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Geology of an Archean Greenstone Belt at Point Lake, Northwest Territories, Canada

Patrick Rowan Considine
Old Dominion University

GEOLOGY OF AN ARCHEAN GREENSTONE BELT
AT POINT LAKE, NORTHWEST TERRITORIES, CANADA

By

Patrick Rowan Considine

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Approved By:

Dr. Randall Spencer, Program Director

Dr. Ramesh Venkatakrishnan

Dr. Frank O. Dudás

Dr. Randall Spencer

ABSTRACT

GEOLOGY OF AN ARCHEAN GREENSTONE BELT
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Several well-preserved circa 2.6 Ga Archean granite-greenstone belts are exposed in the Slave Province of Northwest Territories, Canada. At Point Lake, a "supracrustal sequence" comprised mainly of mafic volcanic and metasedimentary rocks lies over and east of a granitoid gneissic terrane. Field and laboratory studies have helped to clarify the petrography and structural relationships of this fold-and-thrust belt. Traditional models have suggested that granite-greenstone belts in the Slave Province are relict continental rifts in which volcanic and sedimentary rocks filled troughs in older sialic crust. However, this study supports a collisional model for the Slave Province, in which oceanic crust and an accretionary wedge were scraped off an eastward subducting plate. The supracrustal sequence consists of a west-verging fold-and-thrust belt which contains metamorphosed graywacke turbidites, ultramafic and gabbroic rocks, pillow basalts, limestone, shale and tuff. A mylonite zone separates the gneissic terrane from the supracrustal sequence. The mylonite is interpreted to be a basal decollement along which the supracrustal sequence was emplaced over gneissic terrane. The sequence of lithologies and

structures at Point Lake resembles Phanerozoic collision zones where rocks of oceanic affinity have been emplaced upon continental crust.

DEDICATION

This Thesis is dedicated to the memory of

Patrick J. Newman

and

Helen M. Newman

ACKNOWLEDGEMENTS

This work was made possible by Dr. Timothy Kusky. Tim invited me to join him in the slave Province during the summer of 1987. By employing me as a field assistant to his own research projects, he provided funding, access and logistical support for my fieldwork. His support throughout the long history of this thesis has been unflagging. Tim's own work was in turn supported by various grants from the National Science Foundation; the Geological Association of Canada; and the Department of Indian and Northern Affairs in Yellowknife.

I am also indebted to my thesis advisory committee, listed in order of appearance:

Dr. Ramesh Venkatakrishnan has provided insight and support from the beginning of this project through its completion. He read rough drafts and work in progress; and provided invaluable guidance to shape the development of the final product. In particular, Ramesh provided thought-provoking concepts of spatial and structural relationships that helped to clarify my tectonic model.

Dr. Sonia Esperança also spent many hours reviewing early drafts. In addition, she worked with me for many hours on the X-ray diffractometer and the petrographic microscopes.

Dr. Frank Dudás arrived at Old Dominion University at a stage when I thought this project was nearly completed.

However, his own experiences and observations in the Slave Province, and his thoughtful and thorough review of earlier drafts led to a major reshaping of this thesis. Consequently, the completion of this thesis took longer than I had planned, but it is a much better work for his contribution, and I am grateful to Dr. Dudás for his time and effort.

Dr. Randall Spencer, as Department Chairman, classroom instructor and thesis committee member, provided review, constructive criticism and encouragement.

The students and faculty of the Geology Department at Old Dominion University contributed not only to this thesis but to an exceptional Geology Department. I especially want to thank Dr. Stephen Culver, Dr. Joseph Rule, Dr. Ali Nowroozi, Dr. Donald Swift, D.T. Hurdle, Bill Decker, Mark Corbin, Charlie James, Ronnie Pinkowski, Eric Collins and Brett Waller for their support, encouragement, camaraderie and insights.

Finally, I wish to thank Megan Hurdle, who provided paste and sunshine.

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CHAPTER 1: INTRODUCTION

The Slave Province is one of eight geologic provinces in the Precambrian Canadian shield. These provinces are distinguished from one another on the basis of radiometric age and petrologic character (e.g., Stockwell, 1982). Of the eight provinces, the Slave is the oldest, comprising rocks that are predominantly Late Archean (2.5 Ga in age) or older. The Slave Province is situated in the Northwest Territories of Canada, lying between Coronation Gulf in the Arctic Ocean and Great Slave Lake (Figure 1; Figure 2).

Greenstone belts, or granite-greenstone belts, are a characteristic feature of Archean terrains. Greenstone belts are terranes composed predominantly of metamorphosed volcanic and sedimentary rocks that lie adjacent to an older gneissic terrane (Condie, 1976 and 1981; Kröner, 1981; Windley, 1984). Several well-preserved greenstone belts are exposed in the Slave Province. One of these belts extends over 100 km in the western part of the Slave Province and passes through Point Lake (Figure 2). The present study focuses on the portion of the greenstone belt that is exposed in the Point Lake area.

STATEMENT OF PROBLEMS

Three widely held but sharply conflicting hypotheses have been offered to account for formation of greenstone belts in

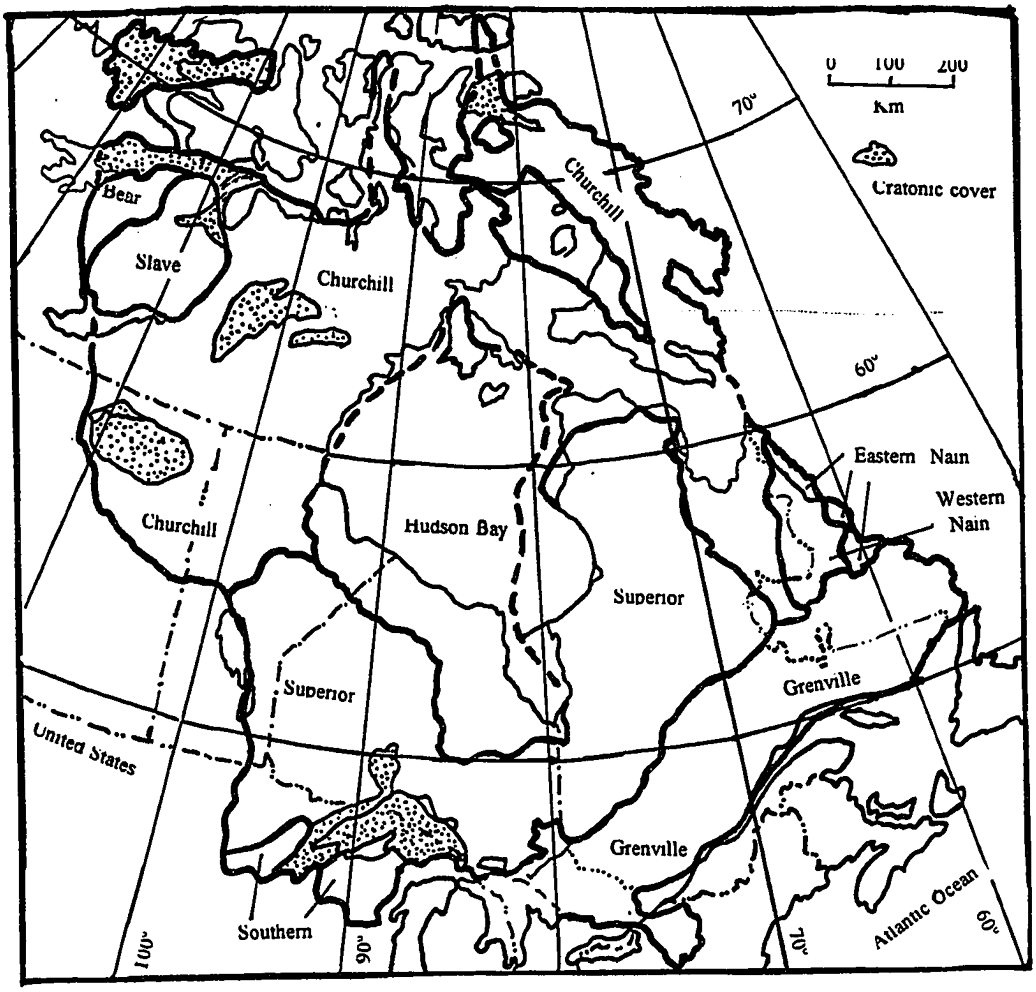


Figure 1. Precambrian Crustal Provinces in the Canadian Shield.
After Stockwell, 1968;1982.

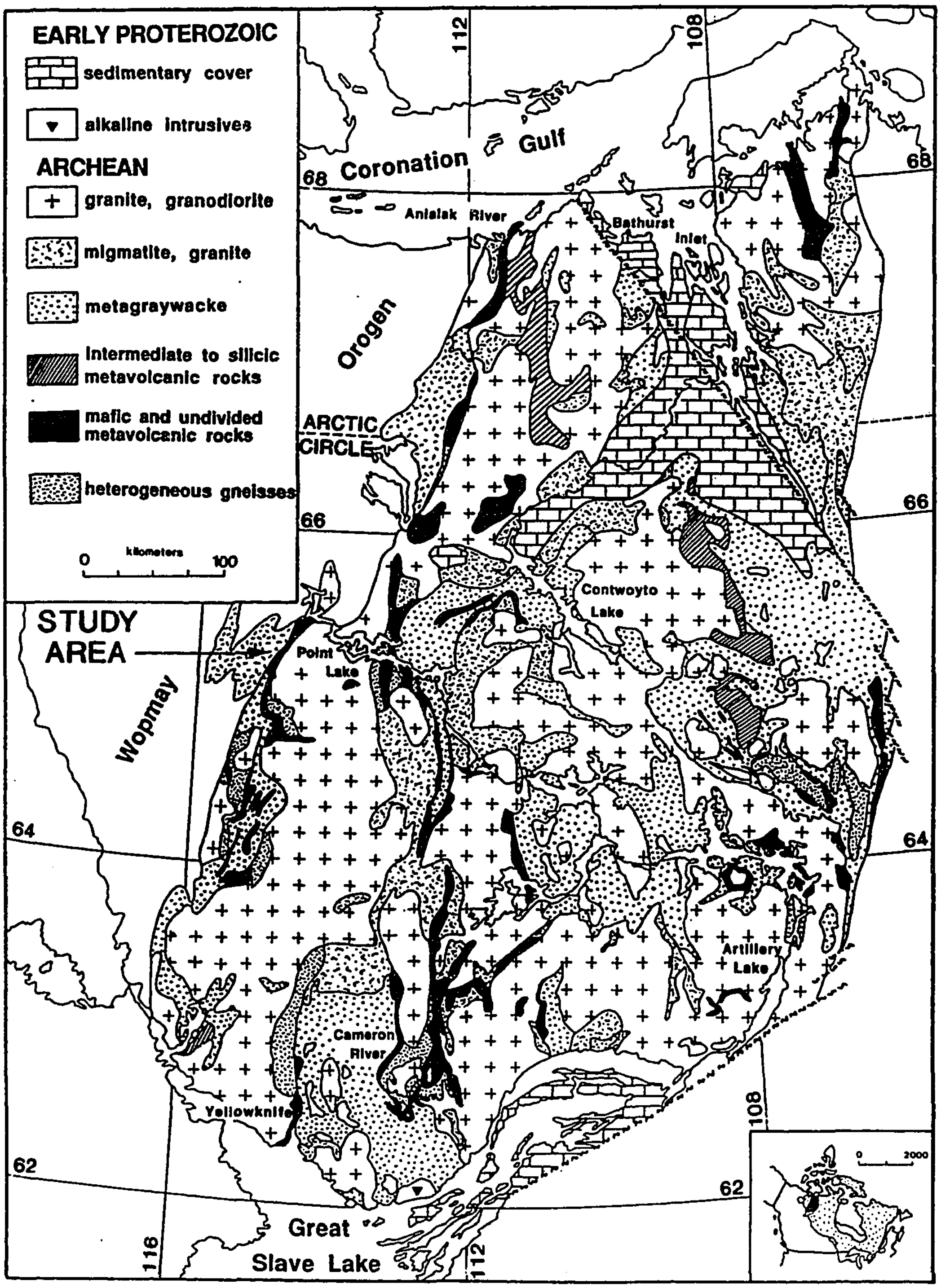


Figure 2. Archean Greenstone Belts in the Slave Province. Taken from Padgham, 1985 (see text).

the Slave Province. One hypothesis holds that Archean greenstone belts represent assemblages of metamorphosed sedimentary rocks and volcanic extrusions that had been deposited directly on ensialic crust. There are several variations on this model. In one version, deformation of greenstone belts results from isostatic downwarping of thin, unstable Archean continental crust (e.g., Anheusser, 1971 and 1981; Kröner, 1981). This first model is referred to as the "sag-subduction" or "sag-duction" model; it is analogous to the tectogene or eugeosynclinal theory used to account for Phanerozoic orogens. The sag-subduction model for the origin of Archean greenstone belts is schematically illustrated in Figure 3.

In another version, greenstone belts represent volcanic and sedimentary rocks that had been deposited in either a back-arc basin or a failed continental rift. Following cessation of rifting, the sedimentary and volcanic rocks were deformed by thermal subsidence and subsequent compression in the crust (e.g., Henderson, 1981, 1985; Easton, 1985a). A back-arc rift model is illustrated in Figure 4.

More recent hypotheses (e.g., Burke and Sengor, 1986; Kidd <u>et al.</u>, 1988) suggest that greenstone belts such as those in the Slave Province were formed by collisional plate tectonic processes in which oceanic crust or segments of an island arc were thrust onto continental crust, and that metamorphism results from the suturing of microcontinents

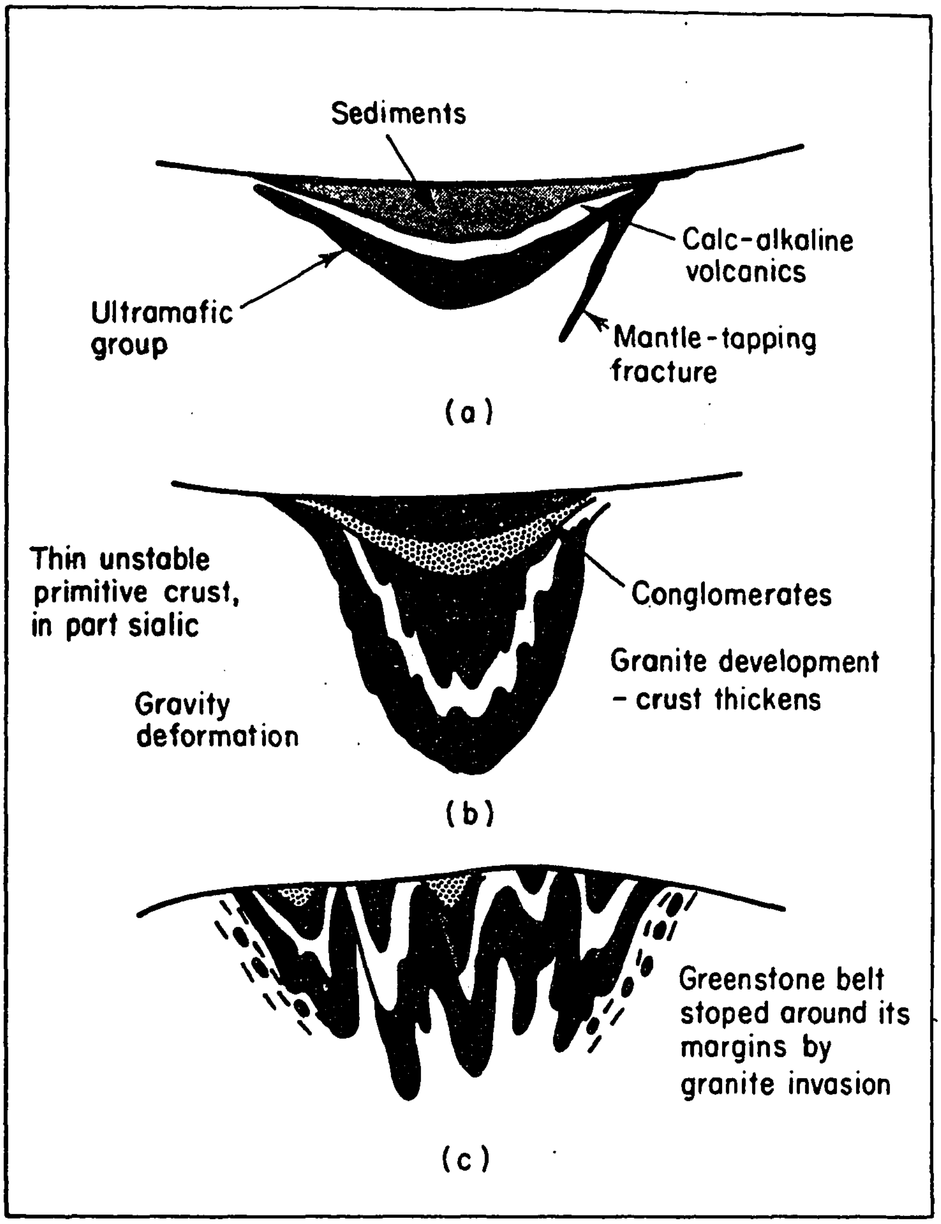


Figure 3. Sag-Subduction Model for the origin of Archean Greenstone Belts. Taken from Windley, 1984, after Anheusser, 1976.

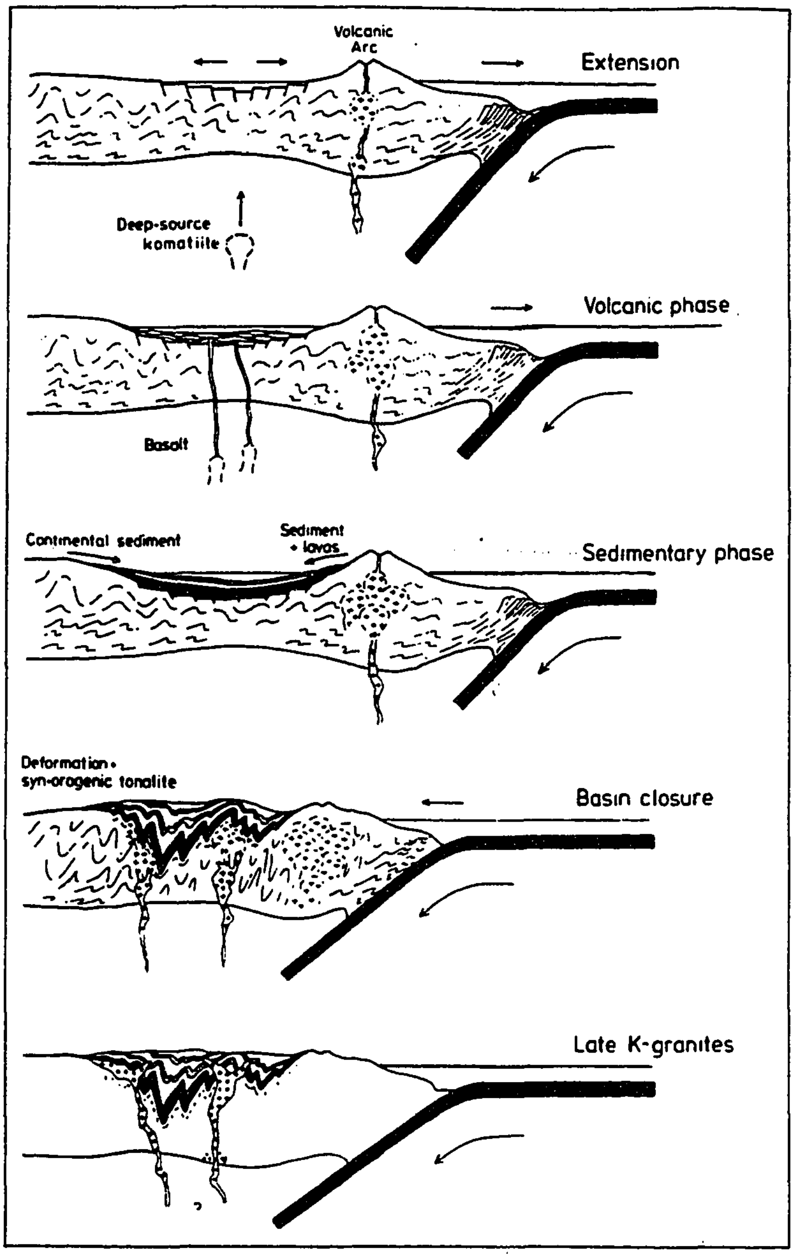


Figure 4. Sag-Subduction Model for the Formation of Greenstone Belts

(Figure 5). According to these models, collisional processes in the Late Archean were analogous to those documented at more recent suture zones. If this hypothesis is correct, processes similar to those involved in plate tectonics have been active since at least the Late Archean.

The Point Lake greenstone belt offers important clues to the understanding of Archean plate tectonic processes, but the geologic history of the greenstone belt remains poorly understood, partly because previous studies of Slave Province greenstone belts were conducted at regional scale, and partly owing to the structural complexity of Slave greenstone belts. The main objectives of this study were to map part of the greenstone belt in detail; to provide petrologic descriptions of the units that comprise the greenstone belt in the study area; and to describe the major geologic structures and their relevance to interpretive tectonic models. Secondary objectives were to discuss a plate tectonic model that is consistent with the observed lithologies and structures, and, if possible, to study the relationship between tectonic setting and trace element geochemistry in the mafic volcanic rocks. The primary emphasis of this study was placed upon field mapping.

The study area at Point Lake was chosen because exposure of the greenstone belt is excellent, the area is accessible from a base camp on an island in Point Lake, and some preliminary geologic mapping had already been conducted

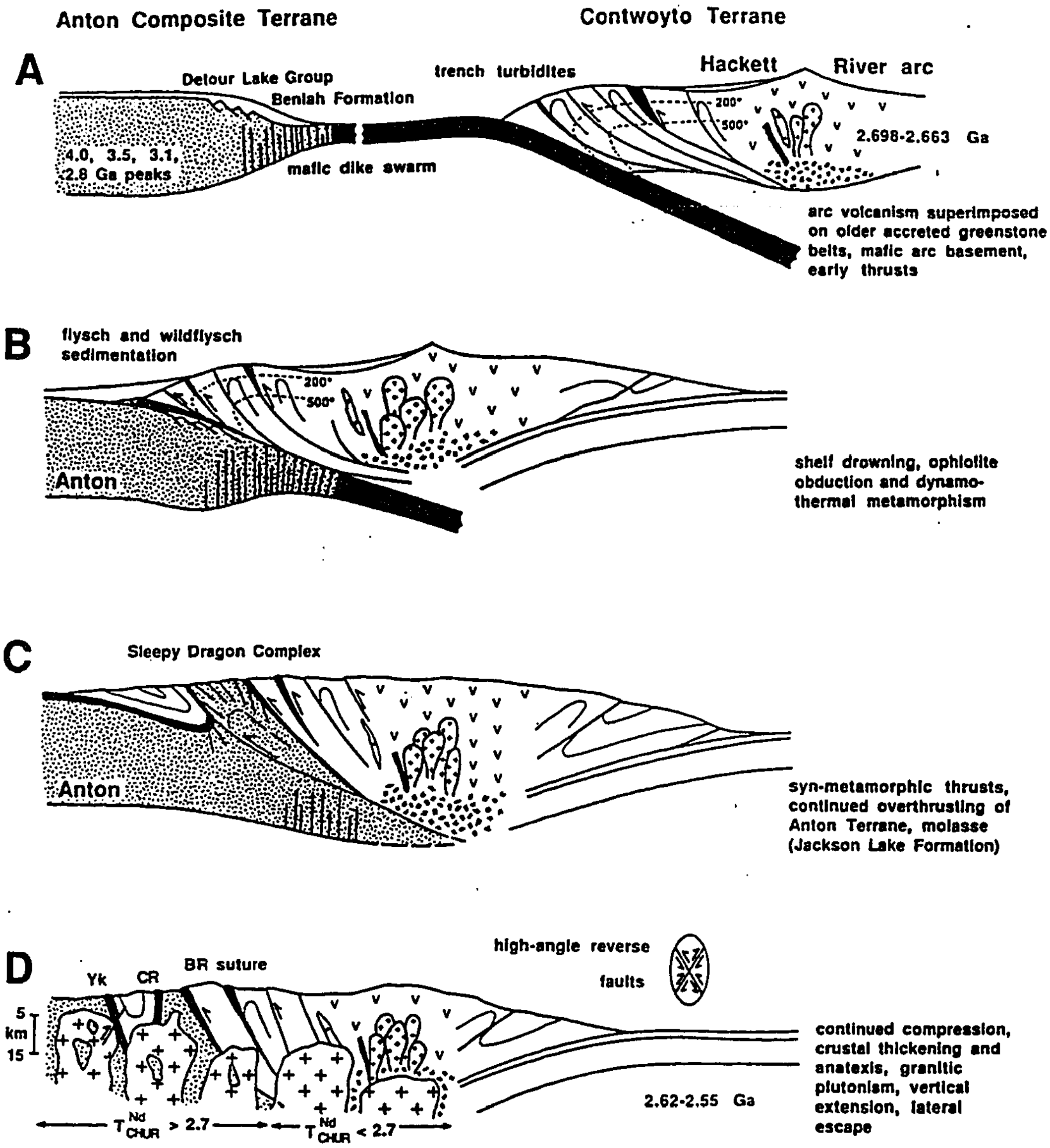


Figure 5. Collisional Model for Slave Province Greenstone Belts. Taken from Kusky, 1990. Locations of terranes indicated on this Figure are shown on Figure 8.

(Bostock, 1980; Henderson, 1981; Jackson, 1984, 1985; Easton, 1985a; Kusky, 1986). The field research for the present work was conducted during the summer of 1987 while the author served as field assistant to T.M. Kusky, then a doctoral candidate at The Johns Hopkins University.

To map the Point Lake area, rock units had to be identified, described, and distinguished from one another. It was therefore necessary in some cases to use petrographic and geochemical methods to distinguish units that appear similar in the field, and in other cases, to demonstrate affinity between units with dissimilar appearances.

LOCATION

The study area is located between 112° 57' and 113° 15' west longitude, and between 65° 13' and °65 25' north latitude (Figure 2). The greenstone belt lies at the boundary between two major groups of rock units, as indicated on early maps (Figure 6), suggesting the possible juncture of two or more terranes (e.g., Kusky, 1989 and 1991) and was thus considered a promising place to search for evidence of Archean plate tectonic processes. The study area encompasses approximately 75 square kilometers. Point Lake lies some 250 km from the nearest permanent settlement or motorable road, and is accessible by float plane after ice breakup in early July. At the latitude of the study area, daylight lasts over twenty hours per day during the summer months, allowing extended

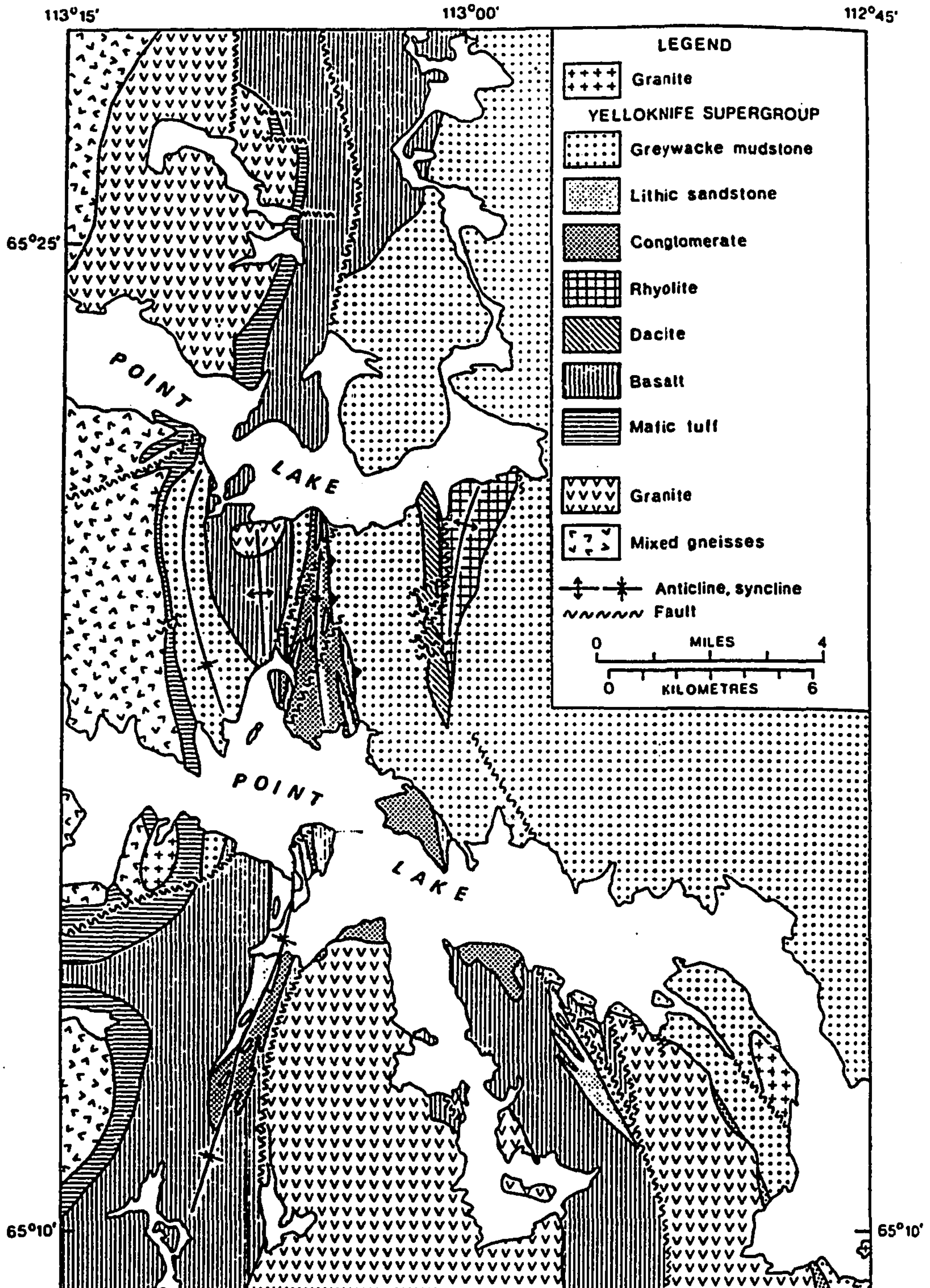


Figure 6. Early Geologic Map of the Point Lake Area. Taken from Henderson, 1981.

working hours. The study area comprises the central part of a peninsula lying between two arms of Point Lake (see Figure 6). In this thesis, the arms of the lake are informally called the "north arm" and "south arm". The area between the arms is referred to as the "central peninsula". The mapping area also encompasses several islands in the arms of lake, and areas near the north and south shores of the lake.

Lying north of the tree line, the area offers excellent visibility and good exposure of rock units, although lichen obscures structural detail in many outcrops. Weather during the summer months is fair, although severe storms become frequent by late August. The topography of the mapping area is characterized by flat expanses and gentle rolling hills, with a few cliffs marking the sites of late brittle faulting. All field work was conducted by foot and inflatable boat.

PREVIOUS WORK

Compared to Phanerozoic terrains, Archean terrains have been less thoroughly studied, are more complex, and are therefore poorly understood. Most of the Slave Province has been mapped only in reconnaissance scale. The Point Lake area was mapped in reconnaissance by Stockwell (1933), Bostock (1980), Henderson (1972), Henderson and Easton (1977), Easton (1981), and Kusky (1989), in somewhat more detail by Jackson (1984, 1985) and Henderson (1981 and 1988). Of these authors, Easton and Jackson accounted for the formation of the greenstone belt through rift models, in which volcanic and sedimentary rocks filled troughs developed through rifting of an ensialic crust. Henderson (1981) invoked a tectogene model, in which volcanic and sedimentary rocks that had been deposited on ensialic crust were subsequently deformed by downwarping in the crust. More recently Kusky (1986, 1989, 1991), Kidd et al. (1988), Wilks (1981), and Hoffman (1988) have proposed collisional models to account for the formation of the greenstone belts in the Slave Province, particularly for the greenstone belt at Point Lake. To date, the petrography and geochemistry of the rocks at Point Lake have not been described in detail.

A generalized geologic map of the study area showing major rock units and geologic structures is shown in Figure 7 (after Considine and Kusky, 1988). This generalized map represents a composite of the work of previous authors, and approximates what was known about the geology of the Point Lake area at the start of the present investigation.

METHODS

The methods employed in this study included field mapping, laboratory study of rock samples and analysis of structural data. The laboratory research for this project included petrographic study of thin sections, and geochemical studies (X-ray diffraction and X-ray fluorescence analyses).

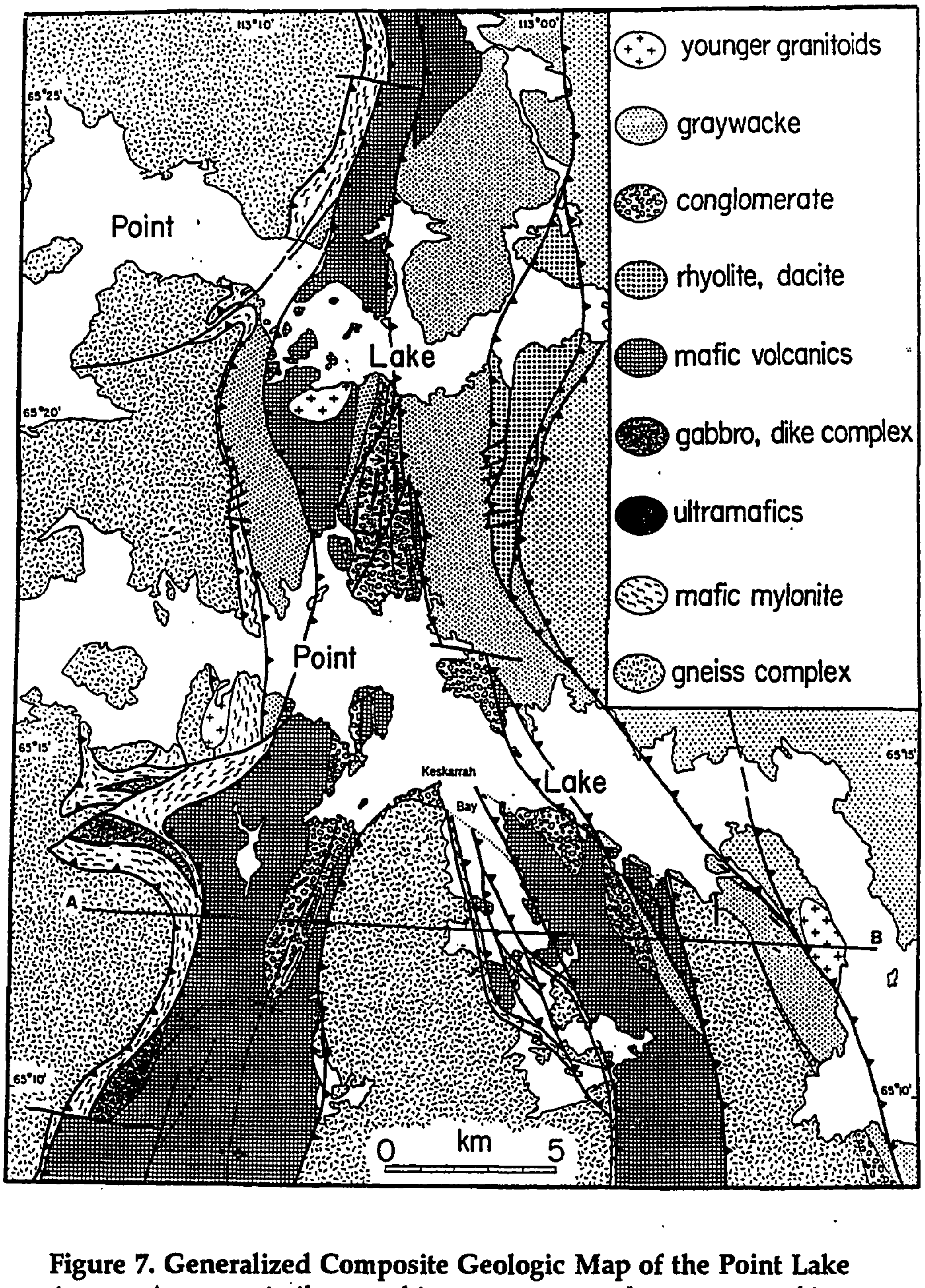


Figure 7. Generalized Composite Geologic Map of the Point Lake Area. A map similar to this one was used to test working hypotheses in the field. Line of section corresponds to Figure 21. Taken from Kusky, 1989, after Considine and Kusky, 1988.

Field Mapping

Field work for the present study was carried out during the period June 1 - August 20, 1987. The first four weeks of this period were spent making regional reconnaissance observations of other greenstone belts within the Slave Province (i.e., Lake Oro, Detour Lake, Yellowknife Bay).

During the mapping phase of this study, nearly every outcrop in the study area was examined, and over 300 rock samples were collected for laboratory study. These samples were later used for oriented structural study, and geochemical and petrographic analyses.

Exposure of the rock units varies in quality in the Point Lake area. Near the shores of the lake, exposure is generally good, but rocks are eroded to flat, "pavement" type outcrops that give only a two-dimensional view of structural detail. Inland, outcrops are smaller in area and generally obscured by varying amounts of lichen. Where possible, the orientations of the following features were measured: cleavages; mineral and crenulation lineations; bedding; fold hinges and axial planes; sense of shear; way up; and fault planes. Where subtle structural features, such as crenulation, were obscured by weathering or lichen cover, oriented samples were collected. Fresh surfaces cut in the laboratory revealed petrographic and structural features that were not observable in the field.

The classification of rock units in the present study is based on petrographic characteristics that were determined predominantly in the field.

Structural Data

Structural data measured in the field were plotted on the geologic map and on stereonets. Statistical interpretation of stereonet projections of structural data was facilitated by use of the DIPS program for microcomputers (Diederichs and Hoek, 1989).

Petrography

Petrographic study was performed using standard microscopic techniques. About 40 thin sections were prepared and examined under the petrographic microscope. An additional 30 thin sections were made available by Tim Kusky, who collected samples from the South Arm and the adjacent area to the south. Photomicrographs of representative samples from important lithologic units are presented in Chapter 3. In some fine grained samples, where mineral grains were too small to obtain an interference figure, the mineralogy was confirmed or identified partly by X-ray diffractionometry (XRD).

Geochemistry

Analysis of samples by X-ray fluorescence spectroscopy (XRF) was carried out at the Geochemistry Laboratories at McGill University, Montreal, Quebec, Canada under the supervision of Dr. S.T. Ahmedali. The geochemical analysis was performed on fused beads prepared from ignited samples. For the XRF analysis, powdered samples were prepared at Old Dominion University by the following technique. Rocks of 1000 g or more were sliced on a slab saw, cleaned of cutting oil with detergent and acetone, then hammered into gravel and crushed with a grinder into powder of approximately 150 mesh size. During the crushing-to-gravel stage, veins and weathered rinds were picked out of the rock samples. The metal plates on the grinder were weighed before and after crushing. During crushing, approximately 10 g of steel from the plates was mixed with about 8000 g of rock powder, with a greater concentration probably going into the harder, more silicic rocks. This level of contamination (less than 0.13 wt.%) is not considered to have significantly affected the results. A chemical analysis of the steel plate is not available; however, it is considered that possible contaminants from the steel include iron, nickel and chromium.

The samples were analyzed for 22 elements, including major elements and minor elements. The detection limit for the major elements (reported as oxides) was 0.01 per cent. It should be noted that the total iron was recalculated as 100% Fe_2O_3, and that the iron content reported may be higher than the actual value. The detection limit for the trace elements was 5 ppm. As a quality control, split samples of one hand specimen (geochemical samples 22 and 25) were analyzed, and the results showed good agreement.

Normative analyses of metaigneous units were calculated using the IGPET program for microcomputers, according to the CIPW method (e.g., Kelsey, 1965), and used to estimate the original petrography of metamorphosed igneous rocks. In calculating the normative composition of the rocks, a ratio of .15 FeO to total iron was used.

CHAPTER 2: REGIONAL GEOLOGY

A generalized geologic map of the Slave Province is presented in Figure 2. The regional geology of the Slave Province is dominated by the distribution of three major rock groups: ancient tonalitic to granitic basement gneisses; greenstone belts; and metamorphosed graywacke turbidites. The approximately 26 greenstone belts in the Slave Province (shown on Figure 2 as mafic and undivided metavolcanic rocks) are distributed along three major bands. One of these bands extends along the western boundary of the Slave, adjacent to the Wopmay Orogen; another such band occurs on the eastern boundary of the Slave, near the Thelon Front. The largest concentration of greenstone belts in the Slave occurs in a fragmented to semi-continuous band that extends across the west-central Slave from Coronation Gulf to Great Slave Lake. The Point Lake greenstone belt is part of this latter band. The distribution of the greenstone belts along bands suggests that the belts share, at least in part, a common geologic history (Padgham, 1985).

A greenstone belt occurs at Yellowknife, at the southern end of the Slave Province (see Figure 2). The rocks that comprise the Yellowknife greenstone belt are collectively assigned to the Yellowknife Supergroup (e.g., Stockwell, 1933;

Henderson, 1972). The Yellowknife Supergroup comprises most of the metamorphosed volcanic and sedimentary rock units in the Slave Province.

The Slave Province greenstone belts have been classified into two major types: Yellowknife-type volcanic belts and Hackett River-type volcanic belts. The Yellowknife-type belts contain a thick lower unit of basalt capped by felsic volcanics. The Hackett River-type volcanic belts reportedly consist predominantly of felsic volcanic rocks (Padgham, 1985). The Point Lake belt has traditionally been classified as a Yellowknife-type belt.

The western part of the Slave Province can be divided into regions distinguished by differences in lithologic type and radiometric age (e.g., Cumming and Tsong, 1975). In general, the oldest basement is restricted to an area that lies to the west of the Slave greenstone belts (c.f. Figure 2 and Figure 8). Figure 8 presents a few of the radiometric dates that have been obtained for the Slave Province. The metamorphosed igneous rocks in the Slave Province are to some extent distributed according to age. However, the significance of intrusive events and their relative timing to the history of the Slave Province remains controversial (e.g., Frith et al., 1977; Kusky, 1989; Dudás et al., 1990).

Figure 8 shows the tentative identification of two terranes in the western Slave, as made by Kusky (1990). In the westernmost part of the Slave, tonalitic to dioritic and

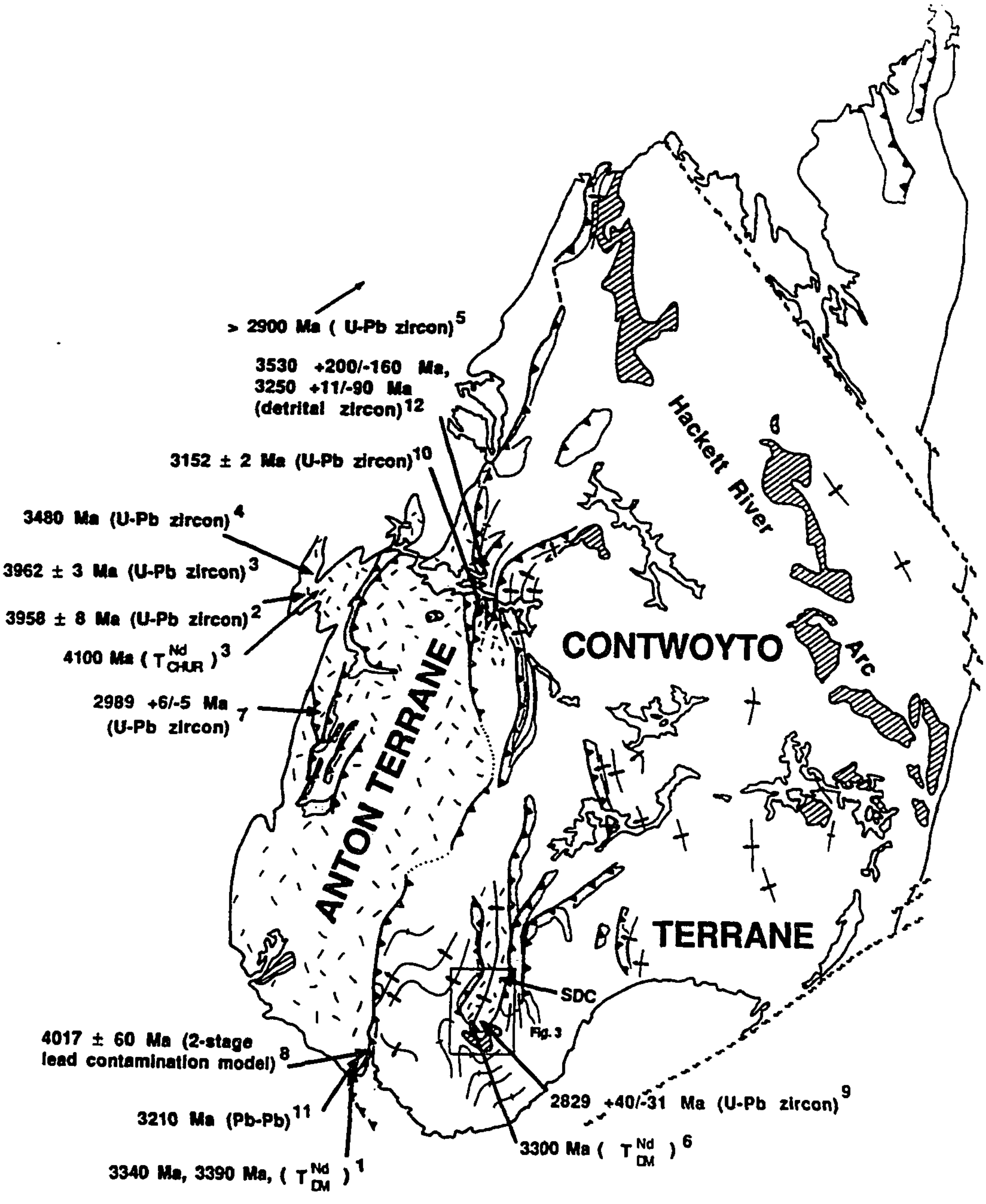


Figure 8. Tectonic Terranes in the Slave Province and Sample Radiometric Ages of the Anton Terrane. Taken from Kusky, 1990.

granitic gneisses comprising the Anton terrane are exposed. Lying to the east of the Anton Terrane is the Contwoyto Terrane, which is composed predominantly of metamorphosed and highly deformed graywacke and mudstone turbidites, black shales, iron formation, and greenstone belts. In this model, Slave Province greenstone belts were interpreted as remnants of oceanic crust distributed along a suture zone marking the closure of an Archean ocean. Key elements of this model are illustrated on Figure 5. In an earlier version of the model, Kusky (1989) proposed the Sleepy Dragon Complex, an assemblage of relatively old granites and gneisses (Figure 5; Figure 8), as a separate terrane (the Sleepy Dragon Terrane) comprising parautochthonous basement nappes.

The terrane model of Kusky (1990) explains at regional scale the restriction of oldest basement to the westernmost Slave; the origin of large tracts of highly deformed turbidites; a predominant compressional style of deformation; and the origin of a band of mafic rocks interpreted as a once-continuous sheet of oceanic crust (Isachsen, 1992). However, this model has not gained universal acceptance, as it fails to explain some important observations in the Slave Province. For example, Dudás (1989) found enriched Nd isotopic signatures in volcanic rocks of the Kam Group (a succession near the inferred base of the Yellowknife greenstone belt), and concluded that these rocks were derived from depleted mantle with some degree of interaction with an older crust.

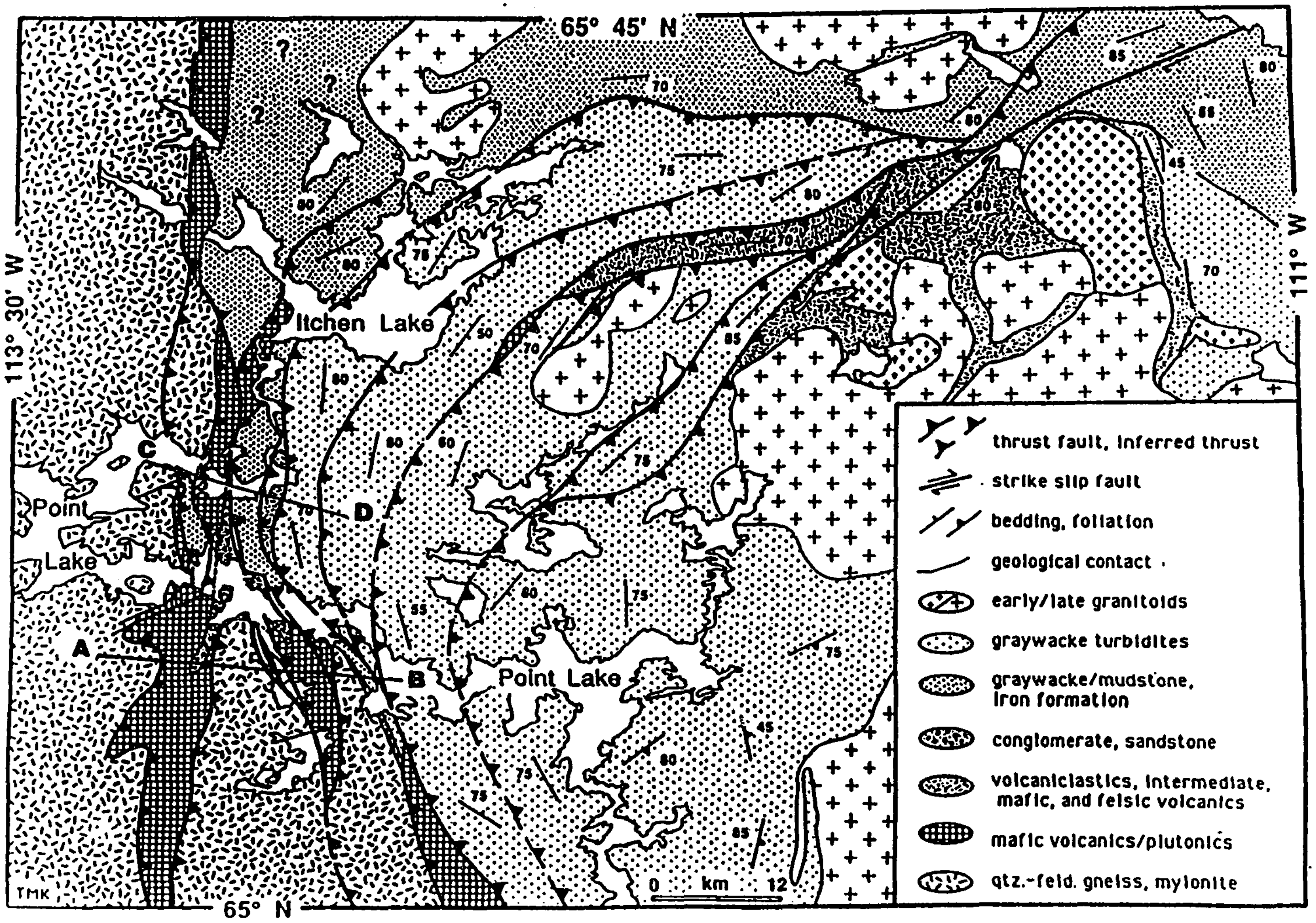
Isachsen (1991; 1992) mapped sections of the Yellowknife greenstone belt in detail and concluded that the lower part of the Yellowknife belt is conformable over sialic basement. Isachsen also reported that structural repetition by thrusting is relatively minor in the Yellowknife belt, and restricted to the upper part of the stratigraphic succession. Furthermore, King et al. (1989) conclude that the structural data used by Kusky are not consistent with their field observations in the central Slave Province.

The Point Lake greenstone belt lies approximately 300 km to the north of Yellowknife. In the western part of the Point Lake area, Early to Late Archean basement gneisses are exposed. To the east, and separated from the gneisses by a wide mylonite zone, are metamorphosed sedimentary and mafic volcanic rocks comprising the greenstone belt. The greenstone belt is separated from the older gneissic terrane (basement) by mylonite complex which ranges from 400 m to 1 km in width locally, and is up to 2 km in width regionally. Deformation in the gneissic basement is complex; much of the deformation is discordant with, and clearly predates, deformation in the greenstone belt. Deformation in the greenstone belt is also complex. However, most of the major thrusts in the greenstone belt dip steeply to the east and strike approximately north-south. The style of folding in the Point Lake area varies from lithologic unit to unit, but in general, the greenstone belt demonstrates intense deformation. The metasedimentary rocks are isoclinally folded about near-vertical axial planes. The folds in the metaigneous rocks are more difficult to trace than the folds in the metasedimentary rocks, but the fairly Rounded to oval shapes of basalt pillows suggests that the metaigneous rocks have undergone less intense deformation than the metasedimentary rocks.

The Point Lake greenstone belt is part of an eastward-opening arc of folding, thrusting and wrench faulting that extends through the western part of the Slave Province (see Figure 9). This arc is characterized on the north flank by dextral strike-slip faults,along the western cusp by tight isoclinal folds and steeply dipping thrusts, and along the southern flank by sinistral strike-slip faulting (Kusky, 1991). The study area of this project is located on the front, or cusp of this fold-thrust-wrench belt. The dominant structural features at Point Lake are therefore part of a larger system that also represents the juncture of two or three terranes of radically different petrographic character.

The Point Lake area is therefore suggested to occupy a position at the juncture of the two terranes tentatively identified by Kusky (1990) and includes the very eastern part of the Anton Terrane and the western part of the Contwoyto Terrane of Kusky (1991). This thesis is therefore a study of the relationship between the Anton Terrane (gneissic basement) and the Contwoyto Terrane (greenstone belt and metasedimentary rocks), with a possible inclusion of the Sleepy Dragon Terrane

Figure 9. Fold-Thrust-Wrench Belt in the Western Slave Province. Lines of Section are represented on Figure 21. Taken from Kusky, 1990.


65° 45' N
65° N
113° 30' W
111° W
Itchen Lake
Point Lake
Point Lake
A
B
C
D
0 km 12
TMK
thrust fault, inferred thrust
strike slip fault
bedding, foliation
geological contact
early/late granitoids
graywacke turbidites
graywacke/mudstone, iron formation
conglomerate, sandstone
volcaniclastics, intermediate, mafic, and felsic volcanics
mafic volcanics/plutonics
qtz.-feld. gneiss, mylonite

(parautochthonous rifted continental margin?).

The rocks of the greenstone belt at Point Lake have been correlated to the Yellowknife Supergroup by some previous workers. This correlation rests on the asssumption that the greenstone belt at Point Lake shares a similar structural succession of metamorphosed igneous and sedimentary rocks with the greenstone belt exposed in the area of Yellowknife Bay (e.g., Henderson, 1981; Padgham, 1985; Easton, 1985b). Although the assemblage at Yellowknife Bay is probably the same in approximate age, and shares a similar general lithology with rocks that comprise the greenstone belt at Point Lake, the correlation is uncertain because the greenstone belt is not continuous over the distance between Point Lake and Yellowknife Bay. Furthermore, reconnaissance observations made by the author on islands in Yellowknife Bay and in other parts of the Slave Province suggest that there are major differences in structural style and lithologic associations between the rocks of Yellowknife Bay and those of the greenstone belt at Point Lake. Although the two successsions may be closely related in age and similar tectonic style, it has not been demonstrated that they are correlative.

Based on structural relationships and radiometric ages, the greenstone belt in the Yellowknife area has been assigned (Green et al., 1968; Green et al., 1971; Frith et al., 1977; Frith et al., 1986; Isachsen and Bowring, 1990; Isachsen,

1992) an estimated age of approximately 2.66 Ga to 2.72 Ga. This age is consistent with both the age of a zircon grain from a metasedimentary rock collected at Point Lake (Frith et al., 1986; Shärer and Allégre, 1982) and a preliminary age of approximately 2.7 Ga assigned to a granodioritc intrusion into the greenstone belt (Isachsen, unpub. data collected during preparation of 1992 dissertation). At this writing, studies are underway to determine the ages of the components of the greenstone belts at Point Lake and elsewhere in the western Slave Province.

CHAPTER 3: GEOLOGY OF THE POINT LAKE AREA

A geologic map of eastern Point Lake is presented on Plate 1. The geologic map was compiled from the results of the mapping phase of the present study. The rock units are divided into three main groups based on inferred relative age, which was interpreted from structural relationships and petrography, and from radiometric dating carried out by others. The main rock groups are identified as follows. Group I includes a basement complex comprised predominantly of granitoid gneisses and migmatites that range in age from 3.97 Ga to 2.65 Ga. The basement also includes parautochthonous conglomerates and basalts that are interpreted here as having been deposited directly on the gneiss. The conglomerates and their interlayered basalts are interpreted as predating the emplacement of the greenstone belt. The Group I gneisses in the study area are interpreted as equivalent to part of the Anton Terrane of Kusky (1991). Group II represents the allochthonous greenstone belt (about 2.65 Ga). Previous workers have traditionally referred to the rock units that comprise the Slave Province greenstone belts as the "supracrustal sequence". The greenstone belt is divided in this work into two main subgroups: a metaigneous subgroup ("greenstone") and a metasedimentary subgroup (the Contwoyto

Formation and related rocks). The greenstone belt may be roughly correlative with the Yellowknife Supergroup of Henderson (1972) in the sense that the two groups of rocks are similar in age and general lithology. However, the collective term "Yellowknife Supergroup" is not intended to suggest that all of the greenstone belts in the Slave Province share a common origin. Group III includes undeformed felsic and mafic intrusives (2.6 to 1.2 Ga) that postdate the greenstone belt.

The lithologic units identified in the Point Lake area are summarized in Table 1. Several important rock units were identified that had not been identified in earlier studies. Additionally, the classification presented in Table 1 provides new information regarding structural, stratigraphic and age relationships between rock units.

In this chapter, descriptions and photomicrographs of thin sections are presented. The purpose of the petrographic investigations was to document the lithologies of important rock units, so that in turn a more accurate geologic map could be made. Rock units that significantly predate or postdate the formation and emplacement of the greenstone belt were not studied in detail. Owing to the large number of rock types represented in the study area, and the wide range of metamorphic grades, it is beyond the scope of the present work to present a detailed petrographic description of each rock type. This section presents a general description of rock units that have not been previously or adequately documented.

Table 1. Summary of Rock Units in the Study Area.

UNIT NO.	ROCK UNIT NAME (THIS STUDY)	DESCRIPTION	CONTACTS	REFERENCE
9	Mackenzie Diabase Dikes	Medium- to dark-gray unmetamorphosed diabase; weathers to red-brown.	Intrudes all other units.	Fahrig and Jones (1969)
8	Late Felsic Intrusives	White to pink unmetamorphosed trondhjemitic to tonalitic intrusives.	Intrudes basement, mylonite complex, greenstone belt.	Jackson (1985) (Unnamed unit)
7	Mylonite Complex	Very fine-grained, finely laminated, dark-green to black. Protoliths: 7a- mafic; 7b-sedimentary; 7c-felsic gneiss.	Fault-bounded.	Henderson, 1981: Tuff; Jackson, 1985: banded mafics; Kusky, 1987: mafic mylonite.
6	High-grade Metagraywacke	Very fine-grained, massive, hard, silicic. 6a: pink; 6b: gray; 6c: mottled.	Fault-bounded massif. May grade on east into lower-grade metamorphics.	Henderson, 1981, 1988 and Jackson, 1985: rhyolite and dacite
5	Contwoyto Fm 5b: Graywacke Member	Massive to laminar-graded, gray-brown to dark-gray graywacke with tuff, quartzite and limestone interlayers.	Depositional over shaly member; fault contact with other units.	Bostock, 1980.
	5a: Shaly Member	Red, brown and black metashales.	Depositional over pillow basalts (Unit 4c).	No previous identification.
4	Greenstone 4c: Metabasalt	Dark-green to nearly black massive and vesicular pillow basalt.	Grades downward into diabase; rare dikes intrude Unit 5a; fault contact with other units.	Henderson, 1981.
4	4b: Diabase 4a: Metagabbro	Light-green to dark-green extensively fractured, variable-textured metabasites.	Grades upward into basalt; grades downward into gabbro	Henderson, 1981.
3	Ultramafics	Light green tremolite schist.	Thrust over basement, mylonite and basalt.	No previous identification.
2	Keskarrah Fm 2b: Metabasalts	Light-green aphanitic and Plag.-phyric calcified pillow basalts.	Basalts are intruding and interlayered with conglomerate; conglomerate is depositional over basement gneiss	St. Seymour, 1988: "Point Lake basalts" (equiv. to Unit 4c).
	2a:Conglomerate	Polymict pebble to cobble conglomerate.		Bostock, 1980.
1	Basement Gneisses	Variable granitoid gneisses.	Basement to other units.	Bostock, 1980.

Locations from which thin section samples were taken are shown on Figure 10. Photomicrographs of representative samples are included at the end of this chapter.

For the present study, geochemical analysis was performed on 34 powdered rock samples, and geochemical analyses performed on five samples for two earlier studies (St. Seymour et al., 1988; Bostock, 1980) were reviewed. Excluding Unit 2a (Keskarrah Conglomerate) and Unit 8 (Late Felsics), representative samples of each major rock unit were analyzed. Table 2 summarizes the rock unit represented by each geochemical sample, and for samples not collected by the author, identifies the source of the sample or analytical data. The main focus of the geochemical investigations was on the metaigneous rocks. Three geochemical samples (samples 8, 11, and 19) were collected from metabasalts in the Yellowknife Bay area; sample 12 was from Sierra Leone. Analytical results for samples outside the mapping area are not presented in this work. Five samples (Geochemical Samples 38-42) represent analytical results reported by St. Seymour et al. (1988). One of these (Sample 39) represents the results of an analysis reported earlier by Bostock (1980). Sample locations for the geochemical samples are presented on Figure 11.

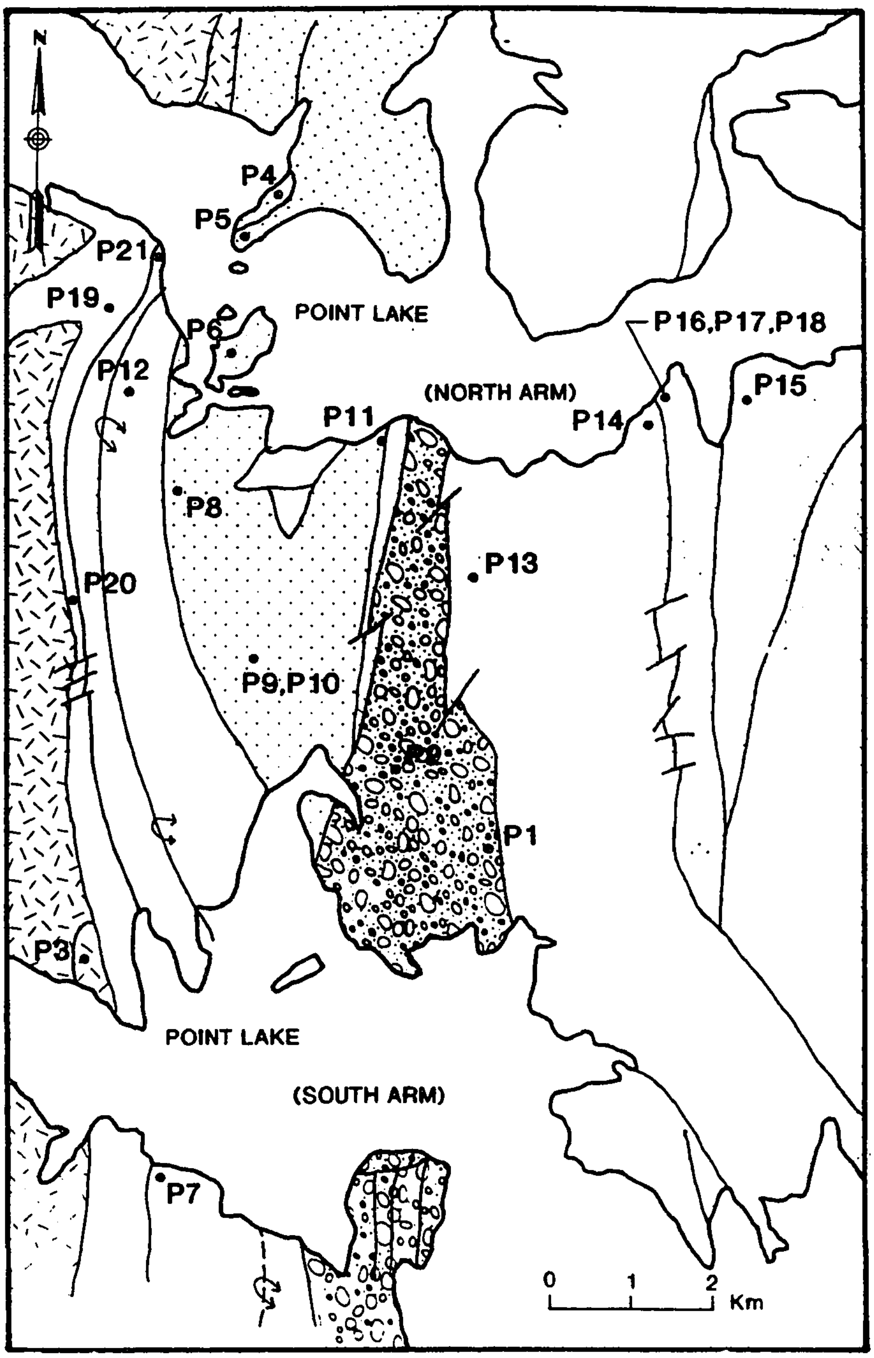


Figure 10. Locations of Thin Section Photomicrograph Samples.

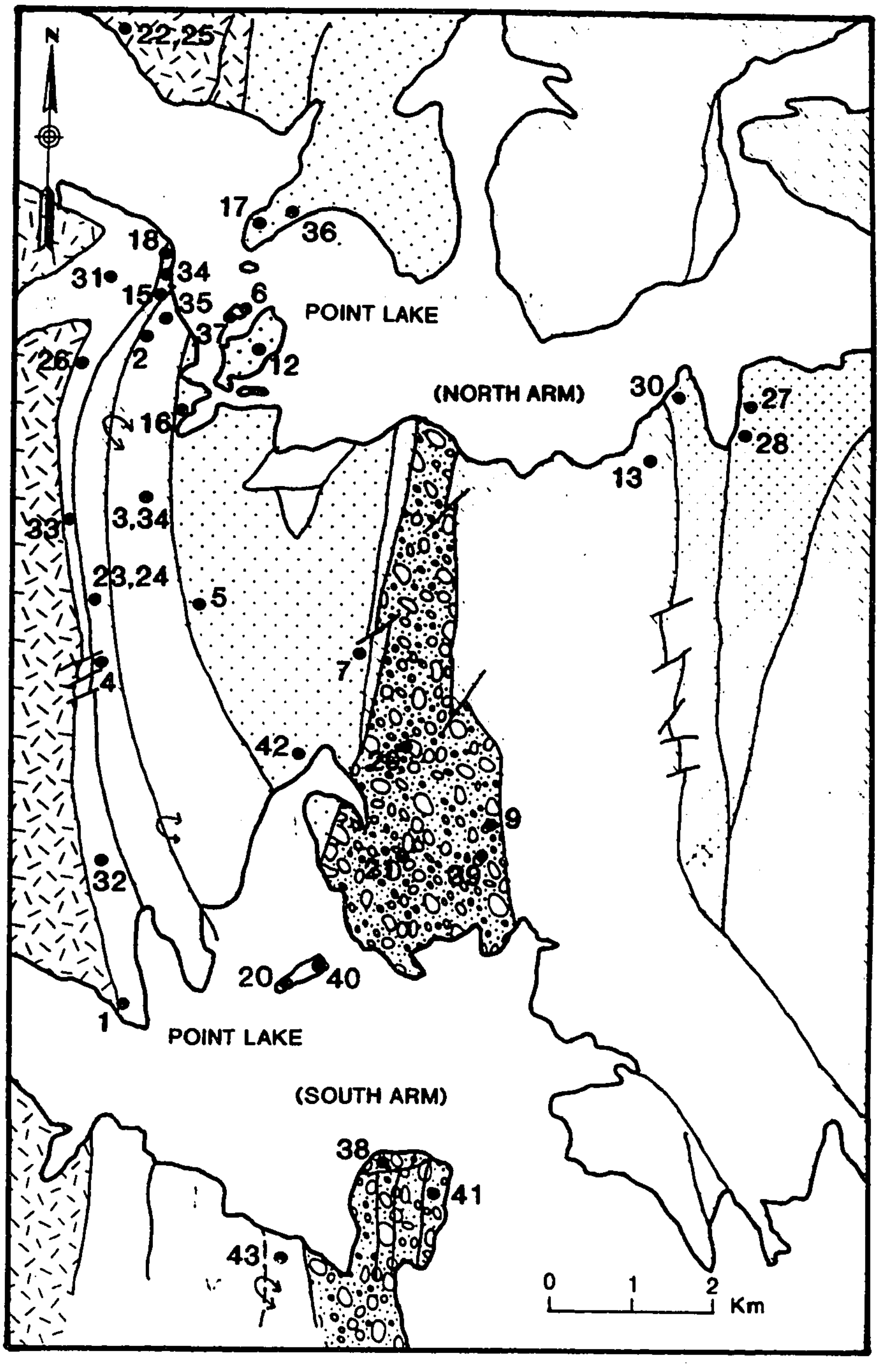


Figure 11. Locations of Geochemical Samples.

Table 2. Summary of Geochemical Samples and Rock Types.

SAMPLE NO.	UNIT NAME	COLLECTED BY	SAMPLE NO.	UNIT NAME	COLLECTED BY
1	Ultramafic	PRC	23	Greenstone (4c)	PRC
2	Contwoyto (low grade)	PRC	24	Greenstone (4a)	PRC
3	Contwoyto (low grade)	PRC	25	Basement Dike	CI
4	Contwoyto (low grade)	PRC	26	Mafic Mylonite	PRC
5	Greenstone (4c)	PRC	27	High Grade Metagraywacke (6)	PRC
6	Greenstone (4c)	PRC	28	High Grade Metagraywacke (6)	PRC
7	Greenstone (4c)	PRC	29	Keskarrah Basalt	PRC
8 *	Yellowknife Bay Mafic	PRC	30	High Grade Metagraywacke (6)	PRC
9	Keskarrah Metabasalt	PRC	31	Mafic Mylonite	PRC
10	Keskarrah Metabasalt	PRC	32	Mafic Mylonite	PRC
11 *	Yellowknife Bay Mafic	PRC	33	Mafic Mylonite	PRC
12 *	Farkaka Amphibolite	RNV	34	Contwoyto (low grade)	PRC
13	MacKenzie Diabase	PRC	35	Contwoyto (low grade)	PRC
14	MacKenzie Diabase	PRC	36	Greenstone (4c)	PRC
15	MacKenzie Diabase	PRC	37	Greenstone (4a)	PRC
16	Greenstone (4a)	PRC	38	Keskarrah Basalt	SS
17	Ultramafic	PRC	39	Keskarrah Basalt	BOS
18	MacKenzie Diabase	PRC	40	Keskarrah Basalt	SS
19	Yellowknife Bay Mafic	PRC	41	Keskarrah Basalt	SS
20	Keskarrah Metabasalt	CI	42	Keskarrah Basalt	SS
21	Keskarrah Metabasalt	CI	43	Greenstone (4c)	SS
22	Basement Dike	CI			

* Indicates sample from outside study area.
PRC = Considine RNV = Venkatakrishnan CI = Isaachsen SS = St. Seymour BOS = Bostock

GROUP I: BASEMENT COMPLEX

Unit 1: Basement Gneisses

Unit 1 is a gneissic basement complex that comprises some of the oldest rocks on the planet. The basement rocks include a wide variety of felsic and mafic plutonic rocks, dikes, ortho- and paragneisses and migmatites. Within the map area, granitoid gneiss constitutes the predominant lithology for Unit 1. These rocks range in age from 2.7 Ga to 3.97 Ga (e.g., Frith et al. 1977; Bowring et al., 1988; Bowring et al., 1989; Isachsen and Bowring, 1990). The basement complex extends for some tens of kilometers beyond the western boundary of the study area, to the western boundary of the Slave Province. Only exposures immediately adjacent to the greenstone belt were examined during the present study.

Gneisses interpreted as parautochthonous and originally part of the basement complex also appear in a thrust-bounded massif on the south shore of the south arm. The gneisses comprise plutons of variable age, composition and deformation. These plutons are similar to other plutons that are widely distributed throughout the western part of the Slave Province, and are interpreted as predominantly Early- to Late Archean in age. One of these plutons, located near the study area, includes the oldest igneous rocks yet dated (Bowring et al., 1988; 1989).

Near the contact with the greenstone belt, metaigneous rocks are most commonly deformed to a thick-banded lit-par-lit gneiss showing evidence of several generations of folding (Figure 12). Near the shear zone that separates the basement from the greenstone belt, the gneiss grades eastward from gneiss to protomylonite, then into mylonite and ultramylonite. Mylonite and ultramylonite, where derived from gneissic rocks, are very fine grained, finely laminated, dense, and medium-gray, with small (less than 1 mm) rotated grains of pink feldspar. At Point Lake, the varieties of mylonite that are derived from granitoid gneisses are sometimes distinguishable in the field from those derived from other protoliths based on the medium-gray color and the presence of pink feldspars. The pink feldspars in the felsic mylonite are rotated porphyroclasts that provide sense of shear indicators.

Metamorphosed mafic intrusions in the gneissic basement are metabasalts and metagabbros of predominantly amphibolite grade. It had been suggested in earlier studies (e.g., Henderson, 1981) that mafic dikes in the basement served as feeders to the greenstone. However, the amphibolite dikes included in Unit 1 are truncated both by the mylonite (Unit 7) and by the overlying conglomerates (Unit 2a). Two samples of amphibolitized mafic rocks intruding the basement were analyzed. The results are presented in Table 3. Structural relationship between rock units strongly suggests that the metabasites that intrude the basement have no traceable continuity into those of the greenstone belt. Further, a geochemical study of the mafic rocks (see subsections on

Figure 12. Refolded Lit-Par-Lit Gneiss.
Photograph taken on the south shore of North Arm.

Table 3. Geochemistry of Mafic Basement Dikes.

Sample No.:	22	25
Outcrop No.:	OC906	OC905
SiO2	49.06	50.26
TiO2	1.12	0.98
Al2O3	14.16	14.01
Fe2O3	14.79	13.92
MnO	0.21	0.20
MgO	7.40	7.87
CaO	11.12	10.35
Na2O	1.92	2.30
K2O	0.18	0.14
P2O5	0.09	0.09
LOI	0.19	0.54
TOTAL	100.33	100.74
BaO	109	99
Cr2O3	403	479
Nb	7	5
Ni	118	137
Pb	<5	5
Rb	<5	5
Sr	123	122
Th	<5	<5
U	<5	<5
V	307	232
Y	20	19
Zr	76	73

NOTES

1.) Major oxides as wt%; Trace elements as ppm.

2.) All iron calculated as Fe2O3.

geochemistry of units) indicates that mafic intrusives in the basement and metabasalts of the greenstone belt crystallized from separate melts.

The basement also contains younger (probably Proterozoic) intrusions of both mafic and felsic igneous rocks. These "late" intrusions display fewer generations of deformation than other rocks in the area. The youngest of these intrusions are the undeformed rocks of units 8 and 9, described below.

In general, the gneissic basement exhibits a complex history of deformation. Jackson (1984, 1985) has compiled structural data that indicates that near their eastern contact with the greenstone belt, the gneisses have undergone at least three generations of deformation. Except in the immediate vicinity of the mylonite zone, deformation is clearly discordant with and more complex than that of the rock units of the greenstone belts, and hence presumably partly predates the greenstone belt. In the south-central part of the study area (near Keskarrah Bay), there is an outcrop of gently foliated gneiss. Gneiss at this particular outcrop has been dated at 3.16 Ga (Krogh and Gibbins, 1978), and lacks the pervasive, multiply deformed foliation of older gneisses to the west, suggesting that much of the deformation in the gneissic basement preceded 3.16 Ga. Since metagraywackes in the greenstone belt contain zircon grains with an age of 2.7 Ga, extensive deformation occurred in the basement prior to deposition of the graywacke and subsequent emplacement of the greenstone belt. This outcrop is interpreted as part of a fault block of basement material imbricated with slices of allochthonous metasedimentary and metavolcanic rocks (Considine and Kusky, 1988; Kusky, 1991).

Unit 2: Keskarrah Formation

The Keskarrah Formation is the name given by Bostock (1980) to a unit of conglomerates exposed at Keskarrah Bay, which is a small bay in the south arm of Point Lake. Lying unconformably over the granitoid gneisses (Figure 13), it is a coarse polymict conglomerate (Unit 2a) with local mafic intrusions and interlayered flows (Unit 2b). It is proposed here that the Keskarrah Formation lithic designation be expanded to include both the conglomerates and the basalts.

Unit 2A: Keskarrah Conglomerate

Conglomerates of the Keskarrah Formation are informally referred to in this work as the Keskarrah conglomerates. The conglomerate contains pebbles and cobbles composed predominantly of granite, altered gneiss, slate and shale, and quartzite. The supporting matrix of the conglomerate is composed of fine gray-green material that has been altered to chlorite schist, with some indeterminate phyllosilicates. Interbedded with the conglomerate are rare layers of graywacke, cross bedded sandstone, and shale (Henderson and

Figure 13. Keskarrah Conglomerate Lying Unconformably Over Basement Gneiss. Photograph taken on the north shore of South Arm.

Easton, 1977; Bostock, 1980; Kusky, 1991). Many pebbles in the conglomerate are of indeterminate weathered pelitic and mafic protoliths, which have been altered to a chlorite-phyllosilicate schist; the degree of alteration in the clasts probably renders a detailed petrography of the clasts in the conglomerate impossible. Some clasts are fine grained, dark green, and have been interpreted as highly altered basalt pebbles (Kusky, 1991). Kusky (op. cit.) further reports the occurrence of rare layers of monomict basalt conglomerate near the base of the unit, but these layers were not observed during the field mapping conducted for the present work.

In the southern part of the mapping area, where conglomerate lies unconformably over gneissic basement, the matrix of the conglomerate is metamorphosed and contains abundant chlorite. The conglomerate exhibits a poorly defined cleavage in which cleavage planes are deflected by the pebbles and cobbles. A northward along-strike traverse across the conglomerate shows increasing flattening of the clasts, and cleavage becomes more pervasive. The size of the clasts also diminishes to the north. The flattened clasts are approximately equidimensional in the plane of flattening, with the short axis very nearly perpendicular to the plane of flattening. The oblate shape of the deformed clasts indicates that flattening was accomplished without a major shearing component (e.g., Freeman, 1987). The flattening direction in the clasts is approximately parallel to both the cleavage and the axial plane of regional folding, which strikes north-south and dips steeply to the east. In the northern part of the study area, the upper and lower contacts of the conglomerate appear to be faults that separate the conglomerate from other metasedimentary members of the greenstone belt.

Unit 2B: Keskarrah Metabasalts

The Keskarrah formation includes interlayers of pervasively cleaved and flattened metamorphosed pillow basalts, and minor localized intrusions of basalt and fine grained diabase into conglomeratic beds. It is therefore proposed here that the designation of the Keskarrah Formation be expanded to include these volcanics, which are here informally named the Keskarrah metabasalts. The Keskarrah metabasalts have not been found to intrude other units. They can generally be identified in the field by their colors, which include characteristic bright greens and pale tans. Field observations also suggest that the Keskarrah metabasalts are more extensively calcified than the other metavolcanic rocks in the mapping area. In general, the Keskarrah metabasalts display an aphanitic texture. Thin section petrography and geochemistry of this unit is presented in the following subsections. The Keskarrah metabasalts are all pervasively metamorphosed, and contain a pervasive cleavage that is roughly parallel to the cleavage exhibited in the conglomerate. In the pillowed forms, a dark colored selvage

1 cm to 2 cm thick typically surrounds the pillow.

On Plate 1, lozenges of Keskarrah basalt are shown near the center of the peninsula. At one of these outcrops, pillow basalt of Unit 2b is interlayered with conglomerate (Unit 2a). Geochemical sample No. 20 was taken from this outcrop, which is proposed as the type location for the Keskarrah basalt (see also Figure 11). At a nearby outcrop, a light-green metabasalt intruding conglomerate (Figure 14) was traced a few meters westward into a fine grained diabase of the same color. At the eastern margin of the outcrop area of the conglomerate, a 30 m by 1000 m fault-bounded ridge of metamorphosed andesitic basalt crops out (the "mugearite" of Bostock, 1980; St. Seymour et al., 1988). Some hand specimens of the Keskarrah Basalts were collected that have a light tan color. Jackson (1985) and Henderson (1988), in their geologic maps of Point Lake, report the occurrence of felsic intrusives at the site from which these samples were collected, near the eastern margin of the outcrop area of the Keskarrah Formation. However, petrographic and geochemical studies of samples from these outcrops reveals that although the rocks are light tan in color and resemble a felsic igneous rock, they have a metabasaltic composition.

Prior to the present study, the basalts included here as unit 2b were not distinguished from the basalts of Unit 4. The mineralogy and geochemistry of the basalts associated with the Keskarrah Formation indicate an origin distinct from that

Figure 14. Keskarrah Metabasalt Intruding Conglomerate. Photograph taken near the middle of the Central Peninsula. Dike was traced westward 10 m to fine grained gabbro.

of the metabasalts described as Unit 4. Further, the Unit 2b volcanics are of limited areal extent (volume), and are not seen to intrude any unit other than the conglomerate.

Petrography of Keskarrah Basalts

Unit 2b includes a fairly wide range of metamorphosed, generally subalkaline basalts. This rock type comprises very fine grained assemblages of feldspar and pyroxene, with minor opaque minerals. Nematoblastic textures appear to be typical for this unit. Representative thin sections of Unit 2b are shown in Photomicrographs 1 and 2.

Thin sections of the Keskarrah basalts show small (about 1 mm) inclusions of quartzose xenoliths with altered reaction rims. These xenoliths indicate crustal contamination. An example is shown in Photomicrograph 2.

Geochemistry of Keskarrah Basalts

The geochemistry of the Keskarrah basalts is summarized in Table 4. Samples of the Keskarrah basalts (Unit 2b) are represented by geochemical samples 9, 10, 20, 21 and 29, and 38 to 42. In general, the igneous rocks which intrude the Keskarrah Formation are sub-alkalic. The alumina, potassium and sodium contents in the Keskarrah basalts are high, as compared to the Unit 4 basalts, and silica content ranges from about 51.3 wt.% to about 59.5 wt.%. Iron content in the Keskarrah basalts, calculated as 100% Fe_2O_3, ranges from 8% to

Table 4. Geochemistry of the Keskarrah Basalts.

Sample No.:	9	10	20	21	29	38	39	40	41	42
Outcrop No.:	OC902	OC383	OC705	OC907	OC901	SS1	BOS2	SS-RI	SS-CP	SS HIK
SiO2	55.5	56.15	59.49	54.31	55.12	57.59	52.48	51.25	51.93	51.7
TiO2	0.86	0.91	1.42	0.61	0.85	1.39	1.40	1.40	1.91	1.41
Al2O3	16.92	16.74	14.45	17.83	17.10	18.96	20.15	17.29	13.85	14.97
Fe2O3	8.00	10.84	13.03	8.32	7.94	6.82	6.37	14.82	16.59	10.02
MnO	0.10	0.13	0.18	0.12	0.10	nr	nr	nr	nr	nr
MgO	5.14	3.09	1.45	6.44	5.19	6.14	5.52	8.05	4.86	7.19
CaO	7.31	7.42	5.48	9.87	7.43	5.34	4.3	3.99	6.46	10.58
Na2O	2.51	3.52	2.69	2.38	2.51	3.32	6.34	3.05	3.78	2.13
K2O	1.07	1.08	1.68	0.17	1.11	0.31	3.31	0.03	0.45	1.93
P2O5	0.25	0.17	0.41	0.13	0.25	0.13	0.11	0.12	0.18	0.12
LOI	2.76	0.005	0.005	0.52	2.7	nr	nr	nr	nr	nr
TOTAL	100.59	100.10	100.36	100.76	100.46	100.00	99.98	100	100.01	100.05
BaO	1081	161	590	106	1146	nr	nr	nr	nr	nr
Cr2O3	164	138	40	202	170	nr	nr	nr	nr	nr
Nb	7	11	22	9	7	20	nr	10	10	30
Ni	121	90	17	161	98	140	130	nr	nr	nr
Pb	7	11	12	10	<5	<5	nr	nr	nr	nr
Rb	13	29	59	9	14	<5	nr	nr	nr	nr
Sr	1134	191	268	260	1112	80	nr	50	100	310
Th	<5	6	<5	8	<5	<5	nr	nr	nr	nr
U	11	6	<5	8	7	<5	nr	nr	nr	nr
V	137	138	87	116	142	nr	nr	nr	nr	nr
Y	9	23	47	15	10	10	nr	20	10	10
Zr	143	159	497	99	142	60	nr	60	100	70

NOTES

1.) Major oxides reported as wt%. Trace elements reported as ppm. nr = not reported.

2.) All iron calculated as Fe2O3.

3.) Samples 38 to 42 were reported by St. Seymour et al. (1988).

16.6%, and Al_2O_3 content ranges from 13.9% to 20.2%.

St. Seymour et al. (1988) reported the occurrence of a wide range of basalt types in the Point Lake area. These basalt types include high- and low-K tholeiites, andesitic basalts, basaltic andesites and mugearite. The occurrence of mugearites in the Point Lake area was first reported by Bostock (1980), but mugearite (sensu Gill, 1981) was not encountered during the course of the present study. In the present work, the metabasalts at Point Lake are classified into two main types (Unit 2a and Unit 4c). As indicated by outcrop locations, all but one of the samples analyzed by St. Seymour et al. represented samples of rocks which are interpreted in the present study as Keskarrah basalts.

Sample 20 was collected by C. Isachsen from a small island in the North Arm; the exact field location of this sample is uncertain. Sample 20 is tentatively included here as a sample of Unit 4 on the basis of its reported map location, although the iron content is higher and alumina content is significantly lower than in the other samples from this unit. Alternatively, Sample 20 may represent part of a mafic intrusion into the gneissic basement, which would explain its apparently anomalous chemistry in comparison to the samples of Unit 4.

GROUP II: GREENSTONE BELT

An assemblage of metamorphosed fine-grained sedimentary rocks and an assemblage of metamorphosed mafic and minor ultramafic igneous rocks lie to the east of the gneissic basement. These two assemblages are strongly deformed and appear to be collectively allochthonous over the basement complex. The term "greenstone", as used in this thesis, refers to the allochthonous metamorphosed ultramafic and mafic rocks. The greenstones do not include the amphibolites which intrude the basement complex, nor do they include the Keskarrah conglomerate or metabasalts. The term "greenstone belt" is used here to denote the collective assemblage comprising both greenstone and metasedimentary rocks, consistent with the definition of Windley (1984). The metasedimentary rocks of the greenstone belt are included in the Contwoyto Formation (Bostock, 1980). Earlier workers have, for various reasons which will be discussed in Chapter 5, classified the Keskarrah Formation as part of the greenstone belt. However, the present study does not indicate an affinity between the Keskarrah Formation and the greenstone belt.

Four major units comprise the greenstone belt: a suite of ultramafic and mafic rocks (Units 3 and 4), and two units of strongly deformed and presumably allochthonous metasedimentary rocks (Units 5 and 6). At Point Lake, the greenstone belt is separated from the gneissic basement by a major mylonite zone and from the Keskarrah formation by thrusts. The mylonite complex (Unit 7) comprises highly deformed elements from both the basement complex and the greenstone belt which together can be mapped as a unit; in the present work the mylonite is regarded as part of the greenstone belt.

SUBGROUP IIA: GREENSTONE

Units 3 and 4 comprise an igneous stratigraphic succession in which ultramafic rocks are overlain by metamorphosed (possibly eucritic) gabbro and diabase, which in turn grade upward into metamorphosed tholeiitic pillow basalt. Gradational changes in both texture and composition at their contacts suggest a common origin for the ultramafic and mafic rocks of units 3 and 4. Most of the exposed rocks in this group have been metamorphosed to greenschist or amphibolite facies, and collectively comprise the greenstone for which the belt is named.

The ultramafic and mafic rocks show a fairly ubiquitous pervasive cleavage which strikes approximately north-south in the center of the peninsula, and northeast-southwest near the north arm, parallel to the upper and lower contacts. In places, a second cleavage is oriented in a northeast to southwest direction. The rocks are also in most places dissected by a dense network of irregular fractures. These and other geologic structures are discussed in more detail in

Chapter 4.

Along major and minor faults that cut the metamorphosed ultramafic and mafic rocks, greenstones are accompanied by milky-white recrystallized calcite, rusty- colored ankerite, and minor clasts of a pink and gray fine-grained siliceous rock in an extensively and irregularly fractured matrix. The siliceous rock has been identified by some previous workers as "chert". The carbonate is highly deformed, making it impossible to determine the original relationship between the calcite (possibly carbonates) and the mafic rock types. The "chert" is hard, very fine grained and silicic, but was not examined in thin section; it may be similar in petrography and origin to the high-grade metagraywacke (Unit 6a) described below. The carbonate melange is interpreted as evidence for tectonic transport of the greenstone along major thrusts.

Unit 3: Ultramafics

Ultramafic rocks lie immediately above fault contacts that separate the greenstone belt from the granitoid gneisses, and occupy a position that is interpreted as representing the lowermost observed unit of an igneous stratigraphic succession. Field observations by this author and by Kusky (1991) suggest that the ultramafic rocks are part of a petrographically layered series of coevally formed rocks. The original thickness of the ultramafic unit is unknown. The observed structural thickness is about 15 m or less at each outcrop at which it has been mapped.

The ultramafic rocks consist of a medium-green chloritized two-pyroxene gabbro (websterite), and its higher-grade metamorphic equivalent, a light green talc-tremolite schist. Kusky (1991) and Bostock (1980) report serpentinized dunites and harzburgites within the unit designated here as Unit 3. However, no olivine-rich ultramafic rocks were encountered in the Point Lake area during the present investigation.

The Unit 3 ultramafic rocks are exposed on the western side of the large peninsula extending into North Arm (see the geologic map, Plate 1), at the western (basal) contact of the mylonite complex with the basement on both shores of the south arm, and at an outlier to the greenstone belt located approximately 2 km south of the mapping area. Small exposures of possibly ultramafic rocks also occur as pods within the mylonite complex. At one outcrop, a tectonic breccia containing angular clasts of chert, limestone and basalt in a talc-tremolite matrix was found at the basal contact of the ultramafic unit.

Petrography of Unit 3 Ultramafics

Ultramafic rocks occur as strongly foliated pyroxenitic tremolite schists and as websteritic gabbro from which the tremolite schists were probably formed (e.g., Winkler, 1979). Rocks from Unit 3 are composed predominantly of pyroxene and tremolite or tremolite and talc. Olivine and serpentine are conspicuously absent from samples of this unit.

Photomicrographs 3 and 4 show two examples of tremolite schist representative of Unit 3. One sample was collected from a shear zone near the south arm; the other sample was collected from an outcrop on the peninsula in the north arm.

Geochemistry of Unit 3 Ultramafics

Two samples of ultramafic rocks from the study area were analyzed. The ultramafic rocks of Unit 3 are represented by samples 1 and 17 on Table 5. The analyses of Unit 3 show MgO concentrations of 19.6% and 22%, respectively, with corresponding silica contents of 54.9% and 47.2%. The concentrations of TiO_2, Al_2O_3, Fe_2O_3, Na_2O, K_2O and BaO, as well as the concentrations of Nb, Zr, Y and Sr are much lower than the corresponding concentrations of these elements in the other metaigneous rocks from the study area. The Cr_2O_3 content is 909 ppm and 3085 ppm for the two samples; Ni content was 517 ppm and 980 ppm, which is substantially higher than in other metaigneous units.

The petrography and bulk chemistry of the ultramafic rocks of Unit 3 are consistent with the petrology of websterite layers in cumulate igneous rocks (Coleman, 1973; Glennie _et al_., 1974). On the other hand, the chemistry of these rocks is not especially consistent with the chemistry of cumulates associated with flood basalts or continental rifts,

Table 5. Geochemistry of Point Lake Ultramafic Rocks.

Sample No.:	1	17
Outcrop No.:	OC427	OC264
SiO2	54.85	47.19
TiO2	0.14	0.35
Al2O3	2.62	6.97
Fe2O3	8.78	10.85
MnO	0.27	0.21
MgO	19.63	22.03
CaO	12.00	8.32
Na2O	0.03	0.005
K2O	0.17	0.005
P2O5	0.05	0.03
LOI	1.7	4.69
TOTAL	100.4	101.05
BaO	94	5
Cr2O3	909	3085
Nb	<5	5
Ni	517	980
Pb	<5	<5
Rb	9	5
Sr	18	21
Th	8	<5
U	<5	<5
V	75	129
Y	5	5
Zr	44	41

NOTES
1.) Major oxides as wt% Trace elements as ppm.
2.) All iron calculated as Fe2O3.
3.) nr = not reported
4.) Samples 38 to 42 were reported by St. Seymour et al. (1988).

where Ti and Mg-rich mafic rocks are not common (e.g., Barker, 1983).

Unit 4: Greenstone

Unit 4 comprises the predominantly chlorite grade metabasites for which the greenstone belt is named. Three members of Unit 4 are identified in the present work: Unit 4a (metagabbro); Unit 4b (metadiabase); and Unit 4c (metabasalt). Gabbro (Unit 4a) and diabase (Unit 4b) lie above ultramafic rocks (in both gradational and fault contacts), above basement gneiss (fault contact) and above metasedimentary rocks (fault contact). The gabbro and diabase of Units 4a and 4b are characterized by a distinct dark-greenish color. Rock samples of this unit typically contain abundant chlorite, and display pervasive cleavage. A possible relict amphibolitic L-fabric observed both in the field and in thin section suggests that the chlorite grade metamorphism may be retrograde. Structural relationships and the chlorite-grade metamorphism make Unit 4 readily distinguishable from the late mafic intrusives (Mackenzie diabase) of Unit 9.

The textures and compositions observed in samples of Unit 4 are extremely variable. The compositionally layered base of the Unit (Kusky, 1991) includes websterite and anorthosite, and probably reflects the affinity of Unit 4a to Unit 3.

On the peninsula that extends from the north shore into the north arm, an outcrop of diabase (Unit 4b) is exposed.

Diabase at this outcrop appears to grade downward into underlying gabbro (Unit 4a) and upward into overlying basalt (Unit 4c). Although it is highly deformed, this diabase shows vestiges of abundant chilled margins within the unit, which may therefore be a remnant of a sheeted dike complex. A sheeted diabase dike complex is reported by Kusky (1991) as occurring on the south shore of the lake. The intercalation of diabase between the gabbro and the pillow basalt suggests that the diabase dikes are rooted in the underlying gabbro and in turn feed the overlying basalt pillows.

Unit 4c consists of a dark-green to nearly black, aphanitic to plagioclase-phyric, pervasively deformed tholeiitic metabasalt. Metabasalt comprises approximately 95% of the surface exposure of the greenstone in the mapping area. The basalts occur both as massive flows and as vesicular pillow basalts, in approximately equal proportion. The true vertical thickness of Unit 4c is estimated at 1000 m to 2000 m (see Plate 1, geologic map and cross section). Metamorphic grade in the basalts is variable; chlorite grade metamorphism appears to be the most common. Amphibolite facies metamorphism is also exhibited in this unit, but higher metamorphic grades appear to be restricted to the vicinity of major faults and shear zones. The basalts of Unit 4c show pervasive cleavage, and faint traces of a linear fabric can be seen on the cleavage planes. This lineation may represent either a relict amphibole mineral lineation or a crenulation lineation: attempts to determine the origin of this lineation by thin section study were frustrated by the degree of deformation in the rock. In either case, early events were to some extent overprinted by later deformation. Unit 4 metabasalts are dissected by a dense network of faults and irregular fractures. Most of these faults and fractures are filled with calcite or calcite with minor ankerite.

A way-up indicator - used with caution - is the shape of pillows in the mafic volcanics. Where large groups of pillows have pairs of concave and convex selvages consistently oriented in the same direction, the convex side is taken to point roughly in the up direction. This feature develops as younger pillows drape over older pillows.

Petrography of Unit 4 Metabasites

Textures and compositions of Unit 4 are highly variable. The more highly metamorphosed samples of the gabbro-diabase unit are composed of chlorite, sericitized calcic plagioclase, and quartz. Thin section observation does not indicate whether the protolith was quartz modal or olivine modal. Most gabbro and diabase samples studied contain abundant chlorite, with sericite inclusions in the altered feldspars. A highly altered rusty-brown mineral found in some samples altering to chlorite, may be relict iddingsite representing an earlier alteration of magnesian olivine. Examples of Unit 4a gabbro are shown in Photomicrographs 5-7.

Petrography of Unit 4c Metabasalt

The metabasalts of Unit 4c are composed predominantly of calcic plagioclase and clinopyroxene, with minor quartz, or olivine and hypersthene as minor components, and minor opaque minerals. Grain size typically ranges from .25 mm to .5 mm. Where quartz occurs with chlorite in this unit, it may be primary, but is probably metamorphic (Winkler, 1979). In most samples, quartz, epidote, chlorite and sericite have replaced most of the original minerals (e.g., Photomicrograph 8). Examples of the greenstone metabasalt are shown in Photomicrographs 8, 9 and 10.

A comparison of Unit 4c with Unit 2b shows differences in petrography and texture that support the field distinction of the two units. The Unit 4c metabasalts do not include the small quartzose xenoliths that were observed in thin sections of the Keskarrah basalts.

Geochemistry of Unit 4

Table 6 presents the analytical results for ten samples of greenstone from the Point Lake area. Nine of the samples presented in Table 6 were collected and analyzed for the present work. The analysis and field location of Sample 43 were presented by St. Seymour et al. (1988) and are interpreted here as representing metabasalt of Unit 4c.

Analytical results for samples of the metagabbro and metadiabase members (samples 24 and 37) are presented in Table

Table 6. Geochemistry of Point Lake Greenstone.

Sample No.:	5	6	7	12	18	23	24	34	37	43
Outcrop No.:	OC316	OC523	OC383	OC818	OC365	OC487b	OC457a	OC268	OC620	55-17
SiO2	50.30	50.33	52.47	49.94	49.75	55.81	48.16	46.44	45.16	50.21
TiO2	2.61	1.98	1.32	0.80	2.95	0.98	3.34	0.81	4.12	1.09
Al2O3	14.25	13.35	14.48	14.32	12.35	13.50	12.22	13.84	12.40	14.91
Fe2O3	15.89	17.01	13.72	14.69	16.02	14.04	19.45	13.97	21.83	12.69
MnO	0.22	0.23	0.16	0.19	0.20	0.20	0.24	0.20	0.27	nr
MgO	4.20	4.47	5.77	7.50	5.98	5.86	4.69	8.90	5.58	6.94
CaO	9.13	7.70	8.52	9.02	9.27	5.09	9.03	10.96	9.64	12.98
Na2O	2.25	2.28	2.15	2.16	2.25	1.76	2.04	2.10	1.79	1.03
K2O	1.05	1.18	0.66	0.22	0.64	1.70	0.89	0.26	0.20	0.05
P2O5	0.40	0.37	0.32	0.08	0.28	0.09	0.58	0.08	0.18	0.10
LOI	0.44	1.02	1.17	1.50	0.77	1.81	0.08	3.38	0.36	nr
TOTAL	100.80	100.03	100.82	100.48	100.56	100.92	100.82	101.02	101.63	100.00
BaO	237	700	337	117	168	280	314	90	180	nr
Cr2O3	99	106	237	270	155	206	119	153	51	nr
Nb	20	13	13	6	13	7	26	8	17	10
Ni	73	44	71	94	91	111	57	73	39	nr
Pb	<5	<5	13	<5	6	14	<5	<5	13	nr
Rb	41	31	19	8	23	73	36	16	11	nr
Sr	218	252	220	150	419	174	232	110	178	110
Th	<5	5	5	<5	<5	5	<5	<5	<5	nr
U	<5	<5	<5	<5	5	<5	<5	6	<5	nr
V	328	290	189	215	420	229	448	411	659	nr
Y	49	35	29	14	28	20	54	23	25	10
Zr	237	254	210	66	182	115	284	71	143	110

NOTES
1.) Major oxides reported as wt% Trace elements reported as ppm. nr = not reported
2.) All iron calculated as Fe2O3.
3.) Sample 43 reported by St. Seymour et al. (1988); Samples 24 and 37 represent fine-grained gabbro (Unit 4c)
5.) Samples 24 and 37 represent fine-grained gabbro (Unit 4b)

6 along with the other greenstone samples. The average SiO_2 content in the metagabbro samples was 49.3%. The samples of unit 4 contained average concentrations of 17.5% and 13.4% for Fe_2O_3 and Al_2O_3, respectively. Geochemical samples 6 and 7 are slightly quartz normative. A sample of Unit 4c metagabbro (# 37), from an island in the north arm, is olivine normative.

Silica content in the greenstone ranges from 45.2 % to 55.8 wt.%. Alumina content ranges from 12.2% to 14.9% in the greenstone. Iron content, calculated as Fe_2O_3, ranges from 12.7% to 19.5%.

Major element chemistry of the greenstone metabasalts is generally consistent with the chemistry of tholeiites, including MORB's, in terms of silica saturation and major oxides content. However, the Unit 4c metabasalts do not readily fit into traditional basalt classifications described in the literature (see, for example, Brownlow, 1979; Best, 1982; Wilson, 1989; and references cited therein). In comparison to sea-floor basalts, the greenstone metabasalts (Unit 4c) contain high iron and potassium contents, and low sodium contents. However, comparison of the Unit 4c metabasalts to calc-alkaline rocks and "unusual" basalt types such as the high-Fe basalts associated with the Abitibi belt in the Superior Province yield even greater discrepancies. The difficulties of interpreting the tectonic origin of basalts on the basis of geochemistry are discussed in Chapter 5.

Unit 5 and Unit 6: Contwoyto Formation

The name "Contwoyto Formation" was given by Bostock (1980) to a unit comprised predominantly of metamorphosed graywacke turbidites. The Contwoyto Formation is named after an Innuit word meaning "place where the rum is given"; its type location is near Itchen Lake a few tens of kilometers to the north of Point Lake. The formation includes metamorphosed shales, graywackes, carbonates, sandstones, tuffs, and iron formation. This unit includes all of the metamorphosed sedimentary rocks in the study area, except for the Keskarrah conglomerate (Unit 2a). It is proposed that the designation Contwoyto Formation be expanded to include Unit 6, as well as Unit 5. Thus, the Contwoyto Formation, as redefined for the Point Lake area, contains three members: a basal shaley unit (Unit 5a); an upper graywacke member (Unit 5b); and a structurally isolated member comprised of possible granulite facies metasedimentary rock (Unit 6), which may be a metamorphic product of the graywacke member.

A generalized stratigraphic column representing the Contwoyto Formation is shown in Figure 15. The structural complexity of the area and the scarcity of large outcrops in key areas precludes a detailed stratigraphic interpretation; however, some important general trends were observed. The contact between the shaley member and the graywacke member of the Contwoyto, for example, shows pervasive strike-parallel cleavage, and might arguably be interpreted as a fault

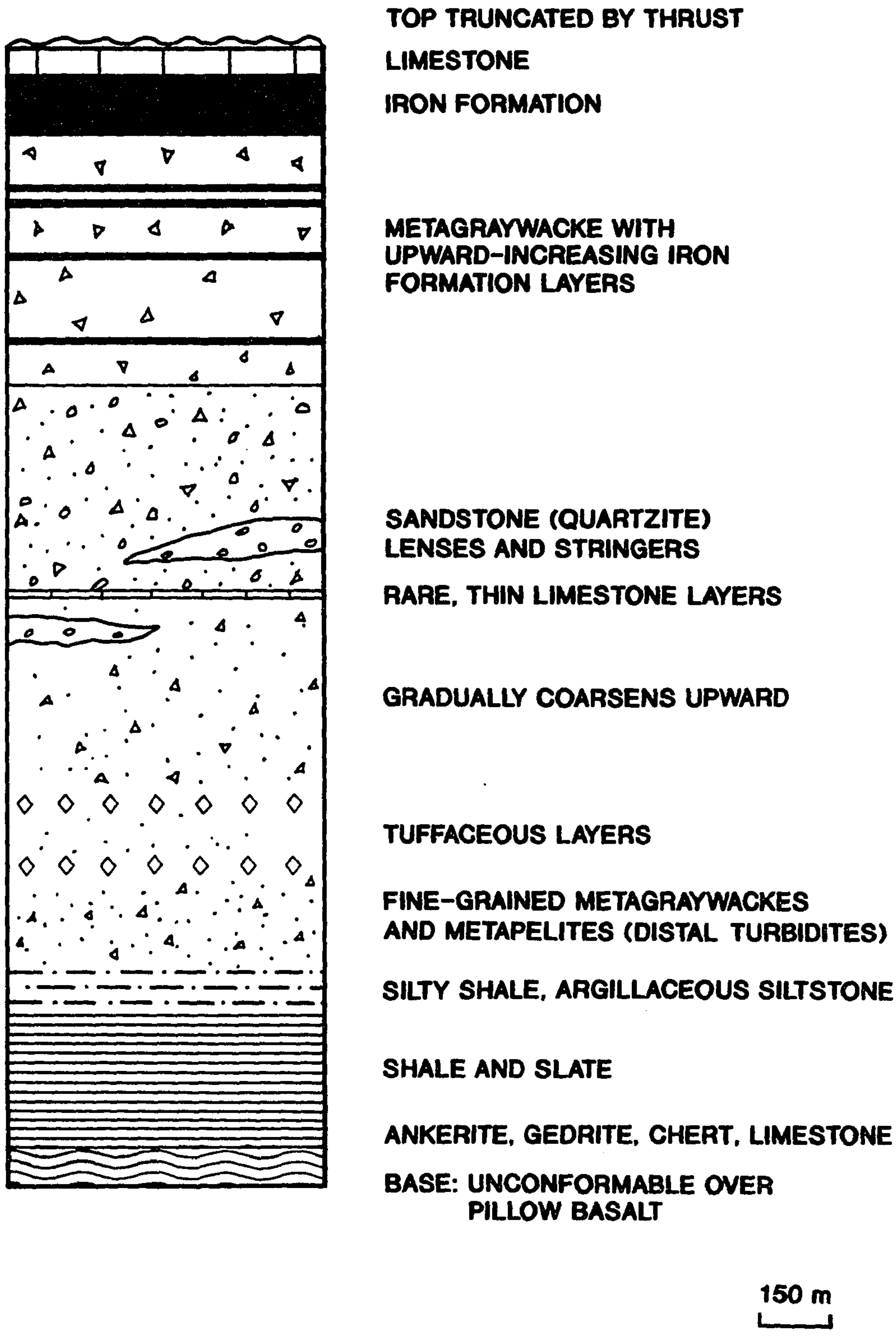


Figure 15. Generalized Stratigraphy of the Contwoyto Formation.

contact. Much of the metagraywacke has a uniform appearance throughout the study area. The discernible differences recognized in the field are attributable to metamorphism more often than to stratigraphy. Within the metasedimentary rocks, large isoclinal folds with smaller parasitic folds at several scales were mapped near the shores of the north arm. These folds indicate the complexity of the deformation to which the unit has been subjected. In other locations, presence of folds is inferred only by reversals in the inferred younging direction of the metasediments. Many other folds and faults presumably lie covered, so that structural repetition of stratigraphic sections is difficult to recognize. However, in contrast, large isoclinal folds are absent or unrecognizable in the greenstone.

Younging direction is indicated at only a few places in the study area. At most outcrops of Contwoyto Formation, the rocks are intensively deformed, making younging direction difficult to interpret. At a handful of outcrops, way up indicators such as graded bedding, cross bedding, flame structures and ripple marks indicate a younging direction to the east. Thin sections of some samples show cross bedding not apparent in hand specimen; some of these microscopic cross sets are deformed (see discussion of "sedimentary crenulations", below).

The sequence of Contwoyto Formation exposed in the western part of the study area is very similar to that exposed in the eastern part. Way-up indicators indicate younging predominantly to the east in both cases, except for the area in the west, adjacent to the mylonite zone. In the western part of the map area, metasedimentary rocks are isoclinally and nearly vertically folded, but way up indicators show younging to be predominantly to the west. The asymmetry of way up indicators may indicate fold vergence during early stages of deformation. The two belts of metasedimentary rocks (see map on Plate 1) are interpreted in this work as representing two separate thrust slices of the same unit, with the eastern exposure containing a more complete section. The western exposure is considered to be equivalent to the lower part of the sequence seen in the eastern exposure.

Sedimentary Crenulations

Kusky (1989) has pointed out that some so called cleavage traces are actually vestiges of different features which had undergone the same deformation event. An excellent example of such a feature are the "sedimentary crenulations" or "sed crens" of Kusky and DePaor (1988), in which transposed minutely layered cross beds in psammitic layers in graywacke have been incorrectly identified as relict cleavage traces from earlier deformation. In Figure 16 an example of this feature is shown. At outcrop or in hand specimen, a faint planar feature can be seen which is seemingly discordant with the main cleavage fabric. In thin section, depositional

Figure 16. Sedimentary Crenulations in the Contwoyto Formation.
Field of view is approximately 3mm x 5mm.

features such as graded bedding and cross bedding become more apparent.

Unit 5a: Metapelites

Unit 5a is a sequence of shaley, slaty and phylonnitic metasedimentary rocks that lies in apparently depositional contact over the metabasalts of Unit 4. The shales and slates are black, brown, red and purple. At exposures near faults, outcrops of Unit 5a show a phyllitic sheen. The grain size in this unit is uniformly very fine, except in the top 5 m interval of the sequence, where shales begin to grade into graywackes of Unit 5b. Near this contact, the shaly unit grades from shales to mudstones and fine siltstones with an increasing abundance of fine pebbles.

At some outcrops, good slaty cleavage striking approximately north-south is encountered, but in most places the rock is highly and multiply deformed, so that attempts at sampling for purposes of structural reorientation yield only handfuls of fine flakes. The higher metamorphic grades within this unit were observed in the field to be coincident with proximity to major faults.

Unit 5b: Metamorphosed Graywacke Turbidites

A graywacke unit (5b) is interpreted as lying stratigraphically and probably conformably over the shaley metasedimentary unit. Unit 5b consists predominantly of metamorphosed, thinly bedded and graded to massive graywacke turbidites. The unit grades upward (?) into iron formation, quartzite, and carbonate. A zircon grain from the graywacke at Point Lake has been dated at 2.7 Ga in age (Shärer and Allégre, 1982). The graywacke turbidites of Unit 5 also contain thin (10 cm to 5 m) discontinuous lenses of quartzite. These quartzite lenses are interpreted as representing the remnants of sandstone-filled channels which fed the turbidite deposits.

The structural complexity of the study area and the stratigraphic monotony of the graywacke preclude a detailed stratigraphy within the graywacke unit. The graywacke turbidites contain deformed quartz and feldspar grains in a fine quartz-rich pelitic matrix. The unit also contains tuffaceous layers containing bipyramidal grains of clear quartz, indicating at least a partial origin from a volcanic source.

About 10 m of iron formation lies conformably over the graywacke. The iron formation member is composed of quartz and magnetite with minor chlorite. The iron formation is dark-gray, weathers rust-brown, and shows cross-bedded laminations. Where they are strongly deformed, the iron-rich beds in the Contwoyto Formation typically show cross bedded lamination only in thin section. In the Point Lake area, the iron formation is not visibly banded with chert on the macroscopic scale, but thin sections show alternating 1 mm thick quartz-rich layers and iron-rich layers. It should be noted that cross-bedded laminae are generally not associated with Archean iron formations. The concentration of magnetite is high enough to create a strong magnetic field, hindering precision in structural measurements made using a Brunton compass.

Lying conformably over the iron member is about 5 m of light gray massive marmotized carbonate, which also represents the top of the observed stratigraphic succession. This carbonate lies immediately beneath a major fault which separates Unit 5 from Unit 6.

The presence of chlorite, biotite, sillimanite, cordierite and muscovite in different samples of this unit suggests variable grades of metamorphism for the Contwoyto Formation in the mapping area. The distribution of metamorphic isograds is considered to be related to distance from both the major faults and Mackenzie Dikes.

Petrography of Unit 5 Metasedimentary Rocks

Thin sections of Unit 5a metapelites show a uniformly very fine texture with rare small pebbles of quartzose rocks, and therefore do not offer much petrographic information. A few thin sections showed a reverse metamorphic grading, in which pelitic layers display coarser textures than adjacent psammitic layers. The matrix is presumably composed of altered phyllosillicate minerals. Because of the very fine grain size and the degree of metamorphism, it is probably impossible to determine the depositional provenance (with regard to tectonic setting) of this unit.

Thin sections of the metagraywacke (Unit 5b) indicate a variable composition and variable metamorphic assemblages for this unit. The most common assemblage includes quartz, alkali and plagioclase feldspars, pale green chlorite, and opaque minerals. The opaque minerals are predominantly magnetite. Examples are shown in Photomicrographs 11-13. Metamorphic grade in the graywacke unit varies from chlorite and muscovite up through sillimanite grade. The mapping of metamorphic isograds was not possible at the scale of the mapping area; however, some contact metamorphism near the Mackenzie dikes was observed.

Samples of Unit 5 taken from the top of the stratigraphic succession show an upward increasing magnetite content. An example of this member is presented in Photomicrograph 14. The iron-rich layers are characterized by thin (1 mm) laminae of quartz and chlorite interlayered with magnetite.

<u>Geochemistry of Unit 5 Metasedimentary Rocks</u>

Geochemical samples 2, 4, 34, and 35 were collected from outcrops of metagraywacke. Analytical results from XRF analysis are presented in Table 7. Silica content in Unit 5 ranges from 65.7% to 70.7%. The bulk chemistry and normative analysis of the rocks of this unit are very similar to that of

Table 7. Geochemistry of the Contwoyto Formation at Point Lake.

Sample No.:	2	4	34	35	27	28	30
Outcrop No.:	OC302	OC473	OC316	OC221	OC503	OC500	OC501
	Low Grade Metasedimentary Rocks				High Grade Rocks		
SiO2	68.14	65.75	66.97	70.73	70.93	71.65	70.45
TiO2	0.63	0.62	0.58	0.48	0.12	0.12	0.33
Al2O3	12.67	14.06	11.87	12.77	11.31	11.38	12.45
Fe2O3	11.53	8.51	14.12	10.31	8.84	7.79	8.68
MnO	0.09	0.06	0.18	0.09	0.09	0.12	0.1
MgO	2.2	2.48	2.59	1.72	0.03	0.08	0.99
CaO	0.86	1.99	2.9	1.49	0.26	0.2	1.35
Na2O	0.97	3.5	0.55	1.41	0.1	0.1	2.98
K2O	2.44	1.43	1.31	2.3	9.03	8.81	3.29
P2O5	0.07	0.07	0.08	0.07	0.05	0.04	0.12
LOI	0.76	1.03	0.005	0.005	0.005	0.005	0.005
TOTAL	100.46	99.62	100.41	101.07	100.84	100.38	100.56
BaO	590	400	231	458	811	872	661
Cr2O3	215	321	186	154	32	21	59
Nb	11	10	12	12	24	20	27
Ni	97	145	98	88	31	22	52
Pb	21	16	55	20	14	15	12
Rb	79	34	69	75	125	124	75
Sr	90	359	59	113	41	36	115
Th	22	15	26	18	10	12	12
U	<5	8	7	<5	<5	<5	5
V	107	134	102	83	24	12	15
Y	17	16	22	14	65	47	59
Zr	189	156	187	162	216	191	508

NOTES
1.) Major oxides reported as wt% Trace elements reported as ppm.
2.) All iron calculated as Fe2O3.
3.) nr = not reported
4.) Samples 38 to 42 were reported by St. Seymour et al. (1988).

rhyolite, with an enrichment in incompatible elements.

Unit 6: High-Grade Metagraywackes

High-grade metagraywackes, possibly of the granulite facies, crop out in two adjacent fault-bounded massifs at the eastern end of the study area. The rocks at these exposures are interpreted as the high-grade metamorphic equivalent of the graywacke turbidites of Unit 5. Possible granulite facies metamorphism, partly overprinted by retrograde amphibolite facies metamorphism, is suggested by a mineral assemblage that includes garnet, enstatite, potassium feldspar and riebeckite, and by the fine-grained equigranular texture of the rock. The texture of Unit 6a is similar to the texture described by de Wit (1986) for cherts in the Barberton greenstone belt. A photograph of a sample of this unit is presented in Figure 17. Unit 6 is subdivided in this work into three informally designated subunits proposed here on the basis of differences in color and texture, which are recognizable in the field.

An elongate 3 sq km massif of granulite breccia of Unit 6a crops out on the south shore of the north arm of the lake. Rocks exposed at this outcrop show a breccia-like texture in which pink, highly silicic clasts are contained in a gray, more mafic matrix. Hand specimens of this unit are microcrystalline and very hard, and resemble chert.

An adjacent massif (Unit 6b) to the immediate east is composed of a uniform dark gray, very fine-grained, hard

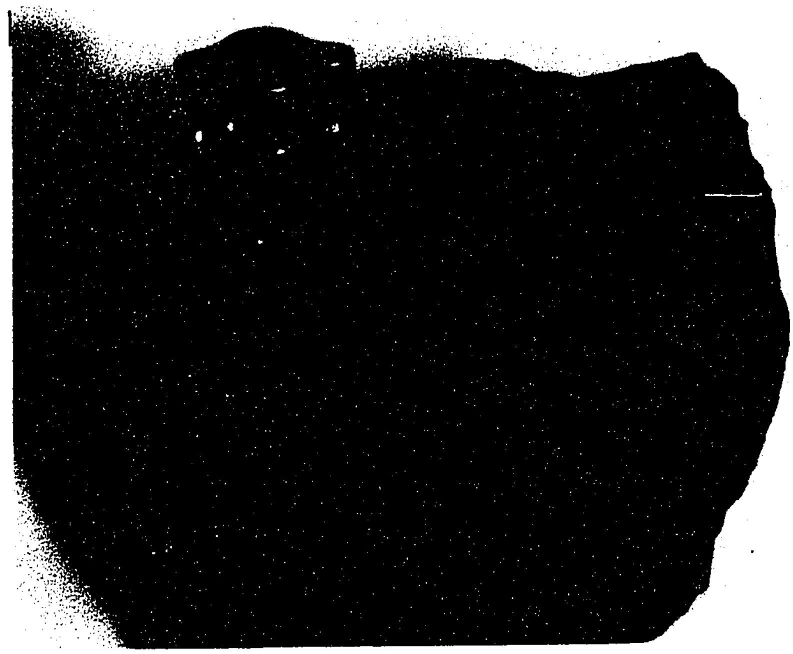


Figure 17. Texture of High-Grade Metagraywacke (Unit 6). Hand specimen taken from south shore of North Arm. For detail, see Photomicrographs 15-18.

silicic rock. Rocks designated here as Unit 6b had been mapped as dacite on previous maps (e.g., Jackson, 1985; Henderson, 1988). This rock type appears to be identical to the dark clasts included in samples of Unit 6a.

Type 6c appears on the north shore of the north arm directly across the lake from the other outcrops, and is composed of a fine grained hard silicic pink rock which appears to be very similar in lithology to the pink clasts contained in unit 6a.

Petrography of Unit 6

The pink clasts in the breccia have a composition of up to 95% quartz, with minor (2% to 3%) magnetite. The metamorphic assemblage of the unit includes enstatite (1-2%), garnet (1%), amphibole (about 10%), alkali feldspar (<5%) and riebeckite (10%), as well as abundant (60% to 95%, and averaging 70%) quartz. Some samples of this unit have a large magnetite content. The enstatite is usually only recognizable in relict form, where cleavage planes remain visible in altered grains. Identification of enstatite in thin section is supported by XRD analysis. Rocks of Unit 6 show the very fine-grained equigranular texture which is characteristic of granulites (Winkler, 1975). Although the very fine grain size in samples of this unit precludes microscopic distinction between quartz and feldspar, normative analysis provides a reasonable means of estimating their proportion.

Analysis by X-ray diffraction indicates the presence of microcline. The assemblage of quartz, alkali feldspar, enstatite and garnet, along with the fine equigranular texture, suggest that Unit 6 may be a granulite formed by the high grade metamorphism of a metasedimentary protolith. On the other hand, the relatively high K_2O content and Rb/Sr ratio (>1), and the presence of presence of hydrous amphibole are considered highly unusual for granulite. The presence of riebeckite and possible magnetite indicate that the rock originated from a sedimentary protolith. Kerr (1977) and Best (1982) report the occurrence of riebeckite in a wide range of metamorphic grades in rocks associated with iron formations. The exposure of Unit 6 lies adjacent to the iron member of the Contwoyto Formation. In Chapter 6, geochemical data are presented that indicate strong similarities between the graywacke and the granulite.

Unit 7: Mylonite Complex

A mylonite zone with a width ranging from approximately 400 m to over 1000 m separates granitoid gneiss basement from the greenstone belt. This unit was described on earlier maps as a mafic tuff (Henderson, 1981; Jackson, 1984), and later as mafic mylonite (Jackson, 1985; Kusky, 1989). However, more detailed field mapping and petrographic study indicate that the zone incorporates rocks of several rock types that share a similar style of deformation. Rock types identified within the mylonite complex include felsic gneiss and mylonite; mafic mylonite and amphibolitized basalt with minor mylonitized ultramafics; and strongly deformed metasedimentary rocks (mylonite, phyllonite, pseudotachylite, slate). In some places, the mylonite zone is composed of a braided network of mylonite interwoven with metabasalts. The metabasalts occur as pillows, which appear similar to those of the greenstone belt (Unit 4). Thin section petrography indicates that in other places, the protolith is alternately a metasedimentary rock (Units 5a and 5b), and felsic rock derived from basement gneisses (Unit 1). It appears, therefore, that the mylonite complex represents a zone of highly deformed rocks in which sections of rocks from both the basement and the greenstone belt were mixed during a major tectonic event. The mylonite zone is treated here as a single mappable unit with three subdivisions (Units 7a, 7b and 7c) based on the predominant protolith (basaltic, metasedimentary, and granitoid).

Along its western edge, the mylonite is in a very sharp, steeply dipping contact with the gneissic basement (Figure 18). The eastern contact of the mylonite zone separates the mylonite from overlying metasedimentary rocks.

Petrography of Unit 7 Mylonite

Grain size in the mylonite is generally very fine, and identification of individual grains under the petrographic microscope is therefore generally not possible. In some thin

Figure 18. Contact Between Mylonite and Gneiss. Photograph taken near the middle of the Central Peninsula, facing north.

sections however, amphibolite-grade deformation is indicated by polygonized quartz-feldspar fabrics, recrystallized biotite- and hornblende-rich layers and quartz ribbons. Some thin sections show relict amphibole in a chlorite-rich matrix, indicating retrograde metamorphism (Simpson, 1985). Identification of mylonite protoliths was generally made in the field, on the basis of color and structural relationships, and by the presence of lenses or pods of less-deformed rock.

Quartz and green chlorite are common in mylonite derived from both mafic and sedimentary protoliths. Examples of the mylonite are shown in Photomicrographs 19 and 20.

A sample of mylonite from the south shore was composed almost entirely of a pale gray mineral with anomalous blue-gray birefringence. This mineral was interpreted to be a magnesian chlorite, and may represent an alteration of the pyroxenitic member of Unit 3. Photomicrograph 5 shows a schist composed largely of magnesium chlorite, which may have been the protolith to the above described rock.

Geochemistry of Unit 7 Mafic Mylonite

Four samples of mafic mylonite (Unit 7) were analyzed. The analytical results are presented in Table 8. The geochemistry of the mylonite is unlike that observed in the other mafic rocks. In general, the Al_2O_3, MgO, Cr_2O_3, Ni, K_2O and Na_2O content of the mylonites were much higher than in the lower grade metabasites.

Table 8. Geochemistry of Point Lake Mafic Mylonites.

SiO2	50.24	45.3	47.18	45.69
TiO2	0.75	1.09	0.32	1.09
Al2O3	12.13	16.00	17.23	16.23
Fe2O3	12.85	16.63	10.44	16.52
MnO	0.21	0.24	0.15	0.24
MgO	10.61	8.56	11.23	7.97
CaO	8.43	9.89	9.91	9.95
Na2O	2.37	2.04	2.03	2.06
K2O	0.40	0.18	0.21	0.27
P2O5	0.04	0.08	0.03	0.09
LOI	2.1	0.96	2.45	0.97
TOTAL	100.21	101.1	101.31	101.17
BaO	122	114	143	100
Cr2O3	465	423	664	365
Nb	6	9	8	8
Ni	142	245	380	145
Pb	<5	<5	<5	<5
Rb	14	11	13	13
Sr	56	127	228	127
Th	<5	<5	<5	<5
U	<5	<5	<5	<5
V	232	289	106	276
Y	13	20	<5	20
Zr	60	82	49	82

NOTES
1.) Major oxides reported as wt%. Trace elements reported as ppm.
2.) All iron calculated as Fe2O3.
3.) nr = not reported
4.) Samples 38 to 42 were reported by St. Seymour et al. (1988).

GROUP III: YOUNGER INTRUSIVES

Two types of post-kinematic intrusive rocks crop out in the study area. It is clear from field observations that both of these rock types intruded the greenstone belt and the older gneisses subsequent to the deformation associated with the emplacement of the greenstone belt. The late intrusives are represented by Units 8 and 9.

Unit 8: Younger Granitoid Rocks

Two undeformed intrusions of granitoid rocks crop out in the study area. A granitoid composed of quartz and plagioclase with minor muscovite and opaque minerals crops out near the shore of the north arm. The intrusion on the north arm contains 1- to 2- cubic meter sized xenoliths of deformed metabasalt (Unit 4c).

A similar intrusion occurs at the southern shore of the south arm of Point Lake, where a pink to white granitic rock crops out. At the outcrop on the south arm, the granite appears to be undeformed, and it clearly crosscuts the mylonite/Contwoyto Formation contact near the western end of the mapping area. The granitic intrusions are considered to postdate the emplacement of the greenstone belt. Further, the late granitoids are considered to be similar in age to intrusions into the greenstone belt in the vicinity of Yellowknife; those granitoids have been dated at 2.56 Ga to 2.62 Ga (Frith et al., 1977; Easton, 1985a; Henderson and van

Breemen, 1987; van Breemen and Henderson, 1988).

Petrography of Unit 8 Late Felsic Intrusives

Only one sample of Unit 8 was examined in thin section. The sample was collected from the exposure on the north arm, and contained subequal amounts of quartz and plagioclase, and minor (5% to 10% each) components of alkali feldspar, muscovite and mafic minerals. The alkali feldspars show both microcline twinning and pericline twinning. The plagioclase was determined by the Michel-Levy method to be in the bytownite-labradorite range. The sample showed some sericitization of the feldspars and some "wavy" quartz, but otherwise no significant metamorphism was observed in this rock type.

Unit 9: Mackenzie Diabase Dikes

Dikes of coarse grained, undeformed diabase intrude both the greenstone belt and underlying basement units throughout the map area. On the basis of a general similarity in petrography, geographical distribution and orientation, the undeformed dikes are interpreted as equivalent to the Mackenzie Diabase dikes described by Fahrig and Jones (1969); Baragar (1977); Hoffman (1980), Fahrig and West (1986), Gibson et al. (1987) and LeChaminant and Heaman, 1990. The Mackenzie dikes comprise one of six major groups of Proterozoic intrusions that crop out in widely distributed locations throughout the Northwest Territories. The group of Proterozoic dikes includes the following:

- Mackay dikes (2400 Ma);
- Dogrib dikes (2200 Ma);
- Indin dikes (2200 Ma);
- Hern dikes (2000 Ma);
- Contwoyto dikes (1790 Ma); and
- Mackenzie dikes (1220 Ma).

In the field, the Mackenzie Diabase is readily distinguishable from the greenstone of Unit 4c by its color, its lack of metamorphism and by its intrusive relationship to the other rock units. The mineralogy of this unit includes calcic plagioclase, clinopyroxene, unidentified opaque minerals, and in some samples, either minor quartz or minor olivine. The Mackenzie Dikes are surprisingly fresh, and lack the pervasive metamorphic cleavage and foliation seen ubiquitously in Archean metabasalts. The unit is distinguished in the field from metabasites of Unit 4 by its bright reddish color on weathered surfaces, its dark gray color on fresh surfaces, and its lack of deformation. In the Point Lake area, the dikes of Mackenzie diabase occur most commonly along NNW-SSE striking faults. Some earlier maps of the area (e.g., Kusky, 1990, Figure 9) include generalizations that may inadvertantly suggest that the dikes predate some deformation at Point Lake. S[illegible] of the dikes were traced continuously and undeformed across major faults; in no case were Mackenzie dikes observed to be cut by faults.

The origin of these dikes has been attributed to minor, but widespread, extension accompanying the Wopmay Orogen of Proterozoic age, or alternatively to widespread extensional stresses associated with a broad region of continental stabilization (Baragar, 1977). More recently, Hoffman (1989, 1990) attributed the origin of the dikes to short-lived episodes of post-orogenic crustal melting associated with the development of an anomalous low-temperature shallow mantle root beneath the Canadian shield.

Petrography of Mackenzie Diabase

The mineralogy of the Mackenzie dikes includes calcic plagioclase, clinopyroxene, and in some samples, either minor quartz or olivine. Considering its age (approximately 1.9 Ga), the Mackenzie Diabase appears astonishingly fresh. A photomicrograph of a sample of Mackenzie Diabase is presented in Photomicrograph 21.

Geochemistry of Mackenzie Diabase

Five samples of the Mackenzie Diabase were analyzed. Geochemical samples No. 3, 13, 14, 15 and 18 on Table 9 represent the Mackenzie Diabase. The samples of this unit have a tholeiitic composition (based on classifications discussed by Irvine and Baragar, 1977 and Brownlow, 1979).

Table 9. Geochemistry of Mackenzie Diabase from Point Lake.

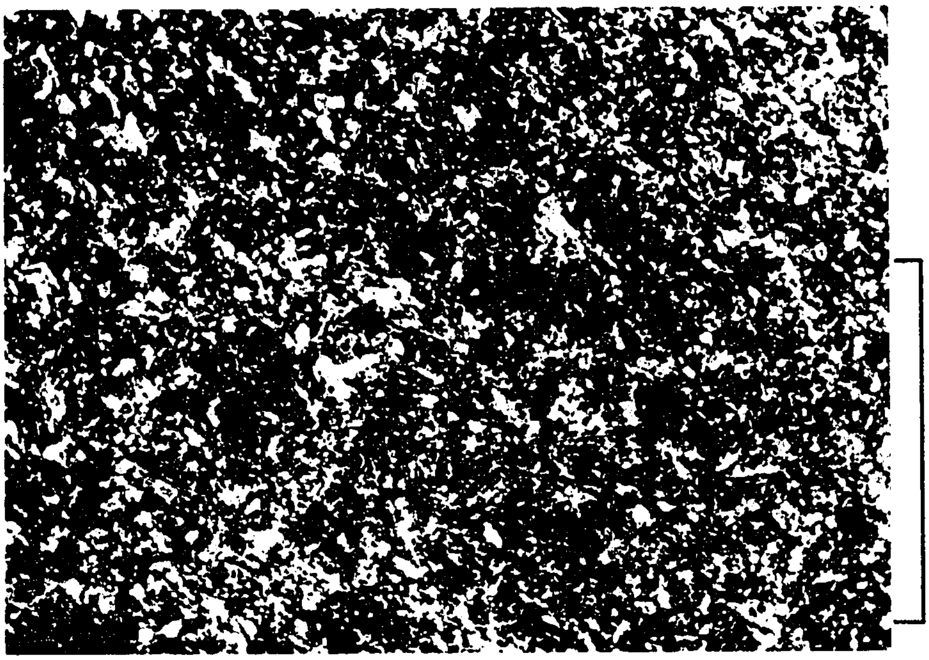
Sample No.:	3	13	14	15	18
Outcrop No.:	OC459	OC566	OC366	OC303	OC220
SiO2	51.10	48.06	49.75	48.29	48.09
TiO2	3.18	3.31	2.95	3.39	3.35
Al2O3	11.88	12.07	12.35	12.08	12.13
Fe2O3	19.65	19.67	16.02	19.28	18.75
MnO	0.25	0.24	0.20	0.24	0.24
MgO	4.74	5.35	5.98	5.49	5.75
CaO	7.68	9.66	9.27	9.86	9.85
Na2O	1.32	1.80	2.25	1.75	1.82
K2O	0.42	0.61	0.64	0.53	0.46
P2O5	0.16	0.52	0.28	0.35	0.32
LOI	0.005	0.005	0.77	0.005	0.005
TOTAL	100.45	101.39	100.56	101.37	100.87
BaO	162	246	168	252	169
Cr2O3	89	147	155	172	176
Nb	12	23	13	17	15
Ni	73	76	91	68	87
Pb	28	<5	6	<5	7
Rb	19	22	23	18	18
Sr	146	223	419	216	196
Th	<5	<5	<5	<5	6
U	<5	<5	5	<5	<5
V	501	482	420	576	601
Y	23	53	28	46	43
Zr	147	273	182	218	204

NOTES
1.) Major oxides reported as wt% Trace elements reported as ppm.
2.) All iron calculated as Fe2O3.
3.) nr = not reported
4.) Samples 38 to 42 were reported by St. Seymour et al. (1988).

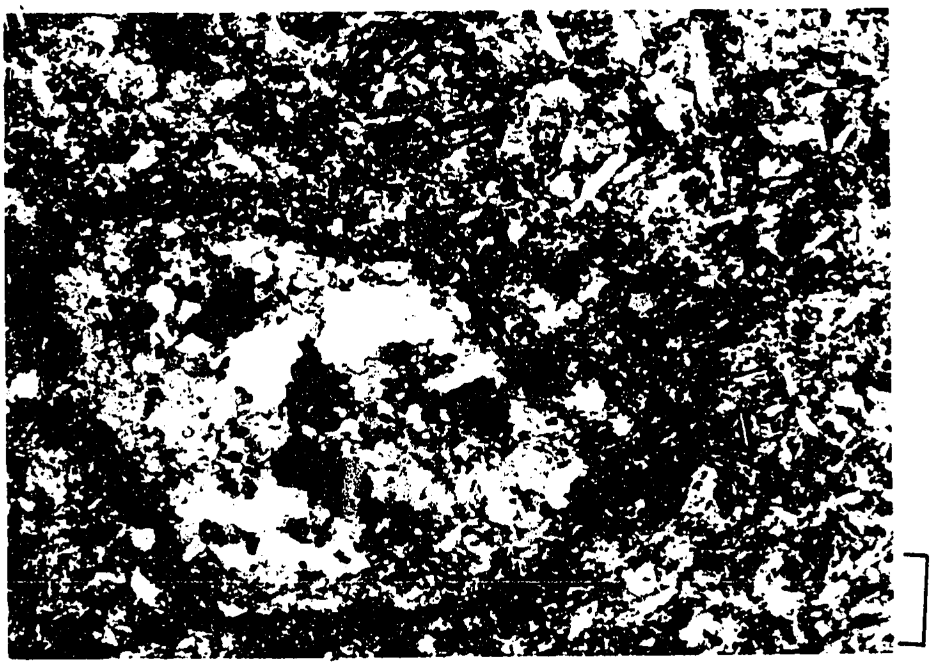
The bulk chemistry and normative analysis (Table 10) indicate a tholeiitic composition, like that of the greenstone. Chemically, the diabase is not distinguishable from the greenstone metabasalt (Unit 4) in terms of Ti, Na, K or other major elements; and there is no significant difference in the distribution of trace elements between the two lithologic types. The range of chemical variation is significantly less in the Mackenzie Diabase than in the other metaigneous units.

Photomicrograph No. 1: Keskarrah Metabasalt (Unit 2b). Typical texture and mineralogy of the Keskarrah metabasalt. Shown through crossed polars; scale bar is approximately 1 mm in length.

Photomicrograph No. 2: Keskarrah Metabasalt (Unit 2b). Typical xenolith in the Keskarrah metabasalt. Note the sericitized feldspar, opaque mineral and reaction rim. These inclusions are generally irregular in shape, without preferential orientation with respect to cleavage. Shown through crossed polars; scale bar is approximately 100 μm.



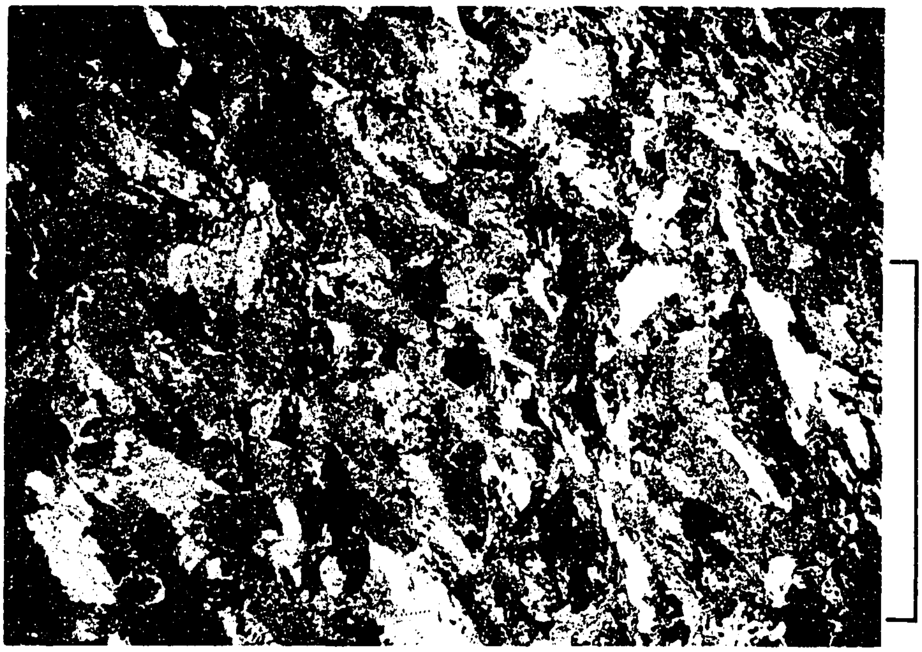
Photomicrograph No. 1



Photomicrograph No. 2

Photomicrograph No. 3: Talc-Tremolite Schist (Unit 3). Sample collected on the north shore of South Arm. Shown through crossed polars; scale bar is approximately 1 mm in length.

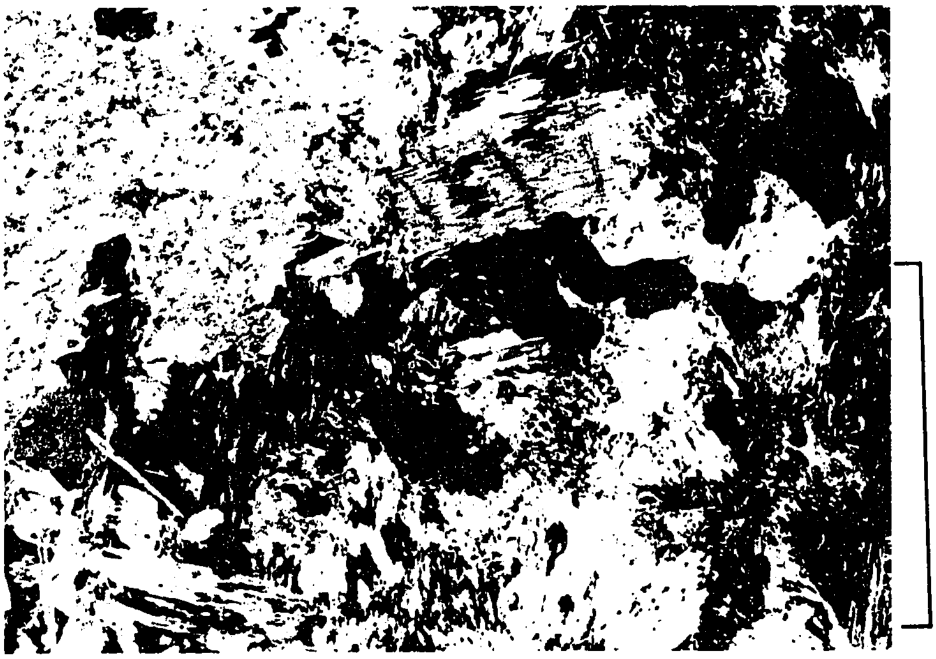
Photomicrograph No. 4: Talc-Tremolite Schist (Unit 3). Sample collected on peninsula in North Arm. Shown through crossed polars; scale bar is approximately 1 mm in length.


Photomicrograph No. 3


Photomicrograph No. 4

Photomicrograph No. 5: Metagabbro (Unit 4a). Altered Mg-chlorite and enststite in a sample from the peninsula in North Arm. This assemblage was typically seen in samples collected near contacts with ultramafic rocks or mylonite. Shown through crossed polars; scale bar is approximately 1 mm in length.

Photomicrograph No. 6: Metagabbro (Unit 4a). Pyroxene, plagioclase, chlorite and opaque minerals in altered gabbro. Compare to Photomicrographs 5 and 21. Shown through crossed polars; scale bar is approximately 1 mm in length.

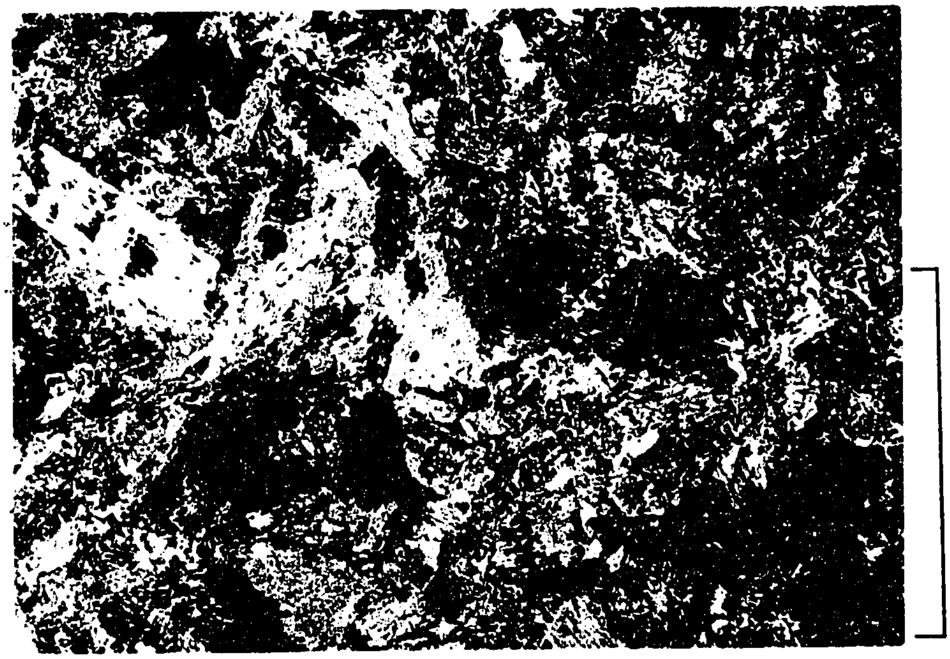


Photomicrograph No. 5

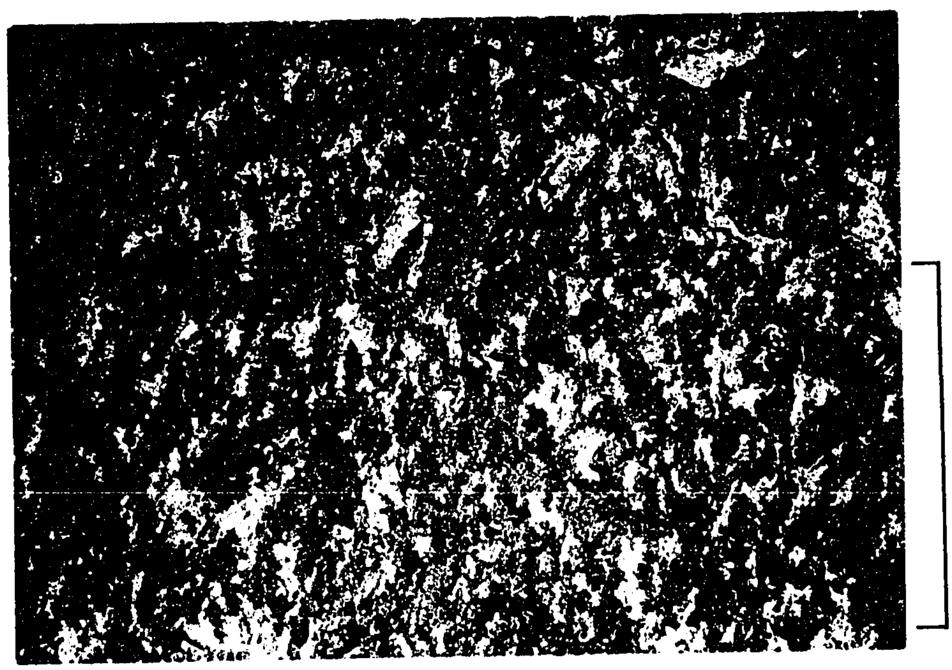
Photomicrograph No. 6

Photomicrograph No. 7: Metagabbro (Unit 4a). Highly altered gabbro from south shore of South Arm. Shown through crossed polars; scale bar is approximately 1 mm in length.

Photomicrograph No. 8: Metabasalt (Unit 4c). Greenstone metabasalt composed predominantly of quartz, chlorite and opaque minerals. Sample collected on the central peninsula. Texture and mineralogy are typical of this unit; compare to Photomicrographs 1 and 2. Shown through plane light; scale bar is approximately 250 μm in length.



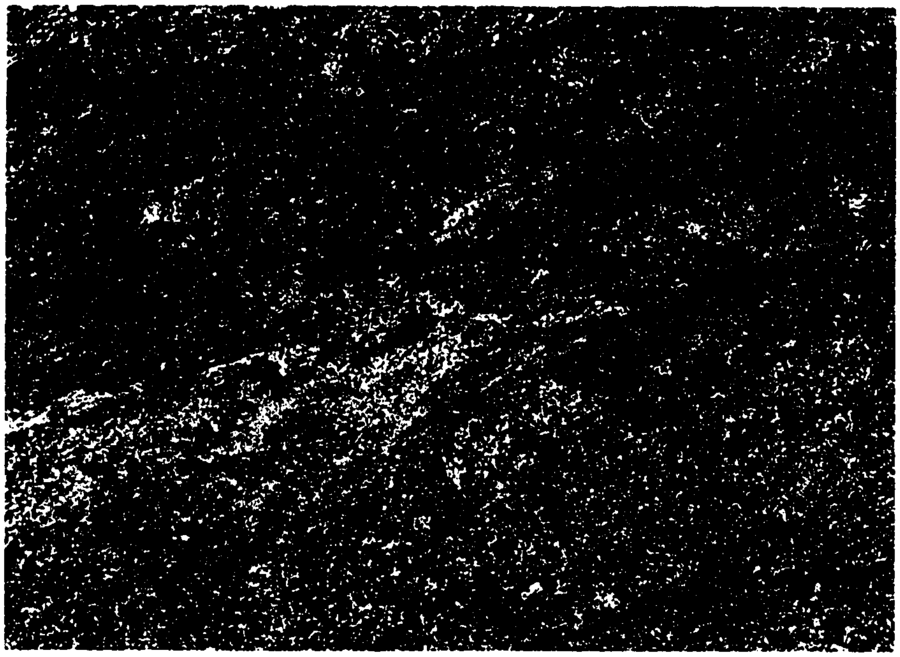
Photomicrograph No. 7



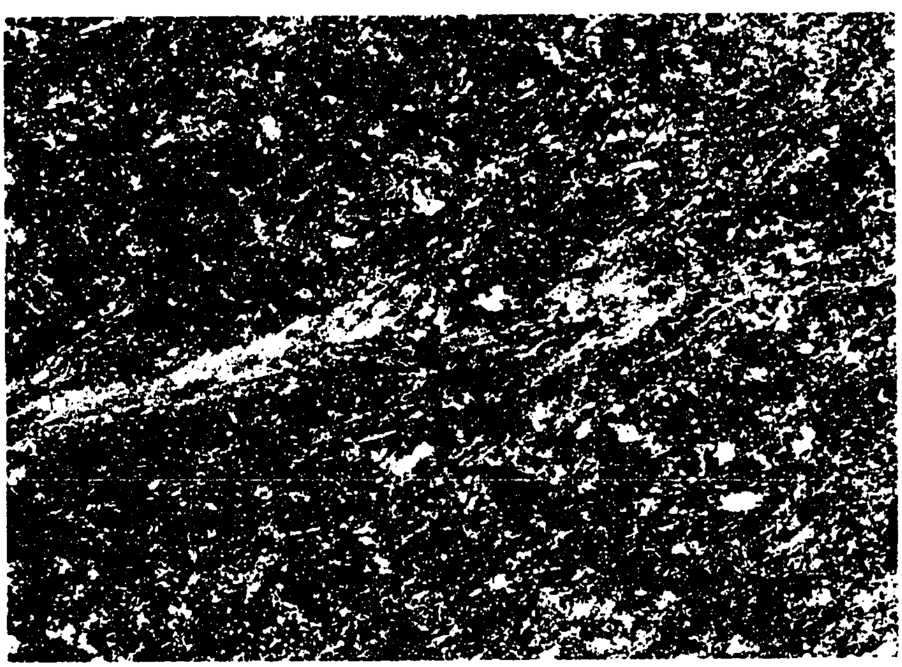
Photomicrograph No. 8

Photomicrograph No. 9: Metabasalt (Unit 4c). Typical mineralogy and texture of greenstone metabasalt. Shown through plane light; Scale bar is approximately 1 mm in length.

Photomicrograph No. 10: Metabasalt (Unit 4c). Same sample as shown in Photomicrograph 9; thin section shown through crossed polars.



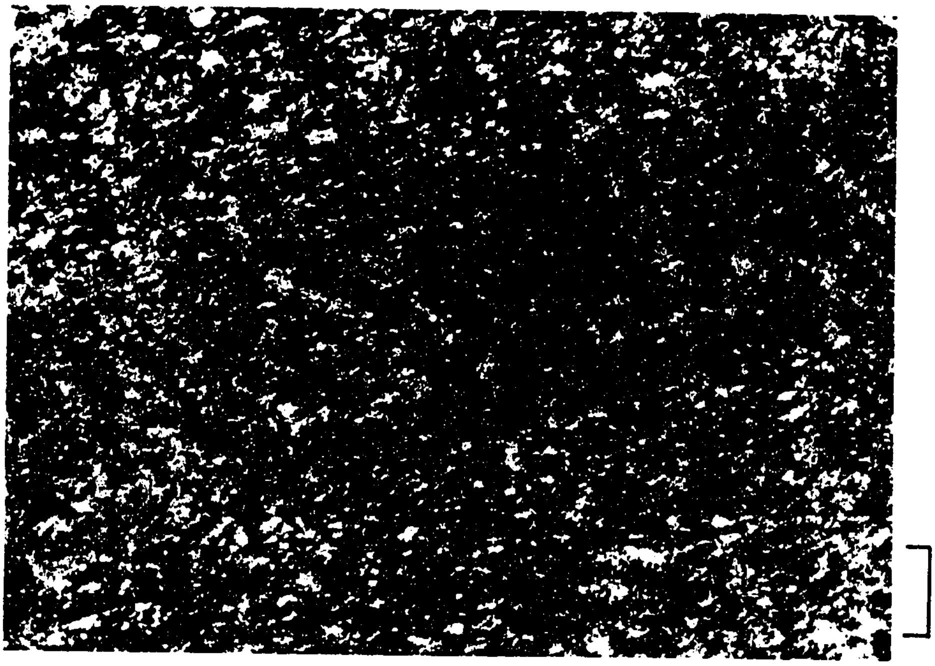
Photomicrograph No. 9



Photomicrograph No. 10

Photomicrograph No. 11: Shaley Member, Unit 5a. Section shows fine psammitic layers (black and white) and altered pelitic layers (tan). Shown through crossed polars; scale bar is approximately 100 μm in length.

Photomicrograph No. 12: Metagraywacke (Unit 5b). Note presence of sillimanite needles apparent in quartzite band. Shown through crossed polars; scale bar is approximately 1 mm.



Photomicrograph No. 11

Photomicrograph No. 12

Photomicrograph No. 13: Metagraywacke (Unit 5b). Pink mineral near center of section is biotite. The milled texture on the right side suggests incipient mylonitization. Shown through crossed polars; scale bar is approximately 1 mm in length.

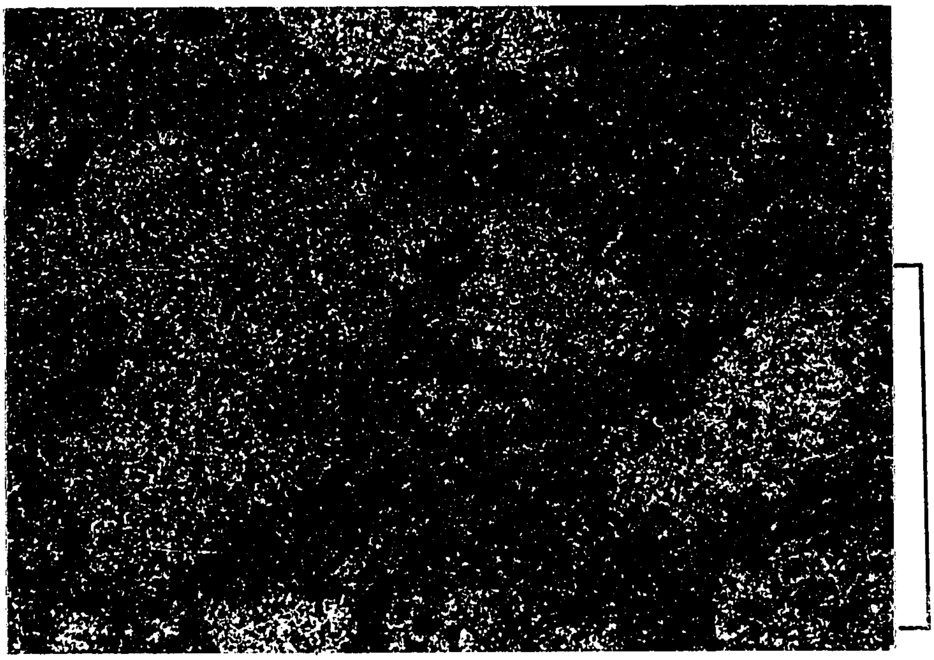
Photomicrograph No. 14: Iron Formation (Unit 5b). Alternating laminae consist of quartz + chlorite and magnetite. Shown through crossed polars; scale bar is approximately 1 mm in length.

Photomicrograph No. 13

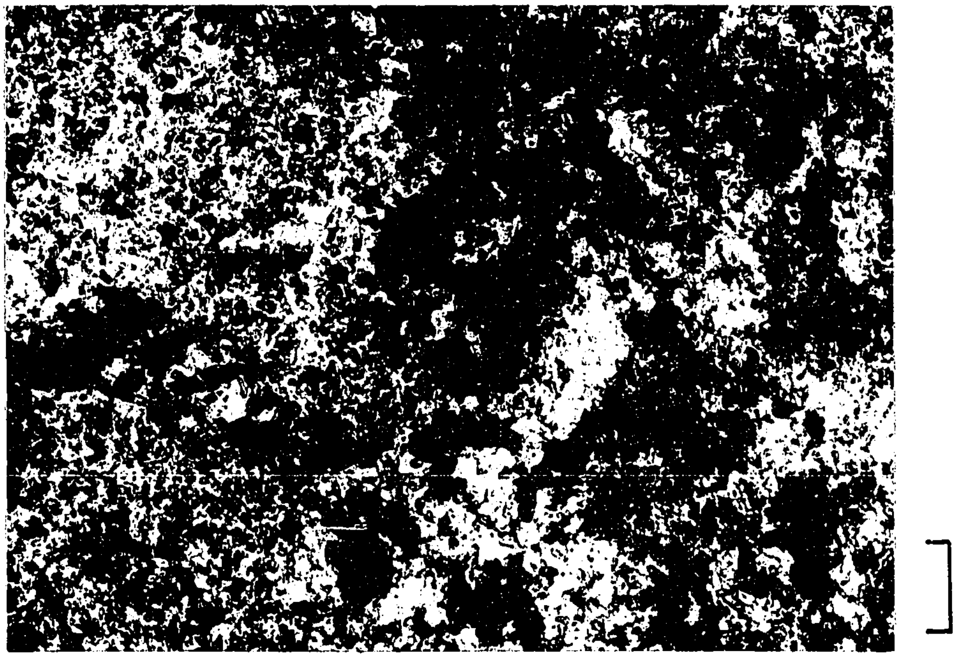
Photomicrograph No. 14

Photomicrograph No. 15: High Grade Metagraywacke (Unit 6). Section shows quart-rich clasts in a darker matrix. Shown through plane light; scale bar is approximately 1 mm in length.

Photomicrograph No. 16: High Grade Metagraywacke (Unit 6). Assemblage includes quartz, amphibolė, riebeckite (blue mineral) and garnet (isotropic mineral with brown fringes). Shown through crossed polars; scale bar is approximately 1 mm in length.



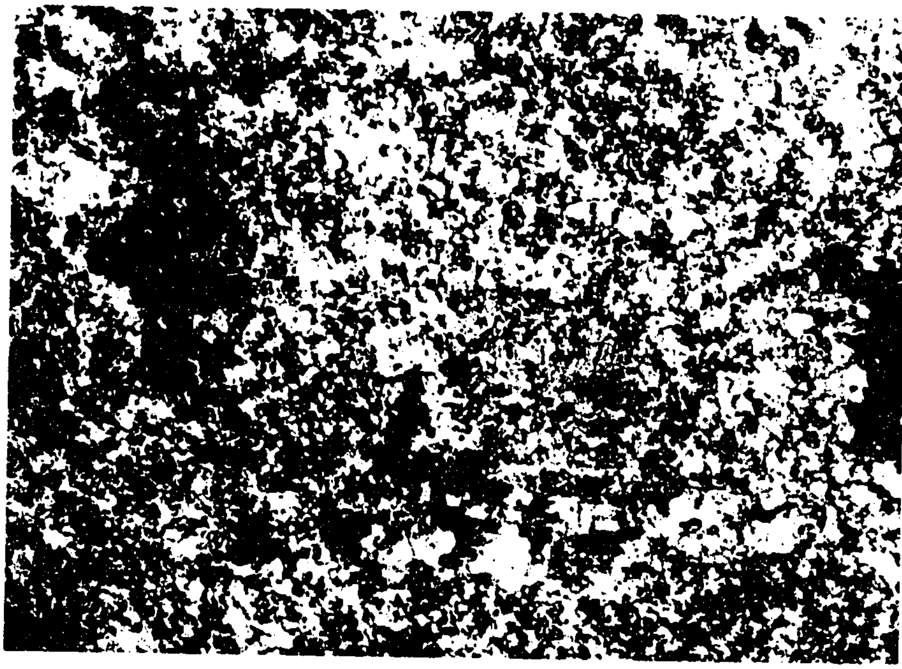
Photomicrograph No. 15



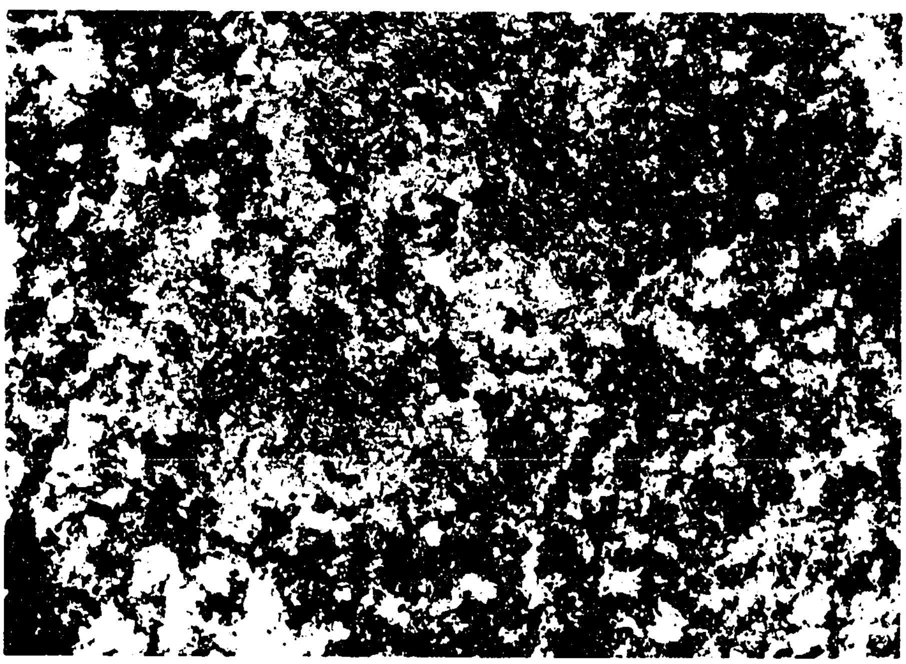
Photomicrograph No. 16

Photomicrograph No. 17: High Grade Metagraywacke (Unit 6). Quartz-rich variety with garnet and relict enstatite. Shown through crossed polars; scale bar is approximately 1 mm in length.

Photomicrograph No. 18: High Grade Metagraywacke (Unit 6). Section shown in Photomicrograph No. 17 with enlargement of relict enstatite. Shown through crossed polars; scale bar is approximately 100 μm in length.



Photomicrograph No. 17



Photomicrograph No. 18

Photomicrograph No. 19: Mylonite (Unit 7b). Mylonitized metagraywacke shown through plane light. Scale bar is approximately 1 mm in length.

Photomicrograph No. 20: Mylonite (Unit 7b). Mylonitized basalt shown through plane light. Scale bar is approximately 100 μm in length.

Photomicrograph No. 19

Photomicrograph No. 20

Photomicrograph No. 21: Mackenzie Diabase (Unit 9). Fresh diabase shown through crossed polars; scale bar is approximately 1 mm in length.

Photomicrograph No. 21

Table 10. C.I.P.W. Norms for Point Lake Rocks.

Sample I.D.	22	25	1	17	5	6	7	12	16	23	24	36	37
Rock Unit No.	1	1	3	3	4	4	4	4	4	4	4	4	4
AN	64.5	58.6	96.3	99.8	57.4	54.1	60.5	61.1	53.3	61.6	55.5	60.8	62.5
Quartz	0.0	0.0	4.7	0.0	3.5	3.4	6.0	0.4	2.6	11.2	2.0	0.0	0.0
Orthoclase	1.1	0.8	1.0	0.0	6.2	7.0	3.9	1.3	3.8	10.1	5.3	1.5	1.2
Albite	16.3	19.5	0.3	0.0	19.0	19.3	18.2	18.3	19.0	14.9	17.3	17.8	15.2
Anorthite	29.5	27.5	6.5	19.0	25.7	22.7	27.9	28.7	21.7	23.9	21.6	27.6	25.2
Diopside	20.8	19.2	42.0	17.6	14.4	11.1	10.2	12.9	18.7	0.6	16.5	21.6	18.1
Enstatite	24.1	25.7	41.8	41.8	22.2	27.1	27.1	32.4	24.1	33.2	26.2	6.9	24.8
Olivine	2.8	2.3	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.4	3.8
Magnetite	3.2	3.0	1.9	2.4	3.5	3.7	3.0	3.2	3.5	3.1	4.2	3.0	4.7
Ilmenite	2.1	1.9	0.3	0.7	5.0	3.8	2.5	1.5	5.6	1.9	6.3	1.5	7.8
Apatite	0.2	0.2	0.1	0.1	0.9	0.9	0.7	0.2	0.7	0.2	1.3	0.2	0.4

Sample I.D.	9	10	20	21	29	35	27	30	18
Rock Unit No.	2	2	2	2	2	5	6	6	9
AN	59.9	47.3	49.6	65.0	60.2	36.8	53.2	19.0	60.4
Quartz	10.1	7.0	17.5	6.7	9.4	41.7	29.6	31.0	2.0
Orthoclase	6.3	6.4	9.9	1.0	6.6	13.6	53.4	19.4	2.8
Albite	21.2	29.8	22.8	20.1	21.2	11.9	0.9	25.2	15.4
Anorthite	31.7	26.7	22.4	37.5	32.1	6.9	1.0	5.9	23.5
Diopside	2.4	7.6	1.8	8.7	2.6	0.0	0.0	0.0	19.5
Enstatite	21.9	18.2	19.4	22.9	21.9	18.5	12.7	14.6	26.4
Olivine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Magnetite	1.7	2.4	2.8	1.8	1.7	2.3	1.9	1.9	4.1
Ilmenite	1.6	1.7	2.7	1.2	1.6	0.9	0.2	0.6	6.4
Apatite	0.6	0.4	1.0	0.3	0.6	0.2	0.1	0.3	0.7

CHAPTER 4: GEOLOGIC STRUCTURES

The study area is part of an extensive fold-thrust-and-wrench belt that extends through most of the western Slave Province. The thrusts and the mylonite zone that extend through the Point Lake area continue as part of a deformed belt for some tens of miles in an arcuate pattern extending to the northeast and southeast of the study area. Figure 9 (after Kusky, 1990) shows the eastward continuation of the compressional and shearing structures that are documented by this study for the Point Lake area. These regional structures present evidence for a major collisional event that is believed to have occurred during the Late Archean. This collisional event is in turn interpreted as the setting for the emplacement of the greenstone belt over the gneissic basement.

The general structural style of the greenstone belt is distinct from that of the basement. Major structures in the greenstone belt, including the bounding faults to the east and west, trend roughly north-south and verge steeply westward. Geologic structures observed in the gneissic basement are more complex and diverse than those observed in the greenstone belt. The structures in the basement gneisses reflect stress regimes oriented in a variety of directions, which presumably represent several generations of deformation that in part preceded emplacement of the greenstone belt.

The oldest plutons in the basement generally show the most complex deformation. Some plutons exhibit several generations of folding in the gneissic foliation, and folding of the veins and dikes which intrude the gneisses. The relative age of deformation in the basement is inferred here from the fact that structures in the basement are more complex than and in large part discordant with the structures in the greenstone belt. Granitoids and gneisses lying immediately adjacent to the mylonite zone are foliated parallel to the fabric of the mylonite, showing that earlier deformations in the gneissic basement were overprinted by the deformation that accompanied emplacement of the greenstone belt.

CONTACTS BETWEEN UNITS

Throughout the study area, the greenstone belt is separated from autochthonous gneissic basement by the mylonite zone. The mylonite zone separating the greenstone belt on the east from the basement complex to the west also marks the boundary between two areas of distinct geologic affinities and structural styles.

Although the basement gneisses are in places intruded by highly deformed mafic dikes, it is apparent from the complex deformation in these dikes that the gneissic country rock has undergone a more complex history than, and therefore presumably predates, the greenstone belt. Furthermore, field observations and geochemical studies (Chapter 3) indicate that mafic dikes incorporated in the basement have a different chemistry, and are therefore of a different origin, than metabasalts of the greenstone belt. At no place in the study area can basalts of the greenstone belt be traced to roots in the basement, nor have any sedimentary units other than the conglomerate been deposited directly upon the gneissic basement.

Contacts of the Keskarrah Formation

On the south arm, the Keskarrah conglomerate lies unconformably over the gneissic basement (Figure 13). On the basis of field observations, contacts between the Keskarrah and all units other than the basement gneiss are interpreted in this work as faults. However, it has been reported that the conglomerate may lie unconformably over rocks of the greenstone belt (Hoffman, 1986; Kusky, 1989). This conclusion is based on the examination by Kusky of three outcrops: one on the south shore of the north Arm; one on the south shore of the south Arm (immediately to the west of Cyclops Peninsula); and one on the north shore of the south Arm (east-northeast of Cyclops Peninsula). The author examined each of these areas, and others, to determine the nature of the contact.

Unfortunately, the contacts between the Keskarrah Formation and units other than the basement gneiss are not well exposed. On the shore of the north arm of Point Lake, the contact between conglomerate and structurally underlying graywacke strikes north-south across the central peninsula. The contact is not well exposed. On the south shore of the north arm, the western contact of the Keskarrah Formation lies in a swampy, low-lying area, which suggests, however inconclusively, the presence of a fault. At his location, a critical 10 m of section is not exposed. The outcrop to the immediate west of the contact consists of medium-grained brown metagraywacke with 2-mm clasts of quartzite and altered feldspar. To the immediate east of the contact, a polymict conglomerate with flattened 1 cm to 3 cm clasts in a light-green mud matrix crops out. The conglomerate shows a pervasive cleavage oriented parallel to the plane of flattening. The units on both sides of the contact are strongly deformed. No recognizable unconformity exists at this location. From the dissimilarity between the two units and the suggestion by surface topography, it is inferred that the metagraywacke and the conglomerate are separated by a fault that passes northward across the north arm and through "Tree Bay" (an informally named feature which can easily be recognized on the geologic map by its salient outline).

At the southern side of the central peninsula, the conglomerate is clearly in fault contact with phyllonitized rocks of the Contwoyto Formation.

Conglomerate appears to be alternately conformable over and intruded by basalt at exposures south of the south arm, on and around Cyclops Peninsula. Approximately 1 km west of Cyclops Peninsula, there exists a calcified fault separating two exposures of metabasalt. Unlike many major faults in the Point Lake area, this fault appears as a strong lineation on aerial photographs. The author examined these outcrops in reconnaissance, without recognizing the distinction between basalt types. The two metabasalt types (Unit 4c, greenstone metabasalt and Unit 2b, the Keskarrah basalts) were not differentiated in investigations predating the present study, for it was assumed by earlier workers that they represent a single unit. Therefore, it is not clear whether the basalt at the base of the conglomerate on the south arm belongs to Unit 4c or to Unit 2b. Kusky (pers. commun.) examined outcrops south of Point Lake (outside the map area of this thesis). His interpretation is that these outcrops show a depositional contact between the Keskarrah Formation and underlying metabasalts. Although this interpretation may be correct, like the studies of St. Seymour et al., Jackson, Easton and Henderson, it fails to distinguish Keskarrah basalts (Unit 2b) from greenstone (Units 4b and 4c), and therefore does not indicate the relative age of the conglomerate with respect to emplacement of the greenstone belt.

On the north shore of the south arm, to the northeast of Cyclops Peninsula and north of Keskarrah Bay, conglomerate and metabasalt crop out in adjacent areas. To date, this area has not been mapped in detail. The contact between conglomerate and metabasalt was not encountered during a reconnaissance traverse by the author. However, a strong topographic lineation occurs along the inferred contact.

Consistent with the results of mapping on the central peninsula, the contact between the Keskarrah Formation and the greenstone is interpreted as a fault. In an alternative interpretation, the conglomerate that is exposed on the south arm lies directly over both metamorphosed sedimentary rocks and mafic rocks, which in turn were thrust over gneiss (Hoffman, 1988; Considine and Kusky, 1988; Kusky, 1989 and 1991). Thus, the metasedimentary sequence would have a coarsening-upward pattern, with shales overlain by graywacke, and finally by conglomerate.

The tectonic significance of various interpretations of the relationship between conglomerate, the Keskarrah basalts and other units are discussed further in Chapter 5.

Relationship of the Contwoyto Formation to the Greenstone

Shaley metasedimentary rocks were generally deposited directly upon pillow basalts. However, one outcrop in the west-central part of the study area shows that locally, basalt intruded the slates. Basalt at this outcrop is dark-green to nearly black, consistent with the appearance of the greenstone basalt. Samples of this intrusion were collected and analyzed as part of the geochemical investigations discussed in Chapter 3. The results of the geochemical analysis are consistent with those from other samples of Unit 4 metabasalts. From regional structural associations it appears very unlikely that basalts other than those of Unit 4c had intruded the Contwoyto Formation. Intrusions of tan-colored basalts, andesitic basalts and "mugearite" of the Keskarrah Formation have not been observed in any unit other than the conglomerate.

Relationship of Metapelites to Metagraywacke

The graywacke member of the Contwoyto Formation appears to have been deposited conformably over the shaly member of the Contwoyto. Limited exposure of the contact, in addition to significant deformation of both rock types in the vicinity of the contact, makes interpretation of the contact difficult. However, there was no evidence to suggest that the contact of the metapelites with the overlying metagraywacke is not depositional in nature.

Relationship of Mackenzie Diabase to Other Units

Figure 19 shows a dike of Mackenzie Diabase (Unit 9) intruding tholeiitic metabasalt (Unit 4c). The distinction between the two rock types can be readily made in the field on the basis of color and deformation. Likewise, intrusions of Mackenzie Diabase are found in all other units including the gneissic basement, and are especially common along the faults separating the units.

Relationship of Granodiorite (Unit 8) to the Greenstone

It has been suggested that basalt intrudes the granodiorite on the north shore of the central peninsula (Henderson, 1981; Jackson, 1985); this outcrop had been interpreted (Jackson, 1985) as a window where intruded basement had been exposed as a result of late anticlinal folding. Field observations reveal two important facts. The

Figure 19. Mackenzie Dikes Intruding Greenstone (Unit 4c). Photograph taken on an island in North Arm.

outcrop in question contains 1- to 2 sq km exposures of undeformed granodiorite (Unit 8) containing xenoliths of deformed metamorphosed basalt. The basalt xenoliths clearly represent older, deformed rock in a younger unmetamorphosed rock (the granodiorite). Second, the granodiorite can be clearly seen to intrude metasedimentary and metavolcanic rocks in several areas. These observations indicate that an outcrop hitherto mapped as a window to the basement is actually a late intrusion of a separate unit. This conclusion in turn weakens support for the idea that the "window" is the core of an anticline.

STRUCTURES IN THE MYLONITE ZONE

The mylonite zone varies in width from about 400 m to 1000 m in the map area, and regionally has a width ranging up to two kilometers. The map pattern of the exposure of the mylonite suggests that it may have been subjected to a late north-south directed folding event. This folding is suggested by the gentle sinuous shape in the central part of the peninsula, and especially in the strongly arcuate shape at the north of the central peninsula and on the south shore of the south arm of the lake. In the mylonite zone, the fabric is approximately parallel to the cleavage exhibited in both the mylonite zone and the adjacent metasedimentary and metabasic units. The fabric of the mylonite is in some cases slightly oblique to the trend of the mylonite zone, i.e., to the map pattern of the shear zone in which the mylonite formed. The fabric of the mylonite dips very steeply to the east, with an average dip of about 80° to 85°.

Sense of shear indicators within the mylonite zone include offset of early faults and fractures by late fractures, asymmetric recrystallized rotated porphyroblasts, vergence of parasitic folds, s-c fabrics in felsic bands, and linear features such as mineral lineation. Sense of shear was determined in the field, based on a general familiarity with the concepts of Simpson (1983, 1985); Simpson and Schmidt (1983); Passchier and Simpson (1986) and Poirer (1985).

Rotated porphyroblasts are predominantly of the sigmoidal type (Simpson, 1985), and seem to indicate a minor component of dextral movement along the northern part of the mylonite zone and sinistral movement along the southern part of the mylonite zone in the field area. However, these porphyroblasts are restricted to the felsic mylonite found in northern parts of the study area, and may not give a representative kinematic account of the entire mylonite zone.

Texture within the mylonite zone varies, especially at the southern end of the field area. Bands of dark, dense, very fine grained, very finely laminated mylonite alternate with bands of amphibolitized and flattened pillows of basalt. Within the mylonite complex, rocks of similar affinity which have been strained to different degrees (e.g., mafic mylonite and amphibolitized basalt) are in many places separated by minor faults oriented parallel to the main foliation in the complex.

MAJOR FAULTS

The part of the study area above (east of) the detachment includes at least seven fault-bounded massifs of contrasting lithologies that are interpreted here as thrust slices. These slices overlie thrusts which are designated here as Faults A to H. Table 11 summarizes the footwall and hanging wall units, and the lateral continuity of these thrusts. A generalized map showing the locations of the major faults is presented in Figure 20.

The mylonite zone in the western part of the study area is interpreted (Considine and Kusky, 1988) as a basal detachment (Fault A) that separates the greenstone belt from underlying basement rocks. Along Fault A, highly deformed rocks derived from various protoliths are juxtaposed over the basement gneisses.

Fault B emplaces overturned metasedimentary rocks of the Contwoyto Formation over the mylonite complex. Metagraywacke strata in the vicinity of Fault B appear to be predominantly overturned about an isoclinal fold, the axial plane of which is approximately parallel to the fault. Mylonite derived from a metasedimentary protolith is presentin the vicinity of Fault B; kinematic indicators in the mylonite suggest an east-over-west sense of movement, with varying lateral-shear component.

Table 11. Summary of Major Thrusts.

A	Gneiss	Mylonite complex	Continuous through map area.	Mylonite.
B	Mylonite	Contwoyto Fm.	Continuous through map area.	Bedding in Contwoyto Fm. overturned near fault.
C	Contwoyto Fm.	Greenstone (Units 3 and 4)	Truncated beneath South Arm by Fault D (?)	Metabasalt on South Arm may be core of breached anticline.
D	Contwoyto Fm./ Greenstone	Keskarrah Fm.	Merges with Fault E beneath "Tree Bay".	Fault E is assumed to truncate top of Fault D.
E	Keskarrah Fm.	Contwoyto Fm.	Continuous through map area.	May truncate an unnamed fault beneath Keskarraqh Bay.
F	Contwoyto Fm: Low Grade (Unit 5)	Contwoyto Fm: High Grade (unit 6)	Merges with Fault H on Central Peninsula.	Possible Granulite facies indicates extensive vertical displacement.
G	Contwoyto Fm: High Grade (unit 6)	Contwoyto Fm: High Grade (unit 6)	Merges with Fault F on Central Peninsula.	Rider to Fault F.
H	Contwoyto Fm: High Grade (unit 6)	Contwoyto or Itchen Fm.	Continues well beyond map area.	Eastern edge of Study Area.

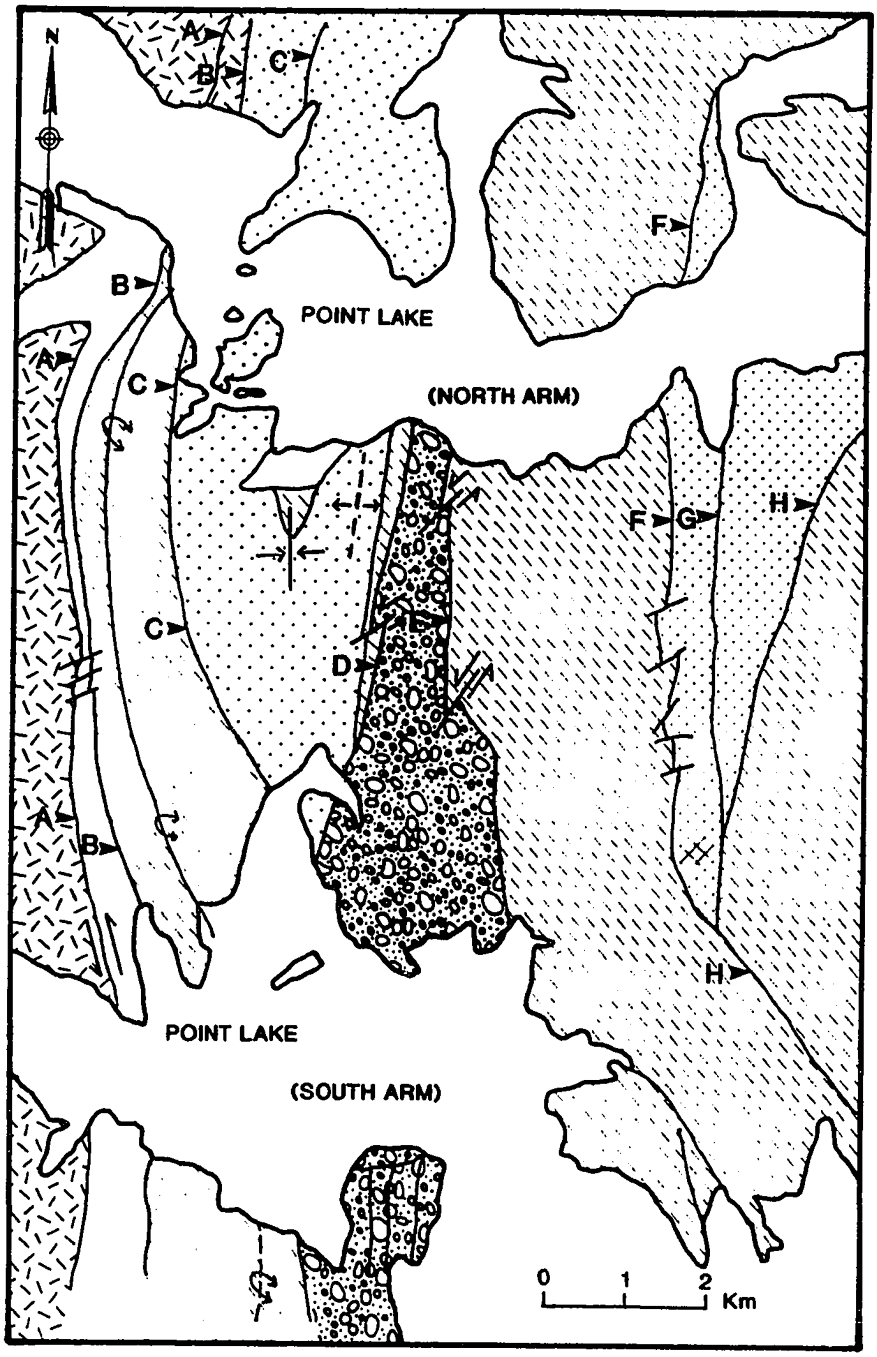


Figure 20. Generalized Geologic Structure Map Showing the Location of Major Faults and Folds.

The next thrust, Fault C, occurs about 2 km east of the mylonite zone, and like the other major faults strikes approximately north-south across the study area. This thrust separates metasedimentary rocks of the lower part of the Contwoyto Formation below (west) from ultramafic, gabbroic and mafic volcanic rocks above (east). A chaotic carbonate melange containing clasts of metasedimentary rock and metabasalt is present along much of this fault. As with Fault B, the orientation of bedding planes along the fault is consistent with drag folding along a thrust. Fault C is continuous through the central peninsula, and is assumed to merge with Fault B beneath the North Arm, because the metasedimentary rocks do not appear on the north shore of the lake. Fault C was not traced to the south shore of the lake for this study, but it may step up and east to merge with Fault D near the south shore.

On the central peninsula, Fault D separates Keskarrah Formation conglomerates (above and east) from Contwoyto Formation shales (below and west). The trace of Fault D apparently ramps upward across several geologic contacts, so that south of the south arm, gneiss may be thrust over greenstone, on the central peninsula, conglomerate is thrust over greenstone, and north of the north arm, metagraywackes are thrust over greenstone.

The present study did not include mapping or petrographic investigations of rocks that occur south of the south arm.

Hoffman (1988) and Kusky (1991) have documented a fault south of Point Lake that juxtaposes gneissic basement over the greenstone belt. In the interpretation of Hoffman (op. cit.) and Kusky (op. cit.), the detachment is truncated by the conglomerates, which are thereby interpreted as being unconformable over the greenstone belt units (Figure 21). However, these previous workers have not differentiated the metabasalts in the Point Lake area into separate units. It is considered that Fault D either ramps upward with a southeast trending trace to join Fault E and continue as the contact between the metasedimentary rocks and the metabasites to the south of the map area, or, more likely, exists within undifferentiated metabasalts which may be partly greenstone (Unit 4) metabasalts and partly Keskarrah (Unit 2b) metabasalts.

Fault E extends from Tree Bay southward across the central peninsula, and then across the south arm to the south shore. On the central peninsula, this thrust separates Keskarrah Formation on the west from rocks of the Contwoyto Formation on the east.

It is considered here that thrusts D and E can be traced southward along strike to the south shore of south arm. On the south shore of south arm, a horse of Middle Archean granite is exposed (e.g., Kusky, 1991; Hoffman, 1988; Considine and Kusky, 1988). It is interpreted in this work that the mappable conglomerate unit (Unit 2a) occurs as the

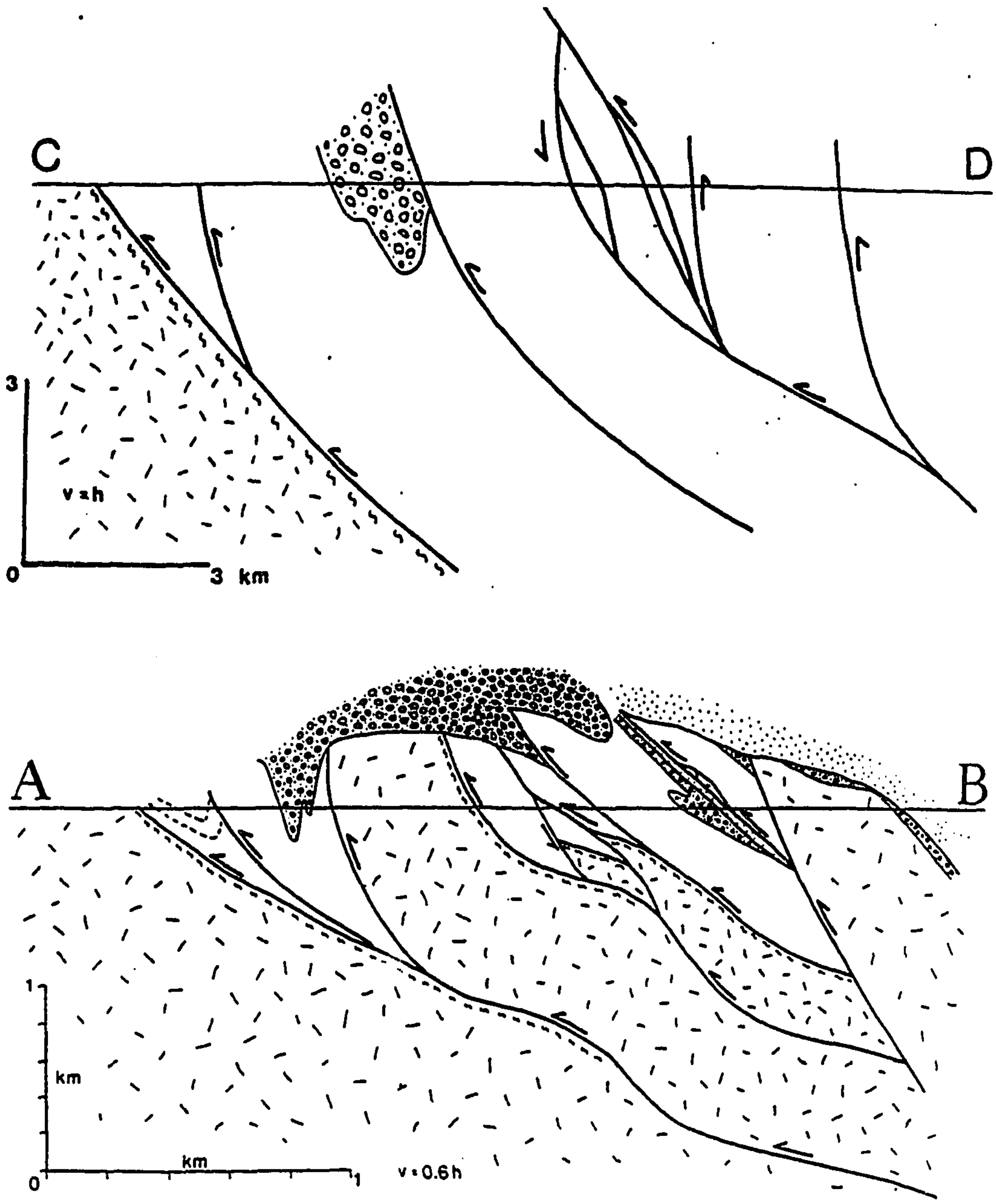


Figure 21. Generalized Cross Section Illustrating an Alternative Interpretation of the Keskarrah Formation Lower Contact. In this interpretation, the Keskarrah conglomerates were deposited directly on other units as a molasse-like sequence in an accretionary wedge during tectonic emplacement of the greenstone belt. Lines of section are indicated on Figures 7 and 9. For comparison, see Figure 31. Taken from Kusky, 1989. Section A-B was modified after Hoffman, 1986.

northward continuation of a stratigraphically higher section of the same horse of basement rock identified by Kusky (1991) and Hoffman (1988).

Near the eastern boundary of the study area a set of thrusts (Faults F, G and H) merges into one major thrust (Fault H) to both the north and south. Fault H separates low-grade metamorphic rocks on the east from high grade metasedimentary rocks to the west. Fault H also marks the eastern boundary of the area mapped for the present work. Beyond the study area, the fault extends for some scores of kilometers in a north-south direction. Lying between the three thrusts (F, G, and H) in the north are two massifs of the granulitic metasedimentary units, which in themselves are suggestive of major tectonic activity. King et al. (1989) interpret this fault as one of a set of Proterozoic faults. However, the presence of possible granulite, marble, and other highly tectonized rocks adjacent to the fault, as well as the orientation and lateral extent of the fault indicate that if it is not coeval with emplacement of the greenstone belt, then another major tectonic event must be accounted for. No evidence was observed to indicate that Faults A-H require more than one event to explain their origin.

The contact between granulite and metagraywacke, on the south shore of the north arm of Point Lake, is a rare silicified slickensided fault, striking 150° and dipping 13 NE, and which may sinistrally offset Fault H. The slickensides at this outcrop trend 310° and plunge 13 . This fault contact is in turn offset by a number of cross faults which strike at approximately 50° and dip 80° SE.

LATE FAULTS AND MYLONITIZATION

Localized late faults in Units 4 and 5 (Set 1) are generally aligned in an east-west direction, with steep to vertical dip. Minor offsets of bedding, cleavage and other features are seen on these faults. Set 1 includes five east-west striking faults offsets the mylonite zone near the middle of the peninsula at the western edge of the study area. Cross faults offsetting the mylonite zone are generally brittle in nature, as evidenced by their slickensided scarps. Slickensides on the east-west striking faults plunge subhorizontally. East-west striking faults of Set 1 may have initially formed as cross faults (tear faults) along bc planes (i.e., approximately vertical planes perpendicular to fold axial planes) in response to the stresses that accompanied the emplacement of the greenstone belt.

The northernmost of the cross faults is a mylonitized east-west striking shear zone. W.S.F. Kidd (pers. commun., and cited in Kusky, 1991) has noted the presence of ultramylonite porphyroblasts in a protomylonitic matrix at an outcrop on the south arm. At this outcrop, the mylonite fabric strikes east-west, i.e., nearly perpendicularly to the predominant fabric of the mylonite zone and extends for approximately 50 m into gneissic basement. The local orientation of mylonite fabric in an east-west direction along one of the faults of set 1 is consistent with a north-south compressive stress and supports the interpretation of the origin of the strike-slip faults discussed in the previous section. This suggests that there occurred at least two separate stages of mylonitization. The first stage of mylonitization occurred during east-west oriented compression accompanying emplacement of the greenstone belt. A second (minor) stage may have occurred during a phase of approximately north-south oriented compression.

Three major northeast to southwest striking strike-slip faults (Set 2) offset rocks in the central part of the greenstone belt, where the Keskarrah conglomerate is exposed (see Figure 20; Plate 1). These faults sinistrally offset the fault contact between the Keskarrah Formation and the Contwoyto Formation. The faults strike at approximately N30°E, and were measured to dip vertically. This orientation coincides with that of a joint set that was measured at a few outcrops, but which is probably obscured in much of the map area by a dense network of irregular fractures. It is considered that these faults arose in a principal stress direction oriented along an approximately north-south trend, and that this stress field postdated the emplacement of the greenstone belt. If this is the case, it would be expected that the wrench faults would have a corresponding conjugate set striking at approximately 150°. This orientation corresponds approximately to the orientations of both the predominant regional cleavage and some of the thrust faults in the southern part of the peninsula. It is therefore suggested that late flexural slip along the S2 planes was accommodated along pre-existing cleavage and fault planes.

The north and south arms of Point Lake lie along east-west trending, steeply dipping faults (Set 3), with slickensided scarps along the shores. The orientation of the faults and slickensides are consistent with those expected from stress-release normal faults that would accompany the cessation of stresses.

FOLDS

Styles of folding vary with lithologic type throughout the study area. The general style of folding in the Contwoyto consists of west-verging tight to isoclinal folds with an associated, nearly vertical, axial planar cleavage. The metasedimentary units, including both the Keskarrah Formation and the Contwoyto Formation, appear to be more strongly folded than the metaigneous units. Major fold axes in the metasedimentary units are shown on Figure 20. In quartzose layers, parasitic folds with wavelengths of a few cm are superimposed on tight to isoclinal folds with amplitudes of 20-50 m. Several of these folds can be traced on the shores of the north arm (e.g., Figure 22). Near the contact between the metasedimentary rocks and the mylonite, metasedimentary rocks are tightly and isoclinally folded. As in other units, the best exposures are near the shore of the lake, and inland outcrops are mostly lichen-covered, so presumably, a great deal of structural information remains concealed. Folds in the metasedimentary rocks hinge about an axial plane which strikes approximately 008°, and dips steeply east to steeply west. The metasedimentary rocks, including the conglomerate, have undergone nearly pure flattening, with tight isoclinal folding about nearly vertical fold hinges.

The pillows in the Unit 4 basalts have been flattened with an accompanying development of pervasive cleavage, but were not visibly folded at outcrop scale.

At one outcrop, the thrust (Fault C) separating the greenstone from the underlying Contwoyto Formation is itself folded. The axis of this fold is parallel to both the axes of bedding-plane folds in the metasedimentary rocks and the thrust; the concordant deformation suggests late-stage deformation during a single protracted event.

The basal mylonite is strongly sheared, and may be refolded about steeply west-verging axial planes with nearly horizontal fold axes. Foliation in the mylonite zone is itself anticlinally folded, indicating either two east-west deformation events, or more likely, late-stage coaxial shear.

On a small island in the north arm, an outcrop of

Figure 22. Isoclinal Fold in the Contwoyto Formation. Photograph taken in the western part of the study area, near North Arm.

metapelite (Unit 5a) was isoclinally folded about an axial plane striking at N47°E and dipping 80° SE. This orientation is concordant with the northern end of the trace of Fault C on the peninsula.

SUMMARY OF FOLDING STYLE

At Point Lake, rocks are tightly to isoclinally folded about axial planes that trend NW-SE to NE-SW. Some of the metasedimentary rocks, especially the more highly deformed samples from the western part of the study area, show two crenulation events, one of which overprints the other, and both of which are overprinted by a preeminent cleavage, leaving only faint vestiges of an earlier event. The number of generations of folding in the metasedimentary rocks remains the subject of controversy. King et al. (1989) present evidence for as many as 7 phases during several major events. However, Kusky presents evidence (Kusky, 1989; Kusky and DePaor, 1991) that there were no more than two deformational events in the metasedimentary sequence, the second of which did not result in intense folding. The author of the present work has observed only one family of large isoclinal folds, with associated much smaller parasitic folds.

CLEAVAGE AND JOINTS

Throughout the mapped area, the metamorphosed rocks exhibit a monotonous steeply-dipping, roughly north-south striking pervasive axial planar cleavage. This cleavage is found in the graywackes, shales, and metabasites and was interpreted as being formed perpendicular to the direction of compaction in the greenstone belt.

The cleavage exhibited in both the mylonite zone and adjacent metasedimentary and metabasic units is approximately parallel to the mylonite fabric. The fabric of the mylonite is oblique to the trend of the mylonite zone, i.e., to the map pattern of the shear zone in which the mylonite formed (Figure 20).

In addition to ubiquitous north-south striking cleavage, steeply dipping spaced cleavage or joint planes were measured that showed a wide range of strike orientations. In most cases, it was difficult to distinguish between cleavage, spaced cleavage and joints, due to the extensive irregular fractures that obscure structural detail in most outcrops in the study area.

Stereonet projections representing the dominant cleavage in the metasedimentary rocks and metabasites from several areas are shown in Figures 24-30. Figure 23 shows the areas in which the measurements were taken. Two patterns are apparent in the stereonet projections: poles to cleavage tend to cluster in two areas as much as 30 degrees apart; and in comparing measurements from the northern and southern parts of the map area, the orientation of these poles rotates a few degrees clockwise about a nearly vertical axis. In other

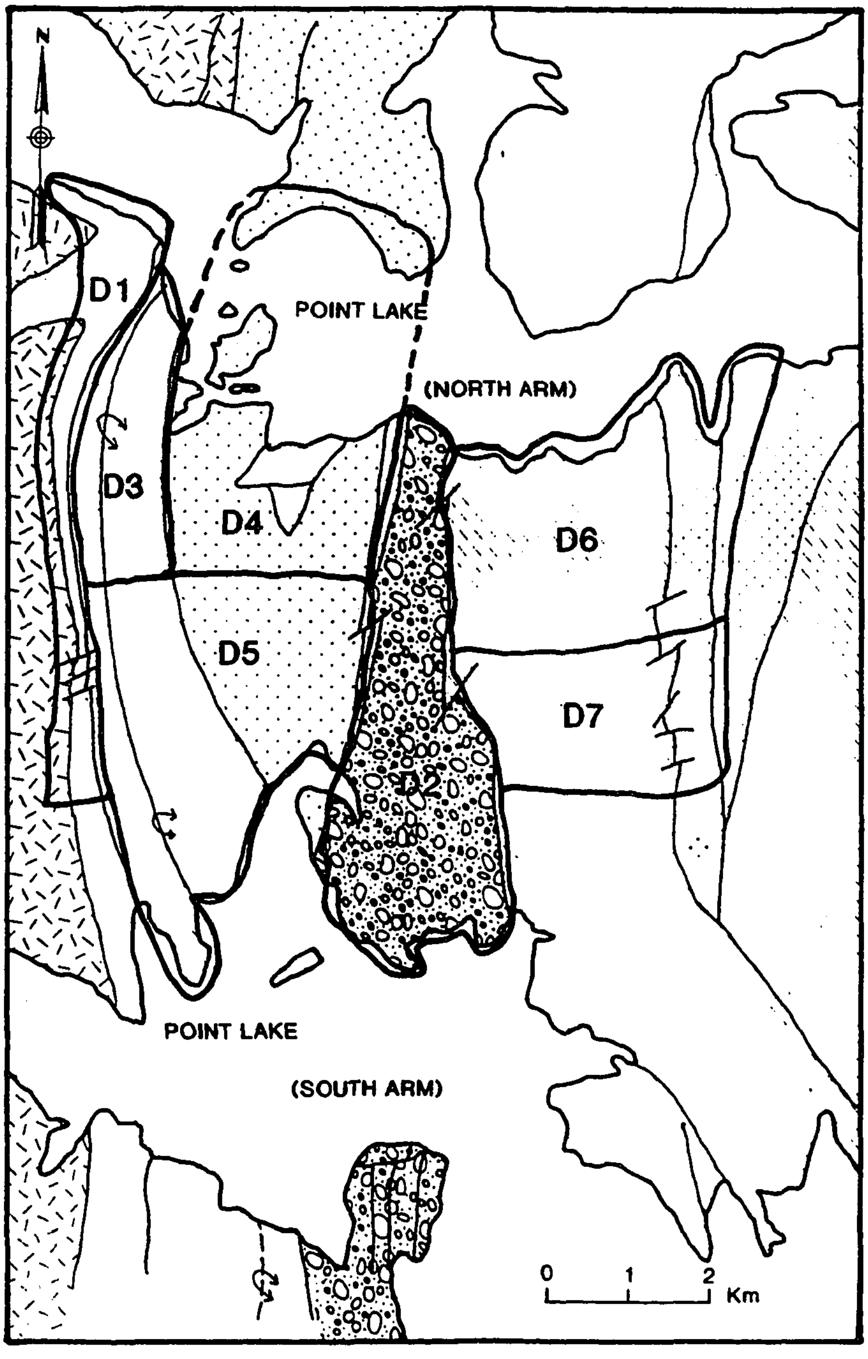


Figure 23. Index Map of Stereonet Projections. Domains D1-D7 show areas from which structural measurements were taken to produce the stereographic projections presented as Figures 24-30.

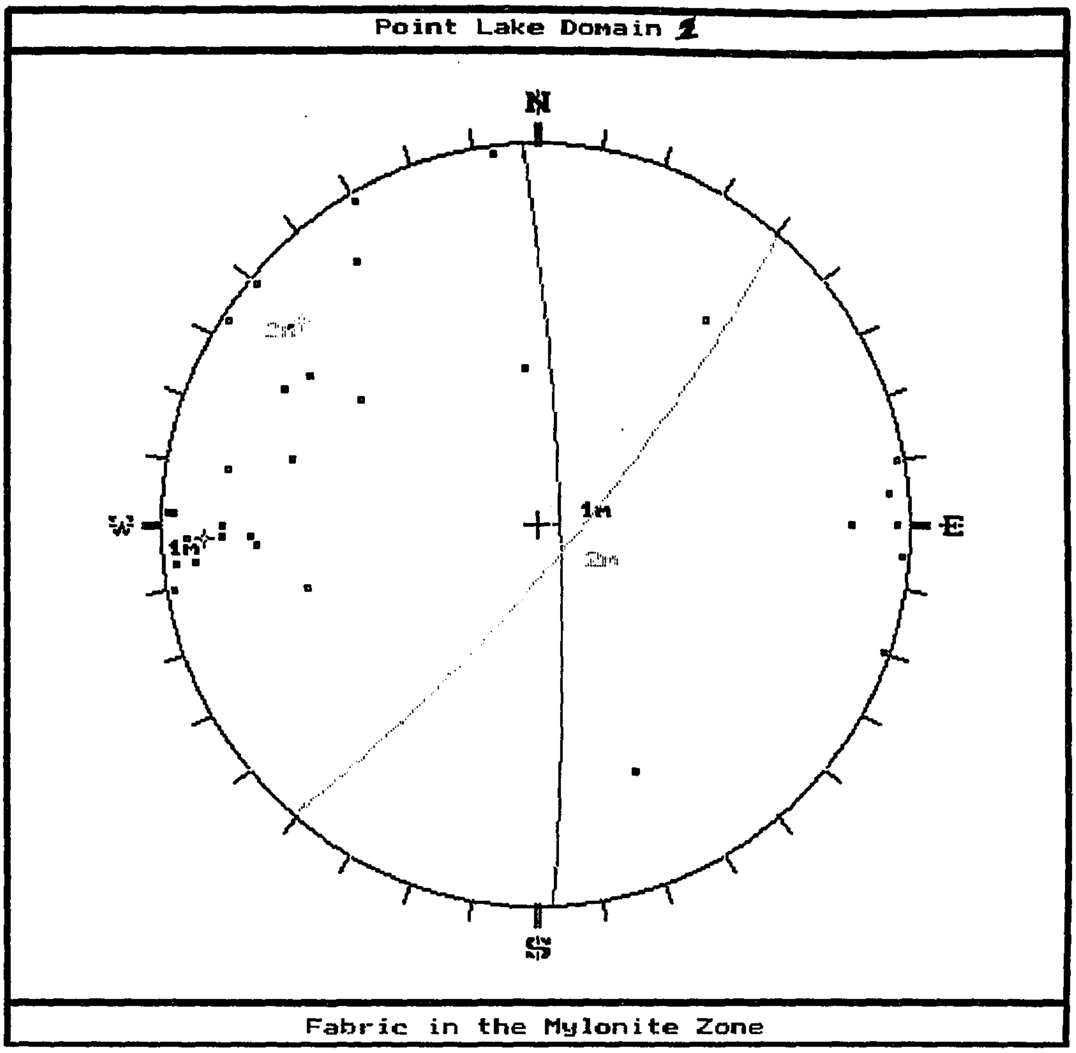


Figure 24. Stereonet Projection: Domain 1.
Lower Hemisphere Equal area projection of poles to mylonite fabric.

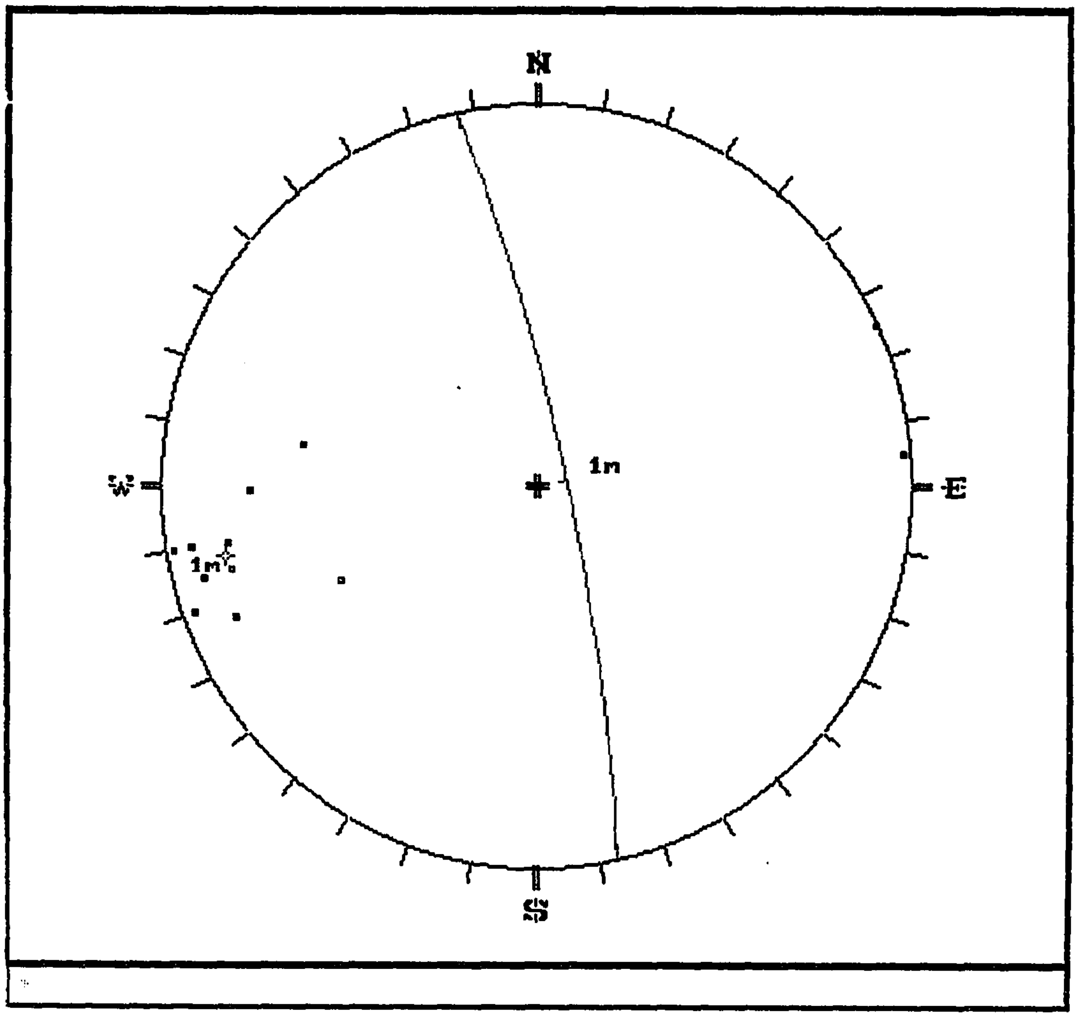


Figure 25. Stereonet Projection: Domain 2.
Lower Hemisphere Equal area projection of poles to cleavage and joint planes.

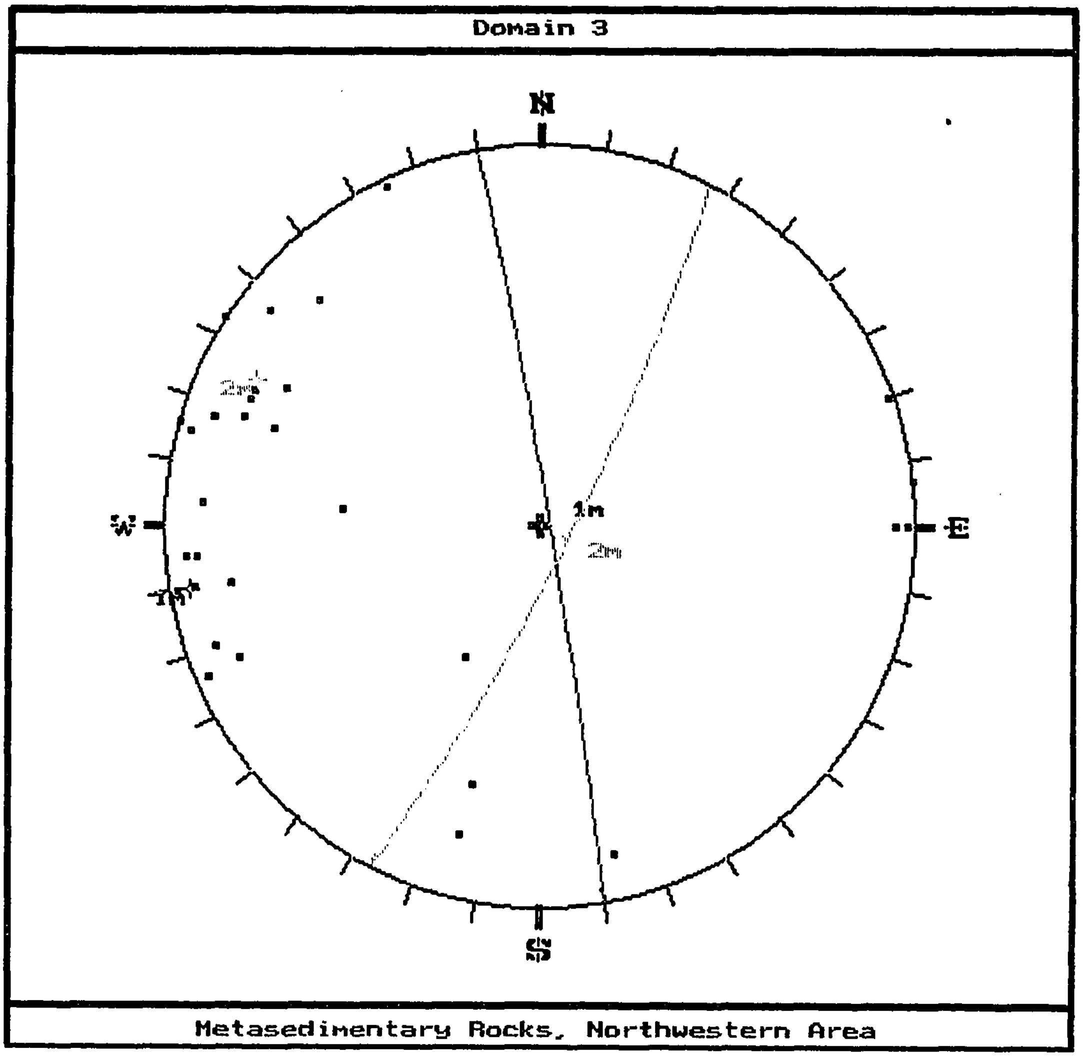


Figure 26. Stereonet Projection: Domain 3.
Lower Hemisphere Equal area projection of poles to cleavage and joint planes.

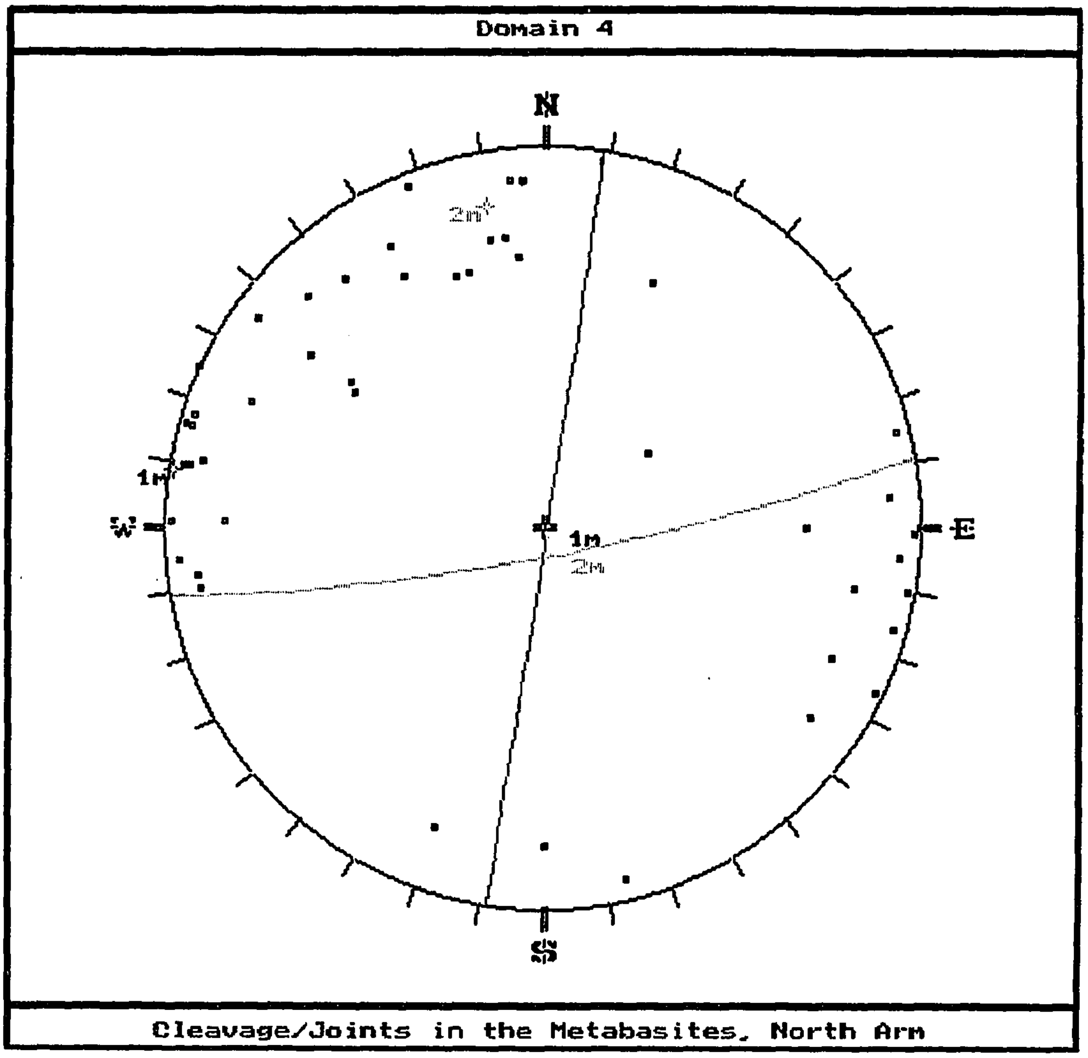


Figure 27. Stereonet Projection: Domain 4.
Lower Hemisphere Equal area projection of poles to cleavage and joint planes.

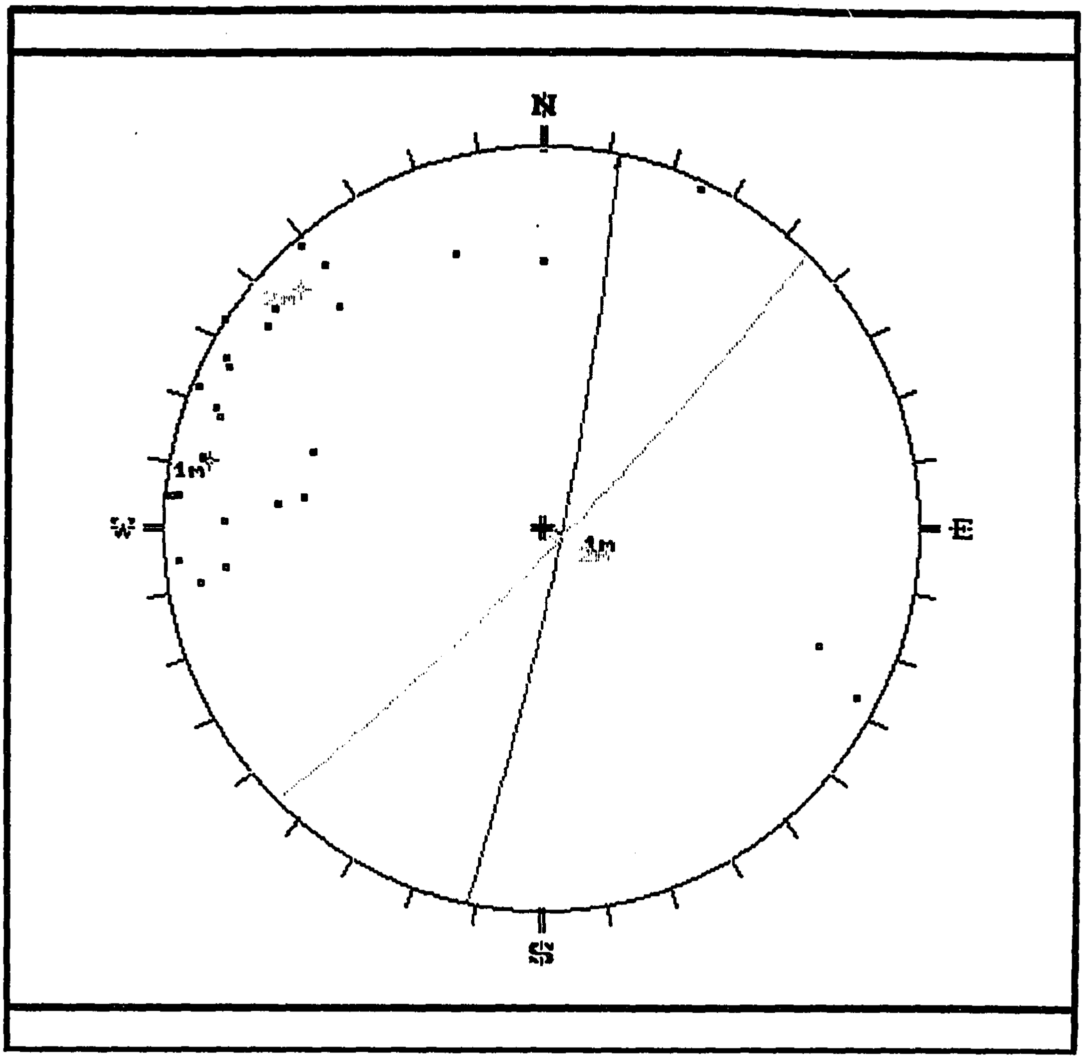


Figure 28. Stereonet Projection: Domain 5.
Lower Hemisphere Equal area projection of poles to cleavage and joint planes.

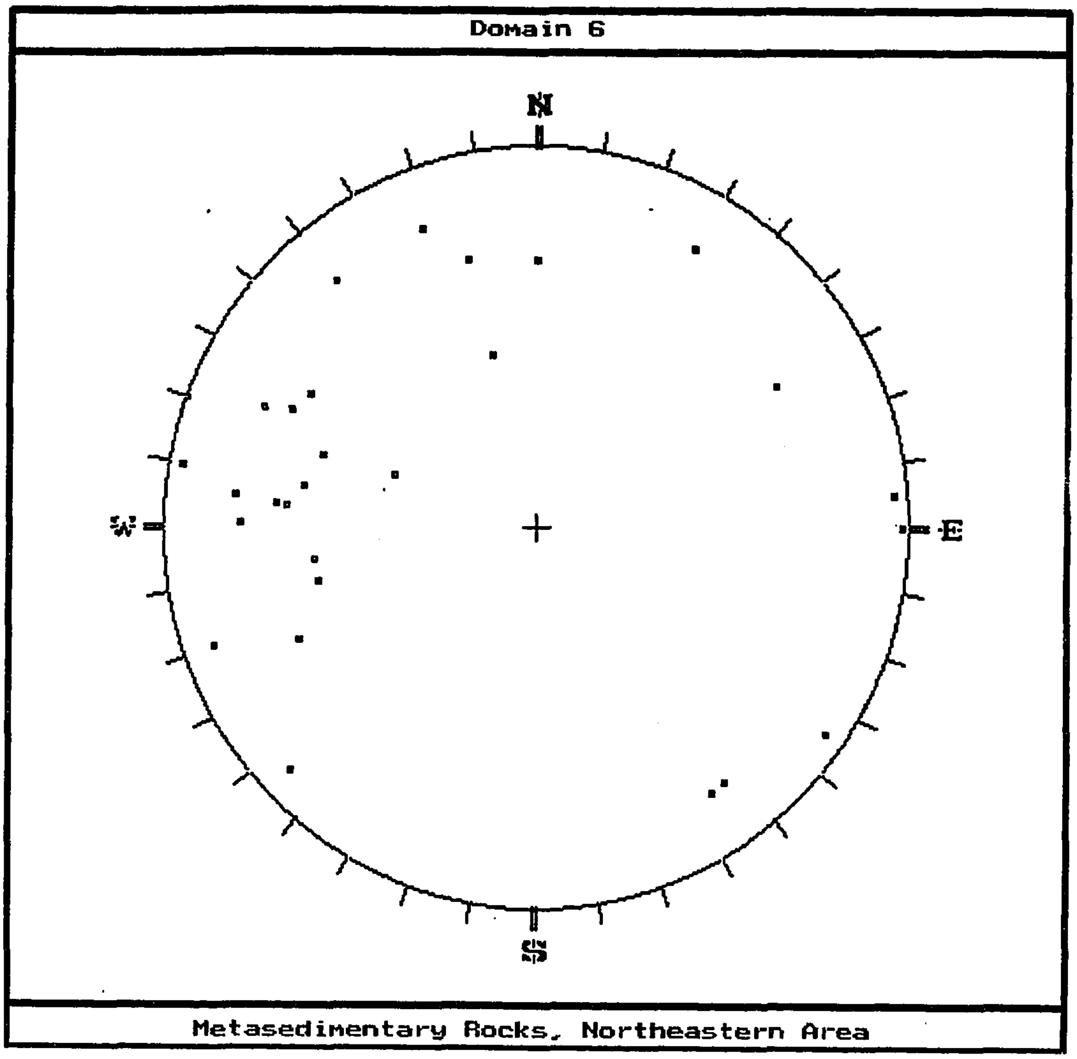


Figure 29. Stereonet Projection: Domain 6.
Lower Hemisphere Equal area projection of poles to cleavage and joint planes.

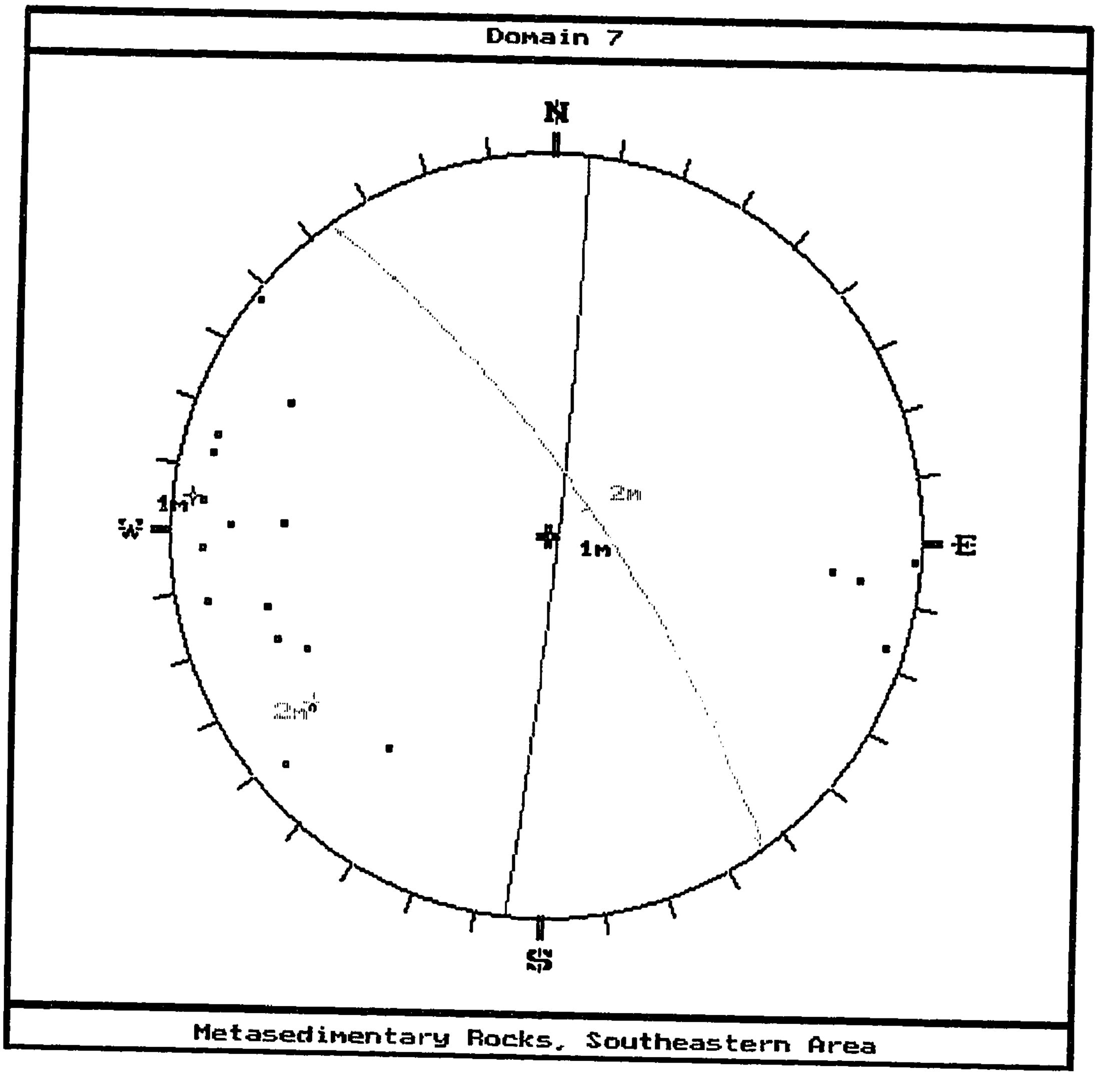


Figure 30. Stereonet Projection: Domain 7.
Lower Hemisphere Equal area projection of poles to cleavage and joint planes.

words, cleavages measured in the north strike northeast, and cleavages measured in the south strike northwest. The two clusters of poles to cleavage suggest that there were two zones of slightly different orientation during a single folding event, with strain axes separated by a few degrees.

A joint set spaced about 10 cm apart was observed in a few outcrops of metasedimentary rocks, and in parts of the mylonite zone. This set strikes at about 75° to 90° and dips steeply north. This orientation is consistent with the expected orientation of b-c joints which would arise from an approximately north-south trending principal stress direction.

LINEATIONS

The most important lineations indicate the orientation of stress and strain axes. Measured lineations included crenulation lineation, fold hinges and mineral lineations, and in the mylonite, some boudins.

Faint crenulation lineations occur on cleavage faces in the metagraywacke. This crenulation can be seen more readily in thin section. At some outcrops, crenulation and cleavage were both subjected to minor folding, indicating that the rocks had undergone earlier stages that were overprinted by the major deformation event. At yet other outcrops, two possible crenulations were measured, both folded. The earlier crenulation is very faint, and may be spurious, but also seems to appear in thin section. If so, it may be argued that locally, the greenstone belt underwent as many as four deformation "phases". Nevertheless, at the regional (map) scale, only one tectonic event is recorded within the greenstone belt, suggesting that the deformation phases represent localized shifting of stress during a single protracted event.

In the mylonite complex, mineral lineations representing present and relict amphibole grains can be measured. In some places, especially in the north part of the study area, the lineation is difficult to detect, presumably because amphibole was replaced during retrograde metamorphism by chlorite and epidote. In the south part of the peninsula, mineral lineations within mylonite fabric plunge approximately 50° to 60° southward. Toward the central part, the lineations plunge nearly vertically, and in the north, they plunge steeply northward. The mineral lineations are stretching lineations, representing the growth of amphibole grains in the direction of movement. The inferred direction of movement is consistent with the sense of shear discussed in the next section.

SENSE OF SHEAR

Because rocks in the western part of the greenstone belt are tightly and isoclinally folded, it is difficult to establish conclusively sense of shear near the mylonite zone on the basis of fold vergence. Another difficulty is that the "cleanest" exposures are pavement outcrops near the shores of the lake, offering a two-dimensional view of shear that may contradict the true vergence. Sense of shear in the mylonite zone was established by studying the map pattern, rotated porphyroclasts in the mylonite, and offset of fractures and other features, and by using fold hinges and mineral lineations to corroborate sigma-2.

In summary, sense of shear indicators observed in the field are consistent with the conclusion that the rocks of the greenstone belt were thrust over the older basement. Field observations show that this thrusting was accompanied or followed by a significant strike-slip shear component, which varies in direction along the mylonite zone.

CHAPTER 5: DISCUSSION

Discussion of Basalt Geochemistry

Basaltic rocks may form under a wide range of tectonic settings, including mid-oceanic ridges, island arcs, oceanic islands (hot spots), active continental margins, and continental rifts. Attempts have been made to discriminate plate tectonic setting of basalts on the basis of major element and trace element geochemistry. Cann, 1970; Pearce and Cann (1973, 1977); Pearce, 1976; and Floyd and Winchester (1975) plotted the ratios of Ti-Y-Zr in ternary discriminant diagrams to identify four tectonic settings: ocean island basalts, volcanic arc basalts, MORB's, and within-plate (continental or oceanic) basalts. Using a similar approach, Mullen (1983) used ratios of MnO-TiO2-P2O5 for discrimination of basaltic types.

Trace element discrimination of tectonic setting for basaltic magmatism in the Point Lake area was attempted more recently by St. Seymour et al. (1988), who applied ternary discriminant diagrams of the type described above to the metabasalts of Point Lake. The results straddled several of the tectonic "fields" defined by Pearce and Cann (1973) and other workers. This pattern was interpreted (St. Seymour et al., op. cit.) as representing a regime dominated by "rifting... with local subduction". One of the original objectives of this thesis was to use trace element discriminant diagrams of this type to determine the tectonic environment(s) in which the metabasalts in the Point Lake greenstone belt formed.

For the present study, some preliminary evaluations of the ternary discriminant diagrams were made. However, the results lay well outside of the predicted fields. Variations in the chemistry of modern MORBs have been attributed to size and age of magma chamber (Karson and Casey, 1983), spreading rate (Thompson, 1978), mantle heterogeneities (Sun and Nesbitt, 1978) and differences in the partial melts of Archean mantle as compared to more recent magmas (e.g., Chase and Patchett, 1988). Furthermore, the relative mobility of trace elements through various grades of metamorphism has not been well documented in the literature. Most of the discriminant diagrams concern the composition of unmetamorphosed basalts; the relative mobility of trace elements at varying metamorphic grades is not considered.

Another method of studying the generation of volcanic rocks is through the use of variation diagrams, in which major or trace element components are plotted against a major component, such as MgO or SiO_2 (Best, 1982; Wilson, 1989). This method is based on the assumption that as melts crystallize, ratios of major and minor elements follow a linear trend along a liquid line of descent. Using the Point Lake geochemical data, a series of variation diagrams was plotted; however, no unambiguous patterns were identified.

It was concluded from the above two exercises that the tectonic setting of greenstones must be interpreted from structural and lithological relationships observed in the field, and not from distributions of trace elements.

Geochemistry of the Contwoyto Formation

The bulk composition suggests that the graywackes of the Contwoyto Formation were derived from a source with abundant felsic igneous rocks. McGlynn and Henderson (1970) and Jenner et al. (1981) concluded from studies of the graywacke in the Yellowknife area that the sediments were derived from 55% felsic volcanics, 25% mafic volcanics, and 20% felsic intrusives. This analysis suggests that the source of the Contwoyto Formation may have been, in part, a volcanic arc, and not entirely the Anton Terrane (granitoid basement). This finding is consistent with the observation of tuff layers with clear bipyramidal quartz within the Contwoyto Formation.

The gray and pink members (Subunits 6b and 6c, respectively) of the high-grade metasedimentary (granulite?) unit correspond to the rhyolite and dacite units of Easton (1985), Jackson (1985, 1986), and Henderson (1988). Mapped as rhyolites and dacites, they spuriously supported a model which included bimodal volcanism in the early stages of rift development. Detailed petrographic and geochemical studies (Chapter 3) conducted for the present work indicate that Unit 6 is actually a high-grade metamorphic rock which was derived from a sedimentary protolith (for description of a similar rock, see de Wit, 1982). The pink clasts in the breccia have a composition of over 95% quartz, with minor (2% to 3%) magnetite, making an igneous origin for the pink-colored rock type highly unlikely.

Lead-lead radiometric dating of zircons collected from this unit yield disparate ages (Isachsen, unpub. data). The varying ages of the zircons in the samples collected from Unit 6 indicates that zircons were derived from a detrital source, and supports the interpretation of the rock having been derived from a sedimentary protolith.

In Table 7, a comparison of rock samples 27, 28, and 30, representing the high-grade metamorphic rocks of Unit 6 with samples of metasedimentary rocks of samples 2, 4, 34, and 35. Apart from high iron content, Table 7 shows major element chemistry not unlike that of granitoid rocks for both the graywackes and the granulites. However, geochemical sample No. 30 (the "dacite" unit of Henderson, 1988) has a chemistry even more similar to that of the metasedimentary rock at outcrop 221 (geochemistry sample No. 35) than to a granitoid. The geochemical data supports the petrographic evidence (Chapter 3) that the rocks are most probably a high grade variation of the metasedimentary rocks.

Origin of the Keskarrah Formation

Various interpretations of the relationship between the conglomerates of the Keskarrah Formation and other units in turn result in radically different interpretations of the tectonic history of the Point Lake area. Direct deposition of the Keskarrah conglomerates over the Keskarrah basalts would be consistent with the coeval origin of the two subunits in a rift setting; however, the direct deposition of the conglomerate on the greenstone would indicate that the conglomerate postdates the emplacement of the greenstone belt. Two distinct collisional models are supported by contrasting interpretations in which the conglomerate is contained in a thrust slice imbricated with slices containing metabasites and metasedimentary rocks, or if, alternatively, the conglomerate was deposited unconformably over the allochthonous massifs representing the rest of the greenstone belt. The interlayering of Units 2a and 2b in the Keskarrah Formation indicates that the volcanics were formed approximately coevally with the conglomerates, and prior to the final stages of deformation in the greenstone belt.

The conglomerates may have been deposited in a narrow, shallow rift graben or half-graben coevally with extrusion of minor volcanics in a continental setting. The preponderance of shales, quartzite, granite and granitoid gneisses in the conglomerate, as opposed to pebbles of mafic, ultramafic and marine sedimentary rocks shows that the conglomerate was formed in an epicontinental or marginal marine environment. The lithology of the clasts in the Keskarrah conglomerate, and the observed depositional contact of the conglomerate over the basement gneiss suggest an in situ origin for the Keskarrah Formation. On the other hand, no direct evidence was observed to indicate direct deposition of the conglomerate over greenstone units, or intrusion of Keskarrah basalts into the greenstone belt.

The Keskarrah Formation is therefore interpreted as preserving a remnant of ancient Atlantic-type margin, in which the assemblage of gneiss-conglomerate-volcanics represents part of a rift sequence formed prior to the emplacement of the greenstone belt. In other words, the greenstone belt may record not only a suturing event, but the ocean-opening event that preceded it. This model is analogous to the interpretation of the Catoctin basalts and conglomerates as rift-facies continental margin rocks imbricated during suturing with allochthonous rocks in the Piedmont of Virginia (Conley, 1985; Rader and Johnson, 1978).

Relationships Within the Greenstone Assemblage

Units 3, 4 and 5 make up an igneous stratigraphic succession in which ultramafic rocks grade upward into gabbro, diabase, and then tholeiitic pillow basalt. This succession bears a strong similarity to the igneous stratigraphy observed in Phanerozoic ophiolites. The vestiges of a possible sheeted dike complex are visible at the south end of the study area (Kusky, pers. commun.), and on a peninsula extending southward into the north arm. Another sheeted dike complex occupies the same position in the igneous stratigraphy of the greenstone belt at Lake Oro, 150 km to the south, and in the Lower Kam Group, Yellowknife Bay (Helmstaedt et al., 1986). The sheeted dike complexes at Point Lake and in other Slave Province greenstone belts are highly reminiscent of those found in Phanerozoic ophiolites. It is important to note that in the southern Slave Province, dense swarms of mafic dikes intrude both greenstone belts and adjacent granitoid terrains (e.g., Lambert, et al., 1991). Therefore, although the sheeted dikes at Point Lake are not presented as a reliable indicator of the presence of an ophiolite, their absence from an igneous stratigraphic succession of possible sea-floor affinity would be conspicuous.

The Contwoyto Formation is a shallowing-upward succession of shales, distal turbidites, iron formation, carbonate and sandstone. The stratigraphy of the metasedimentary rocks suggests that the basal members were deposited in an abyssal environment that gave way to a shallower and more tectonically active environment.

Interpretive Cross Sections

The field mapping conducted for the present investigation supports the hypothesis that the Point Lake greenstone belt and the rocks in the adjacent areas to the east are dominated by laterally extensive compressional geologic structures. These structures include steeply west-verging and vertical isoclinal folds with an associated pervasive axial planar cleavage, and steeply dipping shear zones and thrusts. The thrusts separate rock units of distinct lithologic affinities, and are in turn connected to a basal detachment which separates two terranes.

Interpretive cross sections of the Point Lake area are shown on Figure 31 and Plate 1. These cross sections suggest a shortening of approximately 50% within the mapping area, corresponding to a minimum 10 km to 20 km of compressional movement in the area. The plate tectonic implications of this inferred compaction are discussed in the following sections.

Plate Tectonic Implications

Collisional Model

The cross sections shown on Figure 31 schematically illustrate a structural assemblage that may be explained by a collisional plate tectonic model in which the greenstone and associated metasedimentary rocks at Point Lake are interpreted as allochthonous westward-transported massifs of oceanic crust obducted onto the older continental crust. The mylonite zone separating the greenstone belt from gneissic basement is interpreted as a basal detachment that separates two major rock groups interpreted as representing two terranes (Kusky,

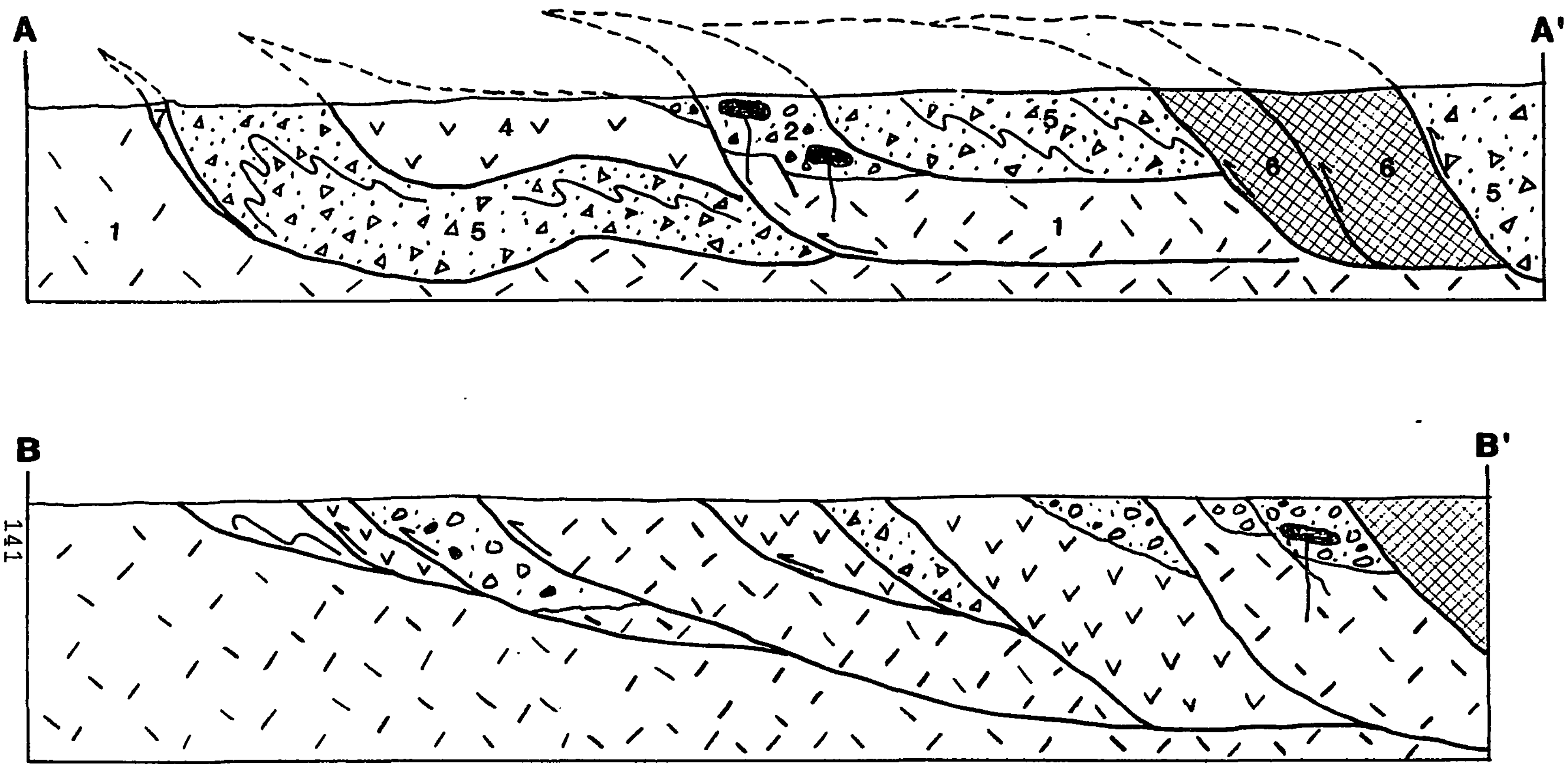


Figure 31. Generalized Geologic Cross Sections. Section A-A' taken across the central peninsula. Section B-B' is a reinterpretation of Section A-B on Figure 21. For detail see text and Sheet 1.

1990). The thrusts in the central and eastern part of the study area are rider faults which merge at depth with the detachment.

The present study of the geology in the area of Point Lake substantiates, in general, the idea of Kusky (1989) that the map area is situated at the juncture of terranes which were sutured during the Late Archean. These terranes are named the Anton terrane (represented by the basement gneisses), and the Contwoyto Terrane (represented by the greenstone belt). In the Anton Terrane, structures are complex and clearly represent several generations of deformation. Within the greenstone belt, the major faults and folds are subparallel, strike approximately north-south and verge steeply westward. The two terranes are joined at a fold-and-thrust belt which is recognizable on the regional scale.

Rift Model

An alternative point of view holds that the entire greenstone belt represents the remnants of a Late Archean rifting event (e.g., Henderson and Easton, 1977). This interpretation fails to account for the fact that the metavolcanics in the greenstone belt are not intrusive into older basement, as the greenstone belt is everywhere separated from the basement by a mylonitized shear zone. Further, no normal faults or other rift-related structures are found in the basement in the area of the contact with the greenstone belt. A rift model interpretation of the Point Lake greenstone belt requires documentation of at least some of the following features, none of which are observed: bimodal volcanism; lavas filling the rift which are rooted in or intrusive into the basement; a fining upward sedimentary sequence with conglomerate at the base; an en-echelon set of normal faults aligned with the rift axis. The local superposition of conglomerate (Unit 2a) over gneiss and granite in the south-central part of the study area does not suggest that the greenstone assemblage (Units 3-7) and late intrusives (Unit 8) at Point Lake were formed in a rift setting, as suggested by Easton (1985b), because there is no evidence that rocks of the greenstone belt were deposited or extruded in situ, let alone directly over the conglomerate. Rather, there is strong evidence that the conglomerate and other units in the greenstone belt were formed at different times in different tectonic environments.

The identification of a sedimentary protolith for the Unit 6 granulites, and the mafic petrology of the light-colored members of the Keskarrah basalts refute reports of the occurrence of felsic volcanic rocks in the Point Lake area, and thus undermine support for the hypothesis of bimodal volcanism in the area which would have accompanied the early stages of rifting.

As a variation on the rift-model interpretation, the mylonite zone has been viewed as a reactivated normal fault marking the western boundary of a rift half-graben in which volcanic and sedimentary rocks were deposited (Easton, 1985b; Henderson, 1981). This interpretation is considered unlikely because of the lack of extensional structural features near the mylonite zone, and because the stratigraphy of the greenstone belt is not typical of a rift association.

Back-Arc Model

In another variation of the rift model, the greenstone belt is interpreted as having formed in a back-arc extensional setting (Figure 4). Although calc-alkaline volcanic rocks of island-arc affinity and evidence of bimodal volcanism are not recognized in the Point Lake greenstone belt, it is possible that the Keskarrah Formation may represent a sliver of volcanic arc terrane incorporated into the allochthon during the suturing process. Given sufficient width, it is considered likely that extreme attenuation of sialic crust beneath a back-arc would be succeeded by production of mafic crust. Such a model would account for tuffaceous layers in the Contwoyto and the aluminous and alkalic volcanic rocks incorporated in the Keskarrah Formation; the conglomerate may represent deposits into an interarc or proximal back-arc basin.

A back-arc setting is not inconsistent with the observations of this study; however, it is considered that the available evidence is not sufficient to fully support this model.

Collisional/Foredeep Model

Another possible explanation for the conglomerates and associated volcanics is that the conglomerates were deposited as a molasse-like sequence in a trench or foredeep. Minor volcanism has been associated with small-scale localized rifting and strike-slip faulting accompanying subduction in Phanerozoic sutures in the Andes, the Alps, and in the Witwatersrand basins (e.g., Hoffman, 1987; Burke and Kidd, 1976; Best, 1982). To apply this model to Point Lake and to paraphrase St. Seymour et al. (1988), this would be a case of "subduction, with local rifting"!

However, the Keskarrah basalt intrusions are conspicuously absent from the metasedimentary rocks of the Contwoyto Formation. If, as has been suggested (Hoffman, 1986; Kusky, 1990), the Keskarrah basalts had intruded molasse-like deposits in an accretionary wedge in the late stages of tectonism, it is difficult to imagine that the intrusions would be so restricted. Furthermore, the clasts in the Keskarrah conglomerate are continental in origin. The absence of clasts of basalt and ultramafic rocks in the conglomerate does nothing to support the molasse hypothesis for the origin of the conglomerate.

Discussion of Archean Plate Tectonics

Heat production within the Earth during the Late Archean was at least twice that of the present rate, and probably six to eighteen times the present rate (Wilks, 1988). The composition of high-magnesium komatiites (in other Archean terrains) indicates an upper mantle 200°-300° hotter than the present-day upper mantle (Sclater et al., 1981). Since convection is the most efficient means of heat transfer from the Earth's interior to the atmosphere, it is safe to assume that the average rate of sea floor spreading was greater during the Late Archean than at present, or that a higher rate of heat flow was accommodated by a greater net length of ridge axes, or both. Any combination of the above two phenomena would result in the extensive production of sea floor. Faster spreading rates would result in differences in the igneous stratigraphy of any ophiolite: in particular, the crust would be thicker and there would be a greater relative abundance of fine-grained rocks over coarse rocks (e.g., Bickford, 1988; Bickle, 1975; Folinsbee et al., 1968; Fyfe, 1974).

The meta-igneous succession in the greenstone belt (Figure 32), including ultramafics, gabbro, diabase, and basalt, is remarkably similar to the igneous stratigraphy of Phanerozoic ophiolite complexes. Wilks (1988), Bickford (1988), and Bickle (1975) describe the differences expected in hotter, faster-spreading Archean spreading centers as compared with modern spreading centers. In particular, it is expected

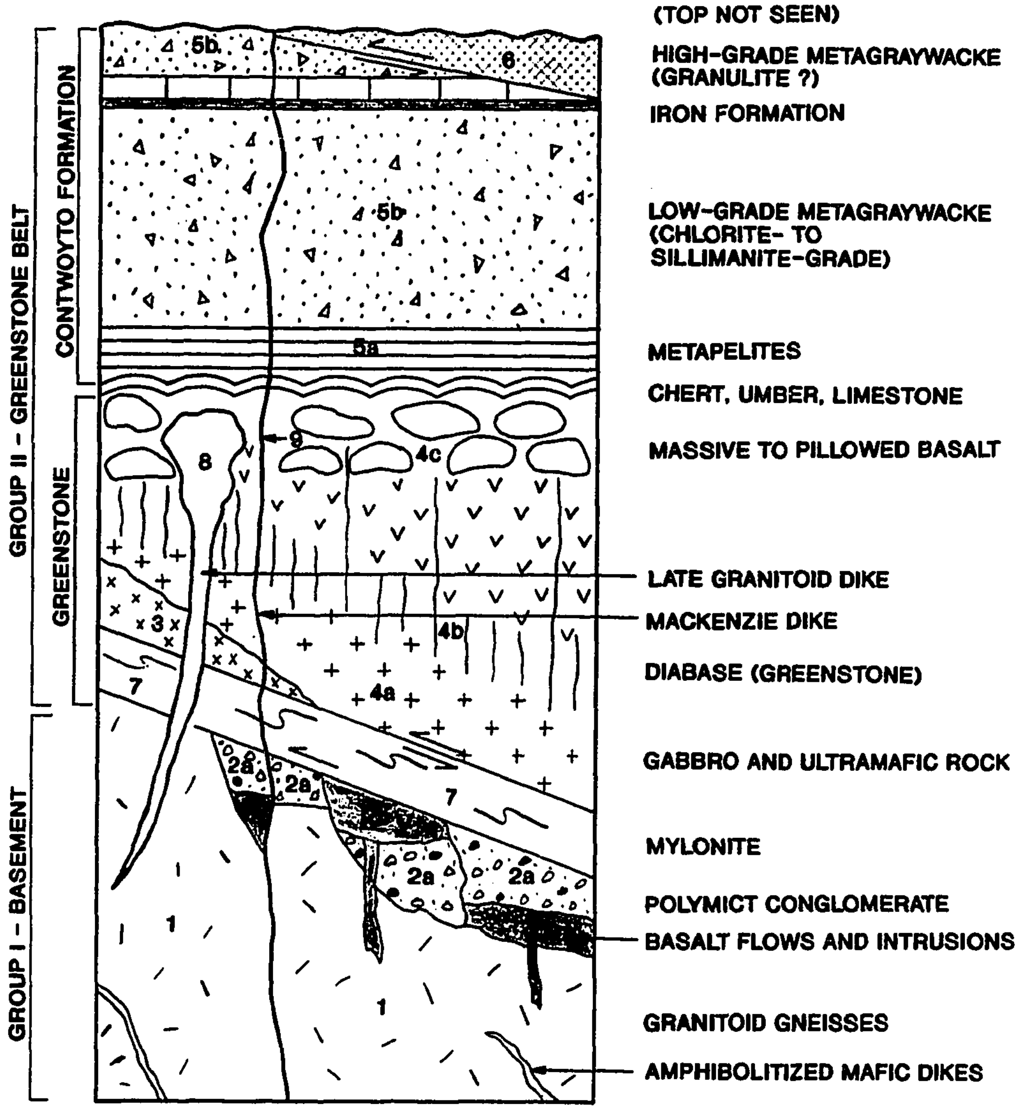


Figure 32. Generalized Lithotectonic Stratigraphy of the Point Lake Greenstone Belt, including relationships to basement gneisses, Keskarrah Formation, and late intrusives. For summary of lithologic units, see Table 1.

that Archean "ophiolitoids" (designating ophiolite-like allochthonous assemblages in which some of the layers are absent) would have much thicker basalt sequences than Phanerozoic ophiolites. Further, if Archean oceanic crust was thicker, a thrust slice of Archean sea floor is less likely to include the bottom layer of an ophiolite, which includes alpine-type peridotites (harzburgite and lherzolite).

Notable differences exist between the greenstone belt and ophiolites at Phanerozoic suture zones (see for example, Glennie et al., 1974; Dewey and Bird, 1971). In particular, the layer of pillowed and massive basalt at Point Lake is much thicker (approximately 1.5 km to 2 km) than that in Phanerozoic ophiolites (typically 500 m), whereas the sheeted dike complex and massive (cumulate) gabbro layers are much thinner. Further, a layer of alpine-type peridotites (harzburgite and lherzolite) is absent in the Point Lake succession. These differences are largely attributable to the theoretically faster spreading rates during the Archean.

Summary

Models invoked to account for the origin of the Point Lake greenstone belt fall under two general categories: extensional and collisional. Extensional models place the origin of the greenstone and associated metasedimentary rocks in either of two alternative settings: a cratonic rift and a back-arc. Collisional models attribute the formation of the greenstone to spreading centers an a back-arc or oceanic setting, and the origin of the metagraywackes to deposition of turbidites in back-arc basins and foredeep settings, respectively.

Major drawbacks to the extensional model include its failure to explain the structural discontinuity between conglomerate and turbidites, the predominant compactional style of deformation, and the lack of observed evidence of bimodal volcanism at Point Lake.

Detailed mapping of the Point Lake area supports a collisional model that explains the formation of the greenstone belt as an analogue of Phanerozoic ophiolites. Use of a collisional model does not preclude acceptance of the formation of the greenstone in a back-arc setting; however, at Point Lake, there is no direct evidence that the mafic crust represented by the greenstone formed on or through attenuated sialic crust.

CHAPTER 6: CONCLUSION

This study has documented structural and petrographic details of the geology of the Point Lake area. Geochemical and petrographic studies helped to distinguish the rock units and clarify the lithologic relationships between units within the greenstone belt. In particular, the results of this investigation show that basalts occur within the Keskarrah Formation that are distinct from the overlying allochthonous greenstone. In addition, high grade metamorphic rocks were identified along a major regional fault, which had previously been identified as rhyolite and dacite. These rocks are interpreted here as metasedimentary in origin and possibly representing the granulite facies. If this interpretation is correct, these rocks represent the highest-grade rocks yet identified in this part of the Slave Province. These details in turn provide important clues for the interpretation of the tectonic history of the area.

The geology of Point Lake area comprises three groups of rocks, each formed under a different tectonic setting. The basement complex (Group I) can be summarized as an ancient terrane comprising rocks of continental affinity subjected to a complex history of deformation and volcanism. The basement corresponds to the Anton Terrane of Kusky (1989). Prior to the emplacement of the greenstone belt (Group IIA), the history of the basement may have included a rifting phase, which would explain the deposition of coarse conglomerates interlayered with basalts. It is interpreted that the emplacement of the greenstone belt was accommodated by an approximate 50% shortening along the line of compaction, and a commensurate doubling of crustal thickness within the map area. Group III comprises late intrusives, formed subsequent to the emplacement of the greenstone belt.

The conclusion drawn from this study is that the greenstone belt at Point Lake is an allochthon representing obducted oceanic crust emplaced onto older continental basement during a Late Archean collisional event. This conclusion is consistent with the observation of an ophiolite-like igneous stratigraphic succession, a flysch-like metasedimentary succession, and the compressive geologic structures in the study area. This interpretation is also consistent with the regional pattern, which shows the Slave Province to consist of several lithologically distinct terranes presumably juxtaposed by continental accretion.

The lack of observed ophiolite-like sequences in the Archean record has been cited as evidence against a Late Archean plate tectonic style that is similar to that in the Phanerozoic. The results of this study indicate that contrary to a widely held belief, collisional plate tectonic processes were operating during the Archean, and as a result of these processes, allochthonous massifs of oceanic crust were obducted onto continental crust at suture zones.

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Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

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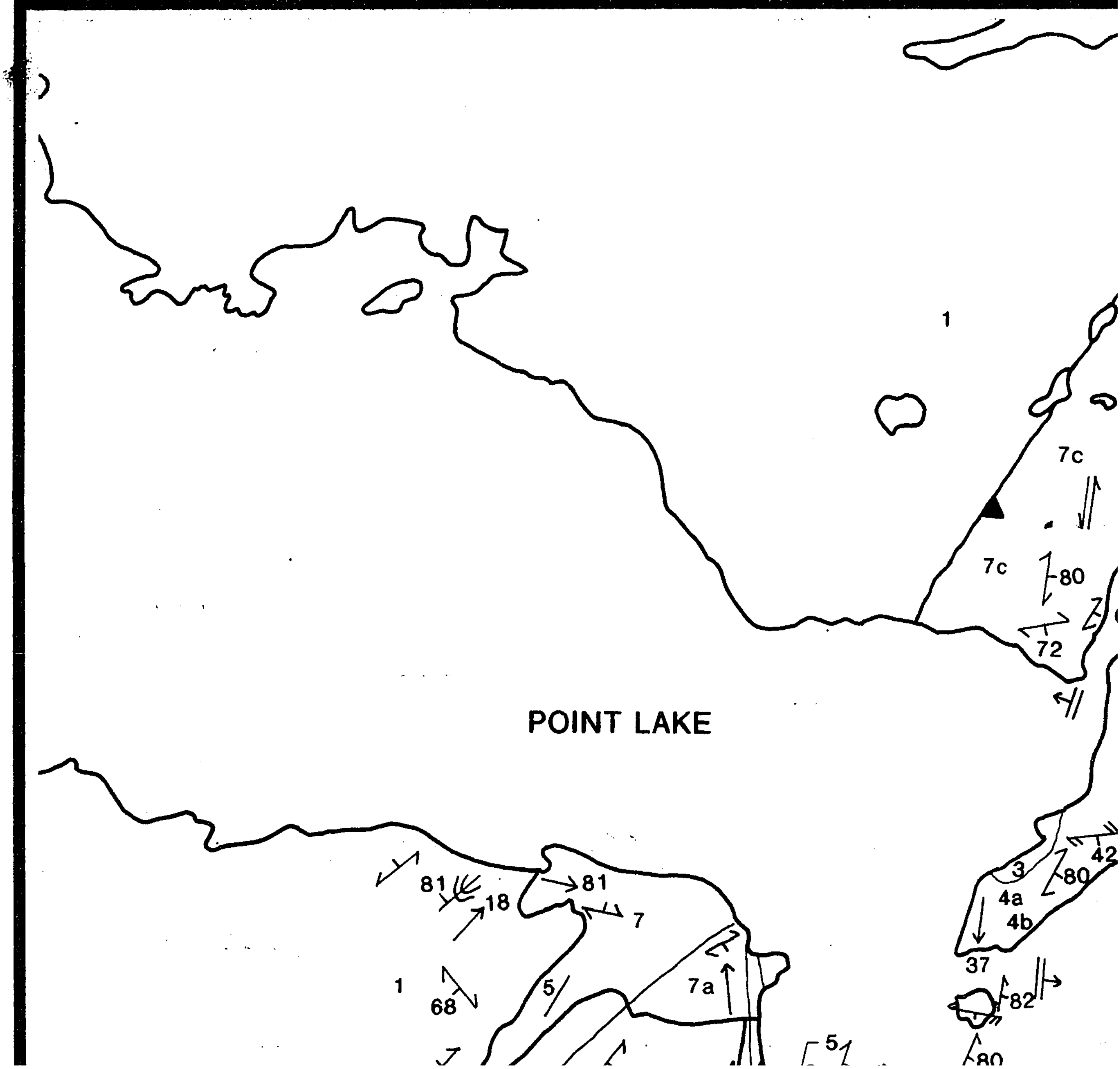
PLATE 1

GEOLOGY OF



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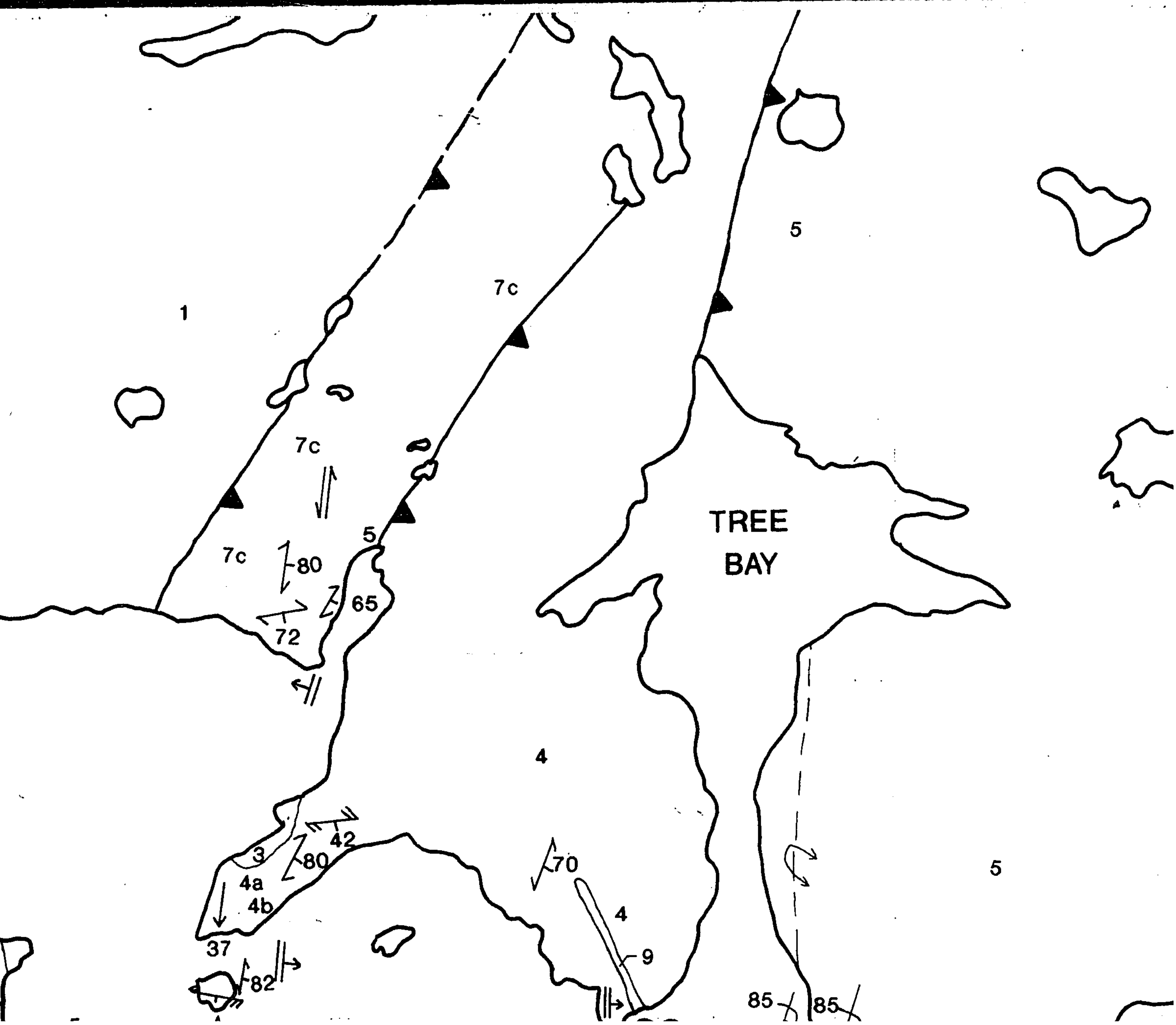

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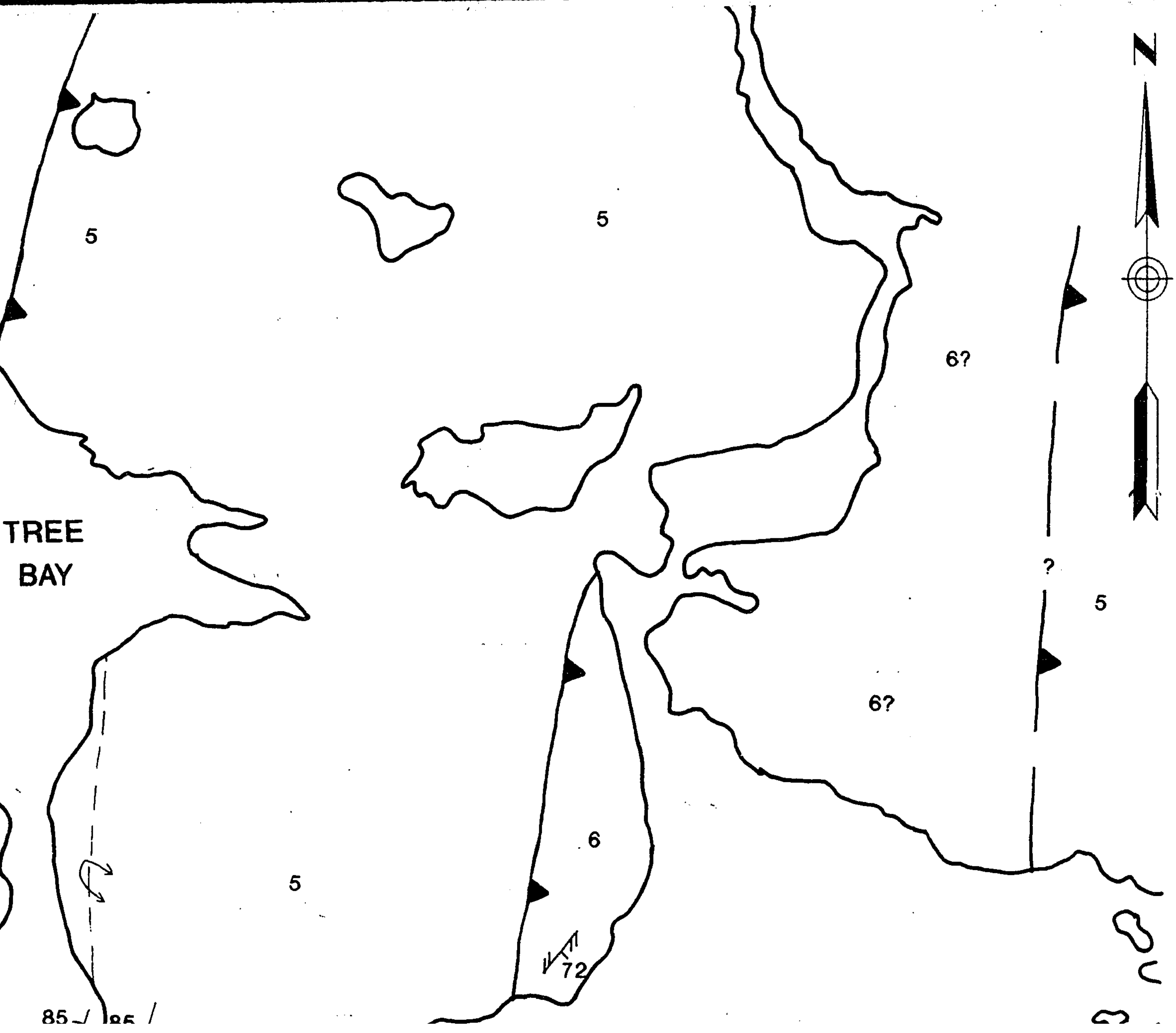

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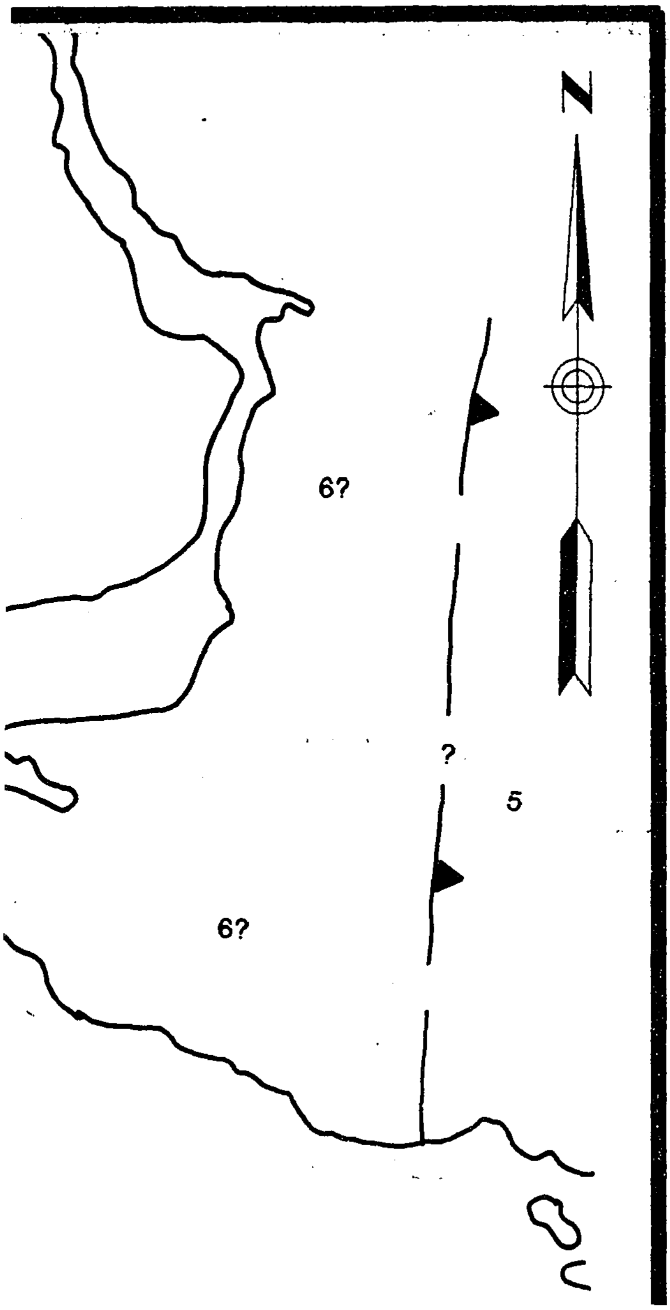

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LEGEND

FAULTS, FOLDS, CONTACTS

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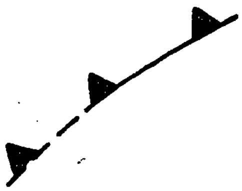

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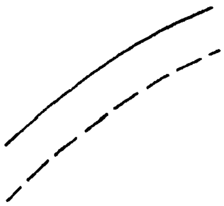

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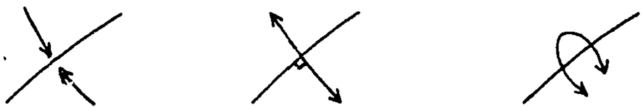
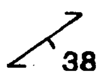


SYNCLINE, ANTICLINE, OVERTURNED ANTICLINE

OUTCROP - SCALE STRUCTURES

(MAPPED AT OUTCROPS)

STRIKE-SLIP FAULT/NORMAL FAULT



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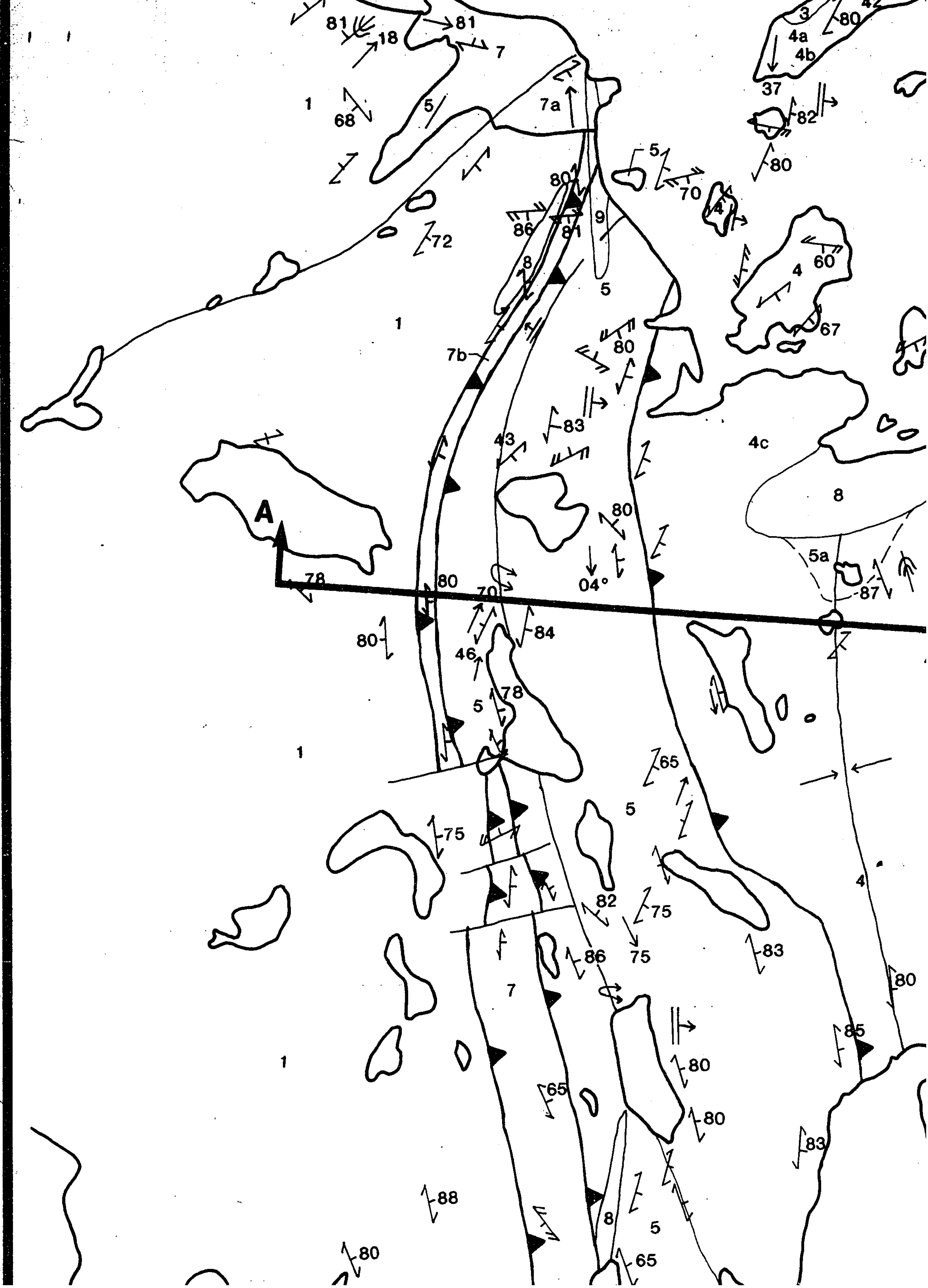
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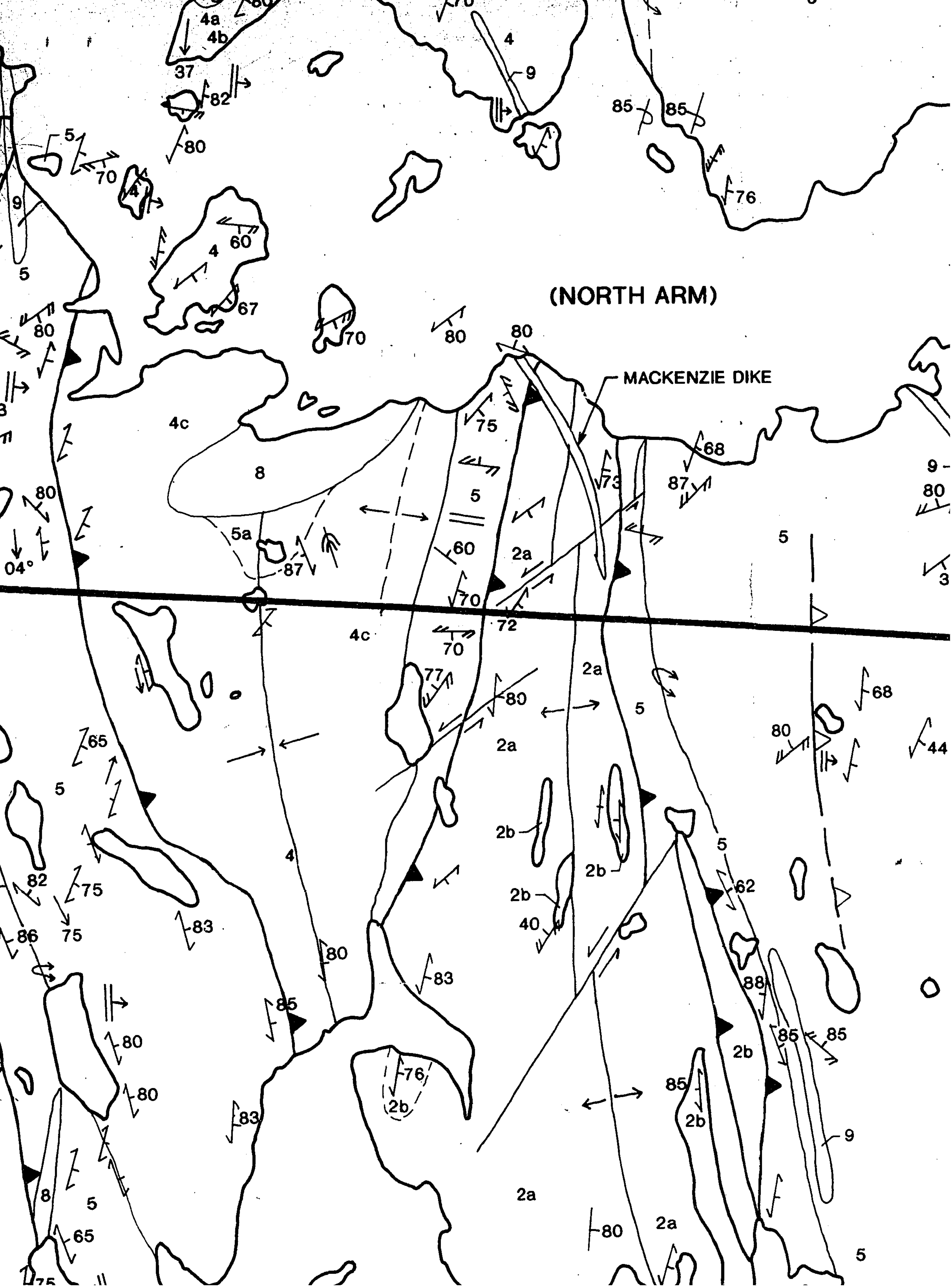
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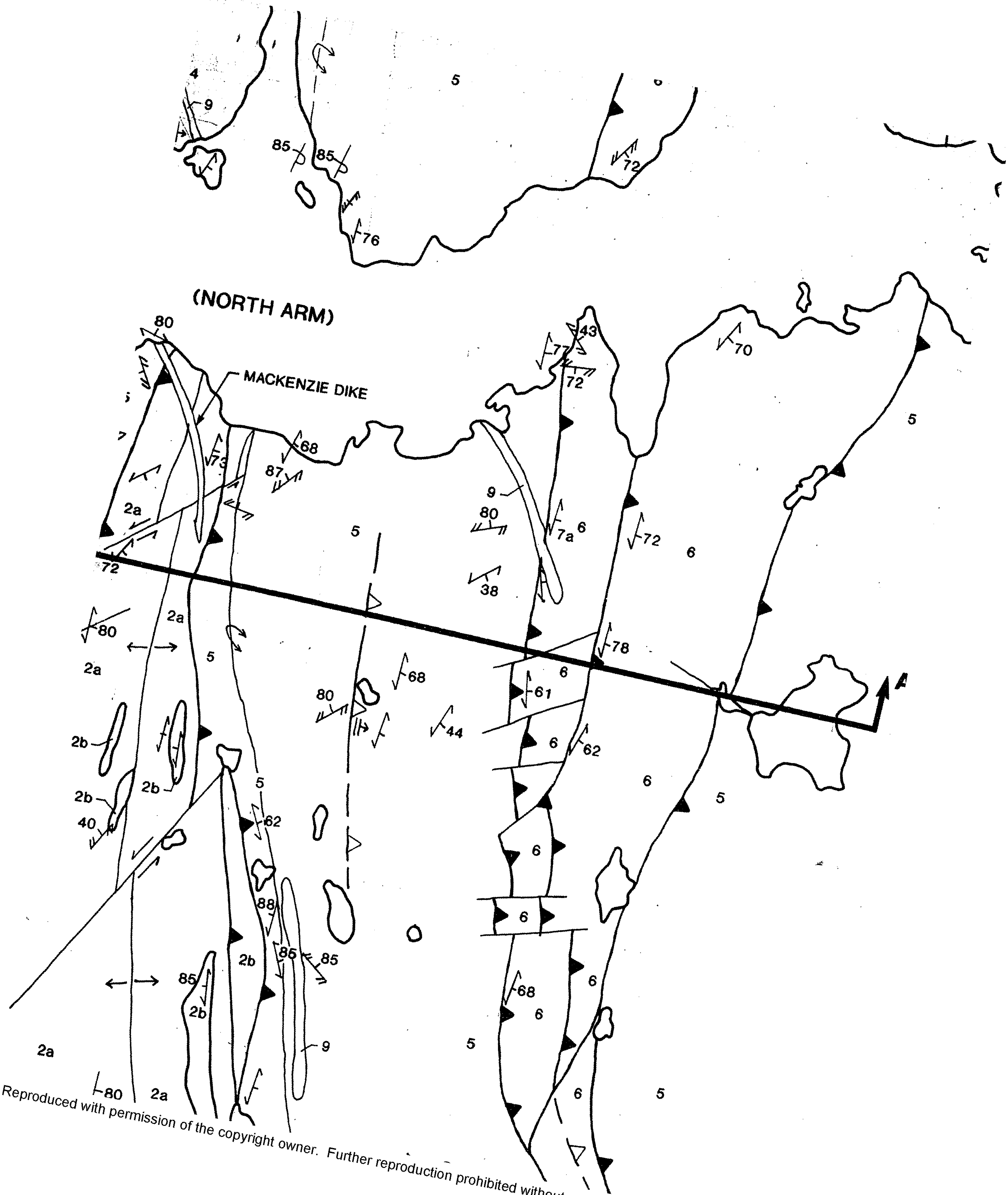
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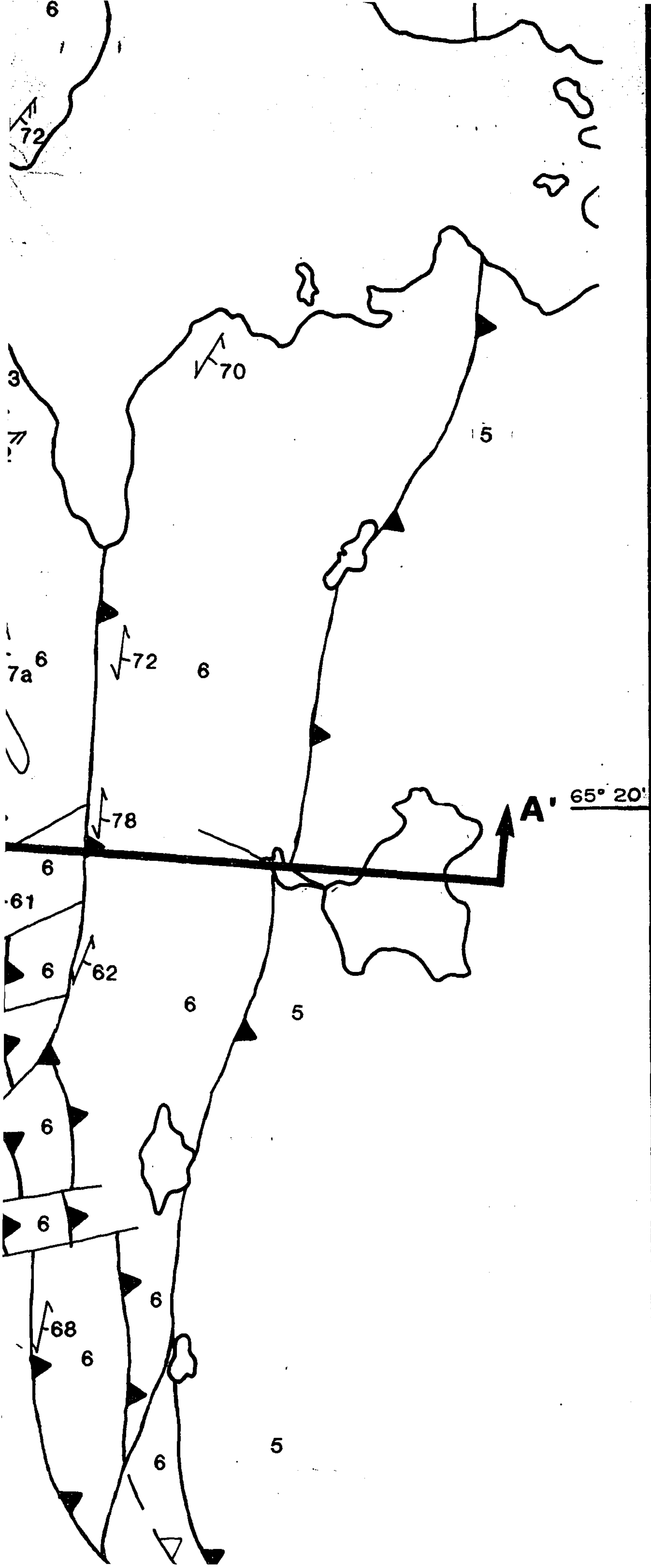

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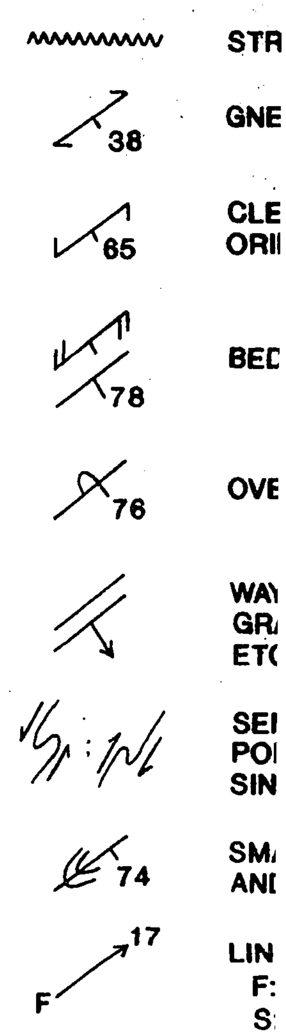


NOTES

1.) GEOLOGY OF THE AREA S(ON JACKSON (1985, 1986)

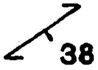
2.) FOR DETAILS, SEE ACCOMI

IDENTIFICATI

UNIT NO.	ROCK UNIT NAME (THIS STUDY)	DESCRIPTION
9	Mackenzie Diabase Dikes	Medium- to dark-gray unm diabase; weathers to red-br
8	Late Felsic Intrusives	White to pink unmetamorph trondhjemitic to tonalitic int
7	Mylonite Complex	Very fine-grained, finely lar green to black. Protoliths: 7 7b-sedimentary; 7c-felsic (

(MAPPED AT OUTCROPS)

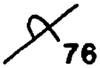
 STRIKE-SLIP FAULT/NORMAL FAULT



GNEISSIC FOLIATION ORIENTATION

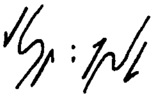
CLEAVAGE OR JOINT PLANE ORIENTATION

BEDDING PLANE ORIENTATION

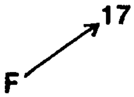


OVERTURNED BEDDING

 WAY-UP INDICATOR (CROSS BEDS; GRADED BEDS, FLAME STRUCTURES, ETC.)

 SENSE OF SHEAR INDICATOR (ROTATED PORPHYROBLAST, C-S FABRIC, ETC.) SINISTRAL; DEXTRAL.

SMALL FOLD AXIAL PLANE STRIKE AND DIP



LINEATION TREND AND PLUNGE
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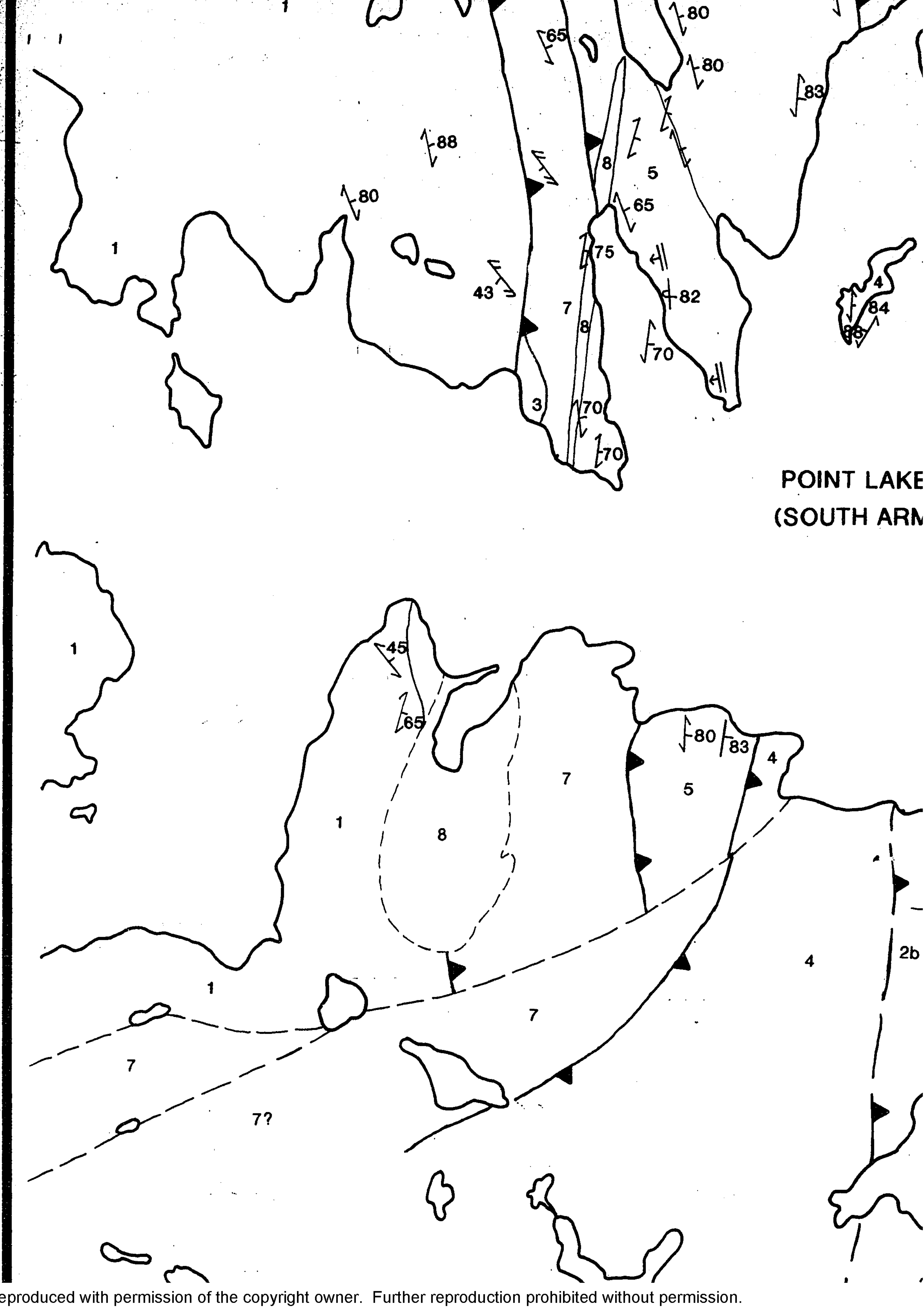
NOTES

1.) GEOLOGY OF THE AREA SOUTH OF SOUTH ARM IS BASED, IN PART, ON JACKSON (1985, 1986) AND KUSKY (1990, 1991).

2.) FOR DETAILS, SEE ACCOMPANYING TEXT.

IDENTIFICATION OF ROCK UNITS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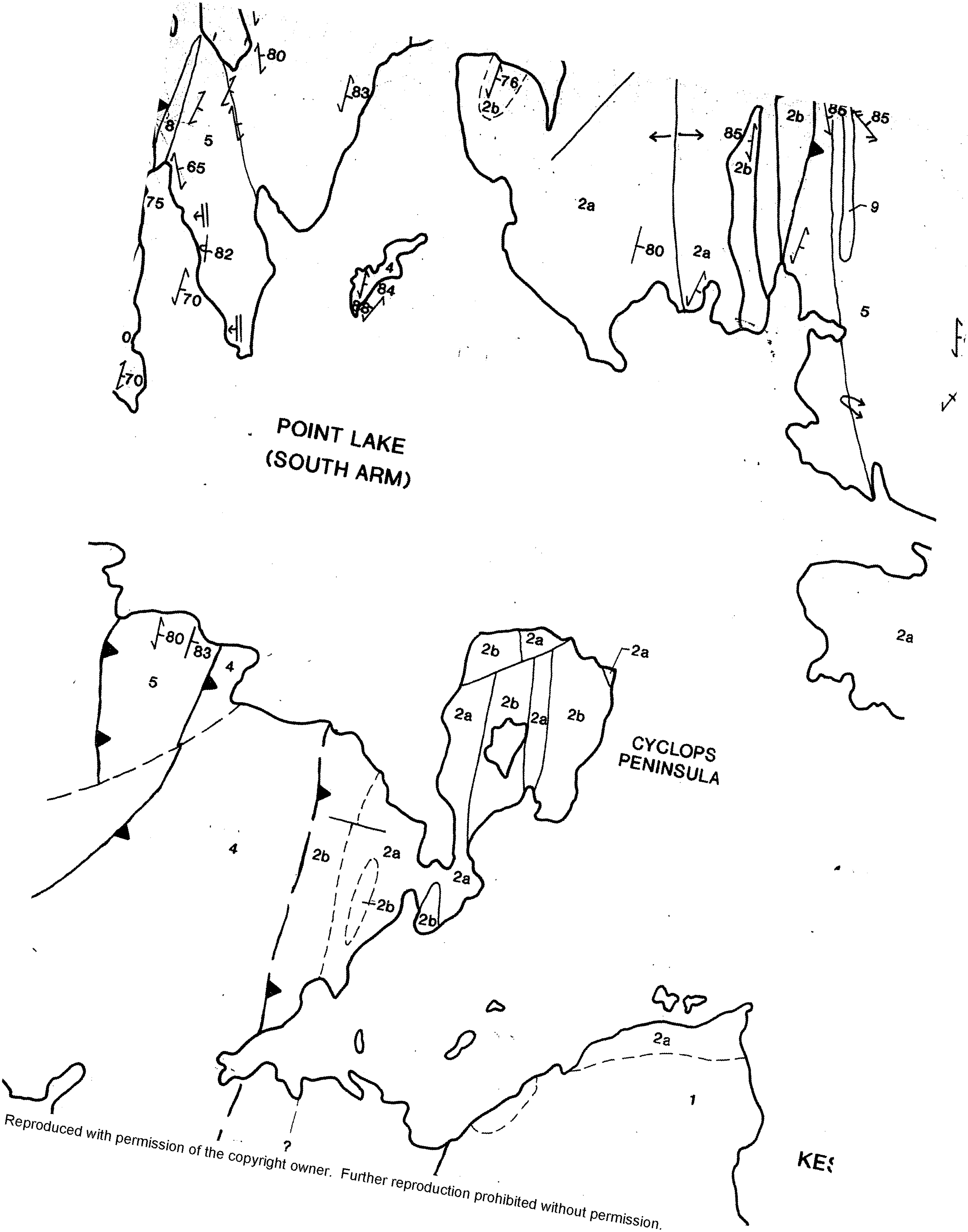
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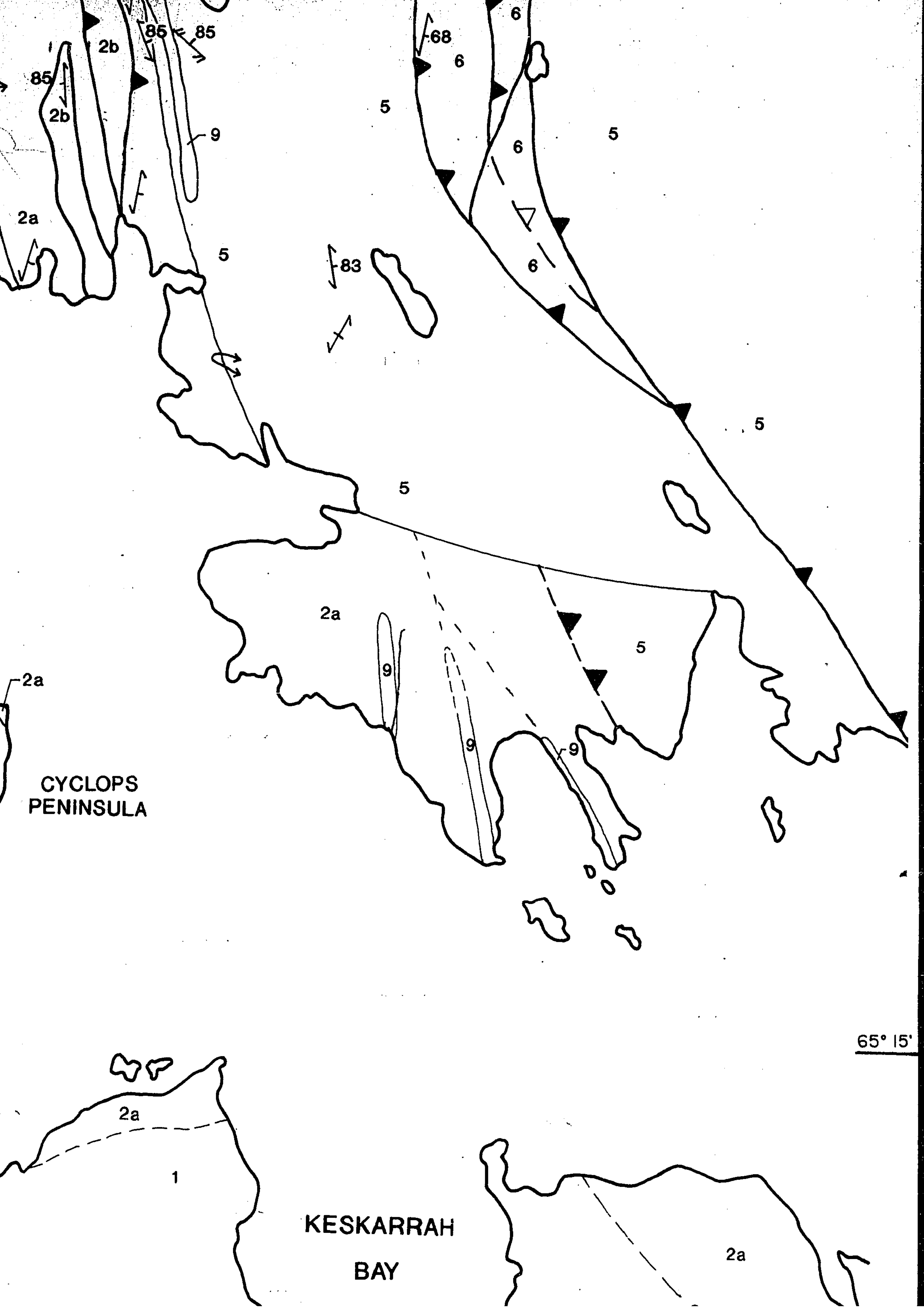

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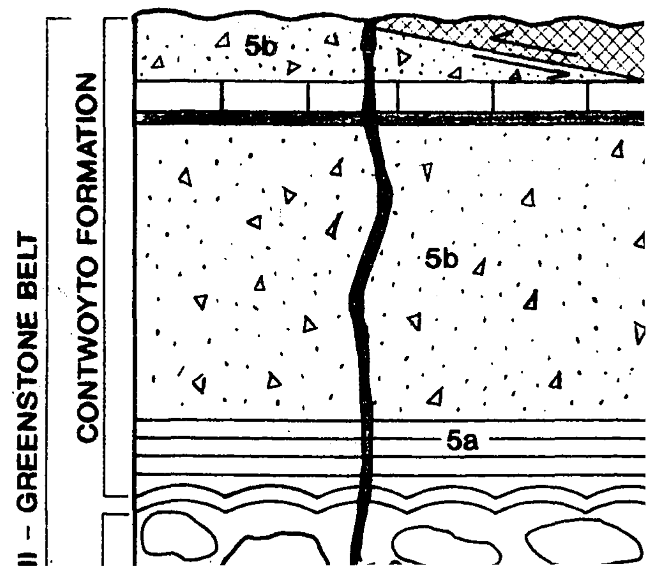
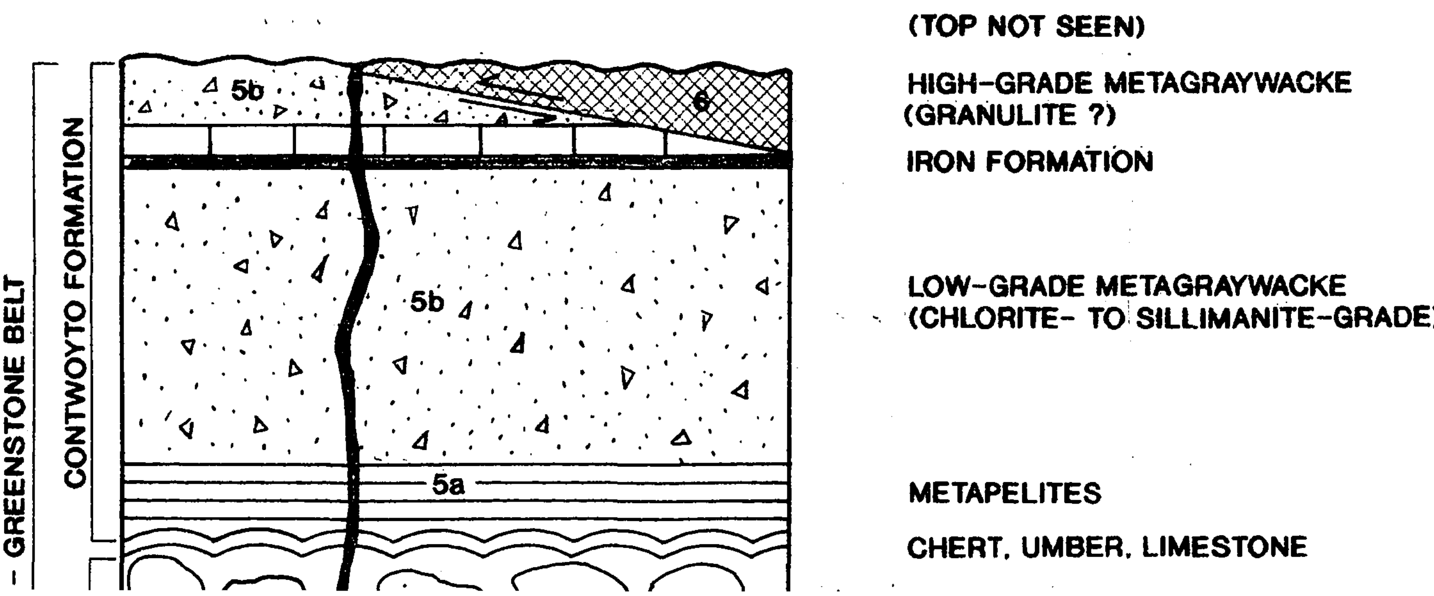
9	Mackenzie Diabase Dikes	Medium- to dark-gray unmeta diabase; weathers to red-brow
8	Late Felsic Intrusives	White to pink unmetamorphos trondhjemitic to tonalitic intrusi
7	Mylonite Complex	Very fine-grained, finely lamina green to black. Protoliths: 7a- 7b-sedimentary; 7c-felsic gnei
6	High-grade Metagraywacke	Very fine-grained, massive, ha silicic. 6a: pink; 6b: gray; 6c: m
5	Contwoyto Fm 5b: Graywacke Member	Massive to laminar-graded, gra to dark-gray graywacke with tu quartzite and limestone interlay
	5a: Shaly Member	Red, brown and black metashal
4	Greenstone 4c: Metabasalt	Dark-green to nearly black mas and vesicular pillow basalt.
4	4b: Diabase 4a: Metagabbro	Light-green to dark-green exte fractured, variable-textured me
3	Ultramafics	Light green tremolite schist.
2	Keskarrah Fm 2b: Metabasalts	Light-green aphanitic and Plag calcified pillow basalts.
	2a:Conglomerate	Polymict pebble to cobble cong
1	Basement Gneisses	Variable granitoid gneisses.

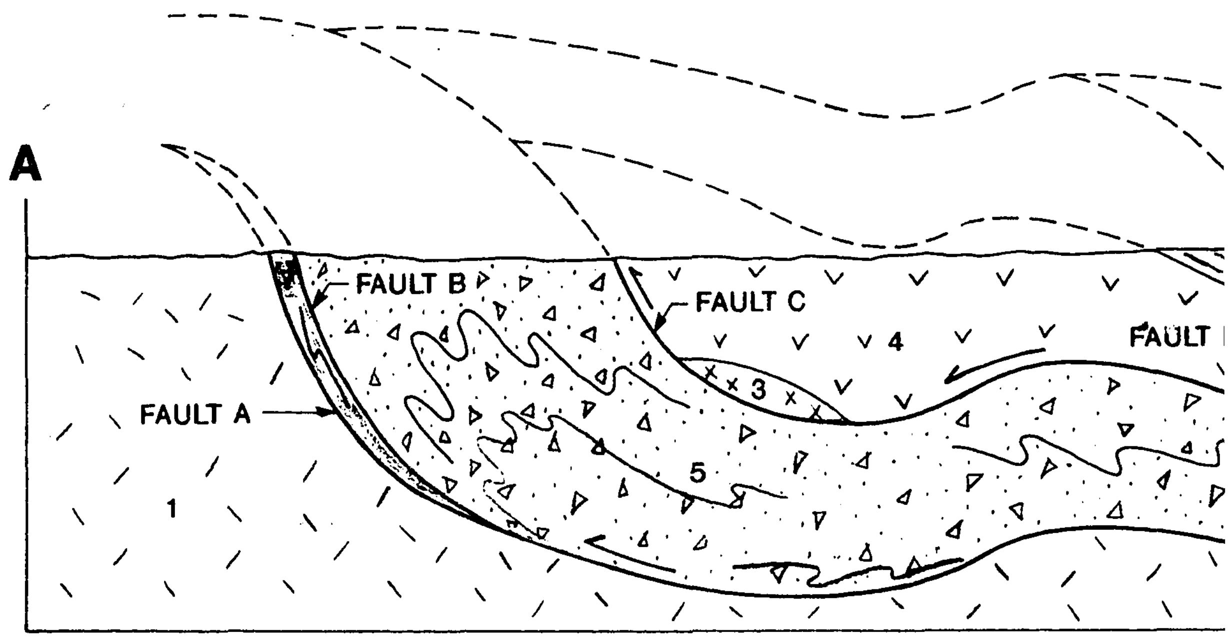
GENERALIZED LITHOT



			lower-grade metamorphics.	and dacite
5	Contwoyto Fm 5b: Graywacke Member	Massive to laminar-graded, gray-brown to dark-gray graywacke with tuff, quartzite and limestone interlayers.	Depositional over shaly member; fault contact with other units.	Bostock, 1980.
	5a: Shaly Member	Red, brown and black metashales.	Depositional over pillow basalts (Unit 4c).	No previous identification.
4	Greenstone 4c: Metabasalt	Dark-green to nearly black massive and vesicular pillow basalt.	Grades downward into diabase; rare dikes intrude Unit 5a; fault contact with other units.	Henderson, 1981.
4	4b: Diabase 4a: Metagabbro	Light-green to dark-green extensively fractured, variable-textured metabasites.	Grades upward into basalt; grades downward into gabbro	Henderson, 1981.
3	Ultramafics	Light green tremolite schist.	Thrust over basement, mylonite and basalt.	No previous identification.
2	Keskarrah Fm 2b: Metabasalts	Light-green aphanitic and Plag.-phyric calcified pillow basalts.	Basalts are intruding and interlayered with conglomerate; conglomerate depositional over basement gneiss	St. Seymour, 1988: "Point Lake basalts" (equiv. to Unit 4c)
	2a: Conglomerate	Polymict pebble to cobble conglomerate.		Bostock, 1980.
1	Basement Gneisses	Variable granitoid gneisses.	Basement to other units.	Bostock, 1980.

GENERALIZED LITHOTECTONIC STRATIGRAPHY





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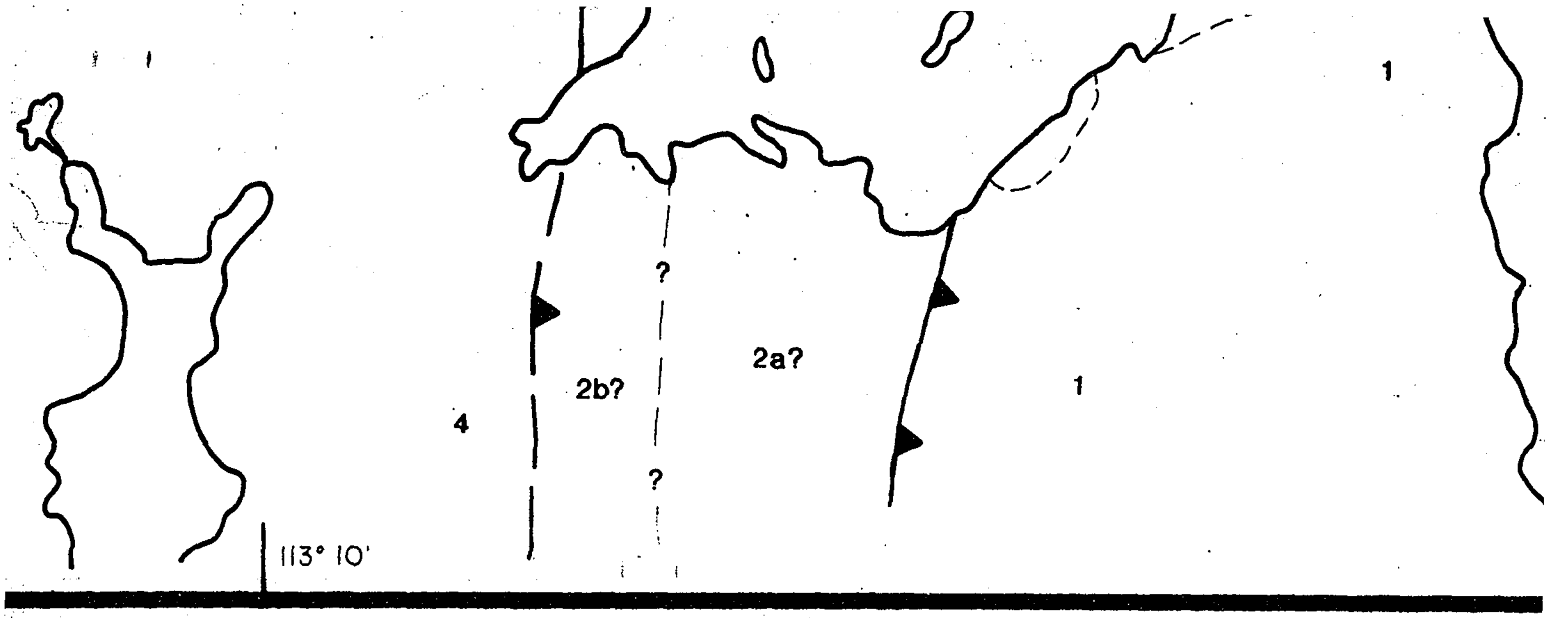
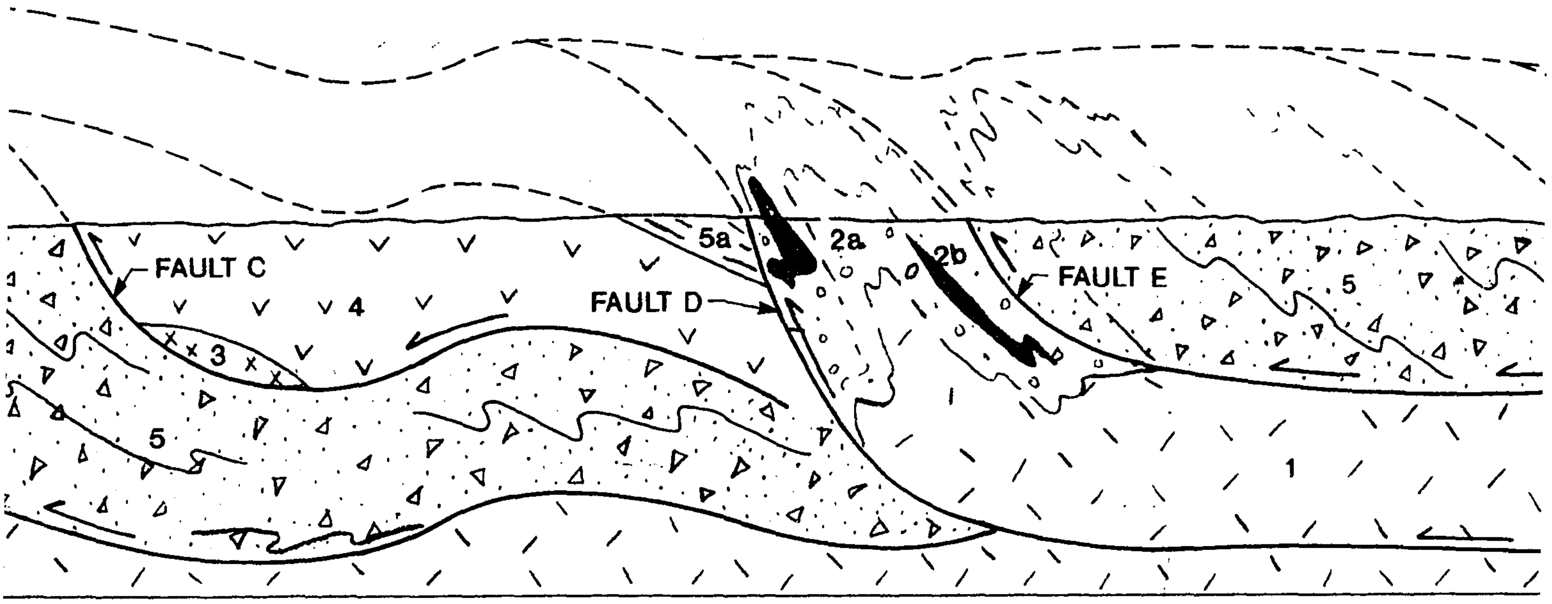
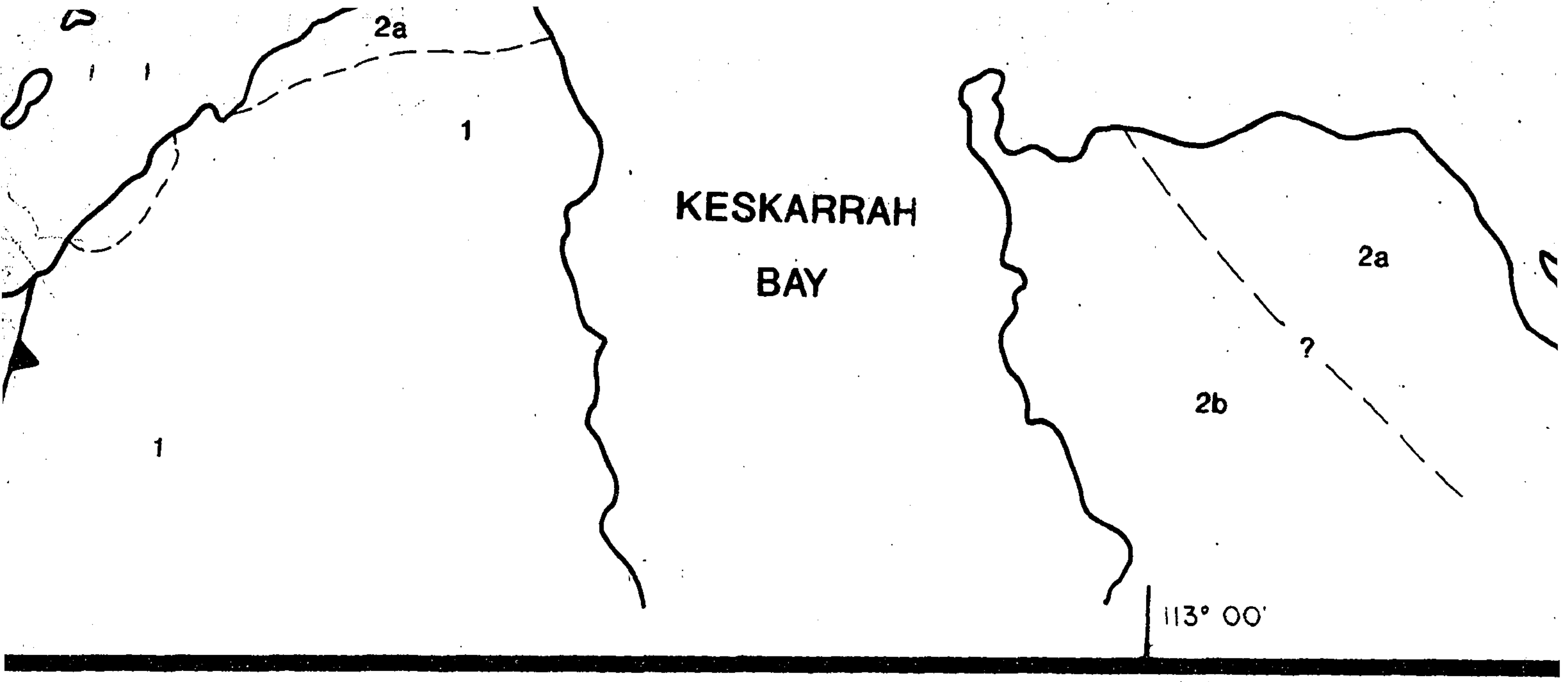




GEOLOGIC CROSS SECTION A–A'

(GENERALIZED DOWN PLUNGE PROJECTION)



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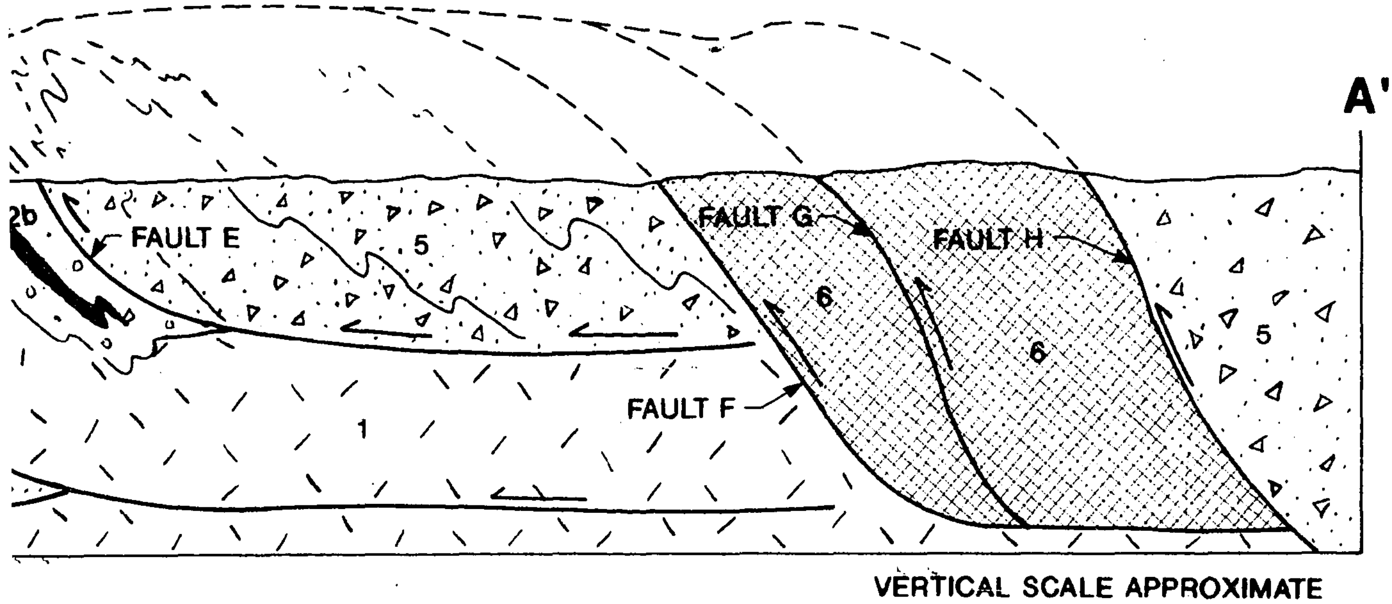
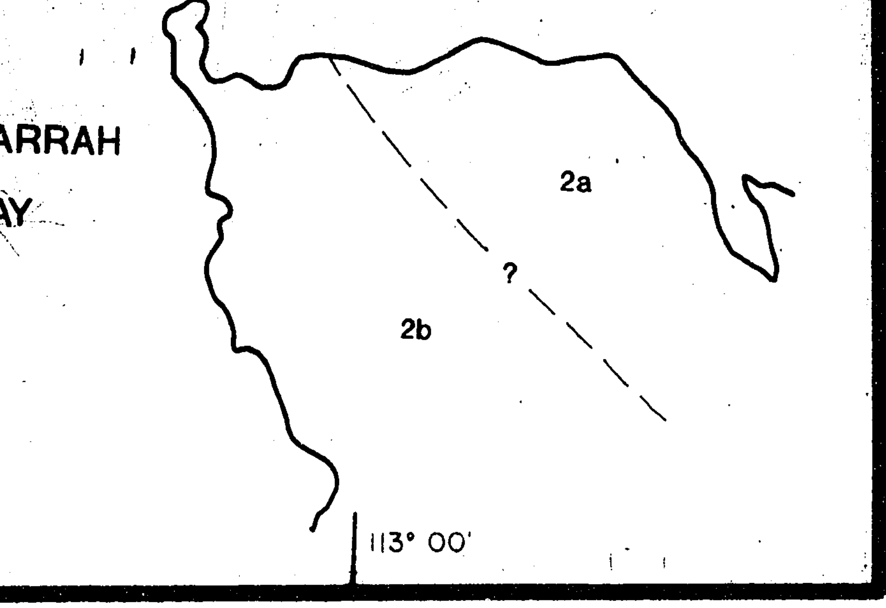


:CTION A–A'

iE PROJECTION)



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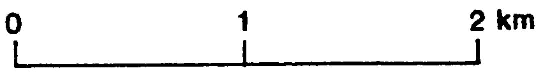

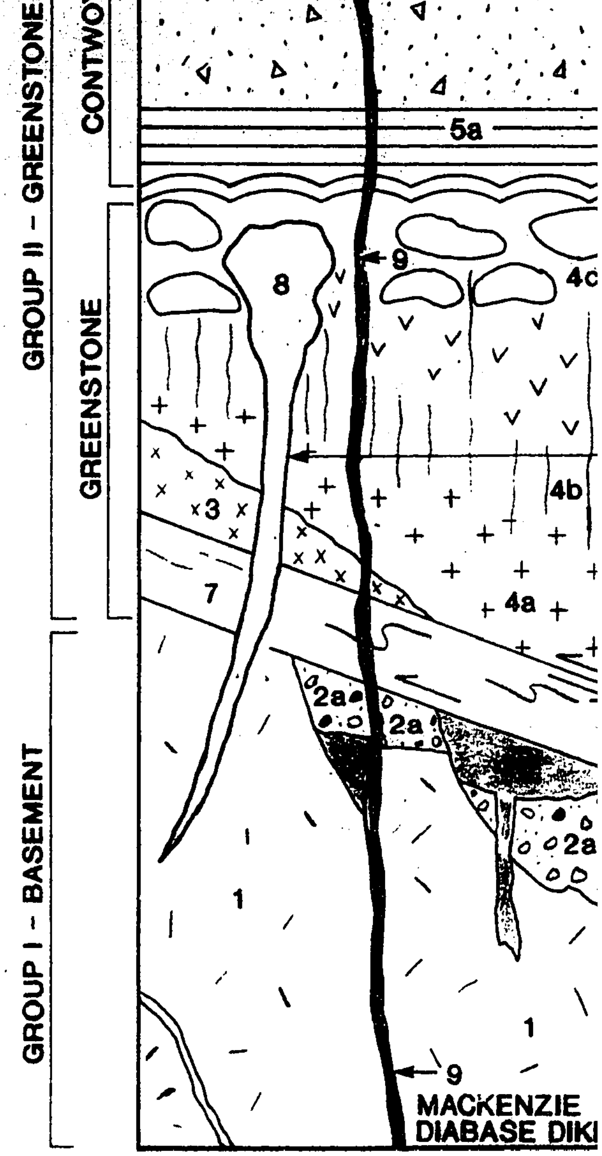

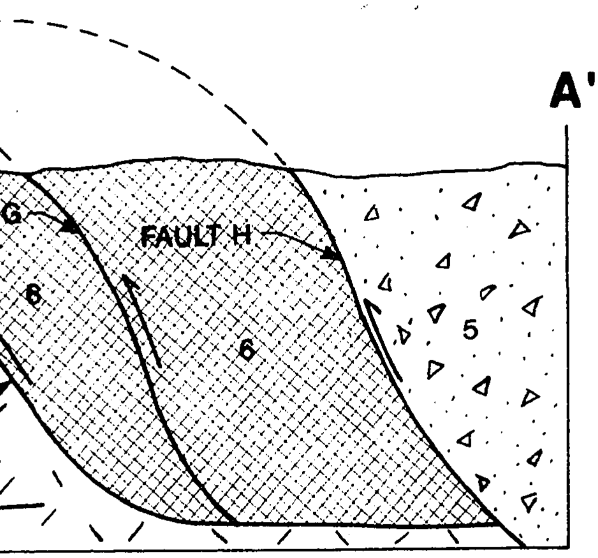

VERTICAL SCALE APPROXIMATE

REFERENCE

BASE MAP PREPARED FROM AERI
OF ENERGY, MINER AND RESOUR
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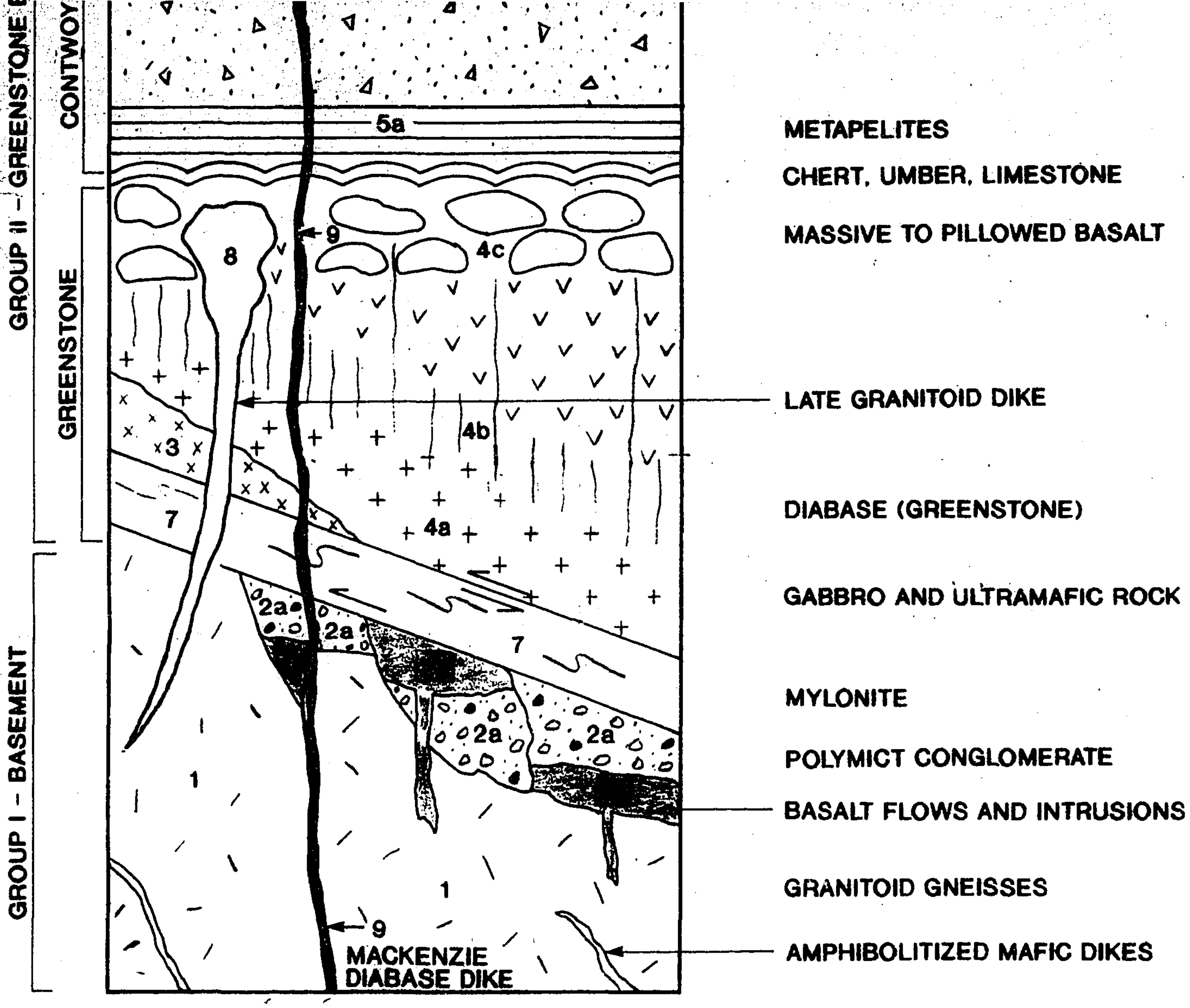

REFERENCE

BASE MAP PREPARED FROM AERIAL PHOTOGRAPHY BY GOVT. OF CANADA, BUREAU OF ENERGY, MINER AND RESOURCES, SERIES A11532, Nos. 237-242, 197-201, AND 315-316.

P.R. CONSIDINE