# ARCHEAN VOLCANISM AND GEOCHEMISTRY WASHEIBAMAGA - THUNDERCLOUD LAKES AREA, WABIGOON SUBPROVINCE - SUPERIOR PROVINCE, NORTHWEST ONTARIO.

BY

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## ABSTRACT

The Washeibamaga - Thundercloud Lakes area in the Wabigoon Greenstone Belt, southeast of Dryden, Ontario, was studied and mapped. Petrographic examination of the various rock types was carried out and geochemical whole rock and trace element data was obtained using X.R.F. methods.

The area can be subdivided into three units:

1) The lower volcanic sequence of metabasalts (lower greenschist facies) is preserved as a steeply-dipping, north-facing homoclinal volcanic pile six kilometres thick. The basalts show trace element (Y, Nb, Zr, Ni, Ba, Rb, Sr), geochemical similarities to modern ocean-floor tholeiitic basalts.

2) The Thundercloud Quartz-Porphyry intrudes the lower sequence and is believed to represent a vent-plug filling a late-stage felsic volcano. Accompanying explosive volcanism produced a three-kilometre thick sequence of coarse pyroclastic and epiclastic rocks and tuffs, hereafter called the middle sequence. Associated dacitic and auto-brecciated rhyolitic flows have calc-alkaline affinities and are chemically distinct from both volcanic sequences. They appear not to be a differentiated product but to have originated as a separate magma.

3) The upper volcanic sequence of metabasalts is composed of tightly folded, massive to pillowed flows. The contact with the underlying epiclastic and pyroclastic rocks is at an angle of thirty degrees, implying either profound angular unconformity or a fault contact. The upper sequence is chemically distinct from the lower sequence. Trace element abundances (K, Rb, Sr, Ba), suggest similarities with modern island-arc tholeiites or back-arc-basin basalts.

The data will be used to compare the thesis area with other Archean settings and with modern analogues. In doing this a tectonic interpretation of the Washeibamaga - Thundercloud Lakes area will be presented.

THUNDERCLOUD LAKE

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# CHAPTER I - INTRODUCTION

## i) Location and Accessibility

The Washeibamaga - Thundercloud Lakes Area is bounded by latitudes 49°20'N and 49°27'N and longitudes 92°32'W and 92°37'W, in the district of Kenora. The area covers over 100 square kilometres, being 8 km wide by 13 km long.

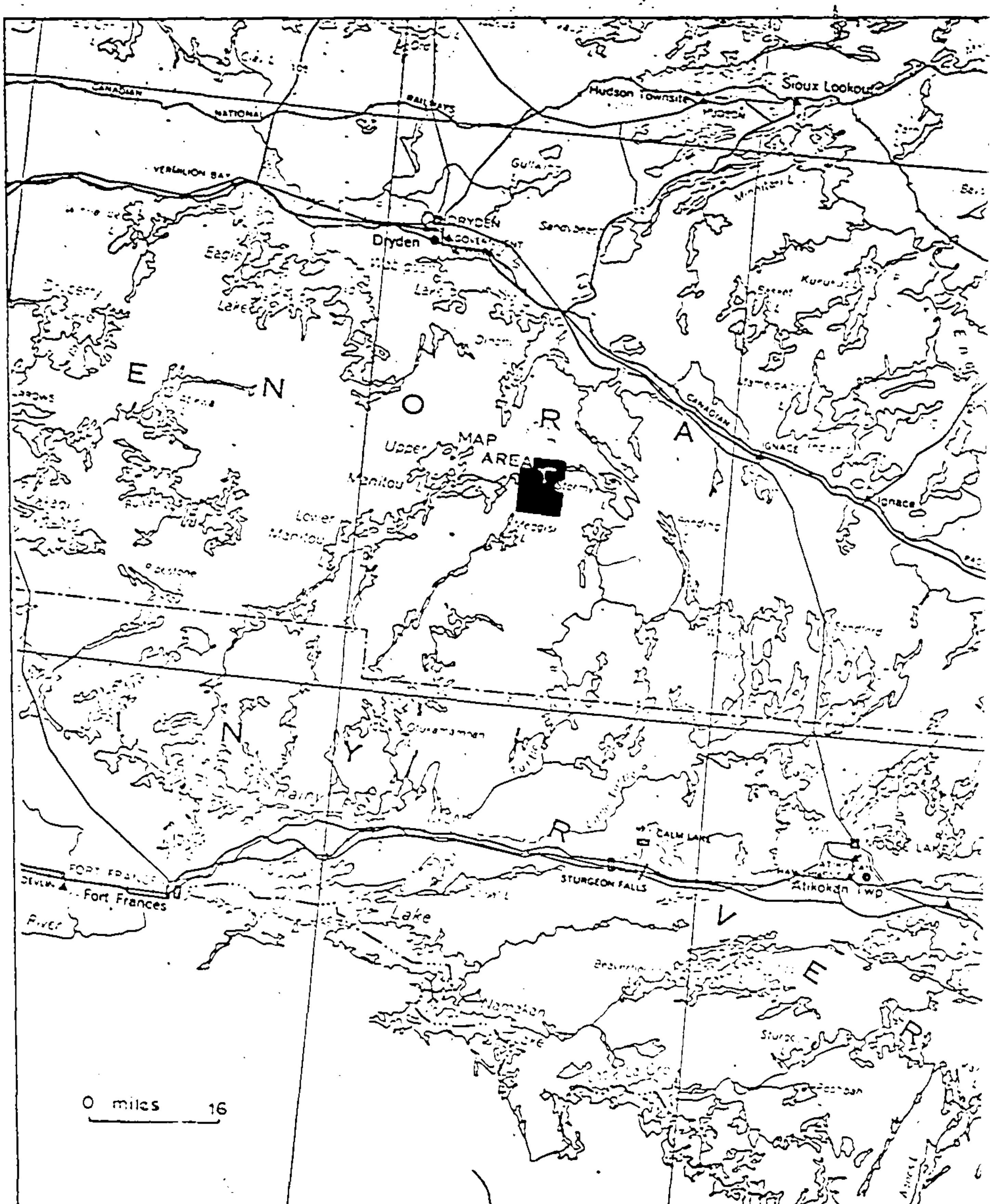
The study area is located on Dryden Sheet (No. 52F) of the National Topographic Series and is included in the geologic map compiled by the Ontario Division of Mines (Thomson, 1933). The area can also be located on Map 2115, Kenora-Fort Frances Sheet, Geological Compilation Series (Davies and Pryslak), 1965.

Access by aircraft or water transport to the study area is possible from Dryden, 52 km to the northwest, or from Fort Frances, 110 km to the southwest, see Figure 1. A lumber road extending south from Highway 17 at Jackfish Lake to Snake Bay is usable in the summer months. Access south of this point, on Snake Bay Road, is possible with permission and key from the Reed Pulp and Paper Company. It extends nearly to the base of the present map area and is mainly a corduroy road.

Within the map area, short portages connect all the lakes and are passible with small canoes.

Location Map





ii) Previous Work

This area has previously been mapped on a reconnaisance scale (1 mile to 1 inch), as part of a larger mapping project of the Manitou-Stormy Lake Area (Thomson, 1933). In 1936-38, Pettijohn (1937) and Bertholf Jr. (1946), in the course of studies on Archean sedimentation, carried out geological mapping in the Mosher Bay area of Upper Manitou Lake and the Washeibamaga Lake vicinity.

A more detailed mapping project (1/4 mile to 1 inch) began in 1972, by the Ontario Division of Mines, under the direction of C. E. Blackburn, and in 1974 and 1975 included the area of this thesis. Preliminary results of this work have been published (Blackburn, 1975).

Other projects that have been carried out in the area include Pichette (1976), Casey (1976) and McMaster (1975). In addition R. Teal has completed a sedimentological study of Manitou Lake and Sabag is working within the Meggisi Lake Batholith.

iii) Statement of the Problem

Previous mapping of the area by Thomson (1933) defined the boundaries of the Manitou Series and the Thundercloud Lake Porphyry. He described the porphyry as "irregular stocks and dikes of the same general age as the Algoman granite". Bertholf (1946) recognised that the delineation of the relative ages of the quartz porphyry and Manitou sediments was important, but was not prepared to undertake an extensive program of chemical analyses, and relied on Thomson's map and field relationships to explain its association.

Thus, a detailed examination (petrographic and geochemical) of the volcanic, pyroclastic, epiclastic, and porphyry rocks in the vicinity of Washeibamaga and Thundercloud Lakes was undertaken, with the following objectives in mind:

1. To map the area, elucidate the detailed stratigraphy, and describe the various lithologies and structures.
2. To determine the inter-relationships between the three major sequences, and the relative time sequence involved.
3. To investigate the spatial and chemical relationships between the porphyry and the volcanics.
4. To outline the processes involved in the formation of the diverse Middle Felsic Sequence.
5. To draw conclusions regarding the nature and tectonic setting of the study area.

iv) Present Study

The present study was carried out over three summers. In 1974, as a geological assistant with the Ontario Division of Mines, the author traversed the mafic volcanics north of Kenny Lake, and became familiar with the Manitou Series on Upper Manitou Lake. In 1975, as a senior assistant with the Ontario Division of Mines, the author independently mapped the area south of Washeibamaga Lake. Mapping in the spring of 1976, east of Washeibamaga Lake to the Snake Bay Road, tied in the remaining part of the map area.

Maps were drawn at a scale of 1" to 1/4 mile, based on shore-line outcrops and pace-and-compass traverses run at 0.4 km intervals roughly perpendicular to the strike of formations. A detailed geological map of the area, Figure 2, can be found in the back pocket of the thesis.

# CHAPTER II - GENERAL GEOLOGY

## Part 1 - Introduction

### i) Regional Geology

The Manitou - Stormy Lake Area is characterized by an arcuate metavolcanic - metasedimentary belt 19 km wide and 80 km long. The belt consists of thick volcanic and sedimentary sequences intruded by porphyry stocks, dikes, gabbroic bodies, and granitic stocks (Blackburn, 1976).

The general stratigraphic sequence of the central portion of the belt (present study area) begins with a lower sequence, 8,200 m in thickness, of pillowed, porphyritic and mafic metavolcanics. The base has been deformed by the intrusion of the Meggisi batholith. The middle sequence, formerly assigned to the Manitou Series (Thomson, 1933), consists of intercalated metavolcanics and metasediments. Amygdaloidal flows, volcaniclastic coarse pyroclastic, epiclastic, and autoclastic units in the Washeibamaga Lake Area are 3,000 m thick. The clastic-metavolcanic sequence is structurally overlain by east-west striking metavolcanic flows and gabbroic intrusions. At both Mosher Bay and Washeibamaga Lake, the strike of the bedding in the clastic sequence is at an angle of 30° to 40° to the contact with the overlying mafic metavolcanics, implying either an angular unconformity, or a fault contact.

Granite rocks at Meggisi Lake are part of the Irene - Eltrut Lakes Batholithic Complex (Sage et al. 1975). It consists of an early, centrally located, medium grained, equigranular granodiorite to quartz monzonitic phase, containing abundant mafic metavolcanic xenoliths. It is succeeded outwards and intruded by a seriate to porphyritic granodiorite to quartz-monzonitic phase (Sabag and Blackburn, 1977).

Two granite stocks intrude the supracrustal sequence in the area. The Scattergood Stock, south of Sunshine Lake in the west, and the Taylor Lake Stock between Sunshine Lake and Washeibamaga Lake, to the east. The Taylor Lake Stock forms the western boundary of the study area. Pichette (1976) described it as a granitoid complex composed of nine distinct phases, ranging from quartz monzonite to granodiorite in nature. It intrudes the apical area of an antiformal structure produced by intrusion of the batholith, and thus, post dates the batholith. An Rb-Sr date of 2640 ± 31 my has been reported by Birk and McNutt (1977).

Quartz-feldspar porphyry plugs and dikes also intrude the lower sequence. Thomson (1933) delineated a large porphyry body, between Washeibamaga and Thundercloud Lakes, (here named the Thundercloud Porphyry) and Blackburn (1975) mapped one south of Sunshine Lake. The stocks are thought to be subvolcanic equivalents of dacitic to rhyolitic flows that occur within the pyroclastic sequence and represent localized felsic vent plugs.

A composite stratigraphic column showing general thicknesses and relative positions of the units has been erected (Figure 3). The Upper Sequence is included for completeness, although time relationships are implied from its position at the top.

ii) Metamorphism

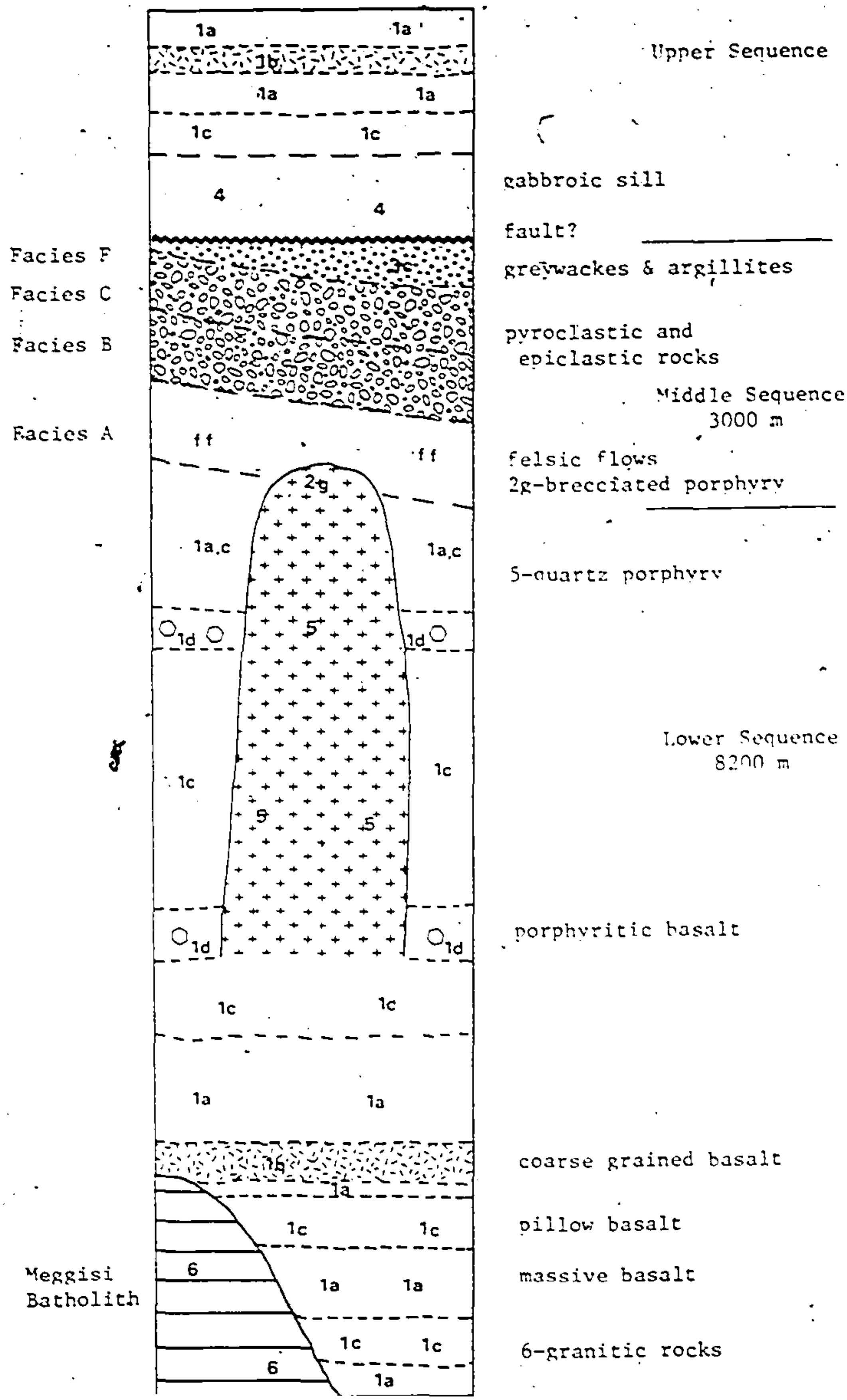
Metamorphic grade is lower greenschist facies or low-grade metamorphism (Winkler, 1974). A typical mineral assemblage for the mafic metavolcanics is; albite-chlorite-actinolite-epidote (Figure 4). The stable epidote mineral at low-grade metamorphism is iron-poor clinozoisite, and occurs as polygons replacing feldspar laths. Pyroxenes and plagioclases are altered to uralite and saussurite respectively.

The porphyry contains abundant sericite and minor biotite, resulting in a mineral paragenesis of albite-biotite-sericite-K spar + chlorite. Tuffaceous (sandstones) rocks of the middle sequence contain abundant biotite and minor amounts of chlorite and chloritoid.

iii) Structure

Structurally, the map area is divisible into three units: the lower metavolcanic unit, the middle felsic unit, and the upper metavolcanic unit.

Figure 3 General Stratigraphic Column



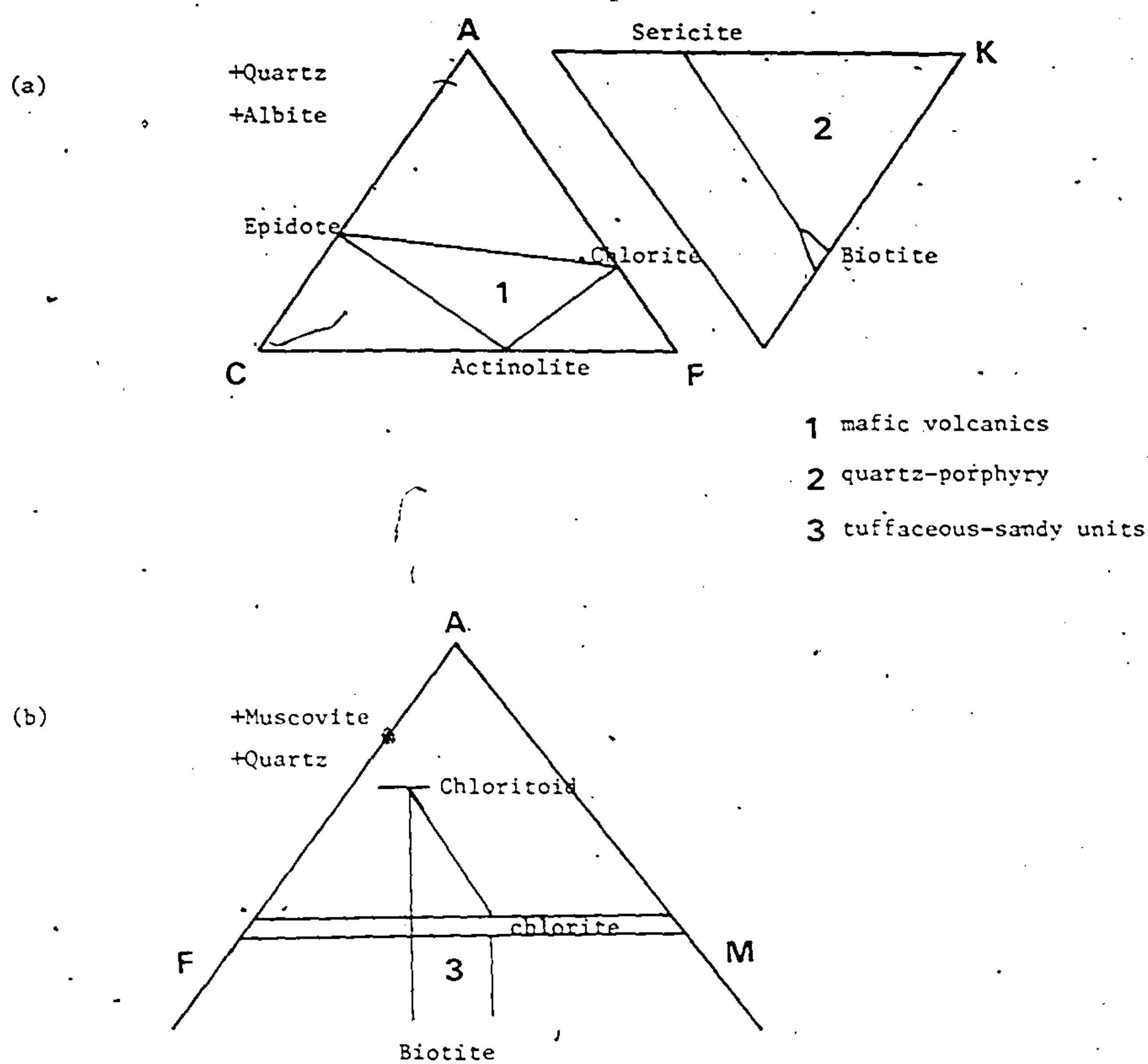
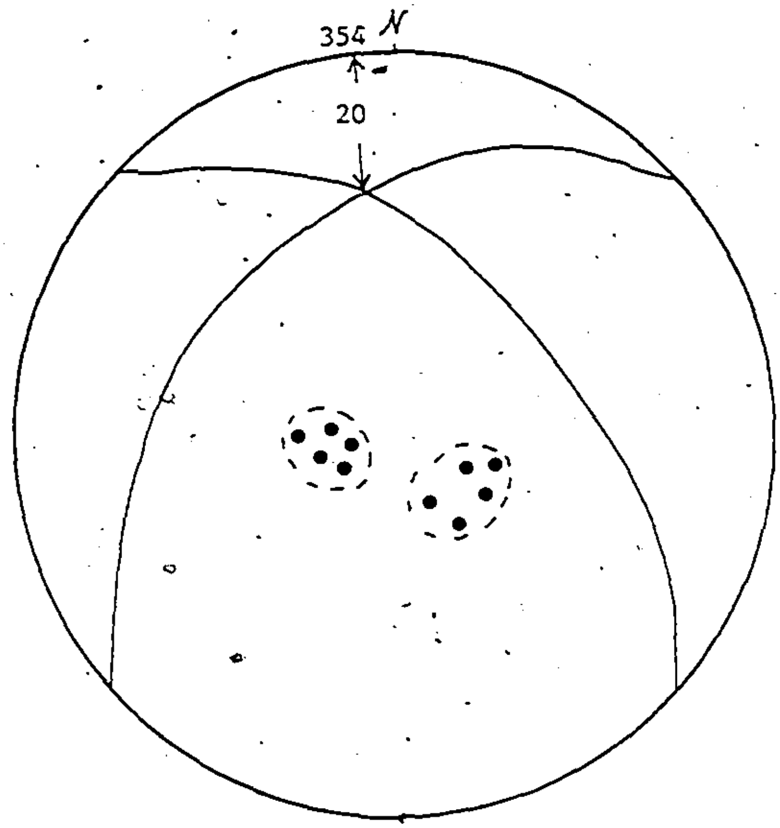



Figure 4 ACF-K and AFM metamorphic facies diagrams, showing composition of average rocks in the thesis area. Diagrams after Winkler (1974).

The lower metavolcanic unit forms the east limb of a broad anticlinal structure. The anticlinal structure may be the result of the intrusion of the Meggisi Batholith. Foliations within 300 m of the contact, in the east have an attitude of 310°/ 30°N, and in the west, south of Secret Lake, 220°/35N°. The surrounding volcanics plunge to the north (354°) at approximately 20° (Figure 5). The nose is in the vicinity of Dorothy Lake (Sabag and Blackburn, 1977), at the southwestern margin of the map sheet.

Correlation of plagioclase-porphyritic units and a coarse gabbroic unit indicates tops to the NNE in the lower sequence. This has been confirmed by top determinations in the pillowed lavas, both to the SE and SW of Thundercloud Lake. In three locations, pillows were horizontal and may have been reoriented by porphyry intrusion and doming. The rocks have shallow dips of 25 to 30° in the vicinity of the batholith, increasing northwards to vertical, the common mode for most of the Wabigoon Belt. N-NW trending faults cut the lower sequence, producing a left lateral displacement of about 270 m in the coarse, massive, and pillowed flows, as well as the Meggisi Batholith.

In the middle felsic unit, the dip is generally near vertical. The strike of the bedding in Facies B and C (see Part 3), based on the long direction of the pebbles, was 120° (300°), similar to that of an amygdaloidal flow unit found within Facies B. In only two places, (1) on the road north of Katisha Lake, and (2) the central joint blocks of Dark Horse Lake, could the orientation of the pebbles be checked against the plane of the outcrop surface.




• pole to foliation

Figure 5 Stereographic determination of plunge and orientation of foliations within the mafic volcanics north of the Meggisi Batholith.

Bertholf (1946), states that "the long-direction approximates the B (intermediate) axis, and the A (long) axis dips into the outcrop with the bedding plane", which is in agreement with observations made by the author. Top determinations were based on scour and fill structures in the thinly bedded tuffs (sands), cross-bedding and normal and reverse grading in the coarse clastic sequences. All indicated tops face roughly 030°NNE.

Bedding within the banded iron formation and argillaceous metasediments north of the Kenneweppeko River also has a strike of 120°.

The northern contact of the Middle and Upper Sequences is thought to be a fault. Clasts in the underlying coarse pyroclastic facies are severely distorted, (Figure 6), up to a meter in length, and are severely contorted with kink banding or "S" drag folds (Figure 7). The exact contact is not seen since a large moraine cuts across the area (Zoltai, 1961). Slickenslides on the north shore of Washeibamaga Lake were reported by Bertholf, and he interpreted the northern block as the downthrown side. The pillows north of the contact are distorted, with lengths up to 4 meters and widths less than 1 meter, the vesicles contained within the selvages are elliptical (Figure 8). Quartz-filled tension gashes, and intensely sheared mafic volcanics were also present (Figure 9).

The upper unit consists of a steeply dipping isoclinal sequence of metavolcanics. Top determinations on pillows indicate tops to the north. Between Washeibamaga Lake and Boyer Lake, two,

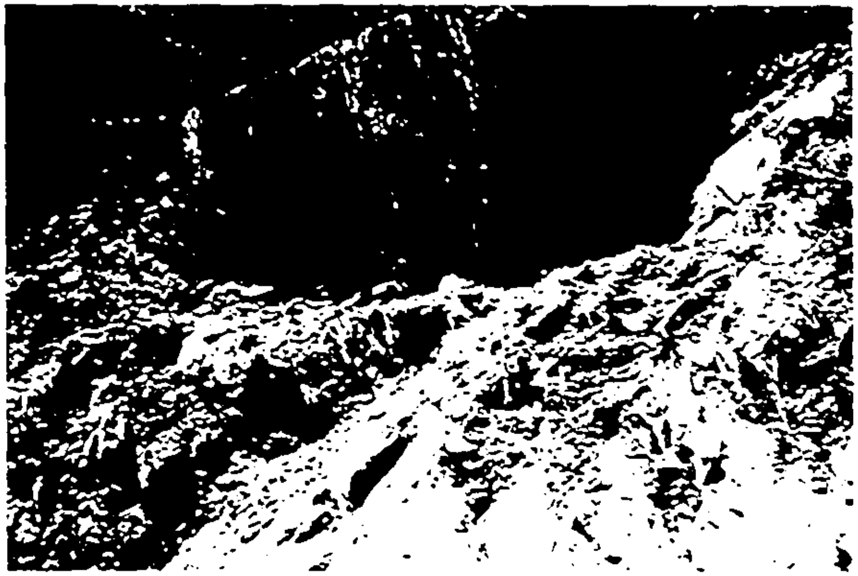


Figure 6 Intense shearing of upper sequence basalts north of Snake Bay, near the contact between the middle and upper sequences.

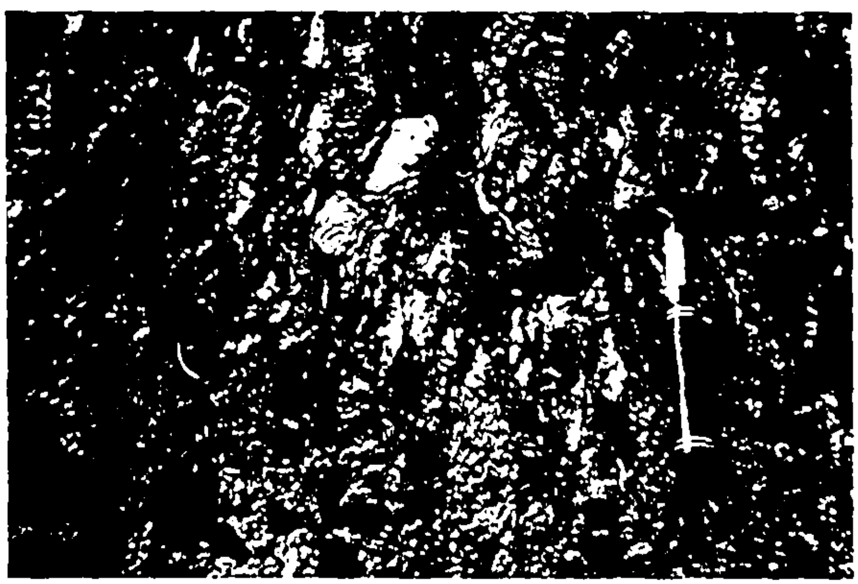


Figure 7 Severely contorted clasts, displaying kink banding or 'S' drag folds, on an island in Washeibamaga Lake just south of the middle/upper sequence contact.

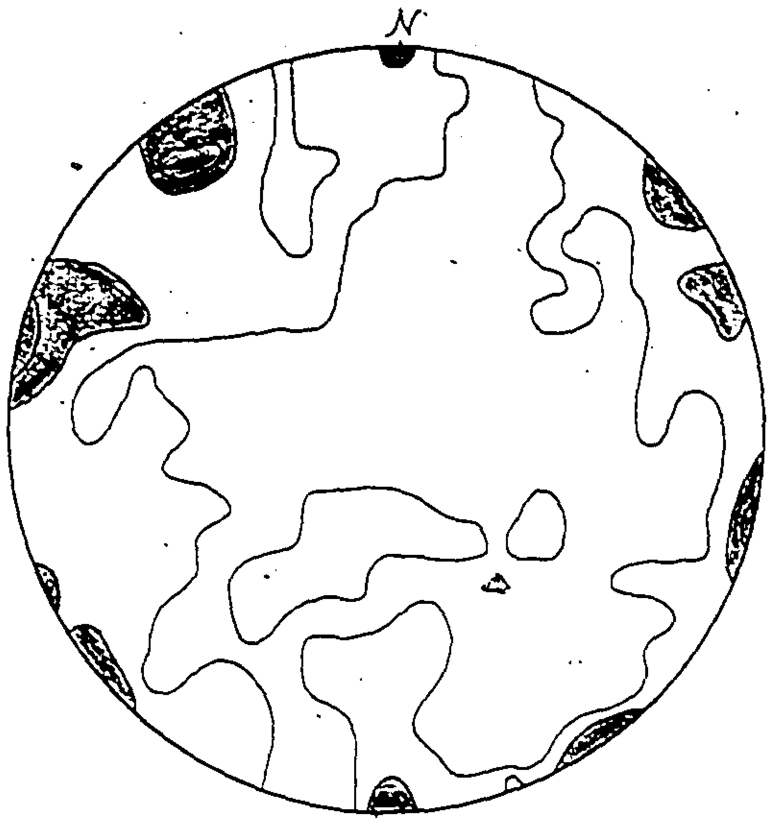
Figure 8 Stretched and deformed pillows north of the middle/upper sequence contact.

Figure 9 Quartz-filled tension gashes in sheared mafic volcanics of upper sequence.

possibly three fold axes are discernible, based on reversals in pillow top direction (Blackburn, 1975). Minor N-NW trending faults are also evident.

Jointing is prominent throughout the area, and controls the major outline of the topography. The orientation of three hundred joints were recorded from all three sequences, and plotted on Schmidt nets. An attempt was made to obtain a uniform distribution of joint data. This is dependent on outcrop control, and there is undoubtedly some bias to lakeshore data. Inspection of the contoured stereograms (Figure 10) showed that a number of trends were present, and repeated in all three groups. Therefore, there is no change of orientation due to lithological variations. Thus, it was possible to reduce the data (Appendix B) to one stereogram (Figure 11), which was contoured using the Schmidt method (Stauffer, 1966). It shows a strong maximum at 290°, with poorly developed maxima in the; 045°m 070°, 320°, 010° directions. The resulting joint sets are: 20°/90°, 315°/85°, 340°/90°, 60°/80°, and 100°/80°. (Standard right hand attitude was used.) The joint trends can be related to a stress system with a N-S compression. Joints $S_1$, $S_2$, are interpreted as shear directions with a conjugate-shear angle of 70°. Joints $T_1$, $T_2$, are extension joints roughly parallel to, and, at right angles to the stress. The weakest joint set, at 100°/80°, is believed to be related to E-W faulting (Figure 12).

The E-W homoclinal sequence in the south, and isoclinal sequence in the north, can be related to a N-S maximum stress.

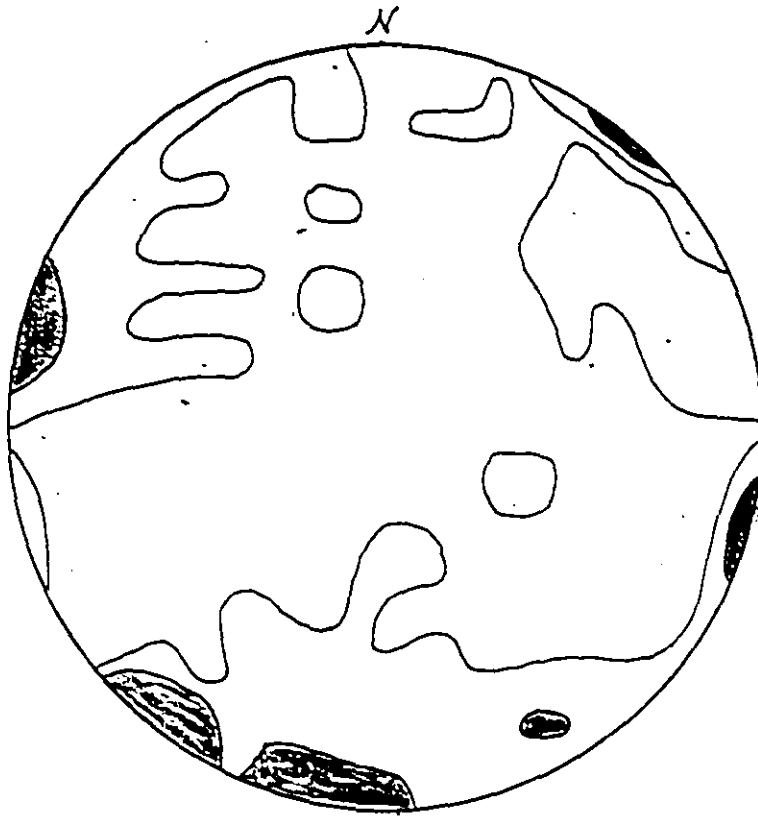



6 joints per 1% area

4-6 joints

1-3 joints

Figure 10a Contoured stereogram of poles to measured joints in lower sequence, using Schmidt method.

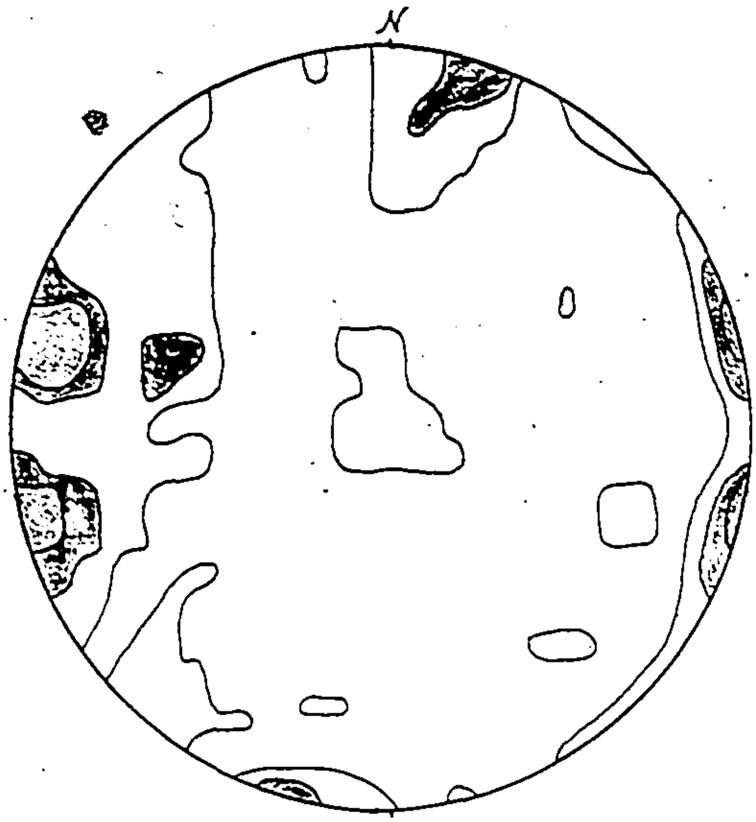



6 joints per 1% area

4-6 joints

1-3 joints

Figure10b Contoured stereogram of poles to measured joints in porphyry, using Schmidt method.




6 joints per 1% area

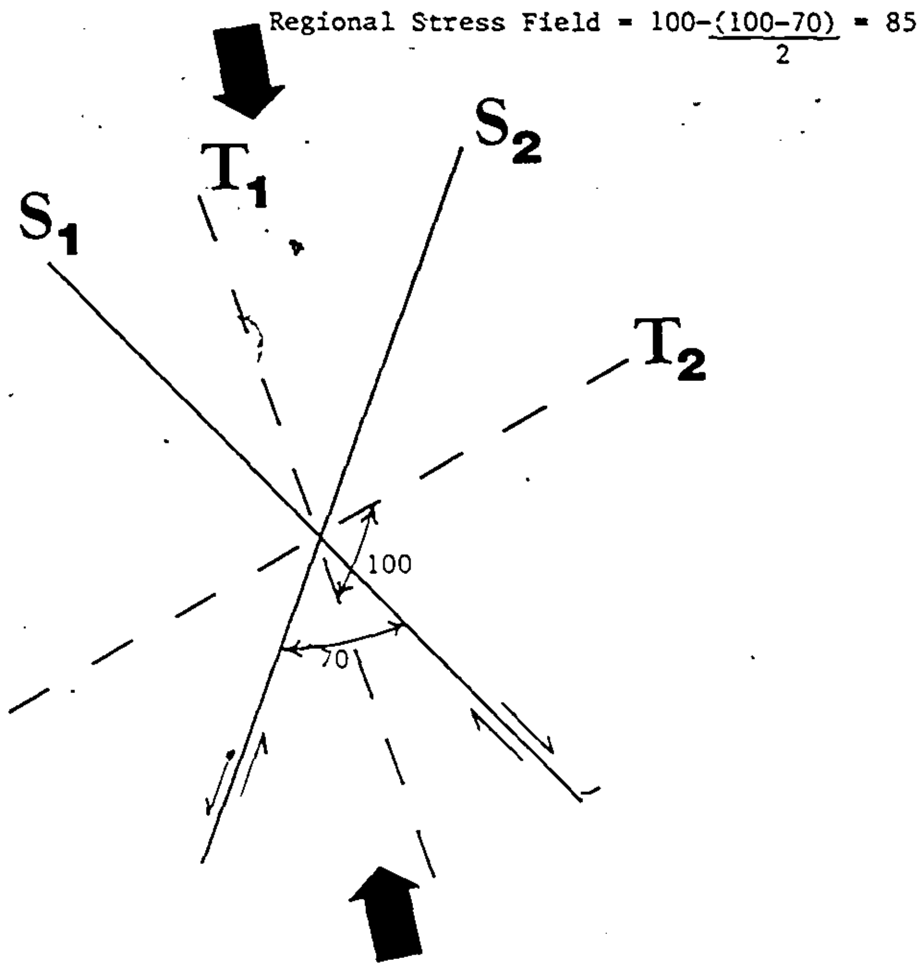
4-6 joints

1-3 joints

Figure 10c Contoured stereogram of poles to measured joints in upper sequence, using Schmidt method.


○ 6 joints per 1% area
● 4-6 joints
○ 1-3 joints

Figure 11 Contoured stereogram of poles to all measured joints in the thesis area, using Schmidt method.




Joint Sets

| | Poles | Major Joint |
|---|---|---|
| A) | 45 | 315/85 - $S_1$ |
| B) | 70 | 340/90 - $T_1$ |
| C) | 290 | 20/90 - $S_2$ |
| D) | 320 | 60/80 - $T_2$ |
| E) | 10 | 100/80 - E-W faulting and folding |

Figure 12 Orientation of joint sets and regional stress field. $S_1$ and $S_2$ are shear joints, $T_1$ and $T_2$ are tensional joints.

Faults with a general orientation of 025° to 030° have left lateral displacement and are associated with $S_1$ - $S_2$ jointing.

## Part 2 - Lower Sequence

The lower sequence consists of over 6 km of massive, pillowed, and porphyritic flows. The lavas are ordinarily fine-grained, dark green to pale yellowish-green to almost grey-green in hand specimen.

Pillowed units are the most common, with flow units achieving thickness' of 1.6 km. Massive metavolcanics of the lower sequence look very fresh in hand specimen, and are devoid of internal structure. No amygdaloidal or vesicular flows were found in the lower sequence. Two porphyritic lava flows can be traced across the entire map area and westward for 16 km. Phenocrysts of feldspar, often euhedral, and up to 25 mm in diameter, occur in flows up to 300 m in thickness (Figure 13). Note that each flow unit may be made of many individual flows.

The rocks of the lower sequence in thin section are generally hypocrystalline, and vary from porphyritic to diabasic in texture. By far, the largest constituent is the fine-grained black matrix, which contains chlorite, calcite, plagioclase, leucoxene, and ilmenite (Figure 14).

Sericitized plagioclase microlites, 0.2 mm to 0.4 mm in size, are found embedded in the matrix. Certain coarse-grained "gabbroic" phases grade into pillowed flows and may represent the central, slowly

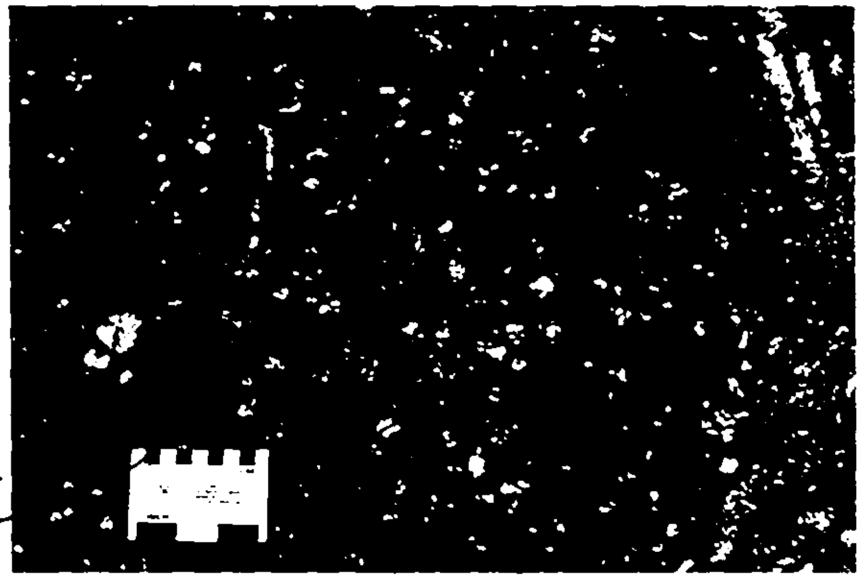


Figure 13 Porphyritic basalt, with euhedral phenocrysts of feldspar, typical of lower sequence. Sample B-22.

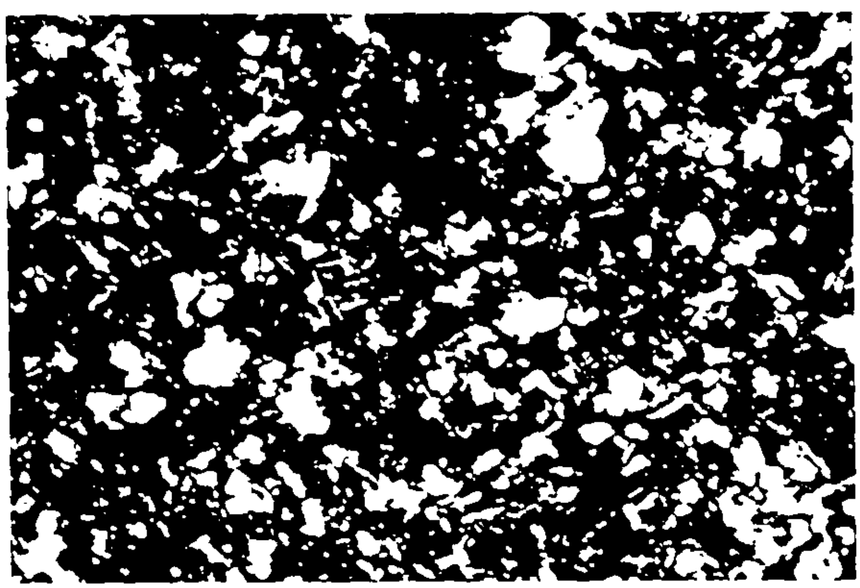


Figure 14 Photomicrograph of typical massive basalt of lower sequence. Sample 6157-1. 63x

cooled zone of a lava flow. In thin section the gabbroic phase is an idiomorphic granular rock with altered plagioclase and pyroxene in a subophitic texture (Figure 15). The plagioclase crystals are poikilitic, riddled by inclusions of clinozoisite, carbonate and chlorite. These saussuritized grains are 0.5 mm to 2 mm in size and are intimately intergrown with each other. As saussuritization increases the twin lamellae become obliterated. The interstitial pyroxene is irregularly fractured and replaced by fibrous amphibole. These crystals are 1 mm to 2 mm in size and some display relict twinning, typical of augite. The uralitization of clinopyroxene yields platey pleochroic fibers of actinolite. Both leucoxene and siderite are present in this phase and occur as irregular euhedral grains.

In areas of dike injection or shearing, carbonate occurs as hypidiomorphic crystals disseminated throughout the slide. It appears to have formed at the expense of both plagioclase and pyroxene. Carbonate also is present as cross-cutting veins. The vein material consists of coarse quartz, up to 3 mm in size, actinolite needles 2 mm in length, euhedral 1 mm carbonate crystals and pyroxene grains, in an interlocking fabric.

## Part 3 - Middle Sequence

Stratigraphically above the lower sequence is a 3 km thick section of coarse pyroclastics, laharic breccias, conglomerates,

63x

Figure 15 Photomicrograph of coarse-grained gabbroic rock of lower sequence. Sample G-32.

epiclastic rocks, dacite flows and porphyry intrusions. This sequence has been subdivided into six facies. Facies is used here to denote the aspect of a rock body or unit. The facies are discriminated on the basis of the following 5 elements:

1) clast (grain) type; 2) clast (grain) size; 3) degree of angularity of clasts; 4) structural relationships (regional and local); 5) textural relationships.

The six facies are listed here:

F Argillaceous Rocks
E Autoclastic Breccia
D Quartz - Porphyry
C Coarse Pyroclastics
B Laharic Breccias and Related Sediments
A Dacitic and Rhyolitic Flows

The section described here refers to a detailed study along the Snake Bay Road. Outcrop percentage elsewhere was less than ten percent and irregular. Shoreline outcrops on Washeibamaga Lake are poorly exposed, severely weathered and eroded by water and winter ice. The identification of clast types in many cases was impossible because of thick lichen cover. If clasts contained distinctive quartz-eyes it was classified as a quartz-porphyry fragment. Individual units could not be traced laterally. They probably represent discontinuous lenses and interbedded pyroclastic and epiclastic rocks associated with the volcanic and sedimentologic events.

For the purpose of this thesis pyroclastic rocks are defined as the entire spectrum of fragmental volcanic rocks formed by and emplaced in any physiographic environment by any volcanic process or mechanism, and consisting of solely synvolcanic, volcaniclastic rocks, i.e., contains no allocthonous material, like granite, (Annells, 1974). Epiclastic rocks are those that are formed by erosion or reworking of original igneous and pyroclastic rocks and have been transported from their original site of emplacement (Parsons, 1969). The size boundaries for ash, lapilli, blocks, and bombs, etc. follows that of Fisher (1961), and Parsons (1969).

i) Facies A

Facies A corresponds to a 0.8 km thick felsic flow unit(s) that outcrops in two locations in the map area. In the northwest it is associated with the northwest limb of the Thundercloud Porphyry. The flow unit is truncated to the west by the Taylor Lake Stock and is superceded by both Facies B and E. In the east it conformably overlies massive basalts at Katisha Lake and is associated with an area of intense quartz-veining. Bedding within the unit, (as observed on the north-central shore of Katisha Lake), is 30°/90°, but weak.

In hand specimen the rock varies from a fine-grained tuffaceous dacite to a "green-blebbed" rhyolite. The latter was the field description given to a whitish weathering rock with green, elliptical blebs, (Figure 16). The blebs are in two forms:

a. as irregular, stretched, dumbell shapes, filled with calcite polygons, and therefore may have been vesicles originally (Figure 17).
b. as irregular patches, 5 to 6 mm in length, of very minute laths of hornblende and pyroxene (?), in a dark black matrix, and may represent basic inclusions (Figure 18).

In thin section the flows are generally crypto-crystalline rocks with a very fine-grained quartzo-feldspathic matrix. Phenocrysts of quartz are deeply embayed, bipyramidal crystals up to 2 mm in size. Feldspar occurs in two forms; (1) as angular crystals, less than 1 mm in size, replaced by clinozoisite and (2) as porphyritic laths, 3 to 4 mm in length. The latter are commonly zoned and riddled by inclusions. Some of the plagioclase laths are rimmed by a fine-grained mosaic of equigranular quartz, feldspar and sericite. Clumps of chlorite and biotite flakes are common around the periphery of the feldspars.

Flow banding is defined by thin seams, rich in chlorite (variety penninite) and tabular chloritoid crystals (Figure 19). Near the contact with the porphyry is a planar schistosity, developed by the elongation of biotite flakes and the presence of cummingtonite wisps. Some of the feldspar phenocrysts and included

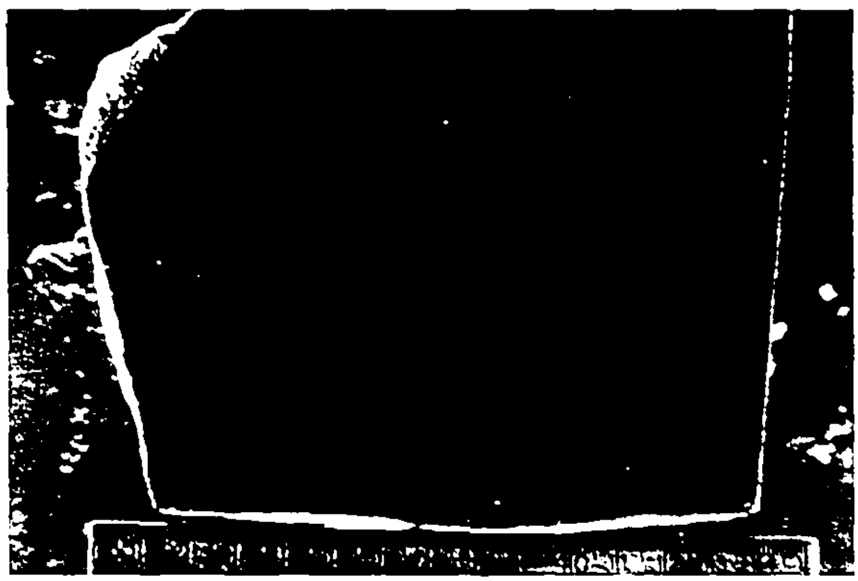


Figure 16 Hand sample of the fine-grained tuffaceous dacite or 'green-blebbed' rhyolite.

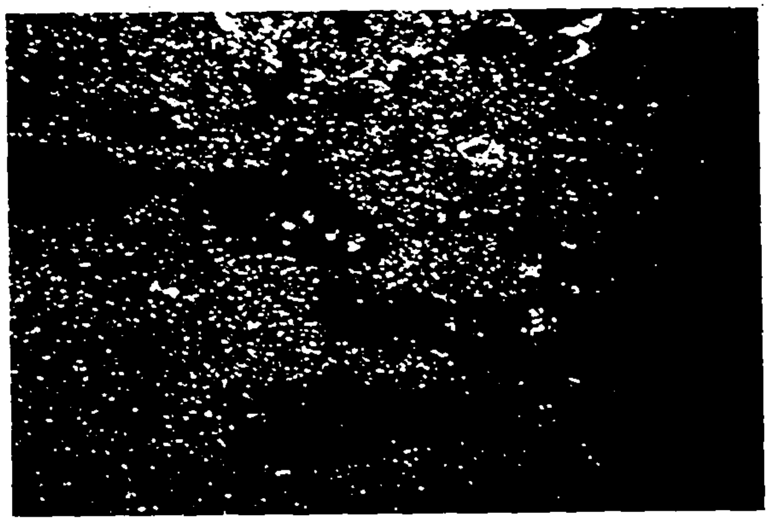


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Figure 17 Photomicrograph of irregular, stretched, dumbell shape of blebs of the 'green-blebbed' rhyolite. Sample 8064.

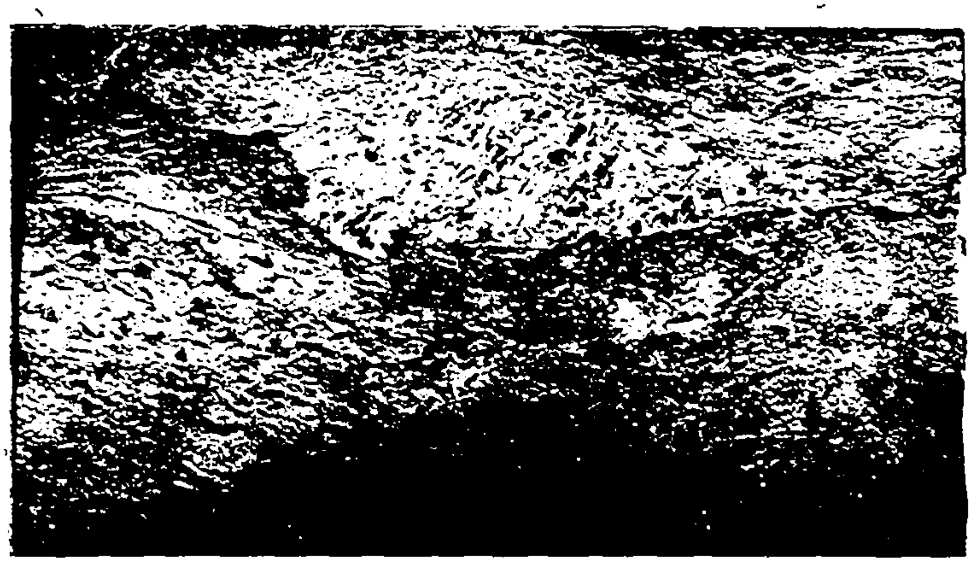

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Figure 18 Photomicrograph of minute laths of hornblende and pyroxene(?) in blebs of 'green-blebbed' rhyolite. Sample 8053-3.

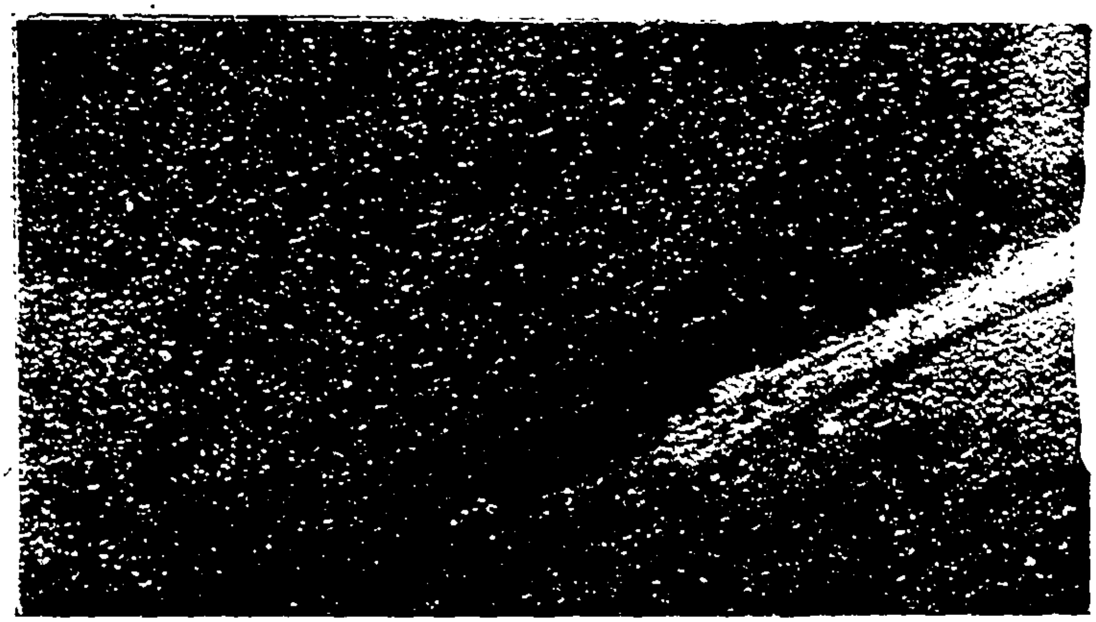

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Figure 19 Photomicrograph of flow banding in felsic flow unit defined by thin seams of chlorite and chloritoid. Sample 8053-2.

sericite needles are bent and deformed. Black opaques are disseminated throughout the sample.

ii) Facies B

Gradationally above the felsic flow unit is a 400 m to 1200 m sequence of interbedded pyroclastics and sediments. The facies thins westward, where it is superceded by Facies' C and E and truncated by the Taylor Lake Stock. Eastward this facies is equivalent to Bertholf's (1946) Sagenak Conglomerate. Lineation direction (strike?) of the bedding, as defined by the long dimension of clasts, is roughly 300° (120°). It is difficult to decide whether the rocks are pyroclastic or epiclastic. The author agrees with Thomson (1933) who said "that it is almost impossible to differentiate the pyroclastic rocks from the clastic rocks in the vicinity of Washeibamaga Lake."

Outcrop is such that only two-dimensional examination of the clasts is possible. Variations in the size of the clasts was estimated in the field by calculating the mean of the largest axis of the ten largest clasts, at individual outcrops. This measurement is hereafter referred to as D/10. By measuring the apparent width (W) and length (L) of the clasts (mutually perpendicular axis), and dividing one by the other D(L/W)/10, the two-dimensional elongation can be determined. Most determinations were carried out on outcrops with areas of 10 to 20 square metres. The measurement data is found in Appendix C.

The basal two metres consists of a tuffaceous rock, containing sparse clasts randomly oriented (Figure 20). The D/10 was 7.2 cm with over 80% of the clasts basaltic in composition. The matrix is a fine-grained felsic mat of quartz and feldspar, showing no signs of sorting or the presence of clastic ferromagnesian minerals. This may represent the basal breccia, of vent material. As the porphyry intruded the volcanic pile the resulting dome (cone?) fragmented, throwing basaltic dome material into the felsic flows and tuffs that were being produced.

The basal section grades upwards through 170 m of pyroclastic material, with a greater percentage of clasts. The D/10 is only slightly higher at 8.8 cm. Basaltic clasts account for about 50% of the clast types, the rest being porphyry and felsic flow material (Figure 21). The average size of basaltic fragmental material decreases and the slight increase in D/10 is the result of the dominance of larger felsic material.

Above the lower 175 m of pyroclastic rocks is 100 to 150 m of interbedded tuff and felsic flow material. Lineation direction (strike), as defined by the long axis of the clasts was 138°. The D/10 was 3.8 cm with D(L/W)/10 of 3.4, significantly different from the unit(s) below. The clasts were lapilli in size and all are felsic. Individual units are up to 15 m in thickness. Associated with this unit is a 0.2 m thick shear zone, over a horizontal distance of 23 m. A minor gabbroic intrusion occurs about 0.8 km north of Katisha Lake.

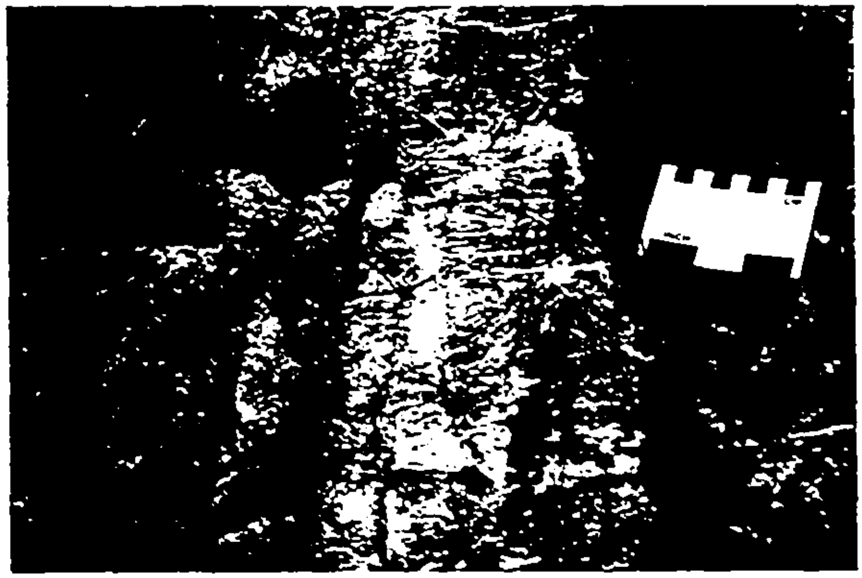

Figure 20 Tuffaceous rock of basal two metres of middle sequence contains random basaltic clasts.

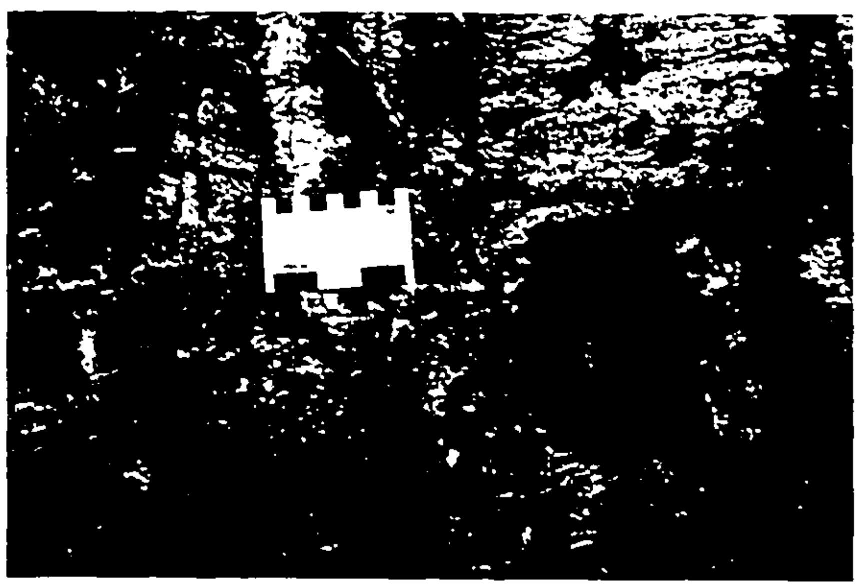

Figure 21 Basaltic clasts(fragments) account for about 50% of the clast types, outcrop just north of Katisha Lake.

The next 450 m consists of interbedded pyroclastic and epiclastic rocks. Many of the clasts are subangular and intersect each other (Figure 22). Other clasts wrap around larger clasts and are pointed or tapered (Figure 23). In one or two instances, elongated chert fragments are found within conglomeratic lenses. Some of the clasts exhibit internal bedding (Figure 24), indicating erosion of consolidated material. D/10 values in the first 200 m are in the range of 26-36 cm with constant D(L/W)/10 ratios of 1.7. Bedding directions determined from long axis orientation, is in the 100-200° range. There is less than 20% matrix material, 90 to 95% of the clasts are felsic, apportioned between quartz-porphyry and dacitic (felsic) flow material in a 3:1 ratio.

Poor exposures made reconstruction of stratigraphic sections difficult and sometimes questionable. One general section (Figure 25), although of limited (traceable) lateral extent, is schematically depicted here and is described below.

The basal 1 to 2 metres of bedded to non-bedded tuff is overlain by 5 m of unsorted fragmental material. Felsic clasts are completely random within the minor tuffaceous matrix. This is capped by 7 to 8 m of inverse-graded volcaniclastic rocks. Clasts 5 to 6 cm in length, increase upwards to 35 to 40 cm. These large clasts project well above the upper parts of the beds. In addition, tuffaceous material drapes over them (Figure 26). Similar relationships are common of debris flows in Oregon and Washington (Schmincke, 1967). Overlying the 1 to 2 m of tuffaceous to sandy material is 5 m of normally graded material. The large

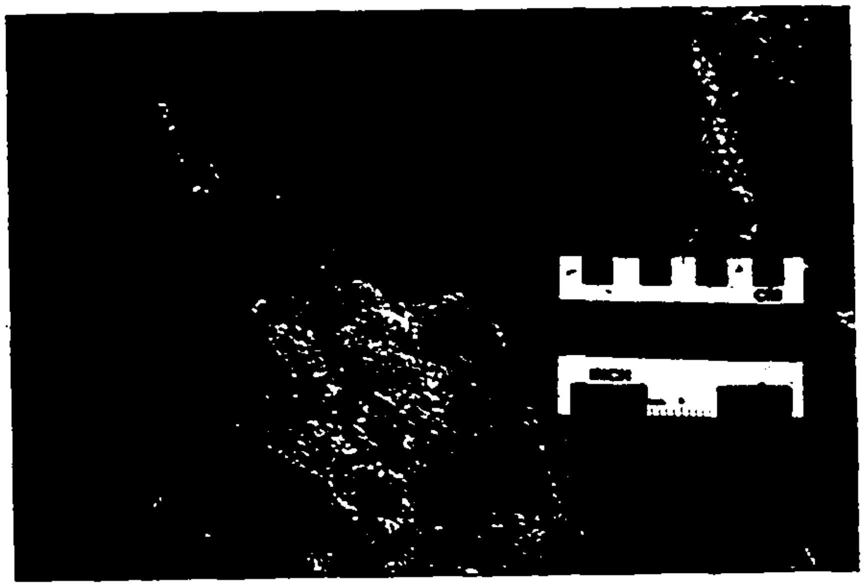

Figure 22 Intersection of clasts and the subangular clast shape is typical of Facies B.

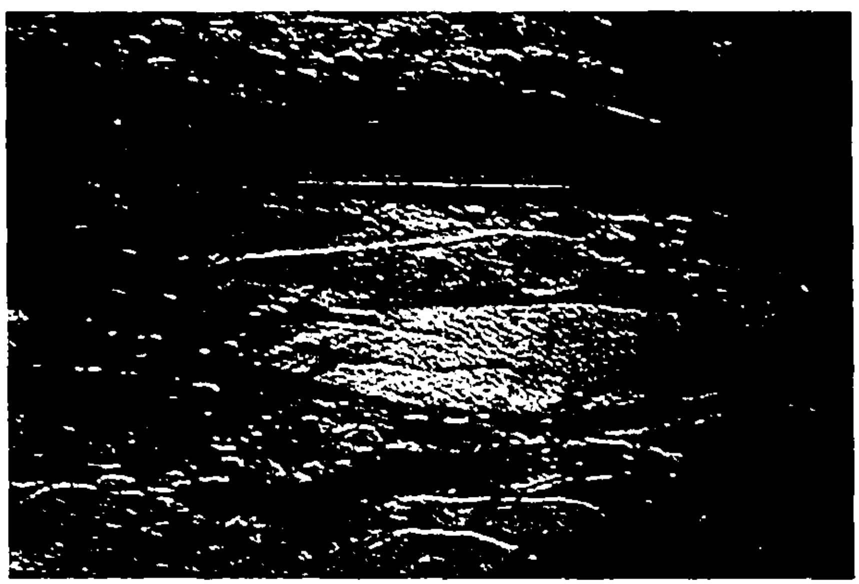

Figure 23 Photograph shows the pointed and tapered habit of some of the felsic clasts.

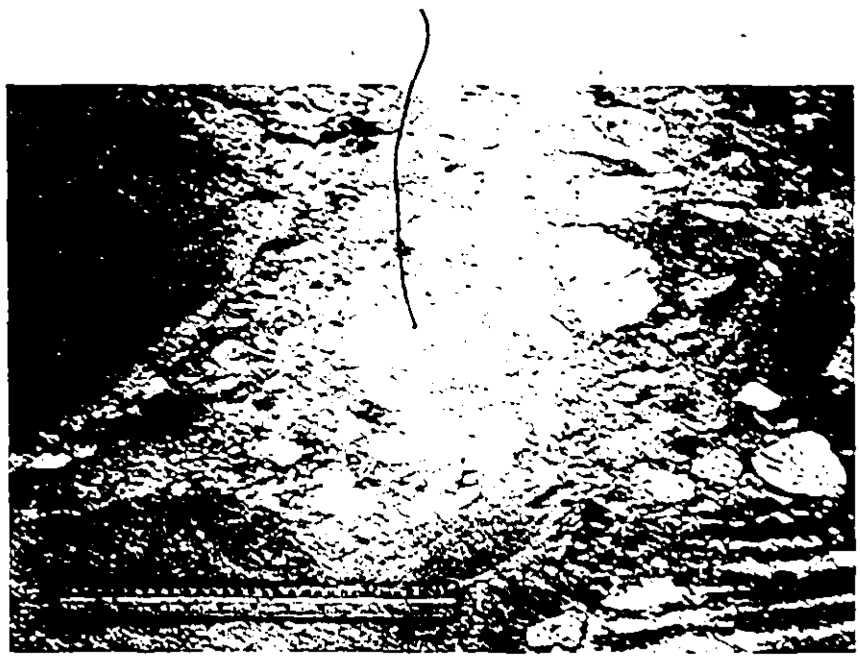

Figure 24 Photograph shows internal bedding of some of the clasts, indicating erosion of consolidated material.

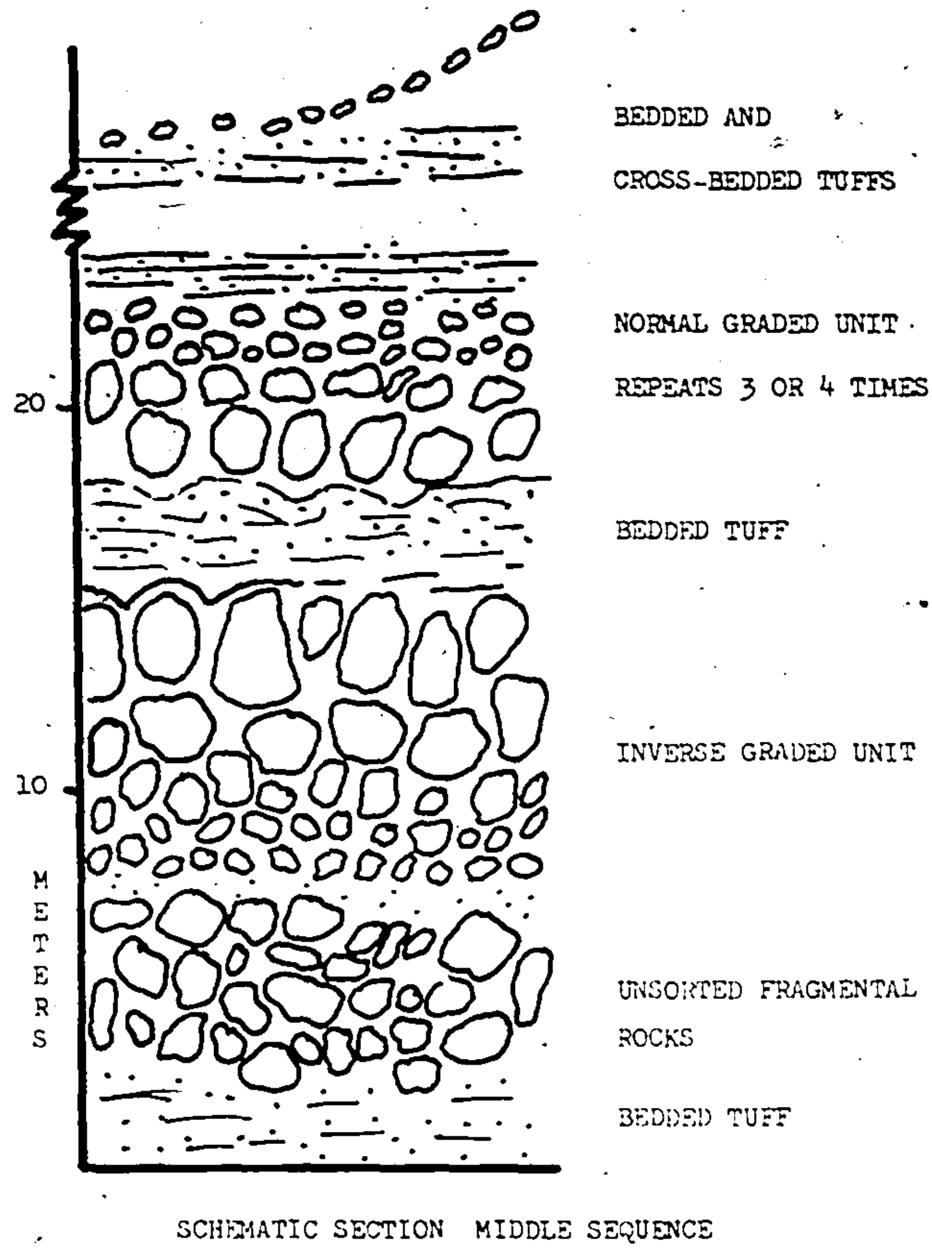


Figure 25 Schematic section of part of the middle sequence, similar to debris flows described by Schminke (1967).

clasts (boulders?) in the base, create load cast features in the underlying tuff (Figure 27). This fining upward sequence is repeated three to five times, the upper contact generally not seen. The upper 5 m is typified by well-bedded sands with cross-bedding. Cross-stratification, represented by a single pebble row, is inclined to regional bedding and top is roughly to the NNE (Figure 28). Similar forms of cross-stratification were found by R. S. Hyde (personal communication) in the Temiskaming area. Thus, the section represents a two-fold sequence:

1) a lower, unsorted to inverse graded fragmental pyroclastic unit, followed by
2) a normal graded epiclastic sequence capped by bedded and cross-bedded sands and tuffs.

Near the top of Facies B is a 15 to 18 m thick amygdaloidal flow, (Figure 29). It contains vesicles, 25 mm to 50 mm in diameter, filled with carbonate. This flow occurs in two locations both at the same stratigraphic level, but separated by about 3 km (see map for location). The flow contacts are parallel to the regional strike of 120°, and cut through clasts (Figure 30). Contained within the flow is a small bed (lens) of clastic fragmental material which has been stretched and boudinaged. The top 10 cm of the entire flow, contains angular mafic fragments of flow material and is thought to represent a flow-top breccia (Figure 31).

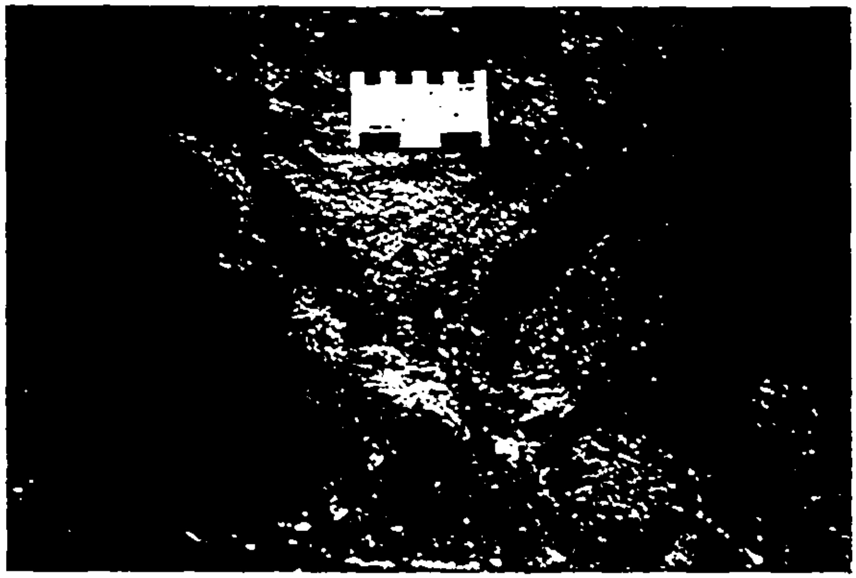

Figure 26 Large clasts project well above the upper parts of the bed, tuffaceous material drapes over them.

Figure 27 Load cast features in underlying tuff caused by large boulders in overlying unit.

Figure 28 Cross-stratification represented by a single pebble row is inclined to regional bedding.

Figure 29 Amygdaloidal flow unit just east of the southeast arm of Dark Horse Lake.

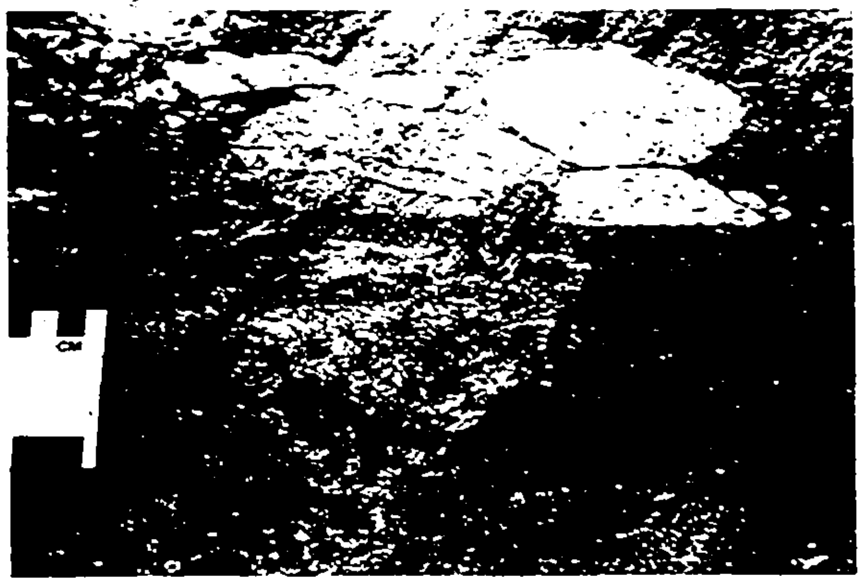


Figure 30 Contact of the amygdaloidal flow unit and the clasts of the middle sequence.


Figure 31 Close-up of contact shows flow top brecciation in the amygdaloidal flow unit.

iii) Facies C

Stratigraphically above (?) Facies B and extending from Washeibamaga Lake eastward, is a unit of massive fragmental rocks 0.4 to 1.6 km in thickness. This unit is noted for the almost total lack of suitable bedding on which to take strike and dip measurements and the lack of tuffaceous and sandy interbeds. The upper contact is nowhere exposed.

Bertholf (1946) subdivided this sequence, his Dark Horse Conglomerate, into lower and upper sections. The base of each contained andesitic pebbles. No such pebbles were positively identified in this study and thus were probably included as felsic fragmental rocks. Over 90% of these felsic clasts were quartz-porphyry in nature.

The bottom 800 m of Facies C contains massive, unsorted pyroclastic material. The D/10 increases upwards from 20 cm to 39 cm with a constant D(L/W)/10 of 1.8. Matrix material accounted for as much as 35%. The porphyry fragments are elliptical to subrounded, many are tapered. In one location a boulder-size clast contained fragments of basalt and quartz-porphyry, but in general little evidence for reworking was present.

The top 900 m is also a massive unsorted pyroclastic sequence. It also has upward increasing clast sizes, with D/10 valves from 24 cm to 78 cm. The fragments are very tightly packed and matrix accounts for less than 10% of the rock (Figure 32). Again two clast types, felsic flow material and quartz-porphyry,

Figure 32 Tight packing of clasts with less than 10% matrix material is characteristic of the upper part of Facies C.

predominate. The D/10 measurement of 78 cm may be a tectonic fabric, however, no evidence to suggest this was observed in the field. The D(L/W)/10, although not entirely constant (a value of 5.3 for the D/10, 78 value) averages about 2.2.

The last 1200 m of this section was very poorly exposed. The D/10 varies from 18 cm to 35 cm. High water levels on Washeibamaga Lake and extensive sand and gravel deposits of the Eagle-Finlayson moraine (Figure 33) obscured the rocks and prohibited any detail work.

iv) Facies D and E

Facies D, the Thundercloud Porphyry and Facies E, the autoclastic breccia, are very similar in appearance. The fragmental rhyolite, previously mapped by Thomson (1933) as porphyry and by Bertholf (1946) as a recomposed porphyry or basal conglomerate is in fact a brecciated form of the porphyry itself. Facies E is thus interpreted to be the autoclastic or flow-top brecciation of the extrusive porphyry and because of similar characteristics, they will be discussed together.

The Thundercloud Porphyry outcrops in the center of the map area around Thundercloud Lake. The southern contact with the lower metavolcanics is concave northwards. Several small, 30 m by 3 m, apotheses project southward and can be traced directly into the porphyry. The contact between the porphyry and lower volcanics in the vicinity of Thundercloud and Seggemak Lakes is unique, in that

Figure 33 Eagle-Finlayson moraine in a gravel pit on Snake Bay.

the volcanics outcrop as large cliffs, 40 to 60 m in height (Figure 34). Generally the area is noted for its lack of relief, except near the porphyry. It is here that the pillows are horizontal, as mentioned previously.

In outcrop the quartz-porphyry consists of a felted gray, or pale yellow matrix containing round, 0.5 to 3.0 mm, glassy quartz-eyes. The rock varies from foliated to massive and is relatively homogeneous throughout. In places it is severely weathered, with the top 20 to 25 mm iron stained and crumbly.

In thin-section the rock averages 60% matrix and 40% phenocrysts. The matrix varies from sericite to quartz-albite rich and is very fine-grained. The phenocrysts are mainly feldspar and quartz. Both plagioclase and potassium feldspar phenocrysts are found (Figure 35). The potassium feldspar is orthoclase. It occurs as anhedral to subhedral phenocrysts, 0.1 mm to 3 mm in diameter, riddled by sericite. In many instances accurate identification between it and similarly altered plagioclase was difficult. Some phenocrysts are fragmental and small microcline crystals have recrystallized in the sutures between the larger fragments of orthoclase. The plagioclase is also altered by sericite and twins were not always preserved. Small, 0.1 mm euhedral, tabular plagioclase crystals have low extinction angles, 10 to 20° (Michel-Levy Test) making them albitic in composition. Other large, 3 mm, subhedral to euhedral phenocrysts had smaller extinction angles and may have been oligoclase. In most cases the determination of An content was approximate.

Figure 34 Large cliffs of mafic volcanic rock in the vicinity of the porphyry on Thundercloud Lake.

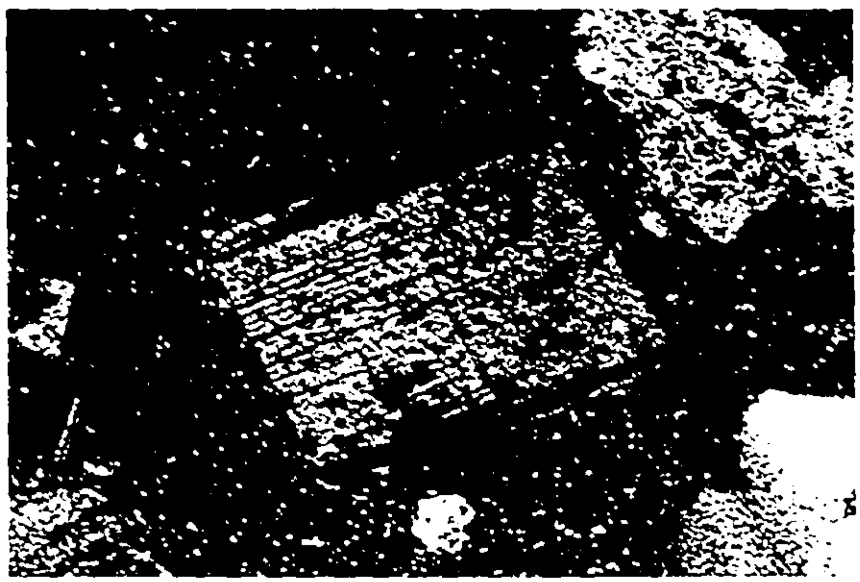

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Figure 35 Photomicrograph of the quartz-porphyry. Sample P-5.

By far the most important (for identification) and most variable constituents within the rock were the quartz-eyes. They are found in approximately six different habits (Figures 36a-f):

a) in subrounded to bipyramidal shapes (strained and unstrained)
b) as heavily embayed quartz-eyes
c) with internally sutured grain boundaries
d) as former quartz-phenocrysts now recrystallized as a coarse mosaic of granular quartz
e) as quartz-eyes with a recrystallized rims of optically continuous groundmass quartz
f) as flattened elliptical phenocrysts including irregular blebs filled with carbonate and matrix material.

The quartz phenocrysts range from unstrained bipyramidal or rounded grains to those displaying undulose extinction, to the formation of elliptical or elongate grain aggregates. In many instances highly strained grains can be found side-by-side with recrystallized grains. Hopwood (1976) has interpreted similar textures in quartz-porphyries of northwest Ontario to represent both primary crystallization and secondary porphyroblastic growth of quartz within a matrix which was actively deforming during the development of regional schistosity.

In some areas, notably the southern end of Washeibamaga Lake, the quartz-porphyry appears to grade into a quartz-porphyry

Figure 36a Photomicrograph of the subrounded shape of some of the quartz-eyes. Sample P-12. 63x

Figure 36b Photomicrograph of heavily embayed quartz-eyes. Sample P-12.

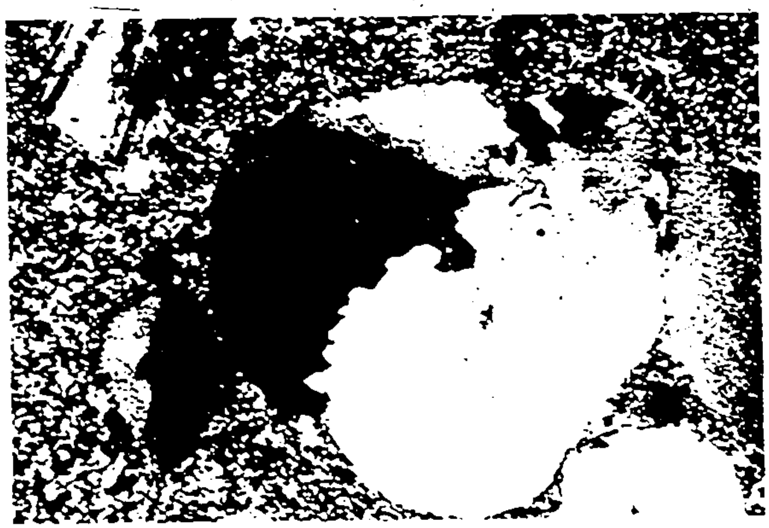

Figure 36c Photomicrograph displays the internal sutured habit of the quartz-eye grain boundaries. Sample P-35.

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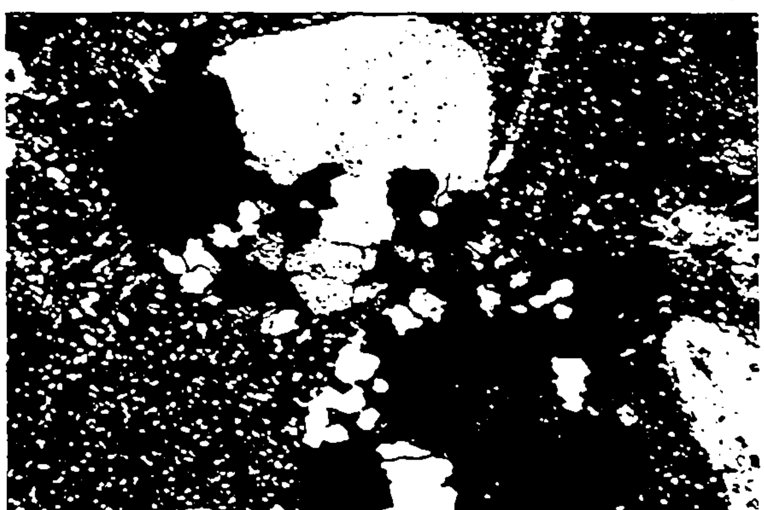

Figure 36d Photomicrograph of quartz phenocrysts now recrystallized to a coarse mosaic of granular quartz. Sample PF.

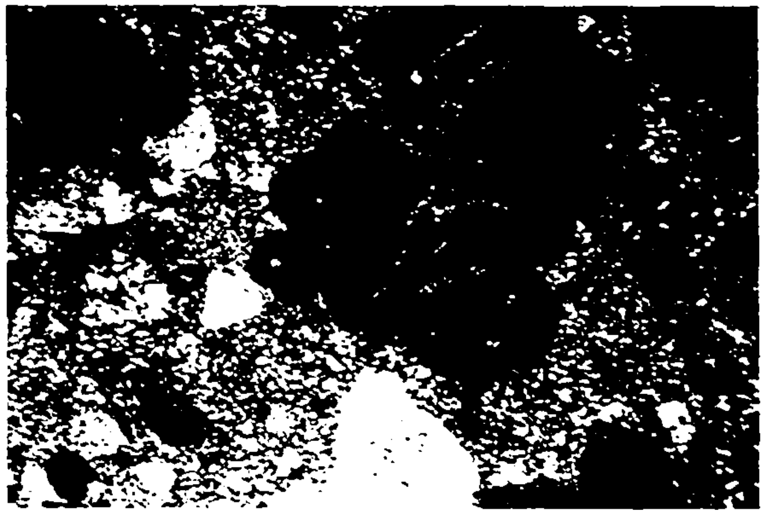

Figure 36e Photomicrograph of a quartz-eye with a recrystallized rim of optically continuous groundmass quartz. Sample P-1. 63x

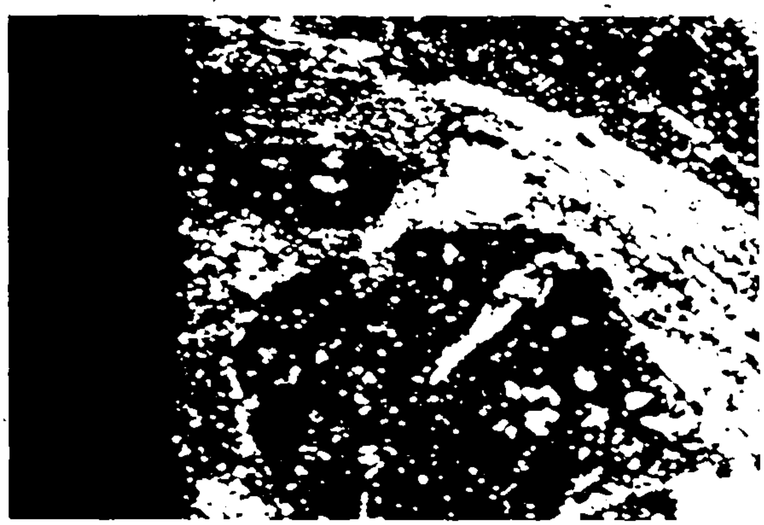

Figure 36f Photomicrograph of poikilitic quartz porphyroblast. Sample P-1.

breccia. This fragmental rhyolite is the rock type referred to as a mill-rock by Sangster (1972), porkose by Reid (1945) and recomposed porphyry by Bertholf (1946). Macroscopically the rock consists of fragments of quartz-porphyry up to a metre in length, in a quartz-porphyry matrix. It grades imperceptibly into the porphyry, and frequently fragments would not have been discerned save for the weathering of the rock which made the angular fragments display slight relief (Figure 37).

In thin-section it is similar to the porphyry, with large phenocrysts of feldspar and quartz. Some angular clasts were rimmed by biotite making them stand out. Euhedral feldspars were as common as in the porphyry and twins were parallel to the crystal outlines.

Just southeast of the southern tip of Washeibamaga Lake a small outcrop of the brecciated porphyry occurs within the porphyry.

v) Facies F

The uppermost portion of the Middle Sequence is composed of fine-to-medium grained epiclastic metasediments, i.e., sandstone, siltstone and argillite. It constitutes a very small part of the preserved sequence, less than 0.3 km, and its true lateral and vertical extent cannot be traced. The type outcrop occurs at the NW end of Washeibamaga Lake, where Kennewapekko River flows into

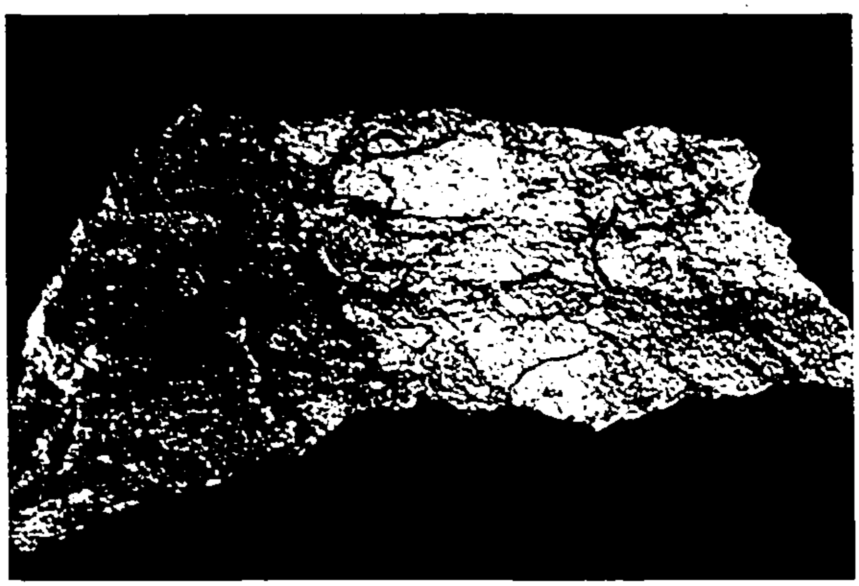

Figure 37 Hand sample of quartz-porphyry breccia.

the lake. This knoll consists of 2 to 5 cm beds of siltstone and argillite.

To the west, a small outcrop, just north of the first waterfall on the Kennewapekko River, and on a small island west of the headland in Washeibamaga Lake, sandstone (greywacke) is the dominant rock type. In thin-section it consists of 0.1 to 0.6 mm sand size clasts of quartz and feldspar. Magnetite occurs as disseminated matrix material. Large clasts, up to 6 mm in diameter, of basalt and quartz-porphyry are common. The basaltic fragments display intersertal textures; the plagioclase laths are distinct but the material filling the interstices could not be discerned (Figure 38). Feldspar fragments were subangular to subrounded, twin lamallae were not parallel to crystal outlines as the outlines had been worn off during transport. Quartz occurred both as subrounded to rounded clasts and in the matrix. The greywacke also contained a large proportion of secondary carbonate material and would be termed a lithicwacke based on thin section description.

Banded iron formation was found in one outcrop. Magnetite bands, 25 mm to 75 mm thick are found interbedded with fine-grained argillite beds, 25 mm to 0.3 m in thickness. Bedding was at 296/80°NE and parallels regional strike. In thin-section the rock is bedded on a very fine scale, 0.5 mm. The bedding in some sections is defined by biotite, but in most cases is defined by magnetite layers. Soft sediment deformation is prevalent, along with microfaulting and microsedimentary structures. The magnetite

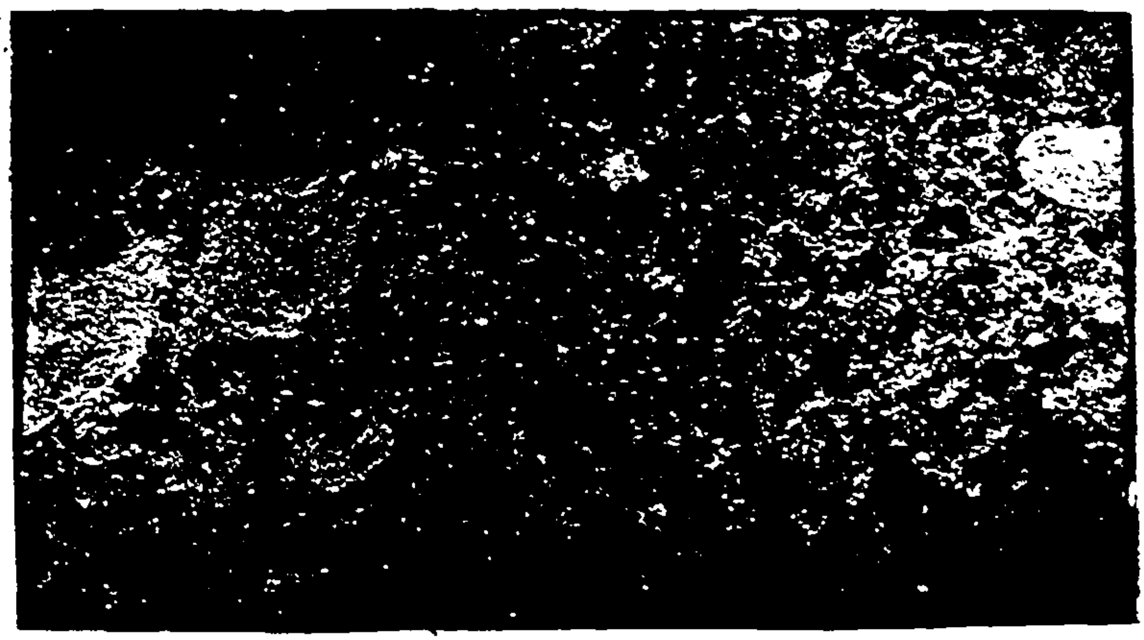

Figure 38 Photomicrograph of the greywacke shows variety of clast types including coarse-grained gabbroic clasts.

displays both normal and inverse grading and defines small scale cross-stratification. Slump features are also present. Granular quartz occurs as mosaic matrix material (Figure 39).

Part 4 - Upper Sequence

The upper sequence consists of over 3 km of massive, pillowed and coarse-grained flows. Only a small portion occurs within the present study area and will only be briefly discussed. Further detail can be found in Blackburn's (1975) report on the Boyer Lake area.

It is isoclinally folded around east-west trending fold axes, with vertical dips. The contact with the middle sequence is not observed but is believed to be fault-bounded (as discussed in the structure section). Therefore, the upper section is part of Pettijohn's (1943) "Keewatin Problem", as to the relative age of the overlying meta-volcanics.

Pillowed sequences are by far the most common, up to 300 m in thickness. The pillows, just north of the fault (?) are stretched, up to 4 m in length, and have vesicular margins. This feature was not found in the lower sequence, but is common in the upper sequence. Some pillowed flows north of this study area, are variolitic and have thick selvages. No porphyritic units were found as far north as Boyer Lake (McMaster, 1975).

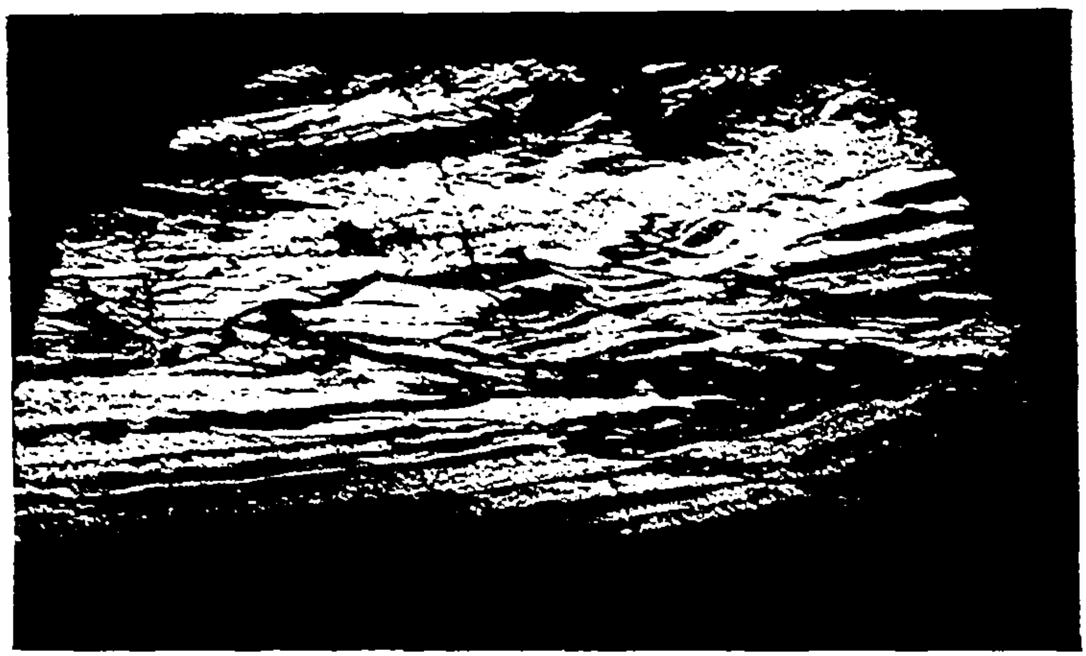

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Figure 39 Photomicrograph of the banded-iron formation on the west end of Washeibamaga Lake. Note the variety of soft sediment deformation styles. Sample 6190-1.

On the north shore of Washeibamaga Lake, a 200 m thick coarse-grained flow or sill outcrops across the entire map area. It consists of coarse-grained gabbroic rocks with large pyroxene phenocrysts. In thin-section, large prismatic pyroxene crystals, 3 to 5 mm in length are warped and bent around interstitial laths of plagioclase. The cores of the plagioclase laths are severely altered and replaced by clinozoisite. Both ophitic and subophitic textures occur. At lease three phases could be defined: a fine-grained chilled margin, a leucocratic equigranular phase and a pegmatitic phase. The latter was very coarse-grained and contained abundant myrmekite (Figure 40). No detailed work has been undertaken but it maybe analogous to the Gabbro Lake Sill (McMaster, 1975).

The basaltic rocks in thin-section are generally hypocrystalline and vary from vesicular to intergranular in texture. By far the largest constituent is the devitrified matrix of fine-grained chlorite, albite, calcite and ilmenite. The plagioclase laths are subangular to sub-rounded and completely saussuritized, no relict twins are visible. Pyroxene, uralitized to actinolite, has no relict cleavages visible. In most cases the petrography of the upper sequence is similar to that of the lower sequence.

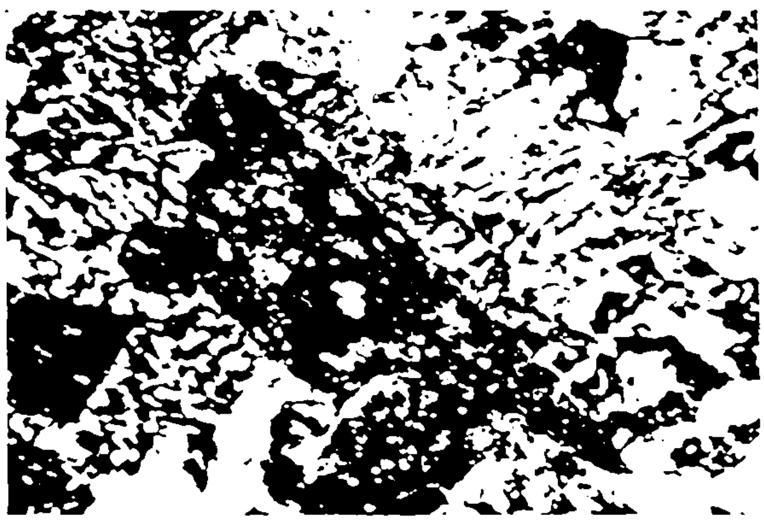

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Figure 40 Abundant myrmekite in photomicrograph of coarse-grained intrusive north of Washeibamaga Lake. Sample 5268.

# CHAPTER III - CHEMICAL NATURE OF THE ROCKS

## i) Introduction

A total of 90 samples have been analyzed by X-ray fluorescence for major and trace elements. The chemical analyses were carried out using a Philips Model 1450 AHP automatic sequential spectrometer. The parameters, machine settings and data are all found in Appendix D. A detailed summary of the analytical errors; precision, accuracy and sensitivity (Appendix D), shows that the results were satisfactory, (i.e., falling within the acceptable range as outlined by Shaw (1969) in his paper on the evaluation of data).

The purpose of doing the descriptive geochemistry is as follows:

1. to chemically classify the rocks.
2. to hopefully use the chemical trends as an aid in the interpretation of the genetic history of the area.

## ii) General Chemical Features

In dealing with Archean rocks we are faced with the possibility that chemical changes have occurred due to metamorphism. For example, Anderson (1969) in his studies of metamorphosed PreCambrian volcanic rocks in Central Arizona, recognized at least three forms of metamorphism; i.e. albitization, sericitization and chloritization with the migration of Na, K and Fe and Mg, respectively.

Cann (1970) and Pearce (1976) also recognized that albitization and sericitization were serious problems affecting Ba, Rb and Sr abundances. Sericitization also results in the formation of amphiboles and epidote. Greenschist facies metamorphism often leads to a depletion of Ca sites, especially when $O_2$ pressure and $CO_2$ pressure are low thereby decreasing the abundance of Sr (Franklin, 1976). However, Nicholls and Islam (1971) point out that no real systematic change can be defined. They also concluded, that for ocean floor basalts along the Mid-Atlantic Ridge, geographic and petrographic character are more important in the variation of elemental abundance, than post solidification processes. Therefore not all original variations are lost during Greenschist Facies metamorphism.

Chayes (1966) suggested that basalts, with $Fe_2O_3/FeO$ ratios greater than 0.6, and $H_2O$ contents greater than 3% by weight be rejected as severely altered. Volatile content, as determined by loss on ignition (see Appendix D), for most of the rocks in the study area was less than 3% and those above 3% were rejected.

Condie (1976) and Pearce and Cann (1973) found that Ti, Zr, Y and Ni were unaffected by diagenesis or low-grade metamorphism. Pearce (1976), used discriminant analyses and was successful (at the 95% level) in classifying metamorphosed Archean rocks within compositional fields consistent with current usage, suggesting that basalts remain closed systems for certain elements.

Care was taken, in this study, to avoid rocks containing secondary carbonate or severely weathered surfaces. The lack of veining and bleaching and the internal consistency of the geochemistry (rock samples of equivalent stratigraphic height but separate geographic locations had similar analyses, e.g. 8035 and B-7, G-32 and 8013-2) argue in favor of isochemical metamorphism. Hallberg et al. (1976a) and Furnes et al. (1977) used similar criteria in their work on metamorphosed Archean rocks.

iii) Graphical Representation

Chemical variation within the rocks of one magma series, or among the rocks of different petrogenetic provinces can be conveniently illustrated by means of variation diagrams. However, the literature shows little agreement among petrologists as to the best variation diagram for graphically portraying chemical data for igneous rocks.

The Harker diagram, a plot of weight percent oxide against $SiO_2$, has been utilized since 1909. MacDonald and Katsura (1964) subdivided one of these diagrams ($Na_2O + K_2O$) vs. $SiO_2$ (modified by Irvine and Baragar, 1971) into the fields of alkaline and subalkaline rocks based on analyses from Hawaiian rocks. Harker diagrams assume that in the evolution of a consanguineous magma series, there is a continuous increase in $SiO_2$, but this is not always true. The tholeiitic trend, for example, does not have $SiO_2$ enrichment and thus Harker diagrams may not be too useful. In spite of this they have been used with success in the description of Archean rocks, Clifford and McNutt (1971), Carmichael et al. (1974), Blackburn (1976), Irvine and Baragar (1971).

Irvine and Baragar (1971) use AFM diagrams, the alkali-silica plot, $Al_2O_3$ vs. normative An content and normative colour index vs. normative An content to discriminate between calc-alkaline and tholeiitic basalts and to chemically classify volcanics.

The plots, $K_2O$ - $Na_2O$ - CaO, and the normative An - Ab - Or are used here. A widely used plot is the AFM triangle. It is based on Wager and Deer's (1939) work on the Skaergaard Intrusion, which shows the change in liquid composition with differentiation. It is useful because it shows the relationship between;

i) MgO which fractionates early into olivine and pyroxene, which results in,

ii) an increase in FeO in the liquid, followed by

iii) pyroxene and plagioclase crystallization, followed by

iv) $Na_2$ + $K_2O$ enrichment in the feldspars.

It is beyond the scope of this thesis to undertake a detailed discussion of the pros and cons of each method. Suffice it to say that all of the aforementioned plots were examined and utilized to some extent. For the purposes of plotting the following units have been given separate symbols:

1. Lower Sequence
2. Felsic flows and Tuffs (Middle Sequence)
3. Quartz - Porphyry
4. Brecciated Porphyry
5. Upper Sequence

iv) Major Element Characteristics

The results are presented in Appendix A and Figures 41-48. The following trends are observed:

1. Table 1 shows the average major element chemical compositions of some typical Archean basalts, representative of different shield areas, compared with the lower and upper sequence of this thesis. Generally the $SiO_2$, MnO, $Al_2O_3$, $Na_2O$ and $P_2O_5$ are very similar in all areas.

The $TiO_2$ content shows a bimodal distribution. The lower sequence of the thesis area and lower mafic unit of Begg's (1975) have low $TiO_2$ values, compared to the higher (1.0%) for the upper sequence. The CaO contents of Begg's (1975) units and the lower and upper

Table 1

## Major Element
## Comparison Chart - Mafic Rocks

| | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | Fe+ | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 48.9 | 1.06 | 14.5 | 11.17 | .21 | 6.27 | 8.74 | 2.51 | .45 | .07 |
| 2 | 50.0 | 1.09 | 14.7 | 11.03 | .21 | 6.11 | 8.93 | 2.21 | .39 | - |
| 3 | 52.36 | 1.42 | 13.52 | 11.03 | .26 | 6.13 | 7.35 | 3.05 | .24 | .22 |
| 4 | 49.86 | .70 | 14.25 | 10.32 | .17 | 7.32 | 10.69 | 2.54 | .16 | .05 |
| 5 | 51.4 | .85 | 15.4 | 11.2 | .22 | 6.8 | 11.9 | 2.19 | .11 | - |
| 6 | 52.2 | 1.25 | 13.3 | 14.8 | .24 | 6.3 | 9.2 | 2.65 | .02 | - |
| 7 | 50.51 | .86 | 14.28 | 13.0 | .21 | 7.65 | 11.24 | 2.23 | .19 | .07 |
| 8 | 51.90 | 1.18 | 14.77 | 11.91 | .20 | 5.50 | 9.94 | 2.73 | .44 | .11 |

1 - average basalt Superior Province, Goodwin (1968)
2 - average Lake of Woods - Wabigoon Belt basalt, Goodwin (1969)
3 - average basalt Meekatharra Australia, Hallberg et al. (1976)
4 - average basalt Onverwacht Group, Viljoen & Viljoen (1970)
5 - lower mafic unit, Sturgeon Lake Area, Beggs (1975)
6 - upper mafic unit, Sturgeon Lake Area, Beggs (1975)
7 - average basalt of lower sequence, Thundercloud Lake Area
8 - average basalt of upper sequence, Washeibamaga Lake Area

sequences are higher than the other basalts. Also the CaO values for the upper units of the Sturgeon Lake area and Washeibamaga Lake are similar and smaller than the accompanying lower units. The potassium content of the upper sequence, like the average basalts of Goodwin (1968), are higher than the other examples. The lower sequence has low $K_2O$, significantly less than the upper sequence. The lower mafic and upper mafic units of Begg's (1975) are analogous to the lower and upper sequences of the thesis.

2. Table 2 shows the average major element chemical composition of some typical felsic Archean rocks compared with the felsic flows, porphyry and brecciated porphyry of this thesis. The $SiO_2$, $TiO_2$, $Al_2O_3$, and $Na_2O$ contents of the middle sequence are similar to those of the rhyodacite of the Lake of the Woods and the felsic flows of Sturgeon Lake. In contrast the middle sequence is enriched in potassium compared to the other two examples. In most elements it is analogous to the felsic flows of the Sturgeon Lake area. The Thundercloud Quartz Porphyry and brecciated porphyry are very similar with no notable differences. Unlike the average rhyolite of the Lake of the Woods, the $Na_2O/K_2O$ ratio for the other areas is in the 2 to 3 range.

Table 2

*Major Element

Comparison Chart - Felsic Rocks

| | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | Fe+ | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 68.1 | .39 | 15.2 | 3.11 | .05 | 1.65 | 3.19 | 2.39 | 1.76 | *n.d. |
| 2 | 74.9 | .25 | 14.8 | 1.10 | .03 | .78 | .89 | 1.85 | 3.29 | *n.d. |
| 3 | 78.2 | .10 | 11.3 | .80 | .03 | .30 | 1.10 | 3.7 | 2.6 | .01 |
| 4 | 71.35 | .31 | 15.02 | 1.96 | .02 | 1.11 | .26 | 6.48 | 2.37 | .08 |
| 5 | 67 | .55 | 15.7 | 6.3 | .10 | 2.6 | 3.7 | 2.56 | 1.54 | *n.d. |
| 6 | 70 | .40 | 16.0 | 3.2 | .08 | 1.4 | 2.3 | 5.36 | .98 | *n.d. |
| 7 | 67.26 | .54 | 15.75 | 4.91 | .08 | 2.5 | 2.4 | 2.89 | 2.55 | .12 |
| 8 | 73.18 | .22 | 15.34 | 1.79 | .03 | .90 | 1.75 | 4.32 | 2.15 | .08 |
| 9 | 73.79 | .19 | 15.15 | 1.25 | .04 | .69 | 1.56 | 5.09 | 2.38 | .06 |

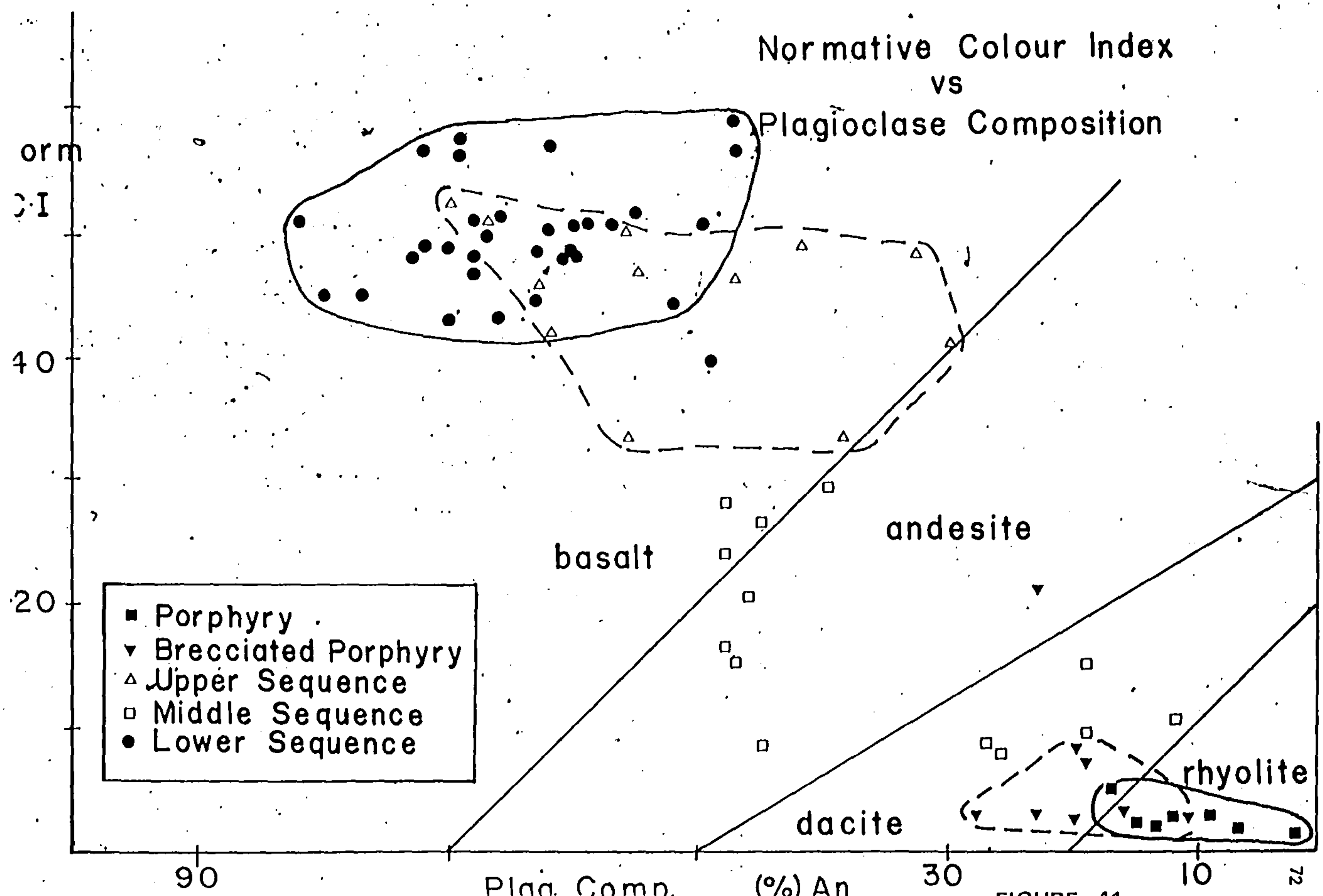
1 - average rhyodacite Lake of the Woods, Goodwin (1968)
2 - average rhyolite Lake of the Woods, Goodwin (1968)
3 - Marda Rhyolite Porphyry, Australia, Hallberg et al. (1976)
4 - Theespruit Komati Porphyry, Barbeton Area, Glikson (1976)
5 - Felsic Flows of Sturgeon Lake Area, Beggs (1975)
6 - Quartz Feldspar Porphyry of Sturgeon Lake Area, Beggs (1975)
7 - Middle Sequence Felsic Flows, Washeibamaga Lake Area
8 - Brecciated Porphyry average, Washeibamaga Lake Area
9 - Quartz Porphyry average, Thundercloud Lake Area

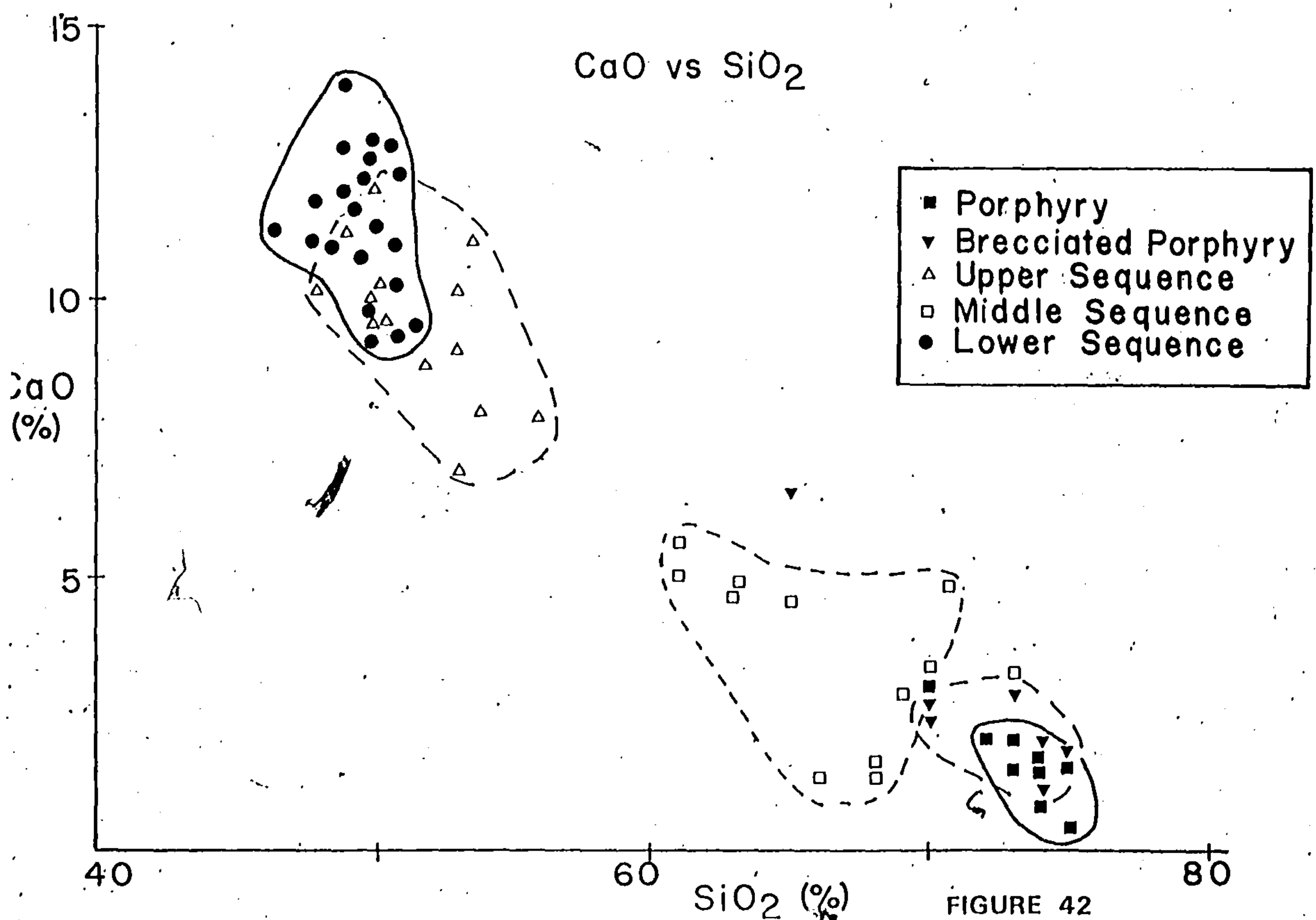
The quartz-feldspar porphyry of Begg's (1975) is unique in that it has a very low $K_2O$ content, with a $Na_2O/K_2O$ ratio greater than 5.

3. Classification of the rock samples in this area following Irvine and Baragar (1971) shows that both the upper and lower sequences classify as basalts, while the porphyry and brecciated porphyry classify as rhyodacites to rhyolites (Figure 41). The middle sequence shows a large scatter from basaltic-andesites to dacite. Some of this scatter may be the result of including tuffaceous material, which may in fact be a fine-grained sandstone or water-laid tuff which are affected by reworking and alteration. They are included for completeness and a statement concerning their parentage based on chemical similarities and differences will be discussed at length later.

4. The CaO vs. $SiO_2$ plot (Figure 42) and the $Al_2O_3$ plot (Figure 43) show that there are no distinct differences between the lower and upper sequences and between the porphyry and brecciated porphyry in the contents of CaO and $Al_2O_3$.

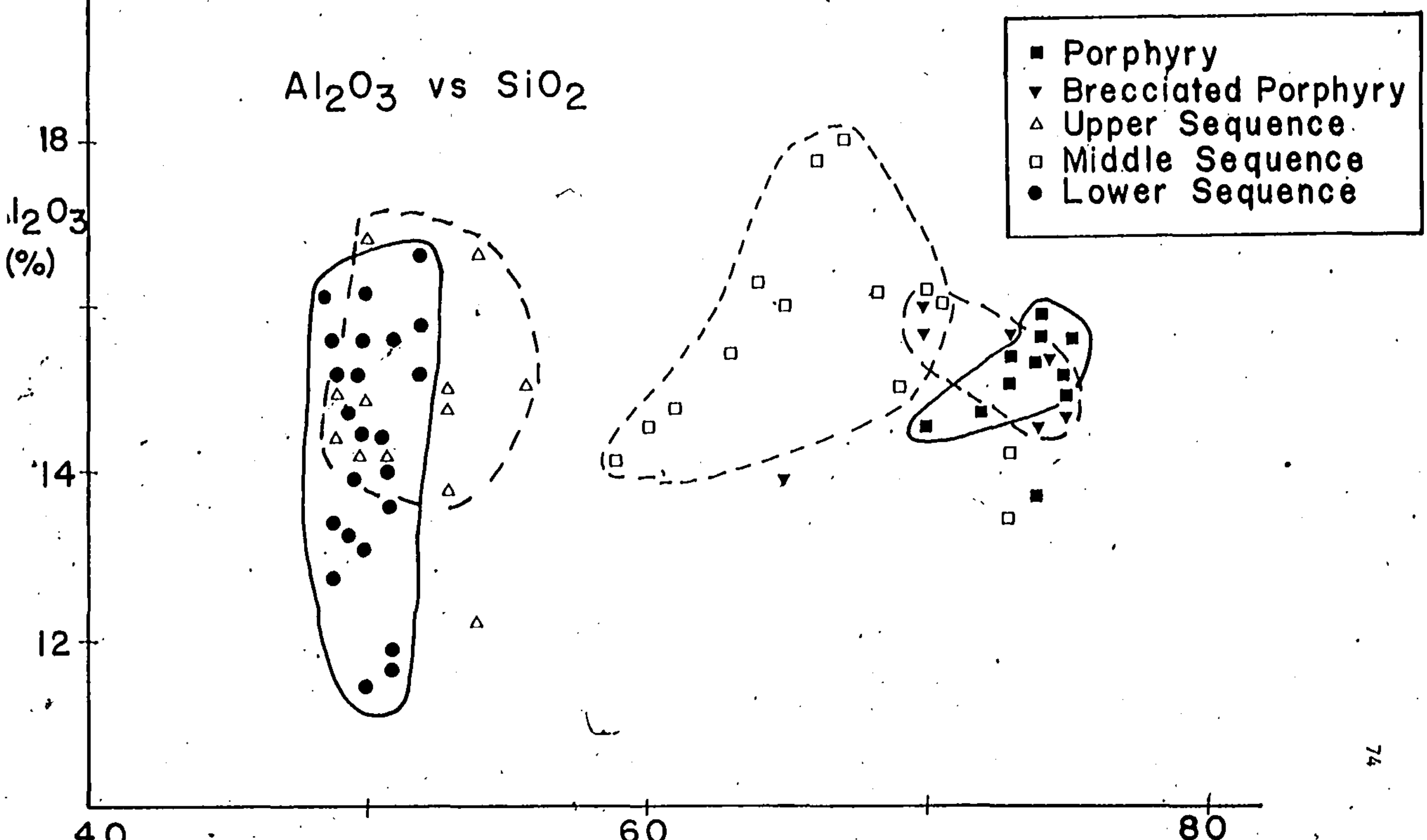
5. The alkalies-silica plot (Figure 44) indicates that all the rocks of the thesis area are subalkaline. The


Normative Colour Index
vs
Plagioclase Composition
orm
C·I
40
20
basalt
andesite
dacite
rhyolite
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
90
30
10
Plag. Comp.
(%) An



CaO vs SiO2
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
15
10
5
CaO (%)
40
60
80
SiO2 (%)


FIGURE 42



$Al_2O_3$ vs $SiO_2$
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
$Al_2O_3$ (%)
18
14
12
40
60
80
$SiO_2$ (%)

FIGURE 43

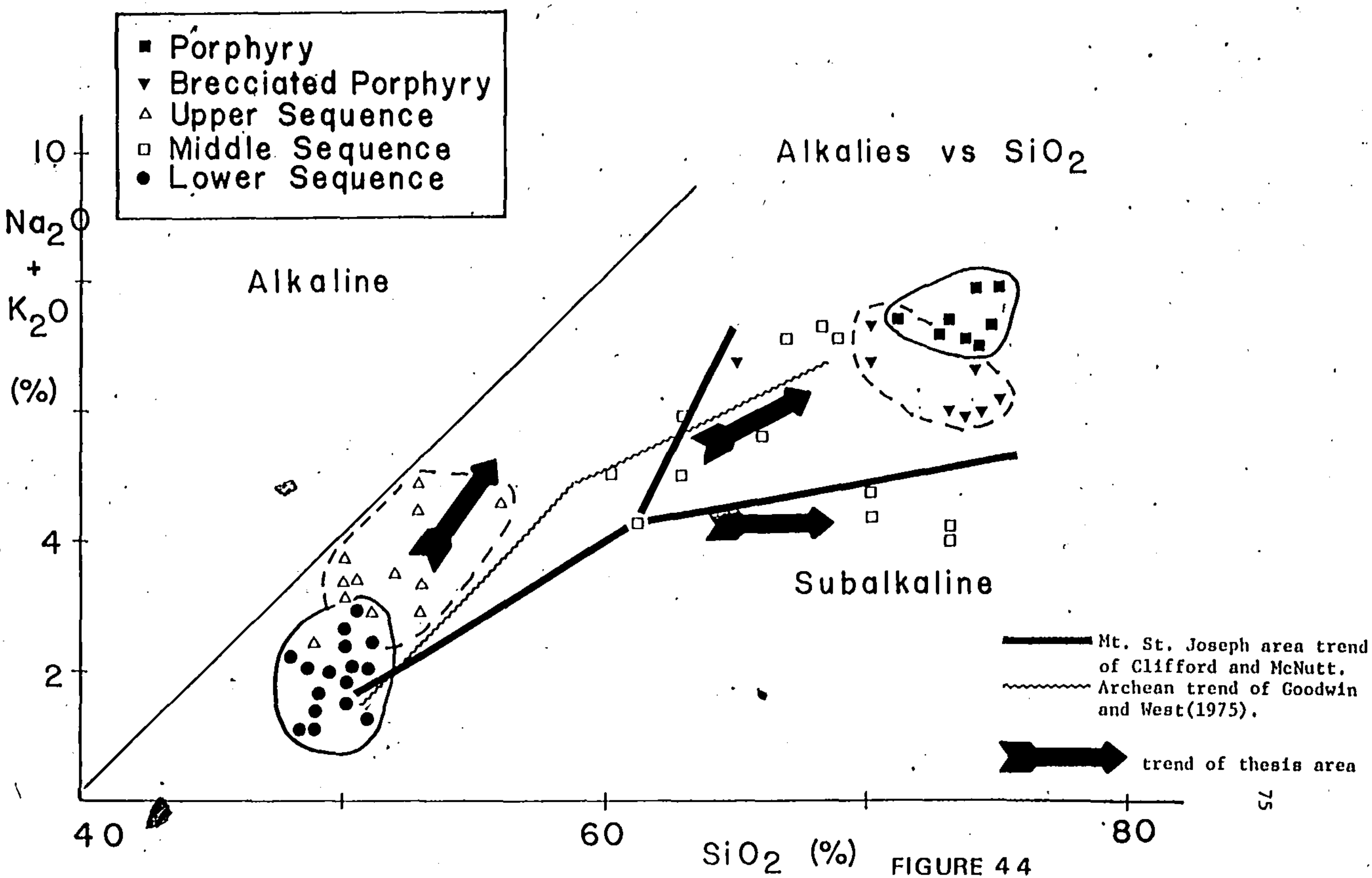
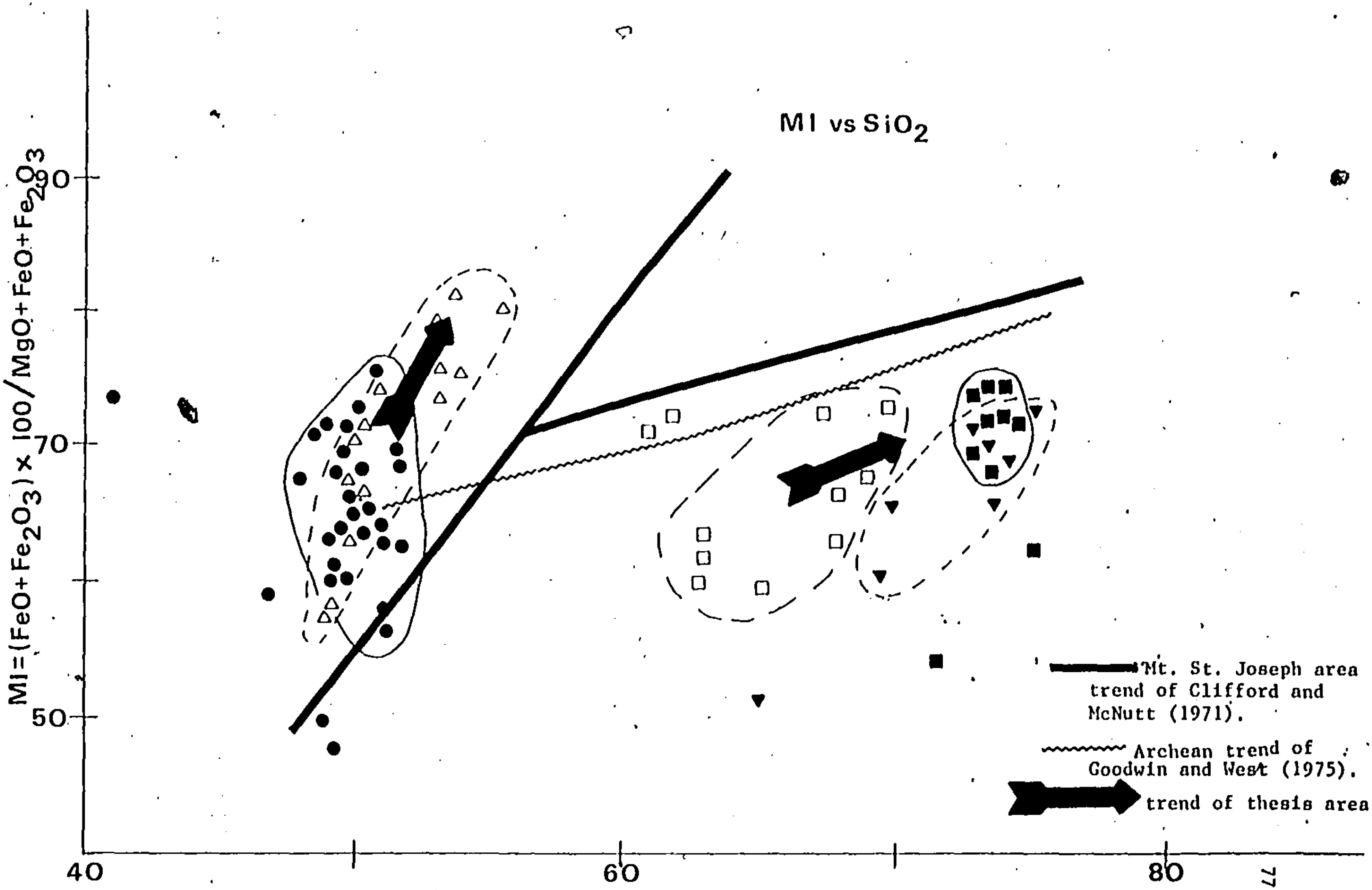

Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
Alkalies vs $SiO_2$
10
4
2
$Na_2O$ + $K_2O$ (%)
Alkaline
Subalkaline
Mt. St. Joseph area trend of Clifford and McNutt.
Archean trend of Goodwin and West(1975).
trend of thesis area
40
60
80
$SiO_2$ (%)

FIGURE 44

trend shown is one of steady alkali enrichment with increasing silica in the basalt range, followed by two trends. The dominant one is to a smaller increase in total alkalies with silica as you go towards the porphyry. A weaker trend, shows no alkali enrichment as represented by the middle unit. A similar two stage trend was found by Clifford and McNutt (1971) in the Mt. St. Joseph area. The pattern is also similar to the Canadian Shield Archean trend of Baragar and Goodwin (1968). Based on the trends, the upper and lower sequences may be related while the porphyry and brecciated porphyry indicate a separate magma source.

6. The mafic index vs. $SiO_2$ plot (Figure 45), shows two broad trends. The lower and upper sequences, if considered as one group display the normal tholeiitic trend of Osborn (1959), of sharply increasing mafic index with a slight $SiO_2$ increase. The felsic group shows the normal calc-alkali trend of essentially constant or slowly increasing mafic index. A similar double trend was found by Clifford and McNutt (1971). Both the Archean trend and the normal igneous trend have higher mafic indices for the felsic rocks and lower mafic indices for the mafic rocks then is shown for the thesis area.



MI vs $SiO_2$
$MI = (FeO + Fe_2O_3) \times 100 / MgO + FeO + Fe_2O_3$
90
70
50
40
60
80
Mt. St. Joseph area trend of Clifford and McNutt (1971).
Archean trend of Goodwin and West (1975).
trend of thesis area
$SiO_2$ (%)


FIGURE 45

7. On all Harker diagrams CaO, $Al_2O_3$, Alkalies, Mafic Index, there is a gap between 53% and 60% $SiO_2$, which corresponds to the andesite gap of Barker and Peterman (1974). In studies of the early PreCambrian crust they found that a bimodal suite of tholeiitic-dacitic magmatism is common in all Archean rocks. Glikson and Lambert (1976) suggested that the scarcity of andesites in the Yilgarn and other greenstone belts, renders progressive fractional crystallization of ascending magmas unlikely, as this should generate a continuous spectrum of composition, including intermediate rocks. Theoretical work by Green and Ringwood (1968) showed that dehydration of the lower parts of a downgoing slab of hydrous crust and upper mantle would release sufficient $H_2O$ to prohibit the formation of andesitic liquid in the upper part of the slab. Based on this and other experimental work Barker and Peterman (1974) believed that the "gap" was characteristic of Archean rocks. However, recent work by Page (personal communication) in the Minnitaki Area shows that this is not always the case. In this thesis area a "gap" does exist and is believed to be real as all rock types were sampled and the analyses represent a complete sequence of rock types within the area. The absence of rocks of intermediate composition in the Coolgordie - Norseman Area led Hallberg (1970) to the conclusion that the

acid porphyries were derived from a separate magma source rather than by differentiation or contamination of tholeiitic magma. Based on these observations it is suggested that the Thundercloud Porphyry and the mafic rocks in the area formed from separate sources.

8. Using the differentiation index as ordinate, the $Fe_2O_3$+ plot (Figure 46) shows two trends. The first is constant $Fe_2O_3$+ content with increasing DI for by the lower and upper sequences. The felsic group shows a negative correlation with increasing DI. The middle unit definitely shows affinities for the felsic group of rocks.

9. On the AFM plot (Figure 47), the lower and upper sequences lie in the tholeiitic field of Irvine and Baragar (1971). The middle sequence shows a distinctive calc-alkali trend with a relatively constant F/M ratio. The lower sequence shows a distinct Fe enrichment trend but not so for the upper sequence. There is no significant MgO enrichment in any of the basalts, therefore no olivine-rich, picritic or komatiitic basalts have been identified in the area.

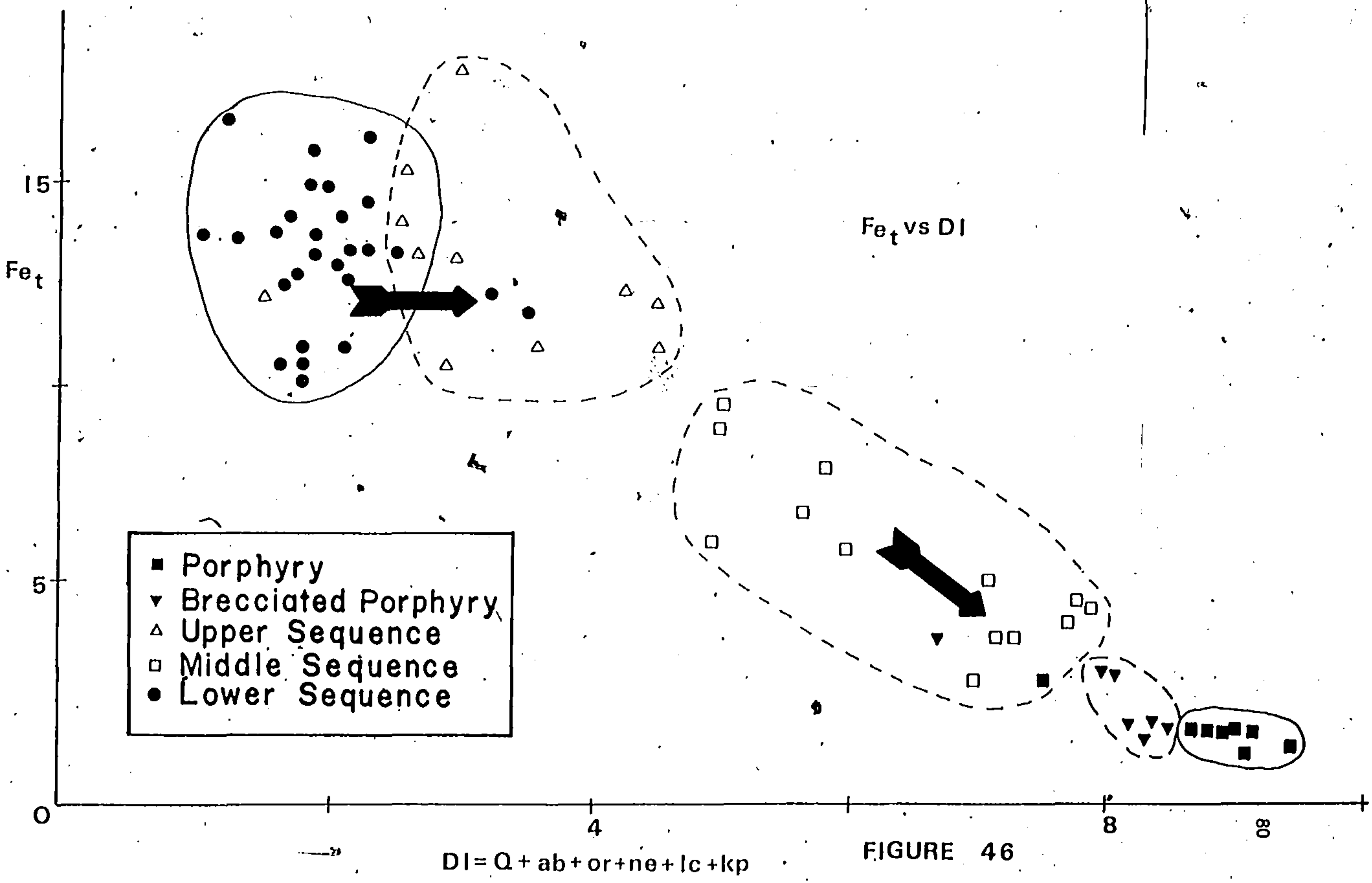

Fet vs DI
Fet
15
5
0
4
8
DI=Q+ab+or+ne+lc+kp
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence

FIGURE 46

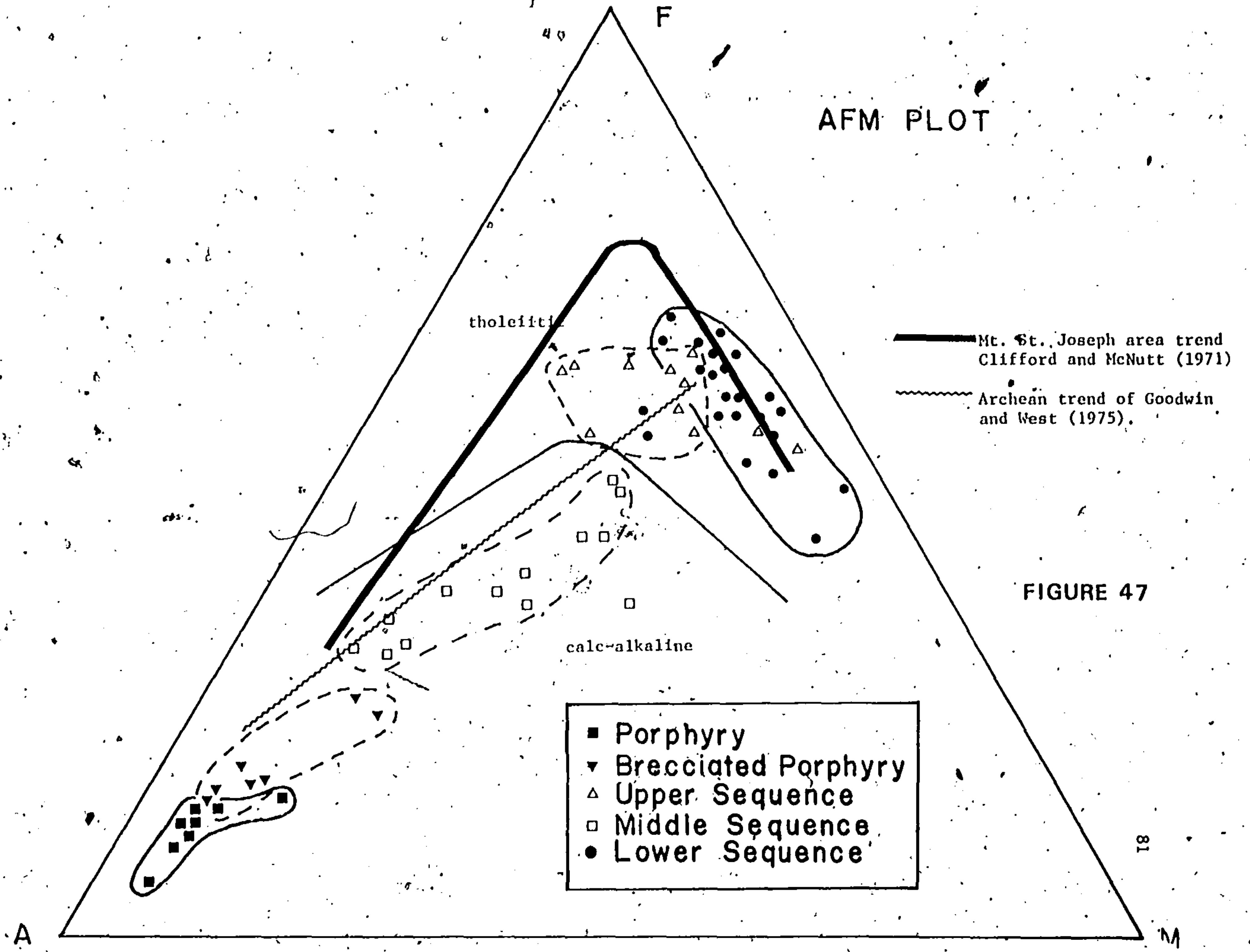

AFM PLOT
F
A
M
tholeiitic
calc-alkaline
Mt. St. Joseph area trend Clifford and McNutt (1971)
Archean trend of Goodwin and West (1975).
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence

FIGURE 47

10. The normative feldspar plot (Figure 48) illustrates the very low and constant content of Or in the mafic sequences, which is to be expected as only plagioclase is crystallizing. The Or content varies considerably in the middle sequence as two feldspars are crystallizing, as well as biotite and hornblende. The porphyry and brecciated porphyry rocks lie in the Na-enriched field of average rocks, which is characteristic of many Archean porphyries. Note that a distinct separation exists between the two mafic sequences in that the upper sequence has consistently higher Or contents. This may suggest that the sources were different for the two mafic sequences.

v) Trace Element Characteristics

The results are presented in Appendix A and Figures 49-54. The following trends are observed:

11. Table 3 shows the average trace element compositions for the thesis area, compared with averages of Baragar and Goodwin (1969) and the Australian Meekathorra basalt of Archean age. Rb and Nb, where determined, are less than 10 ppm. Note that the Rb values for the lower sequence are quoted as being less than 1 ppm.

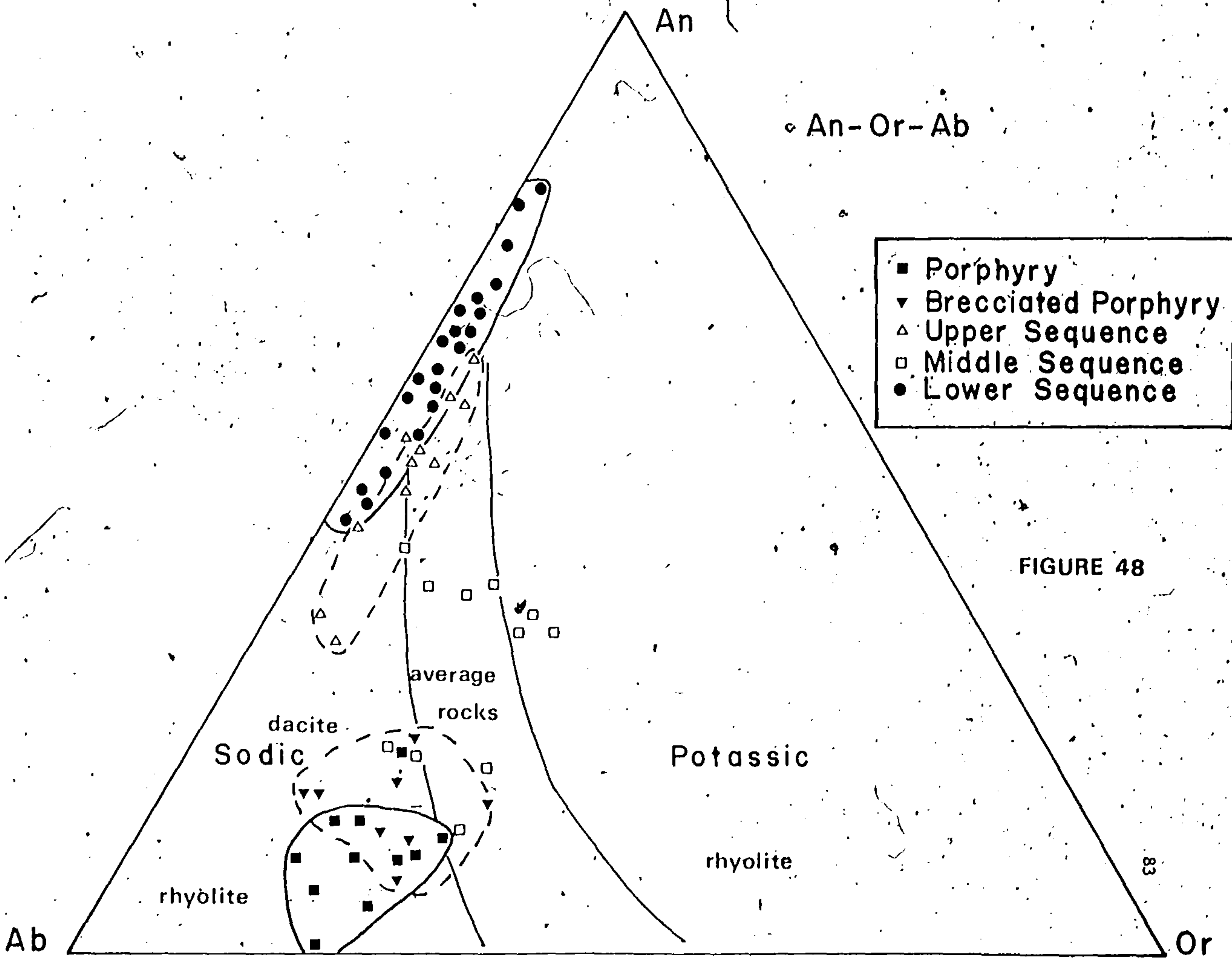

An
An-Or-Ab
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
average
rocks
dacite
Sodic
Potassic
rhyolite
rhyolite
Ab
Or

FIGURE 48

Table 3

Trace Element
Comparison Chart - Mafic Rocks

| | Rb | Sr | Ba | Ni | Y | Zr | Nb | K | K/Rb | Rb/Sr |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | 214 | 194 | 89 | 17 | 160 | | | | |
| 2 | - | 217 | 122 | 110 | 18 | 133 | | 3240 | | |
| 3 | 8 | 81 | 413 | 78 | 27 | 89 | <3 | 1992 | 249 | .098 |
| 4 | <1 | 120 | 43 | 125 | 25 | 57 | 6 | 1300 | (1300) | (.001) |
| 5 | 9 | 154 | 138 | 69 | 31 | 95 | 7 | 4040 | 448 | .058 |

1 - average mafic rock Superior Province, Baragar & Goodwin (1969)
2 - average Lake of the Woods basalt, Baragar & Goodwin (1969)
3 - average basalt Meekatharra Australia, Hallberg et al. (1976)
4 - average basalt of lower sequence, Thundercloud Lake Area
5 - average basalt of upper sequence, Washeibamaga Lake Area

Table 4

Trace Element
Comparison Chart - Felsic Rocks

| | Rb | Sr | Ba | Ni | Y | Zr | Nb | K | K/Rb | Rb/Sr |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | 317 | 450 | 19 | | 210 | | | | |
| 2 | 71 | 111 | 1104 | 12 | 31 | 171 | 9 | 21000 | 296 | .6 |
| 3 | 46 | 346 | 673 | 2 | 14 | 126 | 9 | 14000 | 317 | .13 |
| 4 | 71 | 267 | 561 | 50 | 12 | 135 | 10 | 22300 | 314 | .265 |
| 5 | 48 | 494 | 713 | 12 | 6 | 102 | 6 | 17200 | 358 | .097 |
| 6 | 73 | 435 | 686 | 7 | 5 | 89 | 3 | 19100 | 261 | .167 |

---

1 - average Lake of Woods rhyolite, Baragar & Goodwin (1969)
2 - Marda Rhyolite Porphyry, Australia, Hallberg et al. (1976)
3 - feldspar porphyry Sturgeon Lake Area, Franklin (1977)
4 - Middle Sequence Felsic Flows, Washeibamaga Lake Area
5 - Brecciated Porphyry average, Washeibamaga Lake Area
6 - Quartz-Porphyry average, Thundercloud Lake Area

Although this value approaches the sensitivity limit (see Appendix D) it is significant that most Rb values for the lower sequence had values of 1 ppm or less compared to 9 ppm (range of 6-14 ppm) for the upper sequence. This distinction between the upper and lower sequences in Rb contents may suggest separate sources. The upper sequence is also enriched in Ba, Sr and Zr and depleted in Ni. The Ba, Zr and Sr values for the thesis area are depleted in comparison to the averages of Baragar and Goodwin (1969). The upper sequence shows close similarities with the Meekatharra basalt except for Sr and Ba.

12. Erlank and Kable (1976) from their study of the incompatible elements of the Mid-Atlantic-Ridge Basalts, demonstrate that the abundances of Zr and Nb are apparently unaffected by sea-water alteration. Therefore the Zr/Nb ratio is considered to be representative of the source and a measure of the degree of depletion. It is interesting that typical Mid-ocean-ridge-basalts have Zr/Nb ratios ranging from 30 to 110, similar to the 5 to 100 range for the lower sequence. In contrast the upper sequence has a range of 7 to 40, similar to high alumina basalts, (Erlank and Kable, 1976, Zr/Nb within the range of 20 to 50). The variation may be

the result of differences in the differentiation processes and/or the related tectonics.

13. On a log plot of K vs. Ba (Figure 49), the porphyry and brecciated porphyry overlap indicating a possible genetic relationship. The middle sequence falls in the region of the porphyry again suggesting similarities between the two sources. The upper mafic sequence is enriched in both K and Ba compared to the lower sequence. The K/Ba ratios of approximately 60 is consistent for all the units.

14. The Sr vs. Ba log plot (Figure 50) shows that the lower sequence overlaps the oceanic tholeiites as defined by Kay et al. (1970). The upper sequence seems to follow the island-arc trend of Jakes and White (1972). However, there is a large scatter for the upper sequence: some samples fall within the mid-ocean ridge trend, while others don't. The average Archean examples show close similarities with the upper mafic sequence.

The porphyry and brecciated porphyry plot near the upper limit of the island-arc trend.

15. The porphyry, brecciated porphyry and middle sequence show a close cluster on the K vs. Sr diagram (Figure

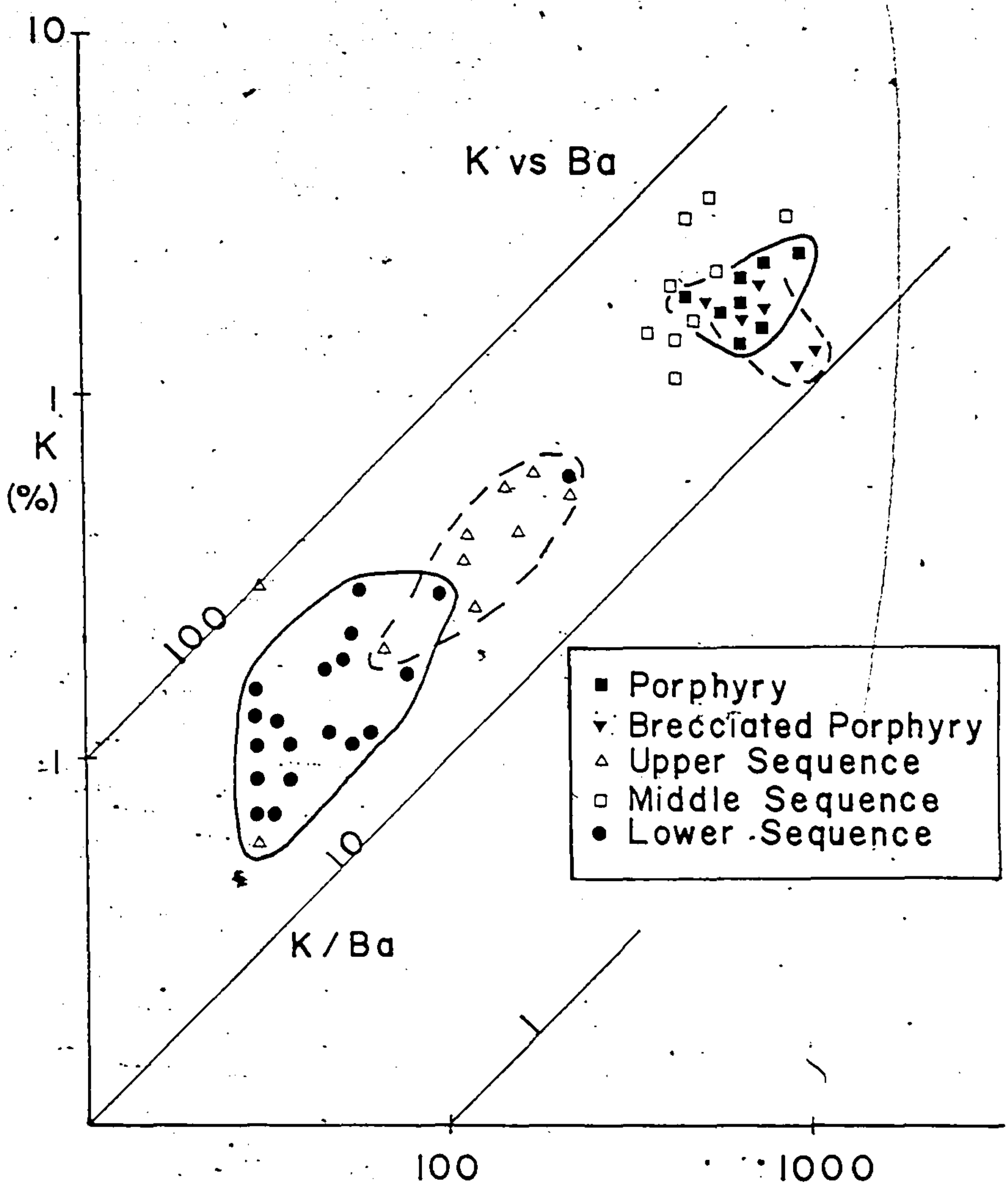
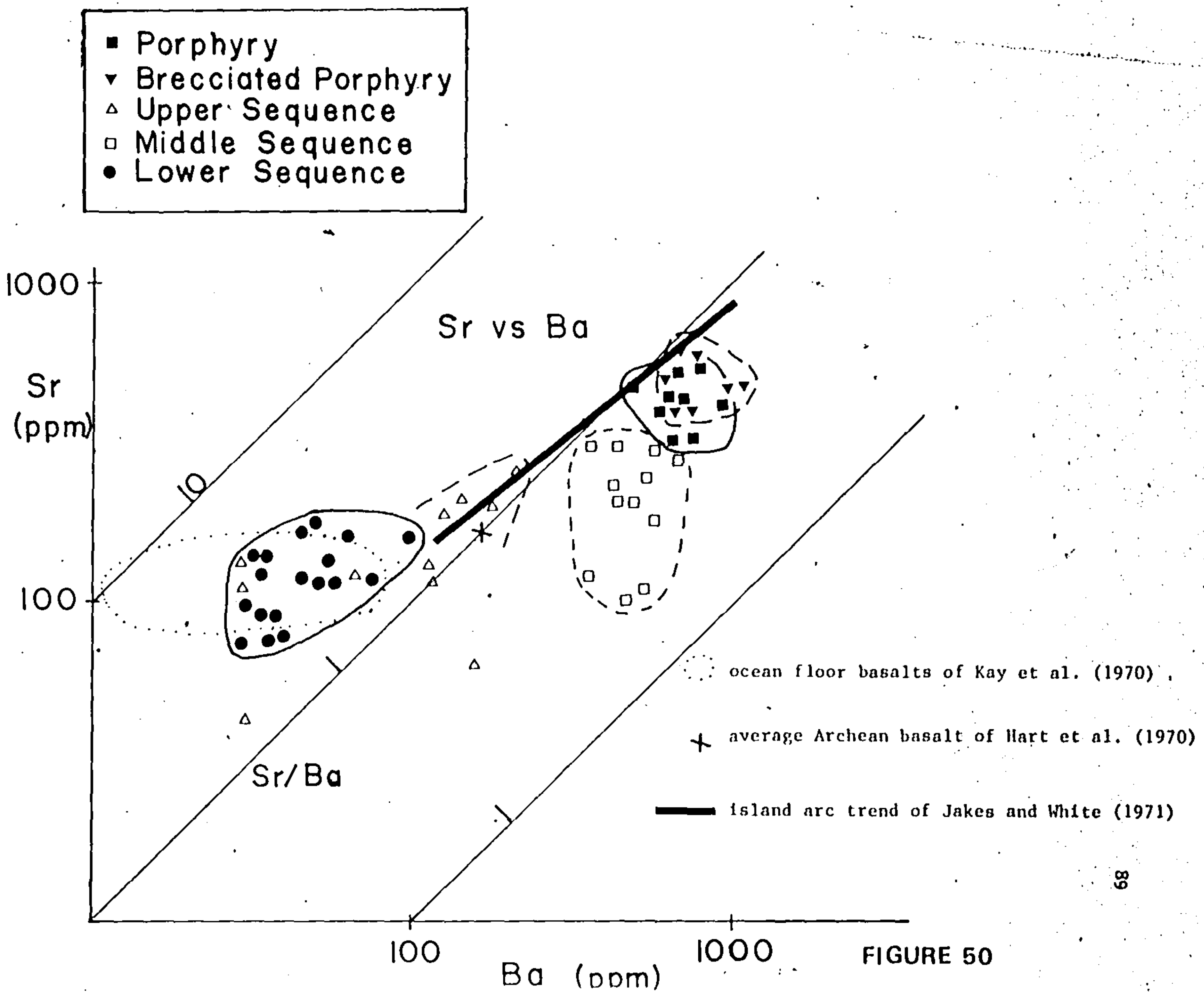

K vs Ba
10
1
K
(%)
.1
100
10
1
K / Ba
100
1000
Ba (ppm)
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence

FIGURE 49



Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
Sr vs Ba
Sr (ppm)
1000
100
10
1
1
Sr/Ba
ocean floor basalts of Kay et al. (1970)
average Archean basalt of Hart et al. (1970)
island arc trend of Jakes and White (1971)
100
1000
Ba (ppm)


FIGURE 50

51) argues in favor of them having one source. The felsic flows and tuffs of the middle sequence show no affinities for either mafic sequence. Unlike the constant K/Ba ratio, the K/Sr ratio varies from a low of 10 for the lower sequence to a high of 100 for the upper sequence.

16. A plot of K vs. Rb (Figure 52) separates the rocks of the thesis area into 3 main groups; the lower sequence, the upper sequence and a felsic sequence made up of the porphyry, brecciated porphyry and middle sequence. The lower sequence is characterised by low K and very low Rb values, with corresponding high (1000 to 3000) K/Rb ratios. The upper sequence has intermediate values for K and Rb and a consistent K/Rb ratios of 400 to 500. The felsic rocks have higher Rb (100 ppm) concentrations but still have a consistent K/Rb ratio similar to the upper sequence.

Work by Shaw (1968) on 21 suites of igneous rocks, using covariance analyses, delineated three principal patterns:

a) main trend - shows a slight decrease in the K/Rb ratio with increasing K and Rb.

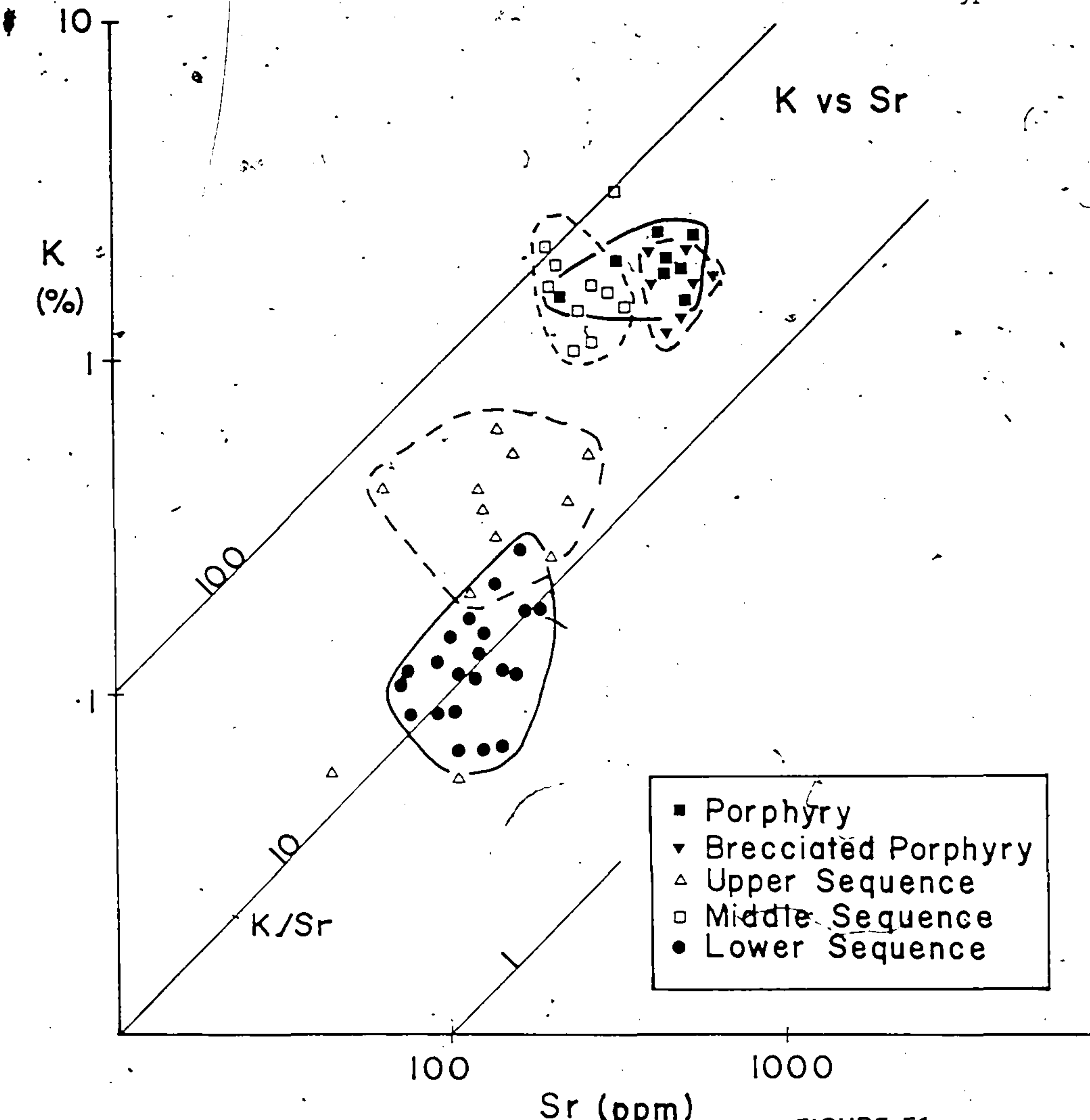
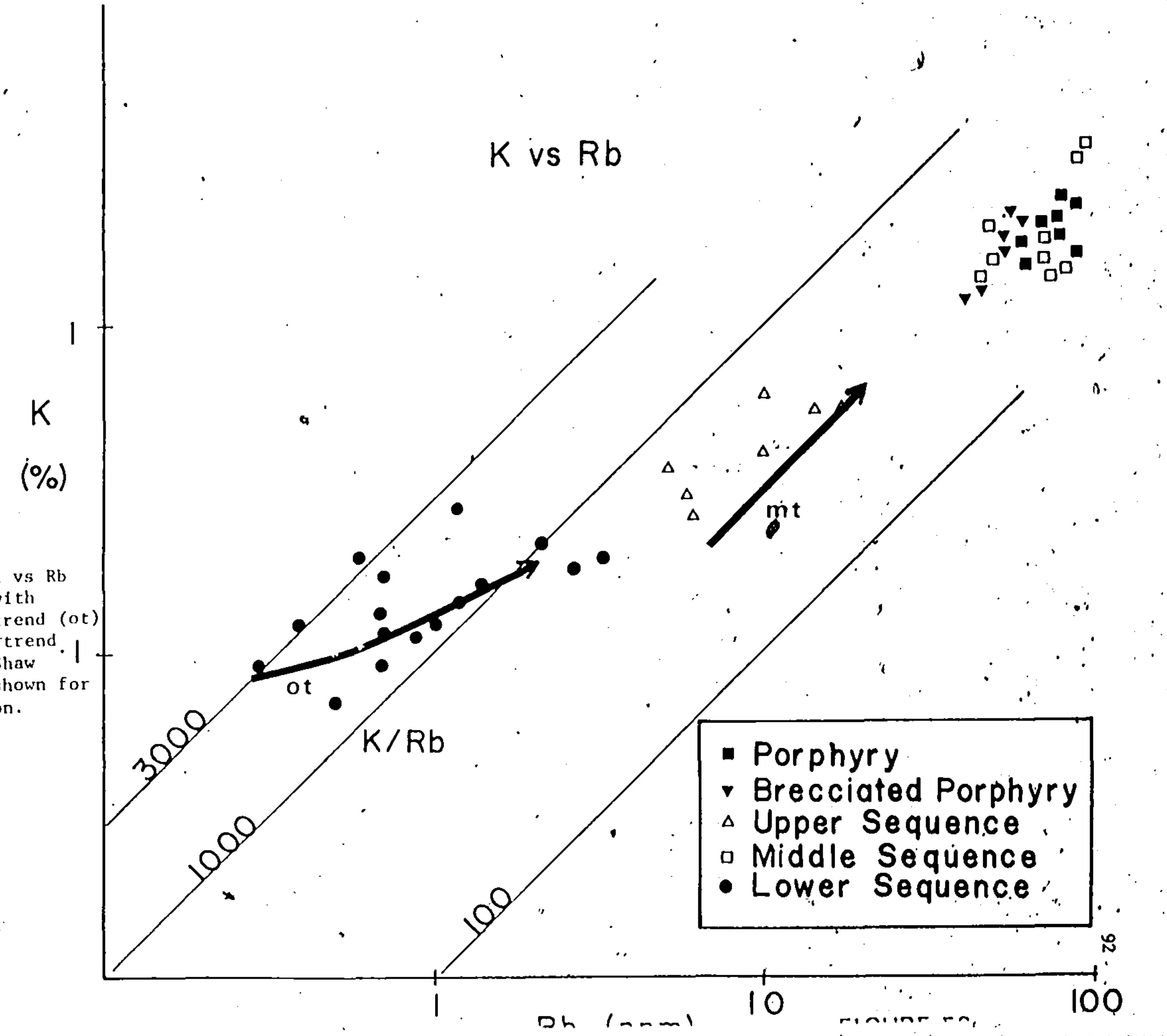

K vs Sr
K
(%)
10
1
.1
100
10
1
K/Sr
100
1000
Sr (ppm)
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence

FIGURE 51

Figure K vs Rb diagram with oceanic trend (ot) and main trend (mt) of Shaw (1968), shown for comparison.



b)- oceanfloor trend - distinct trend of K/Rb decreasing from 3500 and merging with the main trend, exists for ocean ridge basalts and achondritic meteorites.

c) pegmatite - hydrothermal trend of extreme Rb.

Comparison with Shaw's (1968) trends shows that the lower sequence falls along the trend for ocean-ridge basalts. The upper sequence follows the main trend, K/Rb ratios being similar to those found by Jakes and White (1970) for island arc rocks. The felsic rocks are an extension of the main trend.

17. On a Rb vs. Sr diagram (Figure 53) the rocks of the middle sequence all plot tightly together with a noticeable separation between it and the upper sequence. There is also a separation between the lower and upper sequences. The Rb/Sr ratio increases by a factor of 100 going from the lower sequence to the felsic group. O'Bierne (1968) and Hallberg (1972) have shown that considerable differences in Sr levels exist between the low K-tholeiites (100 ppm) and the acid porphyries of the Kalgoorlie region (600 ppm). They point out that this separation argues against

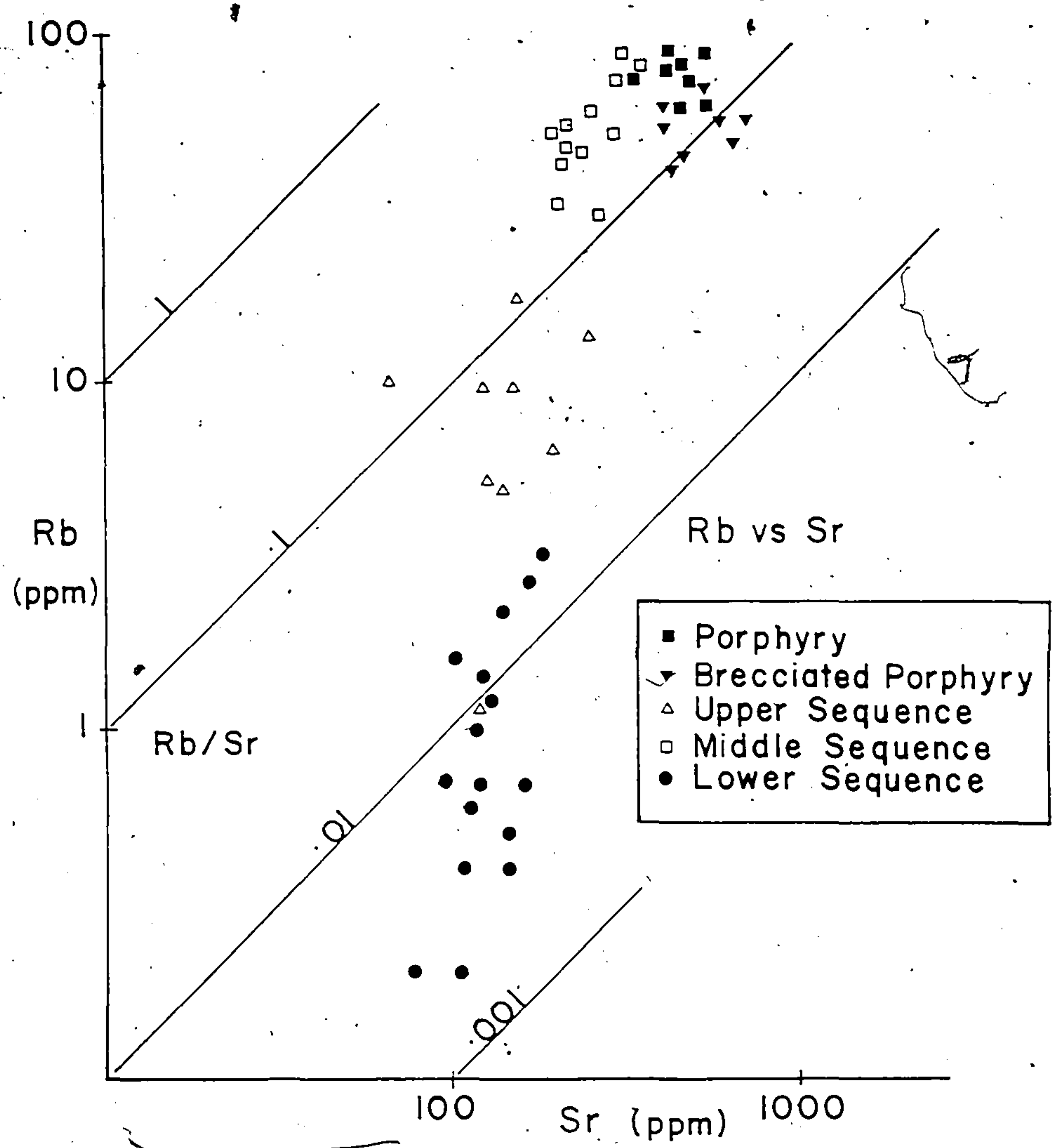

100
10
1
Rb
(ppm)
Rb/Sr
.01
.001
Rb vs Sr
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
100
1000
Sr (ppm)

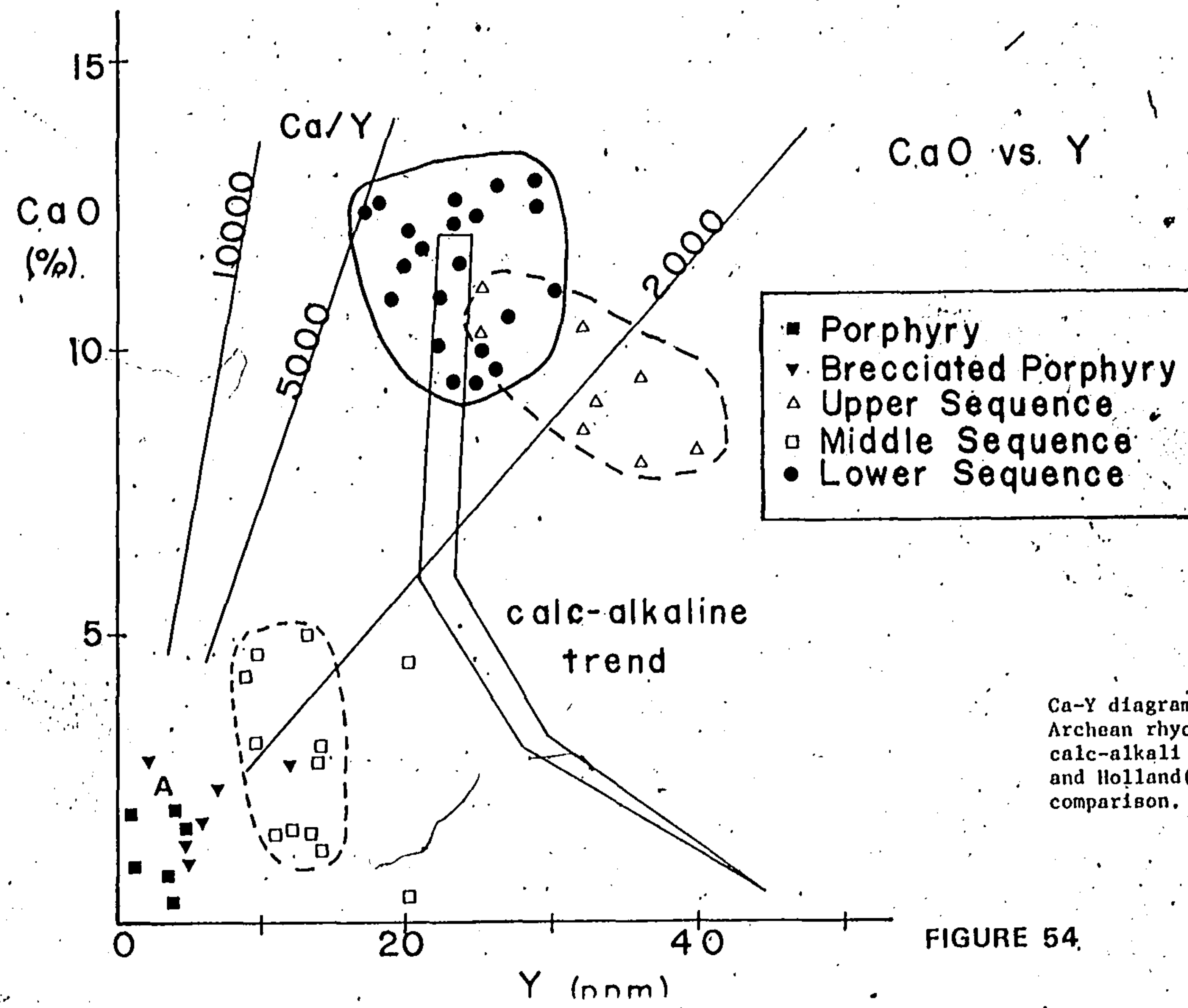
FIGURE 53

fractional crystallization as a sole mode for the origin of the porphyry from tholeiitic magma.

In the thesis area the distinct separation of the sequences on the Rb vs. Sr diagram suggests varying tectonic styles for all 3 sequences (lower, upper and felsic).

18. Yttrium follows calcium in igneous, metamorphic and sedimentary rocks due to its incorporation in Ca minerals. Figure 54 shows the relative locations of the various units compared to the calc-alkaline trend and specific examples of Lambert and Holland (1974). The calc-alkaline trend represents a compilation of averages of rocks from different settings (e.g., Tonga, Yeoval Complex, West Indies). The resulting shape is caused by clinopyroxene-plagioclase fractionation.

The lower sequence falls at the upper end of the curve. The upper sequence Y values are generally higher (however low values, 8 ppm, do exist) and fall to the right or Y-rich side of the trend. The porphyry and brecciated porphyry have low CaO and Y value and plot in the vicinity of the Archean rhyolites. In sedimentary processes the Ca/Y ratio becomes lower in




Ca-Y diagram with average Archean rhyolite (A) and calc-alkali trend of Lambert and Holland(1974) shown for comparison.

FIGURE 54

shales and sandstones as reflected by the middle sequence.

vi) Summary

The stratigraphic separation of the three sequences is seen in their chemical trends. The middle felsic sequence can also be separated into three units (felsic flows and tuffs, brecciated porphyry and porphyry) based on chemical similarities and differences. Most plots show that the porphyry and brecciated porphyry are chemically identical and can be considered the same rock type. The middle sequence shows close affinities for the porphyry and brecciated porphyry and is thought to have originated from the same source. Some of the tuffs/sandstones compare closer to the upper sequence basalts and thus may be actually sedimentary derivatives from the upper sequence.

The lower and upper sequences, although similar in many major element concentrations (Figures 41, 42, 43), show marked separation based on trace element analyses (Figures 50, 51, 52). This is interpreted to reflect differences in the magma sources and/or the differentiation history for the two mafic sequences. Comparison with modern examples show that the lower sequence had Mid-ocean-ridge or Mid-ocean-floor basalt affinities, while the upper sequence compares favourably with Island-Arc Tholeiites.

# CHAPTER IV - PETROGENESIS

The petrogenesis of the rocks of the Washeibamaga - Thundercloud Lakes Area will be discussed in three parts:

Part 1 - The Volcanics

Part 2 - The Porphyry and Brecciated Porphyry

Part 3 - The Volcaniclastic Rocks

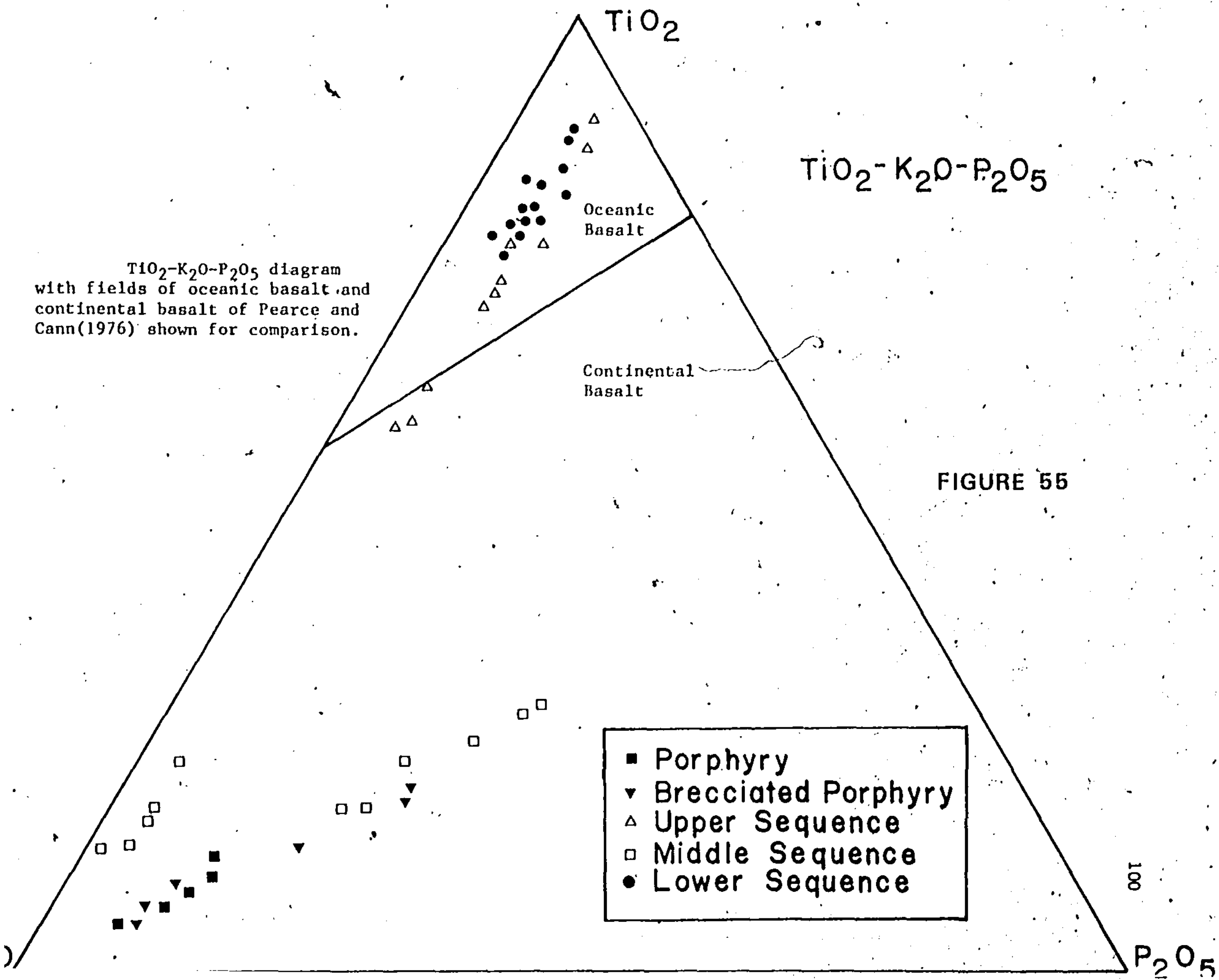
## Part 1 - The Volcanics

i) Introduction

Archean volcanic rocks of the Canadian Shield and other shield areas compare closely in nature and composition with present day volcanic rocks of known tectonic settings. The geochemical patterns exhibited by recent and ancient volcanics are remarkably similar and many authors (Goodwin and West 1975, Glikson 1971, Hart et al. 1979, White et al. 1971) interpret this in terms of similarities in the tectonic environments. If these patterns are interpreted with respect to plate tectonic theory, it appears possible to use the geochemistry of ancient volcanics to study the early tectonics of the earth.

Volcanic activity on the Earth is concentrated in four geographic-tectonic settings; 1) ocean ridge systems, 2) island arcs, 3) oceanic islands and 4) continental basalts. The first two groups comprise, volumetrically, the most significant volcanism active today and are therefore of prime importance to the integrated theories of petrogenesis (McMaster, 1976). Although tholeiitic basalts are dominantly generated at oceanic ridges or in association with island arcs, continental basalts of tholeiitic affinities cover large areas. Pearce et al. (1975) compiled a large number of analytical data on both oceanic and continental tholeiites and by means of a $TiO_2$ - $P_2O_5$ - $K_2O$ diagram were able to discriminate between the two types. Figure 55 shows such a plot using the thesis data. From this it is concluded that no continental type basalts occur in the thesis area. Rock associations in Archean greenstone successions suggest the existence of two tectonic settings; the equivalents to (1) modern ridge basalts and (2) calc-alkaline association with island arcs.

The basic tenent of ocean-ridge (floor) basalts are now reasonably well understood due to intensified oceanographic studies (DSDP, Project Famous, etc.). Basalts predominate, although differentiated rocks in the series, basalt-andesite-rhyolite do occur, they are rare. Recent geochemical and petrological studies of ocean-floor basalts have shown that the rocks are the result of partial melting of upper mantle rocks along linear zones. The ascending peridotitic mantle material undergoes 10-20% partial fusion in the depth range, 15-30 km, yielding predominantly silica-




$TiO_2$-$K_2O$-$P_2O_5$ diagram with fields of oceanic basalt and continental basalt of Pearce and Cann(1976) shown for comparison.

FIGURE 55

saturated low-K basaltic liquids (Glikson 1971, Condie 1976). Specifics of the melting and subsequent fractionation of ocean-ridge basalt parental melts need not be considered here - the important point is that the products of this process appear to maintain a first order chemical homogeneity on a world wide basis. Bryan et al. (1972) found that over the whole earth, ocean-floor basalts show only slightly greater diversity than that shown at a single well-sampled Mid-Atlantic-Ridge site.

There presently exists no model of arc volcanic petrogenesis which can suitably explain all the constraints (petrographical or geochemical) inherent in the data (Tarney et al., 1975). Lateral variations in the composition of the volcanic rocks across island arcs and their correlation with depth to the Benioff Zone has been established (Jakes and White 1970, Miyashiro 1974, Green and Ringwood, 1968). Tholeiites occur on the oceanic side of island arcs, followed landward by low, medium and high potassium calc-alkaline rocks and finally by shoshonites or alkaline rocks. Shoshonites are rare in the Archean (Smith and Longstaffe, 1974), and will be omitted from further discussion. The two main suites of rocks are island arc tholeiites and calc-alkaline rocks. Petrogenetically the two series can be explained by underthrusting of a slab of hydrated oceanic crust enriched in alkalines. $H_2O$ released from amphibolite in the subducted oceanic crust causes partial melting to occur in the pyrolite wedge above the Benioff Zone and subsequent differentiation under high $PH_2O$ of such a liquid would produce a tholeiitic magma (Ringwood, 1974). As deeper levels are tapped (dependent on angle and rate of underthrusting) calc-alkaline magmas are generated. The range of rock types and characteristic plagioclase phenocrysts of both suites suggest that they have undergone extrusive and probably near-surface fractionation (Jakes and Gill, 1970).

Comparisons of ancient and recent volcanics from most of the shield areas have been attempted. Viljoen and Viljoen (1971) show that the lower Onverwacht series of basic rocks correlates with oceanic tholeiites, while the upper Onverwacht dacites and rhyolites show affinities for island arc domains. The Norseman greenstones of Western Australia are so similar chemically to island arc tholeiites that they may be considered to be metamorphosed arc equivalents (White et al., 1971). K, Rb, Sr, Ba and REE data of volcanic rocks from the Vermilion greenstone belt of north-east Minnesota, suggests that these rocks were formed in an ancient island-arc system (Jahn et al., 1974). For the Knee Lake - Oxford Lake greenstone belt of Manitoba, Hubregtse (1975) concluded from his data that correlation with ocean-floor basalts seemed more plausible. Franklin (1977) and Beggs (1975) found that the volcanic rocks of the Sturgeon Lake area showed close affinities for island-arc tholeiites and calc-alkaline rocks.

ii) Comparisons with the Study Area

A similar comparison is made for the thesis area. Most of the data was presented in Chapter III. Tables 5 and 6 compare the

Table 5

Major Element Comparison Chart

| (wt%) | LS | US | MS | OFB | IAT | IAF | BAB |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 50.51 | 51.90 | 67.26 | 49.94 | 51.57 | 66.80 | 49.25 |
| $TiO_2$ | 0.86 | 1.18 | 0.54 | 1.51 | 0.80 | 0.23 | 1.66 |
| $Al_2O_3$ | 14.28 | 14.77 | 15.75 | 16.69 | 15.91 | 18.24 | 17.74 |
| Fe+ | 13.00 | 11.91 | 4.91 | 11.49 | 9.78 | 2.27 | 9.15 |
| MnO | 0.21 | 0.20 | 0.08 | 0.18 | 0.17 | 0.06 | 0.11 |
| MgO | 7.65 | 5.50 | 2.50 | 7.28 | 6.73 | 1.50 | 5.92 |
| CaO | 11.24 | 9.94 | 2.40 | 11.86 | 11.74 | 3.17 | 11.23 |
| $Na_2O$ | 2.23 | 2.73 | 2.89 | 2.76 | 2.41 | 4.97 | 3.26 |
| $K_2O$ | 0.19 | 0.44 | 2.55 | 0.16 | 0.44 | 1.92 | .45 |
| $P_2O_5$ | 0.07 | 0.11 | 0.12 | 0.16 | 0.11 | 0.09 | .14 |

LS, US, MS of thesis area.
OFB ocean-floor basalt (Engel et al., 1965)
IAT island-arc-tholeiite (Jakes & White, 1972)
IAF island-arc felsic rock (Jakes & White, 1972)
BAB back-arc basalt (Page, 1977)

Table 6

Trace Element Comparison Chart

| (ppm) | LS | US | MS | OFB | IAT | IAF | BAB |
|---|---|---|---|---|---|---|---|
| Rb | 1 | 9 | 71 | 1 | 7 | 50 | 5 |
| Sr | 120 | 154 | 267 | 115 | 207 | 305 | 186 |
| Ba | 43 | 138 | 561 | 15 | 100 | 520 | 38 |
| Y | 25 | 31 | 12 | 30 | 19 | 20 | - |
| Zr | 57 | 95 | 135 | 95 | 52 | 100 | - |
| Ni | 125 | 69 | 50 | 125 | 20 | 5 | 69 |
| K | 1300 | 4040 | 22300 | 1400 | 2500 | 17100 | 4100 |

LS, US, MS of thesis area.
OFB ocean-floor basalt (Engel et al., 1965)
IAT island-arc-tholeiite (Jakes & White, 1972)
IAF island-arc felsic rock (Jakes & White, 1972)
BAB back-arc basalt (Page, 1977)

major and trace elements of the thesis area [lower sequence (LS), upper sequence (US), and middle sequence (MS)] to averages for ocean-floor basalts (OFB), island-arc tholeiites (IAT), calc-alkaline felsic rocks (IAF) and back-arc basalts (BAB). The latter represent another mechanism of producing tholeiitic magmas related to island-arc development, i.e. active spreading and volcanicity behind the arc. Such phenomena have been documented for the Mariana trough basalts (Hart et al., 1970) and the Lau Basin basalts (Hawkins Jr., 1976). They show no fundamental differences from mid-ocean ridge basalts and seem to be generated from similar sources and by similar petrogenetic processes. Karig (1970) thus concluded that spreading plate margins, in both large and small basins produces rocks of the same compositional range. Subsequent work by Page (personal communication, 1977) points out that most back-arc basalts are enriched in Al, K, Ba, Rb and Sr, and depleted in Ni and Ti, compared to ocean-floor basalts.

From the major element comparison table it is evident that both the lower and upper sequences are low in $TiO_2$, $Al_2O_3$ and high in Fe compared to modern basalts. The lower sequence has low $K_2O$ and normal MgO values analogous to ocean-floor basalts, while the upper sequence is low in MgO and high in $K_2O$.

The significance of potash with respect to the origin of tholeiitic basalts has been discussed by Jamieson and Clark (1970). The average value for oceanic tholeiites is 0.16% and for IAT is 0.44%. These are extremely close to the values reported for the lower sequence (0.19%) and upper sequence (0.44%) respectively.

The relationship between Fe and Mg in the thesis is (the lower sequence has higher values for both) comparable to that of ocean-floor basalts and island-arc tholeiites. This relationship, that of lower sequence basalts and ocean-floor basalts, upper sequence basalts and island-arc tholeiites is also borne out by $SiO_2$ and MnO contents. The low aluminum levels of the lower sequence (14 to 15%) are typical for Archean rocks. According to Glikson (1971) this indicates that the melts did not originate or equilibrate at depths greater than 15 km, from which high-alumina liquids are derived due to the instability of plagioclase.

The elemental abundances of K, Rb, Sr and Ba, in Table 6, have been normalized against those of ocean-floor basalts and depicted in a plot similar to that of Jahn et al. (1974). It is clear from Figure 56 that the lower sequence basalts have patterns similar to ocean-floor basalts, with low K, Sr and Rb but the Ba contents of the thesis rocks are higher than that of ocean-floor basalts. The tholeiites of island-arcs and the upper sequence are similar as the curves are parallel, however, there also seems to be some analogies with back-arc basalts for everything but Ba.

In terms of Sr vs. Ba (Figure 50) the lower sequence is comparable to the mid-ocean ridge values of Kay et al. (1970) the upper and middle sequences fall along Jakes and Whites (1972) island-arc trend. Other Archean data gathered by Hart et al. (1970) show association with the upper sequence data. On the K vs. Rb diagram (Figure 52), as previously discussed, the high K/Rb ratio for the lower sequence is similar to the ocean-floor basalts

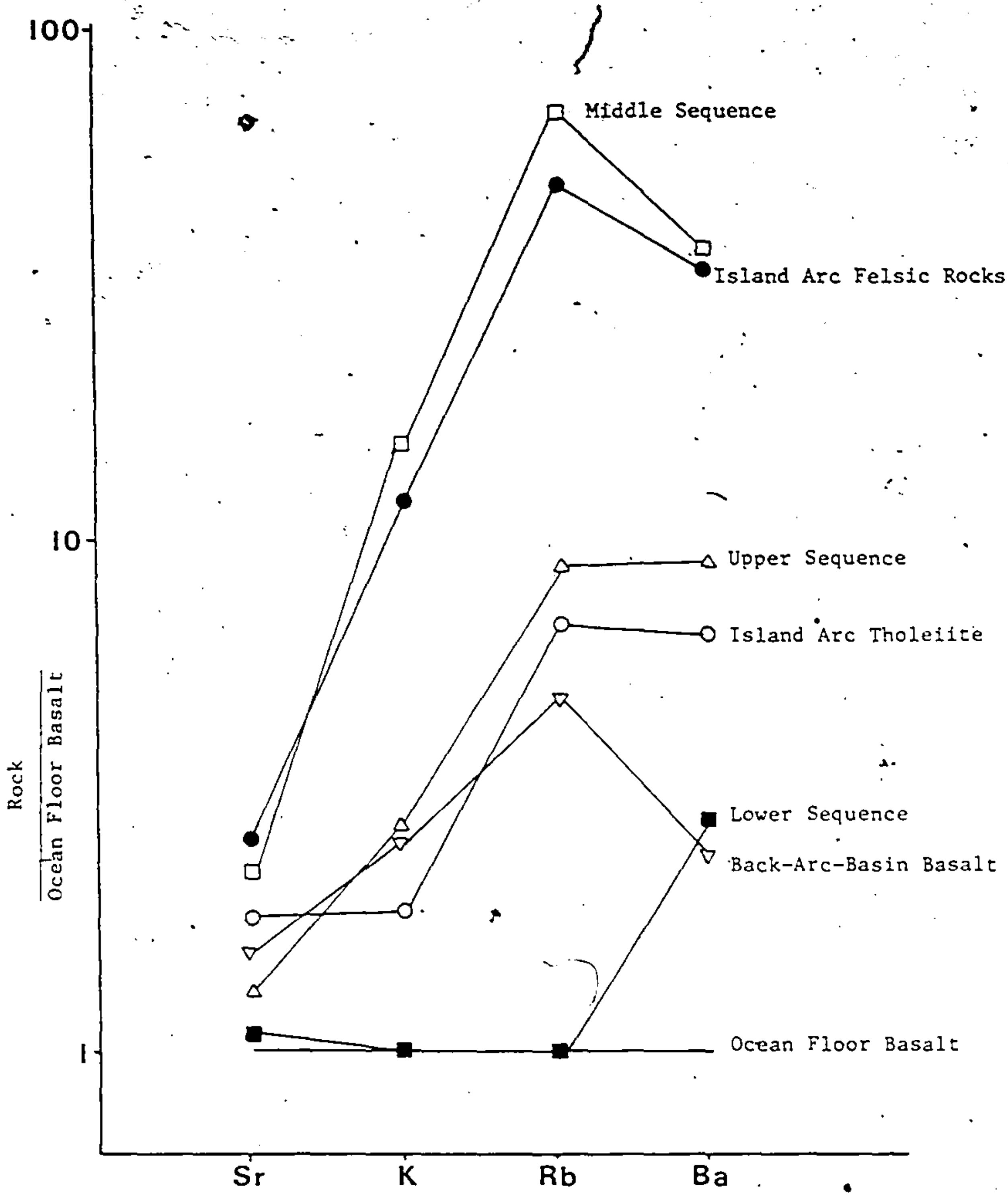


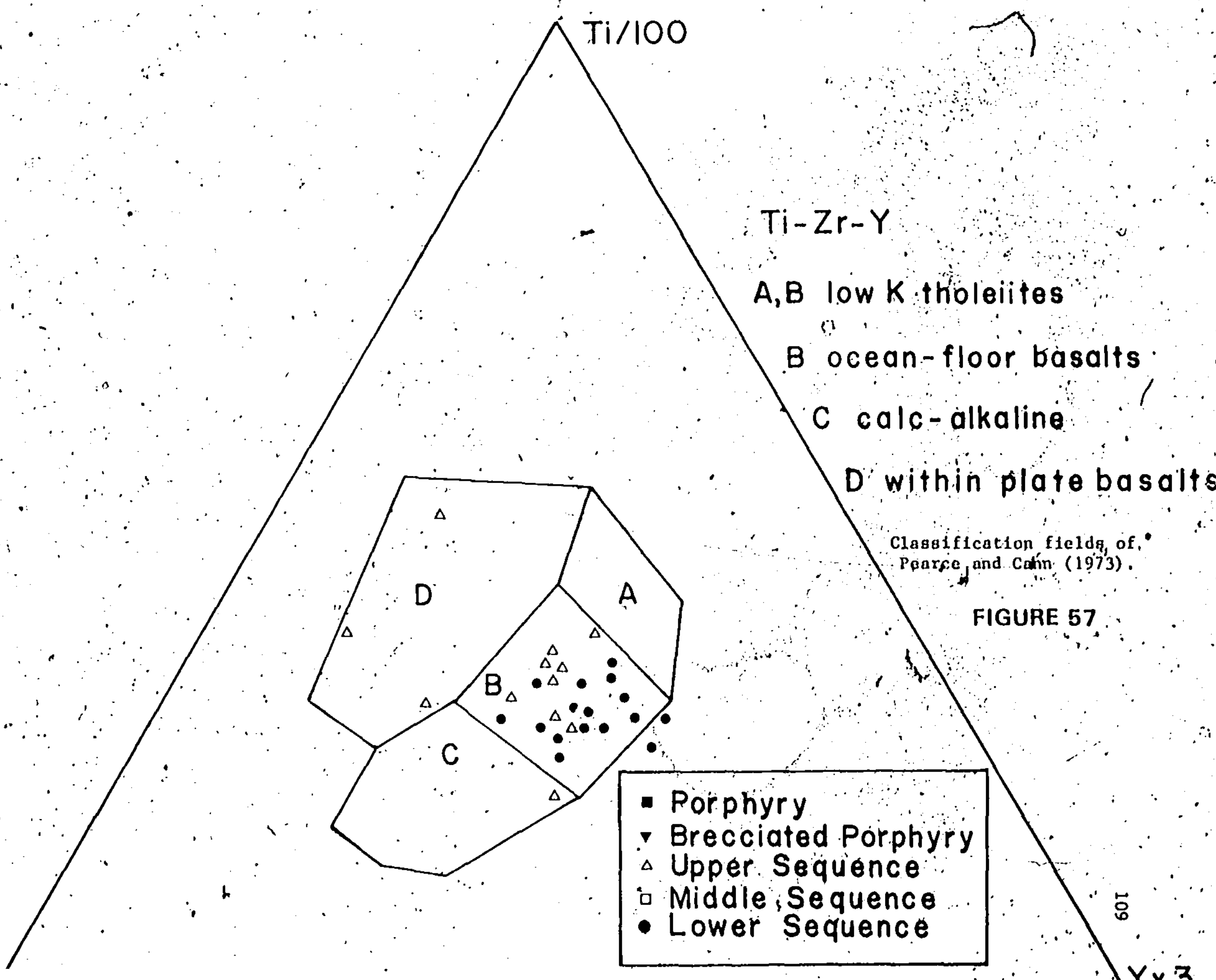

FIGURE 56

Sr-K-Rb-Ba variation diagram for various types of volcanic rock. All rock values are normalized against the value for oceanic floor basalt, after Jahn et al. (1974).

of Engel et al. (1965), the upper sequence and middle sequence fall on the main trend of Shaw (1968). However caution must be used in any interpretation based on K, Rb, Sr and Ba because they are mobile elements.

Reported Ni values of oceanic tholeiites fall within the range 70 to 200 ppm, the average for Mid-Atlantic Ridge tholeiites being 123 ppm which is very close to 125 ppm for the lower sequence. The Ni values for the upper sequence seem closer to those of back-arc basalts than island-arc tholeiites. The Ni values for both the upper and middle sequences are considerably higher than those for corresponding island-arc environments, a common feature of Archean basalts.

Pearce and Cann (1971) found that Y, Zr, Ti and Nb apparently preserve their original abundances through complex post-volcanic processes. Using discriminant analyses they were able to classify recent volcanic environments schematically on three basic diagrams: Ti-Zr-Y, Ti-Z, and Ti-Zr-Sr. Their basic composition requirement was that 20% > CaO + MgO > 12%. On the Ti-Zr-Y plot (Figure 57) the lower sequence falls within field B, i.e. ocean-floor basalts and low-K tholeiites. The upper sequence values essentially fall in field B also but a few are in the within-plate-basalt classification. On the Ti vs. Zr plot (Figure 58) the lower sequence shows definite affinities for ocean-floor basalts. The upper sequence falls in fields C and D, calc-alkaline basalts and ocean-floor basalts respectively. The Ti-Zr-Sr plot (Figure 59) shows that the lower sequence clusters in the ocean-




Classification fields of Pearce and Cann (1973).

FIGURE 57

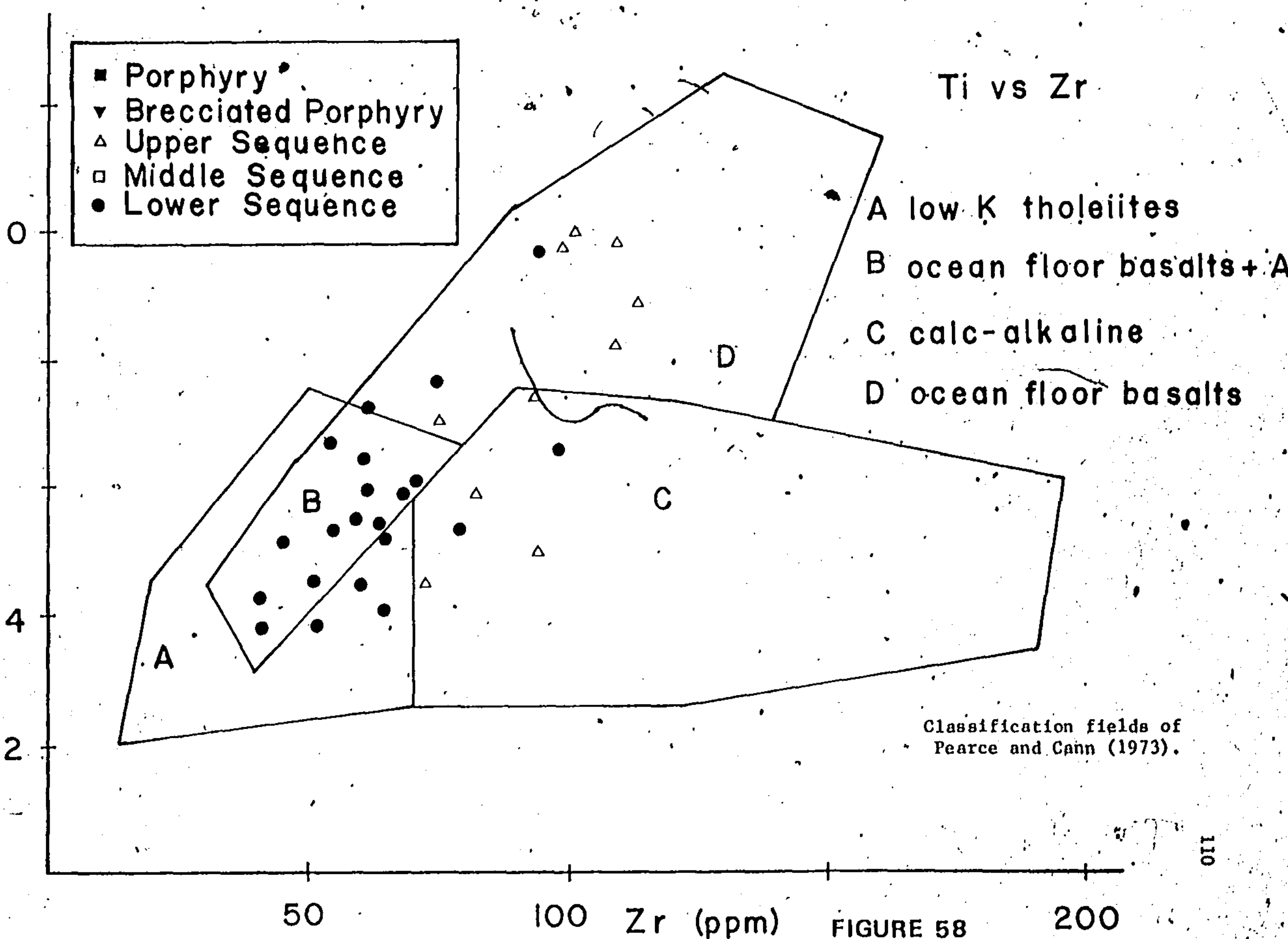

Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
Ti vs Zr
A low K tholeiites
B ocean floor basalts + A
C calc-alkaline
D ocean floor basalts
A
B
C
D
0
4
2
50
100
200
Zr (ppm)
Classification fields of Pearce and Cann (1973).

FIGURE 58

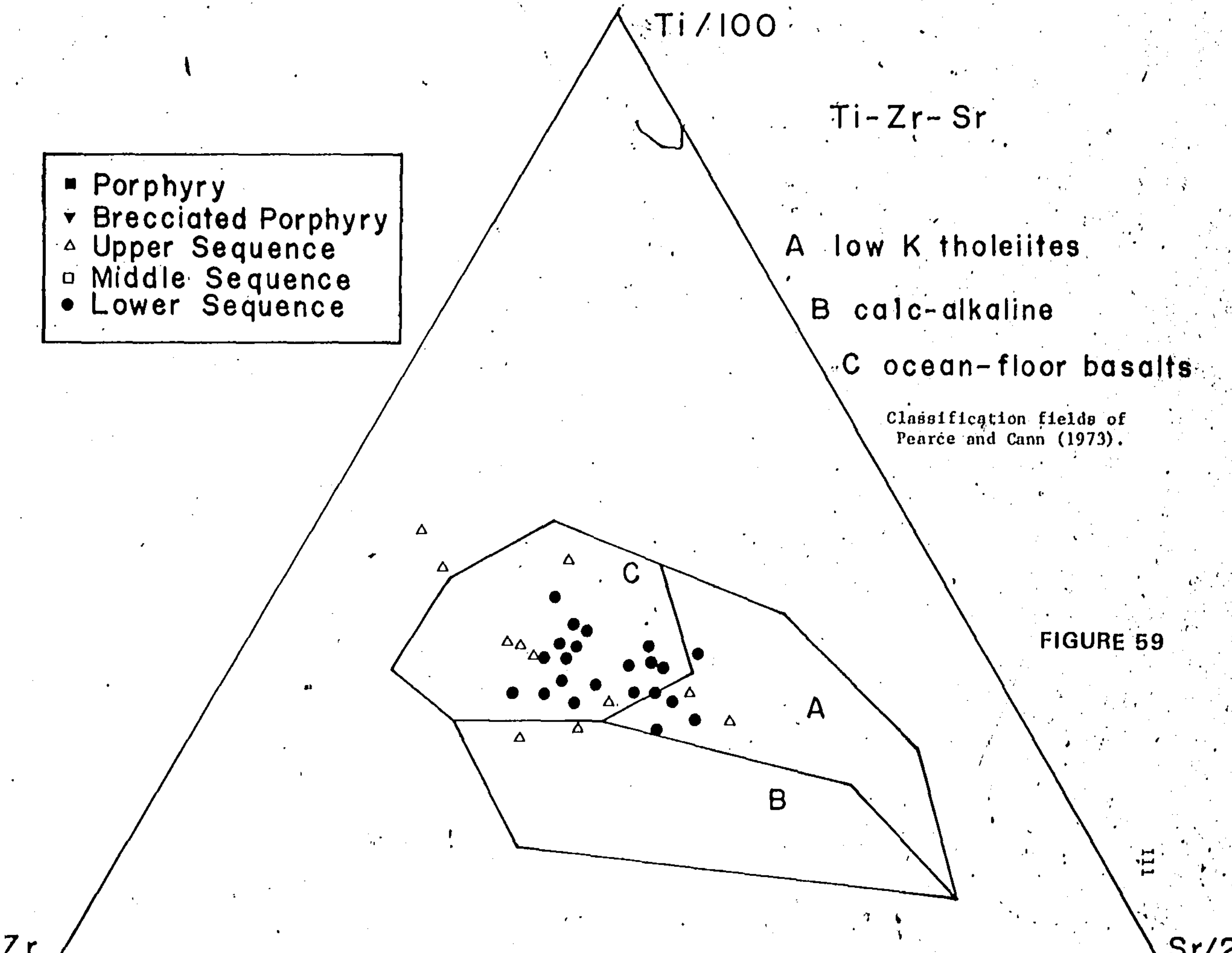

Ti/100
Ti-Zr-Sr
Porphyry
Brecciated Porphyry
Upper Sequence
Middle Sequence
Lower Sequence
A low K tholeiites
B calc-alkaline
C ocean-floor basalts
Classification fields of
Pearce and Cann (1973).
C
A
B
Zr
Sr/2

FIGURE 59

floor basalt field, while the upper sequence is dispersed in all three fields. This may be the result of metamorphic processes affecting the amount of Sr, as previously discussed.

Ca-Y data (Figure 54) suggests that the upper and lower sequences are separate entities.

iii) Magma Sources

One of the potentially most valuable applications of trace element distributions in Archean greenstone belts is the study of the processes of magma generation, that is it may be possible to evaluate the role of fractional crystallization and progressive melting in the formation of greenstone magmas. It is interesting to note that the Sr contents in the basalts of very different ages are quite similar (115 ppm for ocean-floor basalts, 120 ppm for the lower sequence). According to Jahn et al. (1974) the distribution coefficients for K, Rb, Sr and Ba are greater than one (dicoeff = $\chi^{melt}/\chi^{source}$). Unless the upper mantle is an infinite reservoir for the trace elements (which is unlikely) continuous extraction would result in depletion in modern rocks. However, observations from trace element abundances in the thesis area show that recent and ancient rocks are almost identical. Jahn et al. (1974) have suggested two possible solutions: a) trace elements have been repeatedly and fully recycled in a closed system during the last 3 billion years, thus liquids derived from the same degree of partial melting would have the same trace element concentrations and b) the loss of trace elements by partial melting and segregation of the melts to the crustal regime, is replenished by addition from the lower part of the mantle, by as yet undefined processes.

In comparison with Condie's (1976) DAT (depleted Archean tholeiites) and EAT (enriched Archean tholeiites), (Table 7), it can be seen that the lower sequence is similar to the depleted Archean tholeiite. The major elements are comparable but differences exist in trace element concentrations. The lower sequence is lower in Ni and Ba and higher in Y. The upper sequence is comparable to the enriched Archean tholeiites. Again major elements are similar but the upper sequence is higher in Ba and Y and lower in Ni. According to Condie (1976) EAT becomes progressively more abundant at higher stratigraphic levels in most greenstone belts. An overall similarity is apparent between DAT and modern rise and arc tholeiites and between EAT and modern calc-alkaline and oceanic island tholeiites. If these similarities are carried into the modelling, it appears that the lower seqaence, like DAT, requires 25-35% melting of lherzolite or 10-20% melting of plagioclase - peridotite to achieve the rare-earth and trace element distributions. EAT and the upper sequence requires 45-55% melting of eclogite (Condie, 1976). The lack of REE analyses negates any quantitative discussion at this time. A detailed discussion of magma generation in Archean times is beyond the scope of this thesis. It is hoped that REE analyses will be carried out by other workers in the area so that definite conclusions can be drawn. Existing trace element data indicates that Archean volcanic

Table 7

Chemistry of Washeibamaga - Thundercloud Area
Compared to Condie's (1976) Archean Averages

| | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | Fe+ | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | Cr | Co | Ni | Rb | Sr | Zr | Ba | Y | Ce |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LS | 50.51 | .96 | 14.28 | 13.00 | .21 | 7.65 | 11.24 | 2.23 | .19 | .07 | - | - | 125 | 1 | 120 | 57 | 43 | 25 | 8.1 |
| US | 51.90 | 1.18 | 14.77 | 11.91 | .20 | 5.50 | 9.94 | 2.73 | .44 | .11 | - | - | 69 | 9 | 154 | 95 | 138 | 31 | 13.1 |
| P | 73.79 | .19 | 15.15 | 1.25 | 0.04 | .69 | 1.56 | 5.09 | 2.38 | .06 | 15 | 50 | 7 | 73 | 435 | 89 | 686 | 5 | 12 |
| BP | 73.18 | .22 | 15.34 | 1.79 | .03 | .90 | 1.75 | 4.32 | 2.15 | .08 | 15 | 35 | 12 | 48 | 494 | 102 | 713 | 6 | 26 |
| DAT | 51.4 | 1.92 | 14.8 | 10.4 | - | 6.7 | 10.7 | 2.7 | 0.18 | - | 350 | 60 | 225 | 4 | 100 | 55 | 80 | 10 | 10 |
| EAT | 49.7 | 1.0 | 14.9 | 11.4 | - | 6.3 | 9.4 | 2.1 | 0.32 | | 175 | 50 | 100 | 10 | 165 | 100 | 90 | 15 | 25 |
| DSV | 71.7 | .19 | 16.4 | 1.6 | - | .5 | 1.7 | 5.0 | 2.0 | - | 12 | 3 | 10 | 41 | 110 | 30 | 480 | 2 | 35 |
| USV | 73.5 | .14 | 12.7 | 2.1 | - | 0.8 | 1.1 | 3.3 | 3.0 | - | 12 | 3 | 10 | 43 | 100 | 350 | 750 | 30 | 95 |

LS - lower sequence, thesis area
US - upper sequence, thesis area
P - porphyry, thesis area
BP - brecciated porphyry, thesis area
DAT - depleted Archean tholeiite (Condie, 1976)
EAT - enriched Archean tholeiite (Condie, 1976)
DSV - depleted siliceous volcanics (Condie, 1976)
USV - undepleted siliceous volcanics (Condie, 1976)

assemblages, as suggested by Condie (1976), are produced by complex multi-stage processes involving both progressive melting and fractional crystallization of the magma.

iv) Conclusion

In concluding the comparison between Archean and recent volcanic rocks, the following observations are pertinent:

a) the basalts of the lower sequence conform to the principal criteria laid down by Engel et al. (1965) for the classification of ocean tholeiites, but are noteably lower in Ti, Al, and Zr, and higher in Fe and Ba. It is concluded that the lower sequence basalts represent the equivalents of those being generated today at actively spreading oceanic ridges.

b) the basalts of the upper sequence show affinities for island-arc tholeiites in terms of most of the major elements (excluding CaO and $TiO_2$) and large ionic lithophile elements (Rb, Sr, Ba). Concentrations for Y, Zr, and Ni are definitely higher in the upper sequence than in island-arc tholeiites and may be analogous to back-arc basalts in these terms. The different field character of the two sequences argues against similar sources and it is suggested here that the upper sequence basalts may have inherited some ocean-floor basalt characteristics from the subducted ocean crust and may have been generated in back-arc basins. Although it cannot be definitely concluded, the upper sequence basalts are taken to be either island-arc or back-arc basin basalt equivalents.

## Part 2 - The Porphyry and Brecciated Porphyry

### i) Introduction

Facies D and E (Chapter II) are very similar in appearance and petrographic criteria. The problem of distinguishing between a graded unconformable contact and an intrusion gained prominence at the turn of the century. The difficulty arises chiefly where such acid igneous rocks as quartz porphyries are the source of the sediments. Bertholf Jr. (1946) realized a similar problem existed in the Washeibamaga Lake - Thundercloud Lake Area. He reached the conclusion that some of the mass was truly a porphyry, but much of it proved to be a sediment of "recomposed igneous rock". Comparisons with other porphyry occurrences in the Superior Province found varying conclusions. In the Vermilion Lake area of northwest Ontario, Hurst (1933) argued that the quartz-porphyry was intrusive into the overlying Abram series of conglomerate. However Pettijohn (1935) believed that the Abram series rests unconformally on the quartz-porphyry. He based this on the total absence of dikes or other intrusive phenomena in the adjacent sediments. In the Stuntz Bay, Vermilion Lake area of northern Minnesota, Smythe and Findlay (1895) did not recognize the brecciated porphyry as a sediment, but included it in pseudoconglomerates formed by brecciation of the quartz - porphyry. However subsequent work by Winchell (1899) and Clements (1903) disputed his conclusion, stating that the conglomerate of the brecciated prophyry is of sedimentary origin. Similar arguments exist for the relationship of the porphyry and brecciated porphyry in the Porcupine, Little Long Lac, and Rouyn district of northern Ontario (Langford, 1938; Reid, 1945; Cooke, James and Mawdsbey, 1931).

Microscopically no significant difference exists. No gradation in grain size was seen and plagioclase twins were observed to be parallel to grain boundaries. Subsequent rounding and evidence of transport is lacking, as all grain boundaries approximate the crystal boundaries. Chemically, for both major and trace elements, the two are identical. On all plots the fields of porphyry and brecciated prophyry overlap and exhibit the same gross patterns (see Chapter III).

ii) Comparison with the Study Area

In describing the Keweenawan Rhyolite on Davieaux Island, Minnesota, Green (1971) found that brecciation occurred near the top of the sheet, where small sub-angular blocks of rhyolite were set in a matrix of continuous rhyolite of identical composition.

These blocks are thought to represent the rapidly congealed top of the rhyolite which was broken and engulfed or injected by the still plastic material moving beneath. This is a possible explanation for the brecciated porphyry, i.e. the result of the breakup of a thick carapace during movement and emplacement of the still plastic lower part of the flow.

According to Condie (1976) the siliceous rocks in Archean greenstone belts fall into two groups based on trace-element distribution (see Table 7). The depleted siliceous volcanics (DSV) have heavy REE and Y depletion compared to modern examples. The undepleted siliceous volcanics (USV), recognized in only a few greenstone belts (Barberton, Yellowknife and Kenya) show no depletion. Both groups have higher Cr, Ni, and Ni/Co ratios than modern arc rhyolites. The Thundercloud Porphyry and brecciated porphyry are analogous in their mafic element values to the DSV rhyolite, however, large discrepancies do exist for Co, Rb, Sr, Zr, and Ba, in that they are higher in the thesis rocks. As noted earlier, some of the early formed feldspar have normal zoning probably formed as a result of local disequilibrium near the margins of the porphyry. The albite rich rims formed on feldspars would trap an excess amount of Sr, due to increase uptake of Sr by An poor feldspars (Phillpotts and Schnetzler, 1970). This may account for the abnormally high Sr content. It appears that the Thundercloud Porphyry doesn't fit into Condie's (1976) classification.

iii) Magma Sources

The fact that transition trace elements are enriched in Archean siliceous volcanics strongly suggests that they have not been produced by fractional crystallization, since the large distribution coefficients of transition elements in fractionating magmas would result in their rapid removal. Based on these and other REE data, Condie (1976) suggests that DSV volcanics result from 10-20% melting of eclogite.

The comparison with the Theespruit Komati Porphyry of the Barberton area, as discussed in the previous chapter suggests that similar sources may have produced the Thundercloud Porphyry. Glikson (1976c), using REE models found that it corresponds to about 25% melting of quartz eclogite of dolerite composition or to 1% melting of quartz eclogite of ocean-floor tholeiite chemistry. Comparison of all analyses from the Coolgardie - Norseman area of West Australia (Hallberg, 1970) shows that no relationship exists between the basalt associations and the acid porphyries. He argues that they were derived from separate magma sources rather than by differentiation of contamination of tholeiitic magmas. Glikson (1976a) suggested that the albite prophyries of the Barberton region may represent shallow-level hypabyssal equivalents of ancient tonalites. This is in keeping with Tauson's (1967) work on crystallochemical dispersion and residual concentrations in abyssal to hypabyssal intrusives in Russia. At this point it is interesting to note that Elbers (1974) has reached similar qualitative conclusions for calc-alkaline plutonism and volcanism in northern Manitoba. He believes that the porphyrtic cupolas, stocks and dikes which occur as magmatic protrusions into the greenstone belts are connected to the major batholiths in the area. In the thesis area this would mean connection of the porphyry and the Megissi Lake batholith. At this time it is impossible to make any definite conclusions. Work is presently being done by Sabag at the University of Toronto to determine the chemical characteristics of the batholith.

Glikson (1976c) argues that experimental data "renders likely concomitant fusion of mantle and mafic crust". The melting of mafic crust in the vicinity of rising mantle diapirs would give rise to the observed ultramafic-mafic-acid cycles in the Onverwacht Group and Kirkland Lake areas.

Normative data for the porphyry have been plotted on a ternary projection, the Q-Ab-Or face of the Q-Ab-Or-An system (Figure 60). The position of the cotectic line at 5Kb $H_2O$ pressure (Winkler et al., 1975) is shown for reference. The average quartz porphyry value is designated by a solid circle in Figure 59. In the Q-Ab-Or part, this rock has 8% An, i.e. it lies only 1 to 2% An above the cotectic surface Q+Pl+L+V (Winkler et al., 1975, Figure 10). In the An-Ab-Or diagram (Figure 48) the composition of the porphyry has only 1% less quartz than it would have had, had it been situated on the Q+Pl+L+V cotectic surface. From this information it is clear that the composition of the porphyry is close to the cotectic surface Pl+Q+L+V. Therefore, after a short

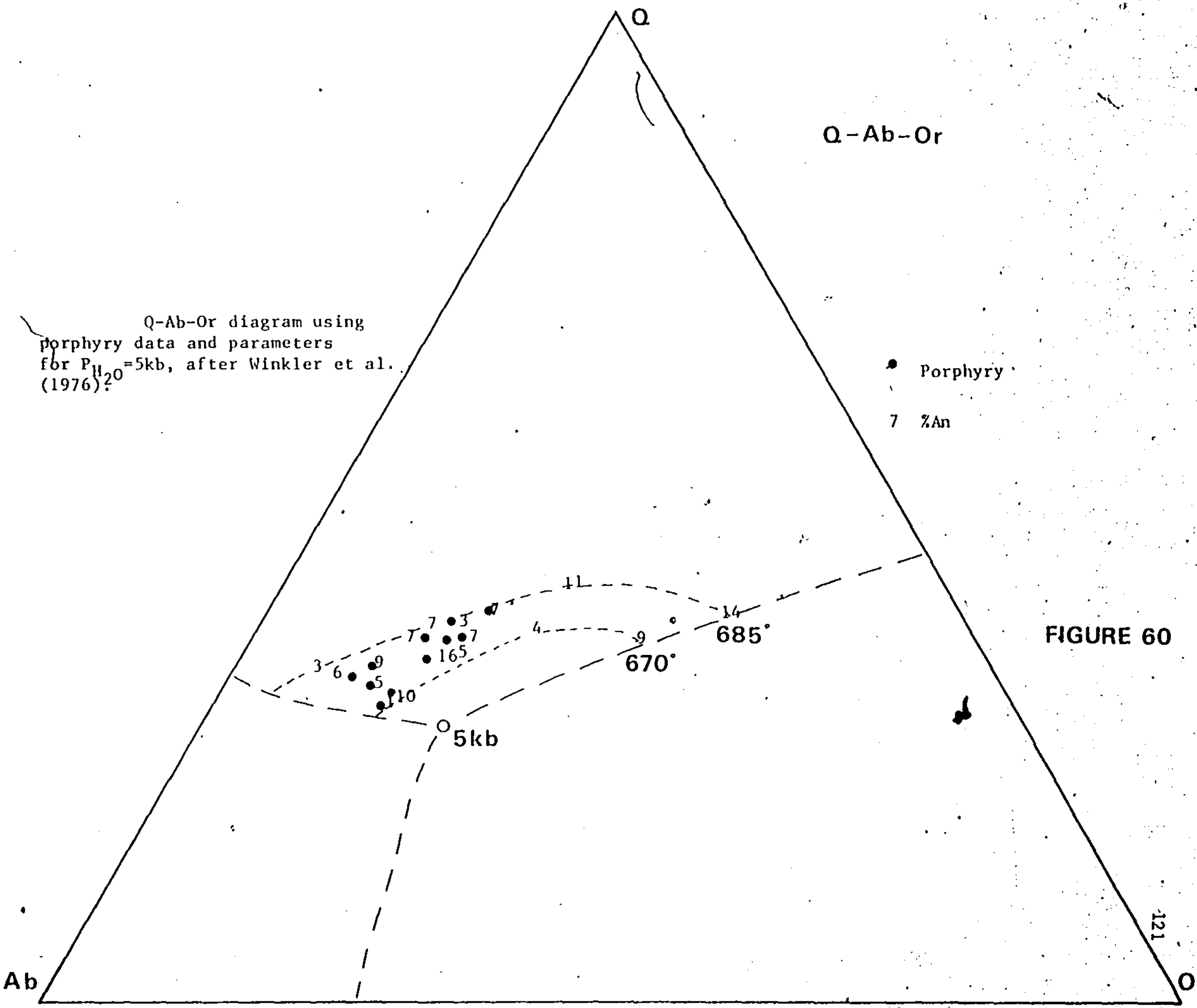



FIGURE 60

Q-Ab-Or diagram using porphyry data and parameters for $P_{H_2O}$=5kb, after Winkler et al. (1976).

temperature interval where only plagioclase crystallizes, quartz will also begin to crystallize. As estimated from Figure 60, the Q+Pl+L+V cotectic surface will have been reached at 670-680°C and with a 15° drop in temperature, the cotectic line will be reached along which alkali feldspar, quartz and plagioclase crystallize together within a narrow range of temperature until all is sold. The deduced sequence of crystallization is:

plagioclase

plagioclase + quartz

plagioclase + quartz + alkali feldspar

When this magma reaches very shallow levels or zones of weakness in the crust it may have erupted onto the surface, producing calc-alkaline volcanism. Spatially quartz porphyry intrusions are commonly associated with felsic volcanics and are chemically similar. In the thesis area the quartz porphyry, the felsic flows (Facies A) and the brecciated porphyry, show obvious similarities as previously discussed (in the field and chemical descriptions). It is suggested then that these are coeval igneous differentiates and that the porphyry represents the ancient volcanic neck and feeder column to felsic volcanism. This conclusion has already been tentatively put forward by Beard (1975) and Blackburn (1976) during reconnaissance work in the area in conjunction with the author.

Beard (1975) in his economic report of the Wabigoon Belt suggested that "the porphyries (Esox Lake, Dash Lake, High Lake, Thundercloud Lake) may represent in part, rhyolite domes made up of rhyolite flows". He goes on to suggest that as such, they offer excellent exploration targets, both for stratabound, exhalative type base metal deposits and for porphyry copper and gold deposits. To this date, the only known economic work in the area has been carried out by Osisko Lake Mines Ltd., on the old Pelham Gold Mines Ltd. property between Washeibamaga and Kennewapekko Lakes in 1973. Considerable trenching, assaying and diamond drilling produced 5.08 ounces/ton of gold. This property, in the lower volcanics, lies within 100 feet of the contact with the porphyry and is associated with two or more coarse-grained mafic dikes. The porphyry of the thesis area is unlike the small, lenticular, structurally conformable bodies of the Abitibi area that have high concentrations of various metals. Detailed economic evaluation and comparison with other areas is beyond the scope of this thesis. Preliminary work is being done by Blackburn for the Ontario Division of Mines (personal communication).

iv) Conclusion

In concluding the discussion of the felsic volcanics the following observations are pertinent:

a) the porphyry and brecciated porphyry are similar petrographically and chemically. The latter is thought to represent the autoclastic brecciation of the roof of the porphyry.

b) crystallization of the porphyry is preceded by highly explosive subaerial, acid volcanism producing pyroclastic deposits and dacitic to rhyolitic deposits and flows.

c) source, as indicated, may be from partial melting and differentiation of related batholiths.

d) the porphyry crystallizes over a short temperature interval beginning at approximately 675°C and 5Kb $H_2O$ pressure to give the characteristic quartz-eye texture. the porphyry represents the final stage of felsic volcanism.

Part 3 - Middle Sequence

i) Depositional Environment

General description of the Middle Sequence permits deductions to be made regarding the volcanic-sedimentary processes and the depositional environments of the volcaniclastic rocks. For this purpose Facies B and C, which inculdes all the coarse clastic rocks of the thesis area, are discussed together because their field relationship indicates deposition in the same general environment but by somewhat different processes. For the purposes of this discussion the coarse volcaniclastic rocks will be referred to as either conglomerates or breccias. No genetic implications should be associated with these terms. The problem of distinguishing between the two was discussed previously. Facies F, the greywacke-argillite (slate) rocks will be discussed separately.

The basic characteristics on which the interpretation of Facies B and C is based, are as shown in Tables 8 & 9.

Turner and Walker (1973) note that there are few modern environments in which conglomeratic material is presently accumulating in large quantities. They list; 1) braided rivers, 2) beaches, 3) turbidite and deep-sea submarine fans, 4) glacial till, and 5) alluvial fans. Based on both positive and negative evidence it is argued that Facies B and C best fit deposition in an alluvial fan environment. The other environments are rejected as possibilities for deposition of Facies B and C following the detailed arguments of Turner and Walker (1973) from their work on the Archean Ament Bay Formation. A brief synopsis of the criteria used are referred to here, additional detail can be obtained from Turner's (1972) thesis. The following environments were rejected for the reasons listed:

(1) Braided Rivers

a) the lack of cross-stratification in the tuffaceous rocks and coarser rocks.

Table 8

Characteristics of Facies B

| Sub-facies | Thickness | D/10 | Description |
|---|---|---|---|
| (1) | 170 m | 7.2 - 8.8 | basal 2 m tuffaceous with random clasts of basaltic material (80%) and a quartz - feldspar matrix grades upwards into 160 - 170 m of conglomerate, with a maximum of 50% basaltic material, decreasing upwards. |
| (2) | 100 - 150 m | 3.4 - 3.8 | interbedded tuff and felsic flow material, clasts are lapilli size and felsic in composition, individual units up to 15 m in thickness. |
| (3) | 450 m | 26 - 36 | interbedded volcaniclastic and epiclastic rocks, subangular to subrounded clasts, some clasts intersect each other, small clasts wrap around large clasts, tapered and pointed clasts common, less than 20% matrix. |

Table 9

Facies C

| Sub-facies | Thickness | D/10 | Description |
|---|---|---|---|
| (1) | 800 m | 20-39 | massive unsorted pyroclastic rocks, up to 35% matrix material, elliptical to subrounded fragments, normally graded on a large scale. |
| (2) | 900 m | 24-78 | massive unsorted, tightly packed with less than 10% matrix material. |
| (3) | 1200 m | 18-35 | poorly exposed, "kink banding" of some clasts, clasts somewhat deformed. |

(2) Beaches

a) thick accumulation (up to 50 m in the thesis area) of conglomeratic material is unlike the generally thin units in transgressive or regressive sedimentary sequences.

b) the angularity and immature nature of most clasts is inconsistent with this high energy shoreline environment.

c) clast shapes are elongate to elliptical in the thesis area, unlike the common disc-like shapes of beach environments.

d) lack of abundant cross-stratification in the tuffaceous interbeds.

(3) Turbidite & Deep Sea Fan Environment

a) absence of repeated sequences of sedimentary structures (Bouma Sequence).

b) general lack of grading (Bouma Sequence)

c) lack of interbedded argillaceous horizon suggests that deposition was in an environment distinctly unfavourable for the slow accumulation and preservation of muds.

d) large scale cross-stratification in the upper part of Facies B is not consistent with a deep basinal environment, more likely it suggests some form of shallow water currents (however it is not inconsistent either, Johnson personal communication).

e) lack of associated greywackes.

(4) Glacial Till

a) lack of glacial textures (grooves, striated and faceted stones).

b) no evidence of dropstones.

c) monomictic character of clasts in the thesis area.

The volcaniclastic rocks of the Washeibamaga Lake area show similarities to younger alluvial fan deposits and it is with an alluvial fan origin that the two facies are discussed. According to Bull (1972), physical characteristics provide the surest means of identifying alluvial fan deposits in the stratigraphic record. In general alluvial fan deposits are characterised by;

(5) Alluvial Fan

a) a tendency to occur as sheets

b) to be made up of greatly differing lithologies, however this is not the case in the thesis area where porphyry fragments account for up to 90% of the clast types.

c) more than one mode of deposition occurs on most fans and the properties of different types of deposits may vary both vertically and in the downslope directions from the fan apex.

Each bed of a fan represents a single depositional event that has resulted from one of a wide spectrum of precipitation and erosion events in the area, due to changes in runoff, source, amount of sediment and mode of transport. Two main modes of transport are recognized; water-laid deposits and debris flow deposits.

a) Water-laid Deposits

Water-laid sediments occur as sheetflood, channel or sieve deposits. Sheetfloods are deposited by surges of sediment-laden water that spreads out from channels on a fan. Deposition is a result of widening of the channel floor which leads to a decrease in depth and velocity of the flow, and thus is not necessarily due to a change in slope. The conglomeratic material is relatively well sorted, large-scale planar cross-stratification is common in the conglomerates. The coarse/fine (conglomerate/sandstone) units are usually impersistent laterally, evidence of erosion is commonly on a scale of 0.5 m and occasionally up to 2 m at conglomerate bases. The most important characteristic is the lack of fines in most of the deposits. This type of deposit is similar to some of the beds of Facies B.

Stream channel deposits are coarser grained and poorly sorted compared to sheetflood deposits. Bedding is poor to crude and is generally less than one metre in thickness. Cut and fill structures are common. Evidence of this type of deposit was observed in the upper part of Facies B, but generally is rare in the thesis area.

Sieve deposits have unique source area conditions that provide little sand, silt or clay so that the material is extremely permeable which allows the flood discharge water to infiltrate the fan entirely before reaching the toe of the fan, resulting in lobes of gravel. Hooke (1967) states that because water passes through rather than over such deposits, they act as strainers or sieves by permitting the water to pass, while holding back the coarse material in transport. Jointed quartzites are typical source rocks, the clasts supplied are predominantly subangular instead of wellrounded gravels. The excellent sorting of sieve deposits results in massive beds and poorly defined contacts between them.

b) Debris Flows

Debris flows by definition (Johnson, 1970) is a process by means of which granular solids, sometimes mixed with relatively minor amounts of water and air move readily on low slopes. Debris flows have high density and viscosity compared to stream flows. The flow is generally laminar, as observed by Sharp and Nobles (1953) on the Wrightwood debris flow of California. The debris is handled gently so that the large boulders and fragile clasts retain their respective identities during flow. The ability of debris flows to carry coarse clasts is due to the high density of the flow, poor sorting and the cohesive strength of the clay-water fluid phase (Rodine and Johnson, 1976). Debris flows typically do not abrade the underlying bed. Since Blackwelder's (1928) classic paper on the subject, Hooke (1967) and Johnson (1970) have conducted numerous experiments on the mechanics of the flow. According to them, debris flows should have a positive-skewed size distribution. Assuming a source material with an approximate normal distribution of particle sizes, all those grains too large to be supported by the fluid should be left near the source while the rest of the material is carried to the site of final deposition. However, Middleton and Hampton (1973) point out that this skewness may be obscured by a strength sufficient to carry almost all material available or by participation of other support mechanisms or by a late-stage period of bed load transport. Many debris flows are irregularly interspersed with fine grain material indicative of quiescence, as evident from Beaty's (1963) work in the White Mountains of California.

One unique type of debris flow is a lahar. Lahar is an Indonesian word that describes mudflows and debris flows originating on the flanks of volcanoes, and was first used by Van Bemmelen (1949). It includes all of the broad textural range of debris and mudflows of volcanic origin, in being; poorly sorted, unstratified, contains subangular components, may be interstratified with fluvial gravel and is generally homolithologic in clast composition. The most detailed work to date has been carried out in Washington State, by Mullineaux and Crandell (1962) in the Mt. St. Helens area and by Schmincke (1967) on the Ellensburg Formation. The latter defined three prominent zones in a typical lahar: a basal, vaguely stratified, fine to coarse sand (tuff) overlain abruptly by a central massive to normally graded zone, consisting of subangular to subrounded blocks in a pebble supported framework grading upwards into an upper bedded sand (tuff), reworked and cross-stratified. The bases of lahars are generally sharp and load features are common. The top of a bed may have clasts protruding above the top of the bed with drape over top.

ii) Petrogenesis - Facies B

Subfacies 1

The basal breccia of the Washeibamaga - Thundercloud Lake Area has a localized distribution and a different composition and texture from the other volcaniclastic rocks higher in the sequence. The fact that the boundary of the basal breccia with the felsic flows is gradational and is not in contact with the prophyry suggests that it is not due to the erosion of the quartz - porphyry body. The abundance of random basaltic fragments (up to 80% in the lower 2 metres) suggests that they may be the result of intrusion into the volcanic pile by the porphyry and the explosive nature of the felsic flows and tuffs being produced. It is unlike the basal conglomerate of the Ament Bay Formation which has a straight and sharp contact with the quartz-porphyry, is massive and contains coarse clasts. This requires that the porphyry in the Ament Bay area be eroded to a plane surface prior to the deposition of the basal conglomerate. Turner (1972) used a flood surge process to produce this deposit. No similar deposits are evident in the thesis area.

Subfacies 2

The origin of the felsic tuffs is questionable. Their massive nature, abundant euhedral feldspars, low quartz content, and restricted composition (essentially that of the quartz-porphyry), suggests that these are not reworked tuffs. According to Ross and Smith (1961) a principal characteristic of ash-flow tuffs is their common occurrence in thick units of typically non-sorted/non-bedded material containing lithic fragments. This is typical of the lithic tuffs on the east shore of Washeibamaga Lake and is here interpreted to be ash-flow material. The tuffaceous deposits on the north shore of the Katish Lake are well bedded and contain no lithic fragments and resemble more closely ash-fall material with interbeds of ash-flow material. The matrix of the felsic tuffs has been recrystallized so that original welded textures have been destroyed.

Subfacies 3

(a) The massive conglomerates and breccias, with sandy to tuffaceous interbeds (upper part of Facies B) are interpreted to be the result of a combination of processes. The lower part consists of chaotically bedded, rounded clasts that contain little original mud and thus are probably not debris flows. The fine grained matrix material can account for up to 20% of the rock and therefore may have been too impermeable to allow sieve deposits to form. As pointed out by Turner (1972), McGowan and Groat's proximal facies of their alluvial fan deposit in the Van Horn Sandstone of West Texas, is predominantly interbeds of sandstone between massive conglomerate units, similar to the upper part of Facies B. The most probable process for the deposition of the Van Horn Sands and the upper part of Facies B is sheetfloods. The disorganized state and lack of preferred orientation of the beds in the thesis area is similar to that described by Walker (1975) which is deposited in feeder channels and canyons near to the source. This is in keeping with McGowan and Groat's (1971) interpretation that their facies was deposited in canyons near the head of the fan where flow was confined. Thus similar restricted channels cut into the volcano's flank may have been the site(s) of deposition of the thick conglomeratic-sandstone interbeds. The lack of crossbedding and paucity of clasts in the arkosic interbeds suggests deposition from less powerful currents or surges, but still sheetflood in origin.

(b) Stratigraphically above this section is a distinct unit, described in detail in Chapter II, which is thought to be a lahar. Like lahars, the basal one to two metres consists of bedded to non-bedded tuffaceous material. Schmincke (1967) suggests two possible hypothesis for the origin of such basal portions:

1) a watery slurry that advanced and greased the way for the remainder of the lahar, or.

2) in inertia flows grains move above the bottom and shearing takes place between the grains, independent of the movement of the flow. Thus, the large grains should tend to drift towards the zone of least shear strain (free surface) while the smaller grains drift towards the zone of greatest shear strain.

The fact that the basal unit coarsens upward into the unsorted random section suggests that hypothesis two may be applicable here. The central zone of most lahars consists of a massive deposit of subangular to subrounded blocks which may or may not be graded. In the unit described the unsorted fragmental zone grades imperceptably into an inverse-graded zone. Large clasts within this zone protrude above the upper bed surface which is typical of debris flows. Draped over these protruding fragments is a thin sandy unit which is similar to Schmincke's (1967) upper bedded, reworked sand and tops off his tripartite subdivision. Cross-beds may be lacking due to erosion of this unit by subsequent depositional processes.

(c) The depositional process changed, as the next unit consists of three to five cycles of arkosic material overlain by normally graded conglomerates, which are impersistent laterally, and topped by large scale planar cross-stratification. This is very similar to stream flood deposits.

Thus Facies B consists of a variety of strata representing a particular set of hydraulic conditions that determined the thickness, particle size, distribution and orientation, and the type of contact with the underlying bed.

iii) Petrogenesis - Facies C

Subfacies 1

The initial 800 m of Facies C is massive and unsorted with a high (up to 35%) matrix component. On a large scale, based on D/10 analyses, the unit is normally graded. D/10 grades from 21 cm to 39 cm upwards in the section. Many of the clasts are tapered or elliptical and some intersect each other without any resulting fragmentation. This type of deposit is not characteristic of either water-laid or debris flows. They closely resemble Parsons (1969) volcanic agglomerate which is part of the cone structure and generally monolithologic in composition. This coarser material tends to accumulate around the vent, is not stratified, and has a high groundmass (matrix) percent, made up of individual angular crystals or lithic fragments.

Subfacies 2

The next subfacies is also massive and unsorted but contains less than 10% groundmass material as the clasts are tightly packed. The unit is normally graded on a large scale, with D/10 values of 24 cm to 78 cm. The clasts are subangular. The absence of fine material negates debris flows, streamflows and sheetfloods as the process (deposit) involved. The good sorting, massive nature and lack of defined contacts between beds suggests that this section probably represents a sieve deposit type mechanism, as it meets most of the criteria previously discussed.

Subfacies 3

The upper subfacies of Facies C is poorly exposed and therefore difficult to interpret.

Thus facies C consists of massive, normally graded deposits which maybe the result of both primary pyroclastic accumulation and sieve mechanisms.

It should be noted here that on the shorelines of Thundercloud Lake a unique type of rock association was found which is not evident anywhere else in the thesis area. The rocks, which may in-fact have been outcrop, were initially considered to be float, that is they could not be accurately identified as bedrock. As shown in Figure 61, the rocks are highly vesicular, subangular to subrounded and pumiceous in appearance. Grading, stratification and cross-

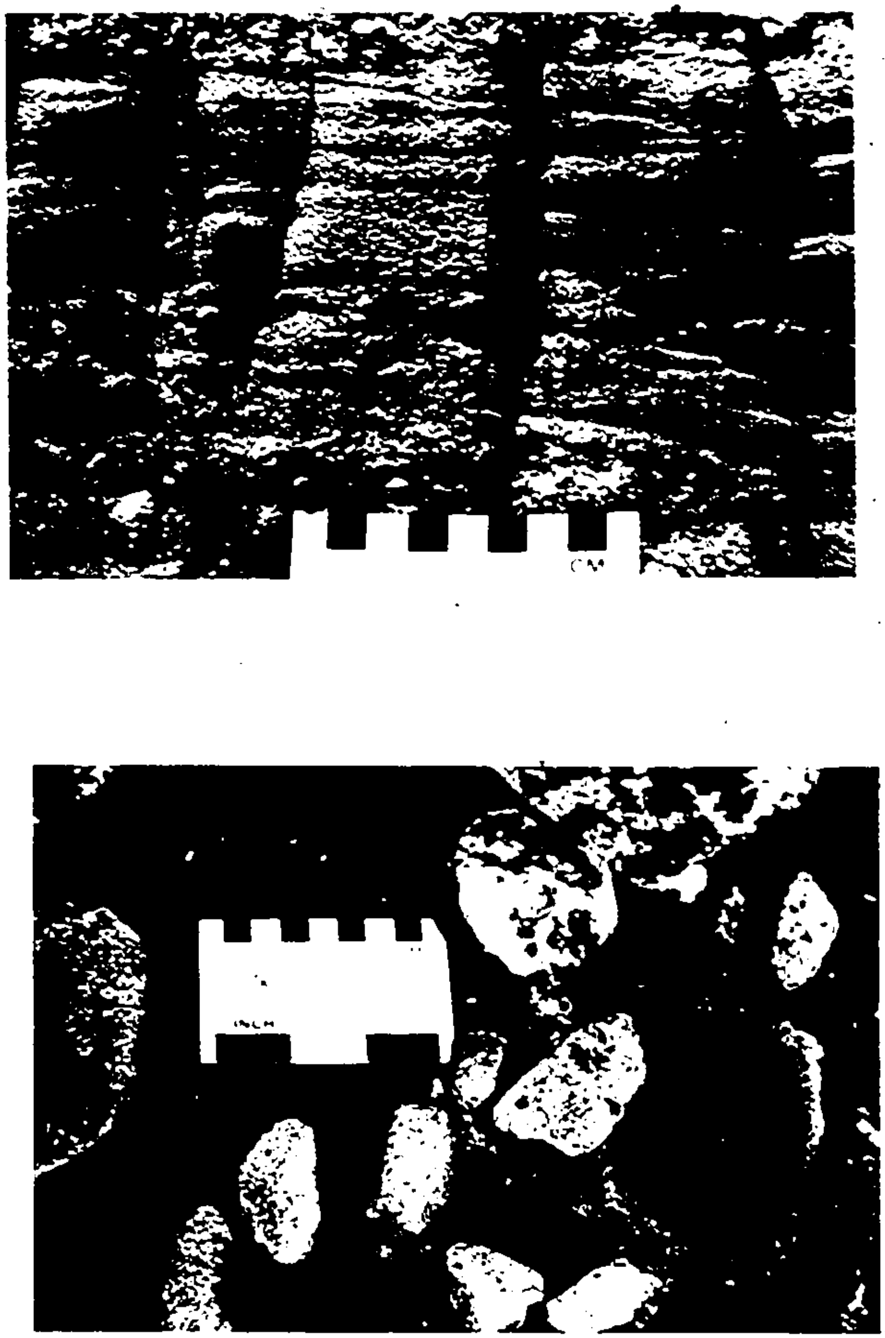


Figure 61 Photograph of outcrops on the shores of Thundercloud Lake, pumice fragments predominate.

stratification are common with some fragments welded together. This type of deposit is typical in the vicinity of volcanic vents, and may be airfall material or pyroclastic flow debris.

iv) Petrogenesis - Facies F

Facies F consists of two subfacies, a greywacke unit and an argillite-iron formation unit. The greywacke subfacies consists of sandsize clasts of quartz, feldspar and basalt. Three types of quartz were recognized; (1) polycrystalline grains, (2) monocrystalline grains with undulatory extinction, and (3) monocrystalline grains with sharp extinction. These and other textural phenomena of quartz led Reimer (1971) to suggest that quartz can be used as a provenance indicator. Ojakangas (1972) in his work on the greywacke of the Vermilion District of northern Minnesota established five criteria used for the identification of volcanic quartz; (1) embayments in the crystal outlines filled with felsitic groundmass, (2) almost complete absence of monomineralic inclusions, (3) exclusively sharp extinction, (4) idiomorphic outlines and (5) bulbous to fine resorption structures. In the thesis area the low percentage of quartz with non-undulatory extinction (volcanic quartz) in the greywackes and the similarity of the quartz in the arkoses to the porphyry suggests that much of the sandstone-greywacke was derived from the disintegration of porphyry bodies and that very little came from volcanic extrusive rocks. Many of the basaltic displayed intersertal textures quite similar to those of the gabbro sill on the north shore of Washeibamaga Lake. Poor exposure limits any detailed work on the greywacke. However, the presence of normal and reverse grading their massive nature, and the inter-bedded relationship with argillite (slate) beds indicates a turbidite sequence.

The argillaceous rocks overlying the greywacke sequence are associated with oxide facies iron formation. Similar relationships studied by Shegelski (1976), Franklin (1976), Dimroth (1975) and Hyde (1978) indicate a turbidite environment in all cases. The debris comprising the turbidite beds is texturally and chemically similar to the surrounding volcanic pile (middle felsic, upper mafic) and theses are considered to be the source for the turbidites.

The parentage of these sediments can be determined chemically (Nagvi, 1975). A chemical analysis of the argillaceous material shows it to have a composition unlike that of the average Precambrian slate (Table 10). It differs in having higher $SiO_2$, $MgO$, $Na_2O$, $CaO$ and a paucity of $K_2O$. The high $Na_2O$ and $CaO$ content of some pelitic rocks of the Carolina slate belt has been attributed to significant quantities of relatively unweathered pyroclastic material, probably rhyodacitic ash (Sundelius, 1970). Thus, the high $Na_2O$ and $CaO$ content in the thesis area is thought to be the result of large amounts of porphyry material from the underlying middle sequence being eroded and incorporated in the turbidite deposition.

Table 10

Composition of Argillite - Slate Rocks

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ | 62.36 | 56.3 | 61.25 |
| $TiO_2$ | .64 | .77 | .43 |
| $Al_2O_3$ | 15.82 | 17.24 | 12.63 |
| Fe+ | 8.01 | 8.92 | 15.90 |
| MnO | .13 | .10 | .15 |
| MgO | 3.70 | 2.54 | 2.33 |
| CaO | 4.31 | 1.0 | .58 |
| $Na_2O$ | 3.20 | 1.23 | 2.56 |
| $K_2O$ | 1.62 | 3.79 | 2.43 |
| $P_2O_5$ | .13 | | |

1 - Argillite of thesis area.
2 - PE slate average (Nanz, 1953)
3 - Savant Lake slate (Shegelski, 1976)

The association of turbidites with iron formation suggests that they were deposited in relatively deep water below wave base. The iron formation has also undergone the same soft sediment deformation as it's host rock. The stratigraphy of the turbidites suggests that continuous sedimentation occurred with fluctuating intensity from volcanic landmasses surrounding the basin. The presence of both felsic and basic debris suggests that it was deposited in an area which was removed from the influence of a slope which would supply material from only one direction.

The iron formation facies are not of the Algoman type. It is very similar to those of the Sturgeon-Savant Lake Area, which Shegelski (1976) identifies to turbidite associated deposits. As for most Archean banded iron formation, it is generally conceded that an exhalative source for the iron is favoured by its common association with volcanic sequences. The delicate laminations within the iron formation may have developed due to a pulsating influx of ferrugenous and non-ferrugenous silica gels. Such gels during consolidation would be subject to slumping, scouring and brecciation due to turbidite traction and soft sediment deformation.

v) Summary

The volcaniclastic rocks of Facies B and C were deposited on an alluvial fan. The massive nature of most of the breccia beds is attributed to violent ephemeral surges or sheet flood processes similar to those of the Ament Bay Formation described by Turner (1972). Facies B and C are considered to be proximal and deposited on the flanks of an erupting volcano in the vicinity of the porphyry at Thundercloud Lake. Facies F represents a more distal position away from the volcano in a deep basin where material was deposited by turbidity currents from both the felsic terrain to the south and the mafic platform to the north.

# CHAPTER V - GEOLOGIC HISTORY & SUGGESTED MODELS

## Part 1 - Introduction

A great variety of volcanic and sedimentary rock types characterize the stratigraphic succession developed in Archean greenstone belts. Although these volcano-sedimentary piles have almost invariably been subjected to complex geological histories, there nevertheless emerges from the seeming disorder a regular and systematic pattern of greenstone belt stratigraphic evolution (Anhaeusser, 1971a).

The knowledge of the lithostratigraphy and structural pattern of the area in conjunction with the geochemistry (of the greenstones) is considered sufficient for a local reconstruction of the sequence of events and subsequent interpretation in light of present day knowledge of global tectonics and magma generation.

The local geologic history will be outlined without tectonic implications followed by a short discussion of tectonic models proposed for the Archean. Finally, a tectonic model envisaged for this area will be presented.

Part 2 - Geologic History

The sequence of events that led to the present configuration of the Washeigamaga - Thundercloud Lakes area is depicted in Figure 62 and outlined below:

1) - the extrusion of a mafic platform

The oldest rocks in the area, in accordance with the oldest rocks found in other greenstone belts, are the volcanics of the lower sequence (Glikson, 1976b). Volcanism was extensive and prolonged, resulting in a platform that covered a large broad area (as the porphyritic units can be traced 16 km to the west). The common occurrence of pillow lavas within this belt suggests that basic subaqueous lava flows were providing much of the volcanic material. The cooling rates of individual flow units varied as both coarse and porphyritic varieties of basalt are common.

2) - explosive felsic volcanism

Following the extrusion of the subaqueous volcanics a period of emergence above sea level resulted in subaerial volcanics (andesites to tuffs) and subaerial sedimentation.

The rather drastic change from conditions of subaqueous volcanism to subaerial sedimentation could be explained if considerable uplift occurred between the deposition of the volcanics and sediments, which may have been related to emplacement of granodiorite bodies. It therefore becomes necessary to visualize the quartz-porphyry stock and volcano as a mountain of considerable relief projecting through the dominantly mafic lowland. The volcaniclastic rocks of Facies B and C were deposited on an alluvial fan. The simultaneous interaction of volcanic and alluvial processes has resulted in the clastic sequence having a high degree of internal complexity. All units are considered to be proximal and deposited on the flanks of an erupting volcano, as illustrated in Figure 63. As explosive activity waned the felsic material rapidly congealed, which was subsequently broken and engulfed or injected by the still plastic material moving beneath, producing the brecciated porphyry.

3) - continued uplift as a result of the Meggisi batholith intrusion
- subsidence below sea level
- eruption of mafic volcanics (upper sequence) unconformably on the felsic pile accompanied by marine turbidite sedimentation

At the cessation of volcanism, constant differential downwarp and uplift between basin and hinterland kept the coastal areas steep and allowed only temporary accumulation of unstable piles of sediment destined to slump and generate turbidity currents. Coarse grained gabbroic clasts and porphyry clasts within the greywackes suggest that the volcanics to the north were being deposited and erosion from both felsic and mafic piles was occurring. No exact time can be affixed to the beginning of mafic volcanism to the north, however a thin amygdaloidal basic unit found between Facies B and C, may imply that prior to the last stages of felsic volcanism, basic lavas were being produced. Within the basin ferrugenous silica gels were deposited as part of the turbidite sequence and produced the oxide iron formation. Extensive calc-alkaline volcanism of the upper sequence brought to an end the sedimentary alluvial fan conditions which existed during the accumulation of the middle sequence.

4) - unroofing of the batholith
- emplacement of the Taylor Lake Stock and other granites
- faulting, folding and metamorphism of the sediments and upper volcanics

Continued uplift of the Meggisi Batholith to the south resulted in its unroofing. Folding and faulting dominated the upper sequence, resulting in the fault contact of the turbidites and the upper sequence and the tight isoclinal folding of the upper sequence. The relationship between the upper sequence and the middle and lower sequence is by no means certain, but observations discussed earlier suggest that the upper sequence is younger than the lower sequence and syn- or post deposition of the middle sequence.

5) - erosion

Glacial denudation of the area accompanied by the deposition of glacial moraines and eskers produced the present topography.

## Part 3 - Greenstone Belt Evolution

Examination of numerous volcanic sections in Australia, South Africa and Canada (Anhaeusser, 1969; Glikson, 1975; Viljoen and Viljoen, 1971; Goodwin and West, 1975) has led to the observation that a generalized volcanic sequence is characteristic of Archean volcanism in all shields. In the Barberton Mountain Land of South Africa and the Kalgoorlie-Norseman area of Western Australia, three main groups exist (Anhaeusser, 1969; Glikson, 1976a,b,c). Table 11 lists the major

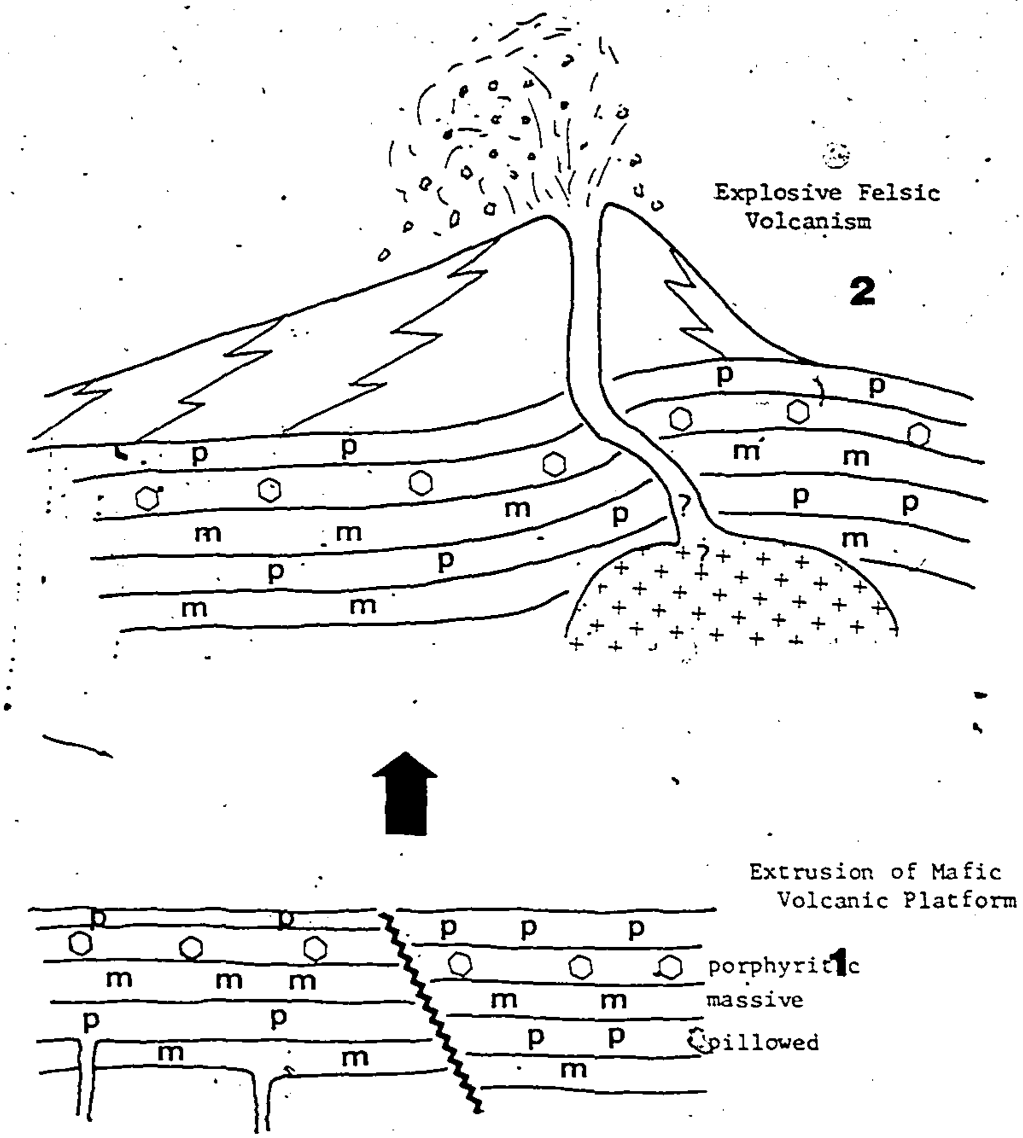



Figure 62 Geologic History of the Washeibamaga-Thundercloud Lakes Area.

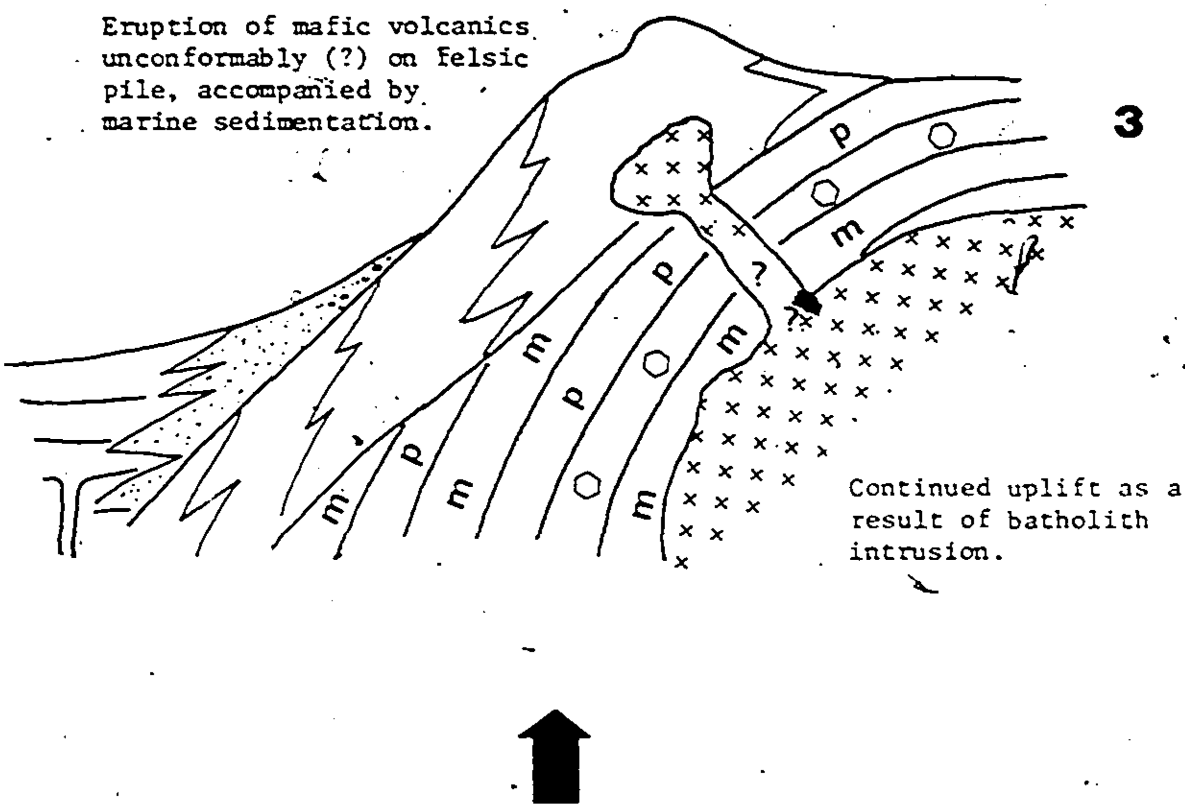



Figure 62 (cont.)

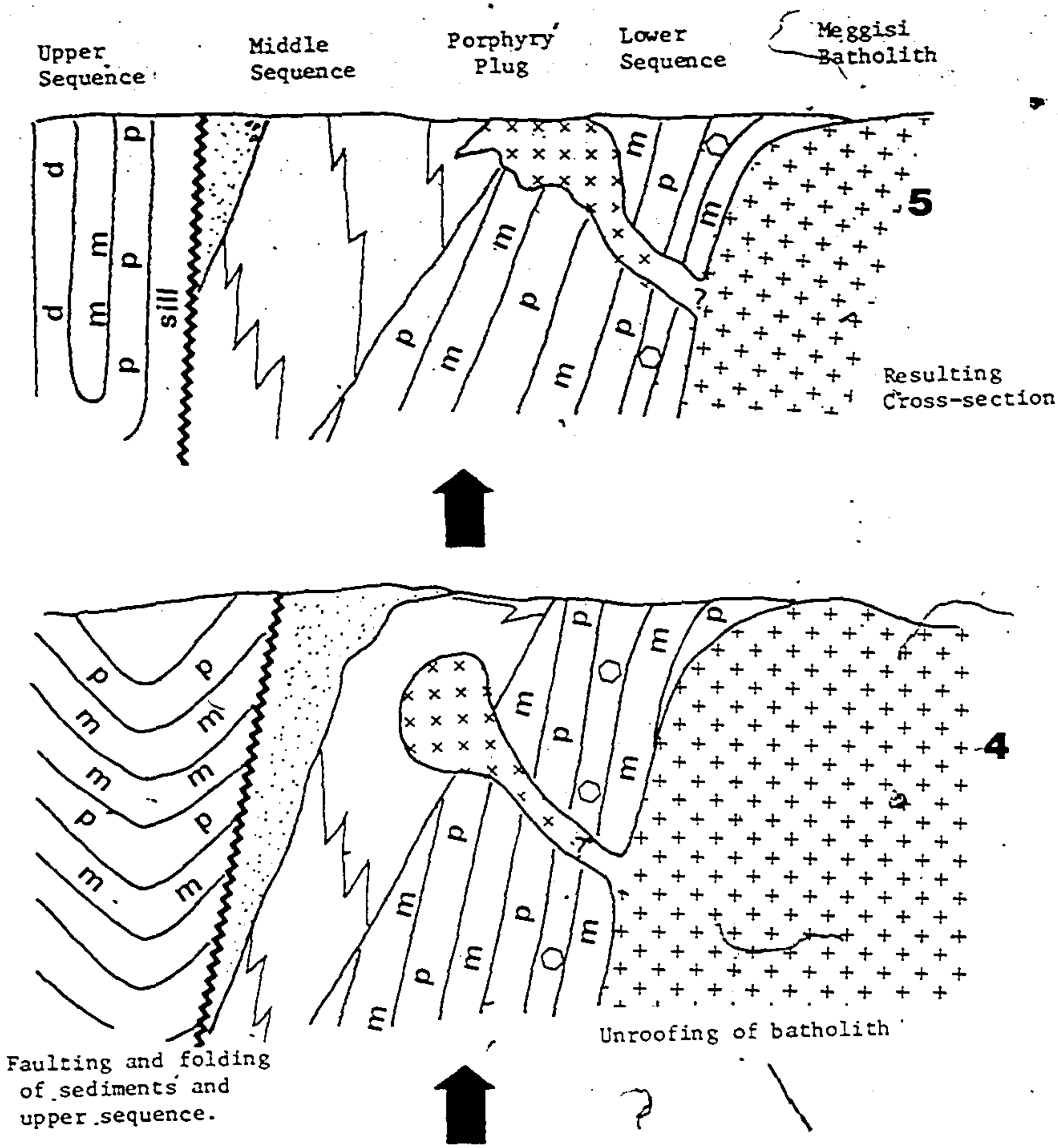



Figure 62 (cont.)

Figure 63 Schematic reconstruction of area during felsic volcanism.

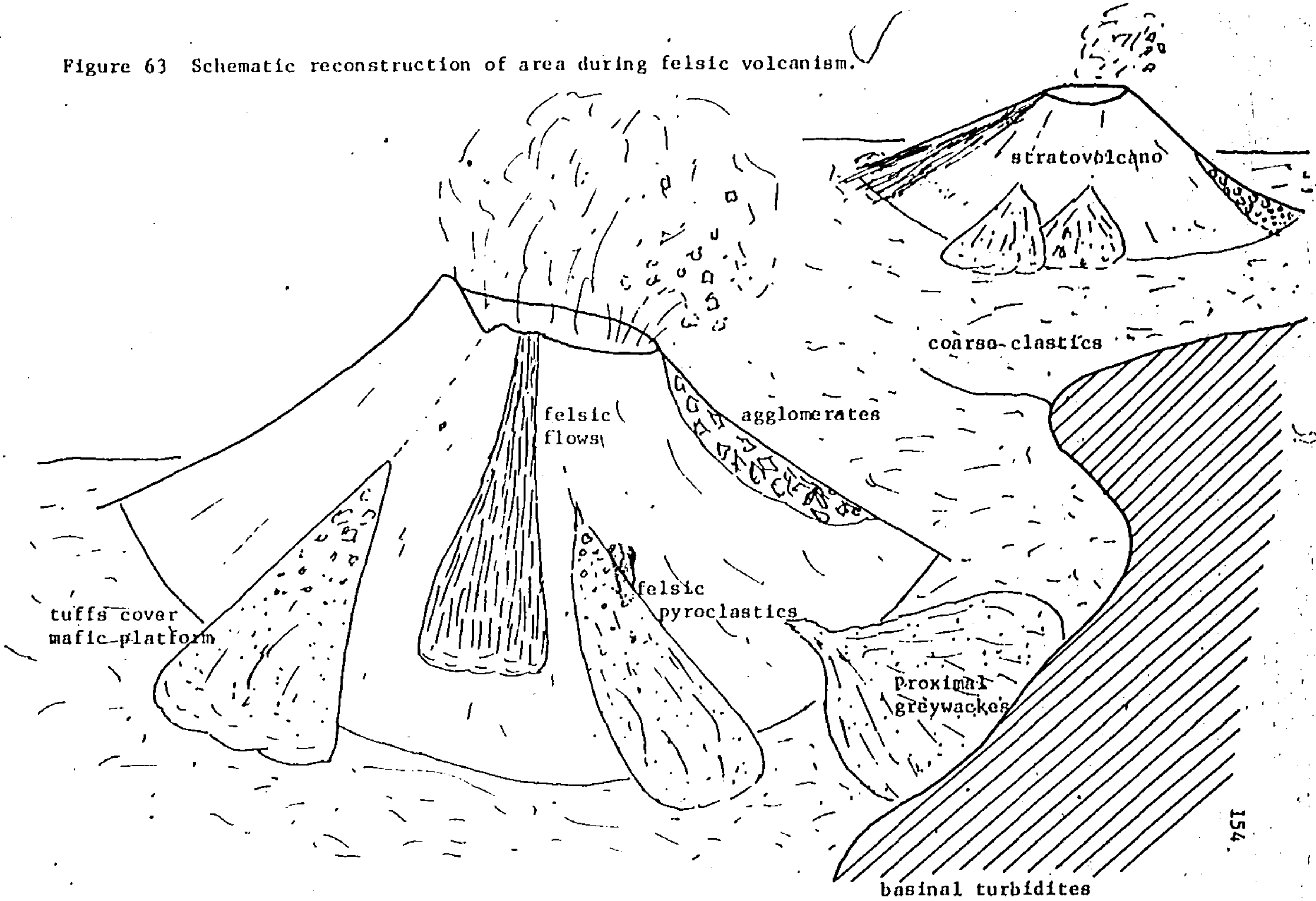


Table 11

Greenstone Belt Subdivisions (Anhaeusser, 1970)

| | |
|---|---|
| Sedimentary Group | - minor volcanism<br>- basin development<br>- increased granitic uplift<br>- some alkalic volcanism<br>- volcanogenic sediments deposited<br>- greywackes, conglomerates, agglomerates<br>- turbidity flows triggered by minor volcanic eruption deposit blackshales<br>- cessation of major volcanism |
| Greenstone Group | - basin subsidence cyclic volcanism<br>- extrusion of mafic-to-felsic lavas<br>- pyroclastic rocks and chert development<br>- extrusion of minor sills<br>- intrusion of Na- and K- rich porphyries |
| Ultramafic Group | - extrusion of ultramafic and mafic lavas and tuffs<br>- development of layered differentiated ultramafic igneous bodies<br>- cyclic magma-type trend from primitive ultramafic and mafic volcanics to tholeiitic volcanics<br>- low alkali, high Ca/Al ratio, high Mg komatiitic and peridotitic |

characteristics of each group. The Ultramafic Group corresponds to Glikson's (1976a) lower greenstone, and the Greenstone Group corresponds to his upper greenstone sequence. The geology is complicated by a number of cycles: super-major-minor-mini (Anhaeusser, 1971a).

A prominent feature of the Canadian Archean is the striped pattern of alternating volcanic-plutonic (greenstone) belts and metasedimentary-migmatite (gneiss) belts. In the western part of Superior Province, six major east-trending belts, including three volcanic belts (Abitibi-Wawa, Wabigoon, Uchi) and three gneiss belts (Quetico, English River, Berens) constitute the basis for the subdivision of the province into its component subprovinces. Within each volcanic belt, but specifically in the Wabigoon Belt, the stratigraphy has been subdivided into four main series (Wilson, 1973). The subdivisions are characterized by variations in:

a) the nature and composition of the flows

b) amount and nature of fragmental volcanics

c) nature and composition of subvolcanic intrusions

d) nature and composition of ore deposits

as outlined in Table 12. A similar cyclic pattern has been proposed by Goodwin (1968) to give a platform stage, edifice stage and erosional stage resulting in the observed mafic-felsic cycles (Goodwin, 1968).

Table 12

Greenstone Belt Subdivisions (Wilson, 1974)

| | |
|---|---|
| Upper Diverse (cyclic) | - appearance of first thick, rhyolite members<br>- fragmental flows interbedded with rhyolite and tuff<br>- variolitic pillows common<br>- volcanism alternates rapidly from one composition to another<br>- each cycle followed by sediments |
| Middle Felsic | - thick, monotonous group of felsic fragmentals<br>- unaltered, layered gabbro-pyroxenite-peridotite intrusion<br>- general characteristics of lahars for volcaniclastic rocks<br>- increase in Si; K; decrease in Ti, $Fe_+$ |
| Middle Basic | - pillowed and massive flows<br>- pillows are vesicular, with well developed rims and concentric structure<br>- large gabbro sills with only moderate flow differentiation<br>- rare fragmental rocks<br>- not too different chemically from lower basic |
| Lower Basic | - monotonous flows of massive and pillowed<br>- non vesicular lavas, no flow brecciation or brecciated flow tops<br>- thin non-extensive, high Ni, Cu, $Al_2O_3$, MgO, $Fe_+$<br>- considered to represent basalt erupted in the abyssal part of ocean after Wilson (1973) |

i) Archean Models

Two basic models have been suggested to account for the noted patterns and stratigraphy of greenstone belts; (a) The Rift Model and (b) The Plate Tectonic Model.

(a) The Rift Model

Anhaeusser et al. (1969) and McGlynn & Henderson (1970) suggested that early Pre-Cambrian greenstone belts evolved as discrete depositories on a relatively thin granitic crust, and were sited along fundamental crustal fractures, the grain of which can often be recognized in many shield areas and along which deep troughs appear to have developed at the initiation of the greenstone belts. Subsequently their shape was modified by various episodes of upwelling of granite and concomitant downwarping of the heavy pile of volcanics and sediments. These structural belts were surrounded by mobile gneiss belts. This model accounts for the rather rapid thinning of stratigraphy away from a thick pile or along a central axis, which clearly suggests deposition in elongate troughs or down-buckles in the earth's crust. The exact mode of formation of the greenstone depositories are open to speculation. Anhaeusser et al. (1969) suggests that the development of roughly evenly spaced, strongly oriented, parallel downwarps of fault-bounded troughs on an unstable thin primitive sialic crust is the most likely process. In these areas vast amounts of lava accrued to form the basal volcanic sequences of the greenstone belts. This model is further supported by numerous observations of tectonic sliding within belts. It is not uncommon to find two synformal structures occurring together without a complimentary antiform, which is probably a response to vertical movements in the crust. The predominance of penetrative schistosity and non-penetrative crenulation cleavage have also been cited as evidence for the rift system (Viljoen & Viljoen, 1971). Figure 64 is an attempt to illustrate diagramatically the evolution of a greenstone belt, using the rift model, as well as some of the conditions that may prevail in a section across the Eastern Goldfields (Anhaeusser, 1971b).

However the rift model raises some questions:

(i) the common occurrence of tonalitic plutons which invade the greenstone belts is more consistent with a continental subduction environment than a continental rift system (Tarney et al., 1973).

(ii) the occurrence of lavas with oceanic geochemistry in a tectonic environment which, in the Proterozoic and Phanerozoic produces alkaline volcanics (Tarney et al., 1973).

(iii) the long linear troughs would provide suitable locations for the accumulation of the broad mafic volcanic platform, however the middle felsic units develop over smaller areas and in more arcuate patterns.

(iv) the steep inclination of cleavage, cited as evidence of vertical rifting, and the overall steep structrure of greenstone belts is quite compatible with collision tectonics, observed in Phanerozoic orogenic belts where incomplete collision has occurred (Burke et al., 1975).

(v) the silica diapirs do not necessarily control the deformation in the Barberton greenstone belt as first thought by Anhaeusser (1969). In fact the majority of rocks in this belt are strongly and complexly deformed in a manner no different from parts of Phanerozoic orogenic belts (Ramsay, 1963).

(vi) this model implies a random pattern of Archean magmatism which is not what is observed in most greenstone belts (Burke et al., 1975).

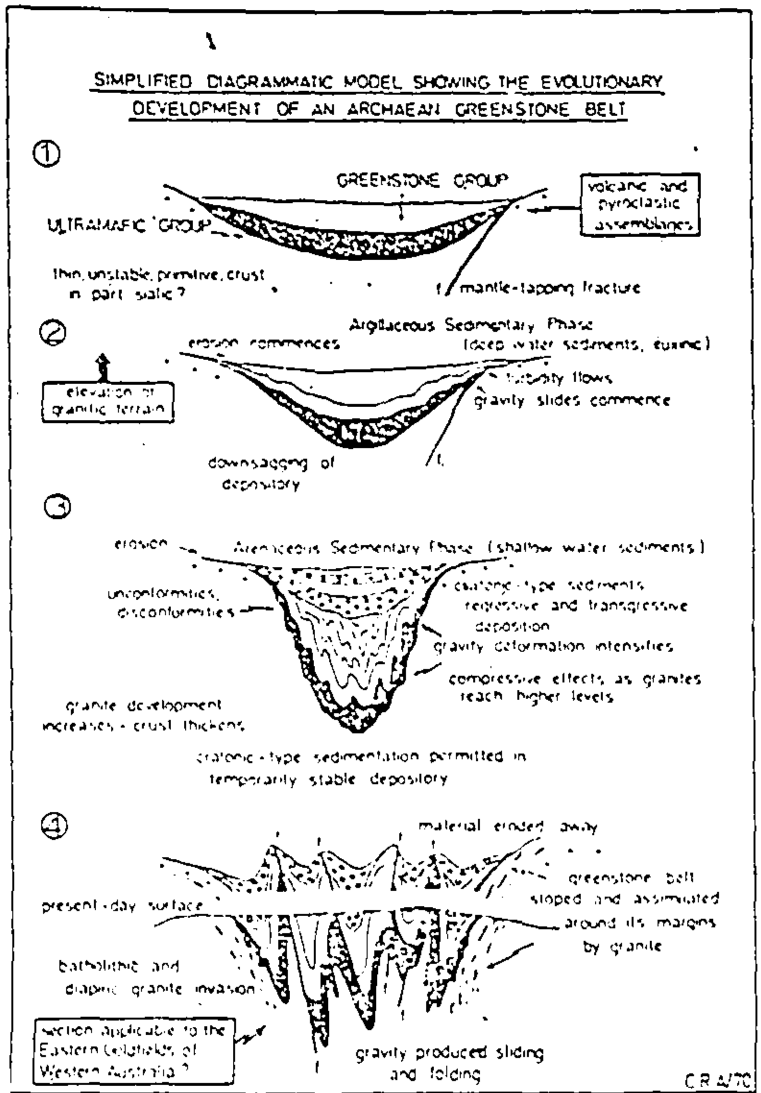



Fig. 3. Simplified diagrammatic model, showing the evolutionary development of an Archaean greenstone belt.

Figure 64 Simplified rift model of Anhaeusser (1969).

(vii) horizontal shortening during collision of arcs and microcontinents is more important then vertical fault tectonics (Burke et al., 1975).

(viii) as yet no explanation has been put forward to account for the noted compositional differences of the lower and upper mafic volcanics.

b) The Plate Tectonic Model

Plate tectonic models for the evolution of the Archean crust have been proposed by several authors, including: Engel (1968); Folinsbee et al., (1968); Jakes and Gill (1970); Burke and Dewey (1972); Talbot (1973); Rutland (1973); Tarney et al., (1975); Burke et al., (1975); Goodwin and West (1975); Glikson (1976a,b,c).

The main reason for suggesting that some kind of primitive plate activity was responsible for the generation of Archean igneous rocks is the increasing evidence that the vast majority of the rocks are little different in major and trace element chemistry to equivalent Mesozoic and Tertiary rocks which did form as a direct result of plate tectonics (White et al., 1971; Engel et al., 1974, Jahn et al., 1974; O'Nions and Pankhurst, 1978). According to this view, the primitive Archean crust consisted of an ultramafic-mafic volcanic assemblage, represented by the lower greenstone (or Ultramafic Group) made up of tholeiites analogous in most respects to modern ocean-floor tholeiites. The development of subduction within simatic regions, controlled by early linear trends (which may be a rifting phase) gives rise to sodic granites and to the tholeiites and calc-alkaline upper greenstones. According to Clifford (1968, 1970), Elsasser (1967) and Ramberg (1967), the spatial juxtapositon within greenstone belts of mantle-derived lower greenstones and the calc-alkaline volcanics of the upper sequence, in terms of the superposition of the different processes is due to small plate size.

Although showing tholeiite affinities, and plotting on some discriminant diagrams in the fields of ocean-floor basalts, it would seem difficult to regard the upper greenstones as true ocean-floor basalts generated at a spreading ridge. Furnes et al. (1977), Tarney et al. (1975) and Burke et al. (1975), point out that similar rocks to the upper sequence can be produced by active spreading and related volcanicity in the back-arc region. Therefore the basaltic material has come from depleted mantle similar to that feeding the oceanic spreading ridge. This would account for the noted association of most upper sequences with metagreywackes and volcaniclastic rocks. The back-arc (marginal basin of Burke et al., 1975) would also account for the observed high concentrations of Ti, Zr, Y and Nb. They could be visualized as the unfractionated partial melt of eclogite where accessory minerals such as rutile, sphene and zircon entered the melt rather than behaving as refractory phases.

Figure 65 is an example of the type of model suggested for the Canadian Archean, and is one of a series of possible schemes suggested by Goodwin and West (1975).

However the plate tectonic model does not satisfy all questions as to an appropriate Archean model.

(i) Island arc volcanic rocks have higher Al and lower Ni, Cr, Co, Fe/Fer + Mg contents than their suggested Archean counterparts (less depleted mantle in the Archean).

(ii) similarity of trace element abundances in volcanic rocks associated with Archean greenstone belts and modern island arcs is itself not sufficient proof of identical tectonic environments (O'Nions and Pankhurst, 1978), however the many similarities are striking and merit further evaluation.

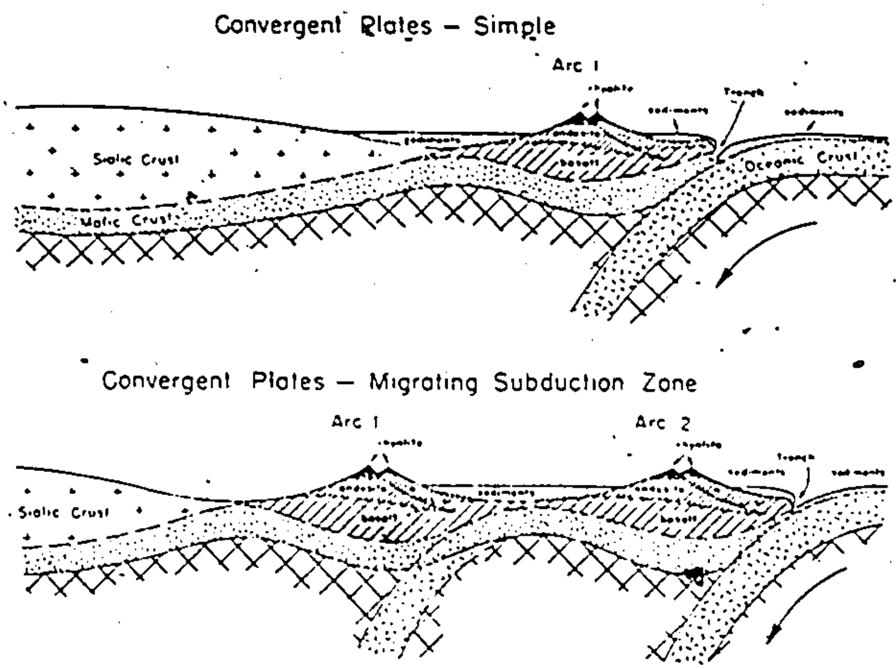



**Figure 4**

*Model IV. Convergent plates – simple. Craton-oceanic plate interface involving subduction of oceanic crust and development of volcanic arc, trench and accompanying sedimentary basins.*

*Convergent plates – complex. Successive migration of the subduction zone to the ocean side results in development of successive parallel volcanic and sedimentary belts.*

Figure 65 Convergent plate model of Goodwin and West (1975).

(iii) the predominant striped pattern of greenstone and plutonic belts is highly suggestive of some sort of vertical tectonic control.

(iv) the complete lack (in Canada at least) of oceanic crust and mantle similar to fully developed ophiolite complexes, although Langford and Morin (1976) point out that the present level of exposure may be too high stratigraphically to contain obducted crust.

(v) the noted absence of blueschists in PreCambrian rocks is unlike typical orogenic belts, however Ernst (1972) showed that this may be due to the limited metastability of blueschist minerals over geologic time.

(vi) subduction of crustal plates may not have been possible because of steep thermal gradients and high heat flow rates (Baer, 1977).

Further criteria are needed to elucidate the origin of the greenstone belts from the plate tectonic system or the rift system.

## Part 4 - Summary

### i) Speculation on a model

Direct comparison of the Washeibamaga - Thundercloud Lakes area with modern environments can be tentative at best. Because the broad regional rock relationships in the thesis area cannot be unequivocally determined due to discontinuous outcrop, and because detailed mineragraphic studies have not been conducted, the geochemical data presented and interpreted in Chapters III and IV, offers the best point for comparison. Thus any model proposed must be considered speculative.

Goodwin and West (1975) presented six models of Archean crustal evolution:

(i) layer-cake crust, faulted and/or folded
(ii) lateral accretion
(iii) simple crustal spreading
(iv) convergent plates, simple or complex
(v) full convection system with double arcs
(vi) inter-arc and back-arc basin

No model preference has been suggested to date. However all but the first model involves some form of island arc development, the last three specifically involve plate tectonics.

Subsequent work by Langford and Morin (1976), although of a reconnaissance nature, suggested that the major features of the Archean of northwest Ontario are similar to those of younger rocks in the Cordillera of western Canada. Thus the Wabigoon, Uchi and Wawa belts, like the Cordillera, originated in island arc environments.

In light of the suggested models, if we consider the data previously described in Chapter IV, the following points are important:

a) the basalts of the lower sequence conform to the principal criteria laid down by Engel et al. (1965) for the classification of oceanic-tholeiites, but are notably lower in Ti, Al and Zr and higher in Fe and Ba. It may be concluded that the lower sequence basalts represent the equivalents of the those being generated today at actively spreading ocean ridges.

b) the basalts of the upper sequence show affinities for island-arc tholeiites in terms of most of the major elements (excluding CaO and $TiO_2$) and large ionic lithophile elements (Rb, Sr, Ba). Concentrations for Y, Zr, and Ni are definitely higher in the upper sequence than in island-arc tholeiites and may be analogous to back-arc basalts in these terms. The different field character of the two sequences argues against similar sources and it is suggested here that the upper sequence basalts are the equivalents of those being generated today in back-arc basins.

c) the middle sequence felsic flows and tuffs show definite chemical affinities for island-arc felsic rocks in having similar concentration of Rb, Ba, Sr and K. The middle sequence rocks are slightly higher in Ti, Fe and Ni and lower in Al and Na. It is concluded here that the middle sequence is part of an island-arc calc-alkaline suite of rocks.

d) the Thundercloud Porphyry and brecciated porphyry represent the final stages of felsic volcanism and may represent the vent of an extinct volcano that was part of an island arc volcanic chain.

e) the volcaniclastic rocks of Facies B and C were deposited on an alluvial fan on the flanks of an erupting volcano in the vicinity of the porphyry, by violent ephemeral surges or sheet flood processes. Facies F represents more distal turbidite sediment accumulation in a subsiding basin away from the volcano.

Langford and Morin (1976), with similar data carry the comparison a step further. They suggest that the island-arc system in the Wabigoon Belt and thus in the thesis area, faced southward away from the craton, therefore the plate was being subducted towards the north. Thus the volcanics south of Wabigoon Lake (upper sequence equivalents) are back-arc basalts, the volcanics in the Kakagi, Manitou Lakes area (lower sequence equivalents) are generated in an ocean-ridge environment. Their model has interesting implications:

1. if the level of erosion were deep enough, obducted material would be expected in the vicinity of the north shore of Washeibamaga Lake. Burke et al. (1975) point to the fact that many Phanerozoic ophiolite complexes were originally identified as intrusive sills. Thus they suggest that some of the differentiated sills in the Archean may represent obducted ultra-mafic crustal material. Could the sill, the ultramafic-gabbroic rocks on the north shore of Washeibamaga Lake be part of an ophiolite complex? Preliminary geochemistry is being done by C. E. Blackburn of the Ontario Geological Survey.
2. The arcuate island-arc chain would indicate that other felsic volcanic centers should exist. In fact mapping by Blackburn and McMaster (1975) has pinpointed a number of vent areas. To date three have been tentatively identified as discussed by Blackburn (1977). The locations are:

1) south of Sunshine Lake (10 km west of Thundercloud Lake)

2) southwest of Cane Lake (9 km southwest of Sunshine Lake)

3) central part of Stormy Lake (14 km east of Thundercloud Lake)

ii) Further Research

Within the field area five avenues of research, present themselves:

1. Detailed mapping and chemical analyses of the gabbroic sill between Washeibamaga and Kenny Lakes: to discern its stratigraphic divisions and emplacement history, to compare it to other differentiated sills at Gabbro Lake (McMaster, 1975) and Kakagi Lake (Ridler, 1966), and to check the possibility of it being original obducted crust.
2. Elbers (1974) suggests that the porphyritic cupolas, stocks and dikes which occur as magmatic protrusions into the greenstone belts, are connected to the major batholiths in the area. In the thesis area this would mean connection of the Thundercloud Porphyry and the Meggisi Lake Batholith.
3. Blackburn (1977) has tentatively identified three other centers of calc-alkaline volcanism. Detailed chemical analyses of the porphyries should be carried out and

compared with the Thundercloud Porphyry, to derive a detailed history of volcanism and elucidate the tectonic patterns in the area.

4. Sedimentological studies of the volcaniclastic rocks surrounding these "vents" should be considered. Tael (1977) has studied the Sunshine Lake clastic rocks (Manitou sediments) and integration of all four areas is warranted.
5. A complete regional correlation of field data and thesis material studied by members of the 'ACE' Group of McMaster University, in the Manitou Lakes - Washeibamaga Lake area [i.e. work by Wallace (1975), McMaster (1975), Pichette (1976), Birk (1978), Tael (1978)] and the present study.

Regional studies and careful field mapping are still the basis of geology - combined with data from various disciplines they provide a powerful tool for deciphering the early history of the earth.

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APPENDIX A

GEOCHEMICAL DATA

Table A-1

Whole Rock Analyses
in
Weight Percent Oxides

| Lower Volcanics | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8002-2 | 49.55 | .91 | 14.89 | 2.41 | 10.45 | .20 | 7.13 | 12.40 | 1.81 | .19 | .07 |
| 8004-2 | 50.61 | .94 | 15.68 | 2.44 | 10.74 | .22 | 6.65 | 9.37 | 3.11 | .18 | .06 |
| B-33 | 50.39 | .95 | 19.10 | 2.45 | 9.20 | .21 | 5.61 | 6.84 | 4.00 | .23 | .10 |
| 8007-2 | 51.80 | 1.01 | 16.63 | 2.51 | 9.34 | .26 | 4.99 | 9.57 | 3.58 | .23 | .01 |
| 8008-2 | 49.84 | .77 | 11.39 | 2.27 | 8.54 | .20 | 11.60 | 12.55 | 1.65 | .71 | .47 |
| 8010-2 | 49.85 | 1.10 | 15.24 | 2.60 | 11.05 | .22 | 5.57 | 12.59 | 1.49 | .22 | .080 |
| 8011-2 | 49.06 | 1.08 | 15.29 | 2.60 | 11.57 | .21 | 6.13 | 11.38 | 2.34 | .27 | .08 |
| 8012-2 | 51.42 | .62 | 14.28 | 2.12 | 8.73 | .18 | 7.75 | 12.40 | 2.31 | .14 | .04 |
| 8013-2 | 50.58 | .75 | 14.16 | 2.25 | 10.61 | .20 | 7.13 | 11.57 | 2.35 | .34 | .05 |
| G-32 | 49.75 | .89 | 15.08 | 2.39 | 10.36 | .18 | 6.09 | 12.86 | 1.66 | .33 | .13 |
| 8014-2 | 49.76 | .62 | 10.04 | 2.12 | 11.56 | .20 | 13.50 | 10.91 | 1.12 | .11 | .06 |
| 8018-2 | 48.86 | .75 | 12.74 | 2.25 | 11.86 | .22 | 9.09 | 12.14 | 1.86 | .17 | .05 |
| 8019-2 | 51.41 | .89 | 11.80 | 2.39 | 11.26 | .19 | 8.15 | 12.39 | 1.35 | .09 | .08 |
| 8021-2 | 50.68 | .86 | 13.58 | 2.36 | 11.02 | .24 | 7.25 | 10.91 | 2.83 | .21 | .05 |
| 8023-2 | 50.92 | .69 | 11.67 | 2.19 | 11.00 | .21 | 10.28 | 10.23 | 2.64 | .12 | .05 |

| Lower Volcanics | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8025-2 | 48.82 | .86 | 14.83 | 2.36 | 10.35 | .19 | 8.55 | 11.89 | 1.95 | .13 | .04 |
| 8028-2 | 49.32 | .87 | 13.41 | 2.37 | 11.24 | .20 | 8.50 | 12.50 | 1.36 | .15 | .07 |
| 8030-2 | 48.66 | .99 | 15.00 | 2.49 | 14.07 | .24 | 6.40 | 11.02 | .94 | .11 | .08 |
| 8031-2 | 48.83 | .90 | 15.62 | 2.40 | 12.35 | .22 | 5.69 | 11.56 | 2.21 | .16 | .06 |
| B-22 | 58.47 | .87 | 14.95 | 2.37 | 7.14 | .16 | 2.88 | 9.38 | 2.89 | .23 | .09 |
| 8034-2 | 49.47 | .72 | 13.33 | 2.22 | 11.41 | .21 | 8.69 | 12.27 | 1.49 | .13 | .06 |
| 8035-2 | 49.20 | .68 | 14.40 | 2.18 | 10.12 | .22 | 6.67 | 14.48 | 1.86 | .16 | .04 |
| B-7 | 51.72 | .45 | 15.25 | 1.95 | 8.38 | .17 | 4.64 | 15.50 | 1.06 | .16 | .08 |
| B-10 | 46.59 | .68 | 14.76 | 2.18 | 10.75 | .19 | 8.90 | 11.60 | 1.84 | 1.26 | .08 |
| 8037-2 | 50.32 | 1.09 | 16.27 | 2.59 | 9.64 | .24 | 4.49 | 12.99 | 2.12 | .14 | .11 |
| 8039-2 | 51.09 | 1.01 | 15.50 | 2.57 | 10.68 | .20 | 7.20 | 9.40 | 2.19 | .15 | .07 |
| 8041-2 | 50.58 | .96 | 14.40 | 2.46 | 10.89 | .20 | 5.58 | 12.92 | 1.80 | .14 | .07 |
| 8044-2 | 49.90 | 1.03 | 14.46 | 2.53 | 12.20 | .22 | 7.41 | 9.96 | 2.16 | .08 | .07 |
| 8103-2 | 50.87 | .74 | 14.07 | 2.24 | 10.57 | .20 | 7.30 | 11.47 | 2.15 | .33 | .05 |
| 8106-2 | 48.42 | .99 | 16.24 | 2.49 | 11.19 | .21 | 6.21 | 11.90 | 2.06 | .23 | .06 |
| 8047-2 | 50.72 | 1.28 | 14.36 | 2.78 | 11.54 | .21 | 4.50 | 12.14 | 2.29 | .09 | .09 |
| 8110-2 | 61.24 | .55 | 15.57 | 2.05 | 5.24 | .12 | 4.61 | 5.68 | 2.97 | 1.88 | .10 |
| 8048-2 | 50.18 | 1.58 | 13.15 | 3.08 | 13.07 | .21 | 6.61 | 9.44 | 2.36 | .14 | .17 |
| 8050-2 | 41.64 | 1.61 | 18.23 | 3.11 | 16.11 | .25 | 6.33 | 8.52 | 3.96 | .13 | .11 |
| 8051-2 | 49.86 | 1.21 | 13.99 | 2.71 | 12.98 | .21 | 6.36 | 10.63 | 1.86 | .07 | .10 |
| 8054-2 | 63.63 | .43 | 16.35 | 1.93 | 3.81 | .16 | 3.11 | .47 | 2.99 | 2.62 | .10 |

| Lower Volcanics | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8055-2 | 66.55 | .50 | 17.70 | 2.00 | 3.02 | .10 | 3.18 | 1.38 | 3.20 | 2.28 | .10 |
| **Middle** | | | | | | | | | | | |
| 5310-1 | 67.35 | .56 | 17.03 | 2.06 | 2.49 | .05 | 1.53 | 1.65 | 3.44 | 3.65 | .20 |
| 5295-1 | 69.48 | .46 | 15.15 | 1.96 | 1.60 | .07 | 1.62 | 2.87 | 4.45 | 2.23 | .11 |
| **Osisko** | | | | | | | | | | | |
| 0-1 | 63.53 | .53 | 15.39 | 2.03 | 4.67 | .12 | 4.03 | 4.65 | 3.15 | 1.80 | .10 |
| 0-7 | 50.40 | 1.50 | 14.29 | 3.00 | 13.62 | .20 | 6.50 | 6.60 | 3.50 | .29 | .10 |
| 0-25 | 53.09 | 2.15 | 12.84 | 3.65 | 13.17 | .22 | 4.97 | 6.94 | 1.38 | 1.50 | .09 |
| 0-11 | 50.05 | 1.15 | 14.58 | 2.65 | 11.28 | .19 | 6.66 | 10.10 | 2.81 | .47 | .07 |
| 0-19 | 50.36 | 1.59 | 13.34 | 3.09 | 12.13 | .23 | 6.03 | 9.51 | 3.38 | .24 | .10 |
| 0-24 | 43.48 | 3.12 | 13.80 | 4.62 | 15.88 | .25 | 5.03 | 11.24 | 1.89 | .61 | .08 |
| **Upper Volcanics** | | | | | | | | | | | |
| 5222-1 | 53.96 | 1.61 | 16.60 | 3.11 | 7.60 | .21 | 3.16 | 10.46 | 2.90 | .31 | .09 |
| 6193-1 | 50.38 | .97 | 16.86 | 2.47 | 7.96 | .17 | 5.78 | 12.25 | 2.40 | .67 | .10 |

| Upper Volcanics | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5261-2 | 53.27 | 2.20 | 13.68 | 3.70 | 7.06 | .22 | 3.86 | 10.75 | 4.35 | .73 | .20 |
| 5256-2 | 55.85 | 1.62 | 15.13 | 3.12 | 8.75 | .20 | 2.70 | 7.90 | 4.11 | .49 | .11 |
| 8113 | 53.43 | 1.66 | 15.09 | 3.16 | 9.44 | .22 | 3.04 | 9.11 | 4.67 | .08 | .12 |
| 8115 | 49.12 | 1.19 | 14.38 | 2.69 | 9.69 | .18 | 8.92 | 11.06 | 1.60 | .08 | .11 |
| 8118 | 48.89 | .72 | 14.96 | 2.22 | 11.26 | .20 | 9.15 | 10.25 | 1.82 | .49 | .06 |
| 5268-1 | 54.10 | 1.49 | 12.22 | 2.99 | 14.82 | .24 | 3.68 | 8.25 | 1.75 | .36 | .10 |
| 5265-1 | 52.45 | .78 | 14.82 | 2.28 | 10.76 | .21 | 6.21 | 8.84 | 3.35 | .24 | .08 |
| 5302-1 | 50.85 | 1.39 | 14.27 | 2.89 | 12.44 | .21 | 5.34 | 9.50 | 2.54 | .43 | .14 |
| 5300-1 | 50.13 | 1.17 | 14.80 | 2.67 | 11.40 | .20 | 6.26 | 10.12 | 2.51 | .64 | .10 |

Misc.

G.F.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8053-2 | 70.60 | .38 | 16.01 | 1.88 | .71 | .04 | .7[illegible] | 4.71 | .53 | 4.23 | .14 |
| 8053-3 | 70.46 | .37 | 16.00 | 1.87 | 1.74 | .04 | 1.64 | 3.26 | .82 | 3.66 | .13 |
| 8065-2 | 68.27 | .52 | 16.24 | 2.02 | 2.20 | .06 | 2.06 | 1.31 | [illegible]4 | 2.36 | .13 |

T & S

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8060-2 | 73.32 | .39 | 13.48 | 2.89 | .63 | .07 | 1.90 | 3.22 | 2.22 | 1.79 | .08 |
| 8093 | 65.49 | .78 | 16.18 | 2.28 | 5.34 | .11 | 1.70 | 4.48 | 2.79 | .73 | .12 |

| T & S | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8137 | 60.78 | .51 | 14.57 | 2.01 | 4.11 | .12 | 5.69 | 7.04 | 2.69 | 2.32 | .17 |
| 8140 | 73.52 | .54 | 14.27 | 2.04 | 2.66 | .05 | 1.02 | 1.55 | 2.37 | 1.90 | .06 |
| 8064-2 | 61.49 | .55 | 14.73 | 2.05 | 6.67 | .18 | 4.61 | 5.09 | 3.21 | 1.31 | .10 |
| Arg. | | | | | | | | | | | |
| 8143 | 62.52 | .67 | 16.76 | 2.17 | 6.58 | .12 | 3.14 | 2.54 | 3.68 | 1.68 | .13 |
| 8145 | 61.53 | .71 | 17.17 | 2.21 | 6.68 | .12 | 3.37 | 2.40 | 3.61 | 2.06 | .14 |
| Amyg | | | | | | | | | | | |
| 8096-3 | 59.42 | 1.28 | 14.21 | 2.78 | 6.88 | .14 | 5.17 | .49 | 3.32 | .91 | .10 |
| Brecciated Porphyry | | | | | | | | | | | |
| 5230 | 73.99 | .19 | 15.32 | 1.37 | 0 | .02 | .52 | 1.06 | 4.30 | 2.43 | .06 |
| 5232 | 73.32 | .35 | 16.09 | 1.85 | 1.13 | .04 | 1.87 | 2.65 | 5.82 | 1.44 | .16 |
| 5233 | 74.21 | .15 | 15.38 | 1.30 | 0 | .03 | .62 | 1.83 | 3.26 | 2.60 | .06 |
| 5240 | 74.22 | .19 | 14.58 | 1.54 | 0 | .03 | .60 | 1.48 | 3.90 | 2.14 | .06 |
| 8131 | 70.10 | .40 | 15.63 | 1.90 | 1.10 | .04 | 1.54 | 2.35 | 5.30 | 1.52 | .13 |
| 8134 | 72.85 | .21 | 15.57 | 1.52 | 0 | .05 | .57 | 2.87 | 4.15 | 2.17 | .04 |

| Brecciated Porphyry | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8136 | 75.05 | .20 | 14.57 | 1.20 | 0 | .05 | .40 | 1.70 | 4.59 | 2.21 | .04 |
| 8142 | 65.41 | .34 | 13.90 | 1.84 | 1.71 | .14 | 3.42 | 6.48 | 4.52 | 2.09 | .14 |
| **Porphyry** | | | | | | | | | | | |
| P1 | 73.97 | .22 | 15.53 | 1.28 | 0 | .03 | .44 | 1.15 | 4.79 | 2.53 | .06 |
| P5 | 73.18 | .18 | 15.10 | 1.37 | 0 | .04 | .54 | 1.45 | 5.77 | 1.77 | .05 |
| P12 | 70.42 | .27 | 14.57 | 1.77 | .55 | .06 | 3.26 | 3.2 | 4.36 | 2.03 | .1 |
| P13 | 71.93 | .19 | 14.84 | 1.59 | 0 | .05 | 1.32 | 2.08 | 5.28 | 2.26 | .07 |
| P23 | 74.68 | .17 | 15.05 | 1.15 | 0 | .03 | .37 | 1.58 | 4.70 | 2.79 | .06 |
| P24 | 73.26 | .21 | 15.42 | 1.23 | 0 | .02 | .41 | 2.09 | 5.44 | 1.86 | .06 |
| P27 | 73.94 | .20 | 15.34 | 1.08 | 0 | .03 | .35 | 1.56 | 5.05 | 2.17 | .06 |
| P28 | 74.19 | .18 | 15.64 | 1.07 | 0 | .02 | .35 | .76 | 4.76 | 2.46 | .05 |
| P34 | 74.22 | .16 | 15.92 | 1.30 | 0 | .03 | .44 | 1.63 | 4.10 | 2.96 | .06 |
| P35 | 75.34 | .17 | 15.66 | .66 | 0 | .03 | .38 | .34 | 6.12 | 2.42 | .03 |
| PF | 74.38 | .19 | 13.61 | .95 | 0 | .04 | .40 | 1.42 | 5.85 | 2.10 | .05 |

Table A-2

Trace Element Analyses
in ppm

| Lower Volcanics | Sr | Rb | Ce | Ba | Y | Nb | Zr | Th | Pb | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| 8002-2 | 129.5 | 1.4 | 9.1 | 30.1 | 23 | 12 | 63 | 2.24 | 3.46 | 14.62 |
| 8004-2 | 101.9 | 1.6 | 12.7 | 30.1 | 25 | 1 | 58 | | | 15.66 |
| 8007-2 | 115.9 | .6 | 5 | 59.2 | 26 | 9 | 71 | | | 137.4 |
| 8008-2 | 142.3 | 22.2 | 103.7 | 224.4 | 17 | 13 | 168 | | | 267.4 |
| 8010-2 | 171.4 | 2.7 | 6.7 | 46.9 | 29 | 1 | 53 | | | 122.[illegible] |
| 8011-2 | 136.5 | 2.1 | 6 | 55.3 | 24 | [illegible] | 97 | | | 124.3 |
| 8012-2 | 76.2 | .1 | 7.7 | 30.1 | 17 | 2 | 51 | | | 99.2 |
| 8013-2 | 163.2 | 12.0 | 15.3 | 69.2 | 20 | 1 | 55 | 2.22 | 1.66 | 116.3 |
| 8014-2 | 93.8 | .7 | 1.6 | 37.8 | 19 | 2 | 41 | | | 446.7 |
| 8018-2 | 125.1 | 1.2 | 4.6 | 30.1 | 20 | 11 | 51 | | | 262.7 |
| 8019-2 | 145.1 | .5 | 9.4 | 32.2 | 25 | 10 | 65 | | | 130.6 |
| 8021-2 | 119.1 | .7 | 0 | 78.3 | 22 | 10 | 64 | | | 92.2 |
| 8023-2 | 77.3 | 0 | 1.7 | 40.4 | 22 | 12 | 65 | | | 249.5 |
| 8025-2 | 114.6 | .9 | 0 | 54.9 | 21 | 2 | 46 | | | 167.2 |
| 8028-2 | 120.1 | 1.0 | 7.4 | 46.3 | 18 | 2 | 55 | .69 | 1.92 | 161.3 |
| 8030-2 | 105.5 | .2 | 5.5 | 30.1 | 30 | 10 | 62 | 2.05 | 3.51 | 82.8 |
| 8031-2 | 129.8 | 0 | 3.5 | 34.6 | 24 | 12 | 78 | | | 42.3 |
| 8034-2 | 109.4 | .1 | 4.1 | 30.1 | 24 | 2 | 41 | | | 157.5 |

| Lower Volcanics | Sr | Rb | Ce | Ba | Y | Nb | Zr | Th | Pb | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| 8035-2 | 94.4 | .7 | 6.9 | 35.3 | 22 | 2 | 40 | | | 100.7 |
| 8037-2 | 109.1 | .4 | 10.3 | 49 | 29 | 1.0 | 61 | | | 116.2 |
| 8039-2 | 99.3 | .7 | 5.3 | 30.1 | 23 | 13 | 62 | | | 130.8 |
| 8041-2 | 141.6 | .4 | 0 | 34.5 | 20 | 10 | 81 | | | 103.9 |
| 8044-2 | 109.2 | 0 | 9.8 | 30.1 | 25 | 11 | 71 | | | 113.7 |
| 8106-2 | 188.7 | 3.2 | 1.6 | 51.1 | 20 | 2 | 68 | | | |
| 8047-2 | 130.7 | 0 | 10.7 | 30.1 | 35 | 10 | 75 | | | 69.6 |
| 8110-2 | 208.3 | 47.9 | 15 | 419.3 | 16 | 1 | 76 | | | 78.8 |
| 8048-2 | 163.1 | .7 | 8.2 | 63.8 | 41 | 11 | 119 | 0 | 2.72 | 85.8 |
| 8050-2 | 76.9 | .2 | 14.9 | 37.1 | 41 | 1 | 94 | | | 54.4 |
| 8051-2 | 109.2 | 0 | 0 | 30.1 | 27 | 2 | 62 | | | 106.1 |
| 8054-2 | 192.9 | 50.0 | 19 | 675.4 | 7 | 1 | 97 | | | 40.2 |
| 8055-2 | 206.2 | 46.8 | 17.7 | 494.8 | 12 | 1 | 121 | 1.70 | 2.57 | 42.3 |
| **Middle** | | | | | | | | | | |
| 5310-1 | 315.8 | 84.9 | 78.9 | 875.8 | 13 | 11 | 169 | | | 75.5 |
| 5295-1 | 562.9 | 68.1 | 26.7 | 693.9 | 7 | 13 | 132 | | | 29.1 |

| Osisko | Sr | Rb | Ce | Ba | Y | Nb | Zr | Th | Pb | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-1 | 304.2 | 79.5 | 19 | 362.6 | 9 | 1 | 102 | | | 76.6 |
| 0-7 | 199.4 | 5.6 | 7.4 | 62 | 36 | 11 | 84 | | | 77.8 |
| 0-25 | 427.9 | 58.9 | 15.3 | 334.9 | 31 | 5 | 96 | | | 27 |
| 0-11 | 232.2 | 15.6 | 7.5 | 49.8 | 28 | 10 | 97 | | | 83 |
| 0-19 | 279.9 | .9 | 14.5 | 41.3 | 32 | 1 | 72 | | | 52.8 |
| 0-24 | 205.8 | 31.5 | 12.9 | 63.4 | 31 | 8 | 108 | | | 41.2 |
| Upper Volcanics | | | | | | | | | | |
| 5222-1 | 198.8 | 6.0 | 7.5 | 124 | 32 | 1 | 100 | 2.35 | 2.57 | 138.7 |
| 6193-1 | 156.3 | 17.0 | 0 | 143.9 | 7 | 1 | 81 | | | 58.1 |
| 5261-2 | 150.5 | 9.8 | 24.7 | 178.4 | 43 | 8 | 103 | | | 18.6 |
| 5256-2 | 62.8 | 10 | 13.7 | 153 | 36 | 12 | 107 | 1.07 | 2.18 | 88.6 |
| 8113 | 44.1 | 0 | 12.6 | 30.1 | 33 | 12 | 100 | | | 92.3 |
| 8115 | 108.9 | 0 | 14 | 30.1 | 25 | 9 | 93 | | | 145.9 |
| 8118 | 124.9 | 9.9 | 2.6 | 112.4 | 12 | 2 | 72 | | | 188.6 |
| 5268-1 | 138.0 | 5.8 | 18.2 | 30.1 | 40 | 9 | 113 | | | 17.3 |
| 5265-1 | 121 | 1.9 | 17.8 | 67.4 | 32 | 1 | 94 | 1.50 | 3.15 | 664 |
| 5302-1 | 129.0 | 5.1 | 11.9 | 112.1 | 36 | 11 | 108 | 1.0 | 2.81 | 79.1 |
| 5300-1 | 261.3 | 13.8 | 8.5 | 213.6 | 25 | 10 | 75 | | | 65.0 |

| Misc. G.F. | Sr | Rb | Ce | Ba | Y | Nb | Zr | Th | Pb | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| 8053-2 | 110.3 | 94.3 | 42 | 526.8 | 10 | 11 | 142 | 5.05 | 7.77 | 13.1 |
| 8053-3 | 102.0 | 86.5 | 44.4 | 469.8 | 10 | 0 | 145 | | | 10.1 |
| 8065-2 | 242.9 | 53.7 | 30 | 449.4 | 14 | 11 | 151 | 3.86 | 2.66 | 28.6 |
| T & S | | | | | | | | | | |
| 8060-2 | 243.6 | 45.7 | 18.4 | 415.6 | 14 | 9 | 39 | 2.52 | 4.54 | 31.2 |
| 8093 | 356.7 | 16.3 | 22.4 | 127.8 | 20 | 1 | 136 | 3.15 | 10.09 | 63.4 |
| 8137 | 1146 | 71.6 | 50.1 | 714.4 | 9 | 9 | 113 | 3.19 | 15.92 | 210.6 |
| 8140 | 300.8 | 51.1 | 11.7 | 494 | 12 | 1 | 102 | | | |
| 8064-2 | 270.9 | 29.6 | 28.5 | 418.3 | 13 | 12 | 108 | .91 | 4.67 | 86.8 |
| Arg. | | | | | | | | | | |
| 8143 | 321.3 | 71.3 | 52.2 | 416.4 | 22 | 9 | 124 | 8.25 | 20.43 | 85.3 |
| 8145 | 271.6 | 89.5 | 51.6 | 309.5 | 21 | 13 | 134 | 9.06 | 17.40 | 79 |
| Amyg | | | | | | | | | | |
| 8096-3 | 262.4 | 58.9 | 10.5 | 695.2 | 20 | 11 | 108 | | | 136.8 |

| Brecciated Porphyry | Sr | Rb | Ce | Ba | Y | Nb | Zr | Th | Pb | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| 5230 | 412.1 | 60.9 | 16.1 | 707.5 | 5 | 1 | 99 | .03 | 11.82 | 14.8 |
| 5232 | 463.1 | 40.2 | 53.2 | 982.5 | 12 | 12 | 133 | 4.76 | 7.16 | 32.8 |
| 5233 | 510.7 | 66.6 | 8.5 | 686 | 5 | 1 | 79 | .09 | 12.37 | 9.7 |
| 5240 | 410.7 | 53.3 | 17.1 | 545.2 | 5 | 1 | 87 | .16 | 10.35 | 8.4 |
| 8131 | 462.3 | 42.8 | 48.9 | 1005.8 | 7 | 1 | 130 | 4.11 | 6.54 | 32.2 |
| 8134 | 604.2 | 56 | 8.7 | 694.8 | 2 | 2 | 91 | .84 | 14.00 | 9.8 |
| 8136 | 529.9 | 55.5 | 6.1 | 624.6 | 6 | 1 | 90 | .75 | 4.73 | 8.9 |
| 8142 | 559.6 | 49.7 | 49.9 | 752.7 | 9 | 10 | 108 | 4.74 | 8.07 | 7.04 |
| **Porphyry** | | | | | | | | | | |
| P1 | 448.8 | 76.5 | 3.8 | 698.7 | 1 | 1 | 83 | 0 | 10.10 | 8.9 |
| P5 | 542.5 | 63.7 | 16.8 | 697.1 | 5 | 1 | 91 | .81 | 6.12 | 8.3 |
| P12 | 417.1 | 86.5 | 28.6 | 597.3 | 3 | 1 | 100 | 3.04 | 8.82 | 7 |
| P13 | 485.8 | 74.6 | 22.3 | 483.7 | 4 | 1 | 84 | .44 | 14.68 | 28.4 |
| P23 | 574.4 | 85.1 | 7.4 | 785.3 | 1 | 11 | 97 | 1.57 | 9.56 | 7.9 |
| P24 | 205.8 | 31.5 | 16.1 | 747.6 | 1 | 2 | - | 2.27 | 15.18 | 7.3 |
| P27 | 442.5 | 59.5 | 9.1 | 671.7 | 5 | 1 | 95 | 0 | 5.40 | 9.3 |
| P28 | 317.1 | 72.5 | 10.8 | 654.6 | 4 | 0 | 93 | .34 | 3.77 | 7.0 |
| P34 | 425.2 | 77.9 | 10.2 | 950.3 | 1 | 1 | 91 | 1.54 | 11.16 | 8.8 |

| Porphyry | Sr | Rb | Ce | Ba | Y | Nb | Zr | Th | Pb | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| P35 | 461.6 | 80.3 | 2.1 | 632.8 | 4 | 1 | - | 2.09 | 5.36 | 6.3 |
| PF | 460.9 | 57.7 | 7.8 | 632.1 | 4 | 13 | 63 | 1.14 | 4.26 | 7.4 |

Table A-3

## Trace Elements

(external lab)[1]

| | P1 | P5 | P12 | P13 | P23 | P24 | P28 | P34 | P35 | PF | 8131 | 5230 | 5232 | 5233 | 5240 | 0-1 | 0-7 | 0-11 | 0-19 | 0-24 | 0-25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Co (ppm)* | 50 | 50 | 40 | 70 | 65 | 55 | 30 | 65 | 70 | 85 | 35 | 40 | 30 | 40 | 30 | 45 | 65 | 60 | 85 | 70 | 60 |
| Cr* | 10 | 5 | 125 | 55 | 5 | 5 | 10 | 20 | 5 | 5 | 50 | 15 | 45 | 10 | 10 | 180 | 115 | 115 | 140 | 5 | 40 |
| Cu* | 15 | 25 | 20 | 30 | 15 | 50 | 5 | 15 | 15 | 65 | 10 | 10 | 5 | 25 | 10 | 40 | 175 | 65 | 30 | 360 | 95 |
| Ga+ | 25 | 25 | 30 | 25 | 30 | 30 | 25 | 30 | 30 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 35 | 25 |
| Li* | 10 | 10 | 10 | 10 | 10 | 15 | 10 | 10 | 20 | 10 | 10 | 15 | 10 | 10 | 5 | 40 | 35 | 30 | 20 | 40 | 110 |
| Mo+ (<1) | | 1 | 1 | 1 | 2 | 45 | 1 | 1 | 25 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 1 | 1 | 2 | 1 |
| Pb* (<10) | 10 | 10 | 10 | 10 | 10 | 20 | 10 | 10 | 10 | 10 | 10 | 40 | 10 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Sc+ | 5 | 5 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 5 | 6 | 5 | 5 | 20 | 40 | 40 | 35 | 45 | 45 |
| V+ | 25 | 25 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 25 | 50 | 25 | 45 | 25 | 20 | 150 | 400 | 250 | 300 | 1300 | 700 |
| Zn* | 45 | 20 | 50 | 45 | 20 | 15 | 15 | 35 | 25 | 15 | 45 | 35 | 50 | 35 | 45 | 75 | 70 | 40 | 85 | 135 | 120 |

* atomic absorption analyses
\+ spectographic analyses
1 all work carried out by Mineral Research Branch Ministry of Natural Resources (1977)

APPENDIX B

STRUCTURAL (JOINT) DATA

# APPENDIX B --JOINT DATA

Table B-1

## Lower Sequence Joints*

| | | | | | |
|---|---|---|---|---|---|
| 20/80 | 264/90 | 194/89 | 350/80 | 180/60 | 70/90 |
| 286/57 | 52/60 | 270/86 | 24/82 | 340/50 | 105/70 |
| 340/90 | 6/90 | 26/70 | 8/80 | 60/80 | 15/90 |
| 350/66 | 240/90 | 79/52 | 130/72 | 344/80 | 165/80 |
| 32/62 | 50/90 | 0/58 | 96/62 | 47/80 | 177/80 |
| 48/54 | 310/48 | 270/54 | 50/80 | 12/90 | 50/80 |
| 242/28 | 324/84 | 60/80 | 100/90 | 337/90 | 106/90 |
| 356/90 | 20/70 | 210/84 | 350/80 | 270/60 | 337/90 |
| 290/32 | 299/25 | 164/82 | 166/80 | 0/80 | 150/80 |
| 328/90 | 18/72 | 140/86 | 50/80 | 325/80 | 160/60 |
| 34/84 | 44/74 | 330/66 | 166/80 | 20/80 | 67/90 |
| 14/82 | 148/74 | 308/90 | 90/80 | 304/28 | 32/90 |
| 150/84 | 46/70 | 300/70 | 20/90 | 20/70 | 167/80 |
| 42/84 | 156/80 | 54/76 | 76/80 | 135/55 | |
| 42/40 | 68/54 | 350/90 | 58/74 | 52/90 | |
| 24/82 | 150/84 | 300/80 | 340/90 | 135/70 | |
| 140/80 | ~~58/90~~ | 30/66 | 10/90 | 101/60 | |
| 80/70 | 136/54 | 320/90 | 270/60 | 280/60 | |
| 274/80 | 30/84 | 210/40 | 0/80 | 348/80 | |
| 130/84 | 50/86 | 30/90 | 80/80 | 34/80 | |
| 194/82 | 16/90 | 128/80 | 120/90 | 55/74 | |
| 248/74 | 50/72 | 224/90 | 160/90 | 62/65 | |
| 260/48 | 140/90 | 166/64 | 150/70 | 292/90 | |
| 4/90 | 209/67 | 276/60 | 30/50 | 342/90 | |

* all readings made using standard right-band orientation

Table B-2.

## Porphyry Joints

| | | | |
|---|---|---|---|
| 244/68 | 344/76 | 270/70 | 336/64 |
| 284/66 | 76/86 | 302/76 | 310/90 |
| 30/50 | 136/66 | 170/82 | 50/72 |
| 130/90 | 206/32 | 110/90 | 24/80 |
| 71/34 | 244/90 | 74/54 | 110/90 |
| 286/60 | 154/70 | 160/90 | 14/72 |
| 290/64 | 260/54 | 190/90 | 44/50 |
| 300/90 | 240/72 | 246/70 | 300/40 |
| 344/50 | 172/74 | 150/48 | 170/80 |
| 320/90 | 130/68 | 208/90 | 100/70 |
| 266/72 | 140/58 | 330/60 | |
| 50/78 | 86/90 | 206/90 | |
| 344/82 | 306/56 | 158/74 | |
| 32/66 | 260/58 | 310/60 | |
| 300/84 | 194/90 | 230/90 | |
| 82/70 | 134/52 | 204/90 | |
| 12/76 | 210/90 | 236/54 | |
| 290/46 | 254/86 | 110/80 | |
| 28/70 | 306/78 | 18/58 | |
| 10/82 | 150/66 | 232/80 | |
| 310/76 | 258/84 | 310/90 | |
| 260/28 | 40/80 | 220/88 | |
| 80/74 | 304/90 | 0/90 | |
| 40/84 | 246/74 | 320/90 | |
| 230/80 | 166/64 | 240/90 | |

Table B-3

Upper Sequence Joints

| | | | |
|---|---|---|---|
| 350/75 | 10/74 | 60/90 | 200/60 |
| 345/90 | 10/59 | 10/74 | 15/80 |
| 340/76 | 15/50 | 75/85 | 60/90 |
| 285/90 | 330/90 | 340/75 | 10/90 |
| 350/90 | 10/75 | 50/90 | 10/80 |
| 15/90 | 15/78 | 50/68 | 210/15 |
| 315/90 | 30/90 | 320/72 | 270/58 |
| 345/82 | 350/90 | 0/77 | 260/30 |
| 95/51 | 30/90 | 300/90 | 90/67 |
| 10/59 | 5/60 | 40/54 | 280/90 |
| 105/85 | 350/48 | 235/60 | 280/86 |
| 28/85 | 10/50 | 300/70 | 350/90 |
| 20/80 | 315/80 | 20/75 | 20/85 |
| 350/90 | 15/70 | 70/20 | 330/85 |
| 305/90 | 110/80 | 10/72 | 45/70 |
| 20/80 | 10/50 | 0/10 | 350/90 |
| 315/48 | 55/90 | 345/90 | 340/90 |
| 305/90 | 315/90 | 15/90 | 100/78 |
| 150/48 | 20/52 | 340/70 | 330/90 |
| 15/48 | 105/90 | 10/80 | 0/90 |
| 105/70 | 25/52 | 40/20 | 90/90 |
| 20/80 | 95/76 | 350/67 | 340/80 |
| 285/60 | 285/90 | 340/80 | 20/90 |
| 0/90 | 20/85 | 90/70 | 340/90 |
| 10/76 | 40/90 | 100/90 | |

# APPENDIX C

## MIDDLE SEQUENCE

## CLAST MEASUREMENT DATA

# APPENDIX C - MIDDLE SEQUENCE CLAST SIZE DATA

Table C-1

## Facies B Data

| Station No. | Values - Length/Width in cm | $D_{10}$ | $D_{10}$ (L/W) |
|---|---|---|---|
| 8060 | 14.5/10.5, 4.5/2.2, 7.0/4.2, 7.5/3.2, 6.6/4.2, 10/1.5, 5.0/1.5, 4.0/2, 4.5/1.5, 4.5/2.2, 8.0/2.7, 4/1.7, 3/2, 2.5/1.2, 4/1.2 | 7.2 | 7.2/3.5=2.0 |
| 8062 | 8/3, 3/1, 3.2/1.2, 8/4, 3.5/2.5, 3.5/2.5, 5/3.5, 7/4.5, 4/2.5, 9/6, 15/8, 13/5, 10/7, 7.5/4.5, 5.5/2.7 | 8.8 | 8.8/4.8=1.8 |
| 8063 | 3.5/1, 3/1.2, 2/1, 3/.5, 4/1.5, 5/2.5, 3/1.2, 3/.5, 1.2/1.2, 1.4/.7, 5/.7, 3/1, 6/1.2, 1.3/.3, 1.2/.3 | 3.8 | 1.8/1.1=3.4 |
| 8068 | 14/9.5, 12.5/11, 18/17, 21/18, 18/12.5, 23/15, 30/20, 30/9, 22/11, 28/14.5, 33/20, 22/8, 29/15, 19/16, 22.5/12 | 26 | 26/15.2=1.7 |
| 8069-1 | 40/36, 30/25, 34/22, 41/24, 35/20, 60/50, 40/20, 30/18, 22/14, 29/23, 25/21, 20/14, 42/18, 36/9, 29/14 | 38.8 | 38.8/24.2=1.6 |
| 8069-2 | 12/8, 14/4, 12/7, 17/2, 22/5, 9/9, 9.5/5, 9/5, 20/12, 13/4, 17/9, 12.5/6, 17/10, 10/6, 11/15 | 15.6 | 15.6/6.7=2.3 |
| 8070 | 19/9, 14/9, 23/15, 16/13, 17/16, 14/10, 15/10, 12/8, 13/10, 11/5.5, 13/8, 18/11, 22/15, 14/12, 22/17 | 18 | 18/13.8=1.3 |
| 8072 | 17/8, 26/12.5, 21/14, 21/16, 21/14, 16/14, 13/11, 10/10, 9/6, 17/11, 14/9, 10/10, 20/4, 9/5.5, 8/6.5 | 18.6 | 18.6/11.3=1.6 |
| 8073 | 22/17, 18/16, 37/28, 30/17, 28/22, 18/14, 18/18, 30/24, 30/22, 23/15, 16/7, 34/22, 44/33, 49/30, 44/21 | 34.9 | 34.9/23.4=1.5 |

Table C-2

## Facies C Data

| Station No. | Values - Length/Width in cm | D₁₀ | D₁₀ (L/W) |
|---|---|---|---|
| 8074 | 25/9, 13/6, 10/4, 22/14, 36/29, 17/10, 15/7, 18/6, 19/8, 16/10, 20/13, 16/8, 16/4, 17/8, 11/3 | 20.6 | 20.6/11.5=1.8 |
| 8075 | 26/15, 30/6, 16.5/8, 30/8, 38/26, 26/9, 23/11, 28/14, 23/13, 37/29, 33/24, 27/15, 29/16, 19.5/10, 19/7 | 30.4 | 30.4/16.2=1.9 |
| 8076 | 49/32, 41/23, 34/14, 23/13, 42/25, 23/15, 21/18, 29/20, 33/19.5, 30/17, 26/12, 30/11, 18/10, 24/15, 18/9 | 33.8 | 33.8/18.8=1.8 |
| 8077 | 30/14, 48/20, 23/14, 65/40, 24/22, 31/20, 30/14, 27/14, 28/18, 20/16, 50/24, 38/26, 38/13, 26/10, 32/20 | 39 | 39/20.9=1.9 |
| 8079 | 15/10, 21/15, 33/8, 19/10, 21/16, 17/17, 30/12, 19/14, 15/10, 25/12, 20/9, 14/11, 25/11, 28/12, 15/17.5 | 24.1 | 24.1/11.9=2.0 |
| 8080 | 19/8, 23/10, 17/8, 12/6, 14/7, 20/10, 33/10, 23/9, 14/4, 23/8.5, 20/8, 28/12, 23/10, 24/9, 64/16, 59/20 | 3[illegible] | 32/11.4=2.8 |
| 8121 | 42/18, 28/17, 29/13, 26/17, 20/[illegible]2, 27/15, 53/22, 38/18, 48/30, 37/21, 59/20, 48/20, 35/15, 39/23, 27/11 | 42.8 | 42.8/20=2.1 |
| 8081 | 62/13, 60/15, 88/13, 120/30, 64/15, 50/14, 100/15, 54/13, 65/8, 40/15, 63/15, 97/8, 45/10, 40/9, 62/14 | 78.1 | 78.1/14.6=5.3 |
| 8122 | 49/28, 26/19, 19/14, 14/10, 17/7, 15/7, 12/9, 16/11, 19/8, 56/33, 11/4.5, 11/5.5, 10/8, 10/5, 17/10 | 24.8 | 24.8/14.7=1.7 |
| 8123 | 20/8, 16/9, 13/9, 14/7, 20/9, 16/8, 14/6, 18/8, 23/12, 12/5, 14/6, 21/13, 12/7, 16/7, 21/9 | 18.5 | 18.5/9=2.0 |

| Station No. | Values - Length/Width in cm | $D_{10}$ | $D_{10}$ (L/W) |
| --- | --- | --- | --- |
| 8120 | 30/8, 31/8, 32/11, 32/12, 24/10, 39/19, 27/10, 49/15, 31/8, 33/7, 36/5, 40/9, 31/6, 31/6, 21/6 | 35.4 | 35.4/10=3.5 |

APPENDIX D

ANALYTICAL PROCEDURES AND ERRORS

# Appendix D - Analytical Procedures and Errors

## i) Analytical Procedures

A total of 80 samples have been analysed by X-ray fluorescence for major and trace elements. These were crushed to -200 mesh using a Spex Industries shatter box with tungsten carbide rings. Care was taken to remove all weathered surfaces before crushing. Major elements were determined using a fused 2:1 mixture of lithium tebraborate and rock powder. Carbon crucibles containing the powder mixture were heated at 1150°C for 30 minutes. Loss on ignition or volatile loss was calculated and accounted for less than 3 wt%. Trace elements were determined using pure rock powder. Pressed discs of each sample were made following the procedure outlined by Marchand (1973).

The chemical analyses were carried out using a Philips, Model 1450 AHP automatic sequential spectrometer housed in the Geology Department at McMaster University. Raw data were corrected for absorption and enhancement effect (Marchand, 1973) and the final values determined against USGS standards.

The major elements analysed were: Si, Al, total Fe, Mg, Ca, Na, K, Ti, Mn, and P. A Cr X-ray tube was used throughout. One sample remained in the spectrometer at all times serving as a drift monitor. Machine settings are given in Table D-1.

The trace elements analysed were: Sr, Rb, Ba, Ce, Th and Pb on a Mo X-ray tube and Y, Nb, Zr, and Ni on a Cr X-ray tube. Machine settings are given in Tables D-1 and D-2.

All raw data were first converted from tape to cards using the Tape-Card Conversion Program of Mudroch (1977). Individual computer programs, developed and proven valid by graduate students, for certain elemental groups were then used to produce the final values. All programs can be found in the computer geology library at McMaster University.

ii) Analytical Errors

There are three sources of error in analytical techniques: statistical error or precision, systematic error or accuracy and sensitivity (Shaw, 1969). These errors were examined in the X-ray Fluorescence analyses of major and trace elements and the results are presented here.

Precision: Variance, standard deviation and coefficient of variation were used to check the precision of the analyses.

Table D-3 shows the results for two whole rock samples run in triplicate. Most oxides fall within the 0.5 to 5.0% acceptable limit for the coefficient of variation suggested by Shaw (1969). The exceptions are $Na_2O$, $K_2O$, and $P_2O_5$. The oxides with high concentrations and count rates show precision within 1 to 4%. Elements with low concentrations and count rates are less precise.

The value for $K_2O$ is satisfactpry in more felsic rocks (e.g., sample P-23 of the porphyry, compared to the basalt B-7).

Accuracy: To judge the accuracy of an analysis, it is compared to a reference or standard sample whose composition is known from preparation. Comparision with W-1 and BCR-1, using the standard values from Abbey (1975) is shown in Tables D-5 and D-6. The bias in all cases was low and within the acceptable range. In calculating the % bias, elements with low concentrations resulted in higher values.

Sensitivity: The lower limit to an analytical method is determined by the point where a weak signal cannot be readily distinguished from background or noise (Shaw, 1969). Following the worked examples of Jenkins and DeVries (1972), the lower limit of detection (LLD) was calulated using the formula:

$$LLD = \frac{2\,\frac{T_P}{T_b}}{m} \quad \frac{R_b}{T_t}$$

where $T_p$ = peak time
$T_b$ = background time
$T_t$ = total analysis time.

$$m = \frac{R_p - R_b}{\%\ \text{value}}$$

$R_p$ = c.p.s. peak
$R_b$ = cps background

Table D-7 lists the lower limit of detection for ten trace elements and the comparison standard.

iii) Summary

The results of XRF analyses are listed in Appendix A. Nb and Th have bias levels in excess of 10% and any interpretation involving these must be guarded.

Appendix A also lists values for; Ag, Au, Be, Co, Cr, Cu, Ga, Li, Pb, Mo, Sc, V and Zn for the porphyry samples and a few of the lower basalts. These analyses have been produced by the Ministry of Natural Resources. No attempt has been made to analyse the values or errors in detail.

C.I.P.W. norms were calculated using a computer program by Mathison (1973). The total Fe content was separated into $Fe_2O_3$ and FeO components based on Irvine and Baragar's (1971) correction:

$$\% Fe_2O_3 = \% TiO_2 + 1.5$$

The results are tabulated in Appendix E.

Table D-1

XRF Settings

| | | | | | | |
|---|---|---|---|---|---|---|
| Program | 2 Whole Rock | 1 Rb-Sr | 4 Ba-Ce | 5 Y-Nb-Zr | 8 U-Th | 6 Ni |
| Tube | Cr | Mo | Mo | Cr | Mo | Cr |
| Crystal | TLAP | LIF 200 | LIF 200 | LIF 200 | LIF 200 | LIF 200 |
| KV-MA | 50- 50 | 90- 30 | 50- 50 | 50- 50 | 85- 25 | 50- 50 |
| Counter | Flow | Scint. | Flow | Flow & Scint. | Scint. | Flow & Scint. |
| Collimator | | Fine | Coarse | Fine | Fine | Fine |
| Vacuum | Yes | No | Yes | Yes | No | Yes |
| Window LL-UL | 250-750 | 250-750 | 350-750 | 250-750 | 250-750 | 250-750 |
| High Voltage | 380-564 | 380-564 | 380-564 | 382-564 | 382-564 | 382-564 |
| No. Samples | 1 Drift, 3 | 4 | 4 | 4 | 4 | 4 |
| Standards | large range | NBS 70A, G-2, GSP-1, AGV-1, W-1, BCR-1 | NIM-N, W-1, BCR, AGV-1, NIM-L, G-2 | GSP-1 + 3 more | AGV, BCR W-1, G-2, GSP, NIM-G | NIM-P, JB-1, NIM-N, Br GSP-1, AGV-1 |

Table D-2

Parameter Values

1 Rb-Sr

| | |
|---|---|
| 1121391 | 6600305 |
| 1124381 | 6600305 |
| 1125801 | 6600305 |
| 1125801 | 6600305 |
| 1126511 | 6600305 |

4 Ba-Ce

| | |
|---|---|
| 4180501 | 1000303 |
| 4179301 | 1000306 |
| 4178241 | 1000303 |
| 4174531 | 1000303 |
| 4171641 | 1000306 |
| 4170741 | 1000303 |

5Y-Nb-Zr

| | |
|---|---|
| 5125801 | 7000303 |
| 5126581 | 7000304 |
| 5124381 | 7000303 |
| 5125101 | 7000304 |
| 5123311 | 7000303 |
| 5123721 | 7000304 |
| 5124551 | 7000303 |
| 5122411 | 7000304 |
| 5121001 | 7000303 |
| 5121351 | 7000304 |
| 5120331 | 7000303 |
| 5120071 | 7000304 |

8 U-Th

| | |
|---|---|
| 8021391 | 6600305 |
| 8025901 | 6600305 |
| 8026151 | 6600305 |
| 8026601 | 6600305 |
| 8027481 | 6600305 |
| 8028251 | 6600305 |
| 8028751 | 6600305 |
| 8039791 | 6600305 |
| 8041781 | 6600305 |
| 8045011 | 6600305 |
| 8048651 | 6600305 |
| 8049501 | 6600305 |

6 Ni

| | |
|---|---|
| 6048201 | 7600305 |
| 6048651 | 7600305 |
| 6049751 | 7600305 |

Precision (Major Elements)

Sample P-23

| | | | | Mean | Var. | Sd. | CV% |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 74.68 | 74.80 | 74.96 | 74.81 | .019 | 0.14 | .19 |
| $Al_2O_3$ | 15.05 | 15.16 | 15.22 | 15.14 | .007 | 0.09 | .57 |
| $TiO_2$ | 0.17 | 0.16 | 0.17 | 0.17 | - | 0.006 | 3.40 |
| $FeO_T$ | 1.15 | 1.13 | 1.14 | 1.14 | .0001 | 0.01 | 0.88 |
| MnO | 0.03 | 0.03 | 0.03 | 0.03 | - | - | - |
| MgO | 0.37 | 0.35 | 0.37 | 0.36 | .0001 | 0.01 | 3.21 |
| CaO | 1.58 | 1.55 | 1.55 | 1.56 | .0003 | 0.017 | 1.11 |
| $Na_2O$ | 4.70 | 4.76 | 5.25 | 4.90 | .091 | 0.30 | 6.16 |
| $K_2O$ | 2.79 | 2.81 | 2.83 | 2.81 | .0004 | 0.20 | 0.71 |
| $P_2O_5$ | 0.06 | 0.06 | 0.05 | 0.06 | - | 0.006 | 9.62 |

*Var = Variance, SD = Standard Deviation, CV = Coefficient of Variation

Table D-3

Precision (Major Elements)

| Sample | B-7 | | | Mean | Var. | Sd. | CV% |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 51.72 | 51.70 | 51.91 | 51.78 | .01 | 0.12 | 0.23 |
| $Al_2O_3$ | 15.25 | 15.73 | 15.70 | 15.56 | .07 | 0.27 | 7.22 |
| $TiO_2$ | 0.45 | 0.43 | 0.44 | 0.44 | - | 0.01 | 2.27 |
| $FeO_T$ | 10.33 | 10.09 | 10.28 | 10.33 | .02 | 0.13 | 1.24 |
| MnO | 0.17 | 0.17 | 0.17 | 0.17 | - | - | - |
| MgO | 4.64 | 4.58 | 4.56 | 4.59 | .002 | 0.04 | 0.91 |
| CaO | 15.50 | 15.61 | 15.85 | 15.65 | .032 | 0.18 | 1.14 |
| $Na_2O$ | 1.06 | 1.30 | 0.99 | 1.12 | .026 | 0.16 | 14.5 |
| $K_2O$ | 0.16 | 0.15 | 0.14 | 0.15 | - | 0.01 | 6.67 |
| $P_2O_5$ | 0.08 | 0.09 | 0.08 | 0.08 | - | 0.006 | 7.22 |

Table D-4

| Precision (Trace Elements) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample 8030 | | | | | Mean | Var. | S.D. | CV% |
| Sr | 104.4 | 104.3 | 105.5 | | 104.7 | .44 | .66 | 0.64 |
| Ba | 30.14 | 30.14 | 30.14 | | 30.14 | - | - | - |
| Ce | 5.55 | 5.04 | | | 5.29 | 0.13 | .36 | 6.82 |
| Y | 33 | 29 | 30 | | 31 | 4.33 | 2.08 | 6.72 |
| Zr | 70 | 73 | 62 | | 68 | 32.3 | 5.68 | 8.36 |
| Nb | 10 | 12 | 10 | | 10.7 | 1.3 | 1.15 | 10.74 |
| Ni | 79.4 | 79 | 82.8 | | 80 | 2.65 | 1.63 | 2.04 |
| Sample P-23 | | | | | | | | |
| Rb | 86.9 | 86.8 | 86.1 | 85.1 | 86.2 | .69 | .83 | 0.96 |
| Sr | 58.4 | 58.0 | 58.3 | 57.4 | 58.00 | .20 | .45 | 0.77 |
| Sample P-34 | | | | | | | | |
| Ba | 950.35 | 951.67 | 948.45 | | 950.1 | 1.45 | 1.21 | 0.13 |

Table D-5

Accuracy (Major Elements)

| | W-I | x | Bias | % Bias | BCR-1 | x | Bias | % Bias |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 52.72 | 52.10 | 0.62 | 1.0 | 54.85 | 54.53 | .32 | .58 |
| $Al_2O_3$ | 14.87 | 14.45 | .42 | 2.8 | 13.68 | 13.54 | .14 | 1.02 |
| $TiO_2$ | 1.07 | 1.14 | .07 | 6.5 | 2.22 | 2.30 | .08 | 3.6 |
| $FeO_T$ | 11.11 | 11.65 | .54 | 4.9 | 13.52 | 13.77 | .25 | 1.8 |
| MnO | .17 | .18 | .01 | 5.8 | .19 | .19 | - | - |
| MgO | 6.63 | 6.14 | .49 | 7.4 | 3.49 | 3.40 | .09 | 2.6 |
| CaO | 10.98 | 10.70 | .28 | 2.5 | 6.98 | 7.04 | .06 | .8 |
| $Na_2O$ | 2.15 | 2.83 | .68 | 31.6 | 3.29 | 3.08 | .21 | 6.4 |
| $K_2O$ | .64 | .67 | .03 | 4.6 | 1.68 | 1.8 | .12 | 7.1 |
| $P_2O_5$ | .14 | .13 | .01 | 7.1 | .33 | .36 | .03 | 9.1 |

Table D-6

Accuracy (Trace Elements)

| | W-I | x | Bias | % Bias | BCR-1 | x | Bias | % Bias |
|---|---|---|---|---|---|---|---|---|
| Rb | 22 | 21.6 | .4 | 1.8 | 48 | 48 | - | - |
| Sr | 190 | 191 | 1 | .5 | 332 | 338 | 6 | 1.8 |
| Ba | 210 | 203 | 7 | 3.3 | 680 | 697 | 17 | 2.5 |
| Ce | 23 | 22 | 1 | 4.3 | 54 | 56 | 2 | 3.7 |
| Y | 25 | 26 | 1 | 4.0 | 46 | 44 | 2 | 4.3 |
| Nb | 15 | 15 | - | - | 14 | 14 | - | - |
| Zr | 105 | 105 | - | - | 185 | 174 | 11 | 5.9 |
| Ni | 78 | 87 | 9 | 11.5 | 16 | 15 | 1 | 6.2 |
| Th | 2.4 | 3.3 | .9 | 37.5 | 6 | 6.2 | .2 | 3.3 |
| Pb | 8 | 9 | 1 | 12.5 | 15 | 14.4 | .6 | 4.0 |

*x = Mean of four determinations

Table D-7

| Element | Standard | Sensitivity LLD[1] (ppm) | LLD[2] (ppm) |
|---|---|---|---|
| Rb | W-1 | 0.8 | 1.0 |
| Sr | W-1 | 0.6 | 1.0 |
| Ba | NIM-N | 17. | 20 |
| Ce | NIM-N | 9 | 10 |
| Y | GSP | 1.7 | 2.0 |
| Nb | GSP | 5.3 | 5.5 |
| Zr | W-1 | 3.7 | 4.0 |
| Th | GSP | 2.1 | 2.5 |
| Pb | GSP | 2.2 | 2.5 |
| Ni | NIM-N | 1.6 | 2.0 |

LLD[1] = calculated lower limit of detection.

LLD[2] = lower limit used for cutoff

016(a)

APPENDIX E

C.I.P.W. NORMS

Table E-1

CIPW Norms

| Lower Volcanics | Q | or | ab | an | di | hy | ol | mt | il | ap | sp | co | he | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8002-2 | .26 | 1.12 | 15.32 | 31.94 | 24.01 | 21.97 | | 3.[illegible] | 1.73 | .16 | | | | 100.01 |
| 8004-2 | | 1.06 | 26.32 | 28.29 | 14.73 | 19.41 | 4.72 | 3.54 | 1.78 | .14 | | | | 100.00 |
| B-33 | | 1.36 | 33.85 | 33.28 | | 17.31 | 7.62 | 3.55 | 1.80 | .23 | | .07 | | 99.08 |
| 8007-2 | | 1.36 | 30.29 | 28.63 | 15.27 | 18.69 | .02 | 3.64 | 1.92 | .16 | | | | 99.99 |
| 8008-2 | | 4.20 | 13.96 | 21.58 | 30.36 | 16.00 | 8.05 | 3.29 | 1.46 | 1.09 | | | | 99.99 |
| 8010-2 | 3.64 | 1.30 | 12.61 | 34.25 | 23.06 | 19.11 | | 3.77 | 2.09 | .18 | | | | 100.01 |
| 8011-2 | | 1.59 | 19.80 | 30.42 | 21.22 | 16.90 | 4.06 | 3.77 | 2.05 | .18 | | | | 100.01 |
| 8012-2 | .39 | .82 | 19.55 | 28.18 | 27.05 | 19.65 | | 3.07 | 1.18 | .09 | | | | 99.99 |
| 8013-2 | | 2.00 | 19.88 | 27.09 | 24.76 | 19.15 | 2.2[illegible] | 3.26 | 1.42 | .12 | | | | 99.99 |
| G-32 | 1.84 | 1.95 | 14.04 | 32.72 | 25.05 | 18.65 | | 3.46 | 1.69 | .30 | | | | 99.72 |
| 8014-2 | | .65 | 9.48 | 22.04 | 25.74 | 31.76 | 5.94 | 3.07 | 1.18 | .14 | | | | 100.00 |
| 8018-2 | | 1.00 | 15.74 | 25.91 | 27.96 | 15.25 | 9.32 | 3.26 | 1.42 | .12 | | | | 99.99 |
| 8019-2 | 4.31 | .53 | 11.42 | 25.87 | 28.88 | 23.64 | | 3.46 | 1.69 | .18 | | | | 100.00 |
| 8021-2 | | 1.24 | 23.95 | 23.73 | 24.79 | 15.51 | 5.59 | 3.42 | 1.63 | .14 | | | | 100.00 |
| 8023-2 | | .71 | 22.34 | 19.64 | 25.17 | 18.40 | 9.15 | 3.17 | 1.31 | .12 | | | | 100.00 |
| 8025-2 | | .77 | 16.50 | 31.33 | 22.46 | 16.97 | 6.80 | 3.42 | 1.63 | .09 | | | | 99.97 |
| 8028-2 | .36 | .89 | 11.51 | 30.04 | 25.92 | 26.03 | | 3.44 | 1.65 | .16 | | | | 99.99 |
| 8030-2 | 3.39 | .65 | 7.95 | 36.39 | 14.87 | 31.07 | | 3.61 | 1.88 | .18 | | | | 100.00 |

| Lower Volcanics | Q | or | ab | an | di | hy | ol | mt | il | ap | sp | co | he | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8031-2 | | .95 | 18.70 | 32.23 | 20.69 | 18.32 | 3.79 | 3.48 | 1.71 | .14 | | | | 100.00 |
| B-22 | 16.14 | 1.36 | 24.45 | 27.14 | 15.74 | 9.30 | | 3.44 | 1.65 | .21 | | | | 99.43 |
| 8034-2 | | .77 | 12.61 | 29.30 | 25.66 | 25.89 | 1.05 | 3.22 | 1.37 | .14 | | | | 100.00 |
| 8035-2 | | .95 | 15.74 | 30.47 | 33.97 | 10.07 | 4.26 | 3.16 | 1.30 | .09 | | | | 100.01 |
| B-7 | 7.59 | .95 | 8.97 | 36.38 | 33.25 | 8.35 | | 2.83 | .85 | .18 | | | | 99.36 |
| B-10 | | 7.45 | 13.37 | 28.29 | 23.57 | | 20.32 | 3.16 | 1.29 | .18 | | | | 98.83 |
| 8037-2 | 3.08 | .83 | 17.94 | 34.47 | 24.41 | 13.20 | | 3.75 | 2.07 | .25 | | | | 100.00 |
| 8039-2 | 2.76 | .89 | 18.53 | 32.02 | 11.67 | 28.41 | | 3.64 | 1.92 | .16 | | | | 100.00 |
| 8041-2 | 3.23 | .83 | 15.23 | 30.80 | 27.34 | 17.01 | | 3.57 | 1.82 | .16 | | | | 100.00 |
| 8044-2 | .37 | .47 | 18.28 | 29.52 | 16.09 | 29.49 | | 3.67 | 1.96 | .16 | | | | 100.02 |
| 8103-2 | | 1.95 | 18.19 | 27.77 | 23.77 | 23.15 | | 3.25 | 1.40 | .12 | | | | 99.99 |
| 8106-2 | | 1.36 | 17.43 | 34.38 | 20.14 | 16.40 | 4.65 | 3.61 | 1.88 | .14 | | | | 100.00 |
| 8047-2 | 3.46 | .53 | 19.38 | 28.64 | 26.02 | 15.29 | | 4.08 | 2.43 | .21 | | | | 100.00 |
| 8110-2 | 15.56 | 11.11 | 25.13 | 23.60 | 3.20 | 17.16 | | 2.97 | 1.04 | .28 | | | | 100.01 |
| 8048-2 | 2.06 | .83 | 19.97 | 24.88 | 17.34 | 27.06 | | 4.47 | 3.00 | .39 | | | | 99.99 |
| 8050-2 | | .77 | 13.58 | 31.58 | 8.37 | | 27.08 | 4.51 | 3.06 | .25 | | | | 100.00 |
| 8051-2 | 2.54 | .41 | 15.74 | 29.62 | 18.73 | 26.47 | | 3.93 | 2.30 | .23 | | | | 99.98 |
| 8054-2 | 19.16 | 15.48 | 25.30 | 23.45 | .04 | 12.71 | | 2.80 | .82 | .23 | | | | 100.00 |
| 8055-2 | 30.31 | 13.47 | 27.08 | 6.19 | | | | 2.90 | .95 | .23 | | 7.69 | | 100.01 |

| Middle | Q | or | ab | an | di | hy | ol | mt | il | ap | sp | co | he | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5310-1 | 27.19 | 21.57 | 29.11 | 6.88 | | 5.85 | | 2.99 | 1.06 | .46 | | 4.90 | | 100.01 |
| 5295-1 | 26.49 | 13.18 | 37.65 | 13.52 | | 4.72 | | 2.84 | .87 | .25 | | .46 | | |
| **Misc.** | | | | | | | | | | | | | | |
| Green Felsics | | | | | | | | | | | | | | |
| 8053-2 | 40.48 | 24.99 | 4.48 | 22.45 | | 1.92 | | 1.32 | .72 | .32 | | 2.33 | .91 | 100.00 |
| 8053-3 | 42.11 | 21.63 | 6.94 | 15.32 | | 5.19 | | 2.71 | .70 | .30 | | 5.07 | | 99.99 |
| 8065-2 | 24.83 | 13.95 | 40.95 | 5.65 | | 6.75 | | 2.93 | .99 | .30 | | 3.65 | | 100.01 |
| Tuff, Sand | | | | | | | | | | | | | | |
| 8060-2 | 44.05 | 10.58 | 18.78 | 15.45 | | 4.73 | | 1.13 | .74 | .18 | | 2.23 | 2.11 | 99.99 |
| 8093 | 31.56 | 4.31 | 23.61 | 21.44 | | 11.07 | | 3.31 | 1.48 | .28 | | 2.94 | | 100.00 |
| 8137 | 13.57 | 13.71 | 22.76 | 20.83 | 10.43 | 14.43 | | 2.91 | .97 | .39 | | | | 100.01 |
| 8140 | 46.69 | 11.23 | 20.05 | 7.30 | | 4.94 | | 2.96 | 1.03 | .14 | | 5.64 | | 99.98 |
| 8064-2 | 16.34 | 7.74 | 27.16 | 21.92 | 2.21 | 20.37 | | 2.97 | 1.04 | .23 | | | | 99.99 |
| Argillite | | | | | | | | | | | | | | |
| 8143 | 20.64 | 9.93 | 31.14 | 11.75 | | 17.23 | | 3.15 | 1.27 | .30 | | 4.58 | | 99.99 |
| 8145 | 18.55 | 12.17 | 30.54 | 10.99 | | 17.88 | | 3.20 | 1.35 | .32 | | 4.97 | | 100.00 |

| Amyg | Q | or | ab | an | di | hy | ol | mt | il | ap | sp | co | he | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8096-3 | 12.51 | 10.69 | 28.09 | 18.53 | 4.15 | 19.33 | | 4.03 | 2.43 | .23 | | | | 100.00 |
| Upper Volcanics | | | | | | | | | | | | | | |
| 5222-1 | 9.19 | 1.83 | 24.54 | 31.36 | 16.58 | 8.73 | | 4.51 | 3.06 | .21 | | | | 100.01 |
| 6193-1 | | 3.96 | 20.31 | 33.25 | 22.05 | 14.59 | .19 | 3.58 | 1.84 | .23 | | | | 100.01 |
| 5261-2 | 1.80 | 4.31 | 36.81 | 15.65 | 29.75 | 1.66 | | 5.36 | 4.18 | .46 | | | | 99.99 |
| 5256-2 | 8.02 | 2.90 | 34.78 | 21.39 | 14.38 | 10.66 | | 4.52 | 3.08 | .25 | | | | 99.98 |
| 8113 | 1.88 | .47 | 39.52 | 19.98 | 20.56 | 9.61 | | 4.58 | 3.15 | .28 | | | | 100.02 |
| 8115 | 1.29 | .47 | 13.54 | 31.82 | 18.20 | 27.28 | | 3.90 | 2.26 | .25 | | | | 99.02 |
| 8118 | | 2.89 | 15.40 | 31.20 | 21.62 | 15.81 | 8.36 | 3.22 | 1.37 | .14 | | | | 100.02 |
| 5268 | 12.73 | 2.13 | 14.81 | 24.43 | 13.51 | 25.00 | | 4.33 | 2.83 | .23 | | | | 100.00 |
| 5265 | .36 | 1.42 | 28.35 | 24.69 | 15.47 | 24.75 | | 3.31 | 1.48 | .18 | | | | 100.00 |
| 5302 | 2.37 | 2.54 | 21.41 | 26.27 | 16.69 | 23.49 | | 4.19 | 2.64 | .32 | | | | 100.00 |
| 5300 | | 3.78 | 21.24 | 27.23 | 18.53 | 21.06 | 1.84 | 3.87 | 2.22 | .23 | | | | 100.00 |
| Porphyry | | | | | | | | | | | | | | |
| P1 | 33.61 | 14.95 | 40.53 | 4.66 | | 1.09 | | | .06 | .14 | .46 | 3.20 | 1.28 | 100.00 |
| P5 | 29.17 | 10.46 | 48.82 | 6.40 | | 1.34 | | | .09 | .12 | .33 | 1.35 | 1.37 | 99.45 |
| P12 | 26.08 | 11.99 | 36.89 | 14.19 | .80 | 7.75 | | 1.19 | .51 | .23 | | | .95 | 100.59 |
| P13 | 26.44 | 13.36 | 44.68 | 9.40 | | 3.29 | | | .11 | .16 | .33 | .26 | 1.59 | 99.61 |
| P23 | 32.99 | 16.49 | 39.77 | 6.97 | | .92 | | | .06 | .14 | .33 | 1.74 | 1.15 | 100.58 |

| Porphyry | Q | or | ab | an | di | hy | ol | mt | il | ap | sp | co | he | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P24 | 29.72 | 10.99 | 46.03 | 9.32 | | 1.02 | | | .04 | .14 | .46 | 1.04 | 1.23 | 100.00 |
| P27 | 32.69 | 12.82 | 42.73 | 6.77 | | .87 | | | .06 | .14 | .41 | 2.20 | 1.08 | 99.78 |
| P28 | 35.19 | 14.53 | 40.28 | 2.89 | | .87 | | | .04 | .12 | .39 | 4.09 | 1.07 | 99.48 |
| P34 | 35.16 | 17.49 | 34.69 | 7.26 | | 1.09 | | | .06 | .14 | .31 | 3.13 | 1.30 | 100.82 |
| P35 | 29.37 | 14.30 | 51.78 | 1.02 | | .95 | | | .06 | .07 | .33 | 2.60 | .66 | 101.15 |
| PF | 29.26 | 12.41 | 49.50 | 4.68 | | .44 | | | .09 | .12 | .34 | | .95 | 98.99 |
| Brecciated Porphyry | | | | | | | | | | | | | | |
| 5230 | 36.92 | 14.36 | 36.39 | 4.28 | | 1.29 | | | .04 | .14 | .41 | 4.04 | | 99.26 |
| 5232 | 22.92 | 8.5 | 49.25 | 12.10 | | 4.70 | | 2.68 | | .37 | .66 | .52 | | 101.72 |
| 5233 | 40.70 | 15.36 | 27.59 | 8.28 | | 1.54 | | | .06 | .14 | .28 | 4.16 | 1.3 | 99.44 |
| 5240 | 39.57 | 12.63 | 33.0 | 6.41 | | 1.49 | | | .06 | .14 | .38 | 3.5 | 1.5 | 98.74 |
| 8131 | 26.48 | 8.98 | 44.85 | 10.81 | | 3.83 | | 2.51 | .76 | .30 | | 1.30 | .16 | 100.01 |
| 8134 | 33.63 | 12.82 | 35.11 | 13.44 | | 1.42 | | | .10 | .09 | .38 | 1.46 | 1.52 | 100.01 |
| 8136 | 35.87 | 13.08 | 38.84 | 7.67 | | .99 | | | .11 | .09 | .35 | 1.82 | 1.20 | 100.01 |
| 8142 | 16.20 | 12.35 | 38.25 | 11.47 | 15.62 | 2.47 | | 2.67 | .65 | .32 | | | | 99.99 |

| Osisko | Q | or | ab | an | di | hy | ol | mt | il | ap | sp | co | he | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-1 | 19.78 | 10.64 | 26.65 | 22.42 | | 16.28 | | 2.94 | 1.00 | .23 | | .04 | | 100.00 |
| 0-7 | | 1.71 | 29.62 | 22.43 | 8.06 | 25.52 | 5.24 | 4.35 | 2.85 | .23 | | | | 100.00 |
| 0-25 | 11.12 | 8.86 | 11.68 | 24.41 | 7.90 | 26.44 | | 5.29 | 4.08 | .29 | | | | 100.00 |
| 0-11 | | 2.78 | 23.78 | 25.78 | 19.76 | 15.99 | 5.73 | 3.84 | 2.18 | .16 | | | | 100.01 |
| 0-19 | | 1.42 | 28.60 | 20.52 | 21.63 | 15.37 | 4.73 | 4.48 | 3.02 | .23 | | | | 100.00 |
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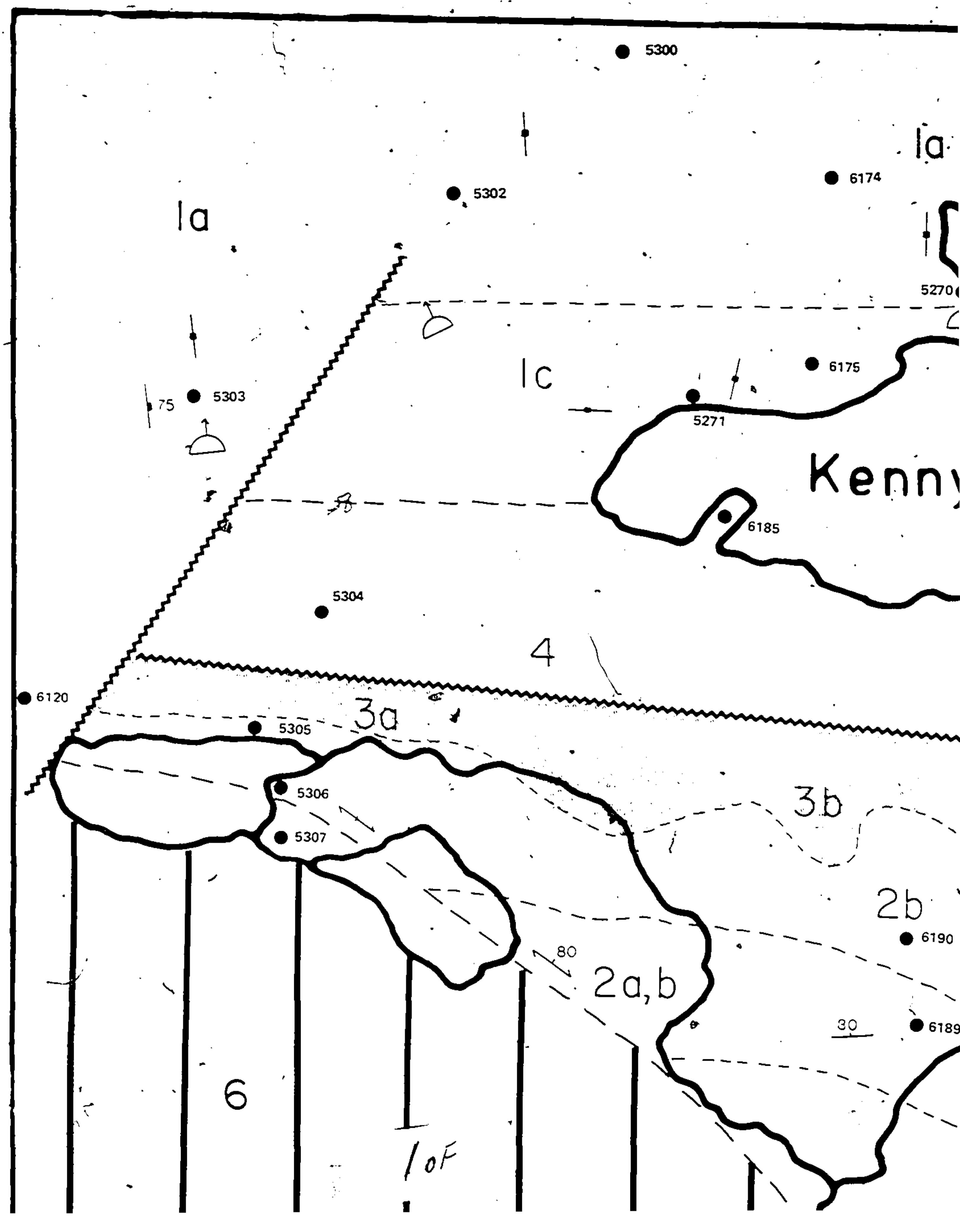
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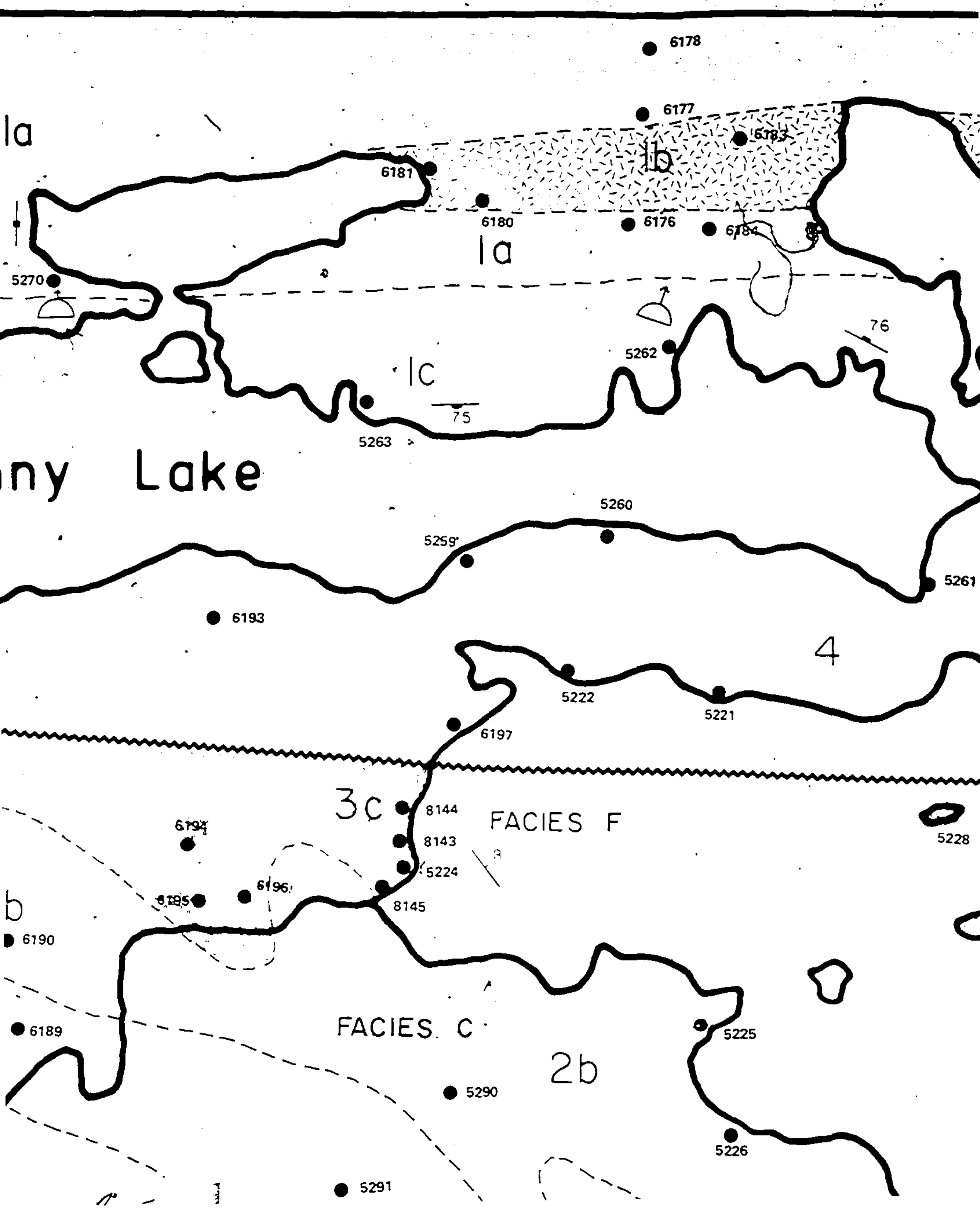

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5259
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FACIES F
6194
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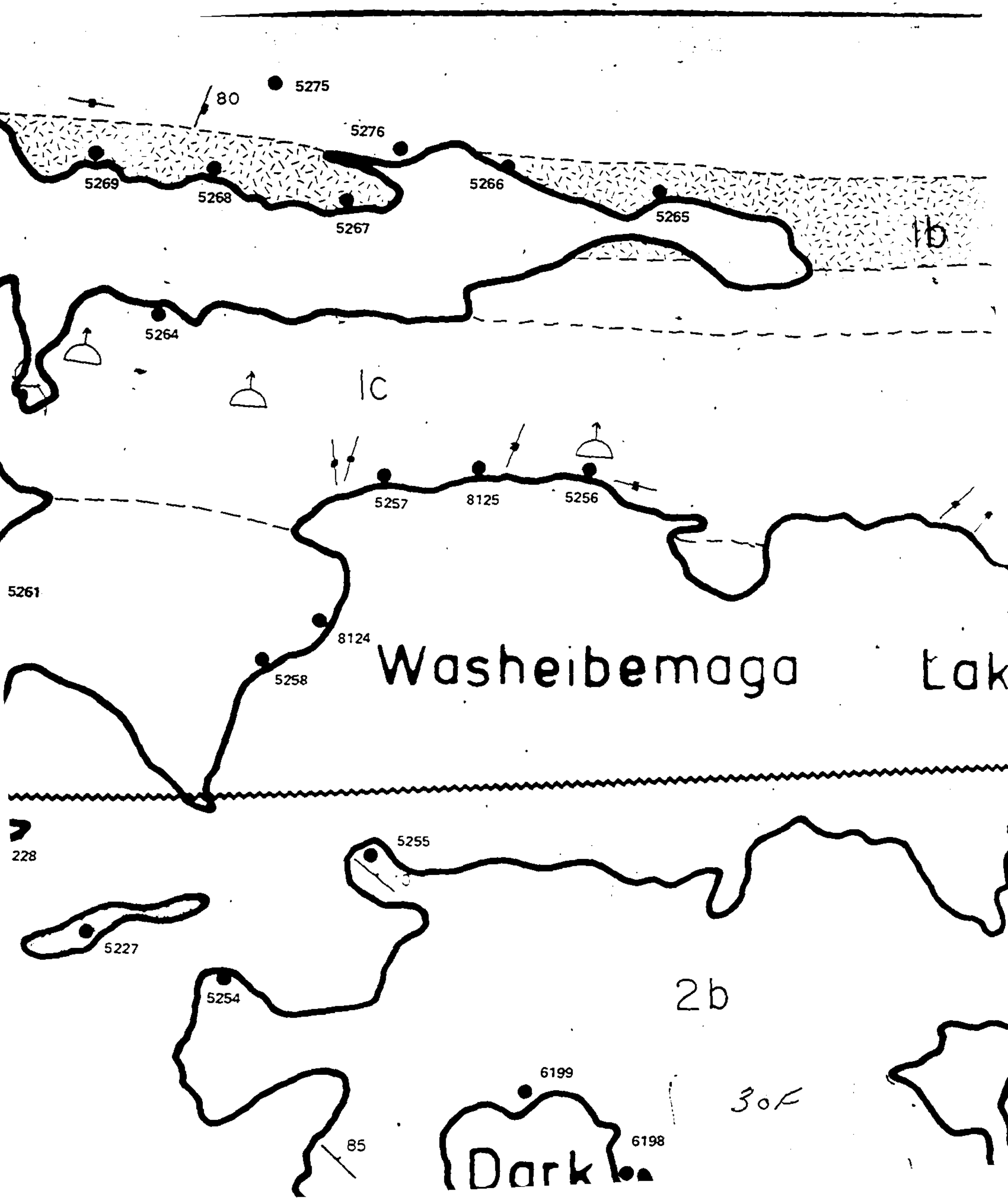
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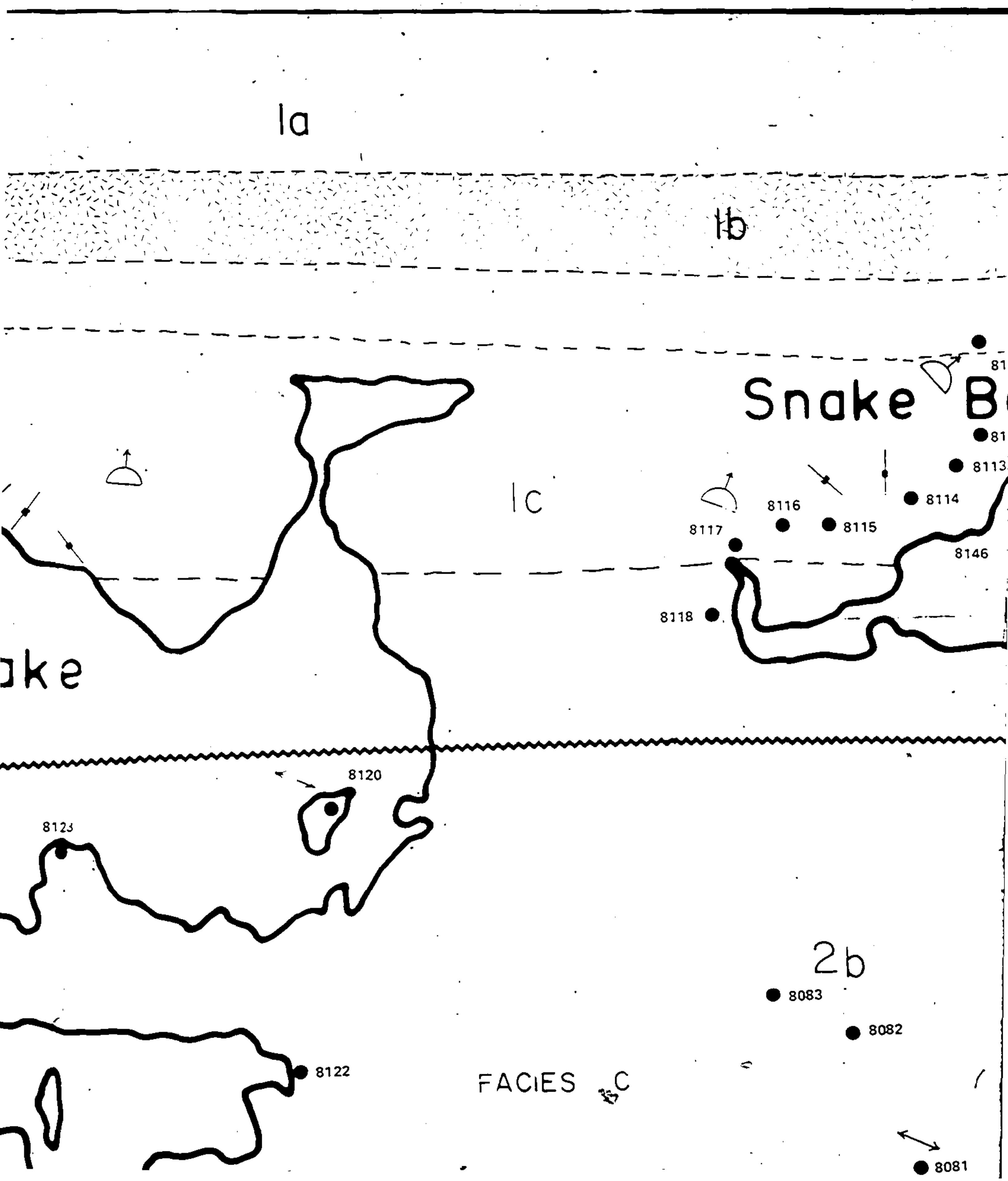

Ia
Ib
Ic
Snake B
ake
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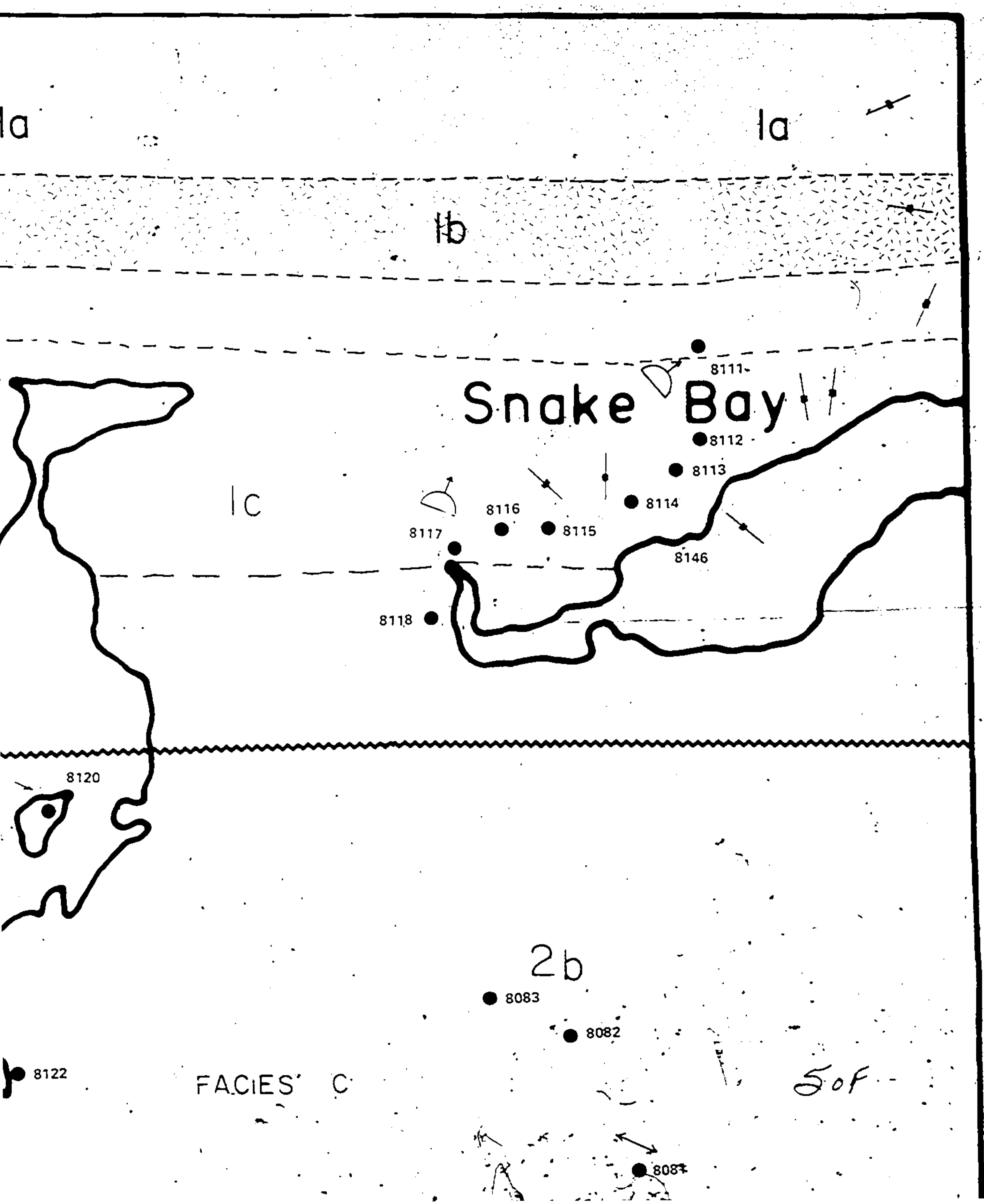

la
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8082
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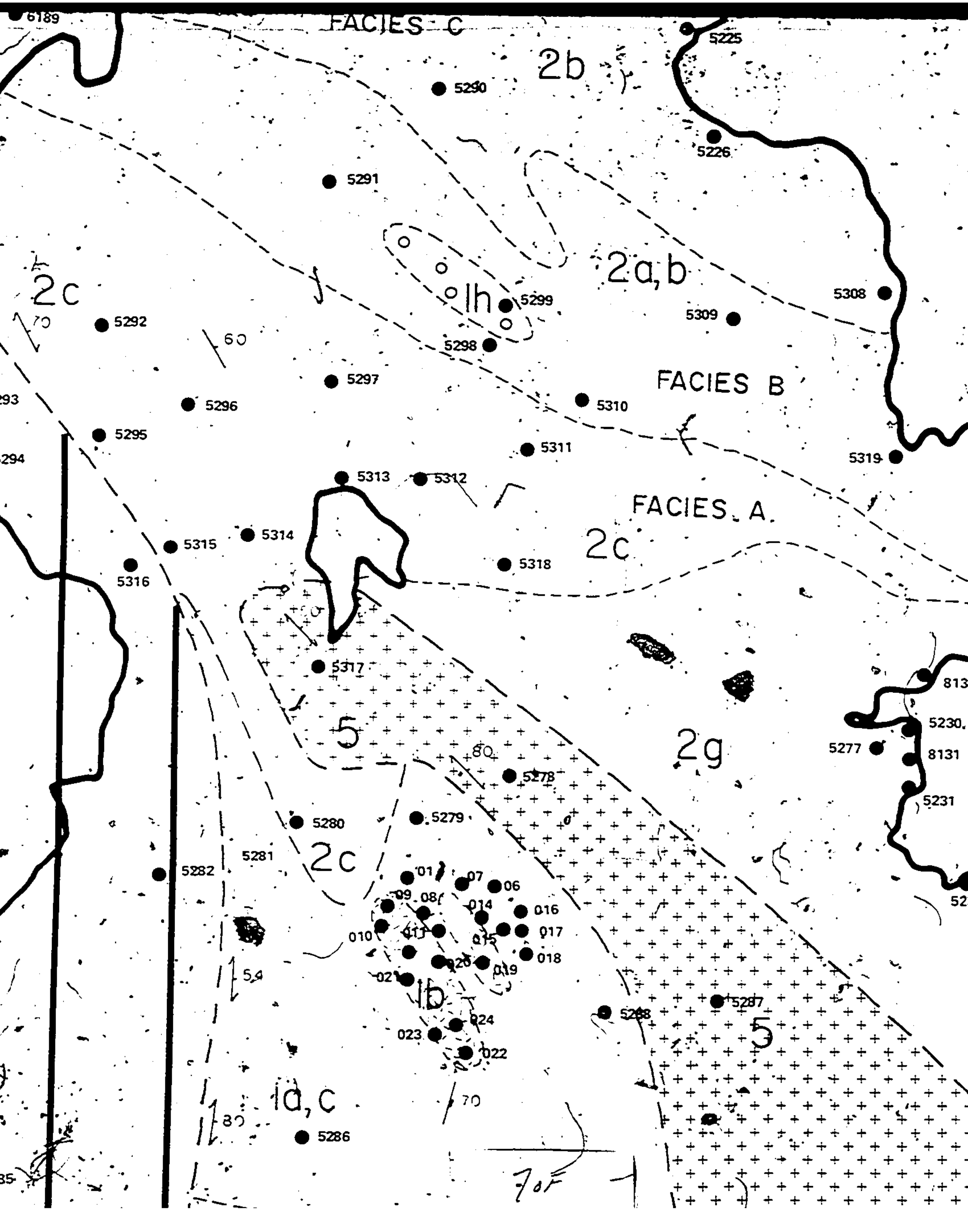
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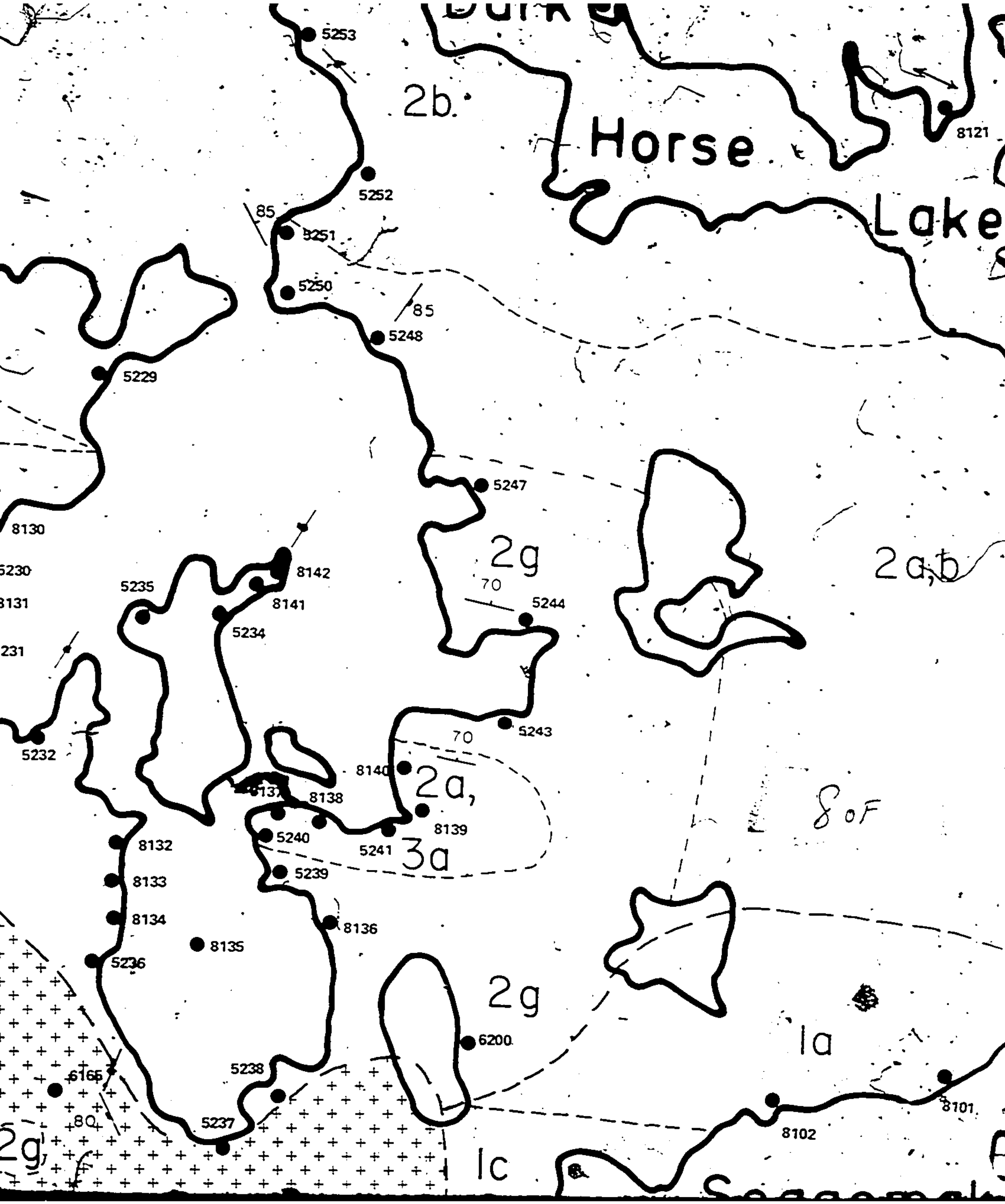

Horse
Lake
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2g
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3a
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1c
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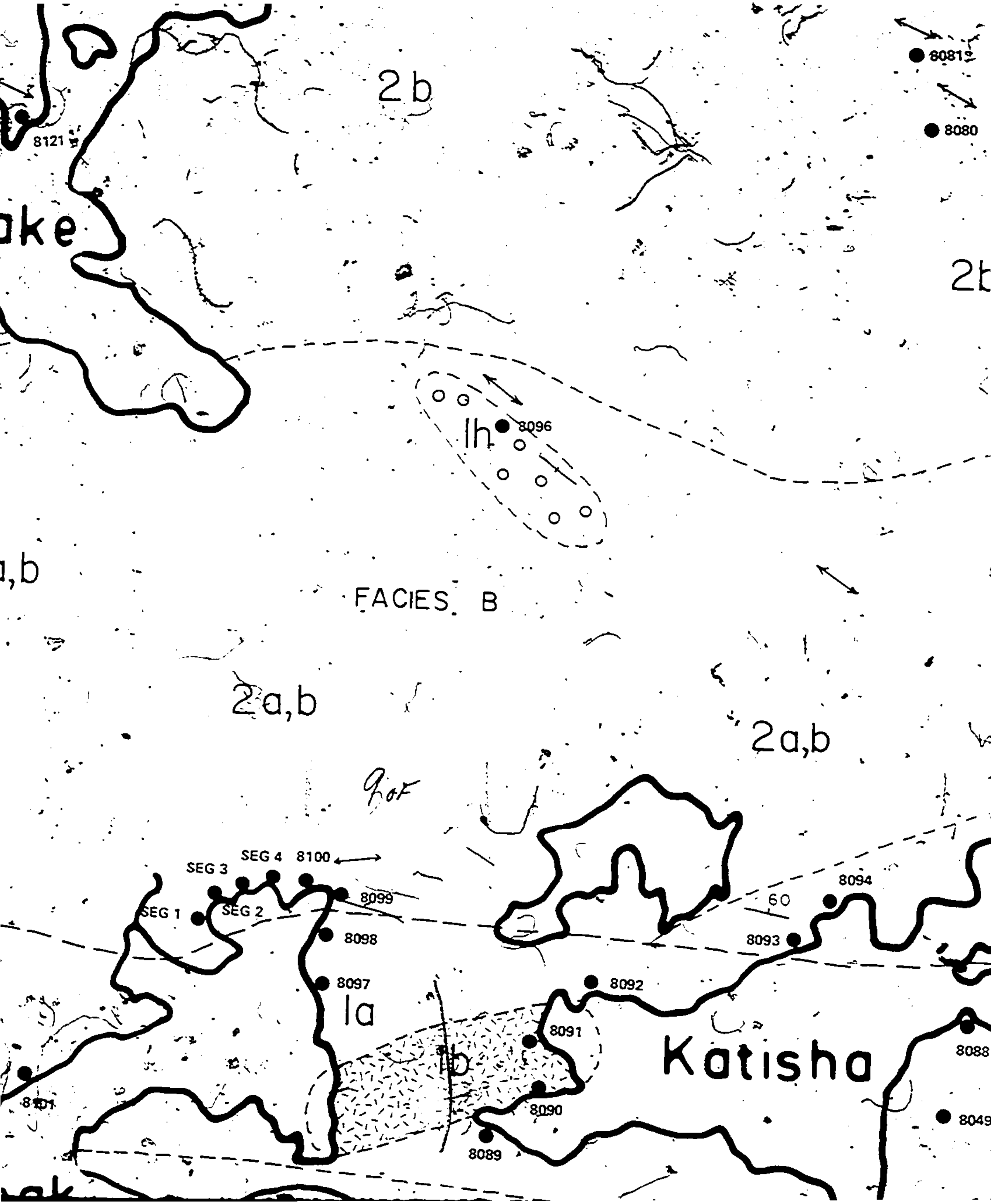
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SEG 3
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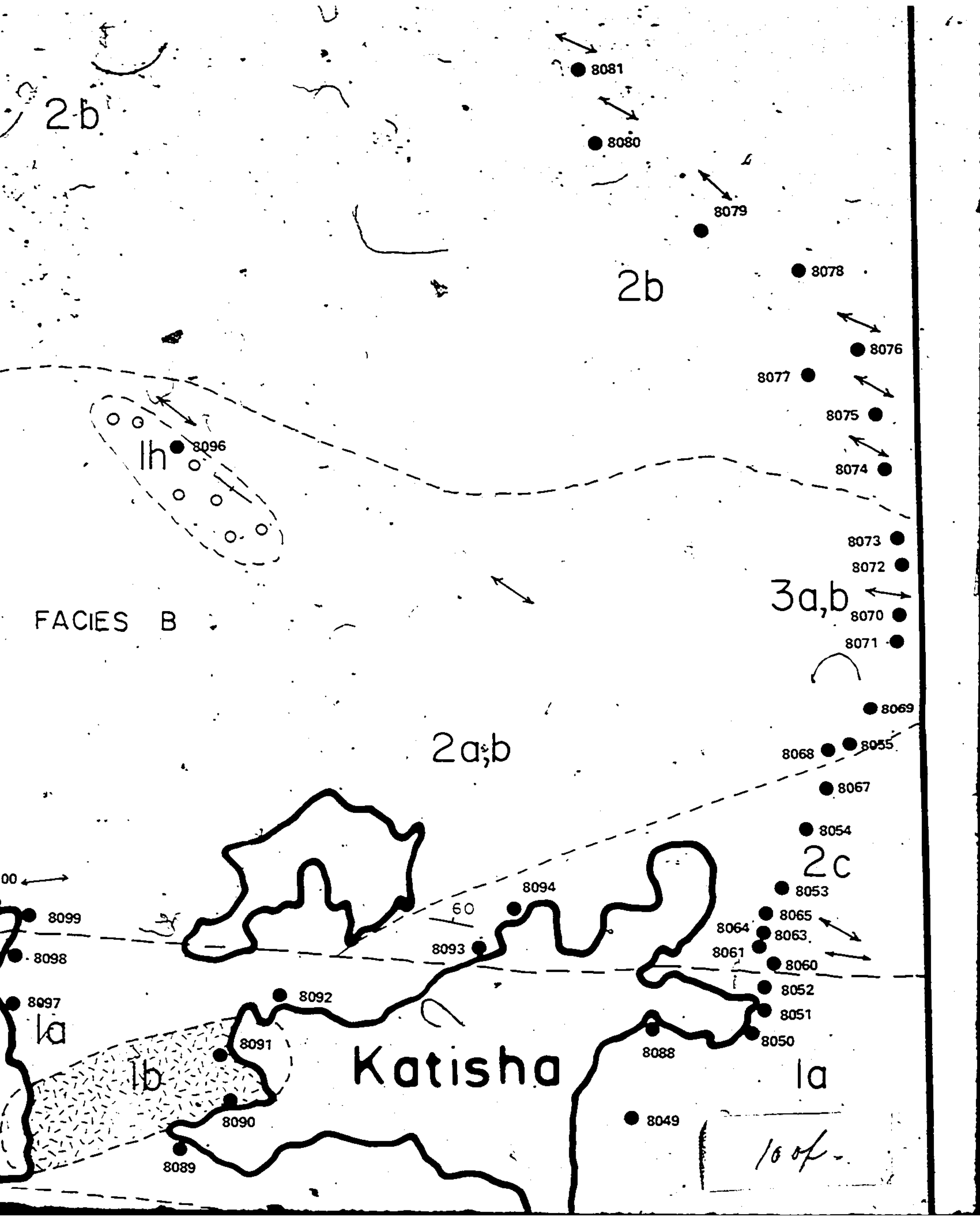
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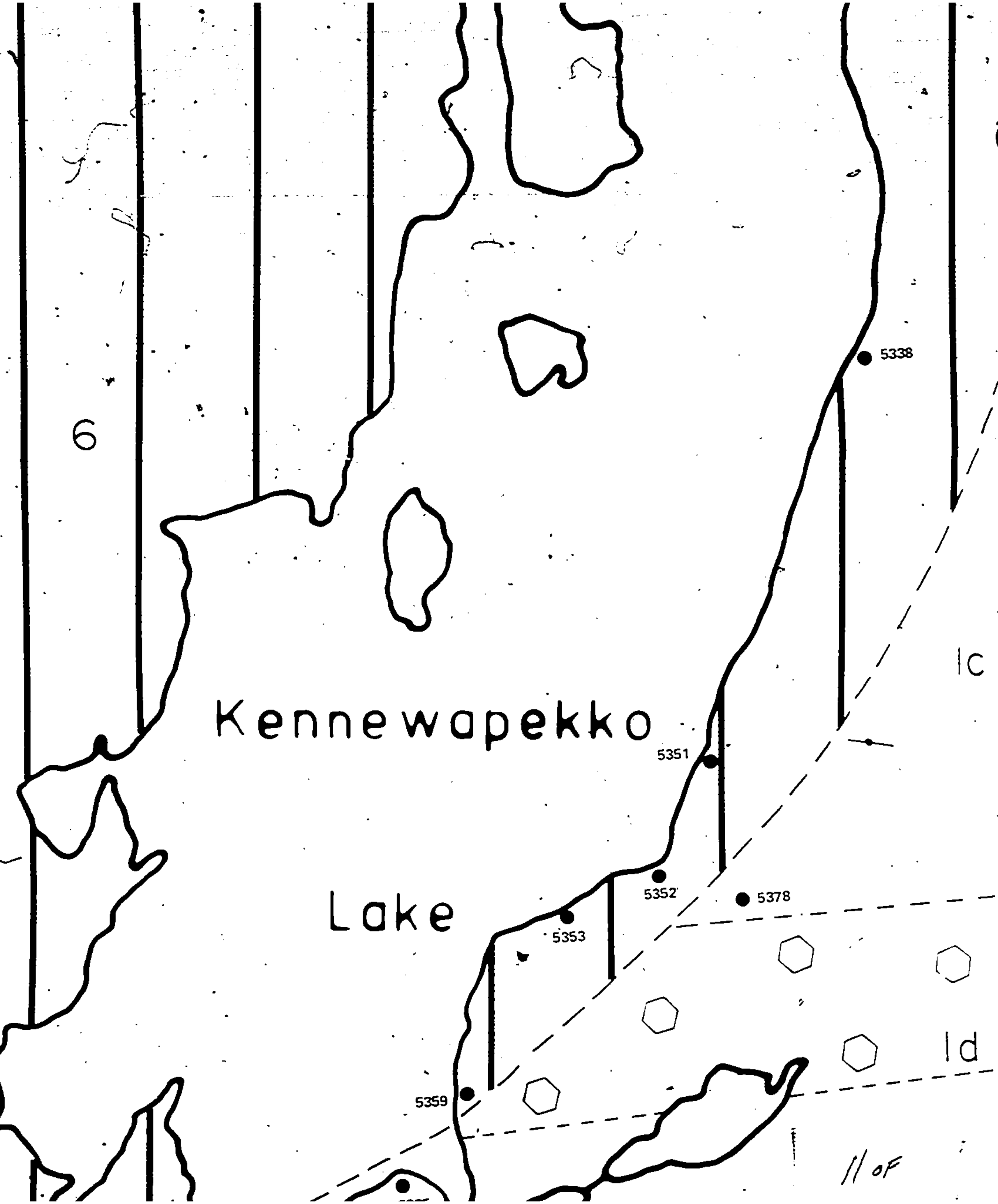
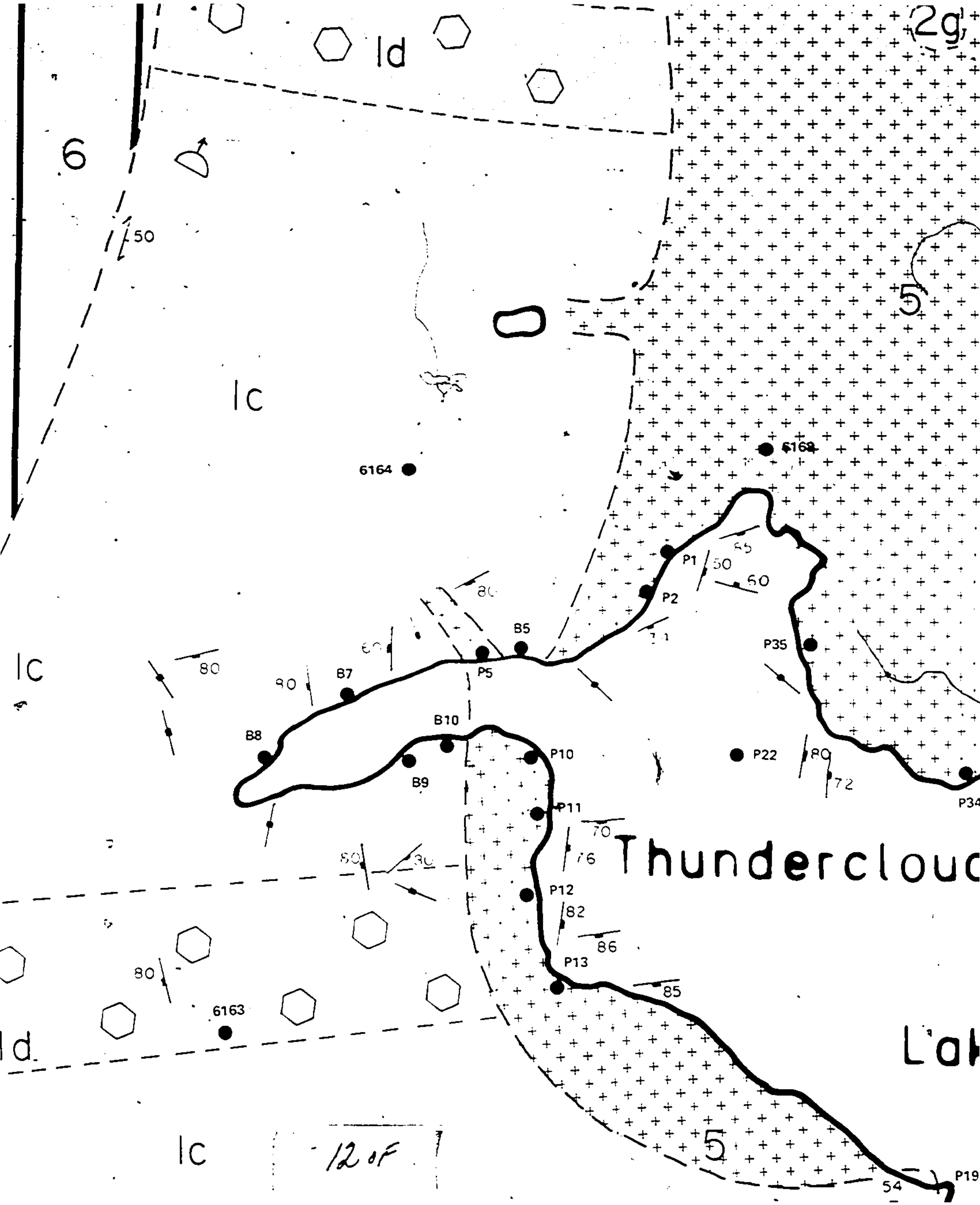



11 of



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B7
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P10
P11
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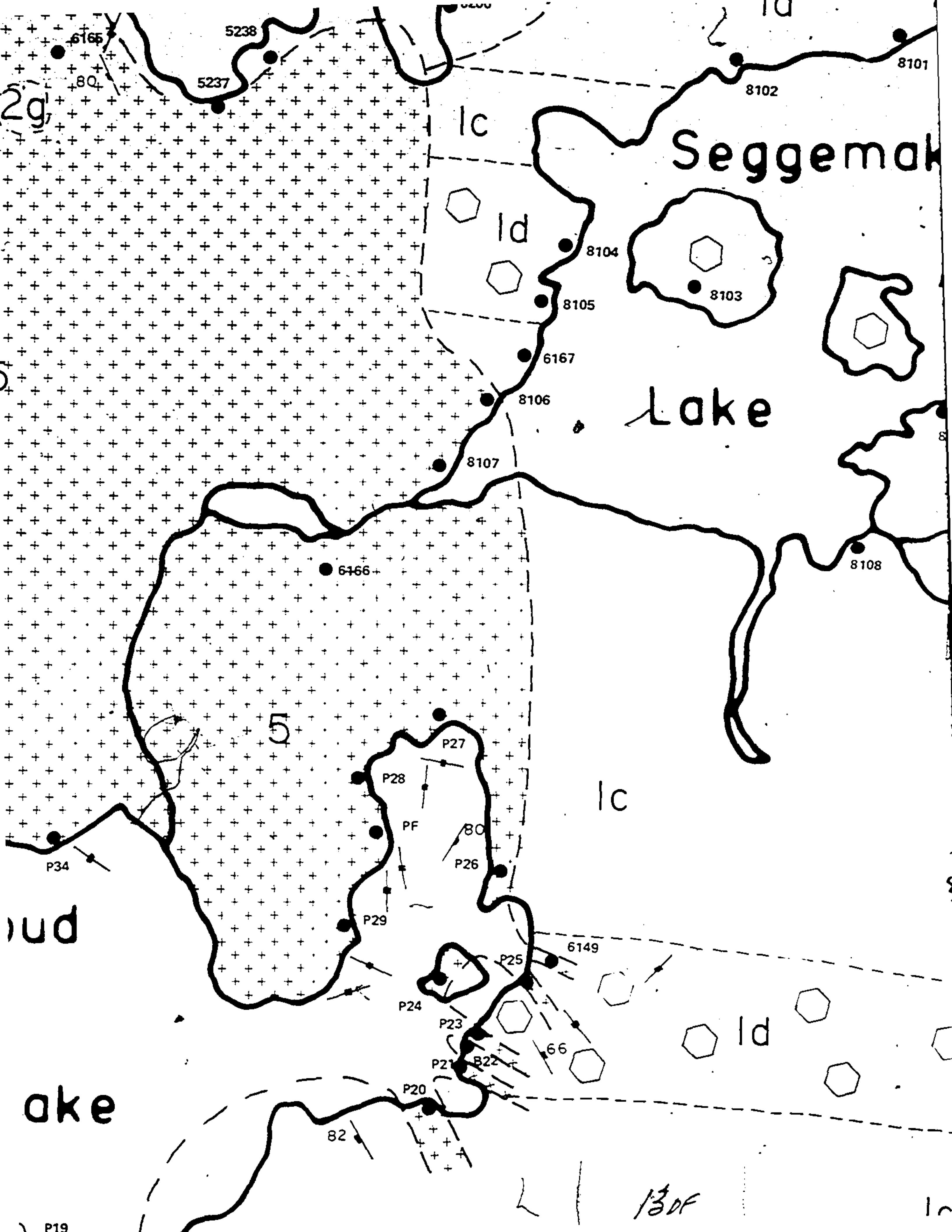
12 of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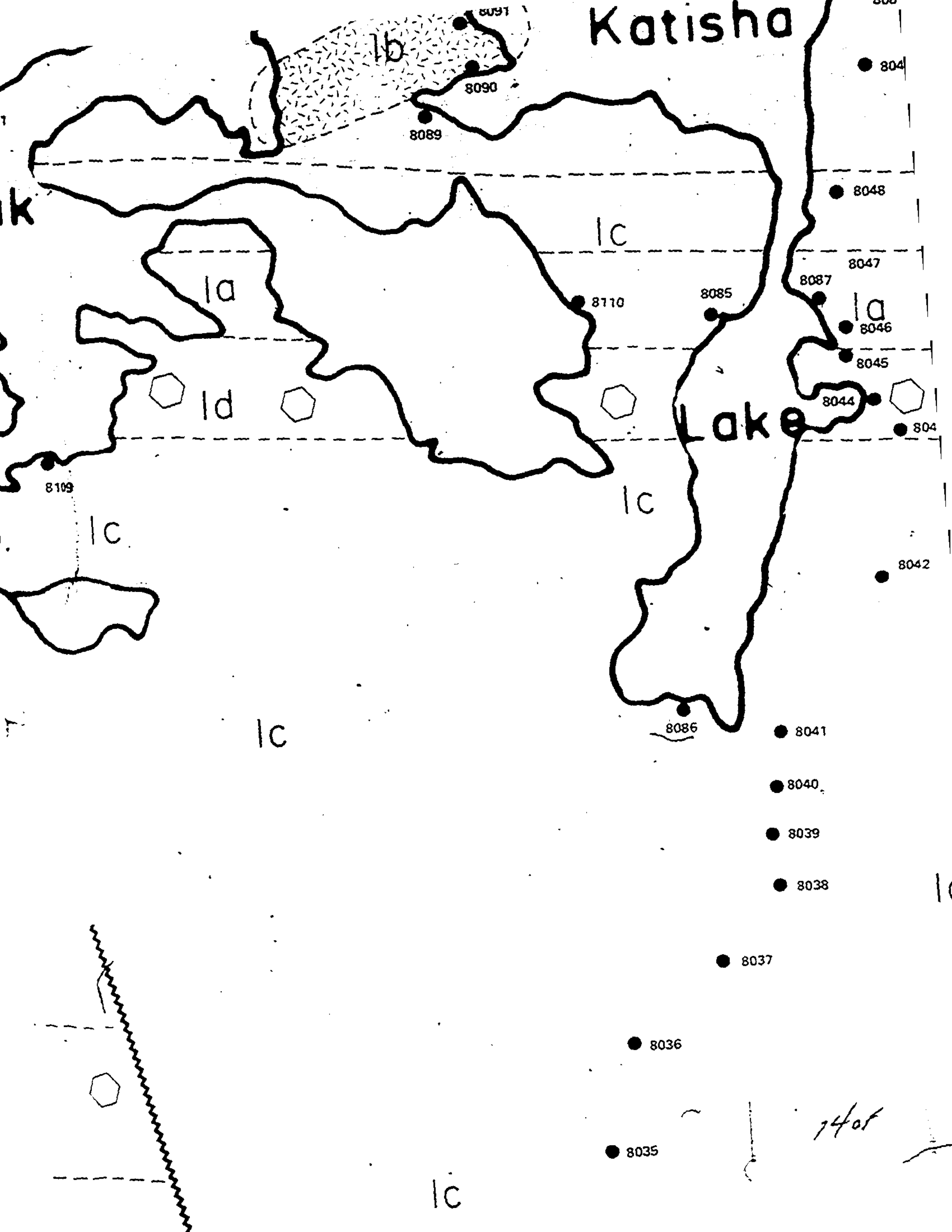
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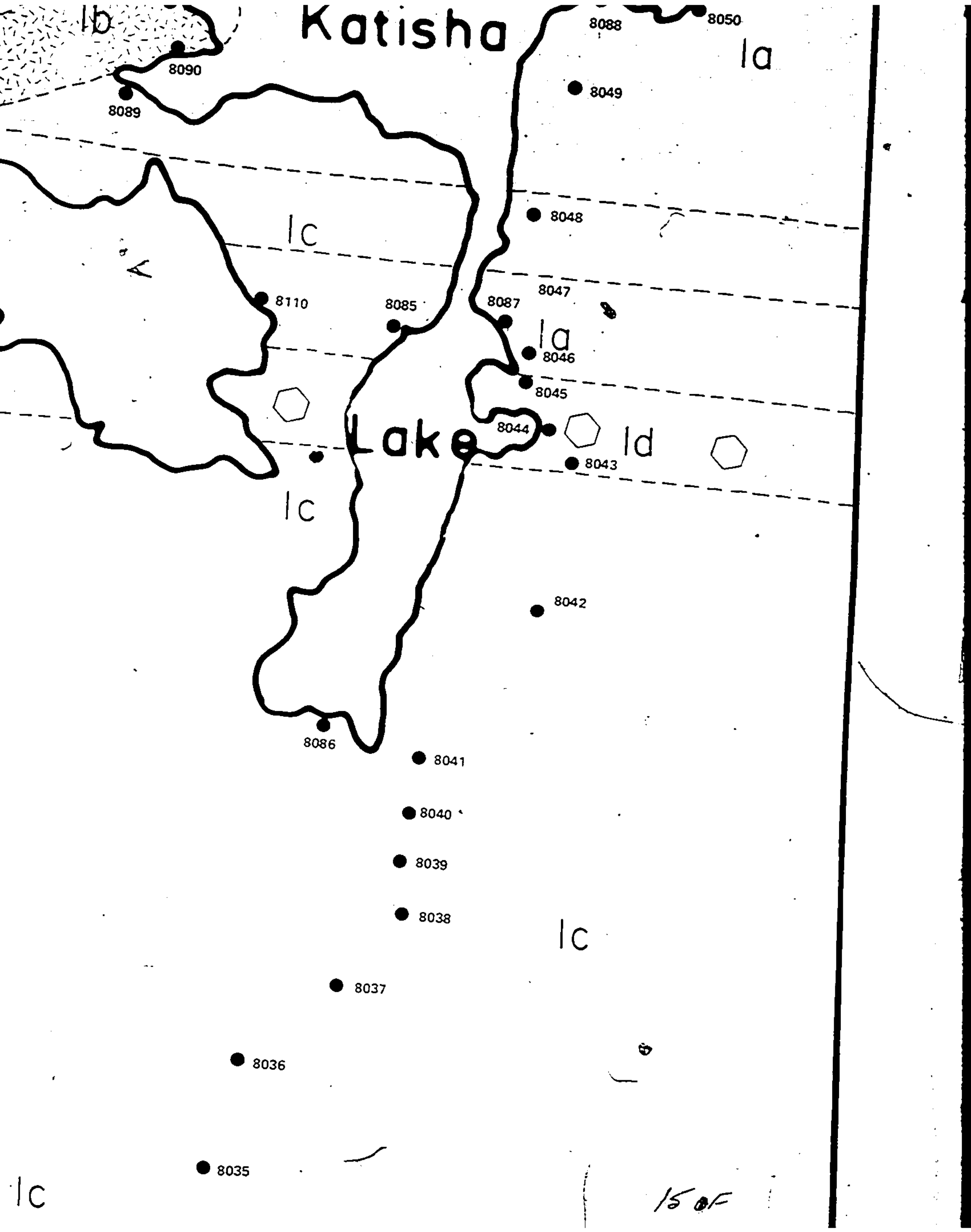

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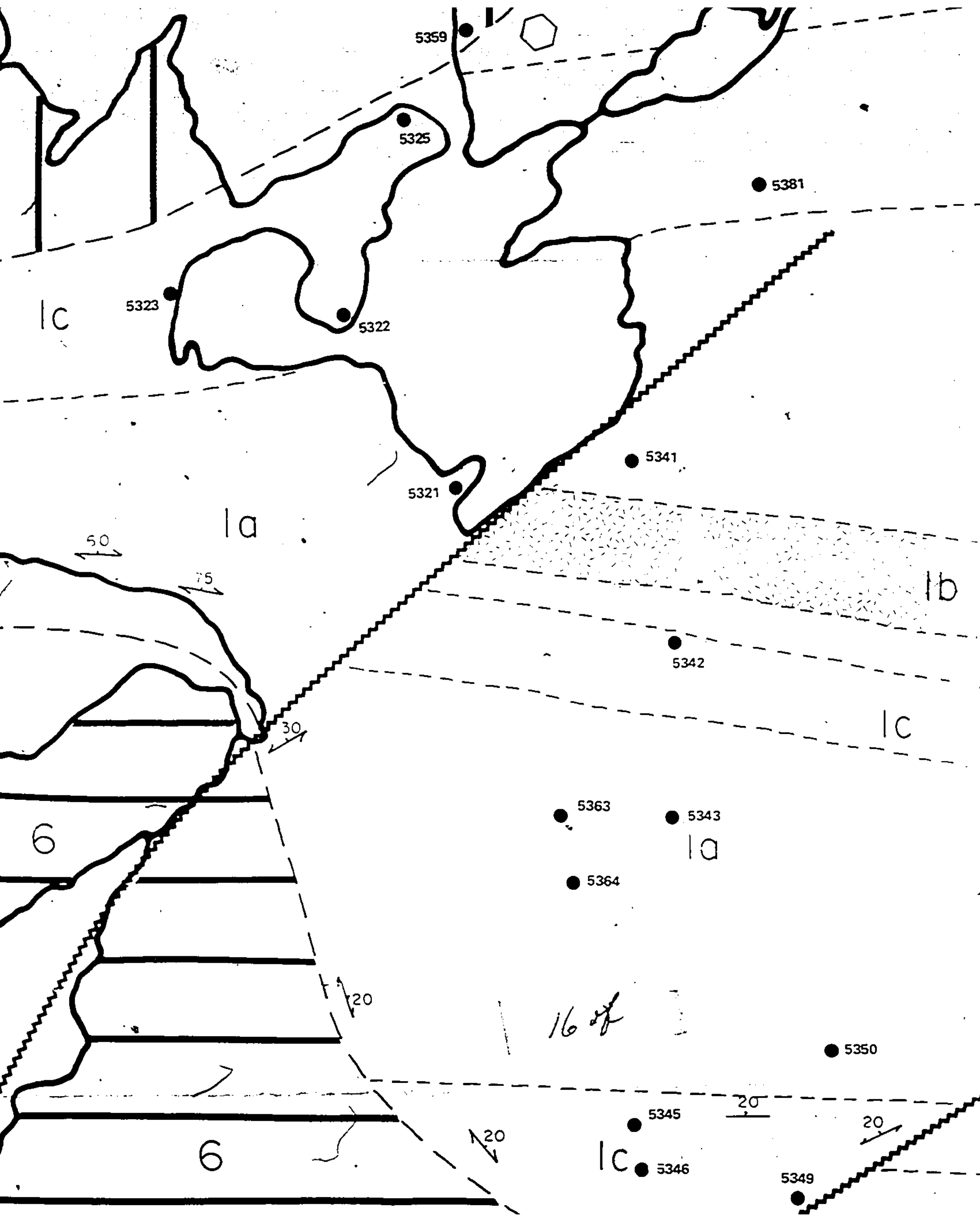
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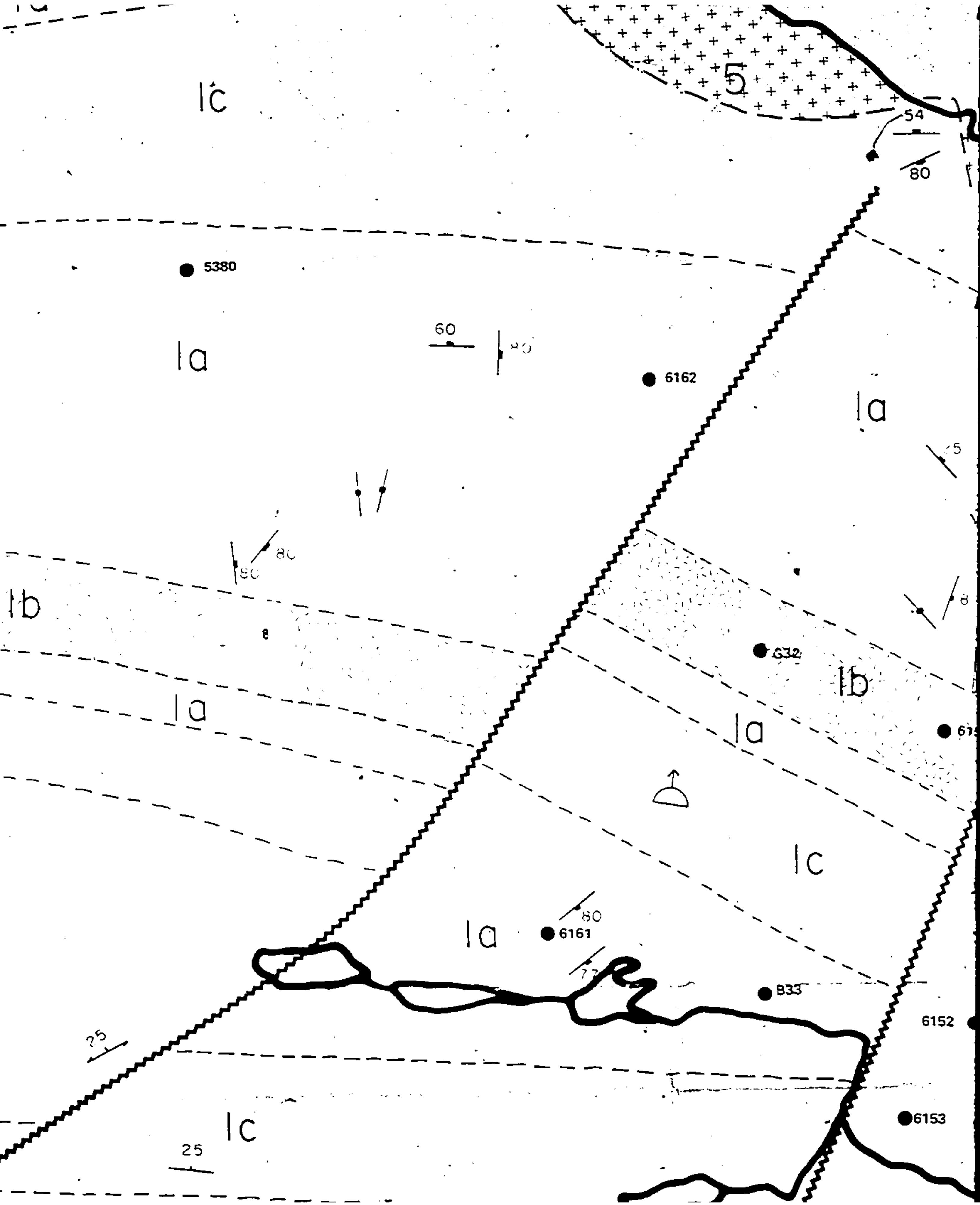

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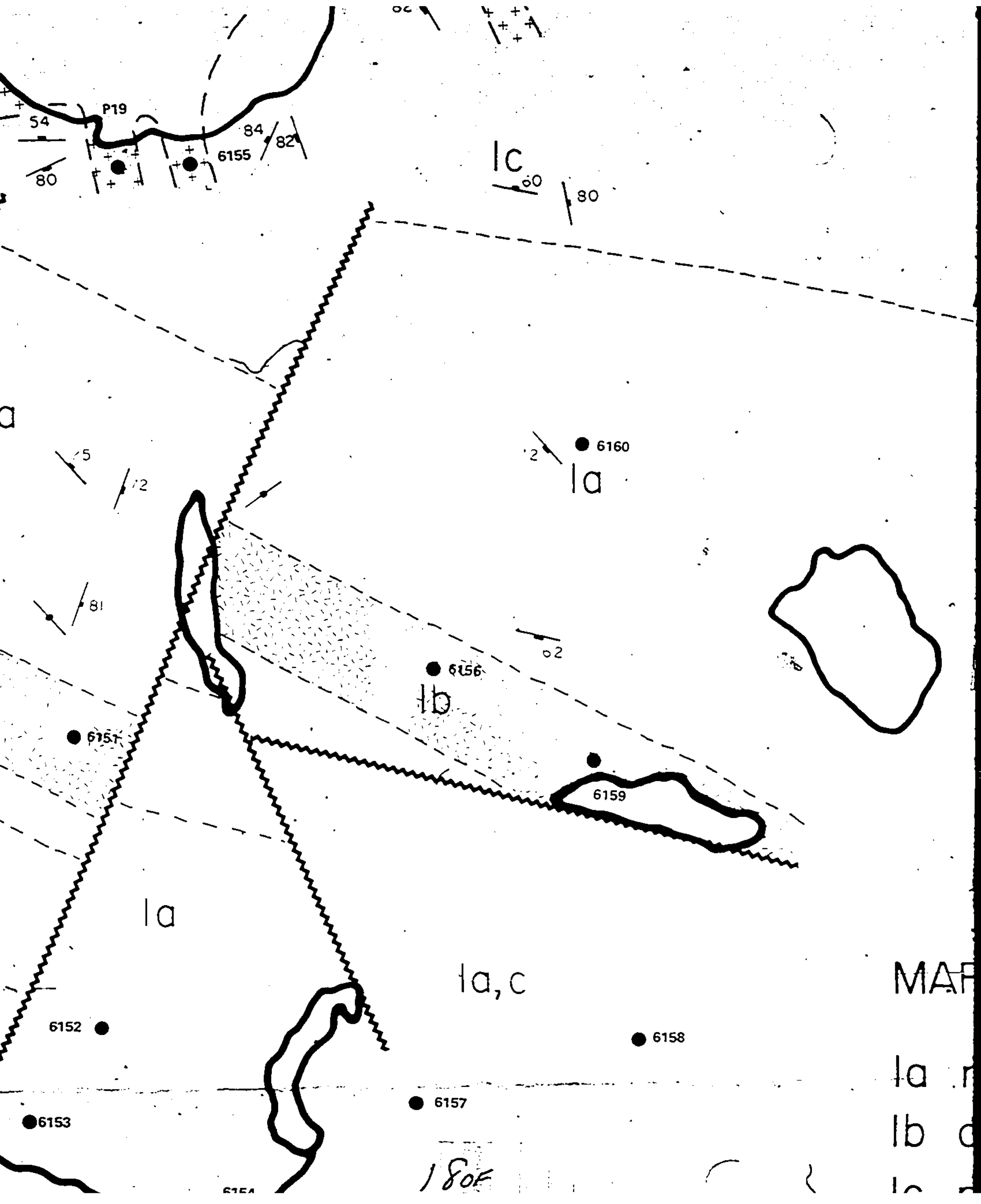
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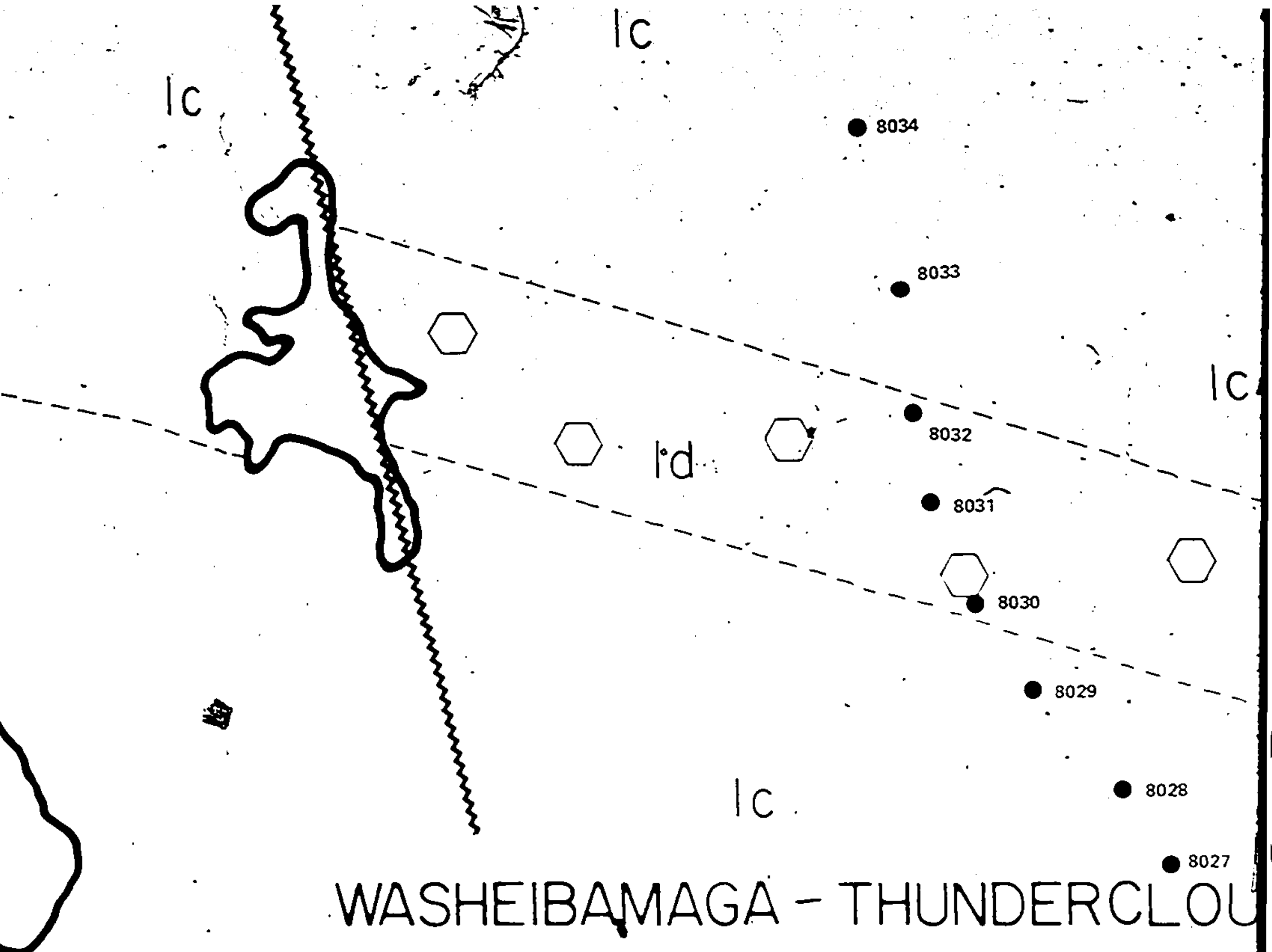



WASHEIBAMAGA - THUNDERCLOU
LAKES AREA

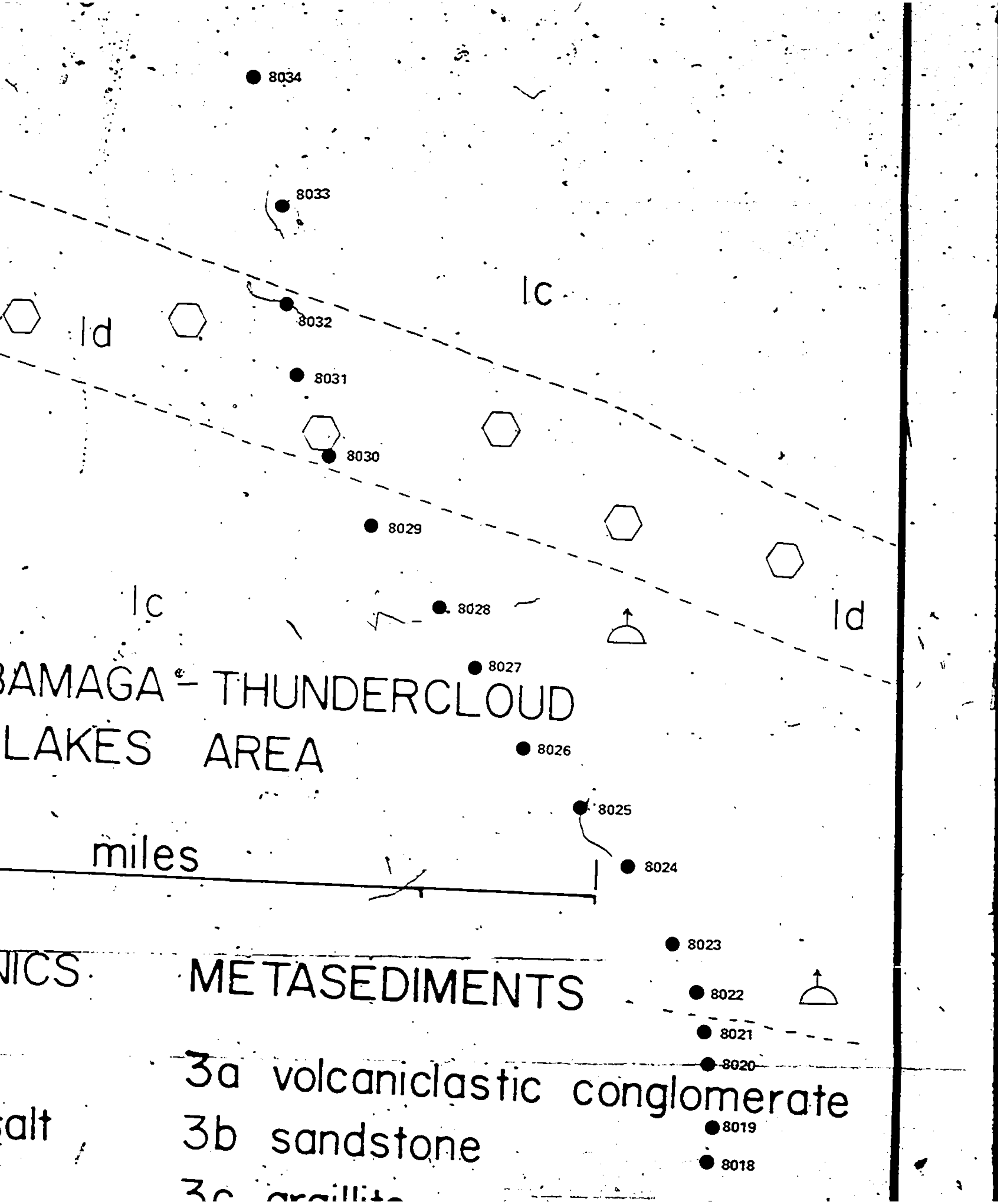
0 miles

MAFIC METAVOLCANICS

1a ~~massive basalt~~
1b coarse grained basalt

METASEDIMEN

3a volcaniclasti
3b sandstone



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BAMAGA - THUNDERCLOUD
LAKES AREA
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8025
miles
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NICS
METASEDIMENTS
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8021
8020
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alt
3b sandstone
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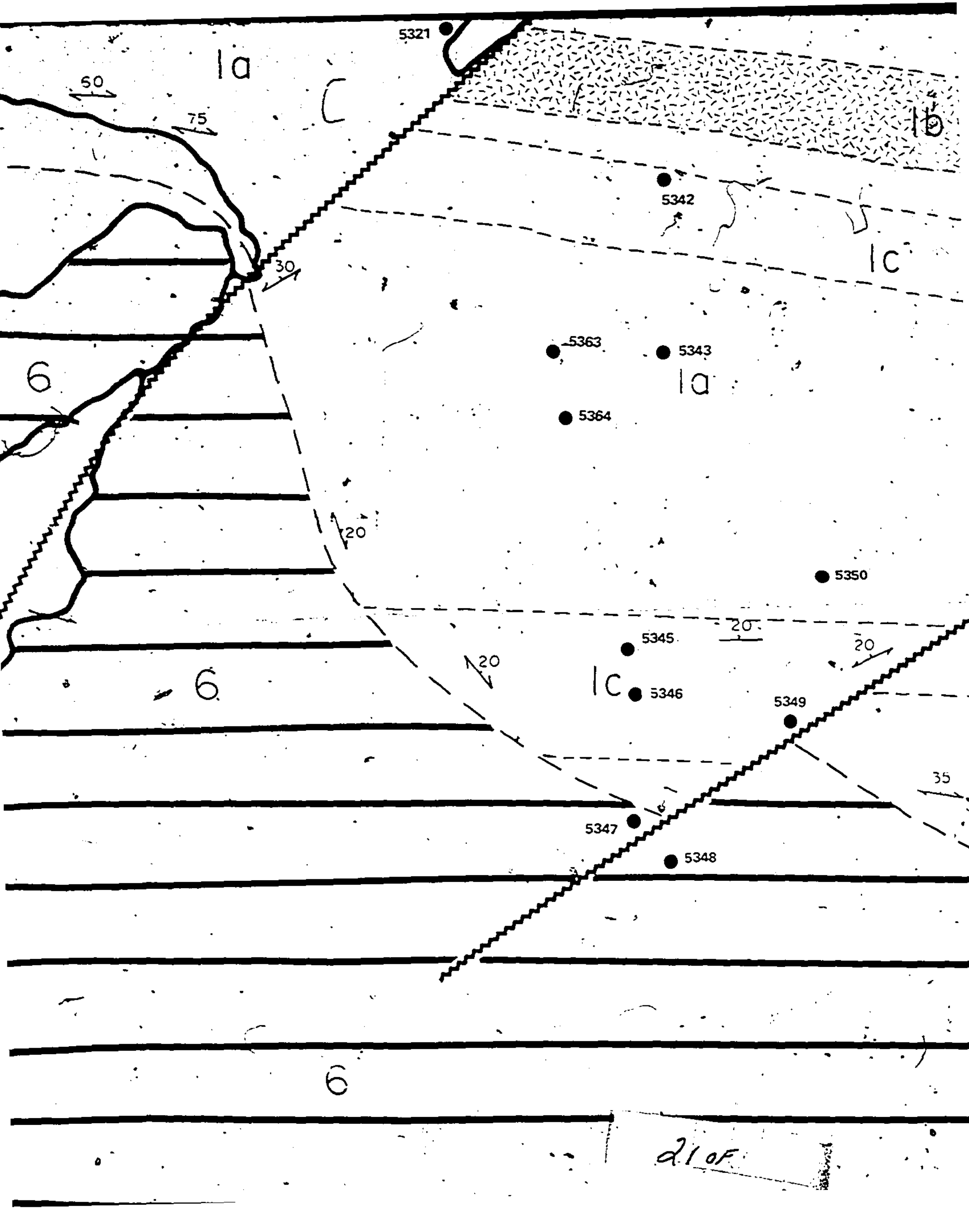
8018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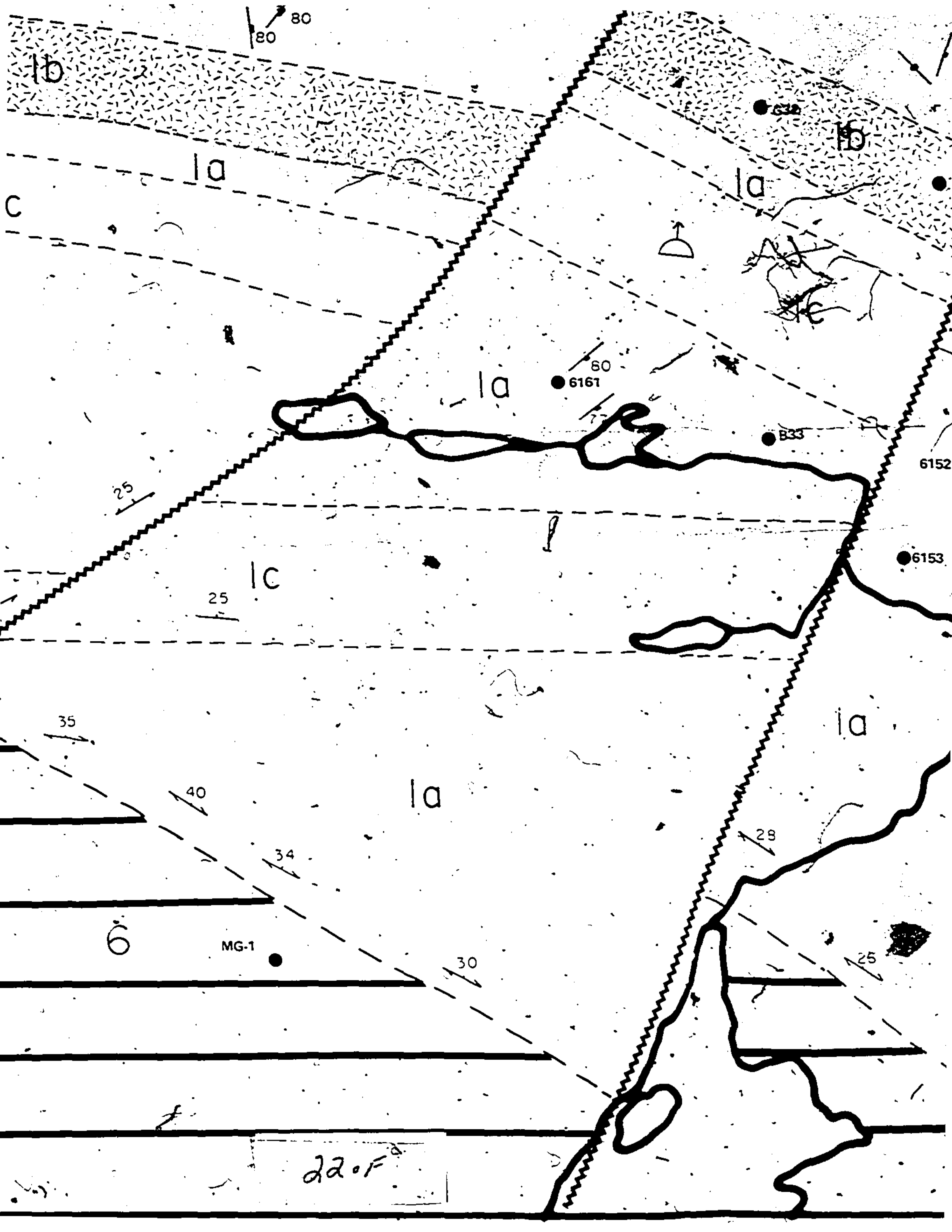

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Ia
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Ia
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MG-1
30
25
22.F


MAFIC

1a ma

1b coo

1c pill

1d por

1h am

FELS

2a fe

2b fe

2c dc

2g br

# WASHEIBAMAGA – THUNDERCLOUD LAKES AREA

8027

8026

0 miles

## AFIC METAVOLCANICS

massive basalt

coarse grained basalt

pillow basalt

porphyritic basalt

amygdaloidal basalt

## ELSIC METAVOLCANICS

a felsic tuff

b felsic breccia, agglomerate

c dacitic to rhyolitic flow

g brecciated porphyry

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## METASEDIMENTS

3a volcaniclastic

3b sandstone

3c argillite

## INTRUSIVES

4 gabbroic rocks

5 quartz porphy

6 granitic rocks

CLAST ELONGATION

FOLIATION

5000's BLACKBURN 1975 (O.D.M.)°

6000's McMASTER 1975 (O.D.M.)°

8000's McMASTER 1976

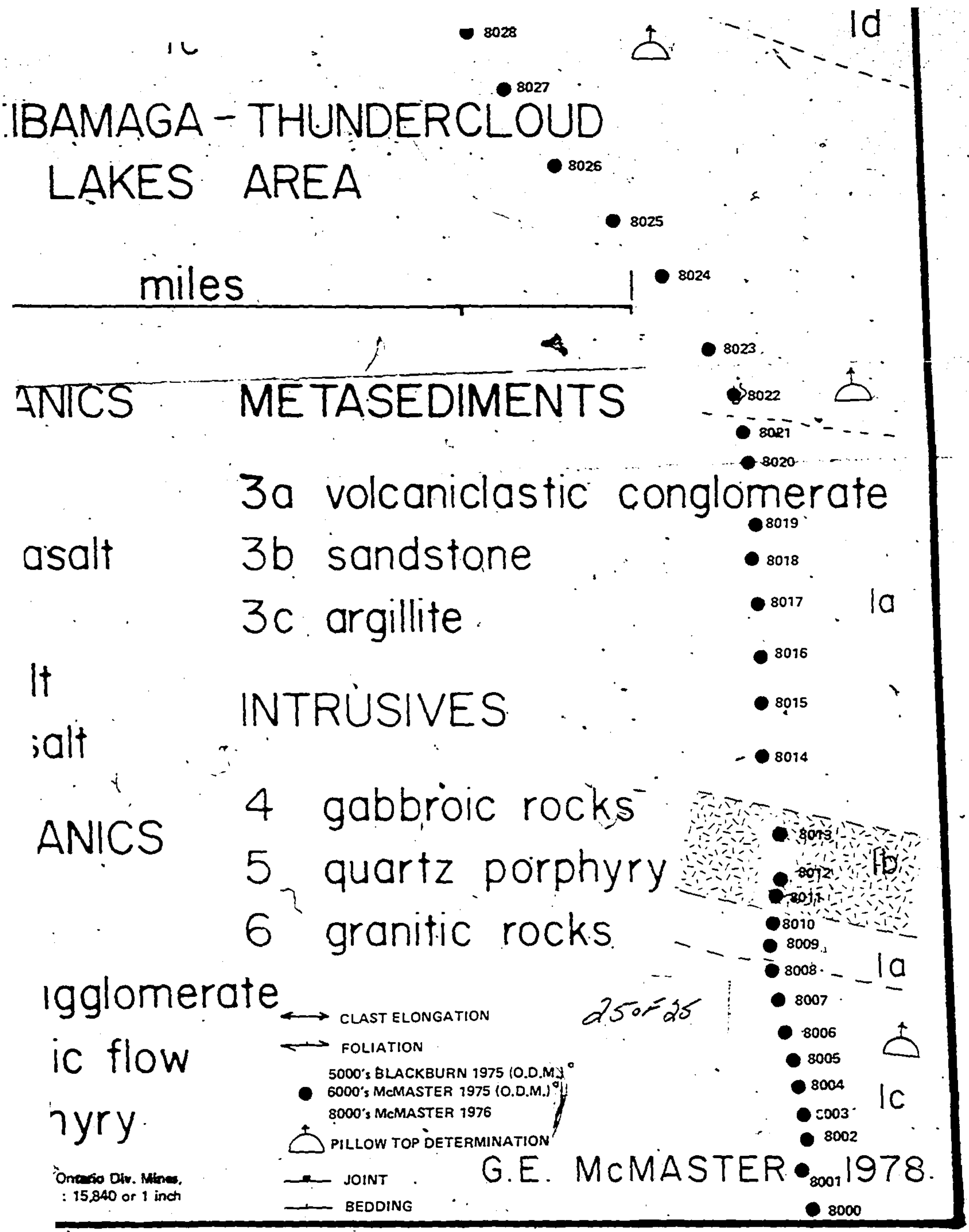
PILLOW TOP DETERMINATION

JOINT

BEDDING

G.E. Mc

° Blackburn, C.E.
1976: Meggisi Lake Area, District of Kenora; Ontario Div. Mines, Prelim. Map P.1188, Geol. Ser., scale, 1 : 15,840 or 1 inch to ¼ mile. Geology 1975.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