Stratigraphy of the Western Lake St Joseph

Greenstone Terrain, Northwestern Ontario

By

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Abstract

The western Lake St. Joseph areain Northwestern Ontario is underlain by Archean metavolcanic and metasedimentary rocks. The strata, referred to as the Lake St. Joseph Group comprise three formations representative of mafic to felsic volcanic cyclicity. The Blackstone Formation, stratigraphically the lowest, contains a lower member compoeed of predominantly high-Mg, low-K tholeiitic pillowed basalts and an upper member composed of rhyoliticflows and pyroclastic rocks. The overlying Western Lake St. Joseph Formation contains a lower member composed of predominantly calc-alkaline massive and pillowed basalts and an upper member composed of dacitic pyroclastic and epiclastic rocks. The overlying Carling Formation contains a volcanic member and a sedimentary member. The volcanic member is composed predominantly of high-Fe, low-K tholeiitic pillow breccias and dacitic to rhyolitic epiclastic and pyroclastic rocks. The sedimentary member consists of basal greywacke turbidites and laminated iron formation of economic potential overlain by chloritic classical turbidites. These sedimentary rocks are overlain by massive and cross-bedded arkosic greywackes which are in turn overlain by conglomerate and pebbly sandstone.

The deformation of the rocks is expressed by isoclinal folding, most evident on Eagle Island, anddevelopment of the regional Lake St. Joseph Fault. Contact and regional metamorphism(lower to middle greenschist facies) have also affected the rocks.

The primary structures, vertical and lateral variations in the felsic volcanic rocks of the Blackstone and Western Lake St. Joseph Formations indicate deposition on a subaqueous paleoslope. Similarly the felsic

volcanic rocks of the Carling Formation indicate subaqueous deposition on a different paleoslope.

The lithologies, primary structures, vertical and lateral variations of the units in the sedimentary member of the Carling Formation indicate deposition on a prograding submarine fan. Meyn and Palonen(1980) support this interpretation.

Reconstruction of the paleoenvironment envisages three stages of evolution. Instage 1 the Blackstone and Western Lake St. Joseph Form-tions are extruded and deposited on the flank of a volcanic edifice. In stage 2 the volcanic member of the Carling Formation is extruded from a separate vent and in part deposited upon the degradation products of stage 1. In stage 3 laminated iron formation is deposited with clastic sediments in a submarine fan-basin plain system to form the sedimentary member of the Carling Formation.

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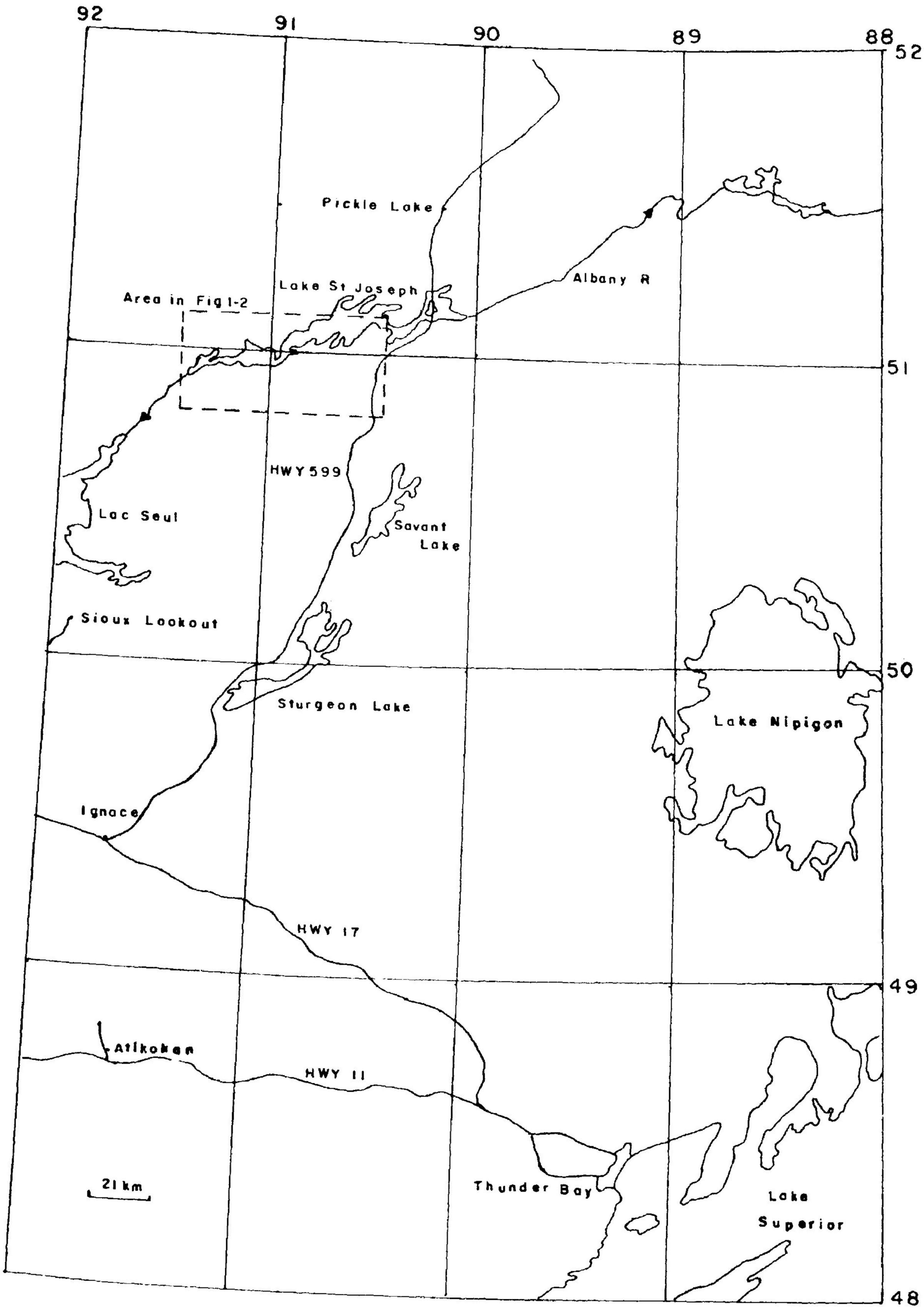
CHAPTER I - INTRODUCTION

GENERAL STATEMENT AND PURPOSE OF STUDY

The Superior Province of the Canadian Shield contains a number of terrains in which volcanic and/or sedimentary rocks are the predominant lithologies. These terrains, referred to as greenstone belts are among the oldest known supracrustal assemblages in the world and are Archean in age. Besides their contribution to man's knowledge of the earth's early history these belts are also economically important as they host a variety of mineral deposits. The stratigraphy of the Archean terrains is commonly organized into mafic-felsic cycles represented by diverse lithologies [Young, (1978); Glikson, (1978); Gorman et al., (1978)].

The Western Lake St Joseph area (Fig. 1-1) is composed of volcanic and sedimentary rocks (Fig. 1-2) amenable to stratigraphic studies. Previous investigations of the area by Bruce (1922), Clifford (1969) and Clifford and McNutt (1971) did not rigourously apply the mafic-felsic cyclic concept to the stratigraphic sequence. Therefore, it is the purpose of this study to demonstrate that the stratigraphy at Western Lake St Joseph is divisible into three volcanic-sedimentary

Fig. 1-1 Location Map



cycles. Documentation of each cycle with respect to physical, structural and chemical properties was undertaken. In addition, interpretation of selected stratigraphic sections permits limited reconstruction of the ancient environment.

METHOD OF INVESTIGATION

An area of approximately 266 square kilometers was mapped during 182 days during the summers of 1977 and 1978 at 1:16,000 scale. Aerial photographs provided the necessary control and are the basis for the maps presented in this thesis (Maps 1 and 2 in pocket). Shoreline and pace and compass traverses as well as controlled grid mapping were conducted over certain parts of the area. Wherever possible the results of ground geophysical surveys completed by exploration companies were utilized forming part of the interpretation of the mapping, especially in areas covered by water. As well, available diamond drill data have been incorporated onto the maps. Hand samples and diamond drill core samples were collected to obtain a representative rock suite of the Western Lake St Joseph strata. These samples formed the basis for 85 thin and polished sections and 39 whole rock and trace element geochemical analyses.

NOMENCLATURE

The Western Lake St Joseph area has previously not been subdivided into cycles. Therefore several new names are introduced to describe the strata. In this thesis the entire rock assemblage is referred to as the Lake St Joseph Group. Three cycles are recognized in the Group and these are referred to as the Blackstone Formation, the Western Lake St Joseph Formation and the Carling Formation in order of stratigraphic superposition. The names for each formation are taken from locally recognized geographical features. The formations are further divided into members on the basis of similarity of lithology, environment or process of deposition.

There are commonly many definitions for one word in the geologic literature. To avoid confusion the following nomenclature for volcaniclastic and sedimentary rocks is used in this thesis. Volcaniclastic rocks include all fragmental volcanic rocks that result from any mechanism of fragmentation (Lajoie 1979). Various forms of volcaniclastic rocks include epiclastic fragments which result from the weathering of volcanic rocks, hyaloclastic fragments which are produced by quenching of lava that enters water and pyroclastic fragments which are formed by explosion and are ejected from volcanic vents (Lajoie 1979). A grain-size classification for pyroclastic fragments used by Fisher (1961, 1966) is adopted in this thesis (see Table 1-1).

Table I-I Classification Scheme

Predominant Grain Size (mm)	Epiclastic Fragments	Pyroclastic Fragments	Pyroclastic Rocks
	Cobble	Block and Bomb	Pyroclastic Breccia
64			
	Pebble	Lapillus	Lapillistone
2			
	Sand	Coarse Ash	Tuff
1/16			
	Silt	Fine Ash	

After Fisher (1961, 1966)

In reference to clastic sedimentary rocks in the arenite size range Blatt et al., (1972) use the name greywacke as a field term arguing that the only petrologic distinction of these rocks is their heterogeneous mineral compositions. This thesis follows the definition of Blatt et al., (1972) with one distinction. Map unit 8b is referred to as an arkose because it is physically distinct from other greywackes in the field. All greywackes in the mapped area are true greywackes because they contain more than 15% matrix (Blatt et al., 1972) .

All the rocks in the thesis area have been metamorphosed and original clay content of the sediments is now represented by biotite, white mica and chlorite. These minerals are considered to be the matrix of the greywackes in accordance with the observations of Williams et al., (1954).

Wherever possible previously proposed place names are used. Three places, Kitty Creek, Bear Island and Mile Five Lake are introduced as new names for convenience of reference. Bruce (1922) numbered all the islands in the Western Lake St Joseph area. Clifford (1969) referred to this numbering system extensively and the present study uses the island numbers as well.

REGIONAL GEOLOGY

The thesis area is within the Uchi greenstone belt of the Superior Province of the Canadian Shield (Fig. 1-2).

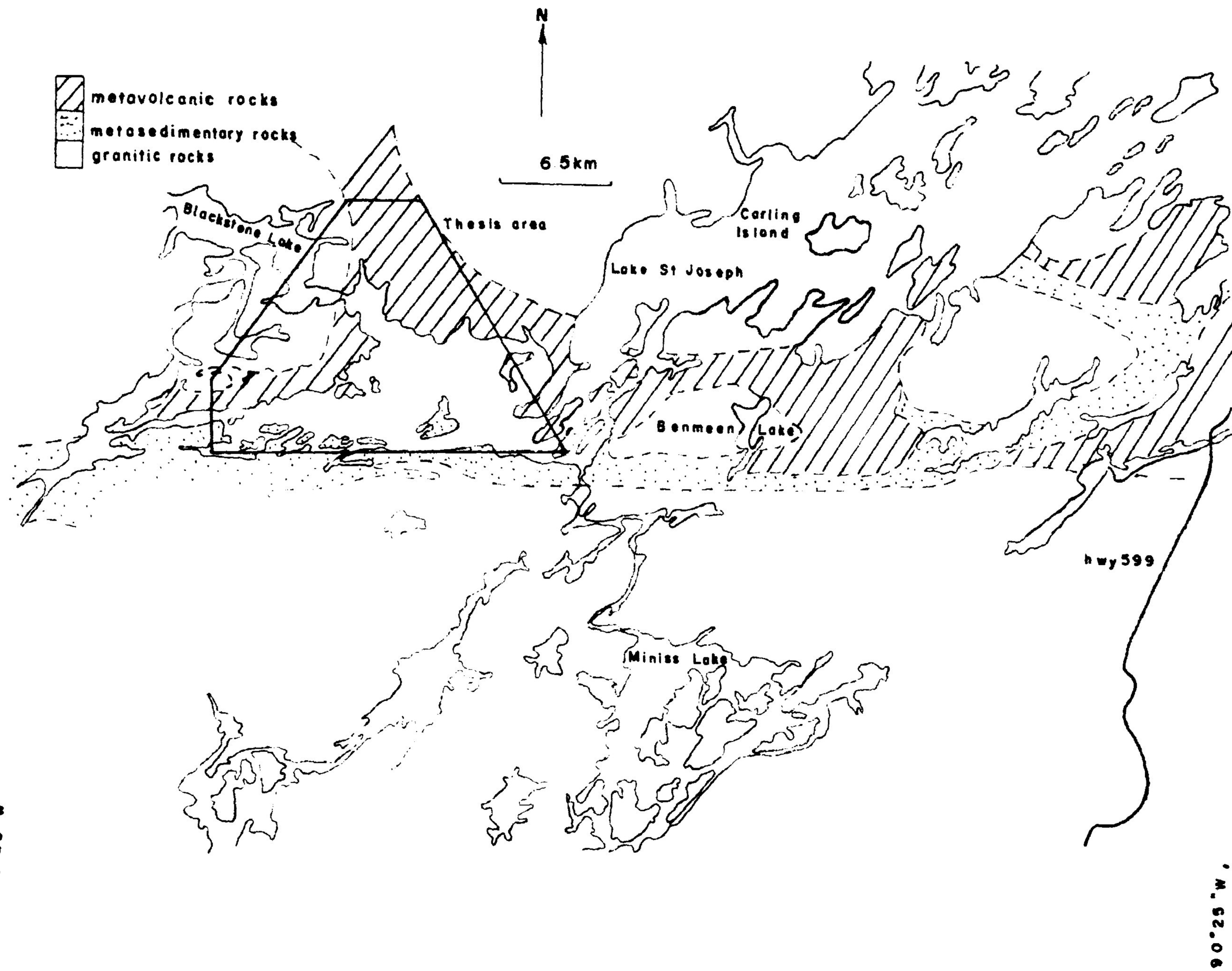


Fig.1-2 Regional Geology (after ODM maps 2169 and 2218)

East of the thesis area the volcanic rocks form a continuous assemblage pinching and swelling around granitic batholiths for approximately 350 km. To the north the Lake St Joseph volcanic rocks intercalate with volcanic rocks of the Bamidji-Fry Lakes and Kapkitchi Lake areas. The volcanic rocks are truncated west of the thesis area by granitic intrusions and faults but elements of the greenstone belt are located about 27 km to the west near Root Lake.

Two large granitoid batholiths intrude the volcanic rocks and define their borders. The Blackstone Batholith forms the western border of the volcanic rocks. It is granitic in composition with numerous xenoliths and roof pendants of metavolcanic rocks along with xenoliths of well banded granitic gneisses (Clifford, 1969). The eastern contact of the Lake St Joseph Group is defined by the Carling Batholith. According to Clifford (1969) this intrusion is more homogeneous than the Blackstone batholith. It is predominantly a biotite-plagioclase-orthoclase-quartz rock which contains porphyritic phases. Near the volcanic contact xenoliths are abundant but more commonly the Carling batholith is a massive, relatively "unlayered" body (Clifford, 1969).

Rocks belonging to the English River gneiss belt form the terrain south of Lake St Joseph (Thurston and Breaks, 1978). These rocks consist of highly metamorphosed paragneisses, migmatites and granitoid intrusions. The contact between the greenstone belt and the gneiss belt is defined by an abrupt change in structure and lithology. In the thesis area the

Lake St Joseph Fault is a physical break between sediments of the Carling Formation and migmatized sediments of unknown affinity in the gneiss belt. Near Pashkokogan Lake 40 km east of the thesis area high grade metatexites are juxtaposed to low grade volcanic rocks emphasizing this dichotomy (Thurston and Breaks, 1978). The geology of the gneiss belt is not relevant to this study and is therefore subsequently treated in a cursory manner.

CHAPTER II - LITHOLOGY AND PETROGRAPHY

INTRODUCTION

The strata at Western Lake St. Joseph is divided into three formations based on the size and extent of the lithologies, primary structures and mineralogy. The following is a detailed description of the lithology and petrography of each member of each formation. Stratigraphic thicknesses have been altered by tectonic deformation and are therefore only approximate. Nevertheless, a sequential stratigraphy has been developed from detailed mapping allowing plausible reconstruction of an ancient, predominantly volcanic terrain.

THE BLACKSTONE FORMATION

The Blackstone Formation is composed of a lower mafic member and an upper felsic member. The mafic member consists of massive and pillowed basaltic flows with minor interbedded greywacke and argillite. The granitic Blackstone batholith has intruded the lower member such that rocks older than the greenstone are not exposed in the thesis area. The "greenstone-granite" contact as observed where the Cat River empties into Johnston Bay (see Map 1) is defined by a change from a xenolith poor granite to a deformed pillowed basalt over a few centimeters.

LOWER MEMBER

The lower member of the Blackstone Formation is exposed over 17 km in the thesis area and extends to the west and north into adjacent greenstone terrains. Thickness of the member is variable from a minimum of 340 m near Kitty Creek (Map 1) to a maximum of 3600 m at island 285 (Map 2). Although tectonic modification of the stratigraphic thickness has occurred this variation in thickness is interpreted to be due in part to original lateral variation in the member.

Pillow basalts are characteristic of this member. They are typically 0.5 to 1 m in size, oval in shape and light green to black (Appendix II, Plate 1). Their primary mineralogy has been altered into a metamorphic mineral assemblage of chlorite + actinolite + epidote + saussuritized plagioclase ± calcite ± quartz. The outer edges of the pillows are vesicular or non-vesicular and contain well defined narrow selvages (avg. 2 cm).

As the contact between the lower member and upper member of the Blackstone Formation is approached pillow shapes become more irregular in the lower member and inter-pillow matrix (Carlisle, 1963) increases (Appendix II Plate 2).

Normal pillowed flows become more vesicular and massive flows which are rare lower in the member become more abundant. Locally mafic lapillistone is present (island 285, Map 2).

The stratigraphy of the lower mafic member is complicated by numerous minor intrusions. These can be divided into four types; gabbro, quartz-feldspar porphyries, intermediate subvolcanic intrusions and a granitic stock.

The gabbros are generally lenticular intrusions up to 100 m wide normally concordant with the foliation or with faults. They appear to be less altered than their volcanic host, are medium to coarse grained and are widely distributed in the lower member.

The quartz-feldspar porphyries (avg. 40 m wide) occur as irregularly shaped lenses which are concentrated near the upper contact of the mafic member. They are found along the north shore of Lake St Joseph and near the Cat River. The porphyries weather white to cream and contain phenocrysts of plagioclase and quartz up to 1 cm in diameter.

The intermediate subvolcanic intrusions are typically schistose, irregular bodies which may be concordant or discordant with the strike of the pillow basalts. They are normally a lighter green than the pillowed flows and have undergone minor but pervasive hematite and carbonate alteration.

A granitic stock has intruded the lower member of the Blackstone Formation near Bear Island (see Map 1). The stock is composed of a hybrid granodioritic rock that has intruded as a ramifying network of veins especially near the "stock-greenstone" contact. Because of its largely granitic character it is assumed to be equivalent in time with the intrusion of the Blackstone batholith.

Reliable top indicators are rare in the mafic volcanic rocks of the Blackstone Formation because pillows are generally oval and are not amenable to top determination. In addition, the lower member has undergone sufficient tectonic deformation to destroy many of the primary structures (Clifford, 1972). However, locally, pillow tops indicate that the sequence youngs to the south or southeast. This is supported by the stratigraphic transition from normal pillows to irregular pillows to massive flows and pyroclastic rocks which as Ayres (1977) documents is indicative of an emerging volcanic pile.

UPPER MEMBER

The upper felsic member of the Blackstone Formation conformably overlies the lower mafic member except where the two members are in fault contact along the Main fault (Map 2). The member is exposed for approximately 11 km along strike and thickens from 100 m in the west to 880 m near island 264 (see Map 2). This is an apparent trend complicated by the faulting pattern. The lateral and vertical variations in the member are much clearer.

In the west end of the thesis area the member is composed of massive rhyolitic flows and subvolcanic intrusions accompanied by minor pyroclastic tuff and lapillistone. Macro-

scopically the flows and intrusions resemble the quartz-feldspar porphyries that intrude the lower mafic member. Pyroclastic volcanic rocks become more abundant east of island 371 (Map 2) and flows become rare. Coarse (up to 1 m) pyroclastic breccias on islands 224 and 227 (Map 2) contain ribbons and blocks of flow laminated rhyolites characteristic of vent facies volcanism.
From island 285 northward the clasts of the pyroclastic and epiclastic rocks progressively fine in diameter laterally and vertically.
On island 264 (Map 2), the volcanic rocks are mainly volcaniclastic and grade into epiclastic sediments along strike to the north. A fault north of island 264 has offset the upper felsic member and it is not exposed between here and island 327 (Maps 1 & 2). On this island the felsic member is composed of sand sized epiclastic rocks which are well bedded and locally graded. A polymict conglomerate is exposed at the contact of the upper felsic member with the overlying Western Lake St Joseph Formation and it contains clasts of iron formation, chert and volcanic rocks.

North of island 327 the upper member has been located only by diamond drilling and consists of the epiclastic material previously described interbedded with graphitic argillite. The member narrows rapidly and is assumed to pinch out along strike north of the diamond drill hole (Map 1).

The changing character of the upper member can also be documented petrographically. The holocrystalline intrusive rocks in the west contain coarse-grained (4 mm avg.) euhedral to subhedral, interlocking crystals of albite and quartz with accessory biotite, chlorite and fluroapatite. Further east on islands 224 and 227 (Map 2) the coarse pyroclastics contain phenocrysts and glomerophyres (up to 2 mm) of euhedral albite and quartz in a very fine matrix of quartz and metamorphic muscovite. On island 264 the volcaniclastic rocks contain rounded or broken albite crystals rather than euhedral shapes. Rounded lithic fragments identical to the matrix described above are also present. Metamorphic muscovite and calcite are more abundant in these volcaniclastic rocks than in the flows and pyroclastic rocks further west. These features indicate that sedimentary processes were dominant over volcanic processes in the eastern end of the upper member.

The felsic pyroclastic rocks of the upper member change in size, shape, composition and primary structures going from west to east. Angular rhyolitic breccia blocks with flow lamination up to 1 m, but averaging 15-30 cm, in diameter are abundant on islands 212, 224 and 227 (Map 2). On islands 285 and 264 (Map 2) the pyroclasts are more rounded, average 2 to 10 cm in diameter and are rarely larger than 15 cm. The majority of the clasts are rhyolitic but accessory pyroclasts and exotic blocks of mudrock (Appendix II Plate3) are mixed in with the beds. Most of the pyroclastic material is poorly bedded in the western part of the upper member but normal graded beds (Appendix II Plate 4) and parallel stratified beds of pyroclastic and volcaniclastic material are common further along strike to the east. The grading indicates younging to the east in conformity with the younging information from pillows of the underlying lower mafic member.

The upper member hosts distinctive breccias on island 212, which contain rounded to angular blocks up to 1.5 m in size set in a deep red iron-oxide, iron-carbonate matrix (Appendix II, Plate 5). The breccia occupies zones a few meters wide which are roughly concordant with the stratigraphy. The iron alteration is pervasive throughout the felsic volcanic rocks and is also found in overlying mafic volcanic rocks of the Western Lake St Joseph Formation up to 2 km from island 212 (Map 2). The alteration is expressed as ankerite-sulphide pods, hematite, dolomite and hematized dolomite dispersed throughout the rocks. Lorenz et al. (1970) explain similar breccias and cement as the result of phreatomagmatic explosions possibly related to diatreme intrusions. Clifford (1969) suggested that brecciated tuff zones which crosscut bedding planes were the result of diatremes intruded into the Lake St Joseph Group. As yet there is no conclusive evidence to support or refute this hypothesis.

THE WESTERN LAKE ST JOSEPH FORMATION

LOWER MEMBER

The Western Lake St Joseph Formation is composed of a lower mafic member and an upper felsic member. The lower member extends laterally for 7.5 km and is approximately 200 m thick. Lensoid basaltic to andesitic massive and pillowed flows are intercalated with or transitional to andesitic lapillistone, hyaloclastite and epiclastic rocks.

The massive flows of the lower member are medium to fine grained rocks which are commonly amygdaloidal. They are of variable thickness and are most common near the base and in the western part of the formation. The pillow morphology of basalts in the Western Lake St Joseph Formation is different from that of the Blackstone Formation. Three types of pillowed flows are found in the lower member of the Western Lake St Joseph Formation; closely packed, well formed amygdaloidal pillows, 50-70 cm diameter; large oblate irregularly shaped pillows up to 5 m in size and pillows with large vesicles concentrated near the selvages. The first two pillow types are found only locally in the lower member but pillows with large vesicles near the selvages are very common. (Appendix II, Plate 6).

The fragmental rocks of the lower member consist of hyaloclastites, lapillistones and epiclastic rocks. The hyaloclastitic rocks contain angular, green to grey fragments of andesite in a dark green chloritic matrix. They are intercalated with or overlie pillowed flows and are best exposed on island 264 (Map 2). The lapillistones consist of white dacitic fragments and andesitic fragments in a dark green chloritic matrix. The epiclastic rocks consist of sand and silt sized mafic grains which are distinctly bedded and locally graded with tops to the east or southeast. Rarely, fragments of sulphide iron formation are found in the sediments.

Lateral and vertical variations within the lower member are poorly developed. Top indicators are rare but conformity with the underlying Blackstone Formation is suggested by the few primary structures observed.

UPPER MEMBER

The upper member of the Western Lake St Joseph Formation is composed predominantly of dacitic and rhyodacitic pyroclastic and epiclastic rocks. The member extends laterally for about 17 km. It is thickest (2650 m) near Eagle Island but thins northward until it pinches out north of Johnston Bay. In the west end of the thesis area (Fig. 1-2) the member terminates at a fault on island 371 (Map 2) where it is juxtaposed to the felsic member of the Blackstone Formation.

The clasts in this member are composed of 90% (avg) white feldspathic dacite-rhyodacite and 10% (avg) chert and lithic fragments. The matrix is composed of primary albite and quartz crystals and metamorphic muscovite and chlorite. The clasts range between 1 mm and 40 cm in diameter but average 2 to 10 cm. The weathered surfaces are white to buff but on fresh surfaces clasts are white and matrix is green. Bedding planes are well developed in the epiclastic rocks on several islands in the central part of the thesis area. Reverse and normal grading and load casts are common features. Younging directions are to the south, southeast and east which is consistent with the stratigraphy so far established. The beds of breccias and lapillistones are commonly 30 cm $\pm$ thick whereas tuff beds may be only 1-2 cm thick. Blue quartz "eyes", are common throughout the member and crosscutting silica veinlets are present west of Eagle Island.

This member exhibits lateral and vertical variations similar to those documented for the felsic member of the Blackstone Formation. The western exposures are chaotically bedded pyroclastic rocks that generally fine upward over 650 m of stratigraphic thickness. In this section lapilli-sized feldspathic dacite-rhyodacite grains are common in a micaceous matrix. As well, lapilli-sized lithic clasts identical in mineralogy and texture to the Blackstone Formation felsic pyroclastic rocks are present. These lapilli are rounded to subangular or rarely elongate. Accompanying the lapilli are euhedral albite crystals which occur isolated in the matrix. These features indicate that the rocks are primarily pyroclastic rather than epiclastic.

Near Eagle Island rocks of the upper member of the Western Lake St Joseph Formation are well bedded and crudely graded (Appendix II, Plate 7). Clasts are up to 40 cm in diameter but the average size is 5 cm. The clasts are rounded or irregular in shape and still have the same composition as those further to the west. Petrographically the clasts show little elongation, and matrix is more abundant. Albite crystals are commonly rounded and locally broken implying that they have been transported. These rocks are epiclastic reflecting the predominance of sedimentary processes during deposition.

North of Eagle Island the upper member thins and the rocks are mixed pyroclastic breccias and epiclastic rocks. The breccias are subordinate to epiclastic rocks and there is a general lateral-fining of clasts to the north. Near Bear Island (Map 1) the pyroclastic breccias are intercalated with greywackes and are volumetrically a minor component. However, further north on the mainland (Map 1) the volcanic component increases and once again dominates the member.

The upper member of the Western Lake St Joseph Formation defines a fining upward sequence which progressively becomes more sedimentary in character. The average clast size decreases from approximately 10 cm in diameter near the base to less than 1 mm near the top. Locally flows are present near the base of the member and bedding is absent. Further up in the member autobrecciation and pyroclastic activity has produced crudely bedded deposits as seen on some small reefs 1.5 km northwest of Eagle Island (Appendix II, Plate 8). Approaching the upper contact of the member bedding becomes well defined and grading becomes distinct. These epiclastic rocks contain sedimentary structures typical of classical turbidite deposits including load casts, grading, scouring and convoluted laminations. They are interbedded with oxide iron formation which forms less than one percent of the total member but it reflects the waning influence of pyroclastic volcanism and the increasing influence of turbidite sedimentation in the evolution of the sequence.

THE CARLING FORMATION

The Carling Formation is a diverse volcanic-sedimentary rock sequence represented by mafic and felsic volcanic rocks, mafic intrusions as well as clastic and chemical sediments which include major oxide iron formations. The Carling Formation is divided into a lower volcanic member and an upper sedimentary member. The volcanic member conformably overlies the Western Lake St Joseph Formation in the north part of the thesis area (Maps 1 and 2). The volcanic member is laterally continuous for over 17 km. It extends east of the thesis area and is in fault contact with greywackes to the north in the Johnston Bay area. The volcanic member has a minimum thickness of 2800 m, including small intrusions, but locally exposures define a thickness of 3500 metres.

VOLCANIC MEMBER

The lower volcanic member is composed of basaltic flows and hyaloclastites which are overlain by a felsic pyroclastic-epiclastic unit. Numerous gabbroic sills have intruded the volcanic rocks at all levels in the member. The mafic lavas are composed of pillowed basalts, pillow breccias and hyaloclastites. Whereas the mafic lavas of the Blackstone and Western Lake St Joseph Formations are devoid of pillow breccias in the Carling Formation they are ubiquitous. The pillow breccias are identified by dark green chloritic selvages around pillow fragments whose cores are invariably lighter coloured (Appendix II, Plate 9). The lighter core is interpreted to be the result of coalesced plagioclase varioles. This interpretation is supported by the presence of relatively undeformed variolitic pillows southwest of island 58 (Map 2). Many of the features described by Carlisle (1963) and Furnes (1972) were observed in the pillow breccias of the Carling Formation. Besides pillow breccias; isolated pillow breccias, globules and hyaloclastites are also developed. The sequence developed at Lake St Joseph closely resembles the Ordovician pillow breccias of Norway described by Furnes (1972) in two aspects; both suites contain varioles and both show a similar vertical stratigraphy. Regarding the last point the Ordovician sequence is observed to pass from pillow lavas to isolated pillow breccia to broken pillow breccia or from pillow lavas to hyaloclastite breccia to fine grained tuff (Furnes 1972). As can be seen from Plate 10, Appendix II pillow lavas change to hyaloclastite breccia over 10 m at Lake St Joseph. This particular sequence is one of at least five such lava sequences developed on the islands east of Eagle Island and serve as a marker horizon in this area. They are reliable top indicators (Dimroth et al., 1978; Furnes, 1972) and in this instance show that tops are to the east in conformity with top indicators in the Blackstone and Western Lake St Joseph Formations.

For the most part pillow breccias of one of the phases described above can be found in the mafic lavas of the lower member. Near the area referred to as "the Narrows" (Map 2) there is locally an increase in the number of massive flows and unbrecciated pillow lavas. However, this lateral variation may be only apparent due to poor exposure. The few massive flows seen in the lower member are thin units (10 m) with a very fine grained homogeneous lithology.

Petrographically all the thin sections made of the pillow breccias are mineralogically similar. Only remnants of plagioclase crystals have survived the metamorphism of this unit. Instead a secondary mineral assemblage of hornblende-actinolite-grossularite-tourmaline $\pm$ biotite $\pm$ epidote is commonly found. The hornblende and actinolite are generally fine grained single crystals or acicular aggregates in a fine interlocking felted mat which acts as a host for larger (up to 7 mm) idiomorphic porphyroblasts of grossularite, tourmaline and less commonly, epidote. Although tourmaline can be found anywhere in the pillow breccia it is most commonly concentrated in the selvages and may represent primary reaction and fixing of boron from sea water into the selvages.

Narrow lenses of felsic pyroclastic and epiclastic rocks with undetermined strike length are found interbedded with the mafic lavas of the volcanic member. One such unit is found on island 17 (Map 2) where rhyolitic pyroclasts up to 20 cm in size are mixed with lapilli and tuff sized fragments. Another unit of dacitic tuff and lapilli is exposed on islands north of island 17.

A previously unrecognized felsic epiclastic to pyroclastic sequence extends approximately 10 km from the island 58 area to the Johnston Bay area and attains a maximum thickness of 350 metres. Pyroclastic breccias and tuffs are locally abundant with pyroclasts up to 30 cm. The unit contains sedimentary structures such as bedding, load casts and grading which indicate that the unit youngs to the east. Lapilli and tuff-sized rhyolite, dacite and chert clasts comprise the bulk of this unit and diamond drill core confirm that graphitic, pyritic and pyrrhotitic horizons are interbedded with the epiclastic detritus. Locally some of the sulphide horizons are up to 30 m thick but generally they are 3 m thick and consist of pyrrhotite, pyrite, chalcopyrite, sphalerite and siliceous fragments in a chloritic matrix.

Quartz, plagioclase (An_{16}) and rare microcline are the detrital components of this unit with muscovite and biotite in the matrix. Deformation and metamorphism has deformed clasts in this unit so that they are distinguished from the matrix only by the absence of mica. In many of the thin sections examined sulphides are finely disseminated throughout the matrix.

Rhyodacitic to rhyolitic breccias and tuffs are interbedded with pyritic and graphitic mudrock horizons near Islands 81 and 58 (Maps 1 and 2). Albite predominates over quartz in the pyroclastic rocks and clasts are up to 30 cm in diameter. Compared to the pyroclastic rocks of the Blackstone and Western

Lake St Joseph Formations these pyroclastic rocks contain less angular clasts, are better sorted and have a higher feldspar to quartz ratio.

The epiclastic-pyroclastic unit becomes progressively more sedimentary along strike from south to north. Pyroclastic breccias and tuffs are more abundant in the south, whereas well bedded epiclastic tuffs are abundant in the northern part of the unit. Along with this observed trend there is a complimentary decrease in average clast size from south to north in the unit.

At the Narrows (Map 2) there is a unique volcaniclastic unit. Angular rhyolitic blocks (up to 50 cm) are set in a basaltic matrix (Appendix II, Plate 11) and form the basal part of a thick graded sequence which fines to the east. This fining upward sequence is repeated with fine-grained sediments containing scour structures and clasts of sulphide iron formation at the top of the unit. The development of such a graded sequence indicates that the volcaniclastic unit formed by high energy surges of debris which acted like turbidity currents (Lajoie 1979). The location of the coarsest debris at "the Narrows" supports the notherly trend of decreasing clast size referred to above.

The volcanic member of the Carling Formation is intruded by several gabbroic to dioritic stocks and sills which are very different in character from the mafic intrusions in the Blackstone Formation. The eastern contact of the volcanic member is truncated by a large gabbro-diorite intrusion which is mainly composed of a mesocratic coarse-grained (5 mm+) rock containing plagioclase and hornblende. Leucocratic and pegmatic phases are common especially near the volcanic-intrusive contact. In the Mile Five area (Map 1) the intrusion is autobrecciated at the contact with the volcanic host rocks. The breccia becomes progressively coarser away from the contact and grades into massive gabbro. Because the breccia is intrusive in origin the block size gradation is not a reliable younging indicator but rather defines the limit of the volcanic rocks.

Quartz diorite sills and stocks are another type of intrusion found in the volcanic member. This type is best exposed on a number of islands east of Eagle Island (Map 2) where blue quartz "eyes" occur in a epidotized medium grained groundmass. The sills are 125 m to 275 m thick and show a crude band segregation of a quartz-magnetite rich phase from the normal diorite. This banding is parallel to the strike of the sills and has been mapped as bedding. Rocks of similar character are found on Island 49 (Map 2) and at the Narrows where a large stock is exposed. This type of intrusion is easily recognized in the field by its pitted brown surface in which quartz crystals (2.5-4 mm) are clearly visible. On fresh surfaces the rocks are mottled by two tones of green and white patches. Examination of thin sections indicates that the two green tones result from zones of predominantly epidote or predominantlt actinolite, whereas the white patches are plagioclase rich zones. Although the plagioclase is partially saussauritized Michel-Levy tests indicate anorthite contents between An_{27-35}.

The LAYERED SILL

A layered sill intrudes the volcanic member of the Carling Formation and is exposed on several islands and on the mainland at the eastern end of the thesis area (Maps 1 and 2). The sill was first recognized in 1977 by the author and by the Ontario Geological Survey which recognized its existence but not its extent(Breaks and Bond 1977). Since that time a B.Sc. thesis by Smith(1977) has examined a portion of the sill and this account expands its documentation.

The sill is a large concordant to slightly discordant intrusion which extends laterally for 11km and is approximately 350 m to 500 m thick. The sill is truncated south of island 58 (Map 2) by a fault and is exposed again on the mainland east of the thesis area. The western contact of the sill is poorly exposed but where observed it has intruded pillow breccias and felsic tuffs. The eastern contact has intruded pillow breccias and clastic sediments near island 58. A small satellite intrusion is exposed on islands 63 and 64 (Map 2) and was interpreted by Smith (1977) to be connected with the main sill to the east. Smith's evidence for a connection relies upon a small gabbroic dike on a reef between the two intrusions. No such dike was found in the present study, rather a quartz-feldspar porphyry intruding pillow breccias was observed. It is proposed that the two intrusions are physically separated in this area, even though both have similar features.

Five different phases of the sill are distinguished in the field from this study and more detailed work such as Smith's (1977) suggests that further subdivision of the rocks is possible. The different phases show vertical and lateral variations such that near Mile Five a typical section is basal peridotite overlain by pyroxenite overlain by gabbro whereas at island 58 the vertical section is basal gabbro overlain by diorite overlain by granophyre. The peridotite is represented by a metamorphic assemblage of serpentine-magnetite-calcite and chlorite. The peridotite appears to have originally been a dunite because pseudmorphs of olivine grains comprise 90% of the rock. The grains are usually rounded and 1-2 mm in size. Slip-face asbestos is common but the peridotite phase is limited to less than 500 m of lateral extent and appears to have been a cumulate phase of the sill.

The peridotite grades eastward into a pyroxenitic phase which is light grey on fresh surface and contains glomero-porphyritic growths of plagioclase and tremolite-serpentine (2-5 mm in size). The plagioclase glomerophyres each contain several euhedral, zoned crystals which comprise about 45% of the rock. The plagioclase crystals are unaltered and show an anorthite content between An_{42-63} as determined by Michel-Levy tests. The tremolite-serpentine glomerophyres are interpreted to be altered pyroxenes and olivines. The glomerophyres suggest that this phase was a cumulate with plagioclase now forming a major part of the sill. The areal extent of the pyroxenite is greater than the peridotite and is exposed laterally over 5 km.

The pyroxenite grades eastward and southward into a gabbro which is characterized by numerous pegmatitic clots averaging 15 cm in size. This phase is referred to by Smith (1977) as a clotty glomeroporphyritic unit. It is the most laterally extensive part of the sill and is characterized by 40-45% plagioclase and 60-55% actinolite-hornblende-chlorite and epidote. Skeletal leucoxene-ilmenite is a minor component which is first seen in this phase. The plagioclase crystals are euhedral but normally broken, strongly zoned and unaltered. Anorthite content varies from An_{40} to An_{60} with most crystals averaging An_{54}. The mafic minerals are secondary but define an original poik ilitic texture where deformation is minor. The composition of this phase becomes more siliceous to the south (see Chapter IV) and concurrently primary structures such as rhythmic layering (5-8 cm) and cross-layering appear. The present study concurs with Smith (1977) that further subdivision of the gabbro is warranted and that several phases of the gabbro could exist. The increased silica content is reflected by the presence of minor quartz grains and also marks the beginning of the overlying phase of the sill.

A diorite-granophyre phase lies east of and is in gradational contact with the gabbro. This phase has a distinctive black and light green or white mottled texture which is caused by concentrations of mafic minerals and epidotized plagioclase respectively. It is called granophyre because quartz occurs mainly in graphic or myrmeketic intergrowths with the plagioclase and locally comprises 10% of the rock. Plagioclase is similar to that of previous phases except that the anorthite content now varies between An_{30} to An_{44} with many crystals at An_{34}.

The last recognizable phase of the sill is a felsic differentiate which clearly intrudes the diorite-granophyre phase. It is restricted to island 58 and was mapped by Smith (1977) as an anorthosite. Although it is leucocratic, it contains only 50% feldspar, 5% of which is perthite. Quartz is abundant (20%) and occurs in identical habit to that of the granophyre phase. The plagioclase is predominantly albite and shows limited crystal zonation with minor perthite rims. Metamorphic hornblende is the major mafic component.

The sill as described can be used as a reliable top indicator. The layers of the sill consistently become more felsic to the east. This is reflected by the decreasing anorthite content in the plagioclase and the increasing quartz content. On this basis the top of the sill lies to the northeast and this is compatible with the younging directions of the surrounding stratigraphic units. In addition the cross layering on island 58 which Smith (1977) interpreted to be similar to sedimentary cross-bedding indicates that tops are to the northeast in the sill. The pegmatitic clots were noted to have greater concentrations of felsic minerals on their northeast sides a phenomenon interpreted by Smith (1977) to be of primary origin and due to the less dense minerals floating at the top of a liquid. Therefore, these observations indicate that the sill is conformable with the regional stratigraphy and was intruded prior to deformation.

SEDIMENTARY MEMBER

The upper member of the Carling Formation is composed predominantly of clastic and chemical sedimentary rocks which host potentially economic deposits of oxide iron formation. In the thesis area, the member is restricted to the islands near the southern shore of Lake St Joseph and has an exposed strike length of 14 km and a maximum thickness of 2 km. The member is subdivided into five units, of which four are sedimentary and one is volcanic. The basal unit is laterally continuous in the thesis area; however, the overlying units are best described as wedges because they either pinch out or become intercalated with each other along strike. The southern contact of the member is truncated by the Lake St Joseph fault across which there is a major change in lithology and style of deformation (Thurston and Breaks, 1978). The contact with the underlying Western Lake St Joseph Formation is conformable and is best exposed on a small reef west of Eagle Island (Appendix II, Plate 12). Here, graded felsic tuffs and lapillistone of the Western Lake St Joseph Formation are in sharp contact with dark green chlorite schists and laminated iron formation of the Carling Formation.

a) Basal Unit

The basal unit of the sedimentary member is organized into laminated iron formation (LIF) Shegelski, (1978) and clastic sedimentary rocks which form a sequence approximately 280 m thick. The LIF is composed of quartz, hematite and magnetite which occur as laminae a few millimetres thick. These laminae locally form sequences of LIF up to 20 m thick. Jasper and white chert form beds or small pods (up to 15 cm) in the LIF but these components commonly form less than 5% of the rock. The clastic sedimentary rocks are composed of chlorite schists and greywacke. They are generally stratigraphically lower than the LIF and form several fining-upward sequences in the basal unit. They contain all of the sedimentary structures typical of classical turbidites (Walker, 1967) (Appendix II, Plate 13).

The chlorite schists are dark green and are erratically dispersed throughout the basal unit. They contain lineated clots of chlorite 5 mm to 1 cm in size and thin laminations of magnetite and hematite spaced about 15 cm apart. In thin section the chlorite clots are rimmed by green biotite. Unaltered plagioclase comprises approximately 25% of the rock. The crystals are angular or broken and have anorthite contents between An_{30-32} as determined by Michel-Lévy tests.

The LIF found in the clastic rocks is identical in mineralogy and texture to the thicker LIF previously described. However, the iron formation forms a minor component of the clastic sedimentary rock being commonly less than 50% of the rock. Such primary features as slumping, soft sediment brecciation and cross-cutting sandstone dikes are common.

The greywacke component of the basal unit is an immature rock composed of quartz, plagioclase, rock fragments and matrix. It is a dark grey or green gray color which reflects the high content of matrix muscovite and chlorite. The greywackes are distinctly graded on Eagle Island but appear to be massive further to the west. In thin section the detrital grains are angular to rounded, sand to silt sized and are composed of quartz and oligoclase (An_{20-28}) in a micaceous matrix of up to 65% volume. Very rare grains of perthite can be found in this otherwise plagioclase-rich sediment.

Vertically, the basal unit is organized into a series of fining upward cycles with massive LIF at the top of each cycle. The clastic sedimentary rocks are composed of proximal and distal classical turbidites (Walker, 1967). The proximal turbidites include lag conglomerates with basal scours and thick "A" divisions of felsic material overlain by iron formation as "E" divisions of the Bouma sequence (Appendix II, Plate 14). The distal turbidites are fine grained, thinly bedded mudrocks which fit the classification similar to that observed in the Savant Lake area and interpreted by Shegelski (1978) as representing "background" chemical sedimentation during accumulation of deep water pelagic sediments.

The basal unit shows a lateral variation between the LIF and clastic sedimentary rocks. For instance, the clastic rocks are volumetrically more abundant in the western part of the unit (islands 371 and 334, Map 2) and LIF is rarely exposed. Further to the east LIF becomes progressively more abundant and on Eagle Island it forms a large, potentially economic deposit. Clifford (1969) represented this lateral variation as an iron oxide to clastic ratio which increases from less than 0.1 in the west to over 10 in the east.

b) Chloritic Greywacke

Overlying the basal unit in the sedimentary member is a chloritic greywacke which is devoid of iron formation. On Eagle Island this unit is clearly turbiditic because the "A", "B", "C" and "E" divisions of the Bouma sequence are well developed at various places in this unit. The greywackes are grey to green and petrographically identical to the greywackes described in the underlying basal unit. They appear to be gradational with the basal unit. Further west these greywackes are massively bedded and their turbidite origin is less clear.

The chloritic greywackes become coarser grained from the base to the top of the unit. Near the base of the unit the average grain size is approximately 0.1 mm which increases to 0.25-1.5 mm near the top of the unit. Quartz increases in volume from the base to the top of the unit and matrix decreases from greater than 50% to less than 50% near the top of the greywackes. The plagioclase in the chloritic greywackes changes composition from An_{20-28} near the base to An_{9-20} near the top of the unit. Potassium feldspar is rare or absent.

c) Arkose

A thin (70 m) wedge of arkose which is exposed along strike for 7.2 km overlies and is partly intercalated with the chloritic greywacke unit. It is distinguished in the field by its light buff weathered surface and red hematitic spots on fresh surface. A number of primary structures including planar and trough cross-bedding and parallel laminations are characteristic of this unit. The trough cross-bedding (Appendix II, Plate 15) consists of large scale cosets up to 50 cm in size with individual foreset beds spaced 5 to 10 mm apart and usually dipping less than or equal to 10°. The lower bounding surface of each set is erosional and appears to be cylindrical in shape. Each foreset is marked by a dark band at its bottom which usually contains pyrite, biotite and hematite. Using the classification scheme proposed by Allen (1963) these are Pi-cross stratifications interpreted to be formed by the migration of trains of large scale asymmetrical ripple marks presumably linguoid in shape.

Petrographically there are three distinguishing features of the arkose; the oxide mineralogy, the silicate mineralogy and the grain size. Concerning the oxide mineralogy hematite is pervasive throughout the arkose and often imparts a reddish hue in the rocks. The hematite is considered to be secondary after primary iron minerals and not an alteration product related to the possible diatreme breccias of the Blackstone Formation. This is based on the observations that the arkose is the only unit of the sedimentary member containing abundant red hematite and that it is spatially removed from the hematite aureole on island 212 (Map 2).

The silicate mineralogy differs from that of the lower greywackes in two aspects. First there is an increase in detrital grains relative to the matrix and secondly, microcline forms a significant proportion of the rock. Commonly between 65% and 75% of the arkose is composed of detrital grains with a matrix of muscovite and biotite. Microcline is a common detrital mineral in the arkose averaging 10% of the grains. In the greywackes previously described microcline is absent or scarce but in the arkose it is greater than or equal to the plagioclase component.

There is a consistent east to west variation in the proportion of detrital minerals and matrix in the arkose. For instance, where the unit is seen at its eastern extension on Eagle Island it is more micaceous than elsewhere averaging up to 50% of the rock. The detrital grains are composed of quartz (50% of grains), lithic fragments of chert and volcanic ash (20% of grains), albite (15%) and microcline (15%). The grains are angular to sub-rounded with varying degrees of sphericity. Further west on Eagle Island where the exposures are representative of the bulk of the arkose, the detrital grains increase to 65% volume and are composed of quartz (50-60%), albite (15-20%), microcline (10-25%) and lithic fragments (0-20%). Where the arkose has been observed furthest to the west (Wolf Island) it contains quartz (80%), microcline (12%), albite (8%) and no lithic fragments.

Concurrent with the east to west variation in detrital grain proportions is grain size variation. On the southeast shore of Eagle Island the arkose consists of coarse sand-granules 0.5 to 4 mm in size. The cross-bedded arkose shown in Appendix II, Plate 15 from the west shore of Eagle Island consists of coarse sand 0.5 to 1 mm in size and on Wolf Island further west the unit consists of medium sand 0.25 to 0.5 mm in size. Thus, not only is there a consistent decrease in grain size from east to west, but in addition, the arkose unit is generally coarser grained than any of the underlying units in the sedimentary member.

d) Conglomerate; Pebbly Sandstone

A wedge of interbedded sandstone and conglomerate conformably overlies the arkose (Appendix II, Plate 16). This unit is poorly exposed except on Eagle Island and becomes intercalated with the arkose and greywacke units proceeding westward from Eagle Island. This unit is traceable over 2100 m along strike and attains a maximum thickness of 75 m on Eagle Island. It was referred to by Clifford (1969) as "pebble-conglomerate" and Goodwin (1965) reports similar beds from the eastern part of Lake St Joseph. Bedding thickness is variable from a single band of "pebbles" to conglomerate beds over 50 cm thick. The sandstone interbeds are also of variable thickness from 1 cm to 1 metre. Primary structures in the sandstone interbeds are well developed and include stratification, grading, local scours and parallel laminations.

The clasts in the conglomerates are of four types: cherty iron formation, lithic volcanic fragments, white "vein" quartz and felsic igneous plutonic rocks. The latter two clast types comprise less than 5% of the clasts, are up to 6 cm in diameter and are always rounded. Mafic and felsic volcanic fragments comprise about 10% of the clasts but locally may be as abundant as 25%. They average 2 cm and seldom exceed 6 cm in dia. (Appendix II, Plate 17). A cursory study of the felsic clasts indicates they are generally more feldspathic than the felsic volcanic rocks of the Blackstone and Western Lake St Joseph formations and more compatible with the felsic volcanic rocks of the Carling Formation.

The largest clast component is cherty iron formation (Appendix II, Plate 16 and 17). The clasts are angular and commonly elongated parallel to the bedding planes. They range in dia. from 1 cm to 15 cm and are composed of grey hematitic bands interlaminated with white creamy chert which were consolidated prior to resedimentation. The clasts of iron formation in the conglomerate are identical to in situ cherty iron formation found on the south shore of Eagle Island and there is little doubt that beds like these were the provenance of these clasts.

The interbedded sandstones are grey-white on the weathered surface and a dark green-grey on fresh surface. They are composed of coarse sand sized (1-2 mm) grains which form massive to laminated beds. Detrital grains comprise about 55% of the beds with chlorite and muscovite comprising the matrix. Quartz is the major detrital component but chert fragments, albite and microcline are also common. The presence of microcline in appreciable quantities (5%) suggests a closer affinity of the pebble beds to the arkose than to the chloritic greywackes.

Southward the sedimentary member of the Carling Formation is covered by Lake St Joseph and the outcrops observed on the south shore of the mainland are sheared, fissile schists. The character of these rocks is radically different from the sedimentary member of the Carling Formation.

They are part of Clifford's (1969) main clastic sequence and further inland become heavily injected with granitic gneiss (Clifford, 1969). Thurston and Breaks (1978) define these rocks as metasediments of the English River gneiss belt and they are also interpreted as such in this thesis. They are not included in this discussion but a cursory examination of them suggests that they are similar to the sediments north of Johnston Bay.

On island 334 and immediately east thereof, a volcanic unit 2400 m in length and 300 m thick is exposed. It is composed of basaltic flows, pyroclastic rocks and schistose equivalents. Pillowed and massive flows are common and the coarsest pyroclasts are lapilli sized (2 cm). The schists and tuffs are very chloritic and locally resemble the chloritic greywackes with which they are locally interbedded.

A brief review of the salient features of the sedimentary member of the Carling Formation are as follows:

1) the member generally defines a coarsening upward sequence from chemical precipitates (LIF and chert) to conglomerate.

2) there is an increasing clastic component going upwards as reflected by the diminished amount of LIF in the strata and the increase of detrital grains over matrix.

3) there is a steady but minor lithic clast component into the sediments in the form of volcanic fragments and plutonic fragments.

4) there is an increased sodic and potassic component going upwards as reflected by the feldspar compositions. The basal unit is characterized by plagioclase with An_{30-32} and minor microcline whereas the upper two units have albite and 5 to 15% microcline.

5) the volcanic unit represents a short-lived volcanic episode and emphasizes the spasmodic transition from volcanism to sedimentation.

OTHER LITHOLOGIES

Besides the rocks related to the stratigraphy of the three formations there are lithologies which appear to be exotic to the stratigraphy. The 2000 m thick unit of clastic sedimentary rocks which extends from Johnston Bay north of the thesis area is one such lithology. These sediments are well defined thinly bedded rocks of greywacke, siltstone, argillite and oxide iron formation. They are commonly deformed and highly metamorphosed and in these respects most closely resemble the meta-sediments south of Lake St Joseph in the English River gneiss belt. The iron formations are very lean consisting of widely spaced bands of magnetite in siltstone. Commonly the argillites are graphitic and they contain minor concretionary pyrite. The greywacke-siltstone component composes the majority of the beds. They are brown to grey thinly bedded (1 to 30 cm) and consistently fine-grained. Locally they are tuffaceous or chloritic; grading is not apparent and primary structures are rare. These sedimentary rocks overlie the mafic member of the Blackstone Formation and are intercalated with both the Western Lake St Joseph and Carling Formations.

CHAPTER III - STRUCTURE AND METAMORPHISM

INTRODUCTION

A long history of deformation and metamorphism typifies many Archean terrains. The rocks of the Western Lake St Joseph area bear abundant evidence of a long evolutionary path effected by complex interaction of tectonism and thermal events. Attempts to develop a tectonic evolution from the present complicated geology is a difficult process which requires explanations for many events for which the field evidence is either unobtainable or sparse.

An essential first step is the recognition of the stratigraphic succession (Hobbs, Means and Williams, 1976). Establishment of bedding and consistent younging directions in the strata are basic requirements for the development of the stratigraphy. The field evidence for the stratigraphic order is presented in Chapter II of this thesis.

Because of good outcrop density most of the structural data were collected from Eagle Island. Interpretations regarding structural history and evolution are based on these data.

STRUCTURE: GENERAL

Figure 3-1 presents the regional distribution of lithologies in the Lake St Joseph area. Of particular importance are the relationships between the granitic batholiths and the greenstone terrain. In the thesis area the geometry of the Blackstone batholith and to a lesser extent the Carling batholith had a great influence on the structure of the Lake St Joseph Group. This is immediately apparent on Maps 1 and 2 where the contacts between the members of the Blackstone and Western Lake St Joseph Formations are concordant with the contact of the Blackstone batholith. The orientation of the cleavage within the Lake St Joseph Group also reflects the influence of the batholiths. In the area west of Eagle Island the predominant cleavage is oriented at 90° which parallels the contact of the Blackstone batholith with the Lake St Joseph Group and the contact of the English River gneiss belt at the southern boundary. These data are presented in Figure 3-2. In the area north of Eagle Island the predominant cleavage is oriented at 170° which again parallels the contacts of the Blackstone and Carling batholiths with the Lake St Joseph Group. These data are presented in Figure 3-4.

Pillow shapes within the pillow basalts of the Lake St Joseph Group are variably deformed depending on their proximity to the batholiths. Clifford (1969, 1972) observed that pillow basalts were more deformed near the contacts of the Blackstone and Carling batholiths than in areas remote

Fig. 3-1 Regional Geology (after ODM maps 2169 and 2218)

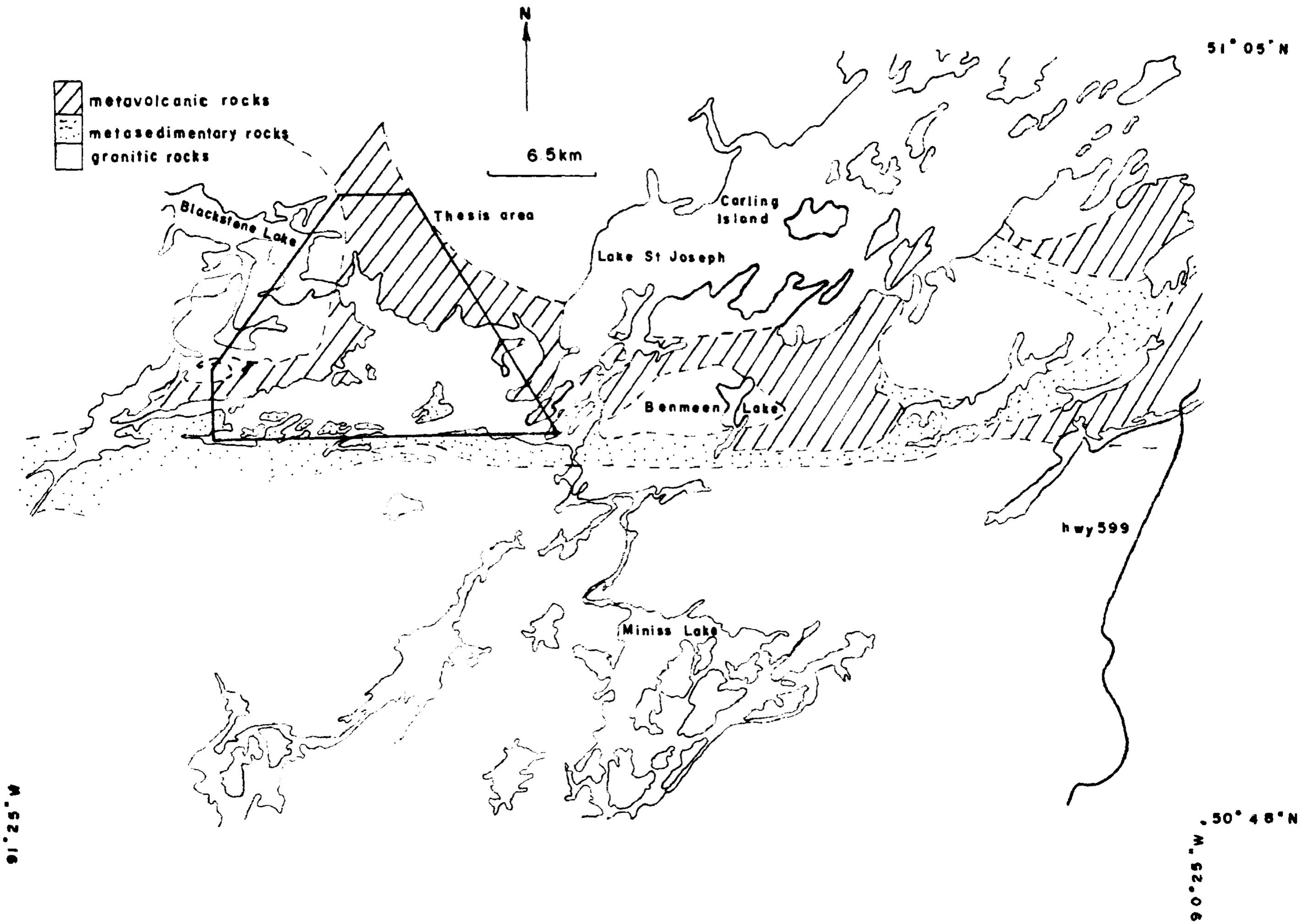


Fig.3-2: Poles to cleavage for the area west of Eagle Island

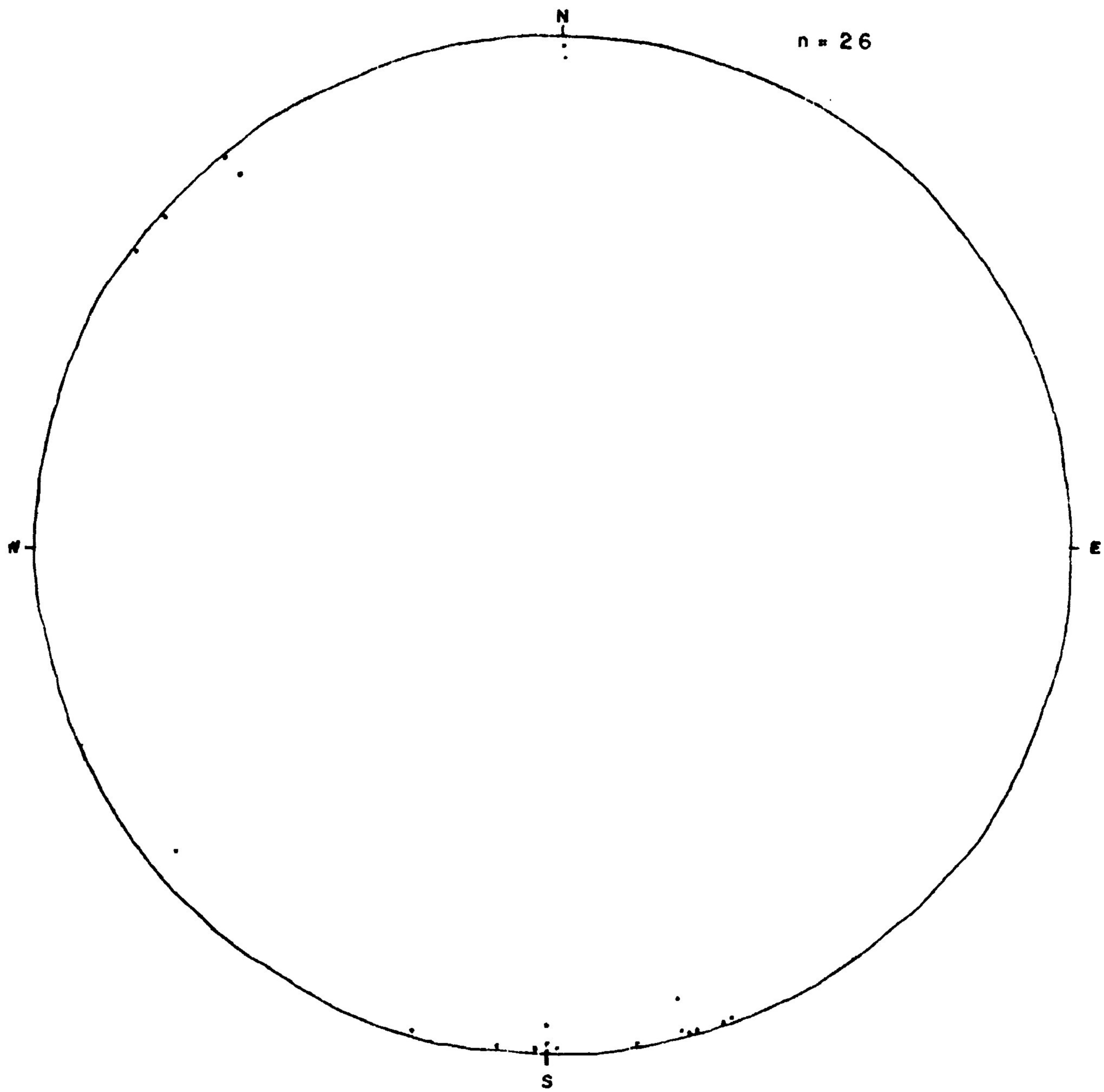


Fig. 3-3: Contour of π-poles to cleavage for the area west of Eagle Island

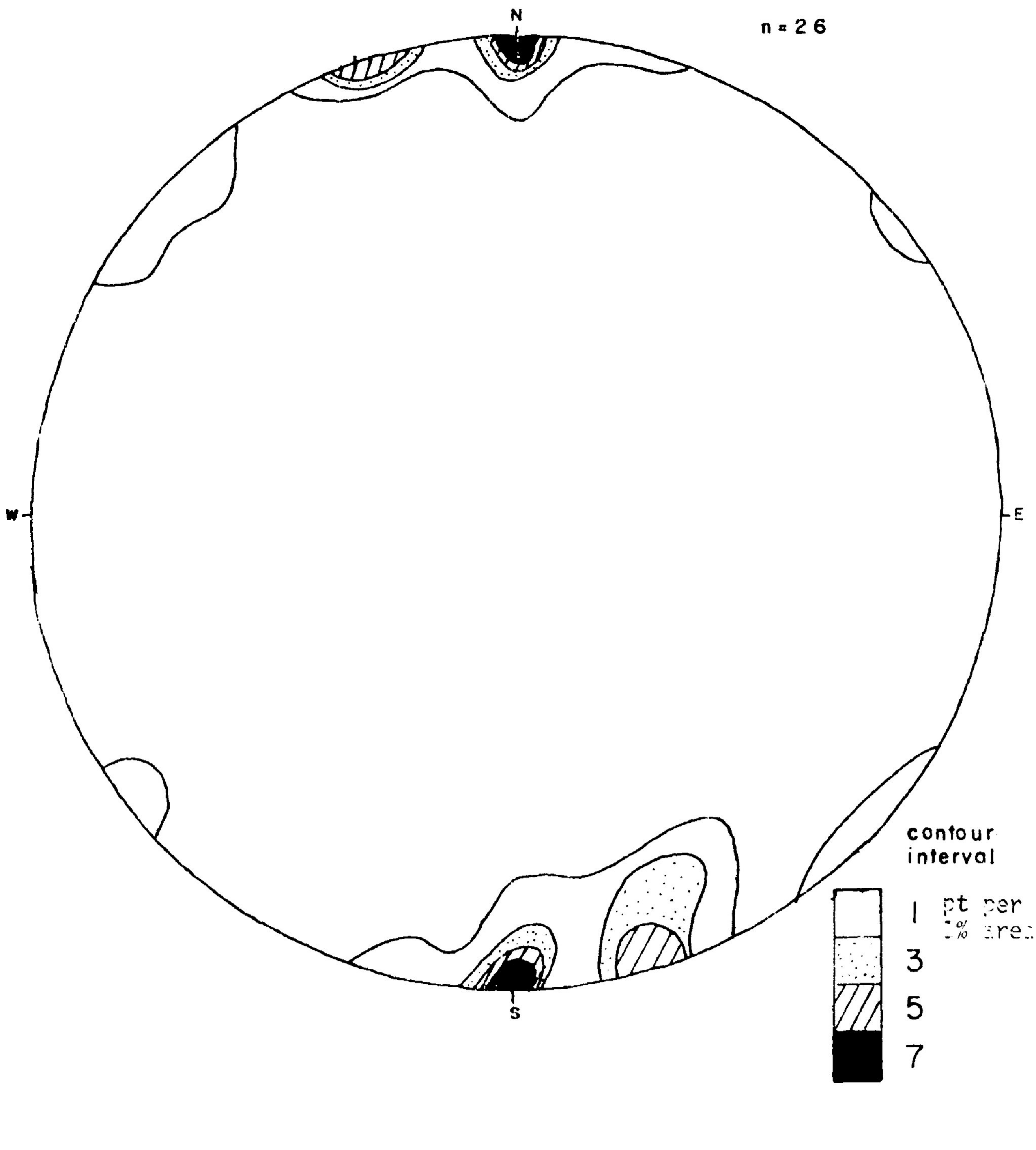


Fig. 3-4: Poles to cleavage for the area north of Eagle Island

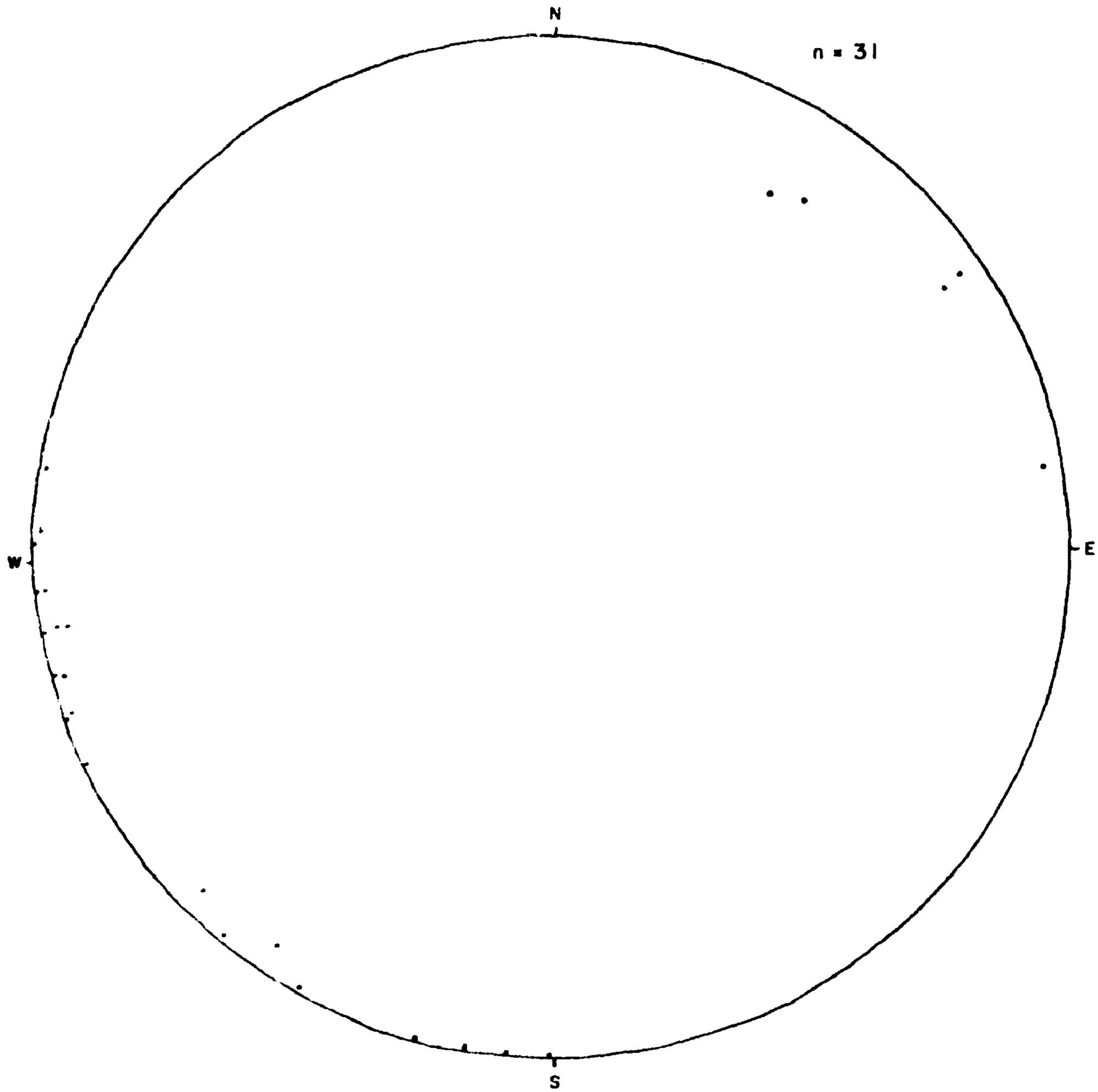
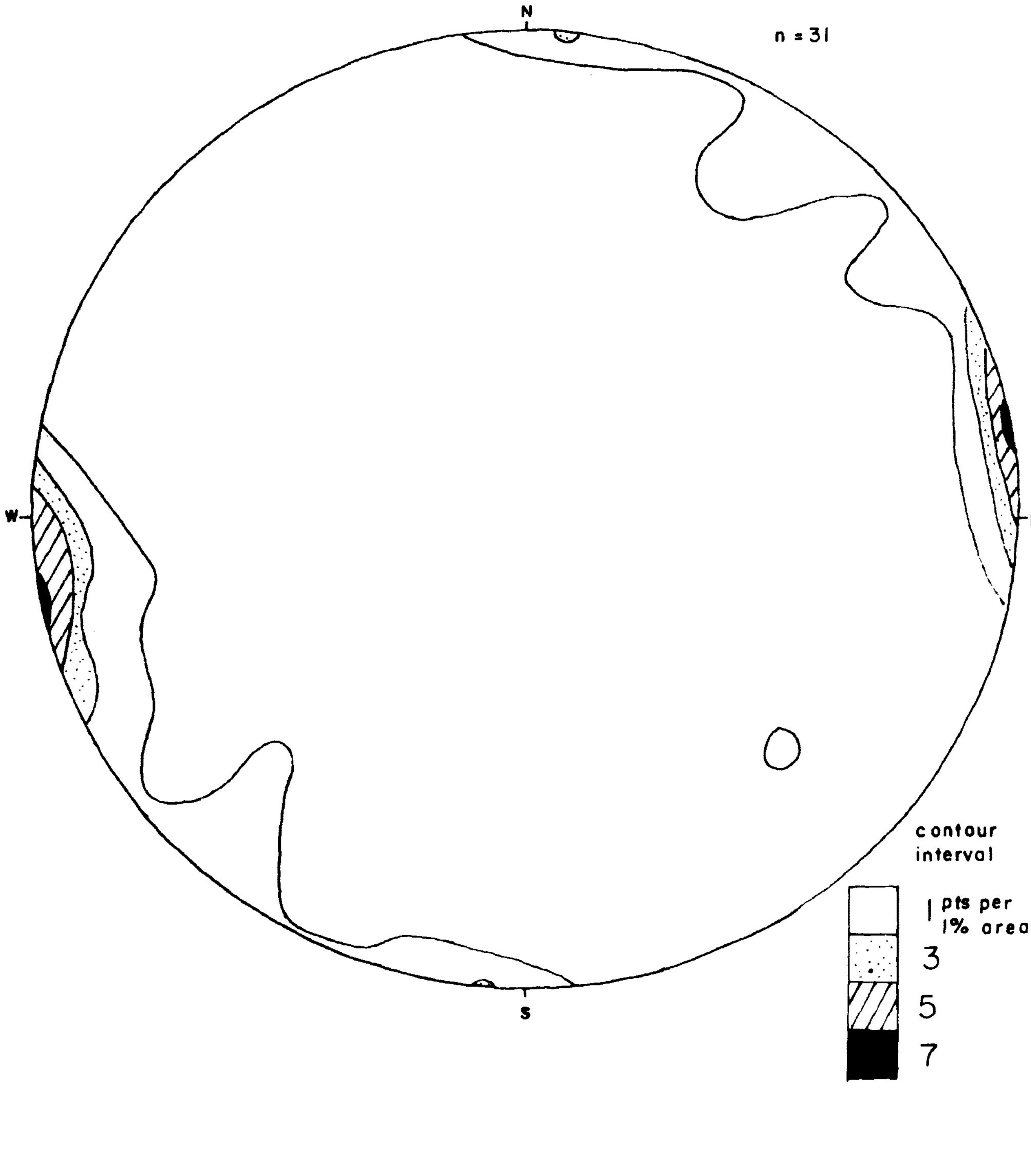


Fig.3-5: Contour of π-poles to cleavage for the area north of Eagle Island



from the contacts. This study generally supports this observation but finds pillow shapes change drastically over a few metres as the cleavage density changes. Where cleavage planes are dense, pillows have been deformed by simple shear. Where cleavage planes are less dense pillows are more equidimensional. The density of cleavage planes varies from outcrop to outcrop and appears to be independent of lithology. The younging from pillows was considered to be reliable only if consistent data was found over a large area (i.e. several outcrops).

Primary structures such as graded bedding and scour marks are susceptible to variable deformation like pillows. However, these structures are more abundant in lithologies distant from the batholiths contacts and generally yield reliable and consistent younging data.

Faults are common in the rocks of the Lake St Joseph Group. They are most evident in the rocks on the islands east of Eagle Island (Map 2). Marker units such as the layered sill (Chapter II) and the quartz diorite sill show notable sinistral strike separation along faults striking between 50° and 70°. In the Mile Five area (Map 1) intensely shattered rocks and strike separation of units mark the position of faults. At some locations in the Mile Five area faults have been interpreted from the offset of geophysical conductors located by exploration companies.

a) Structure: Eagle Island

Map 3 shows the distribution of the lithologies on Eagle Island. Chapter II clearly documents the field relationships of these units and establishes their relative ages based on local younging information. The orientation of bedding planes on Eagle Island have been measured and the data are represented on a stereographic projection (Fig. 3-6). The S-pole data are distributed about a great circle girdle. A distinct maximum occurs along this girdle and the resulting β-axis is steeply plunging. Mesoscopic fold axes and bedding-cleavage intersection lineations measured in the field are in good agreement with the β-axis and support the fact that the β-axis is a fold axis. Field relationships between younging and bedding plane orientation indicate overturning of beds is common on Eagle Island.

Orientations of cleavage planes were measured and the data are represented on a stereographic projection (Fig. 3-8). The S_2-pole data are distributed about a great circle girdle. There is a distinct maximum along this girdle which corresponds to a prominent cleavage which strikes 80° and dips steeply. This cleavage is pervasive in the rocks and at certain locations on Eagle Island is axial planar to mesoscopic folds. The cleavage data agrees well with the S_2 axial surface interpreted from the data on Fig. 3-7. Based on this evidence the 80° cleavage was formed by the folding of the rocks on Eagle Island and is axial planar to the folding.

Fig.3-6 : Poles to bedding and lineation for Eagle Island

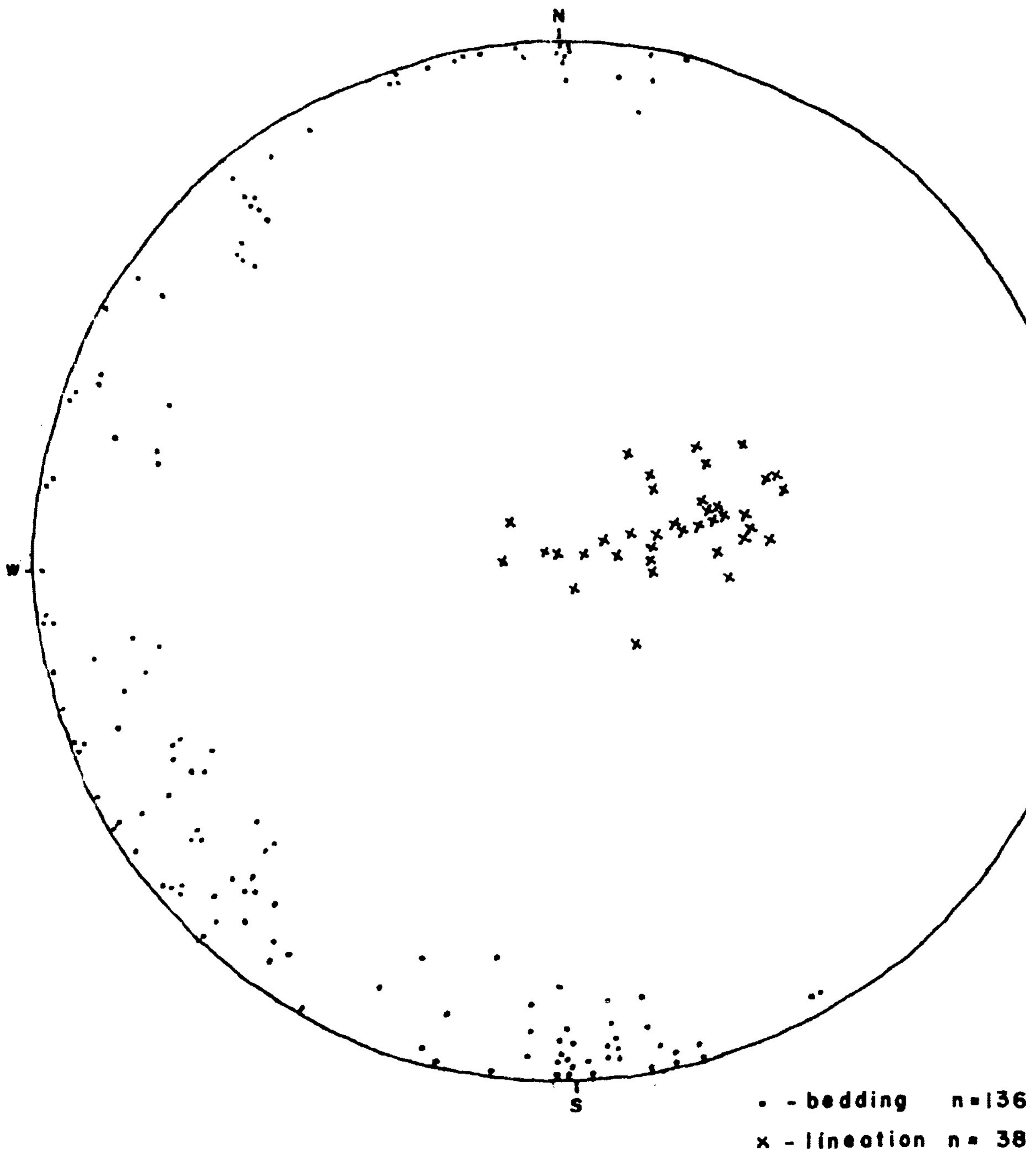


Fig.3-7: Contour of π-poles to bedding and lineations on Eagle Island

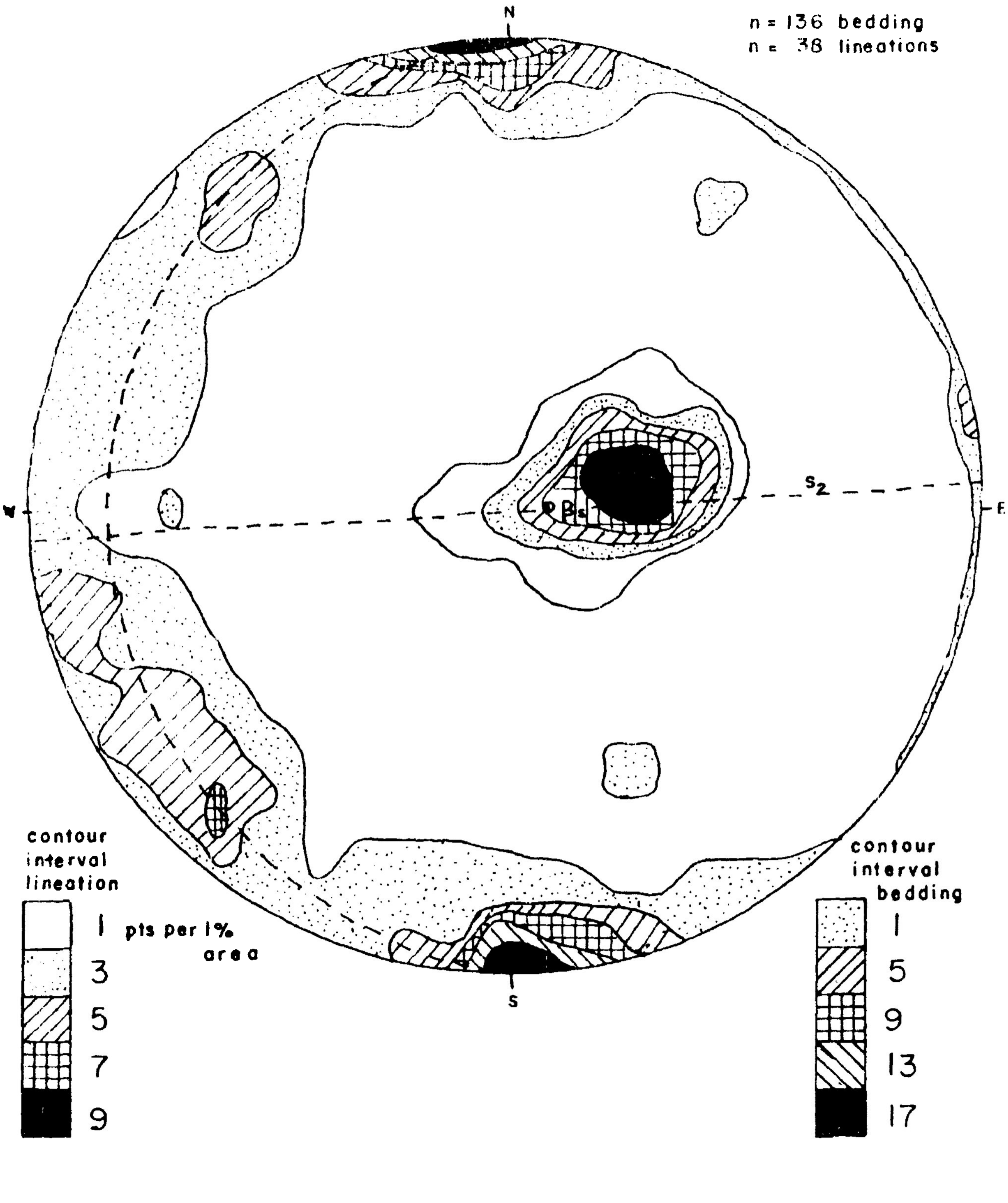


Fig.3-8 : Poles to cleavage for Eagle Island

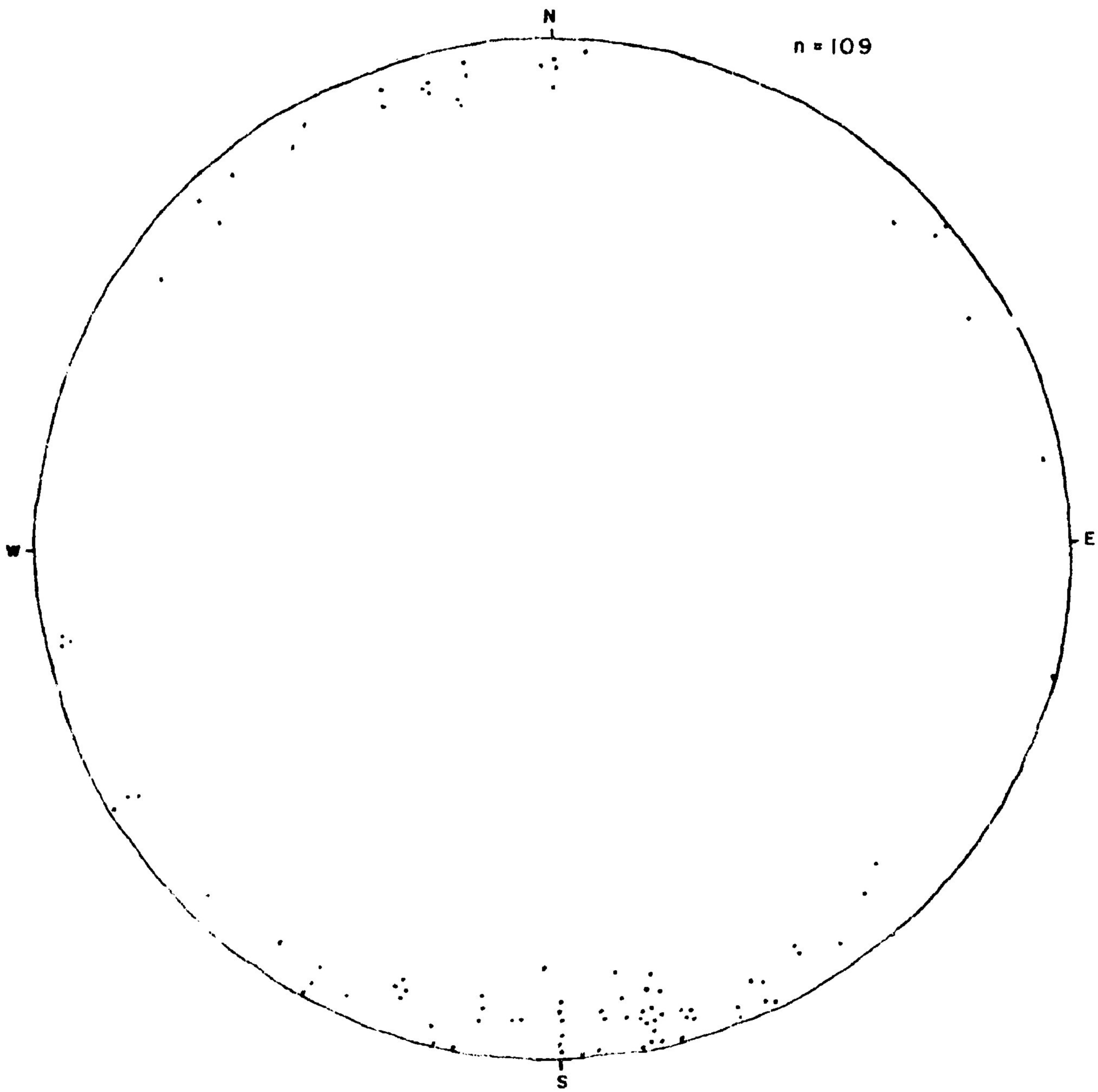
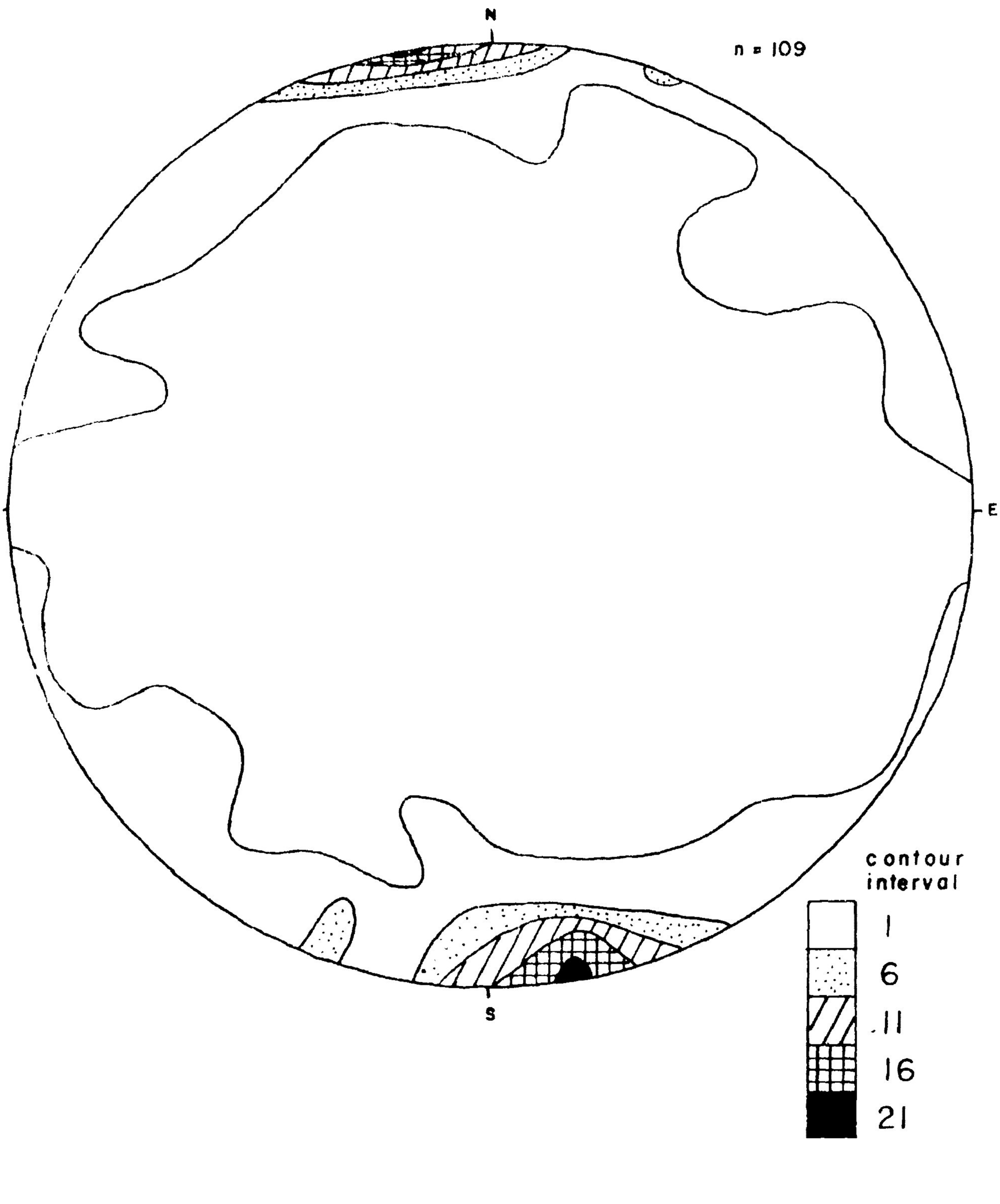


Fig. 3-9: Contour of π-poles to cleavage for Eagle Island



The girdle distribution is interpreted to represent convergence or divergence of the axial planar cleavage (Hobbs; Means and Williams, 1976, Ramsey, 1967, Turner and Weiss, 1962).

The distribution of the lithologies and local younging data provide the basis for the location of traces of axial surfaces on Eagle Island (Map 3). These axial surfaces define synclines and anticlines. Mesoscopic folds indicate that these structures are isoclinal and formed about steep easterly plunging fold axes. Figures 3-6 and 3-8 are consistent with isoclinal folding patterns (Hobbs, Means and Williams, 1976). Bedding-cleavage relationships support the interpreted locations of the axial surfaces. The angle the axial planar 80° cleavage makes with the bedding was used to determine whether an outcrop was on the limb or the hinge of a fold (Hobbs, Means and Williams, 1976,Ramsey, 1967). The derived pattern is consistent with the interpretation on Map 3.

The symmetry of mesoscopic folds provides further evidence supporting the interpreted location of the axial surfaces. Map 3 shows the location of "S" and "Z" symmetry. The vergence described by this symmetry generally conforms with the interpreted closures. Locally, however, there are variations in the symmetry of mesoscopic folds which suggest the folding pattern is more complex than shown on Map 3. This is evident on the northwest shore of Eagle Island.

The curvature of the axial surfaces on Map 3 is concordant with the geometry of the Blackstone batholith. This pattern suggests that the folding was controlled by the intrusion of the granitic batholiths. The concordant relationships between the lithologies and cleavage with respect to the batholiths in the thesis area suggest that the deformation of the Lake St Joseph Group was caused mainly by the intrusion of the Blackstone and Carling batholiths. Clifford (1969, 1972) and Thurston and Breaks (1978) arrived at a similar conclusion. Thurston and Breaks (1978) evidence relies on regional mapping and is very general in scope. Clifford (1969, 1972) cited the vertical extension of conglomerate pebbles and pyroclasts as evidence that the volcanic-sedimentary rocks were compressed by the uprise and apparent convergence of the flanking granitic batholiths.

A late-stage deformation which has affected the rocks of the thesis area is the formation of the Lake St Joseph Fault. This fault as first defined by Parkinson (1962) is expressed as a regional lineament extending 195 km from the Armstrong area to west of Uchi Lake. In the Lake St Joseph area the fault is recognized as a zone of cataclastic deformation which postdates the youngest granitoid intrusions (quartz monzonite) and regional metamorphism (Thurston and Breaks, 1978). In the thesis area the fault marks the boundary between low grade metamorphic rocks of the chlorite-biotite zone belonging to the Uchi greenstone belt and higher grade rocks of the staurolite-chlorite-biotite zone typifying the English River gneiss belt (Thurston and Breaks, 1978). The amount of movement on the fault is unknown but Clifford (1969) estimated that the vertical displacement was less than 10 km. Work on the associated Sydney Lake cataclastic zone, west of Lake St Joseph, suggests that dextral displacements up to 16 km and vertical movements of up to 4 km are possible (Thurston and Breaks, 1978). Hudec (1965) recognized the Miniss Lake Fault which is a southwest trending branch of the Lake St Joseph Fault and concluded that the sense of movement was essentially dip slip on a high angle reverse fault. His evidence relied mainly on the study of slickensides and changes of metamorphic grade across the fault zone from higher metamorphic grade southeast of the fault to lower metamorphic grade northwest of the fault.

The Main Fault in the central channel of Lake St Joseph appears to be temporally related to the Lake St Joseph Fault. It strikes approximately 80° and Parkinson (1962) shows that it joins with the Lake St Joseph Fault west of the thesis area. The Main Fault is marked by fissile sericite-chlorite schists, hematite and carbonate alteration. The fault has been traced for 5 km and may be equivalent with the fault offsetting the layered sill near island 81 another 7 km to the east.

The deformation caused by the Lake St Joseph and Main Faults increases in intensity as the faults are approached.

On Eagle Island the open style of folding (Map 3) changes as the Lake St Joseph Fault is approached. On the south shore of Eagle Island there is a tightening of the fold closures which are possibly the result of transposition of bedding along east-west cleavage planes. This effect increases in intensity southward so that sedimentary rocks on the south shore of the lake are barely recognizable as turbidites and stratigraphy is no longer valid south of Eagle Island.

METAMORPHISM

Two separate stages of metamorphism have affected the rocks at Western Lake St Joseph. They are recognizable by different mineral assemblages and textures in rocks of the same composition. One stage is associated with the intrusion of the gabbroic sills and stocks which have locally prograded the rocks to the hornblende-hornfels facies of contact metamorphism (Winkler, 1976). A more pervasive but generally lower grade regional metamorphism has overprinted and in part retrograded the mineral assemblages associated with the contact metamorphism. Low to medium grade greenschist facies has been attained during the regional event (Winkler, 1976). Table 3-1 lists the mineral assemblages for the various lithologies and with which each stage of metamorphism is associated.

TABLE 3-1: Metamorphic mineral assemblages

Lithology	Contact Metamorphic Stage	Regional Metamorphic Stage
Mafic Volcanic Rocks	hornblende + actinolite + grossularite + epidote ± tourmaline	chlorite + actinolite + epidote
Felsic Volcanic Rocks	Ti-rich biotite ± tourmaline ± chlorite	chlorite + muscovite ± green biotite ± epidote
Greywacke Sedimentary Rocks	actinolite + Ti-rich biotite ± tourmaline ± chlorite	chlorite + muscovite ± green biotite ± epidote

a) Contact Metamorphism

The contact metamorphic assemblages are developed in the volcanic member of the Carling Formation in rocks adjacent to gabbroic intrusions. Idiomorphic garnet and tourmaline porphyroblasts up to 1 cm are commonly developed in the mafic volcanic rocks. X-ray diffraction scans indicate that the tourmaline is a ferroan dravite and that the garnet is grossularite with a large spessartine component. The matrix of the porphyroblasts is composed of fine-grained hornblende-, actinolite and minor epidote arranged in a "felt-textured" mosaic typical of contact metamorphic assemblages (Williams, Turner and Gilbert, 1954). Chlorite is absent in these rocks and preferred crystallographic orientation is poorly developed.

In the sedimentary and volcaniclastic rocks the diagnostic minerals of the contact metamorphic aureole are actinolite and titanium-rich biotite. The actinolite occurs as poikiloblastic blades or doubly terminated crystals with distinct cleavages. The biotite is red-brown and strongly pleochroic which indicates a high titanium content (Deer, Howie and Zussman, 1971).

The contact metamorphic stage occurred before the regional metamorphic stage. There are two lines of evidence for this statement. The contact metamorphic mineral assemblages are best developed in rocks adjacent to but not in the layered sill. The sill has probably been the cause of the contact metamorphism based on the distribution of the mineral assemblages. In Chapter II it was shown that the layered sill was intruded prior to the deformation of the Lake St Joseph Group. Thurston and Breaks (1978) suggest that the main deformation and regional metamorphism of the Uchi greenstone belt were synchronous events. This statement is based on their regional and detailed investigations of the Uchi and English River gneiss belt subprovinces. This implies that the contact metamorphism preceded the regional metamorphism.

Further evidence is derived from the relationship of biotites in the sedimentary and felsic volcanic rocks that have undergone contact and regional metamorphism. The titanium-rich biotite is associated exclusively with contact metamorphosed rocks in the Lake St Joseph Group. These biotite porphyroblasts become well formed as the contacts of the gabbroic intrusions are approached. Locally, however, the titanium-rich biotite occurs as allotriomorphic flakes which are overprinted and in part changed to green idiomorphic biotite. The green biotite is associated with the regional metamorphosed assemblages. The texture described above is interpreted to be the result of the regional metamorphism overprinting the contact aureole and in part retrograding the mineral assemblages.

b) Regional Metamorphism

Widespread regional metamorphism has affected all the rocks in the thesis area. Conditions typical of the greenschist facies are prevalent. Ayres (1978) noted that for greenstone terrains there is a general increase in the grade of metamorphism near the contacts of granitic batholiths. Rocks containing almandine and andalusite are present in the sedimentary rocks north of Johnston Bay and Goodwin (1965) observed almandine, staurolite and andalusite bearing assemblages in the metasediments east of the thesis area.

Most of the rocks in the Lake St Joseph Group are low grade schists. Typical mineral assemblages are given in Table 3-1. Carbonates are ubiquitous in all rocks commonly in the form of calcite. Dolomite rhombohedrons and ankerite are locally present especially near the Main Fault. These minerals are secondary in origin as evidenced by cross-cutting veins, polycrystalline aggregates and replacement of feldspars. In the mafic volcanic rocks recrystallization is well advanced and the primary mineralogy is difficult to discern. Plagioclase is saussüritized. A foliated mat of Mg-chlorite, epidote and actinolite constitutes the fabric of these rocks. The felsic volcanic and the sedimentary rocks contain muscovite and Fe-chlorite in all thin sections examined. Green to green-brown biotite is common in many of the rocks and is diagnostic of the regional metamorphism in the thesis area. Epidote is rarely developed in the felsic rocks. The platey minerals in all lithologies show a strong preferred orientation parallel to the local cleavage which contrasts with the fabric developed in contact metamorphosed rocks.

CHAPTER IV - GEOCHEMISTRY

INTRODUCTION

The strata at Western Lake St Joseph are physically divisible into three formations represented by mafic to felsic volcanic-sedimentary cycles. An attempt was made to chemically discriminate among the rocks of these formations. Towards this end 39 rock samples from all formations were subjected to whole rock and partial trace element analysis. The data obtained were plotted on various discrimination diagrams constructed by previous workers and limited success was achieved in separating the formations. The raw data and analytical procedures are outlined in Appendix I.

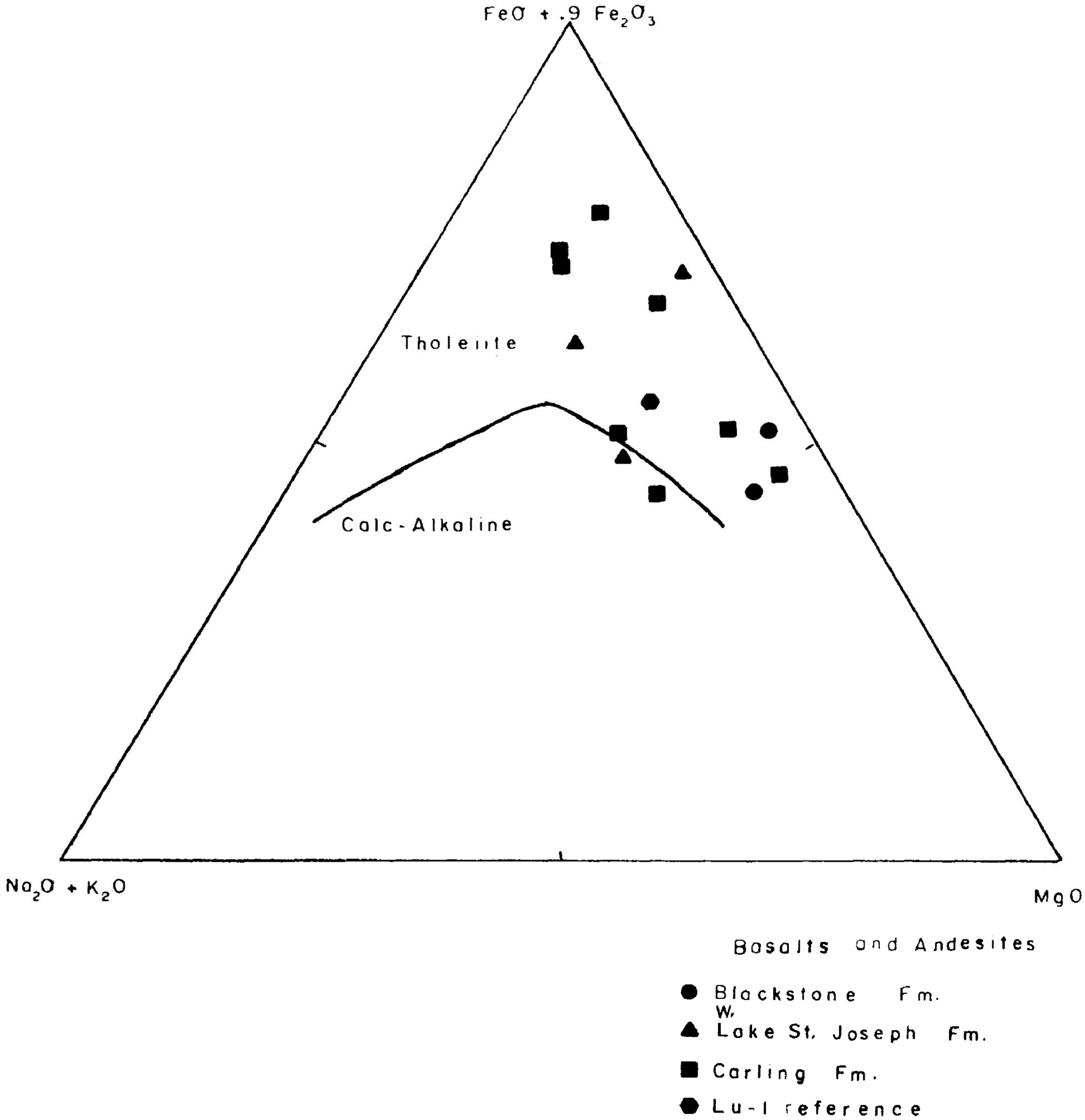
DISCRIMINATION DIAGRAMS

Discrimination diagrams are commonly used to indicate petrogenetic and chemical affinities of various rock suites. Binary and ternary systems based on major and trace element concentrations have been used to such ends in this study.

One of the more widely used diagrams is the AFM plot after Irvine and Baragar (1971), (Fig. 4-1). This diagram was devised in Canada for use with metamorphosed and fresh

Fig. 4-1

AFM Plot after Irvine and Baragar 1971

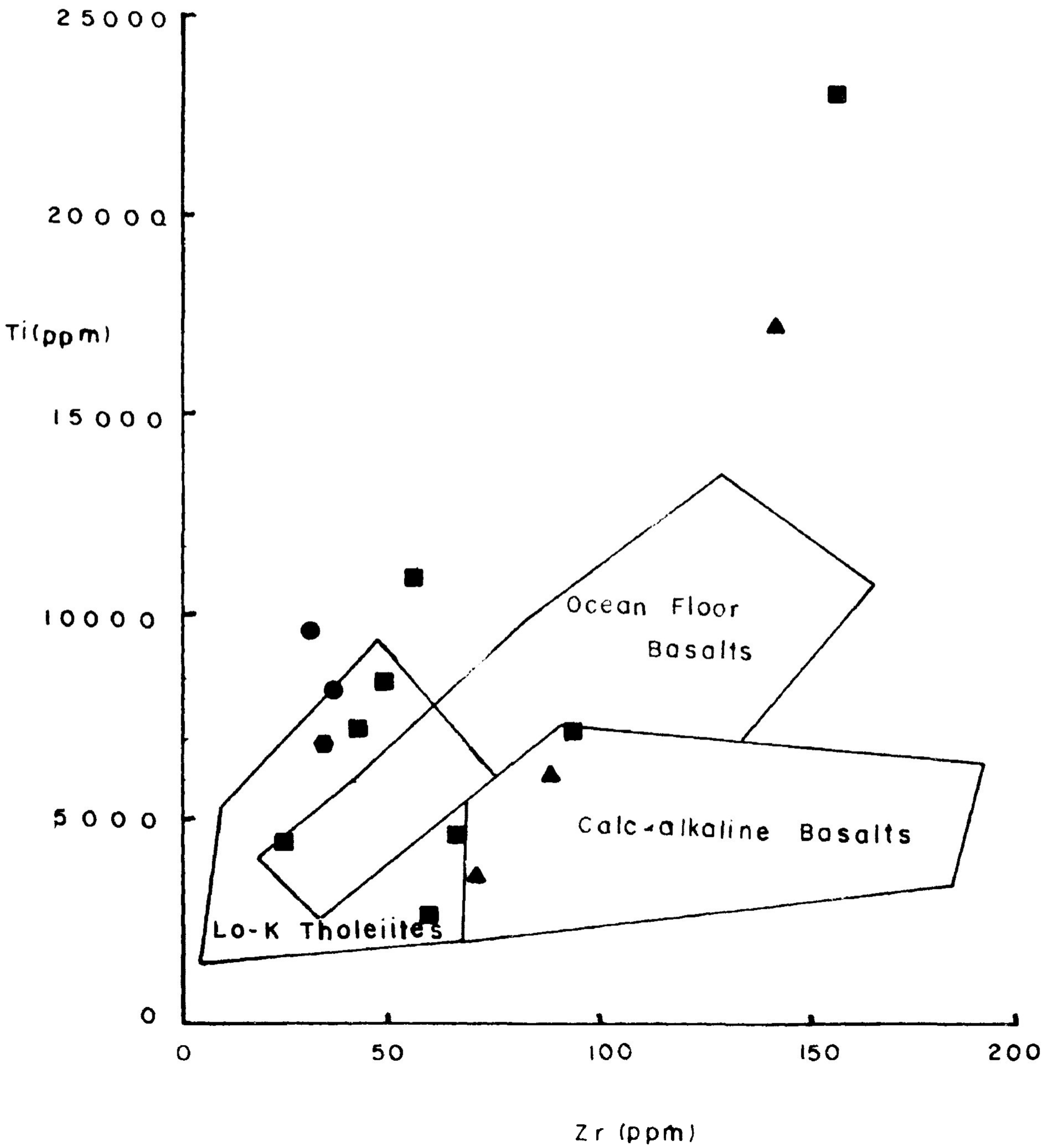


basalts and andesites. It is intended to show the division between tholeiitic and calc-alkaline rock suites. Of the thirteen "basalts" analyzed eleven are tholeiitic in character and the remaining two are near the boundary (Fig. 4-1). There is no separation of the formations and this distribution is similar to that found in other Archean and modern tholeiitic suites (Irvine and Baragar, 1971).

Numerous authors (Cann, 1969; Condie, 1976; Floyd and Winchester, 1978) have indicated that the alkali elements are mobile during metamorphism. Therefore the validity of AFM plots could be questioned in this respect. It is appropriate, then, to consider discrimination plots of basalts using immobile elements. Cann (1970) and Pearce and Cann (1973) demonstrate that titanium and zirconium are relatively immobile during alteration processes and they have developed a discrimination plot using modern volcanic rock suites to construct boundaries that outline three separate fields. Basalts and andesites from the Lake St Joseph Group are plotted with respect to these fields in Figure 4-2 using the same samples as those plotted in Figure 4-1. Most of the Lake St Joseph Group basalts plot in the low potassium tholeiite field (Lo-K on Fig. 4-2) with some scatter and some overlap into the calc-alkaline field. In this respect the Lake St Joseph rocks are similar to other Archean basalts (Condie 1976, Glikson 1978, Irvine and Baragar, 1971). Two samples also appear to contain anomalous concentrations of

Fig. 4-2 Ti vs. Zr Plot (after Pearce and Cann 1973)

same legend as Fig.4-1



TiO_2. There is no apparent separation of the formations and the scatter of the data suggests that the mafic volcanic rocks in the Lake St Joseph Group contain Ti and Zr contents which differ from those of the modern rock suites of Pearce and Cann (1973).

Discrimination plots designed specifically for metamorphosed volcanic rocks work best at separating and defining trends in the Lake St Joseph Group. These plots have the added advantage of permitting the felsic volcanic rocks to be plotted with the basaltic rocks. Figure 4-3 is a plot of SiO_2 v. Zr/TiO_2 after Floyd and Winchester (1978) and shows the distribution of the rocks of the Lake St Joseph Group. The plot indicates that the basalts are subalkaline tholeiites and the felsic rocks are dacites and rhyodacites. There are relatively few andesites and alkaline rocks. This trend towards a bimodal distribution between basalts and dacites is a worldwide feature of Archean terrains (Glikson, 1978). This suggests that the Lake St Joseph Group represents a "normal" bimodal Archean volcanic assemblage. Figure 4-3 also points out the correspondence of the chemical classification with the field names assigned to each rock which supports the stratigraphy described in Chapter II of this study.

The Jensen Cation Plot (Jensen, 1976) (Fig. 4-4) resolves the basalts of the three formations of the Lake St Joseph Group into separate fields. The Blackstone Formation is characterized by high magnesium tholeiitic basalts, the

Fig. 4-3

Plot of SiO_2 vs Zr/TiO_2

after Floyd and Winchester 1978

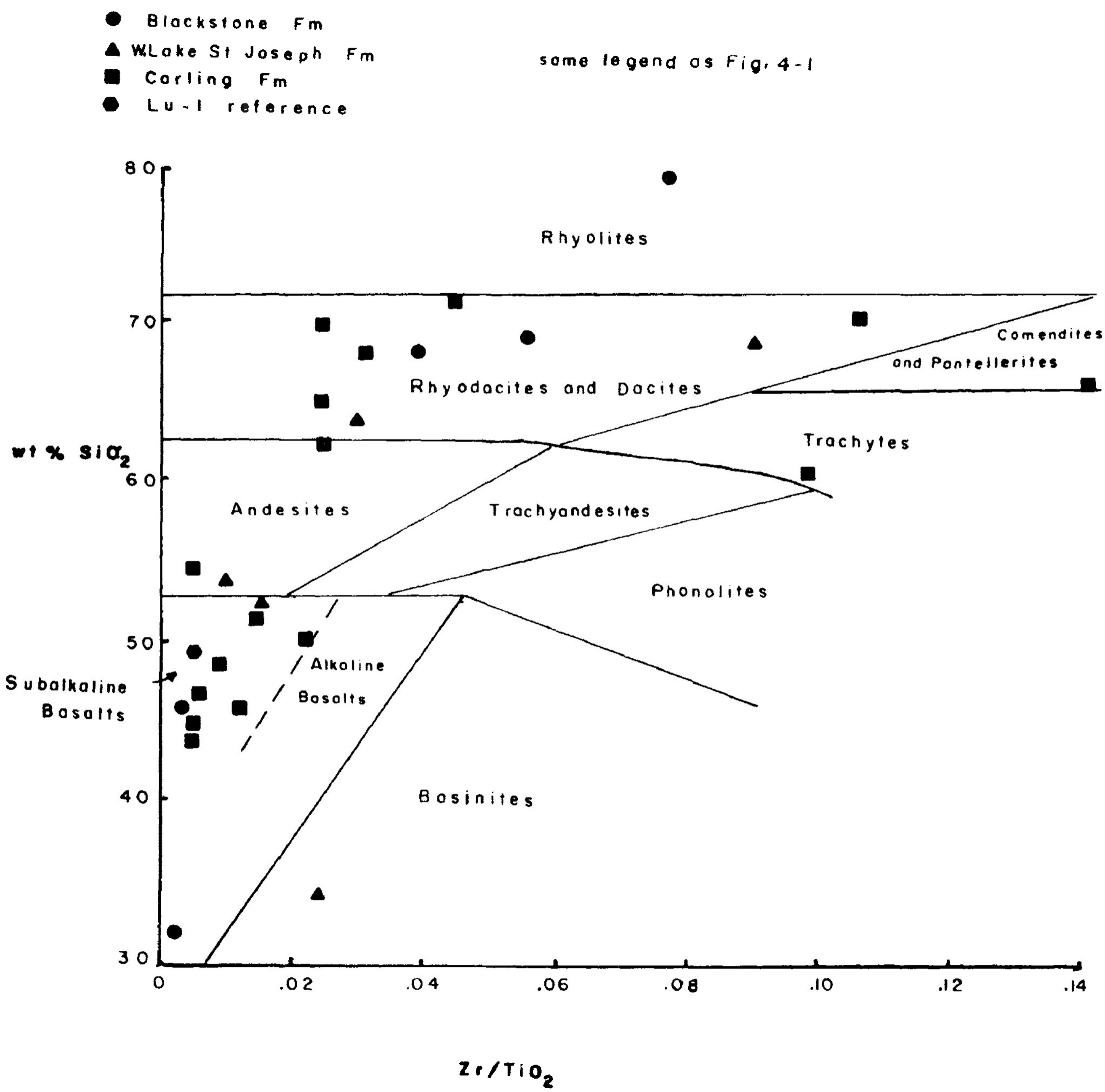
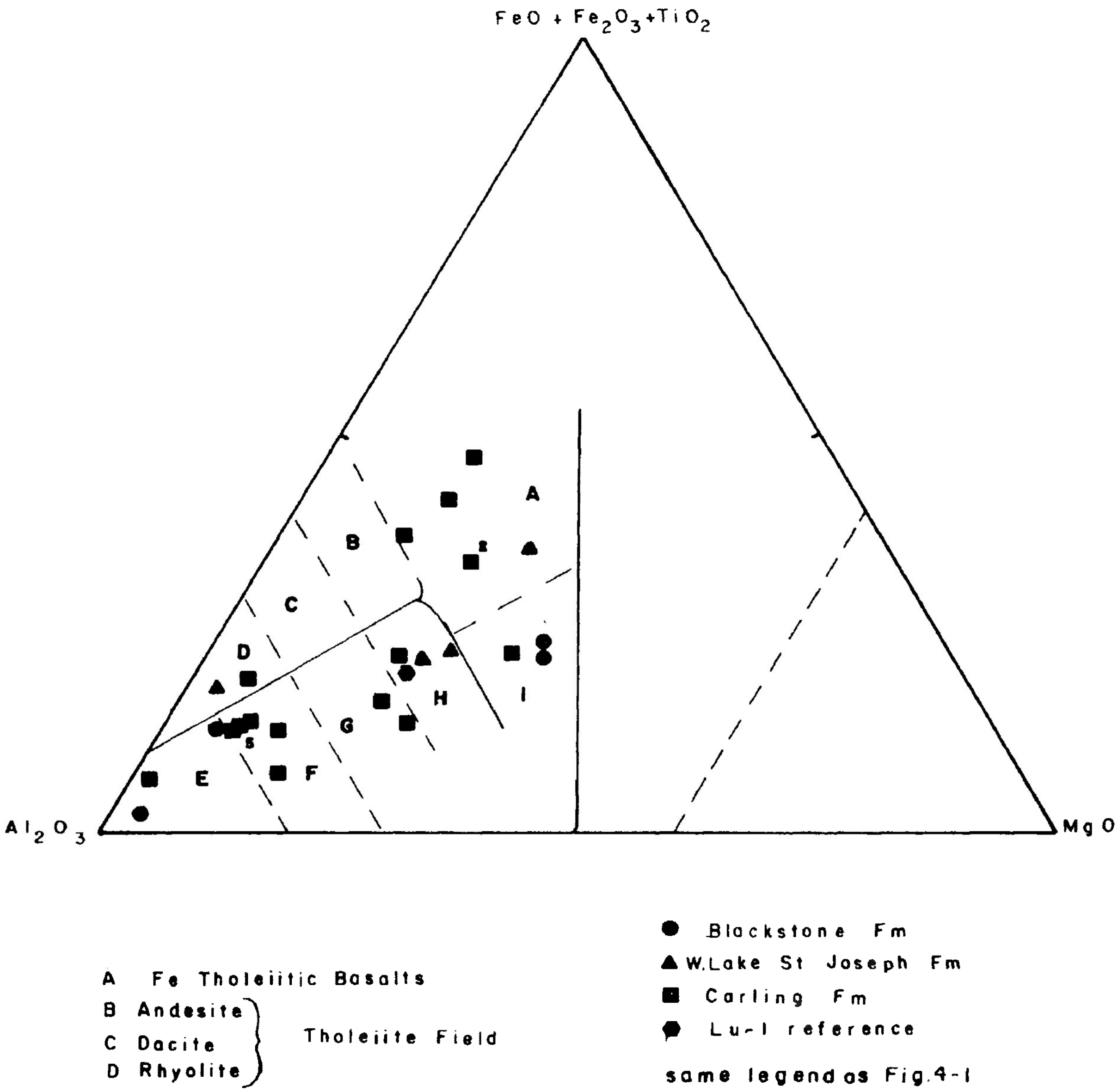


Fig. 4-4

Jensen Cation Plot



A Fe Tholeiitic Basalts

B Andesite, C Dacite, D Rhyolite — Tholeiite Field

E Rhyolite, F Dacite, G Andesite, H Basalt — Calc-alkaline Field

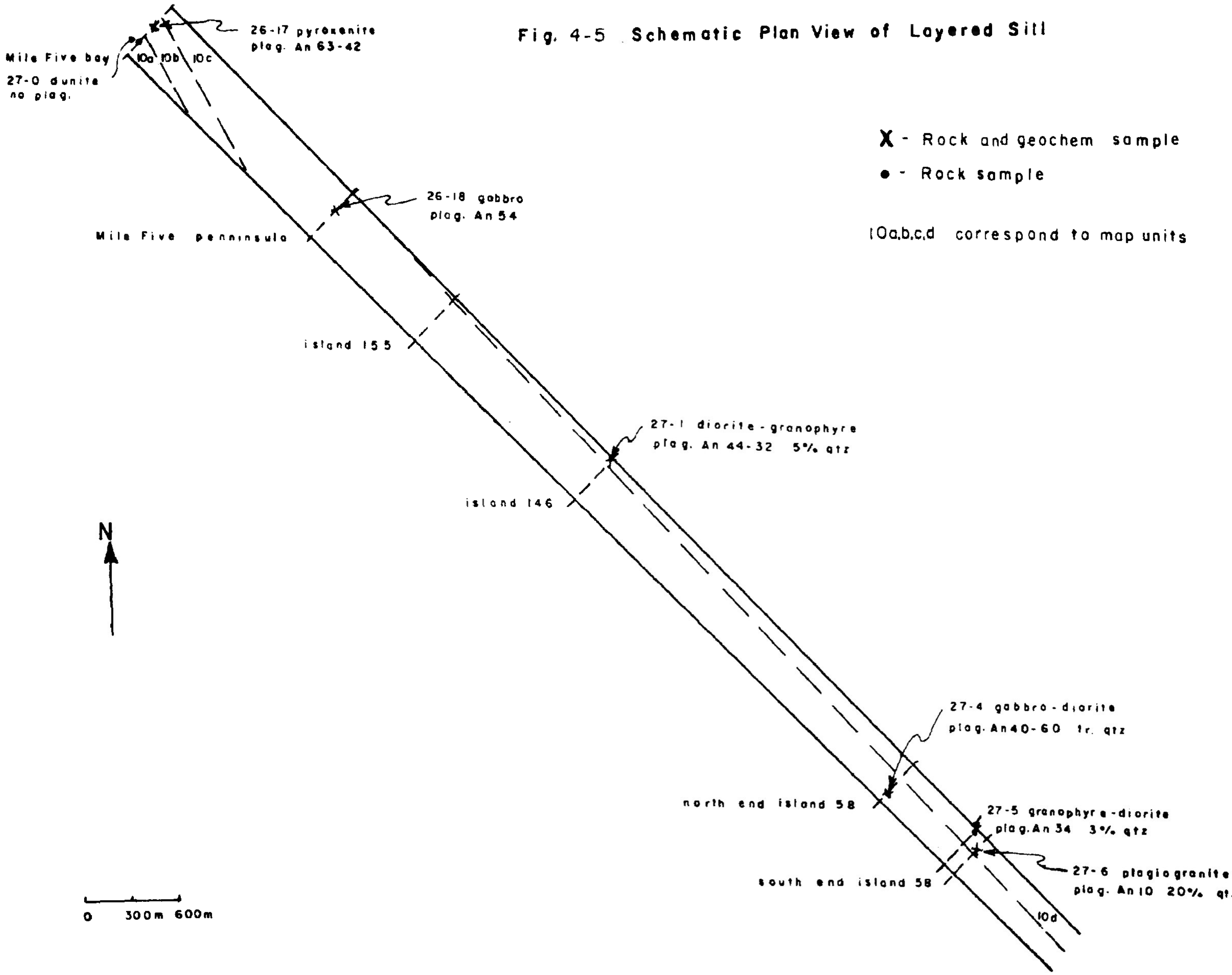
I Mg Tholeiite Basalts

Western Lake St Joseph Formation is characterized by a predominance of calc-alkaline basalts and the Carling Formation is characterized by a predominance of high iron tholeiite basalts. The felsic volcanic rocks cluster near the calc-alkaline dacite field and are inseparable in terms of their respective formations. This plot, like Figure 4-3, shows a bimodal distribution between basalts and dacites with relatively few andesites. It is suggested that this distribution is real rather than a function of sampling because both Figure 4-3 and Figure 4-4 delineate a bimodal trend. Furthermore the calc-alkaline trend for the Western Lake St Joseph Formation is indicated in Figures 4-1 and 4-2 suggesting that this is also a valid characterization of this Formation. The Jensen Cation Plot adequately separates the basalts of the three formations and demonstrates that the physical separation of the formations as represented by the mapping is also chemically expressed.

GEOCHEMISTRY OF THE LAYERED SILL

Samples of the layered sill that intrudes the volcanic member of the Carling Formation were collected and analyzed to see if observable lateral and vertical chemical variations could be detected. Figure 4-5 shows the location of the geochemical samples within the sill relative to geographic positions. It also shows the inferred contacts of the identified phases of the sill based on the first and last

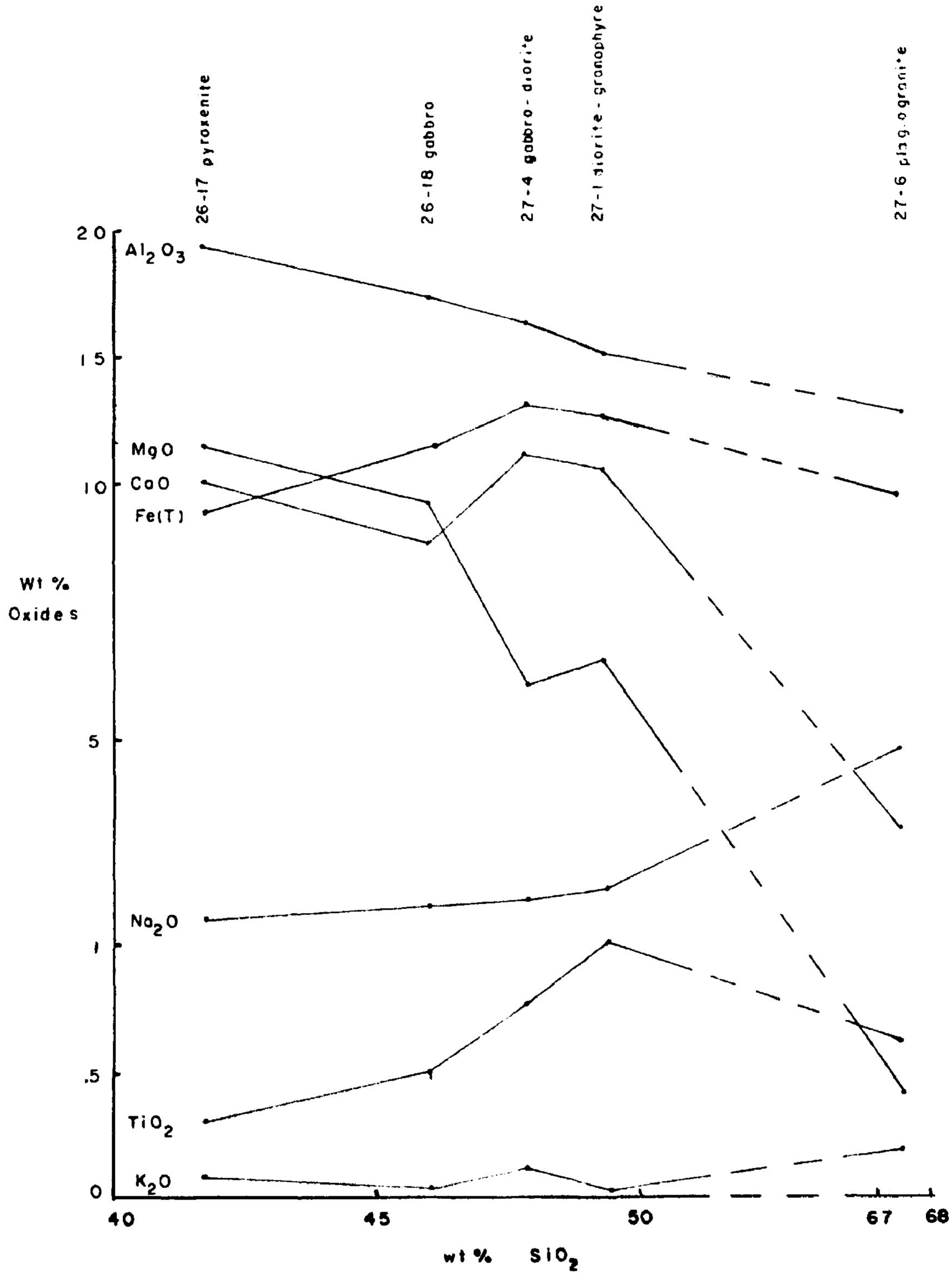
Fig. 4-5 Schematic Plan View of Layered Sill



field appearance of each phase. Figure 4-6 shows the chemical composition of each phase and the lateral and vertical variation within the sill. It is apparent that the sill becomes more siliceous and more alkaline from northwest to southeast. Conversly, the alumina and magnesium contents decrease in the same direction. The plagiogranite phase is considered to be a product of a residual liquid and consequently is expected to deviate from the other phases which are considered to be the products of magmatic differentiation and gravity settling.

The layered sill is not directly analogous to previously documented Archean and younger layered sills. However, general chemical trends are similar and comparison of these trends is useful in establishing the stratigraphic sequence of the phases in the sill. Naldrett and Mason (1968) demonstrate that an Archean layered sill in Dundonald Twp. of Northern Ontario is divisible into five phases namely, peridotite, pyroxenite, iron-oxide rich gabbro, normal gabbro and granophyric gabbro from base to top of the sill. This division is reflected chemically by a progressive increase in silica, and total alkali content from base to top along with a progressive decrease in magnesium. MacRae (1969) shows that layered sills in Munro Twp., of similar dimensions to the Western Lake St Joseph sill, are progressively more siliceous and alkaline from base to top and progressively less magnesian upsection. A younger example which shows these same trends is the Palisade sill in New York (Hyndman, 1972).

Fig. 4-6 Variation Diagram for Layered Sill



On the basis of these examples it is concluded that the chemistry of the layered sill at Western Lake St Joseph supports the stratigraphic interpretation. This indicates that the sill and consequently the Carling Formation youngs to the northeast. The fact that the contacts of the five phases are discordant with the sill's contacts is interpreted to be due to the original orientation of the sill at the time of intrusion. In other words, the sill was likely intruded at an angle to the horizontal and that this paleoslope was possibly controlled by the original volcanic stratigraphy.

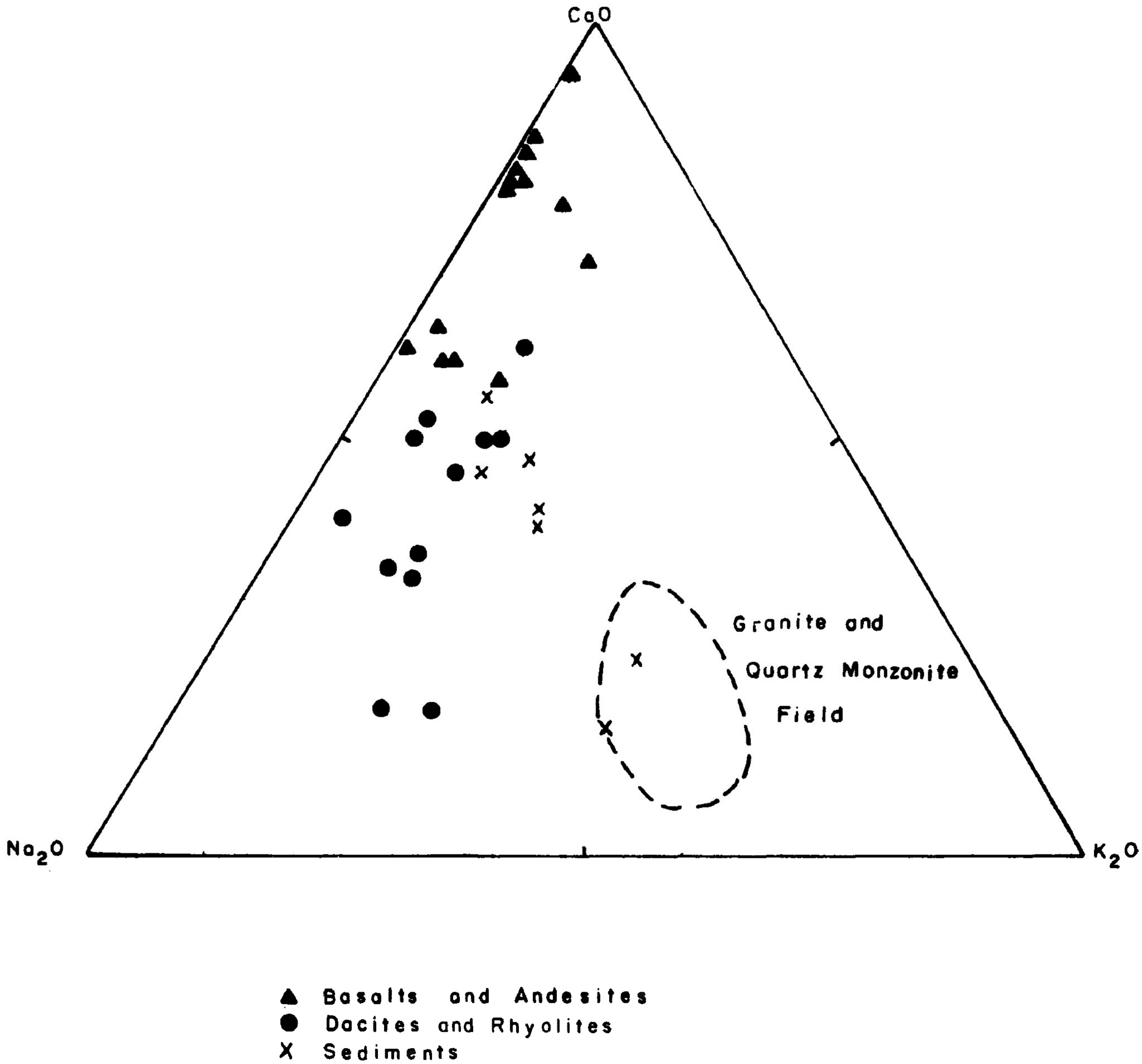
One trend which complicates the chemical interpretation is that of alumina. The sill at Western Lake St Joseph shows a pronounced decrease upsection whereas the two Archean examples cited show upsection increases in alumina. The main aluminum bearing mineral in these sills is plagioclase and variations in this mineral account for the different trends. At Western Lake St Joseph plagioclase appears first in the pyroxenite and persists at that same volume (approx. 40%) into the upper phases of the sill. As documented in Chapter II, the plagioclase becomes more sodic (An_{63} in pyroxenite to An_{10} in plagiogranite) upsection. Deer, Howie and Zussman (1971) show that sodic plagioclase contains less alumina than calcic plagioclase. In the case of labradorite (An_{50-70}) differentiating to albite (An_{0-10}) there is a 33% decrease in aluminum which could possibly account for the observed decrease in alumina in the Lake St Joseph sill

(Deer, Howie and Zussman, 1971). The Munro Twp. and Dundonald Twp. sills show first crystallization of plagioclase in the pyroxenite phases but plagioclase increases in volume rapidly upsection. The increasing alumina content in these sills is possibly a reflection of increased volume rather than change of composition of the plagioclase.

PROVENANCE OF SEDIMENTARY ROCKS

Tuffaceous sedimentary rocks and greywackes of the Carling Formation were analyzed in an attempt to demonstrate their provenance. Petrographically the sedimentary rocks of the Carling Formation reflect the increased mixing of a granitic source with a volcanic source as the rock sequence becomes younger (see Chapter II). This trend is demonstrated chemically in Figure 4-7 which was used by Condie (1967) to show the provenance of Precambrian Wyoming greywackes. The plot shows the distribution of the Lake St Joseph Group volcanic rocks and the Carling Formation sedimentary rocks and reveals a distinct divergence in their respective trends. The sedimentary rocks are progressively enriched in potassium from the tuffaceous rocks in the lower volcanic member of the Carling Formation to the arkose of the upper sedimentary member. The arkose (samples 26-21, 25-4 A1-1, Appendix I) plot in the granite-quartz monzonite field as outlined by Condie (1967). The Lake St Joseph Group volcanic rocks are

Fig. 4-7 $CaO-Na_2O-K_2O$ Plot (after Condie 1967)



low in potassium relative to the sediments. This divergent trend between the volcanic and sedimentary rocks is interpreted to be the result of the waning influence of a volcanic rock provenance (i.e. cessation of volcanic activity) and increasing influence of a plutonic provenance (i.e. erosion of a granitic source).

CHAPTER V - DISCUSSION

INTRODUCTION

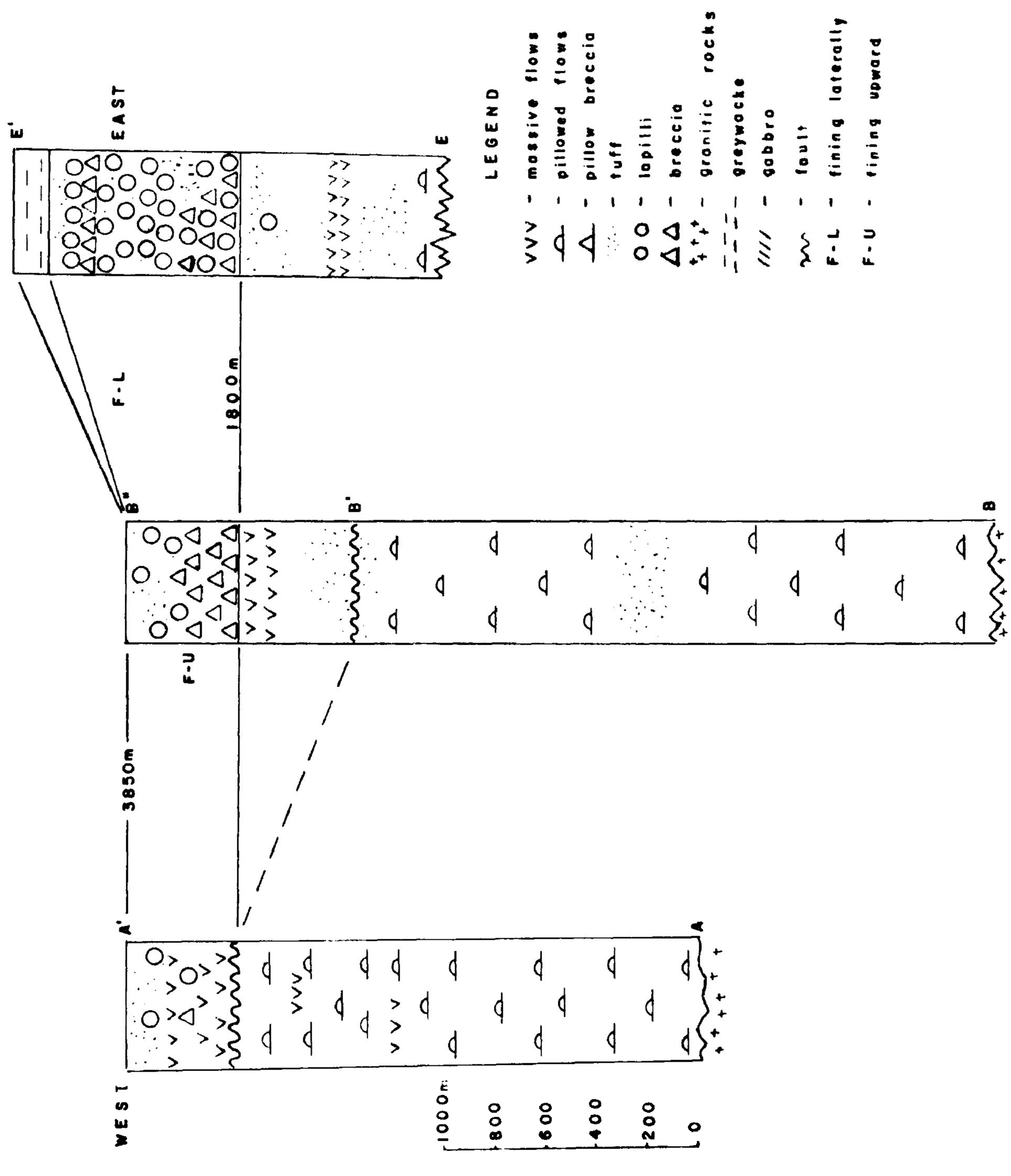
The Western Lake St Joseph greenstone terrain is a succession of metavolcanic and metasedimentary strata of Archean age. In this study the strata are grouped or combined into three formations assuming that volcanic cyclicity occurred. The present distribution of lithologies is the result of primary deposition, metamorphism and structural deformation. However, it is useful to attempt an interpretation regarding the evolution of the greenstone terrain as a basis for future studies in areas of similar geologic setting.

The combination of stratigraphy, primary structures and geochemistry as applied to selected stratigraphic columns has been used to reconstruct the depositional environments of the Lake St Joseph Group. Central to this reconstruction is the application of facies models which permit inferences to be made about environments and depositional processes.

BLACKSTONE AND WESTERN LAKE ST JOSEPH FORMATIONS

Figure 5-1 shows stratigraphic columns with vertical and lateral variations in the Blackstone Formation. The lower

Fig. 5-1 Vertical Sections: Blackstone Formation

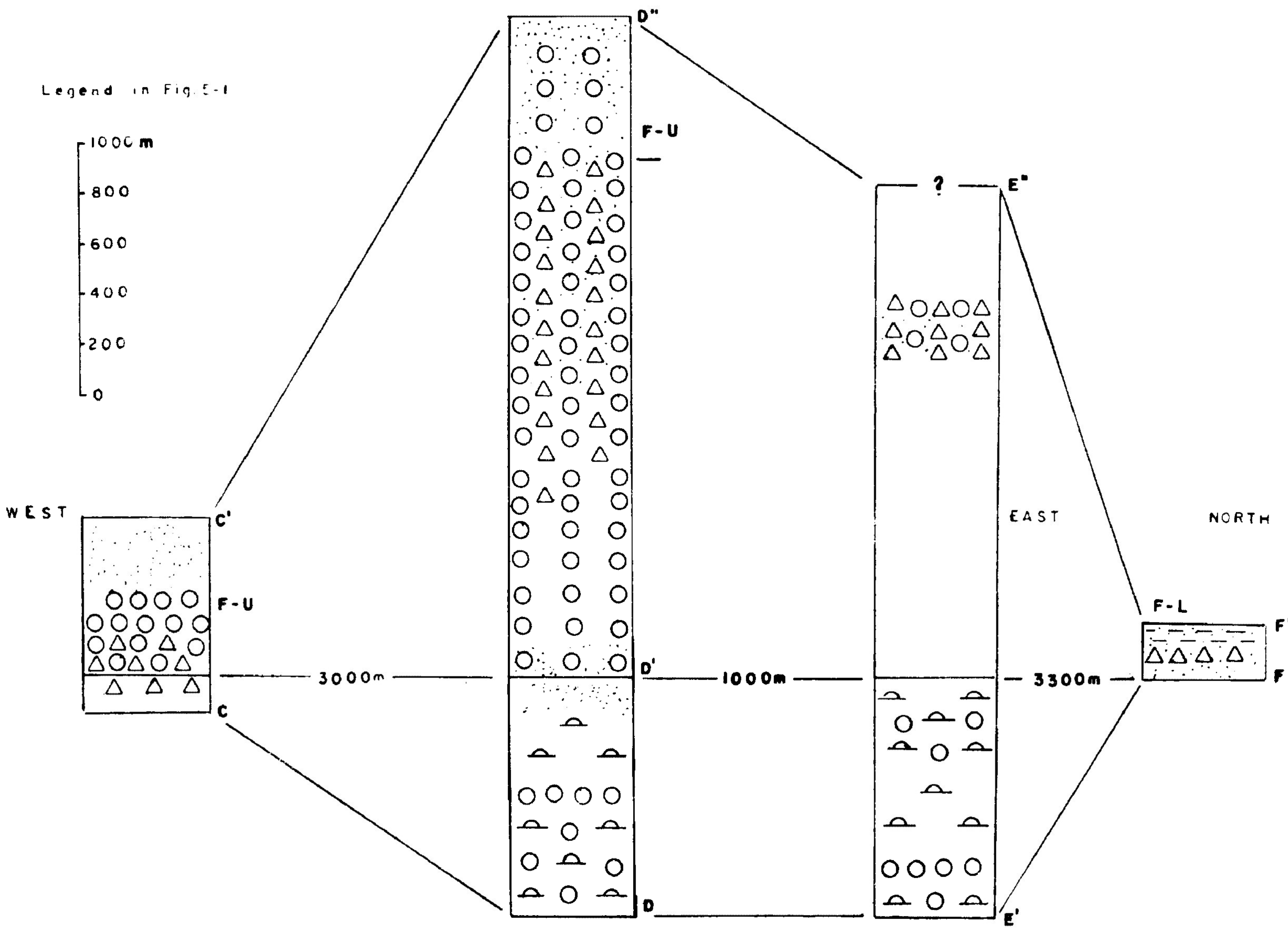


member is composed of low-K, high-Mg tholeiitic basalts. Pillowed flows predominate but massive flows and pyroclastic volcanic rocks become more numerous near the top of the member especially in section E-E' (Fig. 5-1; island 285 on Map 2). The upper member is composed of dacitic and rhyolitic flows as well as pyroclastic and epiclastic volcanic rocks. The member defines a crude fining upward (F-U) sequence and a crude laterally fining (F-L) sequence from west to east.

Figure 5-2 shows stratigraphic columns with vertical and lateral variations of the Western Lake St Joseph Formation. The lower member is composed of calc-alkaline basalts and andesites. Massive flows, amygdaloidal pillowed flows and mafic to intermediate pyroclastic and epiclastic volcanic rocks are distributed so that fragmental and sedimentary rocks are more abundant in the eastern and northern parts of the member. The upper member is composed of dacitic to rhyodacitic pyroclastic and epiclastic debris. These lithologies define a crude fining upward and laterally fining sequence from west to east like the upper member of the Blackstone Formation.

Because there is a similarity in trends between the Blackstone and Western Lake St Joseph Formations they are considered to be trends produced by the same paleoslope. The stratigraphic columns in Figures 5-1 and 5-2 are interpreted to represent the effects of an emerging volcanic pile as has been documented by Ayres (1977). Evidence supporting this contention comes from the vertical variations in size, shape

Fig. 5-2 Vertical Sections: Western Lake St. Joseph Formation



and vesicularity of pillow lavas as well as the distribution of the volcaniclastic rocks and massive flow rocks.

Concerning the last point, massive flows are common in the upper member of the Blackstone Formation (Fig. 5-1) and in the lower member of the Western Lake St Joseph Formation. At Amisk Lake, Saskatchewan, Ayres (1977) documents an increase in the volume of massive flows from a subaqueous to a subaerial environment. This is a relatively weak point since Well et al. (1979) note that massive submarine flows are more common in Archean terrains than in equivalent modern terrains.

The size, shape and vesicularity of pillowed flows supports an emerging volcanic pile model. Ayres (1977) describes deeper water pillows as being regular in shape with very little interstitial material as is the case of the pillows of the lower member of the Blackstone Formation (Appendix II, Plate 1). Shallow water pillows (Ayres, 1977) become more irregular and interstitial material increases in volume. These features are found in the upper stratigraphic levels of the lower member of the Blackstone Formation (Appendix II, Plate 2).

Furnes and Fridleifson (1979) argue that deep water pillows should be smaller than shallow water pillows for basaltic melts of the same composition. The Blackstone Formation pillows are smaller on average (0.5-1 m) than the pillows of the Western Lake St. Joseph Formation(0.7-3m). Although this feature may in large part be due to viscosity contrasts of the different magmas or rate of extrusion of magma it could also be due in part to decreasing water depths.

More convincing is the increase in the volume of vesicles and amygdules of pillow lavas from the Blackstone Formation into the Western Lake St. Joseph Formation. Moore(1965), Jones(1969), and Ayres(1977) show that pillow vesicularity and abundance of amygdules are inversely related to water depth during pillow formation. Pillowed flows become more vesicular towards the top of the lower member in the Blackstone Formation and are commonly amygdaloidal in the overlying Western Lake St. Joseph Formation.

The most convincing evidence in favour of an emerging volcanic pile is the abundance of pyroclastic material in the Western Lake St. Joseph Formation relative to the Blackstone Formation. McBirney(1963) concludes that expansion of gases promoting pyroclastic activity is favoured at water depths of less than 500 meters. Below this depth explosive activity is inhibited and flows are more likely to form. Sparks(1978) shows that pyroclastic activity is promoted by high viscosity of felsic magmas which permits slow removal of gas bubbles. Therefore, at constant depth magma viscosity relations promote pyroclastic in siliceous magmas. This suggests that the abundance of pyroclastic material is not necessarily an indication of shallowing water. However Fig.5-1 and 5-2 show that the upper member of the Blackstone Formation contains massive flows and pyroclastic rocks and the upper member of the Western Lake St. Joseph Formation contains mainly pyroclastic and epiclastic rocks. Figures 4-3 and 4-4 shows that the compostions of the upper members of the two formations are nearly equivalent. Therefore the abundance of the flows in the upper member of the Blackstone Formation is attributed to extrusion at greater water depth than the upper member of the Western Lake ST. Joseph Formation. Ayres(1977) documents the following primary features in the pyroclastic rocks at Amisk Lake: cross-bedding, intraformational conglomerate, normal graded bedding, scour strustures and heterolithic breccias with clasts upto 1.3m. All except cross-bedding arepresent in the upper members of the Blackstone and Western Lake St. Joseph Formations.

The Amisk Group is 8 km thick but the subaqueous to subaerial transition is documented over the upper 3900m (Ayres,1977). At Western Lake St. Joseph the Blackstone and Western Lake St.Joseph Formations show a maximum thickness of 7.2 km but most of the evidence for an emerging volcanic pile is in the upper 3 to 5 km. Therefore the stratigraphic thicknesses are comparable further supporting the emerging volcanic pile concept at Western Lake St. Joseph.

Ayres(1977) documents flow-foot breccias, pipe amygdules and reaction rims an tephra which are considered to be proof of subaerial volcanism at Amisk Lake. These features have as yet not been observed at Western Lake St.

Joseph. Therefore there is inconclusive evidence that the volcanic edifice breached the water surface during the development of the Blackstone and Western Lake St Joseph Formations.

Figures 5-1 and 5-2 show the development of a consistent lateral variation within the Western Lake St Joseph Formation and the upper member of the Blackstone Formation. There is a progressive increase in volcaniclastic material in an easterly direction expressed as a laterally fining sequence. This distribution is interpreted to be a function of the proximity of the material to a volcanic vent, the finer material being further from the vent. Ayres (1977) classified the pyroclastic units at Amisk Lake as lahars and avalanche deposits that developed on the flanks of subaerial volcanic cones. The lack of conclusive evidence for subaerial deposition at Western Lake St Joseph suggests that the name "lahar" should be avoided at Western Lake St Joseph.

Shegelski (1978) describes proximal pyroclastic environments from the Savant-Sturgeon greenstone terrain which contain thick lenticular piles, turbidites, normal grading and chaotic beds. Profile shapes of these piles are initially conical representing areas of localized relief. The volcanic vents act as point sources for pyroclastic debris which is transported radially downslope. This causes fining, sorting and reworking of the debris as it is removed from its source. Similar features are also observed at Western Lake St Joseph. A model proposed by Tassé et al. (1978) and Lajoie (1979) is used to explain the sequential lateral change from chaotic bedding through normal graded bedding to parallel bedding observed in the upper member of the Western Lake St Joseph Formation. According to this model type A beds (Lajoie 1979) thicken in the direction of material transport. Type A beds are more massive proximal to the volcanic source and become reversely and normally graded with increasing parallel laminations in the distal parts of the beds. Lajoie (1979) and Shegelski (1978) proposed that the massive or chaotic proximal deposits are formed by debris flows. The distal parts of the beds formed from turbulent suspensions analogous to turbidity current (Lajoie 1979).

The model above in conjunction with the laterally fining sequence previously described defines a paleoslope, presently oriented so that the downslope direction trends from west to east. The Western Lake St Joseph Formation and the upper member of the Blackstone Formation were deposited on this paleoslope. The vertical sequence in these two formations defines an emerging volcanic pile that may have had a subaerial component.

There is a chemical trend from low-K tholeiitic basalts to calc-alkaline basalts-andesites, dacites and rhyolites in the lower two formations of the Lake St Joseph Group.

This trend has often been compared to modern island arc geochemistry [Condie and Harrison (1976), Young (1978), Ringwood (1974), Hart et al. (1970)]. Condie and Harrison (1976) describe the geology and geochemistry of the Archean Bulawayan Group of Rhodesia and interpret its evolution as that of an emerging arc system. This group consists of a lower Mafic Formation composed of pillowed low-K tholeiites overlain by calc-alkaline basalts, andesites and dacites in the Maliyami and Felsic Formations. The similarity between the Rhodesian Bulawayan Group and the Blackstone and Western Lake St Joseph Formations of this study is apparent and could be considered compelling support for the present interpretation. However, there are alternative explanations. The geochemistry presented in Chapter IV demonstrates that the Lake St Joseph Group data cannot be accurately compared to modern analogues. This point is emphasized by Glikson (1976) and Glikson (1979).

Furthermore, Hawkesworth and O'Nions (1977) argue that the trace element geochemistry of Archean volcanic rocks in South Africa and Rhodesia differs significantly from that of modern island arc volcanic rocks. They show that the tholeiitic to calc-alkaline trend can be generated by a rifting mechanism which taps and fractionates magmas from progressively shallower regions of the mantle. Therefore, the emerging volcanic pile documented by the Blackstone and Lake St Joseph Formations cannot be definitively assigned to either an island arc system or to a rifting system at present.

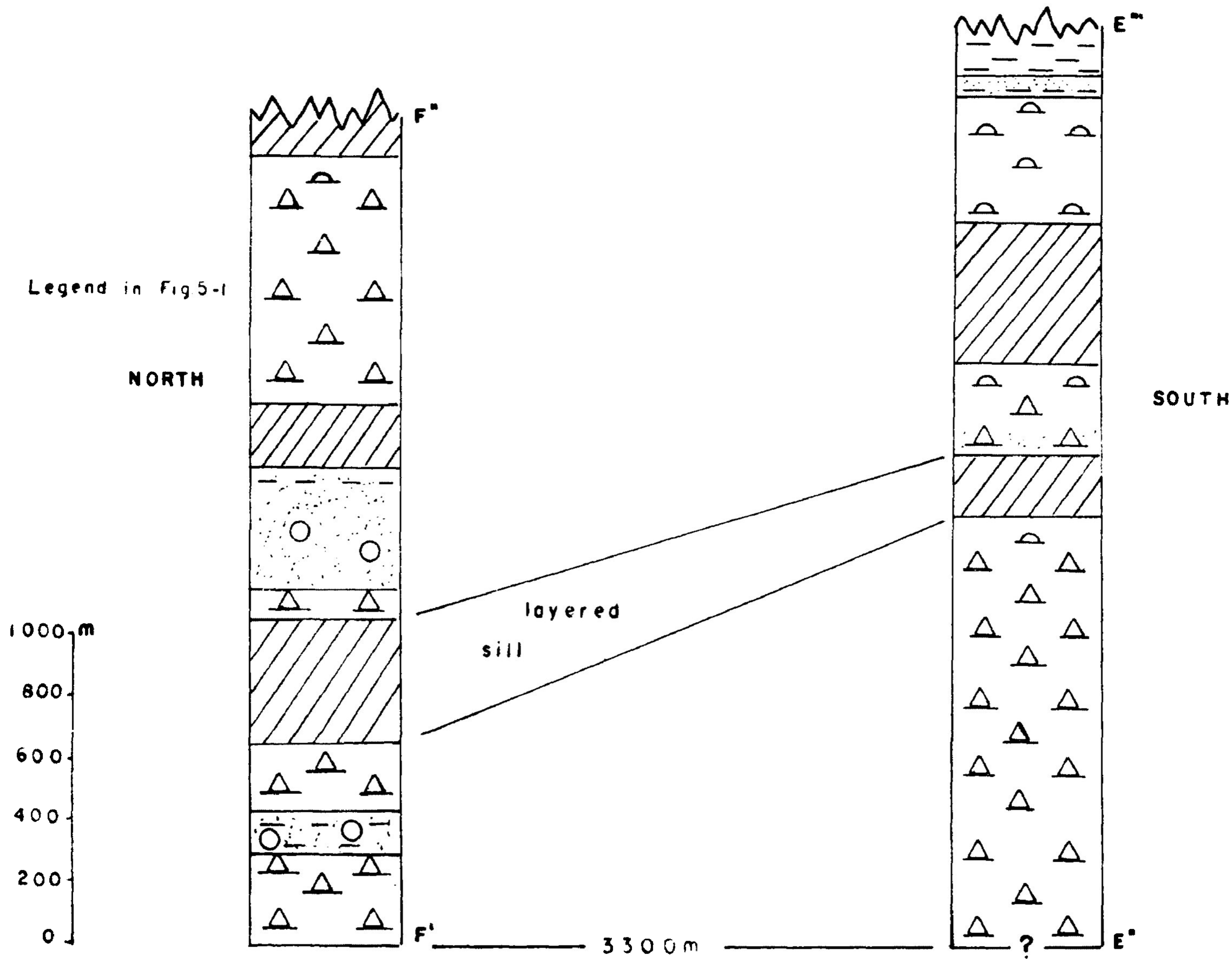
VOLCANIC MEMBER OF THE CARLING FORMATION

The volcanic member of the Carling Formation is a diverse assemblage of volcanic and intrusive rocks (Fig. 5-3). Units are lenticular and volcanic cyclicity is poorly developed but a mafic to felsic sequence has been defined. Vertical and lateral variations in the volcanic rocks are crudely developed and inconsistent with those of the Blackstone and Western Lake St Joseph Formations. The layered sill is a marker unit in the stratigraphy and indicates a paleoslope which is presently oriented south to north. This is defined by the lateral variation in silica, magnesium and alkalis as well as the composition and distribution of rock phases within the sill (Chapter IV). It is suggested that the volcanic member of the Carling Formation was derived from a different source than the one that produced the Blackstone and Western Lake St Joseph Formations. This is supported by the different flow morphology and the different chemistry of the mafic rocks in the volcanic member.

Geologically the volcanic member closely resembles the "Upper Diverse Group" described by Morrice (1974). The presence of pillow breccias, variolitic pillows, numerous intrusive rocks and interlayered sedimentary horizons matches other Archean sequences assigned to the "Upper Diverse Group".

The rapid alternation between mafic and felsic volcanism is another characteristic feature but the predominance of mafic lavas suggests volcanic edifices of "considerable magnitude" (Morrice, 1974).

Fig 5-3 Vertical Sections: Volcanic Member, Carling Formation



The "Upper Diverse Group" is commonly the youngest volcanic sequence developed and is overlain by thick sedimentary sequences such as the Temiskaming type in Canada and the Fig Tree in South Africa (Morrice, 1974). This group is considered to be orogenic and in part contemporaneous with granitic diapirism (granitic boulders in conglomerates as evidence). These features are very similar to the upper member of the Carling Formation.

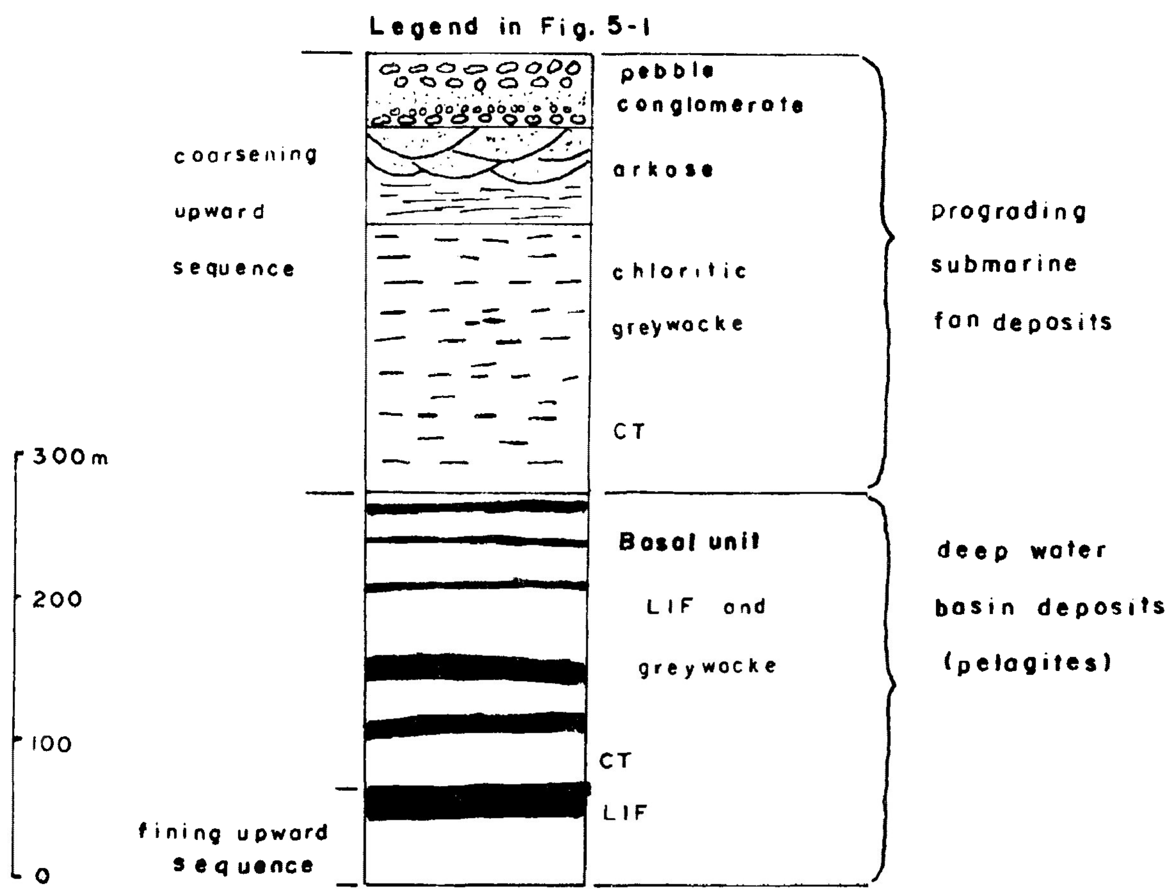
Chemically, however, the analogy between the volcanic member of the Carling Formation and the "Upper Diverse Group" does not apply. Wilson and Morrice (1974) suggest that the basalts of the "Upper Diverse Group" are magnesium rich and calc-alkaline. The basalts of the volcanic member of the Carling Formation are iron rich and tholeiitic.

SEDIMENTARY MEMBER OF THE CARLING FORMATION

The sedimentary member of the Carling Formation is considered to have been formed in a submarine deep water environment. The primary structures, their vertical and lateral variations and changes in mineralogy in the strata suggest that deposits of a basin plain are overlain by a prograding submarine fan.

The submarine fan facies (Walker, 1979) has been reconstructed from outcrops on Eagle Island and is presented in a generalized form in Figure 5-4. At Western Lake St

Fig. 5-4 Idealized vertical section of stratigraphy of the Sedimentary Member of the Carling Formation



CT - classical turbidites

LIF - laminated iron formation

Joseph the stratigraphy shows the development of a fan facies from the outer fan to the channeled portion of suprafan lobes or the inner fan channel fill. The outer fan segment of the submarine facies is represented by the basal unit of the sedimentary member. The laminated iron formation and greywackes are organized into fining upward cycles and are analogous to distal classical turbidites (Walker, 1967). The coarse epiclastic material derived from the Western Lake St Joseph Formation near the lower contact of the basal unit is not related to the development of the submarine fan being described. Rather these deposits were apparently formed by erosion of the volcanic edifice which produced the Western Lake St Joseph and Blackstone Formations.

The basal unit is overlain by the chloritic greywackes which are generally coarse grained. They form a coarsening upward sequence and interlayered classical turbidites indicate that these deposits are part of the suprafan lobes. The petrographic equivalence of the chloritic greywackes with the clastic portion of the basal unit indicates a similar provenance for both sediments. This provenance is interpreted to be that of volcanic rocks from the underlying formations. Geochemically these plagioclase rich greywackes are depleted in magnesium and potassium relative to greywackes in the above cited references. The lack of K-feldspar in most Archean greywackes has been attributed to rapid degradation of these detrital grains (Henderson, (1972), Condie

(1967) . Chemical analyses showing elevated K_2O suggest that potassium feldspars were present and a granitic source has been invoked for these greywackes [Henderson (1972), Donaldson and Jackson (1965)]. In the Carling Formation greywackes, however, the lack of K-feldspar is considered to be a primary feature related to provenance. Figure 4-7 shows that these greywackes have a strong chemical affinity to the Lake St Joseph Group volcanic rocks and only a weak chemical affinity to potassium rich plutonic rocks. Therefore, it is probable that the volcanic rocks provided the bulk of the detritus to the plagioclase rich greywackes. Furthermore, the low magnesium trend suggests that the intermediate and felsic volcanic rocks made a greater contribution to the sediments than did the mafic volcanic rocks. The extensive volume of dacitic pyroclastic material generated during the formation of the upper member of the Western Lake St Joseph Formation and the upper volcanic part of the Carling Formation could have provided the necessary components to the plagioclase rich sediments. It is suggested that the development of the submarine fan follows Walker's (1979) hypothetical model most closely up to this point in the stratigraphy.

Overlying and partially intercalated with the chloritic greywackes is the arkose unit. The presence of cross-bedding, coarse sand to grit and occasional scours suggests that this unit represents the channelled portion of the suprafan lobes.

This unit is analogous to Walker's (1979) massive and pebbly sandstones. However, this unit has several features which are controversial (as will be outlined below) and does not clearly fit into a submarine fan model.

The arkose unit is isoclinally folded (Chapter III) so that an apparent thickness of 140 m is observed. Even if the arkose is only 70 m thick it would still be thicker than most sandy bodies (60 m thick) known in modern and ancient submarine fans [Stanley and Unrug (1972), Rupke (1977)]. Thin shaley interbeds which are supposed to be characteristic of submarine channel deposits (Walker, 1979) and which are present in the arkose can also be found in alluvial deposits (Bull, 1972). Dish-shaped dewatering structures (Walker, 1979) are characteristic of submarine fans but they are delicate and would have a poor preservation potential especially in the deformed arkose of the Carling Formation. Ricci-Lucchi (1975) and Rupke (1977) describe submarine massive sandstones as being equi-granular along strike. In particular, Rupke (1977) described a submarine fan deposit in Spain as being uniformly medium grained. The arkose at Western Lake St Joseph defines a laterally-fining sequence from coarse sand and granules in the east to fine and medium sand in west. Another controversial feature is the large scale trough-cross-bedding (up to 50 cm) found in the arkose. Although large scale features are known to be present in deep water environments they are more likely to occur in shallow-agitated water (Turner and Walker, 1973).

An alternate interpretation of the arkose and overlying pebble-conglomerate units is that they are alluvial-fluvial fan deposits. This interpretation is favoured by Goodwin (1965) for similar lithologies in the Kashkokogan Lake area immediately east of the present study. Such deposits of sand-sized material are commonly thick sequences of up to 200 m (Bull 1972, Turner and Walker 1973, Rust 1979, Walton 1979). One of the distinctive features of alluvial deposits is a rapid downslope decrease in grain size (Bull 1972, Russ 1979, Walton 1979). Clay and shale are rare or absent in these deposits (Bull 1972), but large scale trough-cross-bedding is common (Bull 1972, Turner and Walker 1973, Walton 1979). This means that the arkose at Lake St Joseph must be considered in context with the surrounding sediments as suggested by Walker (1979). Because classical turbidites and deep water marine sedimentary rocks underlie, overlie and are gradational with the arkose it is assigned to a submarine fan facies.

The pebble-conglomerate unit overlies the arkose and is interpreted to represent channel fill deposits of the mid to inner fan region. It is poorly exposed but becomes intercalated with the arkose and chloritic greywackes to the west of Eagle Island. Walker (1979) shows that the imbrication of resedimented submarine conglomerates is distinctly different from the imbrication of alluvial-fluvial conglomerates. However, the deformation of the pebble-conglomerate at Western Lake St Joseph precludes a study of this type. The primary structures that are preserved in the pebble-conglomerate clearly indicate a submarine fan origin. In particular the thin regular beds of conglomerate, abundance of "shaley" (LIF) clasts, development of normal and reverse grading and the association with greywackes are most characteristic of submarine fan conglomerates (Turner and Walker, 1973). Additional structures such as scours and parallel laminations in the arkosic interbeds indicate a high energy environment which is necessary for development of the inner fan channel fill.

The lateral variations observed in the upper member of the Carling Formation are considered to be a function of the paleoslope upon which the sedimentary rocks were deposited. There is an east to west lateral increase in the clastic to iron oxide ratio and typically the iron oxide forms the "E" division of the Bouma cycle. This association of iron formation with turbidites has been noted at Savant Lake by Shegelski (1978) and in Western Australia by Dunbar and McCall (1971). They concluded that the iron was deposited in a deep water environment (i.e. below storm wave base). Dunbar and McCall (1971) argued that the iron minerals had constantly settled through the water during deposition of the turbidites. This suggests that the iron be regarded as the equivalent of pelagic sedimentation forming a continuous "background" sediment. Shegelski (1978) presents convinging arguments that this type of Archean iron formation was formed as a distillation product of volcanic exhalation in the Savant-Sturgeon Lakes greenstone terrain. By analogy, volcanic exhalation is invoked as the probable source of the iron formation at Western Lake St Joseph. This implies that as the source of iron emanation is approached the volume of accumulated chemical sediment will increase as long as there is restricted circulation in theoriginal depositional basin. It is proposed that the variable distribution of the iron formation at Western Lake St Joseph is a function of the proximity to the iron source and that sediments on Eagle Island were closer to that source than the sediments further to the west during deposition of the iron formation. Accompanying volcanic activity in the form of ash (chlorite schist) and silica emanations (chert) supports this interpretation.

In conjunction with the formation of the iron deposits the submarine fan shows an east to west laterally-fining trend in the arkose and pebble conglomerate units. Primary structures such as scours and cross-bedding on Eagle Island indicate a high energy environment whereas further west such structures are not found. This is interpreted to represent the westward progradation of the submarine fan along a paleoslope.

The stratigraphy of the sedimentary member of the Carling Formation reflects a dynamic evolution with contributions from at least four provenances. The development of a prograding submarine fan plus the vertically increasing clastic to iron oxide ratio implies that an orogeny occurred prior to the main deformation of the strata. The evolution of the submarine fan shows a transition from a volcanic exhalative source (LIF) interbedded with volcanically derived pelagic sediments (chloritic greywackes) through clastic sediments derived from felsic plutonic rocks (arkose) to clastic sediments derived from a mixed source (pebble-conglomerate). Previous arguments in this thesis show that the iron formation was most likely derived from an exhalative volcanic source and that the chloritic greywackes were derived from the Lake St Joseph Group volcanic rocks. The arkose with its abundant microcline is interpreted to have had a felsic plutonic rock source. This is a necessity because the felsic volcanic rocks do not contain sufficient microcline to provide the quantity observed in the arkose. The compositions of clasts in the pebble-conglomerate indicate mixed provenances but the predominance of iron formation pebbles indicates that erosion of the basal unit of the member provided the bulk of this detritus. Therefore the progressive change of provenances going up through the stratigraphy indicates that uplift, or localized faulting, progressively exposed different sources to erosion. The vertically increasing clastic to iron oxide ratio requires an increased weathering and degradation of areas of positive relief either during or after tectonic uplift. Degradation of a complex volcanic edifice without uplift might account for some of the sedimentary rocks in the Carling Formation but development of the pebble-conglomerate requires some component of uplift in order to erode an otherwise deep water iron formation.

Meyn and Palonen (1980) have examined the sedimentary rocks of the Carling Formation. They concluded that these rocks were deposited on a submarine fan, a similar conclusion as this thesis. Four lithologies: iron formation, sandstone, a cross-bedded unit and a pebble conglomerate unit were described by Meyn and Palonen (1980). These units differ slightly from the units described in this thesis as a result of differing interpretation of contacts and definition of "iron formation". Further, this thesis has a structural interpretation lacking in Meyn and Palonen (1980) which accounts for differences in stratigraphic superposition and unit thicknesses between the two studies. However, this thesis agrees with Meyn and Palonen's (1980) conclusions and has expanded on them.

CHAPTER VI - SUMMARY

The purpose of this study was to show that the Archean terrain at Western Lake St Joseph was divisible into three formations based on the concept of volcanic cyclicity. The formations have been collectively called the Lake St Joseph Group. Each formation has been named and subdivided into two members based on its characteristic morphology and chemistry. The following is a summary of the stratigraphy at Western Lake St Joseph.

BLACKSTONE FORMATION

The Blackstone Formation is divisible into a lower mafic member and an upper felsic member. The lower member is composed of pillowed and massive low-K, high-Mg tholeiitic basalts. It is intruded by gabbroic and quartz-feldspar porphyritic dikes and sills as well as the granitoid Blackstone batholith. The basal portion of the member is predominantly pillowed but increasing numbers of massive flows occur near the top. The upper member is conformable with the lower member and is composed of massive and volcaniclastic rhyodacites and rhyolites of calc-alkaline affinity. Pyroclastic and epiclastic rocks define fining upwards and laterally fining sequences which are interpreted to be the result of volcanic cyclicity and deposition on a paleoslope.

WESTERN LAKE ST JOSEPH FORMATION

The Western Lake St Joseph Formation conformably overlies the Blackstone Formation and is divisible into a lower mafic member and an upper felsic member. The lower member is composed of massive and pillowed calc-alkaline basalts and andesites. Pillows are generally larger and more amygdaloidal than their Blackstone Formation counterparts and there are numerous massive flows. Mafic pyroclastic rocks form a significant portion of the member. The upper member is composed of calc-alkaline dacitic and rhyodacitic pyroclastic and epiclastic rocks. They define fining upwards and laterally-fining sequences with trends similar to those of the upper member of the Blackstone Formation. The epiclastic rocks best fit Type A beds (Lajoie, 1979) which thicken in the direction of material transport and exhibit internal organization which changes from chaotic to normal grading to parallel stratification in the transport direction. This implies material deposition by debris and turbulent flow proximal to a volcanic edifice (Lajoie 1979, Shegelski 1978).

The primary structures and lithologies of the Blackstone and Western Lake St Joseph Formations are interpreted to represent an emerging volcanic pile that probably had a subaerial component west of the thesis area if not in it.

CARLING FORMATION

The Carling Formation is divisible into a lower volcanic member and an upper sedimentary member both of which overlie the Western Lake St Joseph Formation. The volcanic member is composed predominantly of low-K, high-Fe tholeiitic pillow breccias and variolitic pillowed basalts. Dacitic pyroclastic and epiclastic rocks overlie and are interbedded with the basalts. They define a laterally fining sequence which suggests that the lower member was produced from a different source than the two underlying formations. This is supported by the geology and geochemistry of a layered sill which intrudes the volcanic rocks.

The sedimentary member is a complex accumulation of clastic rocks and potentially economic oxide iron formation. The basal iron formation unit is composed predominantly of laminated specular hematite-magnetite beds which have been incorporated into proximal and distal turbidites (Walker, 1967) as the "E" division of the Bouma sequence. Volcanically derived greywackes increase laterally and vertically in the unit defining a coarsening upward sequence. A plagioclase rich chloritic greywacke unit overlies the iron formation unit and is in part equivalent with an arkose unit and pebble conglomerate unit. The greywackes contain all the primary structures of classical turbidites. The arkose contains more quartz than the greywacke unit and is distinguished petrographically by the presence of abundant microcline. It is massive to trough cross-bedded and defines an east to west laterally fining sequence. Overlying the arkose and in part intercalated with it and the chloritic greywacke is a wedge-shaped pebble-conglomerate unit. This unit contains graded-stratified beds with clasts of iron formation, volcanic fragments, vein quartz and plutonic fragments. Microcline grains in its matrix and the presence of arkosic interbeds suggest an affinity to the arkose. The arkose and pebble conglomerate together define a coarsening upward sequence.

The spatial arrangement of the lithologies suggests that four provenances (1. volcanic-chemical; 2. volcanic-clastic; 3. plutonic-clastic; and 4. sedimentary-clastic) contributed sediment into a restricted basin through a westward prograding submarine fan. The volcanically exhaled iron was introduced as pelagic chemical sediment and became interbedded with volcanically derived greywackes of intermediate and felsic composition. As exhalation waned the chloritic greywackes became dominant but orogenic uplift exposed felsic plutonic rocks and laminated iron formation to erosion. The products of this degradation, the arkose and pebble conglomerate respectively, overlie the greywackes.

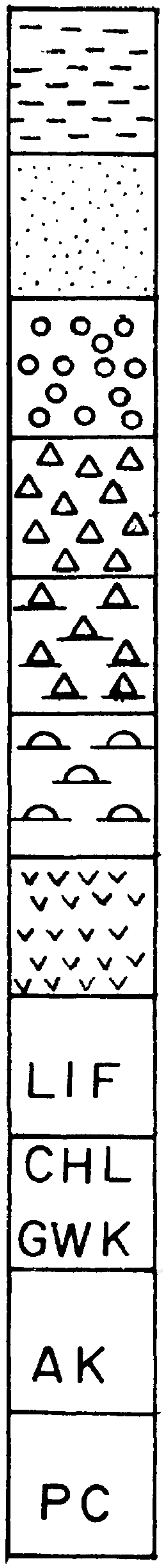
The intrusion of the layered sill and other gabbroic bodies locally prograded the host rocks to the hornblende-hornfels facies of contact metamorphism. The Lake St Joseph

Group was then deformed by the intrusion of the Blackstone and Carling granitic batholiths. This deformation caused lithologic contacts and cleavage orientation to become concordant with the contacts of the granitic batholiths. The deformation produced isoclinal folding in the sedimentary rocks on Eagle Island. Regional metamorphism is contemporaneous with the deformation (Thurston and Breaks, 1978). A late stage deformation is responsible for the development of the Lake St Joseph and Main faults. They are regional features with strike-slip and dip-slip components in the thesis area (Clifford, 1969, Hudec, 1965). The Lake St Joseph Fault caused movement along east-west planes and is responsible for transposition of bedding and tightening of the isoclinal fold hinges as the fault is approached.

A paleotopographic reconstruction of the Western Lake St Joseph terrain envisages a three stage evolution of closely spaced volcanic vents erupting sequentially. In the first stage (Fig. 6-1, 6-2) the Blackstone and Western Lake St Joseph Formations are extruded. Their products represent an emerging volcanic pile cf. Ayres,1978) which was eroded during and following volcanism. The laterally-fining and fining-upward sequences developed in these formations define the paleoslope upon which these rocks were deposited.

During the second stage the volcanic member of the Carling Formation was extruded from an independent vent at a

Legend for Figures 6-1, 6-2, 6-3, 6-4



Epiclastic sediments

Tuff

Lapillistone

Breccia

Pillow breccia

Pillowed flows

Massive flows

Laminated iron formation

Chloritic greywacke

Arkosic wacke

Pebble conglomerate

Fig. 6-1 Stage Ia: Development of early volcanic edifice: Blackstone Formation

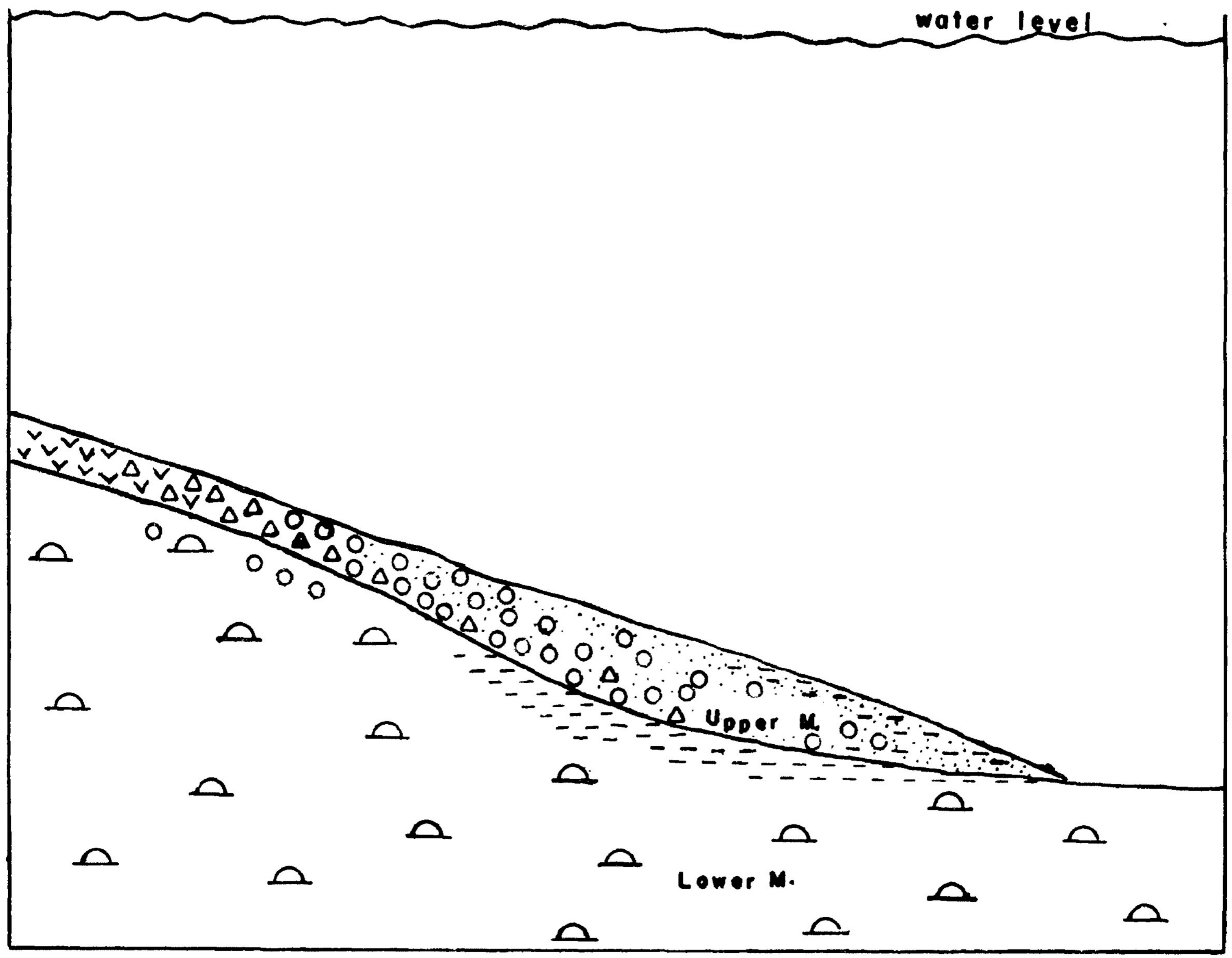


Fig. 6-2   Stage Ib: Development of early volcanic edifice
Western Lake St Joseph Formation

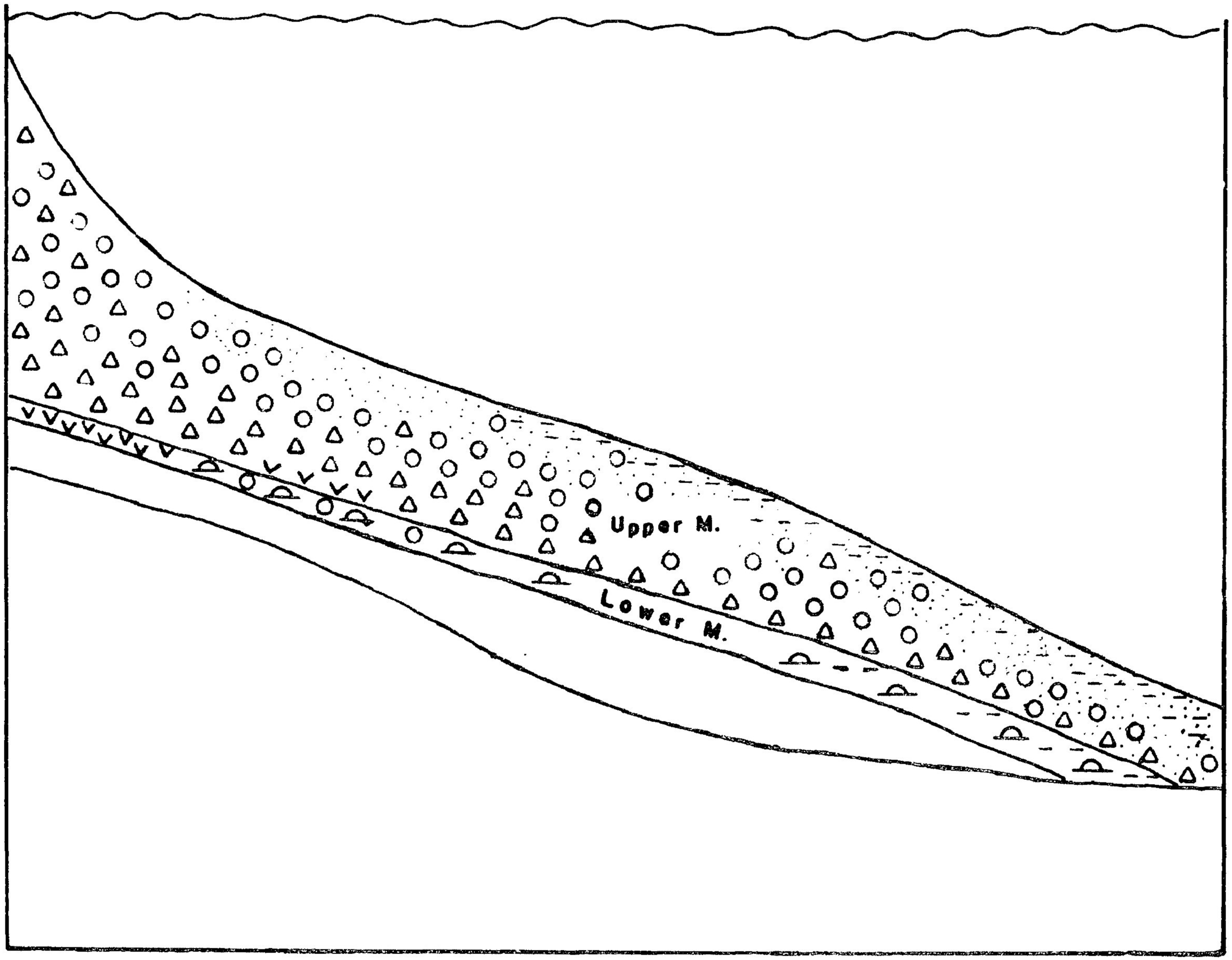


Fig. 6-3 Stage 2 : Degradation of early volcanic edifice
Extrusion of Volcanic Member; Carling Formation

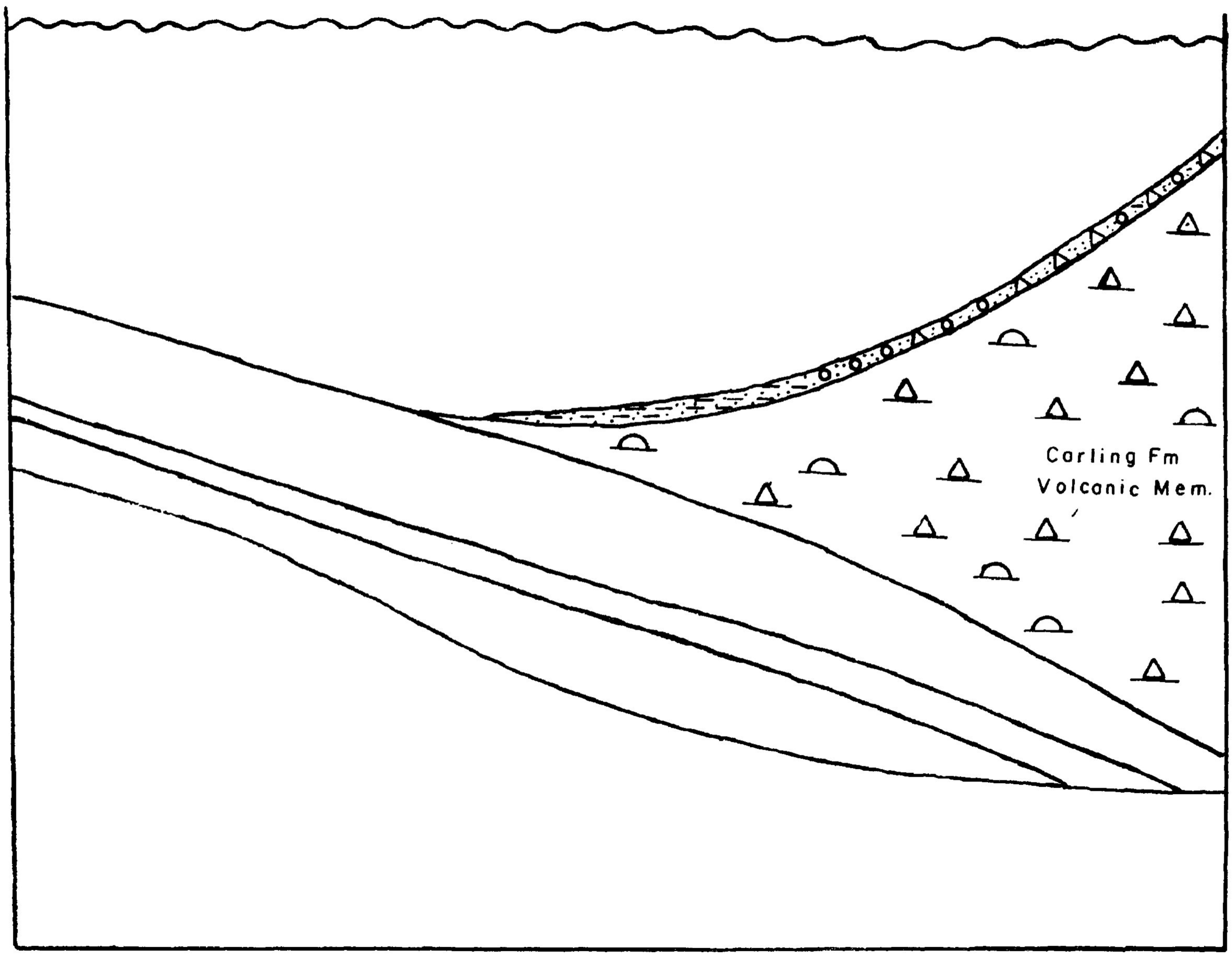
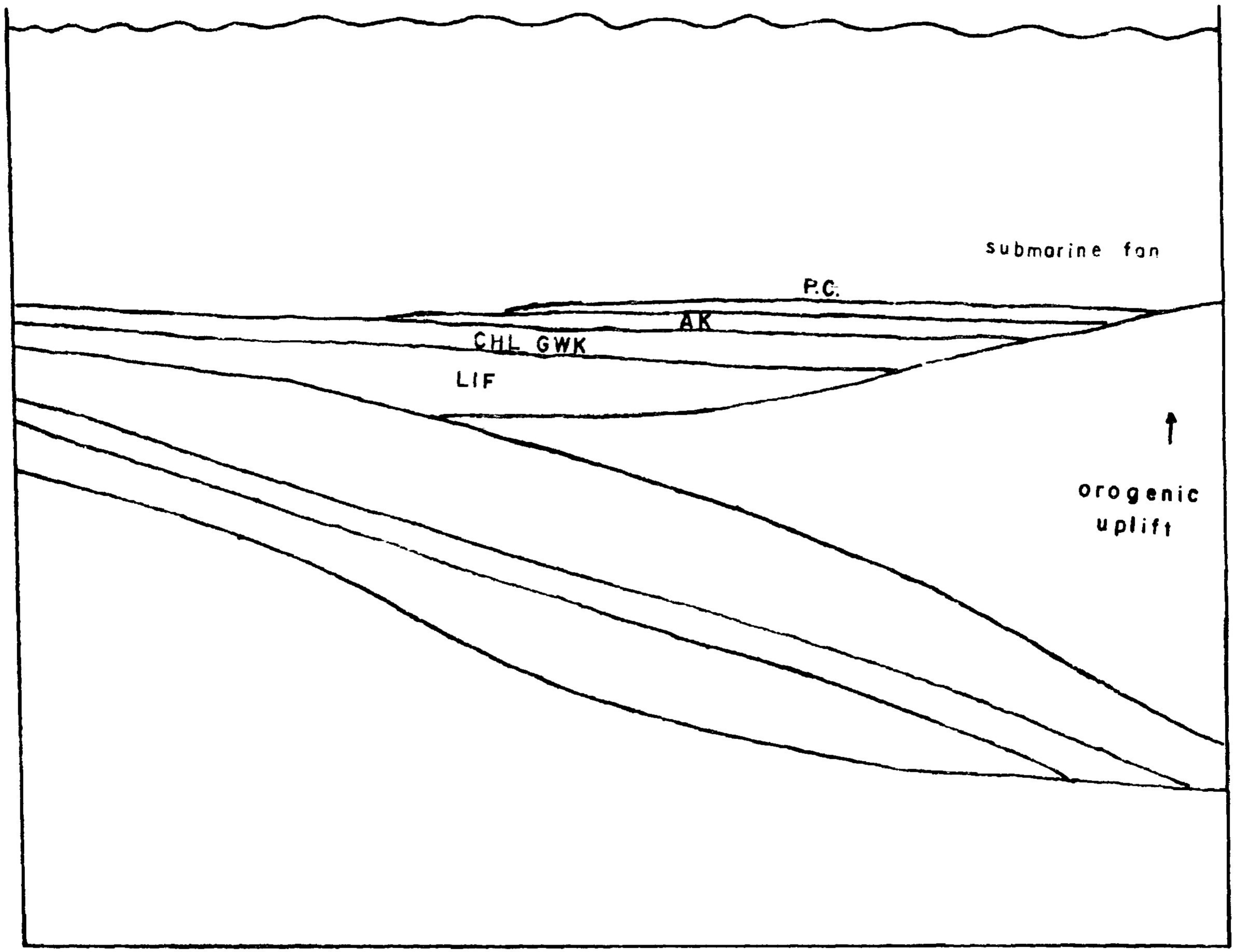


Fig. 6-4 **Stage 3: Continued** Erosion; Exhalation of iron; Orogenic uplift; Development of submarine fan sequence



time later than the Stage 1 vent. The products of this member partly overlaid the Blackstone and Western Lake St Joseph Formations (Fig. 6-3). This created a semi-restricted basin between the two vents.

The third stage involved volcanism and the exhalation of iron which was deposited with volcanogenic detritus as pelagic sediment into the basin. The iron is concentrated in the "E" division of classical turbidites (Walker, 1967). As volcanic exhalation waned clastic input from the eroding volcanic edifices became dominant and clastic sediments were deposited in the basin by a prograding submarine fan. Orogenic uplift first exposed a granitic terrain and then the iron formation to erosion. The products of the erosion, the arkose unit and the pebble conglomerate unit, were deposited on the submarine fan (FIg. 6-4). The fining-upward and laterally-fining sequences in the volcanic rocks and the sedimentary rocks define a paleoslope which was different than the paleoslope defined in Stage 1.

The limitations imposed by the size of the thesis area, the amount of exposure and preservation of primary structures permits only a partial interpretation of the historical geology at Western Lake St Joseph. The results of this study are not proposed as a model for Archean evolution; rather they are an interpretation of the observed features. Future work at Western Lake St Joseph and in adjacent areas may revise or refine the ideas presented in this thesis but the study forms a useful data base from which to start.

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APPENDIX 1

1. Introduction and Sample Preparation

A total of 39 rocks from the Lake St Joseph Group were analyzed for their major oxide and trace element content (Table A1-1). Prospective samples were examined macroscopically or microscopically and those which appeared to be the least altered and most homogeneous were selected for analysis. Since pillowed-lava flows comprise the bulk of the mafic component of all cycles at Lake St Joseph several samples were analyzed. Care was taken to use only the cores of pillows since this portion usually displays the most consistent and representative geochemistry (Baragar et al., 1979). In addition, at least one massive flow from each cycle was analyzed. Mafic pyroclastic rocks being volumetrically the smallest mafic component were therefore not analyzed.

Felsic pyroclastic and epiclastic rocks, on the other hand, form a significant portion of the stratigraphy of each cycle and therefore cannot be ignored. In sampling these units ash tuffs were normally selected. However, in the Carling Formation the matrix and clast of two different pyroclastic breccias were separated and analyzed to document the observed field and petrographic differences. In addition, massive felsic flows were also analyzed from the Blackstone Formation.

Clastic and volcanoclastic sedimentary rocks from the Western Lake St Joseph and Carling Formations were also analyzed. Fine grained homogeneous samples were selected and where stratigraphy was well documented, duplicate samples were analyzed to show lateral variations.

In addition a suite of five samples were analyzed from the layered sill to document lateral and vertical variations with the intention of determining the stratigraphic top.

Each sample chosen for geochemistry was prepared in the following manner. First, an unaltered hand sample was obtained by cutting away weathered portions on a rock saw. The remaining rock was inspected for altered veins and cracks and powdered in a carbide ball mill if none were found. The powder then became the primary stock for x-ray fluorescence, wet chemical methods and volatile analysis.

2. X-ray Fluorescence

a) Major Oxides

X-ray fluorescence methods using a Philips PW-4280 analyser was employed to determine SiO_2, Al_2O_3, TiO_2, total iron as Fe_2O_3, CaO and MgO in the rock samples.

Rock powder and a flux were fused into glass discs using the method established by Norrish and Hutton (1969) as modified by Harvey et al. (1973). This procedure involves mixing the sample and flux in a non-wetting Palau crucible which is covered and heated over a bunsen burner until a homogeneous melt is obtained. The melt is poured onto a preheated aluminum mold and allowed to cool slowly thus forming a glass disc which is representative of the original sample composition. This method is preferred to pressed powdered discs because the flux acts as a dilutent to reduce the concentration of elements and it gives relatively consistent matrix effects when the sample is irradiated.

A chrome source tube was used for all the X-ray fluorescence analyses. Depending upon the elements to be detected, different machine settings, crystals and 2θ angles were used (see Table AI-2). The samples were run in groups of four with five readings of Kα peaks and backgrounds being made for one element on each run. In this way a reference sample was read first and last to maintain drift control. A calibration curve for each element was established by running reference standards from which apparent fluorescence values could later be determined.

b) Trace Elements

X-ray fluorescence was also used to detect the abundances of the trace elements Ba, Ti, Rb, Sr, Y, Zr and Nb.

Sample preparation involves putting a small amount of the sample powder in a hollow die which is then removed. The powder is covered by a layer of boric acid, then the assemblage is placed under a hydraulic press at a pressure of ten tons for 20 seconds. This produces a pressed pellet with a smooth surface set in a boric acid backing.

XRF apparatus then measured the Kα radiation intensities for Ba and Ti peaks and the Kβ radiation intensities for Rb, Sr, Y, Zr and Nb peaks.

The Ba and Ti analyses were run concurrently by measuring the background at $2\theta = 88.07^{\circ}$ for 1 second; the Ba peak at $2\theta = 87.17^{\circ}$ for 10 seconds; another background reading at 86.87° for 1 second; the Ti peak at $2\theta = 86.14^{\circ}$ for 10 seconds and another background at $2\theta = 80.92^{\circ}$ for 1 second. The settings for TiO_2 (see Table AI-2) were used for this analysis. Once again standards were used to establish calibration curves and the following absorption coefficients were used: 210 for gabbros and ultramafics, 199 for basalts, 201 for felsic and intermediate volcanic rocks, 193 for volcanoclastic sedimentary rocks, 192 for arkose and 214 for greywackes.

The trace elements Rb, Sr, Y, Zr and Nb were determined in a similar manner using Kβ radiation. The specifications are listed in Table AI-3.

A computer program provided by K.M. Poulsen was used to process the data. This program is designed to remove the overlap effects of peaks and to generate trace element concentrations.

3. Wet Methods

a) Preparation of Solutions

The solutions were prepared by the following method, which is adapted from Hounslow and Moore (1968):

i) weigh 0.500 g sample into a teflon beaker;
ii) add a few drops 5% HNO_3 and swirl to release available CO_2;
iii) fill beaker with acid mixture of 1 part HNO_3 to 3 parts HF;
iv) place beaker on hot plate (95° C) and evaporate to dryness;
v) fill beaker with 5% HCl and simmer for 30 minutes then transfer to 100 ml volumetric flask; wash the beaker well with 5% HCl then with distilled water using teflon policeman to ensure all of the sample is removed, bring solution up to volume with double distilled H_2O;
vi) shake solutions vigorously and allow to sit for 24 hours; if a precipitate remains, remove tops and place on low heat (70° C) for 24 hours; after precipitate dissolves, bring up to volume again.

The solutions are now available for the determination of Na_2O, P_2O_5, MnO, MgO and K_2O concentrations by atomic absorption and colorimetry.

b) P_2O_5 Determination

Phosphorous is determined using a colorimetric method adopted from Riley (1958). The process involves the mixing of 10 ml of rock solution, 20 ml of reducing solution and 20 ml of double-distilled water in a small polyethylene bottle which is capped and allowed to stand 24 hours. The reducing solution consists of 200 ml of 3N H_2SO_4, 100 ml of ascorbic acid solution (1.6 g ascorbic acid in 100 ml H_2O), and 100 ml of ammonium molybdenate solution (1.2 g in 100 ml H_2O).

The absorbance of both standards and unknowns are measured in 1 cm cells at a wavelength of 800 nanometers using a high P_2O_5 solution as a reference. A Baush & Lomb Precision spectrophotometer was used.

c) Atomic Absorption - K_2O, MnO, MgO, Na_2O

The principle of atomic absorption is that the tube emits radiation characteristic of a particular element. The radiation passes through a flame which contains an aspirated solution. The ions of that particular element in solution act as a filter for that element when aspirated into the flame. In this way, the absorption of the radiation passing through the flame is proportional to the concentration in the solution.

By comparing the intensity of radiation leaving the tube to that which passes through the flame, a relative measure of the concentration of that element in the flame (thus in the sample) is obtained. A calibration curve of absorbance versus concentration can be constructed by using known concentrations of an element and thus the concentration of that element in the unknown sample can be determined.

A Perkin-Elmer Model 303 atomic absorption spectrophotometer was used for the analyses. A lamp was chosen for the particular element to be detected and the apparatus was set according to specifications on the lamp and in the Perkin-

Elmer Standard Methods Manual. Once the apparatus is allowed to warm up for at least 15 minutes the flame is adjusted according to the manual. An acetylene flame was used for all elements analyzed.

The samples were aspirated until the one with the highest concentration of the element was found and its absorbance level was established. A reference solution with a slightly greater absorbance than the unknown was used as a drift monitoring sample. The reference solutions and unknowns were then aspirated twice each, followed by the aspiration of a blank with the highest reference standard run every fifth time.

A calibration curve can then be established, and the elemental concentration of the unknowns can be determined.

The process was repeated for each of the elements analyzed.

d) FeO Determination

The ferric iron concentration in the samples was determined by titration involving a redox reaction between the iron ions in solution and chromium (Cr^{+7}) with a diphenylamine sulfonic acid acting as an indicator for Cr^{+7}. (1 ml of Cr_2O_7 = 0.4% FeO).

A 0.5 g sample of powdered rock was placed into a 25 ml telfon crucible to which was added 10 ml of 9N H_2SO_4 and 5 ml of conc. HF. The crucible was covered and brought to a boil on a hot plate for 10 minutes.

Then 10 g of boric acid was dissolved in 500 ml of distilled water in a large beaker and 20 ml 9N H_2SO_4 and 15 ml of the indicator solution (0.1 g sodium dyphenylamine sulfonate in 500 ml H_2O and add 250 ml 85% H_3PO_4). After 10 minutes of boiling the contents of the teflon crucible were washed into the beaker with distilled water. The dichromate solution (1.364 g potassium dichromate in 1 l H_2O) was then titrated into the beaker until the end point of the redox reaction was reached (a purple colour persisted for 20 seconds). The volume of the dichromate solution used was then converted to the equivalent concentration of FeO.

4. Volatiles

The volatile components of the powdered rock specimens were analyzed using a Perkin-Elmer Model 240 CHN analyser. The system combusts the sample at 1200° C and then weighs the liberated volatiles trapped in specific absorbers for each of the three elements.

For the purposes of the whole-rock analyses it was assumed that all C exists as CO_2, the measured value of H was the total H_2O in the sample and the N indicated the amount of organic impurities in the sample (i.e. lichen).

5. Experimental Precision

The whole-rock analyses were carried out in two sessions during 1979. The second session duplicated many of the analyses done the first time. Sample LU-1 was analysed twice to check for accuracy and precision, the results of which are shown in Table AI-4.

The procedures outlined in this appendix produce only apparent fluorescent values which must be corrected to true elemental concentrations. This is accomplished by use of a computer program provided by K.H. Poulsen. The results of the whole-rock analyses are presented in Table AI-1.

TABLE A1-1 : Whole-rock Geochemical Analyses

sample numbers — Basalts

Element	28-3	24-10	27-12m	25-10	25-17	270	25-9	28-2	44	26-15	24-14
SiO_2	45.27	46.16	51.64	31.74	34.51	46.8	52.68	48.67	46.13	55.79	53.68
Al_2O_3	16.97	16.14	14.21	16.73	11.64	13.89	15.93	14.3	14.91	16	15.07
TiO_2	.84	.83	.46	.96	.31	.71	.61	.55	.71	1.09	1.71
FeO	8.22	7.52	10.2	11.16	13.28	14.8	5.38	6.36	13.74	6.84	6.82
Fe_2O_3	2.3	3.26	4.97	1.77	2.11	3.84	3.46	2.59	2.68	1.38	5.33
MgO	10.38	9.86	2.84	10.74	6.09	3.81	5.31	10.56	5.47	4.46	3.91
MnO	.17	.08	.23	.25	.33	1.52	.08	.1	.61	.08	.16
CaO	9.73	8.72	3.99	9	11.78	8.92	5.34	9.34	8.87	4.74	5.78
K_2O	.08	.13	.3	.08	.1	1.54	.08	.08	.14	.42	.3
Na_2O	1.51	1.73	2.45	1.39	.43	2.12	3.32	1.5	1.92	2.74	3.1
P_2O_5	.09	.11	.1	.14	.11	.13	.1	.09	.13	.1	.14
LOI	4.05	5.2	8.18	13.94	15.76	1.68	7.56	5.45	4.47	5.54	3.91
Total	99.62	99.75	99.57	97.9	96.44	99.77	99.85	99.59	99.78	99.18	99.9
Ba	312ppm	253ppm	369ppm	120ppm	-	1934ppm	403ppm	502ppm	50ppm	633ppm	480ppm
Rb	2.2	-	11.4	-	-	76.5	20.5	10.2	5.4	22.7	21.5
Sr	208.9	197.4	246.7	96.1	92.1	90.2	539.4	133.1	71.9	275.9	173.8
Y	23.9	22.4	23.3	28.3	22.7	24.8	22.9	24.2	15.5	25.6	12.7
Zr	49.5	36.9	66	30.4	69.8	40.8	89.4	11.9	93.5	53.6	139.6
Nb	18.7	10.9	16	9.8	10.2	15	19.5	15.2	4.7	16.6	13.2

TABLE A1-1 : Whole-rock Geochemical Analyses(con't)

Basalts(con't) — Felsic Volcanic Rocks

Element	26-13	27-14	26-19	27-12c	27-7	298	24-12	26-11	24-6	27-2c
SiO_2	43.93	49.28	71.8	65.43	68.08	70.3	68.55	68.98	69.44	66.09
Al_2O_3	17.39	11.42	14.47	14.27	16.03	15.01	15.99	14.47	15.5	19.64
TiO_2	.45	2.3	.45	.37	.41	.43	.4	.47	.3	.39
FeO	6.38	8.68	2.48	3.94	2.64	1.42	2.6	3.36	2.46	.72
Fe_2O_3	5.37	10.89	.97	1.21	1.11	.69	1.15	1.33	1.19	.65
MgO	9	3.7	1.06	1.01	1.34	1.21	1.1	.4	.8	.55
MnO	.17	.23	.08	.11	.04	.04	.06	.11	.04	.07
CaO	13.55	7.62	2.62	4.74	4.11	4.68	4.47	4.12	1.22	4.25
K_2O	.4	.06	.95	.75	.53	1.07	1.41	1.4	1.69	.42
Na_2O	1.43	1.46	3.9	3.64	3.61	3.99	3.1	2.76	4.72	6.03
P_2O_5	.1	.25	.15	.17	.15	.14	.16	.16	.14	.16
LOI	1.88	4.21	.99	3.96	1.56	1.03	.83	2.31	2.04	.87
Total	100.06	100.11	99.93	99.59	99.61	100.01	99.83	99.87	99.52	99.84
Ba	412ppm	120ppm	100ppm	95ppm	560ppm	294ppm	966ppm	532ppm	500ppm	253ppm
Rb	4.3	-	42.7	17.5	29.5	45.6	41.6	49	99.4	8.8
Sr	226.2	160.8	346.7	432.7	310.2	382.7	316.3	308	159.8	474.9
Y	25.6	50.4	25.9	24.7	27.5	14.1	24	15.8	10.3	14.9
Zr	23.5	158.5	195.9	88.1	122	507.5	152.7	412.3	166.4	566.1
Nb	14.5	11.7	17.3	19.8	10.1	10.6	19.1	14.2	9.9	13.2

TABLE A1-1 : Whole-rock Geochemical Analyses(con't)

Felsic Volcanic Rocks(con't) — Sedimentary and Epiclastic Rocks

Element	27-2m	27-11	24-7	23-4	264	26-21	25-4	24-1	24-2	186
	Felsic Volcanic Rocks(con't)				Sedimentary and Epiclastic Rocks					
SiO_2	61.32	70.23	79.69	64.19	.62.31	77.17	80.36	70.41	67.36	62.57
Al_2O_3	19.26	14.95	11.98	16.38	16.74	11.83	10.65	13.82	13.67	13.93
TiO_2	.71	.46	.04	.51	.57	.31	.24	.38	.45	.83
FeO	3	1.7	.29	.6	4.14	1.12	.52	3	3.12	6.48
Fe_2O_3	1.18	.31	.33	3.06	.94	1.25	1.23	.89	3.22	2.47
MgO	2.58	2.17	.15	.95	2.69	.67	.56	1.45	1.52	4.84
MnO	.04	.1		.04	.15	.04		.09	.04	.08
CaO	3.36	2.54	1.02	6.18	4.89	1.26	.65	3.31	3.02	2.53
K_2O	1.9	.72	1.56	1.16	.77	2.36	2.21	2.1	1.94	1.05
Na_2O	5.09	4.08	3.76	2.87	2.99	2.18	2.27	2.63	2.54	1.62
P_2O_5	.17	.14	.1	.12	.15	.12	.12	.2	.2	.24
LOI	1.08	2.81	.91	3.77	3.24	1.67	1.19	1.88	2.61	3.38
Total	99.62	100.23	99.84	99.84	99.59	99.98	100	100.16	99.7	100.03
Ba	470ppm	217ppm	278ppm	88ppm	527ppm	742ppm	743ppm	605ppm	738ppm	301ppm
Rb	58.1	23.3	59.8	40.1	16.3	88.3	56.1	93.8	100.6	45.9
Sr	507.4	443.5	111.7	580.6	338.6	300.6	330.5	355	373.2	109.3
Y	13.9	25.3	25.5	25	30.6	15.8	24.2	25.4	17.9	20.2
Zr	629.8	116.6	30.2	136.5	114.3	412.3	46.9	122.7	486	30.2
Nb	14.6	18.2	13.2	16	34.6	14.2	11.4	16.4	10.6	14.6

TABLE A1-1 : Whole-rock Geochemical Analyses(con't)

	Sedimentary and Epiclastic Rocks(con't)		Layered SillRocks				
Element	125	228	27-6	26-17	27-1	26-18	27-4
SiO_2	50.51	64.93	67.5	42.82	49.41	46.08	47.84
Al_2O_3	19.25	15.52	12.69	19.23	15.09	17.24	16.24
TiO_2	.26	.68	.63	.32	1.09	.51	.79
FeO	5.58	4.04	5	7.2	7.82	9.75	8.84
Fe_2O_3	1.12	1.63	4.75	2.27	4.82	1.75	4.34
MgO	5.37	3.05	.41	11.33	6.41	9.7	5.99
MnO	.13	.07	.13	.13	.18	.17	.17
CaO	11.94	4.41	3.15	10.09	10.36	8.81	11.01
K_2O	.94	1.18	.19	.1	.05	.05	.15
Na_2O	2.19	3.6	4.83	1.59	2.04	1.7	1.83
P_2O_5	.18	.15	.16	.06	.09	.09	.09
LOI	2.15	.76	.65	4.34	2.25	3.98	2.77
Total	99.63	100.02	99.79	99.48	99.61	99.83	100.06
Ba	23ppm	306ppm	162ppm	140ppm	150ppm	151ppm	149ppm
Rb	65.4	56	-	-	-	-	--
Sr	480	326.9	106.2	153.1	154.1	128.8	164
Y	26.2	18.9	102.9	6.5	24.3	11.3	15.4
Zr	58.8	413.2	308.3	137.4	186.1	103.6	173.8
Nb	23	16.6	14.4	8.3	10.4	11.0	8.5

Table AI-2 Settings for X-ray Fluorescence

Element	Collimator	Dectector	KV/mA	LL	Wd	Z	Peak	Background	Time(Peak)	Time(Background)	Crystal
SiO_2	coarse	flow	50/50	250	350	2	109.1°	111.1°	100 sec	10 sec	PET
CaO	fine	flow	50/40	275	250	3	113.17	114.77	10	1	LIF
TiO_2	fine	flow	50/40	250	250	3	86.15	88.05	10	1	LIF
Fe_2O_3(T)	fine	flow	50/40	350	450	3	5745	56.45	40	4	LIF
Al_2O_3	coarse	flow	50/50	100	125	3	145.2	143.7	100	10	PET
MgO	coarse	flow	50/50	250	250	1	136.6	135.6, 137.6	200	100, 100	ADP

Table AI-3 Settings for Rb-Sr-Y-Zr-Nb analysis

2θ	Channel	Radiation being measured
27.37	1	background
26.6	2	Rb peak
25.83	3	background
25.05	4	Sr peak
24.27	5	background
23.70	6	Y peak
23.11	7	background
22.45	8	Zr peak
21.67	9	background
21.35	10	Nb peak
20.93	11	background

collimator - fine
detector - flow
time (peak, bkgd) - 10 sec.
KV/mA - 50/50

Z = 5
LL = 250
Wd = 300

Table AI-4 Precision of geochemistry using Lu-I as reference

Element	Run I wt%	Run 2 wt%	Accepted Values wt%
SiO_2	49.47	49.77	48.88
Al_2O_3	15.4	15.1	15.54
TiO_2	.76	.69	.75
Fe_2O_3	6.31	6.34	6.36
FeO	2.14	1.81	2.15
MgO	4.1	4.36	4.23
CaO	9.97	10.21	10.31
MnO	.21	.16	.19
K_2O	.37	.4	.43
Na_2O	1.88	1.89	1.97
P_2O_5	.1	.1	.08
LOI	9.26	9.17	9.19
Total	99.95	100.00	100.08
Ba	311 ppm	311 ppm	240 ppm
Rb	7.1 "	16.6 "	16 "
Sr	171.5 "	208.1 "	154 "
Y	22.4 "	16.3 "	16 "
Zr	65.9 "	35.8 "	55 "
Nb	7.8 "	12.2 "	3 "

APPENDIX II - LIST OF PHOTOGRAPHIC PLATES

Plate 1: Typical pillow shape; Lower Member, Blackstone Formation (hammer is 40 cm long)

Plate 2: A typical pillow shape; near top of Lower Member; Blackstone Formation, note: increase in interstitial material between pillows (hammer is 40 cm long)

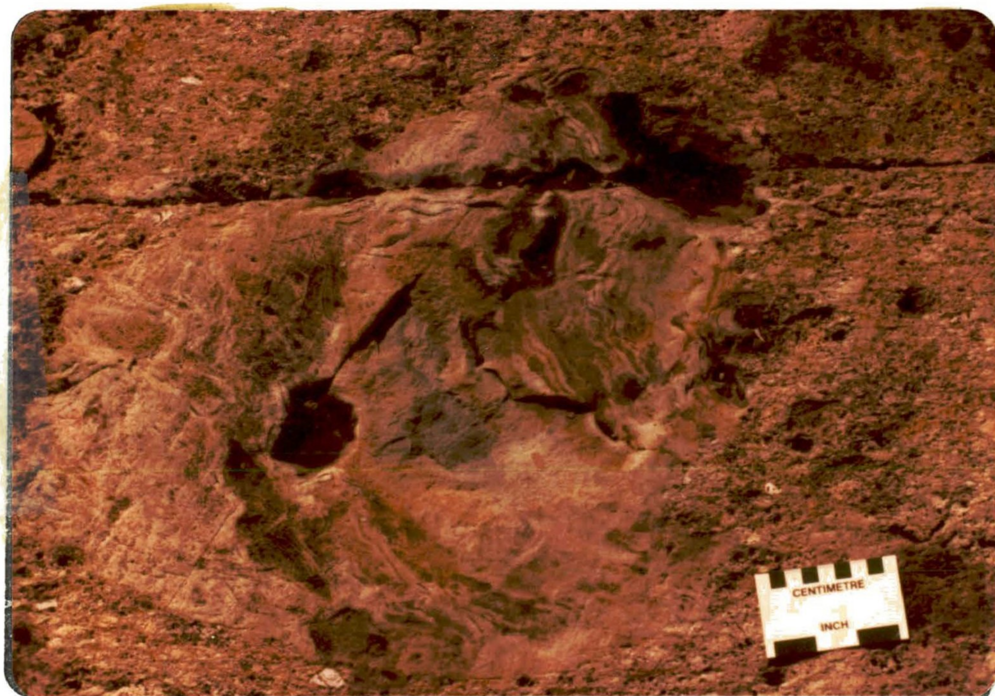


Plate 3: "Ripped-up" sedimentary block in epiclastic-pyroclastic rocks; Upper Member, Blackstone Formation

Plate 4: Graded bedding in Upper Member, Blackstone Formation

Plate 5: Breccia with iron-carbonate matrix; related to phreato-magmatic explosions?; Upper Member, Blackstone Formation (hammer is 40 cm long)

Plate 6: Typical pillow shape; Lower Member, Western Lake St Joseph Formation, note: large vesicles near rim, (photo is about 1.5 m across)

Plate 7: Bedded epiclastic-pyroclastic rocks cut by basaltic dike; Upper Member, Western Lake St Joseph Formation (hammer is 40 cm long)

Plate 8: Pyroclastic and auto brecciated deposits in Upper Member, Western Lake St Joseph Formation, note: crude bedding (hammer is 40 cm long)

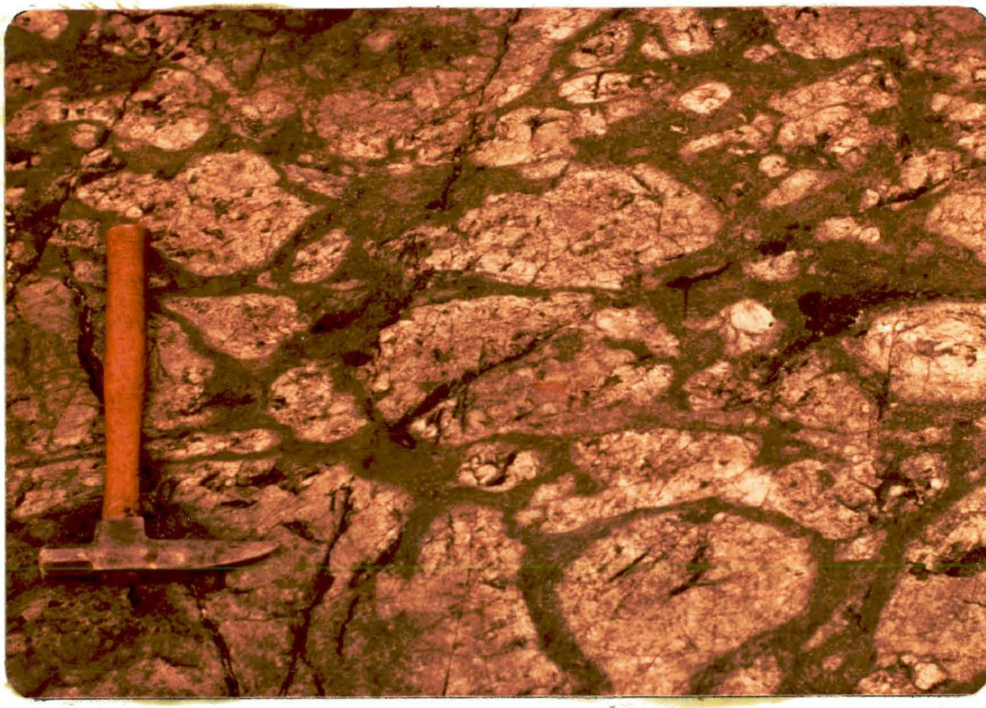


Plate 9: Pillow breccia; Volcanic Member, Carling Formation (hammer is 40 cm long)

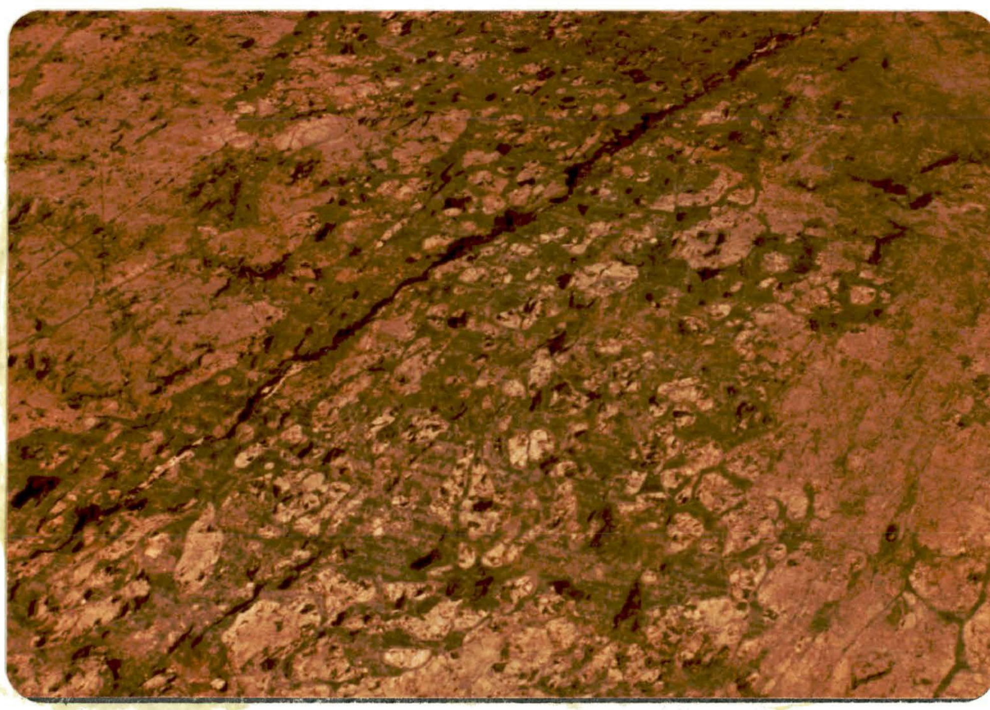


Plate 10: Transition from pillow flows (right) to pillow breccia in Volcanic Member, Carling Formation, (photo is about 3 m across)

Plate 11: Pyroclastic breccia at "the Narrows" formed by high energy surges of debris (of samples 27-12m, 27-12c, Table AI-1, Appendix I) Volcanic Member, Carling Formation (photo 10 m across)

Plate 12: Contact between Upper Member, Western Lake St Joseph Formation (under hammer) and LIF of Sedimentary Member, Carling Formation, note: LIF in Upper Member (hammer is 40 cm long)

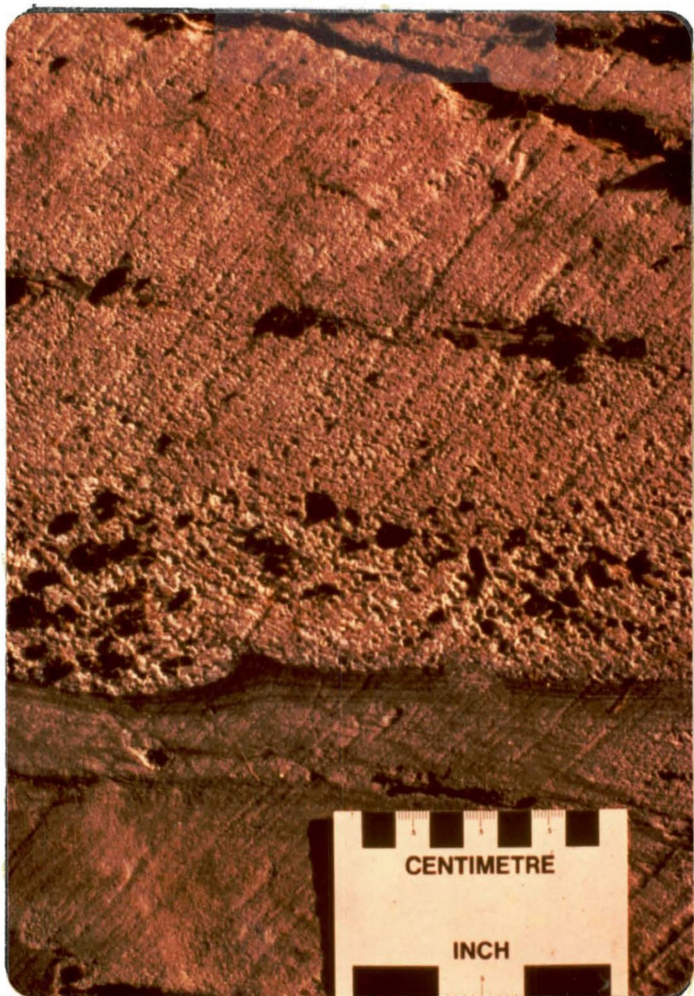


Plate 13: Classical turbidite with LIF forming "E" division of Bouma sequence; Basal Unit Sedimentary Member

Plate 14: Organization of Basal Unit of Sedimentary Member; LIF interpreted to be equivalent to pelagic sediment, deep water environment

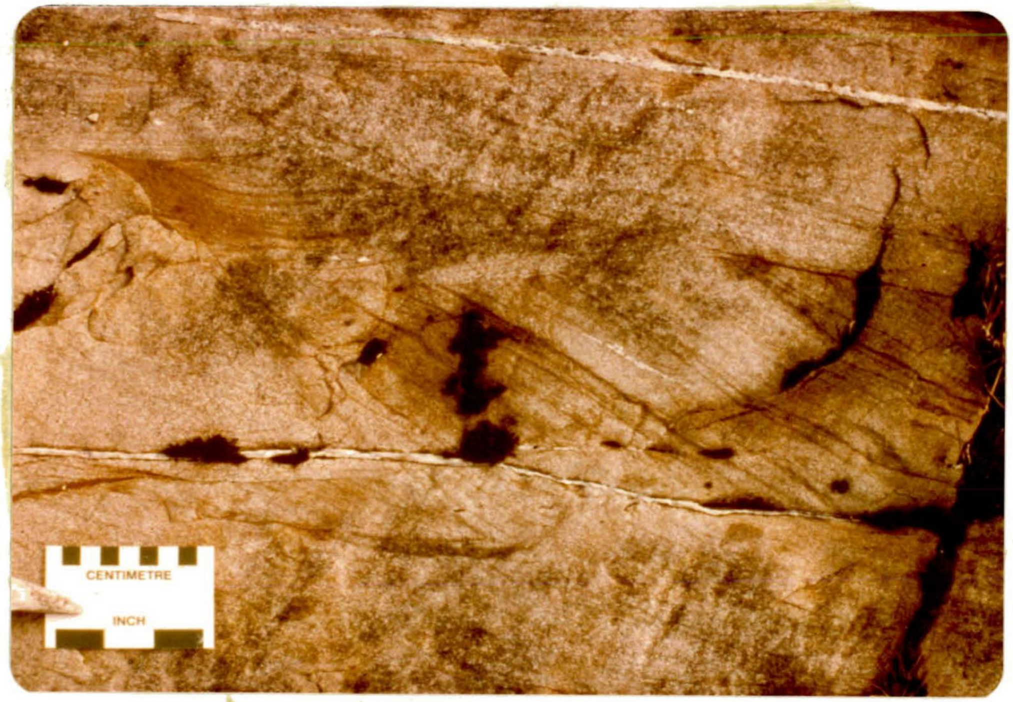
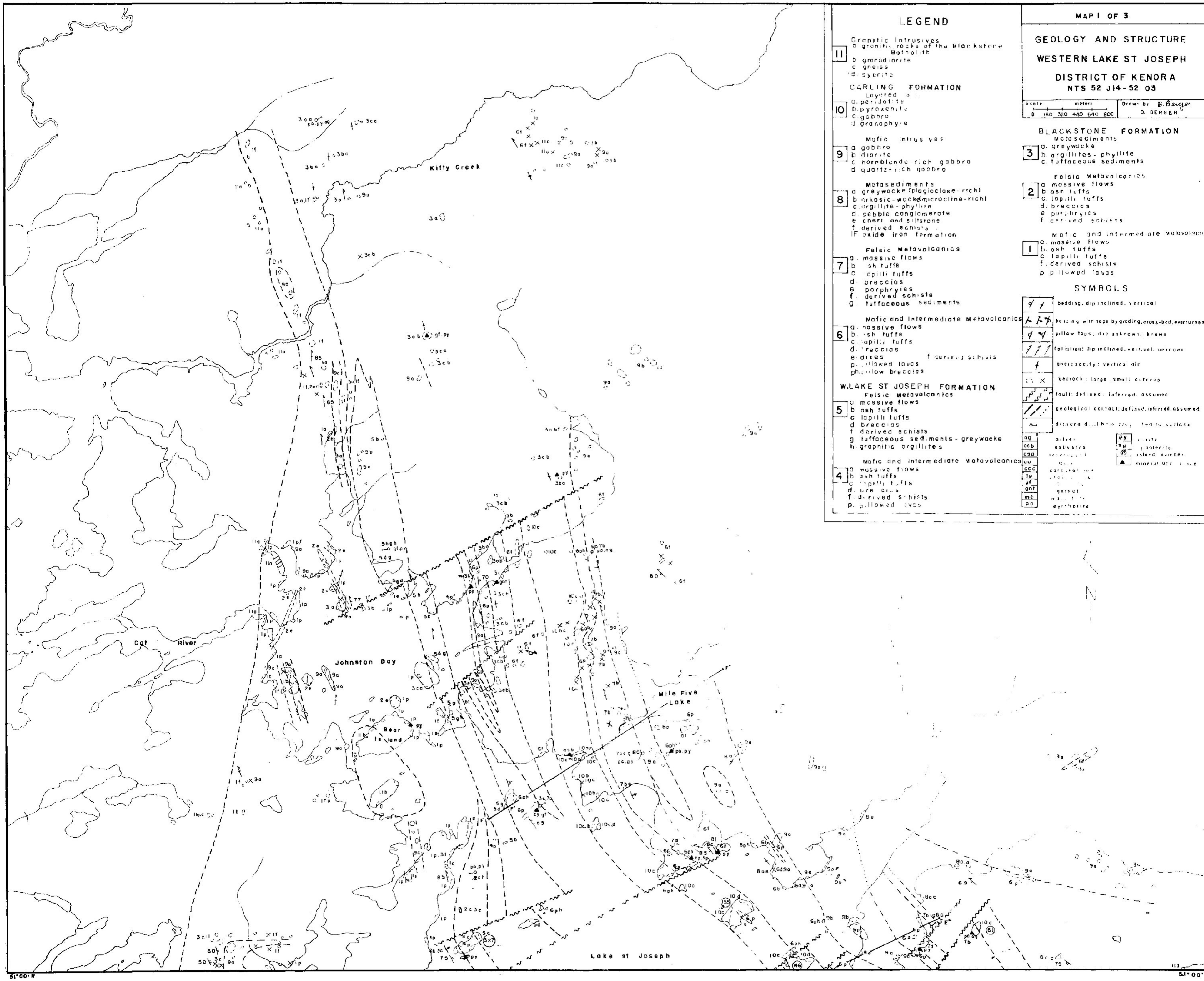
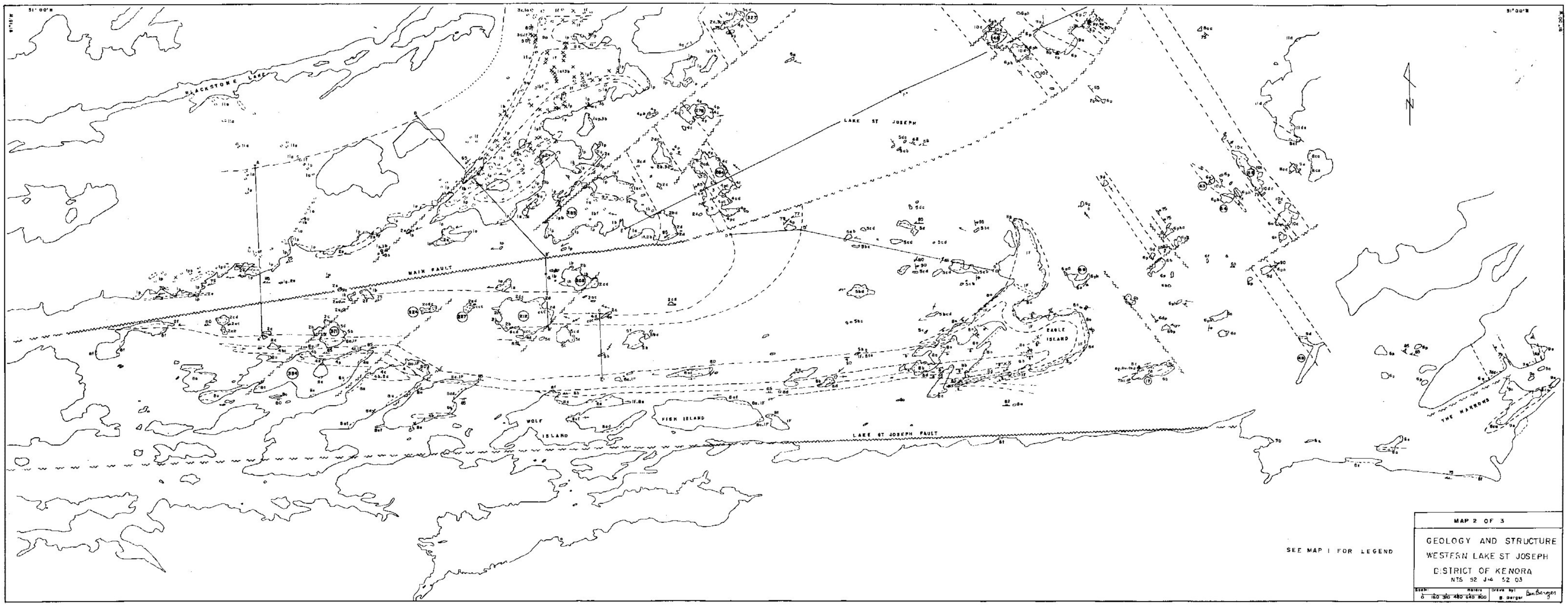


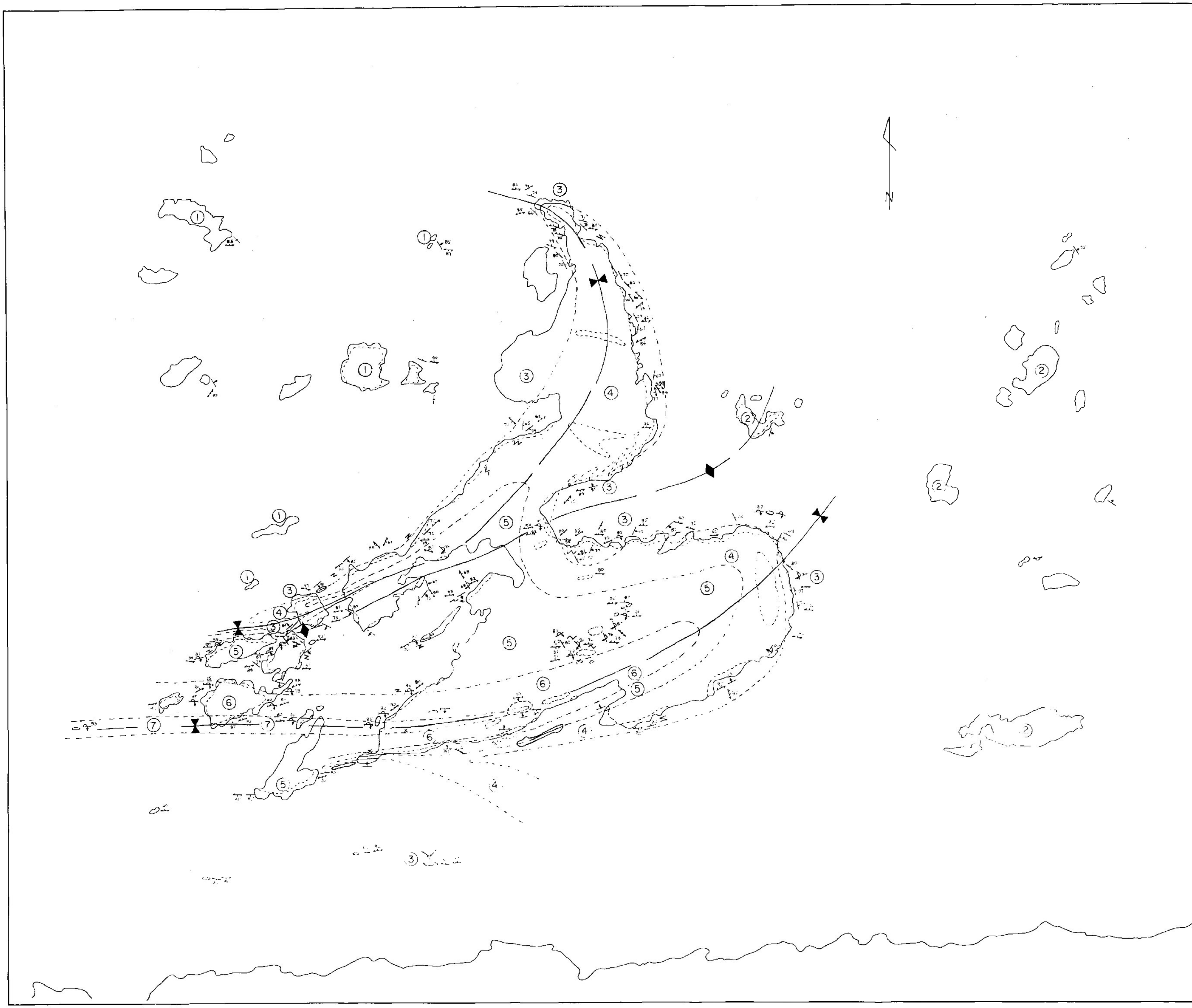
Plate 15: Trough cross-bedded arkose unit Sedimentary Member, Carling Formation

Plate 16: Conglomerate, pebbly sandstone unit, part of submarine fan facies, Sedimentary Member, Carling Formation (hammer is 60 cm long) ·

Plate 17: Predominance of cherty LIF pebbles in conglomerate, along with felsic and mafic volcanic lithic fragments in a sandy matrix, Sedimentary Member, Carling Formation (tip of hammer is 5 cm long)


MAP 1 OF 3
GEOLOGY AND STRUCTURE
WESTERN LAKE ST JOSEPH
DISTRICT OF KENORA
NTS 52 J14-52 03
Scale: meters
0 160 320 480 640 800
Drawn by B. Berger
B. BERGER
LEGEND
Granitic Intrusives
11
a. granitic rocks of the Blackstone Batholith
b granodiorite
c gneiss
d. syenite
CARLING FORMATION
Layered
10
a. peridotite
b. pyroxenite
c. gabbro
d. granophyre
Mafic Intrusives
9
a gabbro
b diorite
c hornblende-rich gabbro
d quartz-rich gabbro
Metasediments
8
a greywacke (plagioclase-rich)
b arkosic-wacke (microcline-rich)
c. argillite-phyllite
d. pebble conglomerate
e chert and siltstone
f derived schists
IF oxide iron formation
Felsic Metavolcanics
7
a. massive flows
b ash tuffs
c lapilli tuffs
d. breccias
e porphryies
f. derived schists
g. tuffaceous sediments
Mafic and Intermediate Metavolcanics
6
a. massive flows
b. ash tuffs
c. lapilli tuffs
d. breccias
e. dikes
f derived schists
p. pillowed lavas
ph. pillow breccias
W. LAKE ST JOSEPH FORMATION
Felsic Metavolcanics
5
a massive flows
b ash tuffs
c lapilli tuffs
d breccias
f derived schists
g tuffaceous sediments - greywacke
h. graphitic argillites
Mafic and Intermediate Metavolcanics
4
a massive flows
b ash tuffs
c lapilli tuffs
d. breccias
f. derived schists
p. pillowed lavas
BLACKSTONE FORMATION
Metasediments
3
a. greywacke
b. argillites - phyllite
c. tuffaceous sediments
Felsic Metavolcanics
2
a massive flows
b ash tuffs
c. lapilli tuffs
d. breccias
e porphryies
f derived schists
Mafic and Intermediate Metavolcanics
1
a. massive flows
b. ash tuffs
c. lapilli tuffs
f. derived schists
p pillowed lavas
SYMBOLS
bedding, dip inclined, vertical
bedding with tops by grading, cross-bed, overturned
pillow tops; dip unknown, known
foliation; dip inclined, vertical, unknown
gneissosity: vertical dip
bedrock: large, small outcrop
fault; defined, inferred, assumed
geological contact; defined, inferred, assumed
ag silver
asb asbestos
asp
au
ccc
cp
gf
gnt garnet
mc
po pyrrhotite
py
sp
island number
mineral occurrence
Kitty Creek
Cat River
Johnston Bay
Bear Island
Mile Five Lake
Lake St Joseph
51°00'N
91°00'W


BLACKSTONE LAKE
LAKE ST JOSEPH
MAIN FAULT
EAGLE ISLAND
WOLF ISLAND
FISH ISLAND
LAKE ST JOSEPH FAULT
THE NARROWS
SEE MAP 1 FOR LEGEND
MAP 2 OF 3
GEOLOGY AND STRUCTURE
WESTERN LAKE ST JOSEPH
DISTRICT OF KENORA
NTS 52 J/4 52 O/3
Scale: meters
0 160 320 480 640 800
Drawn by:
B. Berger



MAP 3 OF 3

GEOLOGY AND STRUCTURE
EAGLE ISLAND

0 50 100 150 200 250m

Drawn by: B. Berger *B. Berger.*

LEGEND

- (7) Pebble Conglomerate
- (6) Arkose
- (5) Chloritic Greywacke
- (4) Laminated Iron Formation (LIF)
- (3) Pelagite, LIF, Epiclastic rocks
- (2) Volcanic Member, Curling Fm.
- (1) Upper Member, W. Lake St. Joseph Fm.
- Outcrop, small outcrop
- Geologic contact, defined, approximate
- Bedding: dip inclined, vertical, overturned
- Younging: grading, cross-bedding, pillow
- Cleavage: dip inclined, vertical, unknown
- Trace axial surface syncline
- Trace axial surface anticline
- Symmetry: mesoscopic folds

0 100 200 300 400 500 600 m.

0 400 800 1200 1600 2000 FT