EVOLUTION OF AN ARCHEAN GREENSTONE BELT IN THE STORMY LAKE - KAWASHEGAMUK LAKE AREA (STRATIGRAPHY, STRUCTURE AND GEOCHEMISTRY) - WESTERN WABIGOON SUBPROVINCE, NORTHWEST ONTARIO.

by

DAVID KRESZ

A thesis submitted to the Department of
Geology in partial fulfilment of the
requirements for the degree of
Master of Science

Brock University
St Catharines, Ontario.

KAWASHEGAMUK LAKE

ABSTRACT

330 km^2 of the eastern part of the Archean Manitou Lakes - Stormy Lake metavolcanic - metasedimentary belt have been mapped and sampled. A large number of rocks were analyzed for the major and trace constituents including the rare-earth elements (REE).

The Stormy Lake - Kawashegamuk Lake area may be subdivided into four major lithological groups of supracrustal rocks :

1) A north-facing mafic assemblage, consisting of pillowed tholeiitic basalts and gabbro sills characterized by flat REE profiles, is exposed in the south part of the map area and belongs to a 8000 m thick homoclinal assemblage outside the map area. Felsic pyroclastic rocks believed to have been issued from a large central vent conformably overlie the tholeiites.

2) A dominantly epiclastic group facing to the north consists of terrestrial deposits interpreted to be an alluvial fan deposit ; a submarine facies is represented by turbiditic sediments.

3) The northeastern part of the study area consists of volcanic rocks belonging to two mafic - felsic cycles facing to the southwest ; andesitic flows with fractionated REE patterns make up a large part of the upper cycle, whereas the lower cycle has a stronger chemical polarity being represented by tholeiitic flows, with flat REE, which are succeeded by dacitic and rhyolitic pyroclastics.

4) A thick monotonous succession of tholeiitic pillowed basalt flows and gabbro sills with flat REE represent the youngest supracrustal rocks.

The entire belt underwent folding, faulting and granitic plutonism during a tectono-thermal event around 2700 Ma ago. Rocks exposed in the map area were subjected to regional greenschist facies metamorphism, but higher metamorphic grades are present near late granitic intrusions.

Geochemical studies have been useful in 1) distinguishing the various rock units ; 2) relating volcanic and intrusive rocks ; 3) studying the significance of chemical changes due to post magmatic processes ; 4) determining the petrogenesis of the major volcanic rock types. In doing so, two major volcanic suites have been recognized : a) a tholeiitic suite, mostly represented by mafic rocks, was derived from partial melting of upper mantle material depleted in Ti, K and the light REE ; b) a calc-alkalic suite which evolved from partial melting of amphibolite in the lower crust. The more differentiated magma types have been produced by a multistage process involving partial melting and fractional crystallization to yield a continuum of compositions ranging from basaltic andesite to rhyolite.

A model for the development of the eastern part of the Manitou Lakes - Stormy Lake belt has been proposed.

ACKNOWLEDGEMENTS

I would like to express many thanks to Mr. C.E. Blackburn who encouraged me in carrying out this research, as many discussions in the field stimulated my enthusiasm. Many thanks go to other members of the field party during the summer of 1980, Ms. V. Opekar, Ms. E. Kristoff, Mr. T. Larivière and Mr. W. Kramer. Mr. Kramer shared the work of an entire field season in 1981.

I wish to express my gratitude to the Ontario Geological Survey for providing many appreciated services. Much time was spent by Dr. A. Van der Voet towards the analyses for the rare-earth elements by ICPS ; Mrs. B. Moore did some of the photography.

Dr. U. Brand and Mrs. J. Morrison made their research facilities, at Brock University, available for the chemical analyses by atomic absorption spectrophotometry and provided training and technical advice. Mrs. J. Pinder helped in carrying out analyses by XRFS and provided technical training as well as much assistance during numerous instrumental malfunctions.

Drs. M.P. Gorton and R. Hancock of the University of Toronto, kindly made the facilities for neutron activation analysis available and gave technical guidance. Dr. C. Cerminiani carried out electron microprobe analyses at the University of Toronto.

.../...

I wish to express many thanks to Dr. W.T. Jolly, my supervisor, for critically reviewing the manuscript and providing financial assistance from his research grant. Dr. H.R. Willaims also reviewed the manuscript and provided helpful comments.

Finally, to my wife, Evelyne, who put up with much work in typing, helping in many boring tasks and sharing one month of field work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

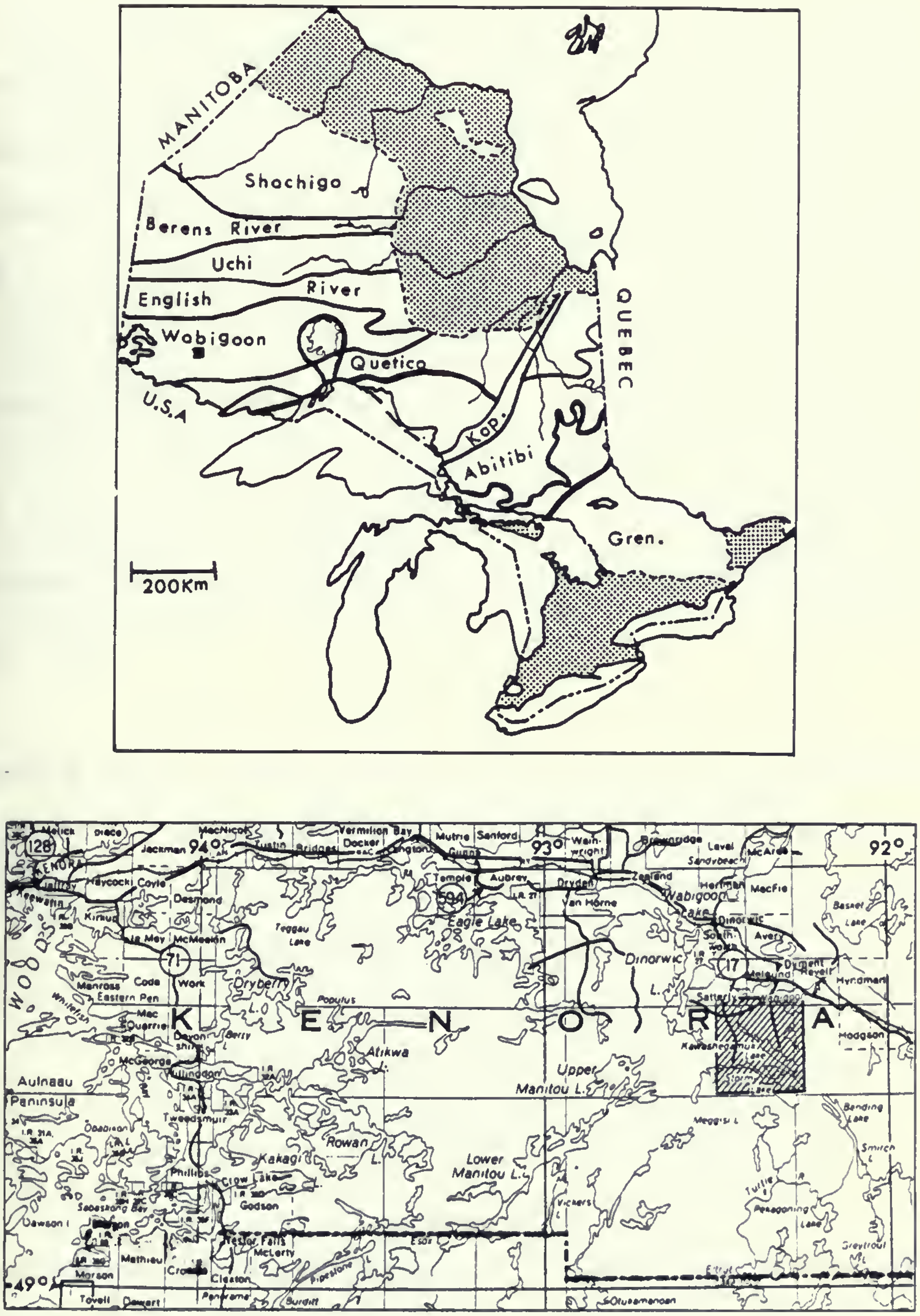
CHAPTER I - INTRODUCTION

i) Location and access

The map area lies between latitudes 49°32'30"N and 49°32'20"N and longitudes 92°I5'W and 92°30'W, in the district of Kenora. The map covers 333 km^2 (I28.5 mi^2), being I8.3 km (II.4 mi) by I8.3 km (Fig.I.I). It is included in the Dryden sheet No. 52F of the National Topographic Series, the O.G.S. Geological Compilation Map No. 2443 (Kenora - Fort-Frances) and the O.D.M. - G.S.C. Aeromagnetic Maps II44G and II45G. Kawashegamuk Lake is 45 km southeast of Dryden, the nearest town situated on the trans-Canada highway (Hwy. I7).

ii) Geomorphology

The Kawashegamuk - Stormy Lakes area shows typical topographic features of the Precambrian shield. It is essentially a nearly level peneplain about 380 m above sea level. The general landform is one of rolling hills not exceeding 80 m in height. Steep hillsides and cliffs at Kawashegamuk and Stormy Lakes give a more rugged aspect to the scenery. Approximately one third of the map area is occupied by lakes. The outline of these lakes is controlled primarily by the underlying bedrock and by structures developed during Archean tectonism such as foliation, shear zones, faults and joints. Most of these lakes are relatively shallow with depths ranging up to 20 m. Numerous air-photo linea-



Scale: 1:1 584 000 or 1 inch to 25 miles

Fig. I.I. : Location map of the study area

ments have been traced and have been added to the map. Some are up to 8 km long.These lineaments are generally interpreted to be faults, shear zones, mineralized zones and joints which have been accentuated by weathering.

iii) Nature of Pleistocene deposits

The glacial features are largely representative of the latest ice movements (Wisconsin) with only fragmental evidence of earlier events (Zoltai, I96I).

I) Moraine deposits : The scarcity of load carried by the glaciers did not favor the building of extensive moraines (Zoltai, I96I). Locally more elevated terrain covered with boulders and shallow till offers evidence of material deposited directly from the ice (Fig. I.2). Just south of Stormy Lake is a thicker cover of ground moraine (Roed, I980).

2) Glaciofluvial and outwash deposits : These are restricted to the west end of Snake Bay, consisting of irregularly stratified sand and gravel filling a pronounced valley. These deposits are covered by glaciolacustrine sediments (Roed, I980), (Fig. I.3).

3) Glaciolacustrine deposits : A broad area at the northwest end of

Fig. I-2 : Glacial deposits consisting largely of boulders and sandy material, south of Stormy Lake.

Fig. I-3 : Stratified gravel and sand deposits filling a valley at Snake Bay.

Kawashegamuk Lake is covered with fine grained sediments consisting of clay and fine sand which may be reworked outwash material by glacial Lake Agassiz (Satterly, 1960). Many calcareous concretions with a botryoidal habit occur in the clays and are most likely to be of diagenetic origin. The presence of those lime rich nodules may have interesting implications as to the source of the sediments. The last ice advance from the north-east as testified by the glacial striations on the Precambrian bedrock, cannot be the source since the Precambrian shield is very poor in calcium carbonate. This would signify that glaciers moving to the southeast originating from an ice centre located in Manitoba would have shed lime rich sediments in the Kawashegamuk Lake area before the last ice advance. The subject necessitates further investigation which is beyond the scope of this study.

Where glaciolacustrine deposits are found streams and rivers have meandering patterns, a feature which has been observed by Satterly in Revell and Melgund townships (Satterly, 1960).

iv) Previous geological work

Since A.C. Lawson first described the geology of the Lake of

the Woods area in 1885, many geological investigations have been carried out in northwestern Ontario, but many areas have been little mapped up to present time and remain poorly understood because many geologists restricted their studies to the vicinity of gold occurrences (Coleman, 1894, 1896 ; Parsons, 1911, 1912 ; Bruce, 1925 ; Thomson, 1936, 1938). Before Lawson's (1885) study in the Lake of the Woods area, the rocks making up the supracrustal assemblage (metavolcanic and metasedimentary rocks) were called Huronian. Lawson put into doubt the correspondence of the Lake of the Woods rocks with typical Huronian rocks on the grounds of contrasting lithologies, general structure, relationships among major rock groups and environments of deposition and thereby defined the Keewatin "series". With the difficulties that Lawson was facing, his work was indeed well ahead of his time and it is not until many years later that his thoughts were confirmed by geochronologic studies using isotopes.

Deformed granitic rocks intrusive in the Keewatin "schists" were called "Laurentian" and later undeformed ones (post-tectonic) were referred to as "Algoman". Sedimentary rocks underlying the metavolcanics (greenstones), later referred as Keewatin, were termed "Coutchiching" while those stratigraphically above the lavas were designated as "Timiskaming" (Pettijohn, 1937).

The present study area has been investigated for the first time during the period 1895-97 (McInnes, 1895, 1896, 1897) and a map published in 1902 by the Geological Survey of Canada includes the western part of the present map area (McInnes et al., 1902). The second notable geological survey covering the Stormy -Kawashegamuk Lakes area

was made in 1932 by J.E. Thomson (1933). At that time an intensive search for gold deposits was going on and the Manitou Lakes area to the west was receiving much attention. Mapping carried out by the former Ontario Department of Mines covered the townships of Melgund, Revell and Hyndman adjoining the map area to the north (Satterly, 1960). To the west in the Manitou Lakes area, C.E. Blackburn carried out mapping to a scale of 1 inch to ¼ mile over the period 1972 to 1975 (Blackburn, 1976, 1979, 1981) and three reports as well as a synopsis of these reports (Blackburn, 1982) have been published.

In 1936, Pettijohn (1937) undertook a regional study of the metasedimentary rocks of northwestern Ontario in an attempt to study Archean sedimentation and to solve some correlation problems. While Pettijohn spent little time in the area studied here, his work elsewhere shed light on metasedimentary rocks occurring in the Stormy Lake area from both a sedimentological and comparative viewpoints.

During the 1963 and 1968 field seasons, A.M. Goodwin (1965, 1970) carried out stratigraphic studies supported by systematic sampling amd subsequent analysis of metavolcanic units over the entire region extending from the Lake of the Woods to the Manitou Lakes.

The study area also has been investigated as part of a regioanl study in 1977 (Trowell et al., 1980) on the stratigraphy, structure, emplacement and timing of mineral deposits in the Savant through Crow Lakes region.

In conjunction with the various mapping projects sponsored by the Ontario government, geochronological studies have been carried out under the direction of D.W. Davis (1980) of the Jack Satterly Geochronology Laboratory, Toronto.

v) <u>Present study</u>

Surveying the Kawashegamuk Lake area began in 1979 as part of a continuing program of mapping at a scale of 1:15840 (1 inch to ¼ mile) under the auspices of the Ontario Geological Survey and supervised by C.E. Blackburn. The project was resumed during the field season of 1980 and field work was carried out by C.E. Blackburn, F.B. Fraser and the present author who was then hired as a field assistant. The present author returned to the field during the summer of 1981 to complete the project, and spent a few weeks in 1982 to collect additional samples. Two preliminary maps covering the Kawashegamuk Lake area have been published by the Ontario Geological Survey (Kresz et al. 1982 a,b).

CHAPTER II - GENERAL GEOLOGY

The study area is located within the Superior Province of the Canadian Precambrian Shield. It is part of the Savant Lake - Crow (Kakagi) Lake metavolcanic - metasedimentary belt (Trowell et al., I980) of the western Wabigoon Subprovince (Goodwin, I970).

The area is composed primarily of Archean metavolcanic and metasedimentary supracrustal units (I). The supracrustals have been intruded by granitic rocks during the Kenora orogeny, from 2.7 to 2.5 b.y. To the west and to the north of the map area, northwesterly trending diabase dikes of middle to late Proterozoic age (Satterly, I960 ; Blackburn, I98I) occur. Such diabase intrusions have not been found in the present map area.

In the past the terms Keewatin volcanics, Coutchiching and Timiskaming sediments, Laurentian and Algoman intrusives were used in a systematic manner. In the intervening years major difficulties were met in trying to define the lower and upper limits of these rock stratigraphic units and major correlation problems have arisen. Thus, present terminology is based on lithologic characteristics rather than age or rock

---

(I) All rocks underlying the map area underwent profound mineralogical, chemical and textural changes following burial and tectonism events ; it is understood that all lithologies described have been metamorphosed.

genesis (Goodwin, 1970).

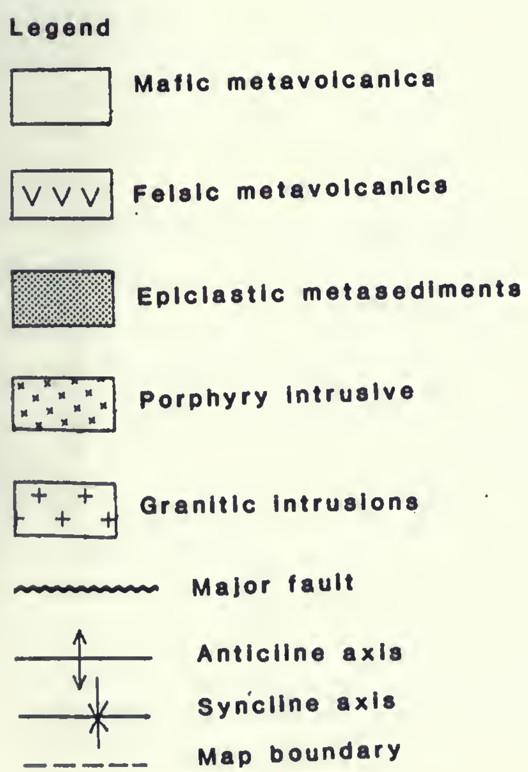
Stratigraphic Nomenclature

All supracrustal lithologies within the mapped area have been assigned to some rock stratigraphic unit with defined or inferred boundaries. Criteria for correlation are based on : 1) field relationships, 2) petrography, 3) chemical data, and 4) structural interpretation. The stratigraphic terminology has been applied in accordance with the recommendations outlined by the current code of stratigraphic nomenclature (American Commission on Stratigraphic Nomenclature, 1970). The names of stratigraphic units have been adopted from previously published material on the area and adjoining areas, since many units are continuous from one map area to the other. Although many units of relatively high rank within the stratigraphic hierarchy have a formal name today, most of the lower key units remain unnamed at the time of writing and therefore do not satisfy the requirements of the Code in conformity with Article 13, remark c,p. 129, and hence will be given informal names.

Part I - Position of the study area with respect to major structures within the western Wabigoon Subprovince.

The map area (Fig. II,I) straddles the east - central part of the crescent-shaped Manitou Lakes - Stormy Lake metavolcanic - metasedimentary belt (Blackburn, 1981) which is approximately 80 km long and 25 km in maximum width. The belt tapers out to the east at Kinmoapiku and Smirch Lakes and to the west at Lower Manitou Lake. Further west it

Fig. II-I : General structure of the "Manitou Lakes - Stormy Lake Greenstone Belt" and position of the study area



is contiguous with a belt of supracrustals that can be traced all the way to Kakagi (Crow) Lake and beyond towards Lake of the Woods and Shoal Lake (Blackburn, 1980 a). To the north, the belt merges with volcanics that extends in a northwesterly direction towards Wabigoon and Eagle Lakes. The so-called Manitou Lakes - Stormy Lake belt is flanked by three granitic batholiths. To the south, the belt girdles the northern part of the Irene - Eltrut Lakes Batholithic Complex (Sage et al., 1975). To the northwest and northeast the volcanics are intruded by the Atikwa Batholith and Revell Batholith respectively. Smaller intrabelt plutons intrude the supracrustals at Scattergood Lake, Taylor Lake and Stormy Lake.

Three major structures can be traced across the Manitou Lakes - Stormy Lake belt :

1) The Manitou Straits Fault (Thomson , 1934 ; Goodwin, 1965, 1970 ; Blackburn, 1981, 1982) is a major shear zone running in a northeasterly - southwesterly direction, essentially parallel to strata (Goodwin, 1965, 1970 ; Blackburn, 1982). Northwest of the fault zone the stratigraphy faces southward and southeast of the fault, facings are toward the north. On this criterion Goodwin (1965, 1970) concluded that the Manitou Straits Fault overprints a regional synclinal axis. If so, this fold would represent a major structure within the belt, however no further evidence has been observed in the field (Blackburn, 1981).

2) The Manitou Anticline (Goodwin, 1970) : Rocks of the west arm of the belt are folded about a major notheast plunging anticline paralleling the Manitou Straits Fault (Blackburn, 1980a , 1982). If the Manitou

Straits Fault indeed represents a sheared synclinal axis, then the rocks of the west arm of the belt are tightly folded by a syncline - anticline couple. Goodwin (1965, 1970) interpolated a syncline - anticline couple within the sequence southeast of the Manitou Straits Fault but mapping by Blackburn (1981) confirmed that rocks are homoclinally facing in a northerly direction.

3) The Kamanatogama syncline (Blackburn in Trowell et al., 1977 ; Blackburn, 1982) : The east arm of the belt is folded about a northwest - southeast trending syncline (Blackburn, 1980 a). The position of the axial trace of the syncline has been defined by means of pillow orientations (Blackburn, 1981, Kresz et al., 1982). Its easterly extension beyond Stormy Lake towards Bending Lake is hypothetical due to the lack of mapping southeast of the present map area.

Part II - Field relationships within the study area

The supracrustal rocks within the map area fall within four major lithological and petrochemical groups, all of which are folded about the centrally located Kamanatogama Syncline. Granitic rocks are scarce except in the northeastern part of the map where an intrusive granodiorite is present.

i) The Wapageisi Lake Group

From previous mapping considerations, the Wapageisi Lake Group (Trowell et al., 1980 ; Blackburn, 1982) is a continuous sequence

at the base of the Manitou Lakes - Stormy Lake belt extending from Lower Manitou Lake in the west to Wapageisi Lake in the east (Blackburn, 1980a). The group consists principally of mafic volcanics occurring as pillowed and massive flows, and minor breccia. Structurally, the Wapageisi Group is a homocline with shallow dips in the south becoming steeper toward the middle of the belt (Blackburn, 1982). West of the map area, Blackburn (ibid) subdivided the Wapageisi Group into several formations, some of which can be traced for up to 10 km. Within the present map area, the Wapageisi Lake Group appears to be composed of a lower mafic sequence stratigraphically overlain by a sequence of felsic volcanics.

I) The lower mafic volcanics ("Subgroup I")

Only the upper part of the mafic sequence is represented within the map area. It consists mainly of relatively undeformed pillowed aphyric and a few porphyritic flows ; diameters of individual pillows range from 25 cm to 60 cm (Fig. II-2). Pillow selvages are characterized by a dark green chloritic rim 0.5-2 cm in thickness on the weathered surface, contrasting with lighter colored interiors. Aquagene breccia and hyaloclastite make up interpillow material. In some places pillows appear to have been brecciated and are characterized by small elongated shapes rimmed by thick chloritic selvages probably representing a fine grained devitrified and altered aquagene basaltic tuff (Fig. II-3). Basaltic flows are characterized by a fine grained texture ; massive flows commonly have medium to coarse grained interiors. In several places the basalts are porphyritic with plagioclase phenocrysts ranging up to 5 cm in size

Fig. II-2 : Undeformed pillows in Wapageisi Lake Group basalts. Pillow sizes range from small pillow buds to large matress-shaped lava toes. Some pillows have shattered, producing hyaloclastite and pillow breccia. Most pillows here show radial cooling cracks.

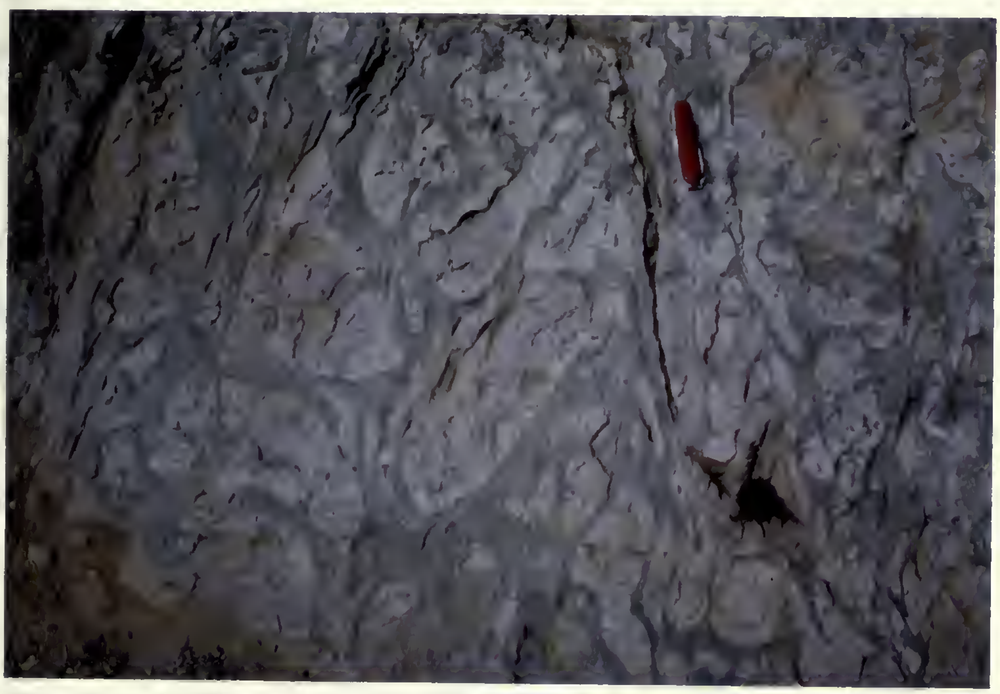


Fig. II-3 : Brecciated pillows in a chloritic devitrified hyaloclastite matrix.

and frequently retain a euhedral outline. In hand specimen the phenocrysts are white with a greenish color due to epidote and have a cherty appearance that results from the decomposition of feldspar to a fine grained mixture of albite and epidote (saussurite). Phenocrysts occur in both massive and pillowed flows. Amygdaloidal basalts with small chlorite-filled vesicles occur locally. One exposure at Katisha Lake shows a variolitic basalt with varioles up to 2 cm in diameter.

2) Mafic intrusives within "Subgroup I"

In many localities no distinction can be made between coarse grained flow interiors and feeder dikes from texture alone. A non equivocal feeder dike has been observed I km due south of Kawijekiwa Lake on the south map boundary. The dike is 2-3 m wide cutting pillowed basalt at high angle. It contains rounded granitic xenoliths (Fig. II-4) presumably from an underlying granitic body.

Two layered gabbro bodies occur within the map area. They are elongated with long axes parallel to bedding which is defined by pillow elongation and packing patterns, and therefore they have been interpreted as sills. One stratified sill occurs at Katisha and Seggemak Lakes ; it is 2.8 km long with a maximum thickness of 600 m. It is here informally called the "Katisha Lake Gabbro". Samples were taken across the sill for chemical analysis. Another 500 m thick layered sill of undetermined length was traced discontinuously for 3.2 km within the map area southwest of the Katisha Lake Gabbro sill. The emplacement of these mafic intrusions is

Fig. II-4 : Granitic xenolith in a gabbro dike. Subgroup II, Wapageisi Lake Group.

Fig. II-5 : Volcanic breccia near the base of Subgroup II (Wapageisi Lake Group). Mafic clasts dominate, but felsic types are common. The large felsic clast at the bottom of the picture shows mafic inclusions ; a reaction rim is visible on the larger mafic fragment to the left. This is indicative that mixing of two magma types in a shallow magma chamber occurred, and may be evidence that explosive volcanism is triggered by magma mixing (cf. Sparks et al., 1977). All clasts are vesicular.

unclear, but it seems reasonable to assume that they probably were emplaced during episodes of magma replenishment in a synvolcanic rift zone or a shallow magma chamber.

3) The upper felsic volcanics ("Subgroup II")

Overlying the mafic composite basalt - gabbro sills sequence is a thick wedge-shaped sequence of felsic pyroclastics. In the west, the wedge tapers off at the western shoreline of Kawijekiwa Lake and in the east just south of Bending Lake (Blackburn, 1980a). The exposed central stratigraphic thickness is approximately 2.5 km after correction for a dip of 45°. The felsic volcanics have been considered to belong to the Wapageisi Lake Group on the assumption that felsic volcanism took place at the closure of the period of mafic volcanism as there is no evidence of an unconformity.

Nature of the felsic volcanics

"Subgroup II" can be divided into three distinct formations :

a) a lower formation ("Formation I") composed of mafic to intermediate lapilli tuff to tuff breccia ;

b) a middle formation ("Formation 2 ") composed of intermediate to felsic lapilli tuff to tuff breccia ;

c) an upper formation ("Formation 3 ") composed of felsic tuff to lapilli tuff.

"Formation I" may be further subdivided into a basal member which is several meters thick and an upper member approximately I50 m thick but gradually thinning out westward.

The basal member ("Member 1A") directly overlies the Wapageisi Lake basalts. Near the contact, a unit no more than several metres thick consists of fine grained thin bedded tuff of mafic to intermediate composition displaying sedimentary structures characteristic of turbidites such as graded bedding, laminations and soft sediment deformation features, including load casts and flame structures. These structures are indicative of subaqueous, distal deposition. A similar occurrence has been observed in the west, where the felsic sequence tapers out just south of the portage linking Katisha and Kawijekiwa Lakes. Other fine grained mafic tuffs have been mapped along strike between the two locations but no conspicuous bedding structures have been noticed. This unit is rapidly transitional into the upper member.

The upper member ("Member 1B") consists of lapilli size to block size fragmentals having a heterolithic composition ; clasts are dominantly mafic (Fig. II-5), and set in fine grained chloritic matrix, possibly a mafic tuff. Variation in size, composition and abundance of the fragmentals differs along strike. It is not clear whether the mafic clasts are epiclastic, reworked Wapageisi basalts or are true pyroclastics derived from the vent that built the felsic sequence.

"Formation I" has been traced discontinuously for 4.5 km across the map area.

"<u>Formation 2</u>" is characterized by intermediate to felsic lapilli tuffs and tuff breccias. the base of the formation presents coarse fragmentals having a bimodal clast composition with mafic and dacitic clasts set in a chloritic tuff. This heterolithologic part is then overlain by monolithologic lapilli tuffs and tuff breccias of dacitic composition. Primary structures are rare : bedding, apparently dipping at steep angles has been recognised in only two places. A strong foliation parallels bedding on the outcrop surface and clasts are highly strained. A few mafic lenses representing sporadic episodes of mafic volcanism occur within the formation. "Formation 2" is probably in gradational contact with "Formation I".

"<u>Formation 3</u> " is much more felsic than the underlying pyroclastics although the contact is probably gradational with "Formation 2 ". Within the map area the formation is thickest at Stormy Lake but it tapers out at the western shoreline of Kawijekiwa Lake.

The bulk of this unit consists essentially of crudely bedded intratelluric crystal tuffs, lapilli tuffs and tuff breccias. At Kawijekiwa Lake, Gawiewiagwa Lake and south of the part of Katisha Creek which enters Snake Bay, the tuffs are homogeneous, consisting of sodic feldspar and quartz crystals and angular fragments of quartz porphyry set in an aphanitic, light colored, sericite-rich matrix. Coarser fragmentals include rhyolitic breccia at Gawiewiagwa Lake. South of Katisha Creek, the intratelluric crystal tuff is exceedingly homogeneous. Petrographic examination confirms the true pyroclastic nature of these rocks (see Chapter III). In the east at the strait linking Stormy Lake and Snake Bay, the felsic crystal tuffs are

laterally transitional into coarser fragmentals being represented by dacitic to rhyolitic lapilli tuffs and tuff breccias ("Formation 4" on Map 2). These coarser pyroclastics probably represent a different volcanic facies. Clasts are highly flattened and the rocks are strongly fissile in many places. Between Snake Bay and Stormy Lake, numerous drag folds plunging to the west suggest that shearing took place. Primary structures within the formation are scarce : bedding has been found as indistinct to crude layering within the tuffs. The general orientation of units of different overall composition and contacts between the formations gives a general trend of the beds.

Just to the west of the strait connecting Snake Bay to Stormy Lake, the felsic tuffs are overlain by a mafic unit 400 m in maximum width, consisting mainly of tuffs and lapillistones with interbedded lenses of dark grey to black colored chert-magnetite iron formation. These lenses range from I0 to 80 cm in thickness at an outcrop situated on the shore of Snake Bay ; continuity of these lenses along strike has not been determined.

ii) <u>The Stormy Lake Group</u>

The Stormy Lake Group (Blackburn, I982) is a 3000 m thick sequence of epiclastic and pyroclastic rocks overlying the Wapageisi Lake Group. It is part of an assemblage that Thomson (I933) called the Manitou "Series", but because the Stormy Lake Group is separated from the Manitou Group (Blackburn, I982) by the Taylor Lake Intrusion and because relationships across it are not clear, Blackburn (ibid) decided

to divide Thomson's Manitou "Series" into two distinct groups.

The western part was mapped by Blackburn (1981) and was included as part of theses projects by Bertholf (1946) and McMaster (1978).

A wide range of distinctive, mappable lithologies have been encountered in the field. Because these lithologies vary laterally as well as vertically, it is impossible to ascertain the timing of deposition of one type of clastic material. Furthermore, various pyroclastic and epiclastic rocks making up the Stormy Lake Group may differ in their physical characteristics but remain genetically interrelated. For these reasons the concept of facies is introduced here in describing the different distinctive units. The sedimentology and criteria for assigning an environment of deposition of the different facies making up the Stormy Lake Group is further discussed in Chapter V.

Based on field relations, the Stormy Lake Group may be divided as follows :

Facies I : Rhyolitic autobreccias, flows and ignimbrites, coarse pyroclastics, laharic breccias, tuff and lapilli tuffs, and related epiclastic proximal sediments ; subvolcanic intrusion.

Facies II : Lithic arenites with conglomeratic beds and lenses (Subfacies IIa) ; coarse polymictic conglomerate (Subfacies IIb).

Facies III : Oligomictic "volcanogenic" conglomerate ; minor pyroclastic lenses and basalt flows.

Facies IV : Feldspathic and lithic arenites, siltstones and argillites ; minor conglomeratic and pyroclastic lenses.

Facies V : Siltstones, argillites, chert-magnetite iron formation.

Facies I is characterized mainly by volcanic deposits and derived epiclastic sediments. The facies is well exposed near the western shore of Washeibemaga Lake but gradually thins eastward and tapers out at Seggemak Lake. McMaster (1978) subdivided this sequence of felsic volcanics into 5 units that he termed Facies A, B, C, D, E. McMaster's Facies D refers to the Thundercloud Lake Stock (Blackburn, 1982) which intrudes the Wapageisi Lake Group just outside the southwest corner of the map area. The intrusion is considered to be a subvolcanic equivalent of autoclastic (McMaster's Facies E) and pyroclastic (McMaster, Facies A, B, C) rocks of rhyolitic to dacitic composition making up Facies I. For this reason the Thundercloud Intrusion is considered to be an integral part of the Stormy Lake Group (Blackburn, 1982 ; McMaster, 1978).

The Thundercloud Lake Stock is a tear drop shaped body 4 km long and 2 km wide, with several apophyses projecting radially outward from the stock and probably linking the intrusion to a series of felsic dikes crosscutting the Wapageisi volcanics. In outcrop, the intrusion is characterized by an aphanitic, white to buff colored rock containing about 40% quartz and feldspar phenocrysts. The quartz phenocrysts appear as 0.5 to 5 mm in diameter glassy eyes and the feldspar phenocrysts, although quite rare, are 15 mm orthoclase euhedra displaying carlsbad twinning. The rock has therefore been called quartz porphyry. It is essentially massive and homogeneous throughout its occurrence ; however, foliated porphyry has been encountered which is probably related to sheared zones being characterized in the field by severely weathered and

iron stained surfaces. The quartz porphyry consistently carries I to 2% pyrite as disseminated small grains in the matrix, strongly suggesting that sulfur was not lost by effervescence of gases. Northward towards Washeibemaga Lake, the Thundercloud Porphyry grades into a brecciated form of porphyry with fragments up to a metre in diameter set in crystal-rich matrix (McMaster, I978). The clastic nature of the porphyry is discernible only in weathered surfaces. The fragmented porphyry has been referred to as a porphyry autobreccia by Blackburn (I98I, I982) and by McMaster (I978). Overlying the porphyry and the porphyry autobreccia is a series of felsic flows, pyroclastic rocks, tuffs and minor associated sedimentary rocks which are genetically related to the Thundercloud Porphyry (Blackburn,ibid.; McMaster, ibid.).

Facies II has been divided into two subfacies with a gradational contact. It is 300 to 400 m wide north of Seggemak and Katisha Lakes, but thickens rapidly at Kawijekiwa Lake finally forming a lens shaped body I500 m wide at Gawiewiagwa Lake, thinning out at Snake Bay. Facies II is essentially a unit of conglomerate characterized by diversified clast lithologies. However, volcanic derived clasts of various compositions are dominant, especially near the lower contact. North of Seggemak Lake, Facies II consists of a sandy matrix-supported conglomerate and lithic arenites with pebble rows (Fig. II-6). Because of the high abundance of arenites and lack of clast supported conglomerates, this constitutes Subfacies IIa. The more conglomeratic parts of this subfacies displays a large variety of clast types and sizes. The clasts range in size from I to I50 mm. The ones which are over I0 mm are generally well rounded while those which are smaller are highly angular ;

Fig. II-6 : Bedding characterized by pebble rows (Subfacies IIa, Stormy Lake Group).

Fig. II-7 : Polymictic conglomerate of Facies II, Stormy Lake Group. Among the clasts are chert (jasper), basalt, dacite, and a foliated type.

90% of all clasts are of volcanic origin ranging from rhyolite (white) through to basalt (dark green). The more pumiceous clasts have chlorite-filled vesicles. Quartz porphyry clasts are found as well, suggesting that the felsic clasts may have been derived from the Thundercloud porphyry and its volcanic equivalents. Clasts of red jasper, vein quartz and schistose types (Fig. II-7) are also present. The matrix containing the clasts is highly chloritic (dark green) with 5% or less of quartz grains. Bedding is clearly visible within the sandy parts of Subfacies IIa where stratification, pebble rows and cross-beds have been observed.

Subfacies IIb makes up most of Facies II. It is of constant thickness from Seggemak Lake eastward towards Kawijekiwa Lake where it abruptly increases in width. It is easily distinguished from overlying Facies III from the wide variety of clast types making up the conglomerate. Primary structures are observed mostly in more sandy parts of Subfacies IIb where bedding, large scale cross-beds, scour marks and pebble rows (Fig. II-8) can be distinguished. The base of Subfacies IIb consists mainly of volcaniclastic conglomerate with clasts ranging in size up to boulder-size material and having subangular to well rounded shapes. The various fragmentals have different rheologic properties when subjected to stress, therefore it is likely that some clasts especially pumiceous fragments have suffered strain and their elongation as a result may not be primary. Most clasts have a felsic to intermediate composition according to the weathering color which is white to light grey, but they seldom bear modal quartz and are often highly vesicular to pumiceous. A large number of these clasts are spotted with dark green chlorite masses that are probably degraded pyroxene or amphibole

Fig. II-8 : Large cross-beds in conglomerate of Facies II, Stormy Lake Group.

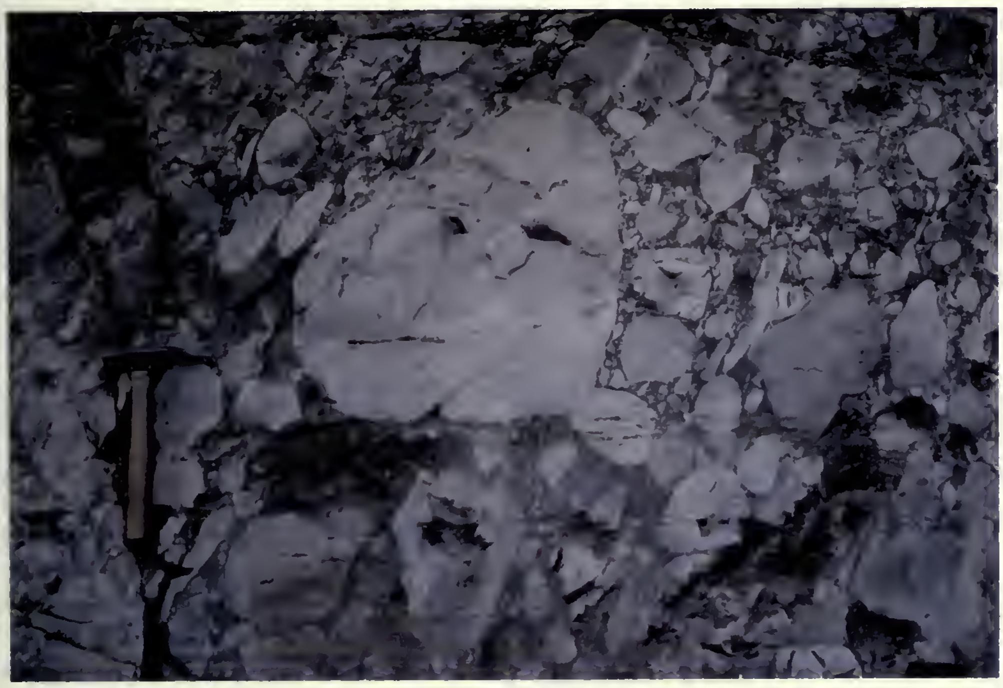


Fig. II-9 : Massive volcaniclastic conglomerate at the base of Facies II. Some felsic clasts are stained green by fuchsite (above hammer) ;a weathering rim is present on the cobble to the right of the hammer. The matrix is a chloritic tuff.

phenocrysts ; no similar rocks have been observed in the Wapageisi Group. Moreover, truly mafic fragments are relatively uncommon and rarely exceed 10% of the total clast content. The matrix tends to be more mafic and darker in color than the fragmentals. The more felsic clasts which tend to have rhyolitic composition are commonly colored yellow green by fusch-site (Fig. II-9). The more volcaniclastic part of Subfacies IIb is over-lain by conglomerates which gradually become more polymictic upward. Among the various clast types, the following lithologies have been observed : volcanics (large compositional range), jasper, jasper-magnetite iron-stone, quartz porphyry, feldspar-quartz and feldspar porphyry, various granitoids some having blue quartz which is common to Archean granitoids, chert of various colorations, vein quartz and conglomerate. There is a wide range of clast sizes up to 1 m in diameter. Most non-volcanic clasts; especially near the base of Facies II display weathering rinds up to 5 cm thick which are lighter in color then the rest of the clast (Fig. II-10). The conglomerates are mostly clast-supported in which the matrix consists of immature, reworked fine grained volcanic material. The conglomerates are interbedded with lenses of lithic and feldspathic arenites whose thicknesses vary up to several meters. The sandy units have distinct bedding, but particle size grading has not been observed. Large scale wedge shaped and trough cross stratification with sets up to 40 cm in thickness is associated with the sandy units. Cosets have not been observed.

Bedding west of Kawijekiwa Lake trends consistently east-west. However, in the thickest part of the facies, the bedding is more incon-sistent, trending north east on the west side of the bulge and changing to south east where the bulge tapers out. Bedding appears to parallel

Fig. II-10 : Volcanic clasts showing weathering rims in a polymictic conglomerate, Facies II, Stormy Lake Group.

Fig. II-11 : Foliation - bedding cross-cutting relationship in a polymictic conglomerate of Facies II. Bedding is defined by a sandy unit.

the general outline of Facies II. The east-west foliation, west of Kawijekiwa Lake becomes progressively oriented in a northwesterly direction to the northeast and east of Kawijekiwa Lake, displaying good crosscutting relationships with bedding (Fig. II-11).

Facies III conformably overlies Facies II. The contact is marked by a decrease in the abundance of exotic clasts and by a net increase in volcaniclastics. West of Kawijekiwa Lake, the contact is defined by thin tuff beds of felsic to chloritic composition associated with felsic lapilli tuffs and tuff breccias containing numerous large euhedral quartz eyes. The facies homogeneously consists primarily of coarse fragmentals, mostly of volcanic nature over a thickness of 2500 m at Washeibemaga Lake. The degree of reworking of the clasts is highly variable throughout the formation. In some exposures, clasts of subangular to subrounded shapes predominate while in others well rounded shapes prevail. In numerous places, exotic clasts such as granitoids, orthoquartzite like material, jasper-magnetite iron-stone and quartz-feldspar porphyry (Fig. II-12) have been observed, but never make up more than 1 or 2% of the total clast content. Normally they are well rounded. Most of the volcanic clasts weather white. The degree of vesicularity of the fragments varies from 0 to 50%. The composition among the clasts is uniform however some exposures reveal more diversified types (Fig. II-13). Size sorting is very poor ; clasts range up to 1 m in diameter. The matrix to the fragmentals consists of tuffaceous material or very immature lithic arenite. The ratio matrix/clasts seems to increase eastward.

Fig. II-12 : Volcaniclastic conglomerate with admixed exotic clasts such as jaspillite (above scale) and granodiorite. Near the top of Facies III.

Fig. II-13 : Clast supported volcaniclastic conglomerate within Facies III. The large clast in the centre of the picture is a basaltic pillow. Note the high vesicularity in every clast.

Fig. II-14 : Cross-beds in a sandy unit within Facies III.

Fig. II-15 : Alternating arkosic and wacke beds. Same outcrop as Fig. II-14.

In the west, the conglomerates are mainly clast supported ; while in the east, where Facies III gradually thins, sandy interbeds or lenses up to several metres thick become more abundant. These sandy units display cross-bedding and cross-laminations (Fig. II-14), crude size-grading and well developed bedding defined by alternations of sandstones and wacke-rich layers (Fig. II-15). The arenitic units consist predominantly of lithic fragments of volcanic origin and feldspar. In the west, abundant quartz grains, 2-3 mm in diameter, occur within the conglomerate, probably as a result of weathering of the Thundercloud porphyry or its derivatives, which carry quartz phenocrysts of similar size. Furthermore clasts with a fuchsitic green coloration are present in the vicinity of Dark Horse Lake, suggesting that some of the fragmentals were derived from adjoining pyroclastics. Rounded cobbles and boulders displaying weathering rims analogous to those found within Facies II are present.

Several single basaltic flows have been delineated within Facies III. These flows are less than 100 m thick and the longest has been traced for 1000 m. They are all characterized by a large number of amygdules composed mainly of sugary white quartz and brown ankerite. In two places lava toes were formed by subaerial flows entering small bodies of water.

Bedding structures strike in an east-west direction at Washeibemaga Lake, but acquire a southeast direction further east. The dip is steeply inclined to vertical. Foliation, which is defined by clast elongation and cleavage, is essentially parallel to bedding and steeply dipping northward.

Facies IV represents a unit with maximum thickness of 2000 m consisting of arenite, siltstone, wacke and mudstone. In the west it overlies Facies III conformably but the nature of the transition is vague due to poor exposure. At Stormy Lake it directly overlies the felsic volcanics, the contact being underwater. The best exposures are at Stormy Lake where outcrops on the shoreline display interbedded sandstone, wacke and slaty argillite. The sandstones are variable in composition, but generally contain up to 40% quartz and 60% white feldspar, lithic fragments and matrix, such that they are termed lithic arkoses and feldspathic litharenites (McBride, 1963). The rocks are usually coarse-grained (0.5 to 2 mm), with angular grains, suggesting little reworking. Sandstone which contains more than 15% of fine matrix is designated as wacke (Young, 1967). Normal size grading is associated with them as well as turbiditic siltstone and mudstone beds. Only the A, B, D and E divisions of the Bouma (1962) model of turbidites have been observed. Argillite beds, ranging from 1 cm to several metres in thickness normally have well developed slaty cleavage. These fine-grained sediments are dark grey in color ; cleavage surfaces are shiny due to fine-grained, oriented sericitic white micas. Rare almandine garnet suggests that pelitic layers are present.

Bedding is oriented in a southeasterly direction, while dips range from 60^{o} to 90^{o}southward. All top direction indicators (graded-beds, cross-beds) suggest that the beds face to the north, implying that strata has been overturned in most places. Foliation attitudes are parallel to subparallel with bedding.

To the southeast towards Bending Lake, the sediments consist of magnetite iron-stone intercalated with sandstones of probable distal

turbidite origin (Trowell et al., 1980), constituting Facies V. The transition between Facies IV and V is beneath Stormy Lake and the extensive drift cover toward the south. Aeromagnetic surveys reveal a strong positive anomaly between Stormy Lake and Bending Lake (O.G.S., Geophysical/Geochemical Series, 1981).

iii) The Boyer Lake Group

The Boyer Lake Group (Blackburn, 1982) is a thick, monotonous sequence of massive and pillowed basalts that is folded about the Kamanatogama Syncline (Blackburn, 1982), the axial trace of which is continuous across the entire map area. The thickness of the Group is indeterminate due to folding, furthermore the relationship between the Boyer Lake volcanics and mafic volcanics to the northeast and the Wabigoon Lake metavolcanics (Trowell et al., 1980) remains unclear.

The contact between the Boyer Lake and Stormy Lake Groups is presumably faulted. Blackburn (1981, 1982) and McMaster (1978) found evidence that a major fault marks the contact west of the study area. Within the present map area the contact is underlain by Washeibamaga Lake, Snake Bay and thick glacial deposits (Fig. I-2) filling a valley between the two lakes. Structures (see Chapter IV) near the contact indicate that shearing occurred. In the Stormy Lake area, the contact is an abrupt transition between Facies IV of the Stormy Lake Group and pillowed basalts. No evidence of an unconformity is present, so it is likely that the relationship between the two Groups is at least in part conformable.

Within the map area, the Boyer Lake Group consists almost entirely of massive and pillowed basalt flows. The basalts are essentially fine-grained but some of the massive flows present a microgabbroic texture which is often difficult to distinguish from intrusions. They are essentially aphyric ; in hand specimen the rocks are typically dark green in color. Pillows are commonly 50 cm to 100 cm in size ; however, they are highly elongated in the vicinity of the Kamanatogama Syncline axial trace and along the southern contact. Many pillows have concentrations of carbonate amygdules along rims. In a few places, pillows contain varioles which increase in size towards the centre of the pillow and coalesce.Some outcrops display brecciated pillows, pillow breccia and individual pillows set in a matrix of aquagene tuff. In the northwest part of the map area fragmentals having a more felsic character occur among pillowed flows and mafic tuffs. They appear as white, highly vesicular and angular clasts from 2 to 20 cm in size, set in a dark green mafic tuff.

In the northeast part of the map area, the supracrustals have been intruded by numerous felsic bodies and have been highly carbonatized by hydrothermal activity ; as a consequence many primary structures have been destroyed.

In the southeast, at Stormy Lake, four bands of sediment interfinger with the Boyer Lake basalts and straddle the Kamanatogama Syncline. These sediments consist mainly of lithic and feldspathic arenite interbedded with wacke displaying graded bedding, siltstone and argillite. Macroscopically, the rocks are analogous to sediments of the Stormy Lake Group belonging to Facies IV, and as a consequence have been considered

as being part of the Stormy Lake Group (Kresz et al., 1982).

The Boyer Lake Group is intruded by numerous extensive mafic sills up to several hundred metres thick. The longest such sill studied here is 8 km in length. Most of the thicker sills have a textural and mineralogical layering. McMaster (1975) who studied the petrography and geochemistry of a thick gabbroic sill just west of the current map area has confirmed the presence of a distinct petrographic and geochemical zonation across the sill. These sills have probably been intruded during Boyer Lake volcanism.

The Boyer Lake Group is considered as a single formation because of its high homogeneity ; the sediments straddling the Kamanatogama Syncline at Stormy Lake may be considered as a distinct unit which belongs to the Boyer Lake Group but additional mapping to the southeast is warranted in order to confirm this.

iv) The Kawashegamuk Lake Group

Underlying the Boyer Lake Group to the northeast at Kawashegamuk Lake is a mixed sequence formed of tholeictic to calcalkaline flows and pyroclastics with a maximum apparent thickness of 7000 m. The group has been named after Kawashegamuk Lake on which it is well exposed (Blackburn and Kresz, 1981). The Kawashegamuk Lake Group is arcuate in shape and encloses the Revell Batholith which probably occupies the core of a major anticline. The trace of the axial plane of this anticline, here informally called the "Tabor Lake Anticline", parallels the northern boundary of the map area so that only one limb is exposed within the area under study. This limb, facing homoclinally to the southwest, is in intrusive contact

with the Revell Batholith, which may have assimilated some of the supracrustals at the base of the Group.

The upper boundary of the Group is marked by the southwestern shoreline of Kawashegamuk Lake at the transition from felsic pyroclastics to monotonous Boyer Lake Group basalts.Since no discordancy exists between the two groups, the contact is presumed to be conformable. The rocks are intensely sheared, altered and mineralized with pyrite and graphite along the contact zone. The lower part of the Group consists of massive and pillowed basalts being generally aphyric. These basalts are dark green to black and display no fabric nor primary structures. Petrographic examinations (see Chapter III) revealed a mineral assemblage characteristic of amphibolite grade metamorphism due to aureole effects.

Overlying these basaltic rocks is a unit of felsic volcanics consisting mainly of tuffs, tuffs breccias, rhyolitic flows and breccias. These felsic rocks have an intricate relationship with the basalts because they appear as highly irregular bodies which interfinger with the mafic lavas. At the Van Houten Gold Mine, a wedge of epiclastic sediments consisting of medium to coarse grained lithic arenite with interbedded siltstones argillite and thin magnetite iron formation beds is intercalated between mafic and felsic volcanics. The picture is further complicated by numerous gabbro bodies of highly irregular shapes. The inconsistent orientation of bedding structures, foliation and in some places the high angle cross-cutting relationship between bedding and foliation suggests that the area has been complexly folded.

This structurally complex assemblage is in turn overlain by another sequence of pillowed and massive basaltic to andesitic flows. These flows are in part aphyric, but horizons of plagioclase phyric lavas, with phenocrysts up to 5 mm in diameter and with up to 20% phenocrysts, may be traced for several kilometres such as "Formation P", Map 2. Many flows have carbonate quartz and epidote filled vesicles, most are relatively small but in some places larges amygdules of several centimetres in diameter are abundant (Fig. II-I6, I7, I8).

The color of the rocks ranges from dark green to light greyish-green ; size and shape of pillows vary and large pillows up to 2 metres are rather common. Pillow outlines have often been modified by strain so that many are flattened (Fig. II-I9), but in the northern part of the map area, notably in the vicinity of Tabor Lake, pillows retain their original shape (Fig. II-I6, I7, 20). Pillow rims are often vesicular throughout the Group. Aquagene breccia, pillow breccia and flow top breccia are much more commonly encountered in outcrop than in the Wapageisi Lake or Boyer Lake Groups.

A spectacular outcrop just west of the Kawashegamuk River and immediately south of Satterly Township displays pillows with peculiar shapes (Fig. II-20, 2I, 22). Many of the pillows occur isolated (Fig.II-23) in a matrix of hyalo-tuff (Fig. II-24) and show an unexplained concentric layering (Fig. II-20).

At Tabor Lake, a northwest trending unit ("Formation V", Map 2), being probably a single flow, stands out because of spectacular variole bearing pillows (see Chapter VII).

A crescent shaped felsic body southwest of Oldberg Lake (Maps I,2) is probably a rhyolite flow. In outcrop the rock is buff to light grey in

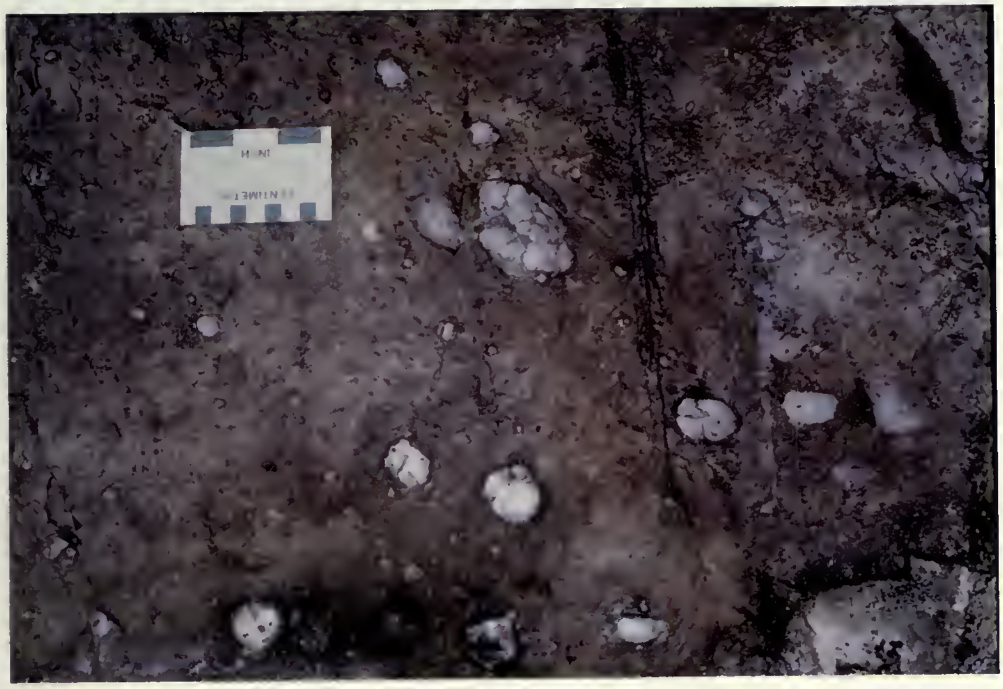


Fig. II-16 : Quartz-filled gas cavities in an andesitic flow, Kawashegamuk Lake Group.

Fig. II-17 : Large pillows in an andesitic flow with a high abundance of vesicles.

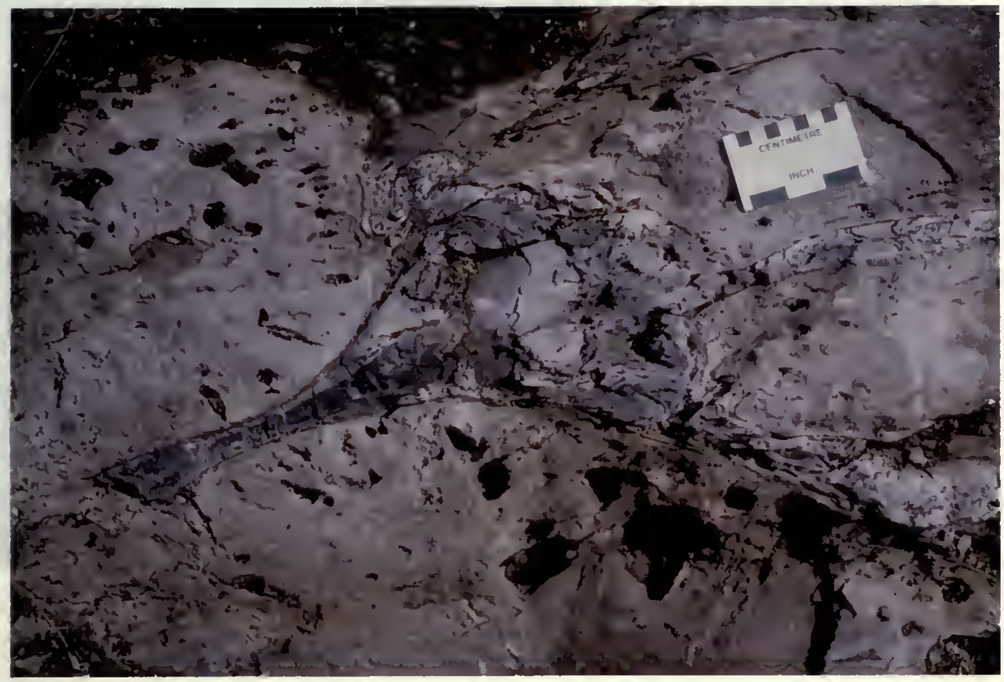


Fig. II-18 : Andesitic pillows with large pipe-shaped vesicles. The interpillow matrix on the picture is a fine-grained wacke which was deposited in the time interval between two flows.

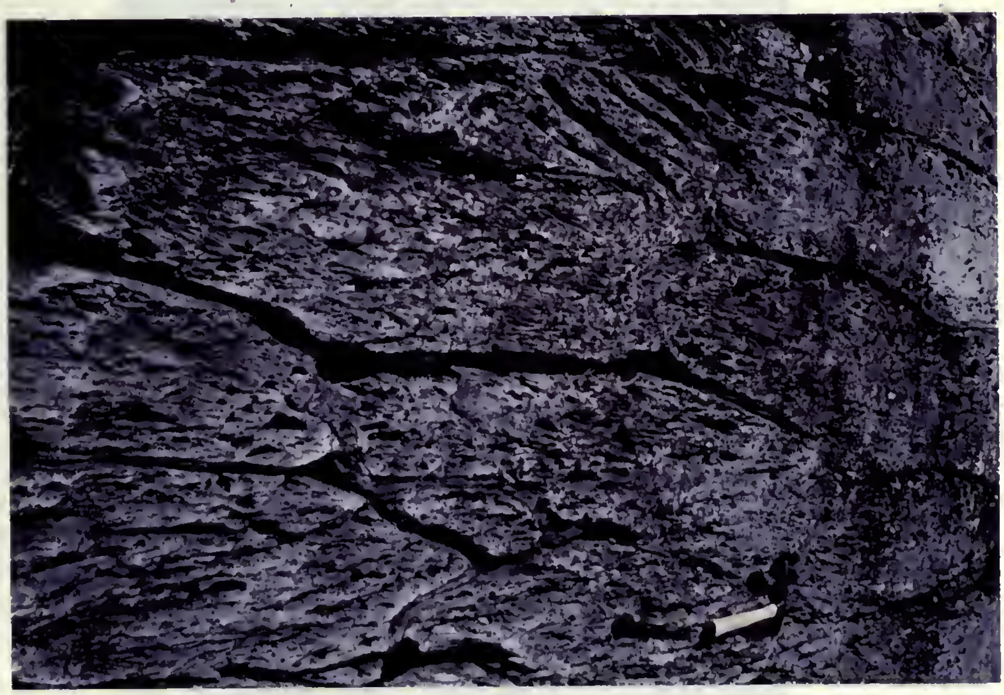


Fig. II-19 : Large flattened andesitic pillows in the upper Kawashegamuk Lake Group. Note the double cusped pillow above hammer. Pillows are highly vesicular.

Fig. II-20 : Highly contorted pillows in a hyalotuff matrix. The shapes are due to lava flowage on steep inclines. The pillows have an unexplained layering (Kawashegamuk Lake Group).

Fig. II-21 : As Fig. II-20. The shape of the large pillow suggests lava flowage on a steep incline covered by mafic tuff. Note the detached pillow on the bottom right.

Fig. II-22 : As Fig. II-23. The tuff layer underneath the pillow bud, probably was deformed when lava flowed over water-logged ash. The flow contains gas cavities which have possibly formed as a result of steam intake.

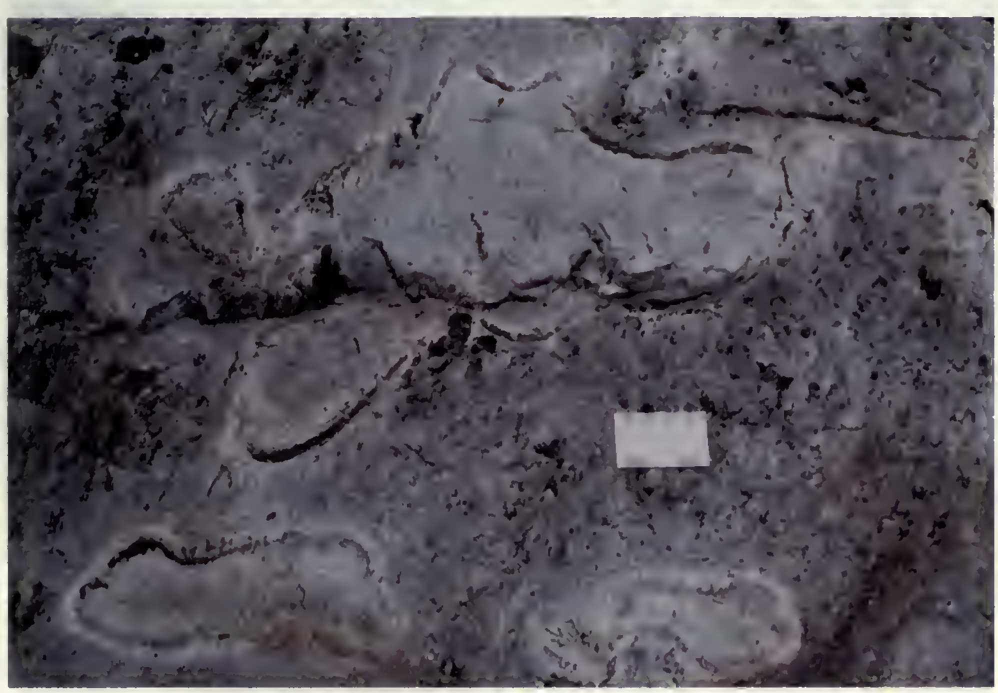


Fig. II-23 : Isolated pillows in a tuffaceous matrix.

Fig. II-24 : Close up view of pillow breccia (fragmented pillows occur in a finer mixture of glass shards and ash).

Fig. II-25 : Porphyritic andesite. The rock contains up to 30% white plagioclase phenocrysts. North shore of Kawashegamuk Lake.

color with small glassy quartz eyes ; it has a homogeneous cherty aspect.

On the northeastern shore of Kawashegamuk Lake, a 500 metre thick unit of mixed felsic pyroclastics overlies the massive and pillowed basalts, consisting of coarse to fine fragmentals of rather heterogeneous composition, ranging from rhyolite to andesite. This more felsic unit is in turn overlain by mafic tuffs and flows many of which are feldspar-phyric; in one exposure at Kawashegamuk Lake, large pillows have a concentration of up to 30%, 1 to 3 mm plagioclase phenocrysts (Fig. II-25).

The nose of the "Tabor Lake Anticline" is defined by a crescent-shaped unit of highly schistose and altered felsic volcanics. In hand specimen these rocks have waxy luster and a yellowish-green color. The convex side of the crescent marks the boundary between the Kawashegamuk Lake and Boyer Lake Groups. On the concave side of the crescent are a series of exposures featuring a sequence of brown weathered, fissile volcanic breccias and flows. They probably represent shear zones along which hydrothermal solutions were channeled. Due to the fact that these rocks have undergone intense hydrothermal alteration , the original composition of the rock is uncertain, but it appears that primary structures have been enhanced by the alterations and subsequent surface weathering. The most striking aspect of these exposures is a breccia displaying highly angular fragments of various sizes that appear to be welded by extremely angular and elongated purplish shards. These shards appear to enclose the clasts, suggesting that they underwent plastic fragmentation before cooling (Fig. II-26). Clasts and shards are microphyric with plagioclase and often display distinct quench textures (Fig. II-27) proving that much of this material was originally glassy. Nearby mafic pillows with similar weathering color to the

Fig. II-26 : Volcanic breccia displaying clasts which appear to have been deformed while in a plastic state ("Formation H").

Fig. II-27 : As Fig. II-26. Highly angular clasts show conspicuous quench textures.

breccia suggest that the latter is of basaltic or andesitic composition.

Owing to the stratigraphic complexity of the Kawashegamuk Lake Group it is impractical to subdivide it into distinct formations. However it is apparent that the sequence consists of two repetitive assemblages of mafic and felsic volcanics ; thus it is appropriate to refer to them as cycles. Each cycle begins with a lower unit of massive and pillowed basalt to andesite which is capped with more felsic rocks ranging in composition from andesite to rhyolite and having a fragmental nature. The lower cycle will be referred to as cycle I and the upper one as cycle II.

v) Intrusive rocks

Most of the abundant intrusions present in the map area are relatively small plutons on the actual erosion surface but they expand to much larger bodies at depth.

Three major categories of plutonic rocks have been recognized within the current map area :

1) those which have been emplaced during or shortly after the deposition of the supracrustal assemblages ;
2) granitoid intrusives which have been emplaced after the deposition of the supracrustal assemblages but before the main orogeny which brought about intense regional deformation (pretectonic intrusions) ;
3) intrusions which were emplaced during or after the main tectonic event (syntectonic and post tectonic intrusions).

I) Intrusions related to volcanism (synvolcanic)

a) Mafic to ultramafic intrusions

These intrusions have already been described for each Group. They occur mostly as sills that are often ramified by short dikes which transect the stratigraphy. Enclaves of volcanic sequences are frequent. Irregular gabbro bodies in the Kawashegamuk Lake Group are probably sills which have been deformed by folding. Mafic sills are intimately associated with basaltic rocks of the Wapageisi Lake, Kawashegamuk Lake and Boyer Lake Groups to which many were probably lava feeders.

b) Lamprophyres

Lamprophyres are relatively insignificant in volume. They occur as black, mafic and biotite-rich, narrow dikes, usually less than I metre thick, cross-cutting all other supracrustal lithologies. They weather more rapidly than surrounding rocks. In one dike occurring at Kawashegamuk Lake, granitic xenoliths are present. Lamprophyres are still poorly understood but they are considered being late magmatic products (see for example Moorhouse, I959). Most lamprophyres in the study area display a distinct foliation imparted by oriented micas.

c) Felsic intrusions

They are usually referred to as quartz feldspar porphyry (QFP), feldspar porphyry and felsite. Porphyries occur as :

I) large irregular intrusions considered to be shallow subvolcanic chambers or pipe conduits ;

2) dikes and sills.

Among the larger scale plutons is the Thundercloud Lake stock which intrudes the Wapageisi Lake Group ; another QFP body occurs at Kawashegamuk Lake, but its size is much smaller (I600 by 400 m). Most dikes and sills observed are less than two metres in width. A high concentration of QFP dikes occur in the vicinity of the Thundercloud Lake Stock. Elsewhere they are common within the Stormy Lake Group and the Kawashegamuk Lake Group.

Feldspar porphyries are characterized by white plagioclase phenocrysts set in an aphanitic dark grey matrix. Within the map area, they occur only as dikes and are not restricted to a particular level within the stratigraphy.

2) Pretectonic granitic intrusives

a) Quartz diorite

Two small bodies of quartz diorite intrude the base of the Kawashegamuk Lake Group in the southeastern part of Kawashegamuk Lake. The two stocks are I by 2 km and I by 0.5 km in diameter respectively, and are only one kilometre apart suggesting that they are part of the same intrusion. The quartz diorite occurs as a light to dark grey medium grained plhase consisting of white plagioclase, 5 to 30% dark minerals and 2 to I0% modal quartz. It has a slight to strong foliation throughout. It is possible that this intrusion is linked to volcanism.

b) Granitoid dikes

They are restricted to the southwest part of the map ; the rocks are usually pink, spotted with chloritic phases displaying a gra-

nitic texture and they have been metamorphosed. Chemical analyses reveal that the dikes have an alkalic affinity.

3) Syntectonic to post-tectonic granitic rocks

a) Quartz diorite

A 200 m thick arcuate body intrudes the Boyer Lake volcanics in the southeast corner of the map area. It consists of a medium-grained, grey, massive and homogeneous quartz diorite. A contact aureole rims the intrusion.

b) Granodiorite

A 2.5 by I.3 km stock of equigranular, pink granodiorite intrudes Facies IV of the Stormy Lake Group at Stormy Lake. Rocks near the intrusive contact have been thermally upgraded. A similar intrusion straddles the southern map boundary.

The Revell Batholith is a 40 by I5 km mass of granitic rocks. Within the map area it consists of light colored, massive and homogeneous granodiorite which intrudes the base of the Kawashegamuk Lake Group. Supracrustal rocks have been thermally metamorphosed at a distance of up to I.5 km from the contact.

c) Porphyry

In the northwest part of the map area numerous porphyry stocks and related dikes intrude the Kawashegamuk and Boyer Lakes volcanics. The stocks are irregular in shape and less than 2 km in diameter. Most of the porphyry has been sericitized and carbonatized and appears as a light colored buff to grey rock. The petrography is further described in

Chapter III. Supracrustals near these porphyries have been sheared and highly carbonatized in a 9 by 6 km zone across the map area. It is most likely that the stocks and dikes are part of a larger intrusion at depth. For later reference purposes the intrusion is here called the "Tabor Lake Porphyry Stock".

vi) Mineral veins

I) Carbonate-quartz veins

Veins consisting entirely of yellow ferroan carbonate and white quartz cross-cut basaltic rocks at Kawashegamuk, Stormy and Seggemak Lakes. These veins pinch out after short distances and are not over 2 m wide. Basaltic breccia with highly angular clasts occurs within the vein. The surface weathers like a typical carbonate rock leaving a deep brown limonitic crust. Associated minerals are fuchsite and pyrite. Lawson (I885) described similar formations in the Lake of the Woods - Shoal Lake area and referred to them as "dolomite veins".

2) Quartz veins

Numerous white quartz veins cut across various lithologies. Most of them are deformed and boudinaged. In the northern part of the map area, notably at Tabor Lake, the Van Houten Mine, Church Lake and Brown Lake, the veins are mineralized with gold and silver. Late stage quartz veins are associated with syn to post-tectonic intrusions.

CHAPTER III - PETROGRAPHY

A detailed petrographic description of all rock units is beyond the scope of this study ; however, an account giving the distinguishing features of the various rock types under the microscope is essential for the following reasons :

I) to make out the primary mineralogies, textures and structures in order to distinguish between rock units ;

2) to assess secondary mineral assemblages and secondary textures for the purpose of evaluating the metamorphic type, grade and facies in various parts of the map area ;

3) to assess the amount of alteration, mineral transformations and metasomatism in order to decide upon the validity of petrochemical results as far as being representative of the original rock and to interpret the significance of chemical data ;

4) to study elemental mobility as a function of alteration.

i) Mafic to ultramafic rocks

a) Basalts and andesites

It is very difficult to distinguish between the basalts making up the Wapageisi Lake, Boyer Lake and the Kawashegamuk Lake Groups on a petrographic basis, because none of the original minerals have been preserved, and commonly only relicts of plagioclase laths and phenocrysts

remain. Mafic to intermediate flows of the Kawashegamuk Lake Group, occurring in Cycle II have a lighter color than basalts from the Wapageisi Lake and Boyer Lake Groups, and a higher modal proportion of plagioclase relicts and secondary albite.

In this section most of the rocks consist of a fine-grained, felted assemblage of chlorite, actinolite - tremolite, epidote, clinozoisite, albite, quartz, calcite and sphene. Calcic plagioclase phenocrysts and laths are completely degraded to a fine-grained assemblage of clinozoisite, epidote, chlorite, albite and quartz (Fig. III-Ia, b); outline of the crystals is preserved only in least deformed rocks. Commonly, plagioclase pseudomorphs are rimmed by clear, secondary albite (Fig. III-Ic). In many rocks, the original ophitic textures are preserved (Fig. III-2). Ultra fine-grained textures, in which individual minerals cannot be identified, probably represent originally glassy material ; such fine-grained textures are found in some variolitic pillows,and basaltic breccias with quench structures and perlitic fractures (Fig. II-27, VII-2m). All ferromagnesian silicates such as pyroxene and olivine have lost their original outline and been replaced by low temperature mineralogies. Accessory phases including magnetite, ilmenite, sphene and apatite have normally retained their original habit. Ilmenite has degraded to a fine-grained, semi-opaque variety of sphene (leucoxene) (Fig. III-3). Basaltic rocks near the margin of late stage syn to post-tectonic granitic plutons are characterized by higher grade metamorphic mineralogies and textures.

Rocks in outer part of the aureoles (I500 to 700 m away from the intrusive contact) carry actinolite recrystallized to green pleo-

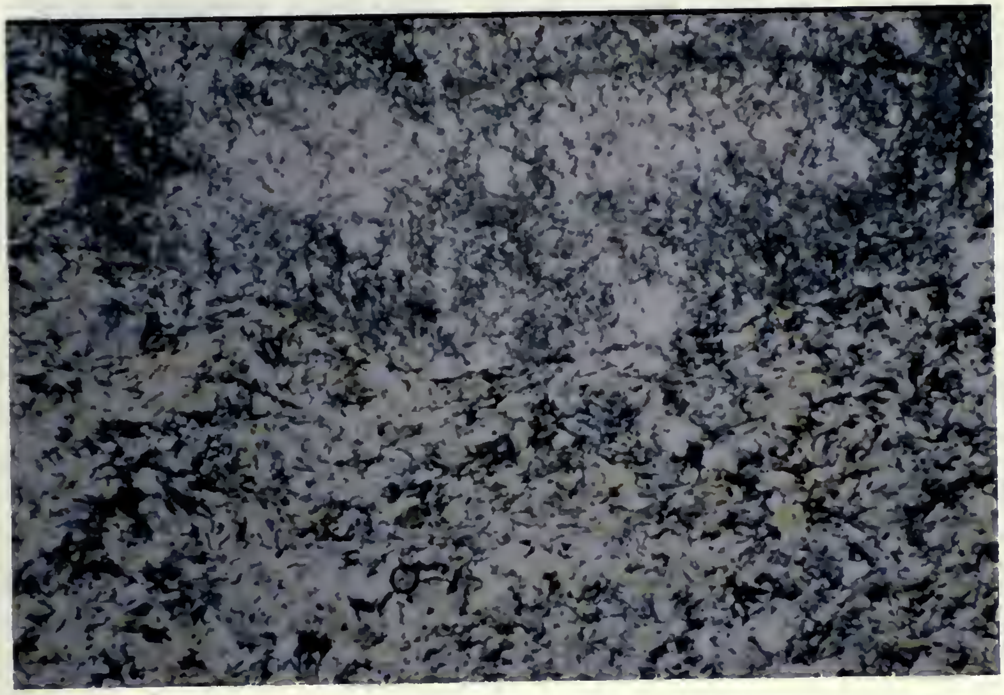


Fig. III-1a : Plagioclase phenocryst in a porphyritic basalt degraded into a mixture of clinozoisite and albite (top) in a matrix of actinolite, albite and chlorite. Crossed nichols, x110 (82-8).

Fig. III-1b : Chlorite riddled plagioclase crystal in a gabbro. Crossed nichols, x110 (82-134).

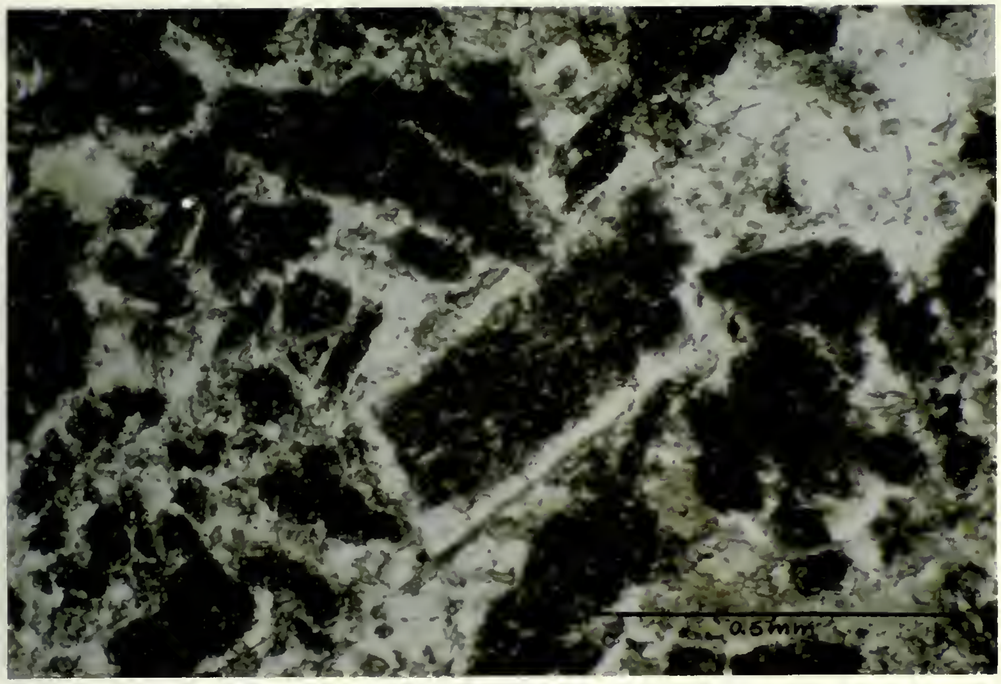


Fig. III-1c : Plagioclase relicts in a gabbro. Original laths have been saussuritized and rimmed by a secondary clear albite overgrowth. Plane light (82-15).

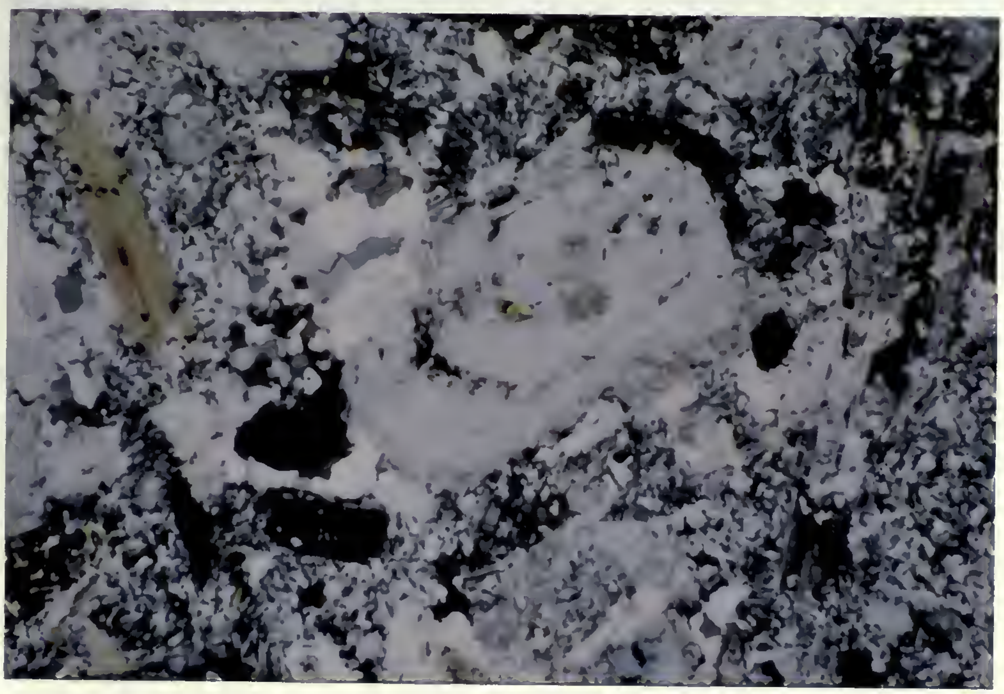


Fig. III-1d : Plagioclase phenocryst showing oscillatory zoning. More calcic zones are degraded to secondary minerals giving a zoned alteration. Recrystallization is seen as sym-pletitic overgrowths (middle top). Crossed polars x90 (82-40).

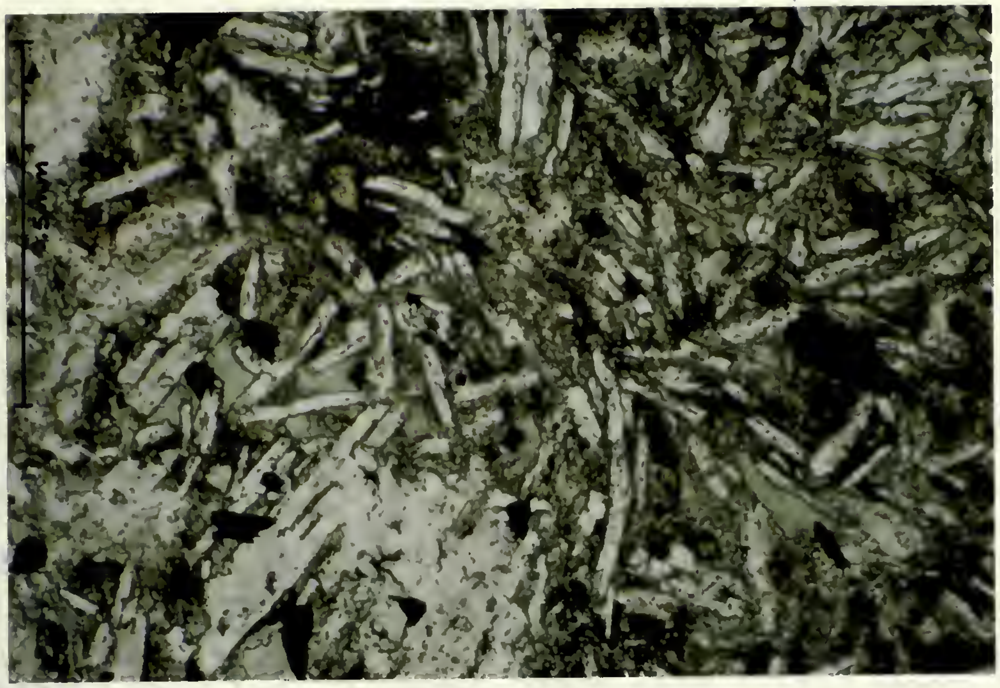


Fig. III-2 : Plagioclase laths ophitically enclosed by ferromagnesian minerals (now actinolite and chlorite) in a gabbro. Plane light, (81-1247).

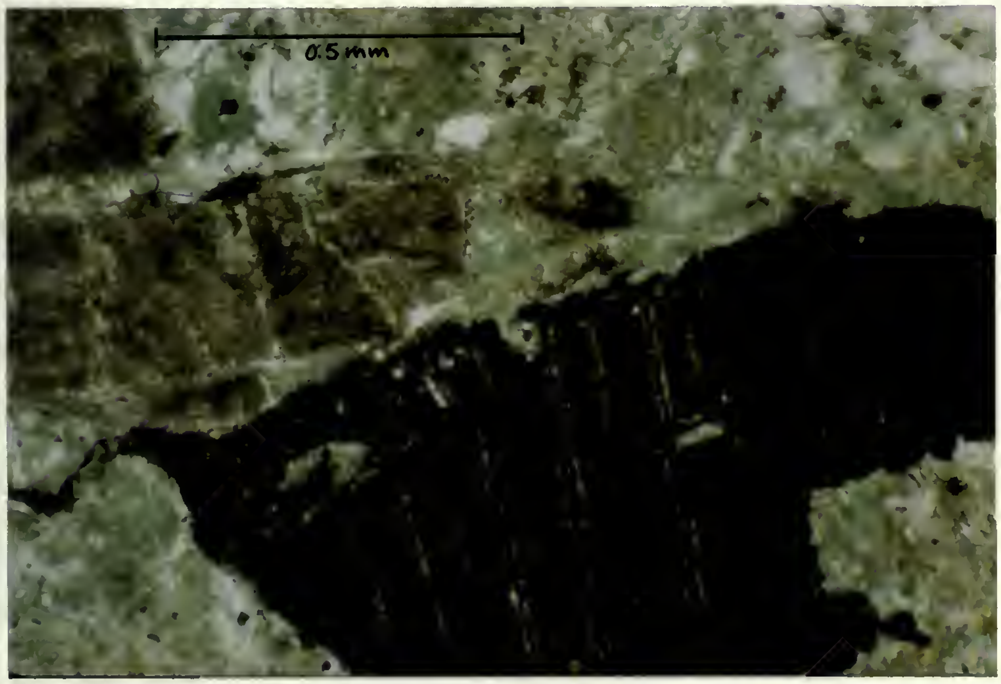


Fig. III-3 : Large magnetite crystal with exolved ilmenite lamellae in a gabbro. The ilmenite has degraded to a fine sphene-rich secondary assemblage (leucoxene).
Note relict plagioclase in a matrix of chlorite, actinolite and quartz. Plane light, (81-1426).

chroic hornblende ; slender amphibole and biotite needles impinge into clear recrystallized albite and quartz ; xenoblastic epidote has recrystallized to idioblastic epidote and clinozoisite crystals and biotite has grown from chlorite (Fig. III-4a).

Rocks near the granitic intrusions (I00 to 700 m) have similar mineralogies, however green hornblende tends to have recrystallized into idioblastic columnar crystals (Fig. III-4b).Plagioclase has recrystallized to clear albite ; biotite crystals are well developed.

Rocks on the margin of the intrusions (less than I00 m) have inherited a granoblastic polygonal texture (Fig. III-4c). Relict textures are completely destroyed. The mineralogic assemblage consists principally of hornblende - biotite - epidote - albite - quartz. Plagioclase is clear and has sharp polysynthetic (albite) twin planes.

In the northwest part of the map area, basaltic rocks have been substantially altered by late hydrothermal activity. Depending on the degree of alteration , basaltic rocks may have retained relict and typomorphic textures, however superimposed textures have completely replaced previous textures in some rocks especially near cataclastic (shear) zones. Microcospic to I.5 mm rhombs of carbonate, a ferroan variety weathering to goethite, embay earlier minerals throughout the altered zone. The carbonate rhombs tend to be concentrated near small fractures or micro shear zones. The amount of carbonate present varies from a few sporadic rhombs to almost 50% of a rock. Ferromagnesian minerals may have been retained as fine felted chlorite patches but have been entirely converted to iron-rich carbonate in heavily CO_2 metasomatized rocks. Feldspars have been altered partly or totally to fine-grained

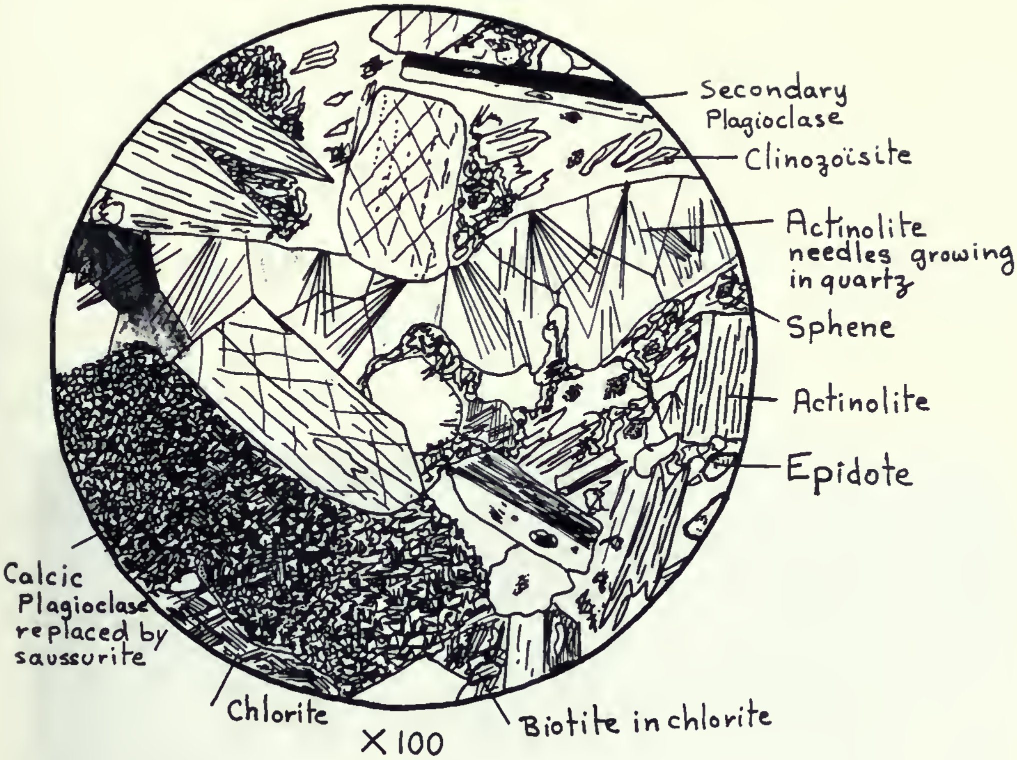


Fig. III-4a : Basalt which underwent recrystallization during thermal metamorphism accompanying the emplacement of the Revell Batholith. Outer aureole. Cross polars, x100 (81-1590 B).

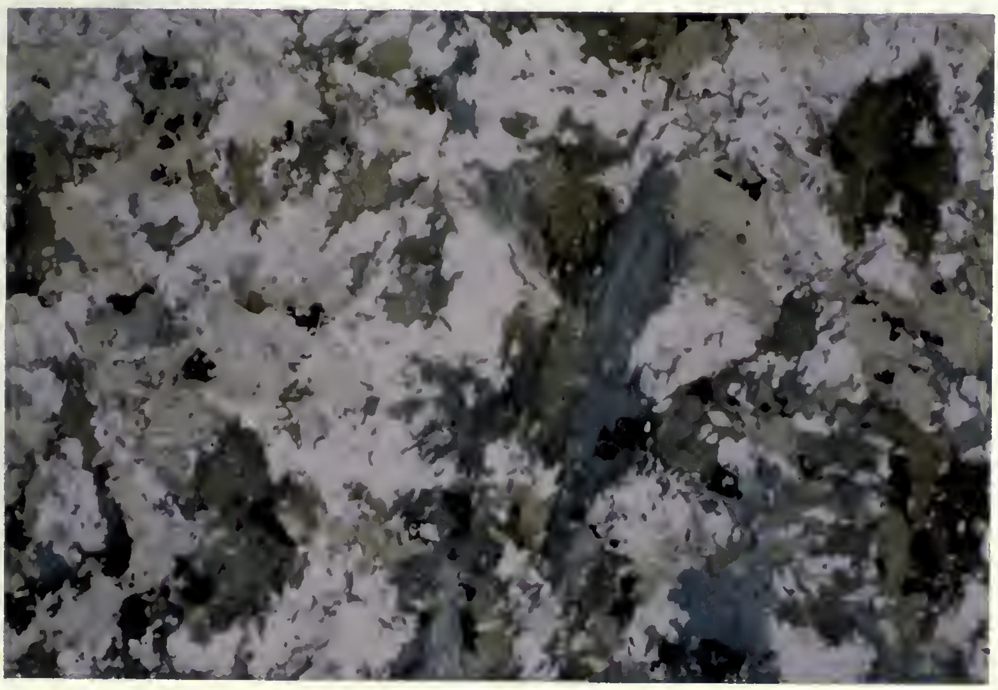


Fig. III -4b : Recrystallized mafic rock (middle part of aureole). The common amphibole is hornblende ; other minerals are biotite, plagioclase, quartz and epidote.

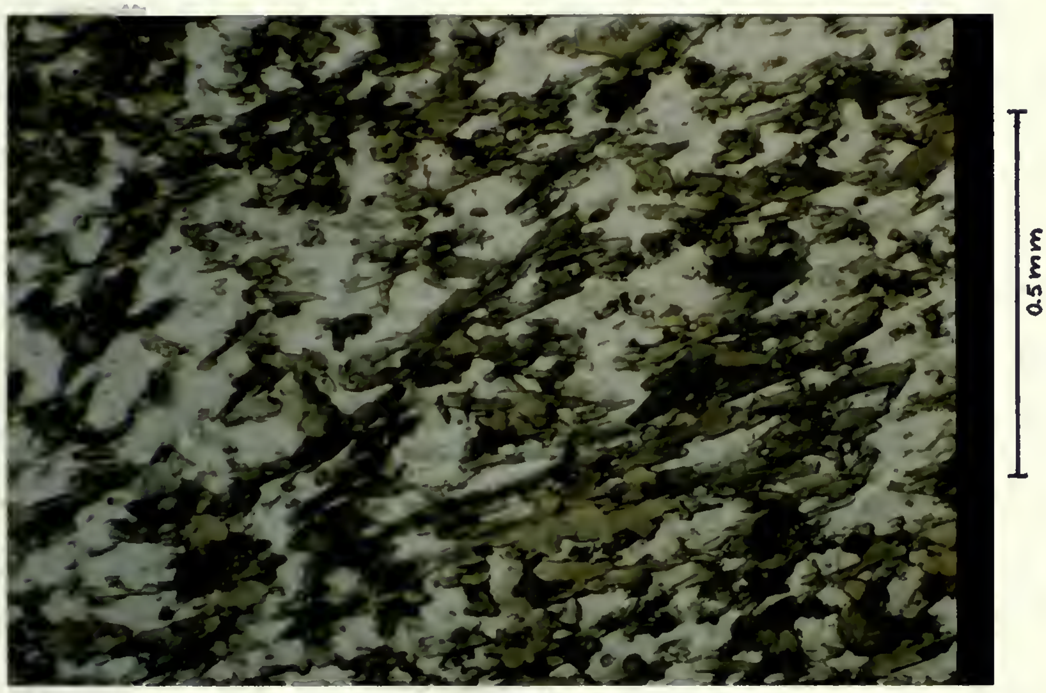


Fig. III-4c : Basalt hornfels (inner aureole) displaying a granoblastic texture. Essential minerals are hornblende, plagioclase and quartz. Plane light; (82-158).

muscovite but despite complete replacement they have commonly retained the original crystal outline. Relict textures are, however, more common in coarser-grained rocks, such as porphyries and gabbros. Where the degree of alteration is very high, recognition of the original rock type is nearly impossible, except where macroscopic features, such as pillow selvages and amygdules outlines, have survived.

b) Mafic intrusive rocks

The petrography of the gabbro sills is analogous to that of the basalts as a result of similar chemical composition. However, minor mineralogical and textural variations are observed. The common amphibole is a pale blue-green pleochroic actinolite, but in higher grade gabbros a strong green pleochroism is exhibited by ferroactinolite , and may be confused with green hornblende. The actinolite is either a fibrous variety (uralite) or long, twinned, columnar crystals several centimetres in length, which penetrate other minerals (Fig. III-5a, b).

I) Epidote and clinozoisite occur often as idioblastic crystals; fine-grained saussurite in plagioclase is recrystallized to a coarser mixture of idioblastic clinozoisite, clear albite and quartz.

2) Patches of fine-grained chlorite are partly recrystallized to biotite, showing acicular crystals, fascicular and bow-tie bundles and radiating acicular aggregates.

3) Feldspar is represented by lath shaped crystals with albite

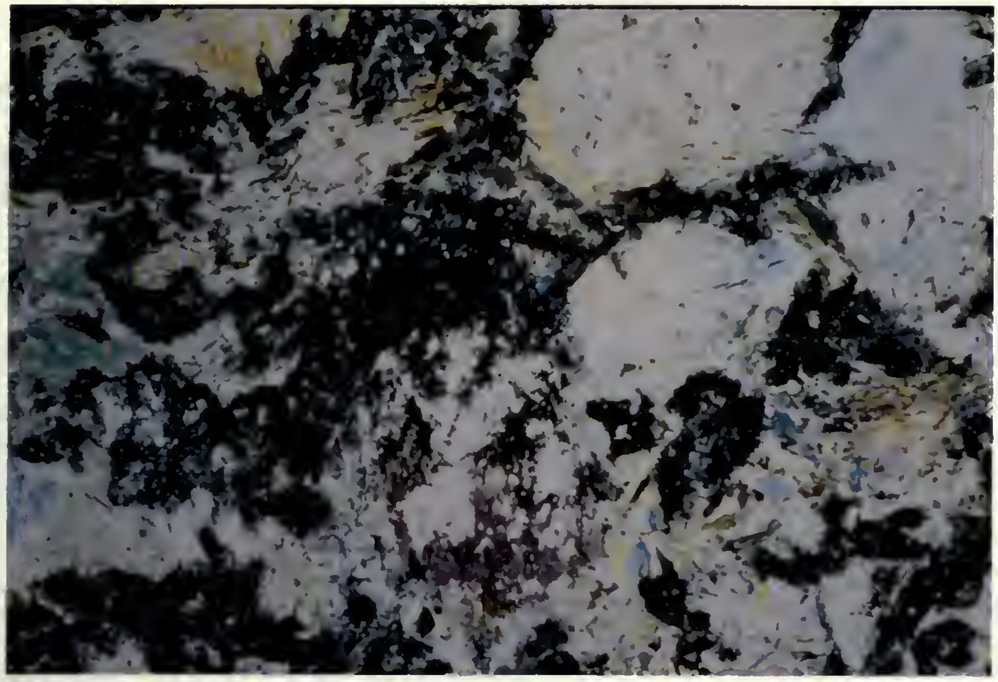


Fig. III-5a : Photomicrography of a gabbro. Pyroxene crystals have recrystallized to a secondary fibrous variety of amphibole (uralite). Plagioclase has been completely degraded to saussurite. Crossed polars, x60 (81-1575).

Fig. III - 5b : Gabbro with recrystallized mineralogy , displaying long twinned ferro-actinolite crystals, albite with lamellar twinning, quartz and biotite. Crossed nichols, x55 (82-151).

twinning. The composition of the recrystallized plagioclase has been determined to be albite by the Michel-Lévy test. Among accessory minerals : magnetite, ilmenite (partly to totally converted to sphene), exsolved ilmenite in magnetite, and apatite are present. In a gabbro sill at Kawashegamuk Lake, a layer containing up to 20% ilmeno-magnetite has been traced for 3300 m.

In thermal aureoles gabbros have a dark green to almost black color and shiny luster. Saussuritized feldspars have recrystallized to idioblastic aggregates of clinozoisite rimmed by clear albite. Amphiboles have recrystallized to dark green pleochroic hornblende idioblasts, poikiloblasts and acicular crystals growing in albite and quartz. Quartz and albite have recrystallized to a granoblastic polygonal texture. Northwest of Kawashegamuk Lake, gabbros have been affected by carbonate metasomatism in the same way as the basalts.

The lamprophyric rocks consist of a secondary assemblage dominated by biotite. Plagioclase phenocrysts are present in non altered dikes. Altered lamprophyres consist essentially of chlorite and chloritized biotite, carbonate, epidote, albite and quartz.

ii) Felsic volcanic rocks

Under the microscope the felsic volcanics reveal a mainly quartzofeldspathic composition with albite, sericite, clinozoisite and clay minerals as the main alteration products. Mineral degradation in least deformed rocks is not as pronounced as in the mafic rocks and therefore igneous and clastic textures are well preserved. Those rocks

which have been highly strained were much more permeable to fluids, hence have been highly altered, and in some areas, primary structures have been completely obliterated ; such rocks have been named sericite schists, due to their high abundance of fine-grained muscovite.

Some rock units originally considered as arenites or quartz-feldspar porphyries were reconsidered as intratelluric crystal-lapilli tuffs containing up to 80% plagioclase and quartz crystals and 10% rock fragments. A large part of "Formation 3" within the Wapageisi Lake Group is formed primarily of such tuffs. Lithification rendered the outline of larger lithic fragments indistinguishable from the matrix consisting of the same components, which had been reduced to a mixture of phenocrysts and fine ash by magmatic explosions. The matrix consists of phenocrysts of feldspar and quartz, most of them broken up, set in a sericite-rich ground mass (ash) ; lithic fragments consist of feldspar-quartz porphyry. The ground mass is quartzofeldspathic and poorly sericitized. Lithic fragments outlined by the contrast in sericitization are highly angular (Fig. III-6).

Sericite schists of "Formation 4" at Stormy Lake contain chloritoid metacrysts up to 2 mm long which form chloritoid-rich bands (Fig. III-7). In outcrop, the chloritoid-rich bands have a darker color due to higher iron content. The chloritoid is probably metamorphic, indicating Fe-Al rich bands in felsic tuffs ; however, Moorhouse (1959) points out that chloritoid may form as a result of metasomatism of green schist facies rocks.

In two places, felsic tuffs having a black color in surface exposures have been found. In thin section the black color is seen as

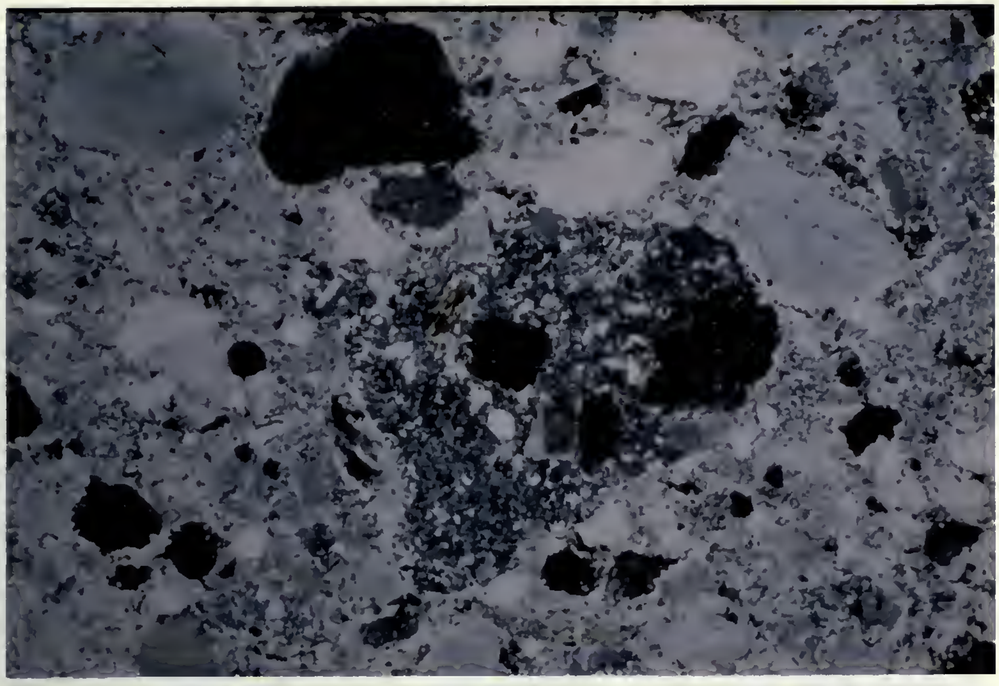


Fig. III-6 : Broken crystals of quartz and feldspar in a fine-grained sericite-rich matrix. The porphyritic clast in the middle is contrasted by a lesser content of white mica in the matrix. Formation 3, Subgroup II.
Cross polars, x60 (82-40).

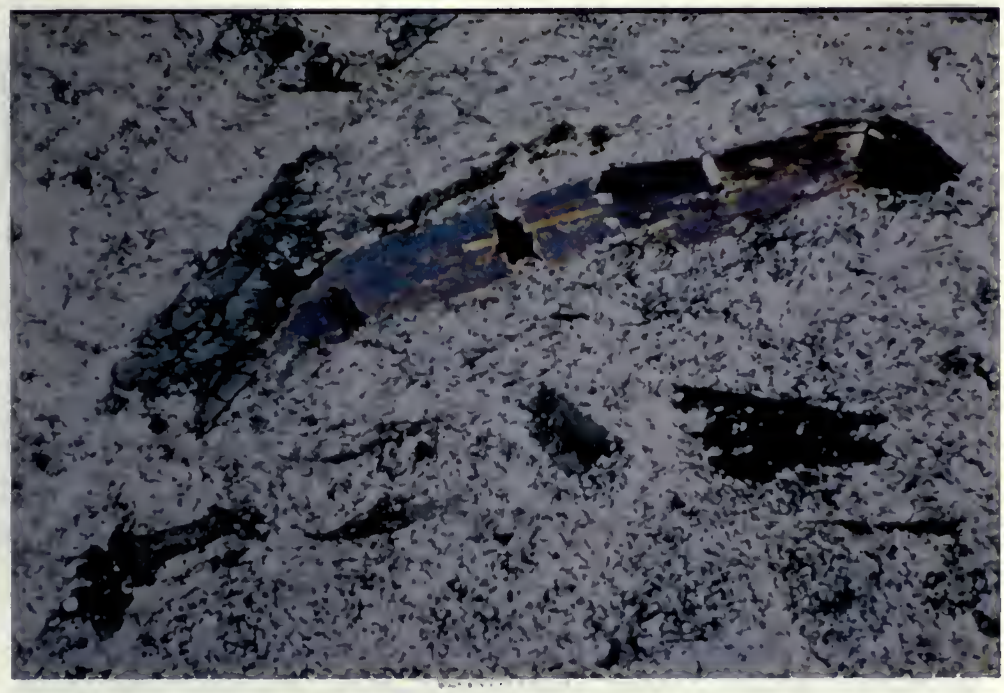


Fig. III-7 : Chloritoid and biotite metacrysts in a volcanic tuff. The biotite crystal is stretched and is parallel to foliation. The random orientation of the chloritoid crystals indicate that crystal orientation is not stress dependent ; Formation 4, Subgroup II.
Cross polars, x 90 (80-1048).

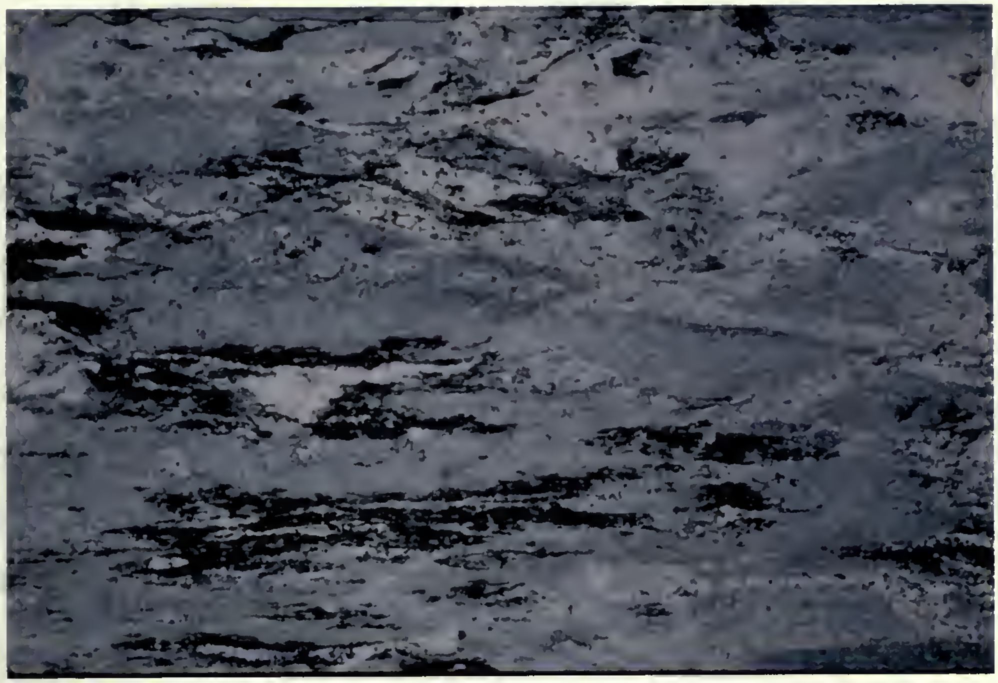
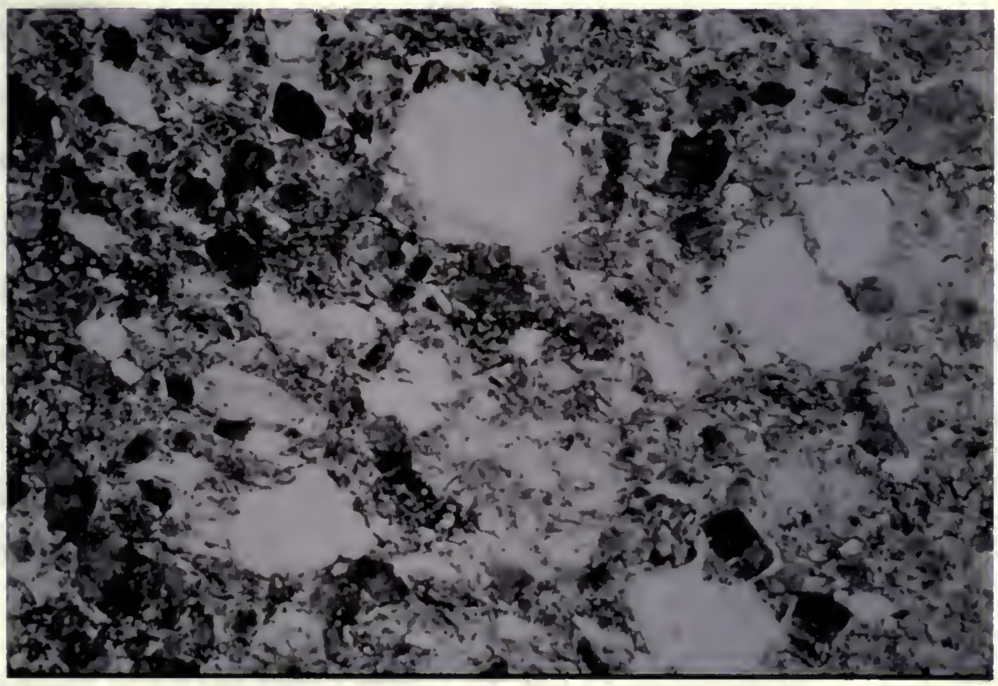


Fig. III-8 : Carbon bearing felsic tuffs.

a) Highly schistose lapilli tuff. Fine-grained carbon in some clasts. Plane light, x 25 (80-1143 B).



b) Carbon bearing intratelluric crystal tuff. The fine carbon particles are contained in the feldspars and the matrix. Plane light, x 35(82-299).

submicroscopic black particles dusting plagioclase phenocrysts and the fine-grained quartzofeldspathic matrix (Fig. III- 8a,b). The black substance is insoluble in hydrofluoric acid and subsequent analysis of the residue revealed a high carbon content. In all felsic volcanic rocks, the predominant feldspar is plagioclase. Some potassium feldspar present as albite-microcline intergrowths occurs as a minor phase, up to 5%, in some very rhyolitic rocks. Among the accessory minerals small euhedral crystals of apatite, sphene and zircon are present as inclusions in feldspar and quartz phenocrysts.

iii) The epiclastic sediments

Only the matrix to the conglomerates, and the arenites are described here, as the larger lithic fragments are highly varied, largelly volcanically derived, and have been described in Chapter II.

a) The matrix to the conglomerates of Facies II and III of the Stormy Lake Group consists of very immature and unsorted sandstone.

Most of the components are lithic fragments of volcanic origin and plagioclase feldspar. Quartz constitutes up to 15% of the grains ; a few are well rounded but most are angular to subrounded. Monocrystalline quartz grains are derived from both volcanic and plutonic igneous sources, while polycrystalline quartz grains with many domains were originally recrystallized cherty material.

b) Sandstones of Facies III and IV have a higher degree of maturity than the sandy matrix to the conglomerates.
The percentage of quartz grains is increased up to 35% and feldspar

up to 40%. Lithic fragments are dominated by felsic compositions.

iv) Intrusive rocks

a) Hypabyssal rocks

1) The Thundercloud Lake Intrusion

A detailed account of the petrography is given by McMaster (I978). The porphyry is mineralogically and texturally exceedingly homogeneous consisting on the average of 40% phenocrysts and 60% matrix.

Phenocrysts constituents are feldspar and quartz (Fig. III-9 a). The common feldspar is a sodic plagioclase which displays albite, pericline and carlsbad twinning, but compositional zoning has not been observed. Potassium feldspar is now microcline forming crystals up to I0 mm. Large phenocrysts still display the monoclinic habit with carlsbad twinning characteristic of orthoclase. Large potassium feldspars are normally poikilitic (Fig. III-9 b). Quartz phenocrysts account for about 20 to 40% of the total phenocryst content ; they occur as small to large (5 mm) crystals often displaying a bipyramidal - hexagonal habit. Many quartz crystals show heavy embayments due to late stage magmatic corrosion. Most crystals are strained and, as a result, some have recrystallized to form polycrystalline grains. McMaster (I978) has observed primary quartz grains rimmed by secondary optically continuous quartz. The matrix consists essentially of fine-grained quartzo-feldspathic material. The common alteration product is sericite which is present in both phenocrysts and matrix. Observed accessory phases include pyrite and zircon.

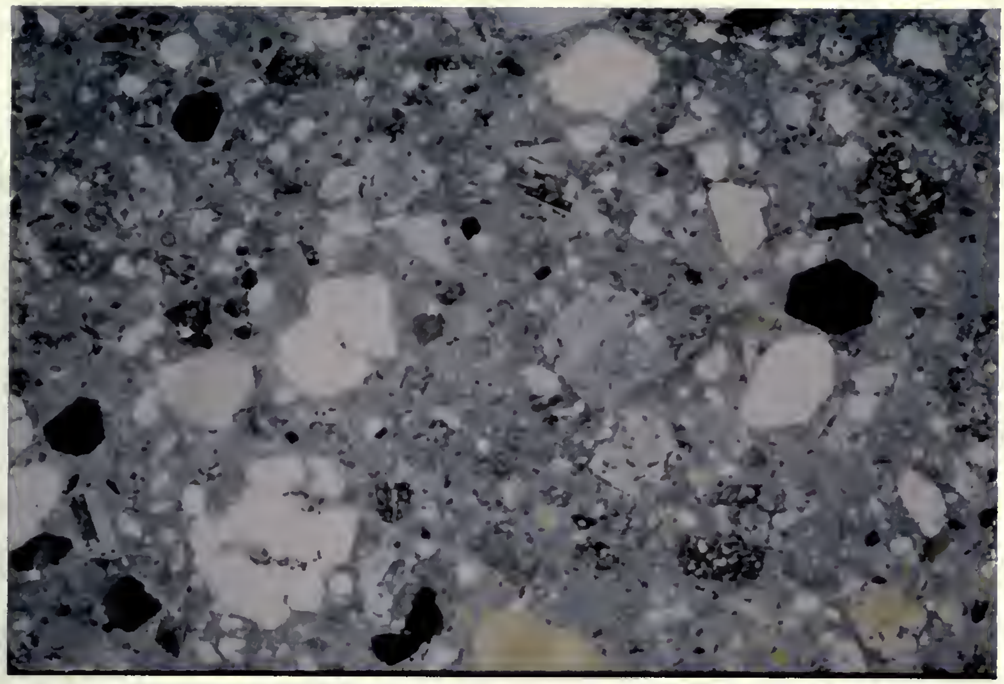
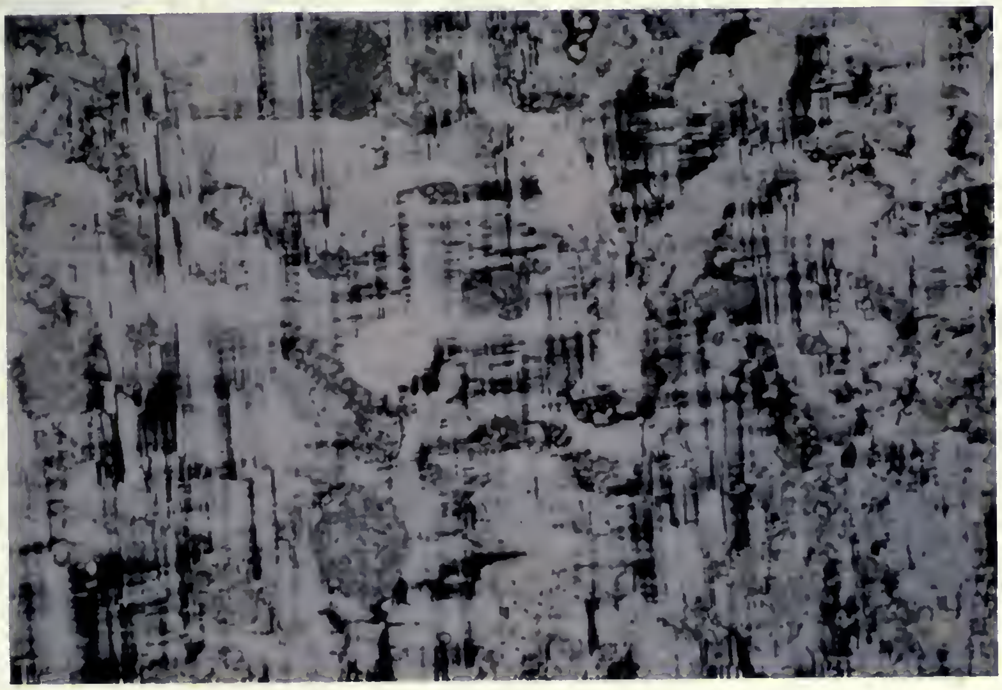


Fig. III-9a : Photomicrograph of the Thundercloud Lake Porphyry : phenocrysts constituents are sodic plagioclase, K-feldspar and low quartz in an aphanitic matrix. Crossed polars x253 (81-T-22).



9b : Large poikilitic microcline (after orthoclase) phenocryst. Crossed polars x 60

The brecciated form of porphyry is petrographically identical to the porphyry stock.

2) Porphyry dikes and felsites

Many felsic dikes intrude the supracrustal lithologies, ranging from quartz porphyries with few feldspar phenocrysts to feldspar porphyries with no quartz phenocrysts ; some dikes carry biotite. It is difficult to relate most dikes with larger intrusive bodies in the area, except for quartz-feldspar porphyry dikes near the Thundercloud Lake stock, and therefore these types are dealt with as separate entities. Most unsheared felsic dikes display remarkably well preserved mineralogies and textures. Phenocrysts are normally euhedral. Plagioclases are commonly zoned especially in feldspar porphyry dikes ; zoning is generally of the oscillatory type and alteration to sericite or saussurite affects only the core or more calcic zones of the phenocrysts (Fig. III-Id). In one feldspar porphyry dike, the plagioclase composition has been determined to be a low Ca andesine by the Michel-Lévy Test. Microcline is often present as phenocrysts in porphyry dikes, but the proportion is higher in the more felsic varieties. Quartz phenocrysts are commonly corroded by magmatic resorption and are rounded or have lobate enbayments. Among accessory minerals, apatite, sphene and zircon are ubiquitous. The matrices are fine-grained quartzofeldspathic material. Some dikes have no phenocrysts and are made up entirely of fine-grained quartzofeldspathic material ; they have been called felsite dikes.

3) The "Tabor Lake Porphyry"

The "Tabor Lake Porphyry" appears as a series of irregular stocks and dikes intruding the supracrustals of the Kawashegamuk Lake and Boyer Lake Groups. The petrography reveals little variation throughout, with only minor changes in phenocryst content (plagioclase and quartz), and the superimposed mineralogies and textures brought by hydrothermal metamorphism. In many stocks and dikes, phenocrysts are so abundant that the resulting texture resembles a plutonic one. Phenocrysts are mostly plagioclase ; they are moderately to highly sericitized and characteristically have clear albite overgrowths and/or symplectitic intergrowths of albite and quartz (Fig. III-I d). Quartz phenocrysts are less abundant than feldspar in all cases and rarely exceed I0% of the total rock ; they are always heavily embayed (Fig. III-I0). The matrix consists of recrystallized albite and quartz with abundant sericite which has recrystallized as radiating fibrous bundles. Carbonate may be present in minor amounts, but in many places, the porphyry shows abundant carbonate as euhedral rhombs as a result of CO_2 metasomatism.

b) <u>Granitic Rocks</u>

I) <u>Quartz diorite</u>

The foliated granitic intrusion at Kawashegamuk Lake is mineralogically and texturally homogeneous, except for variations in the abundance of dark minerals. Plagioclase laths generally moderately to completely replaced by saussurite make up 45 to 65% of the rock ; they are subophitically enclosed by secondary actinolite and chlorite which

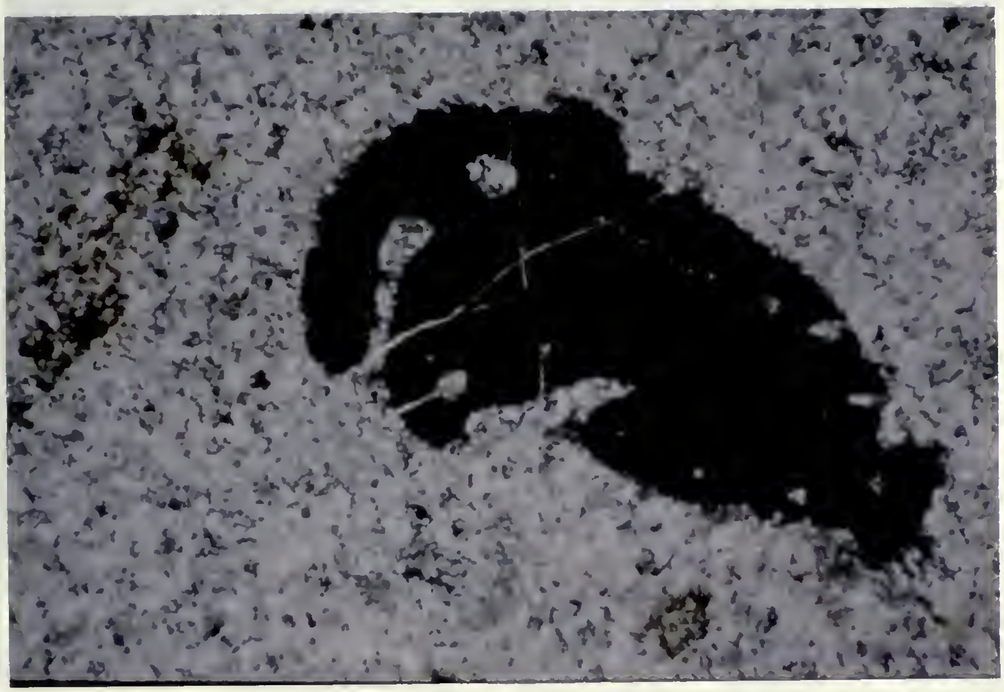


Fig. III-10 : Embayed quartz phenocryst in a felsic porphyry. Crossed polars, x 60 (80-1187)

Fig. III-11 : Post tectonic granodiorite showing good mineral textures indicating the order of crystallization : plagioclase/ biotite →quartz →K-feldspar (stained). The plagioclase crystals are zoned in an oscillatory manner. Plane light, x 23 (80-1051).

are replacing hornblende. Modal quartz up to 20% is interstitial. Due to the proximity of the Revell Batholith, thermal metamorphism has affected the mineralogy of some parts of the stock : actinolite has converted to light pleochroic hornblende, chlorite has partly recrystallized to biotite, saussuritized feldspars have recrystallized to clear albite and idioblastic clinozoisite, and interstitial quartz has acquired a polygonal texture.

2) Granodiorite

All granodiorite occurrences in the map area are similar. Plagioclase, the main constituent, is often zoned in an oscillatory or normal manner (Fig. III-11). Late hydrothermal alteration has mildly to moderately sericitized the plagioclase, and the sericite flakes are commonly oriented parallel to the main crystallographic directions.

The common dark colored mineral is biotite, however, hornblende is present near the contact of the Revell Batholith where mafic xenoliths have been observed ; hornblende is not present in the interior of the batholith, it is concluded that the crystals are xenocrystic, probably originating from rocks near the base of the Kawashegamuk Lake Group. Potassium feldspar occurs as microcline and perthitic intergrowth with albite. Other primary minerals are quartz, muscovite, apatite, sphene and zircon.

CHAPTER IV - METAMORPHISM

From field relationships and petrographic observations, it has been concluded that several types of metamorphism have affected the rocks underlying the map area. Three episodes of prograde metamorphism have been recognized (Fig. IV-1, in back pocket) :

1) Regional dynamo-thermal metamorphism

2) Post-tectonic thermal metamorphism

3) Post-tectonic hydrothermal metamorphism

Beside these three types, sea floor alteration, burial metamorphism and locally pretectonic thermal metamorphism may have affected the rocks to some extent. However, if these events left their imprint, evidence has likely been removed due to overprinting effects and/or retrogressive metamorphism.

1) <u>Metamorphism of basaltic rocks</u>

a) Dynamothermal metamorphism

Ample evidence is provided for regional dynamothermal metamorphism. Penetrative deformation, producing a schistose fabric, is ubiquitous ; basalts, andesites and their intrusive equivalents bear the typical mineral parageneses of low grade metamorphism (Winkler, 1979) or greenschist facies. The characteristic mineral assemblage in mafic rock is : albite - actinolite - clinozoisite/epidote - chlorite - sphene quartz - calcite - white mica (muscovite/phengite/paragonite) - biotite. Most

basaltic rocks display the characteristic albite - actinolite - chlorite zone of low grade type metamorphism (Winkler, 1979), (Figs. III-1 ; IV-2a,b).

b) Thermal metamorphism

In the vicinity of post-tectonic intrusions, the supracrustals have been affected by thermal metamorphism and changes are noticeable as far as 1 km away from the Revell Batholith - erosion surface intersect. Smaller plutons on surface display only narrow contact aureoles. The recrystallization of mineral phases under low stress conditions removed earlier planar and linear fabrics characteristic of dynamothermal metamorphism, and the rocks are typically massive hornfelses. The most distant thermal effect from plutons may have given rise to the albite - epidote hornfels facies of Winkler (1979), (Figs. III-4a ; IV-2c), which is superimposed over low grade regionally metamorphosed rocks, and is identified by the recrystallization of some mineral phases, especially ferromagnesian mineralogies. However, relict igneous textures, mainly represented by plagioclase, are still preserved. Closer to plutons, hornblende is the diagnostic amphibole and the mineral assemblage pertains to the lower hornblende hornfels facies (Figs. III-4b,c ; IV-2d). One occurrence of fine-grained sediments near the contact of the granodiorite stock at Stormy Lake shows thin bands where small almandine garnet porphyroblasts have formed. Mn-rich almandine garnet is often found at contact aureoles (Deer, Howie and Zussman, 1978) and it is known that garnets of such composition form also at low temperatures (Winkler, 1979), thus garnet is not a good metamorphic grade indicator unless the composition is ascertained (Winkler, ibid.).

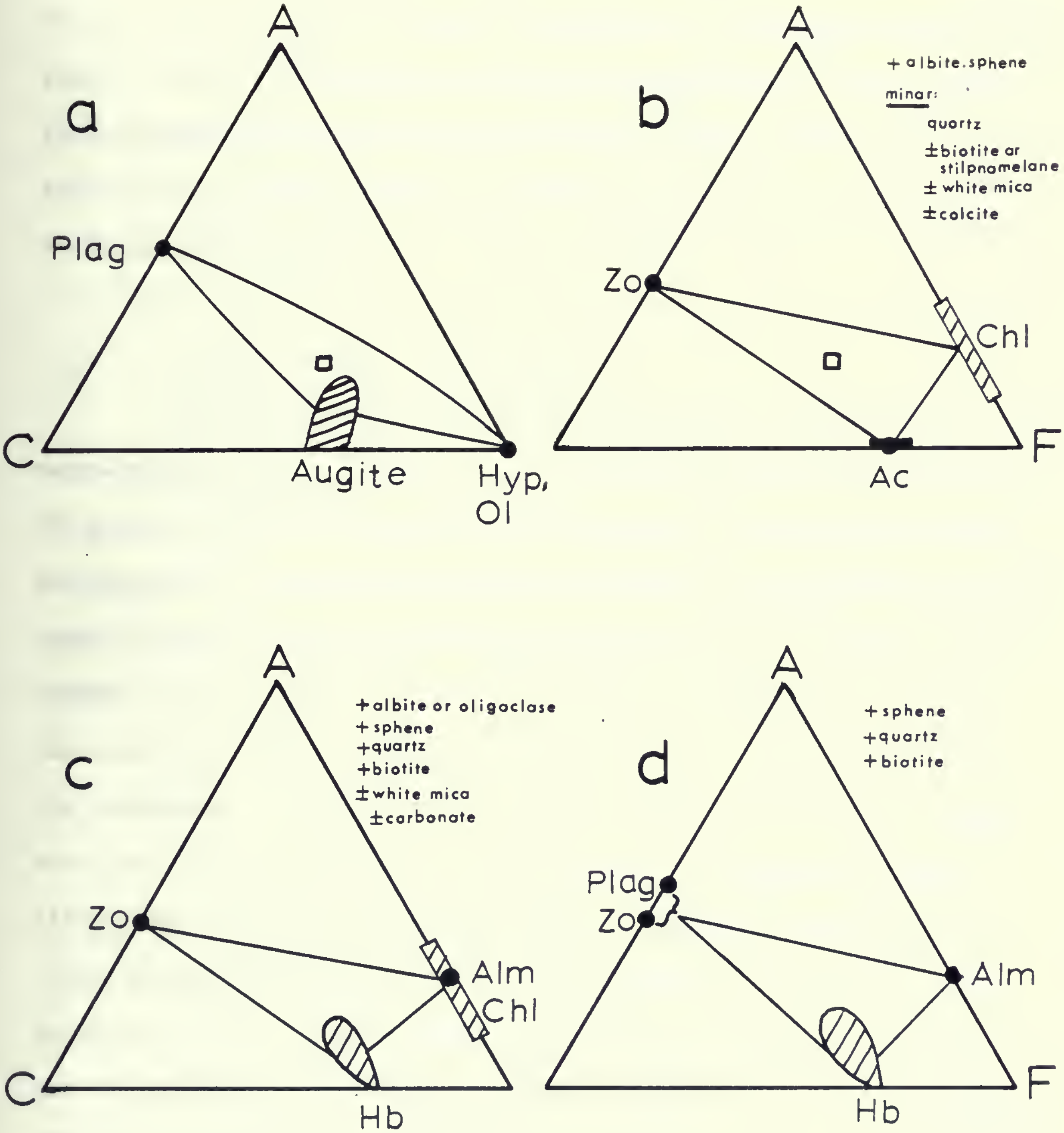
Fig. IV-2: Metamorphic facies types encountered in the Stormy Lake - Kawashegamuk Lake area represented on ACF diagrams (after Winkler, 1979).

a - Mineral paragenesis of basaltic and andesitic rocks. The square indicates the mean composition of tholeiites. Plagioclase is commonly between An 65 and An 40.

b - The albite - actinolite - chlorite zone. Low grade metamorphism of mafic rocks : most supracrustal rocks in the Kawashegamuk Lake area carry the mineral paragenesis depicted on this diagram.

c - The albite/oligoclase - hornblende - chlorite zone of low grade higher temperature metamorphism as represented by the outer part of contact aureoles.

d - Andesine/oligoclase - amphibolite zone of medium grade metamorphism. This assemblage is represented in contact aureoles close to intrusions. Garnet is absent from most rocks.


A
a
Plag
C
Augite
Hyp,
Ol
A
b
+ albite, sphene
minor:
quartz
±biotite or stilpnomelane
± white mica
±calcite
Zo
Chl
F
Ac
A
c
+albite or oligoclase
+sphene
+quartz
+biotite
±white mica
±carbonate
Zo
Alm
Chl
C
Hb
A
d
+sphene
+quartz
+biotite
Plag
Zo
Alm
F
Hb

No direct evidence of pretectonic thermal metamorphism aureoles has been found around the two diorite stocks at Kawashegamuk Lake, as a result of retrogressive reactions that re-equilibrated the rocks under later dynamothermal metamorphic conditions. However, in view of the size of the intrusion, rocks around the quartz diorite stock must have undergone some changes.

c) Hydrothermal metamorphism

In the northwestern part of the map area, a special type of metamorphism has affected the rocks of the Kawashegamuk Lake and the Boyer Lake Groups. The supracrustal lithologies, as well as the "Tabor Lake Porphyry", have been distinctly overprinted by hydrothermal effects which metasomatized the rocks with respect to CO_2. As a result, a large number of major and trace elements have been redistributed, including the relatively "immobile elements" such as Al, Ti, Zr, Y and possibly the lanthanide group elements (see Chapter VIII) ; the degree of metamorphism is highly variable. Numerous linear shear zones are highly altered and probably represent channels through which hydrothermal fluids migrated. The CO_2 was possibly furnished by the porphyry stock, which has relatively low carbonate content, but is highly sericitized and albitized. This may be explained by the hypothesis that CO_2 escaped into the surrounding country rock.

2) <u>Felsic rocks</u>

Being originally composed of mainly quartz and alkali feldspar, the felsic volcanics have undergone less alteration than mafic lithologies because of the increased stability of these phases in the metomorphic

environment. As a consequence most original textures have been preserved in rocks which have undergone little straining (Figs. III-6, 8, 9, 10). The common secondary mineral in felsic rocks is white mica which has been produced from the degradation of the feldspars. Petrographic evidence indicates that the amount of alteration product is related to the permeability of the rocks. Thus, pyroclastic rocks and foliated types (Fig. III-6,7) are invariably more altered than massive flows or intrusions with no fabrics (Fig. 9a). Strained rocks have recrystallized to various degrees and highly sheared types generally consist of a microcrystalline mixture of quartz and white mica (sericite). Subordonate secondary minerals are calcite and epidote. High temperature forms of alkali feldspars have reverted to low temperature polymorphs namely albite and microcline (Fig. III-9b).

3) Epiclastic sediments

The sediments largely consist of conglomerates and quartzo-feldspatic sandstones. The conglomerates are made up of volcanic and plutonic components which have been metamorphosed consistently with other igneous rocks exposed in the area. Arenites and fine-grained sediments being essentially derived from volcanic-plutonic terrains have behaved similarly to volcanic rocks. No evidence characterizing pelitic rocks has been found.

CHAPTER V - STRUCTURAL GEOLOGY

The entire Stormy Lake - Kawashegamuk Lake area underwent a period of intense folding, faulting and granitic intrusion that predates the emplacement of the post-tectonic Taylor Lake Stock dated by U-Pb on zircons at 2678 M.a. (Davis et al., 1982).

Both the geological map and the aeromagnetic maps (O.G.S. Geophysical/Geochemical Series, 1981) reveal that major structures are oriented in east-west and northwest-southeasterly directions. On the aeromagnetic maps, the boundaries between the four major lithological groups are characterized by distinct magnetic intensity contrasts. Owing to the lack of exposure in some areas, aeromagnetic maps were a definite aid in establishing major lithological transitions.

The general northwest-southeasterly structural trends indicate that deformation was principally due to a compressional episode which was oriented northeast-southwest within the map area.

i) Folds

The most important structure within the map area is the Kamanatogama Syncline, about which the Boyer Lake Group is tightly to isoclinally folded. The position of the axial trace has been ascertained from numerous pillow top determinations, graded bedding in turbiditic sediments and the magnetic expression on the aeromagnetic maps. Bedding attitudes indicate that the interlimb angle at Stormy Lake is

very small but it gradually increases to the west. West of Stormy Lake, the syncline is plunging in a westerly direction, however the plunge is reversed at Stormy Lake and it is to the southeast at Bending Lake (Blackburn, personal communication). Foliation is very strong near the axial trace, particularly in the Stormy Lake area but it diminishes in intensity west of Noxheiatik Lake where the interlimb angle increases. Throughout the map area, the foliation is parallel to the axial trace of the syncline ; it also parallels the bedding trace. However, the three dimensional relationship of cleavage and bedding has, in most rocks, remained undetermined due to the following reasons : rock exposures are generally flat because of glacial erosion ; bedding is often poorly defined on a small scale particularly within mafic flows, pyroclastic deposits and conglomerates ; in highly deformed rocks, primary structures have been highly subdued.

At Stormy Lake, four periodic repetitions of a sedimentary unit is interpreted as resulting from three parasitic fold structures associated with the hinge zone of the syncline (Fig.IX-4e). Cobbold (1976) reproduced such a fold pattern experimentally using a layer of stiff material surrounded by a matrix of softer material. Provided that the rate of amplification of the folds produced by buckling was much larger than the rate of propagation, a minimum of 3 adjacent folds would result. The difficulty in reconciling this idea with the fact that the sedimentary layer was acting as a less competent unit than the surrounding basalts brings in the idea that buckling of the strata at the hinge zone may have occurred during the tightening of the Kamanatogama Syncline, thereby generating an "M" shaped fold.

The Kawashegamuk Lake Group is folded about a broad anticlinal axis plunging to the west : the "Tabor Lake Anticline". The position of the axial trace is not as well established as the Kamanatogama Syncline due to the lack of top indicators. However, mapping to the north (Satterly, 1960) suggests that the axial trace straddles the northern boundary of the map area ; further to the east it becomes oriented in a northwest-southeasterly direction paralleling the long axis of the Revell Batholith, which presumably intrudes the core of the anticline. At the present stage of regional mapping, this statement is conjectural because the boundaries of the Kawashegamuk Lake Group have not been defined outside the map area. In the vicinity of the Van Houten Gold Mine, variation in bedding direction and high angle cross-cutting relationship between bedding and cleavage in fine-grained tuffs indicate folding on a smaller scale.

ii) Faults

The fractures along which relative displacement took place may be classified into the following two types :

1) faults formed along preexisting weakness zones such as lithological boundaries and unconformities ;
2) faults that transect rock units at high angles and are apparently not associated with a previous weakness zone.

Faults of the first type are represented by the Mosher Bay - Washeibemaga Lake Fault (Fig. II,1), and by various zones of pronounced schistosity, particularly at the transition between the Kawashegamuk

Fig. V-1 : A strong shear zone has developed at the Kawashegamuk Lake - Boyer Lake Groups boundary. At the northern part of Kawashegamuk Lake, basaltic rocks are strongly schistose and have acquired a subvertical lineation (amygdules are highly stretched). This exposure shows well developed calcite filled tension gashes.

Fig. V-2 : Highly sheared pillow basalt on the north shore of Snake Bay with rock gouge. Two highly stretched pillows are seen in the middle of the photograph.

Lake and the Boyer Lake Groups (Fig. V-I). A number of these high schistosity zones have been called shear zones rather than faults because the amount of relative displacement in most cases is unknown and because of their complex nature (Fig. V-3b).

The contact between the Stormy Lake Group and the Boyer Lake Group has been interpreted as being faulted in part (Blackburn, I98I, I982 ; Kresz et al., I982a). Evidence supporting this hypothesis is as follows :

I) the presence of an angular discordance between the Boyer Lake and the Manitou Lake Groups (Blackburn, I98I, I982),

2) intense shearing along the contact of the Manitou Lake / Stormy Lake Groups and the Boyer Lake Group, and the presence of minor tight mesoscopic folds and crenulations in the Manitou Lake Group (Blackburn, I98I) and in the Stormy Lake Group near the contact. At the west end of Snake Bay, crenulated folds plunge in a northeasterly direction at about 45^{o}. Furthermore, strong lineations plunging to the northeast at steep angles (see Map I) are associated with the sheared rocks at Washeibemaga Lake and Snake Bay.

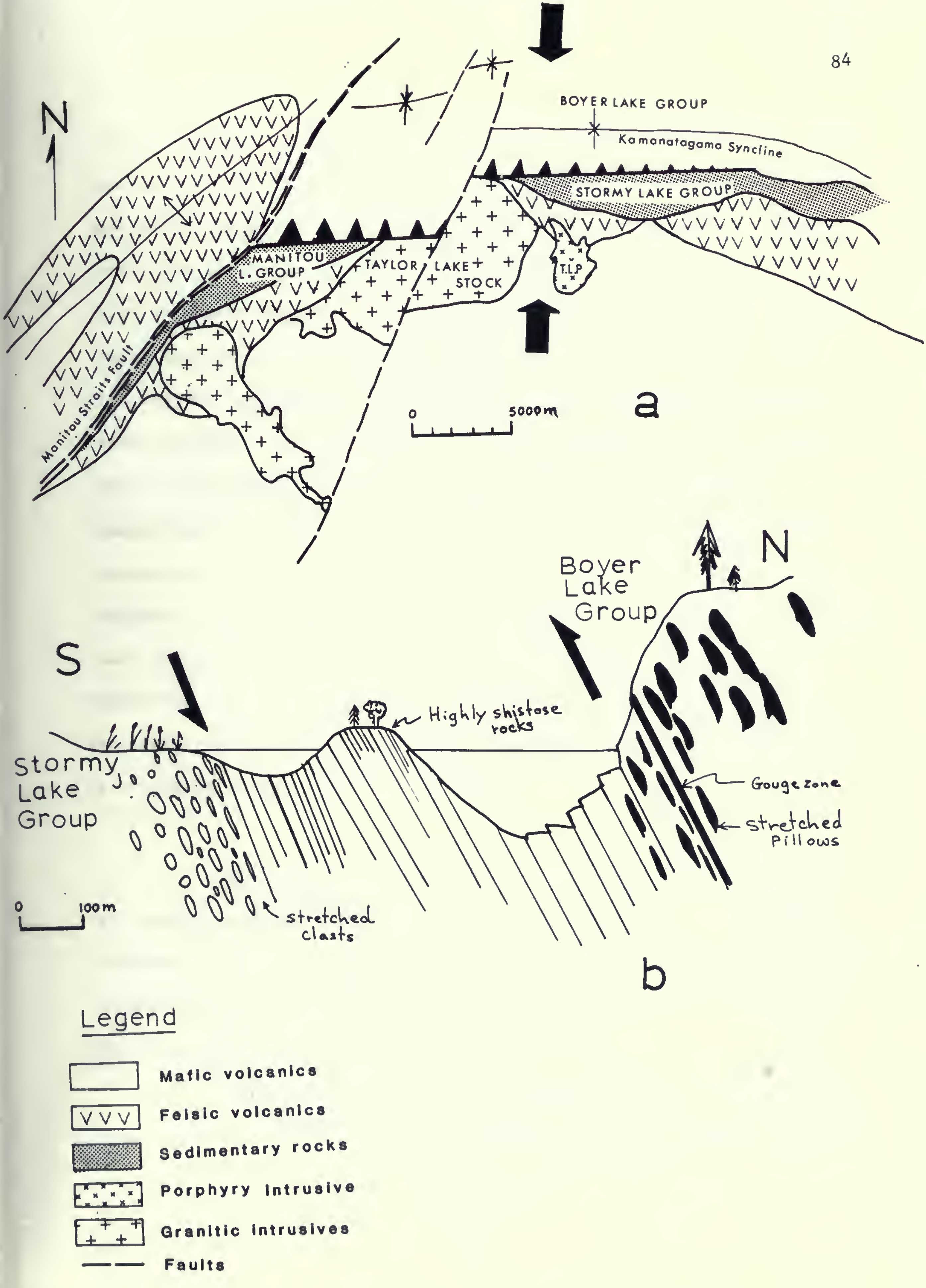
3) the presence of steep hills and cliffs on the north shore of Mosher Bay, Washeibemaga Lake (Blackburn, I98I) and Snake Bay coupled with the great depth of these Lakes (up to 60 m). The three lakes are all oriented in an east-west direction.

4) a steep rock face in pillowed basalts on the north shore of Snake Bay displays a zone having a maximum width of I.5 m along which intense shearing took place. The shear plane is oriented 090/65S (Fig.V-2). Deformation has been so strong that the rock has been reduced to a fine-

Fig. V-3 : Interpretation of the Mosher Bay - Washeibemaga Lake (MB-WL) Fault.

a) Map showing the position of the Fault within the Manitou Lake - Stormy Lake belt. Overthrusting of the Boyer Lake Group over the Manitou Lake and Stormy Lake Groups decreases eastward to zero schematically indicated by the size of the teeth. Arrows represent direction of maximum stress that generated east-west trending structures.

b) Schematic cross-section through the western end of Snake Bay showing the typical topographic features seen along the MB-WL Fault and associated structures. Arrows indicate sense of motion across the structure.


N
BOYER LAKE GROUP
Kamanatagama Syncline
STORMY LAKE GROUP
MANITOU L. GROUP
TAYLOR LAKE STOCK
T.L.P
Manitou Straits Fault
0 5000m
a
S
N
Boyer Lake Group
Highly shistose rocks
Stormy Lake Group
Gouge zone
stretched Pillows
stretched clasts
0 100m
b
Legend
Mafic volcanics
Felsic volcanics
Sedimentary rocks
Porphyry intrusive
Granitic intrusives
Faults

grained chloritic gouge. The gouge zone is in sharp contact with strained but coherent pillow basalt. On the opposite shoreline, mafic rocks are highly schistose. It thus appears that the deformed rocks along Snake Bay belong to an east-west trending shear zone hidden in large part by water. Mapping to the west (Blackburn, 1981) confirms that the fault terminates at the Manitou Strait Fault (see Fig. II-1), while its eastern termination is undefined. The above described features associated with the fault fade to the east presumably due to diminishing displacement. Blackburn (1980b) interpreted the Mosher Bay - Washeibemaga Lake Fault as a thrust, with the Boyer Lake Group overthrusting the Stormy Lake and Manitou Lake Groups. The present study suggests that the Boyer Lake Group overthrusts on the Manitou and Stormy Lake Groups such that offset is maximized at Mosher Bay. The offset diminishes progressively to zero amplitude in the east at the pivot of the fault. From this interpretation, the Mosher Bay - Washeibemaga Lake is a reverse scissor fault (Fig. V-3a).

Other faults within the map area are of limited length and are mainly of the second type ; they are all oriented in a northeast-southwest direction. These faults were perhaps generated during the main deformational episode and acted as transform mechanisms to dissipate differing strains across major folds.

A large number of airphoto lineaments have been traced (see Map 1). Many of them trend in a northeast-southwest direction (Fig. V-4).

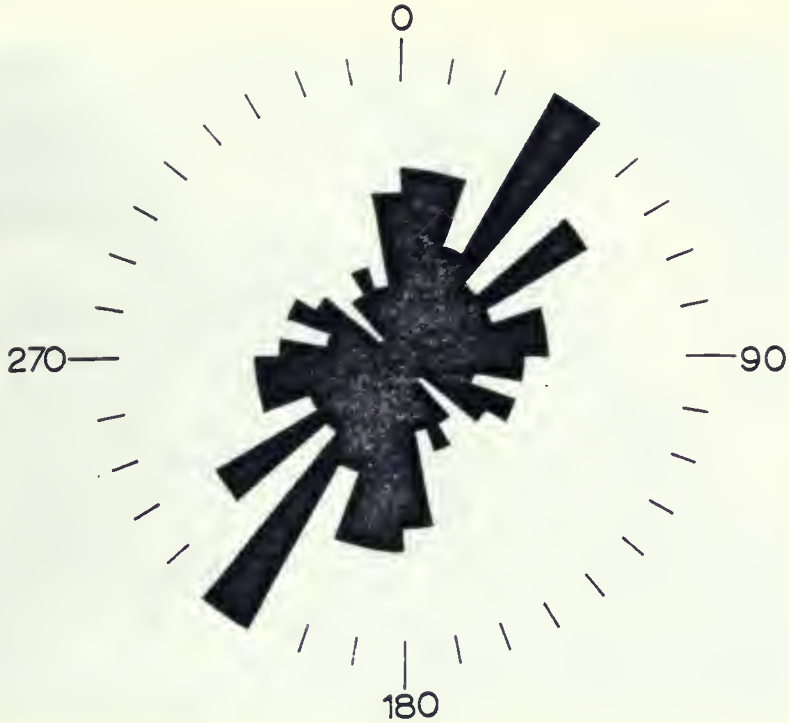


Fig. V-4 : Rose diagram showing orientation of airphoto lineaments represented on Map No 1.

iii) Fabrics

During regional deformation, penetrative fabrics, such as foliation and lineation, imparted by platy and prismatic minerals, and lithic clasts, were pervasively developed throughout the study area.

The various lithologies have responded differently to stress. Felsic pyroclastic units, especially pumice and scoria tuffs in the Kawashegamuk Lake Group have been highly strained (Fig. V-6). Good strain indicators, on which all three principal azes (X,Y,Z) lend themselves to measurements, are rare. The relationship $X > Y > Z$ is applicable in most areas and is particularly well developed within felsic rocks of the Kawashegamuk Lake Group (Fig. V-5). Along the Kawashegamuk Lake Group - Boyer Lake Group contact, a highly schistose zone displays a well developed lineation characterized by stretched clasts, amygdules and minerals (Fig. V-1). In one place, the mean deformation ellipsoid has the form 6:I:0.2, $K \approx 1$ on a Flinn (I962) diagram.

Fig. V-5 : Strong lineation developed in a lapilli tuff.

The lineations invariably plunging to the southwest at angles between 50 and 80° are probably associated with a wide northwest-southeast shear zone.

North of Tabor Lake, pillow lavas appear undeformed (Fig. II-16), however, a distinct lineation imparted by elongated varioles and chloritic amygdules has been observed. The varioles and amygdules, originally considered spherical, deformed to prolate spheroids with $K = \infty$ on a Flinn (1962) plot. This distinct lineation plunges at 90° and may be related to the close proximity of the "Tabor Lake Anticline" axis.

Pillowed horizons in mafic lavas are excellent strain indicators as pillow axial ratios and selvage thickness after deformation can

be used to deduce the amount and principal directions of strain (Borradaile and Poulsen, 1981) ; unfortunately, the pillow shapes can be viewed only in two-dimensions. Within the map area, pillows have been deformed to a high degree mainly near major structures and lithological boundaries. In such places, pillows appear flattened (in most exposures, only their Y and Z axes have been observed). Pillow shapes and cusps positions reveal that the finite strain ellipse, in many areas, is symmetrically disposed with respect to the dimensions of the pillow implying that the breadth of the pillow may be used as the bedding marker (Fig. II-19).

Certain massive flows and intrusive rocks (gabbro and felsic porphyries in particular) have apparently escaped penetrative deformation and have developed instead a widely spaced fracture cleavage represented by faults and joints.

iv) Cross-sections through the Stormy Lake - Kawashegamuk Lake area (see Fig IX-4d, e and 5).

CHAPTER VI - SEDIMENTOLOGY OF THE STORMY LAKE GROUP

The geology of the Stormy Lake Group has already been described in Chapter II, and the intent, here, is to : I) postulate the environment of deposition of the various units making up the Stormy Lake Group in light of well established sedimentary sequences in modern environments, as well as other Archean provinces, i.e., constructing a facies model ; 2) establish the provenance of the detrital material, that is, to identify volcanogenic versus crustal derivation of the sediments.

In Chapter II, the Stormy Lake Group has been divided arbitrarily into broad subdivisions within the realm of sedimentary rocks and according to the lithologic make up of the sediment constituents (Fig. VI-I), nonetheless, the differences among the units are by no means implying differences in genetic factors. Mapping of the Stormy Lake metasediments has been carried out at a reconnaissance level. Detailed analysis of individual units remains to be done for a more complete understanding of sedimentary processes that took place in the area. Nevertheless, the amount of data already collected in the field is sufficient to give some preliminary conclusions. The identification of Archean sedimentary environments is rendered more difficult than for Phanerozoic sedimentary sequence for the following reasons :

I) outcrop density is often scarce, providing the geologist with a fragmentary picture of the sedimentary sequence,

2) the complete lack of fossils,

3) the limitation to a two-dimensional picture due to steeply inclined strata and lack of topographic relief,

4) tectonic deformation is often intense. As a consequence, it is often impossible to distinguish primary fabrics (e.g. imbrications, flat pebbles) from tectonic fabrics.

Following the scheme outlined in Fig. VI-2, it is essential to distinguish sediments which have been deposited in a terrestrial environment, from those deposited under a large body of water, presumably the Archean ocean. In so doing, it is of prime importance to discriminate between diagnostic and non diagnostic features. For instance, small scale cross-stratification alone (set thickness of I-4 cm) is of little value because such structures can form in many environments (Turner and Walker, I972 ; Selley, I969). However, cross-stratification in sets greater than I0 cm is more useful as their presence precludes a deep marine environment (Turner and Walker, I972) where quiet conditions prevail.

The Stormy Lake Group can be divided into two parts on a lithologic basis, in the west a broad assemblage consisting of coarse conglomerates, coarse immature sandstones and non remobilized volcanic deposits making up Facies I, II and III, in the east an assemblage of sandstones, grey wackes, mudstones displaying features characteristic of turbidites and iron formation constituting Facies IV and V. These two parts display fundamental differences based on : I) lithologic make up,

2) size and sorting of clasts,

3) sedimentary structures,

4) special features.

These differences are summarized in Table VI-I.

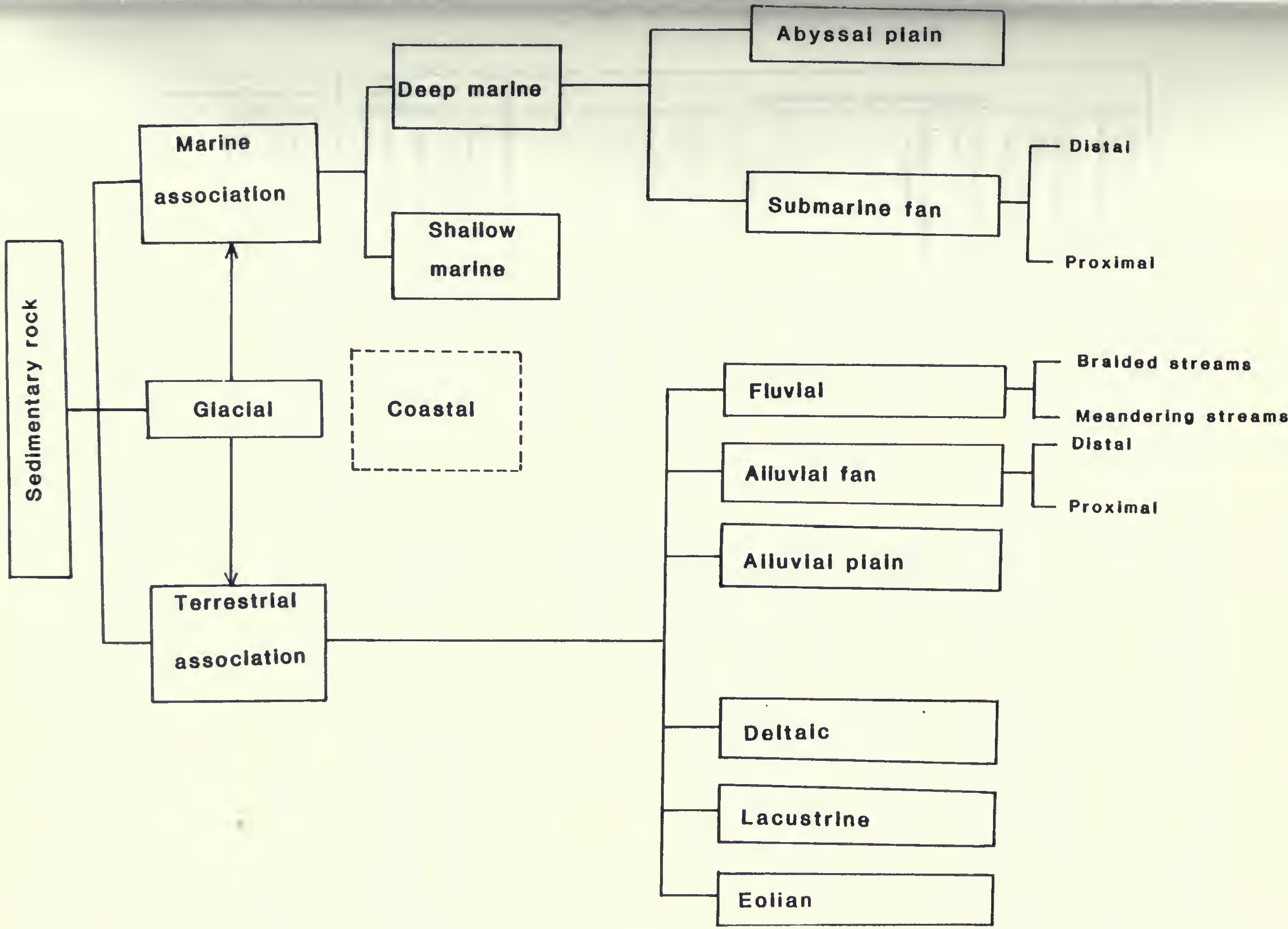


Fig. VI-2 : Flow chart outlining major modern sedimentary environments for which Archean analogs may be recognized.

Table VI-1 : Summary of sedimentary characteristics of each facies (mappable units) within the Stormy Lake Group accompanied by sedimentary processes and deduced environment of deposition.

	Facies I	Facies II	Facies III	Facies IV	Facies V
Lithological characteristics	- Autoclastic breccias. - Felsic lava flows - Volcanic breccias and tuffs - Minor epiclastic sediments	- Coarse conglomerate - High clast-matrix ratio. - Highly diverse clast lithologies - Poorly sorted. - Well rounded clasts - Poorly bedded conglomerates. - Sandstone interbeds with restricted lateral continuity. - Immature sandstone. - Large scale cross-stratification in sandy units. - Scour marks. - No graded bedding in sandy units. - Common weathering rims on clasts.	- Cobble to boulder conglomerate. - Essentially volcaniclastic with a few exogeneous clasts near the top. - Angular to well rounded clasts. - Very poor size sorting. - High to low clast - matrix ratio. - Very immature matrix. - Some bedded sandstone with restricted lateral continuity. - Large scale cross-beds in sandy units. - No graded bedding. - A few clasts show weathering rims.	- Stratified arenite, siltstone and slate. - Normal grading characteristic of turbidites, Bouma (1962) cycles A and B. - A few thick bedded, poorly graded and poorly sorted, coarse arkoses and lithic arkoses. - Common interbedded siltstone and slate. - Some conglomeratic beds in the west. - No large scale cross-stratification.	- Slates predominate with some siltstone beds, Bouma (1962) cycles C, D, E. - Abundant iron-formation of oxide facies at Bending Lake.
Sedimentary processes	- Vent facies volcanic deposits. - Lahar flows. - Mass wasting.	- Sheet flows. - Debris flows. - Channel deposits.	- Sheet flows. - Debris flows. - Channel deposits. - Sieve deposits?	- Deposition mainly by turbidity currents. - Some sediment creep on unstabilized slopes (poorly sorted, non graded beds).	- Deep basin sedimentation, background sedimentation interrupted by turbidity currents, very quiet conditions.
Interpreted environment of deposition	- Deposition on volcanic slopes. - Shallow marine to emergent island.	- Terrestrial, alluvial fan.	- Terrestrial, alluvial fan.	- Submarine fan on basin slope.	- Lower fan to basin plain.

The entire sedimentary pile represented by the Stormy Lake Group rests upon a thick volcanic sequence (the Wapageisi Lake Group), that has been entirely deposited underwater. The contact appears to be unconformable based on the fact that the conglomerates immediately overlying the Wapageisi Lake Group have been deposited subaerially (weathering rims on clasts, large scale cross-stratification) and bedding within the Wapageisi Group is at an angle to the contact. Immediately above the contact and in the west, are the conglomerates and coarse sandstones making up Subfacies IIa. It is chiefly a heterogeneous assemblage of highly unsorted conglomerates and sandstones. About 80% of the clasts are volcanogenic and of varied composition ranging from mafic (greenstone) to rhyolitic. Much of the fragmentals appear to have been supplied from the Thundercloud Porphyry and its pyroclastic derivatives for the following reasons :

I) The relatively high content of angular quartz porphyry clasts, which have a striking resemblance to the Thundercloud Porphyry.

2) The high content of angular dacitic to rhyolitic fragments.

3) Quartz grains I to 4 mm in size are a major constituent in coarse sandstones and grits. These large grains are similar in size to the abundant quartz phenocrysts present in the porphyry.

No more than 20% of the remaining fragmentals are from non volcanic origin including plutonic rocks of sialic composition, chert-hematite iron formation, vein quartz and foliated rocks (Fig. II-7). The association of these units of non-volcanic debris with volcanic-derived material is in strong support of the presence of a non-volcanic hinterland, which appears already to have undergone a complex geological history.

Subfacies IIb is similar to Subfacies IIa in many respects, but differs in the increase in clast size, chaotic arrangement of clasts and exogeneous clasts. The high content of granitic material could be derived from two possible source areas :

I) an emergent non volcanic hinterland of sialic composition (craton) ;
2) the unroofing of granitic plutons in the Wapageisi Lake Group following an epeirogenic episode that preceded deposition of the Stormy Lake Group. Several arguments point against the latter case :
I) the highly diversified granitic clasts coupled with the presence of non volcanic supracrustal material,
2) no early granitic phases have been observed within the Wapageisi Lake Group,
3) the Meggisi Pluton (Map 3 in back pocket) yielded a U/Pb (Zircon) age of 2722 ± 2 M.a. for the seriate phase (Davis D.W., personal communication, I984) which probably postdates the deposition of the Stormy Lake Group (see further comments in Chapter IX).
4) the high degree of roundness of most granitic clasts suggests long range transport.

Many lines of evidence point towards an agitated environment of deposition :

- Numerous well worn clasts indicate transport in a high energy medium, probably fast running water. Two other possibilities include reworking in a beach environment and glacial reworking. Beach conglomerates would be expected to be well sorted because of constant winnowing by wave action, secondly the sandy fraction would be enriched in minerals

which are resistant to mechanical and chemical breakdown ; this has not been observed in the field. No evidence of glacial reworking has been observed, furthermore, none of the features characteristic of pleistocene glacial deposits have been identified.

- Large scale cross-stratification is indicative of strong current activity and therefore virtually excludes abyssal sea floor, continental slope and rise where size grading, siltstones and mudstones are abundant (Turner and Walker, I972 ; Hyde, I975).

- Stratified and cross-stratified pebble rows (Fig.II-8) in poorly sorted sandstones suggest strong current flow, and is most likely representative of a channel deposit. It is, however, unclear from this observation alone whether the environment was a river or distributory channel on an alluvial fan.

The intimate interbedding of the conglomeratic and sandy beds tend to indicate that they shared a common environment of deposition.

Proposed facies model for Facies II :

The mode of occurrence of the various sediments and observed structures are very similar to well studied Phanerozoic alluvial fans (Bull, I972). It is likely, nonetheless, that the conglomerate (basal?) represented by Subfacies IIa has been deposited by a river. At a later stage following continuing uplift, the quantity of exogeneous clasts increases towards the top of Facies II ; an alluvial fan started forming (Subfacies IIb). This would be in agreement with a regressive sequence.

Processes by which sediments deposit on an alluvial fan are of three kinds : 1) stream channel deposits, 2) sheet flood deposits, 3) debris flows,(Bull, 1972). The rather massive beds of chaotic conglomerate have probably been deposited by stream floods and sheet floods during storm surges, while finer-grained units, in particular those which exhibit cross-stratification, were deposited by distributary channels. Since some conglomerates are devoid of matrix, sieve deposits may have formed. However, according to Bull (1972), sieve deposits are favoured by angular blocks and not rounded gravels. Debris flows, being of high density and viscosity, take place only if there is a high amount of fines (Turner and Walker, 1972 ; Bull, 1972 ; Blatt et al., 1980). Conglomeratic mudstones have not been observed.

The possibility of Facies II being a submarine fan deposit is not supported by field evidence : conglomerate beds are frequent in submarine fans but modern observations and well established ancient fans have confirmed that turbidites are intimately associated with submarine fans (Stanley and Unrug, 1972 ; Turner and Walker, 1972 ; Hyde, 1975 ; Meyn and Palonen, 1980 ; Nelson and Kulm, 1973 ; Walker, 1975). The ample support for an alluvial fan model is further backed by the general plane geometry on the present erosional surface of Subfacies II. The highly symmetrical disc-shaped outline with the centre bulge points towards an alluvial fan (Fig. VI-3). The base of the fan is made up by mostly volcanic derived material. It is likely that during the initial stages of sedimentation, the fan was supplied by volcanic debris shed from nearby volcanic centres ; later an increased influx of exogeneous material provided by an emerging non volcanic craton and diminished volcanic activity, blanketed the mainly volcaniclastic conglomerate.

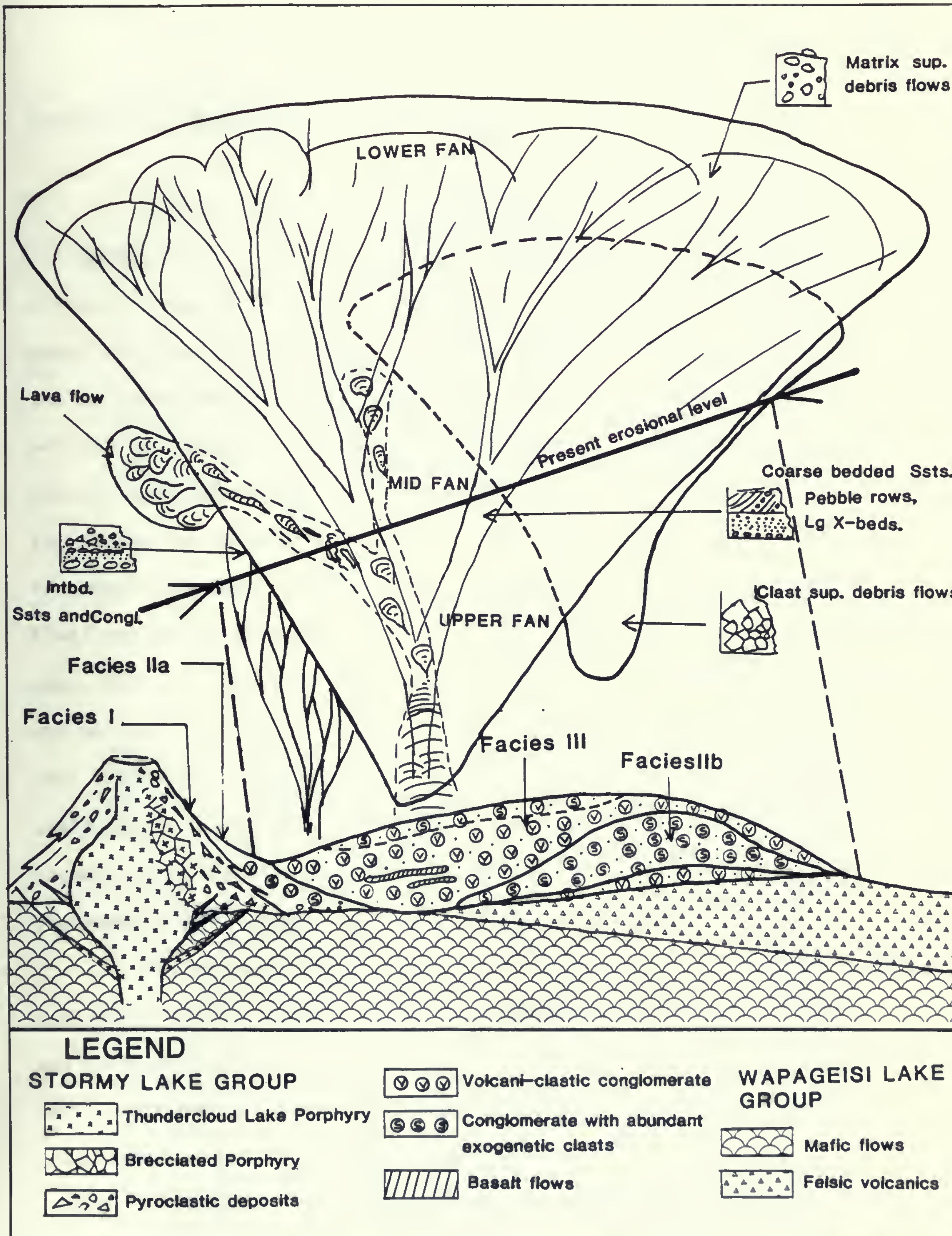


Fig. VI-3 : Interpretational sketch of the Stormy Lake Group.

Facies III : an overlapping alluvial fan

Facies III is in many respects similar to Facies II. The main difference lies in the fact that most fragmentals have been supplied by a volcanic source. Exotic clasts are rare, except at the top near the south shoreline of Snake Bay, where well rounded exotic clasts are similar to those found in Facies II (Fig. II-12). The fragmentals are never well sorted. Their outline is commonly angular to subrounded (Fig. VI-4); nevertheless, well rounded clasts are common (Fig. VI-5). Clasts with some degree of rounding do not necessarily imply extensive reworking by transporting agents : a large number of them are highly vesicular (Fig. VI-4) and therefore would wear rather rapidly in a high energy environment. Matrix to clast ratio in many conglomerates is rather high. Because the matrix is composed of fine-grained chloritic tuffs, it is plausible that debris flow processes occurred (Blatt et al., 1980). The mainly volcanic debris accumulation of Facies III strongly suggests that volcanism resumed after a period of subdued activity ; this is supported by the presence of interbedded, non-reworked volcanic material :

- The base of Facies III is marked by a unit of rhyolitic breccia, which is in turn overlain by well stratified, fine-grained felsic and chloritic tuff (Fig. VI-6) interpreted to be an ash fall tuff. This tuff is directly overlain by conglomerates and cross-stratified (large scale sets) unsorted lithic arenites.

- Several single basaltic flows occur within the conglomerates. They are highly vesicular and are massive, except for some pillow-like structures which are interpreted to have formed in a small body of water.

Fig. VI-4 : Monomictic conglomerate within Facies III, composed of highly vesicular volcanic clasts in a tuffaceous matrix. The high matrix/clast ratio and the lack of bedding suggest that transport occurred as debris flows.

Fig. VI-5 : Poorly reworked volcanic material in Facies III, which was rapidly deposited on the slope of an alluvial fan. A more distant source has supplied well rounded granitic clasts.

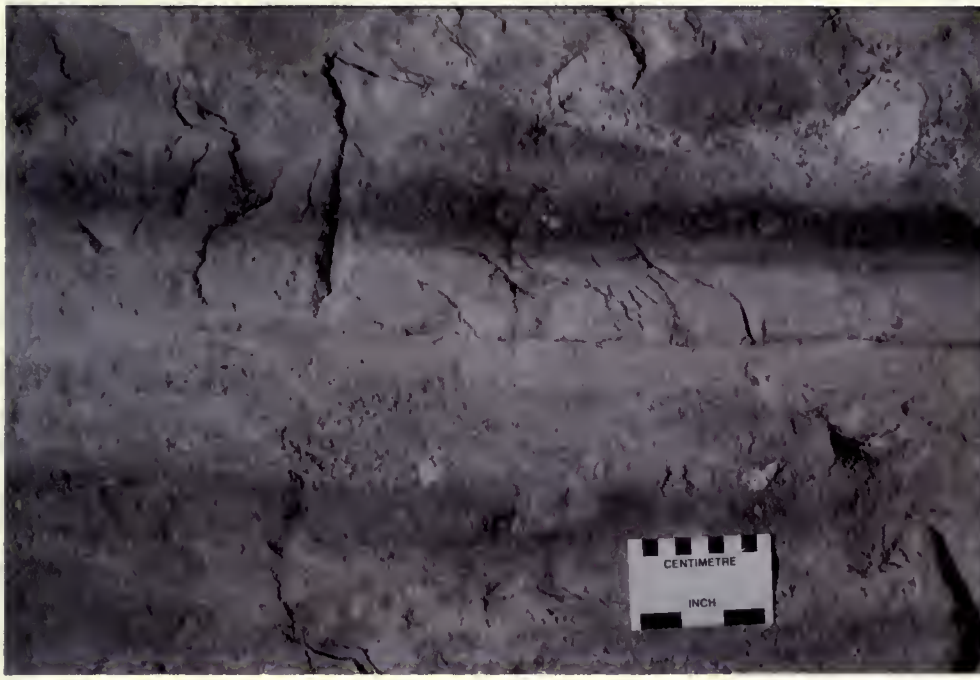


Fig. VI-6 : Well stratified air-fall tuffs. The felsic layer in the middle shows normal grading ; the mafic tuff overlying it consists of a thin ash layer which is succeeded by a layer of lapilli size material. Conglomerate directly overlies the tuffs.

Proposed model for Facies IV and V

The eastern part of the Stormy Lake Group entirely consists of sandstone , wacke, siltstone , and slate , and oxide facies iron formation towards Bending Lake, all of which display features characteristic of turbidites : the arkosic nature of the arenites (Goodwin, I968 ; Turner and Walker, I972) and the ubiquitous Bouma cycles associated with most of Facies IV and V. Walker and Pettijohn (I97I), Turner and Walker (I972), Walker (I978a), asserted that turbidity currents can take place in any depth of water ; however, structures characteristic of turbidites will only be preserved if no reworking either by storm or ocean currents takes place. For thick turbidite sequences to accumulate, depths well below storm wave base are required. Furthermore, slate facies in a basin is considered to be the background sediment and quiet conditions prevail (Walker and Pettijohn, I97I). Well stratified siltstones and slates within the map area show no evidence of agitated water (ripples, cross-bedding, scour marks nor bed material disruption of any kind). Following the arguments of Walker, there is little doubt that Facies IV and V have accumulated in a deep water environment (below storm wave base).

Facies IV with abundant coarse grained arkosic sandstones display divisions A and B of the Bouma cycle with the higher divisions in the finer sediments, but further east, Bouma divisions C, D and E prevail in the more distal sediments which were most likely deposited in a pelagic environment. It appears that the more proximal association of Facies IV, and more distal association of Facies V are time equivalent.

It could be envisaged that Facies IV represents a submarine fan similar to the model of Walker (1978b) (Fig. VI-7) because of the sedimentary variations taking place across Facies IV : conglomerates, massive, pebbly and graded sandstones, thin bedded and fine-grained turbidites have all been observed, and are possibly deposits characteristic of the different structures of the fan such as : channels, levees and interchannel deposits.

It is unclear how Facies V fits within the deep submarine model, because most of it lies outside the map area. Whether it is part of the lower fan or has been deposited in an abyssal plain, it is most likely a deeper water facies than Facies IV.

Transitional environments :

Although two major sedimentary environments of deposition have been recognized within the map area : a terrestrial and a deep submarine environment. No evidence of shallow marine or beach facies have been observed. The significant lack of outcrop along the boundary of Facies II, III and IV would make the recognition of a narrow facies difficult. However, other studies within the Canadian Archean have failed so far to identify non-equivocal intervening facies types (Wood, 1980 ; Turner and Walker, 1972 ; Teal and Walker, 1977 ; Hyde, 1980 ; Henderson, 1972). It is inferred from this that the Archean paleoslope in the Stormy Lake area was too steep to develop a shallow shelf ; consequently, if beaches were present, they must have been very restricted, and the input rate of sediments into the sea was likely high. This could have been true in the

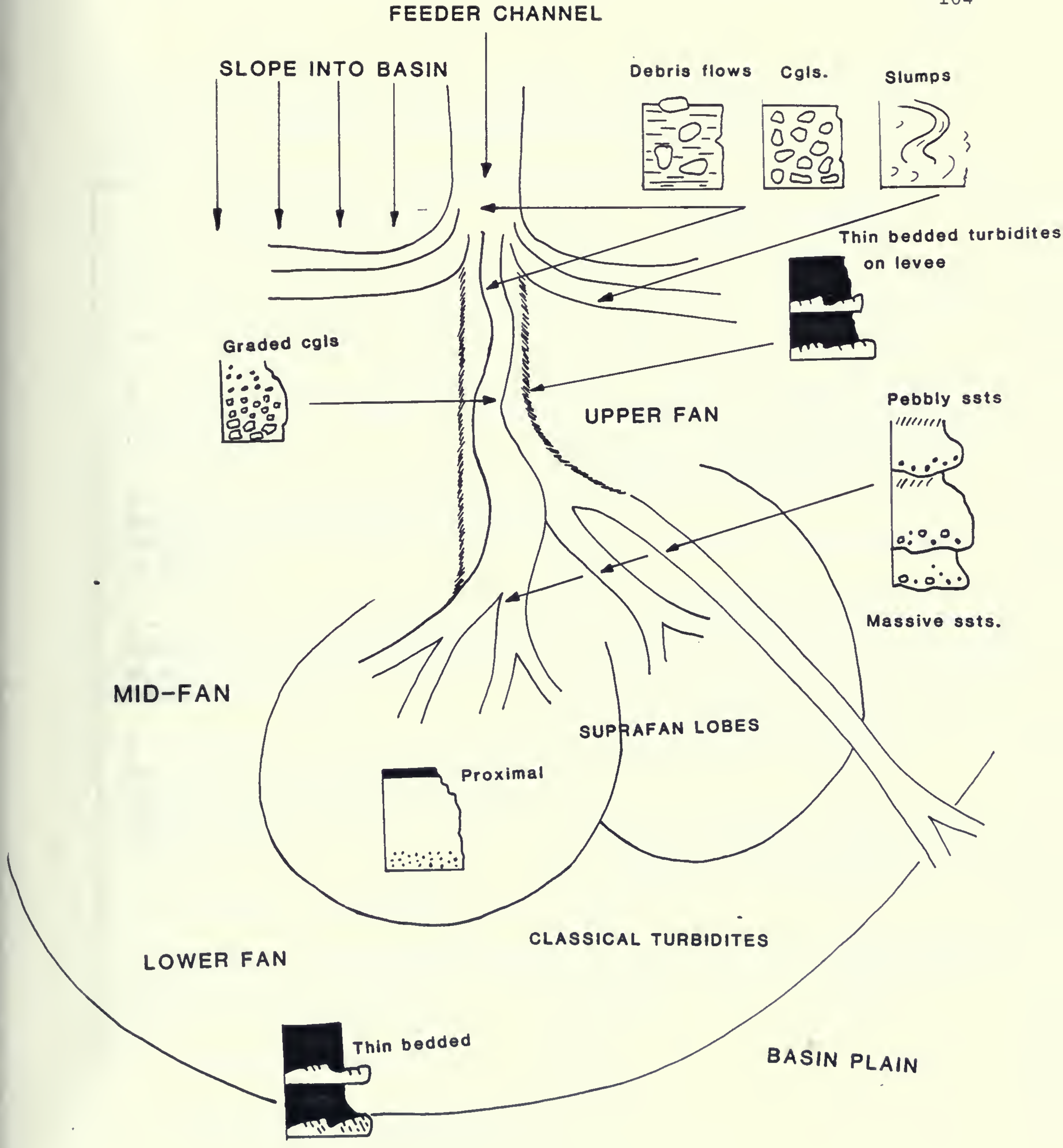


Fig. VI-7 : Submarine fan model after Walker (1978b, fig. 13)

Table VI-2 : Synopsis of events responsible for the deposition of the Stormy Lake Group and the Manitou Lake Group.

STORMY LAKE GROUP	TAYLOR LAKE INTRUSION	MANITOU LAKE GROUP (Teal, 1979)
1 - Thick accumulation of mafic flows (Wapageisi Lake Group, Subgroup I).		1 - Thick accumulation of mafic flows (Wapageisi Lake Group).
2 - Central felsic volcanism took place near the end of mafic volcanism (Subgroup II).		2 - Felsic volcanism begins and formation of a pyroclastic pile with interfingering flows ; emergence of the volcanic pile that initiated underwater.
3 - Uplift and emergence of the Wapageisi Group. Emplacement of the Thundercloud Lake Stock and accumulation of Facies I.		3 - Break in volcanic activity.
4 - Deposition of volcaniclastic conglomerates by streams and initiation of an alluvial fan (volcaniclastic member of Facies II).		4 - Initiation of alluvial fans on the flanks of volcanoes accompanied by development of a braided river system flowing perpendicular to the alluvial fan and bringing in non-volcanic debris. A short-lived lake received some fine-grained sediments.
5 - Continued uplift. Volcanic activity ceases. Emergence of a sialic hinterland. Continued development of alluvial fans (polymictic member of Subfacies IIb).		5 - Following deposition of the above, the entire area was submerged, probably rapidly, and was covered by a submarine fan.
6 - Resumption of volcanism.		6 - Resumption of mafic volcanism covers the entire Manitou Group with a basalt sequence.
7 - Erosion of newly formed volcanoes contributes coarse sediments to a new alluvial fan (Facies III).		
8 - Volcanic activity ceases.		
9 - Formation of a submarine fan in adjacent basin during events 3 to 7.		
10 - Rapid subsidence. A transgressive submarine fan covers the terrestrial sediemnts.		
11 - Mafic volcanism resumed : deposition of the Boyer Lake Group.		

unstable tectonic environment studied here : the turbidites of the Stormy Lake Group overlying the subaerially deposited sediments are indicative of rapid subsidence (transgressive sequence).

Evolution of the Stormy Lake Group : an interpretation model.

Table VI-2 summarizes the sequence of events that highlighted the history of the Stormy Lake Group. As a comparison, the evolution of the Manitou Group, as interpreted by Teal (1979), is also presented. The similarities of the two Groups make a correlation across the Taylor Lake Stock possible.

CHAPTER IX - VOLCANOLOGY

i) Introduction

The supracrustals within the study area consist almost entirely of volcanic rocks and derived sediments. The highly diversified types of volcanic deposits are divided into three major categories :

1 - Accumulations made up of flow units,

2 - Accumulations generated by central type volcanoes with physical characteristics that indicate explosive volcanism,

3 - Accumulations consisting mainly of redeposited epiclastic volcanic material.

It may be argued that lithologic units made up of reworked volcanic debris should all be called epiclastic sedimentary deposits. However, it is commonly difficult to distinguish between truly volcanic and sedimentary mechanisms. For example, an ash fall settling in a subaqueous environment will most likely display sedimentary features such as those produced by turbidity currents, or a pyroclastic deposit produced by the sloughing of ejectamenta from the flanks of a volcanic cone may display structures inherent to any "sedimentary" debris flow. It is therefore stressed that sedimentary and volcanic processes are interrelated to produce volcanic deposits and one cannot describe a lithology based on a rigid volcanic or sedimentary classification terminology. On these grounds, it may not be possible to assign a specific label to

units such as the tuffaceous units at the base of the felsic sequence of the Wapageisi Lake Group and parts of the Stormy Lake Group. Following these arguments, volcanic rocks may belong to either of two associations :

1 - An in-situ volcanic association (Parsons (1969) vent complex facies),
2 - A reworked association (including Parsons (1969) alluvial facies).

The in-situ volcanic association comprises flows, subvolcanic intrusives, autoclastic and alloclastic breccia, and pyroclastics while the reworked association is distinguished by pyroclastic deposits with structures indicative of water or eolian transport, such as tuffs with well defined bedding, and bedding related structures found in arenites deposited by running water or turbidity currents, many heterolithic breccias and tuffs, and volcaniclastic conglomerates.

Pyroclastic rocks are described here using Fisher's (1966) fragment size classification scheme (see Appendix D,a).

Also, for descriptive purposes, the chemical character of volcanic rocks (basalt, andesite, dacite, rhyolite) is based solely on color index and mineral composition as encountered in the field. However, more appropriate terms are from analyzed rocks.

ii) Facies of basaltic rocks

Basaltic rocks are the predominant type of volcanics . The Wapageisi Lake Group and the Boyer Lake Group consist almost entirely of mafic flows but the Kawashegamuk Lake Group has approximately equal proportions of mafic and more felsic lithologies.

Basalts occur mostly as massive and close-packed pillowed flows. Fragmental rocks consist mainly of hyalotuffs making up most of interpillow material, pillow breccias and flow top breccias. Locally, these lithotypes predominate over non brecciated flow material and in the Kawashegamuk Lake Group they are common, presumably because flows had a higher viscosity due to the more calc-alkaline character of the lavas. However, vast amounts of hyalobreccias and tuffs forming distinct mappable units are absent, suggesting that basalts were erupted under relatively quiet conditions, thereby precluding surtseyan type eruptions.

Pillow lavas are assumed to have originated by the same process as those found in modern subaqueous environments (Moore, 1975 ; Moore et al., 1973 ; Jones, 1968) which have been shown to form by spreading and budding of lava lobes and toes. Arndt (1973) and Dimroth and Rocheleau (1979) claim to have seen free pillows occurring as closed sacs in the Abitibi lavas. It is most likely that pillowed flows consist of both long lava lobes and closed sacs which rolled down a slope. Size of pillows vary greatly from place to place and there appears to be little relationship between size range and chemical composition of the lavas. Shapes are highly varied, ranging from subspherical in small pillows (Fig. II-2) to mattress shape for large pillows ($>$ 1m). Isolated pillows in a tuffaceous matrix commonly have ameboid shapes (Fig. II-23). Large pillows (megapillows) commonly connect with massive flows. It is reasonable to assume that massive flows have formed during high rates of lava emissions and that the production of pillows increases away from the vent (Fig. VII-1).

In the discrete flows within the Stormy Lake Group, the observed pahoehoe toes have very thin chilled margins suggesting subaerial

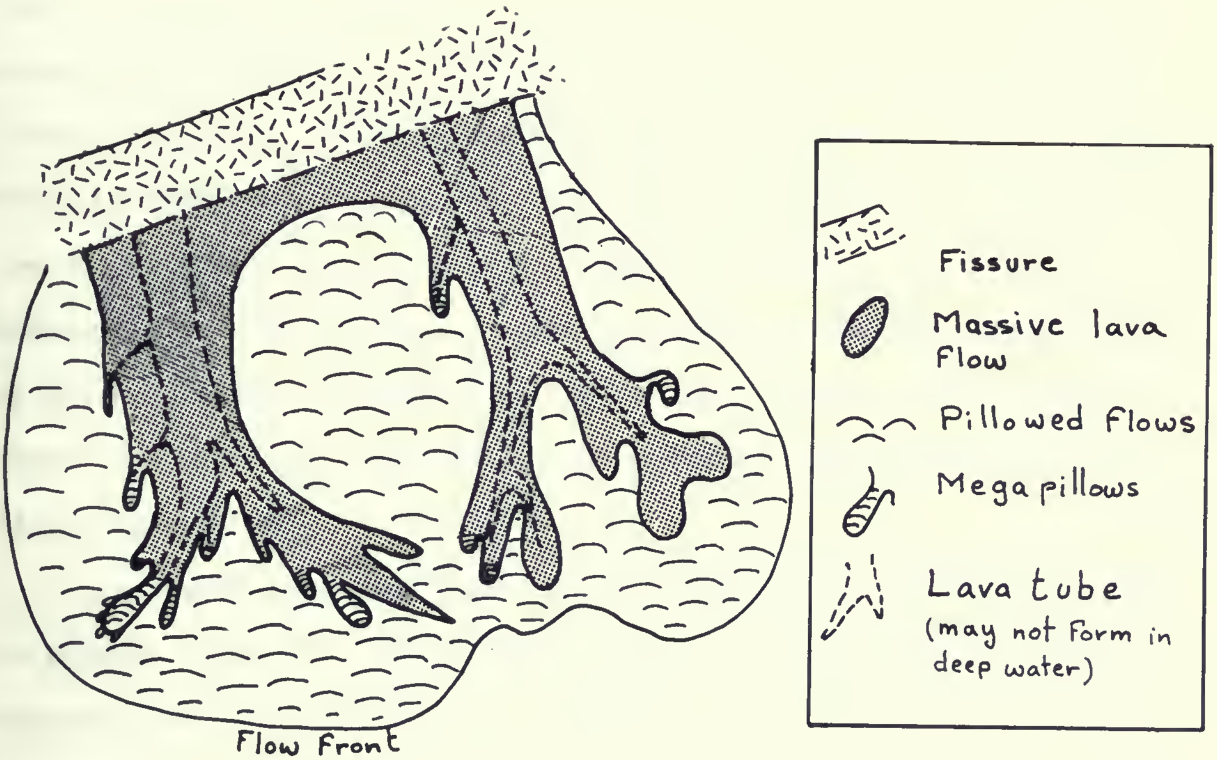


Fig. VII-1 : Structural organization of a submarine basaltic lava flow showing the different facies types (after Dimroth and Rocheleau, 1979).

cooling. Evidence for feeder tubes in pillows, such as lava levees and collapse breccia, have not been observed. Vesicles are common in pillow lavas, particularly in the Kawashegamuk Lake and Boyer Lake Groups ; they are concentrated in the rim zone. The individual basalt flows in the Stormy Lake Group have a high abundance of vesicles at the flow margins. These flows possess a higher proportion of vesicles than any of the massive and pillowed flows erupted under water, suggesting that there is a correlation between water depth and vesicle abundance and size (Jones, 1969).

The abundance of breccias and aquagene tuffs (Carlisle, 1961) is greater in the Kawashegamuk Lake Group ; breccias include both flow top and broken-pillow breccias. In numerous rocks, close-packed pillow lava grades into pillow breccia zones with isolated pillows (Fig. II-23). The pillow breccia consists mainly of highly angular fragments having a similar aspect to pillow selvage material mixed with varying amounts of pillow fragments.

Variolitic lavas

Variolitic flows are restricted in areal extent, although they have been found in several stratigraphic horizons : (1) at the top of the Wapageisi Lake Group, near Katisha Lake ; (2) in the Boyer Lake Group, and (3) in the Kawashegamuk Lake Group, near Tabor Lake, where variolitic rocks have been traced discontinuously along strike for approximately 3 km ("Formation V"). Stratigraphically, the variolitic formation is situated near the bottom of a thick mafic-felsic cycle (Cycle II).

North of Tabor Lake, variolites are relatively undeformed and the finest structures and textures have been remarkably well preserved.

Petrographic description :

a) Varioles

The varioles occur as distinct felsic bodies set in a dark green iron-rich chloritic matrix. They range in size from 0.1 to 10 mm and invariably increase in size towards the middle of the pillow. The abundance of varioles also increases toward the centre of the pillow where they tend to coalesce.

Varioles, modified by strain (Fig. VII-2t), occur as stretched rounded bodies in one direction, but they appear to have been spherical before deformation set in. The boundary, although it appears smooth macroscopically, is ribbed when viewed under the microscope (Figs. VII-2e, 1).

Three types of varioles have been observed :

1) randomly occurring varioles ranging up to 10 mm in diameter (Figs. VII-2a, b).

2) "minivarioles" : they have been found only in one location. Morphologically, they are similar to type 1) varioles but have a constant size ranging from 0.1 to 0.5 mm in diameter. They are dispersed randomly throughout the matrix and are very abundant (Fig. VII-2q).

3) coalescing varioles at fracture sites. They may be of type 1) or 2) varioles (Figs. VII-2p, q, r).

Mineralogy : Assemblages consist of fine-grained secondary minerals of which individual grains are indistinguishable, so that the variole appear to be almost amorphous in thin section. Nevertheless, there is little doubt that originally they were composed of a fine intergrowth of prin-

cipally alkali feldspar and quartz.

Varioles show a distinct concentric color zonation (Figs. VII-2c, d), which is believed to be primary : mineral zoning in spherulitic growths occurring in obsidian have been observed (Fig. VII-2v).

Some varioles display a distinct radiating pattern of acicular feldspar crystals, which radiate from the variole core (Figs. VII-2e, f). Quench plagioclases showing buckle and swallow tail shapes (Figs. VII-2a, j) may have served as nuclei to spherulitic growth (Fig. VII-2g) ; on the other hand, many of such crystals occur in a concentric layer in the rim zone of the variole (Fig. VII-2i). Slender crystals, believed to be plagioclase, are arranged in a radial pattern ; at the rim, these crystals are covered by spherulitic growth giving a ribbed or dendritic outline to the variole (Figs. VII-2e, 1).

Type 2) varioles are different only by their small size. In addition, lavas possessing both type 1) and 2) varioles have distinct bimodal size distribution of varioles (Fig. VII-2q).

Type 3) varioles are distinguished from other types only because they are concentrated at hair-line fractures in the matrix (Figs. VII-2p, q, s). These fractures have probably been generated by thermal contraction of a cooling viscous liquid. Their convoluted shape is likely due to deformation which took place in the pillow while it still was in a plastic state. The very high concentration of varioles at fracture sites led to coalescence and formation of distinct convoluted bands of felsic material (Fig. VII-2r). Thus it appears that fracturing has triggered a high number of nucleation sites where varioles grew in a viscous paste before complete solidification.

Fig. VII-2 :

a : Variolitic pillows showing size grading of varioles (K9)

b : Varioles in a chloritic matrix showing perlitic textures
Plane light,x2 (K9)

c : Varioles showing concentric zoning. Plane light,x6 (K9)

d : Varioles in a quenched matrix. Plane light,x20 (K9)

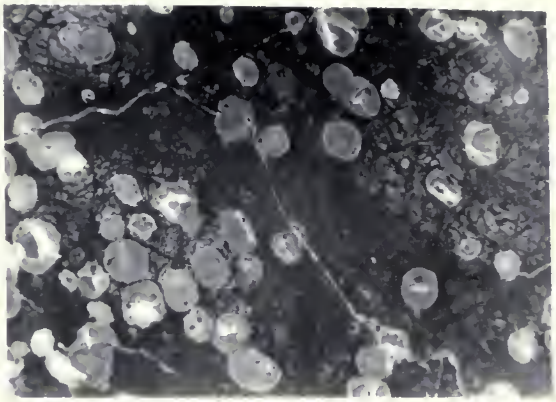
e : "Coalescing" varioles showing a radial structure. Plane light,x 25 (K5)

f : Enlarged view of Fig. 2e, showing distinct radial structure. Plane light,x80 (K5)

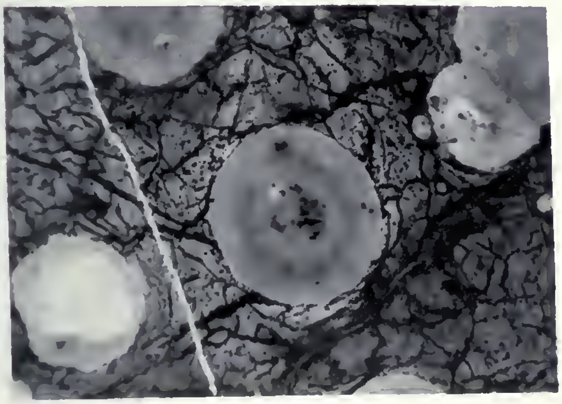
g : Two "coalescing" varioles. Plane light,x40 (K9)

h : Chlorite-filled vesicle squeezed between two varioles. The opaque mineral is sphene after ilmenite. Plane light, x64 (K9)

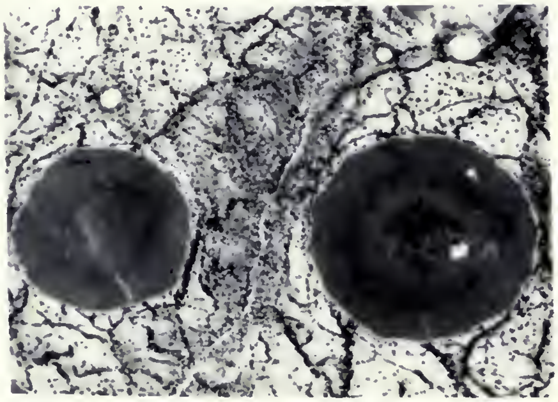
a



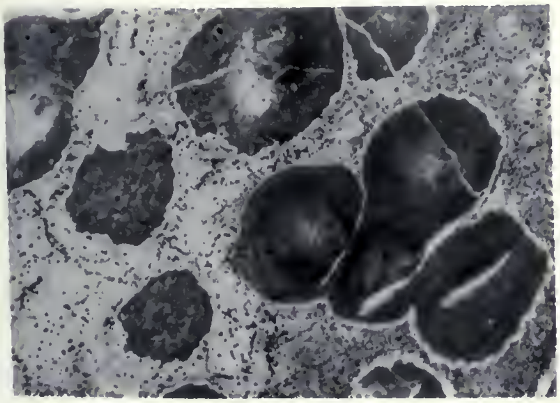
b



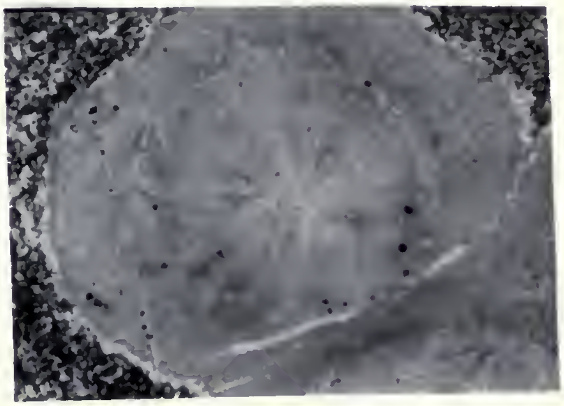
c



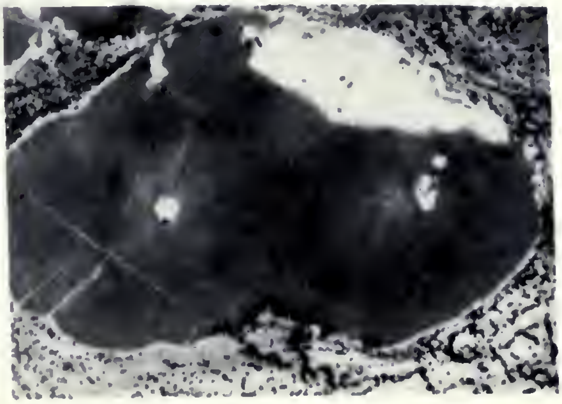
d



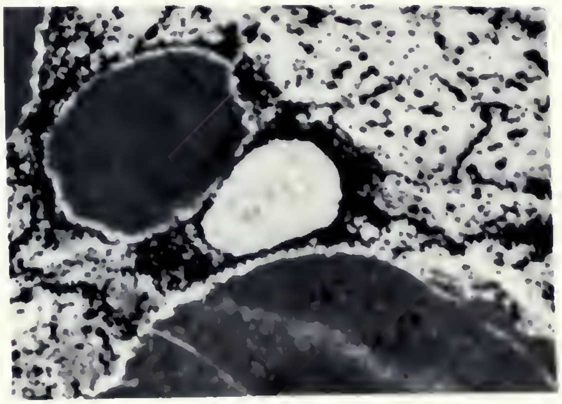
e



f



g



h

Fig. VII-2 (cont'd) :

i : Variole with quench plagioclase crystals and a marginal concentration of crystals. Plane light, x30 (K5).

j : Detail of a variole showing quenched plagioclase laths with characteristic swallow-tail terminations. Plane lighr, x120(K5).

k : Spherulites in a tertiary rhyolite obsidian from Utah. Crossed nichols, x24 (M1).

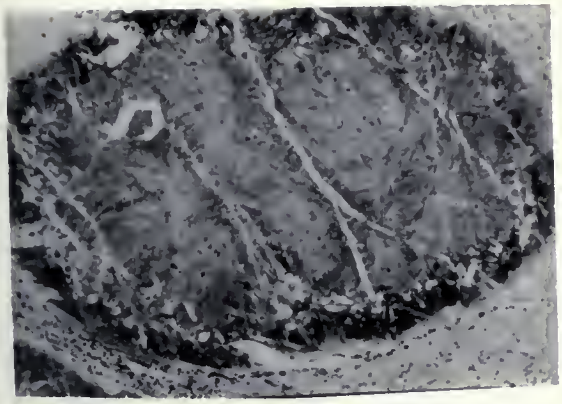
l : Variole with numerous feldspar crystals. Note the jagged outline produced by spherulitic crystallization. Plane light, x64 (K5).

m : Trails of ilmenite (now sphene) blebs outlining perlitic cracks in the mafic matrix. Plane light, x38 (K9).

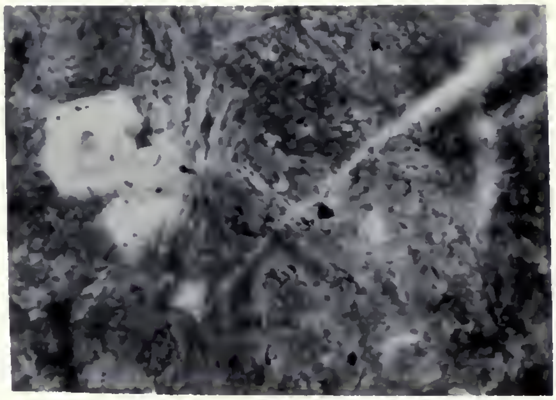
n : As Fig. 2m. The small dispersed prismatic crystals are epidote. Plane light, x128(K9).

o : Enlarged view of Fig. 2a showing a brecciated pillow margin (K9).

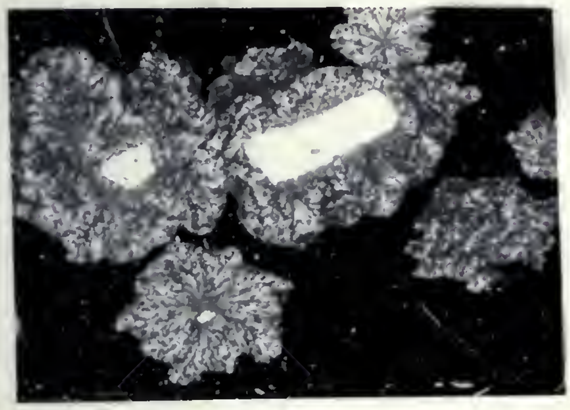
p : Varioles trails along hairline fractures produced during thermal contraction (K9).



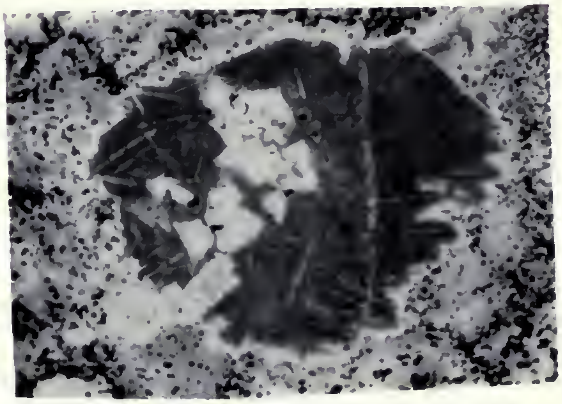
i



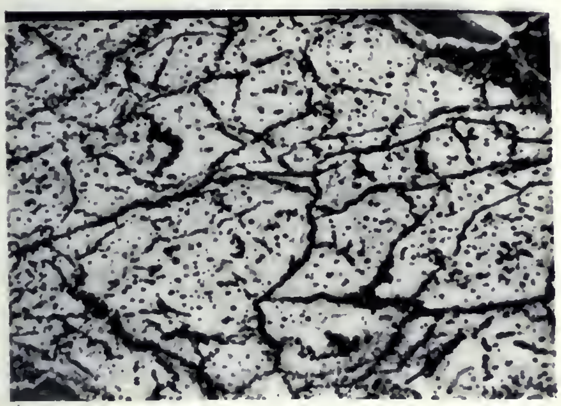
j



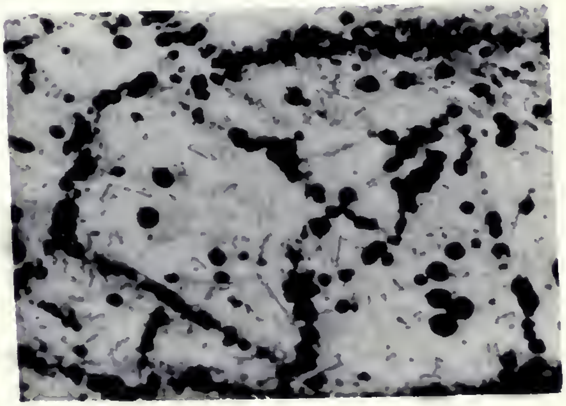
k



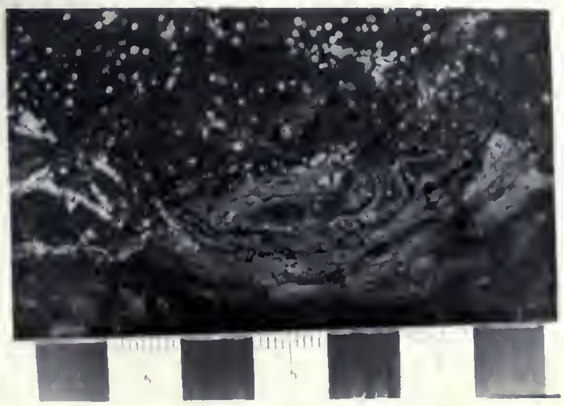
l



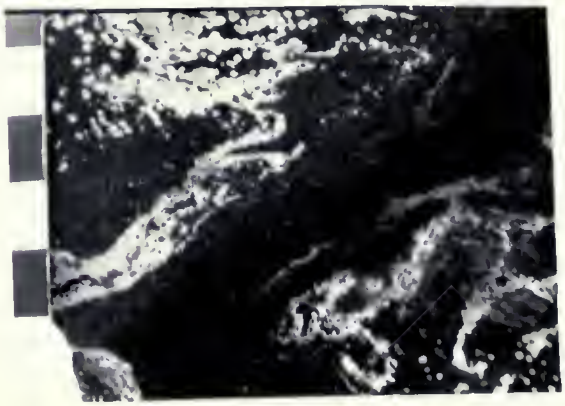
m



n



o



p

Fig. VII-2 (cont'd) :

q : Photograph showing large varioles and minivarioles as well as spherulitic growth along hair-line fractures. Plane light, x 25 (K5)

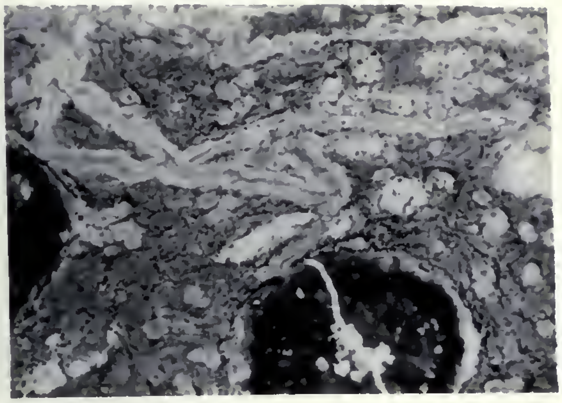
r : Enlarged view of Fig. 2q, showing coalescing "minivarioles" at a hair-line fracture. Plane light, x100(K5)

s : Obsidian from Utah showing spherulitic growth at a hair-line fracture.

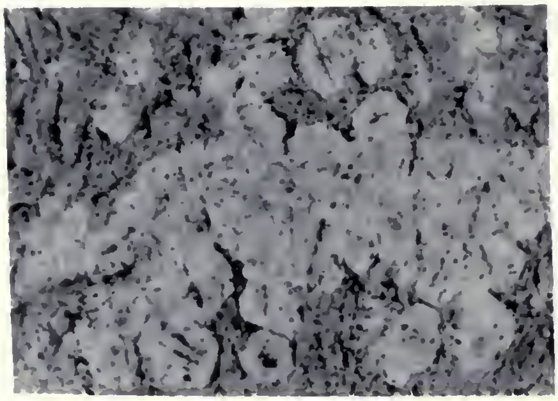
t : Stretched varioles with quartz-filled tension gashes. Plane light, x13 (K9)

u : Coalescing spherulites in obsidian from Utah showing concentric zoning

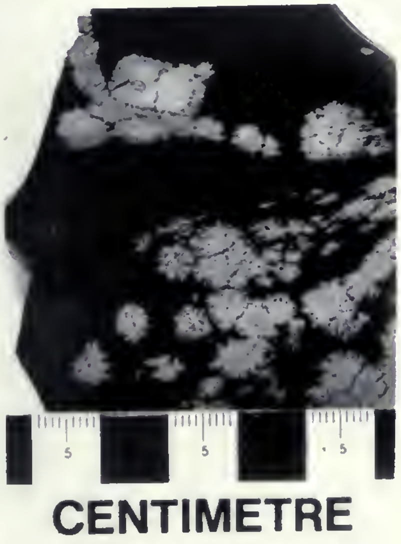
v : Laboratory produced spherulitic growths in a lithium metaborate glass. The disc to the left shows two coalescing growths. Note the smooth outline.



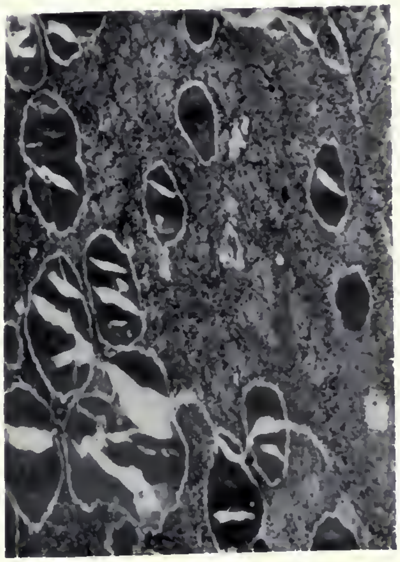
q



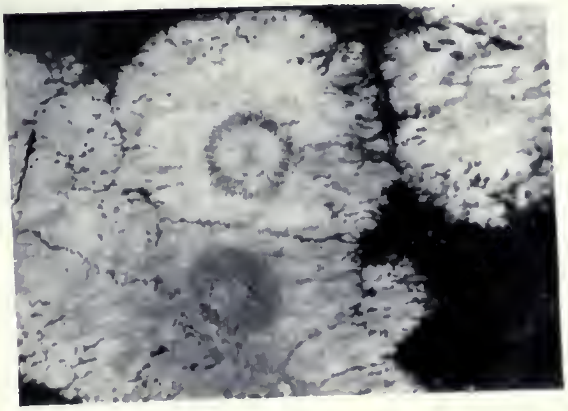
r



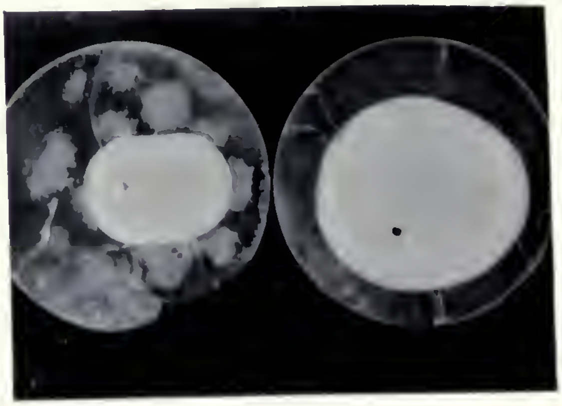
s



t



u



v

b) Matrix

Like the varioles, the matrix consists of an ultra fine-grained assemblage of secondary minerals. The common mineral is chlorite (pennite) in which prismatic epidote crystals have formed (Fig. VII-2n). A characteristic feature is the presence of well developed perlitic cracks which occur throughout the pillow (Figs. VII-2b, m, n), suggesting that the lava did not acquire a holocrystalline state during cooling. The perlitic cracks are defined by chains of spherical to elliptical blebs of coalescing sphenes after ilmenite (Fig. VII-2n). These blebs also girdle around the periphery of varioles, vesicles and phenocrysts (Fig. VII-2h). The process of formation is not clear, but the modal amount of these blebs is reflected by high Ti values (see Table VIII-1).

c) Vesicles

Vesicles ranging in size from 0.1 to 2 mm occur randomly throughout the variolites, and have formed in the matrix as well as in the varioles. They are usually filled with chlorite, but some have chlorite lined walls and epidote, albite and quartz filled interiors. They probably represent segregation vesicles.

d) Hyaloclastite

Pillow margins are well defined by brecciated zone up to 5 cm thick, consisting of splintery glass fragments which spalled from the pillow edge during the quenching of the lava by sea water (Fig. VII-3). Matrix and varioles have been fractured alike during quenching . The color between the breccia and the pillow interior is the same.

e) Conceptual model of the formation of a pillowed variolite: see Fig. VII-3 with accompanying legend.

Environment of mafic volcanism

The widespread and uninterrupted occurrence of basalts forming the Wapageisi Lake and Boyer Lake Groups suggests that large amounts of lava were issued through extensive fissures in the Earth's crust, being possibly linked with incipient rifting. The volcanics, consisting essentially of flows, are believed to have accumulated rather rapidly, because little or no interflow sediments are present.

In two locations, along strike, near Katisha Lake, a thin bed of fine-grained siliceous water-lain ash with turbiditic structures is intercalated within the thick mafic assemblage, indicating distal felsic volcanism,perhaps pertaining to Kawashegamuk Lake Group volcanism.

It is not known whether lava was erupted from shield volcanoes or poured out uniformly from long fissures forming lava plains ; but it is likely that most of the flows were issued from rifts which were fed by the forceful injection of magma within the volcanic strata. The conduits and subvolcanic holding chambers would now be represented by the numerous layered gabbroic sills.

Pillow lavas are ubiquitous at all levels of the volcanic stratigraphy across the map area, implying that all of the mafic volcanics were deposited underwater. The water depth was probably great enough to prevent surtseyan eruptions, which are characterized by lava fountaining and eruptions of large volumes of mafic ash and cinder (Dimroth and Rocheleau, 1979). Presumably, the mafic flows from the Kawashegamuk Lake Group were deposited in water shallow enough to allow the formation of

shallow enough to allow the formation of large vesicles and gas cavities (Figs. II-16, 17, 18). In the Boyer Lake Group, vesicle size and density are smaller and less abundant, reflecting greater water depth. The Wapageisi Lake basalts are the most depleted in vesicles, and according to Jones'(1969) criteria, they would have been deposited under greater water depth than the basalts of the other groups. Nevertheless, a few vesicular flows have been observed near the top of the Wapageisi Lake Group, suggesting that the latter was emplaced in a shallower marine environment.

iii) Facies of felsic rocks

Within the map area, felsic volcanics are volume-wise less abundant than basaltic rocks. From field relations, it is clear that the onset of felsic volcanism occurred at the closure of mafic volcanism. Felsic rocks have been erupted by central volcanoes. At least four distinct rock units, representing separate vents, have been recognized within the study area :

(1) the Thundercloud Lake Porphyry intrusion - Facies I of the Stormy Lake Group
(2) Subgroup II of the Wapageisi Lake Group
(3) the felsic tuffs and breccias of the Kawashegamuk Lake Group
(4) minor felsic breccia units within the Boyer Lake Group near Boyer Lake.

The felsic breccias within the Boyer Lake Group are not extensive enough to be representative of a true felsic volcano ; rather,

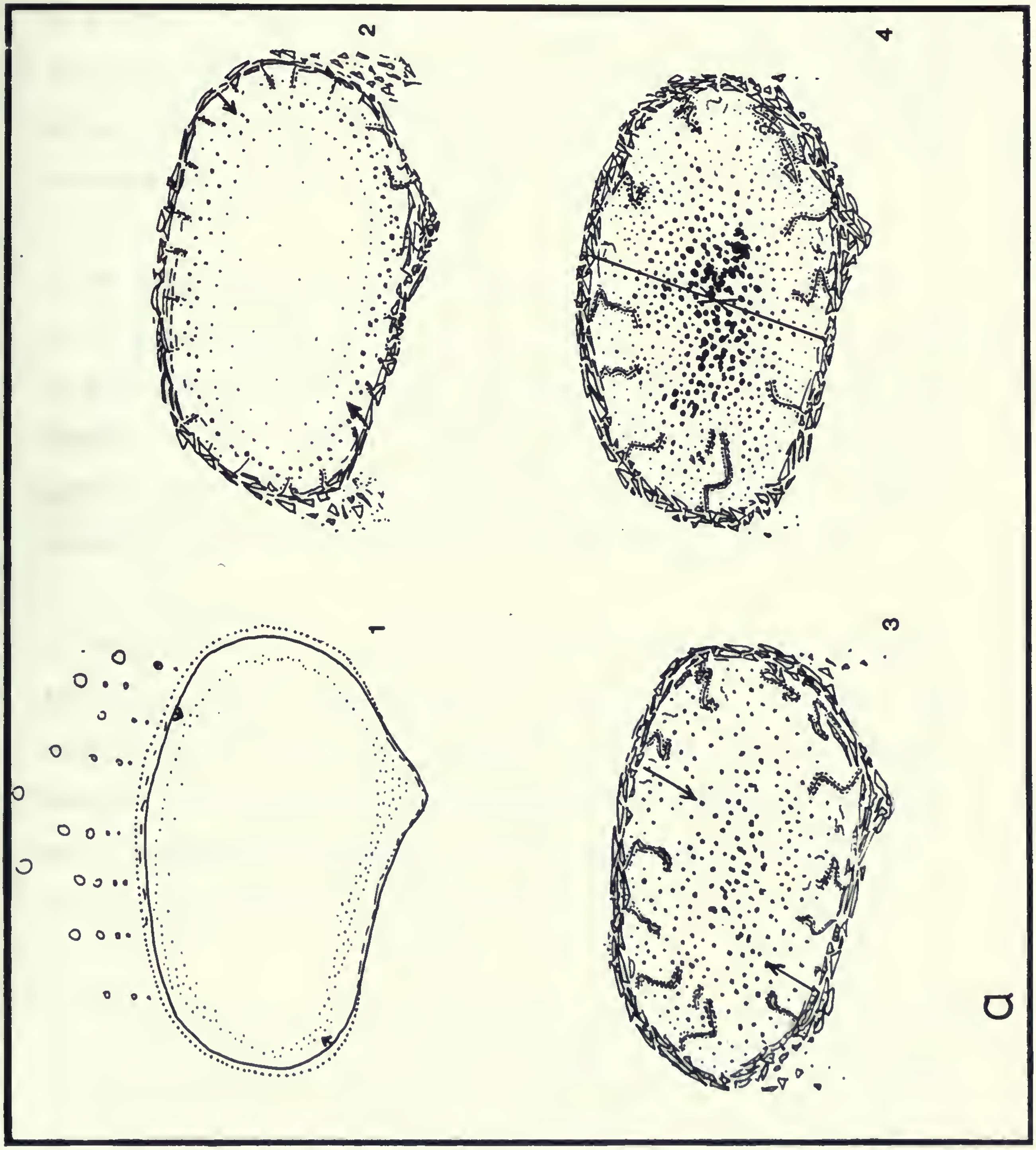

1
2
3
4
a

Fig. VII-3a : Formation of a variolitic pillow.

1. A pillow or lava toe buds from a main flow and is isolated from surrounding water by an envelope of water vapor. A very thin crust forms rapidly and spherulitic growth begins in the rim. (The formation of a steam layer may not take place around lava extruded in deep water).

2. The pillow walls have cooled, allowing the envelope to collapse ; water comes in direct contact with the pillow, resulting in the formation of hyaloclastite. The rim zone is quenched ; spherulitic growth ceases ; however, the pillow interior is still very hot and variole formation progresses inward as the temperature drops below the liquidus, allowing nucleation to take place. Radial cooling cracks begin to form.

3. Variole formation has invaded the entire pillow. As cooling and solidification progress inward, peripheral variole growth is stopped ; spherulitic growth continues in the central part of the pillow. Thermal contraction of the pillow causes the development of cooling cracks along which the number of nucleation sites is dramatically increased ; the cracks are deformed by continuing flowage inside the pillow.

4. The pillow interior loosing heat slowly allows the formation of large varioles which "coalesce". When the viscosity inside the pillow has reached a certain value, spherulitic growth ceases. The whole pillow is in a super-cooled state consisting entirely of basaltic glass and spherulitic bodies.

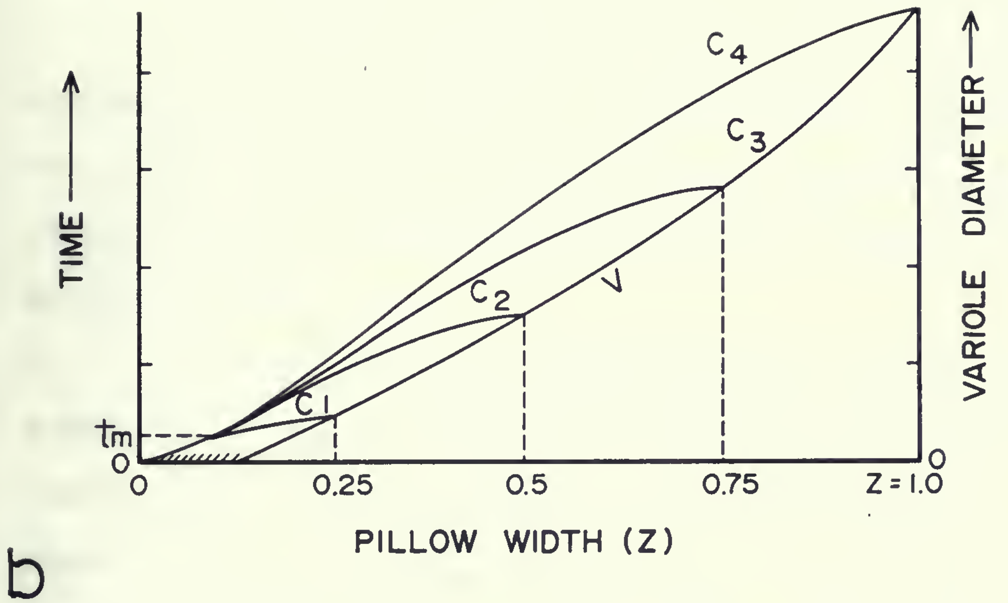


Fig. VII-3b : Variance diagram showing the time required to pass from the liquidus temperature ≈ 1500°C to solidus temperature ≈ 900°C across a pillow as a function of pillow width (after Marshall and Cox, 1971) : curve C1, pillow size Z = 1 ; C2 : Z = 0.75 ; C3 : Z = 0.5 ; C4 : Z = 0.25.

Note : The time required to quench the margin is independant of Z. Variole size has been plotted as a function of Z (curve V).

felsic matter has been erupted from a basaltic vent, possibly the product of differentiation that took place in a shallow magma chamber. Exposures show fragmented dacitic pumice in a vesicular mafic matrix .

The felsic fragments present a reaction rim which has an intermediate color and marginal vesicles are filled with basaltic material, whereas vesicles away from the edges are filled with quartz. This strongly indicates that both basaltic and dacitic lava was erupted simultaneously from a vent.

1 - The felsic vent centered at Thundercloud Lake probably represented a small felsic volcano which emitted rhyolite flows, breccias and pyroclastic matter (McMaster, 1978) directly on a basaltic floor. Near the porphyry stock, most volcanics appear to have been deposited in-situ (Facies I), however, there is a progressive gradation into an alluvial facies (Facies IIa).

2 - The felsic assemblage which extends from Kawijekiwa Lake to and beyond the southeast shore of Stormy Lake, probably represents a cross-section through a felsic cone, away from the center. The base of the volcano, defined by rocks of mixed composition, tends to indicate that mafic to intermediate rocks, as well as felsic (dacitic) types, were erupted during the early stages of felsic volcanism. In subsequent episodes of the volcanic evolution, the magma became more felsic yielding dacitic to rhyolitic pyroclastics. The tuffs at Gawiewiagwa Lake may represent an ignimbrite sheet composed of crystals and lithic fragments (Sparks et al., 1973). The very high concentration of feldspar and quartz crystals is most likely not representative of the original phenocryst content of the magma, but is rather due to some kind of mechanical concentration process which

place during the explosive emanation of a pumiceous lava (Walker, 1972). According to G.P.L. Walker (ibid.), the vitric fines would be lost above the vent or the moving pyroclastic flow. Presently, some of the pumice is probably represented by the sericitic matrix to the crystals (Fig. III-6). Recent pyroclastic flows that underwent crystal enrichment have been described in the Azores, Chile, Guatemala and Santorin (Walker, 1972), and Hay (1959) has noted that volcanic bombs from La Soufrière volcano (St Vincent) carry up to 45% phenocrysts, while tuffs from glowing avalanches had up to 73% crystals, a concentration which is similar to the one found in the Gawiewiagwa Lake felsic tuffs.

Environment of deposition

The lower part of the felsic sequence was undoubtedly deposited underwater, because volcanic tuffs possess features intrinsic to turbidites (cf. "Member 1a", "Formation 1", p. 19, Chapter II).

"Formation 2" lacks well-developed primary structures. "Formation 3" is poorly bedded which is a characteristic of ignimbrites (Parsons, 1969). A thin chert-magnetite iron-formation at the top of Subgroup II, probably formed by subaqueous fumarolic activity on the flank of the volcano, clearly indicates that "Formation 3" was deposited underwater. Furthermore, it appears that the tuffs show no welding between fragments and therefore seem to indicate that they settled as a cold mass. Thus it is likely that most of the rocks exposed at the present level have been emplaced underwater. This by no means implies that the volcanics were erupted underwater, as the central part of the volcano is not exposed : it is known that pyroclastic flows

Fig. VII-4 : Stratigraphic sections through the Kawashegamuk Lake Group

A : Section from the Van Houten Gold Mine → west.

B : Midway through the map area, SW-NE cross-section.

C : South part of the map area, SW-NE cross-section.

Massive and pillowed mafic flows.

Mafic tuff and breccia .

Tuff breccia and breccia of intermediate to felsic composition.

Lapilli tuff and lapilli stone of intermediate to felsic composition.

Intermediate to felsic tuff .

Rhyolite flows.

Epiclastic sediments of turbiditic facies.

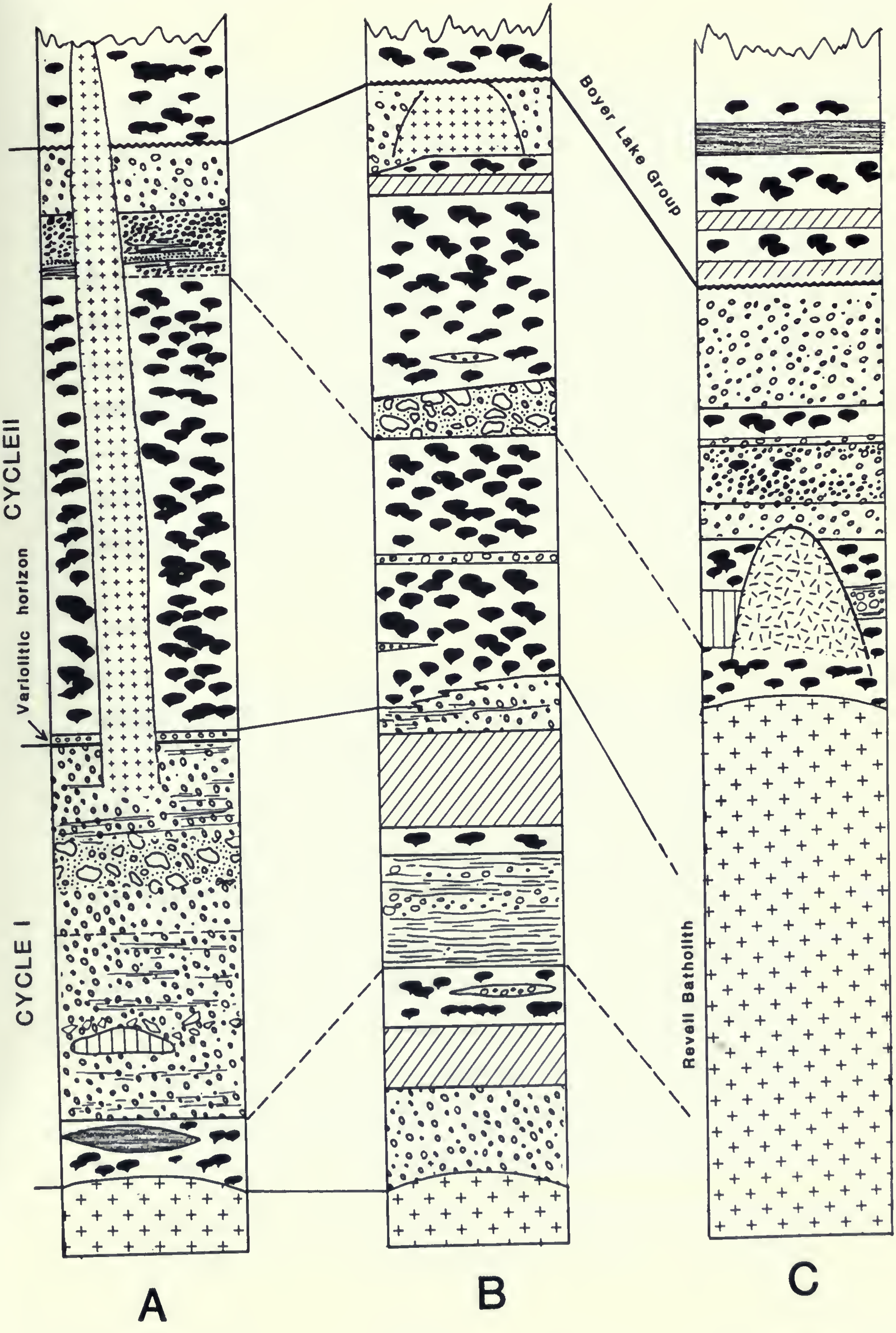
Gabbro sills.

Tonalite intrusion.

Quartz-feldspar porphyry intrusives.

Late granitic intrusives.

Faulted contact.



CYCLE II
Variolitic horizon
CYCLE I
Boyer Lake Group
Revell Batholith
A
B
C

which have originated subaerially can be distributed across long distances underwater (Fiske, 1963 ; Fiske and Matsuda, 1964 ; Lacroix, (1904).

3 - The felsic rocks of the Kawashegamuk Lake Group occur as several distinct units and lenses separated by thicker units of mafic flows. On a broad basis, they can be divided into two felsic assemblages belonging to two cycles. The felsic assemblage of Cycle I extends from Mennin Lake to Tabor Lake ; the felsic volcanics of Cycle II represent the uppermost part of the Kawashegamuk Lake Group and extend discontinuously from the upper left corner to the lower right corner of the map area. Figure VII-4 shows the stratigraphic composition across the Kawashegamuk Lake Group.

a) Cycle I : Felsic rocks between Church and Mennin Lakes have a uniform rhyolitic composition and consists mostly of coarse breccias having a monolithologic character. Due to the lack of matrix, they are interpreted as flow breccias. They are interbedded with lapilli tuffs. In the northern part of the map area, the rocks have a higher matrix to clast ratio being represented by tuffs showing fine bedding structures and rhythmic layering, lapilli tuff, lapilli stone and tuff breccia. The environment of deposition was certainly subaqueous as pillowed lavas underlie and overlie the felsic volcanics ; bedding structures characteristic of water lain material further support this statement.

b) Cycle II is represented by numerous felsic members which interfinger with thick mafic units. The felsic rocks which are exposed along Kawashegamuk Lake consist mainly of tuffaceous breccias, lithic breccias and lapilli tuffs. Some lithic breccia units show clasts displaying quench textures (Fig. XII-5) indicating that eruption products entered water while very hot. "Formation H" (Map) is an example.

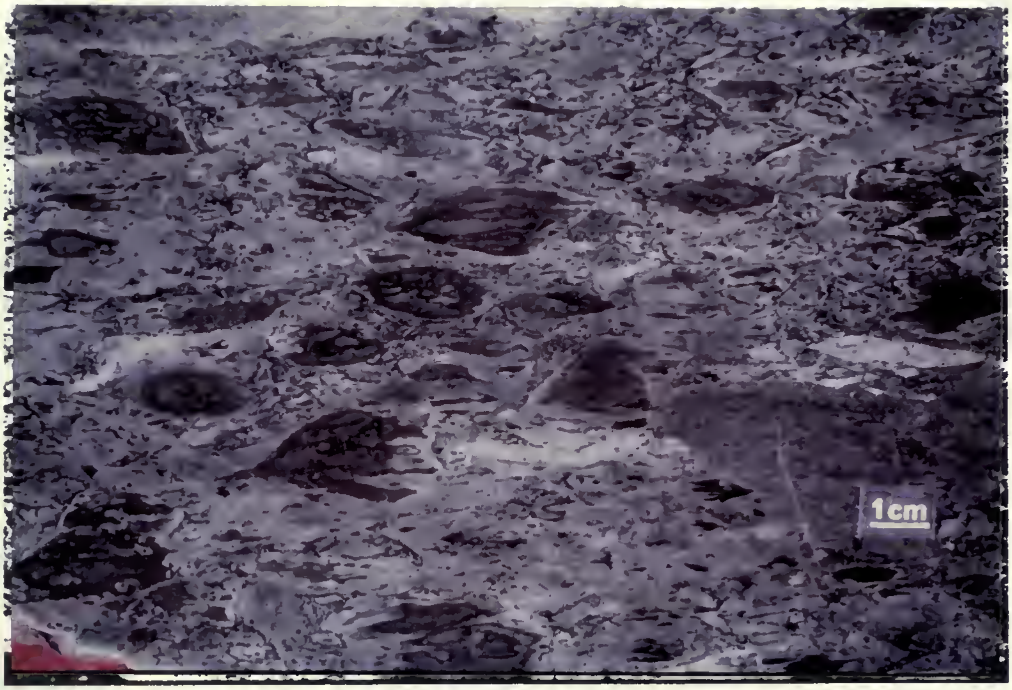


Fig. VII-5 : Volcanic breccia showing quench structures.

Fig. VIII-6 : Volcanic bomb embedded in ash.

The fact that there is very little evidence of reworking within "Formation H", which would have taken place in a fast moving pyroclastic flow, and that many devitrified glass shards have been wrapped and molded around other clasts (Fig. II-26) favors the idea of the brecciation of a felsic lava flow by the quenching action of sea water. The northwest part of Cycle II is rather obscure because of lack of exposure and intense deformation (sericite schists).

As a whole, Cycle II felsic volcanics are highly diversified in the nature of the deposits, as well as in their chemical composition. The volcanics have all been deposited in a subaqueous environment as mafic units underlying, overlying and within the felsic cycle are pillowed. Tuffs are well bedded and quench textures are common. Short lived volcanic islands may have formed and subaerial eruption took place : Fig. VII-6 shows a volcanic bomb that likely was hurled above sea level and subsequently became embedded in submarine deposits.

The Stormy Lake Group which is chiefly an epiclastic sequence contains beds of non-reworked volcanic material such as felsic breccias and fine-grained bedded tuffs from ash falls. Owing to the limited thickness of these units, the source of volcanism is obscure.

CHAPTER VIII - GEOCHEMISTRY

Part 1 : Introduction

Some 200 rock samples (1) have been selected for chemical analysis of major, minor and tràce constituents for the following purposes :

1) to compare the chemical nature of the volcanic suites and to determine their petrogenesis ;

2) to compare the volcanic rocks with related intrusive bodies ;

3) to attempt to correlate rock units across major tectonic structures, such as the Kamanatogama Syncline ;

4) to study the extent and significance of chemical redistribution during metamorphism and alteration.

i) Sampling procedure and sample preparation

Samples for chemical analysis were taken in least altered parts of exposures, away from mineral veins, sheared zones, mineralized joints or pillow margins. In the laboratory, representative samples were freed from weathered surfaces and mineralized cavities using a rock saw. Metal contamination from the saw blade was removed using a polishing lap.

---

(1) Sample locations have been indicated on Maps 2 and 3 (back pocket).

Each sample was reduced in a jaw crusher ; fragments were carefully examined for metal contamination before being pulverized in a disc mill using tungsten carbide barrel and rings (1). To ensure homogeneity, the rock powders were sieved through a -60 mesh screen ; any remaining coarse particles and micas were powdered in a sintered alumina mortar and pestle.

ii) Analytical procedures

170 rocks were analyzed for the major and minor constituents including Si, Al, Fe, Mg, Ca, Na, K, Ti, Mn and P by X-ray fluorescence spectometry (XRFS) using a Philips PW 1450 sequential automated spectrometer. Data reduction was done using standard techniques for absorbance, fluorescence and machine drift correction. Elements were calculated as oxides.

The following elements : Mg, Na, Mn have been determined independently by Atomic Absorption Spectrophotometry (AAS) using a Varian 1475 spectrometer.

The trace elements including Ba, Cr, Cu, Ni, Rb, Sr, V, Y, Zn and Zr were analyzed by XRFS, and Ba, Cu, Ni, Sr, Zn have been analyzed separately by AAS.

39 samples have been analyzed for rare-earth elements (La, Ce, Nd, Sm, Eu, Gd, Dy, Yb, Y) abundances with Inductively coupled plasma Spectroscopy (ICPS) by the Geoscience Laboratories of the Ontario Geolo-

---

(1) Rocks should not be reduced in tungsten vessels if W, Co and the lanthanide group elements are to be determined.

gical Survey ; 28 out of 30 samples were checked for La, Ce, Sm, Eu, Tb, Yb and Lu by Neutron Activation Analysis (AAS) ; the package included other elements such as Fe, Na, Ba, Cr, Sc, U, Th and Zn, some of which were used in double checking the quality of results obtained by XRFS and AAS (1).

Finally, 4 samples were submitted for Electron Microprobe Analysis (EMA), which was carried out at the University of Toronto.

Sample preparation techniques and instrument parameters of the various methods of analysis are described in Appendix B . Precision and accuracy have been determined by analysis of duplicate samples (approximately every tenth sample), and by using deviation curves of rock standards. All information pertaining to quality of analytical data is given in Appendix B, part 3.

To supplement the data compiled for this study, analyses performed on samples collected by C.E. Blackburn in 1977 during the Savant Lake - Crow Lake regional study have been used. The samples are from two geochemical traverses across the Boyer Lake Group (A series) and the Kawashegamuk Lake Group (KAW series).

iii) Presentation of the data

All analytical results have been tabulated in Appendix C. For analyses which have been determined by more than one method, the

---

(1) Due to anomalous values obtained by ICPS, especially for Eu, and higher sensivity of NAA, only the data by NAA has been compiled for the lanthanides.

most reliable value is given in the tables. Major constituents have been determined in weight percent of the oxide, trace elements in parts per million (ppm) by weight. All iron has been calculated as Fe_2O_3 in the tables, but in variation diagrams it is shown as FeO^t ($FeO = 0.8998\ Fe_2O_3$), because the present oxidation states of iron are unlikely to reflect original conditions. Volatile constituents present (H_2O^-, H_2O^+, CO_2 and S) also were altered during metamorphism and hydrothermal activity ; significant concentrations of these components have entered the structure of numerous secondary minerals. The net effect results in dilution of the other constituents. The total volatile content in each rock has been determined as Loss on Ignition (LOI) which is probably an accurate value of the total volatile content for rocks containing little Fe^{2+}. Unfortunately, rocks with high volatile contents may have suffered significant elemental redistribution besides straight dilution, particularly with respect to the alkalies, Ca and Si, which are generally regarded as being highly mobile during low grade metamorphism (Smith, 1968 ; Jolly, 1972 ; Jolly and Smith, 1972).

In consequence, chemical analyses with LOI higher than 4.5 wt % have been ignored for interpretation of igneous processes. It is hoped that the large number of analyses reflect original igneous trends based on the assumption that lithological units as a whole have behaved as closed systems during metamorphism. Further considerations regarding chemical mobility during metamorphism and alteration is given in a subsequent section.

To facilitate interpretation of various processes leading up to the present rock composition, elemental abundances plotted on varia-

tions diagrams are recalculated on a volatile free basis.

Part 2 : Petrochemical discrimination among the volcanic rock types

i) Subalkalic versus alkalic rocks

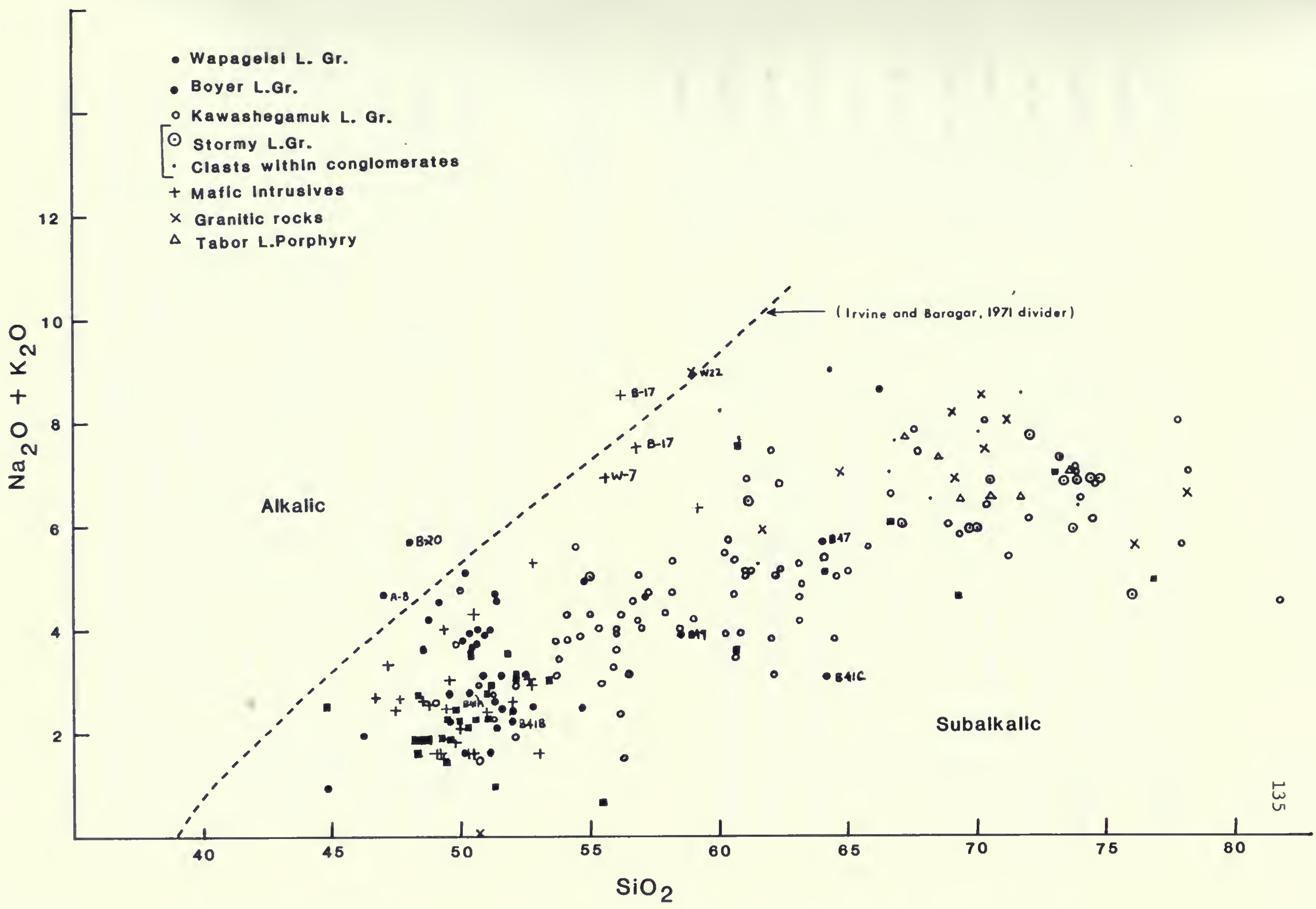
All analyzed rocks have been first classified into two broad groups defined by Chayes (1966) as the subalkalic and alkalic rocks based on whether the rocks are undersaturated (Ne normative) or supersaturated (Q normative). These terms are used here as suggested by Wilkinson (1968) to include both the tholeiitic and calc-alkaline basalt series.

The alkalies versus silica diagram is used to distinguish between subalkalic and alkalic rocks (McDonald, 1968), because it makes direct use of the analytical results ; the arbitrary division of the two fields is the one adopted by Irvine and Baragar (1971). Most rocks fall well within the subalkalic field (Fig. VIII-1). These types that plot above the dividing line, or slightly below at higher silica values, are rocks occurring as dikes and have been described in the field as alkalic rocks, syenites and lamprophyres ; they are typically devoid of modal quartz.

ii) Tholeiitic and calc-alkalic volcanic rocks

The subalkalic rocks fall within two series which have undergone distinct differentiation trends : one trend is represented by iron-

Fig. VIII-1 : Alkalies versus silica diagram. All analyzed rocks have been plotted, including unpublished data from Blackburn (A series and KAW series, see Map 2 in back pocket for sample location).


Wapagelsi L. Gr.
Boyer L.Gr.
Kawashegamuk L. Gr.
Stormy L.Gr.
Clasts within conglomerates
Mafic Intrusives
Granitic rocks
Tabor L.Porphyry
(Irvine and Baragar, 1971 divider)
Alkalic
Subalkalic
$Na_2O + K_2O$
SiO_2
12
10
8
6
4
2
40
45
50
55
60
65
70
75
80
W22
B-17
B-17
W-7
B-20
A-8
B47
B41C
B41B

enrichment and in the last stages of differentiation silica enrichment takes place ; the other trend is characterized by continuous iron depletion throughout differentiation. The two trends have been referred to as the tholeitic and the calc-alkalic series respectively by Nockolds and Allen (1953, 1954, 1956). Because the two series differ in their FeO^t/MgO ratios, they can be distinguished on SiO_2 versus FeO^t/MgO diagrams as applied by Miyashiro (1974). In this study, the well known ternary $Na_2O + K_2O - FeO^t - MgO$ (AFM) diagram (Wager and Deer, 1939) has been used. As the diagram is very effective in distinguishing the two series (Irvine and Baragar, 1971), more evolved members ranging from dacite to rhyolite, and the alkalic rocks are not easily distinguished (see Figs. VIII-2a, 8).

1 - <u>The Wapageisi Lake Group</u>

Only the upper part of the Wapageisi Lake Group is exposed within the map area and the samples analyzed for this study are insufficient to portray the entire group ; thus some of Blackburn's (1980) analytical data from lower parts of the Wapageisi Lake Group have also been used. The combined data from across the group clearly shows a progressive increase in the Fe/Mg ratio with stratigraphic height (Fig. VIII-2b), a feature characteristic of a tholeiitic trend of magma differentiation (Fig. VIII-3). Although the base of the mafic pile is more Mg-rich, i.e. less evolved, true ultramafic and komatiitic lavas have not been found (Blackburn, 1980). The Wapageisi Lake Group basalts are classified as magnesian tholeiites (lower part) to normal tholeiites

Fig. VIII-2 : A($Na_2O + K_2O$) - F(FeO^t) - M(MgO) diagrams of the principal volcanic rocks and intrusives which are suspected of being related to volcanism in the Stormy Lake - Kawashegamuk Lake area.

a. Kawashegamuk Lake Group. Numbers in brackets refer to C.E.Blackburn's (I977) data (KAW traverse).

● Cycle I, mafic lavas

○ Cycle I, felsic lavas

○ Cycle II, mafic and intermediate lavas

⊙ Cycle II, felsic lavas

+ Gabbroic intrusives

▲ Quartz diorite intrusive

b. Wapageisi Lake Group. Numbers in brackets refer to C.E. Blackburn's (I982) data (Starshine Lake section).

● ∘ Mafic lavas

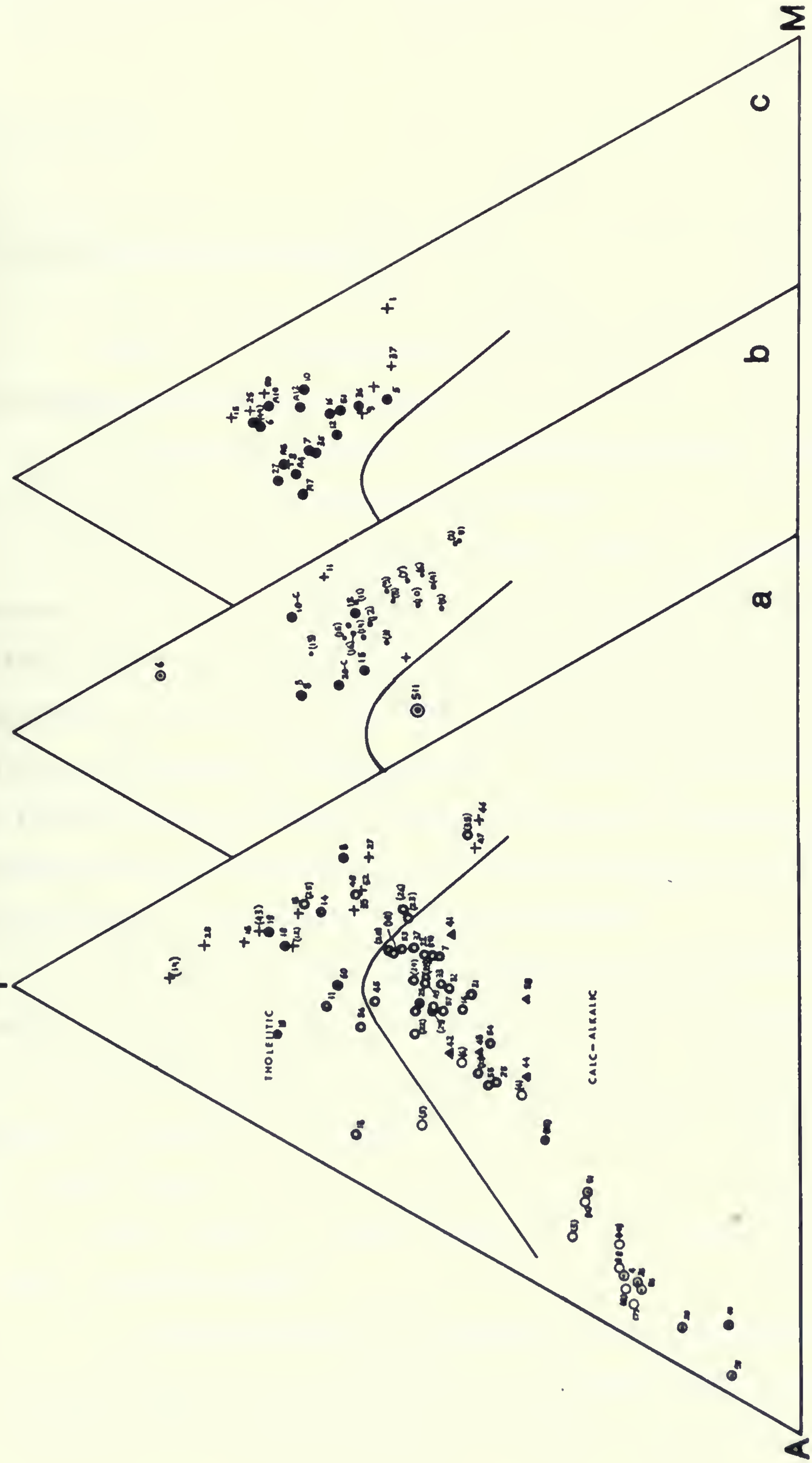
+ Gabbro intrusives

◉ Single basalt flow within the Stormy Lake Group (sample S11)

c. Boyer Lake Group. Sample numbers preceded by "A" are from C.E. Blackburn (I977) (A traverse).

● Mafic lavas

+ Gabbro intrusives


F
A
M
a
b
c
THOLEIITIC
CALC-ALKALIC

(upper part).

2 - The Kawashegamuk Lake Group

Mafic to intermediate lavas of Cycles I and II are well distinguished on the AFM (Fig. VIII-2a) :

- The basalts of Cycle I fall within the tholeiitic field, showing a trend of iron-enrichment (Fig. VIII-3).

- Most mafic to intermediate rocks of Cycle II fall well within the calc-alkalic field along a distinct trend of iron-depletion which is characterized by lower FeO^t/MgO ratios (Fig. VIII-2a). Along the differentiation path, rocks become progressively enriched in SiO_2, Al_2O_3 and the alkalies. In hand specimen, the rocks are distinguished by green-grey to grey colors, whereas the tholeiitic counterparts are normally dark green ; towards the top of the Kawashegamuk Lake Group, feldspar-phyric lavas become increasingly abundant.

The tonalite stock south of Oldberg Lake is compositionally similar to the lavas. However, the chemical variations and mineralogical changes across the stock, observed in the field to result from variations in proportions of amphibole and quartz contents, suggest that the stock is zoned.

Felsic rocks of Cycles I and II overlap and cannot be distinguished on an AFM diagram.

A striking feature is the presence of an unequivocal compositional gap between the mafic and the felsic suites of rocks, so that a continuum of lava compositions within the highly diversified Kawashegamuk

Fig. VIII-3 : AFM diagram showing the different fields within which lie the principal volcanic assemblages.

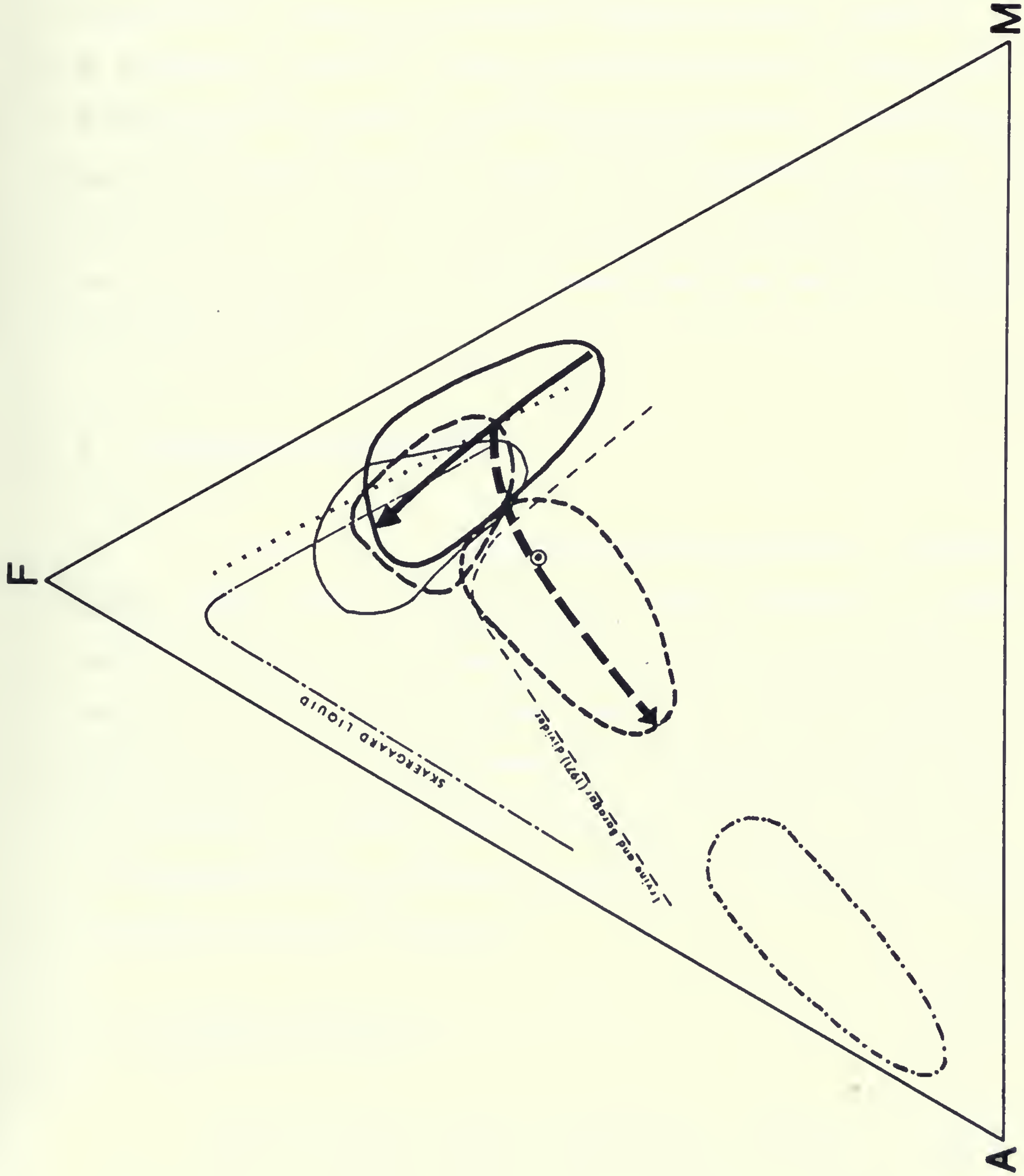
- Wapageisi Lake Group (Subgroup I) volcanics
- Differentiation path of the mafic volcanics within Subgroup I

- Boyer Lake Group volcanics

- Basalt flow within the Stormy Lake Group

Kawashegamuk Lake Group

- Cycle I, mafic flows
- Cycle II, mafic flows
- Cycle I and II, felsic volcanics
- Differentiation path of the mafic and intermediate volcanic rocks
- Trend of gabbro intrusives


F
M
A
SKAERGAARD LIQUID
Irvine and Baragar (1971) divider

Lake Group was not being erupted. The compositional gap on the AFM plot coincides with a sharp drop in silica abundances in the range 58 to 60 wt % SiO_2 (Fig. VIII-8). All gabbro intrusives within the lavas have a strong tholeiitic affinity and plot along a trend which coincides with the trend of iron-enrichment of Skaergaard liquids (Wager and Deer, 1939) (Fig. VIII-3) ; thus it appears that there is no relationship between mafic sills intrusive in the Kawashegamuk Lake Group and the volcanism which gave rise to Cycle II.

3 - The Boyer Lake Group basalts

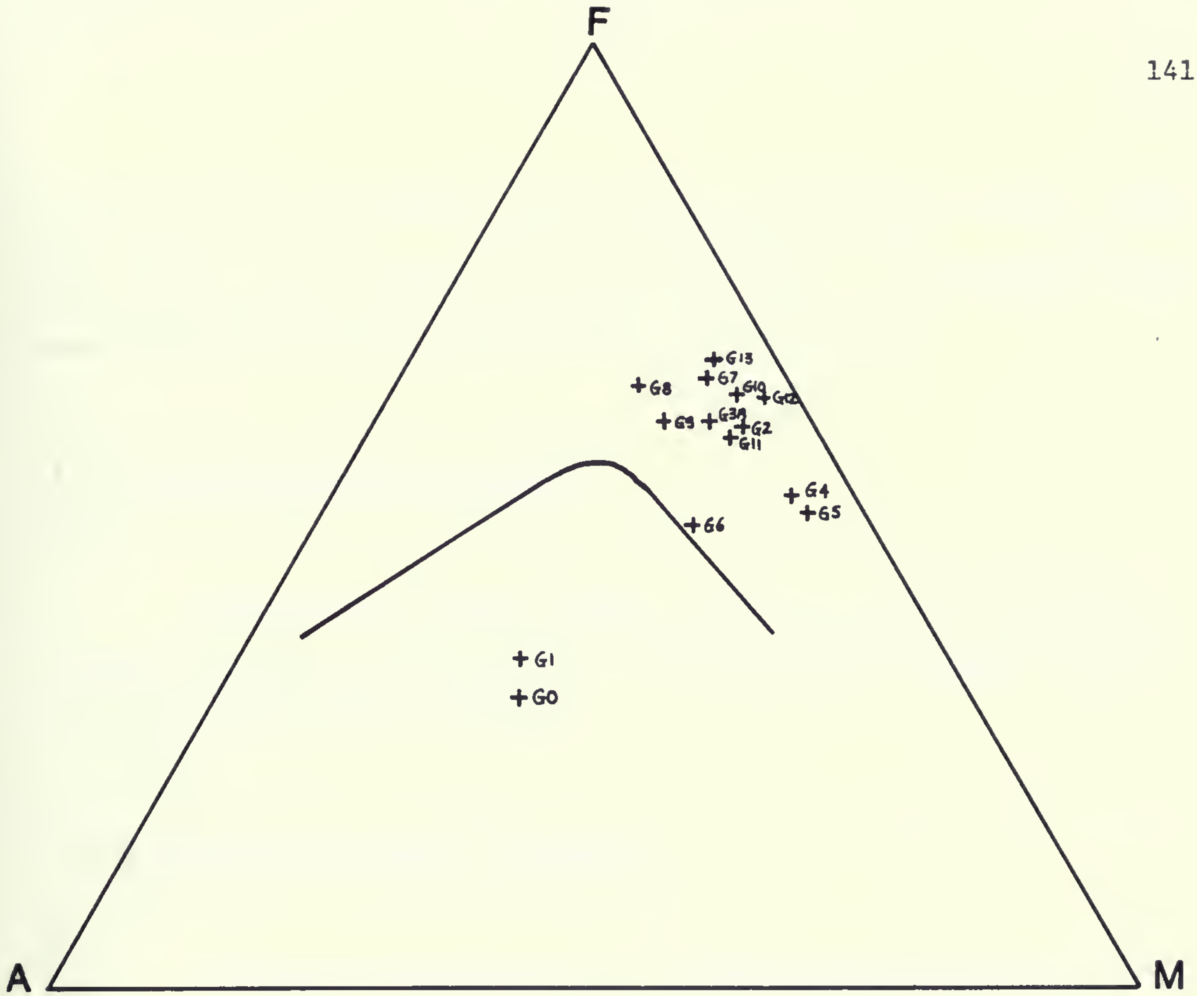
On Fig. VIII-2c, the Boyer Lake basalts cluster in a tight compositional range within the tholeiitic field. The Group as a whole is more evolved than the Wapageisi Lake Group because high Mg-types are lacking ; also, the differentiation trend is not as well defined, implying that the lavas are the product of a more advanced stage of differentiation , and perhaps, that the Boyer Lake Group was deposited in a relatively short time span, a view which is supported by the uninterrupted succession of the lavas.

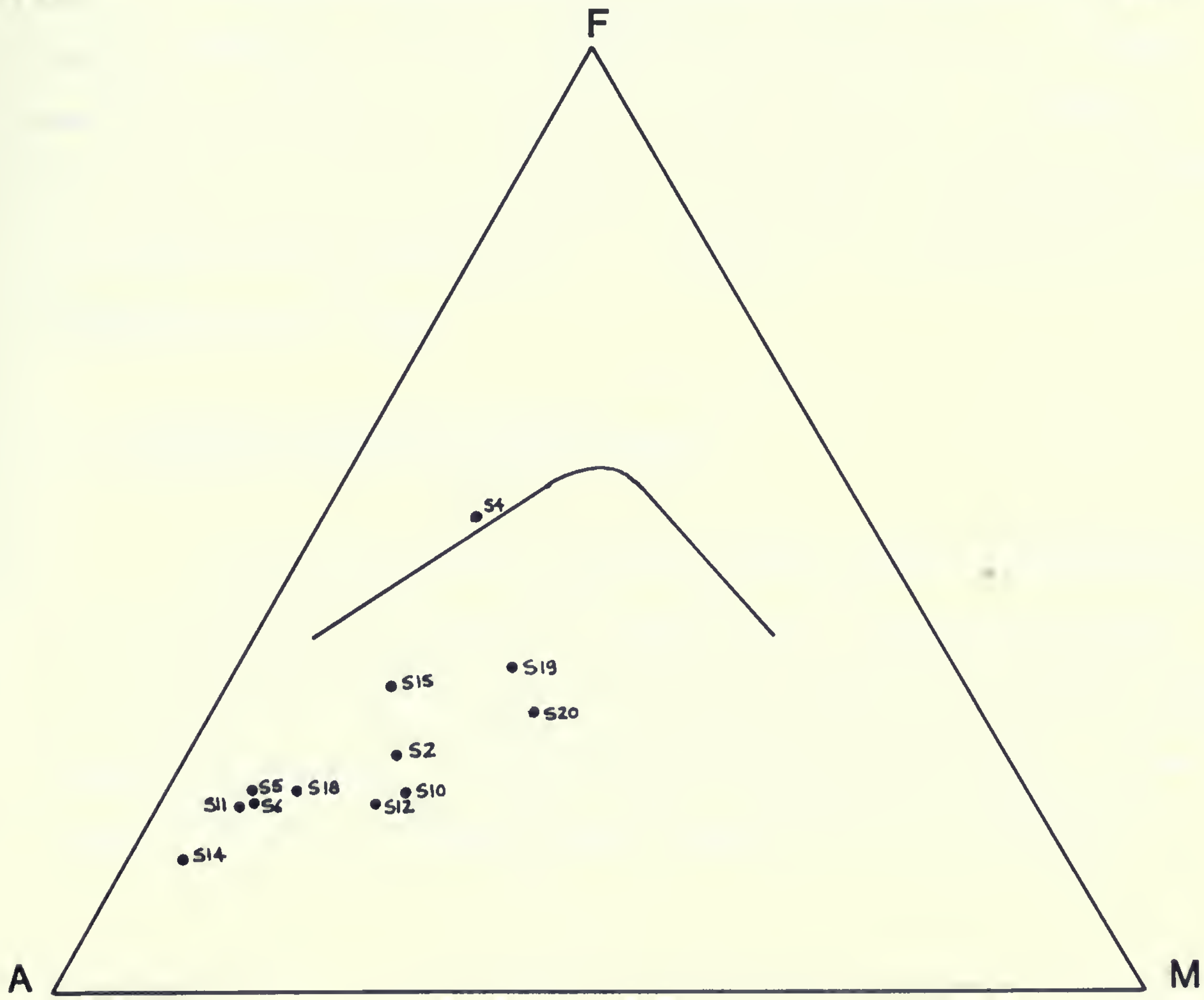
4 - The Stormy Lake Group

The Stormy Lake Group is essentially an epiclastic assemblage represented by lithologies which do not correspond to those exposed in the volcanic parts of the study area. A number of clasts have been analyzed and plotted on an AFM diagram (Fig. VIII-5) : compositions show

Fig. VIII-4 : AFM diagram of samples taken across the "Katisha Lake Gabbro Sill".

Fig. VIII-5 : AFM diagram of volcanic derived clasts from the Stormy Lake Group.


F
G13
G7
G10
G12
G8
G9
G3
G2
G11
G4
G5
G6
G1
G0
A
M


F
S4
S15
S19
S20
S2
S5
S18
S10
S11
S6
S12
S14
A
M

overlap with the volcanics within the map area except for felsic types. One basaltic flow (sample S11) has been analyzed ; its composition falls well within the calc-alkalic field of the AFM diagram.

5 - The "Katisha Lake Gabbro Sill"

Thick gabbroic sills display variations in mineralogy and texture across : on an AFM diagram the "Katisha Lake Gabbro" shows a tholeiitic trend (Fig. VIII-4).

6 - Wapageisi Lake Group, Subgroup II

Because of the clastic and highly tuffaceous nature of the felsic assemblage overlying the Wapageisi Lake basalts, only a limited number of samples have been analyzed for major elements. On the AFM plot they fall on the typical calc-alkalic differentiation trend (Fig. VIII-6) and cannot be distinguished from , for example, the felsic rocks of the Kawashegamuk Lake Group.

7 - The Thundercloud Lake Porphyry stock

Compositions of this body fall near the A apex of the AFM triangle (Fig. VIII-6), and scatter is restricted to a limited part of the calc-alkalic differentiation trend, which is consistent with field observations that indicate a remarkable homogeneity across the stock. A possible relationship may exist between the stock and the two granitic

Fig. VIII-6 : AFM diagram of felsic volcanic and plutonic rocks.

- ■ Felsic volcanics (mostly tuffs) of Subgroup II, Wapageisi Lake Group
- ⊙ Felsic breccia, Stormy Lake Group
- ● Thundercloud Lake Porphyry. Smaples T32 and T38 are brecciated phases, S7 is a felsic tuff.

Meggisi Pluton ; data from Sabag (1981).

- + Early phase
- o Late phase
- • Felsic porphyry dikes

A
F
M
W2
W17
T38
T32
S1
W24
W27
W26
T1
T17
T10
T19
T28
S7

phases making up the Meggisi Pluton (see Map 3 in back pocket) described by Sabag (1979). On the AFM diagram, the Thundercloud porphyry, the two phases making up the Meggisi Pluton (an early granodiorite phase and a late seriate phase consisting of quartz-monzonite) and four porphyry samples from dikes near the margin of the pluton, all fall on a single calc-alkalic field (Field VIII-6). None of the intrusions overlap to a significant degree. The Thundercloud Lake Porphyry falls between the early Meggisi phase, which is less differentiated, and the late Meggisi phase, which is the most differentiated, together with Sabag's porphyry dikes. The intrusions can also be distinguished on a Na_2O - K_2O - CaO diagram (Fig. VIII-7) which shows that the Thundercloud Lake Porphyry is more sodic than the phases that belong to the Meggisi Pluton. Thus from a petrogenetic point of view the Thundercloud Lake Porphyry could not have been derived from the later, seriate phase of the Meggisi Pluton.

8 - Miscellaneous rock types (Fig. VIII-8)

Pre and post-tectonic granitic and alkalic rocks, and the "Tabor Lake Porphyry" are distributed along an iron-depletion trend, but their relationship to the volcanics is obscure.

iii) Classification and compositional abundances of volcanic rocks

All volcanic rocks have been classified on a volatile-free silica content : ultramafic basalt (43 - 48% SiO_2); basalt (48 - 52%

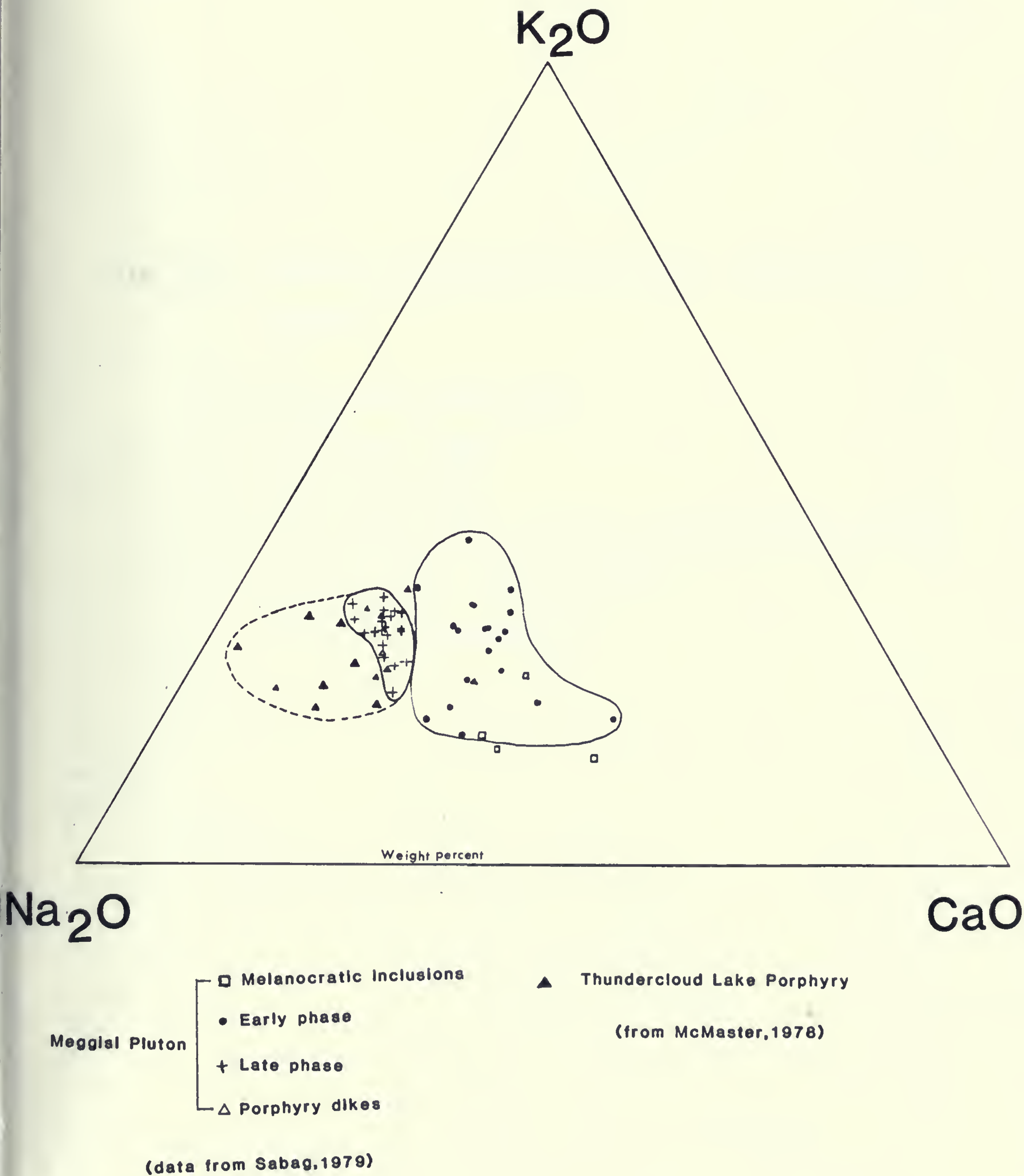


Fig. VIII-7 : Na_2O - K_2O - Cao diagram for the Meggisi Pluton (Sabag, 1979) and the Thundercloud Lake Stock (McMaster, 1978).

Fig. VIII-8 : AFM diagram of diverse rocks occuring as dikes and small stocks.

● Ultramafic and mafic dikes

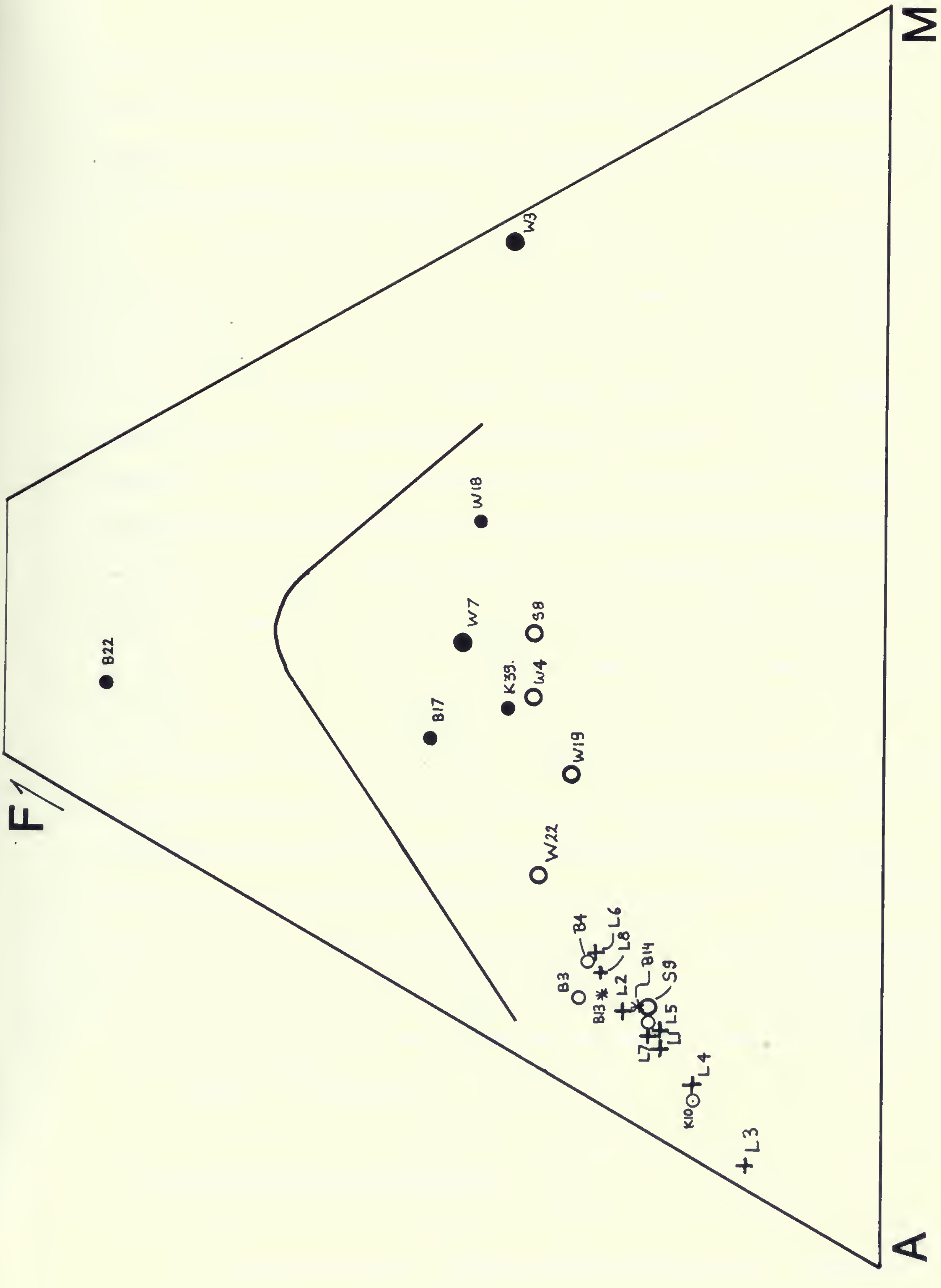
• Lamprophyric rocks

O Alkalic dike rocks

✱ Post-tectonic tonalite intrusion within the Boyer Lake Group

o Felsic porphyry, "Tabor Lake Stock"

+ Post-tectonic granodiorite


A
F
M
B22
W18
W7
S8
K39.
W4
B17
W19
W22
W3
B3
B4
L6
L8
B13
L2
B14
S9
L5
L7
L4
K10
L3

SiO_2) ; basaltic andesite (52 - 56% SiO_2) ; andesite (56 - 64% SiO_2) ; dacite (64 - 68% SiO_2) and rhyolite (> 68% SiO_2). Rocks that underwent significant alteration may have been subjected to Si metasomatism and have been treated with caution.

The volcanics of each of the three major lithological groups are compared on the basis of their silica content (Fig. VIII-9). Both the Wapageisi Lake Group (Subgroup I) and the Boyer Lake Group have unimodal distributions with a narrow range of silica content ; nearly all rocks fall into the basalt field (Fig. VIII-9a, b). The felsic Subgroup II consists of rocks with a silica content around 70%. Field observations suggest a chemical evolution from the base of the felsic sequence to the top, where pyroclastics with abundant modal quartz are present. Intermediate rocks are scarce. Similarly, McMaster (1978) noticed a lack of volcanics with SiO_2 content between 53 and 60% within the felsic sequence overlying the Thundercloud Lake Porphyry. The Kawashegamuk Lake Group also shows a bimodal distribution as the silica frequency diagram (Fig. VIII-9c) displays a distinct minimum in the andesite region from 58 to 60% SiO_2 with maxima at 57 and 61% SiO_2. Another low is observed around 70% SiO_2, but it may not be real as the number of analyzed felsic rocks is small. Numerous Archean studies have revealed the existence of a compositional gap, the so-called "Daly Gap" (Daly, 1925) within volcanic suites (Barker and Peterman, 1974 ; Glikson and Lambert, 1976 ; Thurston and Fryer, 1983).

iv) Differentiation of the lavas

Distinct trends of magmatic differentiation have already been

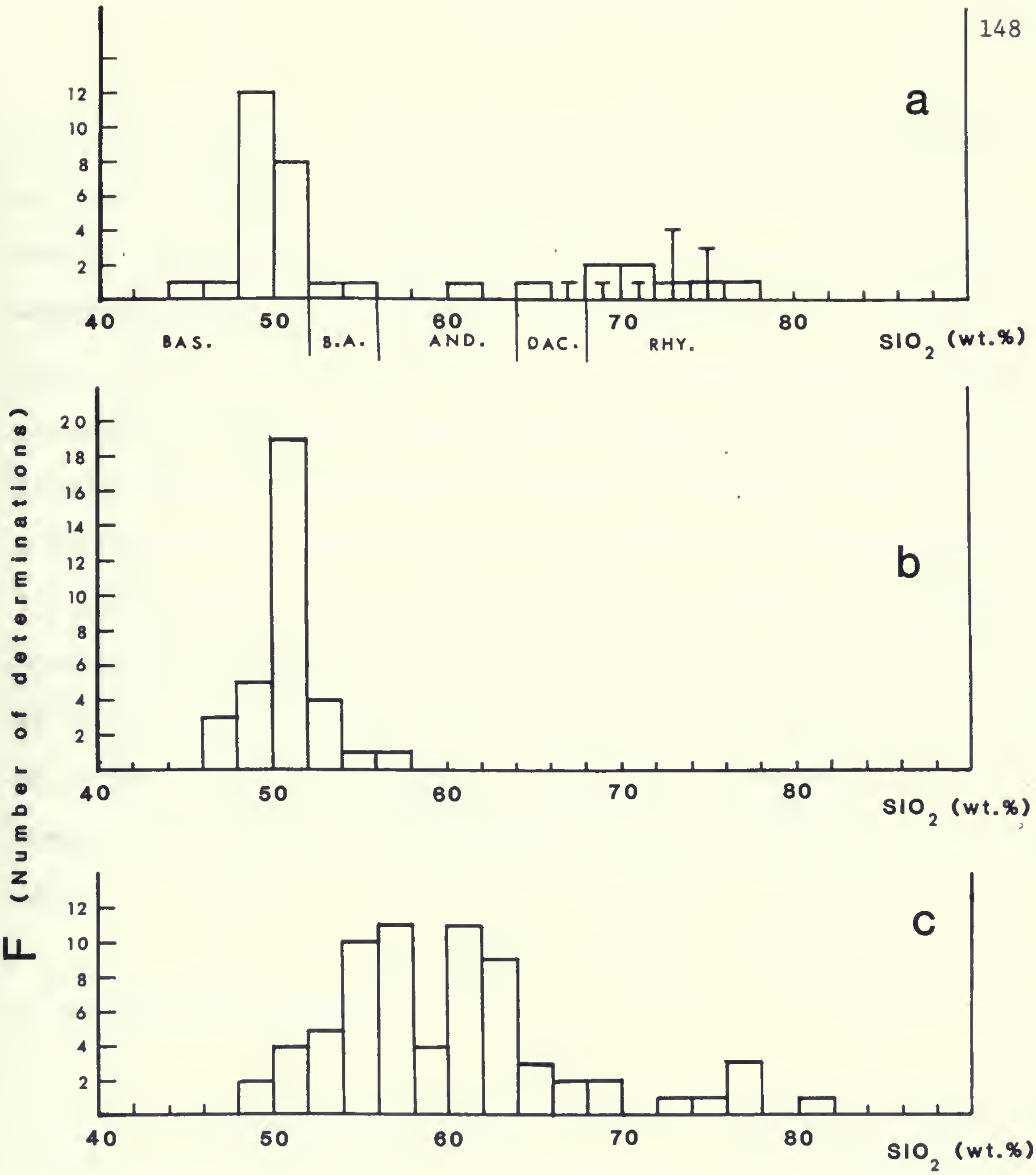


Fig.VIII-9: SIO_2 frequency histograms for metavolcanics of the Stormy-Kawashegamuk Lakes area.

a) Wapagelsi Lake Group, Subgroups land II (Bars depict the Thudercloud Lake Porphyry)

b) Boyer Lake Group

c) Kawashegamuk Lake Group, Cycles I and II.

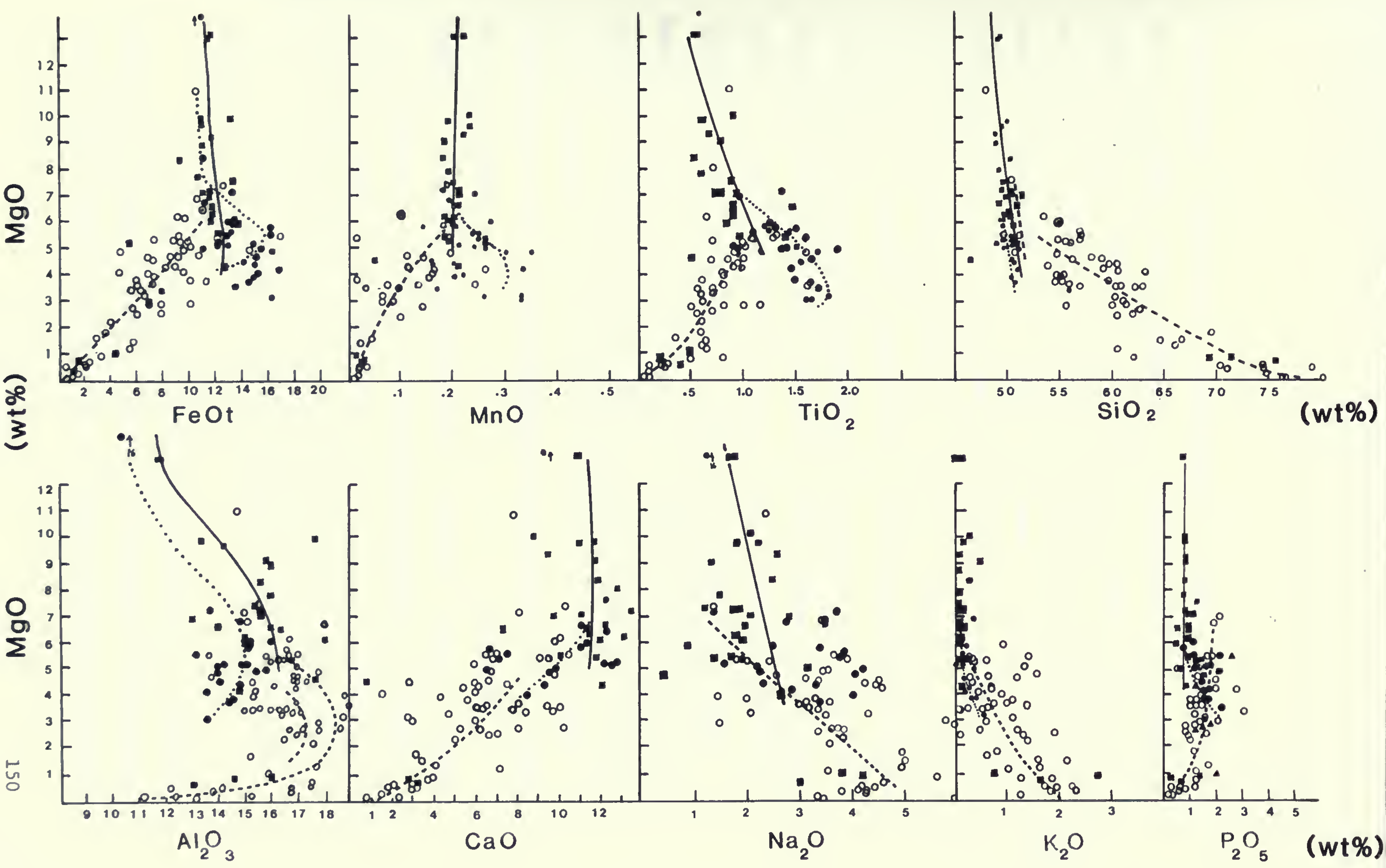
All silica values have been calculated on a volatile free basis.

defined on the basis of AFM diagrams (see Figs. VIII-2 and 3). Field observations have shown that a complete spectrum of volcanic rocks ranging form basalts to rhyolite, is found in the map area, although some rock classes are much less abundant than others. In an attempt to determine the processes that produced these magma types, such as partial melting of mantle versus crustal material, fractional crystallization within a magma chamber, mixing of two magmas (hybridization), contamination by crustal material (assimilation) or liquid immiscibility, petrography is of little use because most original mineralogies have degraded to lower temperature assemblages during metamorphism. As fractional crystallization is probably responsible for the occurrence of a wide variety of rock types, diagrams showing the variation of a number of elements relative to MgO have been established (Figs. VIII-10, 11).

1. <u>MgO variation diagrams</u>

Plots of all major elements oxides (including the minors, Mn and P) show two distinct trends suggesting fundamental differences in the evolutionary path of the magmas (Fig. VIII-10), whereas variations of the trace elements versus MgO clearly do not reflect the pattern outlined by the major elements (Fig. VIII-11). The two trends in Fig.10 discriminate between the Wapageisi Lake basalts (WLV) and the Boyer Lake volcanics (BLV) on one side and the Kawashegamuk Lake volcanics (KLV) on the other. It is worth noting that the elongate fields defined by WLV, BLV and KLV seem to meet at distinct angles, however there is neither

Fig. VIII-10: Variation diagrams of volcanic rocks from the Wapageisi Lake Group (■), Boyer Lake Group (●), Kawashegamuk Lake Group (○) and a mafic flow within the Stormy Lake Group (⊙), where all major elements are shown against MgO. Unpublished data from C.E. Blackburn (A and KAW traverses) has also been plotted.

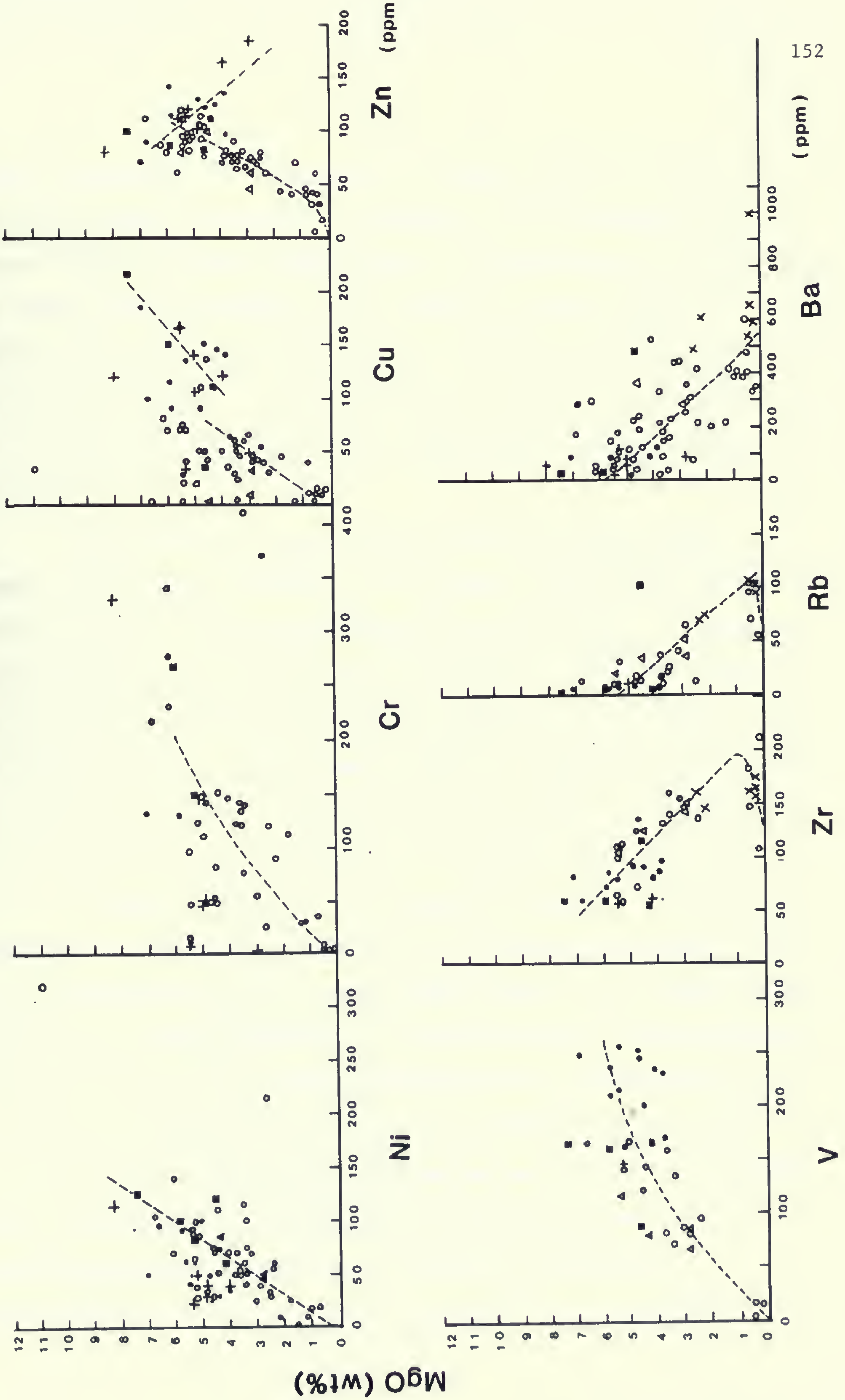


MgO
(wt%)
FeOt
MnO
TiO2
SiO2
(wt%)
MgO
Al2O3
CaO
Na2O
K2O
P2O5
(wt%)

overlapping nor crossing of trends, except in the MgO - Na_2O plot, which shows significant scatter possibly due to Na mobilization during metamorphism. On a MgO - FeO^t plot, WLV and BLV are characterized by a line of constant Mg-depletion corresponding to olivine fractionation. At about 7 wt % MgO, BLV shows a sudden enrichment in Fe, Mn and Ti ; concurrently the MgO - CaO diagram show a sharp decrease in Ca, which is also accompanied by a drop in Al on the MgO - Al_2O_3 plot. This suggests that the observed iron-enrichment is due to plagioclase removal. Olivine (34% SiO_2) fractionation during early stages, followed by calcic plagioclase (52% SiO_2), results in a slight increase in SiO_2, Na_2O, K_2O and a dramatic increase in Fe, Mn, Ti, which are concentrated in pyroxenes (pigeonite) and Fe - Ti oxides. Crystallization of these phases then leads to enrichment of Si, Na and K in the liquid ; the resulting liquids fall into the tholeiitic andesite, dacite and rhyolite classes depending on the degree of fractionation. From the plotted data, the BLV appears to be more differentiated than the WLV as it has higher Fe and Ti contents. The chemical trends reflect the fact that plagioclase-phyric horizons, commonly carrying large phenocrysts, are common throughout the Wapageisi Lake Group, whereas such porphyritic flows have not been observed in the Boyer Lake Group. A complete spectrum of tholeiitic differentiation, similar to lavas of Thingmuli volcano, Iceland (Carmichael, 1964), has not been observed.

The trend defined by the KLV is essentially one of progressive depletion of the femic elements (Mg, Fe, Mn, Ti) and Ca, and enrichment in the salic components (Si, Al, Na, K). Either enrichment or depletion

Fig. VIII-11 : Relationship between MgO and selected trace elements for volcanic rocks of the Wapageisi Lake Group, Sub-group I (■), Boyer Lake Group (●), Kawashegamuk Lake Group (○) ; gabbro sills (+), tonalite intrusion within Kawashegamuk Lake volcanics (▲), Thundercloud Lake Porphyry (×). Additional unpublished data from Blackburn for Ba, Cr, Cu, Ni, Zn. All trace elements in ppm by weight, MgO in weight %.


Zn
Cu
Cr
Ni
Ba
Rb
Zr
V
(ppm)
MgO (wt%)

trends are virtually linear except for Al. Large variations in Al content are probably due to different amounts of feldspar fractionation ; however the curved trend suggests that Al was concentrated in the liquid by removal of Al-poor phases, such as olivine, pyroxenes and Fe - Ti oxides, before substantial fractionation of feldspars. If Ca-rich plagioclase crystallizes in the early stages, Al enrichment is subdued, giving a trend of lesser curvature, as examplified by the WLV and BLV trends.

The variation of trace elements in WLV, BLV and KLV show simple linear trends of depletion or enrichment. Those elements having mineral - liquid partition coefficients (Kd) greater than 1 are progressively depleted in the melt. They are classified as compatible elements because they are easily partitioned in olivine (Ni, Cr), pyroxenes (Cr,V) and plagioclase (Sr). Those elements with Kd $<$ 1 (Zr, Rb, Ba) are enriched in the liquid until late stage minerals such as zircon, alkali feldspars and micas begin to form. Cu and Zr may be removed as sulphide phases.

Ni shows a linear trend of decreasing abundances with decreasing MgO content in WLV, BLV and KLV being compatible with a model involving olivine fractionation. A lack of reliable data for Cr, particularly concerning WLV and BLV renders the Cr relationship for these two sequences difficult. For KLV, Cr is high ($>$ 200 ppm) in some tholeiitic lavas with more than 5 wt% MgO and the Cr content deacreases dramatically with decreasing MgO, possibly because of fractionating olivine rich in chrome-spinel inclusions. At MgO contents below 5 wt%, the decrease is more gradual being possibly controlled by pyroxene fractionation. V, an element which is easily partitioned in pyroxenes, has an analogous

distribution to Cr. Cu and Zn are not regarded as being useful petrogenetic indicators because of their strong affinity for sulphur, thus it is difficult to postulate the meaning of the linear relationship in the MgO-Cu and MgO-Zn diagrams. The MgO-Zr diagram clearly reveals the progressive enrichment in Zr with decreasing MgO which could result from differentiation ; Rb and Ba show similar relationships.

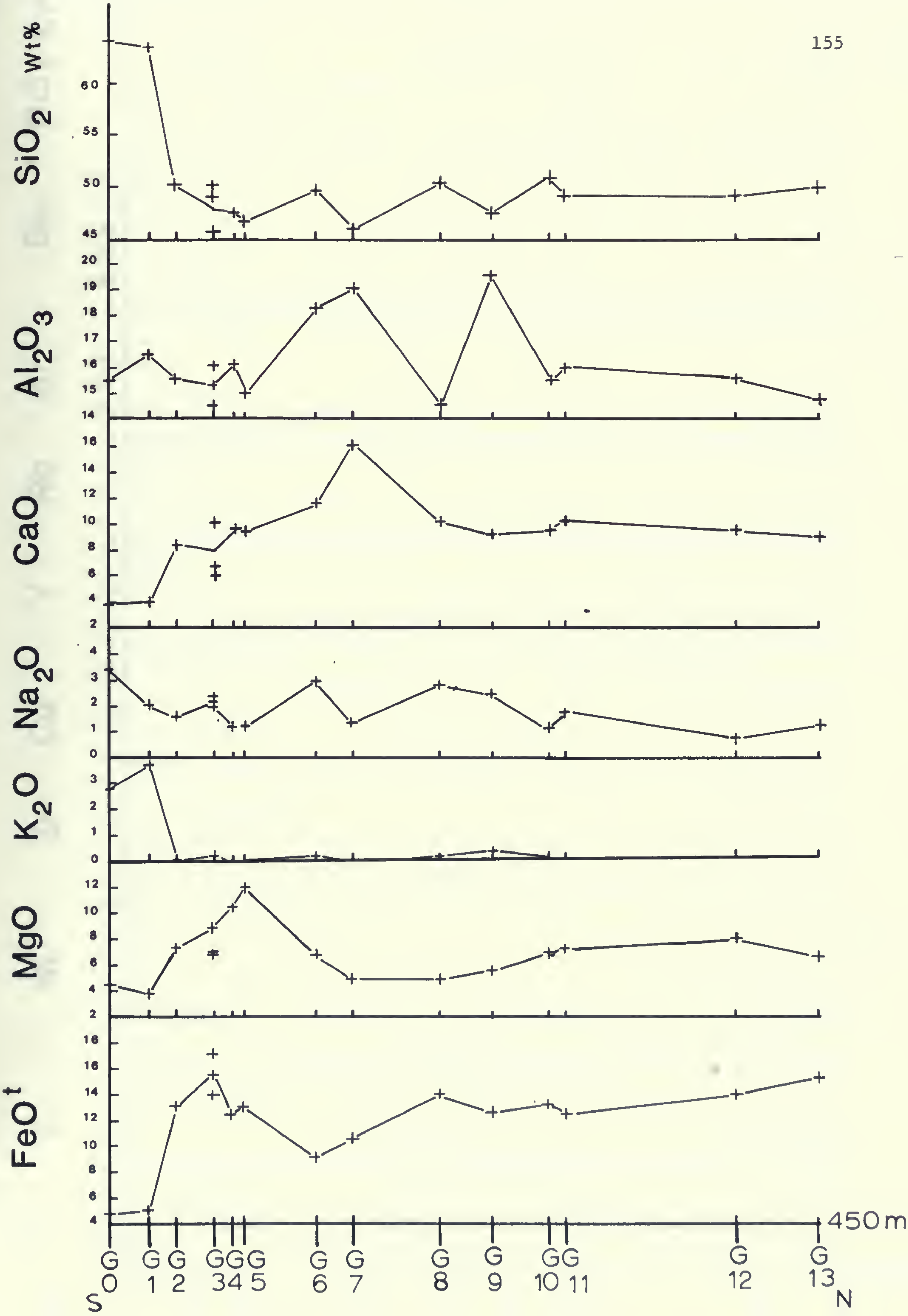
2. Differentiation of mafic intrusives : the "Katisha Lake Gabbro Sill"

The "Katisha Lake Gabbro Sill" is well exposed at Katisha Lake and has been sampled for petrochemical analysis. Table VIII-1 gives a brief description of each sample. Abundances of major element oxides and trace elements have been plotted as a function of stratigraphic height (Fig. VIII-12). The variation diagram shows a distinct chemical zonation from the south to the north margin of the sill : 1) a zone

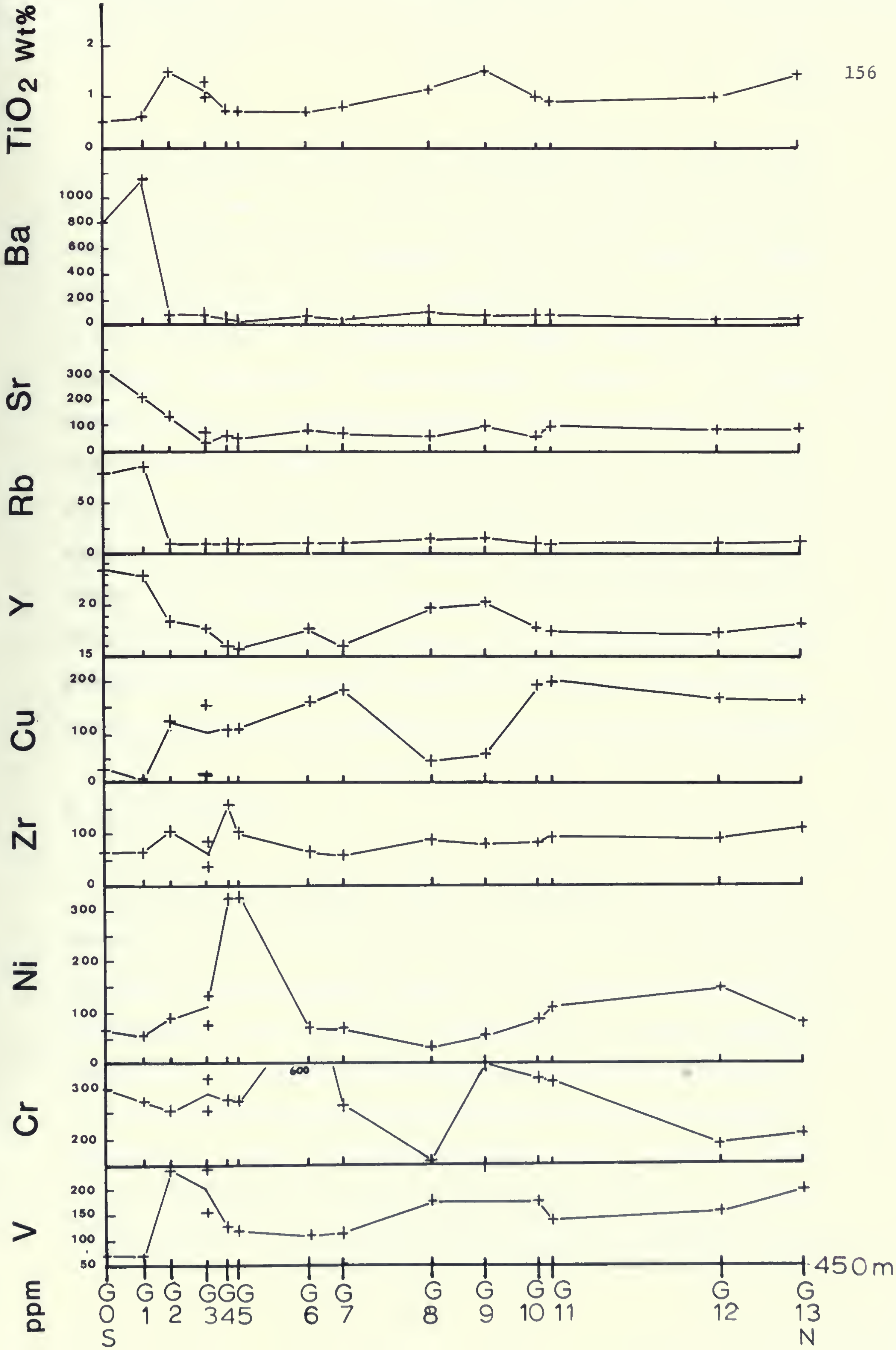
G0	: Med. gr.; dark grey-green, 25% dark colored min., 75% white feldspars ; foliated.
G1	: Similar to G0 ; weak foliation
G2	: Fine gr. ; green color ; basaltic appearance : chill margin or basalt enclave ; massive.
G3A	: V. coarse gr. ; dark green ; abund. diss. oxide phases (leucoxene); massive.
G3B	: F. to med. grained rock ; dark green ; basaltic aspect ; massive.
G3C	: Med. gr. ; dark green ; diss. oxides : massive.
G4	: V. coarse gr. to pegmatitic ; amphibole crystals 1cm+ ; porphyritic.
G5	: Pegmatitic gabbro with amphibole crystals 2cm in size ; massive.
G6	: Med. gr. ; light green-grey ; approx. 20% mafic phase ; 5% oxides ; massive.
G7	: Similar to G6 ; mineralogy dominated by white feldspar.
G8	: Med. gr. ; dark grey-green ; large magnetite grains ; abundant tiny specks of ilmenite ; massive.
G9	: Med. gr. ; green-grey ; 40% dark minerals ; 10% large brown grains of leucoxene ; foliated.
G10	: Med. gr. ; similar to G9 ; faint foliation.
G11	: Med. to coarse gr. gabbro ; diabasic texture ; grey-green ; massive.
G12	: V. coarse gr. gabbro ; dark green ; massive.
G13	: Coarse gr. gabbro ; dark green ; abundant Fe-Ti oxides ; massive.

Table VIII-1 : Macrocospic description of samples taken from the "Katisha Lake Gabbro Sill".

Fig. VIII-12 : Oxide (weight %) and trace elements (ppm) variation from south to north across the "Katisha Lake Gabbro Sill". See map 2 for sample location.



SiO2 Wt%
Al2O3
CaO
Na2O
K2O
MgO
FeOt
450 m
G 0
G 1
G 2
G 3
G 4
G 5
G 6
G 7
G 8
G 9
G 10
G 11
G 12
G 13
S
N


TiO2 Wt%
Ba
Sr
Rb
Y
Cu
Zr
Ni
Cr
V
ppm
600
450 m
G 0 S
G 1
G 2
G 3
G 4
G 5
G 6
G 7
G 8
G 9
G 10
G 11
G 12
G 13 N

enriched in salic components and the incompatible trace elements, and having a very low Fe and Ti content ; 2) a zone enriched in the femic components (Mg, Fe) and the compatible trace elements which is immediately succeeded by strong Al and Ca enrichment. In the field, the high Ca phases (G6 and G7) are characterized by light colored rocks rich in feldspar, lightly spotted by ferro-magnesian minerals ; 3) a wide zone showing only gradual changes approaching a more mafic composition towards the northern margin. The chemical data, coupled with fragmentary petrographic observations, supports the view that differentiation took place by fractional crystallization due to gravity settling to form layers rich in ferro-magnesian minerals (G3, G4, G5), feldspar (G6, G7) or oxide facies minerals (G9). However, the uneven trend makes a simple straightforward interpretation difficult. The almost complete lack of primary textures and relic mineralogies further obscures interpretation.

3. Ti - Zr relation

Most elements have a predictable behaviour during magmatic processes. If the proportions of the various components remain unchanged during later processes, *viz.* metamorphism, then relationships between components may be very useful (cf. Rb/K, Ba/K, Rb/Sr ratios), unfortunately a number of elements behave unpredictably during post-magmatic events and as a consequence, the usefulness of these constituents is significantly reduced. Ti and Zr are known to remain relatively undisturbed during metamorphism and have been used for petrologic modeling (Nesbitt and Sun, 1976 ; Pearce and Cann, 1973). By plotting Ti against

Zr for ultramafic and mafic lavas, Nesbitt and Sun (1976) obtained a linear relationship between the two elements. They showed that concentration of the incompatible elements is inversely proportional to the degree of partial melting, and that Ti/Zr ratios are comparable to chondritic values. Low-Mg tholeiites in general and MORB fall on the same trend.

Tholeiitic basalts from within the present study area fall along the chondrite line (Fig. VIII-13). Lower Ti/Zr ratios than chondritic values are explained by fractionation of Ti-rich augite and/or ilmenite, whereas abnormally high ratios may be analytical or induced by local mineralization or weathering. When the stage of silica enrichment is attained, the Ti/Zr ratio suddenly drops as a result of precipitation of Fe - Ti phases ; enrichment in Zr continues. At extreme fractionation levels (rhyolite), the trend of the felsic liquid swings again due to zircon crystallization and follows a path of Zr and Ti depletion. Within the map area, felsic rocks having evolved from a tholeiitic liquid line of descent have not been identified, however a sharp departure occurs at Ti/Zr ratios in the neighbourhood of 80 : rocks falling on the trend of decreasing Ti/Zr ratios belong mostly to the Kawashegamuk Lake Group. The trend is linear suggesting fractional crystallization and differentiation probably was controlled by settling of pyroxenes and Fe - Ti oxides. At Ti/Zr $\simeq$ 9 the trend is again reversed and becomes one of Ti - Zr depletion : those rocks which plot on that line are all rhyolites. It is here suggested that fractional crystallization is the most viable process to produce the pattern of Fig. VIII-13, however the early departure from the chondrite line of the calc-alkalic

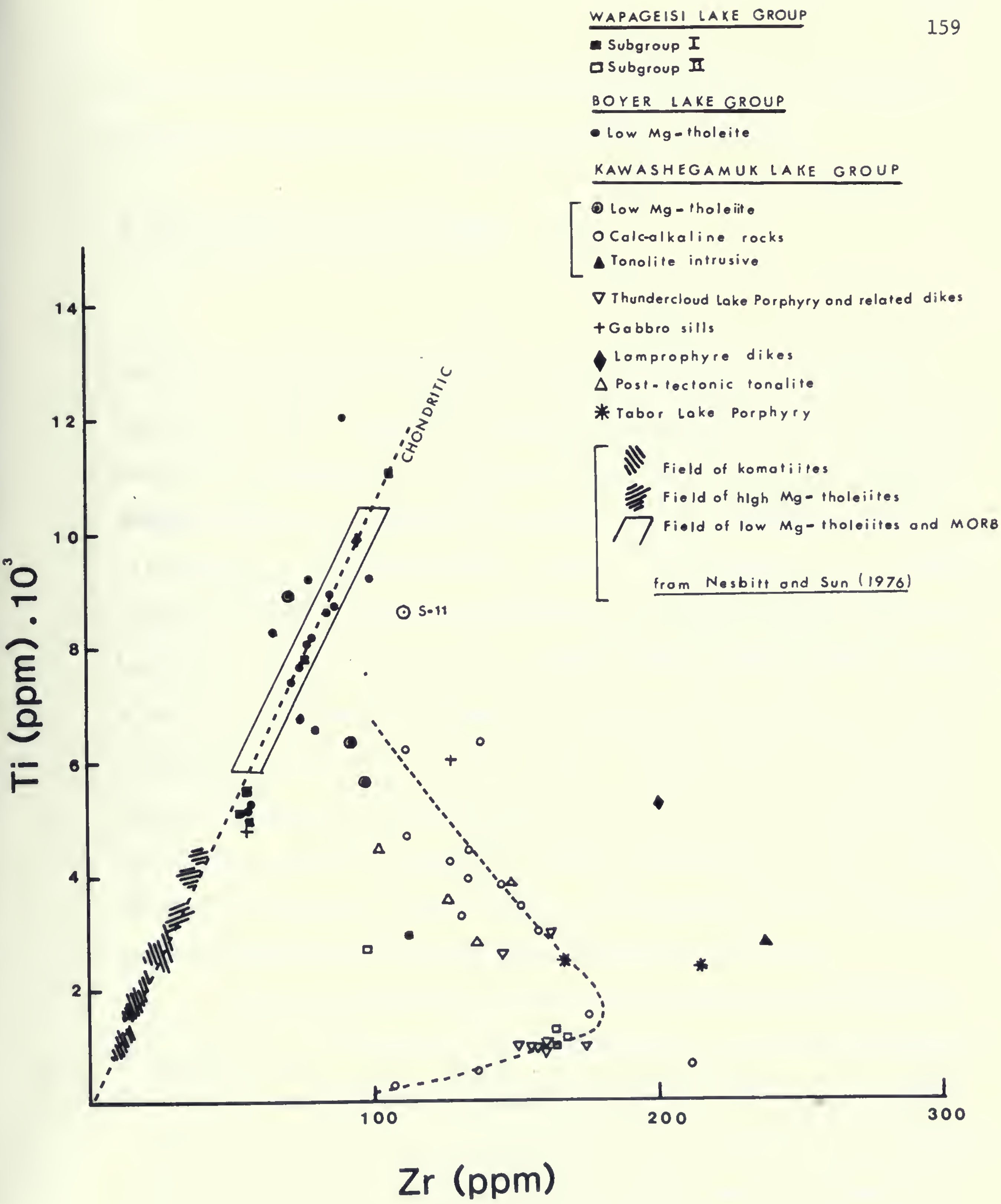


Fig. VIII-13 : Diagram showing the relationship between Ti and Zr for a variety of rock types sampled in the Kawashegamuk Lake area.

suite may imply melting of lower crust material which is followed by fractional crystallization during the ascent of the magma.

4. The rare-earth elements (REE)

The rare-earth elements have gained increasing importance during the last decade in the field of petrogenesis. The concept which led to their widespread usage results from the fact that all REE from La to Lu have similar chemical affinities due to their constant oxidation state of +3, except for Eu which may also occur as Eu^{2+} under low pO_2, and their relatively constant ionic radius.However, the trivalent ions from La to Lu have a regular decreasing ionic radius with increasing atomic number, a property which has been shown to directly affect the behaviour of REE in igneous rocks (Coryell et al., 1963). Variations in the ionic radius impart differing crystal field energies which in turn are reflected by differing Kd values in minerals : Sneltzer and Philpotts (1970), Nagasawa and Sneltzer (1968) and other studies have demonstrated the relationship between mineral-melt Kd's and atomic number (Fig. VIII-14).

The partitioning of the REE in some essential rock forming minerals have inevitably led to the development of igneous models (e.g. Arth and Hanson, 1975 ; Sun and Nesbitt, 1978). Abundances of the REE in chondritic meteorites have been shown to be very uniform (e.g. Haskin, 1977 ; Nakamura, 1977 ; Taylor and Gorton, 1977) and are thought to be similar to abundances in the terrestrial mantle. If the chemical data are normalized against chondritic values, the ratios provide an indica-

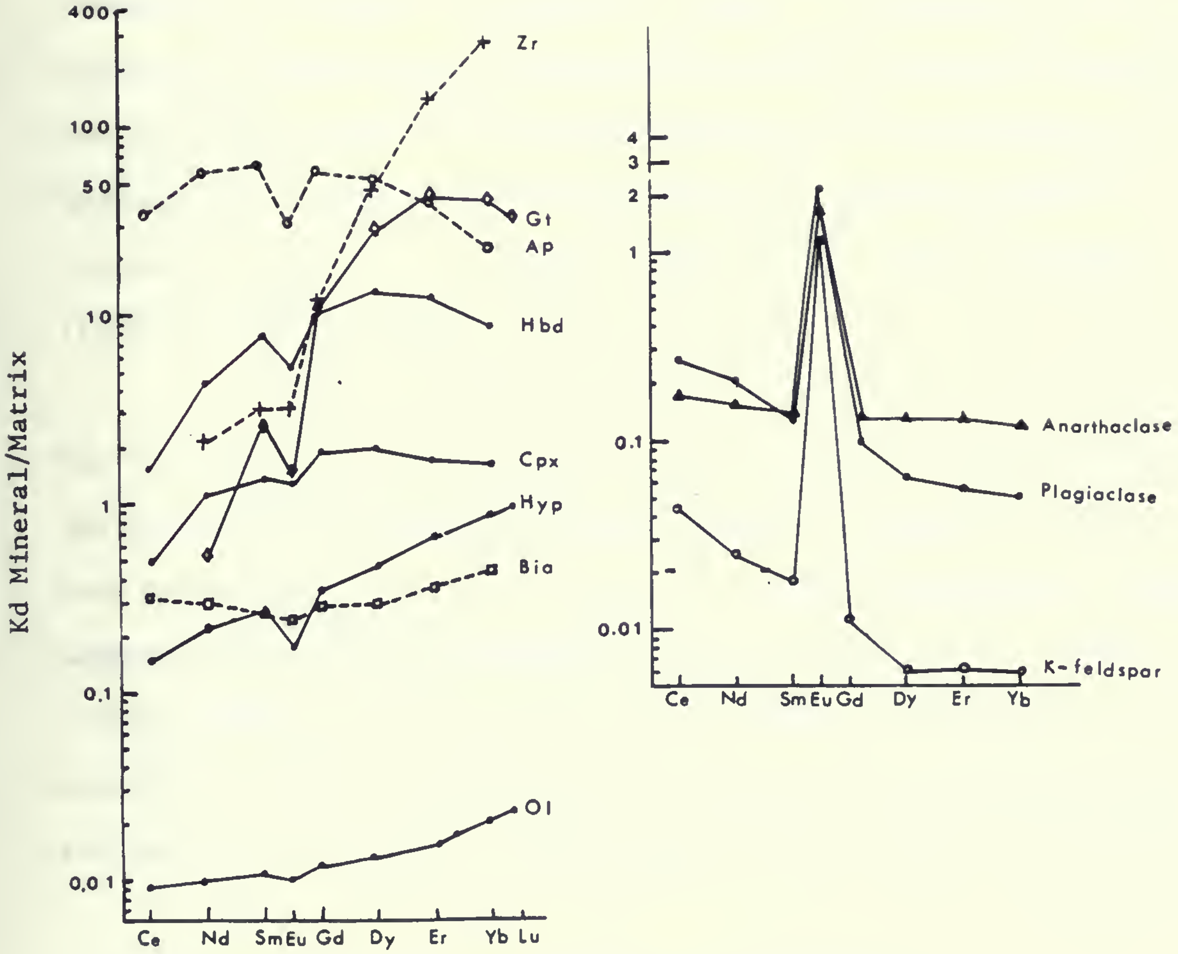


Fig. VIII-14 : Mineral/Melt distribution coefficients for REE (after Hanson, 1978 and Haskin, 1977).

tion of the relative enrichment of each lanthanide species in the rock investigated, besides, it brings each element to the same level by removing the inherent zig-zag pattern which otherwise obscures variations due to igneous processes. For more information on the development of applications of REE in igneous petrology, the interested reader is referred to Coryell et al. (1963), Haskin (1977), Haskin and Paster (1978) and Hanson (1978).

Twenty-eight samples have been analyzed for La, Ce, Nd, Sm, Eu, Tb, Yb and Lu by Instrumental Neutron Activation Analysis (INAA) at the University of Toronto. The data is shown in Appendix C . It has been established by many that the REE are not very susceptible to post-magmatic changes (Sun and Nesbitt, 1978 ; Dostal and Strong, 1983), hence a large number of determinations is not necessary. Results have been normalized against average chondritic values (Taylor and Gorton, 1977) and plotted on a logarithmic scale against atomic number (Fig. VIII-15).

a) <u>The Wapageisi Lake Group basalts (Fig. VIII-15a)</u>

The REE patterns are essentially flat, being slightly more enriched in the heavy rare earth (HREE) as compared to the light rare earth (LREE). The total REE content has undergone a 10-fold enrichment with respect to chondrites. There is no Eu anomaly. The trend suggests that Subgroup 1 basalts have been produced by partial melting of a garnet-free source. The slight relative depletion in the LREE may be explained by removal during previous melting episodes in the mantle, because LREE have a higher degree of incompatibility than the HREE.

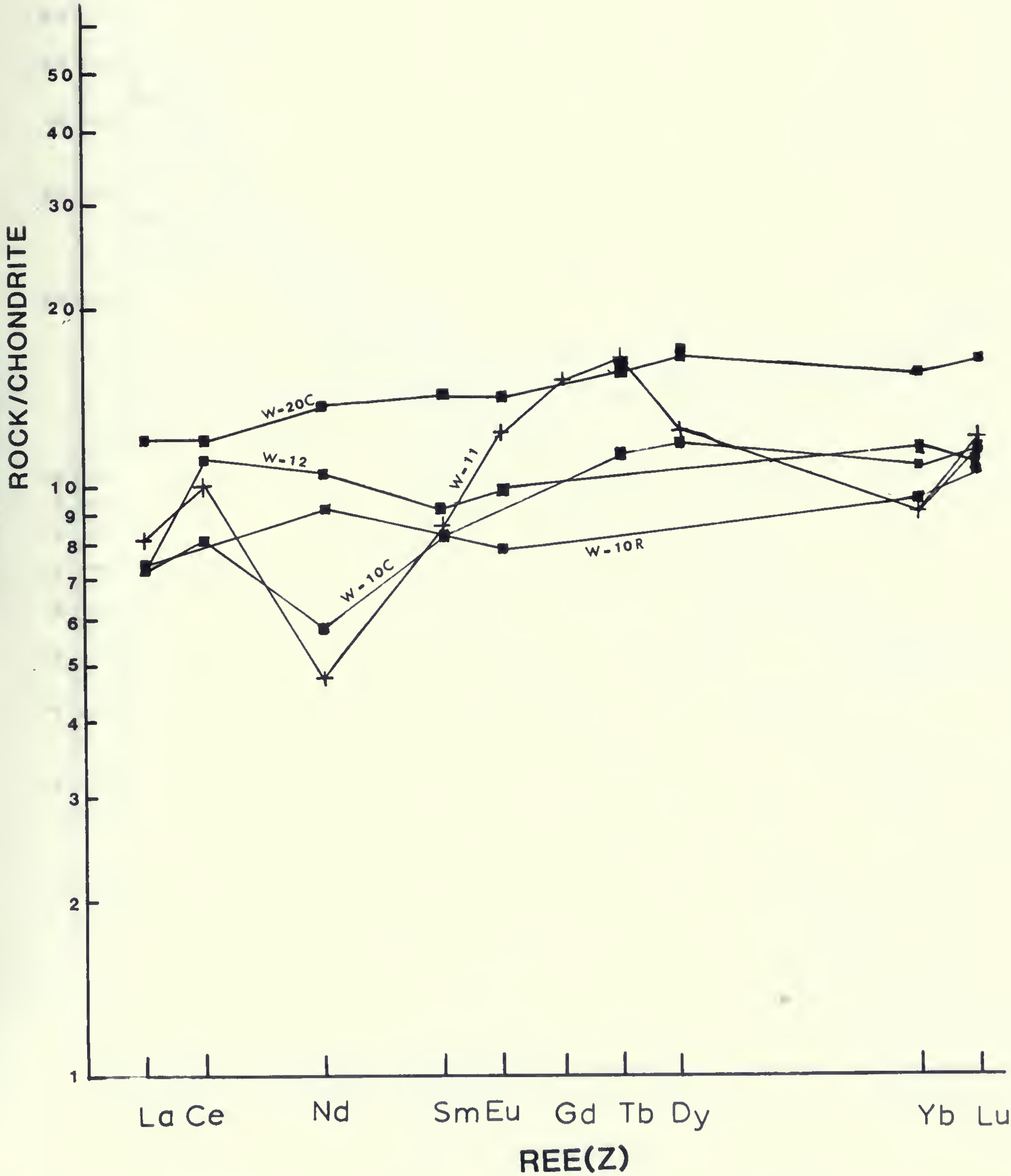
Fig. VIII-15 : Rare earth elements abundances in volcanic rocks.

a. Wapageisi Lake Group (Subgroup I): W10-C and W10-R are from a basaltic pillow core and rim zone ; W11 is a gabbro intrusive in the mafic lavas.

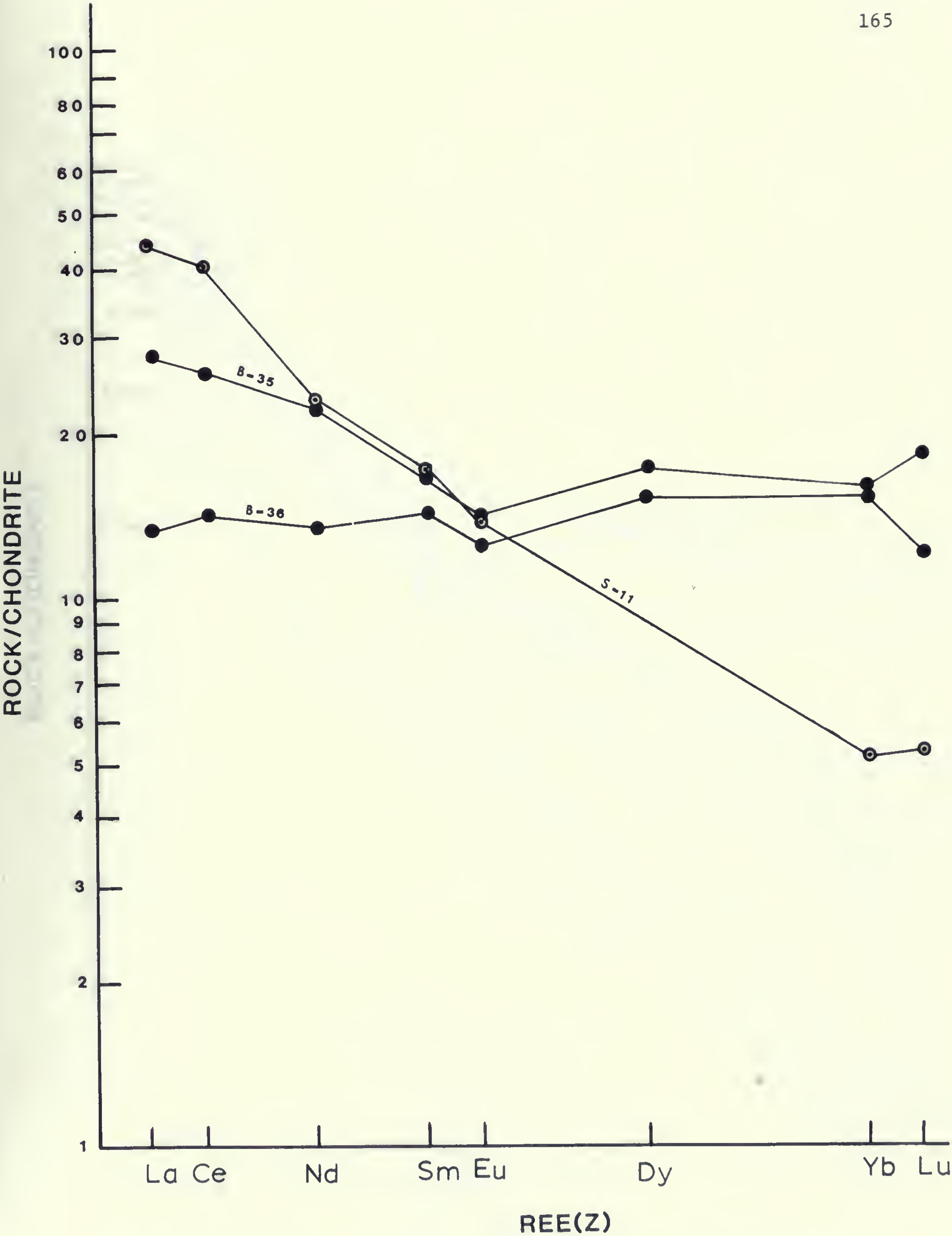
b. Boyer Lake Group (B35, B36).
Stormy Lake Group, amygdaloidal basalt flow (S11).

c. Kawashegamuk Lake Group :
K18 : Cycle I, tholeiitic flow.
K11, 18, 20, 21, 25, 44, 50 : Cycle II, basaltic and andesitic flows.
K24 : quartz feldspar porphyry stock, upper part of Cycle II.
K40 : rhyolite porphyry flow.
K43 : pretectonic tonalite intrusive in Cycle II volcanics.

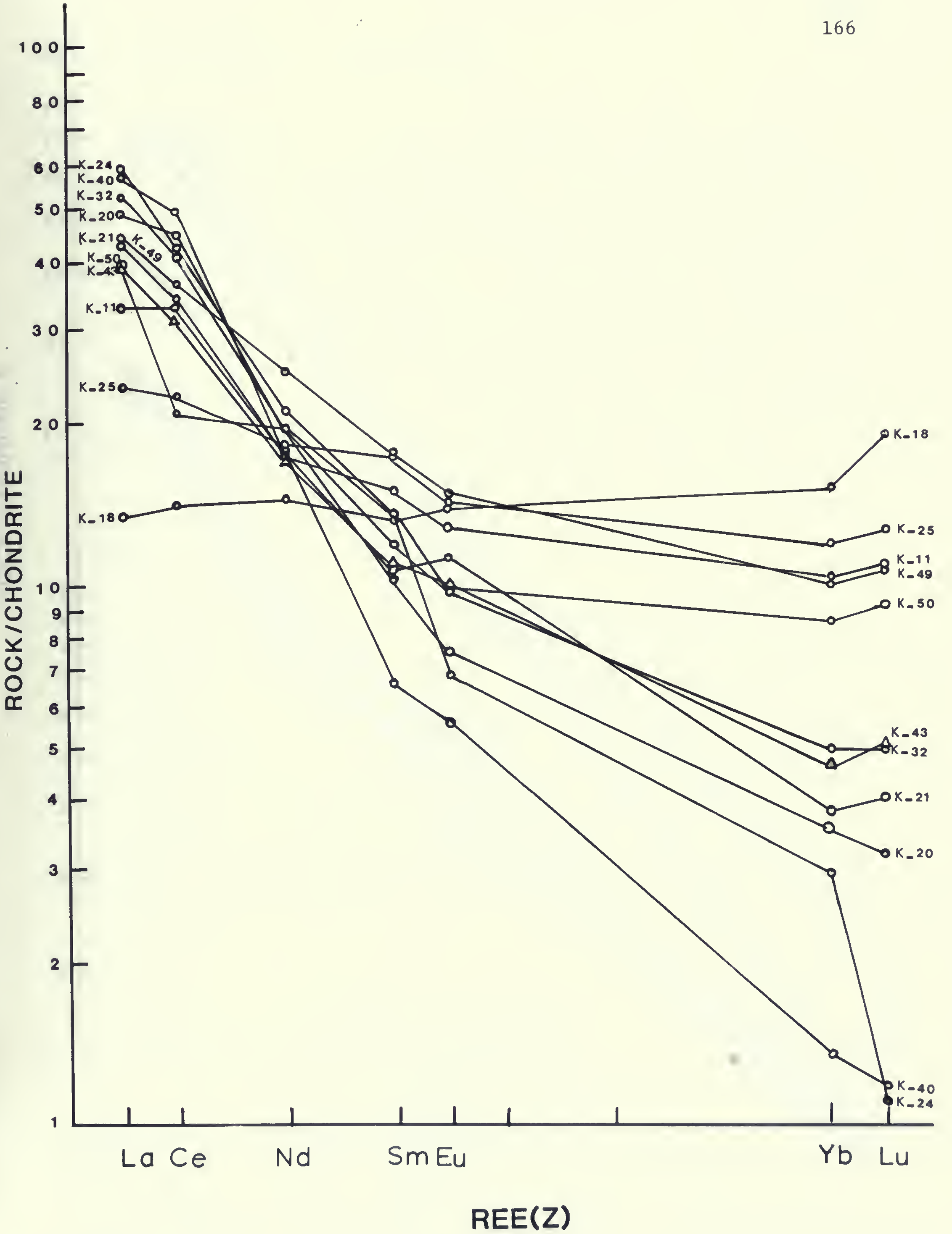
d. Wapageisi Lake Group (Subgroup II) : W26 and W27.
Stormy Lake Group : rhyolite tuff (S1).
Thundercloud Lake Porphyry : T1, T10, T17, T19 ; brecciated porphyry : T32, T38.


ROCK/CHONDRITE
50
40
30
20
10
9
8
7
6
5
4
3
2
1
W-20C
W-12
W-11
W-10C
W-10R
La Ce
Nd
Sm Eu
Gd
Tb
Dy
Yb
Lu
REE(Z)

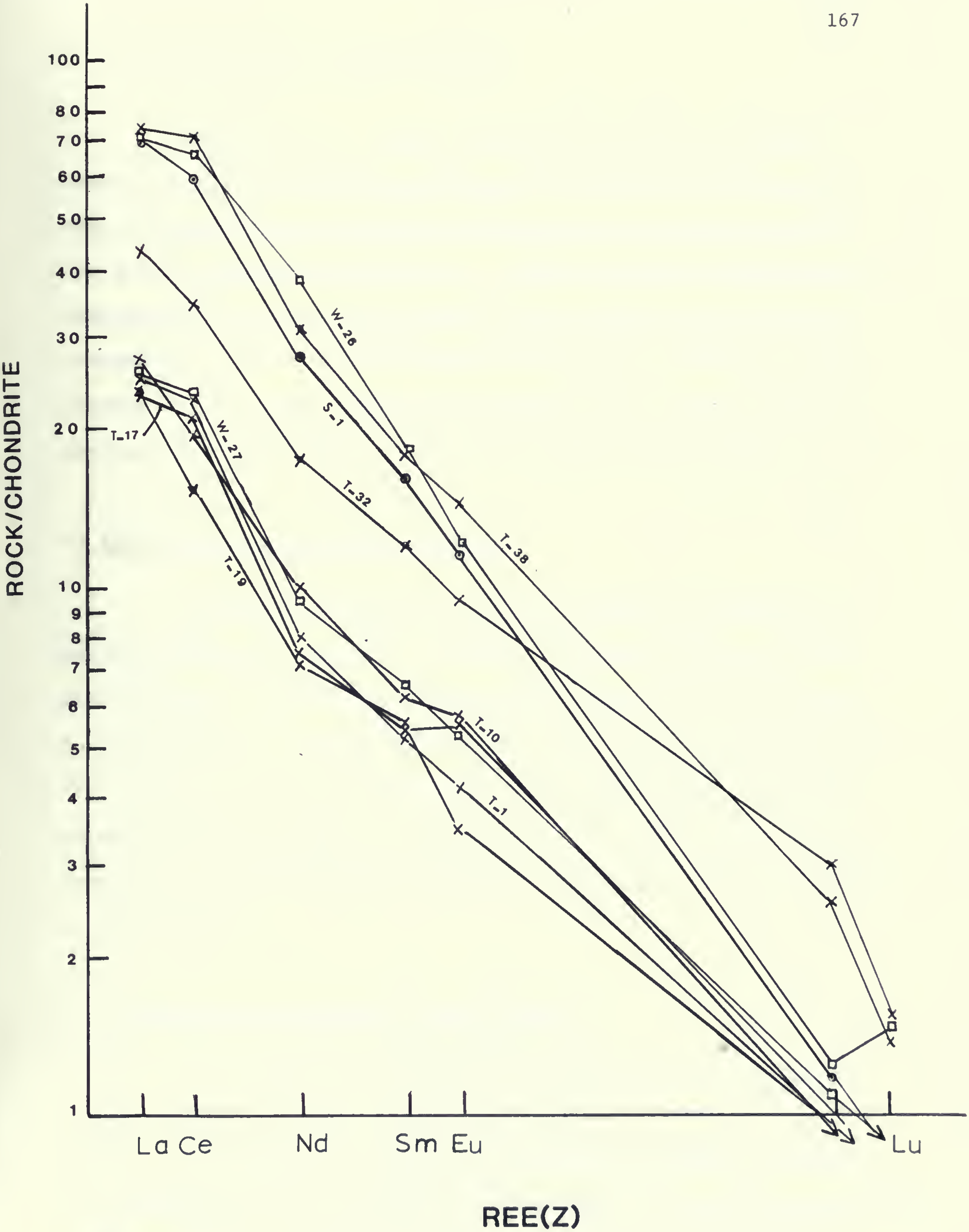
a


ROCK/CHONDRITE
100
80
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
B-35
B-36
S-11
La
Ce
Nd
Sm
Eu
Dy
Yb
Lu
REE(Z)

b


ROCK/CHONDRITE
100
80
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
K-24
K-40
K-32
K-20
K-21
K-49
K-50
K-43
K-11
K-25
K-18
K-18
K-25
K-11
K-49
K-50
K-43
K-32
K-21
K-20
K-40
K-24
La Ce
Nd
Sm Eu
Yb Lu
REE(Z)

C



100
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
ROCK/CHONDRITE
W-26
S-1
T-32
T-38
T-17
W-27
T-19
T-10
T-1
La Ce
Nd
Sm Eu
Lu
REE(Z)

d

b) The Boyer Lake Group (Fig. VIII-15b)

The REE trend is similar to Wapageisi Lake Group basalts. Sample B35 shows a pronounced enrichment in the LREE which is probably due to clinopyroxene fractionation ; garnet is not involved because of the unfractionated HREE ($Sm_N/Yb_N = 1$). A small Eu anomaly indicates that some plagioclase has also been removed, which agrees well with the interpretation given on the MgO variation diagram (Fig. VIII-10). It thus appears that the Boyer Lake basalts originated from a similar source to the Wapageisi Lake basalts, but have been somewhat fractionated.

c) The Stormy Lake Group (Fig. VIII-15b)

An individual basalt flow occurring among the conglomerates has been analyzed (sample S11). It shows a strongly fractionated trend with $Ce_N/Yb_N = 8$. A Eu anomaly is not evident because of the lack of data for the intermediate - heavy REE. The flow, having a calc-alcalic affinity (Fig. VIII-2), may have been contemporaneous to Kawashegamuk Lake Group volcanism. The REE profile is consistant with the more differentiated lavas of the Kawashegamuk Lake Group (Fig. VIII-15c) and may thus indicate a common origin.

d) The Kawashegamuk Lake Group (Fig. VIII-15c).

The chondrite plot reveals a wide spectrum of differentiation trends. A basalt from Cycle I (K18) shows a typical primitive trend identical to the Wapageisi Lake and Boyer Lake Groups basalts, and hence is interpreted to have been derived from the same or a similar source. Lavas from Cycle II show slightly to strongly differentiated trends with Ce_N/Yb_N ratios ranging from 2 to 50. The REE data strongly supports a

model involving closed system fractional crystallization whereby HREE have been depleted by removal of clinopyroxene followed by hornblende. Thus felsic rocks are strongly enriched in LREE which have very low Kd's with respect to most fractionating minerals in a melt.

e) Wapageisi Lake Group, Subgroup II and the Thundercloud Lake Porphyry

Two rhyolitic tuffs from the felsic sequence of the Wapageisi Lake Group yield highly linear trends with strong enrichment in the LREE and depletion in the HREE. Sample W27 has Yb and Lu values less than chondrites.

The Thundercloud Lake Porphyry displays an equally steep trend, suggesting that it is a highly fractionated magma. As with other elements, the REE content shows little compositional variation within the stock. The closeness of the trends further suggests that metamorphsim has had negligible effects on REE concentrations. Samples T32 and T38 are from a brecciated form of the porphyry which is less felsic. These two samples carry higher HREE concentrations than the unbrecciated porphyry, but have higher Ce/Yb ratios. The higher enrichment in LREE in the brecciated porphyry is an indication that the unbrecciated porphyry was depleted by precipitation of a phase which partitions large amounts of REE, probably apatite. Fig. VIII-13 shows that Zr content is identical for the brecciated and unbrecciated forms of the porphyry thus implying that zircon has not been significantly depleted.

Sample S1 is a rhyolite tuff from the Stormy Lake Group overlying Facies II ; it shows the trend characteristic of rhyolites from within the map area.

5 - Chemical composition of variolites

Three variolites of "Formation V" of the Kawashegamuk Lake Group have been selected for chemical analyses because they are relatively unstrained and little altered. This study is aimed at determining independently from petrography (see chapter VII) whether the "Blake River type" variolites of Gélinas et al. (1976) have formed by liquid immiscibility (splitting of a magma into two liquids or mixing of two magma types) or by spherulitic crystallization.

The felsic varioles and their enclosing mafic matrix have been analyzed using X-ray fluorescence and Electron Microprobe analysis (EMA). EMA analysis proved to have advantages over XRFS analysis for the following reasons :

1) The sample preparation requires very little work (polished thin section) whereas analysis by XRFS involves a tedious separation of the mafic and felsic components in the rock.

2) Rapid analyses can be performed on various parts of a variole so that chemical changes throughout the variole can be detected, and the nature of the chemical transition across the variole-matrix interface can be determined.

3) Analytical quality is not inferior or invalid because of "contamination" : numerous varioles contain quartz-filled tension gashes that could not have been eliminated during the separation process. Furthermore, some varioles contain recrystallized parts that may have lost or gained various elements.

Microprobe analyses were performed at the University of Toronto using a ETEC Autoprobe instrument with an attached Energy-Dispersive

Spectrometer (Gasparini, 1976). Two or three analytical tests have been performed on each selected variole from two variolites (samples K5 and K9) using a defocussed electron beam 100 microns in diameter and a counting time of 100 seconds. The area covered by the beam encompassed a number of mineral grains large enough to give a reasonable whole rock composition of the variole region of interest. One duplicate run was done to check precision (see results in Appendix II). An in-house kaersutite standard was used for calibration. The matrix of the varioles have been analyzed by XRFS and AAS (sample K5 and K9). In addition, the felsic component of sample K9 was tested by XRFS and a whole variolite composition was determined for sample K6 by XRFS.

The chemical data of different variolite components is presented in Table VIII-2. Table VIII-3 presents the calculated normative mineralogies from data in Table VIII-2. It is clear from the Tables that there is strong compositional contrast between the mafic matrix and the varioles. Furthermore, varioles in samples K5 and K9 have differing compositions with respect to most elements.

a) Varioles

- Varioles of sample K9 have a very low silica content and have nepheline in the norm compared to varioles of sample K5 which are oversaturated with respect to SiO_2.

- The varioles show a strong peralkaline character ; this is especially true of sample K9 which shows abundant nepheline and wollastonite in the norm.

Table VIII-2 : Major element composition (anhydrous) of 2 Archean variolites (K), varioles (F) and matrices (M).

	K5-M (XRF)	K5-F2	K5-F2A	K5-F4	K5-F4A	K5-F (XRF)	K9-M (XRF)	K9-FI	K9-FI Dupl.	K9-FIA	K9-FIB
SiO_2	48.52	70.4I	69.23	65.50	66.79	64.80	46.76	48.40	48.40	48.76	47.63
Al_2O_3	I8.27	I4.24	I4.87	I3.75	I3.82	I4.I8	I5.07	I5.I3	I5.70	I6.06	I5.0I
FeO^t	I6.03	I.70	I.69	I.7I	I.82	2.58	I8.4I	4.72	4.78	4.56	4.79
MgO	7.20	0.00	0.00	0.00	0.00	0.90	8.52	I.09	I.23	I.I0	I.03
CaO	2.78	I.39	2.0I	6.38	5.39	8.85	5.76	I8.30	I8.22	I6.40	I9.I2
Na_2O	I.35	9.45	8.87	I0.9I	I0.28	6.32	0.47	I0.24	9.68	II.06	I0.30
K_2O	I.24	0.97	I.5I	0.20	0.38	0.38	0.05	0.00	0.00	0.00	0.00
TiO_2	2.44	I.70	I.83	I.58	I.52	I.60	2.53	I.92	I.95	2.06	2.I0
MnO	0.I6	0.00	0.00	0.00	0.00	0.08	0.20	0.I6	0.00	0.00	0.00
P_2O_5	0.2I	0.00	0.00	0.00	0.00	0.I4	0.I5	0.00	0.00	0.00	0.00

	K9-FIC	K9-F3	K9-F3A	K9-F5	K9-F5A	K9-F6	K9-F6A	K9-F7	K9-F7A	K9-F7B	K6
SiO_2	50.57	48.09	45.86	46.00	43.73	42.08	44.38	52.55	48.02	48.90	54.07
Al_2O_3	I6.I7	I5.60	I4.72	I4.66	I4.2I	I3.60	I4.I4	I5.I3	I4.65	I4.59	I4.38
FeO^t	5.42	5.86	5.2I	5.88	6.28	4.55	4.3I	3.4I	4.05	4.05	9.37
MgO	I.32	I.83	I.3I	I.60	2.I2	0.38	I.II	0.35	0.60	0.65	3.87
CaO	I4.03	I6.30	2I.43	20.53	22.72	28.26	23.80	I5.I8	20.48	I9.29	II.I5
Na_2O	I0.36	I0.09	9.20	9.54	8.5I	9.02	9.96	II.55	I0.06	I0.46	3.2I
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62
TiO_2	2.I2	2.43	2.26	2.09	2.25	2.09	2.09	I.82	2.II	I.89	I.92
MnO	0.00	0.00	0.00	0.00	0.I6	0.00	0.22	0.00	0.00	0.I7	0.I7
P_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20

	K9-F	K5-F	A(var)	A(mat)	Pillow core
SiO_2	47.37	67.34	59.09	35.33	47.I6
Al_2O_3	I4.96	I4.I7	26.69	I5.2I	I5.84
FeO^t	4.85	I.90	3.47	I4.56	I0.77
MgO	I.I2	0.I8	3.52	I3.46	6.36
CaO	I9.58	4.80	0.66	4.03	5.52
Na_2O	I0.00	9.I7	5.96	0.59	5.6I
K_2O	0.00	0.69	0.44	2.I9	0.44
TiO_2	2.08	I.65	-	3.44	2.02
MnO	0.00	0.00	-	0.32	0.I4
P_2O_5	0.00	0.00	-	0.I9	0.30
			(LOI 6.6)		

Table VIII- 2 (cont'd) : Average composition of varioles from variolites K5 and K9 . A : major element composition (hydrous) of a pillowed variolite from the Swiss Alps (Vuagnat, I946).

	K5-F	K9-F	K5-M	K9-M	K6
Ap	0.00	0.00	0.48	0.30	0.48
Il	2.24	2.80	3.40	3.90	2.74
Or	4.00	0.00	7.20	0.50	3.75
Ab	75.50	II.75	II.95	4.60	29.50
An	0.00	0.00	39.60	30.60	23.58
Mt	0.00	0.00	4.50	4.60	4.I7
Wo	8.20	29.80	0.00	0.00	0.00
En	0.00	0.00	I8.80	24.53	I.27
Fs	0.00	0.00	II.85	I6.56	0.54
Di	I.00	6.00	I.59	0.00	I9.34
He	I.I2	8.8I	I.00	0.00	6.94
Q	7.85	0.00	0.37	9.27	8.62
Ne	0.00	39.8	0.00	0.00	0.00
C	0.00	0.00	0.00	4.50	0.00

Table VIII- 3: Normative minerals for variole averages, matrix and a whole variolite (sample K6), (expressed in cation %, after Barth, I959).

- The very high calcium content in sample K9 is calculated as normative wollastonite because the alumina and silica contents are too low to form anorthite.

- Na content is high, in contrast K is comparatively low in sample K5 and is less than 100 ppm in sample K9.

- Ti content is very high compared with rocks of similar overall composition.

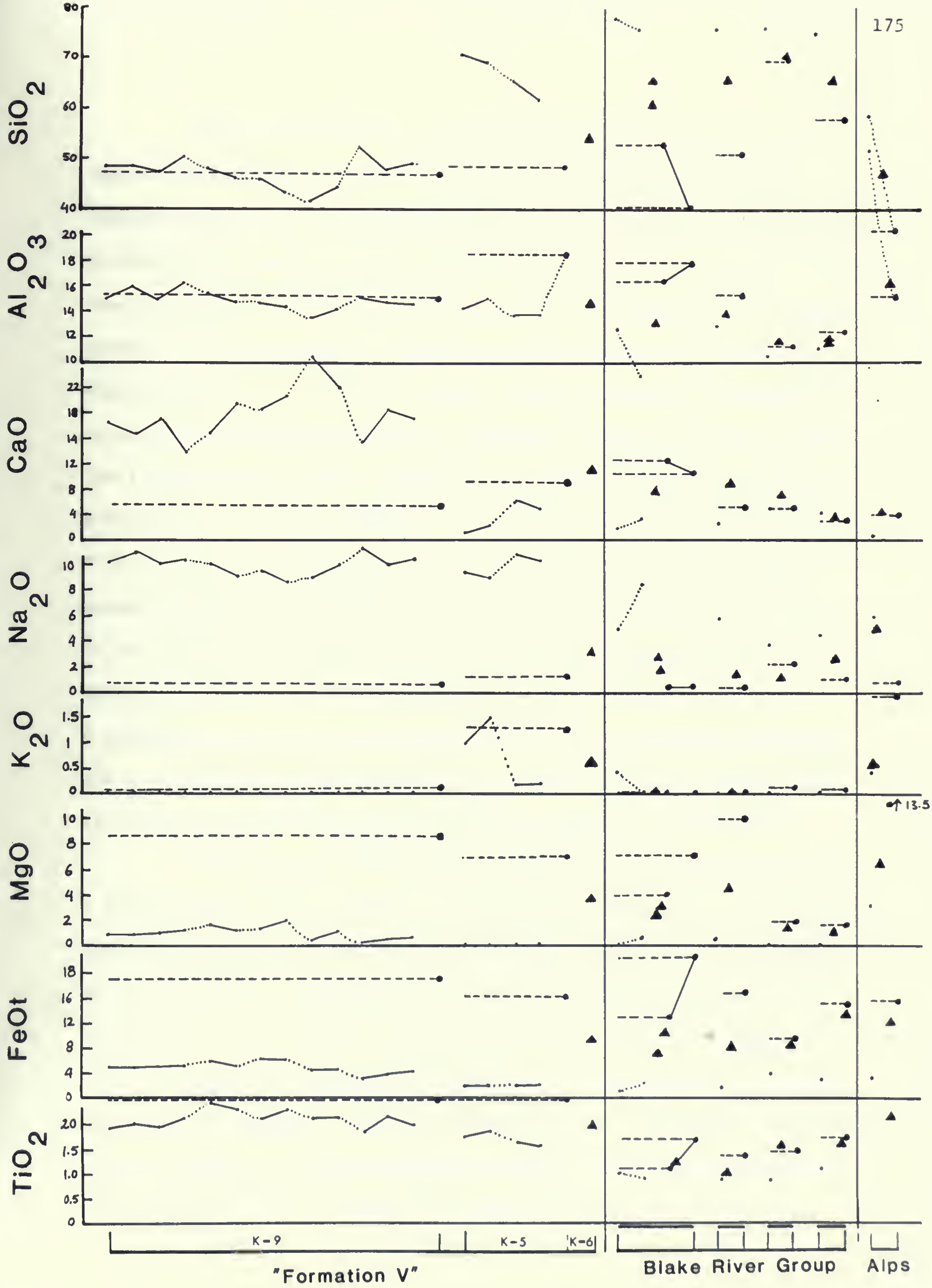
In comparison, varioles from the Blake River group (Gélinas et al., 1976) show striking similarities with respect to K, Ti, Fe and Mg content however Si is very high and Al, Ca, Na are lower. An analyzed variole from the Alps (Vuagnat, 1946) shows an anomalous high Al content (Table VIII-2).

b) Matrix

The matrices are characterized by an iron-rich composition, with high Mg and Ti content ; sample K9 is also high in Al and is corundum normative. Alkali content is typical of normal tholeiitic basalts. However, surprisingly, K_2O is nearly all contained within the iron-rich matrix, contrary to expected enrichment in the felsic varioles. The matrix from Abitibi variolites (Gélinas et al., 1976) are similar in composition.

A whole variolite containing about 25% varioles (sample K6) has a composition which does not deviate from a typical Cycle II basalt or andesite except for the high Ti content. The pillow basalt studied by Vuagnat (1946) is remarkably similar in composition (Fig. VIII-16).

Fig. VIII-16 : Compositional variations of variolites (▲), felsic varioles (•) and matrix (●) from "Formation V", the Blake River Group, Québec (from Gélinas et al., 1976) and the Swiss Alps (Vuagnat, 1946).


SiO2
Al2O3
CaO
Na2O
K2O
MgO
FeOt
TiO2
K-9
K-5
K-6
"Formation V"
Blake River Group
Alps
↑13.5

Despite differences in composition between varioles of the variolites considered, chemical contrasts between varioles within a single pillow are minor. Nevertheless, chemical variations between different areas probed within a single variole indicate that the variole does not have a homogeneous composition. This is compatible with color zoning within the varioles. A graphical representation of the chemical data is given in Fig. VIII-16. Variole-matrix pairs have been plotted on an AFM diagram (Fig. VIII-17) : they show a very simple relationship; the iron-rich matrix falls within the tholeiitic field, while varioles plot near the "A" apex. Varioles of sample K5 have a constant composition, whereas varioles of sample K9 display a linear compositional spread attributable to chemical zoning within the variole (Figs. VII-2c, d). All data points fall along a common linear trend, and the positions occupied on the diagram suggest that variole-matrix pairs are complementary such that a whole variolite (K6) falls somewhere between the two compositions. Compositions of immiscible glasses found in some terrestrial tholeiites (Philpotts, 1982) are shown for comparison.

The position of variole-matrix pairs have also been shown in a Greig (1927) diagram, which is convenient because it takes all elements into consideration (Fig.VIII-16). Furthermore, components at the apices ($Na_2O + K_2O + Al_2O_3$ - $FeO^t + MgO + MnO + TiO_2 + P_2O_5 + CaO$ - SiO_2) have been allocated so as to reproduce the ternary system fayalite - leucite - silica in which low temperature (1140°C) liquid immiscibility is known to take place (Roedder, 1951). If a liquid has a composition which falls along a line a-a', it splits into two liquids. The variolite compositions fall well away from the field of immiscibility in Fig. VIII-18, and

Fig. VIII-17. AFM plot of the mafic and felsic constituents of two pillowed variolites of "Formation V", Kawashegamuk Lake Group.

(●) Compositions of the mafic matrix of samples K5 and K9.

(○) Compositions of varioles for sample K5 (4 analyses on 2 varioles) and K9 (I3 analyses on 5 varioles.

(▲) Whole variolite.

The striped envelopes represent the positions of immiscible iron-rich and silica-rich glassy globules from terrestrial tholeiites (philpotts, I982).

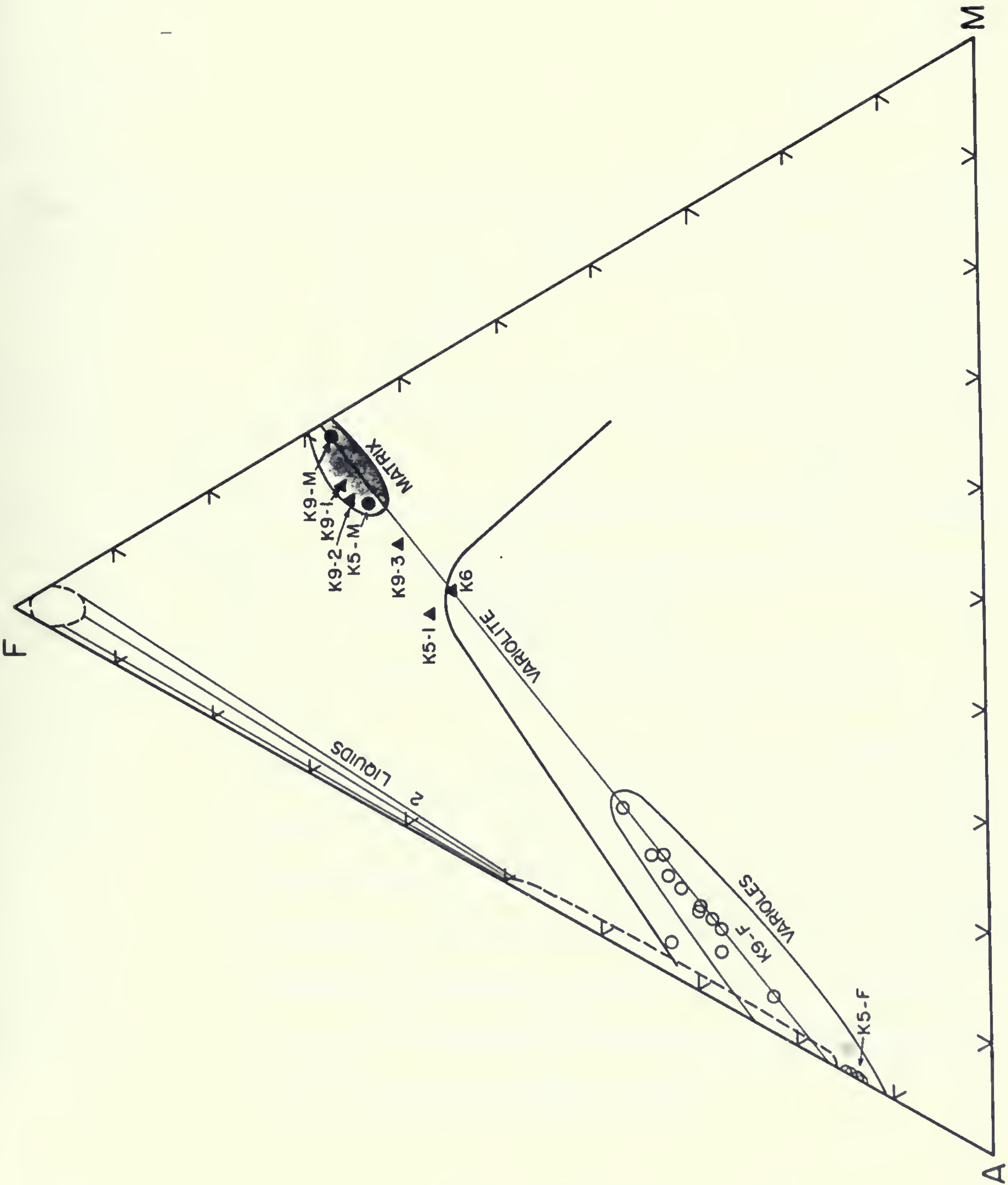

F
M
A
MATRIX
K9-M
K9-1
K9-2
K5-M
K9-3
K6
K5-1
VARIOLITE
LIQUIDS
2
VARIOLES
K9-F
K5-F

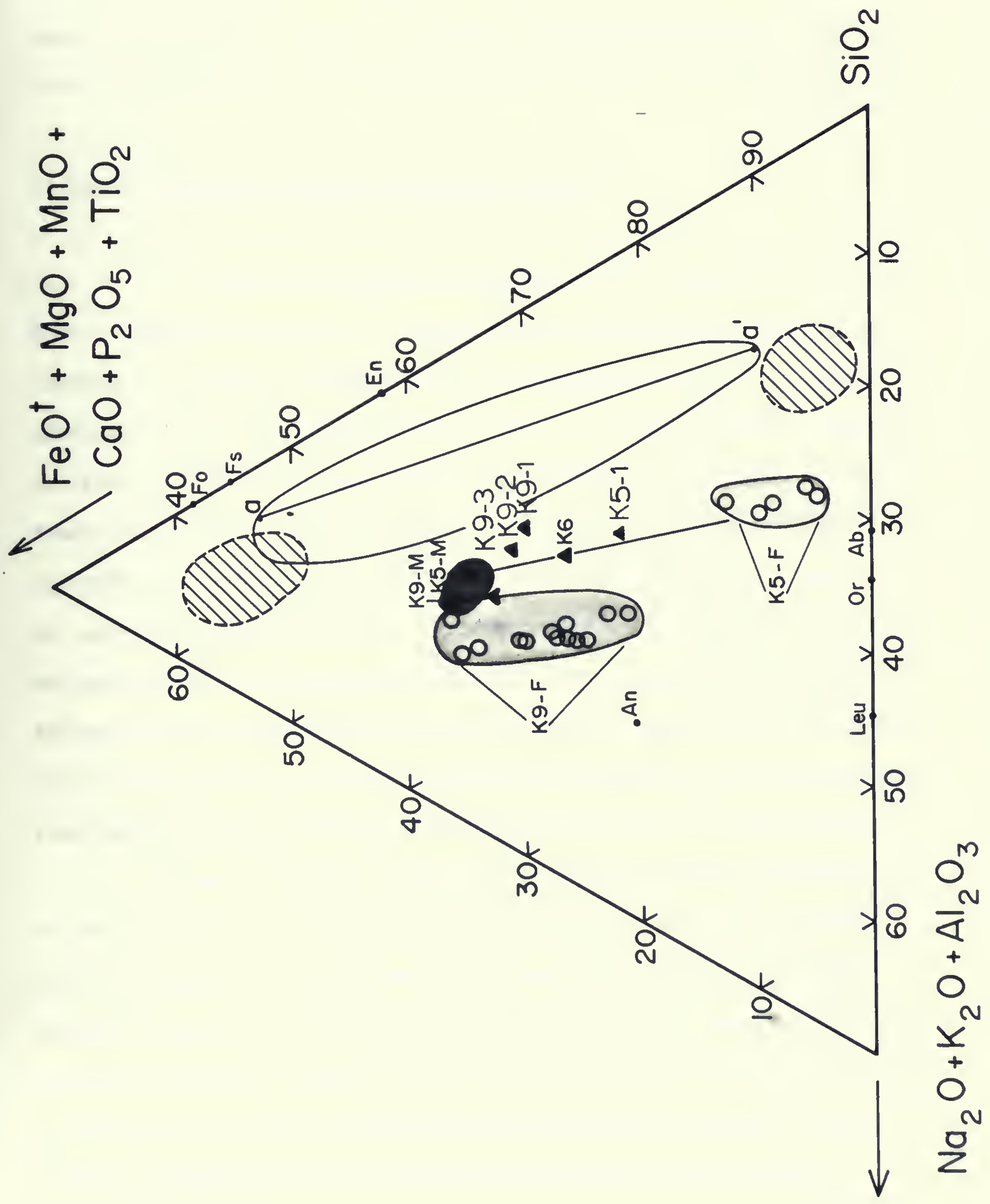
Fig. VIII-18 . Ternary diagram after Greig (1927) in terms of weight % SiO_2 - Na_2O + K_2O + Al_2O_3 - FeO + Fe_2O_3 + MgO + MnO + TiO_2 + CaO + P_2O_5.

(●) Intervariole mafic matrix; samples K5-M and K9-M (analyses by XRFS).

(o) Variole material ; sample K5-F (4 analyses on 2 varioles by EMP, 1 analysis by XRFS) ; sample K9-F (13 analyses on 5 varioles by EMP).

(▲) Whole variolite ; sample K6 (analysis by XRFS).

Stippled fields are from mafic and felsic immiscible glass compositions of terrestrial tholeiites (Philpotts, 1982). Immiscible globules from lunar basalts (Roedder and Weiblen, 1970) plot in similar positions. The low temperature immiscibility field and one 2-liquid tie line (a-a') is shown for the system fayalite-leucite-silica at 1140°C. (Roedder, 1951).



FeO^t + MgO + MnO +
CaO + P2O5 + TiO2
SiO2
Na2O + K2O + Al2O3
10
20
30
40
50
60
70
80
90
Fo
Fs
En
An
Leu
Or
Ab
a
a'
K9-1
K9-2
K9-3
K6
K5-1
K9-M
K5-M
K9-F
K5-F

variole-matrix pairs do not show a high enough chemical contrast to support liquid immiscibility. It now seems highly probable that variolites within the map area have not been formed by liquid immiscibility.

v) The effects of alteration on rock chemistry

It is unlikely that the original chemical compositions have been retained in rocks since Archean times. However, the question concerning the amount of change is worthy of consideration. Evaluating chemical changes on a quantitative basis is a difficult task, although the problem has been investigated (Beswick and Soucie, 1978). For this study the concern is to know whether or not elements have been added or removed in significant amounts. A number of elements have been used in variation diagrams and the trends obtained are largely due to igneous processes rather than redistribution because alteration effects result in scattering of data points. It is then safe to assume that the degree of scattering along a trend is a function of mobility of an element during metamorphism, assuming that analytical errors are insignificant.

Because diffusion processes in rocks are greatly accelerated in the presence of a fluid phase (Krauskopf, 1967 ; Winkler, 1979), it would be expected that intrusive rocks and massive flows are better preserved chemically than more porous and permeable lithologies such as tuffs, breccias, vesicular rocks and pillow basalts. Similarly, unstrained rocks are more impermeable than foliated and sheared types. All these criteria have been taken into account during sampling.

The various metamorphic episodes may have had different

impacts on the chemistry of the rocks : for example, hydrothermal processes that altered most rocks in the northwest part of the map area have likely had a different effect than, say, the thermal effects imposed on rocks near the Revell Batholith, which underwent dehydration.

It is virtually impossible to evaluate the effects of a certain type of metamorphism on rock chemistry when two or more events have been superimposed. The gain or loss of an element will affect the concentration of all other species by dilution or concentration. In the instance of secondary introduction of volatiles, the problem is easily solved by recalculating the percentage of each element on a volatile-free basis. However, changes involving other substances may not be easily noticed and decisions as to accept the validity of the data has to be dealt with on an arbitrary basis.

A number of studies (Vallance, 1965 ; Smith, 1968 ; Jolly and Smith, 1972 ; Wood et al., 1976 ; Condie et al., 1977 ; Humphris and Thompson, 1978) have evaluated the effects of low grade metamorphism on basaltic rocks. Many of them (Vallance, 1965, 1974 ; Hart et al., 1974 ; Humphris and Thompson, 1978) are related to sea-floor alteration effects on pillow basalts. Because of the large surface area to volume ratio of pillow lavas one could expect ion exchange between sea-water and the rocks. Because of subsequent overprinting by regional metamorphism (burial, dynamothermal), it is difficult to evaluate the effects of sea-floor alteration.

It has been demonstrated that the initial stages of alteration produce marked heterogeneity within rocks (Hart et al., 1974 ; Vallance, 1974 ; Condie et al., 1977). Smith (1968) and Jolly and Smith (1972)

	W10			W20			
	Selvage	Rim	Core	Selvage	Rim	Core	
SiO_2	36.63	57.50	51.31	38.13	56.60	51.33	wt%
Al_2O_3	18.89	14.43	14.90	18.03	14.16	14.60	
Fe_2O_3	25.16	9.44	14.03	22.19	11.33	13.66	
MgO	12.75	4.23	5.91	7.90	4.63	5.42	
CaO	4.52	10.66	11.81	10.47	7.10	10.05	
Na_2O	0.43	2.59	0.92	0.64	4.46	3.18	
K_2O	0.02	0.06	0.05	0.02	0.06	0.05	
TiO_2	1.14	0.84	0.84	2.20	1.34	1.36	
MnO	0.32	0.13	0.18	0.30	0.15	0.18	
P_2O_5	0.12	0.07	0.05	0.13	0.16	0.15	
Ba	0	25	25	22	22	23	ppm
Sr	688	100	367	141	48	276	
Rb	7	8	7	6.2	9.0	8.0	
Zn	205	69	86	184	90	99	
Cu	90	204	153	23	54	41	
Ni	146	93	99	121	80	84	
Cr	369	220	232	310	220	216	
V	225	158	158	295	234	226	
La	-	2.4	2.3	-	-	-	
Sm	-	8.3	8.2	-	-	-	
Yb	-	2.0	2.2	-	-	-	
Y	-	14	13	-	-	-	
Zr	49	65	57	83	85	78	

Table VII-4 : Major and trace element abundances within selvage, rim (8 cm away from pillow margin) and core zones of two basaltic pillows.

have described patchy patterns cross-cutting primary structures in mafic rocks which underwent very low grade metamorphism. These differences in color shades are due to the migration of Ca, Na, K, Mg, Fe and changes in the oxidation state of Fe to form epidote, pumpellyite, chlorite, albite (spilitic)-rich monomineralic domains. Smith (1968) has shown that the composition of the domains are complementary and a bulk composition encompassing several domains approaches the original composition. In the present study area, no mineralic metadomains have been observed except localized epidote rock along veins; this does not mean that they never have developed before rocks became subjected to higher rank greenschist facies metamorphism. Jolly (1974) and Hart et al. (1974) pointed out that at higher metamorphic grades or increased alteration, rocks acquire a homogeneous state.

Because much of the basalts in the map area occur as pillows, it is important to evaluate the chemical changes that occurred within pillows. Analysis of selvage, inner rim and core zones have been carried out for two pillows (samples W10 and W20) within Subgroup I of the Wapageisi Lake Group. The results are displayed in Table VIII-4. In the field, pillows have normally a dark green chloritic selvage 1 to 3 cm thick, a pale green marginal zone, 3 to 5 cm thick, and a dark green core zone (Fig. VIII-19). The mineralogical changes across pillows are reflected by strong contrasts in chemical composition. The two pillows sampled reveal trends of striking similarity, suggesting that alteration of pillow lavas within the map area followed a constant pattern : depletion in Si, Na, K, Cu and Rb, and enrichment in Al, Mg, Fe, Ti, Mn, P, Ni Cr in the selvage ; depletion of Al, Fe, Mg, Mn and enrich-

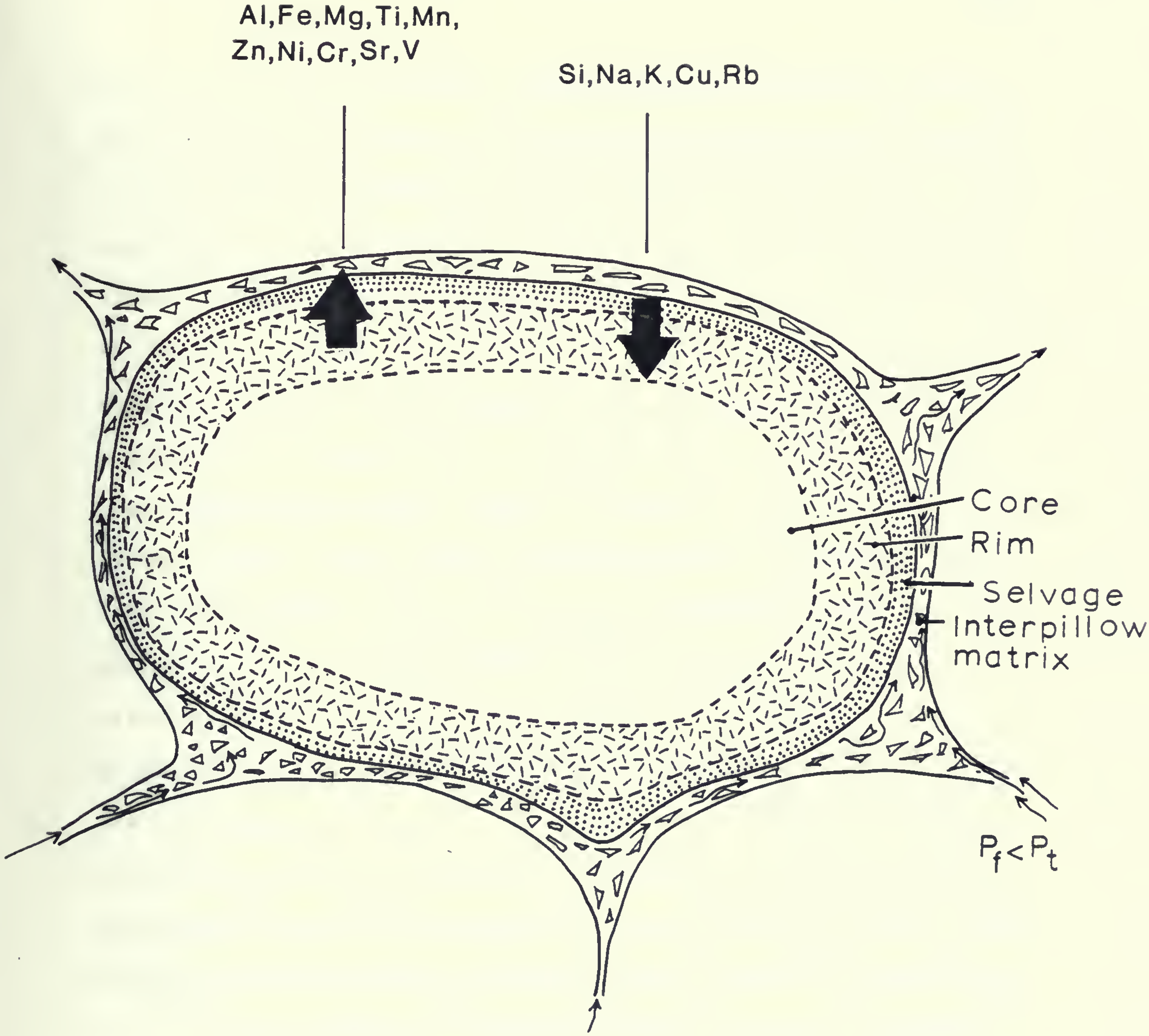


Fig. VIII-19 : Cross-section of a typical pillow. Large arrows indicate direction of migration of elements shown during metamorphism.

ment in Si, Na, K in the light colored rim zone. The behaviour of Ca and Sr appears to be erratic. The so-called immobile elements including Al, Ti, P, show no differences outside analytical error between the rim zone and the core zone and thus, probably, reflect the pristine composition in these elements ; however, the elements Si, Ca, Mg, Na, K, Fe, Rb, Sr, Ba, which have been demonstrated by many to be very mobile, show significant differences. Because the core lies somewhere between the selvage and rim compositions, it is assumed that selvage and rim have complementary compositions, and on that basis it is assumed that most of the chemical changes have occurred between the rim zone and the selvage. These changes have likely taken place because of adjacent inter-pillow channel ways : hyaloclastite tuffs, produced by quenching of pillow margins, are highly permeable compared to the holocrystalline pillow interiors. Hence, if a fluid pressure gradient developed through the stratigraphic pile ($P_f < P_t$), similarly to the Keweenawan basalts (Jolly and Smith, 1972), hydrous fluids must have circulated through the pillowed sequence and exchanged various ions with the pillow border zones. Fluids were probably produced in deeper parts of the stratigraphic pile which underwent dehydration under higher rank metamorphism. In higher parts of the stratigraphy, water was then consumed in the production of hydrous minerals such as chlorite and micas.

Vallance (1965), who undertook a study on chemical variation across spilitic pillows in metamorphosed sequences of the British Isles, showed considerable variety in the distribution of components. He obtained similar trends to those observed in the present study area, except that Na is strongly enriched within the pillow cores studied by Vallance;

	B41A	B41B	B41C	
SiO_2	45.60	46.50	58.30	wt%
Al_2O_3	15.80	16.60	16.00	
Fe_2O_3	14.10	13.90	7.91	
MgO	6.78	3.47	1.38	
CaO	5.40	5.41	4.33	
Na_2O	2.45	1.10	1.87	
K_2O	0.02	0.91	0.85	
TiO_2	1.23	1.36	0.69	
MnO	0.17	0.14	0.09	
P_2O_5	0.05	0.06	0.08	
CO_2	4.08	6.83	4.68	
S	0.01	0.00	0.00	
Ba	40	230	170	ppm
Co	48	52	35	
Cr	298	201	93	
Cu	95	6	140	
Li	34	18	11	
Ni	84	112	107	
Rb	5	5	5	
Zn	117	66	46	
LOI	8.40	10.70	7.80	wt%

Table VIII- 5 : Major and trace element abundances across a carbonatized zone in a gabbroic body. B41A : least altered, B41C: most altered. (Analyses by the Geoscience Laboratories, Ontario Geological Survey).

Ca and Sr were erratic. For petrogenetic purposes, the composition of pillow cores is more reliable for sampling, and altered glasses should be avoided because elemental mobility during recrystallization in the presence of H_2O is very high, particularly for Si, Na, Ca and Mg (Vallance, 1965 ; Noble, 1967).

Effects of hydrothermal alteration and CO_2 metasomatism

A wide zone in the northwest part of the map area has undergone extensive hydrothermal alteration, and the rocks show extensive carbonatization. A zone several metres in width across a gabbro body showing progressive alteration has been sampled (B41A, B41B, B41C). Sample B41A is from least altered part of the gabbro, sample B41B is moderately altered and B41C is from the most altered part where the rock is yellow and has a rusty weathering crust. Table VIII-5 lists the composition of the three types. Assuming that all rock samples had a similar composition before carbonatization, the following elemental changes from leat to most altered rocks are : progressive increase in Si (silicification), K, P, CO_2, Ba, accompanied by a progressive decrease in total Fe, Mg, Mn, Ca, Ti, Cu, Li and Zn.

It appears from these changes that there is an antipathetic relation between silica and the alkalies, and the ferro-magnesian elements. Al appears to have been stable except for dilution and the trends followed by Ca and Na are not clear. Surprisingly, Ca has not been significantly mobilized as the solubility of Ca is considerably increased in the presence of CO_2. The results however may not be conclusive due to limited sampling.

CHAPTER IX - DISCUSSION

i) Introduction

The descriptive aspects of the Stormy Lake - Kawashegamuk Lake area have been presented in Chapters II to VIII. The chemical investigation proved to be of much use in distinguishing among the various volcanic units. However, in studying the evolution of complex and highly deformed terranes, such as Archean provinces, only multi-disciplinary studies can effectively clarify the problem. In recent years, a reliable method of dating rocks using U and Pb isotopes on zircons has put time constraints on the evolution of greenstone belts. Unfortunately, Archean tectonism is still a matter of much controversy, and it would be premature to explain processes and construct models based on modern plate tectonics as Archean greenstone belts have no present day analogs (Anhaeusser et al., 1969 ; Pankhurst and O'Nions, 1978 ; Sun and Nesbitt, 1978 ; Platt, 1980) despite some similarities in lithologic successions.

ii) Igneous processes in the Archean

The nature of the volcanics is not significantly different from phanerozoic volcanics. As in many other Archean greenstone belts, the volume of mafic volcanics exceeds felsic rocks. Basaltic rocks occur mostly as flows which were probably extruded from extensive rift

zones and dike swarms covering large areas. The widespread occurrence of close packed pillows indicate that volcanism was probably entirely confined to a submarine environment. The onset of calc-alkalic volcanism, generating a range of compositions from basaltic andesite to rhyolite, has taken place from central edifices which where built on a basaltic platform near the end of dominantly tholeiitic volcanism. Eventually, mafic volcanism resumed to begin another tholeiitic - calc-alkalic cycle. The cyclical character of the volcanism is comparable with other Archean provinces (Anhaeusser, 1971 ; Condie and Baragar, 1974 ; Hubregtse, 1976 ; Thurston and Fryer, 1983).

Genesis of the volcanic rocks

A number of mechanisms have been proposed for the generation of highly diversified Archean magma types. Among the more common are :

1) partial melting of mantle or crustal material ;
2) fractional crystallization ;
3) Magma mixing (hybridization) ;
4) assimilation (crustal contamination) ;
5) liquid immiscibility.

The intent is here to outline the principal petrogenetic processes which gave rise to the observed compositions. Two principal rock suites have been described within the map area : 1) a tholeiitic suite and 2) a calc-alkalic suite. A third suite of alkalic rocks is only scarcely represented by narrow dikes.

a) <u>The tholeiitic suite</u>

It is represented by mafic flows making up the Wapageisi Lake, Boyer Lake and part of the Kawashegamuk Lake Groups. Despite some iron enrichment, they are highly homogeneous and show no variation in REE abundances (Figs. VIII-15a, b, c). According to most models, tholeiitic basalts have been produced by partial melting of peridotitic mantle source. This process would produce flat REE trends parallel to chondritic abundances, as all the incompatible elements have high liquid/crystal partition coefficients, and enter predominantly the melt fraction, even at low percentage of fusion in the source. If garnet was a residual mineral during partial melting then the REE pattern would be considerably depleted with respect to HREE. One could argue for an upper mantle strongly depleted in the LREE. However, the trends are similar to many tholeiites from other Archean provinces (Arth and Hanson, 1975 ; Condie, 1976a ; Sun and Nesbitt, 1978) and modern abyssal and arc tholeiites (Gast, 1968 ; Jakeš and Gill, 1970 ; Frey, 1974 ; Kay and Hubbard, 1978). Furthermore, the constancy of Sm_N/Yb_N ratio near 1 does not favour the presence of garnet in the residuum.

Partial melting models of upper mantle (Arth and Hanson, 1975), predicted by the equations for partial melting of Shaw (1970), suggest 25% melting of a peridotite source to yield REE abundances of 10-12 times chondrite.

b) The calc-alkalic suite

Most of the volcanics which range from basaltic andesite to rhyolite in composition have a calc-alkalic affinity and are characterized by a fractionated REE pattern (Figs. VIII-15c, d). Several mechanisms for producing rocks ranging in composition from basaltic andesite to rhyolite may be envisaged :

1) partial melting of peridotite at various P-T conditions ;
2) differentiation of a mantle derived melt ;
3) partial melting of mafic crust at various P_{H_2O}-T conditions followed by fractionation to yield dacitic to rhyolitic compositions ;
4) magma mixing (hybridization) ;
5) liquid immiscibility ;
6) assimilation of sialic crust ;
7) anatexis of deeply buried sediments.

A discussion of each genetic model is given :

1) Direct partial melting of peridotite would likely produce flat to slightly fractionated REE trends. Moreover, it is highly unlikely that low degrees of partial melting of peridotitic material would produce Si-enriched liquids but rather silica undersaturated derivatives (Yoder and Tilley, 1962 ; Arth and Hanson, 1975 ; Carmichael et al., 1974 ; Frey et al., 1978).

2) Crystal fractionation of a mantle derived liquid under relatively high P_{H_2O} normally results in the production of tholeiitic magmas

(Ringwood, 1974). In order to produce calc-alkalic liquids, iron oxide phases and aluminous amphiboles or subsilicic pyroxene would have to be fractionated together with olivine : an unlikely process from petrologic experiments (Yoder and Tilley, 1962).

3) Partial melting of basaltic material at great depth is considered by many to be the most likely mechanism to produce rocks of intermediate and felsic compositions in island arcs and active continental margins. Green and Ringwood (1968) have experimentally produced compositions ranging from basalt to rhyodacite by fractional crystallization of a mafic melt at P_{load} in the range of 10-20 kb and near 35 kb, and Yoder and Tilley (1962) have produced a granitic liquid by partial melting amphibolite at 10 kb ; at higher degrees of partial melting, liquids of more mafic compositions would be generated. Therefore, experimental considerations have shown it is possible to derive intermediate to felsic rocks by direct partial melting of amphibolite or eclogite (single stage process), or by fractional crystallization of a mafic liquid previously derived by melting large fractions of amphibolite (multi-stage process). Green and Ringwood (1968) in their experiments found that silica enrichment of the liquid was produced by the extraction of aluminous amphibole (40% SiO_2) and subsilicic pyroxenes from the melt. Another means of increasing the silica content of a melt is by crystallizing iron oxides under increasing oxygen pressure (Osborn, 1959). This mechanism has probably been effective because layers containing up to 15% Fe-Ti oxides have been observed in gabbro sills within the map area ; however, it is likely that formation of oxide phases was late and occurred mostly at shallow depths.

4) Mixing of magmas

After Wager and Deer (1939) completed their study on the Skaergaard intrusion, they postulated that any basaltic magma would differentiate along a liquid line of descent that characterize the various compositions of the layered intrusive and that andesites from orogenic areas are the product of mixing. While some intermediate rocks may have formed by mixing (e.g. Eichelberger, 1975), it is difficult to conceive that most calc-alkalic rocks have formed that way : direct evidence for mixing would be observed through inhomogenized eruption products instead of uniform compositions such as the numerous inclusion trails, bands,clots and swirls observed in dacites by Eichelberger (ibid.) at Glass Mountain and Lassen Peak, California ; furthermore, it is difficult to explain the high Al content of basaltic andesites and andesites by hybridization.

5) Liquid immiscibility is a viable mechanism for producing two liquids of highly contrasting compositions. While it has been observed on a small scale in natural glasses (Roedder and Weiblen, 1970, 1971 ; Philpotts, 1982), immiscibility on a large scale has not provided any supporting evidence. The presence of variolites in volcanic sequences has led some to believe that they have formed by splitting of a magma. However, evidence presented in chapters VII and VIII suggest that felsic varioles are the product of a crystallization phenomena related to cooling. Thus, it is concluded here that liquid immiscibility has not been a significant factor in generating felsic rocks.

6) Assimilation is a normal process taking place during intrusion of a magma. For example, it is common to see digested xenoliths and xenocrysts of the invaded country rock in a plutonic mass. It is highly likely that the invading magma became somewhat contaminated with country rock minerals by either fusion or ionic exchange. Total assimilation requires the melting of the country rock at or above liquidus temperatures, a process which is unlikely to generate large volumes of magma.

7) Anatexis of deeply buried sediemnts (graywacke) probably is responsible for the emplacement of some granitic plutons in high grade terranes (e.g. Arth and Hanson, 1975) but it is most unlikely that anatectic melts are involved in volcanism.

Andesite rocks occurring as homogeneous lavas are abundant in the Kawashegamuk Lake Group. The variation diagrams against MgO (Figs VIII-10, 11), the Ti-Zr plot (Fig. VIII-13) and the REE profiles (Figs. VIII-15c, d) strongly support an origin consistant with partial melting of a basaltic source to produce rocks of intermediate compositions. Felsic rocks on the other hand are produced by a multi-stage process involving differentiation. Figure IX-1 shows the evolution of REE profiles for the tholeiitic basalt - rhyolite range of compositions within the study area from patterns shown in Figures VIII-15a-d. High degrees of partial melting of a basaltic source having a flat REE trend (Profile 1 on Figure IX-1) would give slightly fractionated REE trends (Profiles 2 and 3). Lower degrees of melting would produce trends with even higher Ce/Yb ratios (Profile 4). Differentiation of a basalt derived melt would continue to increase the Ce/Yb ratio by enriching the

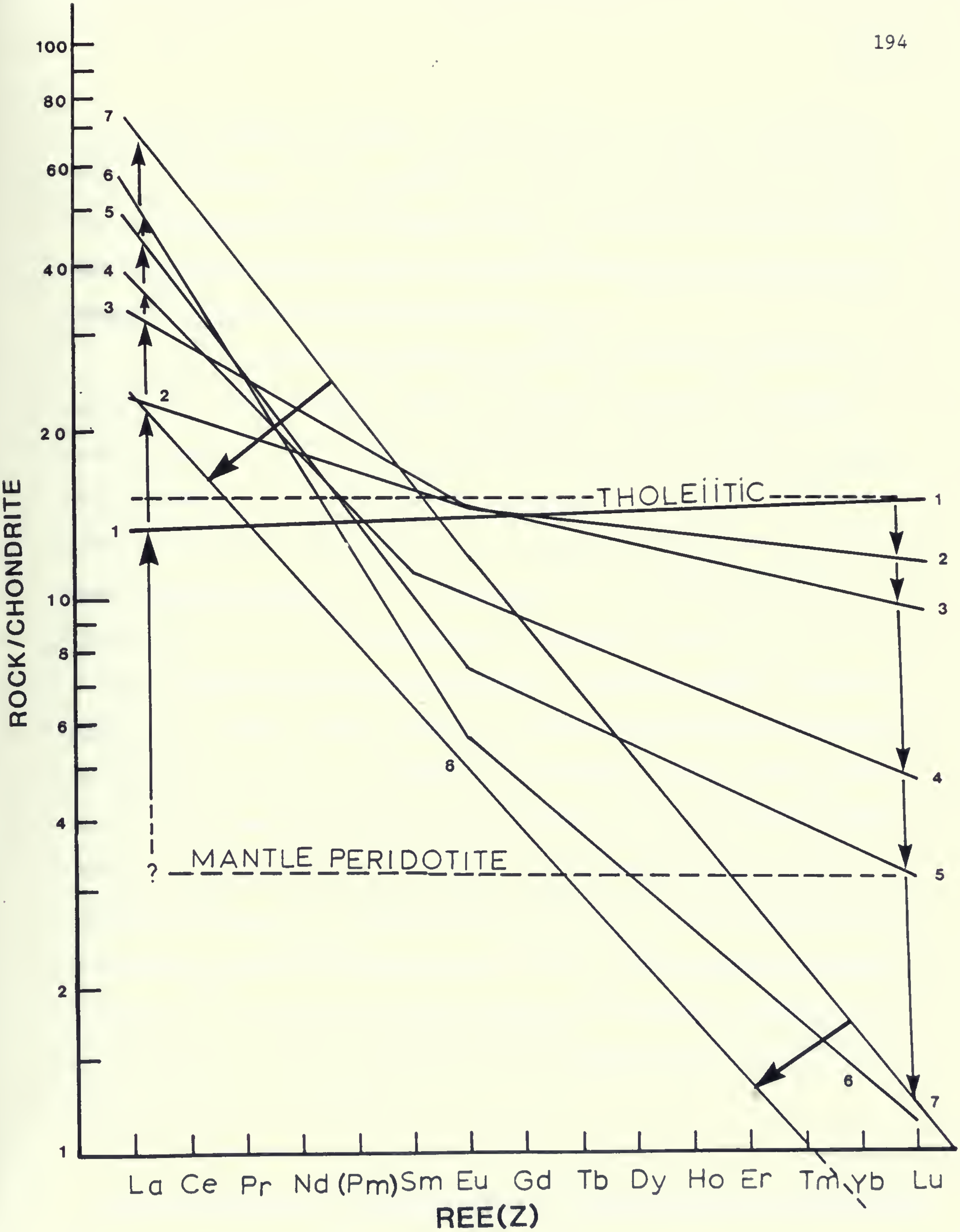


Fig. IX-1 : Evolution of rare-earth element patterns from least evolved rocks (profile 1) to most evolved types (profile 8) for volcanic rocks occurring within the Stormy Lake - Kawashegamuk Lake area.

the liquid in LREE (Profile 5). Dacitic rocks have the strongest fractionated patterns with high LREE (La $\approx$ 80 times chondrite) and chondritic values for Yb and Lu (Profiles 6 and 7). Rhyolites have lower total REE contents, probably because of advanced fractionation involving the removal of apatite and zircon (Profile 8).

The narrow compositional gaps between 58% and 60% SiO_2 is somewhat puzzling. Studies in some greenstone terranes have pointed out the lack of a wider range of compositions commonly from 55 to 65% SiO_2 (Hallberg, 1972 ; Barker and Peterman, 1974 ; Thurston and Fryer, 1983). On the other hand, calc-alkalic sequences with abundant andesites have been described in the Marda Complex of southwest Australia (Hallberg et al., 1976), the Abitibi Belt (Goodwin and Baragar, 1969 ; Jolly, 1975) and in southwestern Manitoba (Hubregtse, 1976). Thus it appears, as Condie (1976b, 1982) noted, that there are two basic types of Archean greenstone successions : 1) greenstone terranes where volcanics of intermediate composition are abundant ; 2) belts having essentially a bimodal character with felsic types overlying an ultramafic - mafic assemblage. Condie (1982) also pointed out that bimodal greenstone belts yield older radiometric ages of 2.8-2.7 Ga than belts with calc-alkalic suites (2.7-2.6 Ga). Unfortunately, at the time of writing, no U-Pb (zircons) ages are available for the Kawashegamuk Lake Group to further test this hypothesis.

iii) The relationship between volcanism and plutonism in the Kawashegamuk-Stormy Lakes area

a) Mafic and ultramafic rocks

Field relationships indicate that the numerous gabbroic sills are in general synvolcanic, as they have been found to truncate neither younger felsic dikes nor post-tectonic intrusions. The compositional similarity between them and the tholeiitic lavas strongly suggests that these sills contributed directly to tholeiitic volcanism. The scarce ultramafic and lamprophyric dikes may not have contributed to volcanism as no volcanic equivalents have been found.

b) Intermediate rocks

Andesitic rocks are the common volcanics within the Kawashegamuk Lake Group. Pretectonic intrusives of equivalent composition have been found only near the southeastern shoreline of Kawashegamuk Lake where two oval shaped bodies of foliated tonalite are exposed. On variation diagrams, their composition cannot be distinguished from andesites or siliceous andesites and their REE pattern is strongly fractionated. It is therefore likely that these intrusives are linked with calc-alkalic volcanism. Another small tonalite intrusion is situated between Kawashegamuk Lake and Stormy Lake. It is a syn-to post-tectonic body and there is nothing to link it with the exposed supracrustals.

c) Felsic rocks

No pretectonic felsic plutonic rocks are exposed within the confines of the map area. Only abundant dacite and rhyolite porphyry

and felsite dikes,and a few stocks transecting the stratigraphy particularly in the Wapageisi Lake and Kawashegamuk Lake Groups are exposed. A close relationship between the Thundercloud Stock and the Meggisi Pluton, which intrudes the base of the Wapageisi Lake Group (see Map 3), is plausible. Sabag (1979) did an extensive study on the Meggisi Pluton and carried out numerous chemical analyses, including REE determinations. McMaster (1978) undertook a geochemical study of the Thundercloud Lake area ; D.W. Davis (1982) obtained a U-Pb (zircon) age for the Thundercloud porphyry and very recently an age for the Meggisi Pluton has been made available. For this study, additional chemical data has been obtained for the Thundercloud Lake Porphyry (TLP) including REE data. Sabag (1979) has recognized two major phases making up the Meggisi Pluton : 1) an early granodiorite phase ; 2) a later crescent shaped, seriate quartz-monzonite phase, intrusive between the granodiorite and the greenstones. In addition, Sabag pointed out the presence of melanocratic inclusions in the granodiorite and quartz porphyry dikes in the greenstones adjoining the seriate phase. The various phases can be distinguished on a Na_2O - K_2O - CaO ternary plot (Fig. VIII-7). It is clear that Sabag's porphyry dikes are well within the seriate phase envelope, and that the TLP, although it slightly overlaps with the Meggisi seriate phase, is more sodic. REE profiles for all rock types (Fig. IX-2) are steep and are parallel to each other. The mafic inclusions and the early granodiorite have high total REE abundances relatively to the other rock types. There is a complete overlap of Sabag's porphyry and the Meggisi late phase. However, the TLP cannot be distinshed from the Meggisi seriate and porphyritic phases. All phases of the

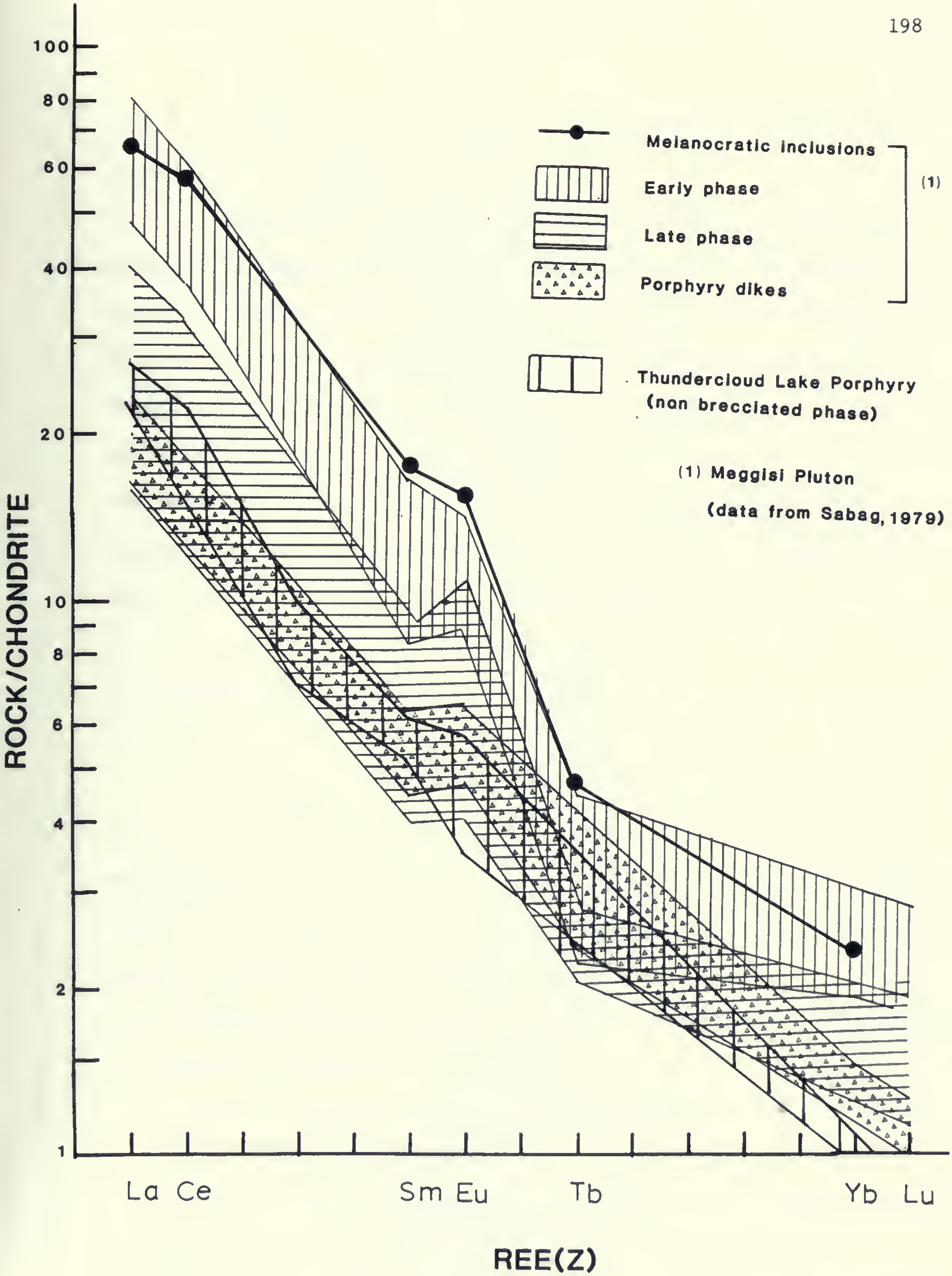


Fig. IX-2 : REE patterns for the Meggisi Pluton and the Thundercloud Lake Stock.

Meggisi Pluton are characterized by a slight but distinct positive Eu anomaly which is lacking in the TLP.

Conclusions from chemical and petrographic data alone are debatable ; however, geochronologic data clarifies any contention points : zircons from the TLP yield a U-Pb date of 2755 Ma (Davis et al., 1982), whereas an age of 2733 ± 2 Ma has been obtained from the Meggisi seriate phase (Davis, 1984, personal communication). An age difference of 33 Ma refutes the possibility that the TLP is linked to the Meggisi Pluton. Due to the chemical similarity between Sabag's porphyry and the seriate phase, it is inferred that the porphyry dikes are consanguineous with the late seriate phase.

iv) Geochronology

Regional geological and geochemical investigations of the Crow Lake - Savant Lake belt (Trowell et al., 1980) have been further supplemented by geochronological studies using U-Pb isotopes on zircons (Davis et al., 1982). Within the Manitou Lakes - Stormy Lake belt, four dates have been obtained so far (Fig. IX-3) :

1) The Thundercloud Lake Porphyry : 2755 Ma (minimum age) ; rock type : porphyritic dacite.
2) Top of the Boyer Lake Group : $2702.9^{+14.6}_{-4.5}$ Ma ; rock type : rhyolite tuff.
3) The Taylor Lake Stock : 2695 ± 3.6 Ma ; rock type : porphyritic quartz monzonite.
4) The Meggisi Pluton, late phase : 2722 ± 2.0 Ma ; rock type : seriate quartz monzonite. (D.W. Davis, 1984, personal communication)

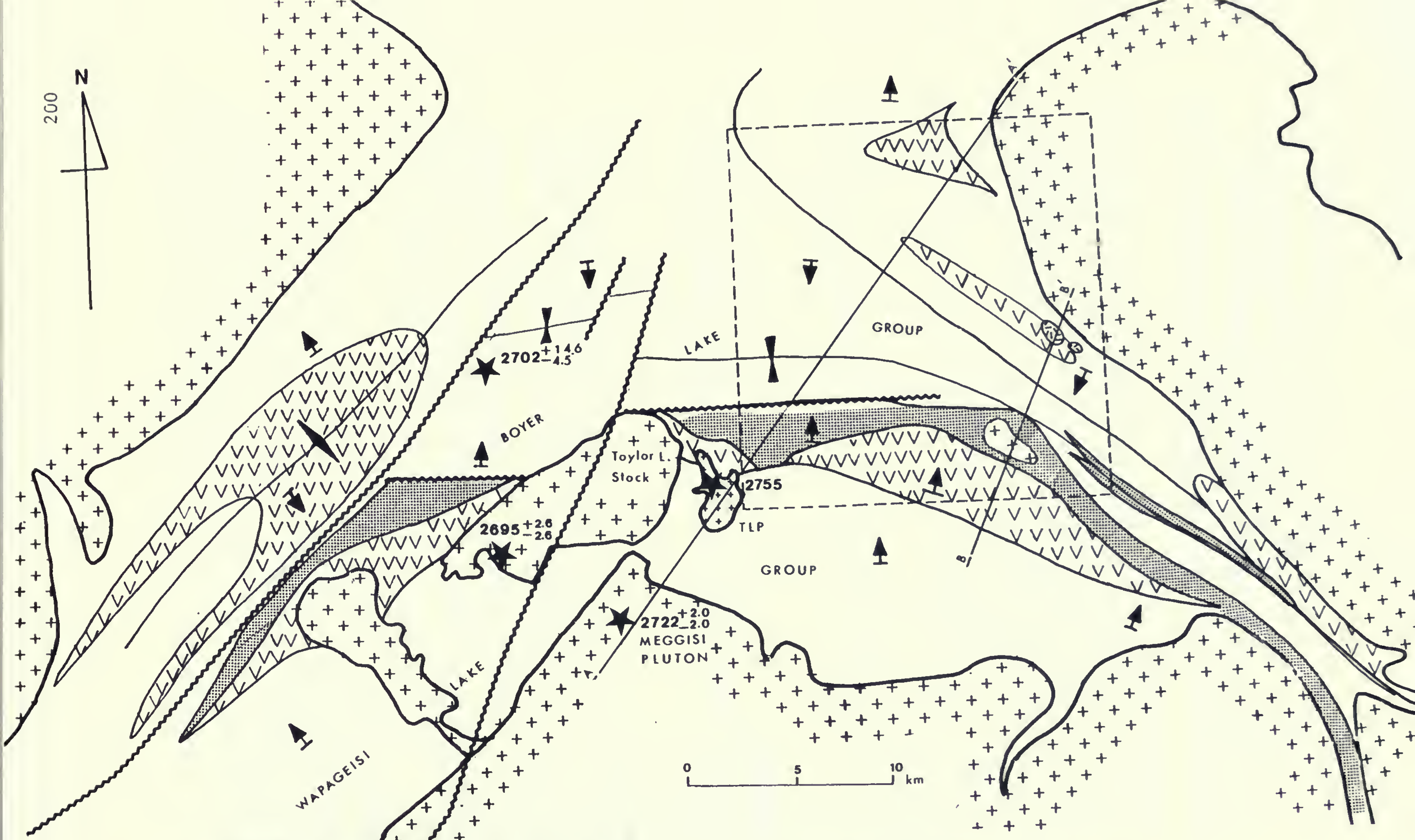


Fig. IX - 3 : Age relations within the Manitou Lakes - Stormy Lake belt. U-Pb (zircon) dates from Davis et al. (1982) and Davis (personal communication).

The Thundercloud Stock is, at the time of writing, the oldest date obtained from the Wabigoon subprovince. As the stock intrudes the top of the Wapageisi Lake basalts, the date gives a minimum age for the top of Subgroup I, implying that the base of the 8000m thick Wapageisi Lake Group is older than 2755 Ma.

The age of $2702.9^{+14.6}_{-4.5}$ Ma for the youngest exposed part of the Boyer Lake Group implies that volcanism evolved in an approximate time span of 50 Ma. Furthermore, the 2695 ± 2.6 Ma old post-tectonic Taylor Lake Stock suggests that the climax of the tectonic activity occurred not long after the final stages of volcanism, perhaps less than 10 Ma later.

v) Proposed model for the development of the Manitou Lakes - Stormy Lake belt

To date three main models have been proposed for the development of greenstone belts :

1) A model invoking tectonic processes inherent to the Archean, which includes the classical or "fixist" theories.
2) The plate tectonic or "mobilistic" model, foundations of which are based on modern day processes, such as large scale rifting and island-arc formation (e.g. Goodwin and Ridler, 1970 ; Talbot, 1973 ; Langford and Morin, 1976).
3) The extra-terrestrial model, proposed by D.H. Green (1972) is based on the theory that magmatism followed major meteoritic impacts.

Despite a great deal of uniformity among greenstone belts in general, it is highly speculative to conclude that processes were iden-

tical from one belt to the other. Thus it is premature and simplistic to equate every greenstone belt with, for instance, the Barberton belt of South Africa, which for many years has been regarded as the model for all greenstone belts (Windley, 1979).

Low grade volcanic-metasedimentary assemblages have evolved from 3300 Ma to 2500 Ma ago and evidence from high grade terrains such as supracrustal remnants in gneisses of west Greenland and Labrador (Pankhurst and O'Nions, 1978) suggest that greenstone belts may be as old as 3800 Ma or perhaps more.

One of the main stumbling blocks for Archean geology is the question of the nature of the basement upon which greenstone belts were deposited. Despite some rare situations where migmatites and gneisses or granitic rocks directly underlie the greenstones and have been claimed to constitute basement, e.g. Stowe (1971), and McGlynn and Henderson (1970), most contacts with greenstone belts are intrusive. This is the case for the Manitou Lakes - Stormy Lake belt being surrounded by younger granitic rocks which impart higher metamorphic grades on the belt margins.

It is relatively certain that at the initial stage of development of the belt studied here, the Earth surface nearby was already undergoing dynamic processes involving volcanism, sedimentation, plutonism as well as tectonism. Stabilized cratonic masses may also have been present nearby. This is supported by the following facts :

1) Early volcanics in the North Spirit Lake area of the Gods Lake Subprovince have yielded a U-Pb (zircon) age of 3013 Ma (Nunes and Wood,

1980), the oldest age so far obtained from the Superior Province.

2) Further south, in the Uchi Subprovince, a tuff from a thick cyclical assemblage represented by ultramafic to felsic volcanics (Thurston and Fryer, 1983) has given a U-Pb (zircon) age of 2959 ±2 Ma (Nunes and Thurston, 1980).

3) A minimum age of 3008 Ma has been obtained from a tonalite gneiss in the Lac Seul area of the English River Subprovince (Krogh et al., 1976).

4) A Rb-Sr isochron age of 2950 ±150 Ma has been obtained from an orthogneiss in the Lake of the Woods area (Clark et al., 1981).

5) Archean gneisses of northeastern Minnesota have yielded U-Pb (zircon) ages of 3550 Ma (Goldich et al., 1970).

6) The extreme compositional diversity of exotic clasts within the Stormy Lake Group suggests unroofing of granitic plutons and denudation of an emergent land mass to the south of the map area, possibly in the present position of the Irene - Eltrut Lakes granitic - gneiss complex.

The evolutionary history of the Archean crust in the Stormy Lake area has been diagramatically represented on Figures IX-4a through 4e (Figures IX-4d and 4e also provide cross-sections along lines a-a' and b-b' which are shown in Fig. IX-3 and the deep structure of the belt underneath the present erosion level).

It has developed in the following stages :

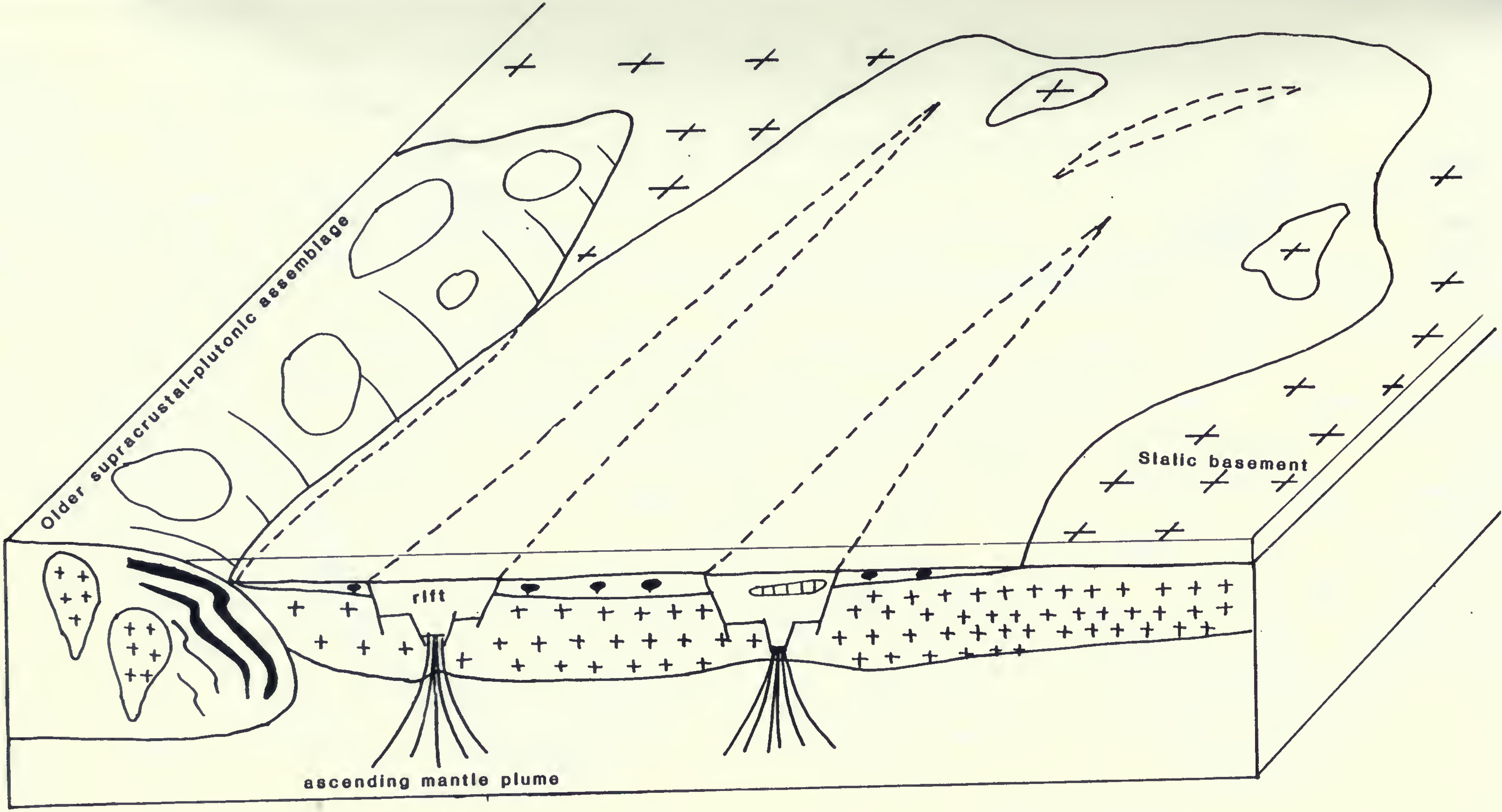
1) Large volumes of basalts have been issued from fractures which formed

in a relatively thin sialic crust of unknown character between older supracrustal plutonic terrains (Fig. IX-4a). These older land masses represented thicker crust and their position now occupies the cores of large granitic-gneiss complexes and high grade terrains.

2) A basin formed and the large volumes of mafic lavas progressively developed into a down-sagging assemblage (Subgroup I, Wapageisi Lake Group) substituting for the volume of material removed from below the crust (Fig. IX-4b). The entire assemblage became very unstable : partial melting at the bottom of the supracrustals began and felsic volcanism ensued (Subgroup II, Wapageisi Lake Group). It is also possible that subsequent melting of down-warped sialic material contributed to late felsic volcanism. Deep basin sedimentation occurred concurrently to felsic volcanism. Iron formations developed in distal parts of the basin, possibly as a result of higher heat flow in the Archean crust.

3) The margins of the unstable pile were then uplifted and felsic volcanism continued ; parts of the basin became subaerially exposed bringing about increased exposure of a neighbouring older supracrustal and granitic hinterland. Erosion of the land mass and of felsic volcanoes produced widespread alluvial fans (Facies II and III of the Stormy Lake Group), and submarine fans (Facies IV) formed in the submerged parts of the basin (Fig. IX-4c).

4) A rapid transgression and mafic volcanism followed with the resumption of extensive submarine flows, thereby forming the Boyer Lake Group (Figs. IX-4c, 5a).


Older supracrustal-plutonic assemblage
Sialic basement
rift
ascending mantle plume

a

Fig. IX-4

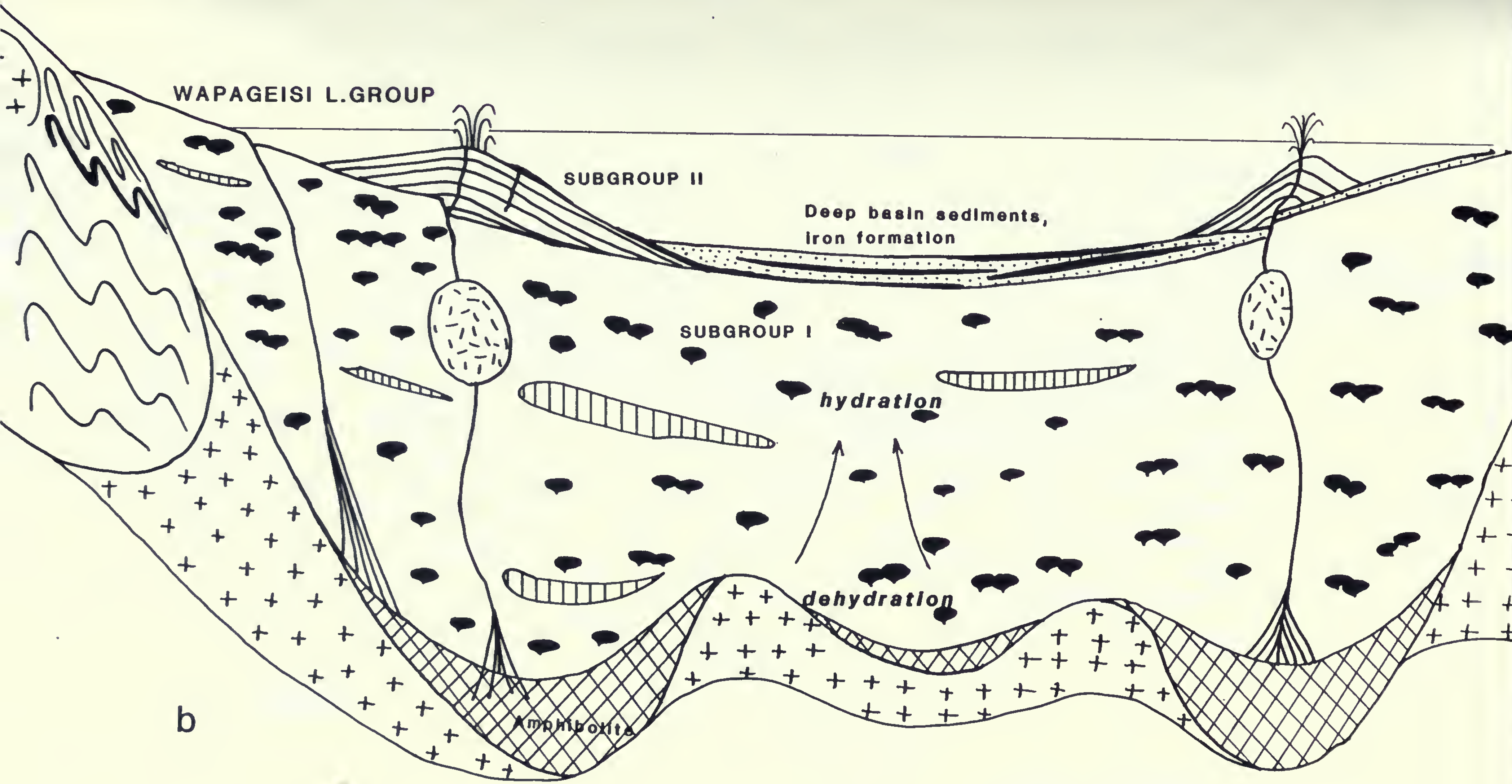

WAPAGEISI L.GROUP
SUBGROUP II
Deep basin sediments,
iron formation
SUBGROUP I
hydration
dehydration
Amphibolite
b

Fig. IX-4

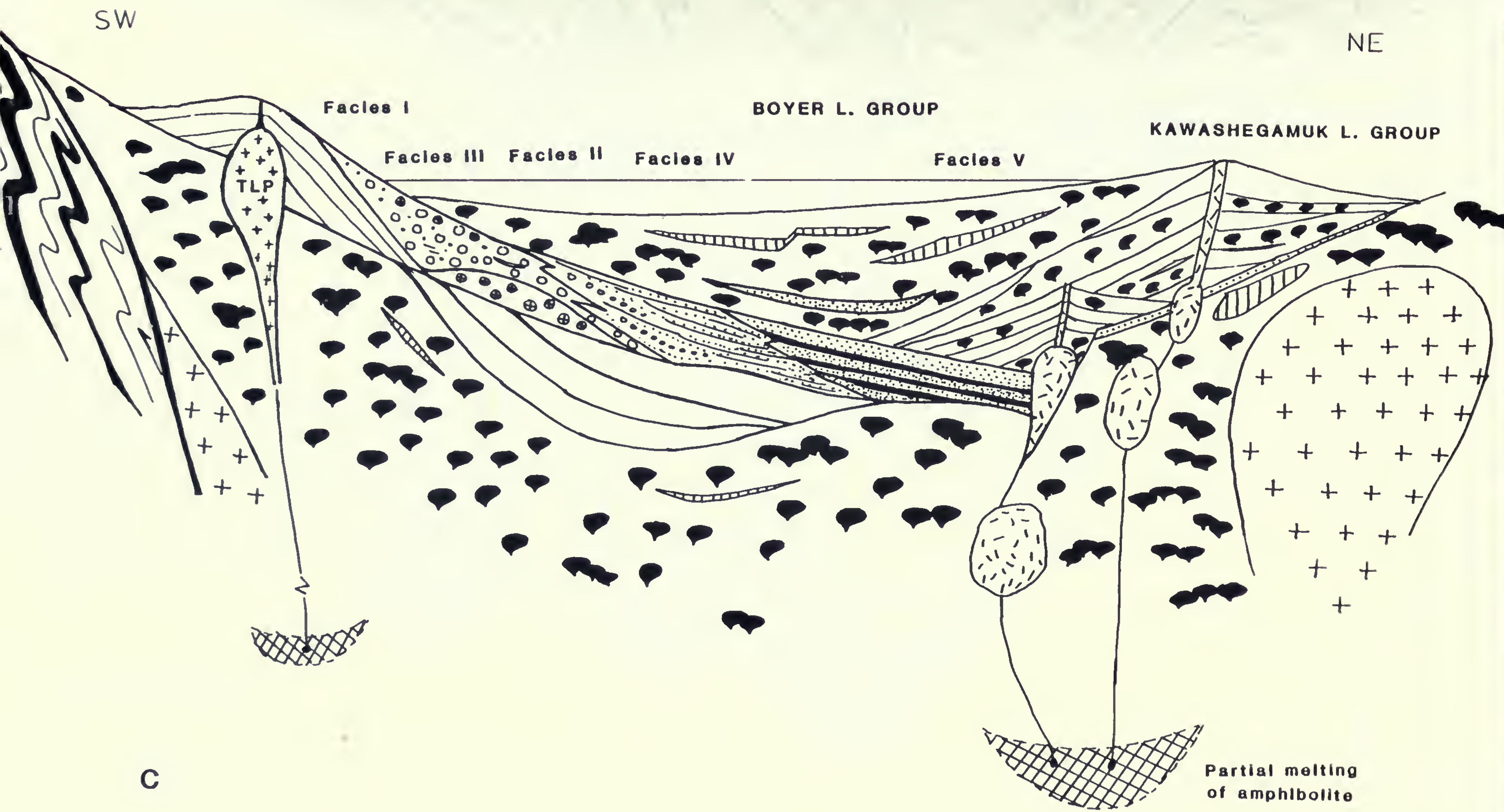

SW
NE
Facies I
BOYER L. GROUP
KAWASHEGAMUK L. GROUP
Facies III
Facies II
Facies IV
Facies V
TLP
C
Partial melting
of amphibolite

Fig. IX-4

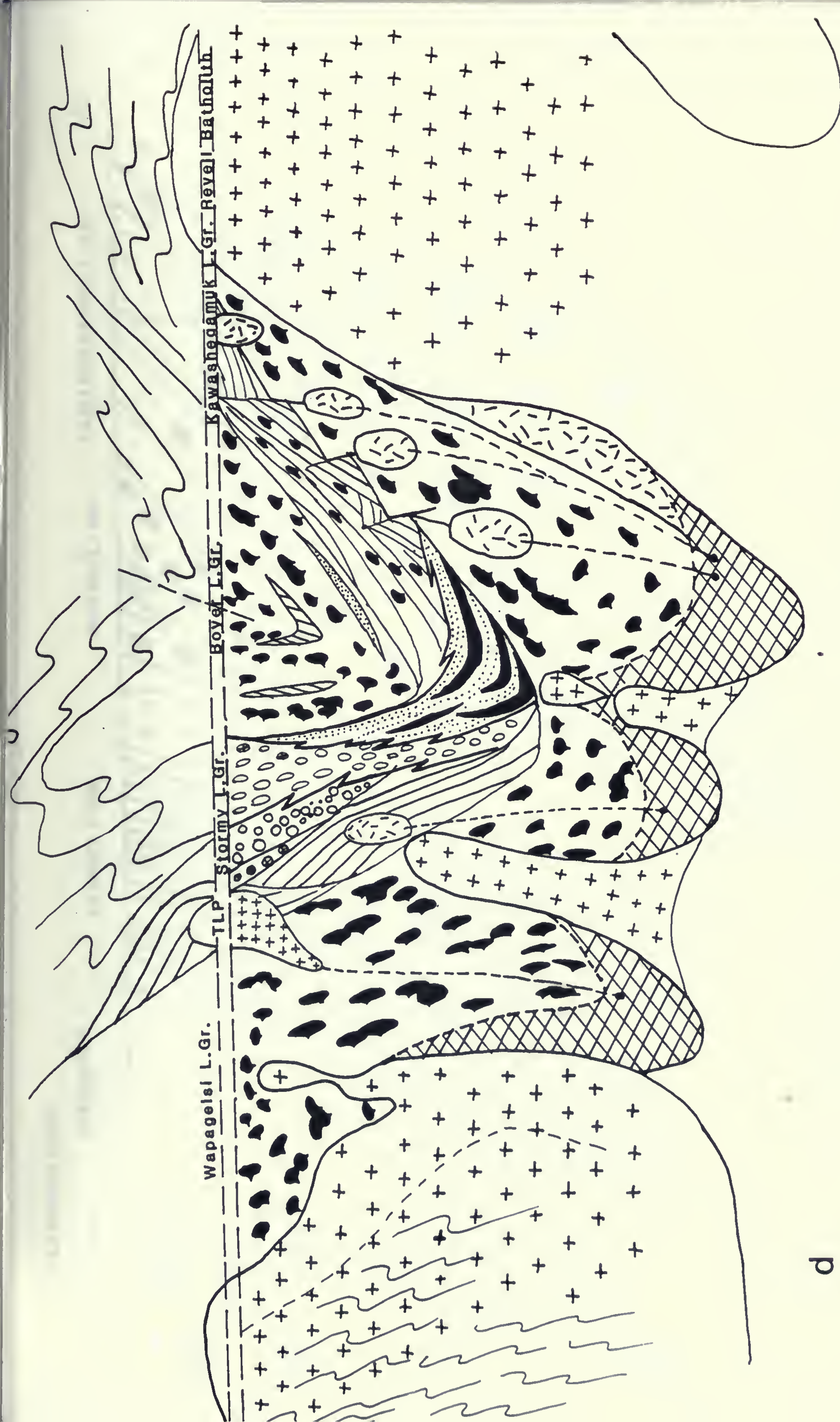

Wapagelsi L.Gr.
TLP
Stormy L.Gr.
Boyet L.Gr.
Kawashegamuk L.Gr.
Revell Batholith
d

Fig. IX-4

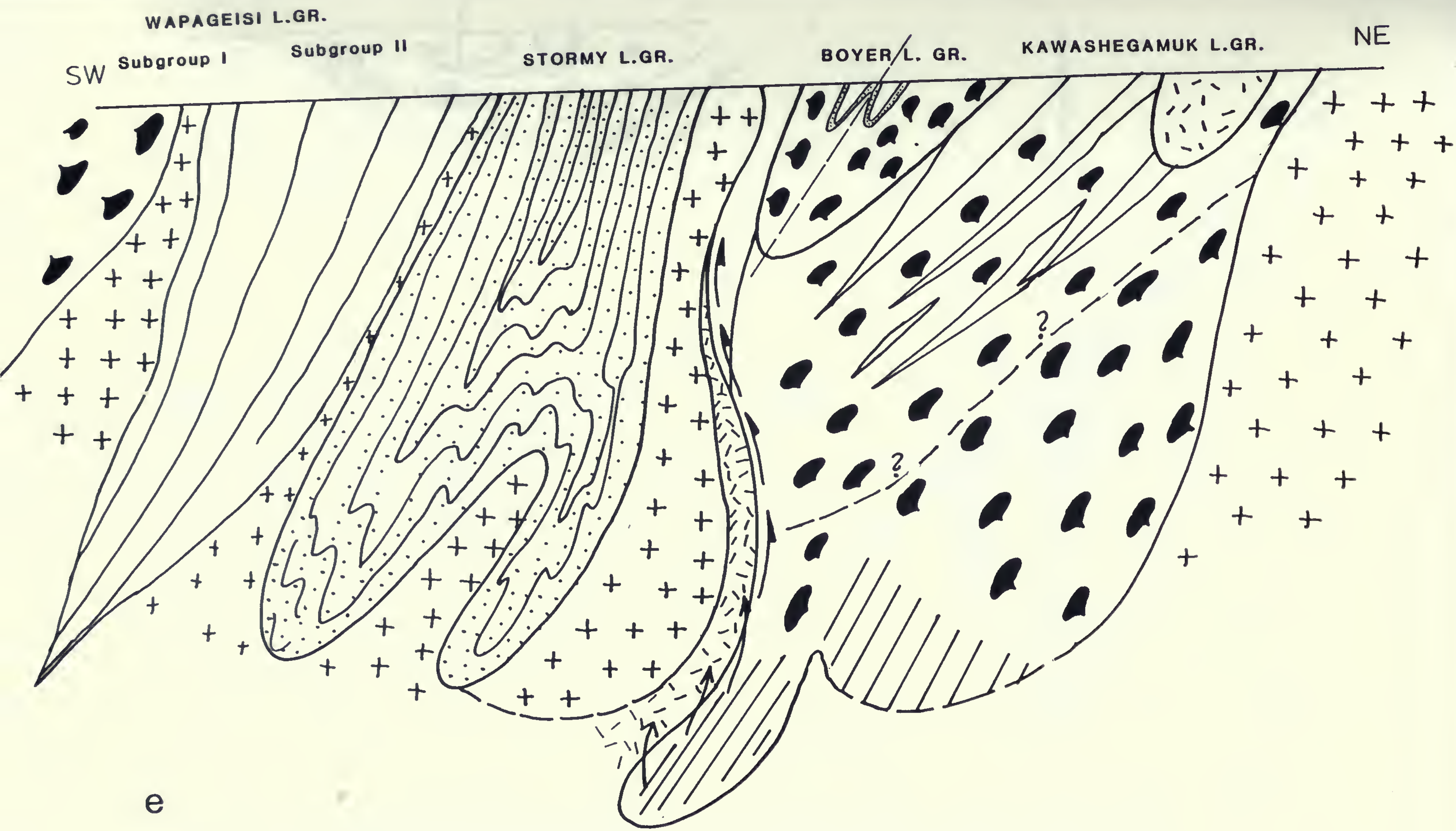

WAPAGEISI L.GR.
Subgroup I
Subgroup II
STORMY L.GR.
BOYER L. GR.
KAWASHEGAMUK L.GR.
SW
NE
?
?
e

Fig. IX-4

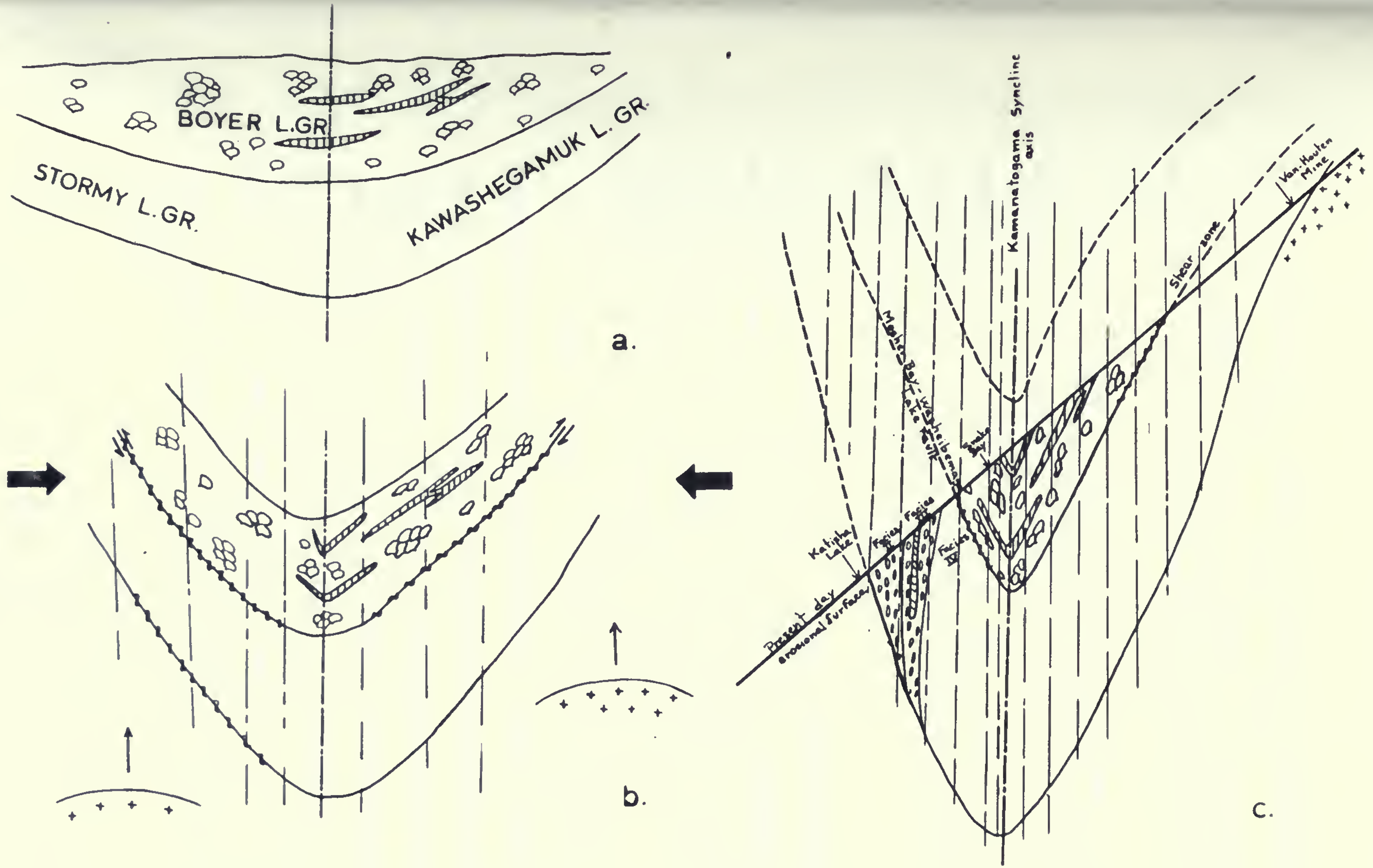


Fig. IX -5 : Evolution of the eastern part of the Manitou Lakes - Stormy Lake belt.
a) Accumulation of the volcanic - sedimentary assemblage in a down sagging basin.
b) The supracrustal assemblage is folded into a synformal structure. Dynamothermal metamorphism sets in and granitic diapirs rise. Shearing and faulting occur particularly along lithological boundaries.
c) Stabilization stage : present day structure.

5) Volcanism ceased and deformation set in, being accompanied by the rising of granitic plutons, particularly at the belt margins, thereby separating the older sialic basement from the greenstones.

6) Granitic plutons invaded the supracrustals and rose preferentially along major lithological boundaries (Figs. IX-4d, e). At this stage, deformation was dominated by large scale folding, thrust faulting and ductile shearing particularly along lithologic contacts (Fig. IX-5b) ; rocks became pervasively foliated.

7) Late granitic intrusions and faulting around 2695 Ma marked the end of the greenstone belt evolution. The entire assemblage became stable and a long period of erosion followed resulting in the unroofing of numerous granitic plutons (Figs. IX-4d, e, 5c).

Mapping inside the confines of the present map area provides only limited insight on major structural styles that characterize the Wabigoon Subprovince. However, U-Pb geochronology on rocks from the Wabigoon Subprovince, as well as from other belts, seem to indicate that tectono-thermal events culminated throughout the entire western Superior Province from about 2730 Ma to 2690 Ma (Nunes and Wood, 1980 ; Davis et al., 1980, 1982 ; Arth and Hanson, 1975) and that all the tectonic belts making up the Superior Province became stable about simultaneously.

CHAPTER X - GENERAL CONCLUSION

A multidisciplinary approach in the investigation of the Archean supracrustal - granitic assemblage of the Kawashegamuk Lake area was effective in providing answers or imposing constraints as to the nature and development of a typical greenstone terrane. The Manitou Lakes - Stormy Lake greenstone belt has evolved in three major episodes : 1) a suprucrustal stage during which a thick volcanic-sedimentary assemblage has accumulated in a downsagging basin, 2) a tecono-thermal event bringing about granitic plutonism,deformation and dynamothermal metamorphism and 3) a stabilization stage marked by late granitic intrusions and faulting followed by a long period of erosion.

1) The supracrustal stage was dominated by volcanism which evolved in two stages : a) the initial stage is represented by eruptions of copious amounts of Mg-tholeiitic basalts through extensive rifts forming a widespread submarine mafic platform ; b) near the end of basaltic volcanism, central type volcanism set in, producing andesitic and felsic flows, and pyroclastic deposits.

2) The sedimentary stage followed erosion of central volcanic vents and an older hinterland complex, after a regressive event. Three facies have been recognized : a) an alluvial facies on land, represented by mainly conglomerates and coarse sandstones (Facies I, II and III of the Stormy Lake Group) ; b) a submarine fan facies represented by turbidite sequences

(Facies IV) ; and c) a distal, deep basin facies with banded iron formation and fine-grained epiclastic sediments.

3) The last episode of supracrustal evolution was marked by a second generation of widespread tholeiitic volcanism following a transgressive event.

4) During the main deformational episode, the stratigraphy within the study area has been folded into a synformal structure. Tectonic fabrics are all vertically or steeply inclined.

5) Tholeiitic lavas have been derived from a mantle source depleted in Ti, K and the light rare-earth elements, probably during earlier melting or differentiation events. Intermediate to felsic volcanics, on the other hand, were likely derived from a multistage process involving partial melting of amphibolite in the lower crust followed by fractionation.

6) The rapid evolution of the Wabigoon subprovince, the enormous amounts of basaltic rocks, the presence of banded iron formation and the absence of low temperature - high pressure metamorphic assemblages, all point towards higher heat flows and a thinner crust during the Archean.

Suggested further studies within the map area :

- Additional U-Pb (zircon) geochronology on the Kawashegamuk Lake Group, the Stormy Lake Group and Subgroup II of the Wapageisi Lake Group in order to impose a time framework which would greatly facilitate correlation across the Kamanatogama Syncline.

- Strontium isotope (Sr^{87}/Sr^{86}) studies to further verify the ideas proposed in this study on magma generation.

- Detailed mapping of the Stormy Lake Group including a detailed analysis of the exotic clast constituents in order to comment on the nature of older supracrustal assemblages.

- A quantitative analysis of strain indicators and tectonic fabrics.

- The area hosts a number of gold showings and has been the scene of considerable exploration for mineral deposits. Studies relating mineralization to the various processes which transformed the Manitou Lakes - Stormy Lake belts are warranted.

REFERENCES

American Commission on Stratigraphic Nomenclature (1970) : Code of Stratigraphic Nomenclature ; The American Association of Petroleum Geologists, Inc., Tulsa, Oklahoma, 22p.

Anhaeusser, C.R. (1971) : Cyclic volcanicity and sedimentation in the evolutionary development of Archean greenstone belts of shield areas, Spec. Publ. Geol. Soc. Am. 3. pp. 57-70.

Anhaeusser, C.R.,Mason, R., Viljoen, M.J. and Viljoen R.P. (1969) : A reappraisal of some aspects of Precambrian shield geology, Geol. Soc. Am. Bull., vol. 80, pp. 2175-2200.

Arndt, N.T. (1973) : Pillows and lava toes in modern and ancient lavas. Geol. Soc. Am. Abstracts with programs, vol. 5 No7, p. 536.

Arth, J.C., and Hanson, G.N. (1975) : Geochemistry and origin of the early Precambrian crust of northeastern Minnesota, Geochim. Cosmochim. Acta, vol. 39, pp. 325-562.

Baragar, W.R.A., and Goodwin, A.M. (1969) : Andesites and Archean volcanism of the Canadian Shield, Proc. Andesite Conf.,Oregon Dept. Geol. Mineral Ind. Bull. 65, pp. 121-142.

Barker, F., and Peterman, Z.E. (1974) : Bimodal tholeiitic - dacitic magmatism and the Early Precambrian crust. Precambrian Research vol. 1, pp. 1-12.

Barth, T.F.W. (1959) : Principles of classification and norm calculations of Metamorphic Rocks ; J. Geology, Vol. 67, pp. 135-152.

Bertholf, W.E. (1946) : Graded Unconformity : Washeibemaga Lake area, Ontario ; Unpublished M.Sc. Thesis, University of Chicago, 45 p., map scale 1:63,360.

Beswick, A.E. and Soucie, G. (1978) : Acorrection procedure for metasomatism in an Archean greenstone belt, Precambrian Research, vol. 6, pp. 235-248.

Blackburn, C.E. (1976) : Geology of the Lower Manitou - Uphill Lakes area, District of Kenora ; Ontario Division of Mines. Geological Report 142, 81 p., accompanied by Map 2320, scale 1 inch to ½ mile.

Blackburn, C.E. (1979) : Geology of the Upper Manitou Lakes Area, District of Kenora ; Ontario Geological Survey, Report 189, 74 p., accompanied by Map 2409, scale 1: 31,680 or 1 inch to ½ mile.

Blackburn, C.E. (1980a) : Kenora - Fort Frances Sheet ; Ontario Geological Survey, Compilation Series, Map 2443, scale 1:253,440 (1 inch to 4 miles). Compilation 1973-1978.

Blackburn, C.E. (1980b) : Towards a mobilist tectonic model for part of the Archean of northwestern Ontario. Geoscience Canada, vol. 7 No 2, pp. 64-72.

Blackburn, C.E. (1981) : Geology of the Boyer - Meggisi Lake Area, District of Kenora, Ontario Geological Survey, Report 202, 107 p. accompanied by Maps 2437 and 2438, scale 1:31,680 or 1 inch to ½ mile.

Blackburn, C.E. (1982) : Geology of the Manitou Lakes area, District of Kenora (Stratigraphy and Petrography) ; Ontario Geological Survey, Report 223, 61p. accompanied by Map 2476, scale 1 : 50000.

Blackburn, C.E., and Kresz, D.U. (1981) : Kawashegamuk Lake area, District of Kenora, pp. 66-69 in : Summary of field work, 1981 ; Ontario Geological Survey, Misc. Paper 100 edited by J. Wood, O.L. White, R.B. Barlow, and A.C. Colvine. 225 p.

Blatt, H., Middleton, G., and Murray, R.C. (1980) : Origin of sedimentary rocks, 2nd edition. Prentice Hall. 772 p.

Borradaile, G.J., and Poulsen, K.H. (1981) : Tectonic deformation of pillow lava. Tectonophysics, 79 : T17-T26.

Bouma, A.H. (1962) : Sedimentology of some Flysh deposits : Amsterdam : Elsevier Pub. Co., 168 p.

Bruce, E.L. (1925) : Gold deposits of Kenora and Rainy River Districts ; Ont. Dept. Mines,Annual Report, vol. 34, pt.5, pp. 1-42.

Bull, W.B. (1972) : Recognition of alluvial-fan deposits in the stratigraphic record. in : Recognition of ancient sedimentary environments. Keith, J., and Hamblin, W.K., edts. SEPM Spec. Publ. NO 16. pp. 63-97.

Carlisle, D. (L961) : Pillow breccias and their aquagene tuffs, Quadra Island, British Columbia. J. Geol. vol. 71, pp. 48-71.

Carmichael, I.S.E. (1964) : The petrology of Thingmuli, a Tertiary volcano in eastern Iceland. J. Petrol., vol.5, pp. 435-460.

Carmichael, I.S.E., Turner, F.J., and Verhoogen, J. (1974) : Igneous Petrology. McGraw-Hill. 739 p.

Chayes, F. (1966) : Alkaline and subalkaline basalts. Amer. J. Sci., vol. 264, pp. 128-145.

Clark, G.S., Bald, R., and Ayres, L.D. (1981) : Geochronology of orthogneiss adjacent to the Archean Lake of the Woods greenstone belt, northwestern Ontario : a possible basement complex ; Can. J. Earth Sci., vol. 18, pp. 94-102.

Cobbold, P.R. (1976) : Fold shapes as function of progressive strain. Phil. Trans. R. Soc. Lond. Ser. A 283, pp. 129-138.

Coleman, A.P. (1894) : Gold in Ontario : its associated rocks and minerals ; Ontario Bureau of Mines, Annual Report vol. 4, Sect.2, pp. 35-100 (Published 1895).

Coleman, A.P. (1896) : Third report on the western Ontario Gold region ; Ontario Bureau of Mines, Annual Report vol. 6, sect 2 ; pp. 71-124 (Published 1897).

Condie,K.C. (1976a) : Trace-element geochemistry of Archean greenstone belts, Earth Science Review, vol. 12, pp. 393-417.

Condie, K.C. (1976b) : Plate tectonism and crustal evolution. Pergamon Press.N.Y. 288 p.

Condie, K.C., and Baragar, W.R.A. (1974) : Rare-earth element distributions in volcanic rocks form Archean greenstone belts. Contr. Min. and Petrol., vol. 45, pp. 237-246.

Condie, K.C., Viljoen, M.J., and Kable, E.J.D. (1977) : Effects of alteration on element distributions in Archean tholeiites from the Barberton greenstone belt, South Africa. Contr. Min. Petrol., vol. 64, pp. 75-89.

Coryell, C.D., Chase ,J.W., Winchester, J.W. (1963) : A procedure for geochemical interpretation of terrestrial rare-earth abundance patterns. J. of Geophysical Research, vol. 68, pp. 559-566.

Daly, R.A. (1925) : The geology of Ascension Island. Am. Acad. Arts Aci. Proc., vol. 60, pp. 1-80.

Davis, D.W., Blackburn, C.E., Trowell, N.F., Edwards, G.R. (1980) : Geochronology of the Savant - Crow Lakes area, western Wabigoon Subprovince, Districts of Kenora, Rainy River and Thunder Bay ; in : Summary of Geochronologic Research, 1977-1979, edited by E.G. Pye, Ontario Geological Survey, Misc. Paper 92, pp.24.

Davis, D.W., Blackburn, C.E., and Krogh, T.E. (1982) : Zircon U-Pb ages from the Wabigoon - Manitou Lakes region, Wabigoon Subprovince, northwest Ontario. Can. J. Eart Sci., vol. 19, pp. 254-266.

Deer, W.A., Howie, R.A., and Zussman, J. (1978) : An introduction to the rock forming minerals, Longman. 528 p.

Dimroth, E.M., and Rocheleau, M. (1979) : Volcanology and sedimentology of Rouyn-Noranda area, Québec. Fieldtrip A1, Québec, 1979. Guide book published by the Geol. Ass. of Canada. 192 p.

Dostal, J., and Strong, D.F. (1980) : Trace-element mobility during low-grade metamorphism and silicification of basaltic rocks from Saint John, New Brunswick. Can. J. Earth Sci., vol. 20, pp. 431-435.

Eichelberger, J.C. (1975) : Origin of andesite and dacite : evidence of mixing at Glass Mountain in California and at other circum-pacific volcanoes. Geol. Soc. Am. Bull., vol. 86, pp. 1381-1391.

Fisher, R.V. (1966) : Rocks composed of volcanic fragments and their classification ; Earth Sci. Reviews, vol. 1. pp. 287-298.

Fiske, R.S. (1963) : Subaqueous pyroclastic flows in the Okanepecosh Formation, Washington. Geol. Soc. Am. Bull., vol. 74, pp. 391-406.

Fiske, R.S., and Matsuda, T. (1964) : Submarine equivalents of ash-flows in the Tokiwa Formation, Japan. Amer. J. Sci., vol. 262, pp. 67-106.

Flannagan, E.J. (1969) : U.S. Geological Survey standards-II : First compilation of data for the new USGS rocks. Geochim. Cosmochim. Acta, vol. 33, pp. 81-120.

Flinn, D. (1962) : On folding during three-dimensional progressive deformation. J. Geol. Soc. Lond., vol. 118, pp. 385-428.

Frey, F.A. (1974) : Atlantic Ocean Floor : geochemistry and petrology of basalts form leg 2 and 3 of the Deep Sea Drilling Project. J. Geoph. Res., vol. 79, pp. 5507-5527.

Frey, F.A., Green, D.H., and Roy, S.D. (1978) : Quartz tholeiites to olivine melilitites from southeastern Australia utilizing geochemical and experimental petrological data. J. Petrol., vol. 19, pt. 3, pp. 463-513.

Gasparrini, E. (1976) : The Energy-Dispersive Spectrometer attached to the electron microprobe : a new tool of investigation for the earth scientist. Min. Sci. Eng., vol. 8 No1, pp. 3-21.

Gast, P.W. (1968) : Trace element fractionation and the origin of tholeiites and alkaline magma types. Geochim Cosmochim Acta, vol. 32, pp. 1057.

Gélinas, L., Brooks, C., and Trzcienski, W.E.Jr. (1976) : Archean variolites - quenched immiscible liquids. Can. J. Earth Sci., vol. 13, pp. 210-230.

Glikson, A.Y., and Lambert, I.B. (1976) : Vertical zonation and petrogenesis of the early Precambrian crust in Western Australia. Tectonophysics, vol. 30, pp. 55-89.

Goldich, S.S., Hedge, C.E., and Stern, T.W. (1970) : Age of the Morton and Montevideo gneisses and related rocks, southwestern Minnesota, Geol. Soc. Am. Bull. 81, pp. 3671-3695.

Goodwin, A.M. (1965) : Preliminary Report on Volcanism and Mineralization in the Lake of the Woods - Manitou Lake - Wabigoon Region of northwestern Ontario ; Ont. Dept. of Mines, Preliminary Report 1965-2, 63 p. accompanied by chart, scale 1:253,440 (1 inch to 4 miles).

Goodwin, A.M. (1968) : Archean Protocontinental Growth and Early Crustal History of the Canadian Shield. XXIII I.G.C., vol. 1, pp. 69-80.

Goodwin, A.M. (1970) : Archean volcanic studies in the Lake of the Woods - Manitou Lake - Wabigoon Region of western Ontario ; Ont. Dept. of Mines, Open File Report 5042, 47 p.

Goodwin, A.M., and Ridler, R.H. (1970) : The Abitibi orogenic belt. Geol. Surv. Can., Paper 70-40, pp. 1-40.

Green, D.H. (1972) : Archean greenstone belts may include terrestrial equivalents of lunar maria?, Earth Planet Sci. Lett., vol. 15, pp. 263-270.

Greig, J.W. (1927) : Immiscibility in silicate melts. Am. J. Sci., vol. 13, pp. 1-44 & 133-154.

Hallberg, J.A. (1972) : Geochemistry of Archean volcanic belts in the eastern Goldfields Region of Western Australia. J. Petrol., vol. 13, pp. 45-46.

Hallberg, J.A., Johnston, C., and Bye, S.M. (1976) : The Archean Marda Igneous Complex, Western Australia. Precambrian Research. vol. 3, pp. 111-136.

Hanson, G.N. (1978) : The application of trace elements to the petrogenesis of igneous rocks of granitic composition. Earth Planet Sci. Lett. vol. 38 No 1, pp. 26-42.

Hart, S.R., Erlank, A.J., and Kable, J.D. (1974) : Sea Floor Basalt Alteration : some chemical and Sr isotopic effects. Contr. Min. Pet., vol. 44, pp. 220-229.

Haskin, L.A. (1977) : On Rare-Earth Element Behaviour in Igneous Rocks in : Origin and Distribution of the Elements 2nd Symposium. Physics and Chemistry of the Earth. L.H. Ahrens Editor. pp. 175-189.

Haskin, L.A., and Paster, T.P. (1978) : Geochemistry and mineralogy of the rare-earths in : Handbook of Rare-Earths, vol. 2, L. Eyring and K.G. Schneider, Editors. Elsevier North Holland Publs.

Hay, R.L. (1959) : Formation of the crystal-rich glowing avalanche deposits of St. Vincent, British Western Indies. J. Geol., vol. 67, pp. 540-562.

Henserson, J.B. (1972) : Sedimentology of Archean turbidites at Yellow Knife, N.W.T.; Can.J. Earth Sci., vol. 9, pp. 882-902.

Hubregtse, J.J.M.W. (1976) : Volcanism in the Western Superior Province in Manitoba. pp. 279-287 in : The Early History of the Earth, edited by B.F. Windley. J. Wiley and Sons Publ., 619 p.

Humphris, S.E., and Thompson, G. (1978) : Hydrothermal alteration of oceanic basalts by sea water. Geochim. Cosmochim. Acta, vol. 42, pp. 107-125.

Hyde, R.S. (1975) : Depositional environment of Archean exhalites, Kirkland Lake - Larder Lake area. Ontario Geol. Soc. Am. Abs., vol. 7, p. 789.

Hyde, R.S. (1980) : Sedimentary facies in the Archean Temiskaming Group and their tectonic implications, Abitibi greenstone belt, northeastern Ontario. Precambrian Research, vol. 12,pp. 161-195.

Irvine, T.N., and Baragar, W.R.A. (1971) : A guide to the Chemical Classification of the Common Volcanic Rocks. Can. J. Earth Sci., vol. 8, pp. 523-548.

Jakěs, P., and Gill, J. (1970) : Rare-earth elements and the island arc tholeiitic series, Earth Planet Sci. .ett., vol. 9, pp. 17-28.

Jolly, W.T. (1972) : Degradation (Hydration) - Aggradation (Dehydration) and Low-Rank Metamorphism of Mafic Volcanic Sequences. XXIVth I.G.C. 1972, Section 2, pp. 11-18.

Jolly, W.T. (1975) : Subdivision of Archean Lavas of the Abitibi Area, Canada, from Fe-Mg-Ni-Cr relations. Earth Planet Sci. Lett., vol. 27, pp. 200-210.

Jolly, W.T., and Smith, R.E. (1972) : Degradation and metamorphic differentiation of the Keweenawan tholeiitic lavas of northern Michigan, U.S.A. J. Petrol., vol. 13, pp. 273-309.

Jones, J.G. (1968) : Pillow Lava and Pahoehoe. J. Geol., vol. 76, pp. 485-488.

Jones, J.G. (1969) : Pillow lavas as depth indicators. Am. J. Sci., vol. 267, pp. 181-195.

Kay, R.W., and Hubbard, N.J. (1978) : Trace elements in ocean ridge basalts. Earth Planet Sci. Lett., vol. 38, pp. 95-111.

Krauskopf, K.B. (1967) : Introduction to geochemistry. McGraw-Hill, Pub. 721 p.

Kresz, D.U., Blackburn, C.E., and Fraser, F.B. (1982a) : Precambrian geology of the Kawashegamuk Lake area, western part Kenora District ; Ontario Geological Survey, Map P.2569, Geological Series. Preliminary Map, scale 1:15840 or 1 inch to ¼ mile. Geology 1980, 1981.

Kresz, D.U., Blackburn,C.E., and Fraser, F.B. (1982b) : Precambrian geology of the Kawashegamuk Lake are, eastern part Kenora District ; Ontario Geological Survey, Map P. 2570. Geological Series. Preliminary Map, scale 1:15840 or 1 inch to ¼ mile. Geology 1980, 1981.

Krogh, T.E., Harris, N.B.W., and Davis, G.L. (1976) : Archean rocks from the eastern Lac Seul region of the English River gneiss belt, northwestern Ontario, part 2. Geochronology. Can. J. Earth Sci., vol. 13, pp. 1212-1215.

Lacroix, A. (1904) : La Montagne Pelée et ses éruptions. Paris. Masson et Cie, 662 p.

Langford, F.F., and Morin, J.A. (1976) : The development of the Superior Province of northwestern Ontario by merging island arcs ; Am. J. Sci., vol. 276, pp. 1023-1034.

Lawson, A.C. (1885) : Report on the geology of the Lake of the Woods region with special reference to the Keewatin (Huronian?) belt of the Archean rocks. Geol. Surv. Can., Annual Report (new series), vol. 1, Report CC.

MacDonald, G.A. (1968) : Differentiation of basalt magmas. in : Basalts, vol. 2. H.H. Hess and A. Poldervaart, Editors. pp. 623-688. Interscience, J. Wiley & Sons, N.Y. 862 p.

McBride, E.F. (1963) : A classification of common sandstones. J. Sed. Petrol., vol. 33, p-. 664-669.

McGlynn, J.C., and Henderson, J.B. (1970) : Archean volcanism and sedimentation in the Slave Structural Province. Geol. Surv. Can. Paper 70-40, pp. 31-44.

McInnes, W. (1895) : Report of field work, in : Summary Report, Geol. Sur. Can., vol. 8, pp. 45-49.

McInnes, W. (1896) : Report of field work, in : Summary Report, Geol. Surv. Can., vol. 9, pp. 34-43.

McInnes, W. (1897) : Report of field work, in : Summary Report. Geol. Surv. Can., vol. 10, pp. 38-43.

McInnes, W., Lawson, W., and Smith, W.H.C. (1902) : Manitou Lake Sheet ; Geol. Surv. Can., Map No 720, scale 1 inch to 4 miles.

McMaster, G.E. (1975) : Petrography and geochemistry of the gabbro sills, Superior Province, northwest Ontario ; Unpublished B.Sc. Thesis, McMaster University, 132 p.

McMaster, G.E. (1978) : Archean volcanism and geochemistry, Washeibemaga-Thundercloud Lakes area, Wabigoon Subprovince, Superior Province, northwest Ontario, Unpublished M.Sc. Thesis, McMaster University, 222 p.

Meyn, H.D. and Palonen, P.A. (1980) : Stratigraphy of an Archean submarine fan. Precambrian Research, vol. 12, pp. 257-285.

Miyashiro, A. (1974) : Volcanic rock series in island arcs and active continental margins. Am.J. Sci., vol. 274, pp. 321-355.

Moore, J.G. (1975) : Mechanism of formation of pillow lava. Amer. Sci., vol. 63, pp. 269-277.

Moore, J.G., Phillips, R.L., Grigg, R.W., Petterson, D.W., and Swanson, D.O. (1973) : Flow of lava under the sea, 1969-1971, Kilauea Volcano, Hawaii. Geol. Soc. Am. Bull., vol. 84, pp. 537-546.

Moorhouse, W.W. (1959) : The study of rocks in thin section. Harper and Row, Pub. 514 p.

Nagasawa, H., and Sneltzler, C.C. (1971) : Partitioning of rare-earth, alkalic and alkaline earth elements between phenocrysts and acidic igneous magma. Geochim. Cosmochim. Acta, vol. 35, pp. 953-968.

Nakamura, N. (1977) : Determination of rare-earth elements : Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. Geochim. Cosmochim. Acta., vol. 38, pp. 757-775.

Nelson, C.H., and Kulm, L.D. (1973) : Submarine and deep sea channels. in : SEPM. Pacific section, short course. Anaheim. Turbidites and deep water sedimentation. 157 p.

Nesbitt, R.W., and Sun, S.S. (1978) : Petrogenesis of Archean Ultra-basic and Basic volcanics. Contr. Mineral. Petrol., vol. 65, pp. 301-325.

Noble, D.C. (1967) : Sodium, potassium and ferrous iron contents of some secondarily hydrated natural silicic glasses. Am. Mineral., vol. 52, pp. 280-286.

Nockolds, S.R., and Allen, R. (1953, 1954, 1956) : The geochemistry of some igneous rock series, I, II, III : Geochim. Cosmochim. Acta., vol. 4, pp. 105-142, vol. 5, pp. 245-285, vol. 9, pp. 34-77.

Nunes, P.D., and Thurston, P.C. (1980) : An absolute age framework for the stratigraphy of the Uchi-Confederation Lakes metavolcanic - metasedimentary belt, District of Kenora. pp. 15-22, in : Geochronology studies 1977-1979. edited by E.G. Pye, Ont. Geol. Surv. Misc. Paper No 92. 45 p.

Nunes, P.D., and Wood, J. (1980) : Geochronology of the North Spirit Lake area, District of Kenora. Progress. Report, pp. 7-14, in : Summary of Geochronology Studies 1977-1979, edited by E.G. Pye, Ont. Geol. Survey Misc. Paper No 92, 45p.

Ontario Geological Survey (1980) : Airborne electromagnetic and total intensity magnetic survey, Manitou - Stormy Lakes area, District of Kenora ; by Kenting Earth Sciences Ltd., for the Ontario Geological Survey, Geophysical/Geochemical Series, Maps No 80460, 80466, 80461 A & B, 80467 A & B, 80462 A & B 80468, 80476, scale 1:20000. Survey and compilation, November-December 1979, and January-February 1980.

Osborn, E.F. (1959) : Role of Oxygen pressure in the crystallization and differentiation of basaltic magmas. Am. J. Sci., vol. 257, pp. 609-647.

Pankhurst, R.J., and O'Nions, R.K. (1978) : Early Archean rocks and geochemical evolution of the earth crust. Earth Planet Sci. Lett., vol. 38, pp. 211-236.

Parson, A.L. (1911) : Gold fields of Lake of the Woods, Manitou and Dryden ; Ont. Bur. Mines, Annual Report, vol. 20, pt 1, pp. 158-198.

Parson, A.L. (1912) : Gold fields of Lake of the Woods, Manitou and Dryden ; Ont. Bur. Mines, Annual Report, vol. 21, pt 1, pp. 169-204.

Parsons, W.H. (1969) : Criteria for recognition of volcanic breccias : Review. Geol. Soc. Am. Memoir. 115, pp. 263-304.

Pearce, J.A., and Cann, J.R. (1973) : Tectonic setting of basic volcanic rocks determined using trace element analyses ; Earth and Planet Sci. Lett., vol. 19, pp. 290-300.

Pettijohn, F.J. (1937) : Early Precambrian geology and correlational problems of the northern Subprovince of the Lake Superior region, Bull. Geol. Soc. America, vol. 48, pp. 153-202.

Philpotts, A.R. (1982) : Compositions of immiscible liquids in volcanic rocks. Contr. Mineral. Petrol., vol. 80, pp. 201-218.

Platt, J.P. (1980) : Archean greenstone belts : a structural test of tectonic hypotheses. Tectonophysics, vol. 65, pp. 127-150.

Ringwood, A.E. (1974) : The petrological evolution of island systems. J. Geol. Soc. Lond., vol. 130, pp. 183-204.

Roed, M.A. (1980) : Northern Ontario Engeneering Geology and Terrain Study No 38. Gold Rock area, Districts of Kenora and Rainy River. Ontario Geological Survey, Map No 5061.

Roedder, E. (1951) : Low temperature liquid immiscibility in the system K_2O - FeO - Al_2O_3 - SiO_2, Am. Mineralogist, vol. 36, pp. 282-286.

Roedder, E, and Weiblen, P.W. (1970) : Lunar petrology of silicate melt inclusions, Apollo 11 rocks, in : Apollo 11, Lunar Science Conference, Proc. 1 : 801-837.

Roedder, E., and Weiblen, P.W. (1971) : Petrology of silicate melt inclusions, Apollo 11 and 12, and terrestrial equivalents, in : Second Lunar Sci. Conf. Proc., Geochim. Cosmochim. Acta, suppl. 2, 1 : pp. 507-528.

Sabag, S.F. (1979) : The geochemistry and petrology of granitoids at Meggisi Lake, N.W. Ontario. Unpublished M.Sc. Thesis, University of Toronto, 283 p.

Sage, R.P., Blackburn, C.E., Breaks, F.W., McWilliams, G.M., Schwerdtner, W.M., and Stott, G.M. (1975) : Internal structure and composition of two granite complexes in the Wabigoon Subprovince ; pp. 24-32, in : Proceedings, Geotraverse Workshop, University of Toronto, 1975.

Satterly, J. (1960) : Geology of the Dyment area ; Ontario Dept. Mines, Annual Report, vol. 69, pt. 6, pp. 1-32 accompanied by Map 1960h, scale 1:63680.

Selley, R.C. (1976) : Ancient sedimentary environments. Chapman and Hall, Pub., 237 p.

Shaw, D.M. (1970) : Trace element fractionation during anatexis. Geochim. Cosmochim. Acta., vol. 34, pp. 237.

Smith, R.E. (1968) : Redistribution of major elements in the alteration of some basic lavas during burial metamorphism. J. Petrol, vol. 9, pp. 191-219.

Sneltzler, C.C., and Philpotts, A. (1970) : Partition coefficients of some rare-earth elements between igneous matrix material and rock forming mineral phenocrysts, II. Geochim. Cosmochim. Acta. vol. 34, pp. 331-340.

Sparks, R.S.J., Self, S. and Walker, G.P.L. (1973) : Products of Ignimbrite Eruptions. Geology, vol. 1 No 3, pp. 115-118.

Sparks, R.S.J., Sigurdson, H., Wilson, L. (1977) : Magma mixing : a mechanism for triggering acid explosive eruptions. Nature, vol. 267, pp. 315-318.

Stanley, D.J., and Unrug, R. (1972) : Submarine channel deposits, fluxoturbidites, and other indicators of slope and base slope environments in modern and ancient marine basins, in : Recognition of ancient sedimentary environments. Keith and Hamblin, Wm.K., editors. SEPM. Spec. Publ. No 16, pp. 287-340.

Stowe, C.W. (1971) : Summary of the tectonic development of the Rhodesian Archean Craton. Geol. Soc. Austr. Spec. Publ. 3, pp. 377-383.

Sun, S.S., and Nesbitt, R.W. (1978) : Petrogenesis of Archean Ultrabasic and basic volcanics : Evidence from rare-earth elements. Contr. Mineral. Petrol., vol. 65, pp. 301-325.

Talbot, C.J. (1973) : A plate tectonic model for the Archean. Phil. Trans. R. Soc. London, Ser. A 273 : 413-427.

Taylor, S.R., and Gorton, M.P. (1977) : Geochemical application of spark source mass spectrography III. Element sensitivity and accuracy. Geochim. Cosmochim. Acta., vol. 41, pp. 1375-1380.

Teal, P.R. (1979) : Stratigraphy, sedimentology, volcanology and development of the Archean Manitou Group, northwestern Ontario. Unpublished Ph.D. Thesis, McMaster University, 310 p.

Teal, P.R., and Walker, R.G. (1977) : Stratigraphy and sedimentology of the Archean Manitou Group, northwestern Ontario, in : Report of activities, part A ; Geol. Surv. Can. Paper 77-1A, pp. 181-184.

Thomson, J.E. (1933) : Geology of the Manitou - Stormy Lakes area, Ont. Dept. Mines, Annual Report, vol. 42, pt 4, pp. 1-40 accompanied by Map 42c, scale 1:63360.

Thomson, J.E. (1936) : Gold deposits of the belt extending from Manitou Lake to Lake of the Woods ; Can. Inst. Min. Metall. Trans., vol. 39, pp. 686-701.

Thomson, J.E. (1938) : Some gold deposits near Gold Rock, Upper Manitou Lake ; Ont. Dept. Mines, Annual Report, vol. 47, pt 6, pp. 1-10 accompanied by Map 47k, scale 1:4800. (Published 1942).

Thurston, P.C., and Fryer, B.J. (1983) : The Geochemistry of Repetitive Cyclical Volcanism from Basalt through Rhyolite in the Uchi-Confederation Greenstone Belt, Canada. Contr. Mineral. Petrol., vol. 83, pp. 204-226.

Trowell, N.F., Blackburn, C.E., Edwards, G.R., and Sutcliffe, R.H. (1977): Savant Lake - Crow Lake Special Project, Districts of Thunder Bay and Kenora ; pp. 29-50, in : Summary of field work, 1977, by the Geological Branch, edited by V.G. Milne, O.L. White, R.B. Barlow, and J.A. Robertson, Ont. Geol. Surv., Misc. Paper 75, 208 p.

Trowell, N.F., Blackburn, C.E., and Edwards, G.R. (1980) : Preliminary Geological Synthesis of the Savant Lake - Crow Lake Metavolcanic - Metasedimentary Belt, northwestern Ontario, and its bearing upon Mineral Exploration ; Ont. Geol. Surv., Misc. Paper 89, 30 p.

Turner, C.C., and Walker, R.G. (1972) : Sedimentology, stratigraphy and crustal evolution of the Archean greenstone belt near Sioux Lookout, Ontario. Can. J. Earth Sci., vol. 10, pp. 817-845.

Vallance, T.G. (1965) : On the chemistry of pillow lavas and the origin of spilites . Mineralogical Mag., vol. 34, pp. 471-481.

Vallance, T.G. (1974) : Spilitic degradation of a tholeiitic basalt. J. Petrol. 15, pp. 79-96.

Vuagnat, M. (1946) : Sur quelques diabases suisses : Contribution à l'étude du problème des spilites et des pillow lavas : Schweiz. Mineral. Petrogr. Mitteilungen., vol. 26, pp. 116-228.

Wagner, L.R., and Deer, W.A. (1939) : The petrology of the Skaergaard Intrusion, Kangerdlungssuag, East Greenland. Meddlelser om Grønland, 105, No 4, pp. 1-352.

Walker, G.P.L. (1972) : Crystal concentration in ignimbrites. Contr. Mineral. Petrol., vol. 36, pp. 135-146.

Walker, R.G. (1975) : Generalized facies models for resedimented conglomerates of turbidites association. Geol. Soc. Am. Bull. 86, pp. 737-748.

Walker, R.G. (1978a) : A critical appraisal of Archean basin - craton complexes. Can. J. Earth Sci., vol. 15, pp. 1213-1218.

Walker, R.G. (1978b) : Deep water submarine facies and ancient submarine fans : models for exploration for stratigraphic traps. Am. Assoc. Pet. Geol., vol. 62, pp. 932-966.

Walker, R.G., and Pettijohn, F.J. (1971) : Archean sedimentation : analysis of the Mimitaki Basin, northwestern Ontario, Canada. Geol. Soc. Am. Bull., vol. 82, pp. 2099-2130.

Wilkinson, J.F.G. (1968) : The petrography of basaltic rocks. in : Basalts, vol. 1. H.H. Hess, and A. Poldervaart, editors.pp. 163-214. Interscience, J. Wiley & Sons, N.Y., 862 p.

Willard, H.H., Merritt, L.L. Jr., Dean, J.A., Settle, F.A.Jr. (1969) : Instrumental methods of analysis (Sixth edition)Van Nostrand Publ.

Windley, B.F. (1979) : The evolving continents. J. Wiley & Sons, Publ. 385 p.

Winkler, H.G.F. (1979) : Petrogenesis of Metamorphic Rocks (5th edition) Springer Verlag. 348 p.

Wood, D.A., Gibson, I.L., and Thompson, R.W. (1976) : Elemental mobility during zeolite facies metamorphism of the tertiary basalts of eastern Iceland. Contr. Mineral. Petrol., vol. 55, pp. 241-254.

Wood, J. (1980) : Epiclastic sedimentation and stratigraphy in the North Spirit Lake and Rainy Lake areas : a comparison. Precambrian Research. vol. 12, pp. 227-255.

Yoder, H.S., and Tilley, C.E. (1962) : Origin of basaltic magmas : an experimental study of natural and synthetic rock systems. J. Petrol., vol. 3, pp. 342-532.

Young, G.M. (1967) : Sedimentology of Lower Visean? Rocks in the western part of the Ballina and Donegal Synclines, northwestern Ireland. Unpublished Ph.D. Thesis, University of Glasgow, 204 p.

Zoltai, S.C. (1961) : Glacial History of Part of Northwestern Ontario. Proc. G.A.C., vol. 13, pp. 61-83.

Appendix A : Sample numbers used in this study and their corresponding original number.

WAPAGEISI LAKE GROUP

Sample number	corresponding O.G.S. number
WI	80-0I98
W2	80-0220
W3	80-I0I4
W5	80-II27
W6	80-II45
W7	8I-I443
W8	82-I
W9	82-3C
WI0-S	82-4
WI0-R	82-4
WI0-C	82-4
WII	82-5
WI2	82-8
WI3	82-I4
WI4	82-I5
WI5	82-I7
WI6	82-22
WI7	82-25
WI8	82-5I
WI9	82-54
W20-S	82-I2I
W20-R	82-I2I
W20-C	82-I2I
W22	82-I3I
W23	82-I32
W24	82-257
W25	82-288
W26	82-290
W27	82-297

BOYER LAKE GROUP

Sample number	corresponding O.G.S. number
BI	80-02I0A
B2	80-II69
B3	8I-II89
B4	8I-II92
B5	8I-I4I3
B6	8I-I427
B7	8I-I429A
B8	8I-I428
B9	8I-I468
BI0	8I-I476
BII	8I-I480
BI2	8I-I482
BI3	8I-I5I3
BI4	8I-I5I6
BI5	8I-I5I7
BI6	8I-I528
BI7	8I-I540
BI8	8I-I620
BI9	82-I46
B20	82-I48
B22	82-I56
B23	82-I69
B24	82-I76
B25	82-I79B
B26	82-I82
B27	82-I84
B28	82-I86
B29	82-I87
B30	82-I89
B3I	82-I90
B32	82-I9I
B33	82-I93
B34	82-203B
B35	82-208
B36	82-228
B37	82-23I
B38	82-275
B4I-A	80-0I4IA
B4I-B	80-0I4IB
B4I-C	80-0I4IC
B44	80-0I44
B45	80-I037
B47	80-II67
B48	80-II77
B49	80-II86
B50	8I-I43I
B5I	8I-I438

	Sample number	corresponding O.G.S. number
THUNDERCLOUD LAKE PORPHYRY	TI	8I-T-I
	TI0	8I-T-I0
	TI7	8I-T-I7
	TI9	8I-T-I9
	T28	8I-T-28
	T32	8I-T-32
	T38	8I-T-38
"KATISHA GABBRO"	G0	82-I0I
	GI	82-I00
	G2	82-99
	G3-A	82-98A
	G3-B	82-98B
	G3-C	82-98C
	G4	82-97
	G5	82-96
	G6	82-I02
	G7	82-I03
	G8	82-I04
	G9	82-I05
	GI0	82-I07
	GII	82-I06
	GI2	82-I08
	GI3	82-I09

	Sample number	corresponding O.G.S. number
STORMY LAKE GROUP	SI	80-0I50
	S2	80-0207
	S3	80-II2I
	S4	8I-I444
	S5	82-42
	S6	82-43
	S7	82-78
	S8	82-82
	S9	82-I36B
	SI0	82-I42
	SII	82-I43
	SI2	82-I45
	SI3	82-278
	SI4	82-286A
	SI5	82-286B
	SI6	82-299
	SI7	I7-I-2A
	SI8	I7-I-2B
	SI9	I7-2
	S20	I7-3
LATE GRANITIC ROCKS	LI	80-0I32
	L2	80-I042
	L3	8I-I3I9
	L4	8I-I638
	L5	8I-I640
	L6	82-I63
	L7	82-203A
	L8	82-280

KAWASHEGAMUK LAKE GROUP

Sample number	corresponding O.G.S. number
KI	8I-I20I
K2	8I-I206
K3	8I-I208
K4	8I-I209A
K5-M	8I-I2I0
K5-F	8I-I2I0
K6	8I-I2II
K7	8I-I2I2
K8	8I-I2I4
K9-M	8I-I2I5
K9-F	8I-I2I5
KI0	8I-I220
KII	8I-I222
KI2	8I-I223
KI3	8I-I233A
KI4	8I-I278
KI5	8I-I290
KI6	8I-I29IA
KI7	8I-I3I0
KI8	8I-I3I3
KI9	8I-I3I6
K20	8I-I329
K2I	8I-I33I
K22	8I-I350
K23	8I-I364
K24	8I-I380
K25	8I-I397
K26	8I-I4I2
K27	8I-I4I9
K28	8I-I426
K32	8I-I450
K33	8I-I452
K34	8I-I453
K35	8I-I462
K36	8I-I467
K37	8I-I47I
K38	8I-I472
K39	8I-I474
K40	8I-I486
K4I	8I-I494
K42	8I-I497
K43	8I-I50I
K44	8I-I505
K45	8I-I5I0
K46	8I-I563
K47	8I-I565
K48	8I-I568
K49	8I-I570
K50	8I-I586
K5I	8I-I587
K52	8I-I590A
K53	8I-I590B
K54	8I-I605
K55	8I-I606
K56	8I-I6II
K57	8I-I6I2
K58	8I-I622
K59	8I-I623
K60	82-I58
K6I	DM-6
K62	DM-II-I
K63	DM-?
K64	80-0I39
K65	80-0I46

Appendix B

Part 1 : Sample preparation techniques.

i) Loss on Ignition determination (LOI).

LOI is the difference in weight resulting from the removal of all volatile content in a rock plus the gain in weight of the necessary amount of oxygen to convert FeO to Fe_2O_3.

Method :

A few grams of sample previously crushed and sieved is dried in an oven at 100°C to remove excess moisture absorbed by the rock powder. 1.0000 gram of sample is then transferred into a porcelain crucible previously weighed to 4 decimal places and placed into a cold muffle furnace which is allowed to reach 1100°C. The crucible is then allowed to cool in a dessicator before being weighed.

$$\text{LOI (Wt \%)} = \left[(W_i(c) + 1.000g) - W_f\right] \times 100$$

where $W_i(c)$ is the empty crucible weight and W_f is the combined weight of the crucible + sample after heating at 1100°C.

ii) Fusion discs preparation (for analysis of the major elements by XRFS).

1.0000g of sample was mixed with an amount of X-ray fusion flux (90% $LiBO_4$, 10% $LiCO_3$) equivalent to 10.0000g plus the LOI weight. The homogenized mixture was then transferred into a platinum crucible which was placed in a preheated muffle furnace at 1100°C. for approximately 30 minutes. The melt was then poured in a hot platinum mold

and allowed to cool.

Success in glass disc making was very much dependant on the sample composition. Discs made from felsic rock powders or powders rich in carbonate minerals had a tendancy to crack. This problem was solved by pouring the melt in the mold and partially draining it so that a thinner disc is produced. The finished discs were then ready for analysis.

iii) Pressed-powder discs preparation (for analysis of the trace elements by XRFS).

7.5000g of rock powder was thouroughly mixed with 1.0000g of binding agent and put into a thin aluminium cup which was then placed into the wafer of a metallurgical press and subjected to a directed pressure of 850 kg/cm^2. The resulting disc was then ready for analysis.

iv) Sample preparation for AAS analysis.

Approximately 0.5g of rock powder was digested in a volume of 20 ml of hydrofluoric acid and 8 ml of perchloric acid in a teflon beaker at a temperature of about $100^{o}C$. The remaining residue in the beaker after evaporation of the acids was then dissolved in an aqueous solution containing 2% HCl and 2000 ppm KCl and stored in plastic bottles. All glass ware and storage bottles were previously washed with aqua-regia to remove adsorved ions on the walls. All analytical reagents used were of "analytical grade quality" and only dionized water was used.

v) Sample preparation for the analysis of the rare-earth elements by INAA .

0.2000 g of homogenized rock powder was packed into a tightly sealed high temperature plastic bag of the type used for boiling food. The samples were then irradiated in the core of a "Slowpoke" nuclear reactor at the University of Toronto, for 16 hours under a constant neutron flux of $2.5x10^{11}cm^{-2}sec^{-1}$ at 5.0 KW power. Samples were then ready for analysis.

vi) Sample preparation for electron microprobe analysis.

Analysis was directly performed on ordinary polished thin sections 40-50 μm thick which were prepared by the technical staff at the University of Toronto. Prior to analysis, the sections were coated with a thin carbon film.

Part 2 : Instrumental methods of analysis.

i) X-ray fluorescence spectroscopy (XRFS).

The principle which lies behind this method is based on the relationship between concentration of a particular element and the intensity of fluorescent emission upon bombardment of a primary, high energy X-ray beam onto the substance to be analyzed. The entire theory and operation of modern XRF spectroscopy is too lengthy to be described here and the interested reader should consult a manual on analytical chemsitry such as "Instrumental methods of analysis" by Willard, Merritt, Dean and Settle, 6th edition, 1981). The various parameter settings used in the determination of the major and trace elements are listed in Table B1.

Table B1 : X-ray spectrometer parameter settings

Element	Tube	Kv	Ma	Detector	Crystal	Background angle	Peak angle	Counting time (s)	Order	Collimator	Window	Lower level
Si	RHODIUM	50	50	Flow	PET	III50	I0923	I00	I	Coarse	500	I00
Al		"	"	Flow	PET	I4350	I4507	40	I	Coarse	500	I00
Fe		"	"	Flow	LIF200	05505	05744	20	I	Fine	500	I00
Mg		"	"	Flow	TLAP	05000	04530	40	I	Coarse	500	I00
Ca		"	"	Flow	LIF200	I0950	II3I2	I0	I	Fine	700	I00
Na		"	"	Flow	TLAP	05690	05522	40	I	Coarse	500	I00
K		"	"	Flow	LIF200	I3500	I3665	I0	I	Coarse	500	I00
Ti		"	"	Flow	LIF200	08529	086I7	I0	I	Coarse	500	I00
Mn		"	"	Flow	LIF200	062I3	06299	20	I	Fine	500	I00
P		"	"	Flow	Ge	I39I0	I4I0I	20	I	Coarse	500	I00
Ba		"	"	Scint	LIF200	0I045	0II02	20	I	Fine	500	I50
Zr		"	"	Scint	LIF200	02920	02256	40	I	Fine	500	I50
Y		"	"	Scint	LIF200	02920	02380	20	I	Fine	500	I50
Sr		"	"	Scint	LIF200	02920	025I5	20	I	Fine	500	I50
Rb		"	"	Scint	LIF200	02850	02662	I0	I	Fine	500	I50
Zn		"	"	Fl/Sc	LIF200	05030	04I85	40	I	Coarse	700	I00
Cu		"	"	Fl/Sc	LIF200	05000	04505	20	I	Coarse	700	I00
Ni		"	"	Fl/Sc	LIF200	05000	04868	20	I	Coarse	700	I00
Cr		"	"	Fl/Sc	LIF200	07400	06936	20	I	Coarse	700	I00
V		"	"	Fl/Sc	LIF200	07400	07696	20	I	Coarse	700	I00

ii) Atomic absorption spectrophotometry (AAS).

AAS is carried out by use of the principle that entails the determination of the absorption of a light source emitting a given resonnance line of the element which emits when transition from ground electronic state to an upper exited state takes place. The energy required for that is given by a flame into which the analyte is being introduced as an aerosol. Concentration of a certain element is related to absorption which is measured by the difference in transmitted signal in the presence or absence of the element to be tested. When the analyte is drawn into the flame, part of the radiant energy of the incident light beam, I_o, will be absorbed. The transmitted intensity, I, may be written :

$$I = I_o \, e^{(-K\nu d)}$$

$K\nu$ = absorption coefficient ; d = average thickness of the absorbing medium (path length of the flame horizontally).

Analyses were carried out for Al, Mg, Na, Mn, Ba, Sr, Cu, Zn and Ni. Calibration of the instrument was done using reference solutions and a calibration curve was established before determination of unknown concentration of a particular element. Standards were analyzed for accuracy and precision control (see part 3). The results obtained for aluminium are unreliable and have been rejected. Al is sensitive to matrix interference and it easily forms complexes especially with F^- (Van Loon, personal communication). Instrumental drift was minimized by resloping the calibration curve after every 10th determination.

Readings were automatically converted from absorbance units into concentration in solution. Concentration of a particular element in the rock was computed using the following equation :

$$Crock\ (ppm) = (Caq. \times V \times DF)/SW$$

Caq. : concentration of the element in solution.

V : volume of solution in which the sample was dissolved.

DF : Dilution factor.

SW : Sample weight in grams.

Mg, Mn and Na were calculated as the weight percentage of the oxide given by :

$$Wt\%\ (oxide) = \frac{[Mx + Oy]}{x[M]}$$

where M is the atomic weight of the element to be determined, O = 16, x and y are intergers.

iii) Neutron activation analysis (INAA).

When a sample is exposed to neutron irradation stable isotopes are converted into radionuclide products. The rate of production of radioactive atoms N* is given by $\frac{dN^*}{dt} = \Phi \sigma N - \lambda N^*$

Φ : neutron flux in (cm^{-2} sec^{-1})

σ : reaction cross-section (10^{-24} cm^2/nucleus)

N : number of target nucleii available

λ : characteristic decay constant.

Each unstable radio-isotope emits a characteristic γ-ray radiation. Thus the concentration of a particular element in a sample may be determined by measuring the intensity of the characteristic γ-ray radiation emitted. This is carried out by using γ-ray spectrometry of the activated sample. It is possible to determine several elements simultaneously by using a multichannel analyzer (MCA). Quantitative analysis is done by the measure of the area of a channel under

the photopeak of interest. The data is digitized and stored in a digital memory module. Concentration have been computed using a BASIC computer program prepared by S.J. Barnes which corrects for interferences. Concentrations have been measured against two in-house standards UTB-1 and UTR-1, making use of the relation :

$$\frac{A\ unknown}{A\ standard} = \frac{N\ unknown}{N\ standard}$$

where A and N are concentration and activity, respectively.

Ce, Cr, Eu, Hf, Sc and Ta have been computed relating the activity to the time elapsed after irradiation. The UTR-1 standard has been used to check accuracy.

Table B2 lists the radionuclides used for the elements sought for. Every sample has been counted for about 3 hours on a high sensitivity scintillation detector on both the 7 and 40 days count. Standards were measured for a longer time.

Part 3 : Precision and accuracy of the data

Analytical precision has been checked on duplicate runs of samples and standards. Reproducibility was mainly dependant on the amount of instrumental drift. Drift was not a problem on analyses carried out by XRFS, however, it was associated with AAS.

Accuracy control was checked against standards.

i) X-ray fluorescence.

The following USGS rock standards : AGV-1, GSP-1, G-H, G-2, BHV-1, BCR-1, PPB-1, BBR-1, MRG-1 and STM-1 have been used as reference standards (Flannagan, 1969). The standards have been analyzed after

Table B2

Element	Radionuclide	γ-ray energy (keV)	Half life
Ba*	131Ba	92.2	11.7d
Ce**	141Ce	145.2	32.45d
Cr**	51Cr	320.1	27.72d
Eu**	152Eu	1408.7	13.2 y
Fe*	59Fe	1099	44.6 d
Hf**	181Hf	482.3	42.5 d
La*	140La	1596	40.22h
Lu*	177Lu	208.4	6.71d
Na*	24Na	1368.5	15.03h
Nd*	147Nd	91	10.98d
Sc**	46Sc	889.5	83.8 d
Sm*	153Sm	103.2	46.44d
Ta**	182Ta	1120.8	115.0 d
Tb**	160Tb	298.6	72.1 d
Th*	233Pa	311.9	27.0 d
U*	239Np	106.1	2.35d
Yb*	175Yb	396	4.21d

* measured approx. 7 days after irradiation

** measured approx. 40 days after irradiation

every 5th run to check for drift. Table B3 graphically represents the error spread form the accepted (true) value for each standard. Precision and accuracy for the major elements oxides are as follows :

SiO_2, ± 1.0 Wt% ; Al_2O_3, ± 0.8 ; Fe_2O_3, ± 0.4 ; MgO (4 Wt%), $^{+1}_{-0.5}$; MgO (4 Wt%), ± 0.5 ; CaO, ± 0.2 ; Na_2O, ± 1.1 ; K_2O, ± 0.05 ; TiO_2, ± 0.03 ; MnO, $^{+0.1}_{-0.06}$; P_2O_5, ± 0.07.

From duplicate samples, precision for the trace elements is as follows : Zr, ± 7 ppm ; Rb, ± 5 ; V, ± 6.

For the determination of the trace elements, the following USGS standards were used : AGV-1, G-2, BBR-1, SCO-1, SDC-1, BHV-1, GSP-1, RGM-1, DTS-1, PCC-1. Accuracy of the trace elements, however, is inferior to precision with Zr, ± 47 ppm ; Rb, ± 18 ppm ; V, ± 20 ppm.

ii) <u>Atomic absorption spectrophotometry</u>.

Analyses by AAS gave more satisfactory results than those obtained by XRFS for Na_2O, MgO (in low concentration), MnO, Ba, Ni, Cu and An. BHV-1, GSP-1, STM-1, MAG-1, SCO-1, standards were analyzed to check accuracy. From duplicate analyses, the precision for the following elements is : Na_2O, ± 0.25 Wt% ; MgO, ± 0.2 ; MnO, ± 0.03 ; Ba, ± 20ppm; Ni, 10 ; Cu, 10 ; Zn, 10 ; Sr, 20. Accuracy from the standards analyzed may be set at 2x precision limits except for Sr which is 3x.

iii) Neutron activation analysis.

Accuracy and precision : La, ± 1.0 ppm ; Ce, ± 3.3 ; Nd, ± 1.0 ; Sm, ± 0.1 ; Eu, ± 0.1 ; Yb, ± 0.5 ; Lu, ± 0.1 ; Hf, ± 0.1 ; Sc, ± 0.2 ; Ta, ± 0.2 ; Th, ± 0.9 ; U, ± 0.2 ; Cr, ± 5% of amount present ; Na_2O, ± 0.1 Wt%.

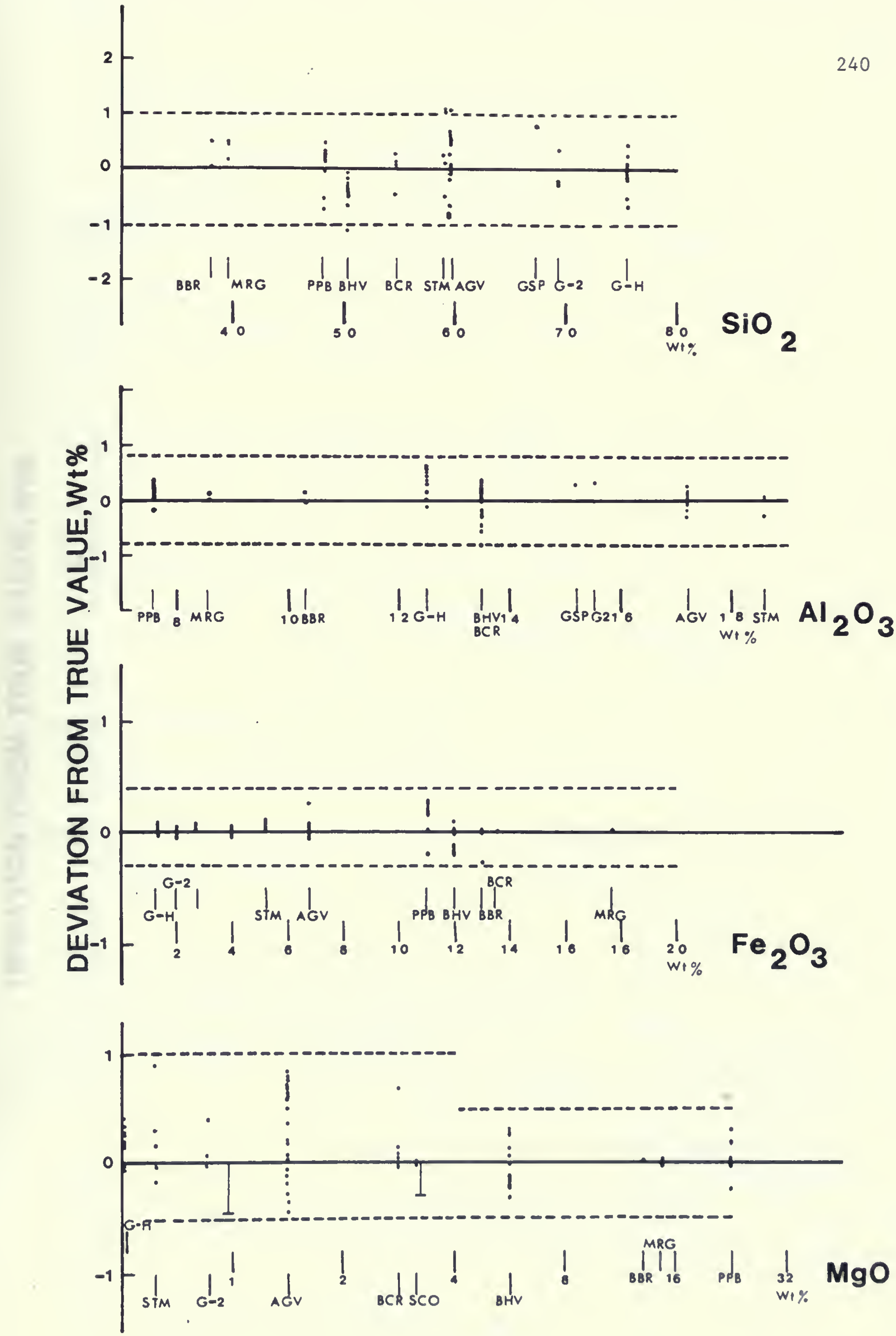

DEVIATION FROM TRUE VALUE, Wt%
BBR MRG PPB BHV BCR STM AGV GSP G-2 G-H
40 50 60 70 80 Wt%
SiO2
PPB 8 MRG 10 BBR 12 G-H BHV 14 BCR GSP G2 16 AGV 18 STM Wt %
Al2O3
G-2 G-H STM AGV PPB BHV BBR BCR MRG
2 4 6 8 10 12 14 16 16 20 Wt %
Fe2O3
STM G-2 1 AGV 2 BCR SCO 4 BHV 8 MRG BBR 16 PPB 32 Wt%
MgO

Table B3

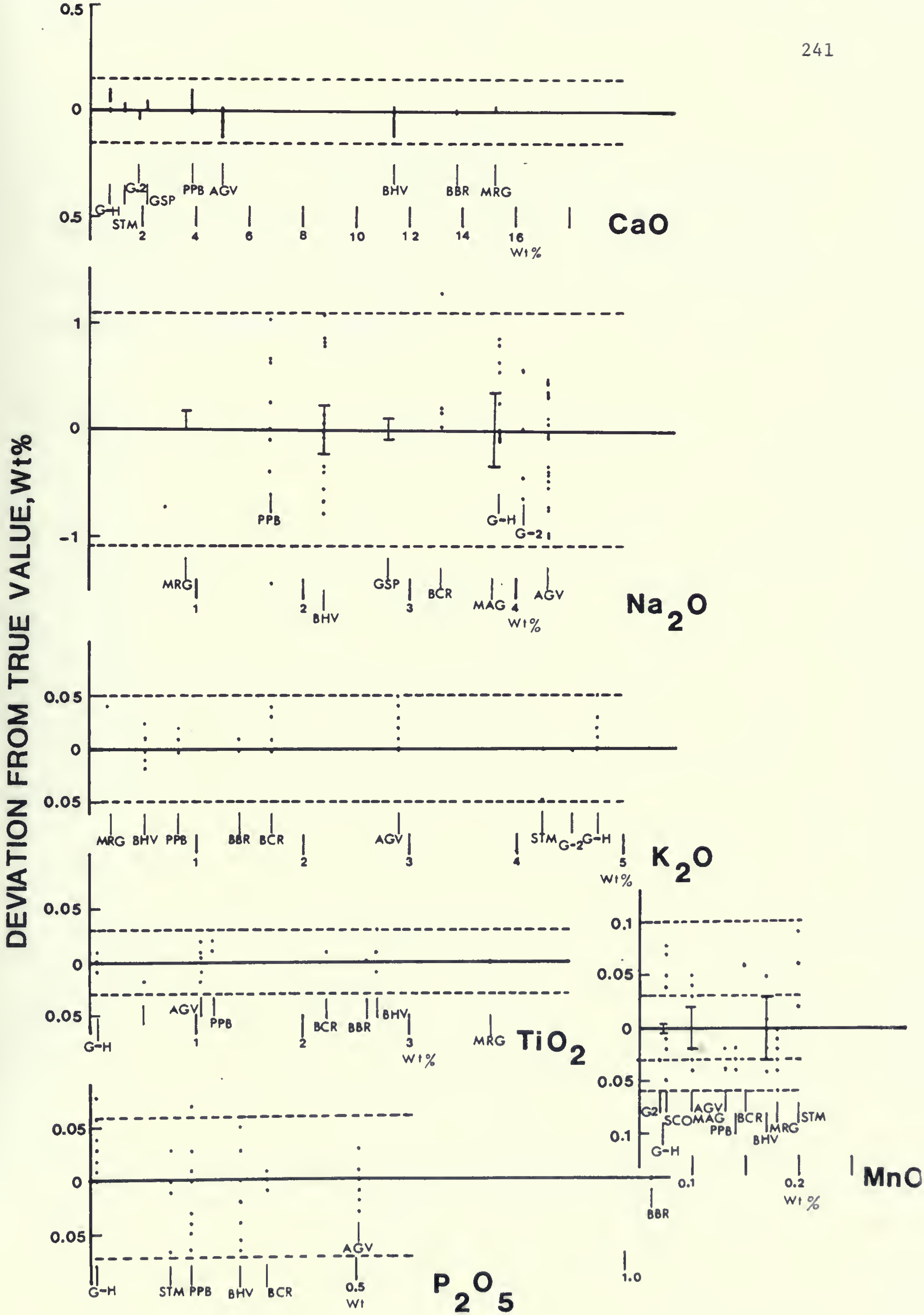


Table B3 (continued)

iv) Electron microprobe analysis.

Precision and accuracy have been determined from repetitive analysis of a kaersutite standard. The values are : SiO_2, ± 1.1 Wt% ; Al_2O_3, ± 0.5 ; FeO, ± 0.3 ; MgO, ± 0.4 MnO, ± ? ; CaO, ± 0.4 ; Na_2O, ± 0.5 ; K_2O, ± 0.1 ; TiO_2, ± 0.1 ; P_2O_5, ± ?.

Appendix C : Chemical data

Table C1 : Major elements

Table C2 : Trace elements

Table C3 : Rare-earth elements

Table C1

Sample #	SiO_2	Al_2O_3	Fe_2O_3 [1]	MgO [2]	CaO	Na_2O [2]	K_2O	TiO_2	MnO [2]	P_2O_5	LOI	Total	Description [3]
WI	63.06	I5.46	4.57	I.95	3.I9	a 3.96	I.74	0.47	a 0.04	0.20	3.95	98.59	Dc, FP, Di
WI-D	63.I9	I5.53	4.44	I.93	3.23	3.75	I.72	0.47	a 0.04	0.20	3.95	98.45	" " "
W2	50.56	I5.5I	0.20	a 5.02	I0.73	a 2.3I	I.07	0.45	a 0.2I	0.I0	4.46	I00.62	BA, Ca, Tf
W3	43.37	5.9I	I0.29	I8.00	7.I6	0.00	0.04	0.39	0.I8	0.I0	I4.56	I00.00	Um, Di
W4	56.77	I3.92	5.I2	4.I4	5.05	a 3.I0	2.43	0.5I	a 0.09	0.25	7.96	99.34	To, Di
W4-D	56.72	I4.33	5.I9	a 4.23	4.97	a 3.03	2.38	0.5I	a 0.09	0.24	7.96	99.65	" "
W5	67.57	I5.6I	4.50	0.96	3.76	3.77	0.73	0.50	0.06	0.I4	I.53	99.I3	Rh, Ca, Tf
W6	54.77	I0.09	I9.83	3.47	9.34	a 0.55	0.II	0.29	0.37	0.I0	I.35	I00.29	Ba, Th, Fl
W7	54.02	I3.45	9.I0	a 6.40	6.44	4.76	I.96	0.77	a 0.II	0.37	2.44	99.8I	Ga, Al, Di
W8	50.55	I4.65	I3.55	a 4.25	II.93	a 2.67	0.I7	0.85	a 0.2I	0.09	I.7I	I00.63	Ba, Th, Fl
W9	73.I0	I4.03	I.II	a I.40	2.00	I.82	2.58	0.I5	a 0.02	0.03	3.76	I00.00	Rh, Ca, Di
WI0-S	34.22	I7.65	23.50	aII.9I	4.22	a 0.40	0.02	I.07	0.30	0.I2	7.25	I00.66	Ba, Th, Fl
WI0-R	55.79	I4.0I	9.I6	a 4.II	I0.35	n 2.52	0.06	0.82	a 0.I3	0.07	3.94	I00.98	Ba, Th, Fl
WI0-C	49.98	I4.49	I3.67	5.76	II.50	n 0.90	0.05	0.82	0.I8	0.05	3.72	I0I.I2	Ba, Th, Fl
WII	48.53	I4.99	I3.3I	a 7.37	I0.64	n I.50	0.05	0.9I	0.I6	0.I3	3.74	I00.27	Ga, Th, Si
WI2	48.I2	I5.I9	I3.49	a 7.40	II.89	a I.84	0.05	0.88	a 0.20	0.I4	2.76	I00.48	Ba, Th, Fl
WI2-D	48.03	I4.74	I3.7I	7.65	II.94	-	0.05	0.88	a 0.20	0.I0	2.76	I00.06	" " "
WI3	48.I7	I4.34	I5.67	a 5.53	8.48	a 3.I7	0.72	I.20	0.I8	0.I3	3.I7	I00.76	Ga, Th, Si
WI4	47.75	I6.I2	II.76	a 5.07	II.2I	a I.33	0.20	0.80	a 0.I6	0.08	7.88	I02.36	Ga, Th, Si
WI5	50.83	I4.70	I3.68	a 6.52	7.I5	a 3.38	0.09	I.45	a 0.I8	0.06	2.06	I00.I0	Ba, Th, Fl
WI6	73.4I	I4.I3	I.24	a 0.40	2.00	5.46	I.95	0.I8	a 0.0I	0.06	0.75	99.60	Rh, Ca, Di
WI7	58.I3	I4.29	5.29	4.96	7.08	3.35	2.05	0.47	0.I4	0.I4	3.39	99.29	Ad, Ca, Di
WI8	50.I2	II.90	9.34	a 9.05	7.87	a 2.87	2.35	0.64	a 0.I4	0.25	5.52	I00.30	Lm, Al, Di

Table C1 (Cont'd)

Sample #	SiO_2	Al_2O_3	Fe_2O_3 [1]	MgO [2]	CaO	Na_2O [2]	K_2O	TiO_2	MnO [2]	P_2O_5	LOI	Total	Description [3]
WI9	6I.7I	I4.23	4.52	a 3.40	4.I4	a 4.70	I.98	0.49	a 0.06	0.22	4.34	99.79	Ad, Ca, Di
W20-S	35.70	I6.87	20.78	7.40	9.80	a 0.60	0.02	2.06	a 0.28	0.I2	6.77	I00.40	Ba, Th, Fl
W20-R	54.90	I3.74	I0.99	4.49	6.89	a 4.33	0.06	I.30	0.I5	0.I6	2.44	99.45	Ba, Th, Fl
W20-C	50.06	I4.24	I3.33	5.29	9.80	a 3.I0	0.05	I.33	a 0.I8	0.I5	3.I9	I00.72	Ba, Th, Fl
W22	56.04	I5.88	5.34	a 2.33	4.94	a 6.75	I.42	0.56	0.06	0.I0	5.50	98.92	Sy, Al, Di
W23	60.69	I6.77	6.49	a 4.40	0.73	a 0.40	4.53	0.48	a 0.05	0.I5	4.40	99.09	Ad, Th, Fl
W24	-	-	I.3I	a 0.52	I.68	a 3.97	2.85	0.I8	0.03	0.0I	I.28	-	Rh, Ca, Tf
W25	65.5I	I5.I0	3.50	a I.54	3.99	a 4.07	I.53	0.37	a 0.03	0.I6	4.08	99.88	Da, FP, Di
W26	75.I8	I2.58	I.36	a 0.65	3.I9	n 3.07	I.6I	0.40	a 0.02	0.07	I.28	99.4I	Rh, Ca, Tf
W27	7I.88	I4.I7	I.92	a 0.8I	2.52	n 4.I0	2.66	0.22	a 0.03	0.03	I.46	I00.00	Rh, Ca, Tf
SI	69.00	I5.68	2.7I	a I.2I	2.20	n 4.20	2.40	0.32	a 0.03	0.I6	2.I9	I00.I0	Rh, Ca, Tf
S2	65.46	I4.5I	3.I4	2.I0	3.82	a 4.48	I.79	0.39	a 0.04	0.I8	2.87	98.78	Rh, Ca, Cl
S3	58.52	I3.68	5.5I	a 7.90	4.68	a 4.40	I.88	0.59	a 0.08	0.I8	2.34	99.76	Ad, Ca, Fl
S4	56.59	I6.I6	7.69	a I.88	4.8I	a 3.39	I.52	0.79	a 0.I2	0.45	5.53	98.93	Ad, Ca, Cl
S4-D	56.56	I5.7I	7.85	a I.82	4.79	a 3.23	I.52	0.80	0.I3	0.53	5.53	98.47	" " "
S5	66.96	I4.98	2.32	a 0.80	I.83	a 4.68	2.45	0.49	a 0.03	0.24	3.89	98.67	Da, Ca, Cl
S5-D	67.08	I4.90	2.28	a 0.80	I.82	-	2.37	0.48	a 0.03	0.27	3.89	98.60	" " "
S6	62.55	I4.70	2.I9	a 0.88	5.27	5.83	I.27	0.53	a 0.06	0.26	5.70	99.24	Da, Ca, Cl
S7	72.03	I4.22	I.02	a 0.40	2.05	4.04	2.58	0.I7	a 0.02	0.04	2.8I	99.38	Rh, Ca, Tf
S8	57.76	I3.04	5.76	5.63	5.09	4.87	0.62	0.55	a 0.08	0.I7	5.2I	98.78	Ad, Ca, Di
S9	64.74	I5.I4	2.53	a I.20	2.69	a 4.67	2.05	0.4I	a 0.05	0.I3	4.59	98.20	Sy, Al, Di
SIO	63.28	I4.43	2.68	a 2.57	4.56	a 4.96	I.65	0.49	a 0.05	0.22	4.4I	99.30	Da, Ca, Cl
SII	52.03	I5.3I	II.35	a 5.98	3.4I	n 3.58	I.33	I.43	a 0.09	0.I5	6.54	I0I.20	BA, Ca, Fl

Table C1 (cont'd)

Sample #	SiO_2	Al_2O_3	Fe_2O_3 [1]	MgO [2]	CaO	Na_2O [2]	K_2O	TiO_2	MnO [2]	P_2O_5	LOI	Total	Description [3]
SI2	64.54	-	2.36	a 2.20	I.35	a 3.23	3.30	0.43	a 0.02	0.07	2.49		Da, Ca, Cl
SI3	60.95	I4.3I	9.54	a 3.40	I.I2	2.99	2.32	0.66	a 0.I4	0.09	3.60	99.I2	Wacke
SI4	74.47	II.36	I.I5	a 0.38	I.27	a 4.96	I.03	0.I6	a 0.02	0.I4	I.I8	96.I2	Rh, Ca, Cl
SI5	62.40	I2.99	3.90	a I.62	3.5I	2.83	2.86	0.56	a 0.I3	0.I2	4.II	95.03	Ad, Ca, Cl
SI6	73.92	I4.04	I.23	a 0.26	I.8I	a 5.I0	I.83	0.I6	a 0.02	0.03	I.53	99.93	Rh, Ca, Tf
SI7	67.72	I6.09	2.I8	a 0.83	I.4I	a 4.46	3.00	0.70	a 0.02	0.24	2.28	98.93	Rh, Ca, Cl
SI8	7I.67	I3.94	2.I0	a I.09	I.53	a 3.64	2.5I	0.28	a 0.02	0.I4	2.39	99.30	Rh, Ca, Cl
SI9	56.94	I5.32	6.8I	a 4.47	3.69	a 6.45	0.78	0.45	a 0.I0	0.2I	5.72	I00.94	Ad, Ca, Cl
S20	57.I7	I6.44	6.I2	a 5.40	I.69	a 4.64	3.0I	0.62	a 0.03	0.24	4.66	99.72	Ad, Ca, Cl
TI	72.25	I6.03	I.43	a 0.52	I.7I	n 3.33	2.43	0.I6	a 0.02	0.I2	I.66	99.66	Rh, QFP, S
TI0	7I.06	I4.90	I.39	a 0.35	2.05	n 4.56	2.58	0.I6	a 0.0I	0.07	2.I4	99.27	Rh, QFP, S
TI7	74.3I	I5.03	I.39	a 0.36	I.87	n 3.72	2.60	0.I7	a 0.02	0.03	0.44	99.97	Rh, QFP, S
TI9	72.I4	I5.35	I.27	a 0.43	2.07	n 4.54	2.I4	0.I6	a 0.03	0.08	I.03	99.24	Rh, QFP, S
TI9-D	72.50	I4.86	I.22	a 0.43	2.06	a 4.73	2.I6	0.I6	a 0.03	0.07	I.03	99.24	Rh, QFP, S
T28	70.88	I5.40	I.33	a 0.46	2.30	4.70	2.95	0.I7	a 0.03	0.05	I.57	99.84	Rh, QFP, S
T32	65.60	I4.73	4.6I	a 2.II	2.I2	n 3.54	2.05	0.43	0.05	0.I3	3.3I	98.69	Da, Bx, S
T38	63.94	I4.29	4.69	a 2.3I	3.48	3.86	I.98	0.50	a 0.08	0.I5	4.43	99.7I	Da, Bx, S
T38-D	64.I3	I4.26	4.57	a 2.32	3.53	3.8I	2.00	0.49	a 0.08	0.I6	4.43	99.78	" " "
BI	48.I0	I6.39	II.35	8.I8	I0.22	I.74	0.64	0.46	0.I8	0.05	3.46	I00.77	Ga, Th, Si
BI-D	47.82	I6.35	II.3I	8.79	I0.3I	-	0.64	0.46	0.I7	0.05	3.46	I0I.I0	" " "
B2	53.0I	I4.62	8.0I	a 3.I5	8.67	a 4.I8	0.07	0.77	0.I6	0.I2	7.2I	99.96	Ad, Th, Fl
B3	66.37	I4.4I	3.20	a 0.82	3.23	3.37	3.53	0.40	a 0.04	0.I3	4.35	99.84	Rh, QFP, S

Table C1 (cont'd)

Sample #	SiO_2	Al_2O_3	Fe_2O_3 [1]	MgO [2]	CaO	Na_2O [2]	K_2O	TiO_2	MnO [2]	P_2O_5	LOI	Total	Description [3]
B3-D	68.61	14.64	2.54	0.36	2.64	-	3.51	0.40	0.04	0.11	4.35	-	Rh, QFP, S
B4	62.81	14.12	3.36	a 1.34	3.94	5.11	2.22	0.42	a 0.05	0.13	6.61	100.10	Da, FP, S
B5	49.67	14.50	11.89	6.67	10.83	a 2.68	0.41	0.88	a 0.18	0.10	2.91	100.71	Ba, Th, Fl
B6	48.31	13.63	16.95	a 4.77	9.31	a 2.23	0.10	1.84	a 0.21	0.21	2.68	100.24	Ba, Th, Fl
B7	48.74	12.69	17.10	5.31	6.88	a 3.67	0.20	1.53	a 0.23	0.21	3.16	99.72	Ba, Th, Fl
B8	48.59	13.56	17.12	4.47	7.91	3.31	0.39	1.37	a 0.19	0.15	2.20	99.26	Ga, Th, Si
B9	51.29	14.24	11.82	a 5.65	10.23	a 2.74	0.10	0.88	a 0.18	0.18	2.69	100.00	Ga, Th, Si
B10	49.44	14.46	12.62	5.08	12.33	1.41	0.14	0.86	a 0.18	0.13	3.89	100.54	Ba, Th, Fl
B11	50.23	13.97	12.19	6.79	9.74	2.35	0.14	0.83	0.18	0.20	3.41	100.03	Ga, Th, Fl
B12	47.25	14.59	14.50	5.63	10.47	3.35	0.16	1.26	0.14	0.08	2.00	99.43	Ba, Th, Fl
B13	66.86	15.19	3.14	a 1.01	2.45	4.80	2.40	0.43	a 0.04	0.19	2.55	99.06	To, Ca, S
B14	65.37	15.10	2.85	a 1.10	2.52	a 5.38	2.39	0.45	a 0.04	0.17	1.37	96.26	To, Ca, S
B15	48.90	13.03	19.08	4.91	10.05	a 1.31	0.32	1.66	0.32	0.13	1.79	101.50	Ga, Th, Si
B16	48.56	14.65	13.96	5.78	10.74	a 2.49	0.21	1.23	a 0.18	0.11	1.75	99.66	Ga, Th, Si
B17	54.06	14.77	8.47	a 3.95	5.34	4.65	2.50	0.87	a 0.13	0.33	4.35	99.42	Lm, Al, Di
B18	63.83	15.25	3.91	a 1.30	3.20	6.03	2.25	0.53	a 0.06	0.29	2.30	98.75	Da, FP, Di
B19	48.72	14.50	14.91	a 3.59	7.89	a 2.85	0.08	1.53	0.22	0.14	7.23	101.66	Ba, Th, Fl
B20	45.14	16.85	12.46	a 4.84	8.33	a 4.75	0.09	1.31	a 0.24	0.11	7.47	101.59	Ba, Th, Fl
B22	49.02	11.88	16.34	a 2.17	8.00	2.94	1.00	1.64	a 0.22	0.25	7.58	101.04	Lm, Di
B22-D	48.07	11.25	16.74	a 2.14	7.95	3.46	0.99	1.64	a 0.20	0.21	7.58	100.23	" "
B23	48.54	12.63	14.58	a 3.92	8.83	2.68	0.20	1.36	a 0.25	0.18	8.25	101.41	Ba, Th, Fl
B23-D	48.59	12.40	14.88	a 4.10	9.02	2.63	0.21	1.37	a 0.25	0.15	8.25	101.85	" " "
B24	46.96	14.62	15.21	4.63	6.36	3.86	0.59	1.29	0.21	0.11	7.74	101.58	Ba, Th, Fl
B25	52.01	13.11	16.59	4.82	8.84	1.44	0.12	1.03	0.24	0.08	2.99	101.27	Ga, Th, Si

Table C1 (cont'd)

Sample #	SiO_2	Al_2O_3	Fe_2O_3[1]	MgO[2]	CaO	Na_2O[2]	K_2O	TiO_2	MnO[2]	P_2O_5	LOI	Total	Description[3]
B26	5I.95	I3.55	I3.80	a 5.36	6.6I	a 2.29	0.03	I.09	a 0.I8	0.06	6.6I	I0I.53	Ba, Th, Fl
B27	49.47	I3.98	I6.44	a 3.74	7.7I	3.34	0.44	I.44	a 0.I9	0.I6	4.07	I00.98	Ba, Th, Fl
B28	48.26	I3.I7	I4.72	a 4.26	9.84	2.22	0.I9	I.45	0.I5	0.I4	5.75	I00.I5	Ba, Th, Fl
B29	53.28	I4.35	II.87	a 4.I0	7.05	a 4.65	0.08	I.53	0.I6	0.08	4.44	I0I.59	BA, Th, Fl
B30	46.5I	I2.I6	I3.30	3.20	9.II	3.92	0.22	I.42	0.54	0.2I	I2.24	I02.84	Ba, Th, Fl
B3I	45.5I	II.23	I6.09	a 3.75	7.85	I.77	0.33	I.28	0.52	0.I2	I3.I7	I0I.62	Ba, Th, Fl
B32	43.67	I3.32	I2.88	a 4.66	8.77	2.05	0.24	I.I2	a 0.I5	0.06	I5.56	I02.48	Ba, Th, Fl
B33	5I.26	I3.29	7.0I	a 2.57	6.56	a 3.24	I.I8	0.66	0.06	0.09	I0.92	96.84	Ba, Th, Fl
B34	6I.82	I5.04	4.27	I.76	3.6I	5.85	2.84	0.57	a 0.I7	0.23	2.63	98.69	Da, FP, Di
B35	47.56	I4.6I	I7.26	a 5.64	6.67	a 3.82	0.25	I.49	a 0.20	0.II	2.39	I00.00	Ba, Th, Fl
B36	49.92	I3.42	I4.45	a 7.02	7.82	a 3.60	0.20	I.34	a 0.I8	0.I3	2.52	I00.60	Ba, Th, Fl
B37	49.45	I5.22	I2.08	7.70	I0.38	2.I5	0.I8	0.62	a 0.20	0.09	2.25	I00.32	Ga, Th, Di
B38	57.84	I5.43	I2.36	a 2.6I	2.30	3.07	I.77	0.64	a 0.09	0.08	2.3I	98.50	Wacke
B4I-A*	45.60	I5.80	I4.I0	6.78	5.40	2.45	0.02	I.23	0.I7	0.05	8.40	95.69	Ba, Th, Fl
B4I-B*	46.50	I6.60	I3.90	3.47	5.4I	I.I0	0.9I	I.36	0.I4	0.06	I0.70	96.28	Ba, Th, Fl
B4I-C*	58.30	I6.00	7.9I	I.38	4.33	I.87	0.85	0.69	0.09	0.08	7.80	96.I8	Ba, Th, Fl
B44 *	63.60	I5.60	3.24	I.03	3.I0	4.66	I.33	0.48	0.04	0.09	5.70	97.96	Da, Ca, Fl
B45 *	37.I0	I0.90	I4.30	8.I2	9.I0	0.73	0.00	0.94	0.20	0.05	I7.30	97.30	Ba, Th, Fl
B47 *	58.80	I5.90	6.27	I.42	3.79	3.98	I.40	0.7I	0.09	0.07	6.I0	96.74	Ad, Th, Fl
B48 *	70.30	I5.70	2.47	0.27	0.72	4.99	I.48	0.35	0.05	0.07	I.70	96.98	Rh, Ca, S
B49 *	53.20	I3.70	9.50	9.03	3.37	3.59	0.00	0.67	0.I4	0.04	6.70	95.76	Ba, Th, Fl
B50	48.45	I3.I7	I7.60	5.94	9.59	I.2I	0.25	I.46	0.27	0.I3	2.6I	I00.93	Ga, Th, Si
B5I	50.86	I5.07	II.35	4.9I	I2.27	a 2.I9	0.I2	0.90	0.I9	0.07	2.I8	I00.II	Ba, Th, Fl

Table C1 (cont'd)

Sample #	SiO_2	Al_2O_3	Fe_2O_3 [1]	MgO [2]	CaO	Na_2O [2]	K_2O	TiO_2	MnO [2]	P_2O_5	LOI	Total	Description[3]
KI	76.37	I2.86	0.99	a 0.I5	0.50	6.I4	0.68	0.04	a 0.02	0.02	0.89	98.65	Rh, Ca, Bx
K2	5I.65	I5.88	I0.96	4.58	5.00	4.73	0.6I	I.I0	a 0.I0	0.I7	6.3I	I0I.09	BA, Ca, Fl
K3	67.65	I4.48	2.24	a 0.59	2.78	6.I8	I.80	0.27	a 0.I9	0.I2	3.34	99.64	Rh, FP, Di
K4	5I.I2	I4.70	I0.0I	a 3.38	8.93	I.77	0.9I	I.05	a 0.I3	0.I4	7.57	99.7I	BA, Th, Fl
K5-M	45.58	I7.I7	I6.74	6.76	2.6I	a I.27	I.I7	2.29	a 0.I5	0.20	6.72	I00.66	Var, Mx
K5-F	59.08	I2.93	2.62	a 0.82	8.07	5.76	0.35	I.47	a 0.08	0.I4	7.I9	98.5I	Var, Vl
K6	48.94	I3.02	9.43	a 3.50	I0.09	a 2.9I	0.56	I.74	a 0.I5	0.I8	9.32	99.84	Var, Fl
K7	59.97	I5.03	5.67	a I.46	5.35	3.22	I.47	0.59	a 0.07	0.I3	6.II	99.07	Ad, Ca, Fl
K8	49.34	I4.76	I3.35	a 7.3I	I0.0I	a I.42	0.03	0.74	a 0.I9	0.II	3.85	I0I.I0	Ba, Th, Fl
K8-D	48.89	I4.I7	I3.68	7.5I	9.93	a I.I6	0.03	0.73	a 0.I9	0.06	3.85	I00.20	" " "
K9	43.5I	I4.03	I9.04	7.93	5.36	0.44	0.05	2.36	0.I0	0.I4	7.52	I00.57	Var, Mx
KI0	70.57	I4.2I	I.62	0.5I	2.I4	5.52	I.I7	0.I6	0.04	0.07	2.55	98.56	Rh, QFP, S
KII	54.20	I6.65	I0.55	a 2.77	7.76	3.53	0.03	I.II	0.I4	0.09	2.76	99.59	Ad, Th, Fl
KI2	68.94	I4.85	2.09	a 0.83	2.82	5.40	0.86	0.26	a 0.04	0.I4	3.I2	99.35	Rh, FP, Di
KI3	56.28	I4.72	I0.08	a 4.02	5.65	3.22	0.44	I.03	a 0.I3	0.27	3.49	99.34	Ad, Th, Fl
KI4	50.03	I5.4I	I2.99	5.32	I0.I8	I.96	0.24	I.05	a 0.09	0.I8	2.63	I00.08	Ba, Th, Fl
KI5	45.8I	II.8I	2I.I8	a 4.37	7.76	2.49	0.I2	2.60	0.3I	0.08	2.7I	99.24	Ga, Th, Si
KI5-D	46.02	II.93	2I.I6	4.4I	7.74	-	0.II	2.57	0.32	0.09	2.7I	99.55	" " "
KI6	58.I0	I5.32	7.22	3.94	4.69	3.83	0.98	0.84	a 0.07	0.I9	3.59	98.77	Ad, Ca, Fl
KI7	70.5I	I4.05	2.90	a 0.93	3.06	4.3I	I.69	0.33	a 0.04	0.06	2.38	I00.26	Rh, FP, Di
KI8	49.08	I3.08	I5.34	a 4.63	9.24	n 2.47	0.25	I.49	0.I8	0.05	4.43	I00.24	Ba, Th, Fl
KI9	48.60	I3.43	I8.40	a 5.5I	9.II	2.45	0.I7	I.38	a 0.I9	0.I7	0.56	99.97	Ba, Th, Fl
K20	78.94	I0.95	0.92	a 0.2I	2.04	3.28	I.I4	0.II	a 0.02	0.03	0.39	98.03	Rh, Ca, Bx
K2I	60.54	I6.45	6.34	a 3.73	5.56	n 3.I0	I.08	0.57	a 0.0I	0.I0	2.I6	99.64	Ad, Ca, Fl

Table C1 (cont'd)

Sample #	SiO_2	Al_2O_3	Fe_2O_3[1]	MgO[2]	CaO	Na_2O[2]	K_2O	TiO_2	MnO[2]	P_2O_5	LOI	Total	Description[3]
K22	50.68	I5.30	9.00	a 5.09	6.85	3.94	0.03	I.03	0.I2	0.I5	7.3I	99.50	BA, Ca, Fl
K23	58.63	I8.22	6.93	a 3.I3	2.66	a 5.64	I.05	0.57	a 0.06	0.I5	2.63	99.67	Ad, Ca, Fl
K24	7I.80	I3.79	2.2I	a 0.55	2.05	n 4.I8	2.I6	0.25	0.03	0.08	2.86	99.96	Rh, Ca, S
K25	53.I7	I9.I5	7.69	a 3.68	9.27	n 2.98	0.73	I.60	0.24	0.20	0.95	99.66	Ad, Ca, Fl
K26	72.02	I3.38	2.0I	a 0.46	I.75	a 4.25	2.24	0.23	a 0.0I	0.I2	3.35	99.84	Rh, Ca, S
K27	48.02	I5.94	II.66	7.27	I2.48	a I.5I	0.07	0.6I	a 0.I8	0.07	2.80	I00.63	Ga, Th, Si
K28	45.43	I2.7I	20.30	4.06	9.82	I.82	0.07	2.96	a 0.22	0.I7	2.50	I00.06	Ga, Th, Si
K32	6I.32	I5.2I	6.08	3.44	5.62	n 3.23	0.30	0.50	0.07	0.II	3.II	98.99	Ad, Ca, Fl
K33	54.83	I5.93	8.04	4.43	5.57	4.29	0.I0	0.74	a 0.I0	0.I2	5.27	99.42	Ad, Ca, Fl
K35	5I.07	I4.65	I3.00	a 6.02	7.33	a 2.74	0.23	I.30	a 0.I7	0.24	2.24	98.99	Ga, Th, Si
K36	7I.82	I4.I3	2.II	a 0.53	I.35	a 5.22	I.7I	0.23	a 0.03	0.07	I.72	98.92	Rh, Ca, Fl
K37	5I.38	I5.67	9.08	a 4.9I	6.I4	a 2.74	0.8I	0.76	a 0.I0	0.I3	7.58	99.38	BA, Ca, Fl
K37-D	5I.57	I5.7I	9.20	a 5.00	6.09	-	0.80	0.77	a 0.II	0.I3	7.58	99.70	" " "
K38	58.I8	I6.I0	6.76	a 2.83	5.55	a I.40	2.I6	0.63	a 0.07	0.20	5.55	99.43	Ad, Ca, Fl
K39	56.27	I5.2I	5.88	4.II	6.5I	3.45	2.55	0.63	0.I3	0.3I	3.95	99.00	Lm, Al, Di
K40	75.5I	II.87	n 0.65	a 0.48	2.85	n 3.7I	I.69	0.09	a 0.02	0.03	2.40	99.30	Rh, Ca, Fl
K4I	5I.89	I7.I5	7.82	5.35	9.8I	a 3.I0	0.46	0.73	0.I2	0.25	2.28	99.00	To, Ca, S
K42	59.30	I5.9I	6.59	2.76	5.I2	a 3.86	0.92	0.63	0.08	0.I7	3.56	98.90	To, Ca, S
K43	6I.4I	I6.22	5.40	a 2.68	6.49	n 3.55	0.9I	0.54	0.06	0.I2	I.76	99.I4	To, Ca, S
K44	58.99	I9.09	4.79	a 2.8I	6.26	a 4.20	I.I3	0.46	a 0.07	0.I5	I.49	99.44	To, Ca, S
K45	56.02	I4.68	9.54	3.39	5.89	a 3.37	0.6I	I.05	a 0.I3	0.30	4.03	99.0I	Ad, Ca, Fl
K46	44.65	I6.40	I0.24	aII.02	I0.I7	2.29	0.28	0.37	a 0.I2	0.I6	3.67	99.I5	Ga, Th, Si
K46-D	44.33	I6.78	I0.45	II.I6	9.98	2.20	0.28	0.39	0.I3	0.06	3.67	99.52	" " "
K47	45.7I	I6.93	I0.I8	I0.06	I0.29	2.90	0.3I	0.45	0.04	0.03	3.92	I00.82	Ga, Th, Si

Table C1 (cont'd)

Sample #	SiO_2	Al_2O_3	$Fe_2O_3^1$	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI	Total	Description[3]
K48	55.83	I5.I8	7.86	4.00	I3.72	a I.47	0.05	0.79	a 0.I6	0.I4	0.80	I00.00	Ad, Th, Fl
K49	56.96	I5.I8	9.34	4.59	7.35	n 4.30	0.33	I.00	a 0.I4	0.2I	0.9I	I00.3I	Ad, Ca, Fl
K5I	66.62	I5.33	3.63	a I.60	3.47	n 4.99	2.25	0.33	a 0.04	0.07	I.I3	99.46	Da, Ca, Tf
K52	47.85	I4.80	I3.20	7.04	II.56	a 2.29	0.22	0.88	a 0.I6	0.I0	2.27	I00.37	Ga, Th, Di
K53	54.I8	I5.68	I0.I3	5.I7	6.6I	3.39	0.42	0.93	a 0.I8	0.I5	2.70	99.54	BA, Ca, Fl
K54	59.00	I6.05	6.60	a 3.5I	6.I8	4.26	I.3I	0.54	a 0.09	0.I4	I.90	99.58	Ad, Ca, Fl
K55	59.50	I7.03	6.73	a 2.88	2.26	5.70	0.58	0.57	a 0.06	0.I2	3.88	99.3I	Ad, Ca, Fl
K56	58.35	I5.74	8.4I	a 2.36	6.55	a 3.63	0.I0	0.65	a 0.09	0.I5	3.33	99.37	Ad, Th, Fl
K57	56.86	I6.64	8.63	a 4.22	5.04	4.54	0.66	0.76	a 0.II	0.I5	2.79	I00.40	Ad, Ca, Fl
K58	55.38	I7.38	5.38	a 4.38	9.I6	a 3.80	I.09	0.58	a 0.09	0.I2	I.78	99.I4	To, Ca, S
K59	77.I5	I2.3I	0.87	a 0.I7	0.8I	3.43	4.45	0.05	a 0.0I	0.03	0.38	99.66	Rh, Ca, Fl
K60	54.48	I6.24	II.99	a 3.78	8.08	a 3.48	0.36	0.94	a 0.I5	0.I2	0.27	99.89	BA, Th, Fl
K6I	65.28	I4.77	5.5I	a 0.63	2.36	a 7.30	0.I8	0.45	a 0.07	0.I5	2.86	99.56	Da, Ca, Bx
K62	6I.27	I6.44	6.32	a 0.83	2.26	a 3.39	I.84	0.59	a 0.I0	0.I5	5.55	98.74	Ad, Th, Bx
K63	70.80	I4.50	I.96	a 0.27	I.27	a 5.43	I.34	0.24	a 0.03	0.I0	2.60	98.54	Rh, Ca, Bx
K64*	58.I0	I3.80	7.79	I.56	3.44	2.I5	2.69	I.28	0.II	0.25	8.20	98.42	Ad, Th, Fl
K65*	5I.20	I6.90	7.53	3.30	7.08	3.47	0.43	0.73	0.I0	0.06	9.40	97.52	Ba, Ca, Fl
G0	60.69	I4.82	5.03	a 4.08	3.66	a 3.36	2.69	0.49	a 0.06	0.25	4.59	99.72	Ga, Ca, Si
GI	59.68	I5.5I	5.22	a 3.63	3.7I	a I.85	3.57	0.54	a 0.06	0.28	5.03	99.08	Ga, Ca, Si
G2	48.82	I5.03	I4.45	7.46	8.I0	I.44	0.08	I.4I	0.I8	0.I5	3.34	I00.46	Ga, Th, Si
G3-A	47.40	I4.70	I5.II	a 6.85	9.64	I.95	0.I6	I.0I	a 0.I8	0.06	2.90	99.96	Ga, Th, Si
G3-AD	47.29	I4.74	I5.0I	6.54	9.62	a 2.I3	0.I6	I.00	a 0.I8	0.07	2.90	99.64	" " "

Table C1 (cont'd)

Sample #	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI	Total	Description[3]
G3-AD	47.37	14.79	15.07	7.63	9.68	a 1.95	0.16	1.02	0.18	0.09	2.90	100.84	Ga, Th, Si
G3-AD	47.47	14.78	15.08	6.72	9.79	1.88	0.16	1.02	a 0.17	0.06	2.90	100.03	" " "
G3-AD	47.38	14.59	15.16	7.62	9.42	1.85	0.15	1.03	a 0.16	0.05	2.90	100.31	" " "
G3-B	49.46	14.31	17.65	6.77	5.82	a 2.27	0.35	1.31	a 0.13	0.16	2.58	100.81	Ga, Th, Si
G3-C	44.45	15.74	18.23	8.69	6.34	a 2.20	0.12	1.09	a 0.16	0.08	3.77	100.97	Ga, Th, Si
G4	46.28	15.68	13.54	10.06	9.38	a 1.19	0.08	0.74	0.17	0.07	4.04	101.23	Ga, Th, Si
G5	44.78	14.44	14.07	11.52	9.14	1.24	0.07	0.66	a 0.17	0.05	4.32	100.46	Ga, Th, Si
G5-D	44.45	14.42	14.47	11.65	8.95	a 1.31	0.07	0.68	a 0.18	0.04	4.32	100.54	" " "
G6	45.43	16.79	9.52	6.17	10.75	a 2.65	0.23	0.61	a 0.15	0.19	8.97	100.86	Ga, Th, Si
G7	42.86	17.71	10.91	a 4.33	15.10	a 1.17	0.04	0.73	a 0.14	0.09	8.39	101.46	Ga, Th, Si
G8	49.61	14.40	1.525	a 4.85	9.99	a 2.77	0.32	1.13	a 0.19	0.12	8.76	107.39	Ga, Th, Si
G9	42.92	17.75	12.39	a 5.01	8.35	a 2.17	0.37	1.34	a 0.19	0.15	10.11	100.75	Ga, Th, Si
G10	45.83	13.86	13.17	a 5.97	8.47	0.99	0.14	0.92	a 0.21	0.07	9.54	99.17	Ga, Th, Si
G11	47.46	15.47	13.20	6.92	10.88	a 1.70	0.08	0.86	a 0.15	0.04	3.46	100.22	Ga, Th, Si
G12	47.17	14.82	15.02	7.48	9.27	0.65	0.07	0.99	a 0.18	0.13	3.87	99.65	Ga, Th, Si
G13	47.83	14.14	16.29	6.24	8.54	1.16	0.12	1.38	0.17	0.14	4.47	100.48	Ga, Th, Si
L1	68.53	15.47	2.35	a 0.84	2.28	a 5.23	2.71	0.34	a 0.03	0.11	1.67	99.56	Gnd
L1-D	68.69	15.20	2.27	a 0.72	2.32	5.18	2.71	0.34	0.03	0.14	1.67	99.27	"
L2	66.79	15.18	2.94	0.95	2.77	a 5.20	2.62	0.42	a 0.04	0.19	1.99	99.09	Gnd
L3	75.47	13.38	1.13	a 0.17	1.11	4.70	2.70	0.09	a 0.02	0.01	0.53	99.31	Gnd
L4	75.79	14.23	1.35	a 0.39	1.99	3.18	2.37	0.15	a 0.03	0.04	0.44	99.96	Gnd
L5	72.68	14.33	2.06	a 0.77	2.57	a 5.04	1.60	0.25	a 0.03	0.11	0.80	100.24	Gnd

Table C1 (cont'd)

Sample #	SiO_2	Al_2O_3	Fe_2O_3 [1]	MgO [2]	CaO	Na_2O [2]	K_2O	TiO_2	MnO [2]	P_2O_5	LOI	Total	Description [3]
L6	66.87	I5.8I	3.34	a I.22	3.8I	a 5.47	I.39	0.36	a 0.04	0.09	0.43	98.83	Gnd
L7	69.08	I4.49	2.78	a 0.93	2.22	a 5.80	2.64	0.4I	a 0.04	0.I5	I.55	I00.09	Gnd
L8	-	-	3.00	a I.03	2.59	a 4.0I	2.79	0.42	a 0.03	0.I0	I.99	-	Gnd

I - Total iron as Fe_2O_3

2 - Data from atomic absorption spectrophotometry (a) and neutron activation analysis (n)

3 - Key to abbreviations :

Ad : Andesite	Al : Alcalic	Bx : Breccia
Ba : Basalt	Ca : Calc-alcalic	Cl : Clast
BA : Basaltic Andesite	FP : Feldspar Porphyry	Di : Dike
Da : Dacite	Mx : Matrix	Fl : Flow
Ga : Gabbro	QFP : Quartz-Feldspar Porphyry	S : Stock
Gnd : Granodiorite	Th : Tholeiitic	Si : Sill
Lm : Lamprophyre	Vl : Variole	Tf : Tuff
Rh : Rhyolite		
Sy : Syenite		
To : Tonalite		
Um : Ultramafic		
Var : Variolite		

Table C2

Sample #	Ba [1]	Zr	Y [2]	Sr [3]	Rb	Zn [3]	Cu [3]	Ni [3]	Cr [1]	Sc [4]	Hf [4]	Ta [4]	U [4]	V
W2		97		378	36	108	90	59						70
W3		66		171	11	36	0	706	x 1936					83
W6		77		482	5	206	53	236						67
W7		185		628	80	84	104	120	x 476					117
W8		53		480	7	108	110	59						176
W10-S	0	49		688	7	205	90	146	x 409					225
W10-R	25	65	13	100	8	69	204	93						158
W10-C	25	57	14	367	7	86	153	99	n 232	41.5	1.2	0.4	0.13	158
W11			14						n 290	41.2	1.0	0.2	-	
W12	24	57	14	297	8	101	215	123	n 264	47.2	1.3	0.3	0.06	166
W12-D		56			7				x 279					166
W14	119	56		79	12	117	35	53	x 450					145
W16	441	160		538	67	22	10	5						14
W18	633	150		430	75	94	91	179	x 792					113
W20-S	22	83		141	6	184	60	121						295
W20-R	22	85		48	9	90	124	80						234
W20-C	n 23	78	21	276	8	99	110	84	n 140	42.6	2.0	0.5	0.06	226
W23	487	114		115	103	82	34	121						85
W24	660	167		237	118	40	97	0						15
W27	n838	165	4	434	63	47	9	12	n 29	4.2	2.2	0.5	0.30	17
S4		307		630	43	142	47	84						105
S4-D	720	305			42	103	39	80						100

Table C2 (cont'd)

Sample #	Ba[1]	Zr	Y[2]	Sr[3]	Rb	Zn[3]	Cu[3]	Ni[3]	Cr[1]	Sc[4]	Hf[4]	Ta[4]	U[4]	V
S6	502	256		153	56	31	38	40						64
S11	n 585	111	9		30				n 340			0.47	0.52	166
S12	1232	188		117	102	33	25	75						74
S16	576	162		21	62	19	13	10						12
T1	n 536	159	4	116	100	41	10	0	n 8	2.5	2.1	0.80	0.20	12
T10	n 996	174	4	140	112	23	0	6		1.9	2.3	0.60	0.48	8
T17	n 648	155	4	278	97		1	16		2.0	2.4	0.80	0.40	12
T19	n 591	158	3	326	92	40	6	2		2.3	2.3	0.80	0.33	10
T19-D	x 564	160		326	90	40	5	2						9
T28		150		126	104	44	9	8						11
T32	n 614	146	8	154	72	61	46	2	n 86	13.2	2.1	0.54	0.52	69
T38	n 474	159	9	214	67	60	39	74	n 186	12.6	2.6	0.51	0.68	74
T38-D	n 491			205		58	38	76					0.68	
B3	400	216	10	79	111	48	3	10						29
B3-D	549	209		111	111	45								26
B4	599	166		97	84	63	3	13						34
B5	274	58		65	13	90	103	94						164
B6	21	88	29	25	8	132	91	49						248
B7	80	79			9		28	63						217
B10	109	57		120	10	94	137	101						164
B14	870	237		353	82	135	7	11						45

Table C2 (cont'd)

Sample #	Ba[1]	Zr	Y[2]	Sr[3]	Rb	Zn[3]	Cu[3]	Ni[3]	Cr[1]	Sc[4]	Hf[4]	Ta[4]	U[4]	V
B16		72		165	8	114	114	91						211
B17	991	199			93	92	37	45						112
B22	203	95		33	24	111	95	16						251
B22-D	180	95		251	22	197	129	22						248
B23	93	81		109	9	127	146	37						237
B23-D	85	82		104	8	125	139	31						237
B26	0	79		131	9	118	72	43						196
B27	120	84		220	8	135	137	68						228
B28	146	87		78	10	123	113	69						200
B29	73	98		125	8	113	200	38						254
B31	188	75	8	280	14	137	164	19						246
B32	101	76		97	11	110	107	93						194
B33	278	134		402	42	64	66	43						104
B35		86	19	141	7	136	90	63	n 129	41.3	2.4	0.38	0.16	236
B36	n 73	77	19	165	7	71	176	48	n 130	46.5	1.9	0.40	0.14	245
B41-A	x 40					x117	x 95	x 84	x 298					
B41-B	x 230					x 66	x 6	x112	x 201					
B41-C	x 170					x 46	x140	x107	x 93					
B44	x 380					x 56	x165	x 7	x 10					
B45	x 200					x132	x146	x250	x 176					
B47	x 200					x 82	x 34	x 20	x 9					
B48	x 480					x 48	x 7	x -5	x 8					
B49	x 80					x 95	x 26	x220	x 288					

Table C2 (cont'd)

Sample #	Ba[1]	Zr	Y[2]	Sr[3]	Rb	Zn[3]	Cu[3]	Ni[3]	Cr[1]	Sc[4]	Hf[4]	Ta[4]	U[4]	V
K9-M		87		126	8	211	45	195	x 444					264
K13	222	124			22	102	16	37						144
K14	77	93		86	11	94	74	85						159
K18	n 41	72	21	120	12	116	112	28	n 23	43.8	1.9	0.28	0.07	243
K19		65		110	10	119	270	29						256
K20	354	211	11	118	56	15	12	2		2.0	3.5	1.70		13
K21	n 329	131	9	141	37	79	35	56	n 120	16.1	2.5	0.60	0.49	80
K22	21	111		83	10	77	65	80						157
K23	418	154		138	38	81	59	20						84
K24	n 598	176	9	47	93	40	3	4		2.9	3.1	1.00	1.14	16
K28		60		130	9	166	121	33						513
K32	n 190	157	10	62	19	69	28	48	n 116	14.8	3.5	0.70	1.02	69
K33	40	134		60	14	89	50	75						122
K34	486	126		171	28	94	36	64						106
K37		111		107	31	92	40	99						142
K38	444	145		88	66	67	64	37						83
K40	n 471	136	6	105	69	5	1	2		1.3	2.1	1.06	0.35	0
K41		102	9	366	19	79		86						116
K42		149		332	35	61	32	51						84
K43	n 193		8							12.2	3.4	0.95	0.23	
K44	284	137		112	52	45	10	48						63
K45	161	139		94	23	89	4	41						135
K49	n 194	127	15	84	14				n 50	25.9	3.4	1.04	0.26	142

Table C2 (cont'd)

Sample #	Ba[1]	Zr	Y[2]	Sr[3]	Rb	Zn[3]	Cu[3]	Ni[3]	Cr[1]	Sc[4]	Hf[4]	Ta[4]	U[4]	V
K50	n 132	115	14	239	21	98	92	104	n 65	22.5	2.2	0.34	0.34	135
K56	72	134			12	79	42	55						95
K58	333	125		146	34	98	4	84						77
K59		107			146	67	6							0
K60	118	97		234	14	93		49						168
K64	x 510					x 74	x 30	x -5	x -5					
K64-D	x 480					x 75	x 31	x -5	x -5					
K65	x 130					x 82	x 35	x 54	x 43					
G0	788	200		111	80	67	30	64	x 296					69
G1	1157	201		59	87	67	8	56	x 277					73
G2	54	75		283	9	111	124	91	x 256					247
G3A	67	59		70	9	87	153	115	x 294					161
G3A-D1	69	59		79	11	80	156	114	x 294					166
G3A-D2	70	60		79	9	84	160	121	x 292					166
G3A-D3	69	60		76	10	82	149	111	x 305					165
G3A-D4	58	60		71	9	80	154	116	x 294					167
G3A-D5		60			9				x 296					166
G3B	86	69		43	14	39	18	74	x 254					240
G3C	40	64		126	9	90	11	136	x 320					198
G4	48	52		155	9	161	147	325	x 280					126
G5	17	44		62	10	100	50	332	x 276					118
G5-D	24	44		59	5	99	105	336	x 281					111

Table C2 (cont'd)

Sample #	Ba[1]	Zr	Y[2]	Sr[3]	Rb	Zn[3]	Cu[3]	Ni[3]	Cr[1]	Sc[4]	Hf[4]	Ta[4]	U[4]	V
G6	79	57		216	13	64	263	72	x 595					111
G7	56	52		170	9	58	185	68	x 267					116
G8	110	68		230	16	88	44	30	x 160					180
G9	68	81		126	16	52	57	54	x 350					246
G10	69	58		178	10	82	191	83	x 320					175
G11	65	60		228	7	86	198	113	x 313					142
G12	21	57		104	9	92	164	145	x 190					161
G13	32	70		66	9	113	162	74	x 209					198
L2	x 948	217		732	89	66	6	16						36

1 : x - Analyses by XRFS

a - Analyses by AAS

n - Analyses by instrumental neutron activation

2 : Analyses by ICPS

3 : Analyses by AAS

4 : Analyses by instrumental neutron activation

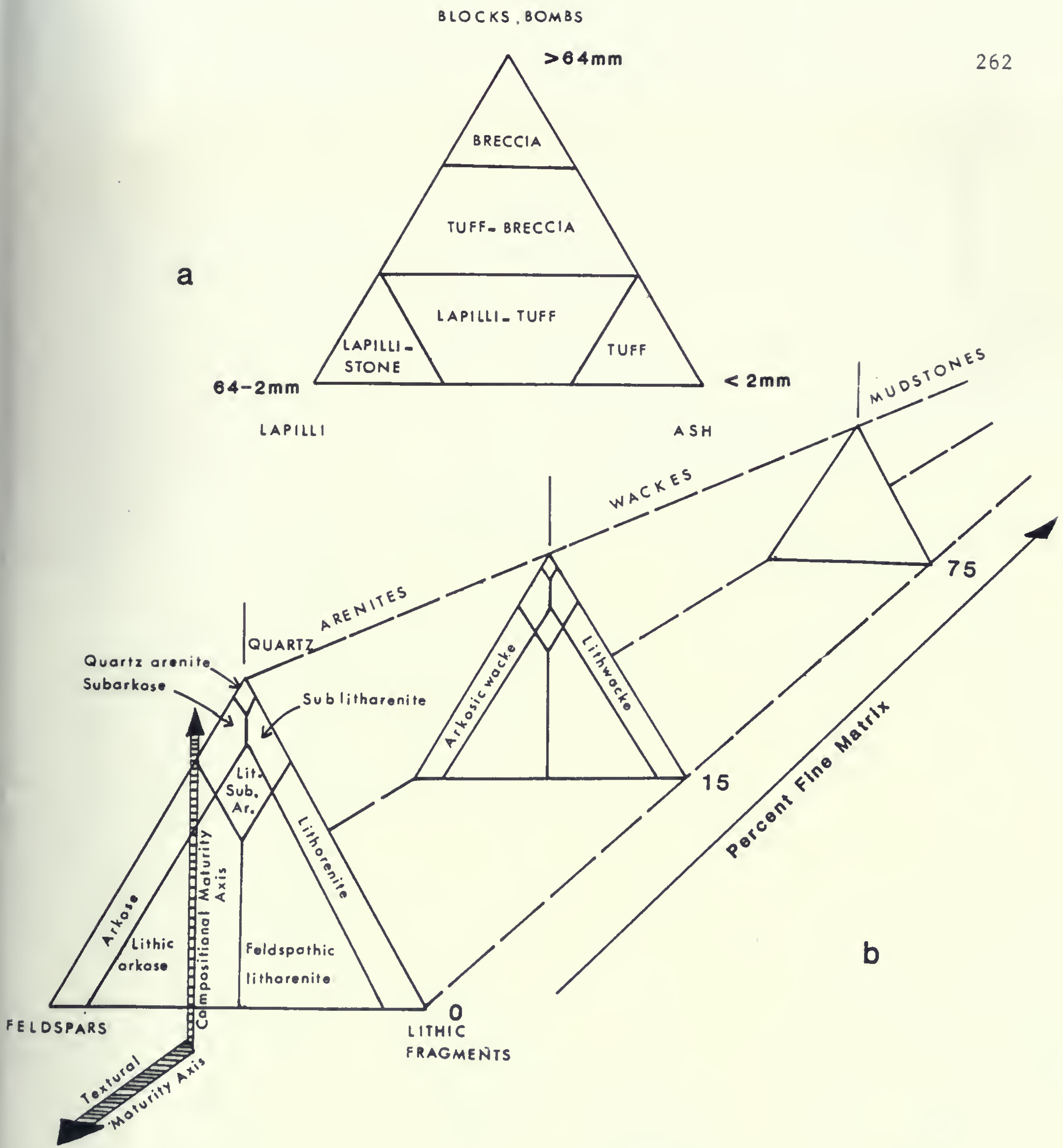
*Negative numbers indicate that concentration is below detection limit.

Table C3

Sample #	La	La_N	Ce	Ce_N	Nd	Nd_N	Sm	Sm_N	Eu	Eu_N	Yb	Yb_N	Lu	Lu_N
W10-R	2.4	7.5	-	-	5.5	9.1	1.6	8.3	-	-	2.0	9.5	0.34	10.5
W10-C	2.3	7.2	6.7	8.2	3.5	5.8	1.6	8.2	0.55	7.6	2.2	10.8	0.37	11.5
W11	2.6	8.1	8.1	10.0	2.9	4.8	1.7	8.6	0.86	12.0	2.0	9.4	0.39	12.0
W12	2.3	7.2	8.9	10.9	6.4	10.8	1.8	9.2	0.81	11.2	2.4	11.6	0.35	10.9
W20-C	3.8	12.2	9.7	11.9	8.3	13.9	2.8	14.3	0.87	12.1	3.2	15.5	0.54	16.6
W26	23.1	73.5	53.5	65.8	22.5	37.8	3.6	18.7	0.85	11.8	0.28	1.4	0.05	1.5
W27	8.0	25.5	18.3	22.5	5.6	9.5	1.2	6.5	0.39	5.4	0.24	1.2	0.01	0.3
S1	22.0	69.7	47.7	58.6	16.0	26.7	3.1	16.1	0.82	11.4	0.26	1.3	-	-
S11	13.8	43.9	33.6	41.3	14.1	23.5	3.3	17.2	1.06	14.1	1.06	5.1	0.17	5.4
T1	7.7	24.4	18.2	22.4	4.5	7.5	1.0	5.3	0.40	5.6	0.06	0.3	0.01	0.4
T10	8.5	26.9	15.8	19.5	5.9	9.9	1.2	6.4	0.42	5.8	0.05	0.2	-	-
T17	7.2	23.0	17.3	21.2	4.9	8.1	1.0	5.2	0.31	4.3	0.08	0.4	-	-
T19	7.1	22.5	12.5	15.3	4.2	7.0	1.0	5.4	0.26	3.7	0.16	0.8	-	-
T32	13.5	42.7	27.6	34.0	9.8	16.5	2.3	11.9	0.68	9.4	0.62	3.0	0.05	1.5
T38	23.0	72.9	57.6	71.0	18.4	30.1	3.4	17.9	1.06	14.7	0.33	1.6	0.05	1.4
T38-D	26.0	82.6	-	-	18.6	31.2	3.7	19.1	-	-	0.55	2.6	0.05	1.6
B35	8.9	28.1	21.2	26.0	13.2	22.2	3.3	16.9	1.00	13.9	3.4	16.1	0.60	18.5
B36	4.2	13.3	11.5	14.1	8.1	13.6	2.9	14.9	0.91	12.5	3.2	15.5	0.38	11.9

Table C3 (cont'd)

Sample #	La	La_N	Ce	Ce_N	Nd	Nd_N	Sm	Sm_N	Eu	Eu_N	Yb	Yb_N	Lu	Lu_N
K11	10.2	32.5	26.5	32.6	10.5	17.5	2.9	15.0	0.78	10.7	21.1	10.1	0.35	10.9
K18	4.3	13.6	11.4	14.1	8.7	14.7	2.6	13.3	1.16	16.1	3.1	14.8	0.61	18.8
K20	15.4	48.8	36.1	44.4	12.4	20.8	2.0	10.2	0.63	8.7	0.7	3.5	0.10	3.1
K21	13.5	43.0	27.5	33.8	10.4	17.4	2.1	10.8	0.80	11.1	0.8	3.8	0.13	4.0
K24	18.6	58.9	34.3	42.2	12.8	21.5	2.6	13.6	0.48	6.7	0.6	2.9	0.04	1.1
K25	7.5	23.6	18.1	22.2	11.0	18.4	3.4	17.9	1.01	14.1	2.5	11.8	0.41	12.6
K32	16.9	53.6	33.2	40.8	11.8	19.8	2.3	11.9	0.64	8.9	1.04	5.0	0.16	4.9
K40	18.4	58.3	40.5	49.8	10.3	17.3	1.3	6.6	0.40	5.5	0.29	1.4	0.04	1.2
K43	12.2	38.7	25.8	31.7	10.2	17.0	2.1	11.0	0.73	10.2	0.97	4.7	0.16	5.1
K49	13.8	43.9	29.4	36.2	15.4	25.7	3.4	17.6	0.94	13.0	2.06	9.9	0.36	11.2
K50	12.1	38.3	16.8	20.7	11.8	19.8	2.6	13.7	0.70	9.8	1.80	8.7	0.29	9.1



a : Classification scheme of pyroclastic rocks after Fisher (1966).

b : Classification scheme of sandstones after McBride (1963) and Young (1967).

Appendix D