of faulting is east-west. Faults trending in this direction have undergone apparent normal dip-slip movement.

Summary of Geological Events

The sequence of events in the geologic history of the map-area is:

1. Extrusion of Wasekwan lavas, deposition of pyroclastics and deposition of derived Wasekwan sediments.
2. Intrusion of gabbro (7a) and diorite (7b).
3. Uplift and erosion of the Wasekwan Group and associated intrusions.
4. Deposition of the Sickle Group unconformably on top of the Wasekwan Group.
5. North-south compression of the Wasekwan and Sickle Groups resulting in the development of an east-west trending foliation and folding along east-west trending axes.
6. Series of granitic intrusions resulting in recrystallization of the Sickle sedimentary rocks and gentle flexing of the earlier-folded Wasekwan rocks along northwest trending fold axes.
7. Intrusion of pegmatite (12).
8. Formation of northeast to northwest trending fault system(s).
9. Formation of east-west trending fault system.
10. Injection of diabase (13) along fractures trending northwest-southeast.

METAMORPHISM

An apparent variation in metamorphic grade and a lack of indicator minerals makes the determination of a regional metamorphic grade for the thesis area somewhat difficult.

Pelitic gneisses of middle to upper amphibolite grade bound the thesis area to the north and south (Hinds, 1970 and Elphick, 1970). These paragneisses contain both sillimanite and cordierite, indicating conditions of high temperature and low to moderate pressure (Abukuma type).

The Opachuanau gneisses and metasedimentary rocks at the northern margin of the thesis area and some of the metasedimentary rocks at the southern extremity of the Rusty Lake greenstone belt appear to have been metamorphosed to the lower amphibolite facies. Pelitic phases of the Opachuanau gneisses contain andalusite and/or cordierite; diopside occurs in more calcareous zones. Diopside is also present in some of the metasedimentary rocks in the southern portion of the greenstone belt. Argillaceous rocks in this area may also contain small pyralspite garnets.

The determination of a metamorphic grade for the metavolcanic rocks presents a much greater problem. They are composed mainly of hornblende and plagioclase although rocks of a more andesitic composition may contain significant amounts of biotite. The highly pleochroic hornblende ranges in color from bluish-green to green and is usually free of any zonations or poikiloblasts. The plagioclase (andesine) generally varies in composition from An_{32} to An_{36} although occasionally was found to be as calcic as An_{42} and as sodic as An_{24}. However, armored relics of labradorite (i.e. a core of labradorite completely surrounded by a rim of andesine) were observed in some plagioclase phenocrysts in porphyritic metavolcanic rocks. The composition of the plagioclase together with the bluish-green to green color of the hornblende suggests that these rocks have been metamorphosed to the lower amphibolite facies. The bluish-green color of the hornblende is very significant in establishing the metamorphic grade (lower amphibolite) of these rocks as Miyashiro (1968) states that hornblende takes on a greenish-brown to brown color when present in rocks of middle to upper amphibolite grade. Small amounts of actinolite and epidote are often present in the metavolcanic rocks and this could indicate that they are of a slightly lower metamorphic grade than the diopside-bearing metasedimentary rocks.

In some restricted areas in the central portions of the volcanic pile small amounts of chlorite were observed in andesitic rocks containing more than 10 per cent greenish-brown biotite. This could suggest local low-grade retrogression. However, these occurrences of chlorite are frequently accompanied by increased amounts of actinolite and epidote and a decrease in the An content (to less than An_{30}) of the plagioclase. This would seem to indicate that the rocks in these areas have been metamorphosed only to the upper greenschist facies.

CONCLUSIONS

1) The order of decreasing abundance in the volcanic pile is basalt - andesite - picrite - dacite - rhyodacite - rhyolite. The volcanic stratigraphy is as follows: a lower volcanic sequence consisting of an intimate interlayering of picrite, basalt and andesite into which was extruded a number of small lenses of acid volcanic rocks and, an incomplete, upper volcanic sequence consisting of basaltic and andesitic sills.

2) There is no chemical difference between the two separate volcanic sequences except that there are no acid volcanic rocks associated with the upper volcanic sequence. Acid volcanic rocks, although confined to the lower volcanic sequence, make up at least 15 per cent of the volcanic pile.

3) The metavolcanic rocks are chemically similar across the whole of the Rusty Lake greenstone belt and, in general, exhibit a high-alumina to tholeiitic character. Tholeiitic rocks are characteristic of continental orogenic regions including the island arc systems (Wilson et al., 1965). Kuno (1960) states that volcanic rocks of a high-alumina character are found in the medial portions of island arc systems as an intermediary zone between the tholeiitic rocks of the continental side and the alkali-olivine rocks of the oceanic side of the island arc system. The writer believes the Rusty Lake greenstone belt to be an island arc system but more

work would be required to substantiate this.

4) Field observations of preserved primary structures suggest that the major part of the volcanic pile was extruded in a subaerial or shallow marine environment.

5) The metavolcanic rocks of the Rusty Lake greenstone belt show six distinctive chemical characteristics: (a) a high and extremely variable Al_2O_3 content, (b) a low TiO_2 content, (c) high FeO/Fe_2O_3 ratios, (d) a high CaO content with a corresponding low MgO content, (e) a low alkali content, especially K_2O and (f) a high volatile (CO_2 and H_2O) content.

6) The intrusive rocks in the Rusty Lake area show only minor differences in chemical and mineralogical composition to their respective extrusive equivalents.

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APPENDIX: PRESENTATION OF VARIATION DIAGRAMS

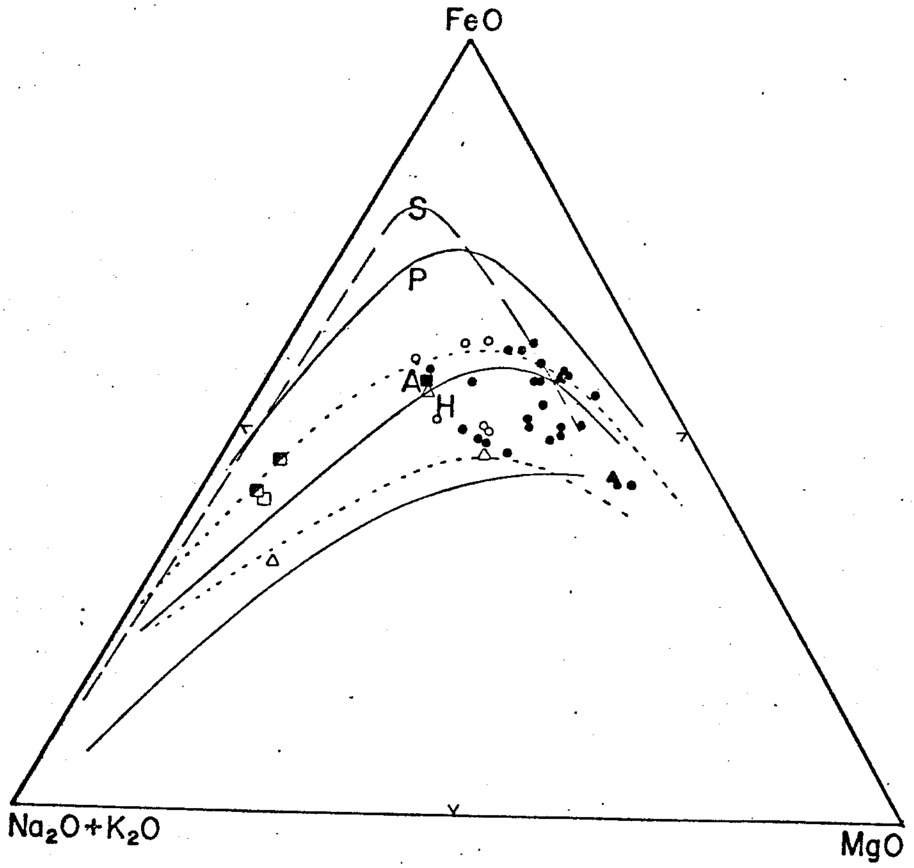


FIGURE 2: MFA ternary oxide diagram. Hypersthenic (H), alkalic (A) and pigeonitic (P) fields have been delineated as well as the variation trend line of the Skaergaard (S) intrusion (after Kuno, 1968).

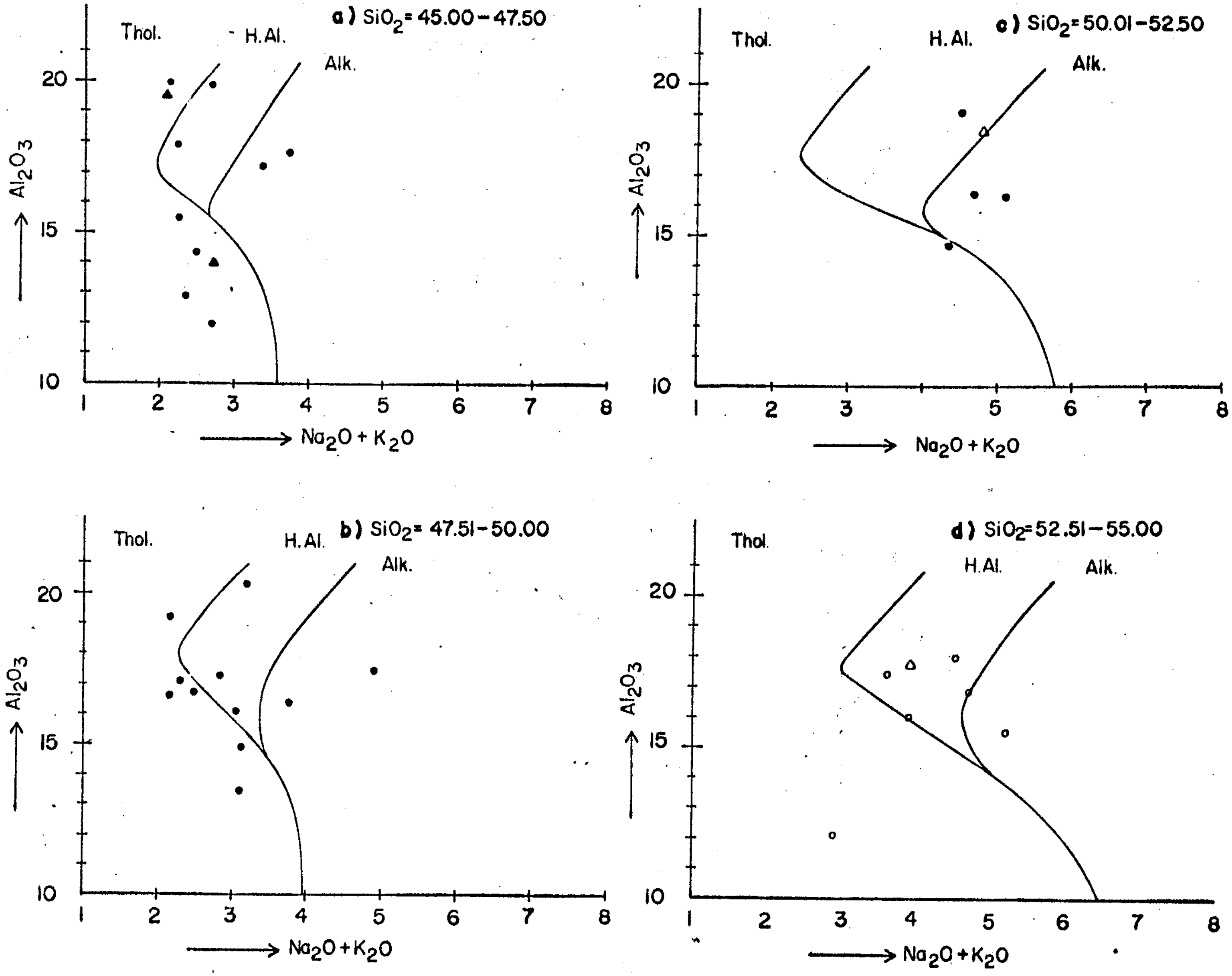


FIGURE 3: Alumina-alkali diagrams. The tholeiitic (Thol.), high-alumina (H.Al.) and alkali-olivine (Alk.) fields have been outlined on each diagram (after Kuno, 1968).

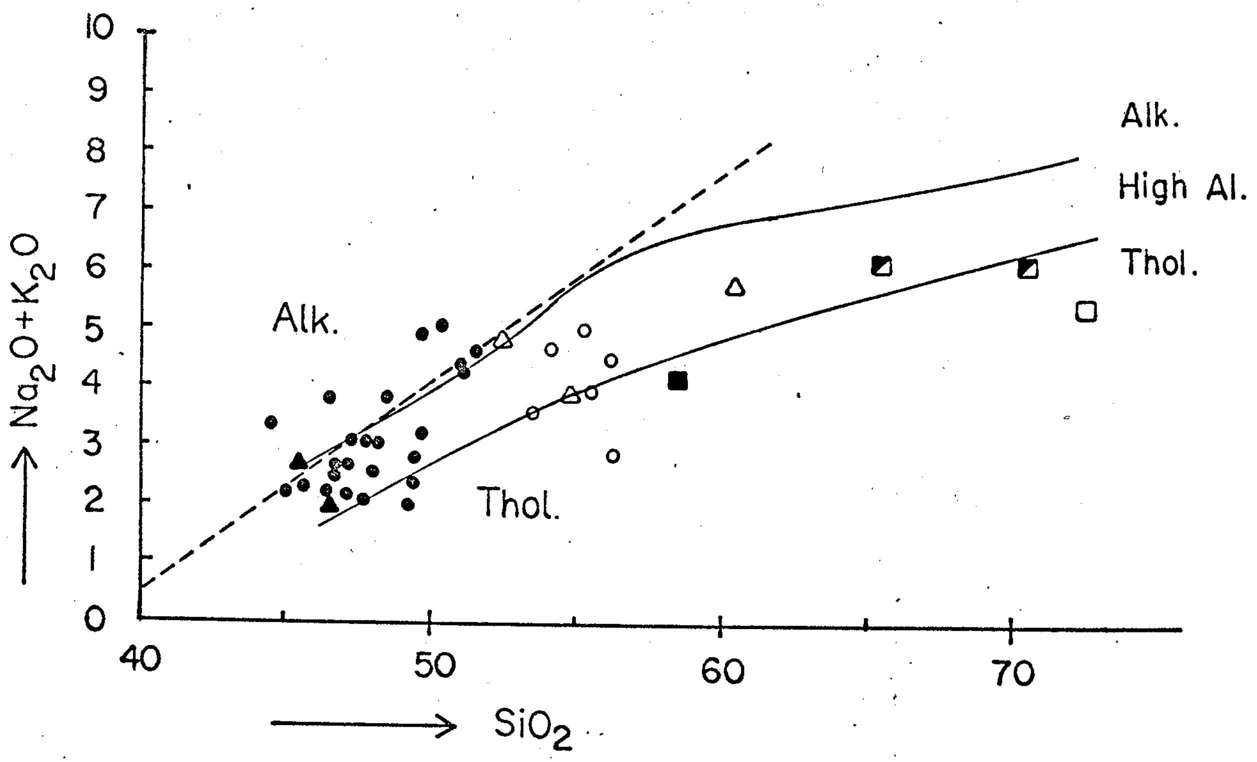


FIGURE 4: Alkali-silica diagram. The solid lines delineate the alkali-olivine (Alk), high-alumina (High Al.) and tholeiitic (Thol.) fields (after Kuno, 1968). The dashed line (after Macdonald and Katsura, 1964) distinguished only between alkali-olivine and tholeiitic rock series.

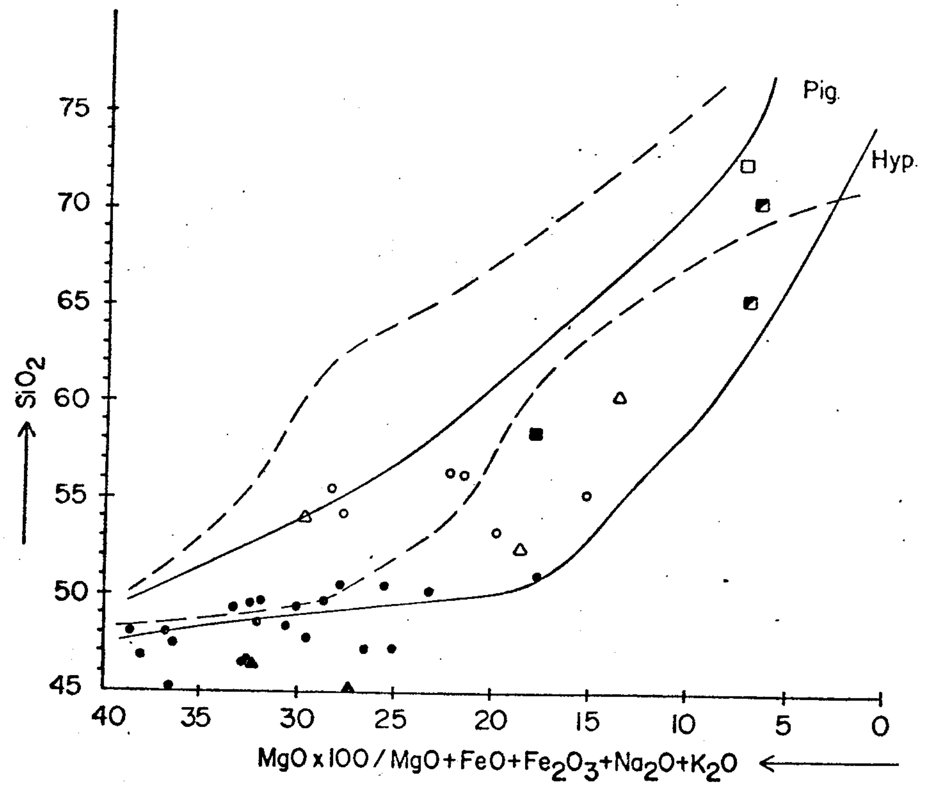


FIGURE 5: Silica vs SI diagram. The pigeonitic field (Pig.) is delineated by the solid lines and the hypersthenic field (Hyp.) by the dashed lines (after Kuno, 1968).

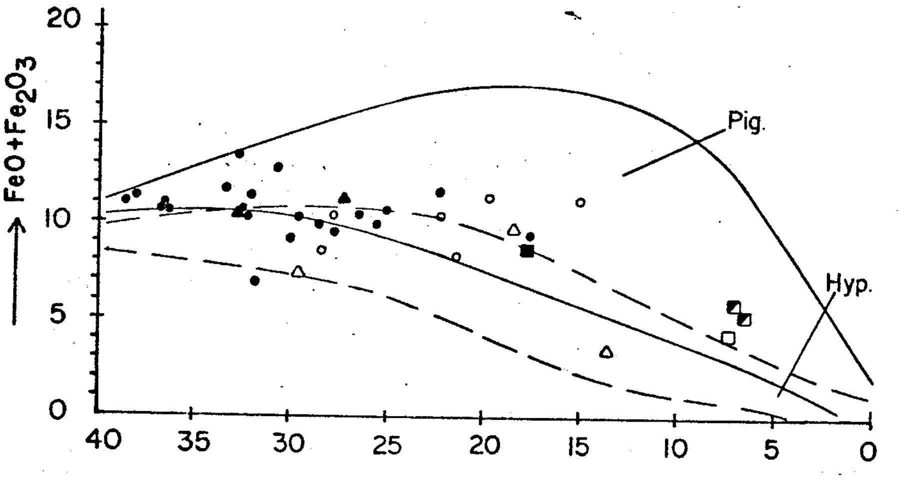


FIGURE 6: Iron oxide vs SI diagram. The pigeonitic field (Pig.) is delineated by the solid lines and the hypersthenic field (Hyp.) by the dashed lines (after Kuno, 1968).

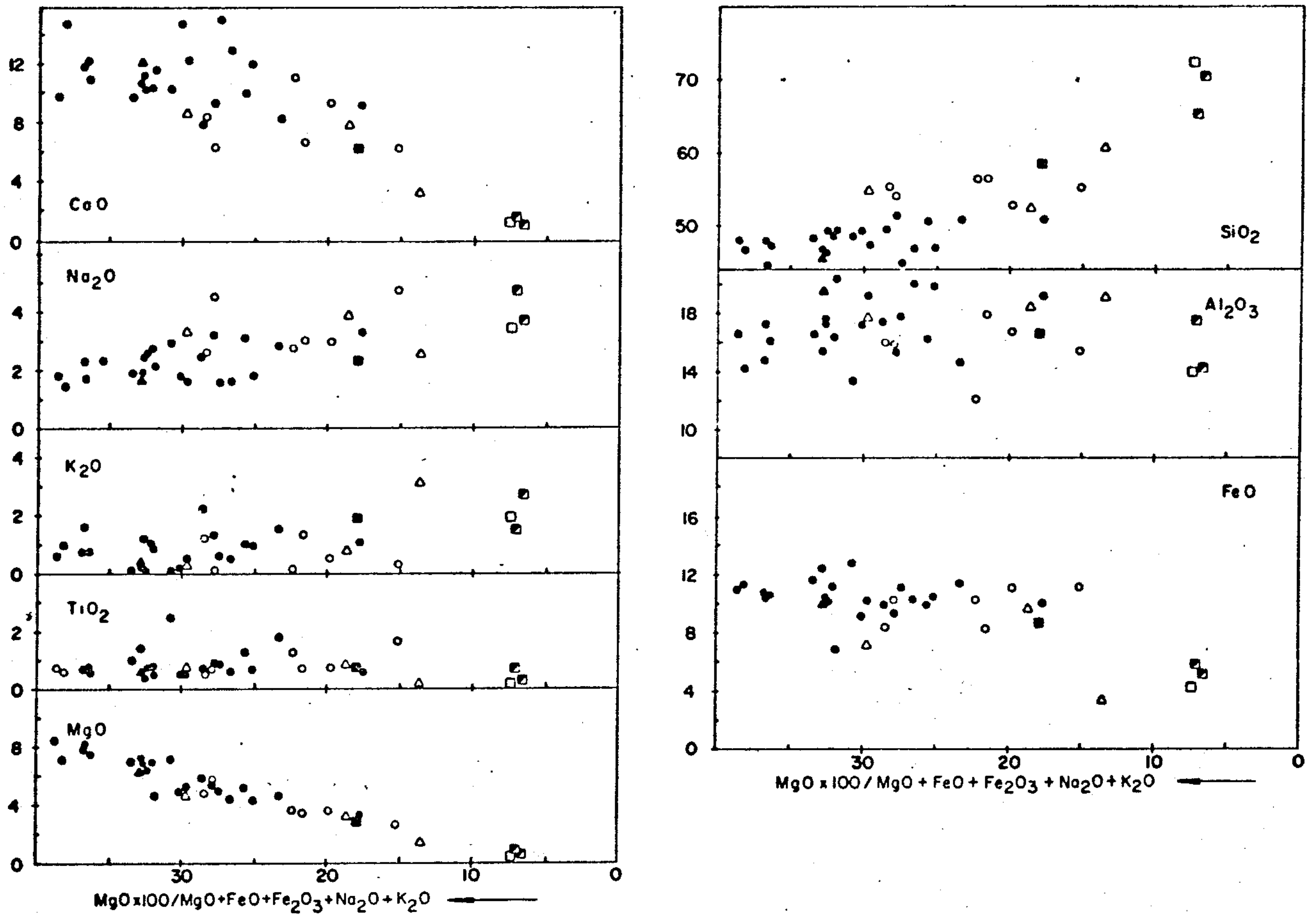
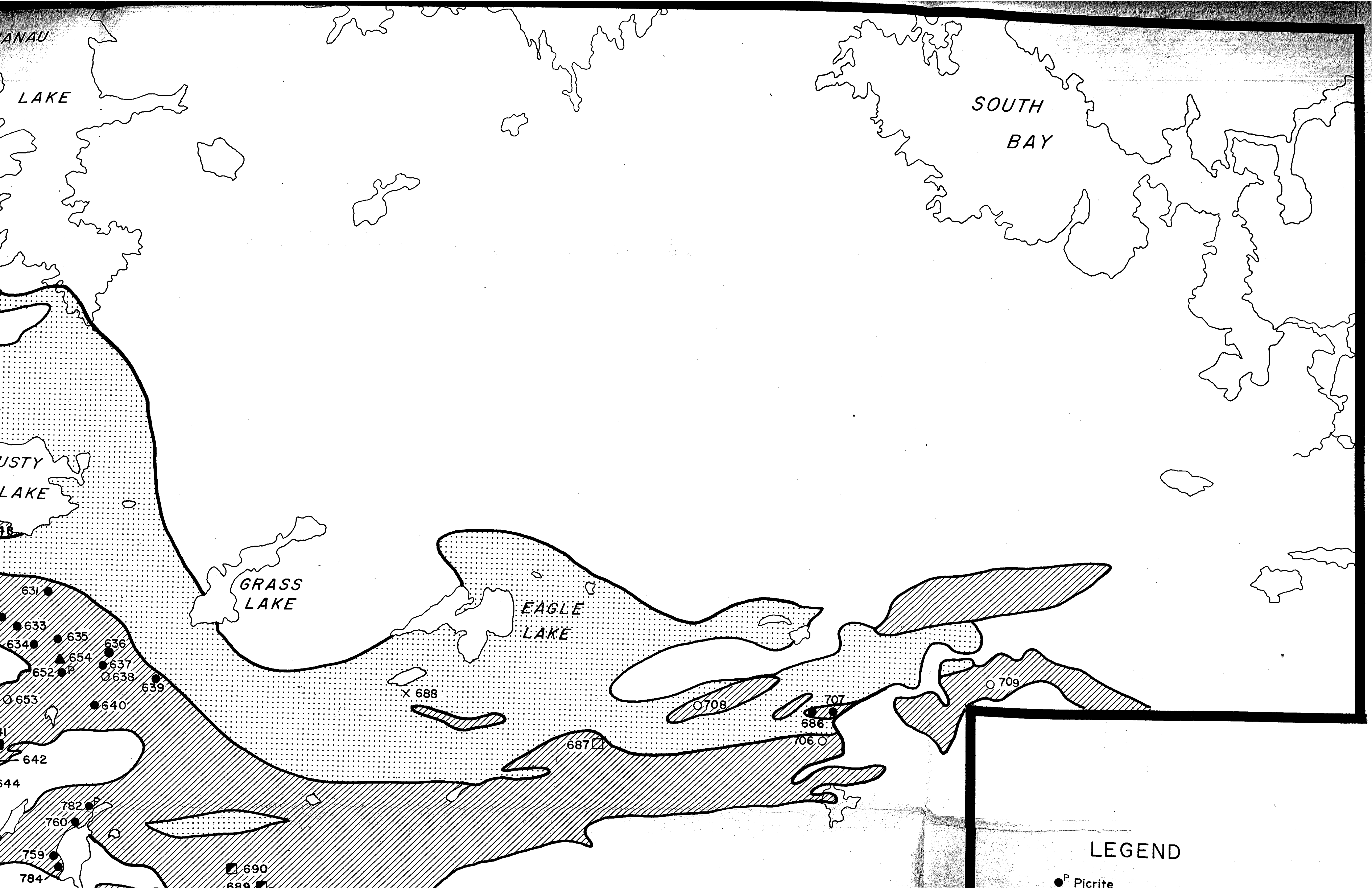


FIGURE 7: Single oxide vs SI diagram (after Kuno, 1968).


ANAU
LAKE
SOUTH
BAY
USTY
LAKE
GRASS
LAKE
EAGLE
LAKE
631
633
634
635
636
637
638
639
640
652
653
654
642
644
782
760
759
784
690
689
688
687
686
706
707
708
709
LEGEND
●P Picrite

nical analyses. The number beside each sample corresponds to its

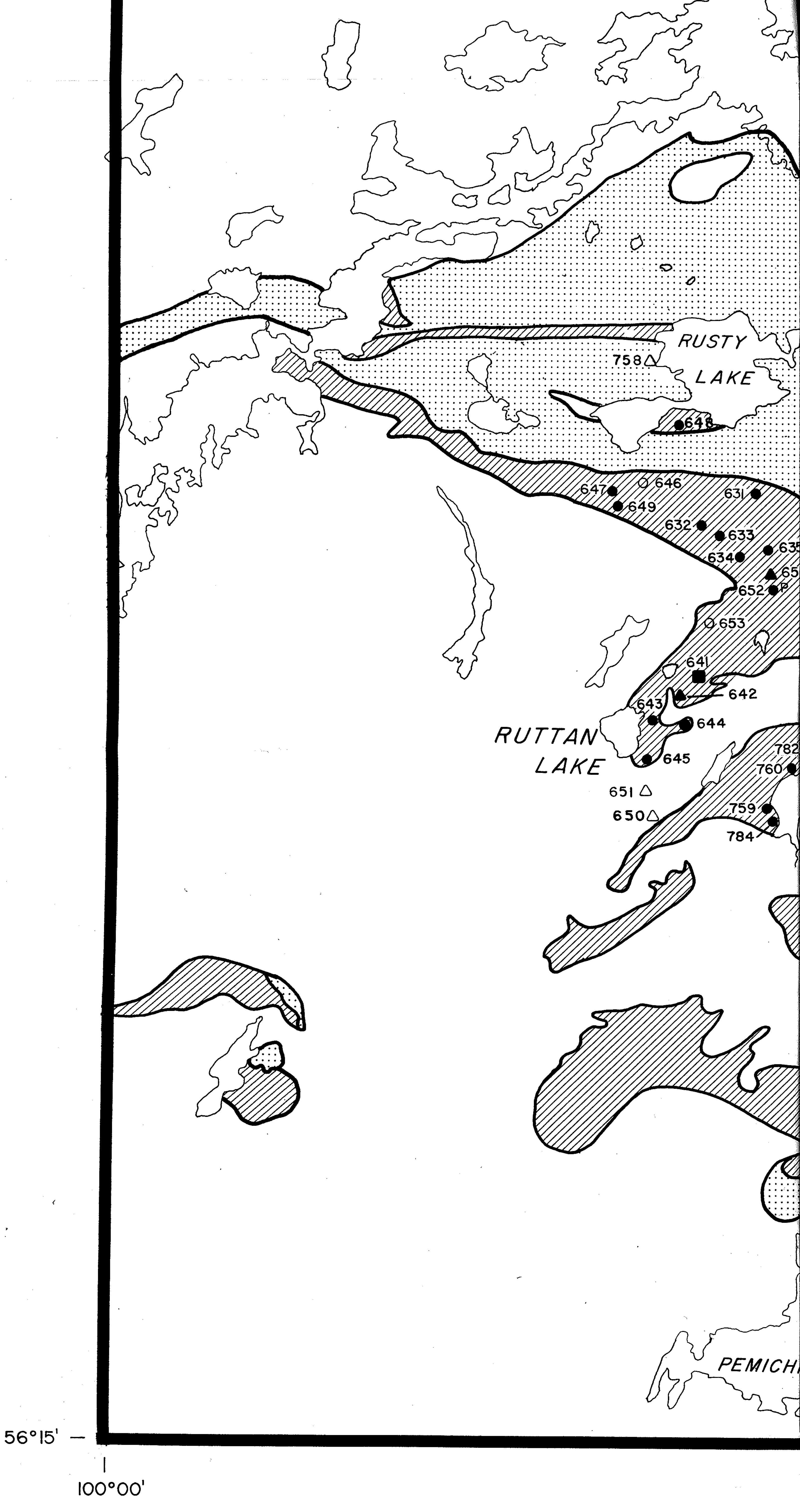
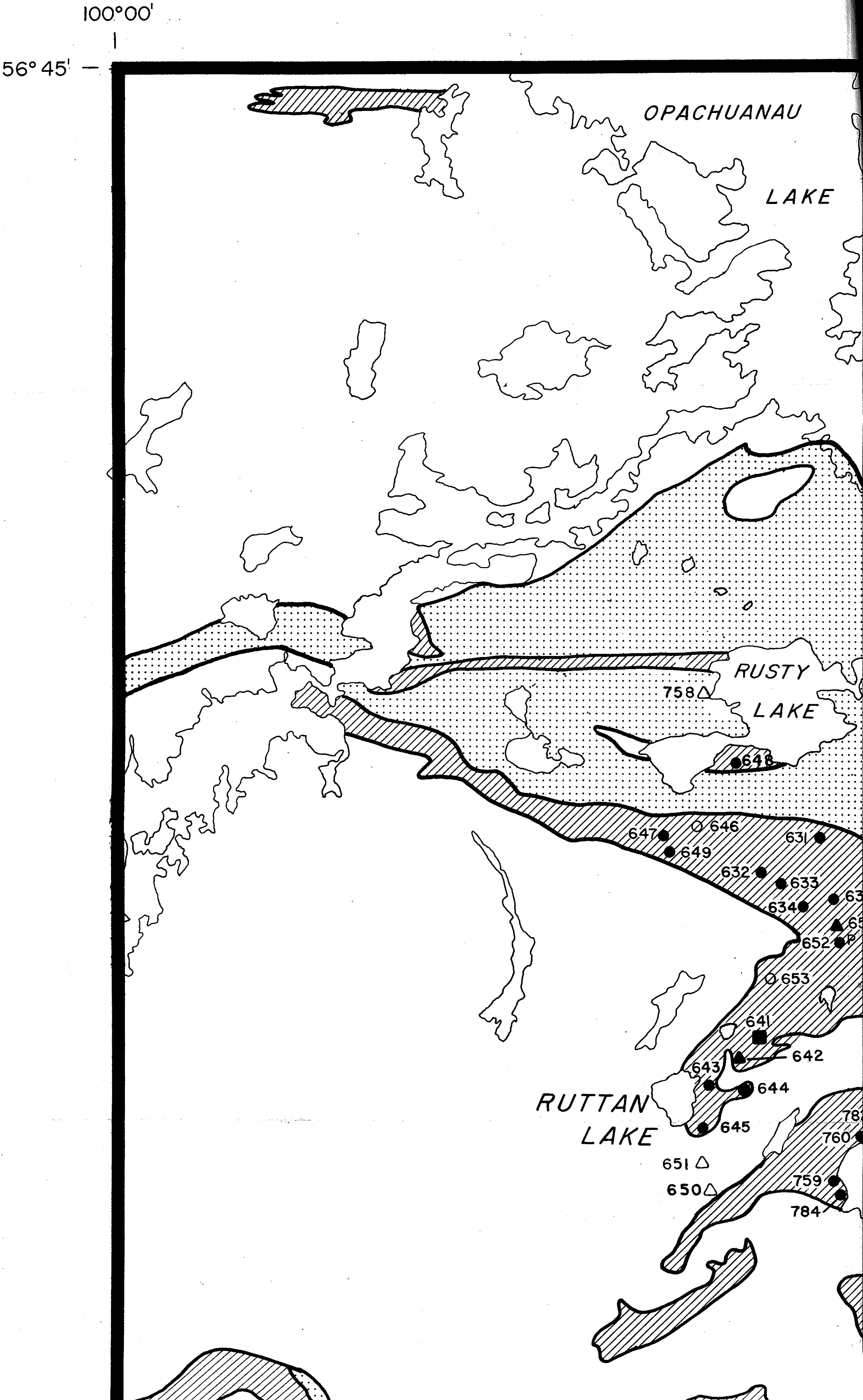
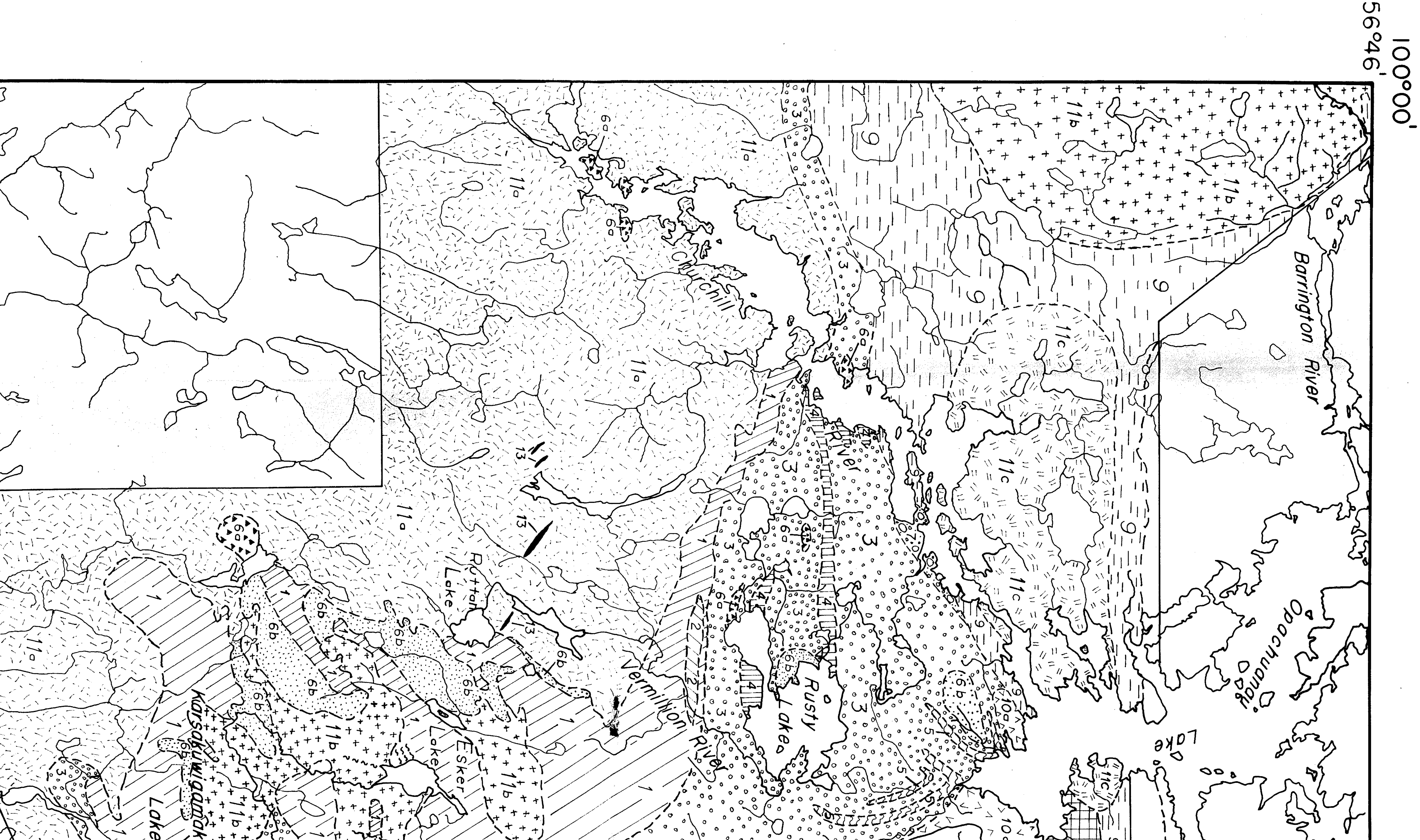
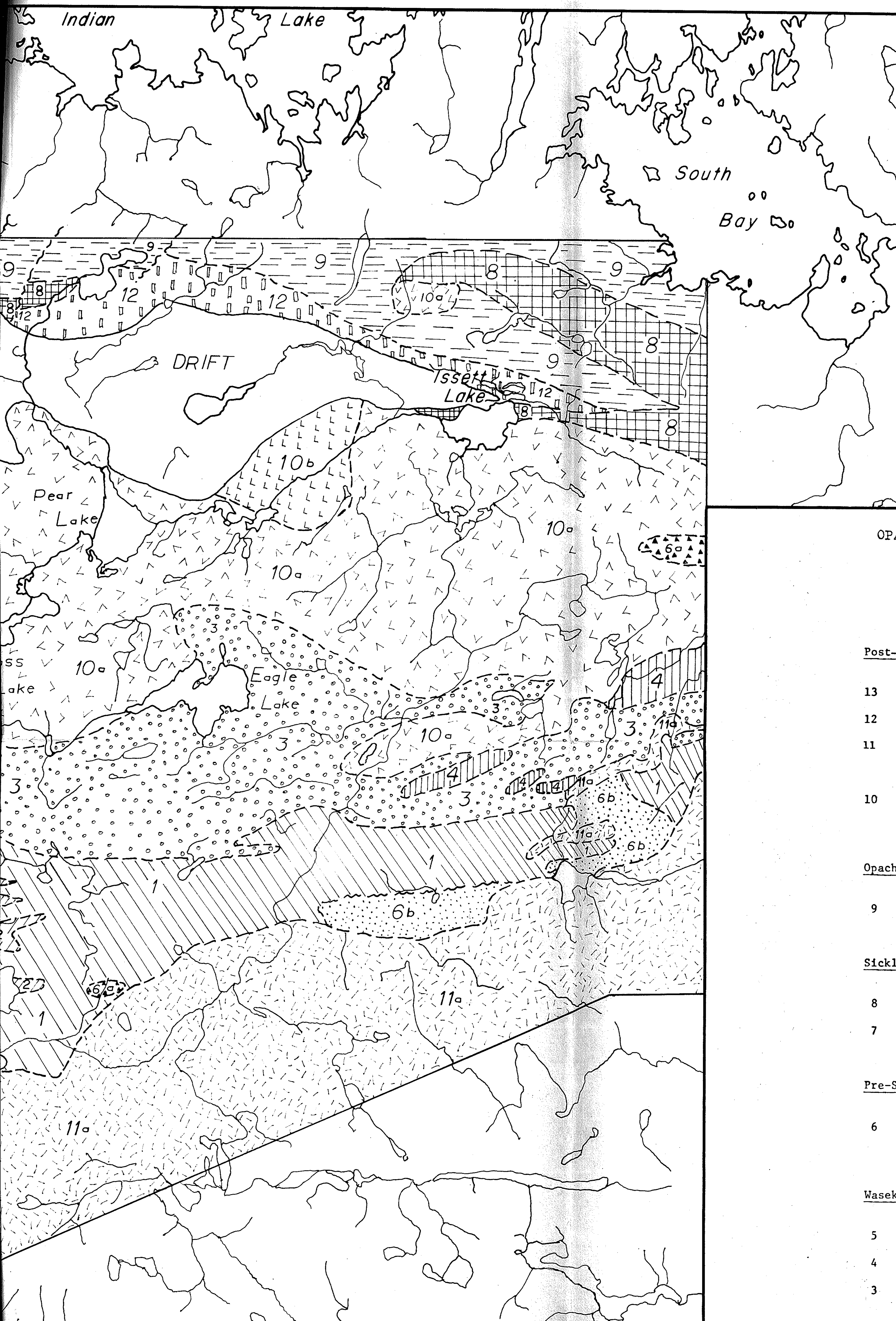


FIGURE 9. Location map of chemical
laboratory number.


100°00'
56° 45'
OPACHUANAU
LAKE
RUSTY
LAKE
758
648
647
646
649
631
632
633
634
652
653
641
642
643
644
RUTTAN
LAKE
645
651
650
760
759
784


100°00'
56°46'
Churchill
River
Barrington River
Rutton Lake
Vermilion River
Rusty Lake
Esker Lake
Karsakuwigamak Lake
Opachuanau Lake
11a
11b
11c
9
6a
6b
13
1
2
3
4
5
10a



OPA

Post-

13

12

11

10

Opach

9

Sickl

8

7

Pre-S

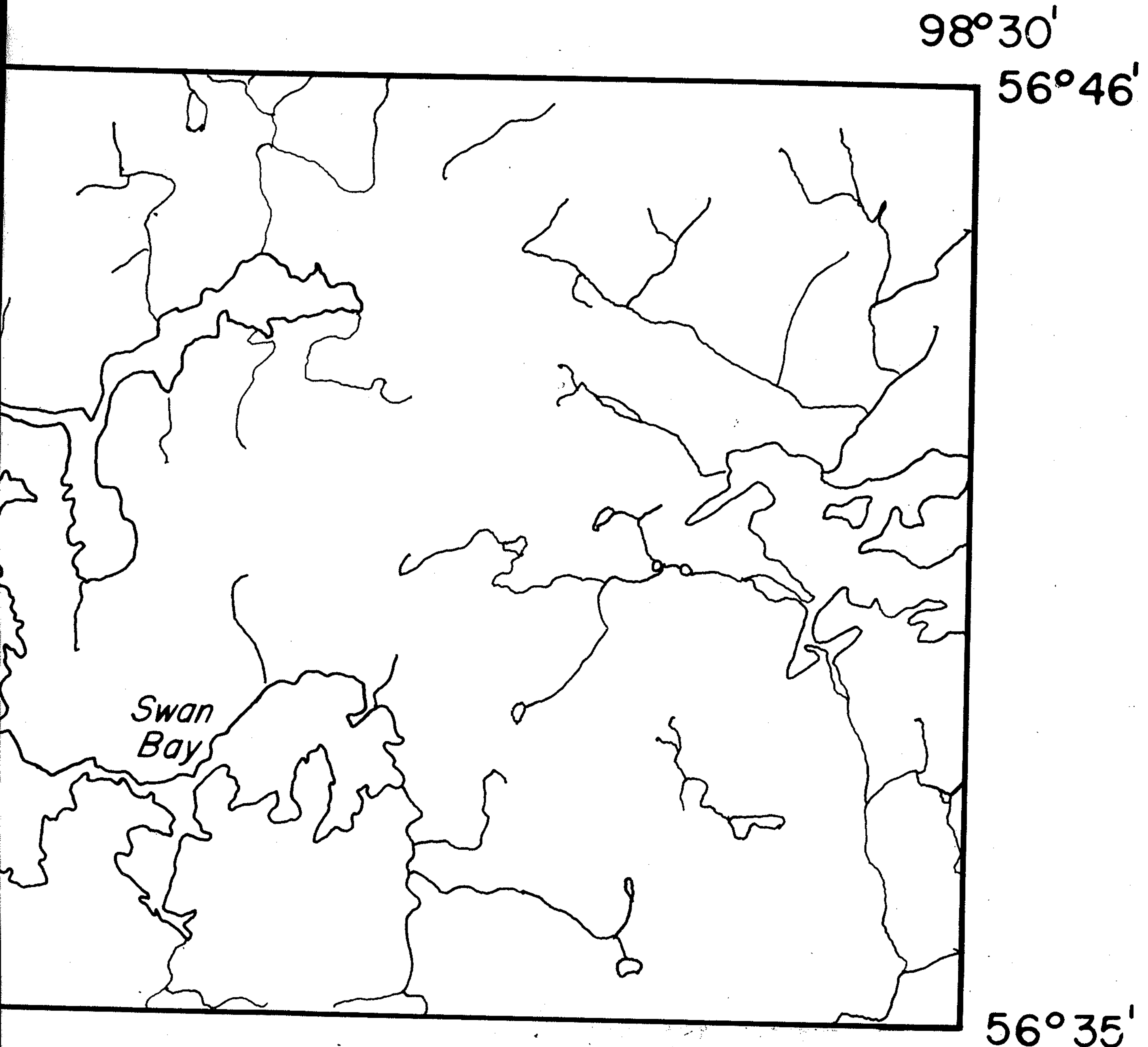
6

Wasek

5

4

3



E-ISSETT LAKE-PEMICHIGAMAU LAKE AREA

LEGEND

ves

-eye granite
iotite quartz monzonite
e-hornblende granodiorite

e-hornblende granodiorite and quartz monzonite
e-hornblende tonalite and diorite

gioclase-quartz gneisses

covite schist

glomerate

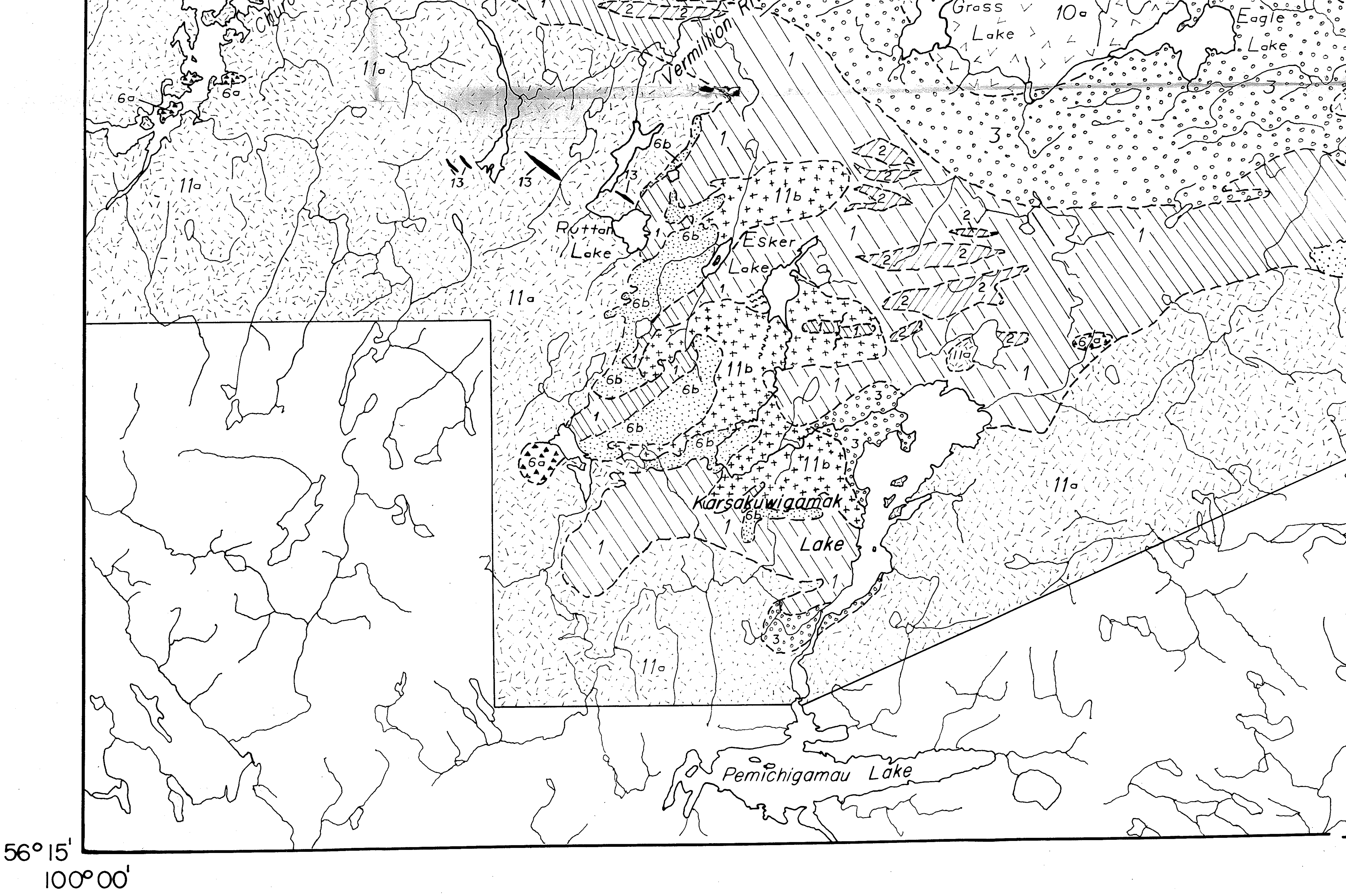
s

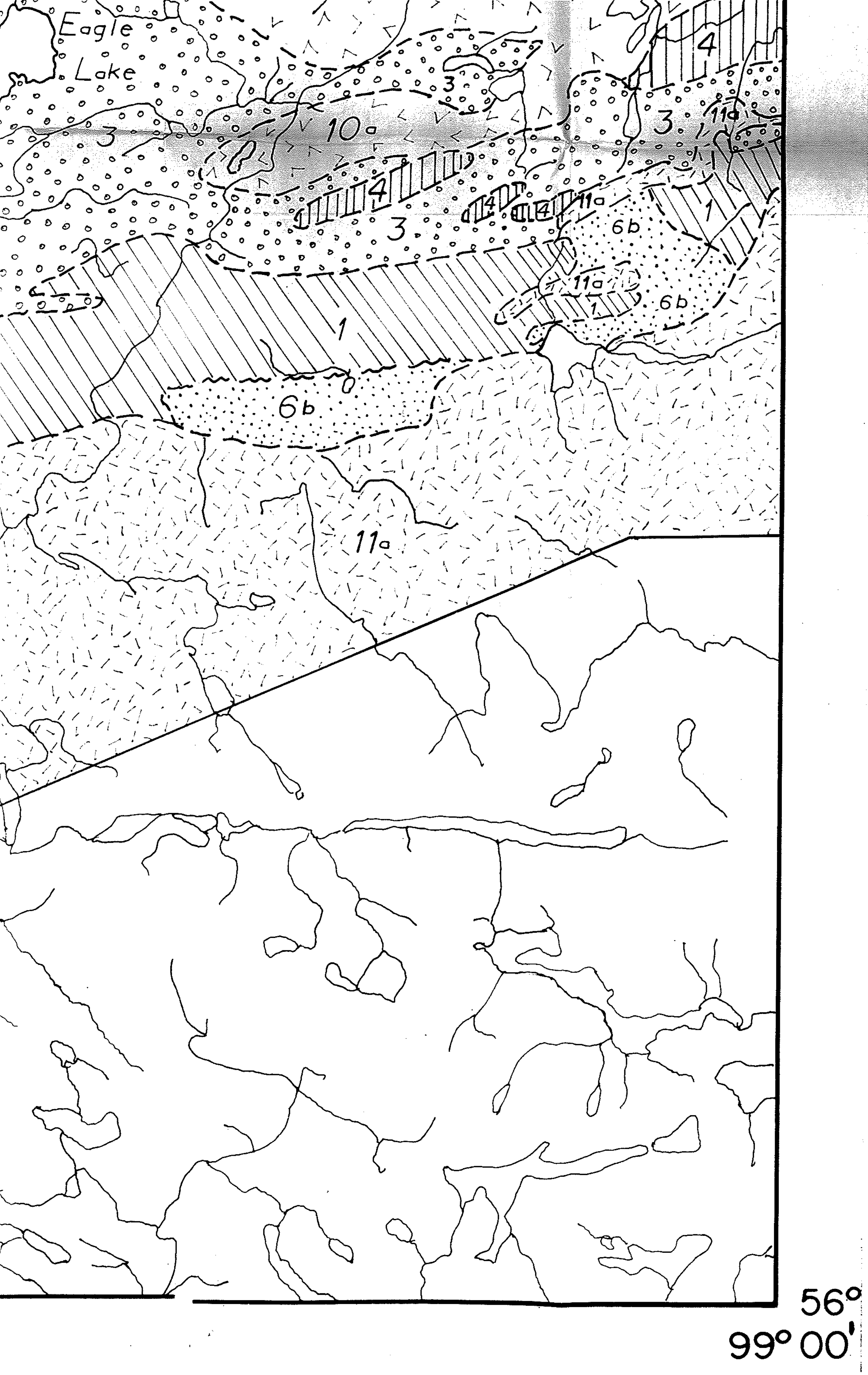
and quartz diorite

rizon

; meta-andesite

ed volcanic wackes and siltstones; greywacke;
gillite; intermediate pyroclastic rocks; medium
se-grained plagioclase amphibolite


Chur
Vermilion R.
Grass Lake
10a
Eagle Lake
3
2
1
11a
6a
13
6b
11b
Ruttan Lake
Esker Lake
Karsakuwigamak Lake
Pemichigamau Lake
56° 15'
100° 00'



Post-Sickle Intrusives

13	**Diabase**
12	**Pegmatite**
11	(c) Quartz-eye granite (b) Pink biotite quartz monzonite (a) Biotite-hornblende granodiorite
10	(b) Biotite-hornblende granodiorite and quartz monzonite (a) Biotite-hornblende tonalite and diorite

Opachuanau Gneisses

9	Biotite-plagioclase-quartz gneisses

Sickle Group

8	Biotite-muscovite schist
7	Arkosic conglomerate

Pre-Sickle Intrusives

6	(b) Diorite and quartz diorite (a) Gabbro

Wasekwan Group

5	Sulphide horizon
4	Meta-basalt; meta-andesite
3	Metamorphosed volcanic wackes and siltstones; greywacke; meta-argillite; intermediate pyroclastic rocks; medium to coarse-grained plagioclase amphibolite.
2	Dacite; minor rhyodacite and rhyolite; acid tuff, agglomerate; volcanic breccia.
1	Meta-basalt; meta-andesite; minor picrite; fine-grained amphibolite

SYMBOLS

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