# PETROLOGY AND SEDIMENTATION OF EARLY PRECAMBRIAN GRAYWACKES IN THE EASTERN VERMILION DISTRICT, NORTHEASTERN MINNESOTA

A THESIS
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BY
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Frontispiece: Sunset over Holt Lake, Boundary Waters Canoe Area, northeastern Minnesota, Section 14, T.65N., R.6W.

ABSTRACT

Archean metasedimentary rocks of the eastern Vermilion district consist primarily of "volcanigenic" graywackes, siltstones, slates, and conglomerates with minor interbeds of reworked tuffs and iron-formations. Most of the metasediments indicate a dominantly volcanic source area consisting of basalt-andesite-rhyolite piles typical of modern continental orogenic belts or island arc systems. However, clasts and detritus of Saganaga tonalite indicate that it was also an important source rock. The Saganaga batholith, located at the eastern terminus of the Vermilion district, may be compared with more recent batholiths which have been described as intruding and unroofing their own volcanic ejecta.

Bouma sequences and other sedimentary structures typical of turbidites are common in the graywackes indicating deposition in a deep water basin or trough. Detritus in the graywackes and conglomerates probably originated as temporary accumulations on the slopes of volcanic piles. Periodic slumpage of the accumulations generated turbidity currents which transported the detritus to submarine fans. The graywackes were deposited as overbank spills while the coarser material was confined to long sinuous channels forming lenses of

conglomerate. Each conglomerate unit crudely represents, from bottom to top, coarser conglomerate beds grading upward into finer conglomerate beds indicating gradual channel abandonment and a migration of channels within the fan system.

The transport direction was to the southwest along the present tectonic strike, away from the Saganaga batholith with most of the supply being at the northeastern end of an elongate basin or trough. Slates and siltstones represent the background sediment of the basin but their deposition was repeatedly blotted out by the arrival of short-lived turbidity currents.

The present structural pattern appears to have resulted from a combination of soft sediment deformation, at least two periods of tectonic folding along northeast and northwest axes, and late phase faulting. Folds, resulting from downslope soft sediment slump movements, range from a few centimeters to over a meter across and are varied in their style and attitude, often becoming chaotic. The major folds, defined by reversals in top directions, were formed during the first period of tectonic deformation and trend northeast with steep axial planes and near-horizontal plunges. These folds appear to have been deformed by a later tectonic event. The later deformation formed minor northwest-trending folds with steep axial planes and plunges. Late phase faulting occurred on a regional scale deforming local areas of all rock bodies and divided the district into several separate segments.

Deformation of the volcanic-sedimentary belt is attributed to Algoman tectonism, 2.7 b.y. ago. Since the Saganaga batholith appears to have been emplaced slightly earlier than the other Algoman granites of the Vermilion district, it may have acted as a buttress against which the younger sediments were folded, as suggested by Gruner (1941).

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# CHAPTER I

# INTRODUCTION

Archean metasediments of the Vermilion district have been interpreted as volcaniclastic deposits derived largely from erosion of volcanic piles. Plutonic detritus present within metasediments in the eastern terminus of the district was derived from the Saganaga batholith which intruded the older part of the volcanic pile.

The main purpose of this investigation was to determine the nature of the source rocks, the environment of depositon, and the deformation of graywackes and conglomerates within a portion of the Knife Lake Group. The area of study is located at the eastern end of the Vermilion district, approximately 65 kilometers northwest of Grand Marais within the Boundary Waters Canoe Area of northeastern Minnesota (Figure 1).

This investigation is one of four masters theses conducted within the eastern portion of the Vermilion district. Feirn (1977) studied an area adjacent to and east of this investigation; Duex (pending completion) studied an area adjacent to the north; and Vinje (pending completion) studied an area adjacent to the south. McLimans (1971) conducted studies on four conglomerate units within the eastern Vermilion district.

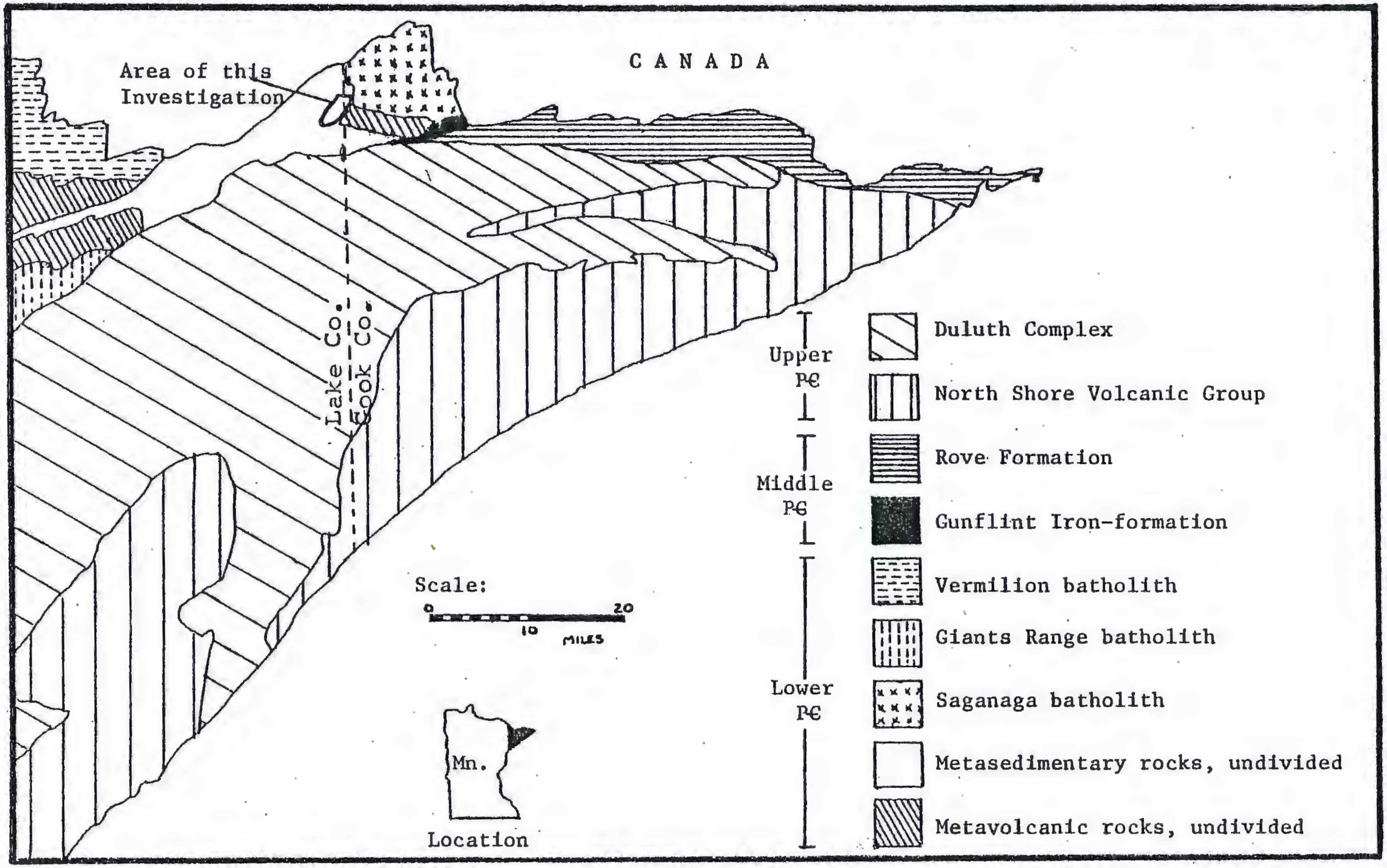



Figure 1: Location of the study area, northeastern Minnesota.

The relationships of the Saganaga batholith to the surrounding metasedimentary-metavolcanic sequences is currently under investigation by Dr. D.M. Davidson and Dr. R.W. Ojakangas (NSF Grant -- "Emplacement, Unroofing and Deformation of the Synvolcanic Saganaga Batholith (Archean), Vermilion District, Northeastern Minnesota").

Regional Geology

The Vermilion district is located in the northern portions of St. Louis, Cook and Lake Counties, northeastern Minnesota. It is a belt approximately 16 kilometers wide and more than 160 kilometers in length extending from the west end of Lake Vermilion northeast to Saganaga Lake on the International Boundary (Figure 2). The belt is an Archean metasedimentary-metavolcanic complex typical of the Canadian Shield. Rocks comprising the belt are: mafic to felsic flows and pyroclastics, volcaniclastic sediments (graywacke and slate), conglomerates, arkoses, and chemical sediments (chert and iron-formation). The district includes five formations (Morey and others, 1970). The Ely Greenstone at the base is stratigraphically overlain locally in the west by the Soudan Iron-formation and the Lake Vermilion Formation, and by the Knife Lake Group to the east. The Knife Lake Group is overlain by the Newton Lake Formation. The surface upon which the Ely Greenstone was deposited has not been found in the Vermilion

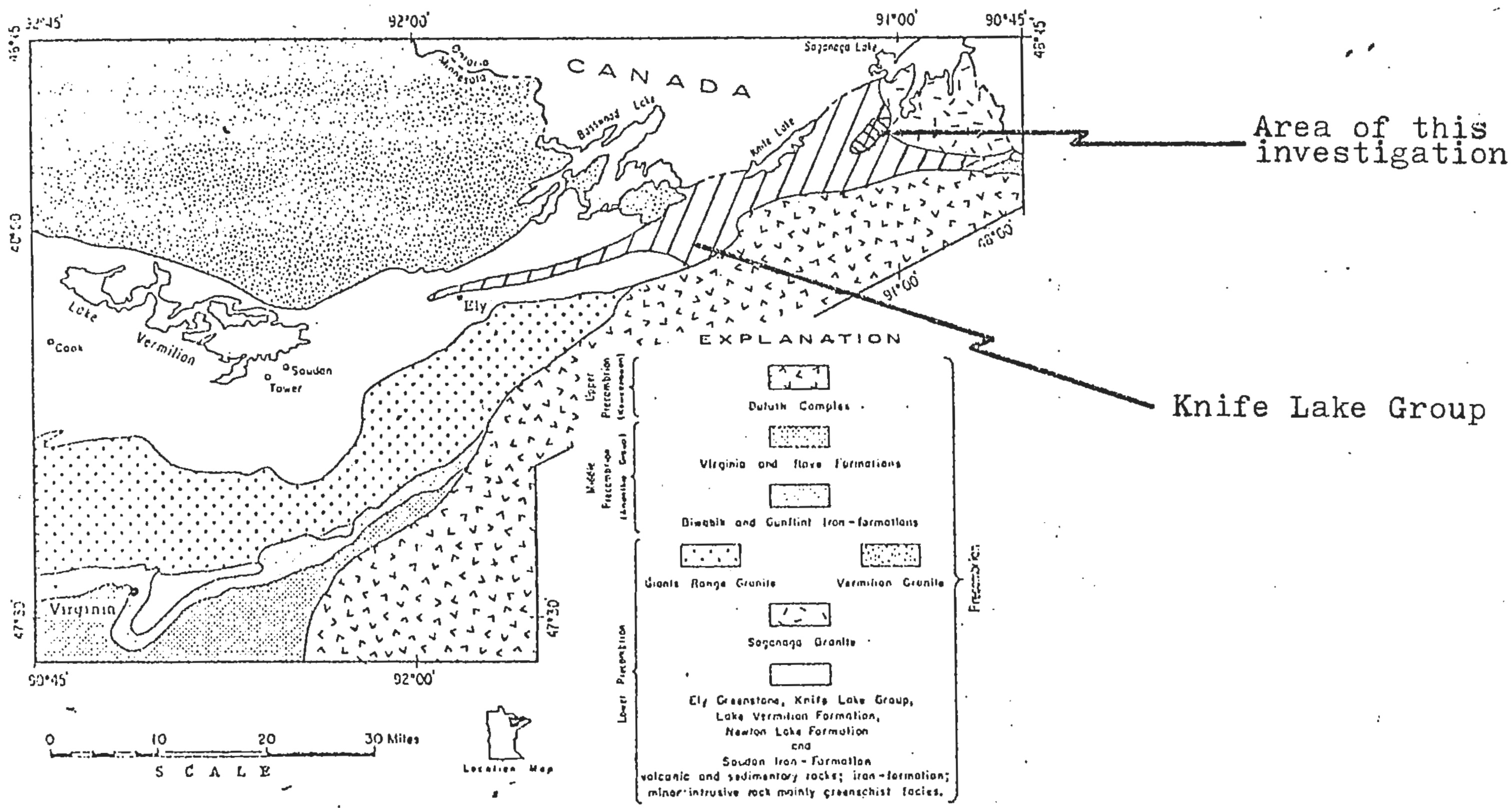



Figure 2: Location of the Vermilion district and the Knife Lake Group northeastern Minnesota (after Ojakangas, 1972a).

district. The formations trend northeast, are steeply inclined with dominant northwest topping directions, and have been subjected to low grade metamorphism (generally greenschist facies), tight isoclinal folding and faulting.

The area is bounded by granitic batholiths (Vermilion batholith to the north, Giants Range batholith to the south, and Saganaga batholith to the east) which were all emplaced at about the same time during the Algoman orogeny, ca 2.75-2.70 b.y. ago (Goldich, 1972). The Saganaga batholith appears to have been intruded and unroofed slightly earlier than the other batholiths and shed detritus into the upper part of the Knife Lake Group.

Sedimentary rocks of this belt have been interpreted as volcaniclastic with detritus supplied by erosion of island-arc basalt-andesite-rhyolite piles (Green and others, 1969; Green, 1970; Sims and others, 1968; McLimans, 1971, 1972; Ojakangas 1972a, 1972b; Sims, 1972; Sims and Morey, 1972). Similar conclusions have been applied to other metasedimentary-metavolcanic belts of the Lake Superior area (Bass, 1961; Goodwin, 1962; Goodwin and Shlanka, 1967; Ayres, 1969; Anhaeusser and others, 1969).

The graywackes and conglomerates were deposited in a subaqueous environment via turbidity currents, as exemplified by sedimentary structures characteristic of turbidites. A few clastic rocks within the Knife Lake Group have plutonic detritus mixed with the volcanic material. McLimans (1971, 1972) looked at four separate conglomerates and determined that all the granitic pebbles, which totaled from 7 to 100 percent of the clasts of the four conglomerates, were derived from the Saganaga batholith.

The Vermilion district is uncomformably overlain to the south and east by Middle Precambrian rocks consisting of dominantly clastic rocks and intercalated iron-formations. They are assigned to the Animikie Group (ca 2.0 b.y. old) and are represented by the sedimentary sequences of the Mesabi Range to the south and the Gunflint Range to the east.

Upper Precambrian rocks (ca 1.1 b.y. old) assigned to the Keweenawan include the North Shore Volcanic Group which erupted into what is now called the Lake Superior basin, and the Duluth Complex which intruded near or at the base of the volcanics. The Duluth Complex truncates and metamorphoses the rocks of the eastern Vermilion district.

Previous Work

The earliest investigations of the Vermilion district were published in a series of "Annual Report [s] on the Geology and Natural Historu Survey of Minnesota" by A. Winchell, H.V. Winchell, N.A. Winchell, and Grant. N.H. Winchell, in 1882, first noted the conglomerate of Ogishkemuncie Lake and recognizing that it contained Saganaga granite clasts determined it was younger than the Saganaga batholith. He later looked at the finer-grained sediments in the area and called them "Knife Lake Slates." Their relationship to the Saganaga batholith was one of controversy. A.H. Winchell (1888) deduced that the granite was younger than the sediments and was derived from them by progressive metamorphism. Lawson (1891) thought the granite intruded the sediments and had no connection with them. N.H. Winchell believed the granite to be older and thus contributed material to the "Knife Lake Slates." Grant (1893) when he first observed arkoses at Cache Bay on Saganaga Lake on the Ontario side of the border, thought that the granite had intruded the sediments and that the arkose beds were thin sheets of altered granite. Upon a second visit (1899) he noted the sedimentary characteristics of the arkoses and the Saganaga boulder conglomerates and concluded that they were derived from the Saganaga batholith.

The above contributions are summarized in "The Vermilion Iron-Bearing District of Minnesota," a U.S.G.S. monograph by Clements (1903). Clements decided that the "Knife Lake Slates" were younger and unconformably overlie the Ely Greenstone, Soudan Formation, and Saganaga Granite. He placed the unit in the Lower Middle Huronian and subdivided it into; 1) a basal "Ogishke conglomerate," conformably overlain by 2) the "Agawa Iron-Bearing Formation" and 3) the "Knife

Lake Slates." The belief was that these sediments were intensly folded; thus the conglomerate was exposed in anticlines while the slate occupied the synclines.

In the "Precambrian Rocks of the Lake Superior Region" by Leith, Lund and Leith (1935) the rocks of the Vermilion district were portrayed on the map as "Knife Lake Series" without definite assignment of age. The authors determined that the formation was older than Huronian and younger than the Laurentian granites (Saganaga) but its exact position on the time scale was not designated. Stark and Sleight (1939) placed the formation in the lower Algonkian system and subdivided the "Ogishke conglomerate" into three separate units

Gruner (1941) mapped the Knife Lake Area (eastern Vermilion district) in order to determine the structural geology. He showed that conglomerates occurred at several stratigraphic horizons and since the "Knife Lake Slates" were interstratified with what were called "Ogishke conglomerate" and the "Agawa Formation", Gruner called them all Knife Lake Series, as did Grout (1933), and suggested that the two other names be dropped. Gruner's map was the first in the state to show faults (major longitudinal faults) which divided the folded Knife Lake rocks into seven structural segments. Due to a lack of correlation between the structural segments, Gruner divided the Knife Lake Group into 21 lithologic members which he estimated to total 3500 to 6400 meters in thickness. The rocks were officially termed the "Knife Lake Group" in 1951 (Grout and others), and reassigned from Middle to Early Precambrian ten years later (Goldich and others, 1961).

During the period 1966-1970, geological investigations were conducted in the western Vermilion district and summarized in a report by Morey and others (1970). The authors subdivided the rocks in the western part of the district into five members -- Ely Greenstone, Soudan Iron-formation, Lake Vermilion Formation, Knife Lake Group, and Newton Lake Formation. Each was determined to be part of a complex volcanic pile accumulation.

Further work on the Vermilion district disclosed that the western portion had been subjected to two phases of folding followed by faulting (Green, 1970; Hooper and Ojakangas, 1971).

The Saganaga batholith appears to have been unroofed early and may be slightly older than the other batholiths of the Algoman orogeny (Ojakangas, 1972a). The Saganaga tonalite is apparently intrusive into older greenstones and metasediments in the belt (Grout and others, 1951) but also provided detritus to younger sediments which lie unconformably upon the tonalite (Ojakangas, 1972a). McLimans (1971, 1972) studied three granite-bearing conglomerate units peripheral to the area of this study and noted that the source areas were mainly mafic to felsic volcanic piles as well as the Saganaga tonalite. He concluded that the conglomerates were deposited by turbidity currents, transport being from east to west away from the Saganaga tonalite and apparently parallel to the present strike of the conglomerates. He also noted that the conglomerate of Ogishkemuncie Lake can be divided into a lower non-jasper-bearing facies and an upper jasper-bearing facies.

Recent works on the Vermilion district are included in "Geology of Minnesota: A Centennial Volume"(1972) which summarizes the current knowledge of all aspects of the geology of the state of Minnesota. Five observations of particular interest to the Lower Precambrian rocks of the Vermilion district follow: 1). The metasediments and metavolcanics of the greenstone belt represent volcanic complexes typical of modern island arcs and continental borderlands (Sims and Morey, 1972; Sims, 1972; Ojakangas, 1972b). 2). There are at least two felsic-intermediate volcanic centers in the district -- one in the vicinity of Lake Vermilion, and the other in the vicinity of Knife Lake (Ojakangas, 1972b). 3). The sediments are dominantly graywackes which were derived by reworking of pyroclastics and deposited via turbidity currents (Ojakangas, 1972b). 4). The Algoman orogeny was restricted to a relatively short span of time, 2.75-2.70 b.y. ago (Goldich, 1972), in which the three major batholiths were emplaced at relatively shallow depths, deforming and metamorphosing the rocks of the Vermilion district. 5). The Saganaga batholith was unroofed while the region was still unstable and contributed material to younger sediments. This has applications to Hamilton and Myer's (1967) statement that batholiths are commonly emplaced under a thin cover of their own volcanic ejecta (Ojakangas, 1972b).

The most recent work, east of and adjacent to the area of this study, was conducted by Feirn (1977) on an older metavolcanic-metasedimentary portion of the Knife Lake Group. The metavolcanic-metasedimentary rocks of the area have been intruded by the Saganaga tonalite and are in fault contact with younger metasediments to the west.

Based on the earlier works and revisions mentioned above, the following geologic succession is offered as a generalized column for the Vermilion district of northeastern Minnesota (Figure 3).

## Present Work

An investigation of graywackes and conglomerates within part of the Knife Lake Group was undertaken to gain information pertaining to the provenance, environment of deposition, and deformation of these rocks. The area studied is an irregularly shaped area of approximately 21 square kilometers located in portions of the Ogishkemuncie Lake and Ester Lake 7-1/2 minute quadrangles. It is in the Boundary Waters Canoe located eight kilometers west of the end of the Gunflint Trail.

| Era | Lithology | Event (approx. age) | Intrusive rocks |
|---|---|---|---|
| Late Precambrian | | | Duluth Complex, North Shore Volcs, and small mafic intrusions. (1.I b.y.) |
| 1.6 b.y. | unconformity | | |
| Middle Precambrian | Rove Formation<br>Gunflint Iron-Formation | Penokean orogeny(?) | |
| 2.7 b.y. | unconformity | | |
| Early Precambrian | Newton Lake Formation<br>[Lake Vermilion Formation<br>[Knife Lake Group<br>Soudan Iron-Formation<br>Ely Greenstone | Algoman orogeny (2.75-2.7 b.y.) | Small syenitic plutons, Giants Range, Saganaga and Vermilion batholiths. |

Figure 3: Generalized geologic column for the Vermilion district, northeastern Minnesota. After Sims and Morey, 1972.

Gruner (1941) previously mapped the Knife Lake area and divided it into seven structural segments on the basis of major longitudinal faults that extend through the folded strata. The area of this particular study is situated within the Kekekabic Lake segments (Figure 4) and the rocks of this investigation are Gruner's "Amoeba Lake graywackes, slates and tuffs" (Unit 9) and, to a lesser extent, "well-banded slates and graywackes" (Unit 5). Unit 9 was mapped and interpreted by Gruner in a generalized manner and estimated to be almost 600 meters thick. No major petrographic work has been previously done on either member.

Approximately 33 days were spent in the field on various visits to the area in 1976-1977. Field work consisted of mapping using Ogishkemuncie Lake and Ester Lake 7-1/2 minute quadrangles as a base (see Plate I in pocket), and Gruner's geologic map (Figure 5) as a reference. The conglomerates and coarse-grained graywackes were sampled for petrographic study. Measurements included: strikes and dips of bedding and cleavage planes, lineation trends, paleocurrent directions (small-scale cross-bedding), and directions of glacial striations. Top indicators were Bouma sequences (A-D), graded bedding, flame structures, and the irregular, loaded bases of beds. Lab work consisted of thin section point counts, pebble counts of cut conglomerate slabs, and analysis of structural data.

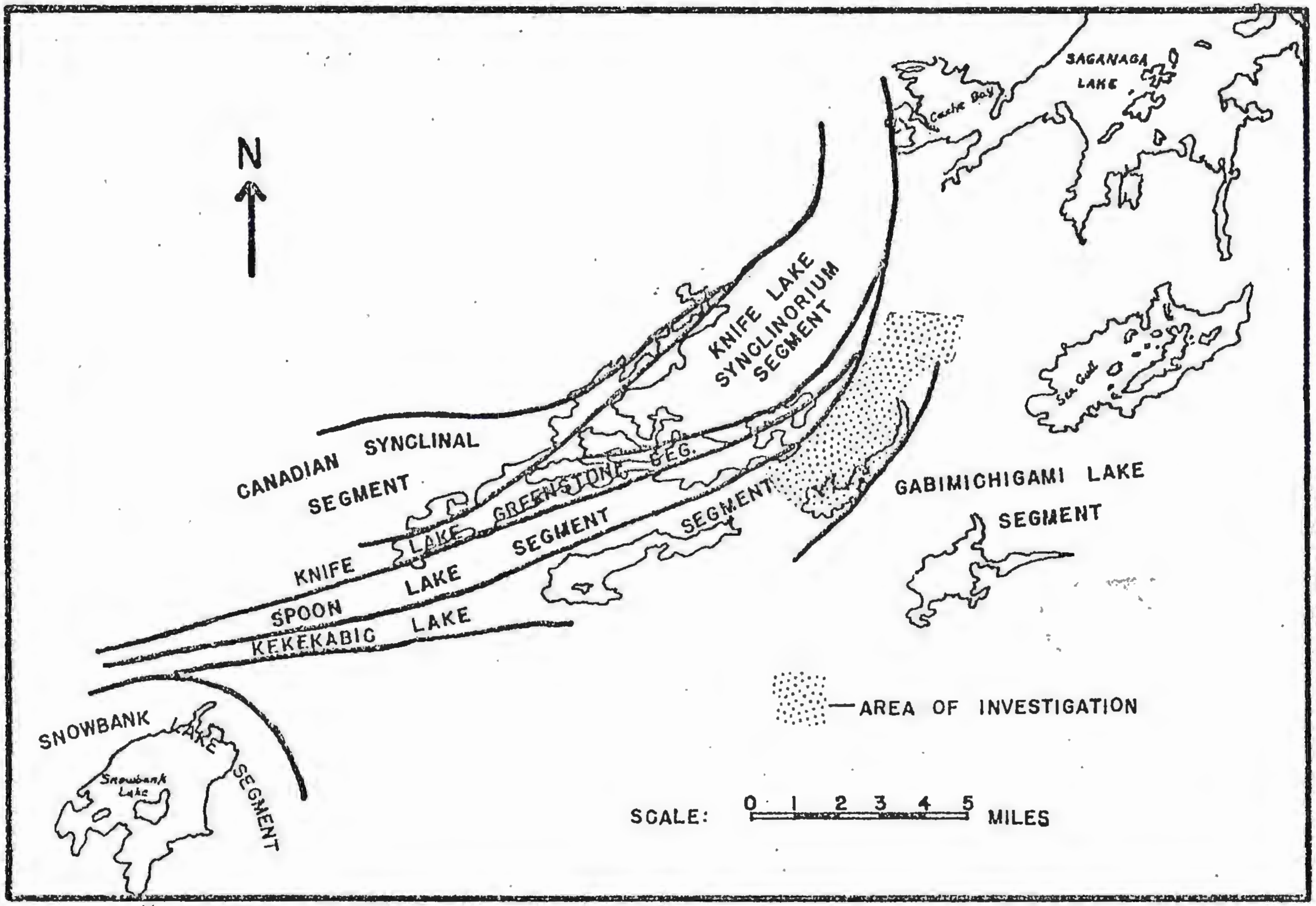



Figure 4, Structural segments of the Knife Lake Group (after Gruner, 1941)

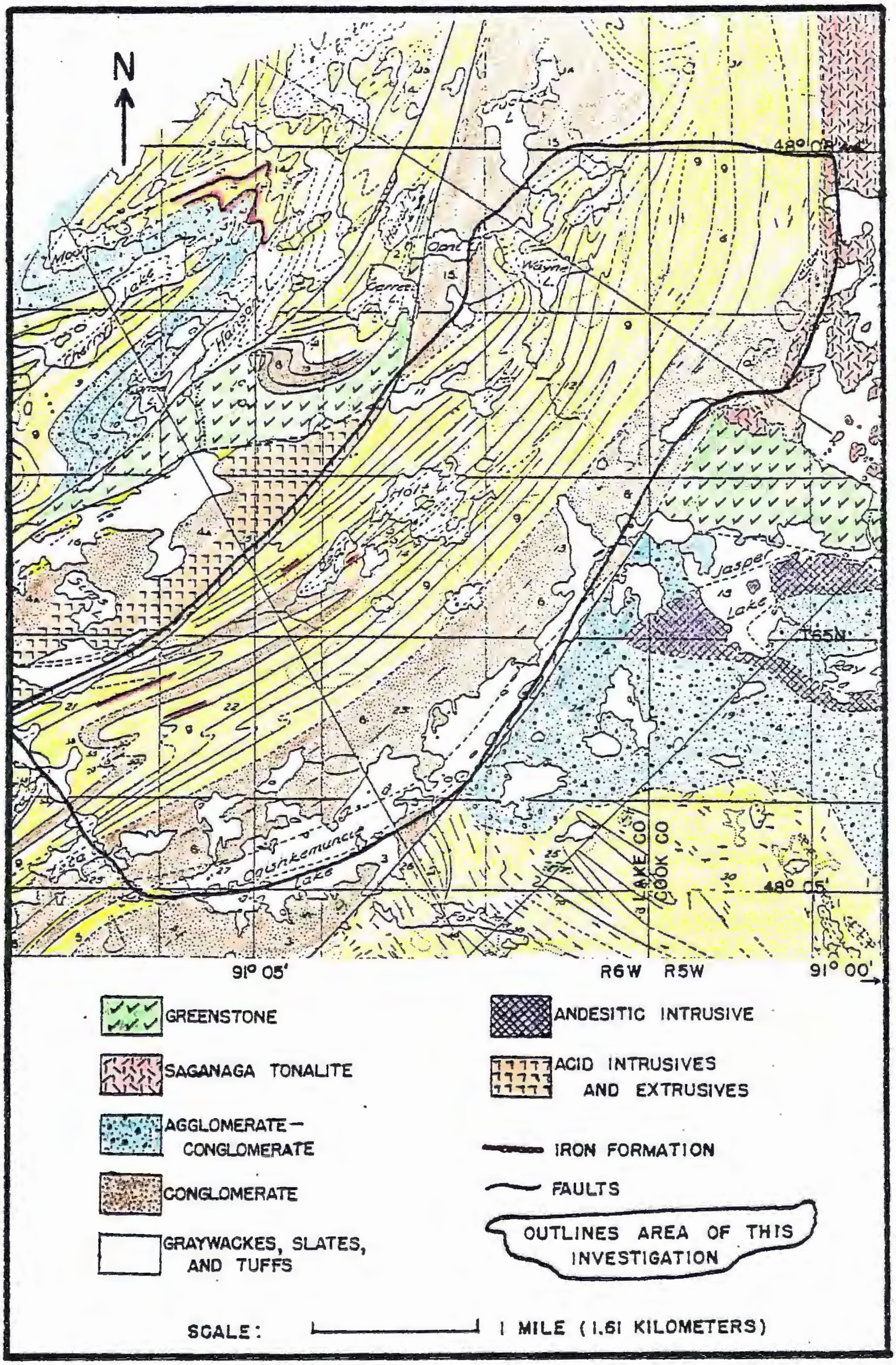



Figure 5: A portion of Gruner's (1941) geologic map of the Knife Lake area used as a reference.

The objectives of the study were to describe rocks on both megascopic and microscopic scales, to provide textural and compositional data, obtain information on the origin of the rocks in the belt and their tectonic development, and determine the nature of the source rocks.

Topography

Locally the area is hilly, with a maximum relief of 60 meters. Elevations range from 505 to 445 meters above sea level. The area is characterized by numerous lakes and swamps with a poor drainage system to the north (Hudson Bay).

It is covered by a dense forest of deciduous and coniferous trees with an undercover of smaller plants and windfalls which make travel by foot difficult.

Acknowledgements

I would like to thank Dr. Richard W. Ojakangas, University of Minnesota-Duluth, who introduced the area to the author, provided valuable assistance and suggestions, and served as thesis advisor. I wish to thank Dr. Donald M. Davidson Jr. and other members of the faculty of the University of Minnesota-Duluth for their suggestions and criticisms. Thanks are also expressed to my field partners who helped and assisted me on numerous visits to my field area. They are Curt Everson, Dennis Laybourn, Lauri Outhouse, Gary Rolek, Art Severson (father), Dan Severson, and Drew Strakele. Special thanks are expressed to the Minnesota Geological Survey for partially defraying the costs of field expenses and thin section preparation.

# CHAPTER II

# STRATIGRAPHY AND GENERAL GEOLOGY

## Stratigraphy

The Knife Lake Group was originally thought to consist of three main units; a basal "Ogishke conglomerate," overlain by the "Agawa Iron-formation" and the "Knife Lake Slates." They were thought to lie unconformably above the Soudan Iron-formation and the Ely Greenstone (basement) which included all mafic volcanics. All these formations were assumed continuous throughout the Vermilion district but due to a complex fold pattern were exposed in a random manner (Clements, 1903).

Clements' concept persisted until Gruner (1941) mapped the Knife Lake area and disclosed that the rock types were more diverse than originally thought, and that major longitudinal faults divide the folded strata into segments making lithologic generalizations impossible. Gruner suggested that the "Ogishke conglomerate" and "Agawa Iron-formation" did not deserve formational status as they are lensoid, discontinuous, and occur at several stratigraphic horizons. He also divided the Knife Lake Group into 20 mappable lithologic types including conglomerates, agglomerates, graywackes, slates, tuffs, and porphyries. All mafic volcanics were still considered "Ely Greenstone."

Because of recent investigations (Green and others, 1966; Morey and others, 1970) the Knife Lake Group has been broken into two formations (Knife Lake Group and Lake Vermilion Formation) which may be correlative. It was also determined that mafic volcanism was not restricted to a single episode; therefore, not all mafic volcanics represent the basement - Ely Greenstone - as first thought.

The present stratigraphic sequence (Figure 6) proposed for the Vermilion district (major emphasis on the Knife Lake area) is based on Gruner (1941) and rêcent field mapping (Morey and others, 1970). Note that this sequence is extremely generalized due to the structural complexities associated with the district which make lithologic correlations almost impossible. The time-stratigraphic relationships have consistently changed with more detailed mapping and will continue to do so in the future. At present many of the true relationships still lie hidden under the lakes, forests, and swamps of northeastern Minnesota.

## General Geology

### Ely Greenstone

Van Hise and Clements (1903) originally classified any mafic volcanic unit within the Vermilion district as Ely Greenstone, which represented the early basement crust. As redefined by Morey and others (1970), the Ely Greenstone is an elongate body of massive subaqueous (pillowed) mafic flows (90 percent basaltic composition)

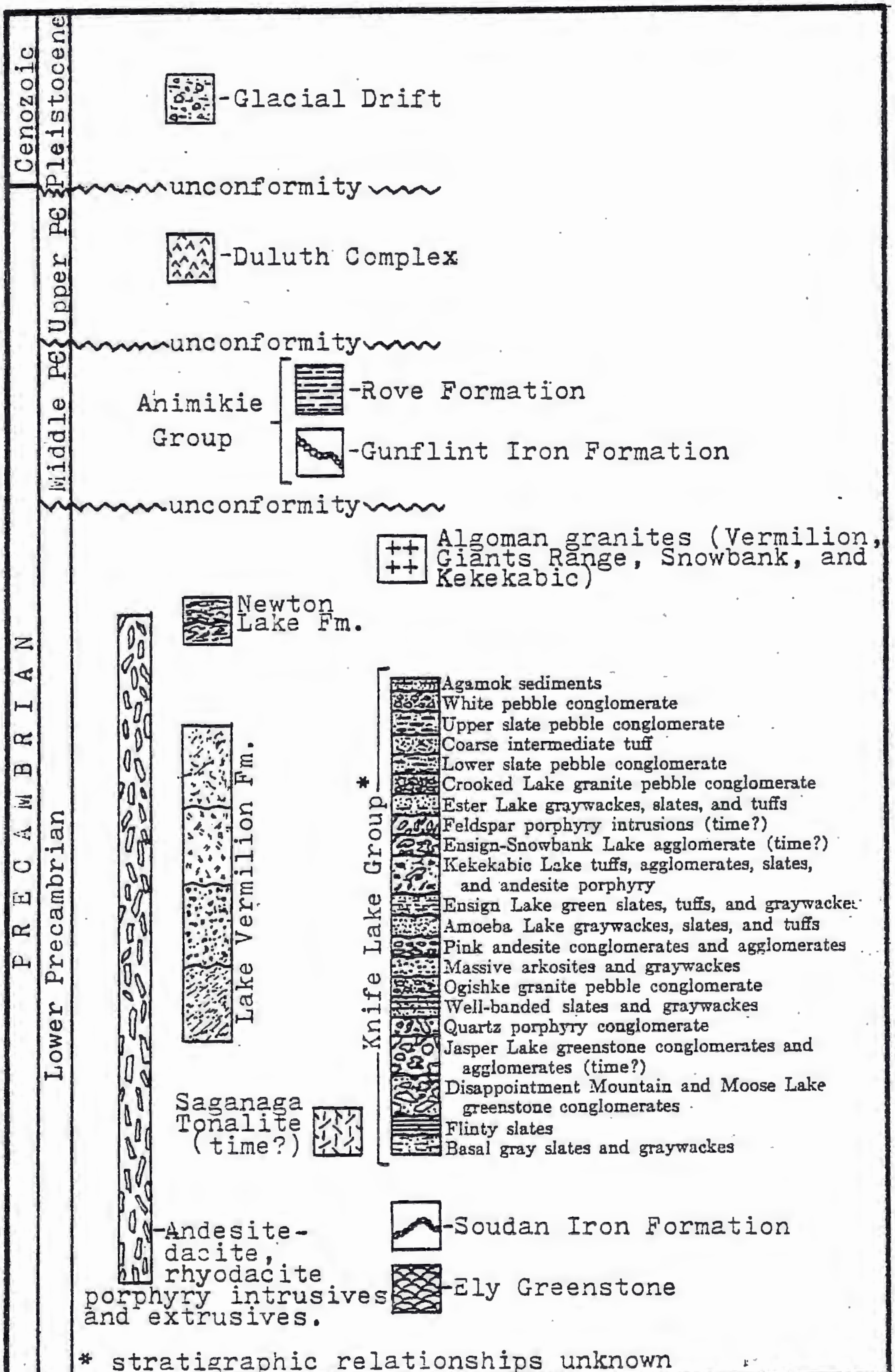



Figure 6: Generalized stratigraphic sequence for the Vermilion district. Data from Gruner (1941) and Morey and others (1970).

and interbedded sediments exposed in the vicinity of Tower eastward to Moose Lake. Field relations indicate that it is not entirely older than other clastic strata (Lake Vermilion Formation and Knife Lake Group) which were contemporaneously deposited with at least the upper part of the Ely Greenstone. The base of the Ely Greenstone is not exposed anywhere in the Vermilion district.

Other mafic flows within the district are recognized as greenstones but are not designated as basal Ely Greenstone.

Soudan Iron-formation

Numerous lenses and beds of banded iron-formation are common throughout the Vermilion district, and were presumed to represent folded portions of a once continuous body. At present, the term "Soudan Iron-formation" is restricted to an elongate body of banded iron-formation that overlies the Ely Greenstone and is overlain by the Lake Vermilion Formation in the vicinity of Tower and Soudan (Morey and others, 1970). At this locality the iron-formation consists of fine-grained ferruginous chert with minor amounts of interbedded fine-grained clastic rocks and metabasalts. The three principal types of chert are: 1) greenish-white chert, 2) lean jasper - less than 20 percent iron content, and 3) banded jaspillite - more than 30 percent iron content (Klinger, 1956).

Other iron-formation exposures within the Vermilion district are too small and discontinuous for formational status.

Lake Vermilion Formation

The Lake Vermilion Formation was originally part of the Knife Lake Group but since it cannot be traced from the type locality, the metasediments and metavolcanics in the vicinity of Lake Vermilion were redefined by Morey and others (1970). The sequence may be correlative with the Knife Lake Group. It is divided into four informal members: 1) feldspathic-quartzite member, 2) metagraywacke-slate member, 3) volcaniclastic member, and 4) mixed metagraywacke-felsic conglomerate member.

Knife Lake Group

The succession of dominantly clastic rocks (graywackes, slates, and conglomerates) with mixed volcanic flows and pyroclastics in the vicinity of Knife Lake was given the name "Knife Lake Group" by Grout and others (1951). It overlies the Ely Greenstone and is overlain by the Newton Lake Formation between Moose and Shagawa Lake (Morey and others, 1970). Gruner (1941) divided the sequence into 20 mappable units which he estimated to be between 3500 and 6400 meters thick.

Two distinct types of metavolcanic-metasedimentary sequences are evident within the eastern portion of the Knife Lake Group; those that were deposited before emplacement of the Saganaga batholith (Feirn, 1977), and those that were deposited after and contain Saganaga tonalite detritus (McLimans, 1971, 1972). The sequence concerned with in this investigation is post-Saganaga in age.

## Newton Lake Formation

The Newton Lake Formation was mapped earlier (Clements, 1903) as Ely Greenstone but has been renamed (Green, 1970; Morey and others, 1970) because it stratigraphically overlies, and may intertongue with, the Knife Lake Group. Exposure of the dominantly mafic metavolcanic sequence occurs as a belt, 2 to 5 kilometers wide, between Ely and Moose Lake. The formation consists of two informal members; a lower mafic metavolcanic member, and a felsic-intermediate metavolcanic member.

## Granites

Within and around the Vermilion district are granitic bodies with diverse compositions, that intruded the metavolcanic-metasedimentary sequence during the Algoman orogeny (2.7 b.y.). The major intrusive bodies - the Giants Range, Vermilion, and Saganaga batholiths - were emplaced virtually synchronously with regional deformation.

The Saganaga Granite, or Saganaga Tonalite as renamed by Hanson and others (1971), is exposed in the eastern terminus of the district in the vicinity of Saganaga and Seagull Lakes. It is a composite intrusion containing several rock types, the most abundant of which is gray medium-grained tonalite. The tonalite (plagioclase being the most dominant feldspar) is characterized by large quartz "eyes", commonly about one centimeter across, that are aggregates of grains one to two millimeters in diameter. The batholith intruded older Knife Lake volcanic-sedimentary sequences in the early stages of the Algoman orogeny, and after rapid unroofing shed detritus into younger Knife Lake sediments.

The Giants Range batholith is composed of numerous plutons ranging in composition from tonalite to granite (Sims and Morey, 1972). It intrudes the Ely Greenstone along the southern edge of the Vermilion district.

Along the northern edge of the district, the Vermilion batholith was intruded into the upper part of the sequence mainly by passive emplacement into folded sedimentary rocks (Sims and Morey, 1972). The Vermilion granite-migmatite massif (renamed by Southwick, 1972) is composed dominantly of gray and pink granite that is interlayered with biotite schist and amphibolite.

Within the eastern Vermilion district there are two stocks of granite (Snowbank and Kekekabic granite stocks) that were emplaced in the Knife Lake Group late in the Algoman event. The bodies represent a family of syenitic rocks that were emplaced under a relatively shallow cover (Sims and Morey, 1972).

<u>Hypabyssal Intrusive Rocks</u>

A variety of intrusive rocks (metadiabase and porphyries that range in composition from andesite-dacite to rhyodacite) are associated with the volcanic and sedimentary rocks of the Vermilion district. Evidence presented by Morey and others (1970) indicates that the porphyries are cogenetic with volcanic rocks and were not emplaced during a single short episode, but over an interval of time that spanned from deposition of a least the upper part of the Ely Greenstone and a part of both the Knife Lake Group and the Newton Lake Formation.

Gunflint Iron-formation

The Middle Precambrian Gunflint Iron-formation occurs as a narrow belt in the vicinity of Gabimichigami Lake and along the Gunflint Trail. It is from 90 to 100 meters thick along the Gunflint Trail, and consists of four main subdivisions: 1) Lower cherty member, 2) Lower slatey member, 3) Upper cherty member, and 4) Upper slatey member.

Rove Formation

The Rove Formation gradationaly overlies the Gunflint Iron-formation. It consists of black to grayish black, locally carbonaceous argillite, argillaceous siltstone, and fine-grained graywacke.

Duluth Complex

The Duluth Complex, Upper Precambrian (1.1 b.y. old), truncates and metamorphoses the rocks of the southeastern side of the Vermilion district. The complex consists of a variety of anorthositic, troctolitic, granodioritic, and granophyric rocks. They were emplaced along a major unconformity between Lower and Middle Precambrian rocks and the Keweenawan lava flows. Gruner (1941) found no evidence that the complex was responsible for any of the structural features in the Knife Lake Group.

Quaternary Deposits

A thin patchy veneer of glacial drift occurs throughout the area but never reaches any considerable thickness. Glacial features include erratics, glacial polish on outcrops, and striations which in the area of study average about S30°W (15 measurements).

# CHAPTER III

# PETROGRAPHY

## Introduction

To present, little petrographic work has been conducted on the metasediments of the eastern Vermilion district. McLimans (1971) studied four conglomerate units within the Knife Lake Group. Ojakangas (1972a, 1972b) conducted a general petrographic study of samples collected throughout the eastern Vermilion district. Gruner (1941) mapped the Knife Lake Group over a 12 year period but only described the rocks megascopically. It was the intent of this study to map a small portion of the Knife Lake Group in more detail and by petrographic study determine the exact nature of the source rocks.

There are numerous problems associated with researching an Archean terrain in northeastern Minnesota, the main one being a lack of good outcrop. For the most part outcrops occur as isolated islands separated by dense forests and swamps. The outcrops (when found) are usually lichen covered preventing detailed description, and after a distance of 10 to 20 meters disappear under a veneer of dirt, moss, and fallen trees. Generally the best outcrops occur along the lakes but even these may be badly weathered or lichen covered.

Disregarding the folding and faulting, another problem incipient to the area is a lack of traceable marker beds. The graywackes are diverse in thicknesses, lithologies, and sedimentary structures making even correlation from one outcrop to another difficult. Conglomerates in the southern half of the area are useful as marker beds but they are lensoidal and pinch out over relatively short distances.

Metasediments within the area studied generally trend northeast and dip to the northwest at approximately 80 degrees. The rocks are highly indurated and weather to varying shades of green, gray, and brown. Fresh surfaces are either dark to light gray, or dark to light green. The conglomerates are differentially weathered giving the clasts some relief above the surrounding matrix.

### Techniques

Field study of the graywackes included measurements of bed thicknesses, determination of the internal Bouma sequences, and top determinations. Actual bed-by-bed descriptions were conducted on large, relatively clean outcrops. Conglomerates were described as to clast types, clast roundness and shape, and thickness. Analyses of clast types were conducted wherever outcrop conditions were favorable. This was done by drawing five lines, one meter in length and spaced at 10 centimeters, across the outcrop perpendicular to the bedding (Figure 7).

The number of centimeters of each clast type traversed by the lines was then recorded. Clasts less than 0.5 centimeters were counted as matrix. The percentage of each clast type was computed by dividing the total length for each clast type by the total length of the five lines. In most cases the outcrops were too weathered or covered to permit such pebble traverses, so large samples were collected for later petrographic work. This was done by cutting slabs of the samples, staining them for potassium feldspar (K-feldspar), and point counting them under a binocular microscope with a 0.5 centimeter grid. Fourteen conglomerate samples were done in this manner, and only two were counted in the field.

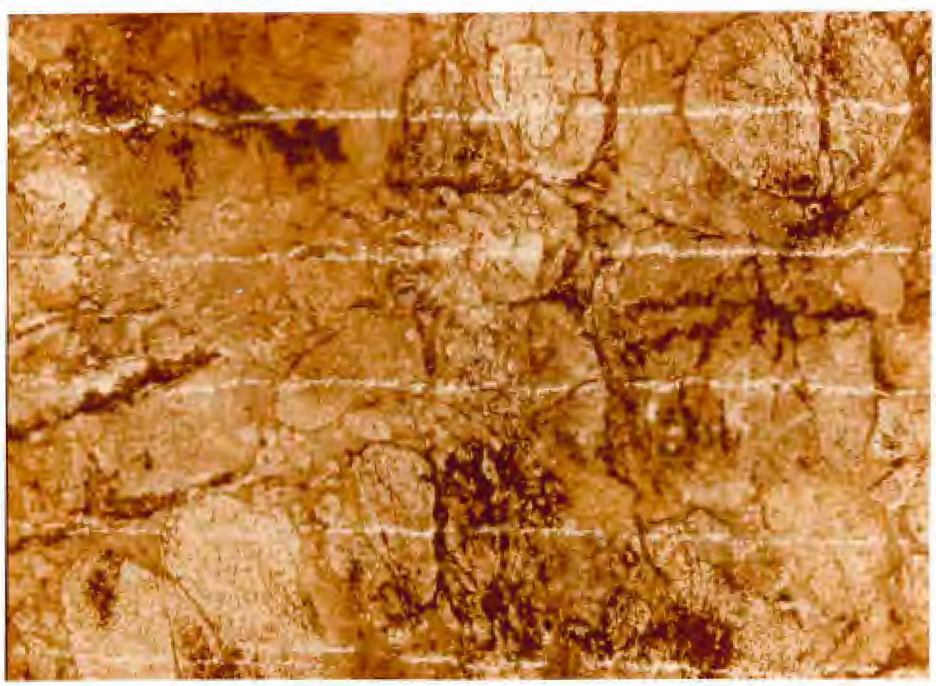


Figure 7: Photograph showing method of conducting megascopic modal analyses on field exposures. Chalk lines are perpendicular to bedding, one meter in length, and spaced at 10 centimeters. Outcrop N-10, SW 1/4, NE 1/4, SE 1/4, Sec. 15, T.65N., R.6W. (Unit IV).

One hundred and thirteen thin sections from selected samples of conglomerates, graywackes, slates, tuffs and iron-formations were studied. Of these, eighty-two (23 conglomerates, 59 graywackes) were point counted. Thin sections were point counted by making traverses normal to bedding, totaling 600 points. Grains with their longest diameter less than 0.03 millimeters were considered matrix.

Staining for potassium-feldspar, both as individual grains and in volcanic clasts, was done on thin section heels and cut conglomerate slabs. The mineral compositions of eight samples were analyzed by x-ray diffraction. Sample locations are shown in the Appendix.

## Descriptions of Clasts

### Classification of Volcanic Clasts

Classification of the various volcanic clasts within the conglomerates and graywackes is based on their relative amounts of K-feldspar, plagioclase, and quartz. Serious limitations to this are twofold in that about 10 percent of the plagioclase grains are untwinned albite and the majority of K-feldspar occurs as fine-grained groundmass. These problems were resolved by staining for K-feldspar with sodium-cobaltinitrate. The nature of the volcanics could then be determined by matching an observed clast under the petrographic scope to the same clast on the stained thin section heel.

When point counting the graywackes, actual matching of one clast in thin section to the same clast on the heel was impossible. In this case the grains were point counted as volcanic rock fragments and later broken down into various percentages of rhyolitic-rhyodacitic and dacitic fragments. The last step was conducted by observing the stained heel under a binocular microscope and visually estimating (with the aid of diagrammatic fields of view found in Compton, 1962) the amounts of volcanic fragments with a yellow stain.

The classification system used in this investigation, based on a field classification of igneous rocks, is portrayed in Table I. This system is generally accurate in determining a clast's relative position in the volcanic spectrum (i.e. more felsic or more mafic), but losses its precision in the finer details (i.e. actual percentages of minerals).

All the porphyritic volcanics are similar in thin section in that they contain large phenocrysts of plagioclase, hornblende, and quartz within microcrystalline groundmasses of varying compositions. Euhedral plagioclase laths are commonly from 0.6 to 1.0 mm in diameter, ranging from 0.05 to 3 mm. Hornblende exhibits well developed crystal forms commonly 1.0 to 2.0 mm in diameter with a range of 0.05 to 6.0 mm. Quartz phenocrysts are rounded (magmatic resorbtion) and range from 0.4 to 5.0 mm in diameter.

TABLE 1.--CLASSIFICATION SYSTEM FOR THE VOLCANIC ROCK FRAGMENTS OF THIS STUDY.

| Texture | Stain (relative proportions of feldspars) | Percentage Quartz | Conglomerate Clast Name | Graywacke Clast Name |
|---|---|---|---|---|
| NON-LATHY, PORPHYRITIC | Deep yellow groundmass, K-feldspar phenocrysts (K-feldspar > 2/3 of feldspars) | >10% | Rhyolite | Rhyolite-Rhyodacite Trachyte-Trachyandesite |
| | Deep to medium yellow groundmass, Plagioclase phenocrysts. (K-feldspar ≥ Plagioclase) | <10% | Trachyte-Latite | |
| | Light yellow groundmass, Plagioclase phenocrysts. (Plagioclase > 2/3 of feldspars) | >10% | Rhyodacite | |
| | | <10% | Trachy-andesite | |
| | Little or no stain, Plagioclase phenocrysts. (Plagioclase >95% of feldspars) | >10% | Dacite | Andesite-Dacite |
| | | <10% | Andesite | |
| Lathy (some phenocrysts) | No stain | -- | Mafic-intermediate | |
| Lathy (no pheno-crysts) | No stain | -- | Mafic | |
| Fine-grained sugary texture | Varys | -- | Felsite | |

Rhyolite

Rhyolite clasts are characterized by phenocrysts of K-feldspar, quartz, hornblende and rare plagioclase within a K-feldspar-rich groundmass (100% yellow stain). In outcrop the clasts are porphyritic and weather to varying shades of gray-white, pink-white, or light brown. In thin section, visual estimation of composition indicates approximately 15% K-feldspar, 15% quartz, 20% hornblende and 50% groundmass.

Volumetrically the rhyolite clasts are unimportant, averaging only 1% of all the clasts studied. The maximum amount, present in only one thin section, is eleven percent.

Trachyte-Latite

Distinction between these two volcanic types is difficult, and since the two appear gradational into one another they are herein classified as one type. They are characterized by phenocrysts of plagioclase, hornblende, and minor K-feldspar, pyroxene, and quartz in a fine-grained groundmass of varying mixtures of K-feldspar and plagioclase. Megascopically they are porphyritic and weather to gray-white, pink-white, or light brown.

Microscopically the clasts are generally porphyritic although some finer-grained clasts exhibiting trachytic texture are present. Plagioclase ($An_{12}$-$An_{27}$ on 11 measured twins) is generally twinned and sometimes exhibits simple reverse or oscillatory zoning. Hornblende is common green amphibole which is usually twinned and sometimes surrounded by reaction rims. Compositions, using diagrammatic fields of view found in Compton (1962), of the trachyte-latite clasts are varied. The approximate compositions of 11 clasts are shown in Table 2.

TABLE 2.--APPROXIMATE COMPOSITIONS OF TRACHYTE-LATITE CLASTS. (percentages of K-feldspar in groundmass based on stain intensity)

| Slide | K-feld | Plag | Quartz | Horn | Pyrox | Groundmass |
|---|---|---|---|---|---|---|
| C-9 | | 15% | | 25% | | 60%(100% K-feld) |
| Kn-16 | | 15% | | 20% | | 65%(100% K-feld) |
| H-10 | | 30% | | 7% | | 63%(100% K-feld) |
| H-10 | | 35% | | 7% | | 58%(100% K-feld) |
| H-10 | 10% | 5% | | 25% | | 60% (80% K-feld) |
| H-10 | | 5% | | 35% | | 60%(100% K-feld) |
| H-18 | | 5% | | 30% | | 65%(100% K-feld) |
| H-30 | | 15% | | 30% | | 55% (80% K-feld) |
| N-10 | | 5% | | 20% | 2% | 73% (90% K-feld) |
| T-11 | 10% | | 5% | 3% | | 82% (90% K-feld) |
| A-6 | | 20% | | | 15% | 65% (80% K-feld) |

Volumetrically the trachyte-latite clasts constitute about 38% of all the clasts studied. Hornblende-rich clasts constitute about 85% of this group. The maximum amount of trachyte-latite seen in one thin section is 58 percent.

Quartz latites (>10% quartz) were also noted in thin section analyses, but since they are volumetrically unimportant (maximum - 4% per thin section) they are included in this group.

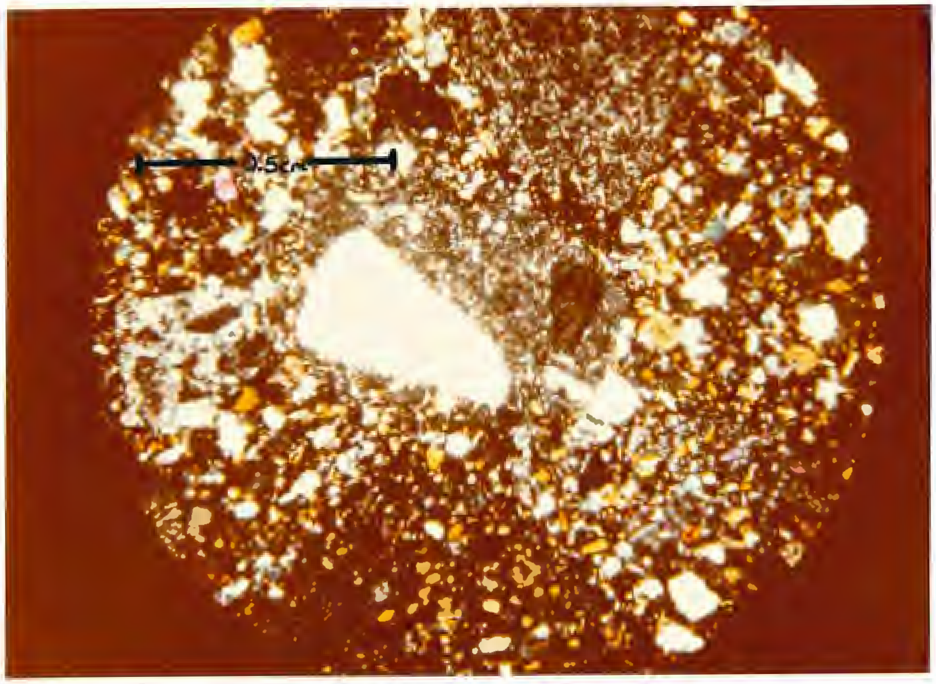


Figure 8: Photomicrograph of volcanic fragments in the matrix of conglomerate VIII (crossed polars). Large rounded fragment at top is mafic-intermediate. Rhyolite fragment at center with large rounded quartz phenocryst. Hornblende trachyte-latite fragments located at bottom (devitrified) and left edge. Note rounded volcanic quartz grains with sharp extinction. Outcrop H-30, Sec. 14, T.65N., R.6W.

Figure 9: Photomicrograph of volcanic and sedimentary clasts in matrix of Conglomerate IV (crossed polars). Hornblende trachyte-latite clasts at top-center and bottom-center. Chert at left and right edges, mafic fragment center. Note hornblende sand between clasts. Outcrop N-8, Sec. 14, T.65N., R.6W.

Rhyodacite

Rhyodacites are characterized by phenocrysts of plagioclase, quartz and hornblende in a fine-grained groundmass which is a mixture of K-feldspar, plagioclase and quartz. Megascopically they are porphyritic and weather to light gray or pink. They are unimportant volumetrically (average 3% of the clasts studied) but may account for as much as 17% of an individual thin section. Visual estimation of composition indicates approximately 20% plagioclase ($An_{12}$-$An_{28}$ on four measured twins), 10% quartz, 10% hornblende, and 60% groundmass (50% K-feldspar -- based on intensity of stain).

Trachyandesite

Volumetrically, the trachyandesites and hornblende trachyandesites account for about 16% of all the clasts studied. They are characterized by phenocrysts of plagioclase ($An_{13}$-$An_{24}$ on six measured twins), green hornblende and minor quartz in a microcrystalline groundmass. Since the trachyandesite clasts also weather to light gray or pink, as do the more felsic volcanic clasts, distinction is based on the staining characteristics. Compositional estimates of five trachyandesitic clast are shown in Table 3.

Dacite

Dacites are the most prominent quartz-bearing volcanics but only account for about 6% of the clasts. In outcrop the dacite clasts are characterized by

TABLE 3.--APPROXIMATE COMPOSITIONS OF TRACHY-ANDESITE CLASTS (percentage of K-feldspar based on intensity of stain).

| Slide | Plag | Horn | Quartz | Groundmass |
|---|---|---|---|---|
| Kn-17 | 10% | 20% | 1% | 69% (50% K-feld) |
| N-10 | 20% | 25% | | 55% (40% K-feld) |
| H-10 | 20% | 10% | | 70% (50% K-feld) |
| H-18 | 40% | 5% | | 55% (40% K-feld) |
| H-24 | 10% | 10% | 1% | 79% (50% K-feld) |

bleached white plagioclase laths (averaging about 0.6 mm across) and round quartz phenocrysts (3.0 mm across) in a light pink groundmass. Since a pink color and a presence of round quartz "eyes" are characteristic of both dacite and Saganaga tonalite, close scrutinization is necessary in differentiating the two.

Microscopically, the dacite clasts are characterized by phenocrysts of plagioclase, quartz, hornblende and sometimes pyrite, in a plagioclase-quartz groundmass which picks up no K-feldspar stain. Visual estimations of compositions of three dacite clasts are shown in Table 4.

TABLE 4.--APPROXIMATE COMPOSITIONS OF DACITE CLASTS.

| Slide | Plag | Quartz | Horn | Groundmass |
|---|---|---|---|---|
| Na-2 | 10% | 12% | 15% | 63% |
| C-9 | 20% | 15% | 2% | 63% |
| C-9 | 30% | 10% | 2% | 58% |

Andesite

Porphyritic andesites are important volumetrically and account for about 16% of the clasts studied. Hornblende andesites total about 62% of this group.

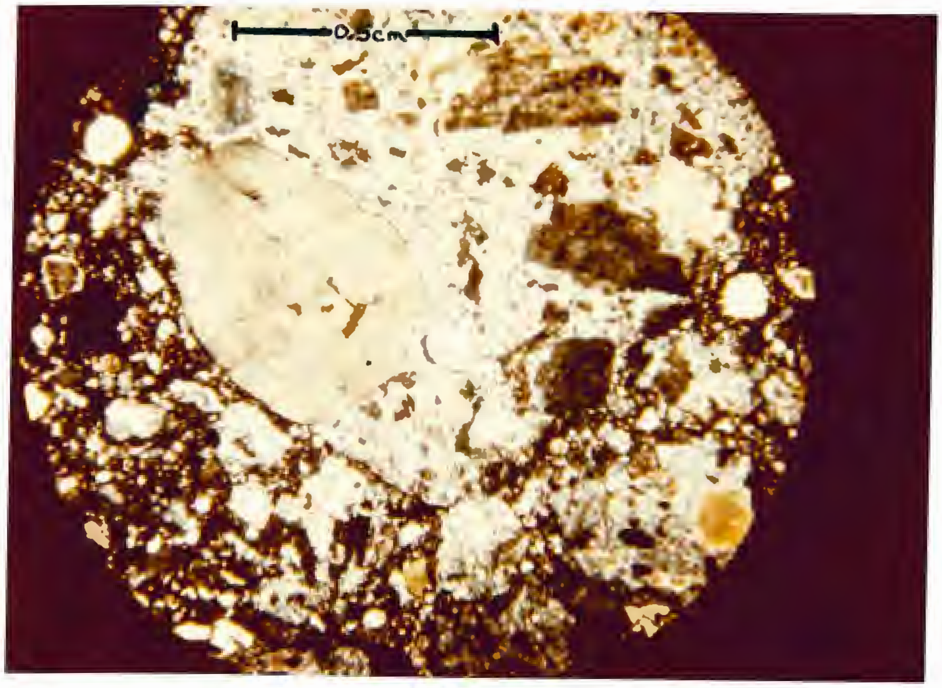



Figure 10: Photomicrograph of a dacite clast in Conglomerate III (crossed polars). Note round quartz phenocrysts and altered plagioclase laths. Outcrop C-9, Sec. 15, T.65N., R.6W.

Megascopically, the clasts exhibit various textures ranging from coarse porphyritic to a finer-grained porphyry consisting of small stumpy plagioclase laths. The andesite clasts weather to dark-gray, dark-red, or black.

In thin section, andesite clasts are characterized by phenocrysts of plagioclase ($An_{10}$ on three measured twins), hornblende, pyroxene, and minor amounts of quartz in a fine-grained plagioclase-quartz groundmass which picks up no K-feldspar stain. Visual estimates of compositions of five andesitic clasts are shown in Table 5.

TABLE 5.--APPROXIMATE COMPOSITIONS OF ANDESITE CLASTS.

| Slide | Plag | Quartz | Horn | Pyrox | Groundmass |
|---|---|---|---|---|---|
| N-13 | 20% | | 25% | | 55% |
| C-6 | 20% | | 15% | | 65% |
| C-6 | 15% | | 20% | | 65% |
| Na-2 | 25% | 5% | 5% | | 60% |
| T-11 | 45% | 5% | | 10% | 45% |

Mafic-Intermediate

The term mafic-intermediate is used herein to designate fine-to medium-grained non-porphyritic volcanic clasts of andesitic to basaltic composition. Megascopically they are fine-grained and weather to dark-brown or dark-green. Greenstone was used as a field term to denote the dark-green clasts.

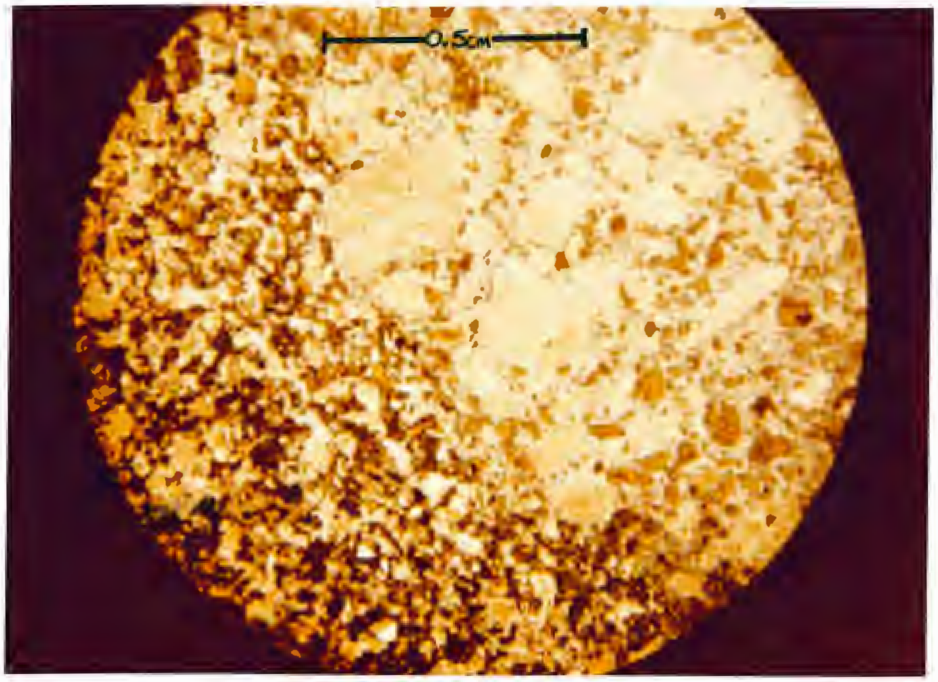



Figure 11: Photomicrograph of a hornblende andesite (upper left) in Conglomerate V (one polar). Outcrop C-6, Sec.15, T.65N., R.6W.

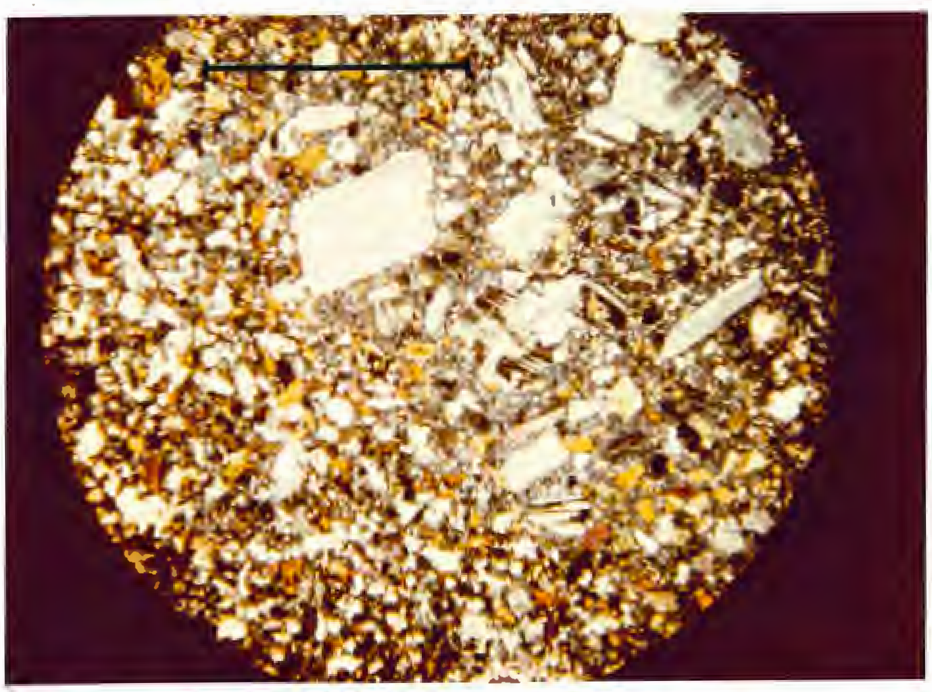


Figure 12: Same as Figure 11 (crossed polars).

In thin section, the mafic-intermediate clasts are characterized by needle-like plagioclase laths with occasional plagioclase phenocrysts, subhedral to euhedral pyroxene (augite), and minor hornblende in a fine-grained green to brown groundmass (in plane polarized light). The plagioclase laths are up to 0.4 mm long and may account for up to two-thirds of a clast. Laths are either randomly oriented, pilotaxitic, or occur as radiating acicular bundles. Pyroxene is commonly about 0.2 mm in diameter and may account for as much as 20 percent of a clast.

Mafic-intermediates volumetrically account for about 11 percent of all the clasts studied.

Mafic

In outcrop, mafic clasts have a fine-grained gritty texture and weather to a tan color. Microscopically, the clasts are characterized by white needle-like plagioclase laths, up to 0.4 mm long, within a dark-brown to black groundmass in plane polarized light. The plagioclase laths are randomly oriented and may account for as much as two-thirds of an individual clast.

The clasts are probably of basaltic composition and volumetrically account for about 6 percent of all the clasts studied.

Ultramafic(?)

Ultramafic clasts are very insignificant. Only two very elongate clasts from two separate conglomerate units

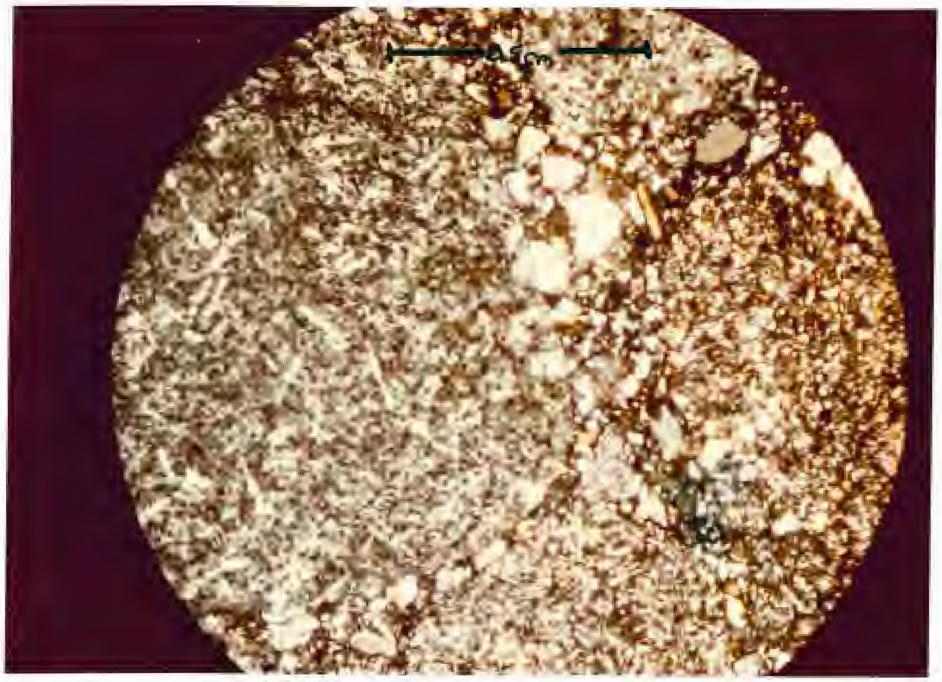


Figure 13: Photomicrograph of four mafic-intermediate clasts from Conglomerate IX (crossed polars). Note the differences in textures and colors. Outcrop T-11, Sec. 13, T.65N., R.6W.

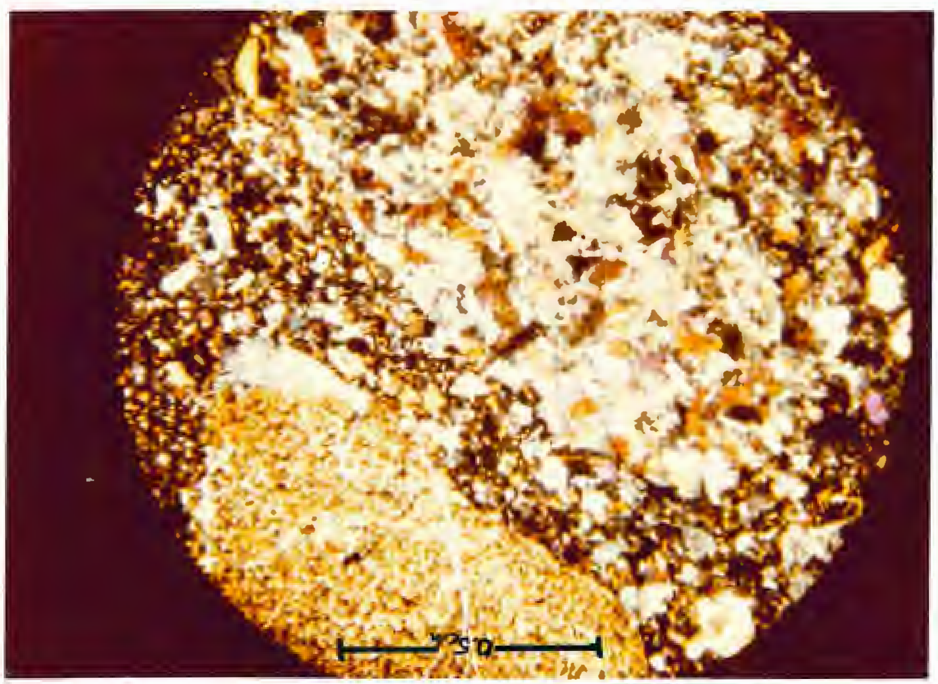


Figure 14: Photomicrograph of chert (bottom) and metadiabase (top) clasts in Conglomerate VIII. Yellow color in chert is due to a very fine-grained mineral, unidentifiable at 320X. Outcrop H-30, Sec. 14, T.65N., R.6W.

were noted during thin section analyses. The original textures have been obscured by recrystallized chlorite and serpentine.

Metadiabase

Metadiabase fragments are exceedingly rare within the metasediments of this study. They are medium-to coarse-grained and composed of approximately: 35% corroded plagioclase laths, 34% pyroxene (augite), 24% hornblende, and 7% interstitial quartz.

Metadiabase clasts were not seen in megascopic analyses.

Felsite

Volcanic felsite clasts are common but unimportant volumetrically, averaging about 1% of all the clasts studied. Megascopically they vary from pink to white and are very fine-grained (1.0 mm or less). The fragments have a sugary texture and under the microscope are seen to be comprised of a fine-grained microcrystalline groundmass consisting of K-feldspar, plagioclase, quartz and minor hornblende. The term felsite is used herein to denote very fine-grained volcanic fragments with varying stain intensities, with no designation as to either rhyolitic or dacitic.

Plutonic Rock Fragments (Saganaga tonalite)

Granitic clasts within the conglomerates of the Knife Lake Group were derived from the Saganaga tonalite (McLimans, 1971, 1972). The clasts, and outcrops, of

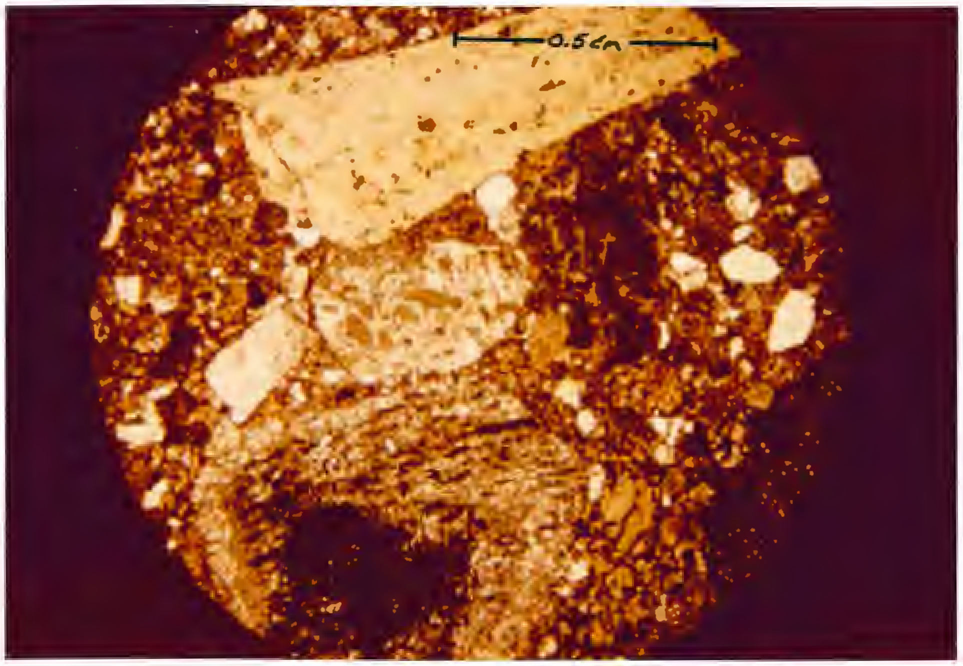



Figure 15: Photomicrograph of various clasts in Conglomerate IX (plane polar). Elongate green clast at top is a serpentinized ultramafic(?). Clear grain at center is a hornblende-trachyte-latite. To its right is a mafic volcanic fragment; to its left is a felsite fragment. Located at the bottom is a banded chert clast containing magnetite. Outcrop T-11, Sec. 13, T.65N., R.6W.

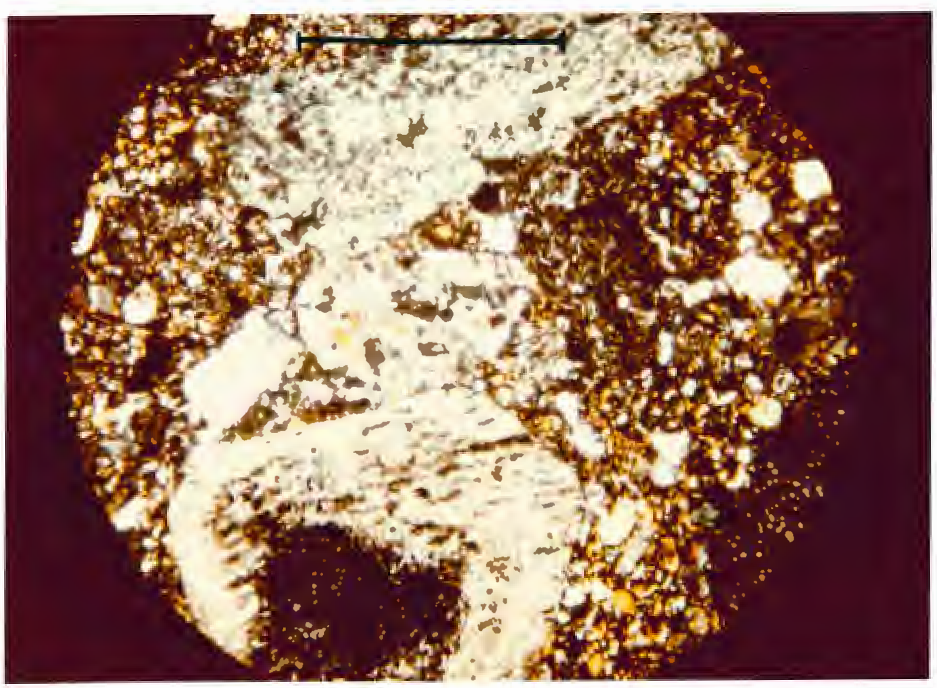


Figure 16: Same as Figure 15 (crossed polars).

tonalite are pink to white with distinctive rounded gray quartz "eye" aggregates up to one centimeter across. As a result of differential weathering, the quartz eyes protrude slightly.

In thin section, the quartz eyes are seen to be aggregates of grains one to two millimeters in diameter. The boundaries between the quartz grains vary from straight to highly crenulated and sutured. The variation in the quartz boundaries may be due to differential stresses within the Saganaga batholith. Deformation of the Saganaga batholith, and surrounding areas, is currently under investigation by Dr. D.M. Davidson and Dr. R.W. Ojakangas.

The Saganaga tonalite is composed of about 50% plagioclase ($An_{33}$), 25% quartz, 15% K-feldspar, 7% hornblende, and 3% secondary chlorite (McLimans, 1971).

In order to avoid biasing the thin section and conglomerate slab point counts, clasts of Saganaga tonalite were not intentionally sampled. However, smaller composite grains of quartz, plagioclase and hornblende derived from the tonalite were present. These are classified as plutonic rock fragments. They average about 3 percent in the graywackes and conglomerates studied in thin section.

Percentages of Saganaga tonalite clasts within the conglomerates were determined by either visual estimation or pebble counts (see Table 8).

Chert

Chert, though insignificant volumetrically (about 1%), is common in the metasediments of this study. It occurs in a variety of colors ranging from white to blue-gray. Some banded cherts and black cherts are also present.

Chert clasts range in size from a few millimeters to over 35 centimeters. Microscopically the chert is characterized by a microcrystalline texture with pinpoint extinction. Grains of magnetite and pyrite may occur within the chert.

Distinction between chert and clasts of fine-grained volcanic groundmass (felsite) is often difficult. Under high power the felsite grains are recognized by minute grains of plagioclase, clear quartz or phenocrysts. Replacement of chert by carbonate is quite common.

Gruner (1923) examined numerous gray chert pebbles from the conglomerate at Ogishkemuncie Lake. Within the pebbles he found what he thought were fossils of blue-green algae corresponding to such modern types as INACTIS or MICROCOLEUS. He stated that the fossils consist of carbonate, and ". . . the matrix of the organisms is a very fine-grained chert containing many minute crystals of carbonate . . . some magnetite, and minute specks of pyrite" (Gruner, 1923, p. 148).

Jasper

Jasper is described separately due to its anomalous presence in some conglomerates and graywacke beds. Grains are generally sub-angular and range from 2.0 to

10.0 mm in diameter, although clasts of about 2.0 cm are not uncommon. The jaspers are bright red which imparts a striking appearance to the outcrop. In thin section the jasper fragments contain grains of magnetite and pyrite.

Siltstone-Slate Clasts

Clasts of gray-green bedded siltstone and very fine-grained black slate were noted during megascopic analyses of the conglomerates. The clasts are generally elongate and range from a few centimeters to over 15 centimeters in length. Rounding of the clasts varies as a function of transport.

Mudclasts

Within the conglomerates are minor mudclasts (now slate). The clast are very fine-grained and dark-gray to black in color. They differ from the slate clasts in that they are extremely irregular in shape, and exhibit flowage around other clasts, perhaps indicating compaction after they were deposited as soft fragments.

Detrital Sand Grains

This section includes grains of plagioclase, K-feldspar, quartz, pyroxene and hornblende. Grains of feldspar, pyroxene and hornblende are generally euhedral in shape with some angular edges indicating little working of the detritus before deposition. Replacement of the feldspars by sericite and carbonate, and of pyroxene and hornblende by chlorite is common.

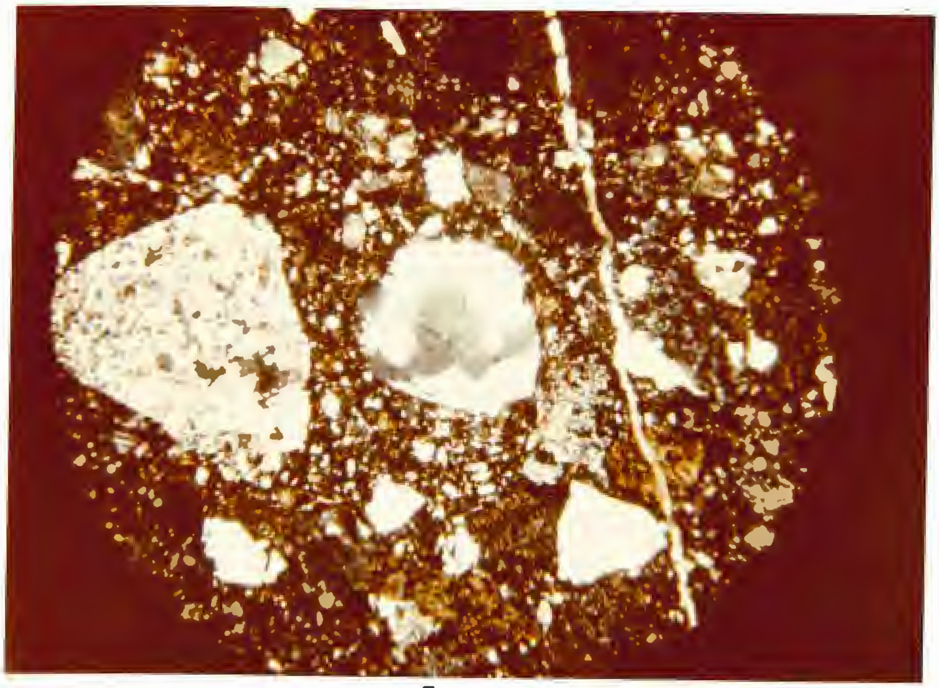
Quartz grains were counted as volcanic quartz, plutonic unit (undulatory) quartz, and polycrystalline quartz. Volcanic quartz grains are unit grains distinguished by their rounded nature (magmatic resorbtion) and sharp extinction. Plutonic quartz grains are characterized by their angular nature and undulose extinction. The polycrystalline grains consist of three or more composite quartz grains with undulose extinction. Boundaries between the composite grains range from fairly straight to highly irregular and sutured. The polycrystalline grains are probably portions of quartz "eyes" derived from the Saganaga tonalite.

<u>Heavy Minerals</u>

One sample of a coarse-to medium-grained graywacke was selected for heavy mineral analysis. The sample was crushed to less than 0.25 mm and separated in tetrabromethane. About 10% by weight of the sample was heavy minerals consisting of approximately 98% green hornblende, 1% pyroxene (augite), and 1% magnetite, zircon and apatite.

<u>Matrix</u>

The matrix consists of smaller particles of the above described clasts and grains. The matrix is varying shades of green, brown and red. For purposes of megascopic analysis, clasts less than 0.5 cm were considered matrix, whereas under the microscope grains less than 0.03 mm were considered matrix. Differentiation



.5 cm

Figure 17: Photomicrograph of fragments in a coarse-grained graywacke (crossed polars). Note the various volcanic fragments, polycrystalline quartz grains with sutured boundaries, and volcanic quartz with sharp extinction. Dark jasper fragment located at top center. Outcrop N-1, Sec. 14, T.65N., R.6W.

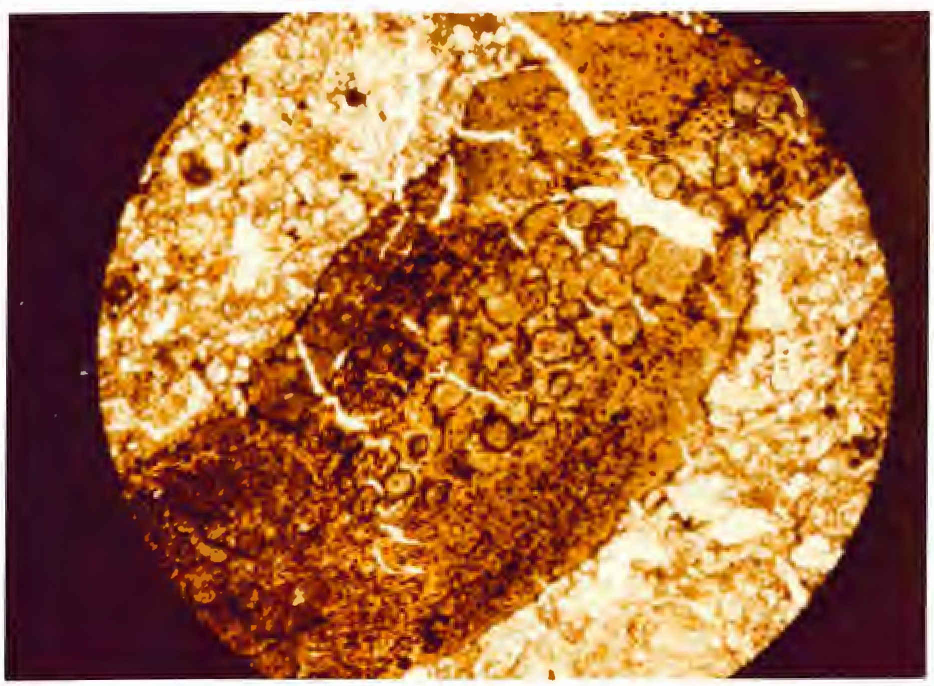


Figure 18: Photomicrograph of a devitrified glass shard with crude spherulitic texture (one polar). Outcrop H-10, Sec. 14, T.65N., R.6W. Field of view is 0.7 mm.

between grains and matrix is often difficult due to alteration of both grains and clays to chlorite, sericite, and carbonate.

In order to determine the composition of the matrix, seven fine-grained samples were analyzed by X-ray diffraction. It was assumed that the components of the finer-grained sediments are similar to the interstitial matrix of coarser-grained graywackes. The matrix as determined by X-ray analyses, consists of in decreasing order of abundance: quartz, chlorite, plagioclase (albite-oligoclase), sericite, epidote, magnetite, hornblende, orthoclase, calcite, and minor amounts of biotite and hematite.

Graywackes

Graywackes are the dominant rock type of the area studied. The term graywacke is used as a field term (as used by Ojakangas, 1972a; 1972b) to denote dark gray, green or black sandstones which contain more than 15% clayey matrix (Pettijohn, 1957) and abundant rock fragments. They are "volcanigenic graywackes" in that the rock fragments are dominantly volcanic. Subgraywacke, with less than 15% matrix and abundant rock fragments (volcanic), are present within the sequence but could not be distinguished from the graywackes in hand specimen. Thus the term graywacke will be used to encompass all the sandstones within the area of study. Subgraywacke is used only where modal analyses are available.

The graywackes exhibit various Bouma sequnces and other sedimentary structures (channeling, flame structures, mud chips, and load casts) typical of turbidites. Bedding is continuous across exposures and varies from 0.5 cm to over 4 meters in thickness. Some exposures consist of thin alternating layers of graywacke, siltstones and slates (Figure 19); while others may contain only massive coarse-to medium-grained graywackes (Bouma A and/or B). The diversity of bedding thicknesses, sedimentary structures and grain sizes of individual beds is portrayed on Figure 20. The graywackes commonly weather to varying shades of gray or brown, and upon fresh fracture are dark to light green. A more detailed description of the sedimentary structures is included in the following chapter.

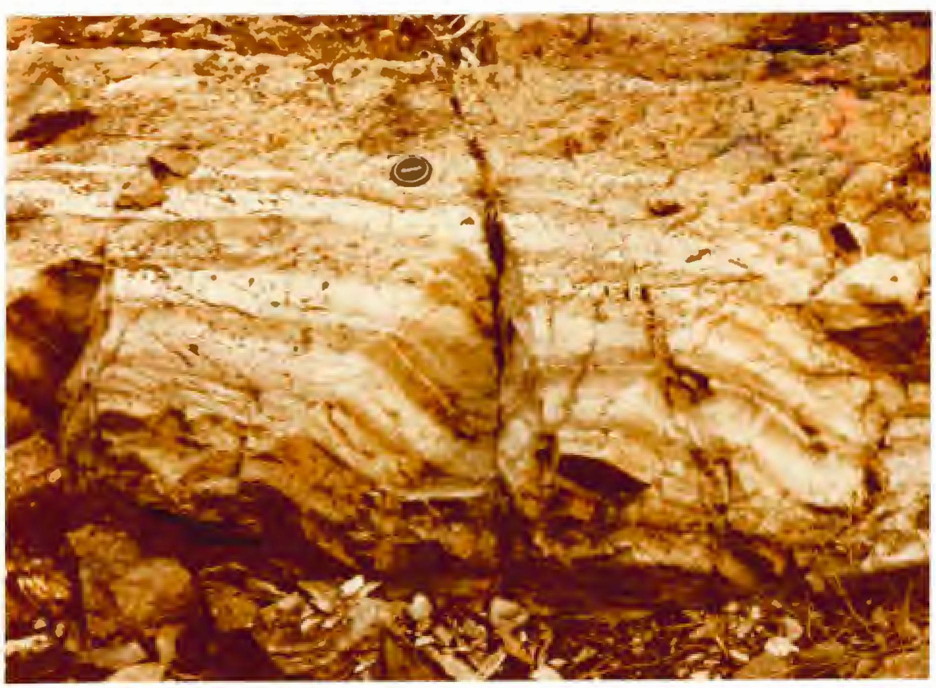


Figure 19: Photograph of an exposure consisting of alternating layers of graywacke, siltstone and slate. Outcrop A-1, Sec. 13, T.65N., R.6W.

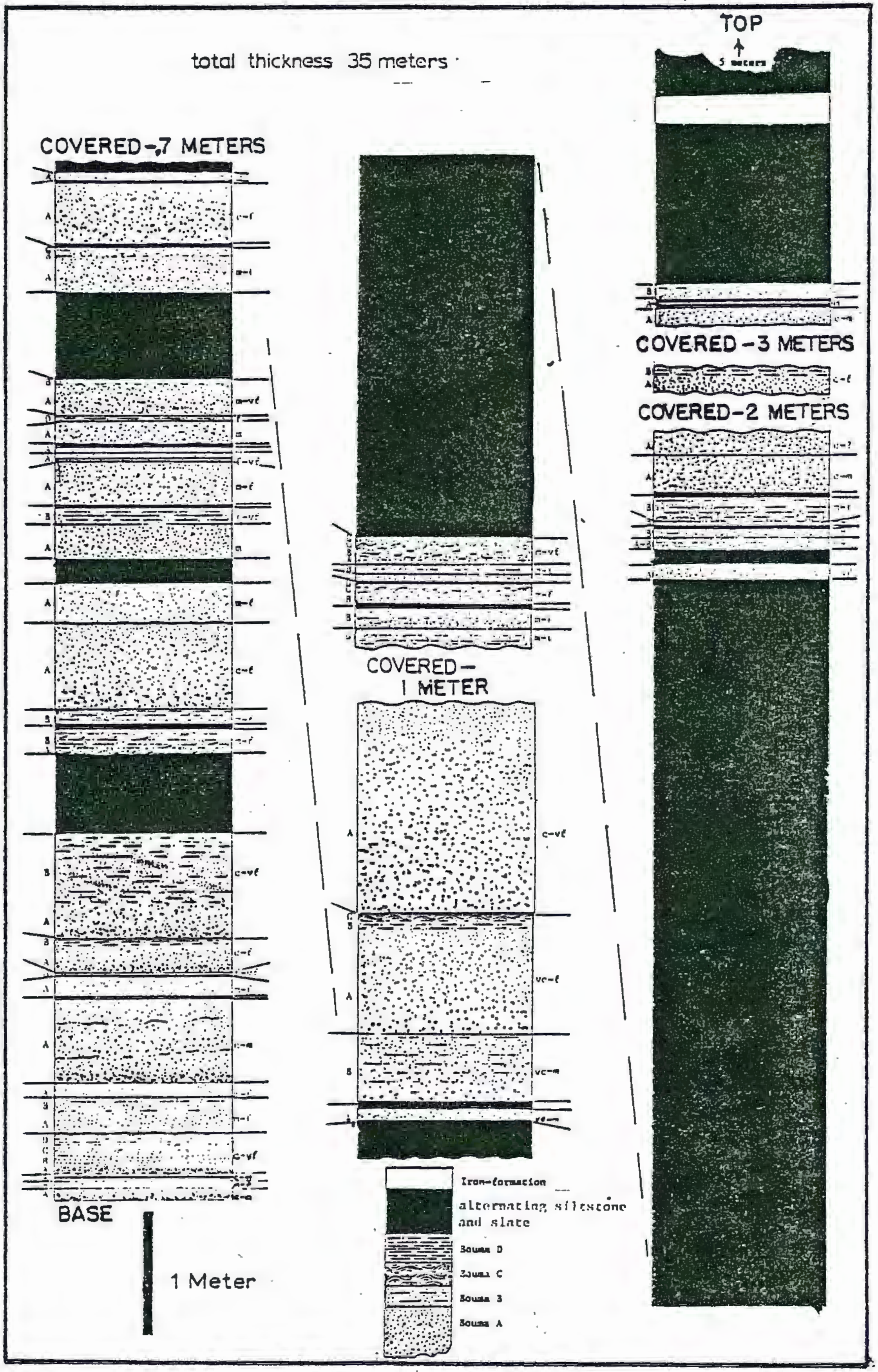



Figure 20: Measured sedimentary sequence at SE 1/4, NW 1/4, NW 1/4, Sec. 13, T.65N., R.6W.(A-1). Right side of column indicates grain size, lines on left side indicate separate beds with various Bouma sequences.

The coarse beds are composed of varying amounts of volcanic clasts, volcanic and plutonic quartz, plutonic rock fragments, plagioclase, hornblende, and sometimes jasper (Figure 21). Grains are generally irregular in shape, range from very-angular to sub-rounded, and exhibit poor sorting.

On the average the graywackes (59 samples point counted) consist of approximately: 48% volcanic material (28% rhyolitic to rhyodacitic, 17.5% andesitic, 1.5% mafic-intermediate, 1% mafic), 13% plagioclase, 5% hornblende, 3% plutonic rock fragments, 3% undulatory quartz, 3% volcanic quartz, 1% chert, .5% polycrystalline quartz, .5% miscellaneous, and 23% matrix (see Table 6). Total plutonic detritus (undulatory and polycrystalline quartz, and plutonic rock fragments) averages about five percent. However, overlying the Saganaga batholith, in the vicinity of Alpine Lake (Samples A1-12 and 13), are coarse-grained graywackes containing approximately 47% plutonic detritus and only 9% volcanic material (Figure 22). The beds are 7 to 15 cm thick, graded, and contain an abundance of quartz eyes up to 3 mm in diameter. Other plutonic-rich graywackes were also noted (Sample F-5, located 2.7 kilometers west of the Saganaga batholith) although the trend is generally a dominance of volcanic material.

Conglomerates

Numerous conglomeratic units occur interstratified with the graywackes throughout the area of study. They are lensoidal in shape and vary from under 2 meters to

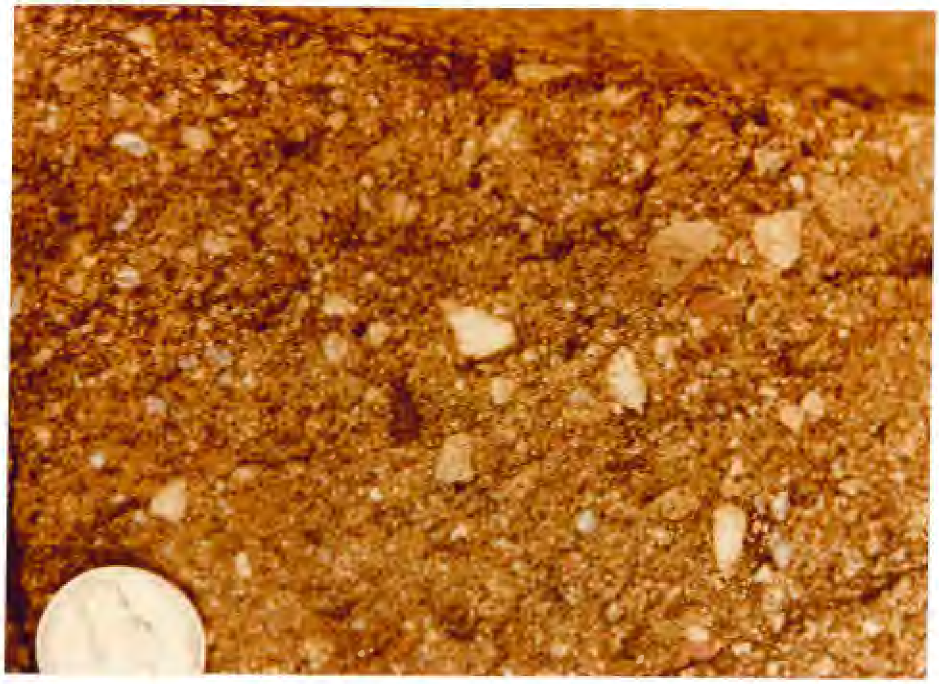


Figure 21: Coarse-grained graywacke containing volcanic rock fragments, volcanic and plutonic quartz, plagioclase, hornblende and jasper. Outcrop Kn-14, Sec. 21, T.65N., R.6W.

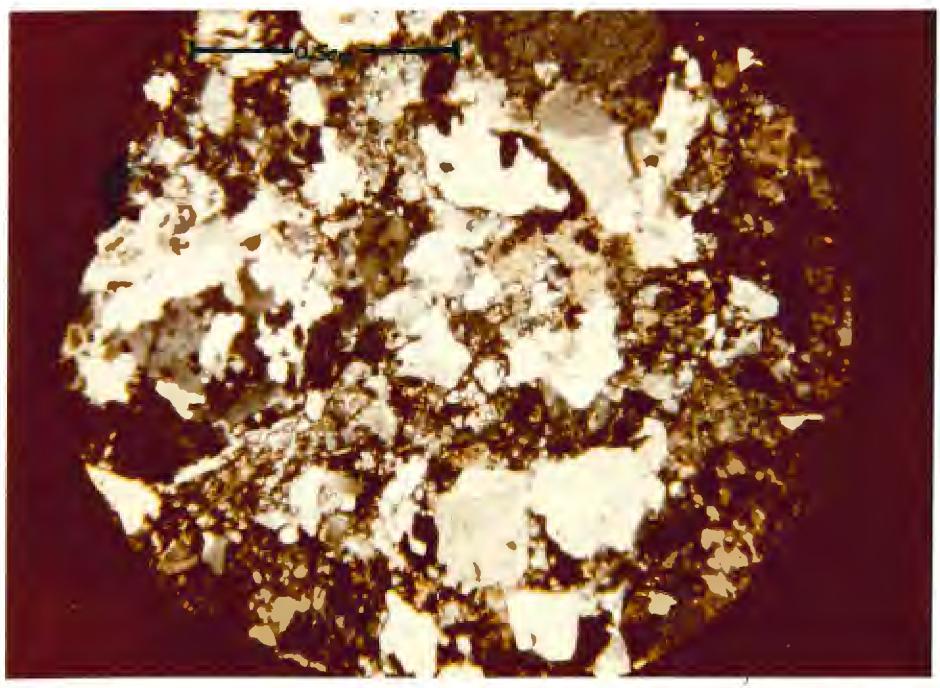


Figure 22: Photomicrograph of a coarse-grained graywacke (crossed polars). Note the sutured quartz grains and presence of a volcanic fragment at top-right and center-right. Outcrop Al-13, Sec. 8, T.65N., R.6W.

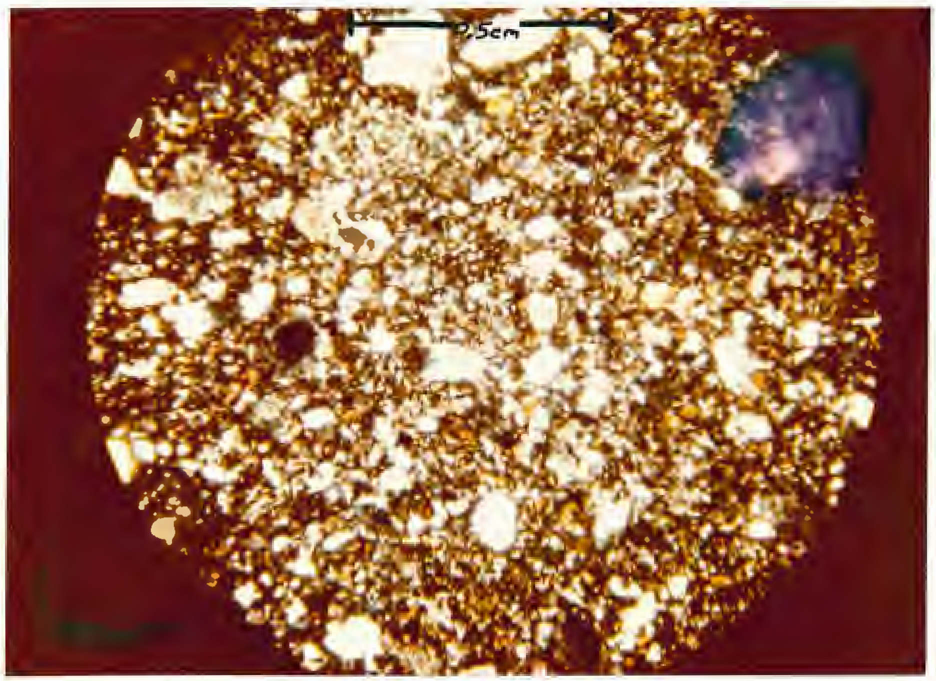



Figure 23: Photomicrograph of a typical medium-grained graywacke containing plutonic and volcanic quartz, and volcanic rock fragments (crossed polars). Note the poor sorting and high proportion of matrix. Outcrop A-2, Sec. 13, T.65N., R.6W.

TABLE 6.--MICROSCOPIC ANALYSES OF GRAYWACKES.

| Sample | Trachyte-Trachyandesite Rhyolite-Rhyodacite | Andesite Dacite | Mafic-Intermediate | Mafic | Felsite | Chert | Jasper | Plutonic Rock Fragments (Saganaga tonalite) | Plagioclase | Hornblende | Volcanic Quartz | Undulatory Quartz | Polycrystalline Quartz | Miscellaneous[1] | Matrix | Average Grain Size (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A-2 | 15 | 21 | 7 | 3 | | 2 | 1 | 5 | 9 | 5 | 4 | 3 | 2 | | 23 | 1.5 |
| A-2 | 8 | 36 | 2 | | .5 | 3 | .5 | 3 | 10 | 5 | 5 | 2 | 1 | | 24 | 0.8 |
| A-3 | 22 | 23 | 2 | | 4 | 1 | | 1 | 19 | | 3 | 3 | 1 | | 21 | 0.5 |
| H-1 | 40 | 5 | 2 | – | | – | – | 2 | 15 | 6 | 1 | – | 1 | | 28 | 0.5 |
| H-2 | 54 | 3 | | | | .5 | .5 | – | 12 | 6 | 1 | 1 | | | 22 | 0.3 |
| H-5(5) | 55 | 3 | 1 | 2 | | – | – | 1 | 13 | 5 | 2 | 1 | 1 | | 16 | 1.0 |
| H-5(6) | 50 | 5 | 1 | 1 | | 1 | – | 1 | 9 | 5 | 2 | 1 | | | 24 | 1.5 |
| H-10-G | 34 | 4 | | | | 1 | | 1 | 17 | 17 | 1 | 2 | | | 23 | 0.35 |
| H-19 | 9 | 21 | 2 | 1 | | – | | 1 | 19 | 17 | 3 | 2 | 1 | | 24 | 0.6 |
| H-8 | 37 | 7 | 1 | 1 | | .5 | .5 | 1 | 14 | 16 | 1 | 1 | | | 20 | 0.8 |
| H-13 | 35 | | | | | | | | 8 | 29 | 2 | 2 | | | 24 | 0.2 |
| H-20 | 4 | 36 | | | | | | .3 | 18 | 10 | 2 | .3 | .3 | | 20 | 0.2 |
| H-21 | 36 | 12 | 2 | 2 | | 2 | – | 2 | 13 | 8 | 3 | 2 | 1 | | 17 | 1.0 |
| H-22 | 42 | 14 | | | – | 1 | – | 1 | 6 | 15 | 1 | | 1 | | 18 | 0.5 |
| H-23-A | 31 | 10 | 6 | 2 | 1 | 2 | | 1 | 9 | 8 | 2 | 5 | 2 | | 21 | 0.8 |
| H-23-C | 17 | 26 | | | | 2 | | 2 | 15 | 8 | 5 | 4 | 1 | | 20 | 0.5 |
| H-24 | 21 | 10 | 6 | 4 | | | | 1 | 11 | 10 | 6 | 5 | 3 | | 24 | 0.5 |
| H-24 | 33 | 6 | 2 | | | 2 | | 1 | 12 | 5 | 4 | 6 | 2 | 4-p | 22 | 1.0 |
| H-24 | 32 | 17 | 2 | 2 | – | | | – | 9 | 9 | 2 | 1 | – | 1-p | 25 | 0.5 |
| H-25 | 38 | 7 | 2 | | 1 | 2 | | 1 | 13 | 11 | 3 | 2 | 1 | 1-p | 18 | 0.5 |
| H-27 | 30 | 19 | – | | – | 1 | | 1 | 12 | 13 | 2 | 2 | – | 1-p | 19 | 0.5 |
| H-28 | 25 | 25 | | | | | | | 20 | 10 | 1 | 1 | | | 18 | 0.15 |
| T-1 | 23 | 24 | – | – | | 2 | – | 2 | 13 | 5 | 4 | 3 | 1 | | 23 | 0.5 |
| T-10 | 11 | 26 | 2 | 1 | – | 4 | | 2 | 16 | 4 | 5 | 6 | 3 | | 20 | 1.0 |
| B-4 | 29 | 13 | 2 | 1 | | 1 | | 1 | 20 | 6 | 2 | 3 | | | 22 | 0.5 |
| B-5 | 47 | 3 | 5 | 1 | 1 | 2 | – | 3 | 7 | 6 | 2 | 2 | 1 | | 20 | 0.7 |
| B-5 | 22 | 20 | 2 | 2 | 1 | 2 | – | 2 | 11 | 6 | 6 | 4 | | 1-p | 21 | 1.0 |
| N-1 | 20 | 41 | 4 | 2 | 1 | 1 | 1 | 5 | 4 | | | 2 | | | 19 | 1.0 |
| N-2 | 13 | 37 | 6 | 4 | 2 | | 2 | | 6 | 5 | 1 | 2 | | | 22 | 1.0 |
| N-3* | 46 | 12 | 4 | 5 | 3 | 3 | | 1 | 3 | 4 | 2 | 3 | 1 | | 13 | 1.0 |

(1) s-sedimentary clast, p-pyroxene (augite), k-potassium feldspar, b-biotite, *-subgraywacke, #-conglomeratic subgraywacke

TABLE 6.--Continued

| Sample | Trachyte-Trachyandesite Rhyolite-Rhyodacite | Andesite Dacite | Mafic-Intermediate | Mafic | Felsite | Chert | Jasper | Plutonic Rock Fragments (Saganaga tonalite) | Plagioclase | Hornblende | Volcanic Quartz | Undulatory Quartz | Polycrystalline Quartz | Miscellaneous[1] | Matrix | Average Grain Size (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S-5 | 49 | 12 | 2 | 1 | | 1 | – | 1 | 2 | – | 1 | 1 | 2 | | 28 | 1.7 |
| E-1 | 4 | 32 | – | – | | 3 | | 1 | 21 | | 9 | 7 | 3 | | 20 | 0.6 |
| E-2-C# | 54 | 6 | | | | | | – | 14 | 11 | 2 | 1 | | | 12 | 3.5 |
| E-4 | | 41 | | | | 1 | | | 25 | | 6 | 5 | 2 | | 20 | 0.6 |
| J-3 | 45 | 5 | – | – | | – | | 1 | 8 | 3 | 3 | 4 | 1 | | 30 | 0.2 |
| J-4 | 7 | 36 | – | | | – | | | 19 | | 2 | 3 | 1 | | 32 | 0.3 |
| J-5 | 2 | 43 | 2 | 2 | | | | 1 | 17 | 1 | 3 | 3 | 1 | | 25 | 0.7 |
| Kn-1 | 44 | 5 | 1 | – | | 1 | – | 2 | 8 | 1 | 2 | 5 | 1 | | 30 | 0.8 |
| Kn-1 | 42 | 6 | – | | | – | – | | 18 | 10 | 1 | 2 | | | 20 | 0.4 |
| Kn-3 | 44 | 8 | – | – | | | – | 2 | 16 | 2 | 3 | – | – | | 25 | 0.6 |
| Kn-4 | 37 | 25 | 1 | 1 | – | – | – | 1 | 5 | 1 | 1 | 1 | 1 | | 26 | 0.5 |
| Kn-7 | 46 | 11 | 1 | | – | 2 | – | 4 | 5 | 1 | 3 | 1 | 1 | 1-s | 24 | 0.5 |
| Kn-8* | 56 | 16 | 1 | | | 1 | – | 1 | 3 | 7 | – | | | 1-s | 14 | 2.0 |
| C-10 | 40 | | 1 | | | | | | 16 | 8 | 1 | | | | 34 | 1.0 |
| F-2 | 7 | 41 | – | | | – | – | – | 18 | | 2 | – | – | | 32 | 0.25 |
| F-2 | 26 | 11 | – | – | | 1 | – | 1 | 18 | 3 | 5 | 7 | 2 | | 26 | 0.4 |
| F-4 | 32 | 4 | 2 | – | | 1 | – | 4 | 14 | 3 | 7 | 6 | 3 | | 24 | 0.6 |
| F-5* | 34 | 4 | 4 | 3 | | 1 | | 22 | 11 | 2 | 3 | 3 | 1 | 2-k | 13 | 1.0 |
| F-8 | 7 | 37 | 1 | | | – | | – | 14 | 1 | 3 | 3 | – | | 34 | 0.3 |
| Fa-3 | | 40 | | | | 1 | | 2 | 21 | | 7 | 3 | 2 | | 24 | 0.4 |
| P-1 | 2 | 42 | | | | | | 1 | 13 | 1 | 4 | 2 | | | 35 | 0.2 |
| P-5 | 17 | 26 | 1 | | 1 | 2 | – | 3 | 14 | | 3 | 5 | | | 28 | 0.8 |
| P-8 | 1 | 42 | 3 | 1 | 2 | 2 | 2 | 5 | 10 | | 4 | 4 | 1 | 1-k | 22 | 2.0 |
| Al-1 | 59 | 6 | | | | 1 | | 1 | 6 | 1 | 1 | 2 | | | 23 | 2.0 |
| Al-1B | 50 | 12 | 1 | 1 | | | | 5 | 4 | 3 | | 2 | 2 | | 20 | 2.0 |
| Al-2 | 51 | 8 | | | | | | 3 | 5 | | 1 | 6 | | | 26 | ? |
| Al-4 | 32 | 8 | 7 | | – | 6 | | 4 | 14 | 2 | 4 | 6 | 2 | | 15 | 2.0 |
| Al-12 | 3 | 4 | | | | | | 33 | 27 | | | 10 | | 1-b | 22 | 1.0 |
| Al-13 | 5 | 6 | | | | | | 40 | 18 | | | 11 | | 1-b | 18 | 1.7 |

(1) s-sedimentary clast, p-pyroxene (augite), k-potassium feldspar, b-biotite, *-subgraywacke, #-conglomeratic subgraywacke

over 35 meters in thickness. At their bases the conglomerates are characterized by poorly sorted, disoriented clasts of varying shapes, sizes and lithologies. The change from graywacke into overlying conglomerate is extremely sharp, indicating a significant change in the provenance and/or sedimentation processes. Tops of conglomerate units are characterized by thin repetitious beds of semi-imbricated conglomerates which grade upward into coarse-to medium-grained graywackes.

According to the classification of Pettijohn (1957) the conglomerates could be termed polymict orthoconglomerates. They are generally clast-supported and exhibit an intact framework of touching clasts with spaces between clasts filled with pebbles and material less than 0.5 cm across. This type is common in Archean conglomerates of the Lake Superior region (Pettijohn, 1957).

The conglomerates are generally composed of a wide variety of clast types indicating a wide variety in the provenance. These include: mafic to felsic volcanics, Saganaga tonalite, chert, jasper, graywacke, slate and mudclasts. On the average, the conglomerates contain approximately: 72% volcanic material, 3% plutonic detritus (undulatory and polycrystalline quartz, plutonic rock fragments, and Saganaga tonalite clasts), 2% sedimentary material (chert, jasper, and sedimentary clasts), 4% hornblende, 3% plagioclase, and 16% matrix (less than 0.03 mm). Field pebble counts of the conglomerates indicates that material less than 0.5 cm ranges from 40 to 60 percent. Microscopic point counts indicate that this material consists of 2 to 37 percent matrix (<0.03 mm).

Clasts vary in size from 2 mm to over 60 cm in diameter. Two-dimensional shapes of the clasts range from spherical to elongate. Large clasts are generally more rounded than smaller clasts. Clasts of tonalite are usually sub-spherical to spherical in shape and well-rounded regardless of size. Stretched clasts were not noted.

There are ten known conglomerate units associated with the graywackes of this investigation. Correlation of one unit to another is hampered by faulting, folding, lack of outcrop, and the apparent lensoidal nature of the conglomerates. Gruner (1941) failed to note lithologic differences between five conglomerate units (Unit II through VI) and incorrectly linked them as one long isoclinally folded conglomerate belt. For simplicity, the conglomerate units will be described separately as to spatial distribution and lithology. Locations and designations of the conglomerates are shown on Figure 24.

<u>Unit I</u> - Ogishkemuncie Lake Area

The most recent work on the conglomerate of Ogishkemuncie Lake was conducted by McLimans (1971, 1972). He noted that the conglomerate can be divided into two separate horizons; a lower non-jasper-bearing unit, and an upper jasper-bearing unit. By megascopic pebble

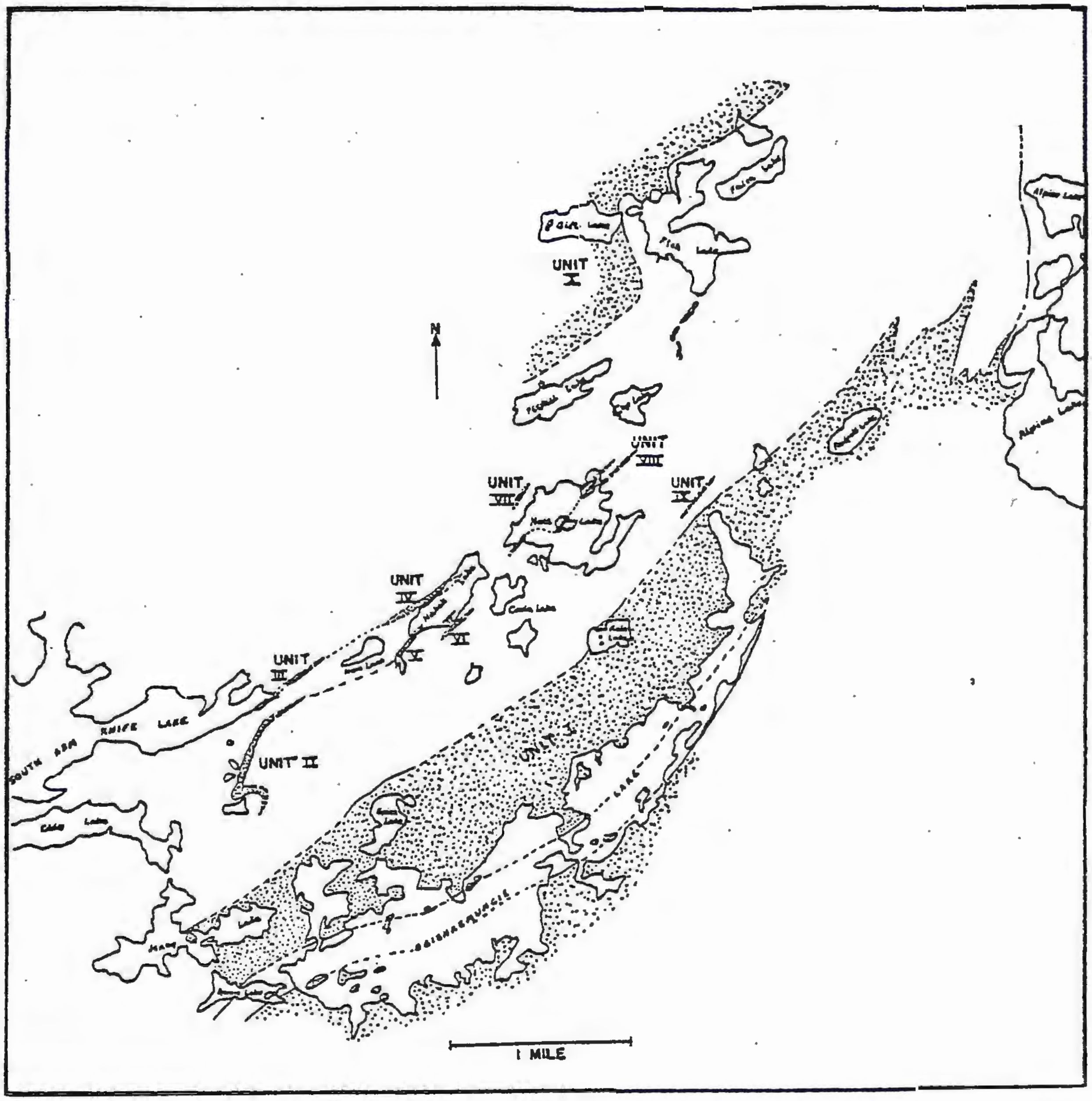



Figure 24: Locations and designations of ten conglomerate units.

# TABLE 7.--MICROSCOPIC ANALYSES OF CONGLOMERATES

## (thin section and cut slabs)

| Unit | Sample | Rhyolite | Trachyte-Latite | Hornblende Trachyte-Latite | Rhyodacite | Trachyandesite | Hornblende Trachyandesite | Dacite | Andesite | Hornblende Andesite | Mafic-Intermediate | Mafic | Felsite | Chert | Jasper | Plagioclase | Hornblende | Volcanic Quartz | Undulatory Quartz | Polycrystalline Quartz | Plutonic Rock Fragments | Saganaga Tonalite | Sedimentary Clasts | Miscellaneous[1] | Matrix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Kn-10 | | | 51 | | | | | | | | | | -- | | 15 | 9 | -- | | | | | | | 25 |
| | Kn-16 | | | 40 | | | | | | | | -- | | -- | | 7 | 4 | | | | | | | | 19 |
| II | Kn-17 | | | 14 | 1 | 75 | | | | | | | | 2 | | | | | | | | | | | 8 |
| | Kn-17* | | 41 | 34 | | 20 | | | | | | | | | | | | | | | | | | | 5 |
| | Lo- 8* | | | 32 | 6 | 18 | | | 5 | 3 | | | | | | | | | | | | | | | 36 |
| | AVE | | 10 | 34 | 2 | 25 | | | 1 | .5 | | -- | | .5 | | 5 | 3 | -- | | | | | | | 19 |
| | Na-2 | | | | | 1 | | 10 | 43 | 2 | 2 | 6 | 2 | 6 | | 2 | | 4 | -- | -- | 4 | X | | | 18 |
| | C-9(a) | | | 58 | | | | | | | | | | | | 16 | 10 | | -- | | 3 | X | | | 16 |
| III | C-9(b) | | | | | | | 50 | | | 14 | | | | | 7 | | 5 | | 1 | | X | | | 20 |
| | C-9(a)* | | | 48 | | 5 | 24 | | | 3 | | | | | | | | | | | | X | | | 20 |
| | C-9(b)* | | | | 12 | | | 39 | 23 | 1 | 2 | | | | | | | | | | | X | | | 23 |
| | AVE | | | 21 | 2.5 | 1 | 5 | 20 | 13 | 1 | 3.5 | 1 | .5 | 1 | | 5 | 2 | 2 | -- | -- | 1.5 | X | | | 20 |
| | N-8 | | | 31 | 2 | | 16 | 1 | 10 | 14 | 3 | 4 | 1 | 4 | | 1 | 11 | -- | -- | -- | | X | X | | 2 |
| | N-9 | 11 | 33 | 9 | 1 | 1 | 1 | | 2 | 4 | 2 | 18 | -- | | | | 8 | -- | | -- | 1 | X | X | | 7 |
| IV | N-10 | | 41 | -- | | | 15 | | 9 | 5 | -- | 8 | | -- | | 2 | 9 | | 1 | | -- | X | X | | 9 |
| | N-14* | | 4 | | | 2 | 44 | | 7 | 33 | 1 | 1 | | | | | | | | | | X | X | | 7 |
| | AVE | 3 | 20 | 10 | 1 | 1 | 19 | -- | 7 | 14 | 1 | 8 | -- | 1 | | 1 | 7 | -- | -- | -- | -- | X | X | | 7 |
| | C-5 | | | | -- | | 61 | | | | | | | | | 9 | 15 | | | | | | | | 5 |
| V | C-6 | | | 14 | | 12 | | | | 51 | | | | | | 8 | 9 | | | | | | | | 6 |
| | AVE | | | 7 | -- | 6 | 32 | | | 27 | | | | | | 9 | 13 | | | | | | | | 6 |
| | C-4 | 9 | 7 | 23 | 2 | | | | 3 | 7 | 12 | 1 | 1 | -- | 4 | 1 | 2 | 3 | 2 | 2 | 3 | X | X | | 18 |
| VI | C-4* | | 6 | 19 | | | 8 | | 8 | 4 | 13 | 2 | | | 6 | | | -4- | | | | X | X | | 30 |
| | AVE | 4.5 | 6.5 | 21 | 1 | | 4 | | 5.5 | 5.5 | 12.5 | 1.5 | .5 | | 5 | .5 | 1 | 2.5 | 2 | 1 | 1.5 | X | X | | 24 |
| VII | H-H* | | 10 | 16 | | 1 | 6 | | 4 | 9 | 13 | 1 | | | | | | -1- | | | | | 2 | | 37 |
| | H-10 | | 7 | 15 | 12 | 14 | 6 | | 8 | 5 | 2 | 1 | 3 | 1 | | 5 | 6 | 1 | 1 | 2 | 1 | X | | 3-s | 10 |
| | H-18 | | 4 | 8 | 12 | -- | 10 | -- | 2 | 6 | 10 | 4 | 2 | 4 | | 5 | 10 | -- | 3 | | -- | X | 3 | | 17 |
| | H-23-B | | 2 | 4 | 2 | | | 10 | 5 | 1 | 34 | 11 | 2 | 6 | | 2 | 4 | -- | 2 | 1 | 3 | X | | | 8 |
| | H-24 | | 2 | 10 | -- | 26 | | 1 | 4 | 3 | 6 | 10 | 4 | 3 | -- | 5 | 5 | 1 | 8 | 5 | | X | | | 7 |
| | H-30(29) | 3 | 3 | 7 | | | | 2 | 2 | 5 | 7 | 3 | 2 | 7 | | 6 | 11 | 7 | -- | | | X | | 13m | 21 |
| | H-30(30) | | | 18 | | -- | 1 | 1 | 3 | 3 | 8 | 7 | 6 | | | 7 | 16 | 1 | 4 | | 2 | X | | | 23 |
| | L-3 | 1 | 7 | 18 | | | 12 | -- | 2 | 3 | 3 | 7 | 4 | 3 | | 6 | 6 | -- | 2 | 1 | 2 | X | | 2-u | 21 |
| VIII | H-10* | | 1 | 46 | | | 6 | | 5 | 5 | 7 | 3 | | 1 | | | | -- | -- | | 2 | X | 6 | | 18 |
| | H-18* | | 15 | 39 | | 4 | 9 | -- | -- | 1 | 9 | 2 | | -- | | | | -1- | | | 2 | X | | | 18 |
| | H-19-A* | | 1 | 7 | 3 | 1 | 9 | 1 | 16 | 19 | 12 | 6 | | | | | | -2- | | | | X | 7 | | 11 |
| | H-23* | | 6 | 19 | | 3 | 2 | | 6 | 1 | 25 | 5 | | 2 | | | | -5- | | | | X | | | 26 |
| | H-30* | | 33 | 17 | | 4 | 7 | | 3 | 3 | 5 | 2 | | | | | | -3- | | | | X | | | 23 |
| | H-C* | | 8 | 19 | | | 15 | 5 | 22 | 5 | 7 | 3 | | | | | | --- | | | | X | 5 | | 11 |
| | AVE | .5 | 7 | 17 | 3.5 | 4 | 6 | 2 | 6 | 5 | 10 | 5 | 2 | 2 | -- | 3 | 4 | 1 | 2 | .5 | 1 | X | 1.5 | 1 | 16 |
| | A-6 | | 11 | 32 | | | 6 | | | 5 | 16 | 3 | 1 | 1 | | 2 | 5 | -- | 1 | | 1 | | | | 16 |
| | A-6 | | 2 | 27 | 17 | | 3 | 1 | | | 11 | 5 | 2 | 1 | | 4 | 7 | | -- | | 3 | | | | 17 |
| IX | T-11(37) | | 30 | 20 | 1 | | | | | 1 | 11 | 3 | 2 | 2 | | 3 | 6 | 1 | 1 | | 2 | | | | 16 |
| | T-11(38) | | 5 | 21 | | | | -- | 5 | | 30 | 10 | 2 | 4 | | 3 | 3 | 2 | 1 | | | | | 2-u 2-m | 9 |
| | T-11(37)* | | 2 | 51 | | | | | 3 | 1 | 12 | 1 | | | | | | -2- | | | | | | | 21 |
| | AVE | | 10 | 30 | 4 | | 2 | -- | 2 | 1.5 | 16 | 4.5 | 1.5 | 2 | | 2.5 | 4 | 1 | 1 | | 1 | | | 1 | 16 |

(1) * cut slab point count with binocular microscope
-- trace, X present in outcrop, m metadiabase, u ultramafic, s volcanic shard

counts he determined that the lower unit contained about: 8% Saganaga tonalite, 17% greenstone (metabasalt and meta-andesite), 8% mafic to mafic-intermediate clasts, 12% felsic to felsic-intermediate clasts, 1% felsite, 1% chert, 4% sedimentary clasts, and 49% matrix (<0.5 cm). The upper unit averages about: 8.5% Saganaga tonalite, 11% greenstone, 7% mafic to mafic-intermediate, 21% felsic to felsic-intermediate, 2% felsite, 1.5% chert, 4% jasper, 3% miscellaneous, and 42% matrix (<0.5 cm).

The total thickness of the conglomerate is estimated to be about 1220 meters (Gruner, 1941). It consists mainly of conglomerate although thin interbeds of graywacke are present throughout the section. The unit strikes northeast and dips steeply to the northwest.

Since the petrography of this conglomerate has already been extensively researched by McLimans, the major concern of this investigation was the unit's relationship to the surrounding finer-grained sediments. Exposure of the base (in Sec. 26, T.65N., R.6W.) illustrates a sharp transition from the underlying fine-grained sediments (Bouma C-E at this locality) into the conglomerate (Figure 25). The base consists of clasts ranging from 1.0 to 10 cm and averaging about 2.5 cm in diameter. The transition into the overlying graywacke at the top of the unit is of a gradational nature rather than a sharp one. At the top there are repetitious small lenses of conglomerate which grade upward into coarse-grained graywackes (Figure 26). As the graywacke unit is

Figure 25: Base of the Ogishkemuncie Lake conglomerate (Unit I). Note the sharp change (Cannon Cap) from the underlying fine-grained graywackes (Bouma C-E) into the conglomerate. Outcrop Og-2, center of NW 1/4, NW 1/4, Sec. 26, T.65N., R.6W.

Figure 26: Top of Unit I exposed on an island on Kale Lake. Note the conglomerate lenses which grade into graywackes, grading is toward the top of the photograph. The well-rounded white clasts are Saganaga tonalite. Outcrop K-3, NW 1/4, SE 1/4, SE 1/4, Sec. 14, T.65N., R.6W.

approached, there is a decrease in the thickness of conglomerate lenses and the average clast size. This is the case for most of the conglomerate units within the area of study.

At its northernmost end, the conglomerate overlies the Saganaga batholith in the vicinity of Alpine Lake. At this locality the conglomerate appears to interfinger with graywackes which also overlie the batholith farther to the north. While making a due west traverse from Alpine Lake (center of NE 1/4, Sec. 7, T.65N., R.6W.) the author first encountered a jasper-pebble conglomerate overlying the Saganaga batholith. Rounded jasper pebbles constitute the only clast type, totaling from 3 to 7 percent of the conglomerate. The jasper clasts range from 0.5 to 3.0 cm, and are widely interspersed within a fine-to medium-grained dark-gray matrix. To the south, along strike, the jasper-conglomerate grades into a polymict conglomerate consisting of volcanic and plutonic detritus as well as jasper. To the north the conglomerate pinches out. Overlying the jasper-pebble conglomerate is a 10 meter series of quartz eye graywackes (Samples A1-12 and 13). This in turn is overlain by a series of massive repetitious beds of conglomerate, graywacke and siltstone. The most massive conglomerate unit containing the largest clasts (up to 30 cm) was encountered along a small lake about 700 meters west of Alpine Lake (center of section 7, northeast of Redpoll Lake).

Unit II

Conglomerate II is best exposed at the top of an 18 meter cliff located at the far east center of section 21. Here the unit strikes about N25E, is approximately 18 meters thick and has a strike length of at least 1830 meters. In outcrop, the conglomerate is clast supported and characterized by sub-rounded elongated pink clasts within a pink matrix of the same material (Figure 27). Clast sizes average about five centimeters in diameter with a maximum size of about sixteen centimeters. The clasts, which total about 71%, are predominantly pink porphyritic volcanic clasts ranging from trachyte to trachyandesite (see Table 7). The remaining bulk of the conglomerate consists of about 19% matrix and 10% miscellaneous (andesite, mafic, and chert clasts; detrital plagioclase, hornblende, and volcanic quartz grains).

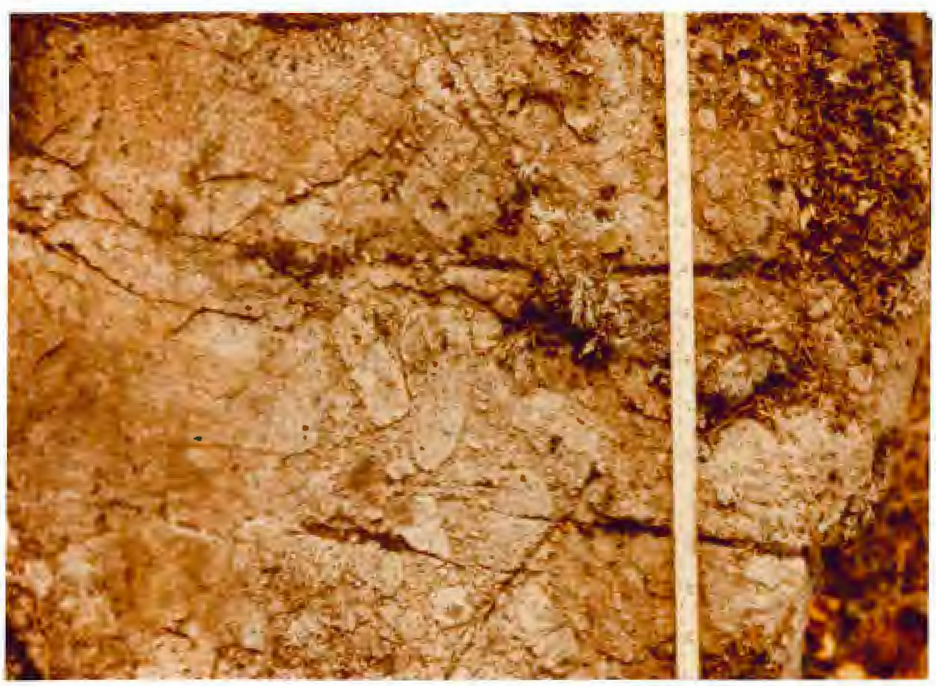


Figure 27: Exposure of Unit II, outcrop Kn-17, NE 1/4, NE 1/4, SE 1/4, Sec. 21, T.65N., R.6W.

This type of conglomerate is different from the other conglomerate units which contain a wide variety of volcanic material. The homogenous nature of the clast types and matrix (pink color) indicates that conglomerate II was derived from either the erosion of a series of felsic flows, or by reworking of felsic pyroclastics.

Gruner (1941) mapped the conglomerate as being isoclinally folded in the SE 1/4 of section 21. Of a series of four broad folds only two were found during this investigation. Location of the two remaining folds was hampered by a lack of outcrop. Gruner also mapped the conglomerate as continuing southwestward from this locality through the portage between Jenny and Eddy Lakes. Exposures at the portage do not contain any conglomeratic beds. Rather, they consist of finely laminated green siltstones and graywackes which strike N50E and top northwest.

Conglomerate II is similar in appearance to Unit V, located at the southern terminus of Nabek Lake. Due to either faulting or a lensoidal nature, the two cannot be traced as one unit.

Unit III

Conglomerate III contains most of the rock types mentioned earlier. It consists of approximately: 68% volcanic clasts, 12% detrital sand grains, and 20% matrix. Boulders of Saganaga tonalite are present but outcrop conditions prevented determination of the amount. Dacite porphyry clasts are prominent, averaging about

20% in the conglomerate samples. Clasts are generally sub-angular and average about 3.5 cm in diameter with a maximum size of 10 centimeters.

The unit trends about N50E through portions of sections 21, 22 and 15. It is at least 4.5 meters thick and has a strike length of about 610 meters. The conglomerate terminates against a shear zone to the south, and thins and pinches out to the north. Although Unit III cannot be traced northeastward to Unit IV, the two may still be correlative. The two are similar in that they both: have the same general appearance, contain boulders of Saganaga tonalite, trend about N50E, and are located approximately along the same horizon.

Unit IV

Exposed along the north shore of the southern half of Nabek (Bear) Lake is a 37 meter thick conglomerate. The unit is mostly massive coarse conglomerate except for the top 3 meters. In this interval conglomerate and coarse-grained graywackes alternate in repeated sequences of about 0.6 meters. The conglomerate retains its massive thickness along a 335 meter long exposure. Determination of its lateral extent is hampered on the east by Nabek Lake, and on the west by a swamp and lack of outcrop. Because of its apparent stratigraphic position, and other reasons mentioned earlier, Unit IV may be correlative with Unit III.

The unit contains all the major rock types mentioned earlier except jasper. Outcrop pebble counts (Table 8)

TABLE 8.--OUTCROP PEBBLE COUNTS OF UNIT IV

| Sample Location | Felsic | Felsic-Intermediate | Mafic-Intermediate | Mafic | Saganaga Tonalite | Chert | Greenstone | Felsite | Matrix | Average Clast size (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| N-9 | 15 | 9 | 4 | 9 | 4 | 1 | | | 58 | 4.2 |
| N-10 | 28 | 9 | 6 | 10 | 2 | 3 | - | - | 42 | 6.3 |
| AVE | 22 | 9 | 5 | 9 | 3 | 2 | - | - | 50 | 5.3 |

Felsic - porphyritic, light color, trachytic to latitic.
Felsic-Intermediate - porphyritic, light to medium color, trachyandesitic.
Mafic-Intermediate - porphyritic to aphanitic, medium to dark color, andesitic.
Mafic - porpyritic to aphanitic, dark color, basaltic.
Greenstone - aphanitic, dark green color, andesitic to basaltic.

Note - The above rock types are "field classifications" based on color and texture only.

indicate that the conglomerate consists of approximately: 3% Saganaga tonalite, 50% matrix (<0.5 cm), 2% banded and black cherts, and 45% volcanic clasts. Thin section and cut slab point counts indicate that the conglomerate contains about 84% volcanic material, 9% miscellaneous, and 7% matrix (see Table 7).

Clasts range in size from 0.5 cm to 33 cm in diameter with an average size of about 5.0 centimeters. They are generally rounded and vary in two-dimensional shape from elongate to spherical. Texturally the clasts are disoriented although some slight imbrication is present indicating a transport direction toward the south.

Unit V

Conglomerate V is located at the southern terminus of Nabek (Bear) Lake. It is similar to Unit II in that it consists of pink porphyritic volcanic clasts within a pink matrix. The clasts are trachyandesitic to andesitic in nature (see Table 7).

Clasts are generally sub-angular to sub-rounded, averaging about 0.7 cm in diameter. Maximum clast size is approximately 3.0 cm in diameter.

The unit has a strike length of about 180 meters, and is approximately 12 meters thick in the vicinity of Nabek Lake. Based on general appearance only, Unit V may be correlative with Unit II.

Unit VI

Unit VI is the only major jasper-bearing conglomerate within the area of study, excluding the top half of Unit I. Jasper clasts total approximately 5% of the conglomerate. In addition to jasper, it contains approximately 62.5% volcanic clasts, 8.5% detrital grains and 24% matrix ($<$0.03 mm). Sedimentary clasts and boulders of Saganaga tonalite are present in outcrop, probably totaling less than one percent.

Clasts generally range from 0.3 to 1.5 cm, although a few large rounded clasts up to 10 cm in diameter are present. The average grain size, approximately 0.5 cm, is much smaller than the averages of the other conglomerate units. Roundness varies from sub-angular to sub-round.

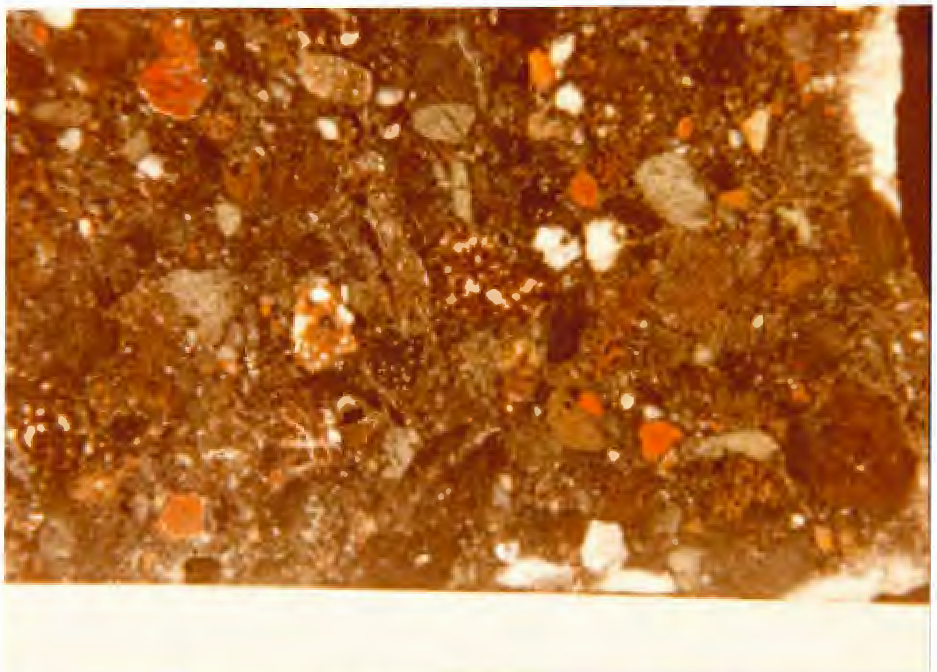


Figure 28: Cut slab of conglomerate unit VI. Note presence of jasper in addition to the various volcanic clasts. Outcrop N-1, NW 1/4, SW 1/4, SW 1/4, Sec. 14, T.65N., R.6W.

Unit VI consists of two separate 3 meter thick conglomerate beds separated by 90 meters of coarse-to medium-grained graywackes. Due to the anamolous presence of jasper, they are referred to as one unit. Both appear lensoidal and are exposed over distances of 45 and 274 meters. Exposures of the two are found on a peninsula along the south shore of Nabek Lake (section 14), and south of Nabek Lake along the western edge of section 14.

Unit VII

Conglomerate VII is northwest of Holt Lake, in the northern center of section 14. It is approximately 8 meters thick, consisting of sequences of 1 meter thick beds. The conglomerate unit is lensoidal and exposed along a 90 meter strike length.

Clasts generally average 1.0 cm in diameter with a maximum size of about 3.0 centimeters. A selected sample from one of the conglomerate beds contains approximately 61% volcanic clasts, 2% sedimentary clasts, and 37% matrix (<0.03 mm).

Unit VIII

Conglomerate VIII is exposed in, and defines, a deformed anticline which extends through Holt Lake. Bedding characteristics and thicknesses, shown in Figure 29, are extremely diverse. The total exposed strike length is approximately 1310 meters.

Average clast size is from three to six centimeters with a maximum size of ten centimeters. The large clasts are generally spherical to elongate in shape and subrounded to rounded. Smaller clasts are irregular in shape and very-angular to angular.

The conglomerate contains approximately 68% volcanic material, 3.5% sedimentary clasts, 11.5% detrital grains, and 16% matrix (<0.03 mm). Clasts of Saganaga tonalite are present and are estimated to total one percent.

Unit IX

Conglomerate IX is a small lensoidal unit located northwest of the northern limb of Ogishkemuncie Lake in sections 12 and 13. It is only 1.5 meters thick and 300 meters long. The average grain size is approximately 4.0 mm in diameter with a maximum size of 1.4 centimeters. Components average about 72.5% volcanic material, 11.5% detrital sand grains and 16% matrix (<0.03 mm).

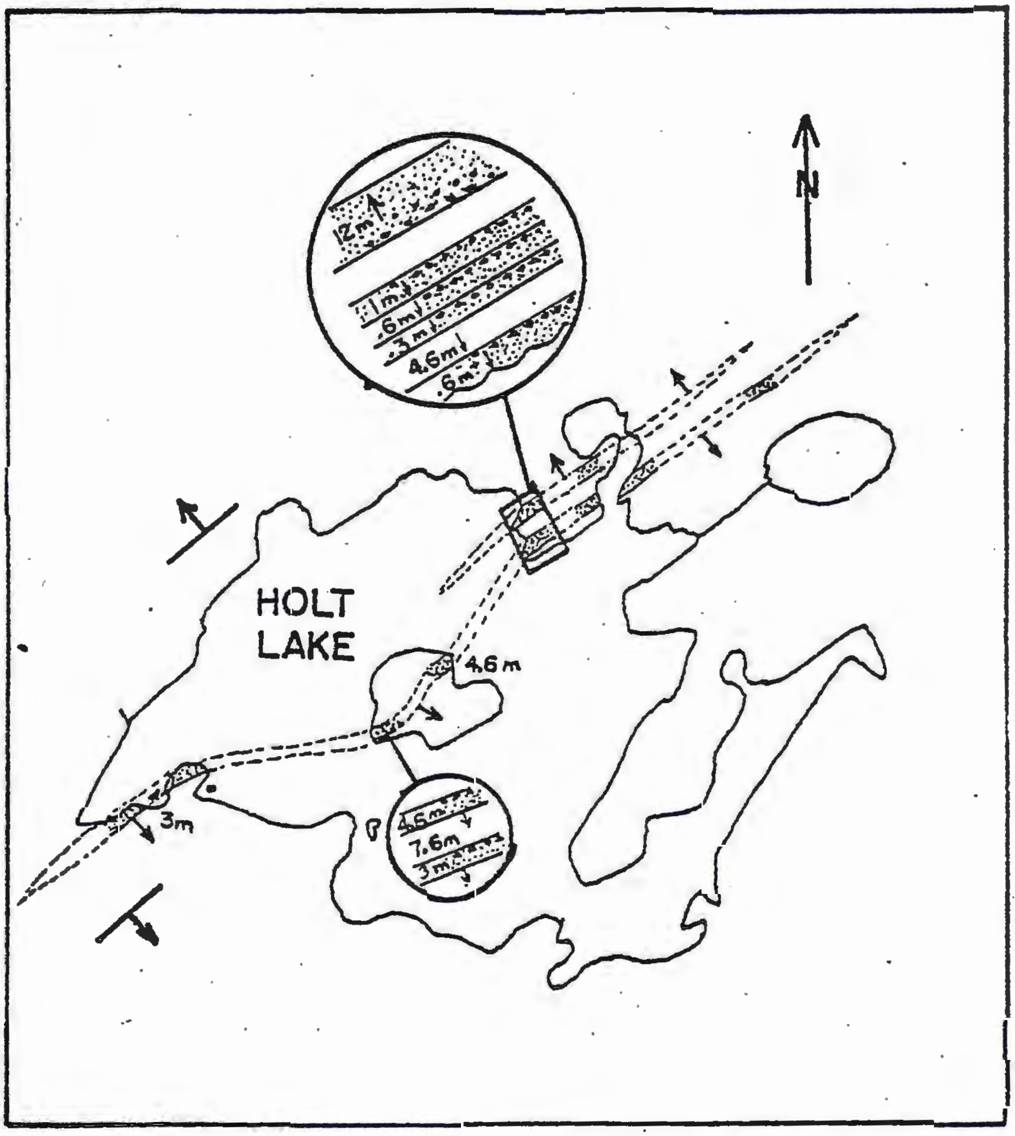



Figure 29: Bedding characteristics, top directions, and thicknesses of Unit VIII. "White" beds between conglomerate beds are graywackes. Tops determined by grading in conglomerates.

Figure 30: Stained slab from conglomerate at Holt Lake (Unit VIII). Staining for K-feldspar aided in differentiating the various volcanic clasts. Note the disoriented closely packed nature of the clasts, the deformed mudclast at center right, and small Saganaga tonalite clast (white) at center left. Outcrop H-10, NW 1/4, NE 1/4, NE 1/4, Sec. 14, T.65N., R.6W.

Unit X

In the vicinity of Nawakwa (Crooked) Lake the graywacke-slate unit of this study is overlain by a massive boulder conglomerate. The conglomerate retains a coarse character throughout and boulders of 30 cm in diameter are common at both the top and bottom. Gruner (1941) estimated this unit to be about 1220 meters thick.

McLimans (1971, 1972) studied the petrography of this unit and determined that the conglomerate averages about: 36.7% Saganaga tonalite, 13.9% greenstone, 3.5% mafic to mafic-intermediate clasts, 1.8% felsic to felsic-intermediate clasts, 0.2% felsite, 0.1% chert, 1.8% miscellaneous, and 44% matrix (<0.5 cm). He also noted compositional differences in the conglomerate on the eastern and western sides of Nawakwa Lake. On the western side of the lake, Saganaga tonalite accounts for about 50% of the conglomerate; while across the lake the dominant clast is greenstone with only about 6% Saganaga tonalite. Due to a lack of outcrop along the east shore of Nawakwa Lake, McLimans interpreted the greenstone conglomerate as a possible basal unit.

However, exposure of the base 460 meters east of Nawakwa Lake, indicates that the greenstone conglomerate is a separate unit within a dominantly tonalite-bearing conglomerate. The base is exposed in the north center of section 1, on a small lake due north of Faith Lake. At this locality, the conglomerate consists of about (visual estimation): 30% Saganaga tonalite, 15% greenstone (dark to medium-green color), 10% mafic to mafic-intermediate clasts (green-gray color), and 45% tonalitic matrix (Figure 31). Tonalite clasts are generally well rounded and spherical to elongate in shape. Maximum clast size is 60 cm in diameter.

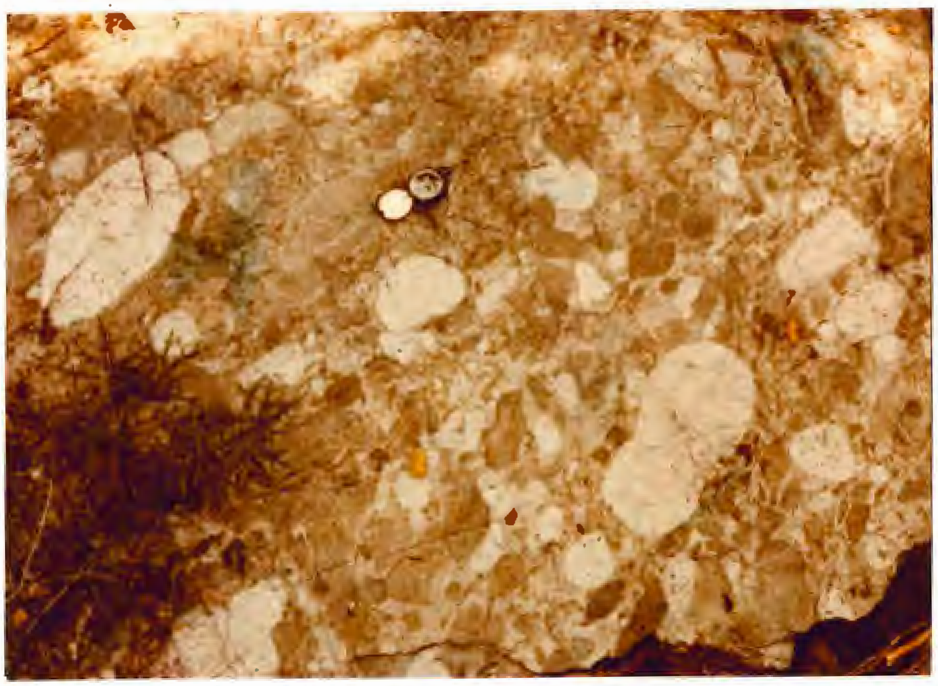


Figure 31: Exposure of the base of Unit X, containing Saganaga tonalite (white), greenstone (dark to medium-green), and mafic-intermediate clasts (green-gray). Maximum clast size is 60 centimeters (Brunton for scale). Outcrop located NW 1/4, NW 1/4, NE 1/4, Sec. 1, T.65N., R.6W.

Siltstones

Fine-grained siltstones and graywackes (Bouma D-E) are the second most dominant rock type within the area of study. They are interstratified with coarser graywackes and conglomerates. They are most prominent at the southern end of the investigated area, and within Gruner's unit 5 (Well-banded slates and graywackes).

Bedding ranges from 1.0 mm to over 6.0 cm in thickness. Color is variable, ranging from dark and light green to medium-brown depending on the nature of the clayey matrix.

Bedding planes are generally distinct and straight although irregular bases are common. Sedimentary structures include: some grading of the coarser beds, micro-flame structures, imbricated mud chips, and micro-crossbeds outlined by either hornblende or magnetite. Minor soft sediment deformation, due to compaction or slumping, is illustrated in some of the siltstones by the presence of clastic dikes; and micro-faults, folds, and boudinage.

Microscopically, the siltstones are characterized by varying amounts of detrital sand grains and volcanic material (yellow stain) within a dark-brown to green matrix. The matrix ranges from 15 to 90 percent of the rock. Most of the detrital sand grains are widely scattered throughout the matrix with the exception of volcanic material, which is generally concentrated in the coarser beds (average grain size 0.05-0.1 mm). Visual estimates of 12 fine-grained siltstones are shown in Table 9.

Grains are either irregular or blocky in shape, exhibiting angular edges. Sizes are extremely variable from bed to bed. A 2.0 mm thick bed consisting of 0.2 mm grains may be overlain by another 2.0 mm bed containing only 0.04 mm grains.

| Slide | Volc. Frags. | Plag. | Horn. | Quartz | Misc. | Matrix | Avg. Grain Size (mm) |
|---|---|---|---|---|---|---|---|
| A-1 | | 5 | | 5 | -j | 90 | 0.07 |
| A-6 | | 10 | | 5 | | 85 | 0.025 |
| H-4-A | 40 | 15 | 20 | 10 | -m | 15 | 0.2 |
| H-6 | 35 | 20 | 10 | 5 | | 30 | 0.05 |
| H-11 | -- | 30 | -- | 15 | 5p | 50 | 0.05 |
| B-1 | | 3 | 2 | 1 | | 95 | 0.18 |
| J-1 | 45 | 20 | | 10 | | 25 | 0.15 |
| Kn-2 | | 30 | | 10 | | 60 | 0.017 |
| S-1 | 40 | 15 | 20 | 10 | | 15 | 0.25 |
| K-1 | 35 | 15 | 20 | 10 | | 20 | 0.15 |
| T-2 | 10 | 40 | | 20 | 3m | 27 | 0.05 |
| T-3 | | 20 | | 10 | 5m | 65 | 0.02 |
| | -- Trace, j-Jasper, p-Pyrite, m-Magnetite | | | | | | |

TABLE 9.--APPROXIMATE COMPONENTS OF SILTSTONES (in percent)

X-ray diffraction of crushed fine-grained samples indicates that the matrix consists of clays altered to varying amounts of chlorite, sericite, epidote, calcite, and hematite.

A dense black slate is located along the north shore of Eddy Lake but will not be described in detail. It is composed of (X-ray diffraction) quartz, chlorite, plagioclase (albite-oligoclase), sericite, biotite, orthoclase, hornblende and minor calcite.

Iron-formation

Small lenses of iron-formation occur interstratified with the graywackes at six known localities (Plate I). They are up to 5 meters thick, weakly magnetic, and characterized by a red hematitic stain. Bedding consists of alternating layers (1.0 mm - 5.0 cm) of hematitic argillites and fine-grained tuffaceous graywacke giving the rock a banded appearance. No jasper or chert was found in any of these lenses.

Beds within the iron-formation are folded and discontinuous (Figure 32) while the underlying and overlying graywackes show no evidence of similar deformation. Other writers also noted the distortion of similar iron-formations but failed to state why. In the opinion of this writer, the deformation was penecontemporaneous with sedimentation, probably due to either slumping or the traction load of an overriding turbidity current.

Figure 32: Exposure showing the deformed nature of finely laminated hematite-magnetite-rich argillites (iron-formation). Outcrop T-4, SW 1/4, NE 1/4, NW 1/4, Sec. 12, T.65N., R.6W.

In thin section, the iron-formation is composed of quartz, feldspar, magnetite, and pyrite within a chlorite-hematite matrix. Hematite occurs throughout, but is generally more concentrated in the finer-grained beds. Stark (1929) determined that the finer-grained iron-rich bands (in iron-formations in the vicinity of Kekekabic Lake) contain approximately: 43% magnetite, 31% hematite, 12% quartz, 5% chlorite, 8% feldspar, and 1% epidote. The iron-poor bands average about: 9% magnetite, 2% hematite, 25% quartz, 50% chlorite, 10% feldspar, and 4% epidote (Stark, 1929).

The iron-formation probably originated in a subaqueous environment as a mixture of both pyroclastic (tuffaceous) and exhalitive volcanism. Deposition

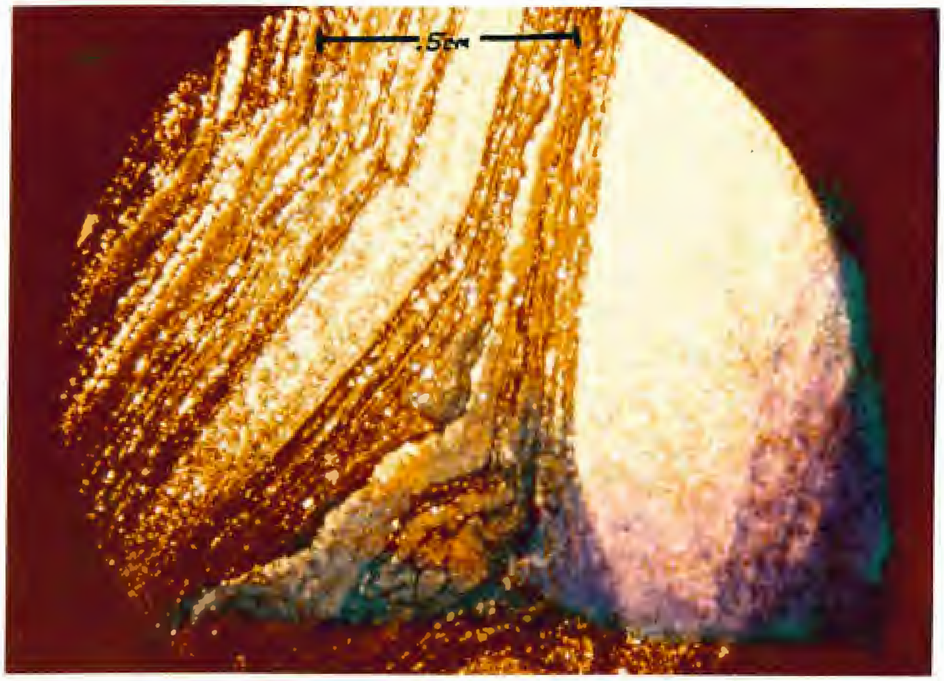



Figure 33: Photomicrograph of finely laminated iron-formation. Hematite is concentrated in the finer-grained beds. Note the flame structure and micro-fault. Outcrop H-9, SW 1/4, NE 1/4, NE 1/4, Sec. 14, T.65N., R.6W.

occurred in small depressions within the turbidite sequence. Exposures of iron-formation were originally thought to represent folded portions of the "Agawa Iron-formation." Since they are small discontinuous lenses, Gruner (1941) suggested that they do not deserve formational status.

Tuffs

Also interstratified with the metasediments are minor reworked tuffs. The tuffs are similar to the graywackes in general appearance and could not be distinguished in hand speciman. The apparent nature of the tuffs was noted only during thin section analyses. They generally contain altered euhedral and broken plagioclase laths, round phenocrysts (magmatic resorbtion) of volcanic quartz, volcanic rock fragments, pyroxene, hornblende, and what appear to be flattened pumice fragments, within an altered matrix of chlorite, sericite and hematite. Relative components of two reworked tuffs are shown in Table 10.

TABLE 10.--MICROSCOPIC ANALYSES OF VOLCANIC TUFFS.

| Slide | Plag | Quartz | Volc Frag | Pyrox | Horn | Matrix |
|---|---|---|---|---|---|---|
| F-6 | 52% | 7% | 19% | | | 22% |
| S-3 | | 5% | 40% | 20% | 5% | 30% |

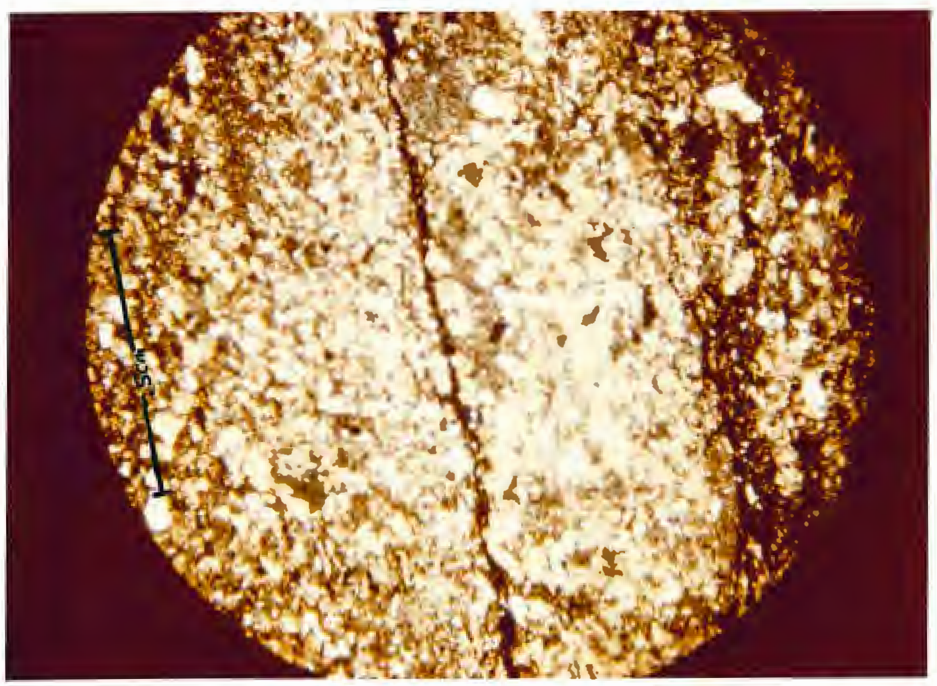


Figure 34: Photomicrograph of a reworked tuff (one polar). Contains volcanic quartz, plagioclase, and volcanic rock fragments (dacitic) within a chlorite-hematite matrix. Outcrop F-6, SE 1/4, SW 1/4, NW 1/4, Sec. 1, T.65N., R.6W.

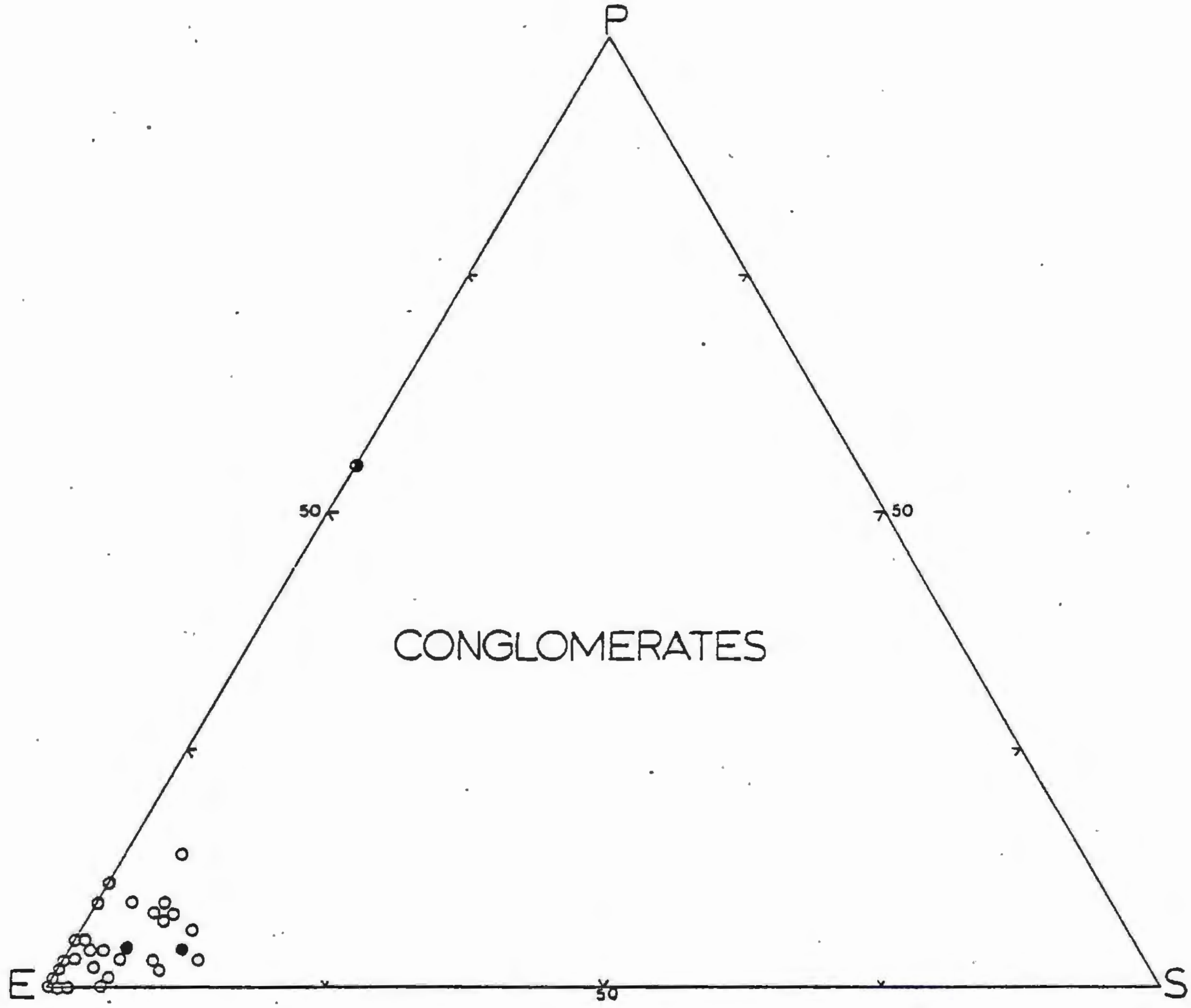
# CHAPTER IV

# PROVENANCE AND SEDIMENTATION

## Provenance

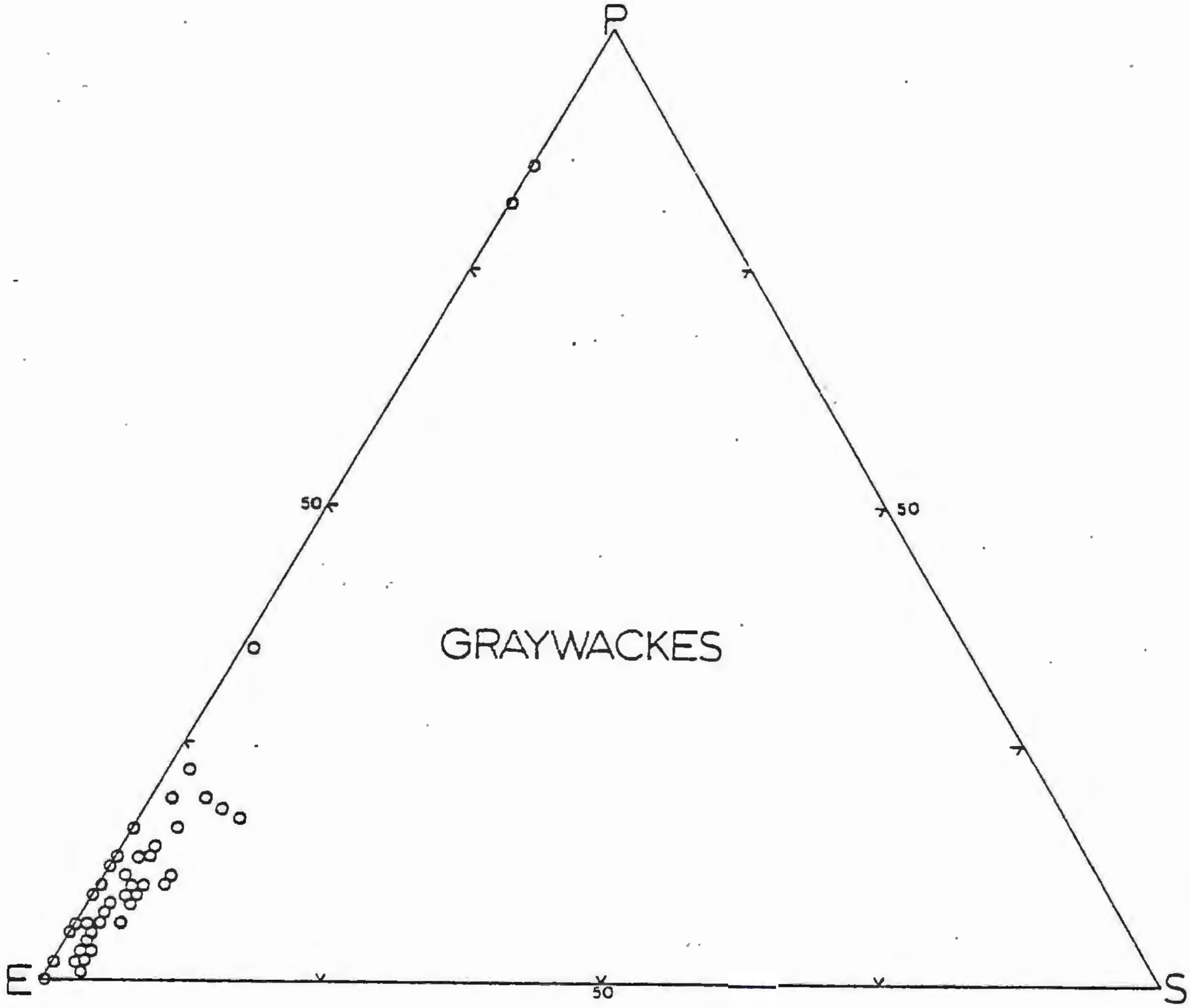
The majority of the sediments can be interpreted as being derived from a dominantly volcanic provenance, whereas others are indicative of a dominantly plutonic provenance, thus illustrating a form of mixed provenance -- volcanic-plutonic orogens or magmatic arcs. Relative component percentages for the conglomerates and graywackes are plotted on Figures 35 and 36.

Volcanic rocks of all the studied greenstone belts of the Canadian Shield belong to the basalt-andesite-rhyolite association typical of continental orogenic belts or island arc systems (Bass, 1961; Goodwin, 1968; Anhaeusser and others, 1969). Other studies (Wilson and others, 1965; Green, 1970) show that the volcanic suites are of a calc-alkaline nature also indicating a primitive continent or island system. Thus the great thickness of volcaniclastic sediments of this study, intimately associated with minor tuffs and iron-formations, indicates contemporaneous volcanism and sedimentation in a very deep subsiding trough flanked by a volcanic chain. The absence of any "shelf facies" suggests steep coastal areas due to uplift of the source areas and




E, eruptive (volcanic fragments and volcanic quartz); P, plutonic (tonalite clasts, plutonic rock fragments, plutonic quartz, and polycrystalline quartz); S, sedimentary (chert, jasper, sedimentary clasts, and mud clasts); O, microscopic point counts; ●, megascopic pebble counts; ◐, megascopic visual estimation.

Figure 35: Relative component percentages of clast lithologies within the conglomerates (diagram from Pettijohn, 1957, p. 252). Volcanic and plutonic quartz grains were not differentiated in megascopic pebble counts.




E, eruptive (volcanic fragments and volcanic quartz); P, plutonic (plutonic rock fragments, plutonic quartz, and polycrystalline quartz); S, sedimentary (chert and jasper); O, microscopic point count.

Figure 36: Relative component percentages of clast lithologies within the graywackes (diagram from Pettijohn, 1957, p. 252).

downwarp of the basin (Goodwin, 1968; Anhaeusser and others, 1969). This allowed for only temporary accumulation of unstable piles of sediment along the margins of the trough, destined to be jarred loose by slumping and transported downslope by the generated turbidity currents.

The presence of different types of volcanic rock fragments proves derivation from a varied source. The rounded nature of the boulders and pebbles within the conglomerates indicates erosion of subaerial flows and pyroclastics. The volcanic clasts consist of, in decreasing order: trachyte-latite, trachyandesite, andesite, mafic-intermediate, mafic (basaltic), dacite, rhyodacite, rhyolite, and felsite. Volcanic fragments total about 93.5% of the clasts in the conglomerates. Plutonic and sedimentary material average about 4% and 2.5% of the clasts respectively.

The clasts and grains of the graywackes average about 89% volcanic material, 9% plutonic material, and 2% sedimentary material. Detrital sand grains of plagioclase and hornblende are not differentiated herein as they occur in both plutonic and volcanic clasts.

"Granitic" clasts and detritus within the conglomerates of the Knife Lake Group have been shown to be derived wholly from the Saganaga tonalite (McLimans, 1971, 1972), which is distinctive due to the presence round quartz "eye" aggregates up to one centimeter across. However, Green (1970) noted other granitic pebbles, which are not of the Saganaga type, in minor conglomerate lenses of the Knife Lake Group in the central Vermilion district. He suggested that the granitic pebbles may represent material derived from either an original granitic crust, or a small now unexposed pluton. No granitic clasts other than the Saganaga tonalite type were noted in the metasediments of this investigation. Plutonic rock fragments generally average 1.5 percent in the conglomerates and graywackes, but some graywacke beds contain as much as 40 percent.

The Saganaga batholith can be compared with more recent batholiths which have been described as intruding and unroofing their own volcanic ejecta (Fiske and others, 1963; Hamilton and Myers, 1967). Hamilton and Myers (1967) envisioned the batholith magmas as rising in detached ballonlike forms through the crust, much like salt domes, towards the surface where they coalesce into shallow, fairly thin complexes. Any pluton that nears the surface is then roofed only by its own volcanic ejecta, and the granitic textures develope as the magma crystallizes beneath its insulating volcanic cover. Since tonalitic-rich sediments are interbedded with volcanic-rich sediments and minor tuffs, it appears that the Saganaga batholith and its volcanic cover were unroofed while volcanism was occurring nearby.

Hamilton and Myers (1967) also noted that batholiths appear to be uplifted selectively two or more times, and if so they must be eroded more than neighboring terrains. This may account for the difference in the dominance of either volcanic or plutonic material in the Knife Lake Group sediments. The conglomerate of Nawakwa Lake (Unit X) contains a high amount of tonalite clasts in respect to volcanic material, whereas the underlying graywackes and conglomerates (Units I-IX) contain a high amount of volcanic material in respect to Saganaga tonalite.

The graywackes of this investigation were found to average about 6.5 percent quartz (2.7 percent volcanic and 3.8 percent plutonic) although some graywackes contain as much as 19 percent quartz. A higher average of 12 percent quartz (volcanic and plutonic) was obtained by McLimans (1971) for graywacke interbeds within tonalite-bearing conglomerates. The average quartz content of the metasediments of this study is low, as opposed to an average 45 percent quartz content of graywackes given by Pettijohn (1957), and can be attributed to a dominantly volcanic provenance. Since the quartz content of the majority of the graywackes is not considered high for derivation from volcanic rocks, extensive weathering is not implied. No granitic provenance other than the Saganaga tonalite is needed to explain the quartz enrichment of some of the graywackes.

Detrital feldspar grains average about 12 percent, and generally exceed the average quartz content in the graywackes. The majority of the feldspar grains are plagioclase, in the albite-oligoclase range, with a very low percentage of K-feldspar. The trend towards sodic plagioclase with only minor K-feldspar is not unusual for graywackes of this type (Bailey, 1959; Donaldson and Jackson, 1965; Morey, 1967; Walker and Pettijohn, 1971; Ojakangas, 1972a, 1972b). The low K-feldspar content of the graywackes could be attributed to the initial source rock composition. The Saganaga tonalite averages only 15 percent K-feldspar (McLimans, 1971, 1972). Staining of volcanic clasts within the conglomerates indicates that K-feldspar occurs, for the most part, as a microcrystalline goundmass with only a small percentage of K-feldspar phenocrysts. Thus both provenance types, plutonic and volcanic, would have contributed minor K-feldspar grains to the basin. However, Walker and Pettijohn (1971) felt that the absence of K-feldspar could be due to a phenomenon of secondary origin as well as a deficiency in the source rocks. They suggested that the original K-feldspar of the rocks had been altered by reaction with sodium in seawater -- the potassium going into clays and being replaced in the feldspar by sodium -- which in itself is an indicator of marine conditions. Since the K-feldspar grains of this study show little evidence of corrosion, and fresh unaltered plagioclase phenocrysts are present within the volcanic clasts, the absence of K-feldspar is probably largely due to a deficiency in the source rocks.

Chert and jasper clasts were thought to have originated from erosion of the Soudan Iron-formation (Clements, 1903). Gruner (1941) thought this was possible, but noted that the proportion of red jasper was much greater than would be expected from studying the exposures of the Soudan Formation at its type locality. Chert and jasper fragments were probably derived from shallow water banded iron-formations, commonly attributed on the shield to volcanic exhalative sources (Goodwin, 1962; Goodwin and Shklanka, 1967), that were eroded and then mixed with other detritus in turbidity currents. The interbedded iron-formations noted during this study are not possible sources in that they contain no chert or jasper. They consist of fine-grained tuffaceous material, magnetite and hematite.

Clasts of slate and siltstone, though rare, are also present within the conglomerates of this study. The clasts are fine-to very fine-grained, bedded, and rectangular shaped. They exhibit breakage along bedding surfaces indicating erosion of a presumably indurated sediment (Figure 37). The clasts may represent erosion of sediments from within a submarine fan, or erosion of pre-Saganaga uplift sedimentary rocks.

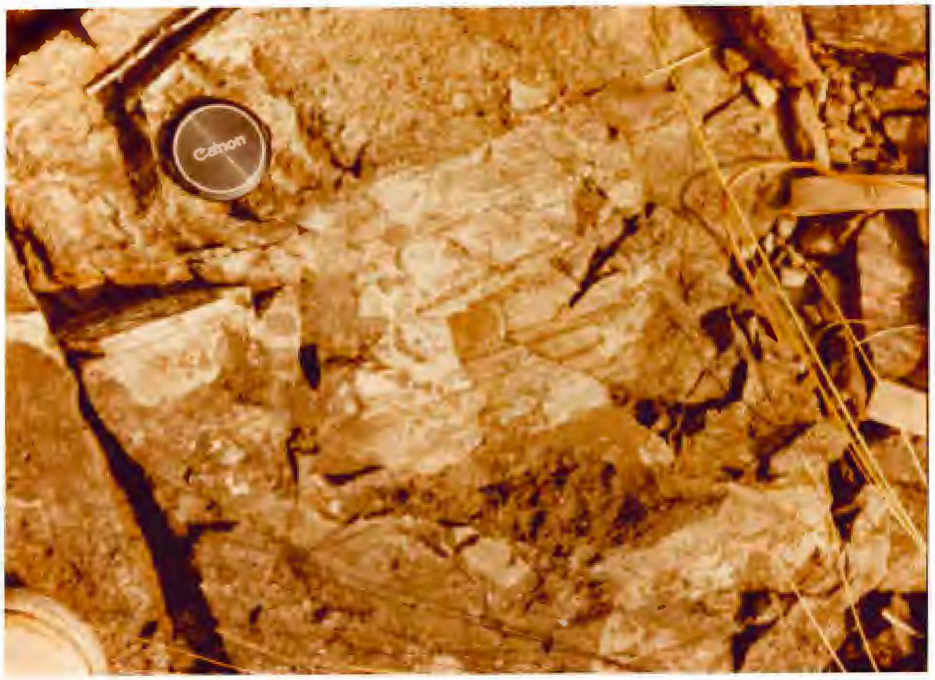


Figure 37: Sedimentary clast (slate and siltstone) in conglomerate (Unit VI). Outcrop N-2, SW 1/4, NW 1/4, SW 1/4, Sec. 14, T.65N., R.6W.

## Sedimentation

The rocks of the study area are characterized by a monotonous succession of graywackes, siltstones, and slates with interbeds of conglomerate, tuff and iron-formations. The dominant rock is immature "volcanigenic" graywacke characterized by angular, poorly-sorted grains within a high proportion of matrix. As mentioned earlier, the components present within the sediments indicate derivation largely from a basalt-andesite-rhyolite pile associated with a continental orogenic belt or island arc system. The thick sequence of sediments are herein interpreted as having been deposited by turbidity currents in a deep water basin. They lack any features indicative of shallow agitated water such as ripples or medium-to large-scale cross-bedding.

The graywackes and conglomerates probably originated as temporary accumulations on the slopes of volcanic piles. These accumulations were periodically jarred loose by slumpage triggered by earthquakes, volcanic eruptions, or storm waves causing submarine landslides, most of which developed into turbidity currents (Ojakangas, 1972a, 1972b). The currents flowed into a deep water basin and deposited sediments with various sedimentary structures and textures depending on the initial velocity and sediment load. Slates and siltstones represent the background sediment of the basin, but their deposition was repeatedly blotted out by the arrival of short-lived turbidity currents. Sedimentation proceeded in this manner throughout Knife Lake time as evidenced by the lack of unconformities between members (Gruner, 1941).

The slope of the basin was relatively steep since Saganaga clasts, up to 15 centimeters in diameter, have been transported to Ensign Lake, some 40 kilometers from the source area (McLimans, 1971, 1972). The presence of well-rounded boulders of all lithologies, and the angular nature of the detrital sand grains and small fragments, suggests rapid erosion of a provenance of substantial relief, and transportation to the unstable piles via high-velocity streams.

Bouma (1962) has described a "complete" turbidite bed composed of five internal units (A,B,C,D, and E). Throughout the study area, especially in the northern half, the majority of the sequences consist of top-truncated A or A-B units. "Complete" sequences (with or without Bouma E -- Figure 38) as well as "truncated base cut-out" sequences with some lower and/or upper units missing are also present. Bouma unit C is usually convoluted although some cross-lamination is present. The types of sequences and their relationships to each other within three measured sections are shown in Figure 39.

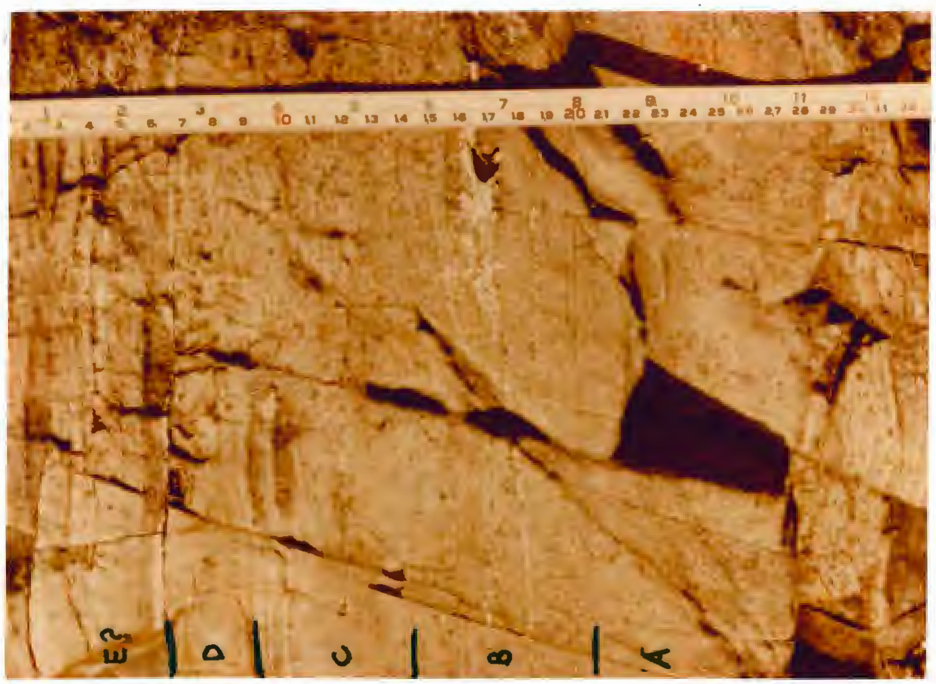
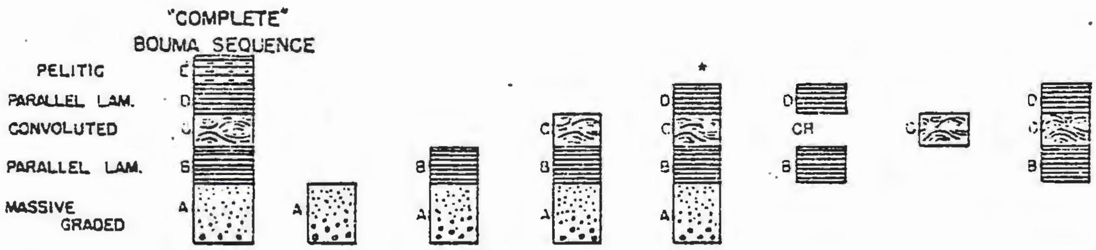



Figure 38: Bouma sequence, A through D (possibly E), east of Holt Lake. Outcrop A-1, SE 1/4, NW 1/4, NW 1/4, Sec. 13, T.65N., R.6W.

Most of the features of turbidites can be explained by a combination of erosion at the head of a turbidity current and deposition from the body and tail of the current (Middleton and Hampton, 1973). Erosion of pre-ceeding turbidite beds would account for the composite




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MEASURED SECT. I (A-1, 49 Beds) | GRADED | 33% | 20% | 4% | 4% | 14% | | 3% |
| | NOT GRADED | 12% | | | | 10% | | |
| MEASURED SECT. II (H-2, 13 Beds) | GRADED | 38% | 15% | | | 9% | 15% | |
| | NOT GRADED | 23% | | | | | | |
| MEASURED SECT. III (J-1, 12 Beds) | GRADED | 17% | 17% | 7.5% | 7.5% | | 17% | 17% |
| | NOT GRADED | 17% | | | | | | |

* with or without Bouma E

| | I | II | III |
|---|---|---|---|
| Thickness of section | 30.25 m | 5.92 m | 1.29 m |
| Number of beds in section | 800 | 33 | 33 |
| Graywacke beds: | | | |
| Percent of total thickness | 42% | 93% | 38% |
| Average bed thickness | 20.2 cm | 50 cm | 4 cm |
| Range of bed thickness | 1-170 cm | 2-120 cm | 0.5-13 cm |
| Number and percent of total | 49-6% | 13-39% | 12-36% |
| Number and percent graded | 38-78% | 6-46% | 6-50% |
| Percent with mud chips | 6% | | |
| Percent with jasper | 8% | 8% | |
| Percent with flames or irregular bases | 14% | 46% | 12% |
| Percent with convolutions (or cross-laminations) | 10% | 15% | 50% |
| Percent composite beds | 6% | 23% | |
| Alternating siltstone and slate: | | | |
| Percent of total thickness | 58% | 7% | 62% |
| Average bed thickness | 2 cm | 2 cm | 4 cm |
| Range of bed thickness | 0.4-5 cm | 1-3 cm | 2.5-5 cm |
| Number and percent of total | 751-94% | 20-61% | 21-64% |
| Percent with cross-lamination | 10% | 5% | 4% |

Measured Section I - Station A-1, SE 1/4, NW 1/4, NW 1/4, sec. 13, T65N, R6W
Measured Section II- Station H-1, SW 1/4, NW 1/4, NW 1/4, sec. 13, T65N, R6W
Measured SectionIII- Station J-1, west center, SW 1/4, NE 1/4, sec. 28, T65N, R6W

Figure 39: Internal bedding characteristics of graywackes (top), and bedding characteristics of measured graywacke-siltstone-slate sections.

A units and Bouma sequences where the top units are missing. An absence of the top units may also be explained by a lack of deposition within the turbidity current, such that the coarse material was deposited nearer the source and the rest of the turbidity current deposited the upper units farther from the source. "Complete" sequences, or sequences with missing lower units, would be deposited from the body and tail of the current as a function of the flow regime -- the units of the sequence representing, from bottom to top, successively lower flow regimes (Walker, 1976). Major factors in determining the flow regime would be the distance traveled and the initial velocity and sediment load of the current.

Walker (1976) suggested that the turbidites can be classed as either "proximal" or "distal" depending on the order of Bouma units. A Bouma A-A-A sequence would be proximal, whereas sequences beginning with unit B or C would be distal. He cautioned however, that the combined characteristics of a large number of beds would be necessary before making such environmental predictions. This concept was applied to the rocks of the study area. However, only a few large outcrops were clean enough to allow detailed measurements (see Figures 20 and 39). Therefore, any environmental prediction is only as accurate as the outcrop conditions permit.

The proximal turbidites of this study are located in the vicinity of Alpine Lake, where they abut against the Saganaga batholith (Plate I). The graywackes at this locality consist of very coarse-grained A-B sequences. To the southwest along strike, in the vicinity of Holt Lake, various Bouma sequences are present (see Figures 20 and 39-I and II), but A-A and A-B units are still the dominant type indicating a proximal environment as well. Evidence for a more distal environment is present within the southernmost end of the investigated area, in the vicinity of Jenny and Eddy Lakes. At one particular locality (Outcrop J-1, Sec. 28, T.65N., R.6W.), the Bouma A and B units are generally finer-grained and more thinly bedded. Basal truncated sequences (B-C-D, B-C, C-D, C) are more common, and unit C is generally more thickly bedded (up to 9 centimeters). This pattern (Figure 40) is the case for most of the outcrops in the southern terminus of this investigation, however some outcrops also consist of massive A-B units. Thus the term "distal", as defined by Walker (1976), would not be feasible for the sediments of the southern terminus; even though they are certainly <u>more</u> distal than the exposures of Holt and Alpine Lakes. A thick black slate unit occurs along the north shore of Eddy Lake, also implying a more distal environment.

The relationship of "proximal" versus "distal", as interpreted from the Bouma sequences, indicates that sediment transport was to the southwest along the present

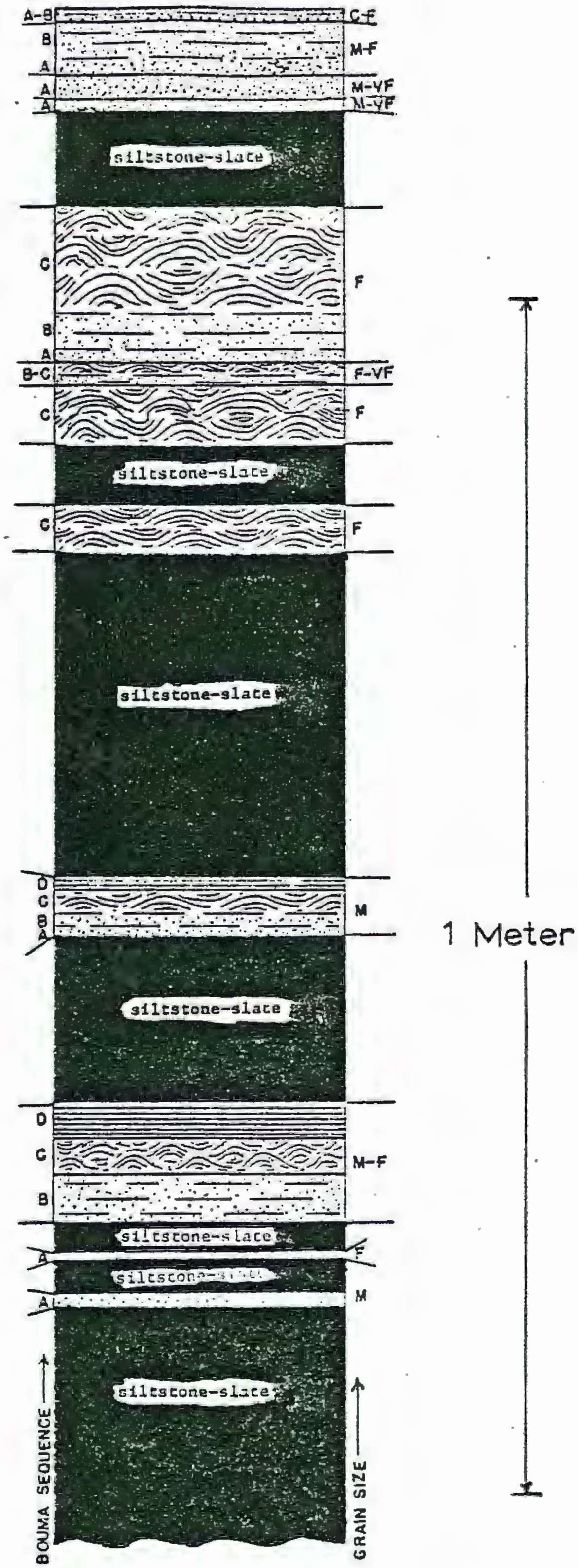



Figure 40: Pattern of Bouma units in the vicinity of Eddy and Jenny Lakes. From outcrop J-1, west center of SW 1/4, NE 1/4, Sec. 28, T.65N., R.6W.

tectonic strike away from the Saganaga batholith, with most of the supply being at the northeastern end of an elongate basin or trough. This coincides with a southward decrease in the size and abundance of Saganaga tonalite clasts in the conglomerate of Ogishkemuncie Lake (McLimans, 1971, 1972). The semi-imbricated nature of the conglomerate on Nabek Lake (Unite IV) also indicates a southerly transport direction. Since bedding is now vertical, the lateral extent of the original sediments cannot be determined.

Soft sediment deformation, due to slumping or compaction, was also noted. Slumpage within iron-formations is illustrated by their folded nature, and by the presence of flame structures and load pockets (Figure 41). Another indicator of slumping is shown in Figures 42 and 43. This phenomenon can be explained by slumpage and accordian-like deformation of a fine-grained siltstone-slate unit. Micro-troughs with crude cross-bedding were later deposited by a turbidity current in the depressions formed by the slumped units. Micro-clastic dikes are also present indicating compaction of non-lithified sediments.

Miscellaneous sedimentary features were also observed. Mud chips are common in the graywacke beds, and apparently are a result of erosion of underlying muddy beds by turbidity currents (Figure 44). No three-dimensional graywacke soles were observed due to the annealing of the graywacke-slate contacts.

Figure 41: Load pockets of coarse-grained sandstone into hematite-rich argillites. Outcrop H-9, NE 1/4, NE 1/4, NE 1/4, Sec. 14, T.65N., R.6W.


Figure 42: Soft sediment deformation (accordian-like) of siltstones and slates, with micro-troughs in depressions. Outcrop K-1, SW 1/4, SE 1/4, SE 1/4, Sec. 14, T.65N., R.6W.


Figure 43: Closeup of micro-troughs with crude cross-bedding. Same as Figure 42.

Figure 44: Mud chips (now slate) in graywacke which overlies the eroded slate bed. Outcrop Kn-14, center of SE 1/4, NE 1/4, Sec. 21, T.65N., R.6W.

Small-scale cross-laminations (2-5 cm thick) were noted within very fine-grained silt-turbidites (Figure 45) and, to a small extent, the upper parts of a few beds. A total of fifteen paleocurrent measurements were taken at only ten locations, shown in Figure 46. These measurements are rotated to the horizontal, with the plunge (determined by cleavage-bedding intersections) taken out and plotted on the lower portion of Figure 46. Paleocurrent measurements of five small cross-laminations (vectors with dots in the lower portion of Figure 46) from one outcrop (A-1, Sec. 14) indicate that sediment transport was in two directions approximately 180 degrees apart. This may indicate that the turbidity currents, which deposited the cross-laminated silt-turbidites, were either: deflected during their dying stages by irregularities on the bottom of the basin, or that the turbidity currents spread laterally within the basin. Therefore, the small-scale cross-beds may reflect only small scale irregularities within the basin, and thus give no clue as to the basin's overall geometry. It should be noted that only one indicator displays a northeast paleocurrent direction towards the Saganaga batholith.

Before reconstruction of the paleotopography can be attempted the conglomerates should be looked at in detail. Walker (1976) stated that conglomerates are restricted to channels mainly in the inner fan, but also in incised


Figure 45: Small-scale cross-laminations within fine-grained silt-turbidites. Outcrop H-4, bottom center, NE 1/4, NE 1/4, Sec. 14, T.65N., R.6W.

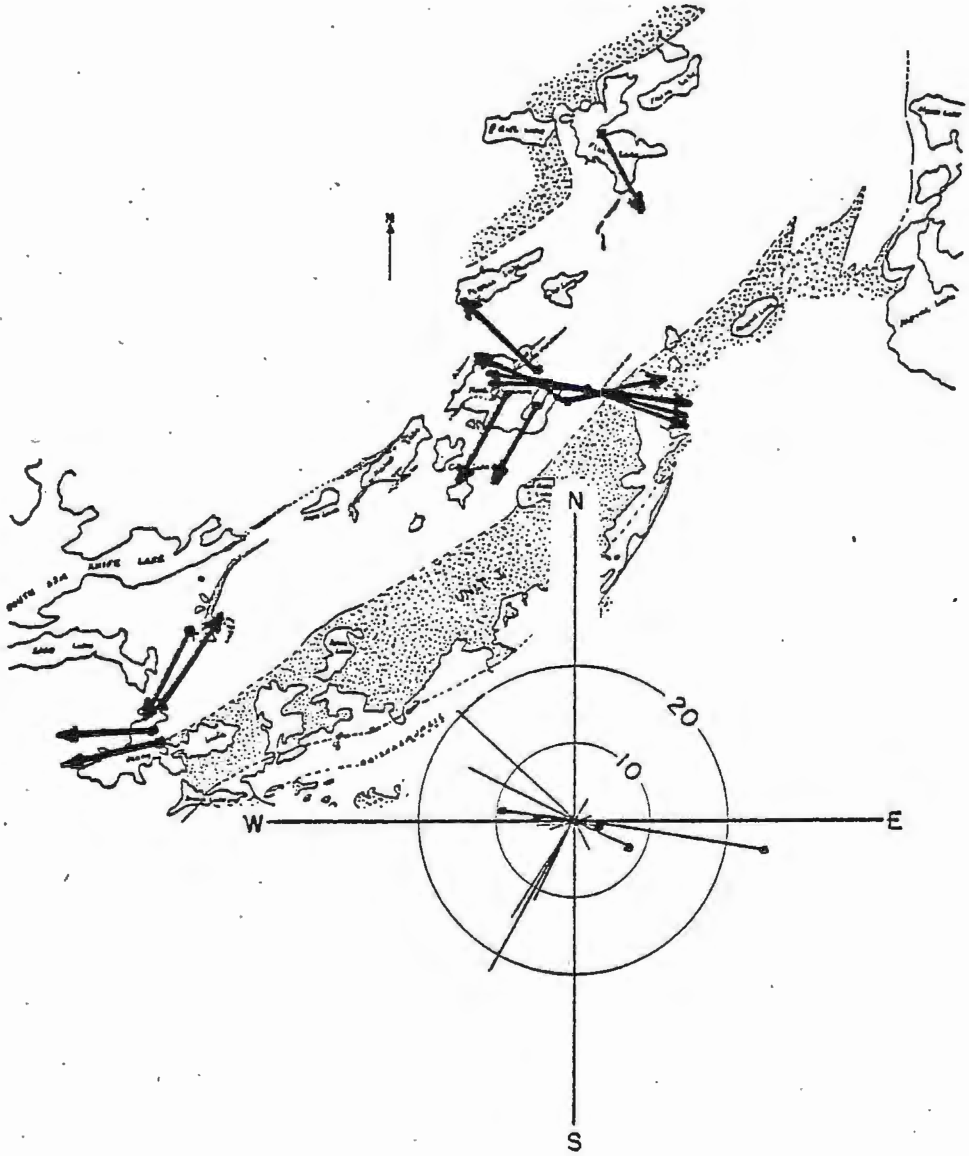



Figure 46: Locations and directions of 15 paleocurrent measurements. Top half illustrates station locations and paleocurrent directions; stippled areas are conglomerates. Bottom half -- plot of cross-laminations, numbered circles denote dip of cross-laminations, vectors with dots denote paleocurrent data from one outcrop.

channels extending across the entire submarine fan. Deposition of the coarse bouldery material within long sinuous channels would explain the lensoidal nature of the conglomerates within the area of study. Since sediment transport was to the southwest along the present tectonic strike, and since bedding is now vertical, only portions of the sides of the long sinuous channels are exposed at the present erosional surface giving the conglomerates a lensoidal nature. This has also been enhanced by the folding and faulting associated with the area.

Walker (1976) has proposed four models for resedimented (deep water) conglomerates. They are, in their relative positions downcurrent: 1). Disorganized Bed -- no grading, no inverse grading, no stratification, and rare imbrication, 2). Inverse-to-Normally Graded -- no stratification, imbricated, 3). Graded Bed -- no inverse grading, no stratification, imbricated, and 4). Graded-Stratified -- no inverse grading, stratified, cross-stratified, imbricated. Beds within the conglomerate units of this study can be subdivided into these four groupings. Usually, the stratigraphic lower portion of each conglomerate unit contains both Disorganized Beds and Inverse-to-Normally Graded beds. Graded beds predominate in the upper portions of the units with some Graded-Stratified Beds (without cross-stratification) at the top few meters of the units. Thus each conglomerate unit as a whole crudely represents, from bottom to top, proximal beds grading upwards into more distal beds. This is the opposite of what would happen in a prograding fan system and therefore, probably resulted from pro-ressive channel abandonment (Walker, 1976). As the channel filled it recieved smaller flows which deposited conglomerates with distal characteristics. As old channels became filled and were abandoned, new ones were incised; thus the channels would migrate within the fan system. This would explain the interfingering of conglomerate and graywacke in the vicinity of Alpine Lake (Plate I).

Most of the conglomerates contain a wide variety of clast types indicating a mixture of debris within unstable piles along the flanks of the source area. Slumpage of the unstable piles generated turbidity currents which transported the material to a fan system. However, some conglomerates are different in that one clast type may predominate over others. The conglomerate of Nawakwa Lake (Unit X) has an abundance of tonalite clasts; Unit VI and the top of Unit I have a high proportion of jasper; and Units II and V contain almost exclusively pink porphyritic volcanic clasts within a matrix of the same material. These differences probably represent either a tectonic change in the source area, or that debris was supplied from an isolated locality within the source area. The conglomerate of Nawakwa

Lake (Unit X) probably represents a significant tectonic change in the provenance and erosion of a dominantly tonalitic terrain. The homogenous nature of Units II and V suggests that they were derived from an isolated source area with no mixing of other debris. The Cache Bay conglomerate, and related arkose, represents an accumulation of tonalitic debris on the shelf near the tonalitic shoreline. The slope may not have been steep enough to give rise to slumping into the basin (McLimans, 1971). The anomalous presence of jasper is probably due to uplift of a volcanic pile and selective erosion of scattered iron-formations along the flanks of the pile.

In looking at the interpretations presented throughout this chapter, a crude approximation of the paleotopography during Knife Lake time can be derived. The sediments of this study were deposited within a subsiding basin that had steep sides as indicated by the presence of large boulders within the conglomerates. It was flanked on the east side by a continental orogenic belt or island arc system consisting of basalt-andesite-rhyolite piles and the Saganaga batholith which had intruded a portion of this system. Another felsic volcanic pile was probably present to the west in the vicinity of Knife Lake (Ojakangas, 1972a, 1972b). Slumpage of unstable piles of sediment along the flanks of the source area generated turbidity currents which flowed southwestward away from the Saganaga batholith. Debris was deposited on submarine fans with the coarse material confined to channels that migrated within the fan systems.

An extremely generalized topographic model of this interpretation is depicted on Figure 47. This portrayal is not intended to illustrate the morphology of the source area and basin throughout Knife Lake time, or even throughout the depositional period of the sediments of this study. The model only suggests a possible relationship of the sediments to the provenance at some point in the depositional history of the basin. Constant tectonic changes were prevalent in the source area which, in turn, exerted an overall control on the textures and compositions of the resultant sediments.

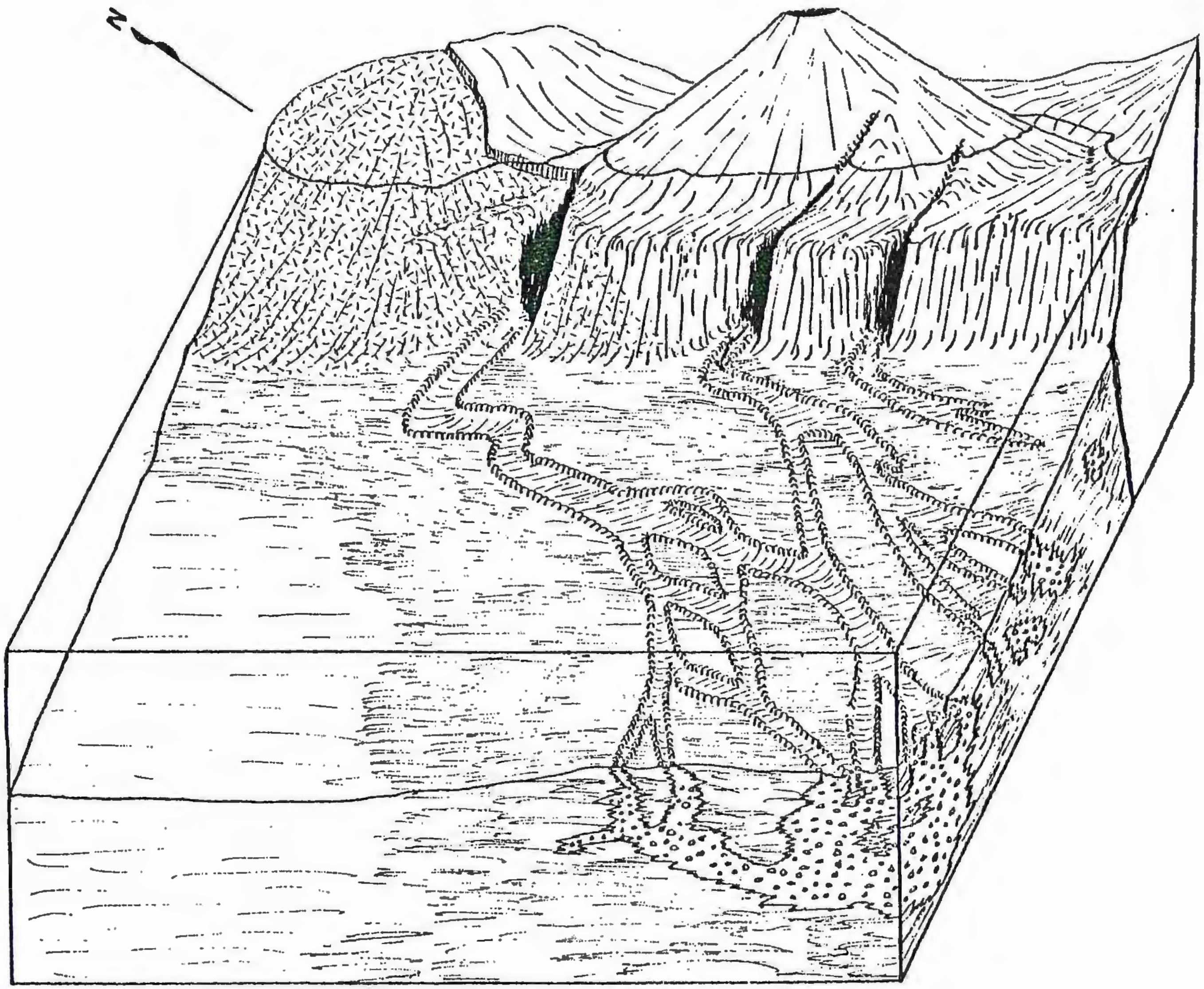



Figure 47: Generalized provenance-sedimentation model of Saganaga batholith and eastern Vermilion district facing west.

# CHAPTER V

# STRUCTURE

## General Statement

The supracrustal rocks of the Vermilion district were deformed and metamorphosed approximately synchronously with emplacement of adjacent batholithic rocks during the Algoman orogeny, 2.7 b.y. ago. The district is enveloped by a granitic terrain and marked by low-grade metamorphism and tight isoclinal folding, as are other lower Precambrian volcanic-sedimentary belts in shield areas of the world (Anhaeusser and others, 1969). However, deformation was not uniformly thorough in that primary structures such as Bouma sequences and pillows are still preserved in certain of the units in the eastern Vermilion district.

Bedding generally trends northeast with steep dips and topping directions to the northwest. Within the eastern Vermilion district, Gruner (1941) observed that cleavage is poorly developed, and wherever found generally strikes about N60 to 90E with steep dips.

All the Archean rock units in the district are folded. In the younger Knife Lake Group sequences the major folds trend east-northeast and are isoclinal with near-vertical axial planes and gentle plunges (Gruner, 1941). Within the Kekekabic Lake segment there appears to have been one major folding episode and a second deformation (McLimans, 1971). The major deformation was the isoclinal folding of the less competent slates and graywackes along northeast-trending axes.

According to the geologic map of Gruner (Figure 48), the conglomerates and graywackes east of the Kekekabic Granite stock top dominantly to the northwest, and the conglomerate west of the stock tops dominantly to the southeast. McLimans (1971) felt that the conglomerates east (lower half of Unit I) and west of the stock may have been contemporaneous and perhaps were originally continuous. He postulated that the rocks east of the stock are part of the south limb of a major syncline, while the rocks west of the stock are part of the north limb of the same syncline. The area of this investigation is situated on the south limb of the syncline postulated by McLimans (1971).

In addition to the folding, major longitudinal faults divide the volcanic-sedimentary sequence into structural segments. Gruner (1941) subdivided the Knife Lake area into seven structural segments based on these faults (Figure 3). The metasediments under consideration here are all in the Kekekabic Lake segment which is bounded on the east by the Saganaga batholith and the Gabimichigami Lake segment, and on the west by the Spoon Lake segment.

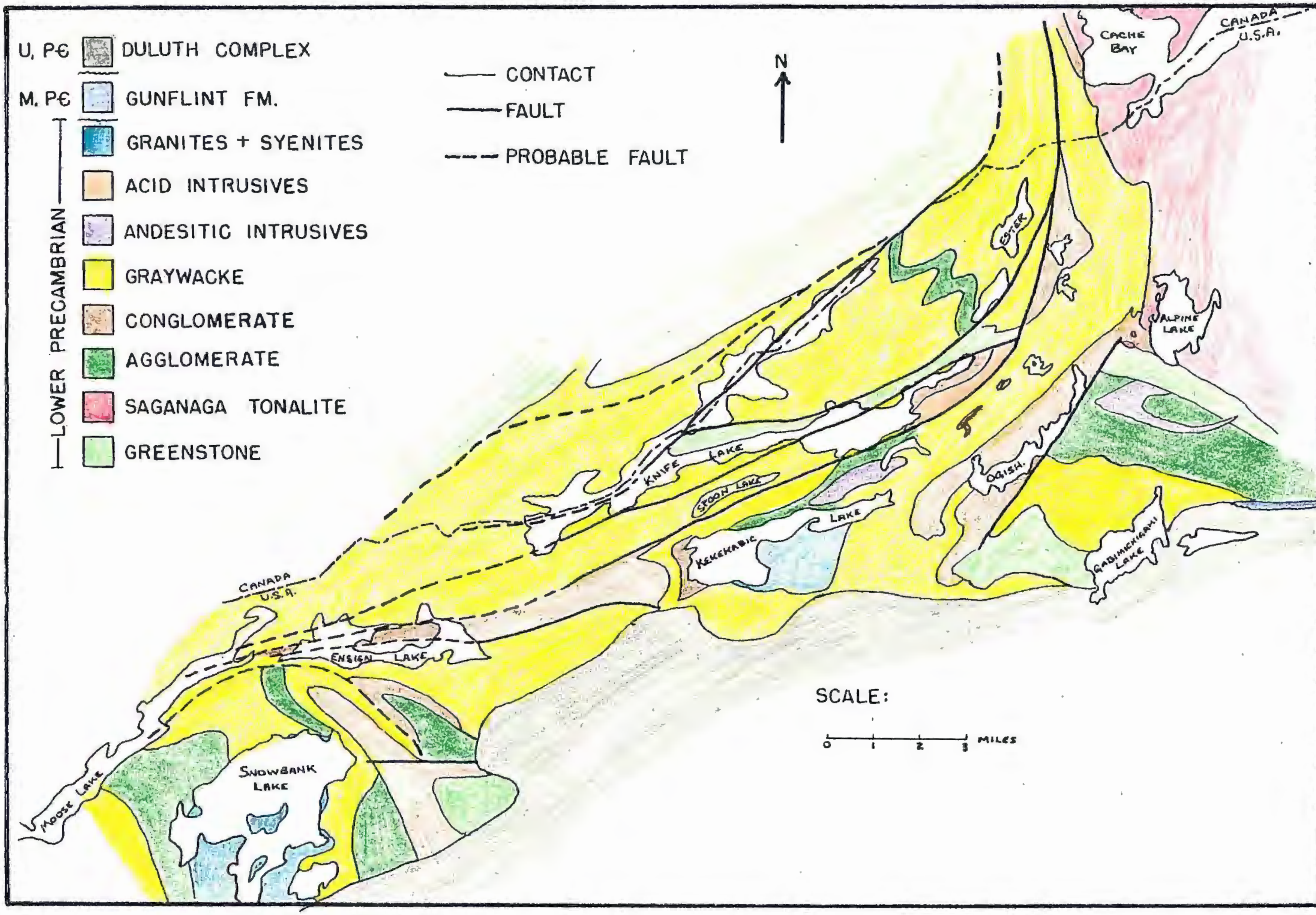



Figure 48: Generalized Geologic Map of the Knife Lake area (After Gruner, 1941).

The thick conglomerate units (Unit I and X) acted more rigidly and minor faulting or fracturing resulted either during or after the major folding event, as demonstrated by sheared clasts (McLimans, 1971).

Penetrative Minor Structures

Cleavage planes and lineations (cleavage-bedding intersections) were measured where developed, and although the data are limited, some generalizations may be made. First, there appear to be two cleavage trends within the area of study (Figure 49). The more commonly developed cleavage plane, designated as $S_2$, generally trends northeast subparallel to bedding ($S_1$). There is a scattering of the $S_2$ poles possibly indicating a later deformational episode, represented by a second cleavage trend designated $S_3$. The $S_3$ trend is less prevalent than the $S_2$ plane and generally trends N60W and dips steeply to the northeast or southwest.

Measurements of lineations (cleavage-bedding intersections) vary in both orientation and amount of plunge. These variations are a result of changes in the trends of both bedding and cleavage. One group of lineations ($L_1$) generally trends northeast or southwest with plunges of 30 to 60 degrees (Figure 50). Their orientation is the result of northeast-trending cleavage planes ($S_2$) intersecting northeast-trending beds ($S_1$). Variations in the $L_1$ plunges may indicate a partial rotation during a later deformation. Another group of lineations ($L_2$)

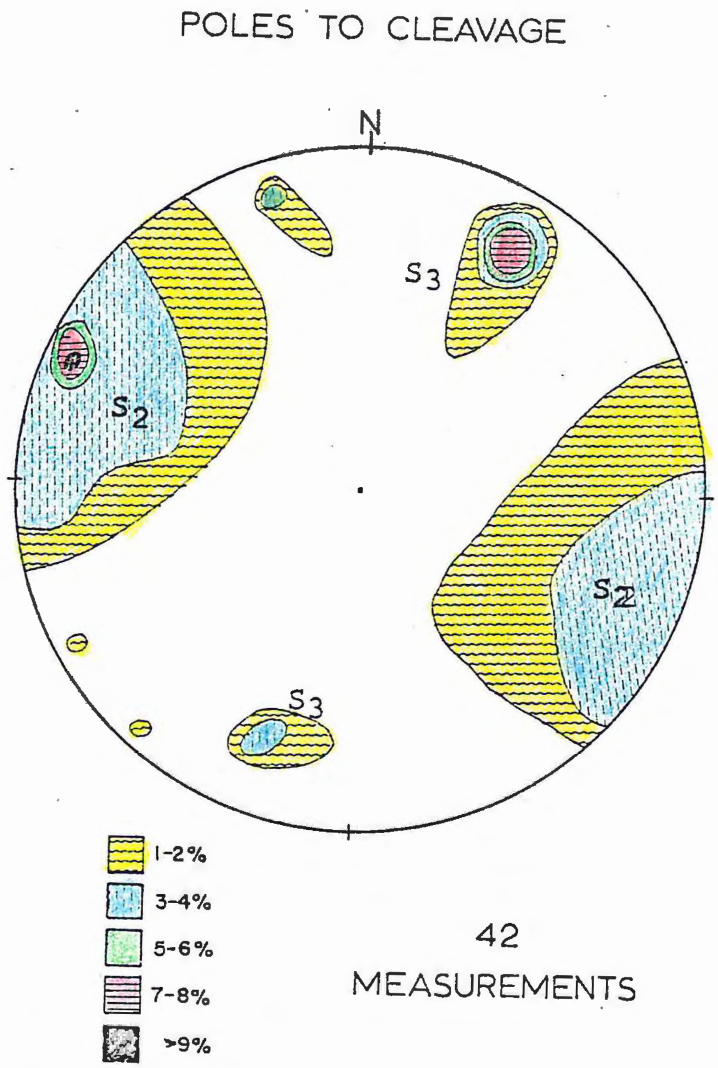



Figure 49: Poles to cleavage for the area of this investigation.

CLEAVAGE-BEDDING INTERSECTIONS

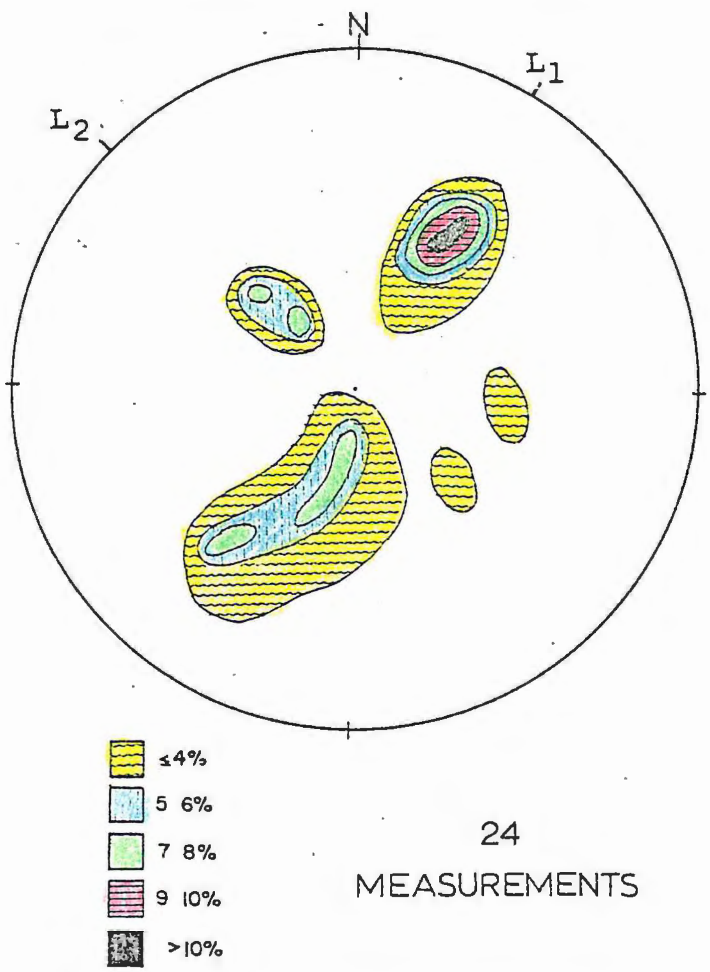



Figure 50: Cleavage-bedding intersections (lineations) for the Holt to Fish Lake structural block (see Plate I).

with steep plunges and a northwest or southeast trend is also present. They are the result of northwest-trending cleavage planes ($S_2$) intersecting northeast-trending beds ($S_1$).

The cleavage and lineation measurements may indicate the presence of two sets of folds. The major folds trend northeast with steep axial planes and moderate plunges to the southwest or northeast as indicated by the $S_2$ and $L_1$ measurements. These folds appear to have been deformed by a later tectonic event which formed minor northwest-trending folds, with steep axial planes and plunges ($S_3$ and $L_2$ measurements), on the steep foliation surfaces produced in the earlier folding episode.

Folds

Minor folds, apparently related to soft sediment deformation resulting from downslope slump movements, were noted throughout the area of study, and a discussion of these features has been deferred until now as it may have a bearing on the origin of the present penetrative structure in the rocks. These soft sediment folds are the most abundant in the vicinity of Holt Lake, especially along the northwest shore. At one particular locality (Outcrop H-14, Sec. 14), there are numerous folds, varying in size from a few centimeters across to over a meter across, separated by less intensely deformed beds (Figure 51). The folds are greatly varied in their style and attitude, often becoming chaotic and in one case forming "dome and basin structures" (Figure 52).

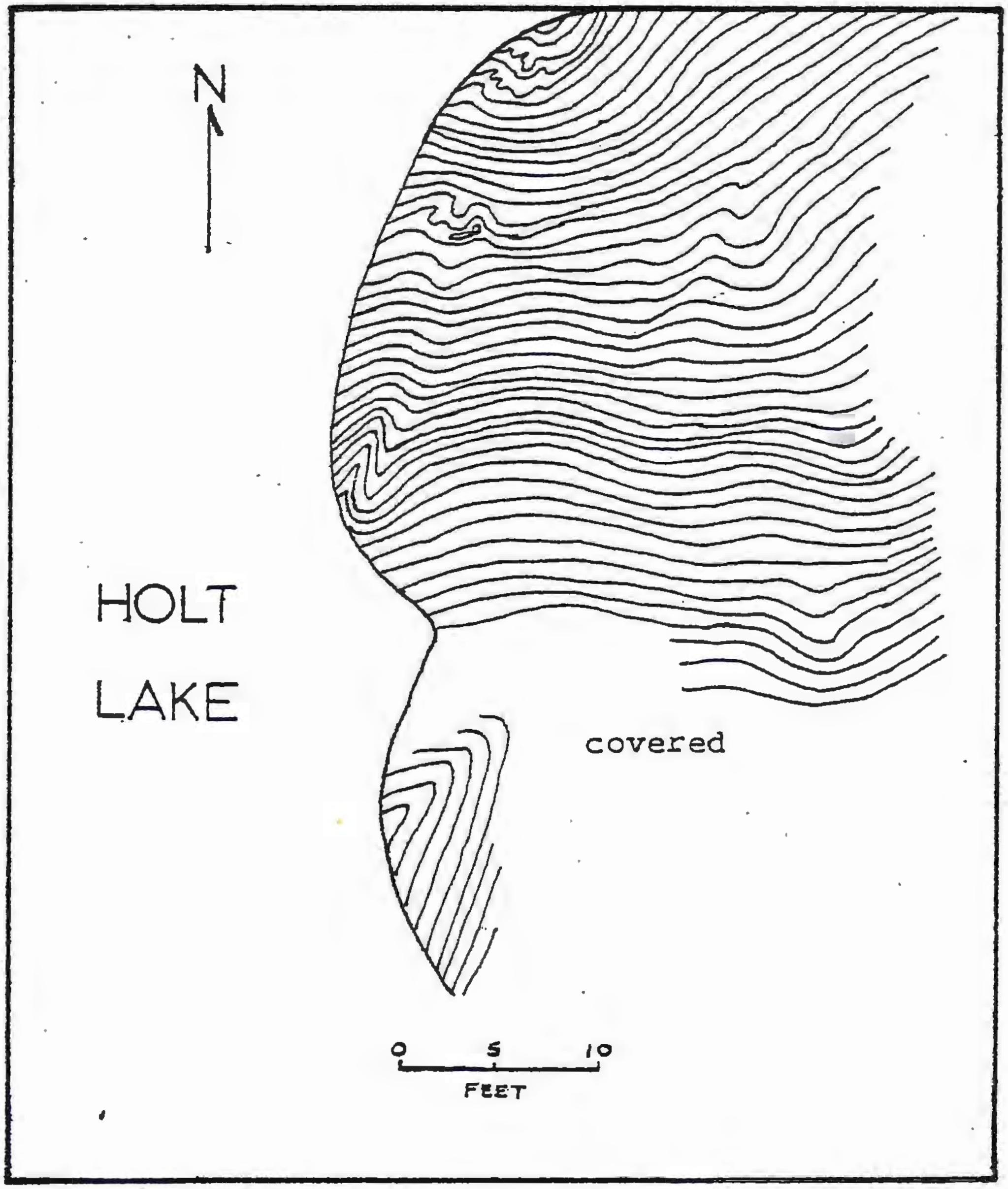



Figure 51: Sketch of the chaotic arrangment of folds attributed to soft sediment slump deformation. Outcrop H-14, NW 1/4, NW 1/4, NE 1/4, Sec. 14, T.65N., R.6W.

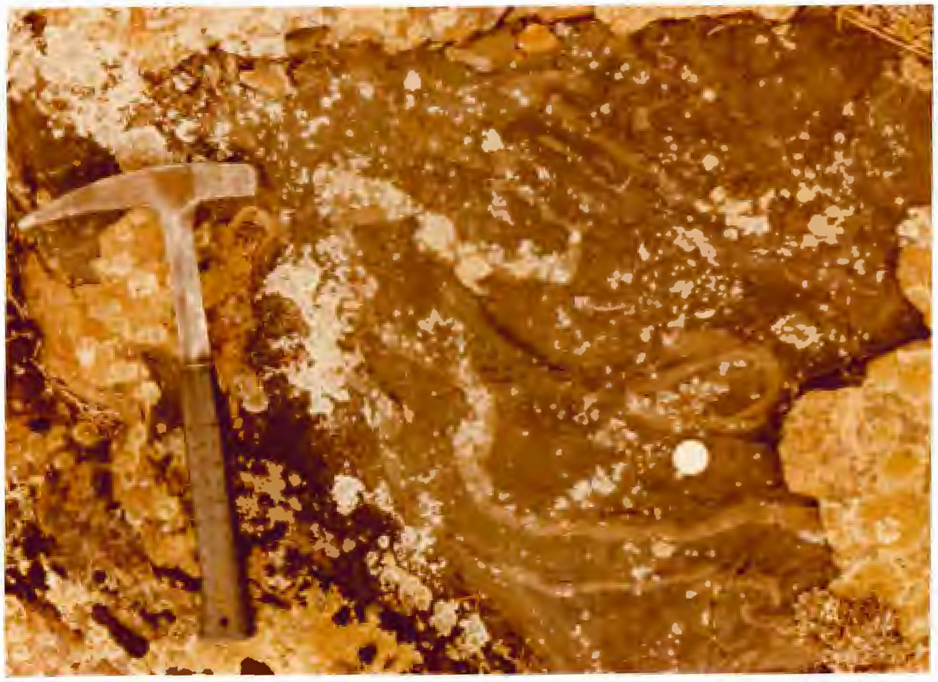


Figure 52: "Dome and basin structures" indicating two periods of folding, formed at the intersections of two anticlines. Outcrop H-14, NW 1/4, NW 1/4, NE 1/4, Sec. 14, T.65N., R.6W.

Such structures have also been recognized by Hooper and Ojakangas (1971) in the metasediments of the western Vermilion district.

One of the folds at this locality was determined to be a symmetrical fold (wavelength of one meter, and amplitude of 0.5 meters) trending N27E with a northeast plunge of 38 degrees and an axial planar dip of 38 degrees to the southwest (Figures 53 and 54). The style of the folded layers correspond to Ramsay (1967) types 1B--parallel or flexural fold, and 3--divergent dip isogons, indicating layer-parallel slip during soft sediment folding and possibly a later flattening of the fold.

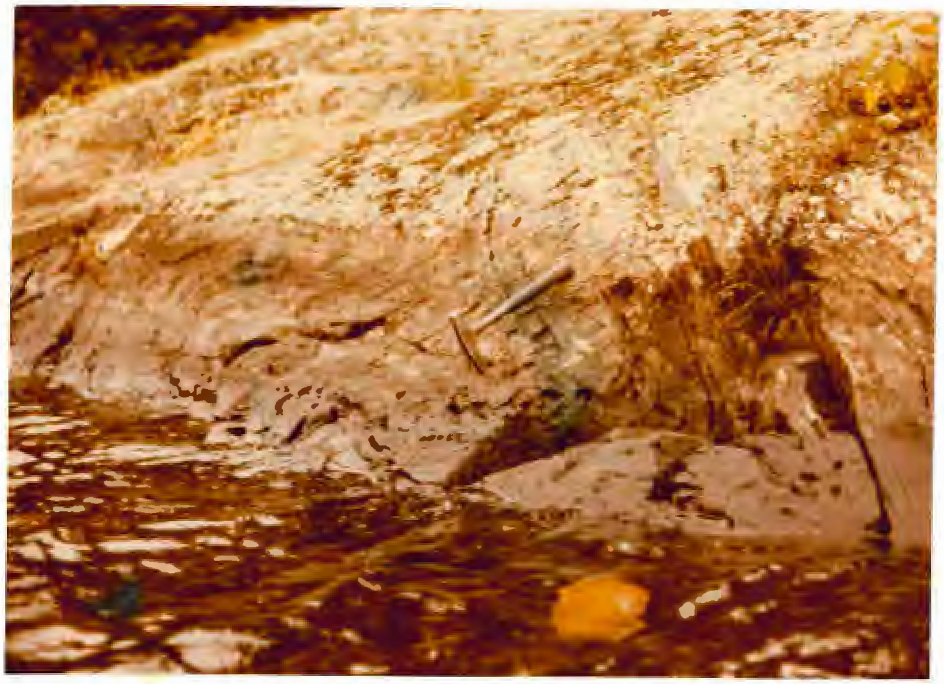


Figure 53: Photograph of Z-shaped fold trending N27E and plunging to the northeast at 38 degrees (into the outcrop). Hinge surface of the fold dips to the southeast at 38 degrees (to right of hammer). Outcrop H-14, NW 1/4, NW 1/4, NE 1/4, Sec. 14, T.65N., R.6W.

Figure 54: Same fold (Figure 53) as viewed sub-parallel to the hinge surface.

As mentioned earlier, the metasediments of the study area generally trend N40E, dip steeply to the northwest, top northwest, and are situated on the south limb of a syncline as proposed by McLimans (1971). Excluding minor soft sediment folds, the metasediments show little evidence of folding within the limb of the syncline except for either local changes in strike directions of alternations in top directions.

A paired syncline-anticline fold, defined by reversals of top directions in generally parallel beds, was found at various locations and probably extends over the entire length of the investigated area sub-parallel to the major synclinal structure (Figure 55). The paired fold is best illustrated in the vicinity of Holt Lake where the axial traces trend approximately N45E and vary in wavelength from 320 meters wide along the north shore of Holt Lake to 670 meters wide between Holt and Canta Lakes. Since fold closures are rarely observed directly it may be inferred that in this case the hinge line is nearly horizontal.

The paired fold system is believed to extend as far south as the eastern one-forth of Sec. 21, T.65N., R.6W. where reversals in top directions and the arcuate nature of conglomerate Unit II indicate a syncline-anticline fold trending about N45E. Although Gruner (1941) mapped the fold at this locality as consisting of two sets of syncline-anticline folds that plunge at

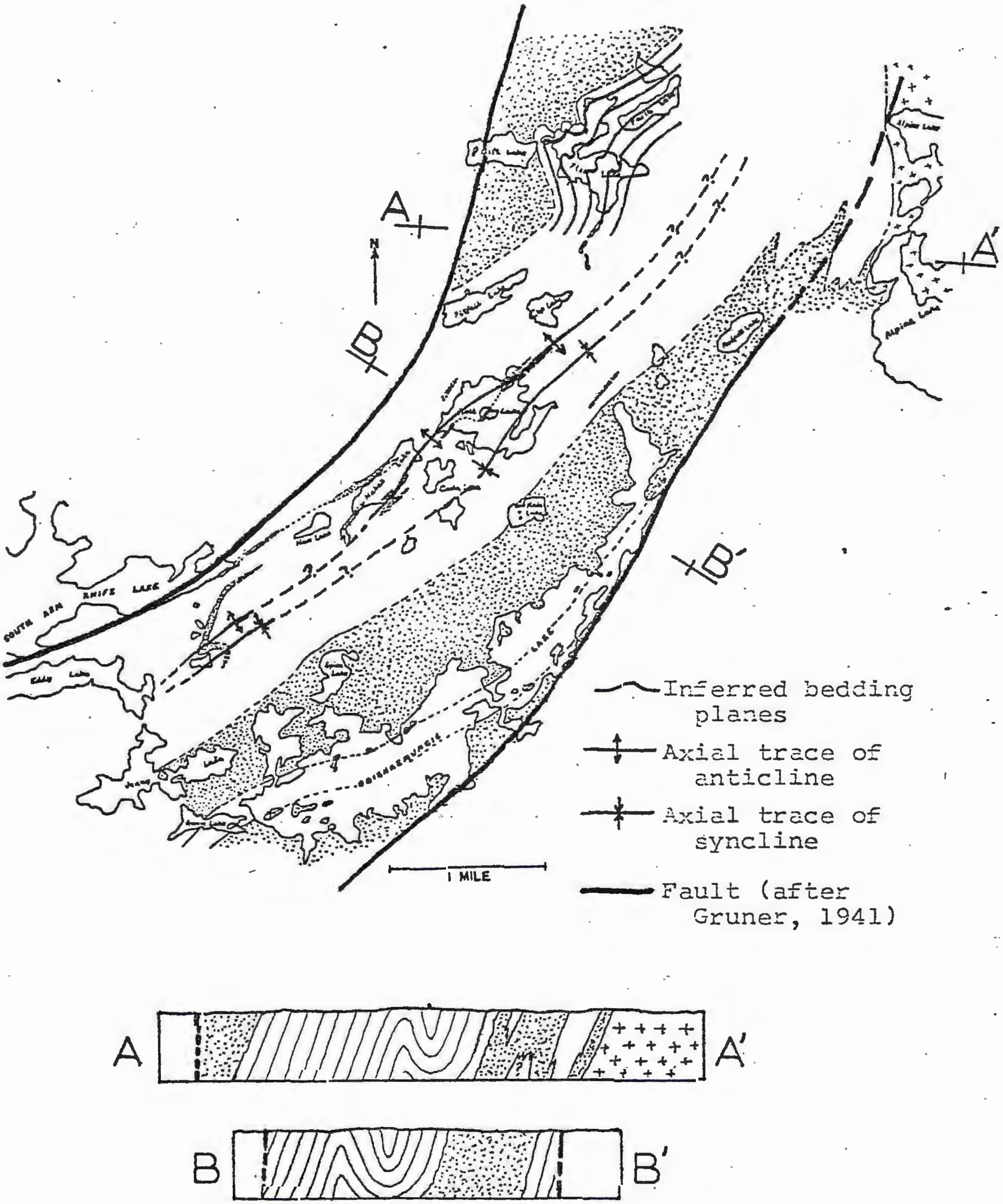



Figure 55: Generalized geologic map of the study area. Dotted areas are conglomerate.

15 degrees to the southwest, only one set of the folds was found in the present study.

The paired fold system extends northward to at least the southern half of Sec. 12, T.65N., R.6W. where a small portion of the antiform is exposed (Figure 56). At this locality the axial plane is near vertical with a sub-horizontal plunge (probably less than 15 degrees to the southwest), and trends N27E. The style of the folded layers at this locality have been classified as types 1B--parallel fold, 1C--flattened parallel fold, and 3--divergent dip isogons, after the scheme of Ramsay (1967). The style of the folds indicates flattening has occurred, as 1C or 3 type folds cannot occur indefinately in space as single fold types.

In addition to the northeast-trending folds, there are northwest-trending folds (as inferred from alternations in strike directions) in the vicinity of Fish Lake (Figure 55). This, and the apparent warping of the axial traces of the paired fold in the vicinity of Holt Lake (Figure 55), may indicate a bending or shortening of the major fold axes due to a second deformational period ($D_2$). These folds were formed on steep foliation surfaces produced during the $D_1$ deformation, and have steep axial planes and plunges as indicated by the $S_3$ cleavage planes and $L_2$ lineations.

A summary of the folding process in the eastern Vermilion district is warrented. It appears that the rocks of the study area were subjected to soft sediment

Figure 56: Exposure of the antiform fold trending N27E with a sub-horizontal plunge (probably less than 15 degrees). Outcrop T-2, NE 1/4, NE 1/4, SW 1/4, Sec. 12, T.65N., R.6W.

deformation and at least two periods of tectonic folding along northeast ($D_1$) and northwest ($D_2$) trending axes.

The presence of "dome and basin structures" in rocks of the western Vermilion district have been interpreted by Hooper and Ojakangas (1971) as indicating at least two periods of tectonic folding. However, Hudleston (1976) states that this type of interference pattern would be difficult to account for in terms of the refolding of isoclinal folds and that, therefore, the first period of folding may have been of a soft sediment nature.

Hudleston (1976) believes that chaotic minor folds, in metasediments within the western Vermilion district, were a result of downslope slump movements in that axial planar cleavage is absent. He also felt that larger paired folds defined by reversals in top directions, and lacking axial planar cleavage, may have been the result of larger-scale downslope movements. The problem inherent to this model is the size of the paired folds, which would involve sequences of slumped unconsolidated sediment hundreds of meters thick, and the preservation of large soft sediment folds during large-scale isoclinal folding. Therefore, because of its width and lateral extent (500 meters by 5000+ meters) the paired syncline-anticline fold of this study is herein considered to be of tectonic origin. Unlike the large folds of the western Vermilion district, the parallelism of the areal $S_2$ cleavage trend and the axial trace of the paired fold may also indicate that the folds are of tectonic origin.

However, problematic to this interpretation is the coaxiality of the areal $S_2$ cleavage, the axial trace of the paired folds, and the major synclinal axis. The paired folds may have formed contemporaneously with the major isoclinal folding event as parasitic folds, or they may have formed later than the major folding event. Since the $S_2$ cleavage also trends northeast, it is difficult to ascertain if it is axial planar to the major syncline, the paired folds, or both. Determination of the time-relationship of the paired folds to the major synclinal structure is beyond the scope of this investigation and for simplicity the two are herein considered to have formed contemporaneously during the first period of deformation ($D_1$).

Faults

The Vermilion district is cut by high-angle faults of two trends, longitudinal and transverse, that divide the district into several separate segments. The faults were contemporaneous with, or later than, emplacement of the batholithic rocks and are considered a late phase of the Algoman orogeny. Their pattern is similar to those in much younger island arc-trench environments (Sims, 1972).

Gruner (1941) noted that in addition to the faults that divide the district, there must be other undiscovered faults, some even with fairly large displacement. The area of this study is further divided into structural blocks (Plate I) based on possible faults not mapped by Gruner. Their placement is based largely on lineaments recognized from aerial photographs.

Since the longitudinal faults parallel bedding, the total displacement and even the relative movement is not known. Gruner (1941) considered the movement on these faults to be vertical with throws of up to 3000 meters. He also felt that the shear zones are so broad that displacement probably is not confined to a single plane.

Actual fault contacts are rarely exposed and ". . . are found only after the realization that certain structures do not "make any sense" when fitted together. . ." (Gruner, 1941,pp. 1637). Field checks usually show depressions in these places which when linked together, are commonly expressed by lineaments on aerial photographs. A sheared and highly foliated fabric (Figure 57) is the most commonly observed evidence of faulting. Unfortunately, the lakes, bogs, vegetation and minor glacial drift cover usually make direct recognition of the fault zones difficult.

Another feature of faulting is the occurrence of calcite in the metasediments adjacent to the fault zones. Calcite replaces the matrix, volcanic rock fragments, and

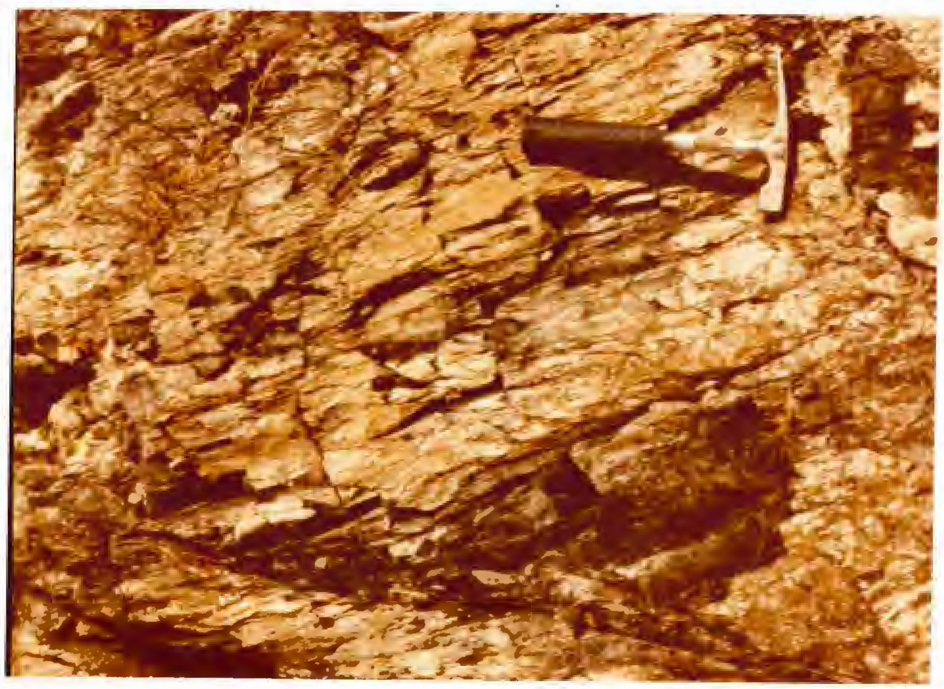


Figure 57: Chlorite-sericite phyllite near a major fault zone. Outcrop Na-2, NW 1/4, NW 1/4, NW 1/4, Sec. 22, T.65N., R.6W.

feldspars of the sediments, sometimes making distinction between the three difficult (Figure 58). This is especially true of the graywackes which abut against the Saganaga batholith in the vicinity of Alpine Lake. Close to the contact the graywackes contain a high proportion of calcite that decreases in content as the distance from the contact increases. The occurrence of carbonate associated with shear zones can be explained as the result of the influence of $CO_2$-rich fluids along the faults. Feirn (1977) also noted the occurrence of carbonate mineral assemblages in and around fault zones.

The east shore of Ogishkemuncie Lake is defined by a large northeast-trending high-angle fault which separates a younger Knife Lake sequence (Kekekabic Lake

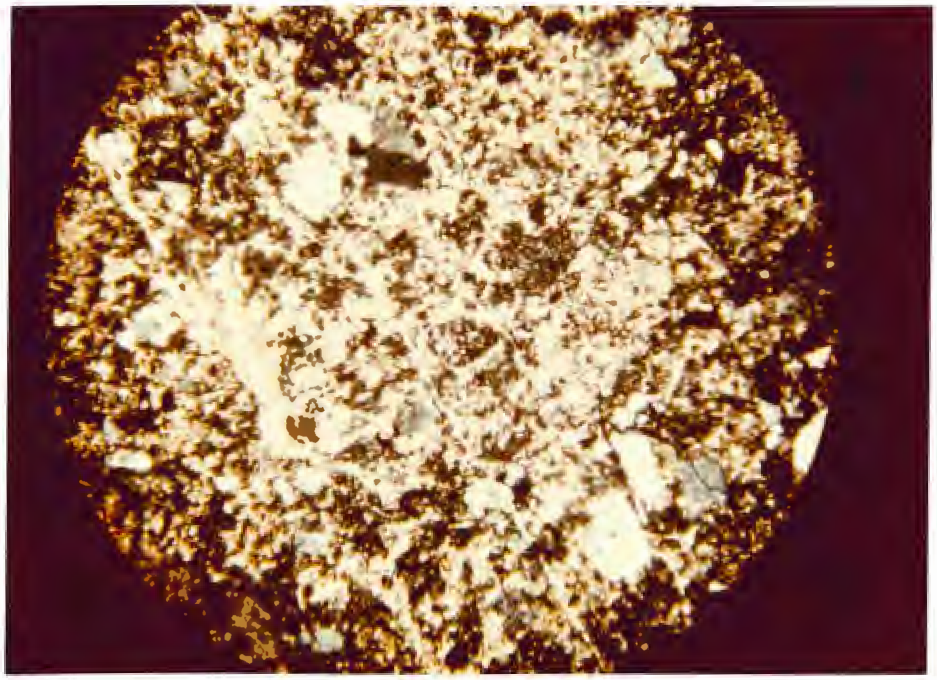


Figure 58: Photomicrograph of a sheared coarse-grained graywacke. Replacement of the volcanic rock fragments, plagioclase grains, and matrix by calcite. Outcrop A1-1, SW 1/4, NW 1/4, NW 1/4, Sec. 5, T.65N., R.5W. Field of view is 1.5 cm across (crossed polars).

segment) on the west side of the fault from an older Knife Lake sequence which has been intruded by the Saganaga batholith (Gabimichigami Lake segment) on the east side of the fault. The fault is characterized mainly by shearing within a zone 150 meters wide (Feirn, 1977).

Gruner (1941) mapped the northern portion of this fault as terminating just west of Redpoll Lake in Sec. 7, T.65N., R.5W. However, an aerial lineament indicates that the fault may continue to the northeast through the younger Knife Lake sediments subparallel to bedding, and into the Saganaga batholith. The only physical evidence of faulting along the lineament is the presence of carbonate within the metasediments, and the occurrence of an altered hornblende andesite unit, approximately four meters thick, within a dominantly turbidite sequence. In outcrop the andesite is characterized by bleached plagioclase laths (2 mm) and hornblende (2 mm) within a purple groundmass. Thin section analysis indicates approximately 25 percent seriticized plagioclase laths, 15 percent psuedomorphs of chlorite after hornblende, and 60 percent groundmass (Figure 59). The andesite parallels the trend of the lineament and may represent a dike which intruded the graywackes along a zone of weakness within the shear zone. It is also highly altered indicating the presence of fluids along the fault zone.

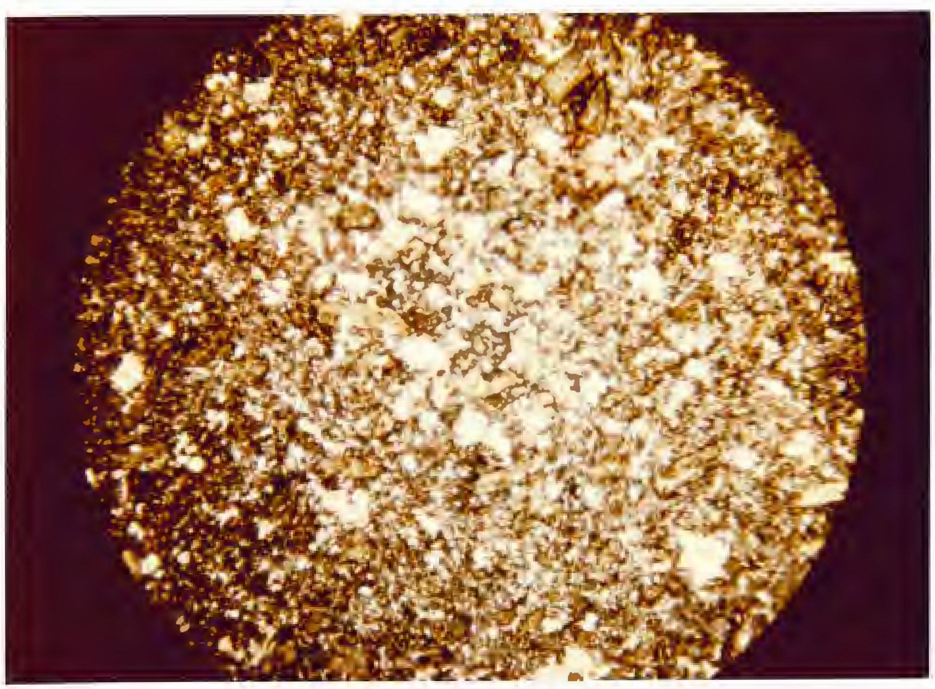


Figure 59: Photomicrograph of an altered hornblende andesite dike located west of Alpine Lake (one polar). Contains sericitized plagioclase, and psuedomorphs of chlorite after hornblende in an altered groundmass. Outcrop A1-18, Sec. 6, T.65N., R.5W. Field of view is 1.5 cm across.

Structural Development

The following model, illustrated in Figure 60, accounts for the structural development of the area. In the account that follows, $D_1$, $D_2$, and $D_3$ designate the three tectonic deformations, from oldest to youngest. $D_0$ is used to designate soft sediment slump folds.

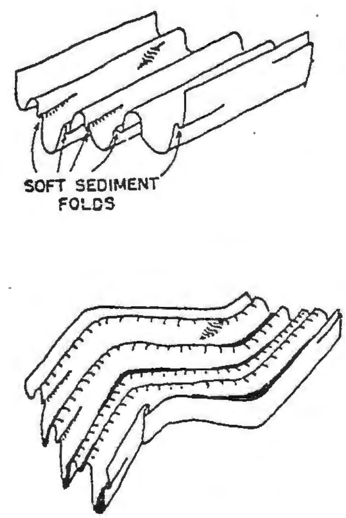
The first period of deformation ($D_0$) involved soft sediment slumping producing a warping of the beds and small isoclinal and recumbant folds ranging from a few centimeters to as much as a few meters across. These folds would be local in extent and varied in style and attitude, often becoming chaotic. The style of the folded layers indicates layer-parallel slip during soft sediment folding and possibly a later flattening of the folds.

A later tectonic deformation ($D_1$) produced cylindrical isoclinal folds with parasitic folds in the sedimentary rocks along northeast-trending axes, and established the prevalant northeast-trending cleavage planes ($S_2$). The folds produced during the $D_1$ deformation have steep axial planes with nearly-horizontal hinge lines, and are defined by reversals in top directions in generally parallel beds.

The $D_1$ folds and resultant cleavages ($S_2$) were deformed during the $D_2$ period which caused minor buckling and shortening of the earlier $D_1$ folds. $D_2$ folds have steep axial planes with near-vertical plunges, and are defined by alternations in strike

D$_0$ – soft sediment deformation

D$_1$




D$_2$

D$_3$ – faulting

Figure 60: Structural development model (no scale implied)

directions (e.g., inferred folds in the vicinity of Fish Lake) or the apparent warping of the axial trace of the paired $D_1$ folds in the vicinity of Holt Lake.

Faulting ($D_3$) occurred on a regional scale deforming local parts of all rock bodies. The faulting is considered to be a late phase of Algoman tectonism in that some of the faults are continuous across both granite and greenstone terrains (Sims, 1972). However, some of the faulting may represent renewed movement on faults developed during the $D_1$ or $D_2$ deformations.

The periods of tectonic folding are apparently related to emplacement of the batholithic rocks during the Algoman orogeny. Since the Saganaga batholith appears to have been emplaced slightly earlier than the other batholiths in the district, the relationship of the metasediments to the Saganaga batholith are important in interpreting at least the first period of tectonic deformation. At the contact with the batholith the metasediments generally dip to the west at 65 to 85 degrees. The problem of how these dips could have developed has received considerable attention. Grout (1936) stated that since no shearing seems to have occurred along the contact, the granite and sediments must have acted as a single unit.

However, the presence of carbonate in the metasediments adjacent to the contact indicates that some shearing has taken place. Although outcrops along the contact are limited, one exposure of sheared tonalite was noted about on the contact in the SW 1/4, NW 1/4, NW 1/4, Sec. 8, T.65N., R.5W. (Outcrop A1-14). In outcrop, the sheared tonalite is characterized by a higher proportion of quartz eyes than usual and closely resembles the arkoses of Cache Bay, although no bedding is apparent. The rock is light green in color due to the presence of epidote. In thin section (Figure 61), the tonalite is characterized by deformed grains of quartz and plagioclase, up to 3.0 mm across, surrounded by small crushed fragments of quartz and plagioclase, and a fine-grained material consisting of carbonate, sericite, hematite, and epidote. Plagioclase is generally more highly crushed and replaced by carbonate and sericite making distinction from the finer-grained material difficult. The quartz eye aggregates are very angular and exhibit suturing between the quartz boundaries.

Although Gruner (1941) did not note the shearing, he noted certain facts which would make the partial overturning of the Saganaga batholith problematic. He stated that the contact between the tonalite and the sediments is not a simple surface but highly complex (e.g., large fold in the tonalite in Sec. 30, T.65N., R.5W.; and large inliers of tonalite surrounded by conglomerate in Sec. 7, T.65N., R.5W.) and that a restoration of the contact to the original position assumed by Grout would submerge portions of the sediments in the older tonalite.

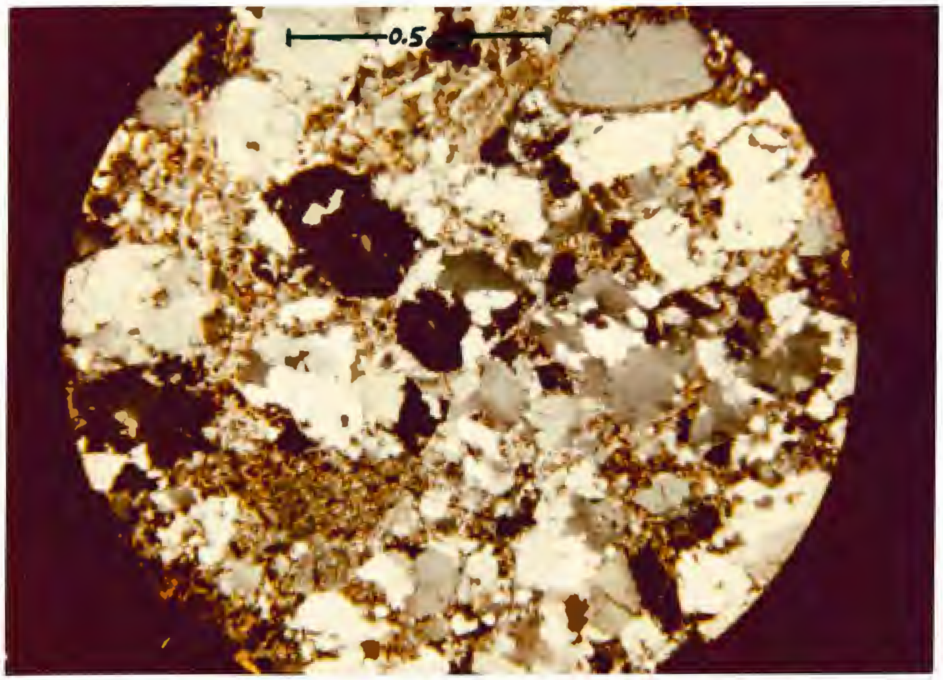



Figure 61: Photomicrograph (crossed polars) of sheared Saganaga tonalite consisting of deformed quartz, carbonitized and sericitized plagioclase, and small fragments of quartz and plagioclase within a fine-grained material consisting of calcite, hematite, sericite, and epidote. Outcrop Al-14, SW 1/4, NW 1/4, NW 1/4, Sec.8, T.65N.,R.5W.

Gruner (1941) suggested that the Saganaga batholith, and the sequence which it intruded to the south (Gabimichigami Lake segment), acted as a buttress against which the younger sediments were folded. The stages of deformation described and illustrated by Gruner (Figure 62) are as follows. The basin of deposition was floored and flanked by crystalline rocks of much greater strength and competence than that of the sediments which were deposited in the basin. A thick cover of sediments within the basin provided the load under which intense folding took place. Pressures were applied from opposite sides as indicated by arrows

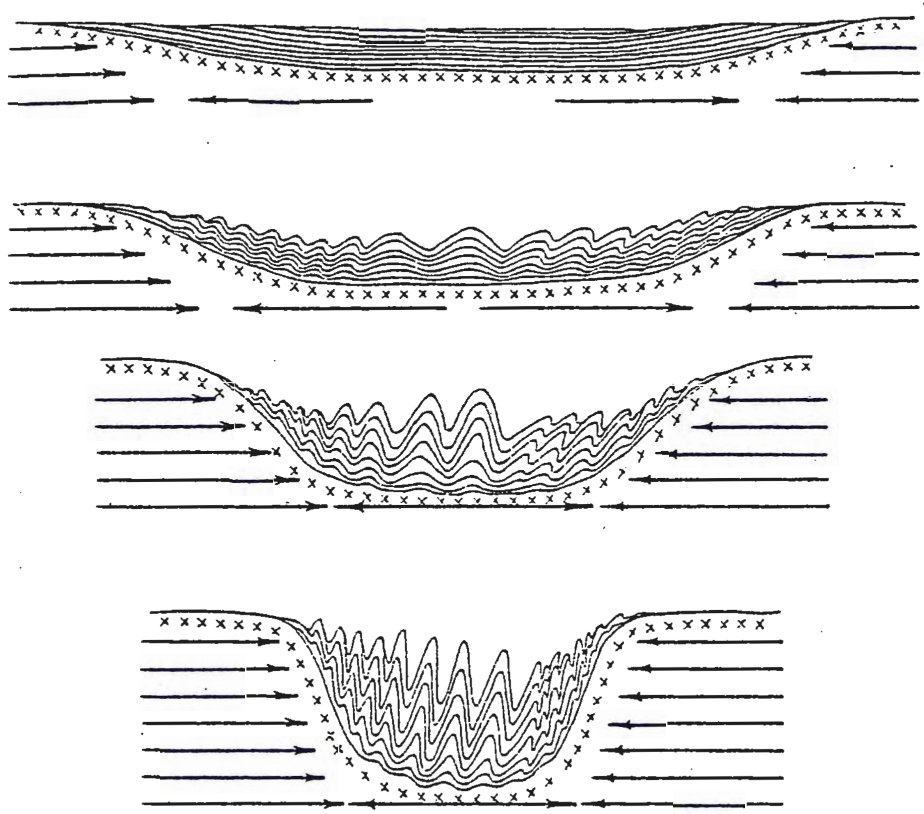


Figure 62: Stages in development of a closely folded synclinorium underlain by a competent floor. Length of arrows not proportional to magnitudes of force (After Gruner, 1941).

in Figure 62. The more competent rock comprising the floor of the basin resisted compression and steepening of the walls resulted from slow flowage. The less competent sediments were folded during this movement and eventually the contact with the tonalite attained a steep dip.

The buttresses, according to Gruner, were the Saganaga batholith and Gabimichigami Lake segment at the southeastern end of the Vermilion district, the Giants Range batholith on the south, and the Vermilion batholith on the north.

The structural theory of Gruner, encompassing tangential compression, is similar to the theory of Anhaeusser and others (1969) in that the same end result is achieved. Anhaeusser and others postulated that the structure and metamorphism of any greenstone belt is a response of the belt to upwelling granites and the concomitant downsagging of the heavy pile of volcanics and sediments in the belt. The structures produced in these belts are a result of essentially vertical movements with compression induced by the diapiric rise of granitic bodies.

Most of the faulting probably was concurrent with or later than emplacement of the batholithic rocks. The faults appear as abundant in the granitic rocks as in older metavolcanic-metasedimentary rocks, some are continuous across both, and are considered a late phase of the Algoman orogeny (Sims, 1972).

Similarily, two generations of folding and a younger generation of deformation including both faulting and later kinking have been recognized in the western Vermilion district (Hooper and Ojakangas, 1972; Sims, 1972). Kink bands were not noted in the area of this investigation.

# CHAPTER VI

# GEOLOGIC HISTORY

Deposition of the Ely Greenstone is the first recorded event in the Vermilion district. The surface upon which these volcanic rocks were deposited has not been found. The presence of a few granitic cobbles in conglomerates of the central Vermilion district may indicate the existence of a granitic basement as suggested by Green (1970). However, no such evidence was found in this investigation. Neither McLimans (1971) nor Ojakangas (1972a, 1972b) found evidence of any granitic terrain other than the post-Ely Saganaga tonalite.

The similarity of the greenstone belts to modern-day island arcs may suggest that the greenstones originated on a thin sialic crust, the remnants of which were consumed by later granites (Anhaeusser and others, 1969). Some of the greenstone belts of the Canadian Shield have been assigned to a largely granitic source area which may have also been the basement (Donaldson and Jackson, 1965; Goodwin, 1968; Walker and Pettijohn, 1971).

Accumulation of the basaltic flows of the Ely Greenstone took place mostly or entirely under water, along with some irregular intrusions and dikes of dacite and rhyodacite porphyry that spanned from at least upper

Ely to Newton Lake Formation time. Local erosion produced thin conglomerate lenses which became more widespread near the close of the basaltic volcanism (Green, 1970).

Termination of extrusion and intrusion of basaltic magmas was followed by uplift and some erosion, producing a greenstone conglomerate on a surface of only slight discordance, such as the greenstone conglomerate southeast of Ogishkemuncie Lake (Gruner, 1941). These were overlain by volcanigenic graywackes, conglomerates, and argillites deposited in water to form the upper Knife Lake Group. Volcanic activity continued during sedimentation as evidenced by a few felsic to mafic lavas, tuffs, and agglomerates (Green, 1970).

The Saganaga batholith, dated at about 2.7 b.y. (Goldich and others, 1970), appears to have been unroofed early and may be slightly older than the other batholiths of the Algoman orogeny (Ojakangas, 1972a). The Saganaga tonalite is intrusive into older greenstones and metasediments of the belt (Gabimichigami Lake segment) but also provided detritus to younger metasediments which lie unconformably upon the tonalite. It appears that the batholith intruded its own volcanic ejecta and that the source area for the sedimentary rocks of this study consisted of both volcanic and plutonic rocks.

Physiographic conditions and topography changed rapidly during Knife Lake time exerting an overall control on the textures and compositions of the resultant sediments. Though graywacke and slate make up the bulk of the accumulation, lenses of conglomerate are found at many horizons. Slumpage of unstable piles of sediment along the flanks of the source area generated turbidity currents which transported the detritus to a submarine fan system. The graywackes were depostied as overbank spills, while the coarse material was confined to long sinuous channels that migrated within the fan system forming lenses of conglomerate.

Most of the metasediments of this study indicate a dominantly volcanic source; however, several horizons contain a dominance of plutonic detritus illustrating differences in the basin topography or tectonic changes in the source area.

The tonalite-bearing conglomerate of Cache Bay (Figure 48) may represent depostition on a slope which may not have been steep enough to give rise to slumping. The tonalite-bearing conglomerate of Nawakwa Lake (Unit X) may indicate a significant tectonic change in the source area, perhaps by faulting. The large size of the tonalite boulders (up to 60 cm) at this site suggests that the relief in the source area was high. This, along with the sudden transition from volcanigenic graywacke to tonalite-boulder conglomerate (Unit X) in the area, might indicate faulting (McLimans, 1971).

Following deposition of the Knife Lake Group, volcanism commenced again with deposition of andesitic, dacitic and basaltic lavas of the Newton Lake Formation in the central Vermilion district (Green, 1970).

The next complex sequence of events constitutes the Algoman orogeny dated at about 2.75-2.7 b.y. (Goldich, 1972). Major folding and faulting, producing nearly vertical strata, was contemporaneous with the early stages of the emplacement of the Giants Range and Vermilion batholiths (Sims, 1972). The Saganaga batholith may represent an early phase of Algoman tectonism and acted as a buttress against which the sediments were folded. Late syn-tectonic or post-tectonic Algoman granites within the Knife Lake area proper are represented by the Snowbank and Kekekabic Granite stocks (Figure 48).

A period of erosion took place during which the Algoman highlands were peneplained, and later the Animikie marine sediments were deposited unconformably over the folded and faulted Lower Precambrian rocks. Animikie rocks are represented by a narrow band of Gunflint Iron-formation and Rove Slate just northeast of Gabimichigami Lake (Figure 48). Along the north-east tip of northeastern Minnesota the Lower Keweenawan Puckwunge Formation, consisting of a basal conglomerate and quartz sandstone, disconformably overlies the Animikie Rove Slate.

The next recorded event of Middle Keweenawan time, about 1.1 b.y. ago (Goldich and others, 1961), was the eruption of a lava sequence several kilometers thick (North Shore Volcanics) into what is now the Lake

Superior basin. The Duluth Complex, consisting of several anorthositic, gabbroic and granitic rocks, was intruded near or at the base of the volcanics (Green, 1970). The Complex truncates the Knife Lake area and forms its southern boundary.

Since Keweenawan time the area has probably been above sea level and undergoing erosion. During Pleistocene time (15,000 years ago), ice sheets of the Rainy Lobe scoured off the rock surfaces and deposited a thin patchy veneer of glacial drift.

# CHAPTER VII

# CONCLUSIONS

1) Source areas for the metasediments of this study were mainly mafic to felsic piles, as well as the Saganaga tonalite. No "granitic" clasts other than the Saganaga tonalite were noted. Volcanic material constitutes about 90 percent of the clasts in the conglomerates and graywackes. The volcanic clasts are, in decreasing order of abundance: trachyte-latite, trachyandesite, andesite, mafic-intermediate, mafic (basaltic), dacite, rhyodacite, rhyolite and felsite.
2) Most of the metasediments of this study indicate a dominantly volcanic source; however, several horizons contain a dominance of plutonic detritus illustrating either changes in the basin floor topography or tectonic changes in the source area.
3) The Saganaga tonalite may be compared with more recent batholiths which have been described as intruding and unroofing their own volcanic ejecta.
4) The conglomerates and "volcanigenic" graywackes were deposited in a basin or trough flanked by a continental orogenic belt or island arc system. Slumpage of unstable piles of sediment on the

margins of the source area generated turbidity currents which transported the detritus to submarine fans. The graywackes were deposited as overbank spills while the coarse material was confined to long sinuous channels forming lenses of conglomerate. Each conglomerate units represents, from bottom to top, coarser (proximal) beds grading upwards into finer (distal) beds indicating gradual channel abandonment and migration of channels within the fan system.

5) Transport direction was to the southwest along the present tectonic strike away from the Saganaga batholith, with most of the supply being at the northeastern end of an elongate basin or trough.

6) The structural pattern within the study area is due to a combination of soft sediment deformation, at least two periods of tectonic folding along northeast and northwest axes, and late phase faulting. Soft sediment folds, resulting from downslope movements, range from a few centimeters to over a meter across and are varied in their style and attitude, often becoming chaotic. The major folds trend northeast, are defined by reversals in top directions, and appear to have been formed during the first period of tectonic deformation ($D_1$). These folds appear to have been deformed by a later folding event ($D_2$) which produced minor superimposed northwest-trending folds.

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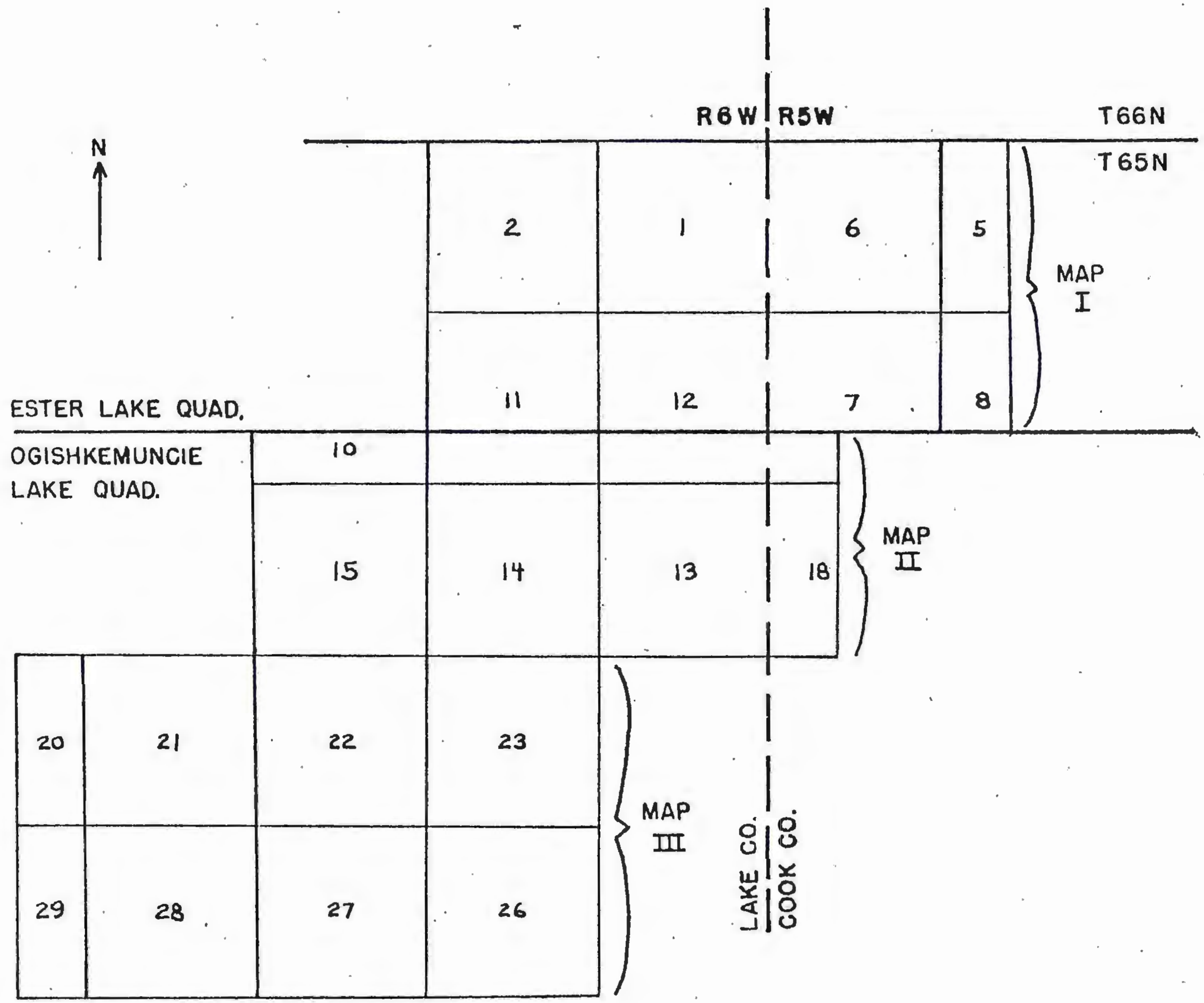
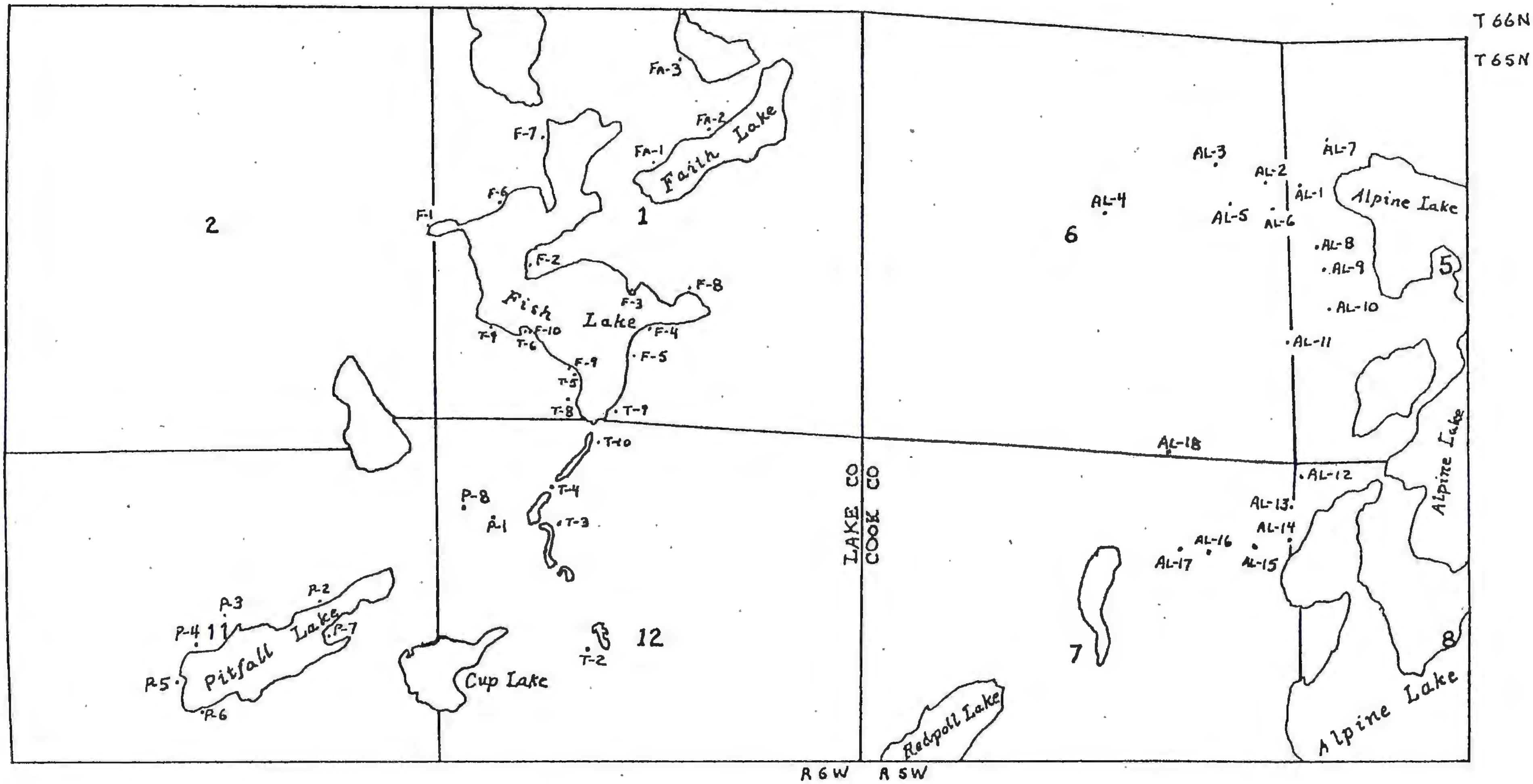
# APPENDIX

## SAMPLING CODE

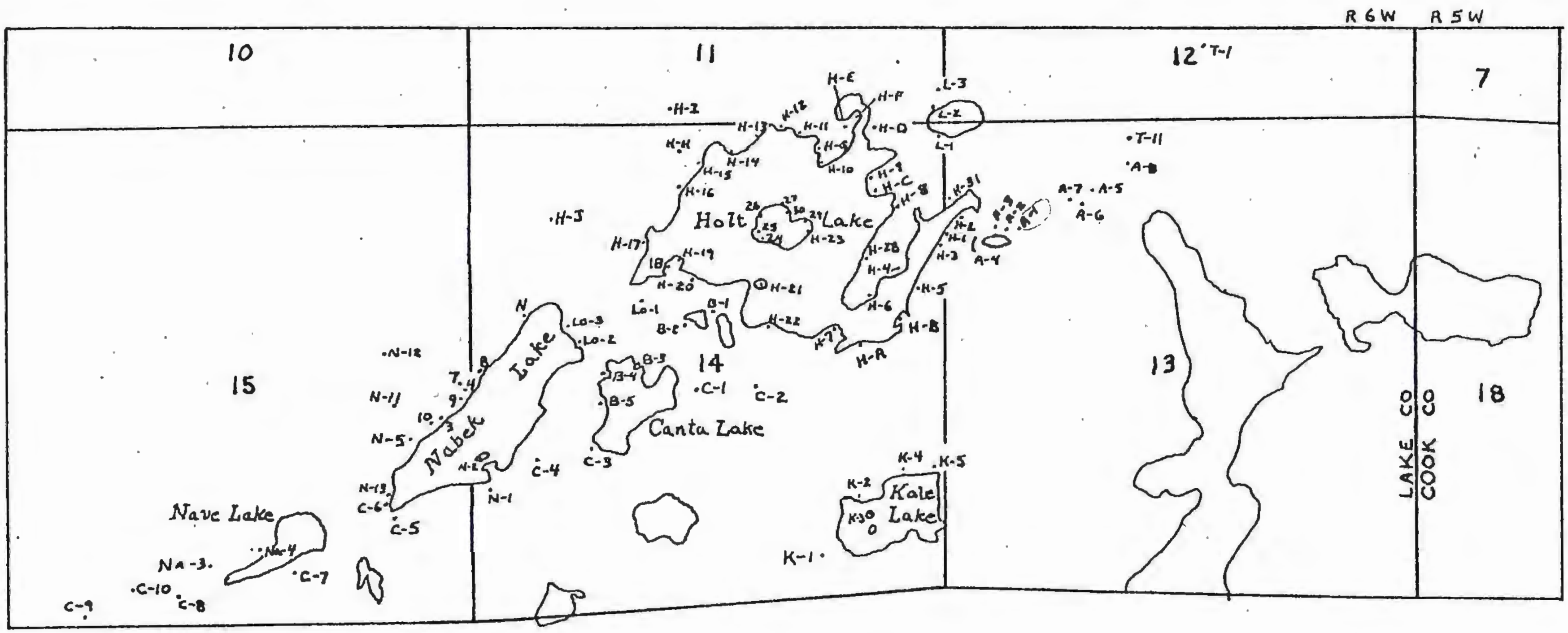
A -- along portage between Holt and Ogishkemuncie Lakes
Al - Alpine Lake
An - Annie Lake
B -- traverse from Holt to Nabeck Lake
C -- traverse from Canta to the South Arm of Knife Lake
E -- Eddy Lake
F -- Fish Lake
Fa - Faith Lake
H -- Holt Lake
J -- Jenny Lake
K -- Kale Lake
Kn - South Arm of Knife Lake
L -- nameless lake northeast of Holt Lake
N --- Nabeck (Bear) Lake
Na - Nave Lake
Og - Ogishkemuncie Lake
P -- Pitfall Lake
S -- Spice Lake
T -- traverse from Ogishkemuncie to Fish Lake



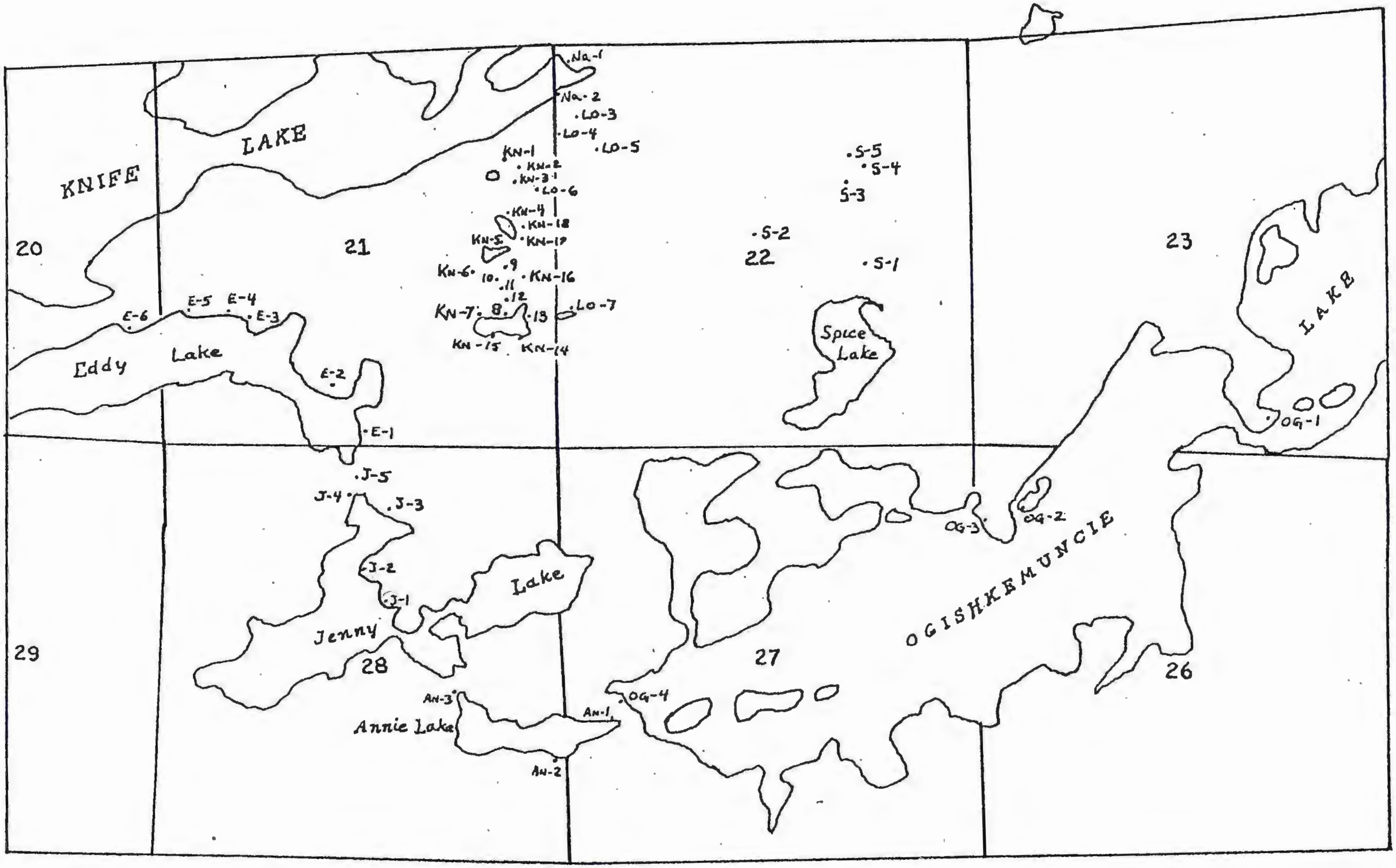

# KEY TO STATION LOCATION MAPS




# MAP I - STATION LOCATIONS




MAP II - STATION LOCATIONS




MAP III - STATION LOCATIONS