

SURFICIAL GEOLOGY AND GROUND-WATER GEOLOGY  
OF THE BABBITT-KAWISHIW AREA, NORTHEASTERN MINNESOTA

WITH PLANNING IMPLICATIONS

By

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## ABSTRACT

Glacial deposits from three ice lobes are preserved in the Babbitt-Kawishiwi area, northeastern Minnesota. Basal tills, deposited by these lobes, are informally termed the Dunka Pit, bouldery and red, sandy tills. Texturally the three tills are difficult to differentiate. Color and pebble content appear to be the best parameters for differentiation. The subsurface Dunka Pit till, dark brown in color, contains pebble types derived from Lower and Middle Precambrian rocks of northeastern Minnesota. The bouldery till, which varies in color from brown to gray-brown, contains pebbles primarily derived from granitic and Duluth Complex rock types. The red, sandy till, generally red-brown in color, contains pebble types common to rocks in the Lake Superior basin.

The glacial geomorphology of the Babbitt-Kawishiwi area is varied. The northern half of the area is an ice-scoured plain. The southern portion contains landforms associated with stagnant ice. Morainic complexes and thicker drift are typical of this portion of the area.

Surficial materials within the Babbitt-Kawishiwi area exhibit a wide range of permeabilities. Highly permeable materials include glaciofluvial and ablation till deposits. Basal tills in the area are generally of moderate permeability. Surficial materials of low permeability include glaciolacustrine and colluvial deposits. Although permeability values for Duluth Complex rocks are low, the permeability of these rocks appears to increase near

surface linear features. These linear features may overlie highly fractured bedrock systems.

In the Gabbro Lake quadrangle (SW 1/4), ground-water basins coincide with surface-water basins. Streams in the area are discharge zones for ground water. Ground-water gradients of 10 to 20 feet per mile are typical of the area.

Environmentally sound copper-nickel development in the Babbitt-Kawishiwi area should include geological input. High capacity ground-water development will probably be restricted to a few small aquifer systems. Surface waters will have to be relied on heavily. Because of their coarse texture, the surficial aquifers that exist could easily become polluted. In addition, fracture systems in Duluth Complex rocks may have the capacity to serve as "conduits" for polluted ground water.

Optimal copper-nickel impoundment sites will probably be located atop swamp and bog deposits enclosed by bedrock areas of high topography. Most of these sites are located to the north of the Vermilion moraine. Because of soil limitations, domestic waste disposal sites will be difficult to locate. Aggregate and fill materials are generally abundant and easily obtainable. Soils developed on basal tills will be subject to intense erosion if soil cover is removed. Critical areas will coincide with areas of steep topography.

## INTRODUCTION

The Babbitt-Kawishiwi area is a forested region located in St. Louis and Lake Counties of northeastern Minnesota. Most of the area lies within the Superior National Forest and except for the taconite mining community of Babbitt, is sparsely populated. Forestry, taconite mining, and recreation are the major economic enterprises. The area is characterized by rolling woodlands, lakes, and poorly drained lowlands.

The study area includes about 200 square miles of area and covers the Duluth Complex bedrock portions of the U. S. Geological Survey topographic quadrangles of Babbitt; Babbitt, NE; Greenwood Lake, N 1/2; Gabbro Lake, SW 1/4; and Kangas Bay (Fig. 1).

Rocks of the Duluth Complex, which underlie the entire study area, contain extensive low-grade copper-and nickel-sulfide deposits. Estimates of the quantity of mineralized rock range from hundreds of millions to billions of tons, with a combined copper-nickel content varying from one-half to one percent. The most common sulfide minerals include pyrrhite, calcopyrite, cuhanite, and pentlandite (Bonnichsen, 1972b). Several mining companies have conducted exploratory drilling and feasibility studies in the study area. A test shaft is currently being developed. Although large amounts of ore have not yet been extracted, it is possible that mines will eventually be developed.

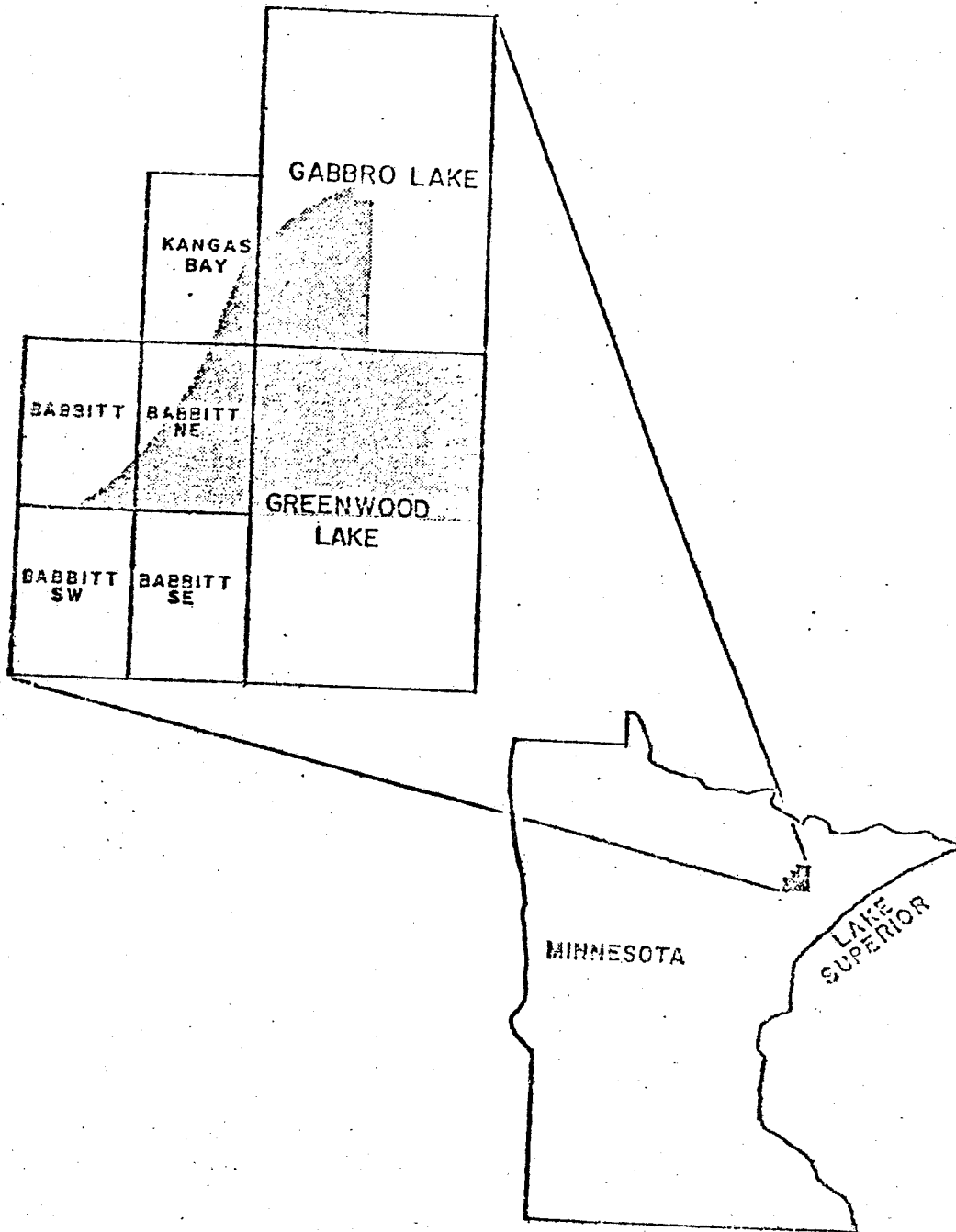


Figure 1. Location of study area (shaded) on 7 1/2 and 15 minute quadrangles

Much of the mineralized portion of the Duluth Complex is located on state and federal lands. In addition, the area lies in close proximity to the preserved wilderness of the Boundary Waters Canoe Area. Because of the environmental problems associated with Minnesota's taconite industry and the public character of the land in which the sulfides are found, considerable concern has arisen regarding the environmental impact of copper-nickel development.

Sulfide mining poses special environmental problems. Sulfide minerals, when exposed to air, oxidize to form sulfuric acid. These acids are produced in sulfide mine-sites from spoil piles, waste dumps, tailings ponds, and cut faces. Being soluble, they can reach surface waters through runoff and ground water by percolation. Acidic waters may be harmful or lethal to fish, wildlife, and plants. Indirectly associated with acid waters are undesirable red and yellow precipitates of iron. Salts of metals, often released from mine-sites, are toxic to fish, wildlife, plants, and aquatic insects in minute quantities (U. S. Dept. of the Interior, 1971).

Mine spoil erosion and sedimentation is a problem common to mined areas. Effects of this problem are readily observable in northern Minnesota's Mesabi Range.

The availability of processing water for mines in northern Minnesota is also a continuing problem (Cotter, Young, Petri and Prior, 1956b). Large quantities of water will be needed if copper-nickel development is undertaken.

In addition to the hydrologic and geologic problems associated with copper-nickel development, environmental planners will be forced to consider mining's affect on biological, atmospheric, aesthetic, social, and economic systems of the mine-site areas.

Environmental problems often result from inadequate knowledge of the systems which operate within an area. This study is intended to provide baseline data on the surficial geology and ground-water systems of the mine-sites in the Babbitt-Kawishiwi area.

#### Purpose

This report describes the surficial geology and ground-water geology of an area in which sulfide mining may be undertaken. It is intended to serve as a planning tool. The text is organized in three parts. Part one describes the occurrence, nature and geologic history of the surficial materials in the study area. The second part describes hydrogeologic systems within a part of the study area (Gabbro Lake quad. SW 1/4). Part three discusses the need for geologic input in planning.

#### Climate

The following summary is Prettyman. Northeastern Minnesota is dominated by a continental climate. In the Superior National Forest, annual precipitation varies from 26 to 31 inches. About 40% of this precipitation occurs as snow, averaging about 65 inches per year. The average growing

season ranges from 100 to 123 days. Summer temperatures in excess of 90 degrees F and winter temperatures of 40 degrees F below zero are common.

### Physiography

The study area lies within the Superior upland, one of the major physiographic divisions of the Canadian Shield (Fenneman, 1938). The Laurentian Divide, which marks the drainage divide between the Great Lakes and Hudson Bay watersheds, lies within the study area. Hydrologically, the study area may be described as a poorly drained headwaters region. Elevations range from 1817 to 1418 feet above sea level.

Wright (1956a, 1972a) has proposed a detailed physiographic classification for northeastern Minnesota (Fig. 2). Using his classification scheme, the study area lies within the Border Lakes Area and Toimi Drumlin Field. The Border Lakes Area, whose southern limit is the Vermilion moraine, is a region of thin glacial drift and locally rugged topography. Orientations of lakes in this area reflect bedrock structure.

South of the Vermilion moraine, in a triangular-shaped region, lies the Toimi Drumlin Field. It consists of thick glacial drift and southwest trending drumlins.

The North Shore Highland, along the Lake Superior shore, is located east and northeast of the study area. Underlain by Precambrian lavas and mafic intrusives, it forms a drift-mantled highland 500 to 900 feet above Lake Superior.

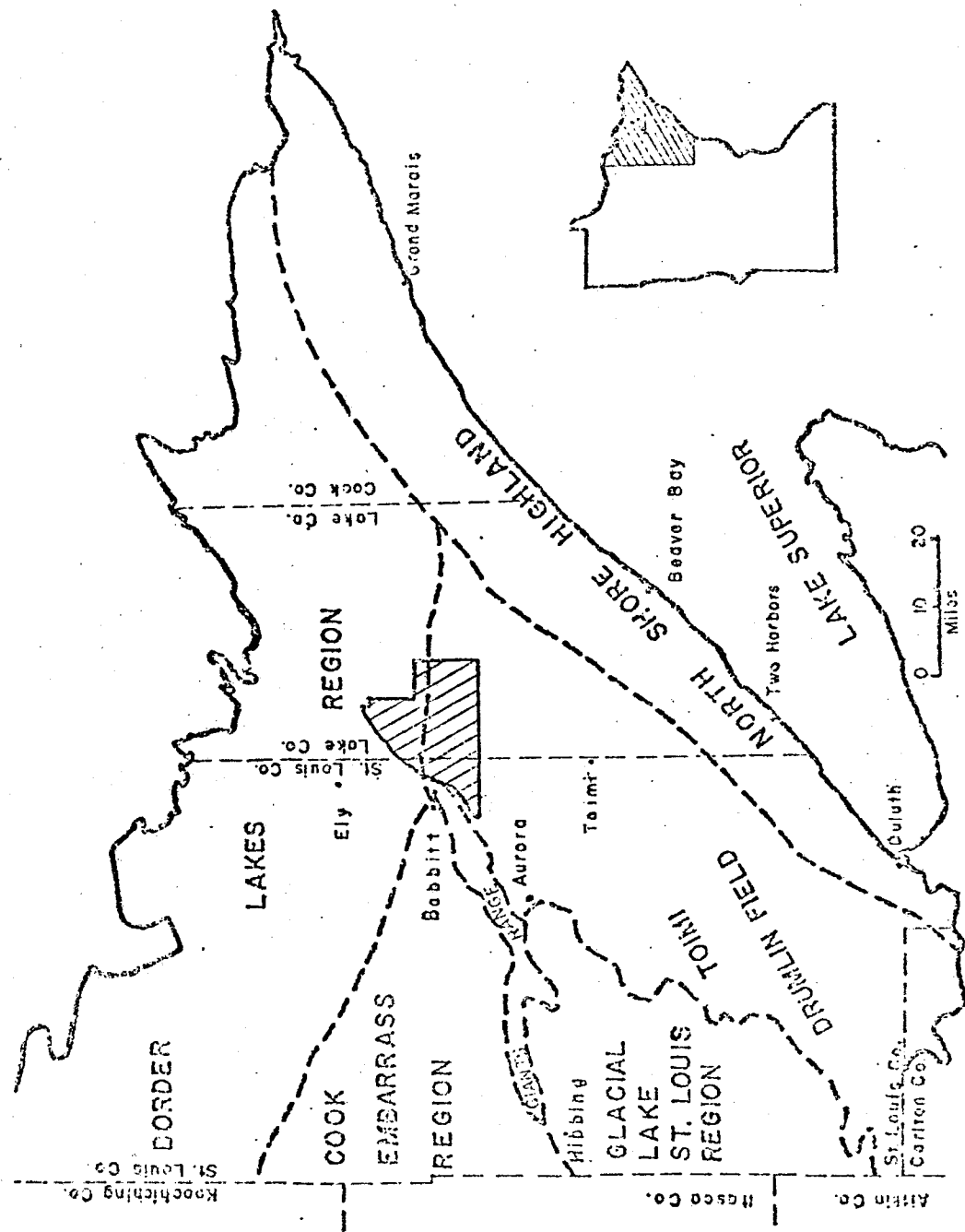


Figure 2. Physiographic regions of northeastern Minnesota with study area in cross-hatching. (adapted from Wright, 1956a)

The area to the west, termed the Cook-Embarrass Region, consists of thick glacial drift and lacustrine deposits.

Between the Toimi Drumlins and the Cook-Embarrass Region lies the Giants Range. It consists of a Precambrian granitic highland, 200-400 feet above the surrounding topography.

#### Bedrock Geology

The area lies atop the basal part of the Duluth Complex (Fig. 3). The Duluth Complex (Bonnichsen, 1972a; Craddock, 1972; Davidson, 1972; and Phinney, 1972a, b, and c), consisting of Upper Precambrian intrusive igneous rocks, crops out in an arcuate pattern extending from the northeastern tip of Minnesota to Duluth. Dated at about 1.1 billion years, this igneous complex was intruded along an unconformity between overlying volcanic rocks and underlying Lower and Middle Precambrian rocks. Having been intruded in several stages, rock types within the complex include anorthosite, troctolite, gabbro, granodiorite and granite.

East of the Duluth Complex, along the Lake Superior shore, the North Shore Volcanic Group is exposed (Green, 1972). This Late Precambrian plateau lava sequence, varying in thickness from 11,000 to 18,000 feet, consists of olivine basalts, intermediate lavas, felsic lavas, and clastic sediments. Structurally, the volcanics strike north or east and dip gently east into the Lake Superior syncline.

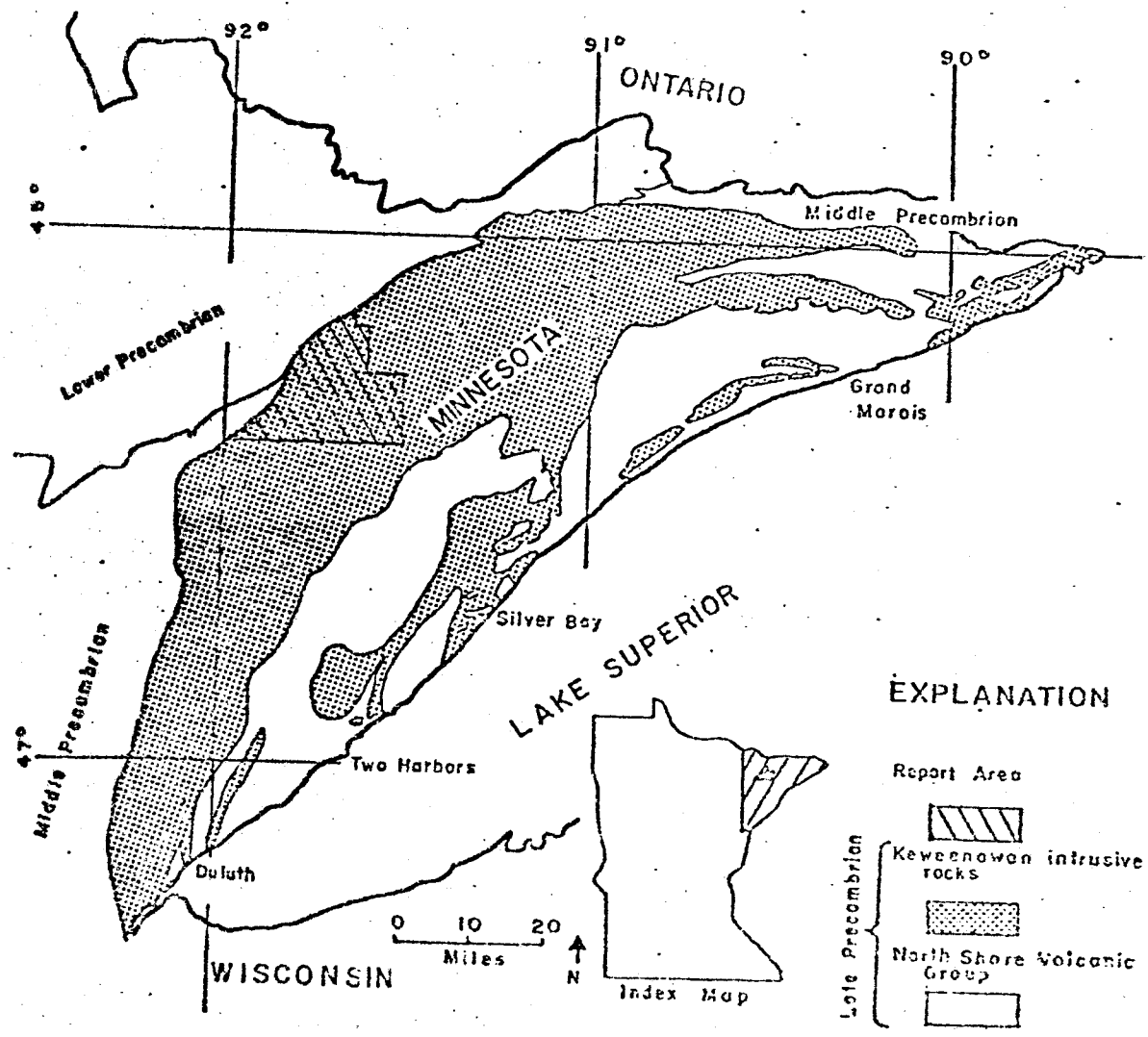


Figure 3. Bedrock geology of northeastern Minnesota (adapted from Green, 1972)

North of the Duluth Complex, Lower Precambrian rocks of the Vermilion District crop out (Sims, 1972a, b). The oldest rocks of the Vermilion District include strongly folded metavolcanic rocks and metasedimentary rocks. Stratigraphic units include the Ely greenstone, Lake Vermilion Formation, Soudan Iron-formation, and Newton Lake Formation. These early rocks are intruded by Lower Precambrian granitic plutons about 2.7 billion years old. The plutons include the Giants Range, Vermilion and Saganaga batholiths.

West and northwest of the Duluth Complex, Middle Precambrian rocks are exposed (Morey, 1972a, b, and c). These rocks, assigned to the Animikie Group, are separated from older and younger rocks by unconformities. To the west, in the Mesabi Range area, Middle Precambrian stratigraphy consists of the Pokegema Quartzite, Biwabic Iron-formation, and the argillite-siltstone-graywacke succession of the Virginia Formation. In the northeast, an equivalent group of rocks includes the Kakabeka Quartzite, Gunflint Iron-formation and Rove Formation. Middle Precambrian rocks of northeastern Minnesota are bracketed between 2.6 and 1.8 billion years. They strike east-northeast and dip southeast at shallow angles.

## SURFICIAL GEOLOGY

### Field and Laboratory Procedures

#### Introduction

Field studies were conducted during the summers of 1974, 1975, and 1976. Field work consisted of reconnaissance surficial geologic mapping of the study area, completion of eleven power auger borings, and collection of samples from outcrops and drill holes. Laboratory techniques included mechanical analysis of sand/silt/clay composition and pebble lithology counts for 111 samples. Color determinations were made on the 41 till samples.

#### Mechanical Analysis

Mechanical analysis of 111 samples was completed using standard dry sieving and Buyocos hydrometer techniques as described by Royse (1970). Boundaries are based on the Wentworth scale (sand = 2mm-.0625mm; silt = .0625mm-.002mm; clay = less than .002mm).

#### Pebble Lithology Counts

During mechanical analysis preparation, each sample was split into four parts. One part was used in mechanical analysis. The remaining three parts were washed through a 2 mm sieve. Pebbles and granules remaining on the sieve were grouped by lithology. Very coarse sand fraction (1-2mm) counts were substituted for pebble counts in lacustrine samples. All samples contained at least 50 pebbles. Most contained more than 75.

### Color

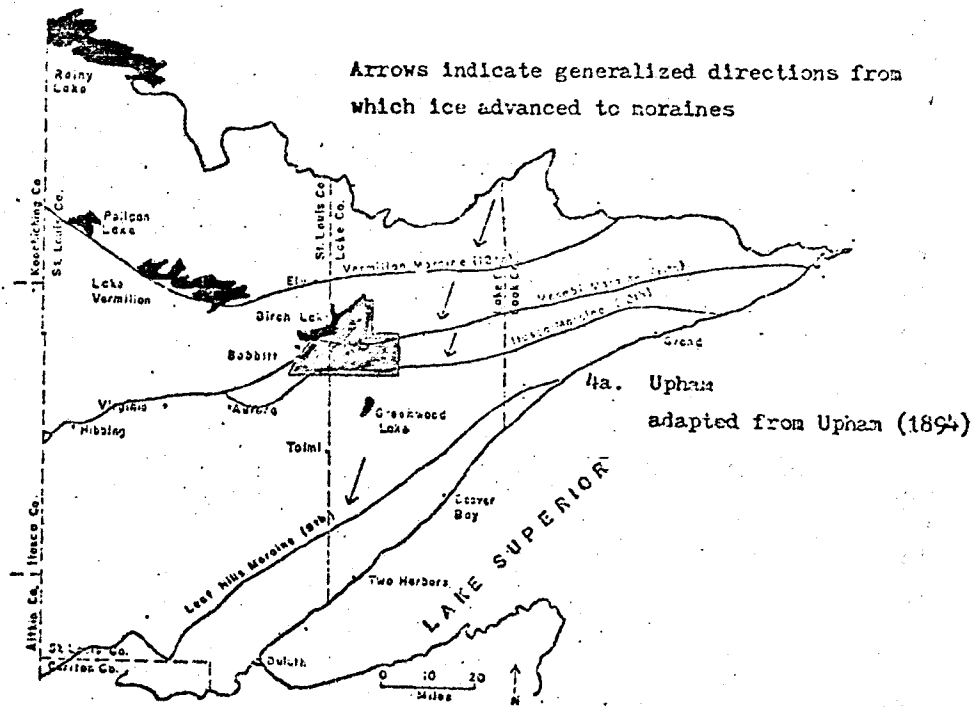
Because till color is recognized as a standard method of differentiating tills, colors of the 41 till samples were determined using a standard Munsell Soil Color Chart. Color determinations were made in the laboratory under artificial light. Both dry and moist colors were recorded.

### Evolution of Glacial Terminology

#### Upham

The earliest work regarding the glacial geology of northern Minnesota was published by Upham (1894). He documented the existence of deposits from only one ice lobe in northern Minnesota. Three distinct tills, however, were recognized. Till in northwestern Minnesota was distinguishable because of an abundance of Paleozoic limestone pebbles. Precambrian crystalline and occasional limestone rock types were termed indicative of till in north-central Minnesota. A third till, in the north-east, was described as containing abundant Lake Superior pebble types.

Twelve moraines, all mapped as recessional from a single ice lobe, were mapped across the state. Those in northeastern Minnesota were termed the Leaf Hills (9th), Itasca (10th), Mesabi (11th), and Vermilion (12th) moraines (Fig. 4a). Although Upham recognized tills in superposition, he did not make clear the relationship of tills to moraines. Ice in northeastern Minnesota was considered, by Upham, to have advanced in a southeasterly direction.



Study area shaded

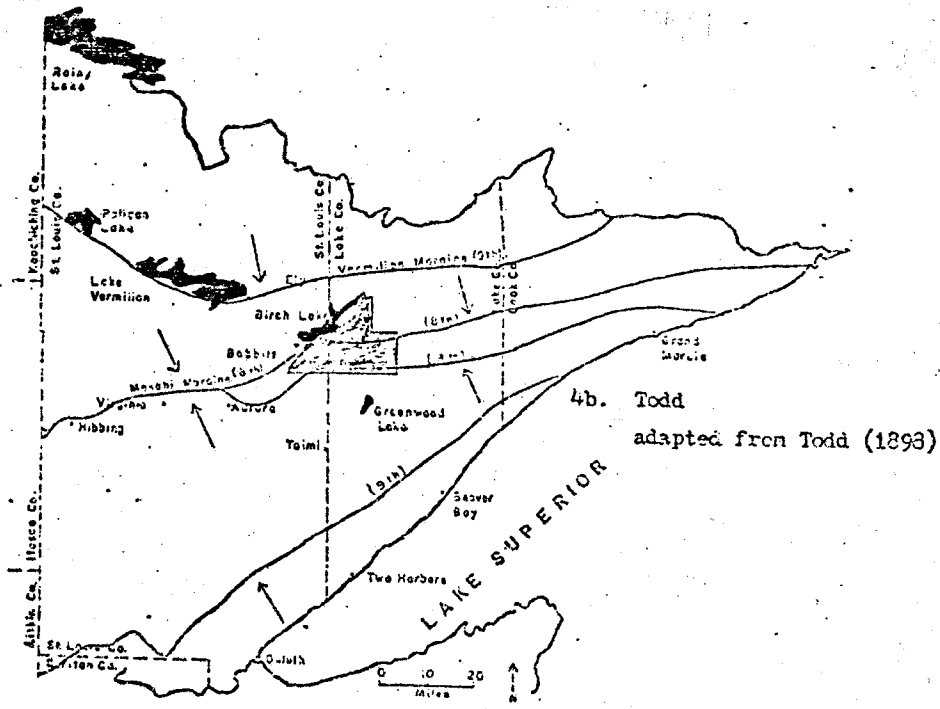


Figure 4. Interpretations of "Rainy" and "Superior" lobe moraines in northeastern Minnesota

Todd

Todd (1898) criticized Upham's interpretation of the direction of ice recession in northern Minnesota. He argued that northern Minnesota had been glaciated by two contemporaneous ice lobes, the Red River lobe in the west, and Lake Superior lobe in the east. Todd believed an interlobate moraine, the Mesabi moraine, formed between the lobes during retreat (Fig. 4b). Continued wastage was thought to have resulted in the formation of an acute angle between these lobes. Eventually, the Vermilion moraine was believed to have formed along the southern edge of the Red River lobe and a correlative moraine (Upham's Leaf Hills moraine) along the northern edge of the Lake Superior lobe.

Elftman

Elftman (1898) published a map of the moraines in northeastern Minnesota (Fig. 5a). He accepted Upham's (1894) interpretation of the extent of moraines in northeastern Minnesota, but changed the name of the Leaf Hill moraine to the Highland moraine, because he questioned Upham's correlation of it to the Leaf Hills moraine in east-central Minnesota.

Elftman documented the existence of two glacial tills in northeastern Minnesota, deposited by two contemporaneous lobes of ice. The Lake Superior lobe, which deposited till containing rock types common to the Lake Superior basin moved down the Lake Superior basin from the northeast. A second lobe, which he termed the Rainy lobe, advanced in a southeasterly

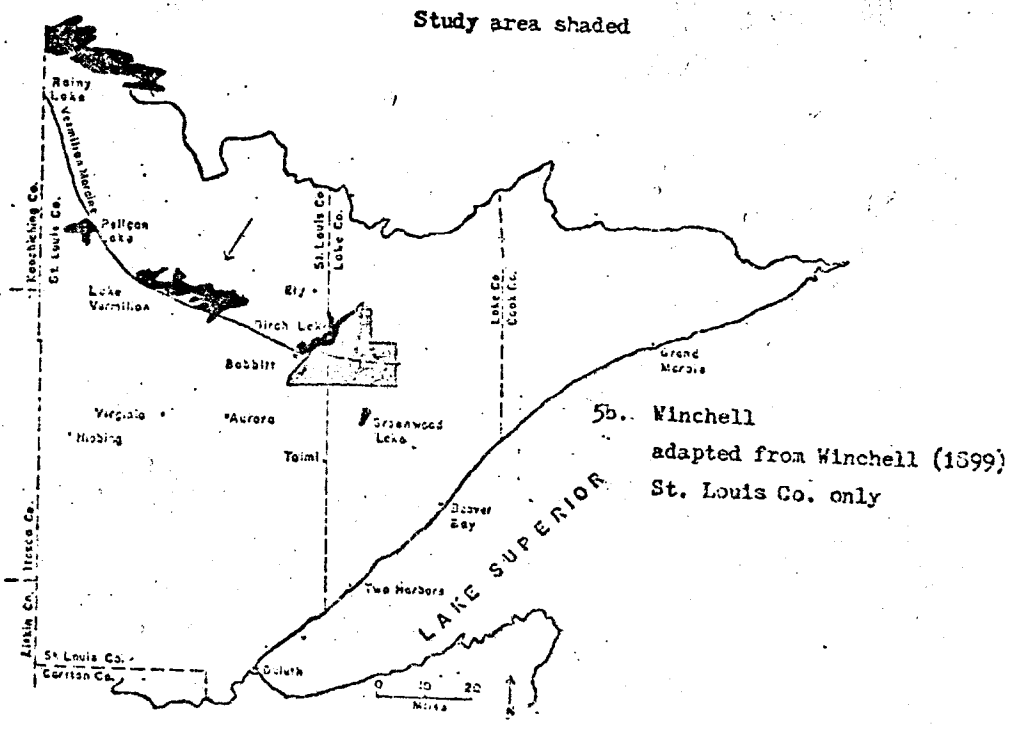
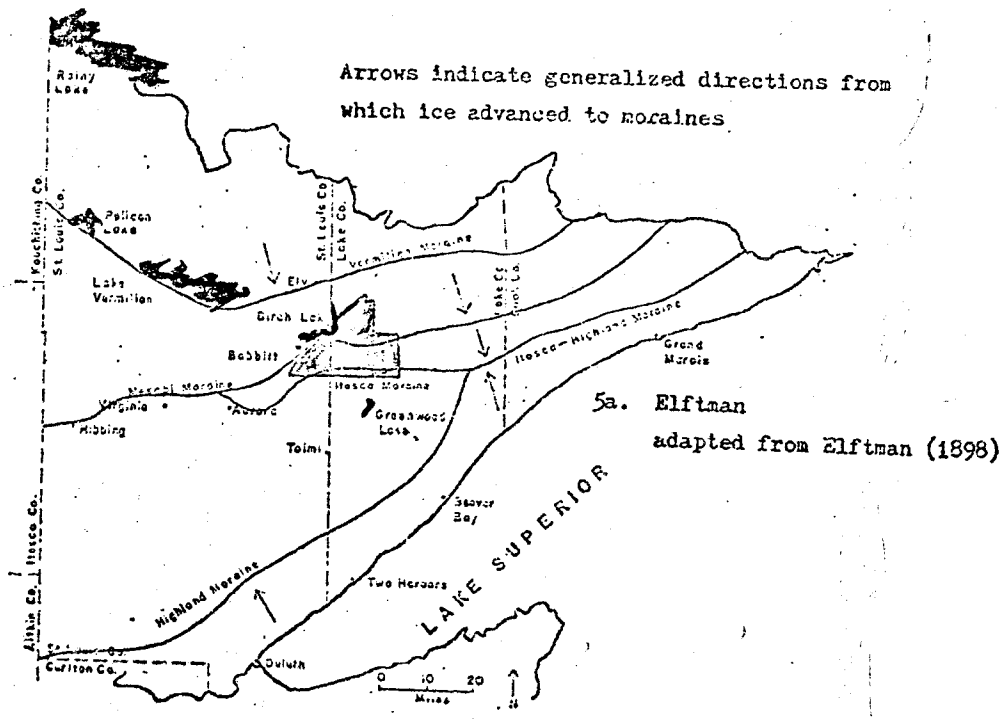


Figure 5. Interpretations of "Rainy" and "Superior" lobe moraines in northeastern Minnesota

direction across the Rainy Lake Region. It left till rich in Precambrian granitic and metamorphic rock types.

Elftman attributed the Itasca, Mesabi, and Vermilion moraines to deposition by the Rainy lobe, and the Highland moraine to the Lake Superior lobe. The combined Itasca-Highland moraine was thought to have formed as an interlobate deposit along the coalesced margins of the ice sheet. Stratigraphic superposition of the tills between the Itasca and Highland moraines was cited as evidence for at least two advances by each lobe.

#### Winchell

Winchell (1899a) published a map of the geology of northern St. Louis County which complemented a report on southern St. Louis County (Winchell, 1899b). The Vermilion moraine is the only moraine depicted on this map (Fig. 5b). The extent of Winchell's Vermilion moraine differed from that of Upham (1894) and Elftman (1898). It was mapped as extending from Lake Vermilion to the south side of Birch Lake, apparently incorporating the Vermilion and Mesabi moraines as mapped by Upham. A moraine near Ely was thought to have been deposited after the Vermilion moraine.

Winchell noted that the Vermilion moraine converged with another moraine, termed the southern moraine, near the west end of Birch Lake. He argued that the southern moraine resulted from deposition by an appendage of the Lake Superior lobe after deposition of the Vermilion moraine by the

northern ice lobe. He suggested that the term Mesabi moraine be continued for the southern moraine, but that it not be extended west across Minnesota.

### Leverett

Leverett and his co-workers published a number of papers dealing with the glacial geology of northeastern Minnesota (Leverett, 1928; Leverett and Sardeson, 1917, 1932) (Fig. 6a). They presented evidence for two Wisconsin ice advances in the region. Glacial deposits associated with the first advance (Rainy and Superior lobes) were termed Patrician drift or young red drift. Ice was thought to have moved across northeastern Minnesota in a south-southwest direction. This advance was believed to have terminated with the deposition of the St. Croix moraine in central Minnesota and eastern Wisconsin (south of the area shown in Figure 6a).

A second advance, from a Labradoran ice center, was termed the Superior ice lobe. It was placed in Leverett's chronology as late Wisconsin (Substage 4). Advancing in a southwesterly direction, it was thought to have reached its terminus 60 miles southwest of Duluth at the Kerrick moraine. Till associated with this advance was described as more clay-rich than older tills. The Highland moraine was thought to have formed from lateral flow out the Lake Superior basin.

A Patrician ice lobe, contemporaneous with the Superior lobe (Substage 4), was depicted as advancing into the highland area of northeastern Minnesota. It was thought to have reached a terminus at a morainic complex

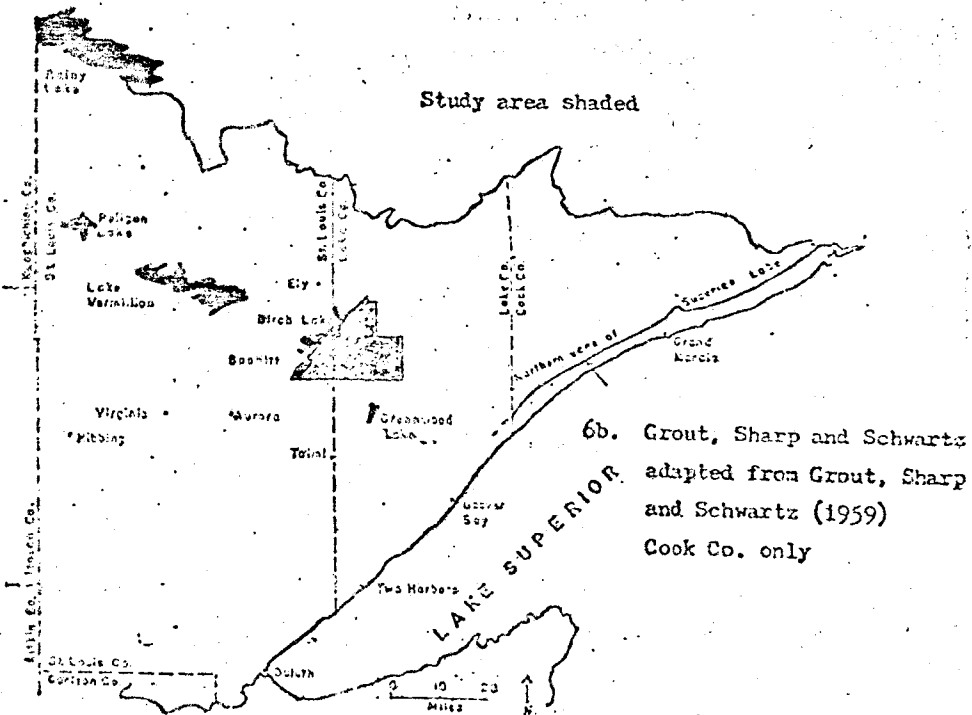
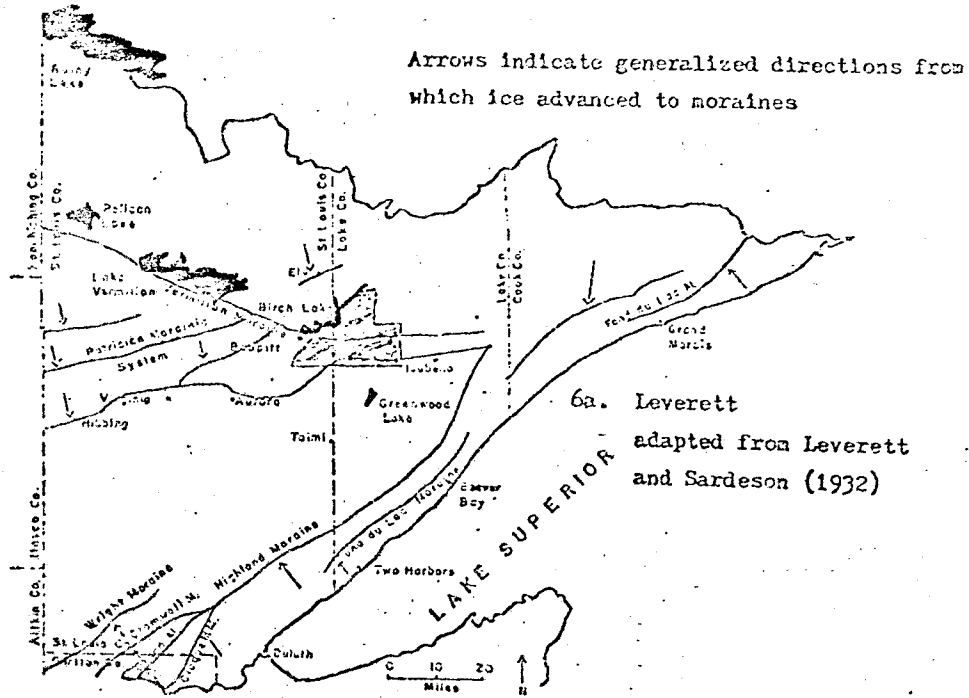


Figure 6. Interpretations of "Rainy" and "Superior" lobe moraines in northeastern Minnesota

in northern Minnesota (Fig. 6a). The northern most moraine in this complex was mapped much as it had been by Winchell. The Patrician morainic system was described as meeting the Highland Moraine near Isabella, Minnesota.

#### Grout, Sharp and Schwartz

During the 1950's, two papers discussing the glacial geology of Cook County, Minnesota were published (Sharp, 1953; Grout, Sharp, and Schwartz, 1959). Sharp argued that Cook County had been glaciated exclusively by the Rainy lobe during the "Cary stade" (Fig. 6b). Till associated with this advance was described as brown and sandy. Moraines mapped by Elftman and Leverett were reinterpreted as drift covered ridges, glaciofluvial deposits and eskers, thus holding no significance as ice-marginal features.

Based primarily on striation directions and pebble lithologies, Sharp's mapping restricted the distribution of Superior lobe deposits to a five-mile-wide swath along the north shore of Lake Superior (Fig. 6b). They were described as red and clay-rich. Found stratigraphically above the brown, sandy till, the red clay-rich till was assigned to either the Mankato or Valdres stades.

#### Wright

Over a period of years, Wright and his co-workers have published a number of papers pertaining, in general, to the glacial history of northern Minnesota (Wright, 1955, 1956a, 1956b, 1969, 1971, 1972a, 1972b, 1973;

Wright, Matsch, and Cushing, 1973; Wright and Ruhe, 1965; and Wright and Watts, 1969). His early works defined two Wisconsin Rainy lobe advances and three advances of the Wisconsin Superior lobe. During the late 1960's and early 1970's, Wright presented a new chronology for the glacial sequence in northeastern Minnesota. In order to avoid errors in correlation, informally defined "phases" were delineated for advances of each lobe.

The oldest widely exposed deposits of the Rainy and Superior lobes were assigned to the St. Croix phase. Together these lobes were thought to have reached a terminus at the St. Croix moraine. This advance, which produced the Toimi drumlins in northeastern Minnesota, has been dated at greater than 20,000 years B.P. Tills of both lobes were described as sandy, distinguishable primarily by color and pebble content.

Following the retreat of St. Croix phase ice, a second advance of both lobes, termed the Automba phase, was documented in northern Minnesota. During this phase, the Rainy lobe is thought to have advanced to a terminus at the Vermilion moraine, which truncates the northern edge of the Toimi drumlins (Fig. 7a).

The Automba Superior lobe was described as advancing in a southwesterly direction to a terminus at the Mille Lacs moraine in east-central Minnesota. Lateral flow within the Superior lobe produced the Highland moraine, which buries the Toimi drumlins in the east. Near Isabella, the Highland and Vermilion moraines are mapped as meeting in an interlobate

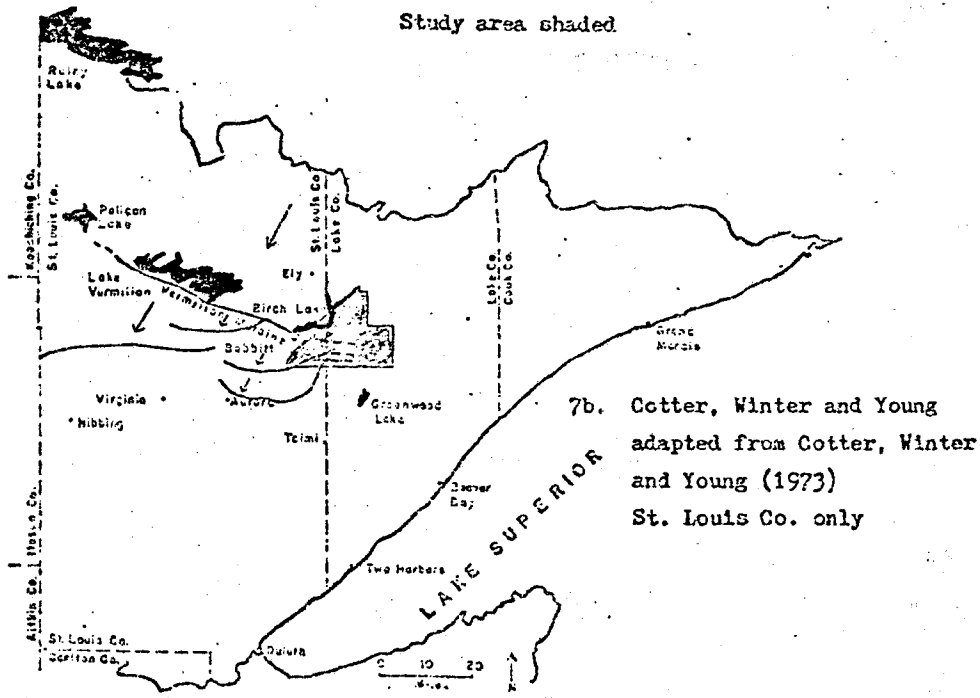
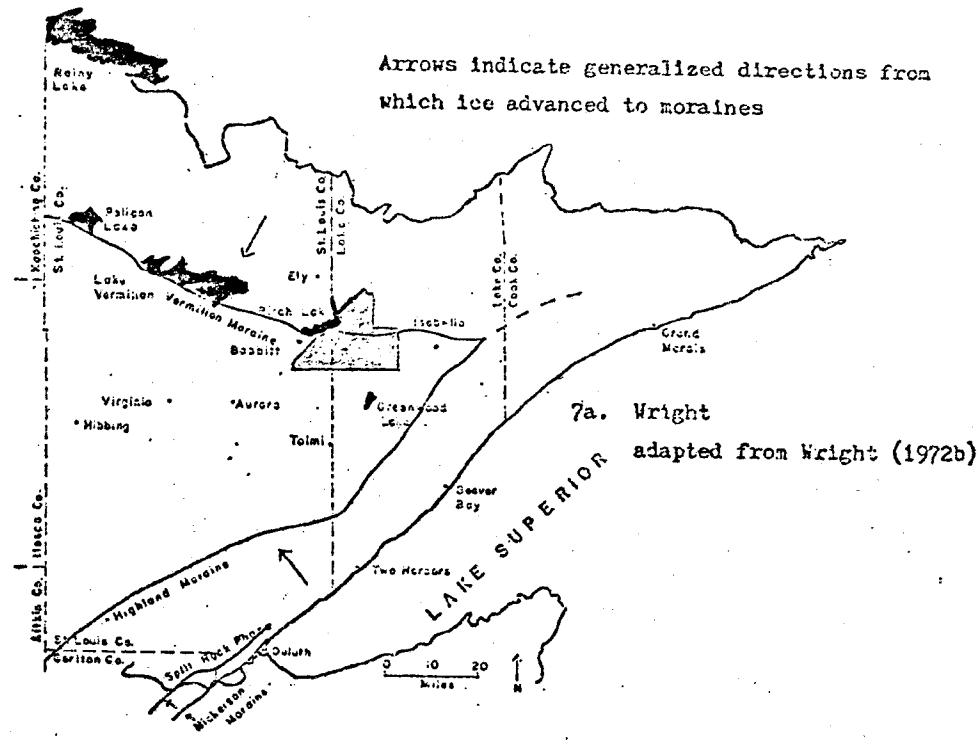


Figure 7. Interpretations of "Rainy" and "Superior" lobe moraines in northeastern Minnesota

junction of eskers. Tills associated with the Automba phase are described as sandy in texture. No absolute dates are available for Automba phase deposits.

Two later advances of the Superior lobe have been documented by Wright (1972b). Both these phases, termed the Split Rock and Nickerson, were restricted to the Lake Superior lowland. These late ice advances eroded proglacial lake beds and deposited red, clay-rich tills. The Split Rock phase is dated at greater than 16,000 years B.P., and the Nickerson phase at about 12,000 years B.P. Table 1 summarizes Wright's phase classification.

#### Cotter, Winter and Young

The most recent work dealing with the glacial geology of northern Minnesota was published during the 1960's and early 1970's (Cotter, Young, and Winter, 1964; Winter, 1971, 1973; and Winter, Cotter, and Young, 1973). They mapped and described glacial deposits in portions of Itasca and St. Louis Counties (Fig. 7b). Evidence was found for at least three glacial advances. Deposits of the oldest advance were termed the basal till. This till, found in occasional mine cuts, was described as boulders, cobbles and gravel in a gray, calcareous, sandy matrix. It is attributed to an ice advance from the west-northwest. Confined on the north by the Giants Range, it is mapped as far east as Aurora. A date of greater than 36,490 years is reported from wood in glaciofluvial sediments atop the basal till. The stratigraphic position of this wood, however, is in question.

Wright (1972b)

Winter (1971)

Nickerson phase 12,000 B.P.? Superior lobe	Alborn phase 12,000 B.P.? St. Louis sublobe of the Des Moines lobe	Surficial till 11,350 B.P. St. Louis sublobe of the Des Moines lobe
Split Rock phase 16,000 B.P.? Superior lobe		
Automba phase no date Superior and Rainy lobes		
St. Croix phase 20,000 B.P.? Superior and Rainy lobes		Bouldery till >35,000 B.P. Rainy lobe
		Basal till >36,400 B.P. Northwestern source

note: Winter's report did not cover the area glaciated  
by the Superior lobe

Table 1. Ice advances and till stratigraphy currently recognized in  
northeastern Minnesota

Glacial till stratigraphically above the basal till was termed bouldery till. It is the thickest and most continuous glacial unit in the area. Texturally this non-calcareous till contains cobbles to boulders in a matrix of silty sand. Colors range from gray, yellow, orange, and brown. Pebbles are predominantly of local origin. Bouldery till is attributed to deposition by the Rainy lobe, which moved into the area from the northeast (Fig. 7b). Although its age is uncertain, a date of greater than 35,000 years B.P. has been obtained from wood in glaciofluvial sediments atop the bouldery till.

The youngest till in the region, existing as a thin but continuous unit, is termed the surficial till. It varies from brown and silty to red and clayey. The matrix is calcareous, containing local pebbles as well as limestone, dolomite, shale, basalt, felsite, and gabbro. Deposition of the surficial till is attributed to the St. Louis sublobe of the Des Moines lobe, which advanced as far east as Aurora. Radiocarbon dates suggest that these tills were deposited about 11,000 years B.P. (Winter, 1971). Table 1 relates Wright's and Winter's classification systems.

#### Quaternary Deposits

The Quaternary deposits of the Babbitt-Kawishiwi area are mainly sediments associated with glacial activity. Minor deposits of alluvium in floodplains of modern streams, colluvium at the base of steeper slopes and organic deposits, in shallow depressions, make up the remainder. Thickest glacial deposits are associated with outwash plains and end moraines. Other

glacial deposits include ground moraine and ice-contact stratified drift. These deposits will be related to those described in previous studies in the section on stratigraphy and Quaternary history.

### Till

Till is defined as poorly stratified sediment carried or deposited by a glacier (Flint, 1971). It may consist of clasts ranging from clay to boulders, or any combination of these sizes. In the study area, three different lithologies are recognized.

#### Dunka pit till

A till exposed in a deep cut at Erie Mining Company's Dunka pit, near Babbitt, is informally termed the Dunka pit till in this report. Lying directly atop bedrock, it crops out in a swale in the bedrock topography, apparently having been protected there from later glacial erosion. Texturally, this well-cemented, calcareous (possibly of secondary origin) till is composed of gravel and cobbles in a matrix of silty sand. Boulders are less common than in other tills of the study area. The Dunka Pit till ranges in color from dark brown to dark greenish brown. Pebbles consist primarily of metasediments, greenstone and iron-formation with minor amounts of chert, quartz, granitic and Duluth Complex rock types.

### Bouldery till

The bouldery till crops out as the surficial till over the western portion of the study area (Plate 1). The informal term bouldery till is taken from a previous report dealing with the glacial geology of northeastern Minnesota (Winter, Cotter and Young, 1973). Field estimates, from the study area, place the volume of cobbles and boulders in the bouldery till at about 30 percent. Its matrix is composed primarily of silty, gravelly sand. Because of its low clay content, generally less than one percent, the till has the loose consistency of outwash. Till color is variable, ranging from brown (oxidized), to gray, greenish-gray and grayish-brown on fresh surfaces. Pebbles within the till consist primarily of Duluth Complex and granitic rock types with minor amounts of volcano-clastic rock, metasedimentary rock, iron-formation, greenstone, schist, gneiss, mafic rock, quartzite and diabase.

### Red, sandy till

Till, exposed as the surficial till over much of the eastern half of the study area, is informally termed the red, sandy till in this report (Plate 1). It contains fewer boulders than the bouldery till. Cobbles and boulders, however, are numerous. The matrix, like that of the bouldery till, is composed of loose, silty, gravelly sand. Till color ranges from brown to reddish-brown. Pebbles within the till are derived primarily from Keweenawan lavas and Duluth Complex rock types. Red sandstone, diabase, quartz, metasedimentary rock,

volcano-clastic rock, agate, mafic rock, shale, greenstone and granitic pebbles are present in minor amounts.

#### Discussion-differentiation of tills within the study area

Texture, color and pebble lithology content were investigated as criteria for differentiating basal till units within the study area. Of these, pebble content appears to be the best criterion for differentiation.

#### Texture

The three glacial till units exposed within the study area are not easily differentiated from a textural standpoint. All tills, including a till sampled from the Toimi drumlins south of the study area, are texturally sand or sandy loam (Fig. 8). Because of the coarse textured nature of tills exposed in the study area, only the matrix can be sampled and analyzed in the laboratory. It seems apparent from field observations that if the bulk composition of these tills could be determined, the bouldery till could be differentiated as the most coarse textured of the tills in the study area.

A second method of analyzing textural differences in sedimentary units includes a comparison of the median grain diameter and degree of sorting. The median grain diameter, by weight, of a sedimentary sample, can be determined directly from the 50th percentile of a cumulative frequency diagram. This measure of central tendency is less affected by extreme values than is the mean (Inman, 1952).

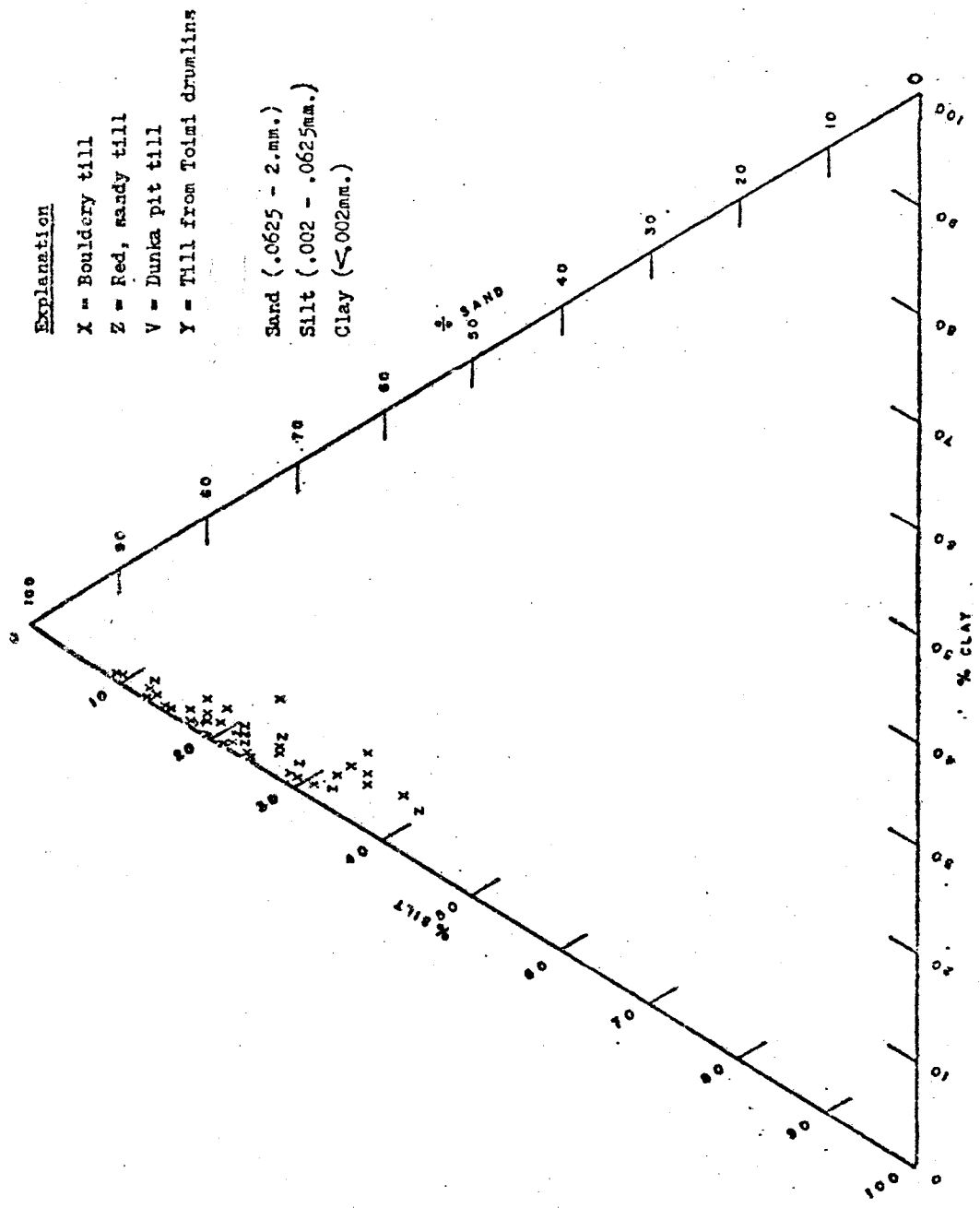


Figure 8. Grain size distribution of basal till samples

A second statistic, termed the Inman Phi deviation, is a measure of dispersion or sorting. It graphically approximates the first standard deviation of a frequency distribution by calculating one-half the distance between the 16th and 84th percentiles, as taken from a frequency curve (Inman, 1952). This sorting coefficient is used in preference to methods which employ data from both the first and second deviates, because in coarse textured sediment using standard sieves, the 5th percentile is most often obtained from the portion of the curve extrapolated beyond measured data. An Inman Phi deviation of 0.0 would indicate a perfectly sorted sedimentary sample.

A statistical summary for all tills sampled in the study area is presented in Table 2. Additional grain size data is contained in Appendix A.

Data summarized in Table 2 indicates that the red, sandy till is texturally finer than the bouldery till. This difference is not evident from the textural diagram since most of the clasts are sand sized. Sorting data is inconclusive.

#### Color

In most instances, the bouldery and red, sandy tills can be differentiated by color. Red, sandy till samples are generally red-brown in color, with hues in the 10 YR range of the Munsell color system. Bouldery till samples, brown to gray-brown in color, most often display hues in the 2.5 Y range. Because of its limited exposure, variability in the color of the dark brown Dunka Pit till has not been examined. Appendix A presents color values

Till	No. of Samples	Average Median Grain Diameter by Weight ( $\phi$ units)	Range ( $\phi$ units)	Standard Deviation ( $\phi$ units)	Average Inman Phi Deviation (Sorting, $\phi$ units)	Range ( $\phi$ units)	Standard Deviation ( $\phi$ units)
Bouldery	30	0.6	-2.0-2.3	1.1	3.5	2.4-5.9	0.6
Red, sandy	9	1.1	-1.0-2.4	0.8	3.6	2.9-3.4	0.4
Dunka pit	1	0.8			2.8		

Table 2. Median grain diameter and sorting-Till samples

for all glacial till samples.

### Pebble lithologies

The best method of differentiating the glacial tills in the study area is by the content of pebbles within the tills. The Dunka Pit till contains primarily metasedimentary rock, greenstone and iron-formation pebble types. In addition, minor amounts of chert, quartz, granitic and Duluth Complex rock types occur.

The most common pebble types within the bouldery till are derived from granitic and Duluth Complex bedrock. The Giants Range granitic batholith crops out immediately north of the study area (Fig. 3). Duluth Complex/granitic pebble ratios in the bouldery till are roughly proportional to the sample site's distance from the Duluth Complex-granitic contact. In general, Duluth Complex pebbles increase and granitic pebbles decrease as the distance from this contact increases (Fig. 9). Other Precambrian rock types, indicative of the area to the north of the study area, are present in minor amounts in the bouldery till.

Red, sandy till samples are readily distinguished from other tills of the study area on the basis of pebble types. An average of 21 percent of the pebbles counted from red, sandy till samples were derived from the North Shore Volcanic Group (Fig. 10), which crops out to the east of the study area (Fig. 3). Bouldery till samples contain an average of less than one percent of pebbles which might be classified as being derived from the North Shore Volcanic Group. Pebble types derived from the North Shore Volcanic Group

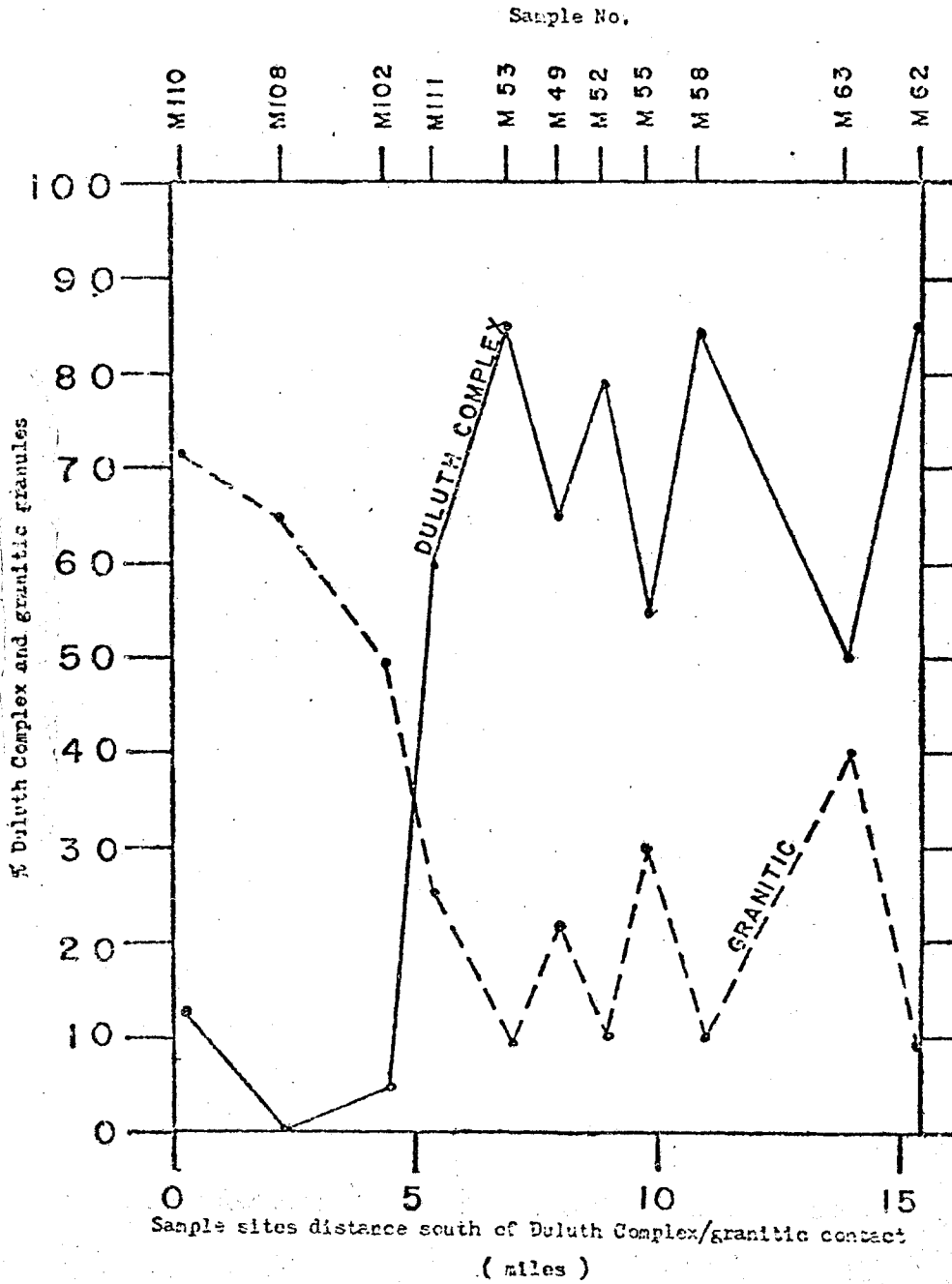


Figure 9. Duluth Complex and granitic granules ( $>2$ .mm.) in bouldery till samples, expressed as percents of total granules counted in each sample

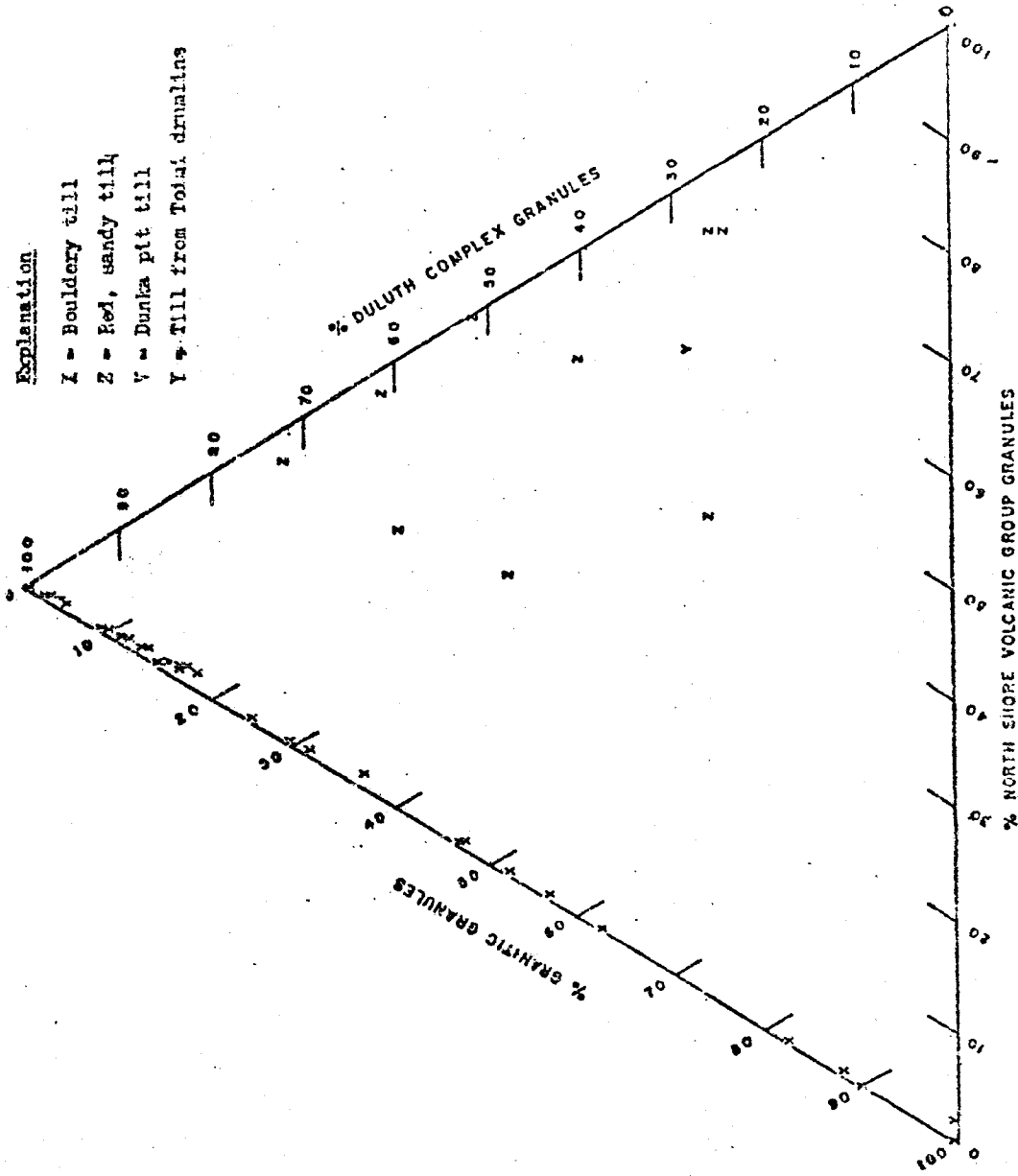


Figure 10. Lithology of granules (>2mm.) in basal till samples

include vesicular lavas and arkosic sandstones. These lava pebbles are readily distinguished from the metamorphosed volcanics which crop out to the north of the study area. Finally, the red, sandy till contains minor amounts of pebbles derived from diabase, quartz, metasedimentary rock, agate, mafic rock, volcano-clastic rock, metavolcanic rock and granitic rock types.

The presence of pebbles derived from the North Shore Volcanic Group appears to be the best method of differentiating the red, sandy and bouldery tills (Fig. 10). A till sample from the Toimi drumlins, south of the study area, seems more characteristic of the red, sandy till, based on pebble lithologies. Pebble data for all samples is contained in Appendix B.

#### Ablation Till

Ablation till differs from basal till in that it is not deposited from the base of a glacier. Ablation tills are deposited during ice wastage. They tend to be coarser textured and more poorly compacted than basal till (Flint, 1971).

Ablation tills associated with both the bouldery and red sandy tills, occurs as surficial deposits over much of the study area (Plate 1). They may generally be described as loose, coarse textured material composed of particles ranging in size from fine sand to boulders (Fig. 11). Of the 21 ablation till samples, all contained greater than 90 percent sand or coarser sized particles by weight. These deposits, probably derived from a super-glacial position tend to be better sorted than basal till samples. The better sorting is possibly due to washing atop ablating ice. Pebbles within these



Figure 11. Road cut in red, sandy ablation till  
(Greenwood Lake quad., N.E.  $\frac{1}{4}$ )  
(SE  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , NW  $\frac{1}{4}$ , Sec. 7, T. 60N., R. 9W.)



Figure 11. Road cut in red, sandy ablation till  
(Greenwood Lake quad., N.E.  $\frac{1}{4}$ )  
(SE  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , NW  $\frac{1}{4}$ , Sec. 7, T. 60N., R. 9W.)

ablation tills tend to be angular and broken, a probable result of frost action (Drake, 1971). Lithologically, ablation till pebbles are identical to pebble types in their correlative tills. Ablation till may be distinguished from outwash, in the field, because it lacks stratification and contains a large percentage of cobbles and boulders. Table 3 compares statistical data from basal tills and ablation tills sampled in the study area.

Because of a lack of deep exposure in the study area and the difficulty involved in augering in stoney deposits, basal till samples are not readily observable. A sample of basal till from Erie Mining Company's Dunka Pit is not significantly different from till samples taken near the surface. All surficial till within the study area, however, may have originated superglacially. Deposits termed ablation till in this report appear to be significantly different, on a textural basis, than deposits termed till. Ablation till textural data is presented in Appendix A.

#### Glaciofluvial Deposits

Glaciofluvial deposits include all sediments deposited by glacial meltwater streams. They may be divided into two categories. Outwash consists of stratified sand and gravel deposited by streams flowing away from a glacier. Ice-contact stratified drift is deposited in close contact with stagnant ice (Flint, 1971). Both types occur within the study area.

Glaciofluvial deposits, associated with both the bouldery and red, sandy tills, occur as surficial deposits over much of the study area (Plate 1). They

Unit	No. of Samples	Average Median Grain Diameter by Weight ( $\phi$ units)	Range ( $\phi$ units)	Standard Deviation ( $\phi$ units)	Average Inman Phi Deviation (Sorting, $\phi$ units)	Range ( $\phi$ units)	Standard Deviation ( $\phi$ units)
Bouldery till	30	0.6	-2.0-2.3	1.1	3.5	2.4-5.9	0.6
Bouldery, ablation till	17	-1.3	-3.8-1.9	1.4	2.1	1.0-3.6	0.7
Red, sandy till	9	1.1	-.1-2.4	0.8	3.6	2.9-3.4	0.4
Red, sandy, ablation till	3	-0.8	-1.5-0.2	0.7	2.8	2.4-3.5	0.5

Table 3. Median grain diameter and sorting-tills and ablation tills

consist of well sorted, stratified sands and gravels (Fig. 12 and 13). Pebbles within these units closely resemble pebble types from their correlative till units. Glaciofluvial deposits in the study area can generally be distinguished, in the field, from ablation till because of the presence of stratification and the lack of cobbles and boulders. Due to the absence of large clasts, glaciofluvial deposits tend to be finer grained and better sorted than ablation tills. Textural data from glaciofluvial samples is presented in Appendix A. Statistical data for glaciofluvial and ablation till samples is summarized in Table 4.

#### Swamp and Bog Deposits

Swamp and bog deposits are abundant surficial materials within the study area (Plate 1). The upper stratum of these deposits is typically composed of organic materials. These peaty materials range laterally and vertically from fibric to hemic to sapric. Peat as thick as 15 feet has been observed by power augering in the Dunka River basin.

Peat deposits are generally underlain by glaciolacustrine or colluvial materials. Glaciolacustrine materials result from the deposition of small particles in ponded glacial meltwater. Colluvium is produced by slope wash. These materials range in size from sandy silt to silty clay. Glaciofluvial silts occur at depth, below glaciofluvial deposits, in the Dunka River basin. Swamp and bog deposits' textural data is contained in Appendix A.



Figure 12. Red, sandy outwash in gravel  
pit near Babbitt  
(SE $\frac{1}{4}$ , SE $\frac{1}{4}$ , SW $\frac{1}{4}$ , Sec. 33, T. 61N., R. 12W.)



Figure 13. Large kame (associated with the  
bouldery till) mined for road fill  
(SW $\frac{1}{4}$ , NE $\frac{1}{4}$ , NE $\frac{1}{4}$ , Sec. 14, T. 60N., R. 12W.)

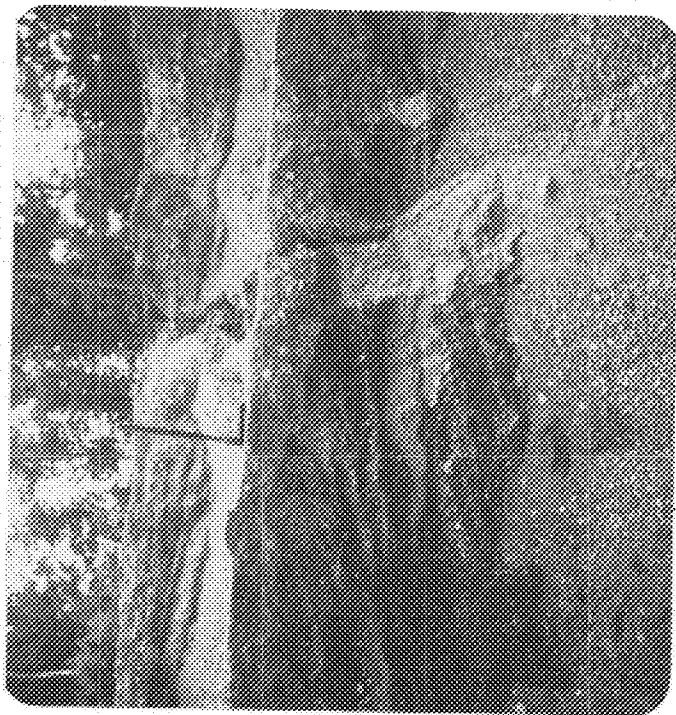


Figure 12. Red, sandy outwash in gravel  
pit near Babbitt  
(SW $\frac{1}{4}$ , SE $\frac{1}{4}$ , SW $\frac{1}{4}$ , Sec. 33, T. 61N., R. 12W.)



Figure 13. Large kame (associated with the  
bouldery till) mined for road fill  
(SW $\frac{1}{4}$ , NE $\frac{1}{4}$ , NE $\frac{1}{4}$ , Sec. 14, T. 60N., R. 12W.)

Unit	No. of Samples	Average Median Grain Diameter by Weight ( $\phi$ units)	Range ( $\phi$ units)	Standard Deviation ( $\phi$ units)	Average Inman Phi Deviation (Sorting, $\phi$ units)	Range ( $\phi$ units)	Standard Deviation ( $\phi$ units)
Bouldery, ablation till	17	-1.3	-3.8-1.9	1.4	2.1	1.0-3.6	0.7
Bouldery, glaciofluvial deposits	16	0.1	-2.7-2.4	1.3	2.0	1.1-3.6	0.6
Red, sandy, ablation till	3	-0.8	-1.5-.2	0.7	2.8	2.4-3.5	0.5
Red, sandy, glaciofluvial deposits	32	0.2	-1.9-3.6	1.4	2.0	.9-4.2	0.7

Table 4. Median grain diameter and sorting--Ablation tills and glaciofluvial deposits

## Geomorphology

The northern half of the study area, north of the third (Vermilion) moraine, lies completely within the extent of the bouldery till. This area, an ice scoured plain, consists primarily of thin, discontinuous glacial till and numerous areas of bedrock exposure (Plate 2, Fig. 14 and 15). Bedrock morphology is composed of partially drift covered elongate, linear ridges. These "rock drumlins" and rouches moutonnees, which trend slightly east of north, are generally less than one-fourth mile long. The largest (Sec 32, T62N, R10W, and Sec 5 and 8, T61N, R10W) is more than one mile long with at least 200 feet of relief. North-east trending bedrock joints (Cooper, 1974), coupled with southwesterly ice flow, apparently resulted in the glacial scour of these features. Poorly drained areas between bedrock highs contain peat overlain by glaciolacustrine or colluvial silts and clays. Scattered small ice contact and ablation till deposits also occur within this portion of the study area.

The region south of the third (Vermilion) moraine consists of terminal and recessional morainic complexes associated with both the red, sandy and bouldery tills (Plate 2). Of these, the third (Vermilion) moraine is the best developed, with boulder strewn hummocky topography. Materials within the moraines include till, ablation till and ice contact stratified drift. Between the moraines, surface morphology consists of ground moraine, scoured bedrock, outwash plains, lake basins and poorly drained lowlands.

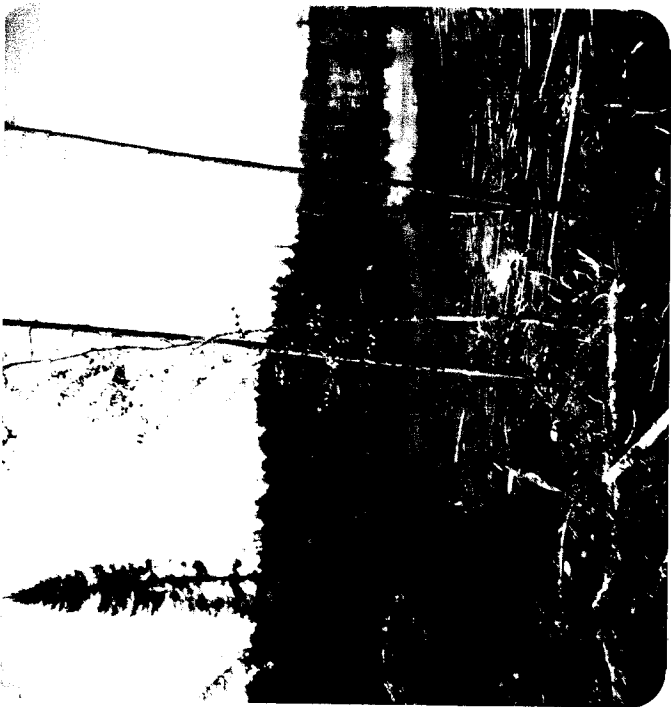


Figure 14. Typical landscape north of the  
third (Vermillion) moraine, showing forestry  
practices



Figure 15. Typical landscape north of the  
third (Vermillion) moraine, showing forestry  
practices



Figure 14. Typical landscape north of the third (Vermillion) moraine, showing forestry practices



Figure 15. Typical landscape north of the third (Vermillion) moraine, showing forestry practices

A large area of thick ablation till occurs south of the Giants Range highland (Babbitt and Babbitt NE Quadrangles). Pitted surface features atop these deposits indicate a genesis with ablating bouldery till ice.

An ice marginal lake basin occupies the Dunka River basin (Babbitt NE Quadrangle). This basin is filled with stratified glaciofluvial deposits which overlie glaciolacustrine silts and clays. The stratified sands and gravels are lithologically similar to the red, sandy till. The area, termed Glacial Lake Dunka (Winchell, 1901), covers about 20 square miles. Large crevasse fills (T60N, R12W, Sec 23 and 24) and a pitted outwash surface atop the stratified drift indicate the presence of stagnant ice in the basin as it filled. This lake, which had an elevation of at least 1600 feet, was apparently short lived, since no well defined beaches are present. The lake drained northward, through the present Dunka River valley.

Within the limits of the red, sandy till (Greenwood Lake Quadrangle, NE 1/4), glacial landforms consist of ground and end moraine and occasional ice-contact deposits. Thick drift and numerous kettle lakes are characteristic of the red, sandy till. End moraine, associated with the red, sandy drift is traceable along the southern and western limits of the red, sandy till. The northern terminus, however, is apparently buried under ablation till associated with the bouldery till. Outwash plains, associated with the red, sandy till occur in the Lake McDougal, Sand Lake, Dunka River and Babbitt areas.

### Overburden Thickness

Data was compiled for a total of 267 holes drilled within the study area. Of these, 221 are exploratory holes drilled by the International Nickel Corporation (Wager, written communication). The remaining 46 were augered holes. Thirty-five were completed by the United States Geological Survey (Olcott, written communication) and eleven by the author. Logs of all augered holes are contained in Appendix C.

A total of 249 of these holes are located north of the Vermilion moraine, most in the International Nickel mine-site area (Gabbro Lake Quadrangle, SW 1/4). Ranging from 0 to 50 feet, overburden thicknesses in these holes averaged 11.5 feet. This average is probably low since holes were generally not drilled in low lying areas filled with peat, colluvium and glaciolacustrine deposits. The figure is probably representative of overburden thicknesses atop highland areas north of the Vermilion moraine.

Thick drift occurs in the Dunka River basin. Overburden in 12 holes augered in the Dunka River basin averaged greater than 40 feet, since not all holes were completed to bedrock.

Because of the difficulty encountered in augering stoney materials, overburden thicknesses south of the Vermilion moraine, exclusive of the Dunka River basin, are not well known. Although thin, except within moraines, drift south of the Vermilion moraine is observably thicker than to the north. Numerous deep kettles and an absence of bedrock outcrop indicate that drift within the extent of the red, sandy till is thicker than other areas.

### Stratigraphy and Quaternary History

The dark brown, coarse textured, well cemented, calcareous Dunka pit till is the lowest observable Quaternary unit in the study area. Exposed only in Erie Mining Company's Dunka pit, the till lies directly atop bedrock. It contains abundant greenstone and metasedimentary pebbles, rock types common to the area north and west of the study area. The calcareous matrix may suggest a west or northwest source, from the Paleozoic carbonates of northwestern Minnesota, North Dakota or Manitoba. Within the study area, the subsurface extent of the Dunka Pit till is unknown.

The occurrence of a subsurface, dark, sandy to silty, calcareous till has been reported to the west of the study area (Winter, 1971, 1973; Winter, Cotter and Young, 1973). It is found stratigraphically below the bouldery till in the Mesabi Range Region. This till has informally been termed the basal till. Till fabric and pebble content data suggest a northwesterly source for the basal till. It has been mapped, in the subsurface, as extending as far east as Aurora. The northern extent of the unit lies at the southern flank of the Giants Range. A radiocarbon date of greater than 36,490 B.P. has been reported from wood in the Duncan Douglas mine (Winter, 1971). Although the stratigraphic position of the sample is in question, it is thought to have been contained in outwash between the bouldery and basal tills. The basal till, therefore, is believed to be at least as old as middle Wisconsin.

The Dunka pit and basal tills may be the same stratigraphic unit. Like

the basal till, the Dunka pit till is found south of the Giants Range. Dunka pit is located about 18 miles northwest of Aurora (Fig. 16).

At Erie Mining Company's Dunka pit, stratified glaciofluvial sediments lie stratigraphically above the Dunka pit till. They, in turn, are overlain by the bouldery till (Fig. 17). Pebbles within this outwash unit suggest a genetic relationship with the bouldery till. Because of a lack of deep exposure within the study area, the lateral extent of this glaciofluvial unit is not known.

A second episode of glacial history is represented by a surficial till exposed south of the study area, in the Toimi drumlins. These drumlins were produced by a southwesterly advance of the confluent Rainy and Superior lobes. Termed the St. Croix phase, the advance reached its maximum at the St. Croix moraine in east-central Minnesota, at least 20,500 years ago (Wright, 1972b). A sample of this till, from near Toimi, is red and sandy, with pebbles indicative of a source in the Lake Superior basin. Elftman (1898) noted stratigraphic layering of northeastern and eastern tills in the Toimi area (south of the study area) and suggested that the confluent margin between the two lobes had shifted repeatedly during advance. These tills are not exposed within the study area.

A third episode of glacial history is represented by the bouldery and red, sandy tills, surficial tills within the study area. They were probably deposited by two ice lobes which converged on the study area from slightly different directions. The southern margin of the tills associated with both

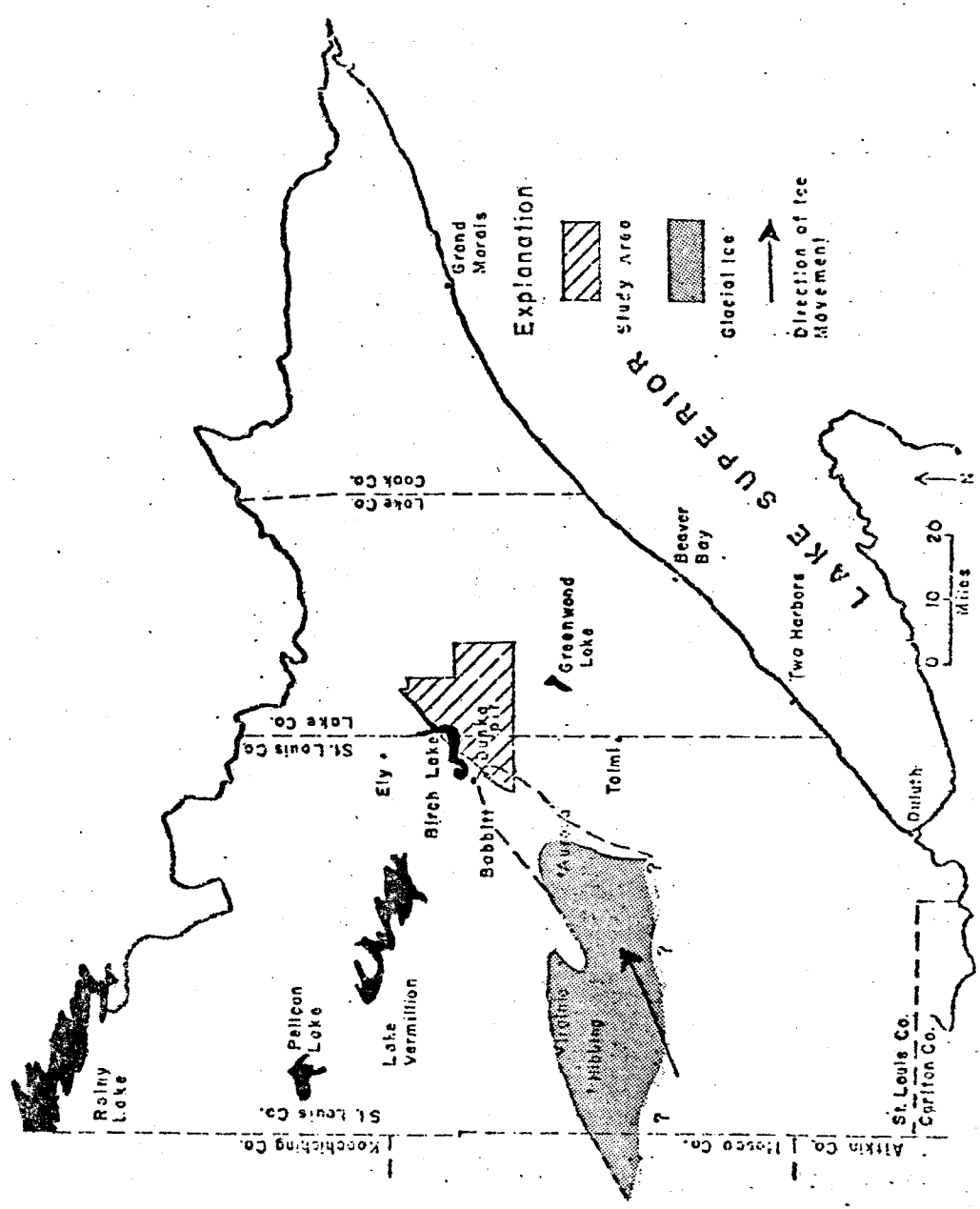


Figure 16. Extent of the ice that deposited the basal till in northeast Minnesota and its relationship to Dunka Pit (adapted from Winter, 1971)

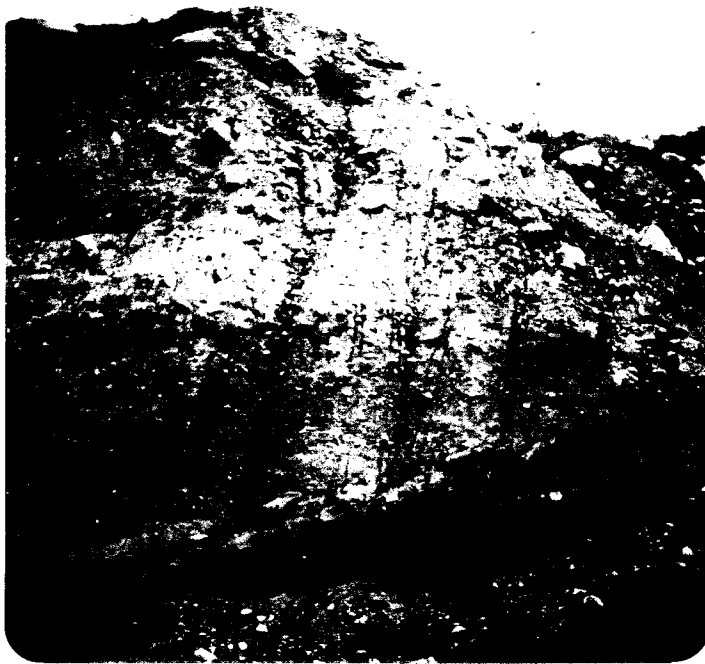


Figure 17. Mine cut showing (from bottom) Biwabik Iron-formation, Dunka Pit till (below yellow notebook), glaciofluvial sediments and bouldery till (Dunka pit mine, NE $\frac{1}{4}$ , SW $\frac{1}{4}$ , NW $\frac{1}{4}$ , Sec. 10, T. 60N., R. 12W.)

lobes truncates the Toimi drumlins. The time equivalence of the ice lobes which deposited the bouldery and red, sandy tills is displayed in an interlobate junction which formed between the converging ice fronts (Greenwood Lake Quadrangle, NE 1/4). At this junction, the southern-most bouldery till moraine (first moraine) bends abruptly northward where it is met by an equivalent moraine (outer moraine) associated with the red, sandy till.<sup>1</sup>

The bouldery till was deposited by a readvance of the Rainy lobe, following wastage of St. Croix phase ice. Wright (1972b) has termed this advance, coupled with a correlative Superior lobe advance, the Automba phase. Wright (1972b), from dates within older and younger tills, believes that the Automba phase reached its maximum between greater than 20,000 and greater than 16,000 years ago. Winter (1971), however, feels that a date of greater than 35,000 years B.P. is representative of the Automba Rainy lobe.

In the study area, the Automba Rainy lobe advanced from slightly east of north as documented by glacial striations and "rock drumlin" trends. Having advanced over the highlands of northeastern Minnesota, pebbles within the bouldery till are primarily derived from Early Precambrian and Duluth Complex rock types. The Automba phase Rainy lobe advance terminated at its southern-most (first) moraine which lies, in part, within the study area. At

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<sup>1</sup>To avoid the confusion I experienced in reviewing the literature, moraines within the study area are given informal names in this report. Those associated with the bouldery till are termed first, second, and third, from south to north, respectively. Moraines associated with the red, sandy till are termed outer and inner, from south to north, respectively.

its terminus, it was met by an ice lobe which advanced out of the Lake Superior basin.

Red, sandy till, surficial till over the eastern part of the study area, was deposited by a small sublobe of the Automba Superior lobe. This advance originated in the Lake Superior basin. Till deposited by this sublobe contains large amounts of eastern indicator pebbles, derived from the Lake Superior basin.

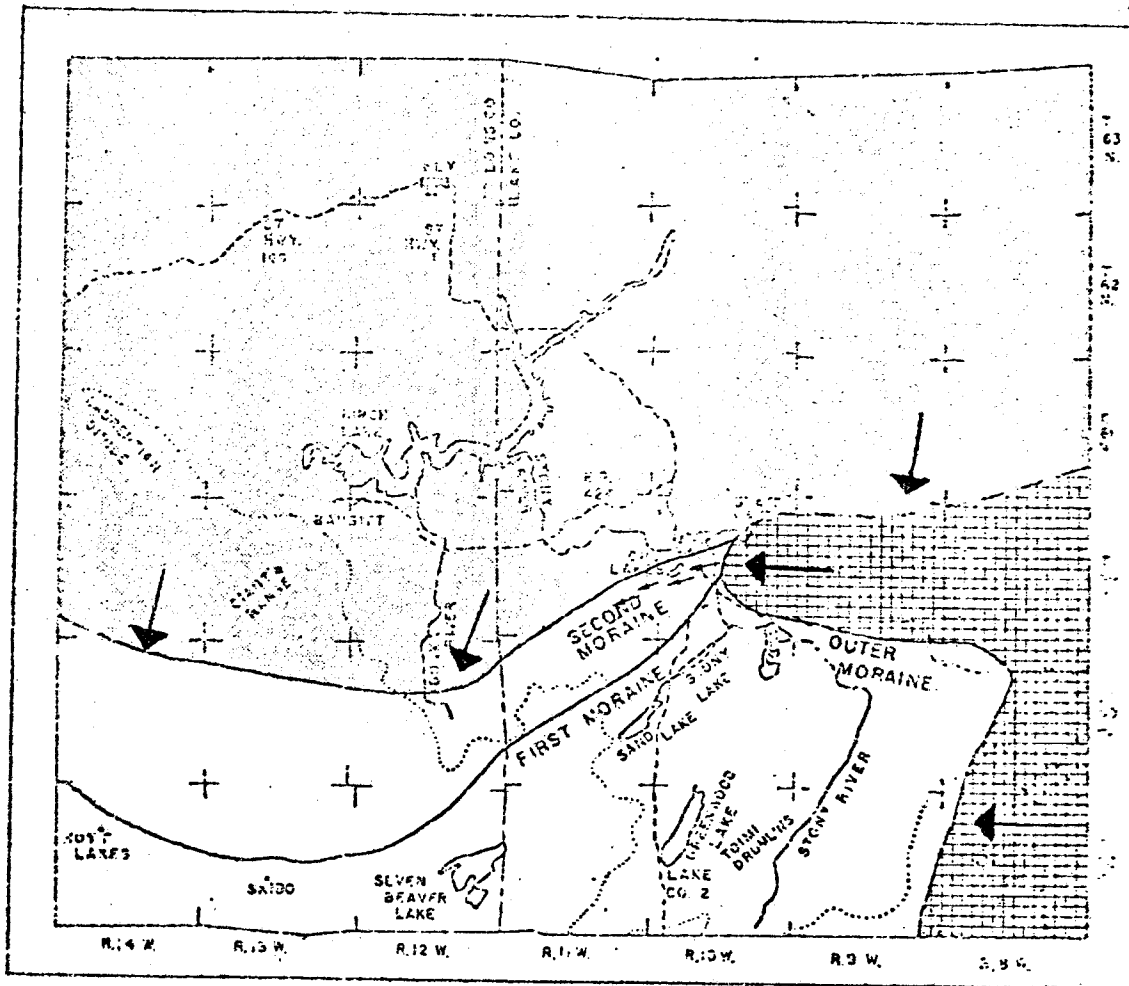
At the close of the St. Croix phase, the Rainy lobe is thought to have wasted at least as far north as the Vermilion moraine. The Superior lobe, however, is believed to have retreated only as far north as the bedrock divide between the Minneapolis lowland and the Lake Superior basin (Wright, 1972b). During the Automba readvance, a sublobe of the Superior lobe apparently advanced into the study area slightly before the Rainy lobe. The timing of these advances, displayed by Rainy lobe moraines which are contorted around Superior sublobe moraines, may have resulted from a larger reservoir of ice behind the Superior lobe. During the Automba phase, ice flow near the eastern margin of the Superior lobe was lateral and northwestward (Wright and Watts, 1969). This northwesterly flow of ice probably produced the advance of Superior lobe ice into the study area. Its extent, slightly beyond the Highland moraine proper, may have resulted from irregularities in bedrock topography. This small sublobe was met, in the study area, by the advancing Rainy lobe (Greenwood Lake Quadrangle NE 1/4, Fig. 18).




Ice of the Superior lobe apparently remained active longer than Rainy lobe ice. This is documented by Superior outwash which overlies bouldery drift within the study area. As the Rainy lobe stood at its southern terminus, outwash from Superior ice discharged south, down the channel presently occupied by Sand and Stony Lakes. This area was marginal to Rainy lobe ice at that time. Kettles within the channel indicate the presence of rafted or stagnant ice. Meltwater crossed the present Laurentian Divide and into the present Cloquet River system (Fig. 18).

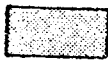
The Superior lobe was apparently still active as the Rainy lobe wasted to its second moraine. Outwash associated with Superior ice is traceable into the Chub Lakes area. This pitted outwash lies atop bouldery drift in an area which was ice marginal to the Rainy lobe as it stood at its second moraine (Fig. 19).


Continued recession of the Rainy lobe resulted in wastage to the third or Vermilion moraine. During this period, outwash from Superior lobe ice, with its terminus at the inner moraine, discharged westward through the valley of the present Stony River. At that time, the outlet of the Stony River into Birch Lake was blocked by the Rainy lobe. The ice, however, was evidently very thin at the margin. Superior lobe outwash was deposited atop Rainy lobe ice near the junction of Forest Road 424 and the Stony River. In this area, pitted Superior sands and gravel bury a portion of the Vermilion moraine. Augered samples have shown that about 40 feet of outwash cover bouldery till.



EXPLANATION

 Superior lobe ice

 Rainy lobe ice

 Direction of ice movement


 Direction of Superior lobe melt-water flow

Figure 19. First stage in the deglaciation of Automba phase Superior and Rainy lobes in northeastern Minnesota (partially adapted from Leverett (1932), Winter (1973), and Wright (1972b))

Being blocked from drainage to the north by the Rainy lobe and Giants Range, meltwater from both lobes ponded in the Dunka River basin. Glacio-lacustrine clayey silts, augered from depth in the basin, contain sand grains derived from both lobes of ice. This small lake, termed Glacial Lake Dunka (Winchell, 1901) was filled with glaciofluvial sands and gravels which poured into the basin from meltwaters of Superior lobe ice. "Crevasse fill" features and kettles in the basin indicate the presence of large stagnant blocks of ice. Large boulders, perched atop these sands, appear to have been ice rafted. The lake had an elevation of at least 1600 feet (Fig. 20).

As Rainy lobe ice wasted, a notched channel opened between the Rainy ice front and the Giants Range. Sandy, red outwash is traceable along the present Dunka River to the pitted outwash plain upon which the village of Babbitt is built. From the Babbitt area, meltwaters discharged west into Glacial Lake Norwood. This lake, named by Winchell (1901) formed between the Giants Range and the Rainy lobe. It drained south through the Embarrass River Gap into the St. Louis River system.

As the ice left the area for the last time, low areas were filled with locally derived silts and clays.

#### Surficial Geology--Conclusions

1. Deposits from three ice lobes are preserved within the study area.
  - a. Basal tills deposited by these lobes are informally termed the Dunka Pit, bouldery and red, sandy tills.



- b. Texturally, the three glacial tills are difficult to differentiate.
  - c. Color and pebble content appear to be the best parameters for differentiation.
    - (1.) The Dunka Pit till, dark brown in color, contains pebble types derived from Lower and Middle Precambrian rocks of northern Minnesota.
    - (2.) Bouldery till samples vary from brown to gray-brown and contain pebbles primarily from granitic and Duluth Complex rocks.
    - (3.) The red, sandy till is generally red-brown in color with pebble types from the Lake Superior basin.
2. The glacial geomorphology of the study area is varied.
- a. The northern half of the area is an ice-scoured plain. It consists of thin drift and elongate bedrock ridges.
  - b. The southern portion contains landforms associated with stagnant ice. Morainic complexes and thicker drift are typical of this portion of the study area.
3. Three episodes of glacial history are represented in glacial stratigraphy of the region.
- a. The first deposited the Dunka pit till. It probably resulted from ice which advanced from the west. The till may correlate with a subsurface till described in the Mesabi Range Region.
  - b. A second episode of glacial history is represented by till in the Toimi drumlins, south of the study area. This physiographic region resulted from an early advance of the Superior and Rainy lobes.

- c. Finally, the Rainy and Superior lobes deposited, respectively, the bouldery and red, sandy tills. These deposits truncate the Toimi drumlins on its north side. Stratigraphic and geomorphic evidence suggest that these lobes coexisted.

## GROUND-WATER GEOLOGY

### Introduction

#### Field and Laboratory Procedures

Field studies were conducted during 1975 and 1976. Field work consisted of the installation of observation wells and a Leopold-Stevens recorder equipped with Keck adaptor. Wells, including copper-nickel exploration holes, were monitored monthly or semi-monthly. Slug tests (permeability tests) were conducted during the summer of 1976 on five copper-nickel exploration holes drilled into the Duluth Complex. Field methods included those described by Ferris and Knowles (1963). Data analysis was performed according to the method presented by Cooper, Bredehoeft and Popadopoulos (1967). Permeability tests, using permeameters, were performed on 25 of the surficial materials samples collected in the study area. Both constant and falling head tests were performed, depending on the texture of the sample. Methodology included that described by Lamb (1951). Most of the ground-water studies were confined to a portion of the study area (Gabbro Lake quadrangle, S.W. 1/4). Surficial permeability values, however, were investigated over the entire study area.

#### Previous Work

Little work has been done with regard to the water resources of the area underlain by the Duluth Complex. Because of the need for industrial water, however, a number of papers have been published which pertain, in

general, to the water resource potential of the Mesabi Range Area. Cotter, Young, Petri and Prior (1965a) describe the hydrologic regime, water quality, and present and potential water development of the Mesabi and Vermilion Iron Range Areas. In a second paper they (Cotter, Young, Petri and Prior, 1965b) discuss the present and potential water supplies of municipalities on the eastern Mesabi Range, including Babbitt. Winter (1973) summarizes the geology and hydrogeology of the south side of the Giants Range.

#### Surficial Materials--Permeability

Permeability is the capacity of a porous medium for transmitting fluid. Permeable materials tend to have large amounts of interconnected void space. A total of 25 of the surficial materials samples collected within the entire study area were tested in the lab for estimates of their permeability. Both constant and falling head permeameter tests were employed, depending on the texture of the sample. Samples were selected by median grain diameter and degree of sorting, so that the complete range of the study area's surficial materials could be classified. In general, permeability was found, as expected, to increase as texture became coarser or as the material became better sorted.

The most permeable surficial materials in the study area are the glaciofluvial sands and gravels. They are abundant over the southern half of the study area. Median grain diameters for glaciofluvial materials tested ranged from  $-3.0\phi$  to  $3.0\phi$ . Their Inman sorting coefficients varied from  $1.0\phi$

to  $2.9\phi$ . Permeability values for these sediments was found, in general, to be related to median grain diameter and sorting. Values averaged 807 gallons per day per square foot and ranged from 2705 to 3 gallons per day per square foot (Table 5). These values are roughly equivalent to published permeability values for sands and gravels (Todd, 1959). They may be classified as good aquifers (Todd, 1959). Field permeability values would probably be somewhat higher than those measured in the lab, due to bedding plane permeability.

A second class of highly permeable materials includes the ablation tills. As a group, they tend to be coarser textured and more poorly sorted than glaciofluvial materials. Median grain diameters for the ablation till samples tested ranged from  $-3.0\phi$  to  $-1.9\phi$ . Their sorting coefficients varied from  $1.75\phi$  to  $2.9\phi$ . Permeability values for these samples averaged 558 gallons per day per square foot and ranged from 1404 to 341 gallons per day per square foot (Table 5). Poor sorting appears to decrease permeability more for these deposits than for glaciofluvial deposits with the same median grain diameter. Ablation tills may also be classified as good aquifers (Todd, 1959).

Glacial tills exposed within the study area tend to be less permeable than either ablation tills or glaciofluvial materials. The lower permeability appears to be related to their finer texture and poorer sorting. Permeability tests were run on till samples with median grain diameters ranging from  $-2.4\phi$  to  $2.1\phi$ , and Inman sorting varying from  $2.9\phi$  to  $3.9\phi$ . These samples had permeabilities which averaged 12 gallons per day per square foot and ranged

	Laboratory coefficient of permeability, Kg, gal/day/sq ft (log scale)						*= tested sample
	.001	.01	.1	1.0	10.0	100.0	1000.0
Glacioluvial sediments			*			** ** *	* * * * *
Ablation tills						*	* * *
Basal tills						*	* * *
Glaciolacustrine or colluvial sediments	*						

Table 5. Permeability values for surficial samples in the study area

from 50 to 0.3 gallons per day per square foot (Table 5). The values correlate fairly well with published permeability data for mixtures of sand and silt (Todd, 1959). They may be regarded as poor aquifers (Todd, 1959). Because of the abundance of cobbles and boulders in glacial tills within the study area, actual permeabilities are probably lower than laboratory values.

The most impermeable materials of the study area include the glacio-lacustrine and colluvial silts and clays of lowland areas. Samples tested ranged in permeability from 0.3 to 0.004 gallons per day per square foot (Table 5). As aquifers, they may be regarded from poor to impervious (Todd, 1959).

#### Duluth Complex--Permeability

Fresh plutonic rocks generally have porosities of less than three percent. In these rocks, pores are usually not interconnected and permeabilities, therefore, are so small that for practical purposes they can be considered zero. Additional porosity and permeability is often developed through weathering and fracturing. Fractures not associated with faults produce only small increases in overall porosity, since these fractures are nearly always closed. Porosity and permeability in fractured rocks decrease rapidly with depth because of the weight of overlying rock and a decrease in weathered openings. Due to parallel orientations of fractures in plutonic rocks, permeability tends to be strongly anisotropic (Davis and DeWiest, 1966).

The weathered mantle atop the Duluth Complex is not well developed because of the short period of time since glaciation. Porosity and permeability within bedrock of the study area results primarily from joints in the Duluth Complex. Joints are relatively smooth fractures in bedrock which often result from tectonic activity. Cooper (1974), in a study on the structure of the Duluth Complex, presents joint set orientation data for bedrock in the southwest quarter of the Gabbro Lake quadrangle. Joint sets consist of populations of joints which are parallel to each other. Although the number and orientation of joint sets varies slightly between lithic units, two trends predominate. These trends have bearings of northeast to north-northeast and west to west-northwest.

Surface lineaments were also mapped within the study area (Cooper, 1974). These lineaments, mapped from air photos, represent surface linear features such as streams and topographic alignments (Fig. 21). Nearly all lineaments in the southwest quarter of Gabbro Lake quadrangle trend in a northeasterly direction. The subsurface cause of these features is not known, but it is believed to be the result of faults and contacts between rocks of slightly different lithologic character (Cooper, 1974). Along transects perpendicular to major lineaments, joint spacing was found to decrease toward these features. Joint spacing in the area varies from less than one foot near lineaments to greater than five feet away from the features (Cooper, 1974).

Fracture trace analysis, using aerial photographs, is recognized as an important hydrogeologic exploration tool in areas of igneous bedrock

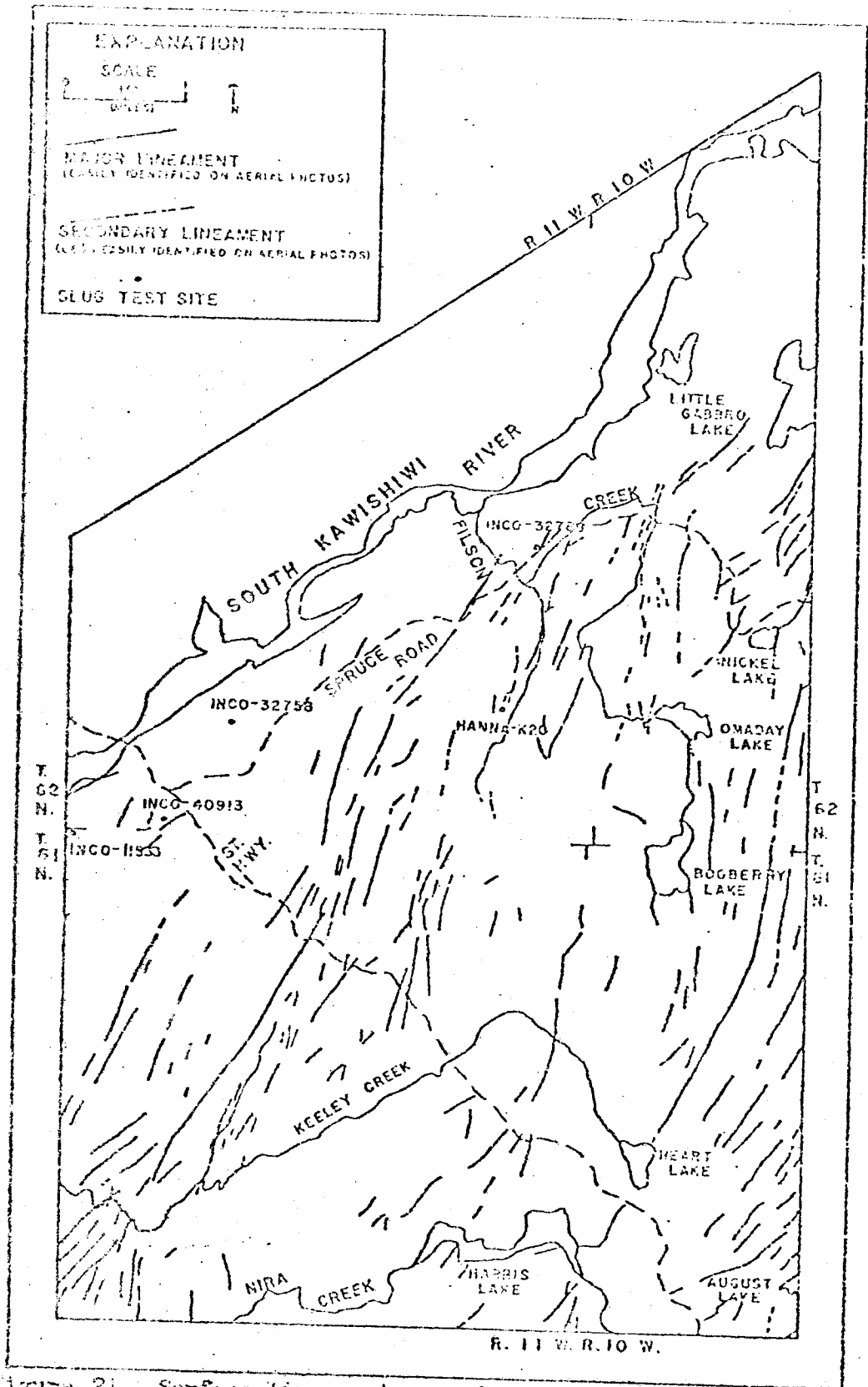


Figure 21. Surface lineament map of the Diluth Complex portion of Gabbro Lake quadrangle (S.W.  $\frac{1}{4}$ ), showing slug test locations (partially adapted from Cooper, 1974)

(Setzer, 1966). Fractures, recognizable on air photos, often overlie fault-fracture systems. These fault-fracture systems generally contain rock more permeable than in non-fractured areas (Setzer, 1966).

Five bedrock permeability tests were performed in the Gabbro Lake quadrangle to test the relationship of bedrock permeability to the site's proximity to lineaments. These tests were run on copper-nickel exploratory drill holes. These holes, drilled to varying depths, are cased through the overburden (Wager, written communication). The tests, termed slug tests, yield a transmissivity value for an aquifer by observing the decline in head in a well after a known volume of water is injected into it. Field methods included those described by Ferris and Knowles (1963). Data was analyzed according to the procedure outlined by Cooper, Bredehoeft and Papadopoulos (1967).

Slug tests estimate the transmissivity of water bearing materials in close proximity to the well. Dividing by the uncased length of the hole yields an average value of permeability. The method assumes a confined, isotropic, medium tapped by a fully penetrating, fully developed well (Cooper, Bredehoeft and Papadopoulos, 1967). Although these assumptions are not fully met by the copper-nickel test holes, hydraulic conductivity values obtained by the method should serve as rough estimates of the bedrock surrounding each hole. Test data for the five slug tests is summarized in Table 6. Test hole locations are shown on Fig. 21.

In general, bedrock permeability appears to be inversely related to the wells distance from a mapped lineament. Because of its great depth,

Well Number	Transmissivity (gal./day/ft.)	Uncased Depth of Well Penetration (ft.)	Permeability (gal./day/ft. <sup>2</sup> )	Distance to Nearest Linear Feature (miles)
INCO # 32786	1113.0	359	3.1	0.03
HANNA #K-20	104.7	250	0.4	0.05
INCO #40913	8.1	2785	0.003	0.05
INCO # 11533	117.1	1300	0.09	0.2
INCO # 32758	21.5	1250	0.02	0.7

Table 6. Slug test data--Copper-nickel test holes (test locations given in figure 19)

permeability values in INCO #40913 may be too low, since joints, at depth are probably closed. Rocks within major linear features may be significantly more permeable than in adjacent areas. The increase in permeability may be related to a decrease in joint spacing. Linear features, therefore, may be optimal sites for bedrock ground-water development. Conversely, they may be areas in which ground-water pollution hazards associated with copper-nickel development are greatest.

The permeability of Duluth Complex bedrock is low. Slug test data for all five sites falls in the poor to impervious aquifer ranges (Todd, 1959). High-capacity ground-water development from Duluth Complex bedrock is probably not possible.

#### Ground-Water Fluctuations

Static ground-water levels were continuously monitored from August 1, 1975 to July 31, 1976 in International Nickel Company's (INCO) hole #32786. This copper-nickel exploration hole, cased through overburden to a depth of 12 feet, is 250 feet deep (Wager, written communication). Water levels, measured in this hole, represents the composite potential of ground-water in the area to a depth of 250 feet, assuming joints are open to this depth. The hole is located in the Gabbro Lake quadrangle and within International Nickel's proposed mine-site (NW 1/4, SW 1/4, Sec 24, T62N, R11W). Monitoring was accomplished with a Leopold-Stevens recorder equipped with a Keck adaptor.

Because of cold weather and vandalism, parts of the record are incomplete.

Precipitation data from a standard eight inch rain gauge, located about one mile from the recorder, was provided by the United States Forest Service (Berrisford, written communication). Ground-water fluctuations and precipitation amounts are shown in Fig. 22. Ground-water fluctuations in INCO well #32786 changed slightly more than two feet during the recorded period. Lows occurred during late August and before the spring thaw in late March. High levels, in early April, correspond with the spring thaw.

Because of monthly or bi-monthly precipitation records, the lag time between precipitation events and ground-water levels are difficult to determine. This lag, however, appears to be on the order of one-half to one month as evidenced by high ground-water levels which occur after precipitation events in September, November and late May through early June.

#### Water Surface Contour Map--Gabbro Lake Quadrangle, SW 1/4

In order to delineate a water surface map of the Duluth Complex portion of the Gabbro Lake quadrangle (SW 1/4), 23 observation wells were monitored from July, 1975 to August, 1976. Ten of these observation wells are copper-nickel exploration holes. These holes in the Duluth Complex, are cased through overburden. The rest, sand points in surficial materials, were installed by either the United States Geological Survey or the author. In addition to observation wells, surface water bodies were used as an

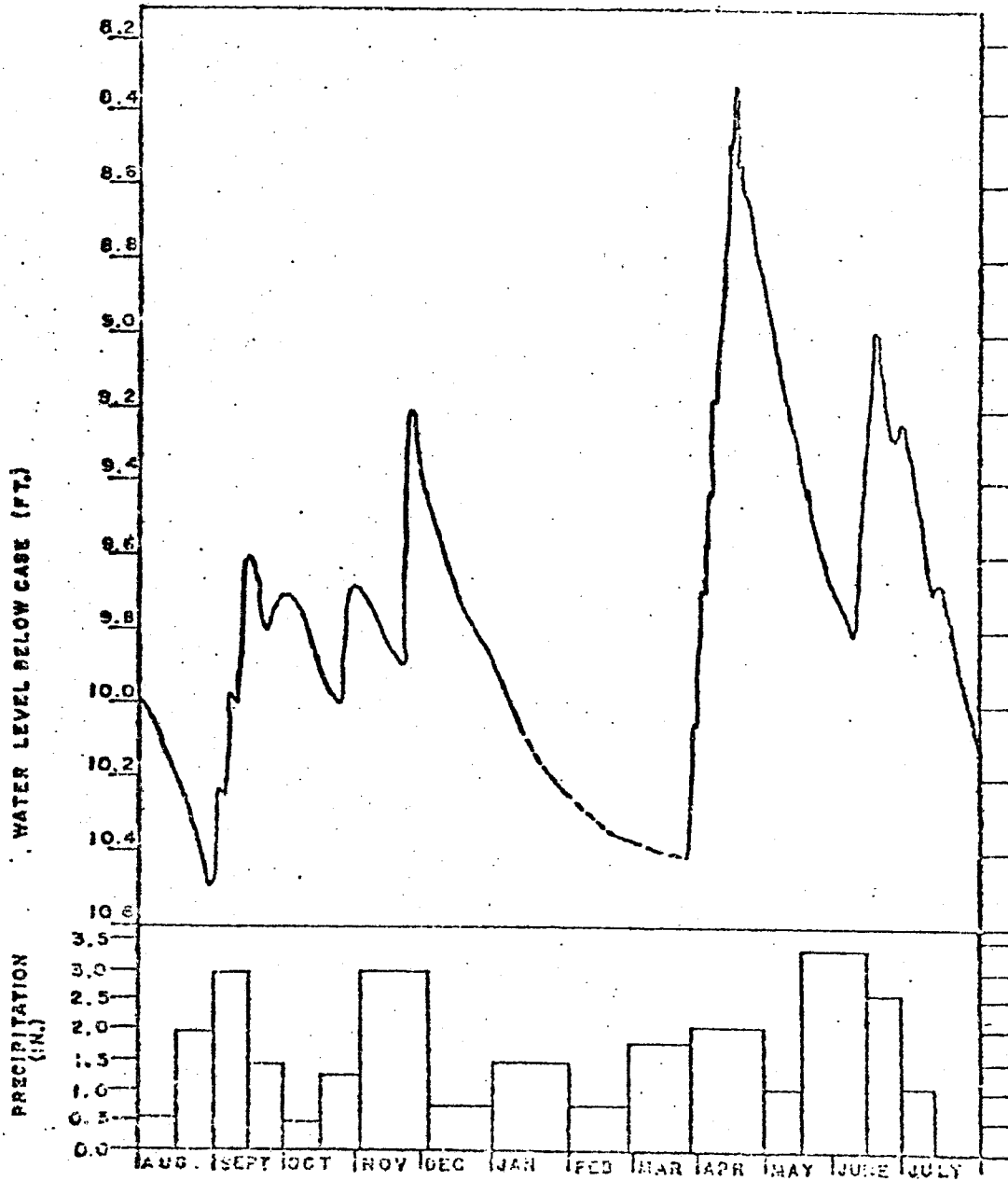


Figure 22. Precipitation (Berrisford) and ground-water fluctuations in INCO hole # 32786 during 1975 and 1976

expression of the water table. Well locations, depths, elevations and water levels are contained in Appendix D and E.

Because some of the observation wells are open to depth in the Duluth Complex, water levels in these holes represent a composite potentiometric surface. Water levels in these holes, therefore, may be slightly different from a true water table water level.

Surficial materials in the Gabbro Lake quadrangle are thin and discontinuous. Topographic highs are generally composed of exposed bedrock, till, ablation till and occasional ice-contact deposits. These surficial materials are generally quite permeable. In most cases, the top of the water table in these high areas lies within the bedrock.

The lowlands typically consist of peat which overlies glaciolacustrine or colluvial silts and clays. The water table in these lowland areas is usually near the surface. The surficial deposits of lowland areas are quite impermeable.

The underlying bedrock also appears to be fairly impermeable. Slug test permeability data indicates that Duluth Complex rock types have permeabilities on the same order of magnitude as the lowland surficial materials. An exception may exist in some of the fractured lineaments. The surficial materials and bedrock aquifers appear to be in full hydraulic connection. Flow paths in the Duluth Complex, however, are probably dependent on joint patterns. The two major joint sets (Cooper, 1974) are roughly parallel and

perpendicular to stream valleys. Streams appear to generally be aligned with the northeast trending joint sets.

Plate 3 shows a general water surface map for the Duluth Complex portion of Gabbro Lake quadrangle (S.W. 1/4). The water surface map shows typical effluent stream conditions. Ground-water basins appear to coincide with surface water basins. Ground-water divides are definable around the Nickel, Filson, Keeley, and Nira Creek basins. Ground-water gradients of ten to twenty feet per mile are typical of the area. An exception lies in the area immediately south of the Kawishiwi River. Due to low permeabilities, ground-water velocities are probably quite low. Ground-water contributions to streams are probably quite small, due to the low permeability of geologic materials in the area. Streamflow, therefore, could be expected to vary greatly with precipitation, at least in smaller streams. The "flashy" nature of these streams may be modified, to some extent, by their typical low gradients.

#### Ground-Water Geology--Conclusions

1. Surficial materials within the study area exhibit a wide range of permeabilities (from 0.004 to 2705 gallons per day per square foot).
  - a. Highly permeable materials include glaciofluvial and ablation till deposits (permeabilities averaging 807 and 558 gallons per day per square foot, respectively).

- b. Glacial till deposits generally are of moderate permeability (averaging 12 gallons per day per square foot).
  - c. Surficial materials of low permeability include glaciolacustrine and colluvial deposits (permeabilities from 0.3 to 0.004 gallons per day per foot square).
2. Although permeability values for Duluth Complex rocks are low, they appear to be related to surface lineament proximity.
  3. Ground-water levels in Duluth Complex rocks appear to lag one-half to one month behind precipitation events.
  4. In the Gabbro Lake quadrangle (SW 1/4), ground-water basins coincide closely with surface water basins.

## GEOLOGICAL PLANNING

### Introduction

In order to plan efficient and environmentally sound developments, planners and engineers must be aware of a wide variety of factors. Geologists should play an important role in any planning process. Geology is essential in the design of water supply, pollution control, foundation design and the acquisition of construction materials. This section is designed to describe, in general, some of the geological potentials and hazards associated with the study area. Actual development will require detailed, site-specific, geological investigation. Table 7 is intended to show, in general, some of the hazards and potentials associated with surficial materials in the study area.

### Ground-Water Resource Potential

The potential for high-capacity ground-water development within the entire study area is probably not good. Extensive aquifer systems do not exist. Presently, ground-water usage is limited to a small number of domestic wells.

Duluth Complex rocks are probably not good sources of ground water. Slug test data suggest that these rocks be classified as impervious to poor aquifers (Todd, 1959). Exceptions may lie in fault-fracture systems underlying surface lineaments. Rocks in these areas may be permeable enough to

	Duluth Complex bedrock	Basal tills	Ablation tills	Glaciofluvial sediments	Swamp and bog deposits
Ground-water development potential	L*	M	H	H	L
Ground-water pollution hazard from mining impoundment sites	L*	M	H	H	L
Ground-water pollution hazard from septic absorption fields	H	M	H	H	H
Ground-water pollution hazard from sewage lagoons	H	M	H	H	H
Ground-water pollution hazard from sanitary landfills	H	M	H	H	H
Aggregate resource potential	L	L	M	H	L
Fill resource potential	L	L	M	H	L
Soil erosion potential	L	H**	M	M	L

\* except in fractured areas

\*\* particularly hazardous on steep topography

L = low

M = moderate

H = high

Table 7. Hazards and potentials associated with surficial materials  
in the study area

yield large amounts of water to wells.

In most cases, surficial materials within the study area are not good sources of ground water. They tend to be either thin, of low permeability or unsaturated. An exception lies in the basin of Glacial Lake Dunka (Babbitt NE Quadrangle). Geologically, this basin consists of glaciofluvial sands and gravels which overlie glaciolacustrine silts. Limited auger data indicates that an average of about 20 feet of these glaciofluvial materials are saturated. Their permeabilities fall in the good aquifer range (Todd, 1959). The ground-water basin probably coincides with the southern part of the Dunka River drainage basin, an area of 53 square miles (Cotter, Young, Petri and Prior, 1965b). The basin is geologically similar to the area from which Babbitt obtains its water supply. A municipal well at Babbitt is capable of pumping 1.5 million gallons per day (Cotter, Young, Petri and Prior, 1965b). The basin of Glacial Lake Dunka is considered a likely source for large-scale ground-water development (Cotter, Young, Petri and Prior, 1965b).

A second area of potential ground-water development lies in the Sand River--Story Lake region (Greenwood Lake Quadrangle). Although auger data do not exist, the area appears to be filled with extensive sand and gravel deposits. The ground-water basin appears to coincide with the Sand River drainage basin. Ground-water appears to move toward the river.

Finally, the area underlain by red, sandy till and ablation till may be a possible site for extensive ground-water development (Greenwood Lake

Quadrangle, NE 1/4). The area is apparently underlain by thick, coarse textured glacial drift. Numerous kettle lakes are indicative of a fairly high water table. Ground water appears to move toward the Stony River.

Within the study area, high capacity ground-water development will probably be restricted to a few small areas. Surface waters will have to be relied on heavily. In general, surface water quality in northeastern Minnesota is better than ground-water quality (Cotter, Young, Petri and Prior, 1965a). Dissolved-solids in surface and ground water average about 100 ppm and 230 ppm, respectively (Cotter, Young, Petri and Prior, 1965a). The most common constituents of both ground and surface waters include calcium, magnesium, and bicarbonate (Cotter, Young, Petri and Prior, 1965a).

#### Ground-Water Pollution Potential

Important ground-water aquifers are a scarce and valuable resource within the study area. Aquifers that exist are limited in size and must be managed in a way that doesn't degrade water quality or quantity. Since these aquifers are unconfined and composed of permeable material, pollutants from the surface could quickly and easily reach the saturated zone.

The degree of bedrock fracturing associated with lineaments atop the Duluth Complex should be fully investigated. If these fault-fracture systems exist, they may serve as channels for rapid ground-water flow from sources of pollution to surface waters. Attempts should be made to locate potential sources of ground-water pollution away from surface lineaments.

In the event that copper-nickel development occurs in northeastern Minnesota, environmentally safe impoundment sites will need to be found. Impoundments will be needed to contain waste rock, tailings and leachate used in secondary recovery processes. These sites must be located in areas which minimize the movement of harmful constituents into ground and surface waters.

Impoundment sites should be located as far as possible from existing bodies of surface water. In addition, the permeability of rocks associated with surface lineaments needs to be examined. These lineaments may overlie highly fractured rocks which could serve as channels for ground-water flow. If these fracture systems exist, impoundments should be located as far as possible from them.

Impoundment sites should not be located atop important surficial aquifers. The region north of the Vermilion moraine seems most favorable, since flow systems in that region are generally contained in impermeable surficial materials or bedrock. Swamp and bog deposits, probably areas of ground-water discharge, seem to be optimal locations for impoundment sites. These areas are generally underlain by glaciolacustrine or colluvial silts and clays. The low permeability of these materials would tend to localize and slow the spread of unfavorable constituents in ground-water. In addition, clay minerals contained in these deposits have the capacity to absorb undesirable ions.

Surface impoundments are usually contained within earth dams. These structures are constructed with impermeable cores and permeable shoulders. The cores minimize water loss through seepage. Shoulders, constructed of materials with high shear strength and compactibility, support the structure and reduce piping. Glaciolacustrine and colluvial deposits appear to be easily obtainable core materials. Shoulders could be constructed from till, sand and gravel, or rock. Elongate bedrock ridges, which commonly surround lowland areas north of the Vermilion moraine, may also be suitable for impoundment berms. If the permeability of rocks within these ridges is found to be low, they would make excellent dams. Fracture grouting may be necessary in bedrock with large amounts of secondary porosity.

The ground-water surface map of Gabbro Lake quadrangle (SW 1/4) is general in nature (Plate 3). It is intended to show ground-water divides and directions of ground-water flow. In the event that impoundment sites are needed, extensive field and laboratory tests should be conducted within site-specific areas.

#### Domestic Waste Disposal

The development of a copper-nickel industry will bring large numbers of people into northeastern Minnesota. People produce waste products, and the disposal of these wastes will become a problem. Domestic wastes may be disposed of in a number of ways. Sewage from individual homes in rural areas is often disposed of through septic tank absorption systems. Municipal

sewage is treated by a variety of methods. One method, which involves soils, is through bacterial decomposition in sewage lagoons. Solid waste is commonly disposed of in sanitary landfills. The implementation of any of these systems will require detailed, site specific, geologic evaluation.

### Septic Absorption Systems

Septic tank absorption fields are subsurface systems of perforated pipe or tile which transfer sewage effluent from a septic tank to the soil. Impermeable soils do not transmit sewage away from the system quickly enough. Ground-water pollution may result from rapid percolation through very permeable soils. Clay, in minor amounts, is desirable because clay minerals have good absorption properties. Shallow bedrock and high water table conditions limit the volume of the absorbing soil. Steep slopes are undesirable because of the problems associated with excavation, erosion, lateral seepage and downslope flow (U.S.D.A., 1974).

Generally, soil materials within the study area are not well suited for septic systems. Lowland soils are undesirable because of high water tables. Soils developed on glacial tills present steep slope, shallow bedrock and excavation problems. Septic system potential in glaciofluvial soils vary from slight to severe, depending on local slopes. Because of their high permeabilities, however, ground-water pollution hazards are high (U.S.D.A., 1974). Septic system evaluation should be conducted on a site-specific basis.

### Sewage Lagoons

Sewage lagoons are shallow ponds designed to hold sewage long enough for the decomposition of solids by bacteria. These lagoons have nearly level floors, with embankments of compacted soil. High permeability, high organic content, steep slopes, poor compactibility and shallow water tables are limiting soil factors (U.S.D.A., 1974).

Soils within the study area are, in general, poorly suited for sewage lagoons. Soils formed in lowlands are limited by shallow water tables and high organic matter content. Soils whose parent materials are glacial till are unfavorable because of shallow bedrock and steep slopes. Glaciofluvial soils are limited by their high permeabilities (U.S.D.A., 1974).

### Sanitary Landfills

Sanitary landfills dispose of solid waste by spreading waste materials in trenches, compacting it and then covering the material with soil (U.S.D.A., 1974). Landfills located in ground-water recharge zones should be sited on soils with moderately slow permeabilities which are spatially separated from the saturated zone by large distances. Those located near surface water bodies should be built on impermeable soils. In addition, soils must be able to withstand traffic and be easy to excavate.

Lowland soils are limited by high water tables and an inability to withstand traffic. Soils whose parent materials are glacial till are undesirable, within the study area because of shallow bedrock, steep slopes,

and difficulties involved with excavation. Glaciofluvial soils are severely limited because of their high permeabilities (U.S.D.A., 1974).

### Sand and Gravel Resources

Sand and gravel are necessary for most types of construction.

Aggregate consists of high quality material used in concrete and asphalt construction. Fill, which may generally be of lower quality than aggregate, is used to establish stable foundations.

The study area contains abundant sand and gravel resources. Present uses are restricted to small-scale road construction and maintenance. Because sand and gravel have low unit value, transportation costs often exceed the value of the resource in the pit. Locating sand and gravel in close proximity to construction sites, therefore, is very important.

### Aggregate Resources

Aggregate includes crushed rock, sand and gravel used in concrete and asphalt construction. High shear strength, uniform size and low clay content (less than 3%) are desirable characteristics. Chert, shale, schist and sulfides are unfavorable rock and mineral constituents (Blyth and deFreitas, 1974). Within the study area, good aggregate resources are probably restricted to glaciofluvial deposits. These are abundant and readily available south of the Vermilion moraine. They grade laterally from sand to coarse gravel. Variability in grain size is usually quite large between beds.

A large supply of aggregate is exposed at the surface in basin of Glacial Lake Dunka. The most accessible of these deposits are located in "crevasse fill" features. Deep pits in other parts of the basin would need to be de-watered in order to be mined. North of the Vermilion moraine, cheap aggregate materials are restricted to small ice-contact features.

#### Fill Resources

Specifications for fill are generally less stringent than for aggregate. They must, however, have moderately good sheer strength and compaction properties. Fill materials are also abundant within the study area. North of the Vermilion moraine, however, large quantities of fill would be difficult to extract from a small area. Boulders and cobbles in tills and ablation tills would present mining and compaction problems.

#### Soil Erosion Potential

Soil scientists have developed a number of equations which predict potential soil erosion from a bare soil. Most commonly, the Universal Soil Loss Equation is used. This method yields a potential, average, annual, soil loss in tons per acre per year. The equation was developed statistically from test plots. The Universal Soil Loss Equation predicts gross erosion, and is only generally related to the amount of sediment delivered to streams.

The soil erodibility factor (K) of a particular soil is related to a soils texture, organic content, structure and permeability (Wischmeier, Johnson

and Cross, 1971). Soils high in silt and very fine sand are easily eroded because these particles are most easily detached by rain-drip impact. Organic matter, a soil binding agent, tends to decrease a soils potential for erosion. Soil structure is the way in which soil particles are held in aggregates. Soils with well developed structure are resistant to erosion because they have high infiltration capacities and are resistant to raindrop impact. Permeable soils yield less run-off than impermeable soils and are, therefore, less vulnerable to transport by water. The combined effect of these parameters is represented by a soils' erodibility factor (K). K values theoretically range from 1.0 for a very erodible soil to 0.0.

Potential soil erosion is also related to surface slope and rainfall intensity (Hudson, 1971). Soil erosion increases with both slope steepness and length. Erodibility is also directly proportional to rainfall intensity, but rainfall variability within a small area is insignificant.

Soil erodibility data, for soils within the study area, is available from a regional soil report (U.S.D.A., 1974). Of these soils, those developed on glacial tills are most erodible, having erodibility factors of 0.37. When compared to most natural soils, these values are quite high (U.S.D.A., 1975). High potential erodibility probably results from loamy texture, low organics and poorly developed structure. Because of their coarser texture and greater permeability, glaciofluvial soils have much lower soil erodibility factors (0.20). Erodibility data for lowland soils is not available. It is,

however, probably quite low.

Any activity which disturbs soil cover in the report area will degrade surface water quality through the introduction of sediment. Critical areas will be those in which glacial tills are exposed on steep slopes. Erosion control practices will probably be necessary.

#### Geological Planning--Conclusions

1. High capacity ground-water development will probably be restricted to a few small aquifers. Surface water will have to be relied on heavily.
2. Because of their coarse texture, surficial aquifers could easily become polluted. Fractures in the Duluth Complex may have the ability to serve as flow channels from polluted areas to surface waters.
3. Optimal impoundment sites appear to be located atop swamp and bog deposits which are enclosed by bedrock highs. Most of these sites lie to the north of the Vermilion moraine.
4. Because of soil limitations, domestic waste disposal sites will be difficult to locate.
5. Aggregate and fill materials are generally abundant and easily obtainable.
6. Soils developed on glacial tills will be subject to intense erosion if soil cover is removed. Critical areas will coincide with steep surface slopes.

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APPENDIX A. LABORATORY DATA

SAMPLE NUMBER	LOCATION				DESCRIPTION	DEPTH (FEET)	UNIT	% SAND AND GRAVEL (>.0025mm)	% SILT (.002-.0625mm)	% CLAY (<.002mm)	MEDIAN GRAIN DIAMETER (φ units)	UNIFORMITY COEFFICIENT (sorting, φ units)	% SAND (.0625-2mm)	% SILT (.002-.0625mm)	% CLAY (<.002mm)	DRY COLOR	MOIST COLOR
	1	2	3	SEC													
1	SW	SW	NW	2 60 13	CP	3	FC	97.6	2.4	0.0	0.2	2.0					
2	SW	SE	SW	33 61 12	CP	3	FC	99.9	0.1	0.0	-1.7	1.3					
3	SW	SE	SW	33 61 12	CP	8	FC	100.0	0.0	0.0	-1.9	1.5					
4	SW	SE	NE	9 60 12	CP	4	FC	99.5	0.5	0.0	-0.8	1.5					
5	NW	NE	NE	14 60 12	CP	30	FC	99.5	0.5	0.0	-0.8	1.7					
6	SW	NW	NE	11 60 12	FC	3.5	FC	99.5	0.5	0.0	-0.4	1.2					
7	EW	NW	SE	11 60 12	FC	3	BT	83.4	16.3	0.3	1.7	3.4	77.2	22.7	.1	5Y6/3	5Y4/6
8	SE	SW	SW	8 60 11	CP	4	FC	98.9	1.1	0.0	-1.5	2.5					
9	SE	NW	SE	30 61 11	FC	4	BT	85.9	13.1	0.0	1.6	3.1	81.6	18.4	0.0	2.5Y6/4	2.5Y4/2
10	SW	SW	SE	30 61 11	FC	3	BT	87.2	12.8	0.0	0.2	2.6	82.9	17.1	0.0	2.5Y6/4	2.5Y3/3
11	SW	SW	SE	30 61 11	FC	4	FC	98.6	1.4	0.0	-1.5	1.7					
12	NE	NW	NW	4 61 11	FA	10	EA	90.7	5.5	0.8	1.9	0.6					
13	SW	NW	NW	29 62 10	FA	16	FC	82.4	16.6	1.0	2.4	2.0					
14	NE	SW	NW	18 60 11	FA	10	FC	86.8	12.5	0.7	0.6	3.2					
15	NE	SW	NW	18 60 11	FA	35	FC	95.0	5.0	0.0	-0.1	2.1					
16	NW	NE	NE	14 60 12	FA	58	FC	84.5	14.8	0.7	2.0	2.0					
17	SW	SE	NE	9 60 12	FA	23	FC	96.9	2.9	0.2	0.0	1.5					
18	SW	NW	NW	13 60 12	FA	12	P										
19	SW	NW	NW	17 60 12	FA	23	FC	95.3	3.7	1.0	0.8	2.5					
20	SW	SE	NE	15 60 12	FA	60	L	7.5	86.3	6.2	6.2	1.7					
21	SW	SE	NE	15 60 12	FA	30	FC	55.8	43.6	0.6	3.6	2.0					
22	SW	NE	SW	25 60 12	FA	9	BT	67.5	28.6	3.9	2.3	3.5	61.2	34.2	4.6	5Y6/2	5Y4/2
23	NW	NE	SW	25 60 12	FA	7	FC	96.8	2.2	1.0	0.2	2.0					
24	SW	SW	SW	36 60 12	FA	9	FC	86.7	11.8	1.5	1.8	2.1					
25	NE	SW	NE	7 60 11	FA	40	FC	94.9	4.6	0.5	-0.3	2.3					
26	SW	SW	NE	18 60 11	FA	29	FC	91.7	8.3	0.0	1.6	1.8					
27	SE	SE	SE	36 61 12	FC	6	FC	96.5	3.5	0.0	0.8	2.1					
28	SE	SW	SE	7 60 11	FC	3	FC	84.6	14.1	1.0	2.1	1.7					
29	SW	NE	NE	18 60 11	FC	3.5	FC	98.7	1.3	0.0	0.0	1.1					
30	NW	NE	SE	18 60 11	FC	3	BT	80.4	19.6	0.0	2.2	2.9	75.2	24.8	0.0	2.5Y6/6	2.5Y3/4
31	SW	SE	SW	18 60 11	FC	3.5	BT	71.2	8.8	0.0	0.2	3.1	85.9	14.1	0.0	2.5Y6/3	2.5Y3/4
32	SW	NW	SE	24 60 12	FC	4	FC	94.7	4.3	1.0	0.2	2.9					
33	SW	SE	SW	35 60 12	CP	5	BT	71.5	25.9	2.6	2.1	3.1	65.3	31.7	3.0	2.5Y6/4	2.5Y3/4
34	SW	NE	SW	31 60 11	FC	3	BT	77.0	20.4	2.6	1.4	3.2	72.9	25.0	2.1	2.5Y6/3	2.5Y3/3
35	SW	SE	NW	25 60 12	FC	4	FC	96.2	3.8	0.0	-1.0	2.0					
36	SE	SW	NW	26 60 12	FC	3	BT	87.2	10.7	2.1	1.3	2.6					
37																	
38	SE	SW	NE	26 60 12	FC	4	FC	98.6	1.4	0.0	-1.3	2.4					
39	NW	SW	NE	25 60 12	FC	4	FC	95.6	3.9	0.5	0.0	1.9					
40	SW	SW	SE	23 60 12	FC	4	FC	93.1	4.7	2.2	2.3	0.9					
41	SW	NW	NE	4 60 12	FC	3	FC	93.9	3.0	3.1	-0.2	1.6					
42	NE	SE	SE	9 60 12	FC	3	BT	79.7	19.4	0.9	0.6	4.1	67.5	31.0	1.5	2.5Y6/6	2.5Y3/4
43	SW	SE	NW	15 60 12	FC	3.5	FC	98.4	1.6	0.0	0.7	1.3					
44	NW	NE	SE	16 60 12	FC	3	BA	92.5	7.5	0.0	-0.3	2.9					
45	FC	SW	FC	12 60 12	FC	4	BA	90.2	9.6	0.2	-0.6	3.6					
46	NW	NE	NE	33 60 12	CP	8	BA	96.3	3.7	0.0	-0.5	2.2					
47	SW	NE	SE	21 60 12	CP	4	FA	97.8	2.2	0.0	-1.6	2.7					
48	FC	SE	FC	21 60 12	FC	3	FC	91.7	8.3	0.0	-0.4	2.8					
49	SW	SW	SW	31 60 10	FC	3.5	BT	87.4	11.8	0.8	0.5	2.7	82.1	16.8	1.1	2.5Y6/3	2.5Y3/4
50	NW	NW	SW	31 61 10	FC	3	BT	97.2	0.8	0.0	-2.0	1.7					

NO.	LOCATION			DESCRIPTION	DEPTH (FEET)	UNIT	% SAND AND GRAVEL (<.0625mm)	% SILT (.002-.0625mm)	% CLAY (<.002mm)	NOMINAL GRAIN DIAMETER (φ units)	IMPAV FILT PERCENTAGE (sorting, φ units)	% SAND (.0625-2mm)	% SILT (.002-.0625mm)	% CLAY (<.002mm)	DRY COLOR	MOIST COLOR	
	S	E	N														
51	NE	NW	SW	1 60 11	CP	3	EC	97.9	2.1	0.0	-0.8	2.5	72.1	26.0	1.9	5Y7/3	5Y4/2
52	NE	SW	SW	2 60 11	EC	4	BT	82.5	16.4	1.1	0.4	3.9	77.6	22.1	0.3	2.5Y5/3	2.5Y4/4
53	NE	SW	NW	26 61 11	EC	3	BT	84.9	14.9	0.2	0.4	3.2					
54	SE	SW	SW	4 60 11	CP	3	BA	99.4	6.6	0.0	-1.2	1.8					
55	NW	NE	SE	8 60 11	EC	3	BT	84.6	15.4	0.0	0.8	3.7	76.2	23.8	0.0	2.5Y6/4	2.5Y4/3
56	NW	SE	SE	8 60 11	CP	5	EG	99.0	1.0	0.0	0.4	1.4					
57	NE	NE	SW	17 60 11	EC	4	EG	99.0	1.0	0.0	-1.1	2.2					
58	NW	SE	SW	16 60 11	EC	3	BT	91.7	8.2	0.1	-1.0	3.8	83.5	16.4	0.1	2.5Y5/4	2.5Y4/4
59	SW	SE	SW	16 60 11	EC	3	BT	84.3	13.6	2.1	-2.0	5.8	64.3	31.0	4.7	2.5Y5/4	2.5Y4/4
60	SE	NW	SW	11 60 11	EC	3	EG	84.1	13.5	2.4	1.2	3.6					
61	NW	SE	SE	32 60 11	EC	3	BT	89.7	10.3	0.0	-0.6	3.7	80.7	19.3	0.0	10YR5/4	10YR3/3
62	SE	NE	SE	2 59 11	EC	3	BT	71.3	25.3	3.4	2.3	4.3	57.1	37.8	5.1	2.5Y5/4	2.5Y3/3
63	SW	SW	NE	32 60 10	EC	4	BT	87.9	10.4	1.7	-0.4	3.8	78.2	18.8	3.0	2.5Y6/3	2.5Y4/3
64	SW	NW	SW	5 59 10	EC	4.5	EC	81.1	18.0	0.9	1.3	3.1					
65	SE	SW	SS	29 60 10	EC	3	EG	98.8	1.2	0.0	-2.7	1.7					
66	NW	SE	NE	28 60 10	EC	3	EG	98.5	1.5	0.0	0.4	1.8					
67	NW	S4	SW	16 60 10	CP	20	EG	96.2	3.8	0.0	-0.6	2.3					
68	NE	NE	SW	16 60 10	EC	3	EG	74.5	22.7	2.8	0.2	4.2					
69	NE	NW	NW	17 60 10	CP	3	EG	99.9	0.1	0.0	-3.0	1.0					
70	NW	SW	NW	8 60 10	EC	4	BT	88.3	10.8	0.9	-0.3	3.4	79.9	18.5	1.6	2.5Y6/3	2.5Y4/2
71	NE	SE	NE	11 60 11	EC	5	BA	99.6	0.4	0.0	-1.8	2.4					
72	SE	SE	SE	25 60 10	EC	3	RT	85.0	13.9	1.1	-0.1	3.7	74.8	23.3	1.9	7.5YR5/2	7.5YR4/3
73	SW	SE	NE	1 59 10	EC	3	BT	84.0	14.8	1.2	0.4	4.0	78.9	19.5	1.6	2.5Y5/6	2.5Y4/3
74	NE	SE	SW	32 60 9	EC	3.5	RT	75.5	22.5	2.0	1.6	2.9	69.9	27.7	2.4	10YR5/3	10YR3/3
75	NE	SE	SW	25 60 10	CP	7	BA	95.2	4.5	0.3	0.2	3.5					
76	NE	SE	NW	29 61 9	EC	5	BA	97.9	2.1	0.0	-2.0	2.9					
77	SW	SE	NW	32 61 9	EC	3	EG	82.7	17.3	0.0	3.4	0.9					
78	NW	SE	SE	1 60 10	EC	3.5	EA	96.4	3.6	0.0	-0.7	1.8					
79	SW	NE	NW	7 60 9	EC	3	EA	97.8	2.2	0.0	-1.5	2.4					
80	SW	NE	SE	13 60 10	EC	4	RT	83.6	15.4	1.0	1.0	3.4	76.9	21.8	1.3	10YR5/3	10YR4/4
81	NW	NW	NW	22 59 8	EC	3	RT	66.5	29.7	3.8	2.0	3.9	72.4	24.5	3.1	10YR5/3	10YR4/3
82	NW	NW	SE	20 60 9	EC	4	RT	65.3	32.7	2.0	2.4	3.9	53.0	44.4	2.6	10YR5/3	10YR4/4
83	SE	SE	NW	25 60 10	EC	3	RT	78.7	19.4	1.9	1.5	3.5	70.7	25.7	2.6	10YR6/4	10YR3/2
84	NE	SW	NE	23 60 10	EC	3	BA	95.5	4.5	0.0	-1.2	2.5					
85	NW	SW	NW	14 60 10	EC	4	BA	95.6	3.9	0.5	-1.9	2.2					
86	SE	NW	SW	2 60 10	EC	3.5	BT	91.7	8.2	0.1	-0.4	3.1	85.7	14.2	0.1	2.5Y6/4	2.5Y4/3
87	SW	NE	SE	4 60 10	EC	3	EG	98.8	1.2	0.0	-1.8	2.3					
88	SW	NW	SW	4 60 10	EC	3.5	BT	81.5	17.9	0.6	0.3	4.1	69.8	29.1	1.1	2.5Y6/3	2.5Y4/2
89	NW	SE	NE	23 60 10	EC	5	EG	95.8	3.2	0.0	1.0	1.8					
90	NW	NE	NW	36 60 10	EC	3	RT	91.6	5.3	0.1	-2.4	3.8	83.7	16.1	0.2	10YR5/2	10YR4/3
91	NW	NW	NW	27 60 10	EC	4	BT	89.7	9.9	0.4	3.2	4.2	87.2	12.3	0.5	10YR5/3	10YR4/3
92	NW	SW	NW	23 60 9	EC	4	EA	97.0	3.0	0.0	-1.2	2.3					
93	NW	SW	NE	23 60 10	EC	4	BA	96.3	3.7	0.0	-1.3	1.6					
94	NW	SW	NW	10 60 12	EC	4.5	BT	83.4	15.7	0.9	0.8	2.8	79.1	19.7	1.2	10YR4/3	10YR2/2
95	NW	S4	NW	10 60 12	EC	3.5	EC	92.6	6.2	1.2	0.1	2.5					
96	NW	SW	NW	10 60 12	EC	2.5	BT	77.7	22.3	0.0	2.2	2.4	89.7	10.3	0.0	2.5Y6/2	2.5Y4/1
97	NE	SW	NE	10 60 12	CP	7	EC	97.5	2.1	0.3	-0.6	2.0					
98	SE	NW	S4	24 60 11	EA	6	L	37.9	46.1	16.0	6.4	5.1					
99	SE	NW	SE	25 60 10	EC	4	BA	97.0	3.0	0.0	-1.9	1.6					
100	NW	SE	SE	15 60 10	EC	3	BT	92.0	7.1	3.0	-0.6	3.4	89.3	10.7	0.0	2.5Y6/3	2.5Y4/2

SAMPLE NUMBER	LOCATION						DESCRIPTION	DEPTH (FEET)	UNIT	% SAND AND GRAVEL ( $\phi$ -.0625mm)	% SILT (.002-.0625mm)	% CLAY (<.002mm)	MEDIAN GRAIN DIAMETER ( $\phi$ units)	INCHAN FILL DEVIATION (sorting, $\phi$ units)	% SAND (.0625-.2mm)	% SILT (.002-.0625mm)	% CLAY (<.002mm)	DRY COLOR	MOIST COLOR
	+	+	+	SE	T	R													
Mn-101	SW	SW	NW	16	61	10	RC	3.5	BA	91.8	8.0	0.2	1.0	2.6					
102	NW	NW	SE	8	61	10	RC	3	BT	75.4	20.3	4.3	0.5	3.8	62.0	31.3	6.7	2.5Y6/4	2.5Y3/2
103	NW	NE	NW	31	61	10	RC	4	BT	83.0	11.6	0.4	0.7	2.8	83.2	16.3	0.5	2.5Y5/2	2.5Y3/2
104	NW	SW	NE	30	61	10	RC	3	EC	99.0	1.0	0.0	0.4	1.6					
105	SW	SW	SW	10	61	11	RC	3	BT	90.5	9.5	0.0	0.8	2.9	86.4	13.6	0.0	10YR6/4	10YR4/3
106	SW	SW	NW	16	61	11	RC	3	BA	99.9	0.1	0.0	-3.8	1.0					
107	NW	NW	SW	9	61	11	CP	4	EC	92.5	7.5	0.0	0.0	1.6					
108	NW	NW	SW	32	62	10	RC	3	BT	80.3	17.1	2.6	1.2	4.2	62.7	32.8	4.5	2.5Y6/3	2.5Y4/2
109	SW	NE	SE	19	62	10	RC	3	BA	99.1	0.9	0.0	-3.8	1.9					
110	SW	SE	SW	24	62	11	RC	3	BT	86.6	10.2	3.2	-1.0	3.6	72.9	20.6	6.5	2.5Y5/3	2.5Y4/2
111	NW	SE	SW	18	61	10	RC	3	BT	83.6	9.9	1.5	0.0	3.7	80.7	16.9	2.4	2.5Y6/2	2.5Y4/1
112*	NE	NE	NW	30	57	11	RC	3	TT	77.7	21.3	1.0	1.4	3.3	69.9	28.7	1.4	10YR5/3	10YR3/2
113	NE	SW	SW	25	60	10	RC	3	BT	83.2	15.8	1.0	0.8	3.4	75.3	23.3	1.4	10YR5/3	10YR4/3

\*--Sampled from outside study area

CP-Gravel pit

RC-Read out

EA-fover auger

HA-Hand auger

MF-Mine face

RC-Glaciofluvial sediments associated with red, sandy till

RC-Glaciofluvial sediments associated with bouldery till

RT-Red, sandy till

BT-Bouldery till

TT-Till from Total drumline

BT-Bouldery pit till

RA-Red, sandy, ablation till

BA-Bouldery, ablation till

L-Glaciolacustrine or colluvial sediments

P-Peat





Sample number	Gabbro <sup>o</sup>	Granophyre	Granitic	Foliated*	Basalt*	Diabase	Volcano-clastic	Siltstone	Graywacke	Quartz arenite	Dark plutonic	Schist	Greenstone	Taconnite	Dacite	Gneiss	Quartz	Slate	Chert	Shale	Arkose**	Agate*	Unidentified	Total
Red, sandy, glaciofluvial sediments																								
Mn-1	14	8	4	39	12	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	1	88
2	13	-	16	31	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	66
3	3	-	21	21	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	53
4	37	2	3	35	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	91
8	58	3	4	53	15	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	135
14	94	5	11	27	16	4	-	2	2	-	-	-	-	-	-	-	-	-	2	-	-	-	-	163
15	71	5	18	61	30	6	1	-	-	-	4	-	1	-	-	-	-	-	-	-	-	-	-	177
17	14	6	11	19	6	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	58
19	35	1	13	10	9	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	73
21	9	10	16	31	19	-	-	1	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	88
23	28	5	2	41	13	3	-	2	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	97
24	111	7	40	44	24	7	-	3	2	-	-	-	4	-	-	-	-	-	-	-	-	-	-	202
25	40	3	3	19	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	75
26	39	2	9	19	6	4	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	82
28	27	1	1	13	5	3	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	53
32	20	3	3	42	5	1	-	-	3	1	2	-	-	-	-	-	-	-	-	-	-	-	-	74
35	3	7	3	39	7	-	-	-	3	1	2	-	-	-	-	-	-	-	-	-	4	1	-	71
38	12	21	16	64	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	136
39	16	11	7	52	9	16	-	6	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	112
40	5	4	6	25	5	-	3	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	51
41	42	15	44	41	7	5	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	1	-	160
43	11	13	9	29	8	-	-	-	-	-	1	-	-	-	-	-	-	1	-	1	2	-	-	75
48	19	11	18	27	7	6	-	6	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	95
57	40	2	17	49	21	5	-	6	-	-	-	-	2	-	-	-	-	2	-	-	-	-	-	144
64	24	5	5	6	10	-	2	2	4	-	-	-	-	-	-	-	-	-	1	-	-	-	-	52
66	13	9	10	20	14	2	2	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	72
67	169	16	16	18	18	8	-	1	4	-	-	-	1	-	-	-	1	-	-	3	-	-	-	235
68	13	6	4	32	11	8	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	77
69	62	13	9	63	15	3	1	6	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	171
77	22	3	9	12	10	4	-	-	2	-	-	-	-	-	-	-	-	-	-	-	2	-	-	64
83	28	2	2	12	3	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	4	-	-	53
97	13	7	5	18	3	2	-	7	-	-	-	2	-	-	1	-	-	-	-	1	3	-	-	62
Total till																								
Mn-112	6	7	7	13	13	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	50
Dunker pit till																								
Mn-2*	5	-	1	-	-	-	-	-	22	-	-	10	11	-	-	-	1	-	5	-	-	-	-	56
Swamp and bog deposits																								
Mn-96*	3	-	45	-	-	-	1	1	1	-	1	-	10	-	-	-	24	-	-	-	-	-	-	93
20*	6	-	10	1/2	4	4	-	4	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	50

\* - 1 - C†  
 † Includes all Duluth Complex rock types except granophyre  
 \*\* Excavator indicator rocks

## APPENDIC C. POWER AUGER DRILL LOGS

H1\* (NW,NW,25,62,11)

0 - 6 Silty clay, sandy to stoney,  
green  
6 - 49.5 Silty clay, sandy to stoney,  
gray  
49.5 Bedrock

H2\* (NW,NW,25,62,11)

0 - 3 Fill, sandy  
3 - 4.5 Feat  
4.5 - 6.5 Silty clay, sandy to stoney,  
organic matter  
6.5 Bedrock

H3\* (NW,NW,25,62,11)

0 - 0 Fill  
5 - 12 Silty clay, sandy to stoney,  
green  
12 Bedrock

H4\* (NW,SW,34,62,11)

0 - 2 Fill  
2 - 13 Sand, coarse to very fine,  
much silt  
10 Bedrock

H5\* (NW,SW,11,61,11)

0 - 4 Fill  
4 - 6 Silty clay, sandy, green  
6 - 7 Silty clay, sandy, brown  
7 Bedrock

H6\* (NW,SW,4,61,11)

0 - 2 Sand, medium grained  
2 - 12 Sand, coarse to medium  
grained, some pebbles  
12 - 18 Sand, coarse grained, some  
pebbles  
18 - 19 Gravel  
19 Bedrock

H7\* (NE,NW,4,61,11)

0 - 2 Fill  
2 - 3 Feat  
3 Bedrock

H8\* (SE,NW,19,61,11)

0 - 3 Silty clay, sandy, brown to  
yellow  
3 - 4 Silty clay, gravelly  
4 Bedrock

H9\* (NE,NE,14,60,12)

0 - 3 Sand, coarse to medium  
3 - 7 Silt, very sandy, green to  
black  
7 - 20 Silt, sandy to gravelly,  
poorly sorted green to gray  
20 - 69 Silt, sandy, green to gray  
69 Bedrock

H10\* (SE,NW,14,60,11)

0 - 18 Feat and muck, brown to  
black, some sand  
18 Bedrock

H11\* (SE,NW,14,60,11)

0 - 1 Fill  
1 - 2 Silt, clayey  
2 - 3 Gravel, silty  
3 Bedrock

H12\* (SE,NW,14,60,11)

0 - 38 Pea gravel, with coarse to  
medium grained sand  
38 Bedrock

H13\* (SE,NW,23,60,12)

0 - 7 Sand, coarse grained, some  
pebbles  
7 - 17 Sand, medium to fine grained  
17 - 27 Sand, fine to very fine  
grained  
27 - 47 Silt

H14\* (SW,SW,14,60,12)

0 - 33 Sand, medium to coarse  
grained, some pebbles  
33 - 42 Sand, medium to fine grained  
42 - 58 Silt, some sand  
58 Bedrock

H15\* (SE,NE,15,60,12)

0 - 2 Feat and muck, some sand  
2 - 22 Sand, coarse to medium  
grained, some pebbles  
22 - 25 Silt and muck  
25 - 47 Sand, medium to coarse  
grained

H16\* (NW,SW,15,60,12)

0 - 3 Gravel, sandy  
3 - 6 Sand, medium to fine grained  
6 Bedrock

H17\* (NW,SW,15,60,12)

0 - 10 Sand, medium to fine grained  
10 Bedrock

H20\* (NW,NE,9,60,12)

0 - 4 Fill  
4 - 15 Sand, very fine grained to  
silt  
15 Bedrock

H21\* (SE,SW,26,60,10)

0 - 6 Silt, sandy to pebbly, brown  
6 - 11 Gravel  
11 Bedrock

H22\* (SW,SW,8,60,11)

0 - 22 Pea gravel, some coarse  
grained sand

H23\* (NW,SW,29,62,10)

0 - 2 Silty clay, sandy and stoney  
2 - 5 Gravel, with coarse sand  
5 - 6 Silty clay, sandy and stoney  
6 Bedrock

H24\* (SW,SW,29,62,10)

0 - 5 Silty clay, sandy, some  
pebbles  
5 Bedrock

H25\* (SE,SW,29,62,10)

0 - 14 Silty clay, sandy, with some  
pebbles and organic material  
14 Bedrock

H26\* (SW,NW,29,62,10)

0 - 1 Fill  
1 - 2 Feat  
2 - 9.5 Silty clay, sandy  
9.5 Bedrock

H27\* (SE,NE,10,61,11)

0 - 6 Silty clay, sandy, brown  
to yellow  
6 - 10 Silty clay, sandy with  
pebbles, red  
10 Bedrock

H28\* (NW,SW,11,61,11)

0 - 2 Fill  
2 - 3 Feat  
3 - 10 Clay, gray  
10 Bedrock

H29\* (NE,NE,15,61,11)

0 - 12 Feat  
12 - 13 Clay, gray, sandy  
13 Bedrock

H30\* (SW,SE,10,61,11)

0 - 2 Fill  
2 - 5 Feat, clayey  
5 Bedrock

H31\* (SE,SW,10,61,11)

0 - 2 Fill  
2 - 8 Feat  
8 - 13 Feat and clay, gray  
13 Bedrock

B-1 (SE, SW, 10, 61, 11)

0 - 2 Fill  
 2 - 6 Peat and clay, black  
 6 - 12 Silty clay, sandy and stoney  
 12 - 17 Sand, silty and sandy  
 17 Bedrock

B-2 (SW, NE, 10, 61, 11)

0 - 2 Fill, gravel  
 2 - 4 Peat  
 4 - 8 Clay, sandy gray  
 8 - 9 Silty clay, sandy and stoney  
 9 Bedrock

B-3 (NE, NE, 5, 61, 11)

0 - 7.5 Silty clay, sandy, green to gray

B-4 (SE, SW, 4, 61, 11)

0 - 3 Fill  
 3 - 4.5 Peat  
 4.5 Bedrock

B-5 (SE, SW, 4, 61, 11)

0 - 3 Fill  
 3 - 6 Peat  
 6 Bedrock

B-6 (SE, SW, NE, 11, 59, 12)

0 - 3 Silty clay, sandy to stoney  
 3 Bedrock or boulder

B-7 (NE, SW, NW, 18, 60, 11)

0 - 1 Brown, sandy soil  
 1 - 11 Red, sand gravel  
 11 - 35 Red, silty sand

B-8 (NW, NE, NE, 14, 60, 12)

0 - 8 Black, organic, medium-grained sand  
 8 - 20 Brown, gravelly sand  
 20 - 58 Brown, sandy silt

B-9 (SW, SE, NE, 9, 60, 12)

0 - 10 Red, gravelly sand  
 10 - 2) Red, medium-grained sand  
 2) Refusal

\* Data from Olcott

B-10 (SW, NW, NE, 13, 60, 12)

0 - 1 Fill  
 1 - 15 Black, fibric, waxy peat  
 15 - 23 Black, silty, medium-grained sand

B-11 (SW, SW, NE, 14, 60, 12)

0 - 20 Red, gravelly sand  
 20 - 50 Red, silty, medium-grained sand  
 50 - 68 Gray, clayey silt

B-12 (SW, SW, NE, 14, 60, 12)

0 - 10 Red, sandy gravel  
 10 Refusal

B-13 (NW, NE, SW, 25, 60, 12)

0 - 9 Red, gravelly sand  
 9 - 10 Gray, silty sand  
 10 Refusal

B-14 (NE, SW, NE, 7, 60, 11)

0 - 44 Red, gravelly sand  
 44 - 45 Gray, silty sand  
 45 Refusal

B-15 (NE, SW, SW, 15, 60, 11)

0 - 23 Red, gravelly sand  
 23 Refusal

B-16 (SW, NW, SW, 23, 62, 10)

8 - 17 Gray, coarse sand  
 17 Refusal

B-17 (NE, NW, NW, 4, 61, 11)

0 - 10 Gray, medium-grained sand  
 10 Refusal

## APPENDIX D. GROUND-WATER OBSERVATION POINT DATA

OBSERVATION POINT	LOCATION T, S, R, Sec, T(N), R(W)	TYPE	TOTAL LENGTH (Ft)	TOTAL DEPTH BELOW LAND SURFACE (Ft)	SCREEN LENGTH (Ft)	HEIGHT ABOVE SURFACE (Ft)	ELEVATION AT TOP OF CASE ABOVE MSL (Ft)
H1*	NE, NW, NW, 25, 62, 11*	2" plastic*	17*	13.5*	0*	3.5*	1471.46
H3*	NE, NW, NW, 25, 62, 11*	2" plastic*	15*	12*	0*	4*	1491.07*
H4*	NE, NW, SW, 34, 62, 11*	2" plastic*	14*	10*	3*	4*	1493.06
H5*	NW, NW, NW, 11, 61, 11*	2" plastic*	11*	7*	0*	4*	1504.51
H35*	NW, NE, NE, 15, 61, 11*	2" plastic*	13*	12.6*	3*	-.2*	1518*
H36*	NE, SE, NW, 10, 61, 11*	2" plastic*	22*	18*	3*	4*	1504.65
V1	NW, SE, NE, 13, 61, 11	1 1/4" OD iron	6.8	3.3	3	3.5	1567.40
V2	SW, SE, NE, 11, 61, 11	1 1/4" OD iron	10.5	8.0	3	2.5	1500.21
V3	NW, NE, SE, 3, 61, 11	1 1/4" OD iron	7.7	5.1	3	2.6	1506.93
V4	SW, SW, SW, 34, 62, 11	1 1/4" OD iron	9.0	5.7	3	3.3	1455.57
V5	NE, NW, NW, 4, 61, 11	1 1/4" OD iron	9.3	8.4	3	.9	1434.25
V6	NE, NE, SW, 26, 62, 11	1 1/4" OD iron	8.0	5.0	3	3.0	1506.66
V7	SW, NW, NW, 29, 62, 10	1 1/4" OD iron	18.7	17	3	1.7	1516.17
INCO 40913**	SW, SE, SE, 33, 62, 11	2 1/4" OD iron case	2796	2725**	2705(uncased)**	1.4	1504.05
INCO 32750**	SE, NE, NW, 34, 62, 11	2 1/2" OD iron case	1251	1250**	1250?(uncased)**	1.5	1500.13
INCO 34839**	NW, SW, NW, 25, 62, 11	2 1/2" OD iron case	250	250**	246(uncased)**	.6	1486.84**
INCO 34852**	NE, NW, NW, 25, 62, 11	2 1/2" OD iron case	250	250**	235(uncased)**	.3	1434.99**
INCO 34859**	SW, SE, SW, 24, 62, 11	2 1/2" OD iron case	231	250**	230(uncased)**	1.1	1435.92**
INCO 32781**	SW, NW, SE, 24, 62, 11	2 1/2" OD iron case	476	475**	475**	.8	1452.66**
INCO 32791**	NW, SW, SE, 24, 62, 11	2 1/2" OD iron case	254	253**	253(uncased)**	1.3	1440.43**
INCO 32786**	SW, NW, SE, 24, 62, 11	2 1/2" OD iron case	371	371**	359(uncased)**	.4	1449.42**
INCO 11533**	SE, SE, SE, 32, 62, 11	2 3/4" OD iron case	1320	1319**	1300?(uncased)**	1.2	1444.30**
RAMMA 420**	SW, SE, SE, 25, 62, 11	2 1/2" OD iron case	250	250**	250?(uncased)**	.5	1524.94
Nickol Lake	NW, 29, 62, 10						1492*
Filson Creek	SE, SE, NW, 19, 62, 10	culvert top					1446.61
Filson Creek	NE, NE, SE, 24, 62, 11	steel post					1437.91
Keeley Creek	SE, NE, SE, 11, 61, 11	culvert top					
South Kawishiwi River	33, 62, 11						
Pond	NW, NW, 9, 61, 11						1470*
Owandy Lake***	31, 62, 10						1505*
Bogberry Lake***	6, 61, 10						1500*
Heart Lake	18, 61, 10						1550*
Harris Lake	24, 61, 11						1515*
August Lake***	16, 61, 10						1535*

\* Data from Olcott

\*\* Data from Wager

\*\*\* Data from US Geological Survey quadrangle map

APPENDIX E. GROUND-WATER OBSERVATION POINT MEASUREMENTS

Well number, date and depth to water below top of case (ft.)

H1		H3		H4		H5	
10-9-75*	9.88	10-9-75*	6.40	10-9-75*	9.83	10-9-75*	5.55
10-20-75*	10.25	10-20-75*	6.23	10-20-75*	6.50	11-5-75*	5.57
10-21-75*	10.80	10-21-75*	9.97	10-21-75*	6.62	2-23-76*	6.71
11-6-75*	10.80	11-6-75*	6.37	11-5-75*	8.04	7-29-76	5.79
2-23-76*	4.63	2-23-76*	6.84	12-4-75*	5.48	8-25-76	6.62
8-26-76	7.20	7-29-76	6.60	2-23-76*	5.65		
		8-26-76	6.45	7-29-76	6.20		
				8-26-76	6.51		

H33		H36		H1		H2	
10-8-75*	12	10-21-75*	5.37	7-25-75	5.40	7-26-75	5.69
11-6-75*	1.27	11-5-75*	5.15	8-2-75	4.85	8-2-75	5.72
8-26-76	1.94	2-26-76*	5.34	8-8-75	4.38	8-8-75	3.45
		8-26-76	7.63	8-16-75	3.95	8-16-75	3.44
				9-2-75	3.90	9-2-75	2.70
				5-29-76	2.60	8-25-76	3.20
				7-29-76	3.40		
				8-26-76	3.87		

H3		H4		H5		H6	
7-26-75	1.83	7-26-75	10.80	7-26-75	4.00	7-26-75	3.80
8-2-75	2.72	8-2-75	10.23	8-2-75	3.95	8-2-75	3.47
8-8-75	3.10	8-8-75	9.66	8-8-75	4.09	8-8-75	3.74
8-16-75	3.37	8-16-75	9.11	8-16-75	4.31	8-16-75	4.10
9-2-75	2.95	9-2-75	8.20	9-2-75	4.23	9-2-75	3.20
5-29-76	2.80	7-29-76	8.25	4-16-76	2.91	7-29-76	3.20
7-29-76	3.05	8-26-76	8.37	7-29-76	3.83	8-26-76	3.95
8-26-76	3.34			8-26-76	4.41		

H7		INFO 40013		INFO 32263		INFO 32264	
8-2-75	4.94	7-26-75	15.13	7-26-75	6.20	7-26-75	1.35
8-8-75	5.14	8-2-75	15.30	8-2-75	7.20	8-2-75	1.01
8-16-75	5.31	8-8-75	15.25	8-8-75	7.48	8-8-75	1.61
9-2-75	5.10	8-16-75	15.52	8-16-75	8.02	8-16-75	1.51
4-16-76	3.78	9-2-75	15.32	9-2-75	3.92	9-2-75	1.10
5-29-76	4.37	7-26-76	15.50	7-29-76	7.20	7-29-76	1.25
7-29-76	5.01	8-26-76	15.62	8-26-76	7.91	8-26-76	1.72
8-26-76	5.30						

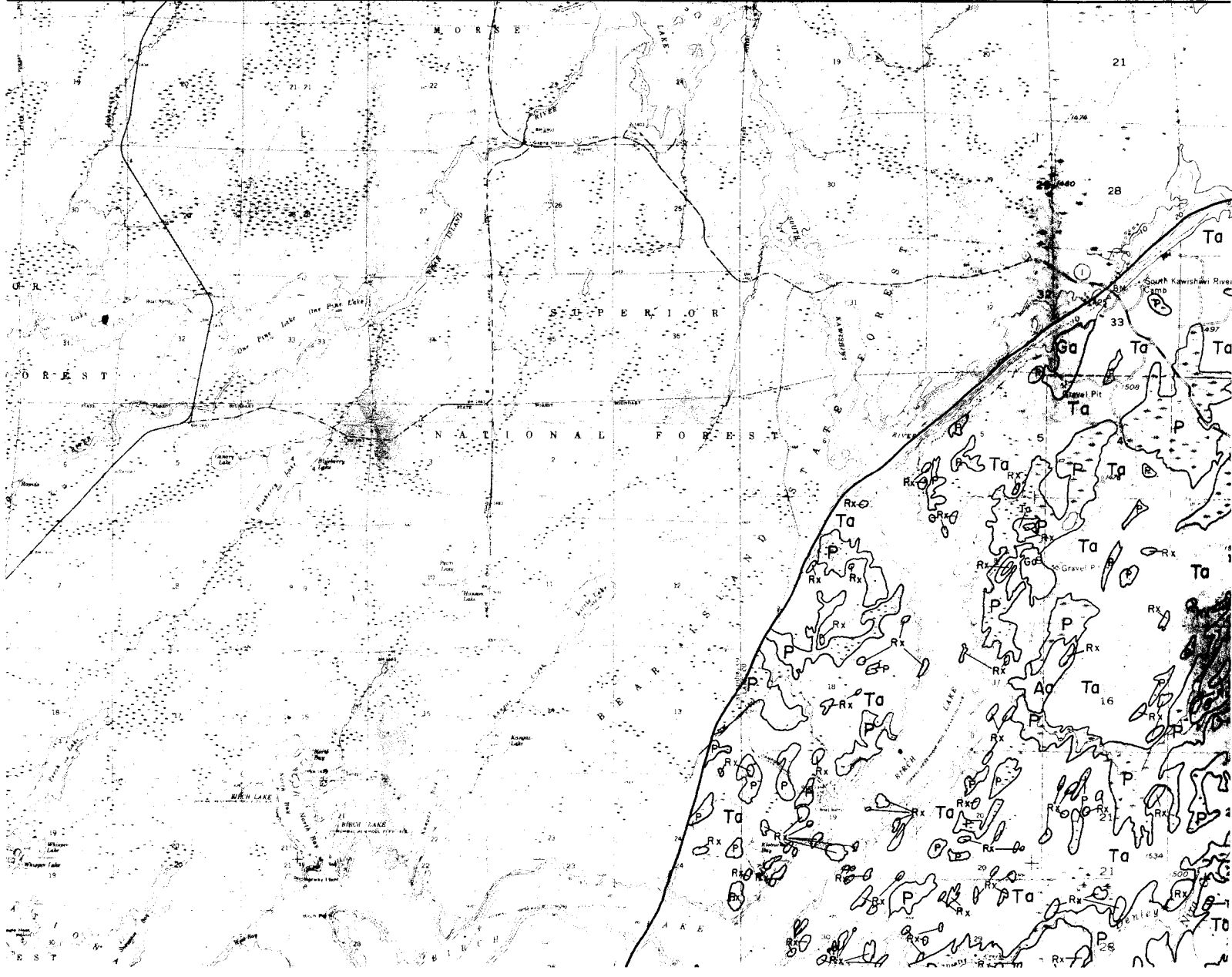
INFO 31852		INFO 31859		INFO 32261		INFO 32261	
7-26-75	.35	8-2-75	.91	7-26-75	9.00	7-26-75	.93
8-2-75	.70	8-8-75	1.63	8-2-75	9.46	8-2-75	1.31
8-8-75	1.10	8-16-75	1.89	8-8-75	9.47	8-8-75	1.52
8-16-75	1.31	9-2-75	1.58	8-16-75	9.82	8-16-75	1.62
9-2-75	.60	7-29-76	.50	9-2-75	9.60	9-2-75	1.31
7-29-76	.65	8-26-76	2.09	4-16-76	6.25	7-29-76	1.40
8-26-76	1.32			5-29-76	8.31	8-25-76	1.60
				7-29-76	6.15		
				8-26-76	9.52		

INFO 32265 continued record, see Figure 20		INFO 11531		INFO 32261	
		7-26-75	17.00	7-26-75	13.55
		8-2-75	17.48	8-2-75	14.19
		8-8-75	21.60	8-8-75	14.82
		8-16-75	17.85	8-16-75	15.15
		9-2-75	18.05	7-29-76	13.85
		4-16-76	15.45	8-26-76	15.02
		5-29-76	16.80		
		7-29-76	17.50		
		8-26-76	19.06		

\* Data from Olcott

R. 12 W.

R. 12 W. R. 11 W.



2

I

R. 11 W. R. 10 W.

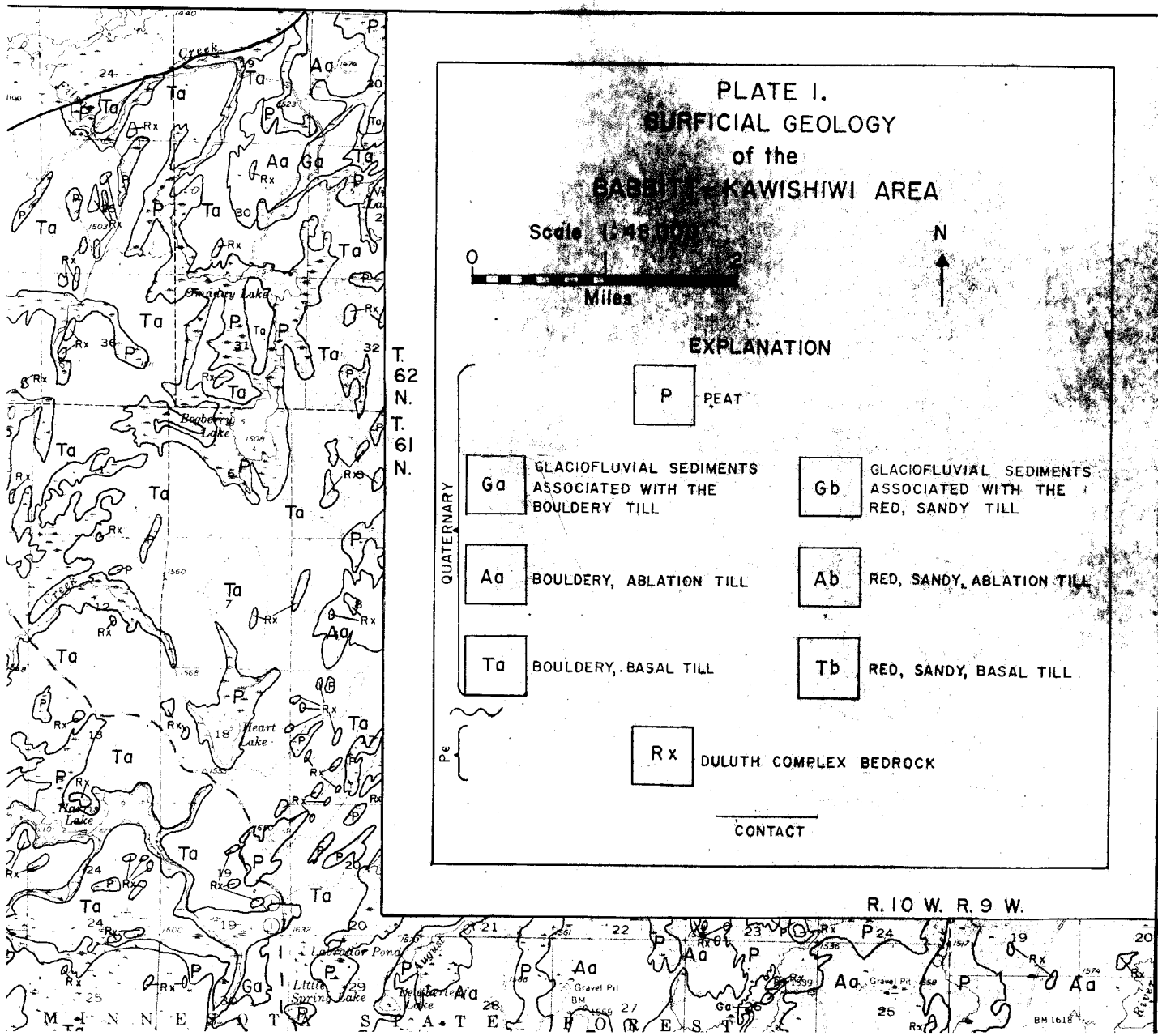


PLATE I.  
SURFICIAL GEOLOGY  
of the  
BABBITT-KAWISHIWI AREA

Scale 1:48,000  
0 1 2  
Miles

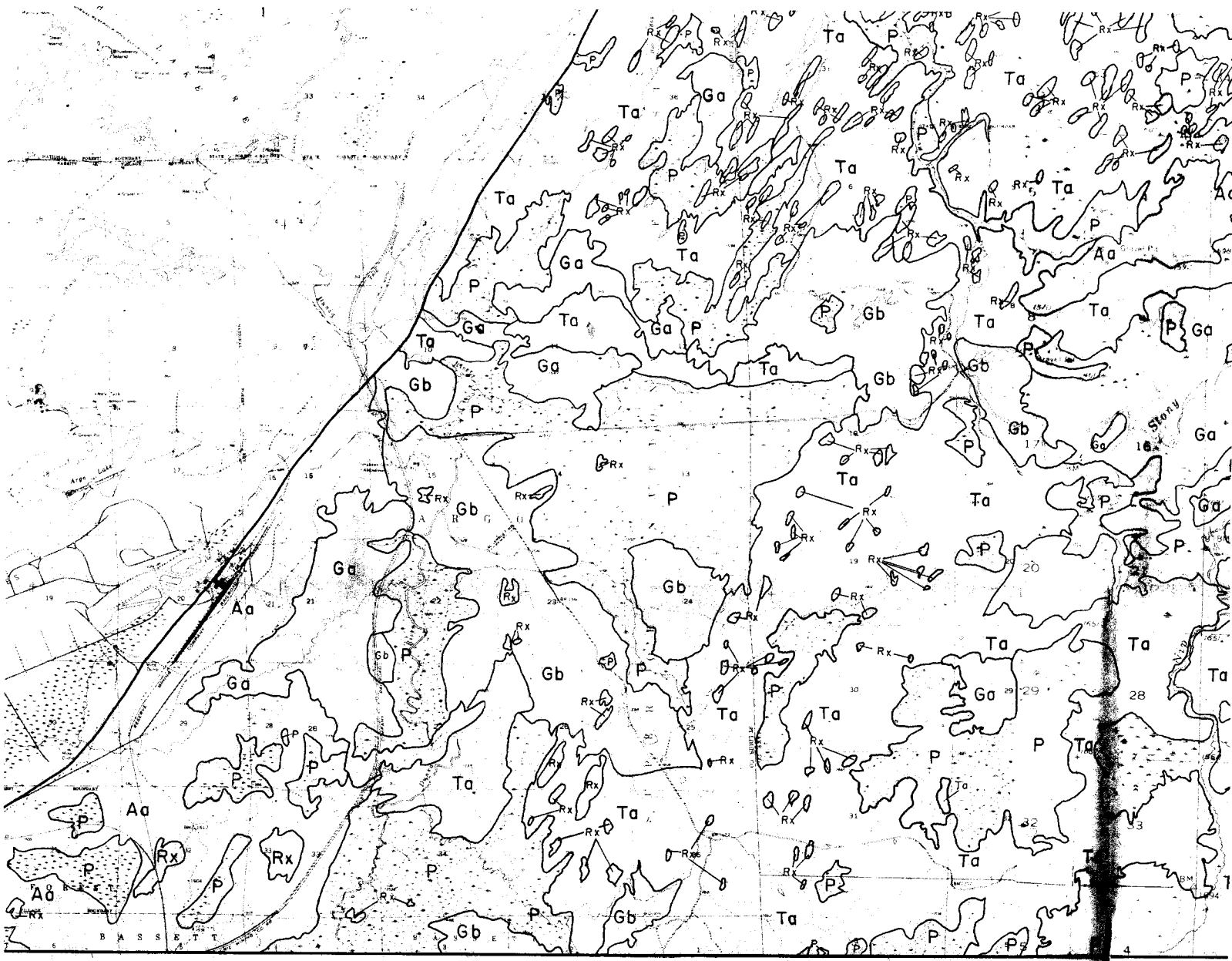


EXPLANATION

- |            |         |   |    |   |
|------------|---------|---|----|---|
| QUATERNARY | P       | PEAT  | Gb | GLACIOFLUVIAL SEDIMENTS ASSOCIATED WITH THE RED, SANDY TILL |
|            | Ga      | GLACIOFLUVIAL SEDIMENTS ASSOCIATED WITH THE BOULDERY TILL | Ab | RED, SANDY, ABLATION TILL                                   |
|            | Aa      | BOULDERY, ABLATION TILL                                   | Tb | RED, SANDY, BASAL TILL                                      |
|            | Ta      | BOULDERY, BASAL TILL                                      | Rx | DULUTH COMPLEX BEDROCK                                      |
|            | Pe      |   |    |   |
|            | CONTACT |   |    |   |
|            |         |   |    |   |

R. 10 W. R. 9 W.

M I N N E S O T A S T A T E F L O R E S T

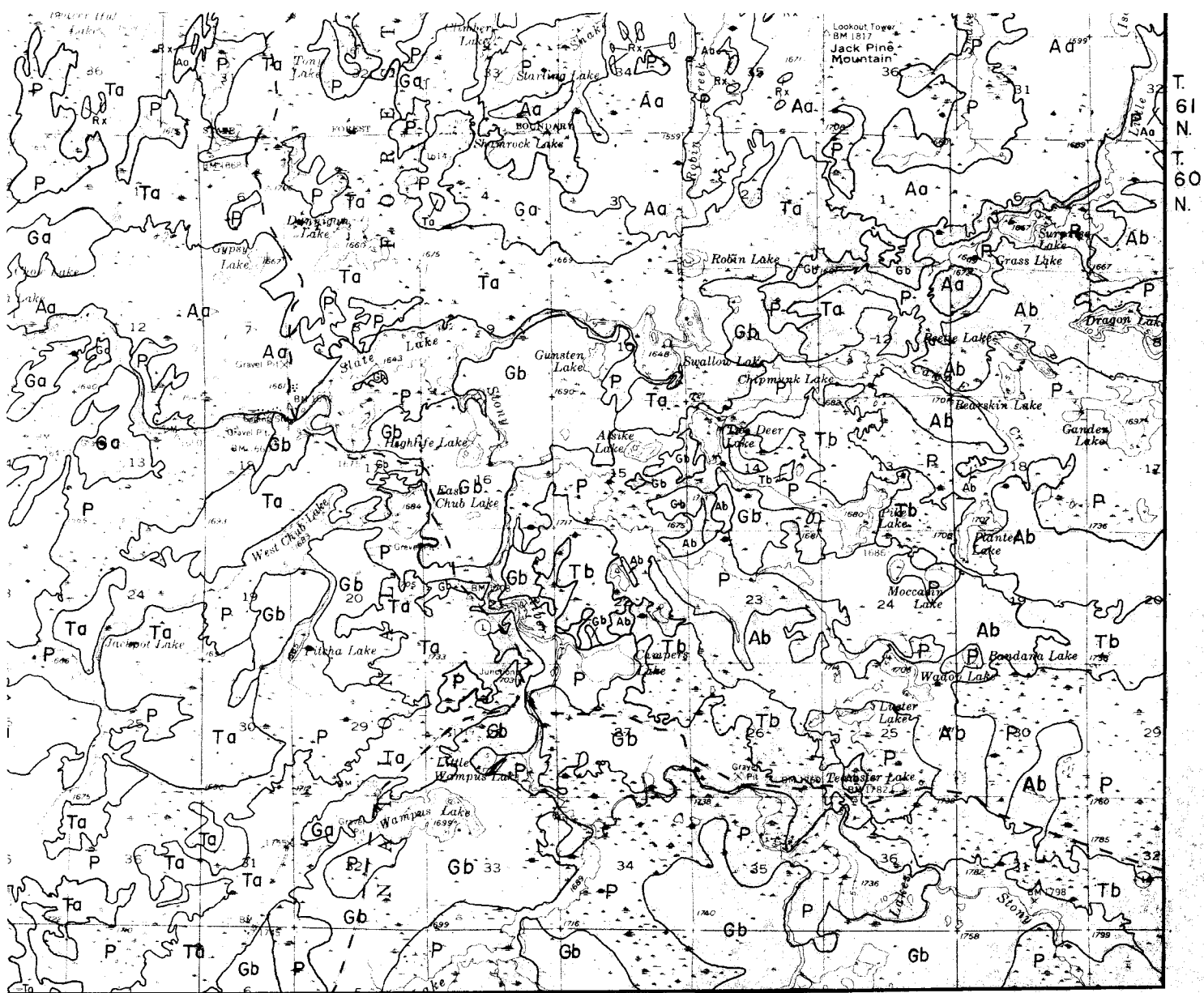


12 W.

R. 12 W. R. 11 W.

3

I



T. 61 N.  
T. 60 N.

R. 11 W. R. 10 W.

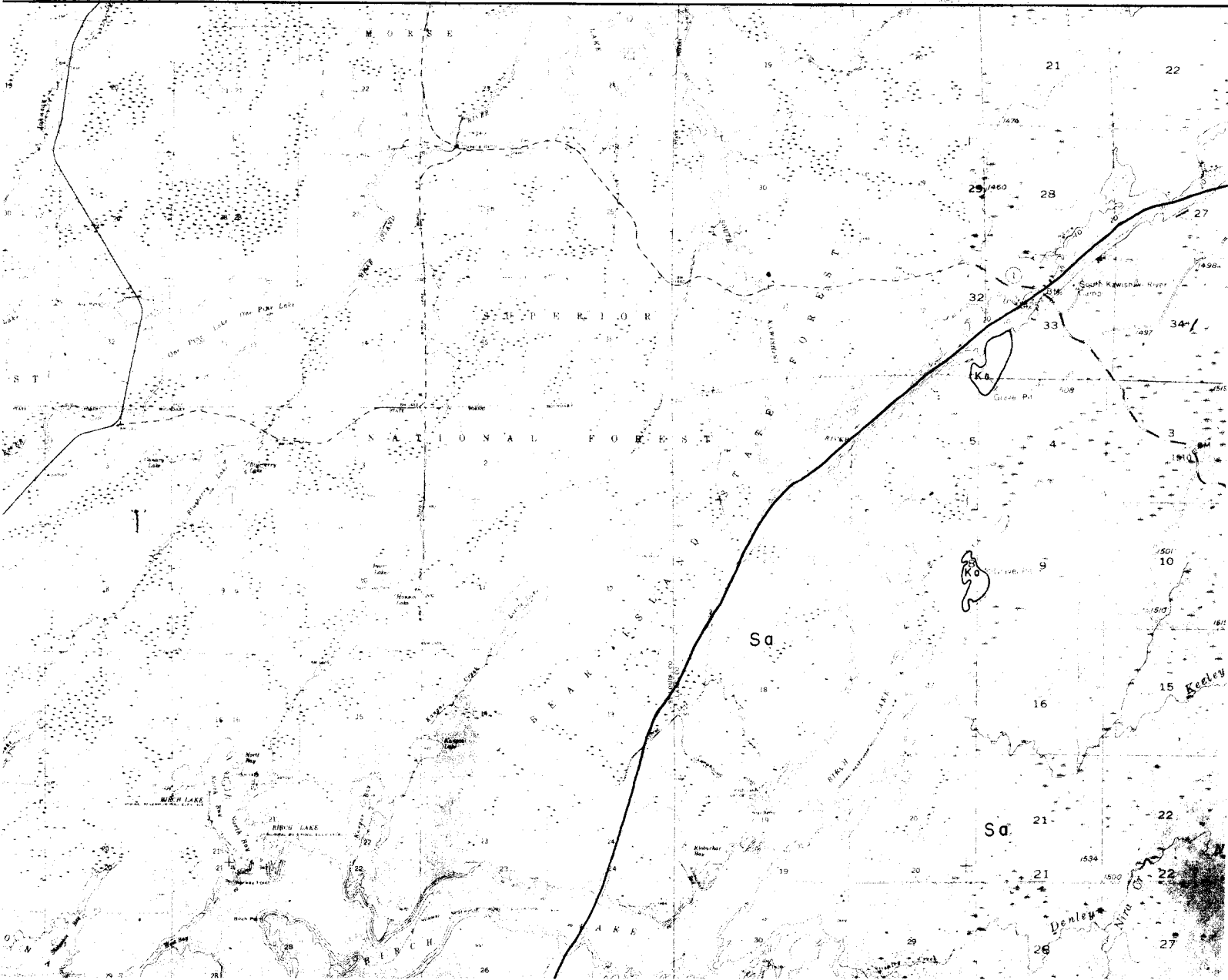
R. 10 W. R. 9 W.

4

I

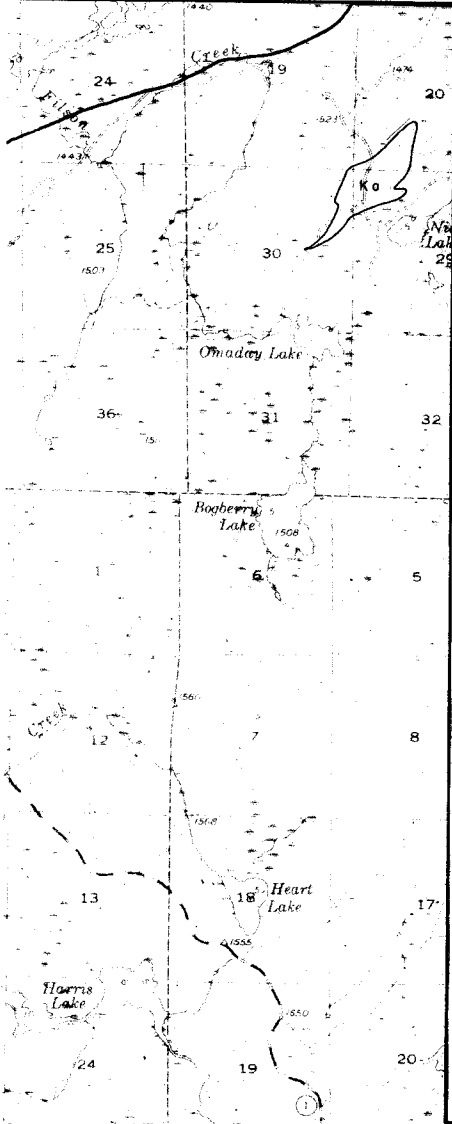
W.

R.12 W. R.11 W.



II 1

R. 11 W. R. 10 W.



T. 62 N.  
T. 61 N.

PLATE 2.  
GEOMORPHIC FEATURES  
of the  
BABBITT-KAWISHIWI AREA

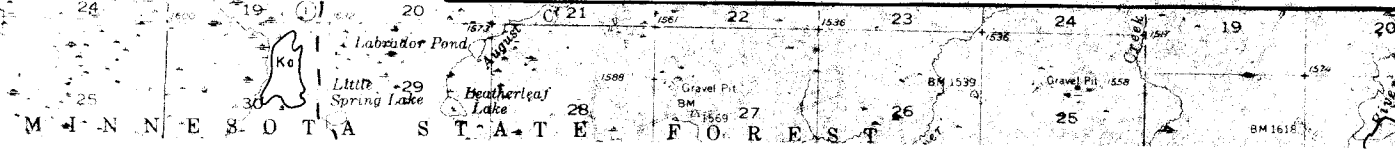
Scale 1:48,000



EXPLANATION

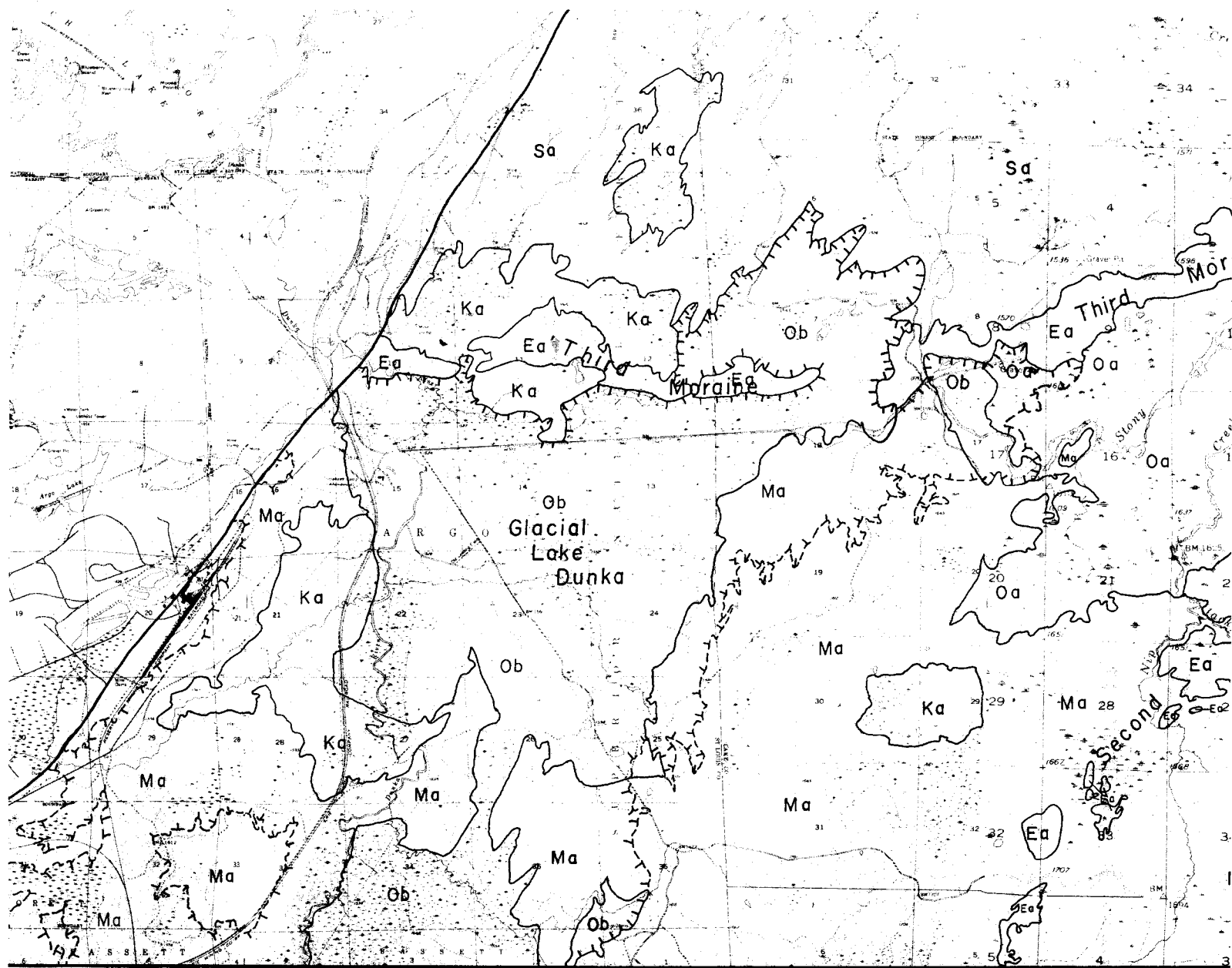
- |  |   |
|--|---|
| <p><b>Sa</b> ICE-SCoured PLAIN ASSOCIATED WITH THE BOULDERY TILL</p> <p><b>Ka</b> ICE-CONTACT FEATURE ASSOCIATED WITH THE BOULDERY TILL</p> <p><b>Oa</b> PITTED OUTWASH PLAIN ASSOCIATED WITH THE BOULDERY TILL</p> <p><b>Ma</b> GROUND MORaine ASSOCIATED WITH THE BOULDERY TILL</p> <p><b>Ea</b> END MORaine ASSOCIATED WITH THE BOULDERY TILL</p> | <p><b>Kb</b> ICE-CONTACT FEATURE ASSOCIATED WITH THE RED, SANDY TILL</p> <p><b>Ob</b> PITTED OUTWASH PLAIN ASSOCIATED WITH THE RED, SANDY TILL</p> <p><b>Mb</b> GROUND MORaine ASSOCIATED WITH THE RED, SANDY TILL</p> <p><b>Eb</b> END MORaine ASSOCIATED WITH THE RED, SANDY TILL</p> |
|--|---|
- CONTACT OF GEOMORPHIC FEATURE      ||||| LIMIT OF GLACIAL LAKE

R. 10 W. R. 9 W.



II 2

M I N N E S O T A S T A T E F O R E S T

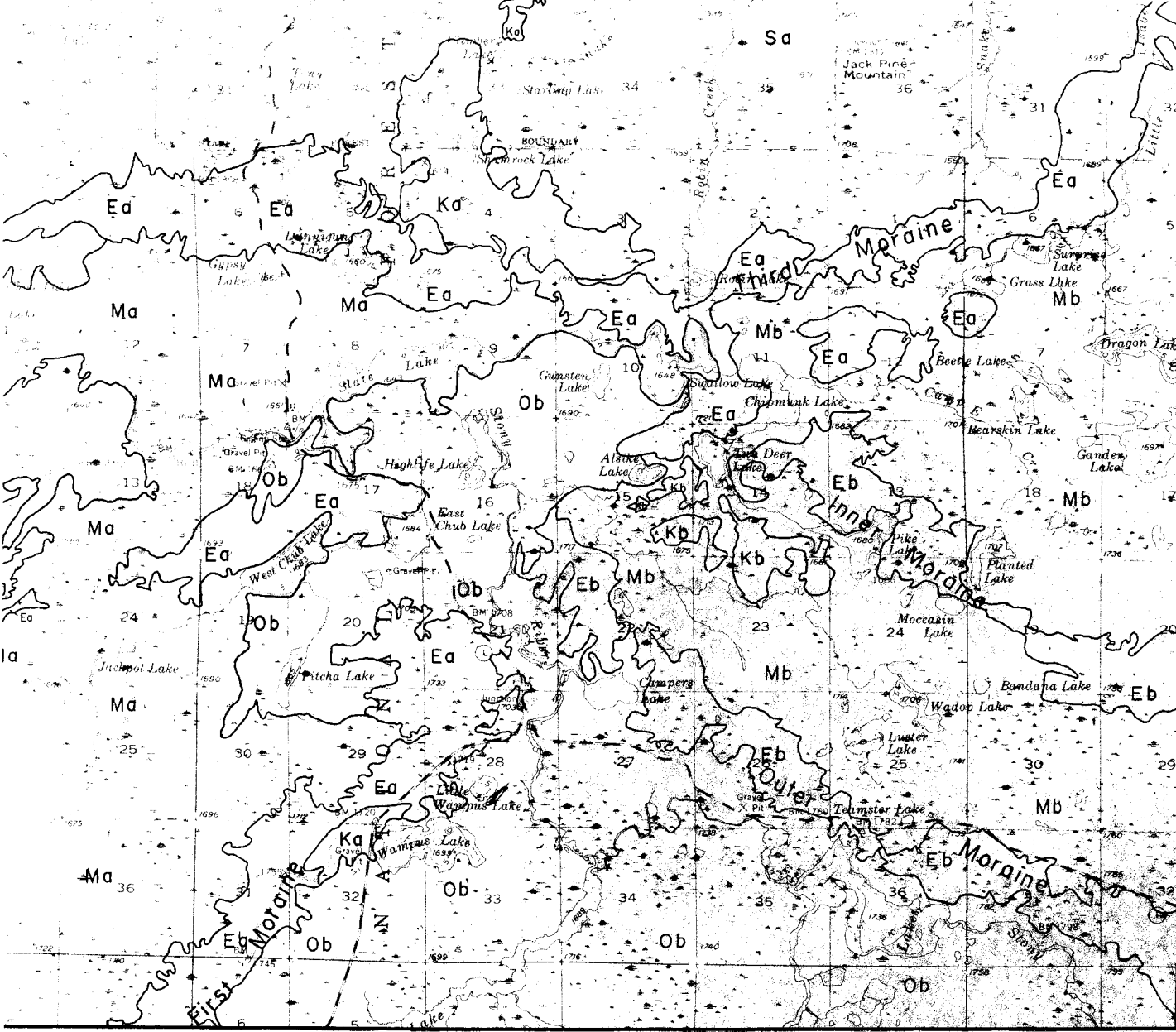


W.

R. 12 W. R. 11 W.

II 3

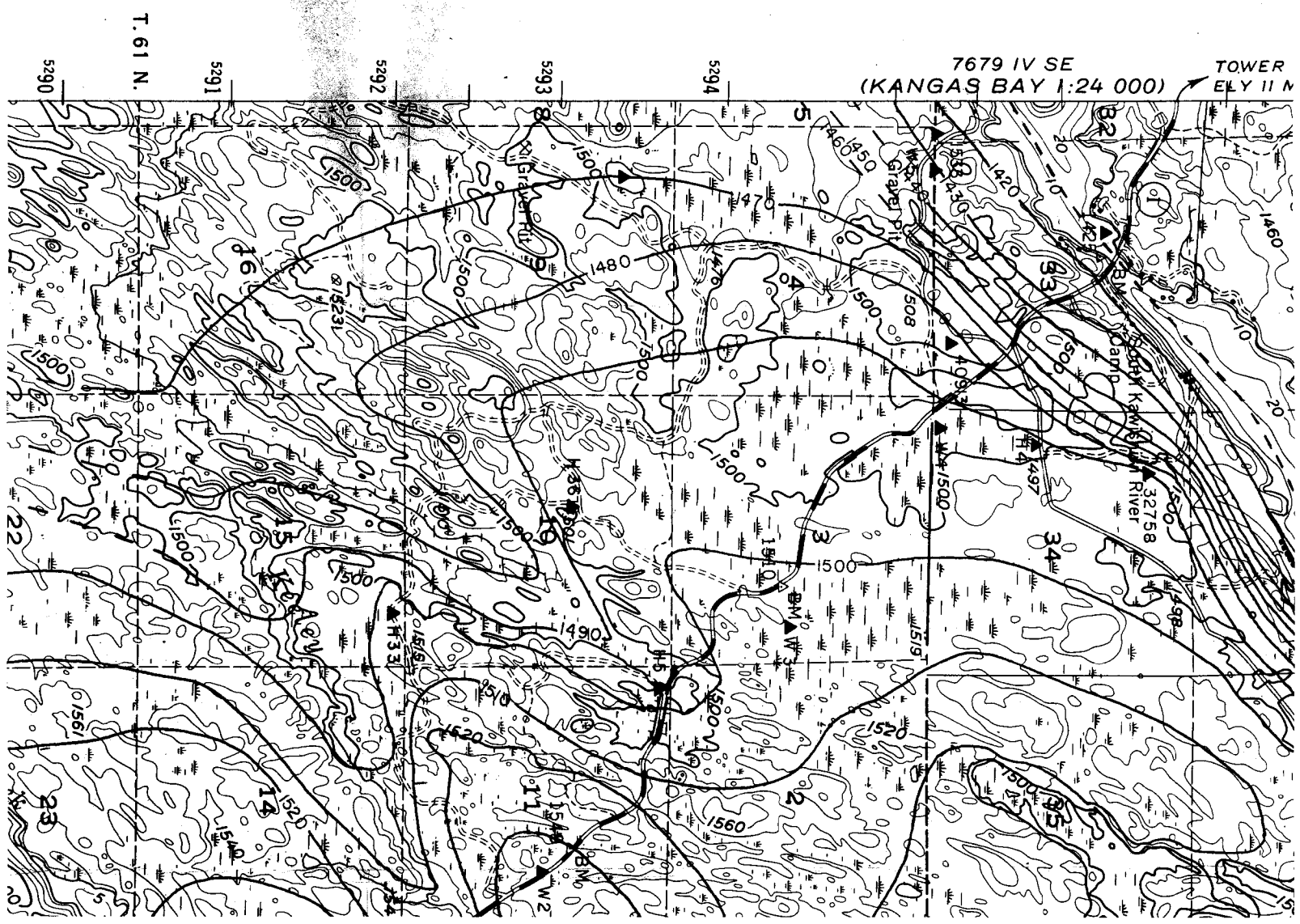
T. 61 N.  
T. 60 N.



R. 11 W. R. 10 W.

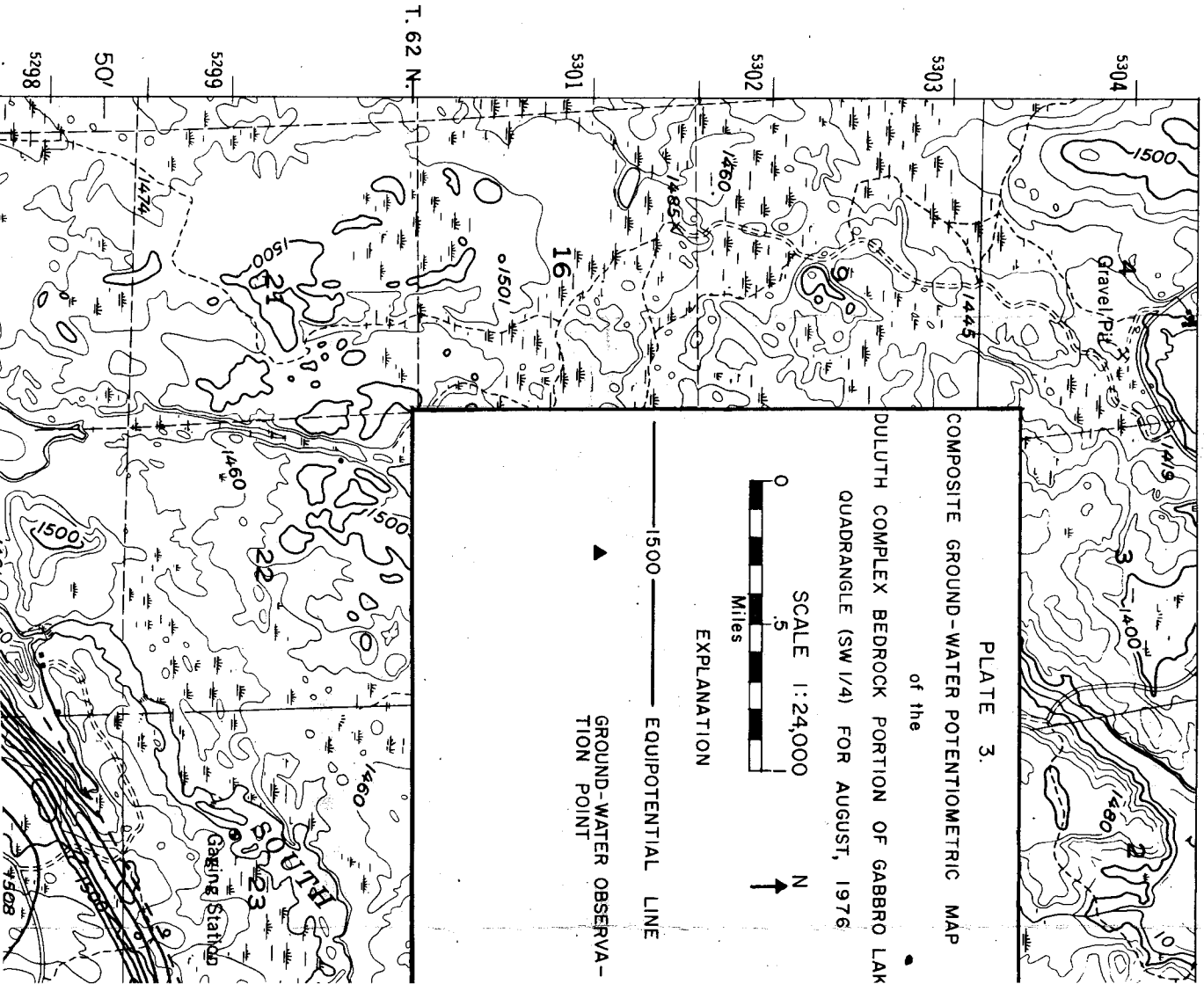
R. 10 W. R. 9 W.

II 4

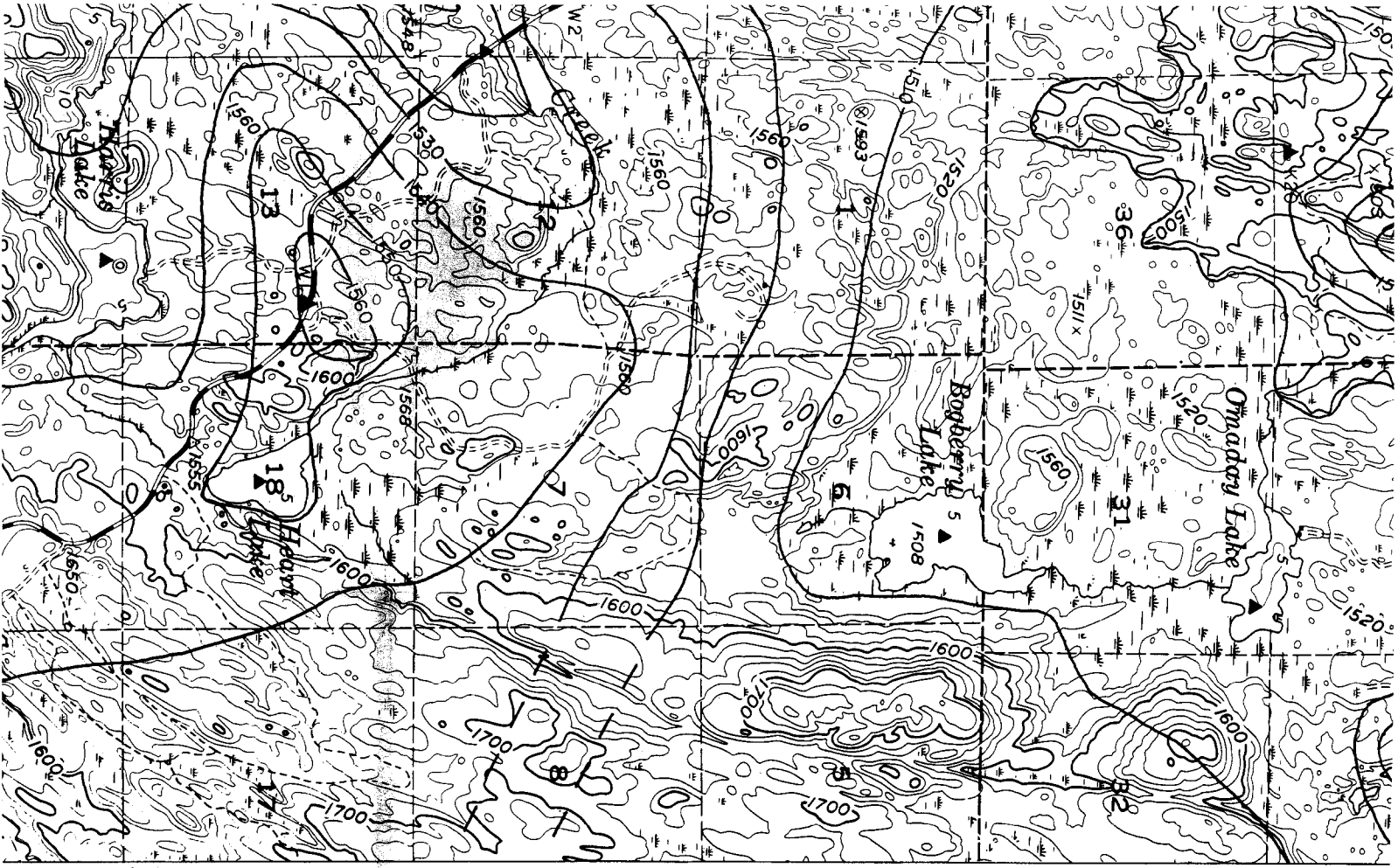


一 月

R. H. W.



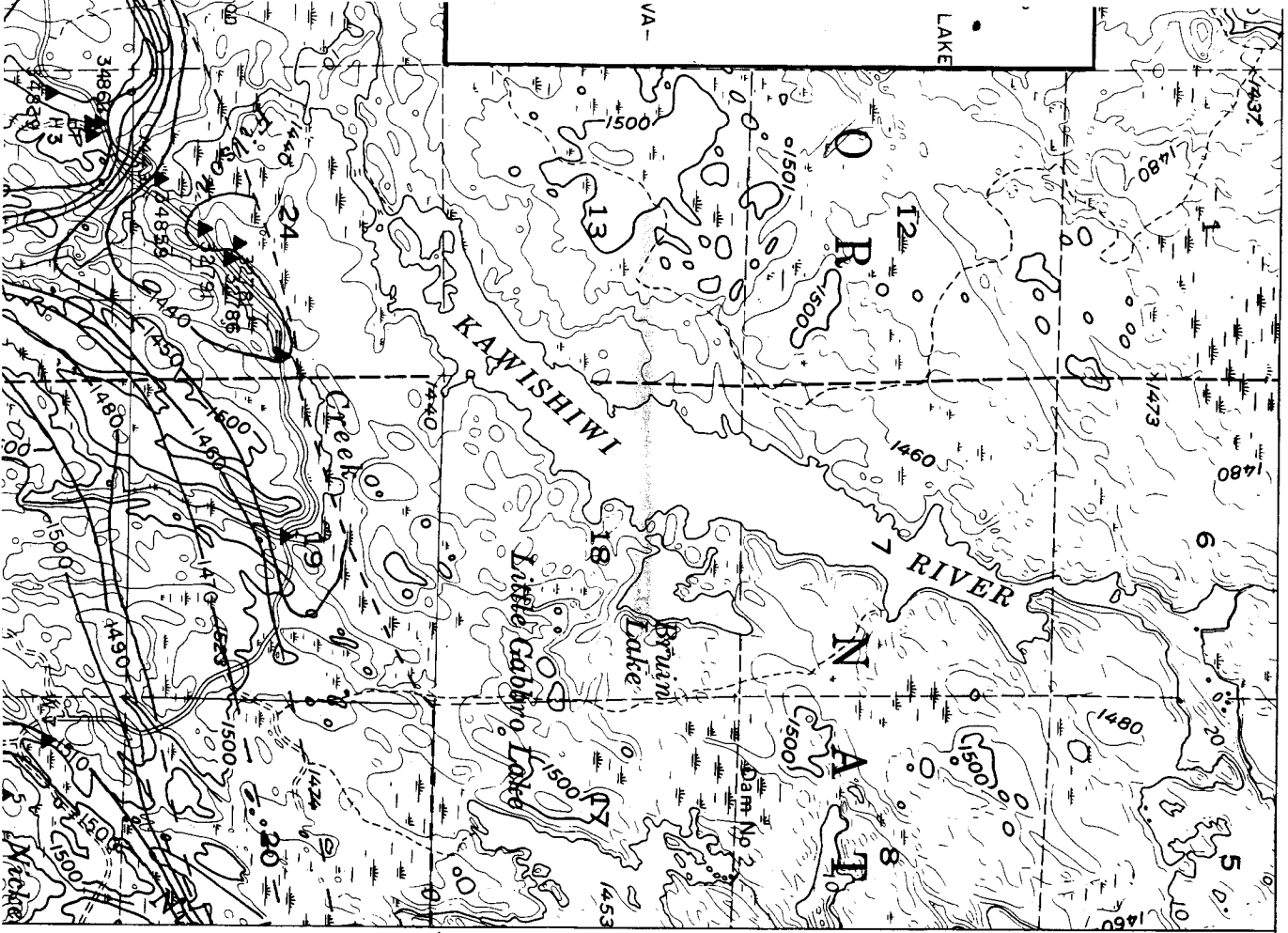
2 H



T 61 N.



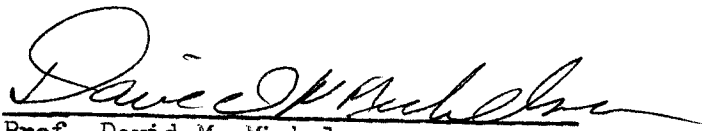
# 3



T. 62 N.

4 11

Approved by:



Prof. David M. Mickelson  
Department of Geology and Geophysics

3/7/77  
Date