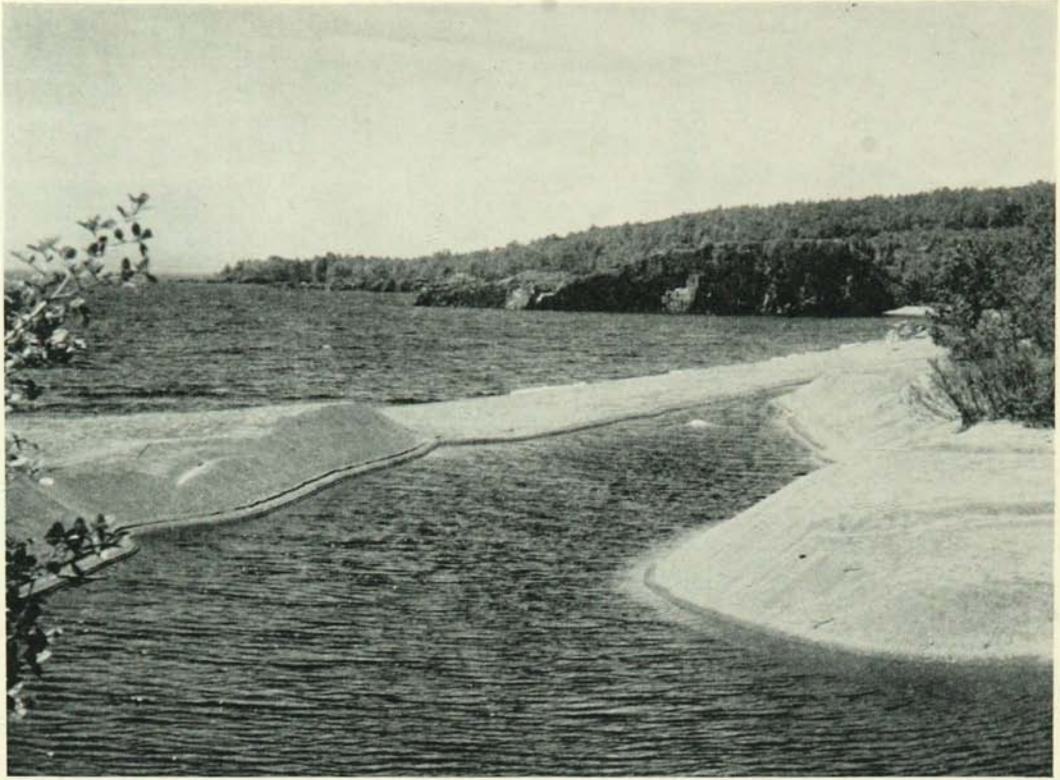
WITH THE WRITER'S COMPLIMENTS

THE GEOLOGY OF COOK COUNTY, MINNESOTA



Wave-built gravel bar damming mouth of small stream west of Deronda Bay on Lake Superior (Sec. 35, T. 63 N., R. 5 E.), looking west. A series of points beyond the bar are characteristic of the shore line of Keweenawan flows which dip gently toward the lake and strike at about 45° to the shore line. The spurs are formed by the main part of the flow and the coves by the amygdaloidal zones.

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The Geology of Cook County Minnesota

BY

FRANK F. GROUT
ROBERT P. SHARP
GEORGE M. SCHWARTZ

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FOREWORD

Cook County forms the extreme northeastern part of Minnesota lying between Lake Superior and the Canadian border. Glaciation has scraped off the ridges, leaving bare rock or thin soil at many places. Preglacial erosion has left a rugged topography only moderately changed by ice action and characterized by beautiful long narrow parallel lakes. The position of the county on the north shore of the largest fresh-water lake in the world, which is also deep and cold, results in a relatively cool climate ideal for summer tourists but not favorable to most types of agriculture. As a consequence most of the county is still forested, a considerable proportion belonging to the Superior National Forest, and roads are at a minimum. A part of the National Forest is included in the so-called roadless area and air space reservation. Access to large areas in the county is mainly by canoe.

The relatively extensive area of rock exposure has naturally led to much interest in the mineral possibilities of the county. For this reason the Minnesota Geological Survey has always been actively concerned in working out the geology of the area as a background for investigation of the mineral deposits. The only preceding description of the geology of the county is a chapter by U. S. Grant in the fourth volume of the Final Report, *Geology of Minnesota,* by N. H. Winchell, published in 1899. It was in this remote and comparatively wild area that Professor Grout started his geological work in 1913 which continued, as conditions permitted, until his retirement in 1948. Literally dozens of assistants have taken part in the difficult task of mapping the nearly 1700 square miles included in the county.

Many of the problems have only been revealed and remain to be worked out in detail. The extensive maps compiled by Professor Grout will furnish a basis for future geological work. A debt of gratitude is owed to him by the state of Minnesota for devoted work extending over the major part of a lifetime. It is fitting that after his death on August 1, 1958, his ashes were spread on the waters of the falls at the outlet of Gunflint Lake.

Robert P. Sharp prepared most of the introductory material and the discussion of glacial geology. George M. Schwartz assisted in preparation of the remainder of the manuscript. It is hoped that the report will be useful in the development of the county.

George M. Schwartz

ACKNOWLEDGMENTS

Work in the county by the senior author of this report began in 1913 and was carried on intermittently to 1956. During this long period Professor Grout was assisted by many students acting as field assistants as well as by other members of the staff at the University of Minnesota. The work, often extremely arduous, of these assistants and staff members is gratefully acknowledged.

Student assistants included Thomas F. Andrews, Robert Bell, Robert Berg, Ronald Brown, D. M. Danielson, Nathan Davies, Lloyd Dreveskracht, E. C. Edwards, M. G. Edwards, Howard Evans, William Fackler, Sigmund Fruehling, Samuel Grantham, Anton Gray, Elliot Griffith, George Gryc, Leroy Hassentab, R. F. Hodgeman, Hugh Kendall, E. H. Lathram, A. I. Levorsen, R. C. Marmaduke, L. M. Miller, John Moga, Clemens Nelson, Edward Nicholson, Lincoln Page, William J. Pettijohn, Warren Pickering, R. A. Ranta, Ronald Sorem, R. P. Sovereign, William Strunk, Stanley Sundeen, Roger Swanson, Donald Taylor, Nelson Taylor, Francis Wells.

Members of the staff who worked as field geologists included T. M. Broderick, J. W. Gruner, F. B. Hanley, G. M. Schwartz, and R. P. Sharp. Much of the work was under the general direction of William H. Emmons, Director of the Minnesota Geological Survey from 1912 to 1944.

Our appreciation and thanks also go out to the many individuals and corporations who have contributed to this report in various ways: Mr. Otto Munson, Johnson Nickel Mining Co., St. Paul; the M. A. Hanna Co., Nashwauk; the E. J. Longyear Co., Minneapolis; Butler Brothers, St. Paul; the Mines Experiment Station, University of Minnesota; the Office of the Commissioner of the Iron Range Resources and Rehabilitation, St. Paul.

Local residents were uniformly helpful in the work and so many were involved that a list would resemble a directory of Cook County. Their cooperation was invaluable, and sincere thanks are extended to all who helped in making the geology of their county better known.

Special thanks are due to the regional office of the U.S. Forest Service at Milwaukee for a set of township maps of the 1948 Timber Survey.

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ABSTRACT

Cook County covers a triangular-shaped area at the extreme northeastern tip of Minnesota between Lake Superior on the south and the province of Ontario, Canada on the north. Its area is approximately 1680 square miles, of which about 274 square miles is covered by several hundred lakes. Its position north of Lake Superior is responsible for a rather moist and cool climate favorable to the growth of timber rather than agriculture. As a result, most of the area is covered by second-growth forest and this, together with the numerous rock-bound lakes, makes it an important vacation area.

The area is hilly with a minimum elevation above sea level of 602 feet at Lake Superior and 2232 feet in the Misquah Hills. Much of the northern part of the county is characterized by long narrow lakes separated by prominent ridges.

The geology is controlled, in a broad way, by its position on the north limb of the Lake Superior syncline. With the exception of glacial deposits the rocks are all of Precambrian age, with the youngest in a general way occurring along the coast of Lake Superior and the oldest in the Gunflint district and near Saganaga Lake.

The older rocks consist of the Ely greenstone, Saganaga granite and Knife Lake group of slates, graywackes, metamorphosed tuffs and various minor types. These form an area of exceedingly complex geology, limited to four townships at the northwest corner of the county.

The next group in age, commonly called the Animikie rocks, consists of a thin quartzite followed by the Gunflint iron formation and this, in turn, by the Rove formation. These are correlated with the Biwabik iron formation and Virginia formation of the Mesabi district.

The Gunflint formation is mainly limited to two of the four northwest townships noted above, but the Rove formation forms a narrow belt along the international boundary from Gunflint Lake to Pigeon Point, a distance of seventy miles. The beds of the Rove formation dip southward at low angles and have been intruded by numerous diabase sills. Erosion has left the sills standing as asymmetrical ridges between valleys occupied by long narrow lakes.

Over two thirds of the county is underlain by rocks of Keweenawan age, consisting of a thin sandstone and conglomerate at the base overlain by an exceedingly thick series of lava flows. These, in turn, are intruded by the eastern part of the huge Duluth gabbro complex and by an extensive series of diabase sills, dikes, and irregular intrusions.

The lava flows consist mainly of somewhat variable basalt plus a much

smaller percentage of rhyolite. The oldest flows crop out near Grand Portage Bay and trend inland so that successive flows occur along shore to the west as far as Tofte, where the sequence is reversed. A total of 92 flows were mapped between Grand Portage and Tofte with an estimated thickness of over seventeen thousand feet.

In the northwestern part of the gabbro exposed in Cook County there is a group of three granite and granodiorite masses of somewhat uncertain origin, but apparently of later age than the gabbro.

During Pleistocene time glaciers probably invaded Cook County several times, but the drift now exposed to view represents deposits from the Rainy Lobe, which probably covered the entire county, and the Superior Lobe which covered only a narrow strip along Lake Superior.

Drift is of sufficient thickness in some parts of the county to rather effectively mask the underlying rocks and leave unanswered questions about their detailed relations. Glacial lakes covered parts of the county during the waning stages of the glaciers and left abandoned beaches at several levels, as well as glacial-lake clay soils.

In spite of the complex geology, Cook County has not furnished productive mineral deposits. Deposits of iron formation, titaniferous magnetite, copper sulfides, and lesser nickel and cobalt sulfides have been investigated from time to time. Forest resources and the resort business are the main sources of revenue, but fishing in Lake Superior and limited agriculture have added to the income. Recently the establishment of Taconite Harbor and a steam power plant by the Erie Mining Company at the end of their railroad from the Mesabi district has been an important addition to the economy.

THE GEOLOGY OF COOK COUNTY, MINNESOTA

1. INTRODUCTION

GENERAL FEATURES

The landscape of Cook County compares favorably with other scenic areas of the upper Midwest. A moderate relief, an abundance of lakes, streams with waterfalls, and an extensive timber cover make this a favored vacation and sporting area. Cook is the northeasternmost county of Minnesota (Fig. 1). It has the shape of an isosceles triangle with a greatest east-west length of seventy-two miles and an extreme north-south breadth of fifty-four miles. Early measurements (Grant, 1899, p. 313) indicate an area of 1680 square miles of which at least 274 square miles are water, excluding Lake Superior. Approximately one eighth of the county drains to Hudson Bay through streams flowing north from Saganaga Lake around Hunters Island. The remaining area lies within the St. Lawrence watershed. The areas drained by the principal rivers are shown on Figure 2.

Although largely a hilly region, Cook County is not mountainous despite the use of "Mount," "Mountain," and "Peak" in the proper names of local high points. The minimum elevation is 602 feet on Lake Superior and the highest 2232 feet in the Misquah Hills, also the highest point in Minnesota. Much of the interior is a rolling upland of low relief.

Surveys of the International Boundary Commission, a line of levels run in 1893 (Berkey, 1894, pp. 134–40), and barometric determinations were long the principal sources of elevation figures. An early Cook County map (Grant, 1899, Plate 69) shows some crude form lines at 100-foot intervals in the north-central and northwestern parts, and Leverett's (1932, Plate 1) map shows form lines at 1000-foot intervals. More accurate topographic sketches of areas underlain by the Rove formation are now available (Grout and Schwartz, 1933, Plates 1–15), and in 1935 the Coast and Geodetic Survey established 286 bench marks in Cook County, of which 137 were found in the summer of 1947. Where these bench marks duplicate previous surveys, some of the older levels are 10 to 15 feet in error. Plate 1 gives representative bench-mark elevations. The United States Geological Survey in cooperation with the Office of the Commissioner of Iron Range Resources and Rehabilitation of Minnesota has started a program of topographic mapping which will complete the county within three years.

The latest published maps of Cook County (1948 Timber Survey) based on aerial photographs by the Forest Service of the U.S. Department of Agriculture, report the highest point in the county is in Sec. 32, T. 64 N., R. 1 W., elevation 2232 feet. The high ground extends beyond the highest

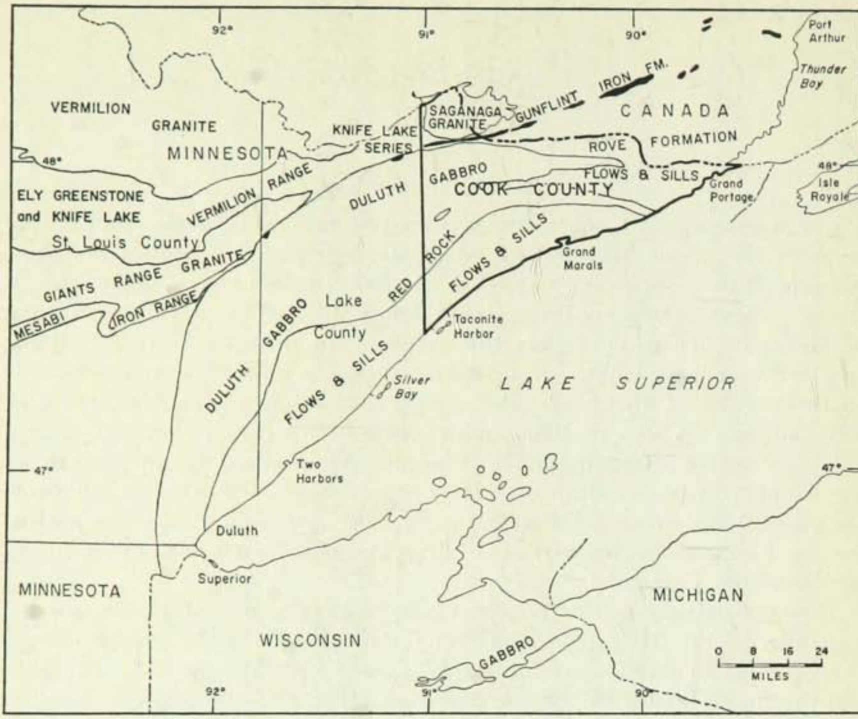

FIGURE 1. — Location of Cook County, Minnesota.

point as a five-mile ridge south of Winchell Lake in T. 64 N., R. 2 W. east to the Lima Mountain Lookout.

PHYSIOGRAPHIC DIVISIONS

The following physiographic divisions are recognized on the basis of physical features: (a) Coastal Hills, (b) Interior Upland, (c) Northern Ridges and Valleys (Fig. 3). As emphasized repeatedly by earlier workers, bedrock lithology and structure have played a major role in determining topographic features of the Lake Superior region. Each of the above divisions is more or less coextensive with a rock formation or group of formations that strongly influence its physiography.

COASTAL HILLS

This physiographic unit extends as a narrow belt along the north shore of Lake Superior northeastward to Grand Portage Bay. It embraces about one eighth the area of Cook County. The major topographic features are long strike ridges and open longitudinal valleys floored with red clay till. Many ridges are cuestas, with steep face to the north and gentle

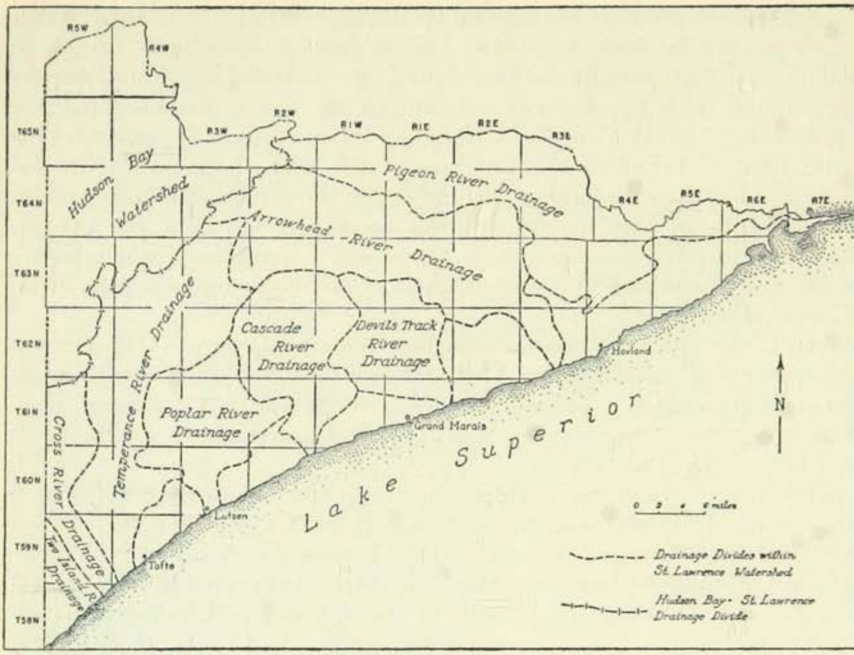

FIGURE 2. — Drainage basins of the principal streams of Cook County.

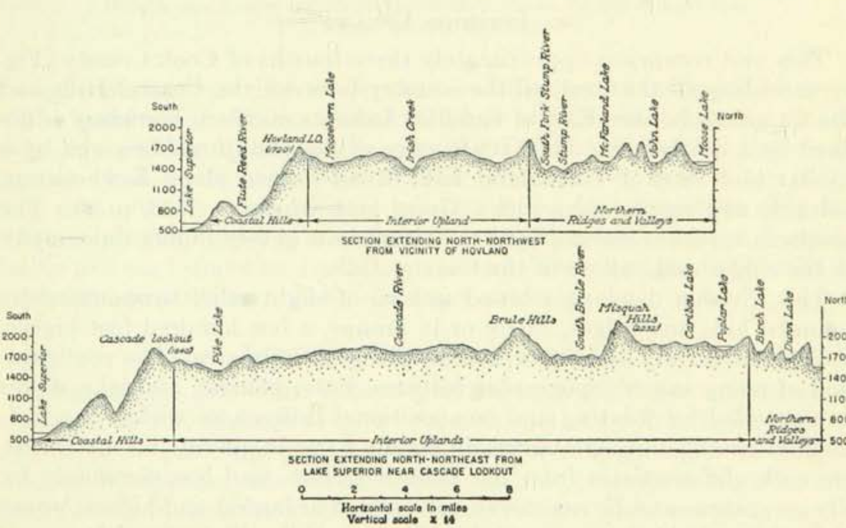

FIGURE 3. — Sections across Cook County showing physiographic divisions.

slope to the south, that are held up by diabase sills and resistant layers in south-dipping Keweenawan flows and intrusives. At places, erosion by glaciers moving parallel to the strike has obscured or destroyed this asymmetry. This division contains one of the two principal displays of "sawtooth mountains" in Cook County, discussed in early writings (Upham, 1894, p. 25). Two kinds of "sawteeth" exist, those formed by two or more cuestas viewed along the strike, and those formed by one or more strike ridges dissected by transverse streams (Irving, 1883, pp. 141–42). This second situation presents a "sawtooth" appearance when viewed from an angle oblique to the strike and is the more common type in the Coastal Hills.

The larger rivers of this division flow mostly in courses transverse to the major ridges and valleys. They descend to Lake Superior with gradients of 130 to 320 feet per mile (Leverett, 1929, pp. 10–11) through deep, narrow rock gorges containing rapids, cascades, waterfalls, plunge pools, and breached potholes.

Elevations in the Coastal Hills range from 602 feet at Lake Superior to approximately 1840 feet on the highest summit (Cascade lookout). Sharpest relief is at Leveaux Mountain near Lutsen which rises to 1570 feet within 1.25 miles of Lake Superior, but the average relief is closer to 250 feet per mile. The fact that Tofte, Leveaux, Cascade, Eliason, and Hovland Forest Service lookouts are located within the Coastal Hills testifies to their height above surrounding territory.

Interior Upland

This unit comprises approximately three fourths of Cook County (Fig. 3), including, in the west, all the country between the Coastal Hills and the Canadian border. East of Gunflint Lake its northern boundary is defined by a north-facing bluff at the edge of the Duluth gabbro, and by a similar bluff east of McFarland Lake Road formed along Keweenawan volcanic and sedimentary rocks (Grout and Schwartz, 1933, p. 89). The southern border is marked by a transition from gently rolling topography to the ridges and valleys of the Coastal Hills.

This division displays a broad upland of slight relief surmounted by rounded hills and ridges, singly or in groups, a few hundred feet higher. Valleys are mostly broad and shallow except in hilly areas. The configuration of many minor topographic features, water courses, and lake shores is controlled by jointing and compositional differences within the bedrock. Highest points are underlain chiefly by granophyre and intermediate rock, differentiates from the Duluth gabbro, and less commonly by Ely greenstone and Keweenawan volcanics. The largest and highest group of knobs and ridges composes the Misquah Hills (Plate 1) with several summits in the neighborhood of 2200 feet. Minimum elevation in the division is about 1300 feet and the average is close to 1500 feet.

Glacial debris is abundant in the southern part of the Interior Upland.

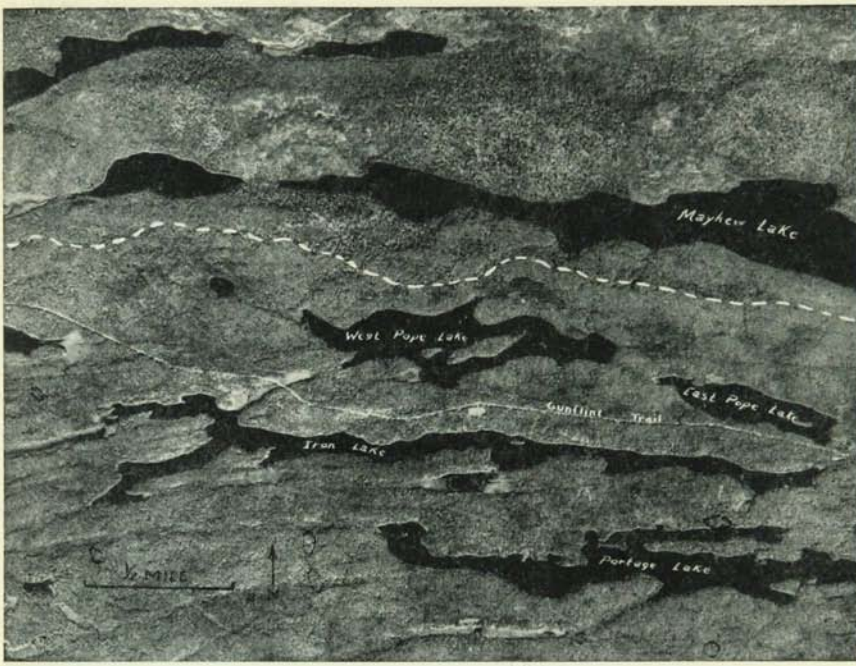

FIGURE 4. — Elongate lakes in Duluth gabbro area. The approximate contact between the Duluth gabbro and the Rove formation is shown by the dashed line. (U.S. Forest Service photograph.)

Irregularly pitted glacifluvial deposits are ubiquitous small-scale features of the landscape. Lakes are numerous, large, and in some instances rather deep, especially in areas underlain by the Duluth gabbro and Saganaga granite. Narrow, elongated lakes in Ranges 2 and 3 W., T. 64 N. are probably controlled by compositional banding in the Duluth gabbro (Fig. 4), which is also expressed in a topographic lineation farther west. A crude trellis pattern formed by the upper Cascade River and its tributaries is controlled by structures in Keweenawan volcanics.

Northern Ridges and Valleys

Long, narrow, lake-filled valleys lying between cliff-faced cuesta ridges characterize this division (Fig. 4). As early noted by Winchell (1879, p. 503) no other part of Minnesota of equal size is so rugged. The ridges are held up by diabase sills intruded into south-dipping Rove argillite and graywacke which underlie the intervening valleys. The "sawtooth mountains" of this division were formerly attributed to faulting (Winchell, 1879, p. 12; Lawson, 1893c, p. 33), but later detailed work (Grout and Schwartz, 1933, pp. 8, 14) shows that the ridges are not bounded by faults. East of McFarland Lake Road the south-dipping cuesta ridges, although

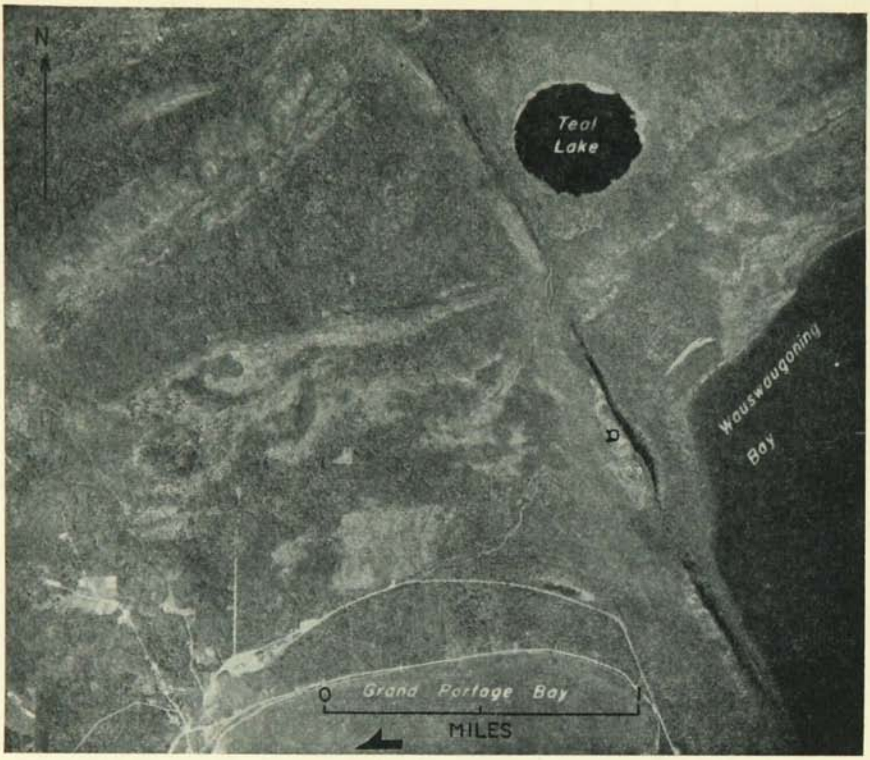

FIGURE 5. — Intersecting ridges formed by diabase dikes (D) and sills in the Rove formation north of Grand Portage. Road ¼ mile inland paralleling shore of Grand Portage Bay is on crest of Nipissing beach ridge 35 feet above Lake Superior.
(U.S. Department of Agriculture photograph.)

continuing, are less prominent, and the lakes are replaced by wide flat valleys floored with glacial lake clay. Eastward from Mineral Center a number of transverse dikes hold up narrow, round-topped ridges, giving a reticulated topographic pattern (Fig. 5). The shoreline of this division, between Grand Portage Bay and Pigeon Point, is island-fringed and highly irregular owing to deep bays and long, narrow projecting headlands.

Major topographic features in the Northern Ridges and Valleys are bedrock controlled, but the western valleys contain eskers and glacifluvial deposits with extremely irregular knob and kettle topography. Aside from the Pigeon River, streams are short and for the most part well-adjusted to bedrock structure. The abundant lakes in the western two thirds are long, narrow, and up to 150 feet deep.

Elevations range from 602 feet to 2100 feet, but most are between 1400 and 1900 feet except near Lake Superior. Relief is locally sharp, as for example near Grand Portage where Mt. Josephine rises 770 feet in one quarter mile. North faces of diabase cuestas rise abruptly 300 to 400 feet above the adjoining lakes and afford other examples of sharp relief.

Rivers

Among Cook County streams, the Pigeon River along the international boundary is largest by volume, flowing an average of 443 cubic feet per second, but the Arrowhead River drains the largest area within the county and is the longest. The Cascade River has the steepest gradient, descending 900 feet in its last three miles. Waterfalls, cascades, and rapids

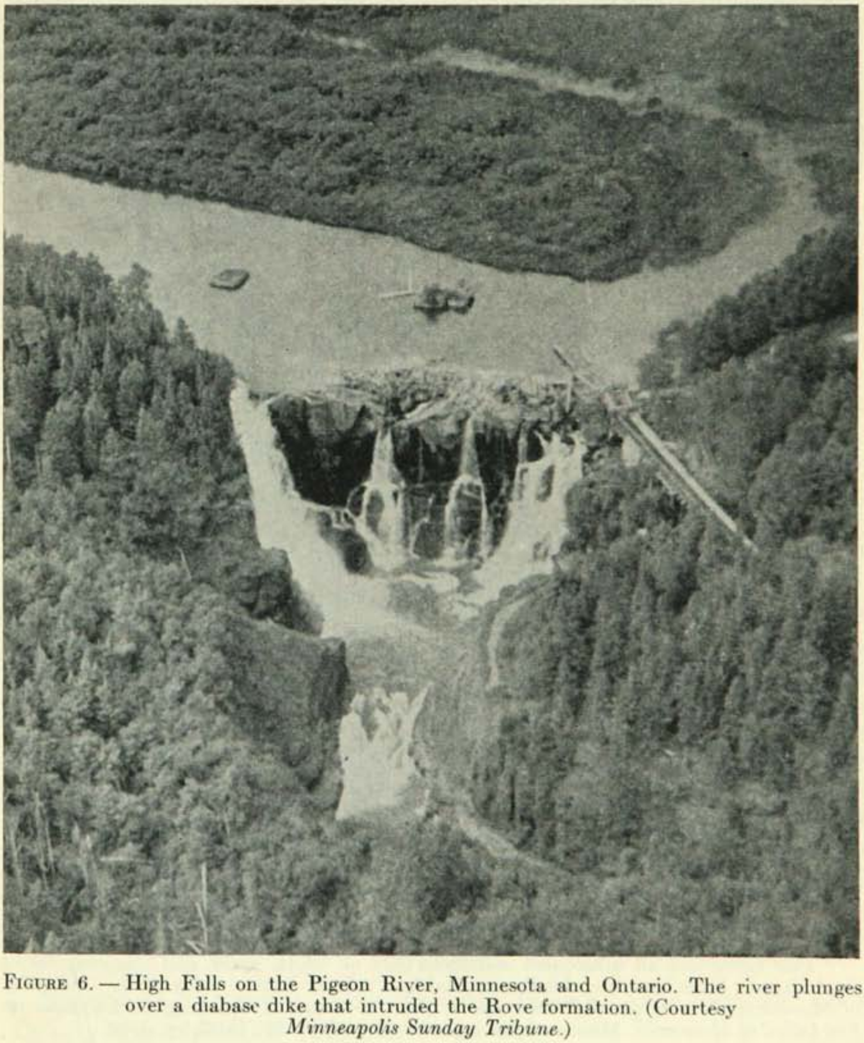

FIGURE 6. — High Falls on the Pigeon River, Minnesota and Ontario. The river plunges over a diabase dike that intruded the Rove formation. (Courtesy *Minneapolis Sunday Tribune.*)

abound, especially in the lower parts of streams flowing to Lake Superior (Fig. 6). Some of the higher falls are on the Cross, Cascade, Temperance, Poplar, and Arrowhead rivers. These are described by Schwartz (1925b, pp. 72, 80–90), who shows that they are determined largely by the differential resistance of Keweenawan volcanic layers dipping gently lakeward. Flows of amygdaloidal and vesicular lava weather quickly, are easily plucked by the fast-flowing water, and yield readily to ground-water sapping. Where such flows are overlain by massive dense rock, a sharp break in stream profile develops. Pothole Falls on the Arrowhead River differs from most, in that a large part of its water pours into a breached pothole. A small falls on Durfee Creek (Sec. 8, T. 61 N., R. 2 E.) pours over the face of the emerged Nipissing Lake cliff (Sharp, 1953a). A number of streams in the Northern Ridges and Valleys have waterfalls, formed mostly by diabase intrusions in the Rove formation (Fig. 6). Pigeon Falls on the Pigeon River, falling about 100 feet over a diabase dike, is said to be the highest in Minnesota (Schwartz, 1925b, p. 87, Fig. 10).

Lakes and Swamps

Cook County is pre-eminently a land of lakes and swamps. It borders Lake Superior, the largest body of fresh water in the world (F. C. Lane, 1948), and within its boundaries are lakes of many sizes and descriptions, totaling at least 1124 in number. The largest lying wholly within the county is Brule Lake, covering 4062 acres.* (For other large lakes see Appendix, Table A.)

Many Cook County lakes exceed 100 feet in depth. These are largely in areas underlain by Saganaga granite, Duluth gabbro, and Rove formation. The shallow lakes, three to ten feet deep, occupy areas largely mantled by glacial drift. Lakes with depths exceeding thirty to forty feet have, in summer, a thermal stratification in which the deeper layers are 20° to 28°F. colder than the surface water. Shallower lakes are almost uniform in temperature from top to bottom and in summer approach 70°F. Several Cook County lakes have dual outlets, and those of Brule Lake, one to the Arrowhead River and one to the Temperance River, have long been on record (Berkey, 1894, pp. 137–38; Grant, 1897, p. 408) but were not cited in a study of multiple outlets (Cabot, 1946).

On a geological basis Cook County lakes are divisible into five classes: (1) lakes lying wholly in bedrock basins; (2) lakes in bedrock basins but with depth of water increased through damming by glacial debris; (3) lakes in bedrock valleys dammed solely by glacial debris; (4) lakes within depressions in glacial deposits; (5) lakes dammed by shoreline bars (Frontispiece). For convenience a list of lakes (except very small ones), together with their location, is given in the Appendix, Tables A and B.

* This figure and all subsequent statistical data on depth, areas, and temperatures of Cook County lakes have been kindly supplied by Professor Samuel Eddy of the University of Minnesota. A more detailed discussion is given by James H. Zumberge in his paper on *The Lakes of Minnesota*, Minnesota Geological Survey, Bull. 35 (1952), pp. 1–96.

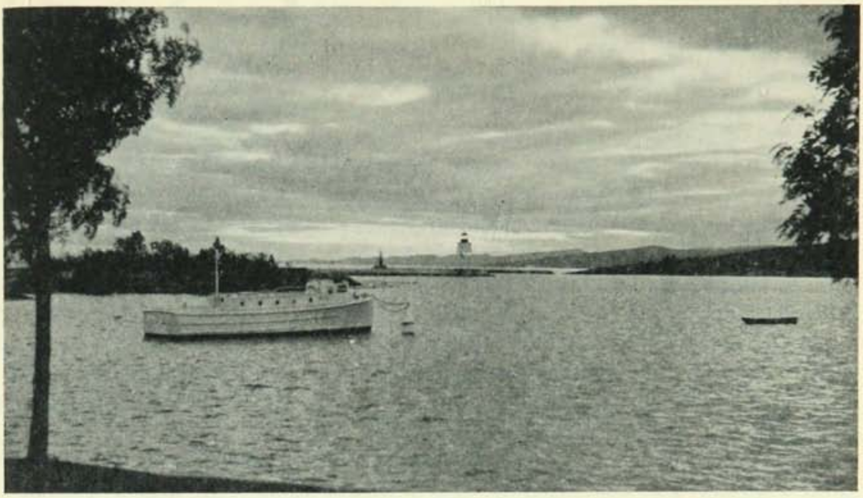

FIGURE 7. — Grand Marais Harbor, sawtooth hills in the background. (Courtesy Hamilton Photo Co., Ames, Iowa.)

Within the county, swampy areas are about as abundant as lakes. Some swamps were probably never lakes, but others seem to have been formed through vegetative and detrital filling of lake basins. Most interior lakes lack strongly developed shoreline features, being too small to have large waves or strong currents. Low wave-cut cliffs have been formed in soft material, and some small ice-shoved boulder ramparts occur.

Lake Superior, on the other hand, has a variety of erosional and depositional shoreline features. Wave-cut cliffs are moderately abundant and attain a maximum height of seventy-five feet. Small coves cut chiefly into red clay till and into jointed or amygdaloidal Keweenawan lavas are abundant (Frontispiece). Beaches are the principal product of shore deposition on Lake Superior. Most are pebbly to bouldery with only small amounts of sand, on the surface at least. Storm ridges up to eight feet above water level are found on some exposed beaches. Bars block the mouths of nearly all streams where water is shallow and debris is abundant (Frontispiece). The harbor at Grand Marais (Fig. 7) is in part the product of shoreline deposition, for it is enclosed on the east by a wide gravel bar by which a rocky offshore point is joined to the mainland. This rocky point was once an island lying a short distance east of the west headland of Grand Marais harbor. Shallow water and an abundance of debris enabled waves to construct a bar, essentially a tombolo, between the island and the mainland.

CULTURE

Because of its position along the north shore of Lake Superior, Cook County was visited by explorers at an early date. The Grand Portage gave access to what are now the international boundary waters, and these led in turn to a great interior area now divided between the United States and Canada. The earliest record was left by Sieur de la Verendrye, who crossed the portage in 1731. The site of Grand Portage Village was occupied by a post of the Northwest Company as early as 1783. The first permanent settlement was founded in 1882 at Grand Marais.

In spite of its early importance the county is only sparsely populated and is largely occupied by federal and state forest lands. The cultivated land is largely restricted to a narrow zone along the shore of Lake Superior as shown by Davis (1940). There were 125 farms in 1940 and the number has not changed materially since that time. A short growing season and distance to market have restricted agriculture, and it seems probable that this situation will prevail until the demand for land is greater than at present. Practically the entire county has been cut-over, active logging having begun about 1892.

Cook County does not have a common carrier railroad. Originally one from Canada was extended to the Paulson mine but was abandoned shortly when the mine failed to produce. A logging railroad entered the county from the west and extended as far as South Lake, but the rails were removed as soon as the bulk of the timber was cut.

The Erie Mining Company has completed a private railroad from the Mesabi Range to an artificial harbor called Taconite Harbor in T. 58 N., R. 5 W. This is the largest industrial development in the county and is a welcome addition to the economy of a sparsely settled area.

Fishing in Lake Superior has been important in the economy of the county but has tended to decrease in importance as other aspects of the economy have grown. With the extension of all-weather roads into the county about 1920, the resort business began to expand and is now of considerable importance; and growth continues without an end in sight.

CLIMATE

The climate of Cook County is that typical of a midcontinent location, modified by its situation on the north shore of Lake Superior whose waters remain cold throughout the year. Winters are long and cold with moderately heavy snowfall; springs are cold and late because of the effect of Lake Superior. The growing season is short, ranging from an average of 100 days inland to 125 days along the lake. The inland climate differs somewhat from that along shore. Winters are colder and snowfall is greater. Summer temperatures average higher inland. Along shore the temperatures range widely in summer depending on the direction of the wind.

The Weather Bureau, U.S. Department of Commerce, compiles records for Grand Marais, and has precipitation records for Grand Portage, Tofte along shore, and Gunflint Lake inland.

The mean annual precipitation at Grand Marais from 1931 to 1952 inclusive was 26.30 inches; this included the moisture from 63.8 inches of snowfall. The mean temperature for the same period was 38.2°F. The mean maximum was 47.0°F. and the mean minimum 29.5°F., the highest temperature 94 and the lowest −34.

Precipitation records show that, at the Pigeon River International Bridge which is just over three miles inland from the nearest point on Grand Portage, the precipitation for the period 1931 to 1950 was 32.5 inches as contrasted with 26.3 for Grand Marais.

Precipitation extends throughout the year but is heaviest in the summer months, with the maximum in June. The minimum month at Grand Marais is February, with a mean of 1.01 inches for the period 1931 to 1952.

The mean date of the last occurrence of a temperature of 32°F. at Grand Marais is May 23 and the first occurrence in the fall, September 29.

2. GENERAL GEOLOGY

The geology of Cook County is largely related to its position on the north limb of the Lake Superior syncline. Thus the younger rocks occur along the north shore of the lake and dip under the lake at angles generally ranging between 10 and 15 degrees. The oldest rocks occur in the northwest part of the county.

In a very general way the formations from Gunflint Lake southward trend in an east-west direction with many irregularities (Plate 2). The oldest rocks occur in the vicinity of Saganaga and Sea Gull lakes where the Ely greenstone, Saganaga granite, and Knife Lake group form a structural complex which is extremely difficult to unravel. Throughout the county, intrusion of later diabase, gabbro, granophyre, and granodiorite has complicated the structure. The rocks are all of Precambrian age, and there is no evidence of rocks of Paleozoic and Mesozoic age ever having been deposited. The Cenozoic is represented only by glacial deposits and recent sediments. Table 1 gives the geologic column currently in use. The general correlation of the Precambrian rocks of Minnesota has been discussed in detail by Grout *et al.* (1951).

ELY GREENSTONE

The Ely greenstone was named by Van Hise and Clements (1901) for outcrops in the town of Ely, Minnesota. Clements (1903) described the formation, and the maps accompanying his report show discontinuous greenstone areas from Ely to near Gunflint Lake. The relations of the greenstone in Cook County to the overlying formations also indicate that the belt of greenstone in Cook County is properly correlated as a part of the Ely greenstone formation.

The Ely greenstone occurs only in the northwestern part of the county as a narrow belt across T. 65 N., Rs. 4 and 5 W. (Figs. III and IV). This is south of Alpine and Sea Gull lakes and along the north side of the Gunflint iron-bearing district (Plate 2). The width of the belt ranges from a thin lens at the east end in Sec. 22, T. 65 N., R. 4 W. to a maximum of one and a fourth miles in Secs. 19 and 30. The greenstone is bounded on the north throughout most of its length by the Saganaga granite which intruded and metamorphosed the greenstone. The approximate extent of the greenstone belt is shown by Clements (1903, atlas).

The greenstone of the belt in Cook County has not been studied in detail except locally. It reprcsents an altered group of basic lava flows and subordinate fragmental and intrusive rocks. Normally there is very little evidence of its structure, but it is involved in an anticlinal structure

TABLE 1. GEOLOGIC COLUMN OF COOK COUNTY

	CENOZOIC
Pleistocene	
Recent sands, clays, etc.	
Wisconsin glacial drift	
	....unconformity....
	PRECAMBRIAN
	LATER PRECAMBRIAN
Keweenawan	
Upper	
(Beneath Lake Superior)	
Middle	
Granodiorites	
Duluth gabbro complex	
Logan intrusions	
North Shore volcanic group	
Lower	
Puckwunge formation	
	....unconformity....
Animikian	
Rove formation	
Gunflint formation	
Pokegama formation	
	....unconformity....
	MEDIAL PRECAMBRIAN
Knife Lake group	
	....unconformity....
	EARLIER PRECAMBRIAN
Laurentian	
Saganaga granites and related dikes	
Keewatin	
Ely greenstone	

in Secs. 7 and 18, T. 65 N., R. 5 W. because rocks of the younger Knife Lake group lie both north and south of the greenstone. Over the length of the belt to the east the structure appears to be monoclinal with the dip to the south, but there are faults of some complexity.

The greenstone where it is not close to the granite contact is a dense greenish, somewhat schistose rock, consisting largely of uralitic hornblende, feldspar and lesser chlorite, leucoxene and magnetite. Veinlets of calcite, chlorite, quartz, and pyrite cut the rock at places. Some of the greenstone shows spherulitic and ellipsoidal structure. The presence of much hornblende rather than chlorite indicates that most of the greenstone has been somewhat altered by the intrusion of the granite and by regional metamorphism.

About 1000 feet from the granite along the portage from Jasper (Frog Rock) Lake to Alpine (West Gull) Lake the effect of the granite becomes noteworthy (Schwartz, 1924b, p. 105). The granite there altered the

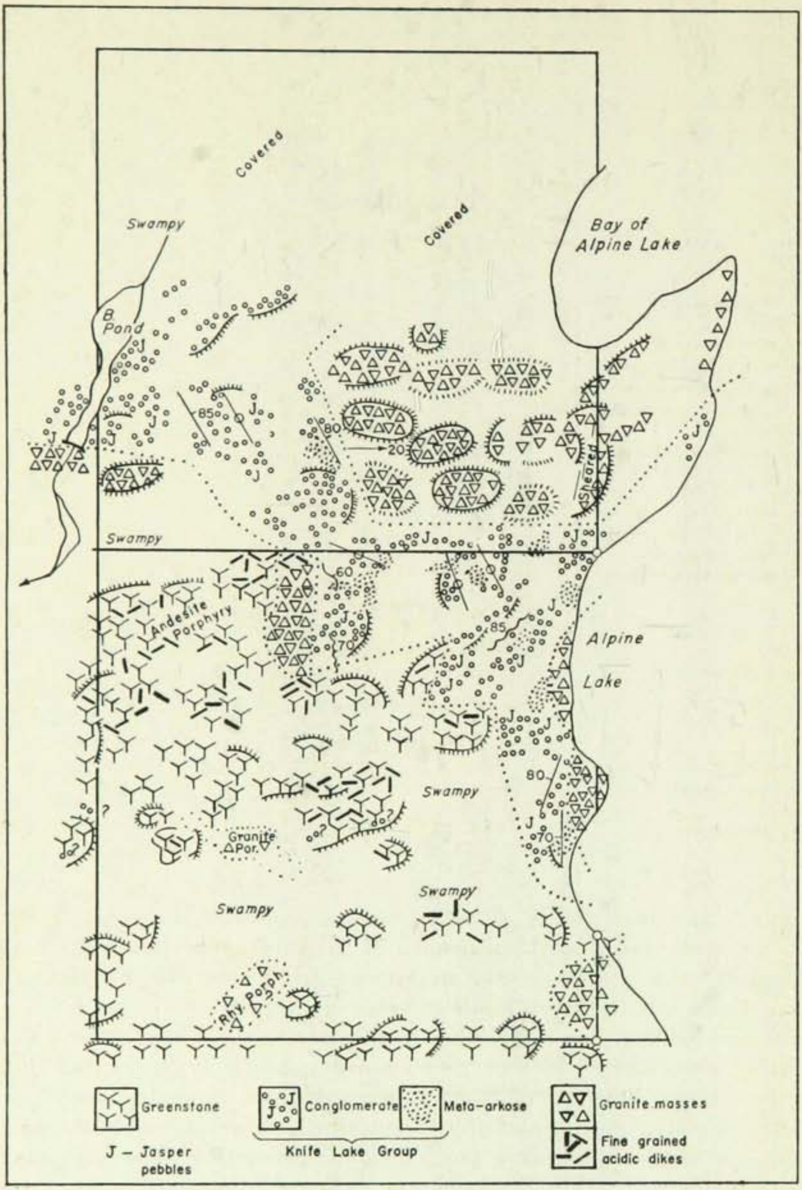

FIGURE 8. — Map of the east half of Sec. 7, T. 65 N., R. 5 W. showing the complex relations on the west side of the Saganaga batholith.

greenstone to plagioclase and hornblende with small amounts of magnetite, leucoxene, chlorite, epidote, and sericite. Within 50 feet of the contact the greenstone has been altered to a granular hornblende rock consisting of 50 per cent hornblende, 40 per cent plagioclase, and 10 per cent accessory minerals. At the contact the greenstone has become schistose and is essentially an amphibolite.

Some of the relations between the greenstone and the overlying rocks of the Knife Lake group are described by Gruner (1941, pp. 1585–88 and 1592).

SAGANAGA GRANITE

The Saganaga granite batholith is exposed in an area about 15 by 25 miles, across and along the boundary of Minnesota and Ontario, about 35 miles northwest of Lake Superior (Plate 2). It has been previously described in some detail by Grout (1929a, 1933). It is named from Saganaga Lake which occupies a large and deep topographic basin in the granite. The intricate shore line is estimated at 100 miles in length and islands add about that much more. Rock outcrops frequently occur and are washed clean by the waves to permit unusually good observation.

The main mass is a somewhat sodic hornblende granite with conspicuous quartz grains which under the microscope prove to be aggregates of smaller grains. This main phase constitutes 85 to 90 per cent of the mass. Toward the borders, except at the west side, the quartz becomes scarcer and hornblende more abundant so that the granite grades into a hornblende syenite. The border granite is estimated to make up 6 per cent and the syenite 3 per cent of the mass. There are some hornblendic rocks near the center in dikes, inclusions, and schlieren of uncertain petrographic relation. Chemical analyses of several facies of the batholith are given in Table 2.

Ely greenstone and later sediments, largely of the Knife Lake group, form the western contacts of the Saganaga granite where exposed, and there are some slates of uncertain age in the complex on the southeast, partly altered to biotite schist near the intrusion (Fig. 8 and Plates 1 and 2). Most of the complex on the south and southeast is covered by the Animikie iron-bearing formation and slate, dipping gently to the south. These beds overlap onto the granite, showing that the granite was exposed to erosion before Animikie time.

The sediments on the west side are of special significance because, at least in part, they derived their fragments from the granite. They lie tilted at steep angles and folded into close folds, but are firmly attached to the granite and to the greenstone walls. It seems evident that the granite and greenstone near the younger sediments were tilted with the sediments at the time of folding.

Foliation in the granite and syenite is not so marked as in the greenstone and gneiss, but is easily detected at many places, especially near the borders. The large quartz aggregates near the borders are flattened

TABLE 2. ANALYSES OF ROCKS OF THE SAGANAGA BATHOLITH *

Constituent	1	2	3	4	5
SiO_2	68.81	49.81	50.41	58.27	63.47
Al_2O_3	16.30	11.43	15.93	15.31	17.11
Fe_2O_3	1.95	2.77	6.13	1.51	.78
FeO	.75	7.22	5.36	3.82	2.36
MgO	.91	12.18	5.32	6.77	2.72
CaO	2.19	13.14	10.55	8.36	6.56
Na_2O	4.97	1.10	2.80	3.26	3.78
K_2O	2.29	.91	1.25	1.61	2.39
H_2O+	1.38	1.58	1.38	.72	.66
H_2O-	.12	.14	.12	.20	.18
CO_2	.30		.10		
TO_2	.22	.35	.40	.62	.30
ZrO_2	.02		.02		
P_2O_5	.07		.12		
S	.03				
Cr_2O_3	.02				
MnO	.02		.24		
BaO	.10		.02		
Total	100.45	100.63	100.15	100.45	100.31

1. Saganaga granite. Sec. 22, T. 65 N., R. 5 W. Analysts, F. F. Grout and A. J. Bauernschmidt.
2. Hornblendite. SE¼ Sec. 33, T. 66 N., R. 4 W. Analyst, George Ward.
3. Shonkinite. North of Saganaga Falls. See location of Analysis No. 1.
4. Porphyritic shonkinite. Island in Saganaga Lake. Sec. 14, T. 67 N., R. 4 W. Analyst, George Ward.
5. Quartz monzonite. Sec. 31, T. 66 N., R. 4 W. Analyst, George Ward.

* For original publication see Grout (1929).

and well oriented; others are spindles as much as an inch long and an eighth to a quarter of an inch in diameter. Hornblende needles are only vaguely oriented in the plane of foliation. At places, however, there are flattened dark inclusions, sheetlike swarms of inclusions, swarms and schlieren of quartz crystals.

The general internal structure of the batholith is shown in Figure 9. Only a part of the batholith lies in Minnesota, a somewhat larger part extending eastward and northward into Ontario. The international boundary follows a tortuous water route from Gunflint Lake to Saganaga Lake (Plates 1 and 2). The massive granite of the main mass forms rounded *roches moutonnées*. Joints are widely spaced and somewhat irregular in attitude.

As shown by Grout (1929a), and in less detail by earlier workers, the outcrops in Cook County consist mainly of a sodic hornblende granite with conspicuous aggregate grains of quartz (one eighth to half an inch across). An average of many thin sections showed about 28 per cent quartz, 25 per cent orthoclase, 35 per cent sodic plagioclase and 8 per cent hornblende. Accessory minerals include apatite, zircon, magnetite, and titanite.

Much of the border of the batholith, except the west side where erosion

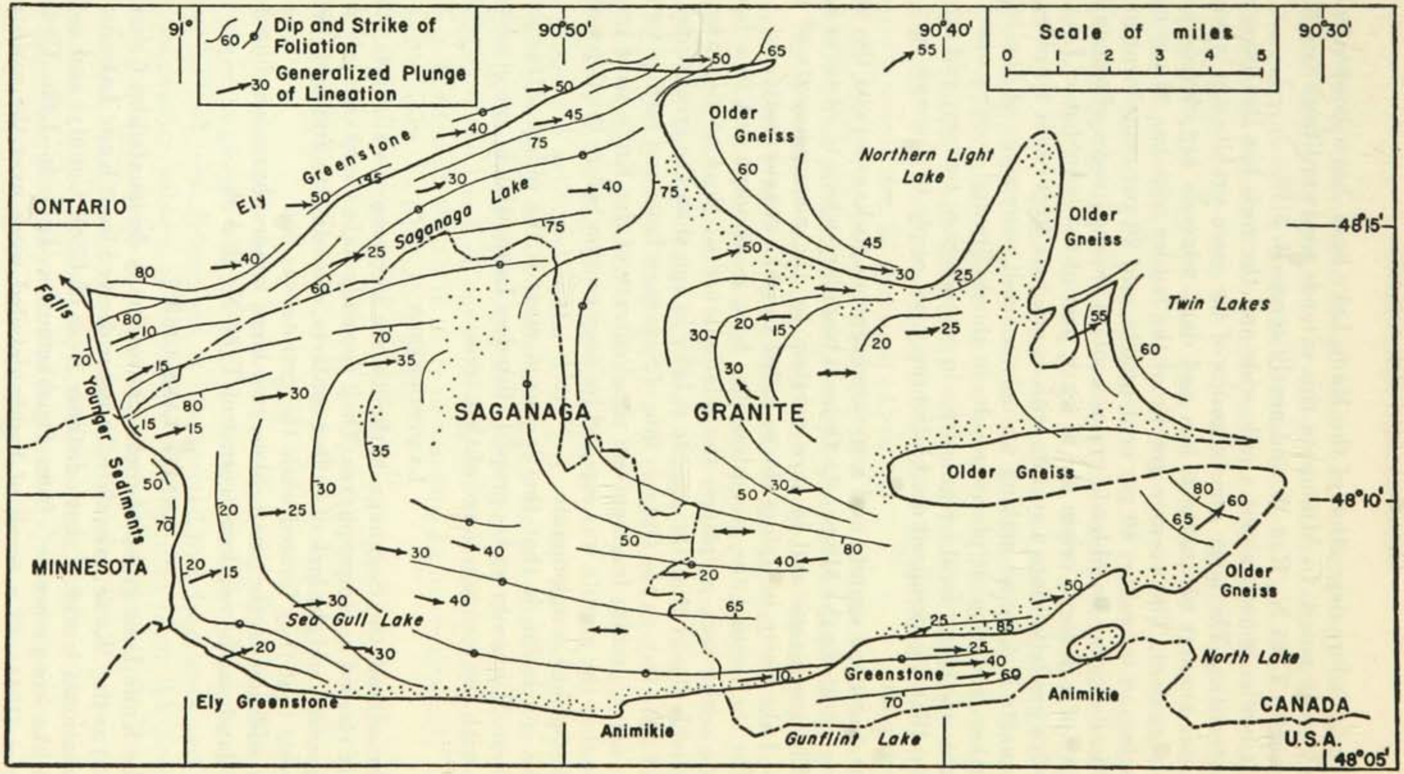

FIGURE 9. — Sketch map of the structure of the Saganaga batholith.

cut deeply before deposition of the Knife Lake beds, has a border facies as previously noted. In Minnesota this extends westward from Gunflint Lake across T. 65 N., R. 4 W. and nearly across R. 5 W.

This border zone is about a mile wide and the rock has the following characteristics. The large quartz grains of the main granite are lacking, the total amount of quartz is less and dark minerals are considerably more abundant. The average granite of the border zone has 25 per cent orthoclase or microline, 20 per cent quartz, and 20 per cent hornblende and biotite. Some hornblende grains contain residual cores of augite indicative of a deuteric origin for, at least, part of the hornblende. Locally there is a gradation into a syenite with as much as 30 per cent hornblende and quartz lacking or making up only a small percentage of the rock. A further gradation, at places, results in shonkinite and hornblendite.

There are many local irregularities in composition, texture, and structure so that a generalized description may not apply to the rock seen at a given point.

The Saganaga granite and associated igneous rocks comprise the only large mass along the Minnesota-Ontario boundary which is intrusive into the Ely greenstone and in turn overlain by the metasediments of the Knife Lake group including the so-called Ogishke conglomerate.

Near the contact the greenstone has been metamorphosed to a hornblende schist and, at places, the relations are so clear as to leave no reasonable doubt that the granite is later in age than the greenstone.

In Cache Bay on the Ontario side of Saganaga Lake and farther southwest, many granite fragments in conglomerate of the Knife Lake group prove that the granite was exposed by deep erosion before the deposition of the Ogishke conglomerate.

The conclusion is that the Saganaga mass is the oldest intrusion in northern Minnesota and is properly listed as Laurentian in age in accordance with the common usage of that term.

Lamprophyres

Throughout the Saganaga batholith are numerous small dikes, commonly classed as lamprophyres. They normally have sharp contacts with the granite, and the lack of chilled contacts, according to Sundeen (1936), suggests that they formed while the granite was hot.

In addition to the small dikes, two large lamprophyres are found on the islands in the northeast corner of T. 66 N., R. 5 W.

KNIFE LAKE GROUP

The Knife Lake group of rocks was originally designated by Clements (1903) as the "Knife Lake slate," a name derived from Knife Lake on the international border a short distance west of Cook County, and as the "Ogishke conglomerate" from Ogishkemuncie Lake in Lake County. Gruner (1941), as a result of highly detailed work over the main area of exposure of these rocks, found that there were nineteen recognizable units and suggested that they be called the Knife Lake series or group.

The outcrops of the Knife Lake rocks in Cook County are limited to the northwest corner of the county, mainly in T. 65 N., R. 5 W. but extending about a mile into R. 4 W., where the formation is so complex structurally that very detailed work by Gruner and Grout leaves the structure of some areas considerably in doubt, especially where exposures are poor. There are two principal belts of Knife Lake metasediments in Cook County. One lies on the west side of the Saganaga granite batholith mass and extends from Sec. 19, T. 66 N., R. 5 W. southward to Sec. 7, T. 65 N., R. 5 W. where it swings westerly into Lake County. The other belt extends along the north side of the Gunflint district in T. 65 N., R. 5 W. There it is bounded on the north by a belt of Ely greenstone. This unit of the Knife Lake group consists of a belt of agglomerates and conglomerates on the north side of the Gunflint formation, extending from a narrow zone in Sec. 25 westward to Sec. 19.

In the southwest corner of T. 65 N., R. 5 W. is an area of complicated structure which probably includes several units of the Knife Lake group, but the structure is so complex and the exposures relatively few that Gruner treated them separately under the name Agamok sediments. The rocks consist of slate, graywacke, and conglomerate layers.

They form a synclinorium lying between Ogishkemuncie Lake in Lake County and Gabimichigami and Howard lakes in Cook County. In Secs. 17, 18, 19, 20, and 21 of T. 65 N., R. 5 W., at Jasper Lake, is a U-shaped mass of intrusive andesite of uncertain age but probably later than the Knife Lake rocks. Another interpretation of such a mass might be that volcanism was active while the Knife Lake group was being deposited. The andesite could be a volcanic plug, and the pyroclastics of andesitic composition surrounding it could have come from the same source.

Eastward the trend of outcrops suggests that some metamorphosed beds in Canada on the north shore of Gunflint Lake are probably to be correlated with the Knife Lake group.

The Knife Lake group of sediments is younger than the Saganaga granite, as pebbles and boulders of the Saganaga granite with its characteristic large quartz grains occur in some of the conglomerate beds of the group.

Some conglomerate beds are rendered especially conspicuous by the red jasper fragments which occur in them. Although the source of this jasper has not been determined, it is suspected that fragments and usually subangular pebbles of red jasper were derived from the Archean Soudan formation which at present does not outcrop in the map area but may be seen near Tower, Soudan, and Ely. The patches of jasper pebble conglomerate in Sec. 7, T. 65, N., R. 5 W. show a highly complex distribution, suggesting that they came to rest on a very uneven erosion surface consisting largely of greenstone and Saganaga granite. The conglomerate, therefore, could be called a basal conglomerate which grades upward (now eroded) and westward into the more common meta-arkosite and graywacke.

ANIMIKIE GROUP

At an early date it was recognized by geologists that an important group of Precambrian rocks was younger than the Ely greenstone, the Knife Lake metasediments, and the granites at Saganaga Lake which intruded the older rocks. T. Sterry Hunt (1873) first used the term "Animikie" for these rocks as exposed in the Thunder Bay area east of Cook County. There is no doubt that in Cook County the three formations of the Animikie compose a conformable group. The Rove formation overlies the Gunflint formation, the two forming a natural group and overlying thin Pokegama quartzite except near the small western exposures.

The Animikie group in Cook County consists of rocks correlated with those of the Mesabi range as follows:

Mesabi Range	*Cook County*
Virginia formation	Rove formation
Biwabik iron formation	Gunflint iron formation
Pokegama quartzite	Pokegama quartzite

There is no direct connection between the Animikie formations of the Gunflint district and those of the Mesabi district, but there is little doubt that they were once connected and later separated by the intrusion of the Duluth gabbro complex. There are many inclusions of iron formation near the base of the gabbro mass and near Disappointment Lake there seems to be a remnant which is still in place.

In Cook County the Animikie belt extends from iron formation in Sec. 34, T. 65 N., R. 5 W., to a belt of iron formation and slate across T. 65 N., R. 4 W. (Plate 3). At Magnetic Bay, on the international boundary, the belt crosses to the Canadian side of Gunflint Lake but reappears on the Minnesota side of the boundary for a few miles near North Lake in T. 65 N., R. 2 W., Secs. 15, 16, 17, 19, 20, 21; the original site for quarrying "gunflints" for the flintlock rifles used by the early fur traders. The slates of the Rove formation overlie the Gunflint rocks, and the Rove is the only Animikie formation recognized from R. 2 W. to R. 7 E. along the boundary.

Pokegama Quartzite

The term "Pokegama quartzite" was first used by H. V. Winchell (1893) for the quartzite which lies below the Biwabik iron-bearing formation in the Mesabi district. It is well exposed at Pokegama Falls on the Mississippi River. Winchell also noted that this was the same as the quartzite at Gunflint Lake in Cook County, and this correlation has been sustained by all available evidence.

The occurrence of the Pokegama quartzite in the Gunflint district is rather insignificant. It occurs as a thin group of beds lying unconformably on the Saganaga granite and conformably below the Gunflint formation from the east side of Sec. 22, T. 65 N., R. 4 W. to Magnetic Lake just north of Gunflint Lake (Plate 3). It is possible that the quartzite lies unconformably on the Ely greenstone in Sec. 22, but outcrops must be small if any occur, and they are not found in the critical areas.

Noted by earlier writers, the quartzite of the Gunflint district was described by Broderick (1920) and has been frequently mentioned since by others. At the base, the formation usually consists of conglomerate made up of pebbles of granite, greenstone, and vein quartz. The conglomerate grades upward into a quartzite consisting of well-sorted quartz grains, enlarged by secondary growth. The conglomerate and quartzite together reach a thickness of at least 10 feet in Sec. 23. A small amount of chlorite gives the rock a greenish cast at places, and more or less green shaly material cements the pebbles in the conglomerate. The quartzite thins out before it reaches the exposures on the Gunflint Trail and none is recorded in Cook County farther west.

Gunflint Formation

The name "Gunflint formation" was first applied to the iron-bearing rocks near Gunflint Lake by Van Hise and Clements (1901). It is of interest to note that the earliest printed reference to iron ore in Minnesota was by J. G. Norwood in his section of a report by D. D. Owen (1852) describing the rocks near "Flint" (Gunflint) Lake. Gunflint Lake was named by the early explorers from the flint or chert obtained from the rocks and pebbles of its beaches to strike sparks, start fires, and ignite gunpowder.

The Gunflint formations in Cook County occur in a relatively narrow band from Sec. 34, T. 65 N., R. 5 W. eastward to Gunflint Lake. A small area of the formation also exists in Cook County on the south shore of North Lake in T. 65 N., R. 3 W. The formation also occurs along the north side of Gunflint Lake and at places far eastward into Canada (Gill, 1926 and 1927). The maximum thickness in Minnesota is about 330 feet, although much higher estimates have been published.

West of Sec. 34, T. 65 N., R. 5 W. into Lake County the Gunflint formation is overlain by or engulfed in the Duluth gabbro mass. Metamorphosed masses of magnetite with quartz show that the gabbro did break and include some of the iron formation. This evidence, plus the similarity of the Gunflint to the Biwabik formation of the Mesabi district, leaves no reasonable doubt that they belong in the same stratigraphic position. The Gunflint formation in Minnesota has been described in some detail by Clements (1903) and by Broderick (1920).

The details of the distribution of the Gunflint formation are shown on Plate 3. From Sec. 34, T. 65 N., R. 5 W. eastward to the center of Sec. 17, T. 65 N., R. 4 W., a distance of six and a half miles, the formation is represented by a narrow band ranging from a few hundred feet to a third of a mile in width. In Sec. 27 a fault causes the formation to be duplicated to the north in Secs. 21 and 22. Beginning at the east side of Sec. 22, the width of the outcrop increases greatly as a result of a much more gentle dip of the formation. A small anticline in Sec. 26 is responsible for the peculiar southward tongue of iron formation. Diabase sills also increase the apparent width of the belt of iron formation. Near the gabbro contact in Rs. 5 and 6 W., the Gunflint material has been recrystallized by the heat of the intrusion.

Broderick (1920) was the first to show that the Gunflint formation consists of four main subdivisions as does the Biwabik formation in the Mesabi district (Table 3).

Lower Cherty Beds. The basal beds have a small amount of conglomerate derived from the older formations. Much of the material, however, is chert and much has granule texture.

TABLE 3. SUBDIVISIONS OF THE GUNFLINT IRON-BEARING DISTRICT
(after T. M. Broderick)

Subdivision	Thickness in Feet
Top: Rove Slate	
D. Upper Slaty Beds	
No. 3. Limestone with silicates; practically no magnetite	10
No. 2. Thin-bedded quartz amphibole carbonate rock with graphitic slate in thin layers, alternating with bands of almost pure cherty silica averaging 1 to 2 inches in thickness; from 5 to 10 per cent magnetite	
No. 1. Similar to No. 2, with thicker and more lenticular cherty beds, some with white quartz septaria; from 5 to 10 per cent magnetite. Thickness of No. 1 and No. 2 together	140
C. Upper Cherty Beds	
No. 2. Massive gray cherty beds with algal structures in middle; little magnetite, but some conglomerate in places; beds of rich magnetite a few inches in thickness above and below the algal structures	20
No. 1. Wavy lenticular gray cherty beds, little conglomerate; thin beds of magnetite, becoming more frequent downward; less than 20 per cent magnetite	25
B. Lower Slaty Beds	
No. 3. Thin-bedded, fine-grained, cherty amphibole magnetite rocks; 25 to 35 per cent magnetite	45
No. 2. Massive cherty beds with a few slaty seams; bottom 8 feet marked by bands of white quartz and green amphibole; little magnetite	25
No. 1. Black thin-bedded slate; little magnetite	10–25
A. Lower Cherty Beds	
No. 3. Massive cherty beds, poorly exposed; about 20 per cent magnetite	10–20
No. 2. Massive cherty amphibole magnetite rock; about 50 to 60 per cent magnetite	5–15
No. 1. Basal beds, conglomerate, shale; massive chert with algal structures common	0–5
Bottom: Saganaga granite, Lower Huronian slate and conglomerate or Upper Huronian quartzite	

Bed No. 2 is the principal iron-bearing zone and has been the locus of most exploration. A sample of 12 feet of beds in Sec. 23 had, according to Broderick (1920, p. 429) an iron content of 38.23 per cent as the mineral magnetite. The important minerals in bed No. 2, aside from magnetite, are quartz and amphiboles. The rock is moderately coarse-grained and is much the same as the best taconite of the Mesabi district, but the bed is too thin to be useful at present.

Bed No. 3 resembles No. 2 but has a lower magnetite content and a correspondingly higher content of quartz and amphiboles.

Lower Slaty Beds. Bed No. 1 is a thin-bedded, black, graphitic slaty rock which breaks easily along the bedding and gives the rock its slaty character. The magnetite content is low and the thickness variable according to scanty outcrop and drill record data.

Bed No. 2 is a massive cherty rock which resembles the beds of the upper cherty division. The rock consists of magnetite, quartz, and amphibole.

Bed No. 3 is a very thin-bedded bluish to greenish black rock. The beds are persistent, the magnetite content is fairly high, but the texture is very fine-grained.

Upper Cherty Beds. The last bed described above grades upward into more massive cherty gray beds, consisting mainly of quartz plus magnetite with the magnetite layers wavy and irregular. The magnetite content is probably less than 20 per cent. The texture is moderately coarse as compared to the very fine-grained slaty material below it.

Bed No. 2 has thicker beds but rich magnetite seams are fewer, the total magnetite content probably less than 10 per cent. This bed contains peculiar black lines on a weathered surface which twist, turn, double back, etc. These are thought to be of algal origin. Associated with these structures is a conglomeratic bed in which the pebbles are composed of magnetite and chert. There are common granule textures in which the original material has altered to quartz, amphibole, and magnetite.

Upper Slaty Beds. These beds as a whole consist of fine-grained, thin-bedded rock with quartz, amphibole, and magnetite the principal minerals. There are numerous lenticular cherty beds between the slaty beds. In some outcrops, septaria and white quartz fill the cracks. Above the septaria beds the rock is somewhat graphitic and very thin-bedded. Near the top a bed of rocks become calcareous and calcic silicates such as diopside and actinolite were noted. The magnetite content of the upper slaty beds is probably less than 10 per cent.

Bed No. 3 is principally a carbonate rock but contains abundant silicates.

Goodwin (1956) recently divided the Gunflint formation into six facies, but this division is based on extensive work in Canada and does not necessarily fit the Minnesota part of the formation better than Broderick's fourfold division with eleven subdivisions.

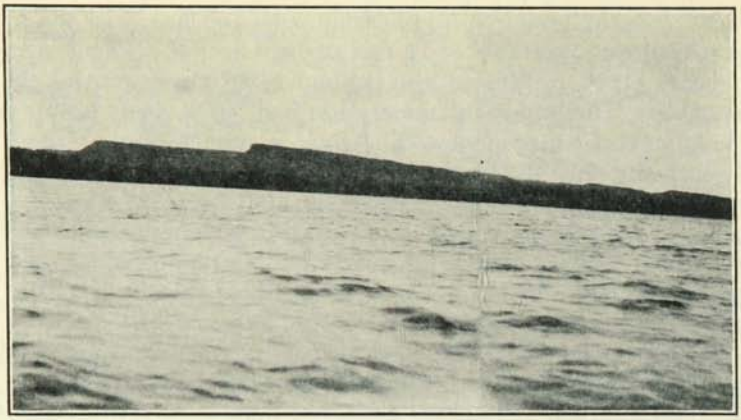

FIGURE 10. — Sawtooth topography of diabase sills in Rove formation. North Lake, looking east.

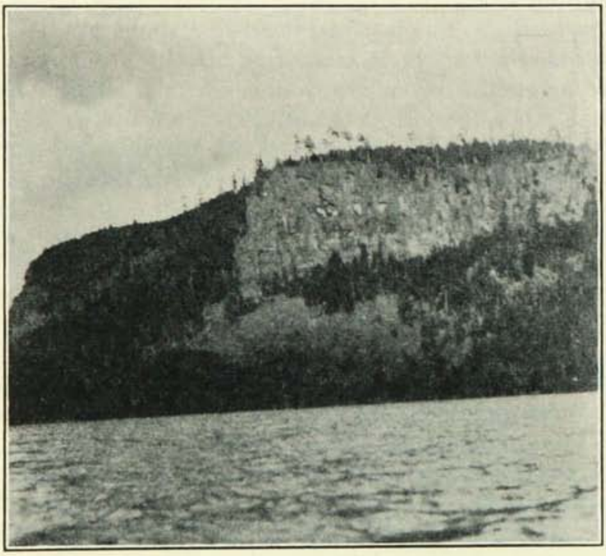

FIGURE 11. — Northward-facing diabase bluff with talus slope beneath. South shore of Clearwater Lake, T. 65 N., R. 1 E.

Additional data on economic aspects of the Gunflint district is given in Chapter 5.

Rove Formation

The Rove formation, originally called the Rove slate, extends from Sec. 26, T. 65 N., R. 4 W. eastward to Pigeon Point (R. 7 E.), and northeastward far into Canada. The term "Rove slate" was introduced by Clements (1903, p. 390) and was suggested by high bluffs of the slate on the south shore of Rove Lake in T. 65 N., R. 1 E., Cook County. Because much of the rock is not a true slate but an argillite, and the remainder largely graywacke and quartzite, the name was changed by Grout and Schwartz (1933) to Rove formation. A detailed description of the formation in Minnesota was published by Grout and Schwartz (1933) and reference should be made to that bulletin for further maps and details.

The formation in Cook County is exposed in a belt that ranges up to about five miles in width. The entire width is not, however, occupied by the formation but at most places is a combination of beds of the formation and sills of diabase. The best exposures are at the bases of cliffs, the north-facing escarpments of a series of saw-tooth ridges (Figs. 10 and 11).

The beds of the Rove formation lie conformably above the Gunflint iron-bearing rocks and are the equivalent of the Virginia formation of the Mesabi district. There is no reasonable doubt that the Virginia and Rove were once continuous, but intrusion of the Duluth gabbro has either engulfed or covered the beds from Babbitt to Sec. 27, T. 65 N., R. 4 W. in Cook County (N. H. Winchell, 1899, p. 470).

Throughout its extent in Cook County the Rove formation is intruded by a complex of sills and dikes of diabase (Fig. 12). The diabase is much more resistant to erosion than the beds of the Rove and stands out as ridges, whereas the areas of the Rove were more easily eroded and valleys resulted which are partly occupied by characteristic, elongate lakes (Figs. 4 and 13). The beds of argillite and graywacke are best exposed at the base of the cliffs which are capped by diabase. The normal dip is about 10–12 degrees to the south, so the cliffs face north and the gentle slopes are to the south, thus forming the so-called saw-tooth topography.

Much of the Rove in Minnesota consists of graywacke, grading from quartzite to thin-bedded argillite. The thin beds have been called slate, but most exposures differ from a true slate in the absence of secondary cleavage. Some secondary slaty cleavage has been noted locally.

The argillite and graywacke are nearly black in most fresh exposures but range to gray and green. The quartzites range from gray to nearly white and are locally red owing to the development of feldspar near some of the diabase intrusions. Because of the many intrusions and incomplete exposures no complete section of the formation is known. The thickness of the formation in Minnesota is therefore unknown but there is a total thickness of about 3000 feet. In a general way there is more argillite in the western area and more graywacke and quartzite to the east.

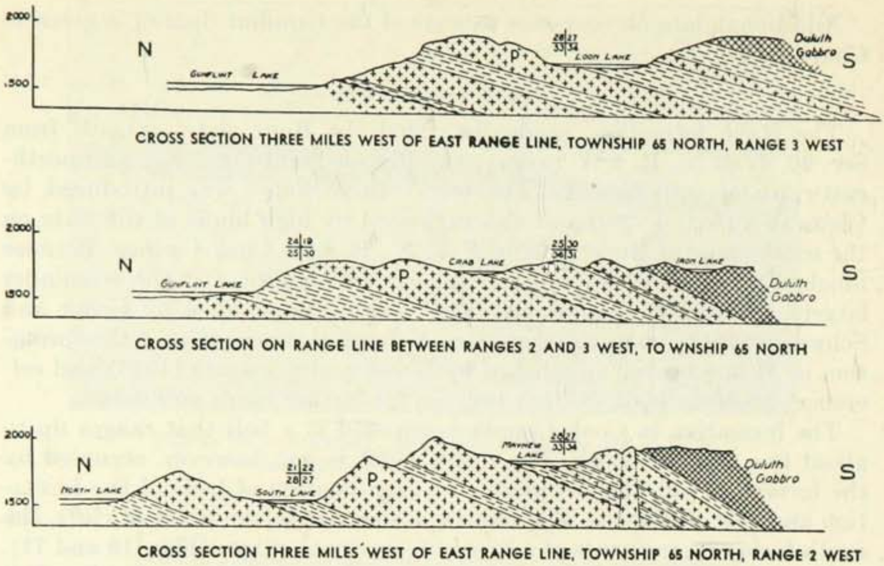

FIGURE 12. — Cross-sections of Rove formation area showing sills and dikes of diabase.

As a whole the formation is well-bedded and has an average strike of about N. 70° E., and most dips are between 4° and 15° to the south. Variations in structure are due largely to the intrusion of sills, dikes, and irregular bodies of diabase. Locally there are small faults, but detailed field work has indicated that these are of minor importance except in one area northeast of East Pike Lake, in Sec. T. 65 N., R. 3 E. Folds are actually rare, but in the Stump River valley, Sec. 10, T. 64 N., R. 3 E., a group of outcrops indicates an anticline and a syncline. Joints are numerous and at places conspicuous both in the argillite and graywacke facies. Many talus slopes consist of rectangular or rhombic joint blocks.

The argillite is dark gray to black and contains considerable graphite in the lower beds. The bedding is thin and slabs resemble slate. The texture is fine, angular fragments are from .01 to .05 mm. across, but these lie in a matrix of extremely fine-grained clays and carbonaceous organic matter.

The minerals are mainly quartz, feldspar, chlorite, biotite, muscovite, pyrite, and graphitic material. Very close to the larger diabase intrusions small "ghost" crystals and, less commonly, good crystals of cordierite have developed. Detailed descriptions of the petrography of the formation are given by Davidson (1926). At a few places limy concretions exist in the argillite, but these are unusual for the formation as a whole and are best seen at Pigeon Point.

Graywacke beds occur throughout the Rove formation and make up its bulk in the central part of the Minnesota belt. The graywacke occurs as relatively massive beds that commonly show regular, blocky jointing. The thinner and finer-grained graywacke beds represent a gradation from argillite to the thicker (1 to 4 feet) and coarser-grained beds. Structures such as ripple marks and cross-bedding do occur but are uncommon. The usual grains range from about .1 to .5 mm. in diameter, some being coarser than, some being as fine as, the grains in the argillite. Quartz constitutes 50 to 60 per cent of most of the graywackes with feldspar, biotite, chlorite, and graphite, and locally there are sericite, calcite, chert, hematite, leucoxene, and sulfides.

Although subordinate in amount to both argillite and graywacke, quartz-

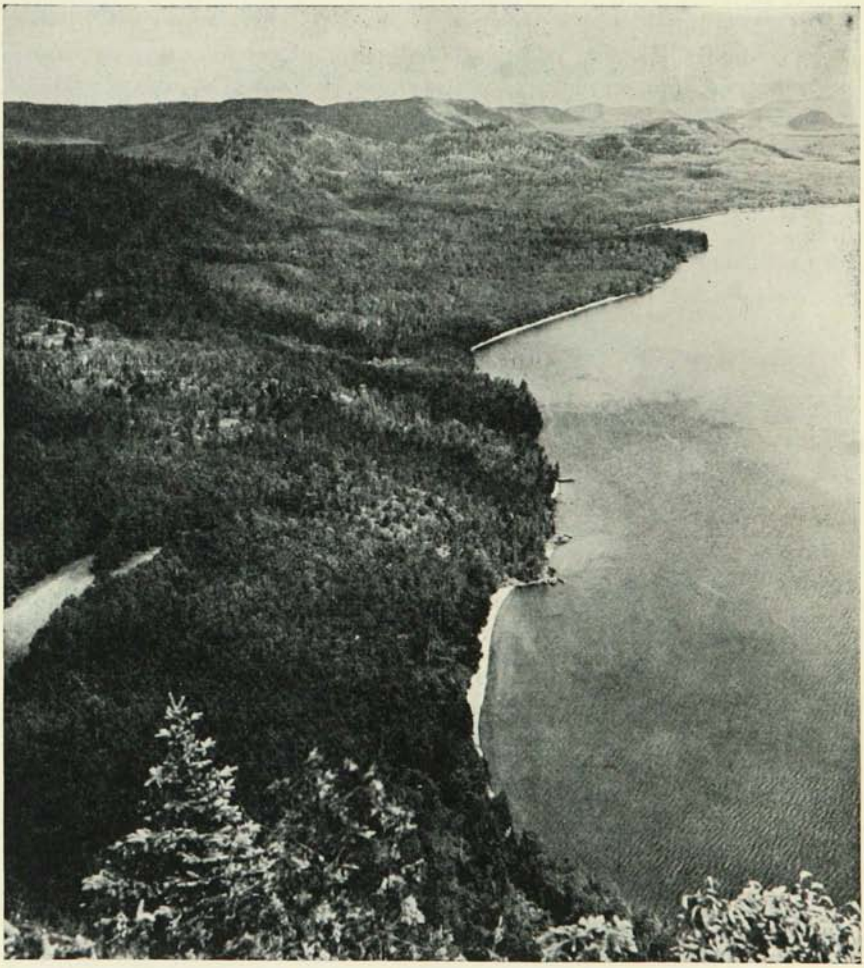

FIGURE 13. — Wauswaugoning Bay, Lake Superior. Rugged diabase hills in the background. Light area in forest to the left is an abandoned beach of Glacial Lake Duluth. (Photograph by Kenneth M. Wright.)

ites form conspicuous beds in the assemblage. Typically they form massive beds that may be several feet thick and grade into both graywacke and argillite. Where the quartzites make up an important part of the formation they form ridges resembling those formed by the sills. The quartzite beds are typically jointed and form rectangular blocks, one set of joints trending about north and south and the other east and west.

Chemical analyses of several of the main kinds of rock of the formation are given in Table 4.

Many outcrops from Stump River to Pigeon Point show a peculiar slabby parting with slightly curved surfaces. These beds are well exposed in Sec. 26, T. 64 N., R. 5 E. Their origin is uncertain and possibly attributable to the filling of shifting shallow channels. Rich (1951) states that irregular lenticularity of bedding is characteristic of his so-called "unda" environment, that is, repeated agitation of the water by waves and currents.

The quartzites consist of from 50 to 80 per cent quartz, plus chert, feldspar, and subordinate constituents.

The various rocks of the Rove formation have been mildly affected by the intrusion of the sills, somewhat more so by large dikes. The Duluth gabbro, being a very large mass, exerted a correspondingly greater influ-

Table 4. Analyses of Rocks of the Rove Formation

Constituent	1	2	3	4	5
SiO_2	64.77	82.15	81.86	64.45	57.77
Al_2O_3	14.45	5.37	9.87	17.36	18.52
Fe_2O_3	1.84	1.47	1.44	2.44	5.23
FeO	4.54	1.08	2.36	.30	2.52
MgO	2.34	2.22	.81	2.84	2.72
CaO	2.33	1.85	.46	.53	3.11
Na_2O	1.37	1.84	1.61	2.11	2.48
K_2O	5.03	1.09	.45	4.44	4.11
H_2O-	.07	.07		.76	.15
H_2O+	1.92	.74	1.43	2.41	2.11
TiO_2	.60	.35		.45	.89
CO_2	.41				
P_2O_5	.20				
SO_3	.60				
MnO	.11			C = 2.59	
Total	100.58	98.23	100.29	100.68	99.61

1. Rove argillite from the west end of Gunflint Lake, in the bed of the Cross River. Analyst, C. M. Chatard. See F. W. Clarke, U.S. Geol. Sur. Bull. 591, p. 73.

2. Analysis of graywacke phase. Sec. 33, T. 65 N., R. 3 W. South of Loon Lake. Analyst, D. M. Davidson (1926).

3. Quartzite from hill in NE¼ Sec. 25, T. 64 N., R. 6 E. Analyst, C. F. Sidener. N. H. Winchell (1900), p. 288.

4. Cordierite slate. West line Sec. 24, T. 65 N., R. 3 W. South of Gunflint Lake. Analyst, D. M. Davidson (1926).

5. Hornfels derived from sandy facies of the Rove formation. SE¼ Sec. 36 T. 65 N., R. 2 W. South shore of Birch Lake. Analyst, D. M. Davidson (1926).

ence, affecting rocks of the Rove formation along the contact for distances as great as half a mile. Within a few feet of the contact the argillites and graywackes have been completely recrystallized to a granular hornfels rock which has lost most of its original characteristics. The details of the contact effects are given in Minnesota Geological Survey Bulletin 24, pages 25 to 35.

KEWEENAWAN GROUP

The rocks comprising the Keweenawan group lie unconformably on the rocks of the Animikie or older groups, and occupy in a general way the central part of the Lake Superior syncline. The Keweenawan rocks are of great extent, thickness, and variety. The thick lava flows in the Northern Peninsula of Michigan, in Wisconsin, and in Minnesota form the most important part of the Keweenawan group, particularly in Minnesota where the sandstones of the Upper Keweenawan are not as important as on the Michigan-Wisconsin side of the syncline.

Puckwunge Formation

The term "Puckwunge conglomerate" was first used by N. H. Winchell (1897) and was later defined more precisely by him (1900). The name was derived from the Puckwunge (Stump) River, a tributary of the Pigeon River in T. 64 N., Rs. 3 and 4 E., Cook County. The formation is at the base of the Keweenawan rocks.

The Puckwunge is extensively exposed at intervals from the valley of the Stump River east to Lucille Island south of Pigeon Point in Lake Superior. An outcrop mentioned by many observers occurs on the north-

FIGURE 14. — Cross-bedding in sandstone of the Puckwunge formation near the village of Grand Portage. The massive rock above is diabase overlying the sandstone.

east side of Grand Portage Island. It is also well exposed in a cliff just west of the village of Grand Portage and on the south side of the Pigeon River in Ts. 63 and 64 N., R. 5 E.

The total thickness of the Puckwunge is uncertain because the lower contact is nowhere well exposed in Cook County. Exposures along the bluffs south of the Pigeon River indicate a thickness of at least 100 feet, and a maximum of 200 feet seems reasonable although only 50 feet is exposed at any one place. The Puckwunge formation has a gentle dip to the south and is structurally conformable to the Rove beds below and lava flows above, but a period of erosion intervened between the deposition of the Rove and the basal beds of the Puckwunge. The base of the formation is a conglomerate at the few fragmentary exposures which have been noted. The major part of the formation is a white to light buff sandstone. At places the sandstone is quartzite but, in general, it is of a much lighter color and less well cemented than the graywackes and quartzite of the Rove formation below. The sandstone is cross-bedded in all of the larger exposures (Fig. 14). The following measured sections are given by Thiel (1947).

SECTION OF PUCKWUNGE FORMATION IN SEC. 1, T. 63 N., R. 5 W.

	Thickness in Feet
Massive, fine-grained, gray sandstone with thin shaly layers	15
Thinly bedded, fine-grained, gray sandstone, slightly shaly	13
Buff, fine-grained sandstone	10
Gray shaly sandstone	12
Total	50

SECTION OF PUCKWUNGE FORMATION ON GRAND PORTAGE ISLAND

Dark gray, dense sandstone	2
Coarse, pink, arkosic sandstone	5
Coarse, gray, pebbly sandstone	3
Pink and gray calcareous sandstone	4
Total	14

NORTH SHORE VOLCANICS

Rocks of Keweenawan age form the greater part of the bedrock of Cook County, and lava flows form the most important group of rocks with the possible exception of the Duluth gabbro mass.

The volcanic group comprises rocks which consist predominantly of basalt and rhyolite flows, but there are interbedded tuffs, shales, conglomerates, and breccias. The lava flows vary considerably in character and have been classified accordingly.

The basic flows may be conveniently classified on the basis of texture as basalt, porphyrite, and ophite; and the acidic flows are mainly rhyolite.

Some basalt flows are remarkably red and in the field may be mistaken for rhyolite unless examined carefully with a hand lens. Under the microscope the diabasic texture is unmistakable, and red earthy hematite is disseminated throughout. The red color occurs commonly in the amygdaloidal parts of flows but some are red throughout. The oxidation evidently followed solidification of the flow but may have occurred during cooling in some flows. In others it may have occurred during hydrothermal alteration, at or just after the intrusion of the diabase dikes and sills or the gabbro.

Distribution. The lava flows and associated rocks of the North Shore volcanic group occupy approximately one half of Cook County. The principal belt lies between the coast of Lake Superior and the upper contact of the Duluth gabbro complex. This zone is from 12 to 15 miles wide in the western part of the county, narrowing gradually to a point at Hovland. Between the southern and northern areas of the gabbro a belt of flows extends from Brule Lake eastward to Lake Superior, between Hovland and Grand Portage. This belt is from one to three miles wide near Brule Lake and widens abruptly in R. 1 E. and eastward to a width of eight miles in the area east of Hovland. Within this area are many bodies of Logan intrusions in addition to the prevailing lava flows.

Basalt. The basalts are fine grained and consist mainly of plagioclase, augite (and other pyroxenes), lesser magnetite-ilmenite, and apatite. Most basalts contain olivine, but this is usually not abundant and frequently has been destroyed by alteration. Some basalts contain a small amount of interstitial quartz. The basalts range in color from black where unaltered, to brown, red, or greenish where altered. Detailed petrographic and chemical studies of the basalts have not been made. They seem remarkably uniform in character but doubtless further investigation would show that they are less uniform than preliminary studies indicate. Thin sections commonly show that the basalts have a very fine-grained diabasic texture, and they therefore differ from the ophites mainly in degree of development of the texture. The ophites are somewhat coarser grained than the non-ophitic facies and show a distinct aggregation of pyroxene to form the mottles, leaving the matrix somewhat more feldspathic.

Ophite. Ophitic flows are fairly numerous and are useful in distinguishing between flows. The ophitic texture consists of a faint to pronounced mottling of the rock, particularly on weathered surfaces. The mottling is produced by crystals of pyroxene of the size of an individual mottle which encloses smaller feldspar crystals. The size of the pyroxene crystals varies with the distance from the top and bottom of the flow, in other words from the cooling surfaces of the flow. This aids greatly in correlating outcrops of an ophitic flow and in determining the thickness.

The principal minerals of the ophites are the same as those of the basalts, but olivine is more abundant. The ophites are commonly reddish or brownish as a result of partial or incipient oxidation of iron.

Porphyrite. Several of the flows are porphyritic, and to these the term "porphyrite" is applied. They are designated on the maps by adding a

"P" to the symbol for basic lava flows. The phenocrysts are composed of plagioclase feldspar of an early generation. The ground-mass normally has a diabasic texture with many small feldspar phenocrysts. At least one flow near Mineral Center shows a clustering of the plagioclase phenocrysts, forming a glomeroporphyry. Thin sections show long lath-shaped crystals of plagioclase in a very fine-grained, slightly diabasic matrix.

All basic lava flows of Cook County are characterized by amygdaloidal and vesicular tops. The original vesicles are normally filled, thus producing amygdules. Fillings consist of quartz, calcite, chlorite, and lesser amounts of zeolites, thomsonite, heulandite, stilbite, mesolite, prehnite, laumontite, saponite, and iddingsite.

TABLE 5. ANALYSES OF RHYOLITES

Constituent	1	2
SiO_2	73.58	75.40
Al_2O_3	13.36	11.53
Fe_2O_3	3.78	4.06
FeO	.69	.22
CaO	.81	.16
MgO	.18	.16
K_2O	2.46	4.44
Na_2O	2.42	3.33
H_2O	1.14	.07
H_2O-	nd	.06
P_2O_5	nd	.04
MnO	nd	.03
TiO_2	nd	.31
Total	98.44	99.73

1. Rhyolite on beach east of Grand Marais. Analyst, J. A. Dodge. Final Report. Minn. Geol. and Nat. Hist. Survey. Vol. 5, p. 256.
2. Rhyolite from road cut on U.S. Highway 61, half a mile west of Grand Marais. Analyst, S. Fruehling. Unpublished Thesis. University of Minnesota. June, 1941.

The amygdaloidal rocks are usually highly altered. Olivine, for example, has been entirely converted into secondary minerals and the other minerals are more or less altered, resulting in a confused mass containing remnants of the original minerals.

Rhyolite. The predominant lava flows of the Keweenawan of the Lake Superior district are basalts and related basic rocks. At intervals, however, rhyolite flows are interbedded and locally are extensive, as in T. 61 N., R. 1 E.

Nearly all the rhyolite flows are red, and this has led to some confusion with the granophyres associated with the Duluth gabbro and the Logan intrusions. The red color is a result of extremely fine-grained hematite diffused throughout the feldspar. The rhyolites vary from fine-grained to porphyritic and consist mainly of red feldspar (anorthoclase), quartz, and minor amounts of other minerals that are mainly alteration products. The

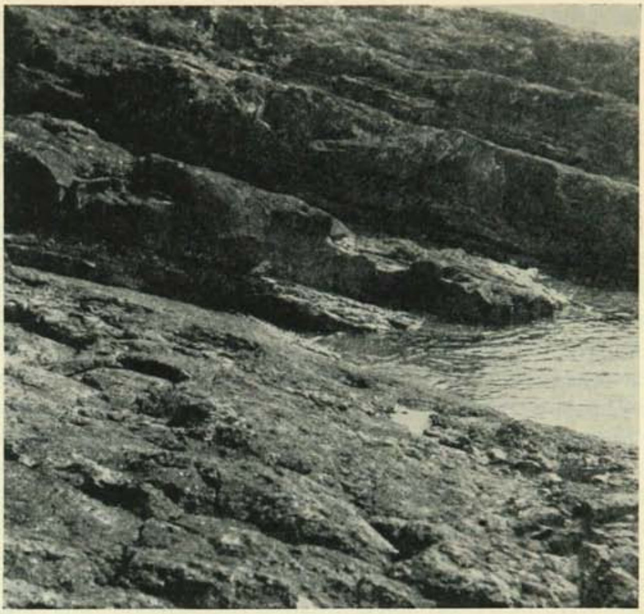

FIGURE 15. — Five flow units at Sugarloaf Point, Lake Superior.

texture of the rhyolites is commonly granophyric and differs from the typical granophyre of the intrusive rocks only in grain size. A few rhyolites have a simple felsitic or finely granular texture, but this seems to be the exception rather than the rule. Some rhyolites have extremely corroded phenocrysts of feldspar and quartz. The primary ferro-magnesian mineral is hornblende, but this has usually been altered to chlorite, epidote, and other secondary minerals. The rhyolite which crops out along the beach east of Grand Marais and in the gorge of the Devils Track River was analyzed by the early survey. Later a more detailed analysis of rhyolite from near the same area was made in the Rock Analysis Laboratory of the University of Minnesota (Table 5).

The rhyolites are extensively jointed into small blocks and normally form bays along the shore of Lake Superior with a gravel or cobble beach. The creeks and rivers erode steep narrow gorges owing to the ease of vertical erosion where the gradient is steep.

Flow Units. One of the most puzzling problems in mapping the Keweenawan flows of the north shore of Lake Superior is the determination of flow units (Fig. 15). When a lava flow advances (particularly a large one), thin sheets of lava may break out of the main mass and move ahead as a tongue to be shortly overridden by another sheet or tongue, and eventually perhaps by the main flow. Nichols (1936) refers to these small sheets as flow-units and defines a flow-unit as a tongue-shaped structure within a flow. The tops of the flow-units are vesicular or amygdaloidal, often more so than a large flow. Where exposures are extensive a flow-unit may be observed to join the main flow, as in the example in New Mexico described by Nichols (1936).

The difficulty in Cook County, and along the north shore in general, is that exposures are excellent along the water's edge and poor inland beyond a few tens of feet at most places. In any event, there are a number of places along shore where several very thin flows may be recognized by their amygdaloidal tops even though the individual flows may be only a few feet thick (Fig. 15). It seems unlikely that these could represent flows of any great extent and it is probable that they are, in fact, flow-units although it may not be possible to prove the case by detailed evidence. Exposures other than along shore are usually not sufficient to enable recognition of units as such except at a few places in river gorges.

Where the strike of the flows coincides closely with the strike or trend of the shoreline the same units may appear along shore for some distance, as in T. 58 N., R. 5 W. In Sec. 2 there are two groups of units separated by four flows. These groups may be recognized as far east as the Temperance River (Plate 5). The highest flow (No. 94) in the sequence is in Sec. 28, T. 59 N., R. 4 W., just west of Tofte. Other units occur in Sec. 13, T. 59 N., R. 4 W. The flows average much thicker east of R. 4 W., and no flow-units were recognized. The flow-units at Sugarloaf Point projecting into Lake Superior, in Sec. 29, T. 58 N., R. 5 W., are good examples (Fig. 15).

Structure. The over-all structure of the lava flows is a general dip toward Lake Superior with an average close to 15°. There are, however, a variety of local structures, even an apparent overturning in T. 61 N., R. 1 E. Where diabase and gabbro intruded the flows the structure has been much disturbed and, to some extent, obscured.

Interflow Sediments. The lava flows were evidently extruded at irregular intervals. Often one flow followed another very closely, the bottom of the later flow forming a tight contact with the amygdaloidal top of the previous flow. In other cases, where considerable time elapsed between flows, erosion set in and sediment was deposited over the top of part or all of some flows. It is probable that the sediment is usually lenticular and therefore traceable for only a limited distance, like some of the occurrences shown on Plates 4 and 5.

The principal examples of interflow sediments which were observed during field work are as follows, listed in order from east to west:

Location	Between Flows
Sec. 32, T. 62 N., R. 3 E.	38 and 39
Sec. 33, T. 62 N., R. 3 E.	40 and 41
Secs. 28, 34, T. 61 N., R. 1 W	58 and 59
Sec. 1, T. 60 N., R. 2 W.	64 and 65
Secs. 11, 16, T. 60 N., R. 2 W.	69 and 70
Sec. 12, T. 59 N., R. 4 W.	76 and 78
Sec. 18, T. 59 N., R. 4 W.	with flow 84

Along the northern part of Sec. 32, T. 62 N., R. 3 E. sandstone between flows is exposed in the small gorges of three creeks. Some of the sandstone is blackened near the basalt. It is probable that the sandstone exposures north of the center of Sec. 32 lie between flows 40 and 41.

The largest exposure and probably the thickest interflow sediment along the north shore of Lake Superior occurs at Good Harbor Bay in Secs. 28 and 34 of T. 61 N., R. 1 W. This may be as much as 500 feet thick and consists of red sandstone and shale, well exposed along U.S. Highway 61. The red color is caused by coatings of earthy hematite on the grains.

There is an outcrop of arkosic sand, and conglomerate, between flows 64 and 65 along the gorge of the Cascade River in SE¼ NW¼ Sec. 1, T. 60 N., R. 2 W. Cobbles of granite up to five inches long occur in the conglomerate.

In Secs. 11 and 16 of T. 60 N., R. 2 W. there are exposures of sandstone, partly tuffareous, along the lake shore and again nearly two miles to the west. Ripple marks indicate deposition in shallow water. Along a secondary road in NE¼ NE¼ Sec. 12, T. 59 N., R. 4 W. is a small outcrop of a lens of Keweenawan sediment between flows 76 and 78. Near the north line of Sec. 12, along the gorge of the Onion River, is a thick amygdaloidal conglomerate, in other words, fragments of amygdaloidal basalt in a fine-grained, sandy red matrix. East of the North Shore Hotel at the beach is an outcrop of amygdaloidal conglomerate with highly vesicular basalt fragments in a fine-grained red matrix composed of iron-stained angular fragments of various minerals. The material is probably a tuff. In general tuffs are remarkably rare for such a large assemblage of flows, but flows that pour out of fissures rather than volcanoes are usually lacking in extensive ash deposits.

Crevice Fillings. There are numerous examples of sandy and shaly fillings of crevices in the Keweenawan lava flows, including those in Cook County. These were noted by the early workers and reviewed briefly by Fackler (1941). These fillings occur near the top of the flows and are best seen along the shore of Lake Superior where wave action has exposed the contact of flows at many places. Good examples are in Sec. 1, T. 58 N., R. 3 W. and in the southwest corner of Sec. 19, T. 60 N., R. 3 W.

The clastic material is usually a reddish sandstone, composed largely of detritus derived from basaltic flows. The abundant grains include plagioclase, augite, magnetite-ilmenite, and fragments of basalt. The red color is a result of the presence of more or less earthy hematite. Where tuff beds occur between flows, the tuffaceous material may extend downward into the flows. The material in the crevices frequently shows good bedding corresponding in attitude to that of the flows.

Sequence of Lava Flows. The Minnesota shore of Lake Superior presents a unique situation with respect to the sequence of Keweenawan lava flows and associated sediments. Both near Duluth and at Grand

Portage Bay, 150 miles apart, the earliest known Keweenawan lava flows rest on the sandstones of the Puckwunge formation. At Duluth the strike of the sandstone and flows is about due north, and at Grand Portage about N. 75° W. The shore of Lake Superior has an average strike from Duluth to Grand Portage of about N. 55° E. Thus the flows strike at an angle to the coast both at Duluth and at Grand Portage, and the strike gradually becomes more nearly parallel to the coast until it is essentially parallel near Tofte in western Cook County. Sandberg (1938) has given a detailed inventory of the flows from the base of the Keweenawan at Duluth to Two Harbors; and Grogan (1940, 1946), from Two Harbors to Split Rock River in Lake County.

During the work in Cook County the sequence of flows was mapped along the coast where exposures, although not complete, are unusually good. Aside from occasional covered zones the principal interruptions are the Logan intrusions. The problems involved in working out a sequence and thickness of flows are discussed by Sandberg (1938) and need not be repeated here in detail. The fact that flows are lenticular, and that some exaggerated thicknesses result, is recognized. Flow-units likewise tend to increase the number of flows so that the actual outpourings from vents are probably much less than the count of flows, except that some covered areas and intrusions conceal flows that cannot be counted.

The thickness of the flows in the situation on the north shore of Lake Superior must be calculated by determining (1) the width of outcrop at right angles to the strike and (2) the dip of the individual beds. In Cook County dips of less than 10° or greater than 15° are not common. It is recognized that accurate determination of the dip of a lava flow is often impossible, but a general average dip can be arrived at without great difficulty.

The dip of all Keweenawan and that of some of the older rocks is almost entirely toward the central part of the basin of Lake Superior. Along the north side of Cook County the well-bedded Rove formation of Animikie age dips southward toward Lake Superior at angles generally between 4° and 15°. The general structure thus shows that the lava flows along the coast should have a gentle dip toward the lake, and no great error due to dip should be involved in calculating thickness. There are interflow sediments in which bedding is well developed, and these serve to check the estimates of the dip of the flows. The average of the estimated dips of 94 flows is 12°. Because accurate determination of the strike is difficult where the outcrops are limited to the immediate shore, some error is bound to result in determining the true horizontal width of the flows at right angles to the strike. On the average, however, these errors probably cancel out.

As shown by Table 6 and Plates 4 and 5, a total of 94 flows were mapped between the base at Grand Portage Bay and the highest exposed flow, which is on a small point about 2000 feet southwest of the dock at Tofte in Sec. 28, T. 58 N., R. 4 W.

TABLE 6. SEQUENCE OF LAVA FLOWS BETWEEN GRAND PORTAGE AND TOFTE

Flow Number	Map	Rock	Estimated Thickness in Feet
1	Pl. 4 HI	Basalt	240
2	" "	Basalt	135
3	" "	Basalt	120
4	" "	Basalt	80
5	" "	Basalt	250
6	" "	Basalt	480
–	" "	Diabase dike	247 (wide)
7	" "	Basalt	560
8	" "	Basalt	95
–	" "	Diabase dike	660 (wide)
9	" "	Basalt	275
–	" "	Diabase dike	478 (wide)
10	" "	Basalt	60
11	" "	Basalt	90
12	" "	Basalt	110
13	" "	Basalt	115
—	" "	Diabase dike	170 (wide)
14	" "	Basalt	335
15	" "	Diabase flow	250
16	" "	Basalt	45
17	" "	Basalt	110
18	" "	Basalt	550
—	" "	Diabase dike	25 (wide)
19	" "	Rhyolite	385
20	" "	Rhyolite	265
—	" "	Diabase intrusion	3400
21	" "	Rhyolite	225
22	Pl. 4 GH	Basalt	102
23	" "	Rhyolite	122
24	" "	Rhyolite	210
25	" "	Basalt porphyry	170
26	" "	Basalt porphyry	170
27	" "	Basalt porphyry	340
—	" "	Diabase sill?	1000±
—	" "	Duluth gabbro near Hovland	3500±
28	" "	Basalt	60
—	" "	Hovland diabase sill	1700
29	" "	Basalt	390
30	" "	Basalt	240
31	" "	Basalt	130
32	" "	Rhyolite	690
33	" "	Basalt	200
34	" "	Basalt	110
35	" "	Basalt	170
36	" "	Basalt	85
37	" "	Ophite	75
38	" "	Basalt	135
—	" "	Sandstone lens	
39	Pl. 4 FG	Ophite	275
40	" "	Basalt porphyry	65
—	" "	Sandstone lens	O–138
41	" "	Basalt	220
42	" "	Basalt	340
—	" "	Sandstone lens	1–24
43	" "	Ophite	250

TABLE 6 — *Continued*

Flow Number	Map	Rock	Estimated Thickness in Feet
44	Pl. 4 FG	Basalt	165
45	" "	Ophite	120
46	" "	Rhyolite	85
47	" "	Basalt	320
48	" "	Rhyolite	415
49	" "	Rhyolite	735
50	" "	Basalt	365
51	" "	Basalt	300
52	" "	Ophite	300
53	Pl. 4 EF	Rhyolite	1140
54	" "	Ophite	330
55	" "	Basalt	275
56	" "	Basalt	120
57	" "	Rhyolite	480
58	" "	Basalt	290
—	" "	Sandstone and shale	65
59	Pl. 5 DE	Ophite	500
60	" "	Ophite	190
61	" "	Basalt	105
62	" "	Ophite	155
63	" "	Ophite	70
64	" "	Basalt	40
—	" "	Sandstone	55
65	" "	Ophite	75
66	" "	Ophite	70
67	" "	Ophite	115
68	" "	Basalt	45
69	" "	Basalt	60
—	" "	Sandstone and shale	205
70	" "	Basalt	70
71	" "	Basalt	72
72	" "	Basalt	70
73	" "	Basalt	75
74	" "	Basalt	50
75	" "	Ophite	50
76	Pl. 5 CD	Basalt	70
77	" "	Basalt	120
78	" "	Ophite	57
79	" "	Basalt	80
80	" "	Basalt Unit	45
81	Pl. 5 BC	Basalt Unit	75
82	" "	Basalt Unit	80
83	" "	Basalt Unit	45
84	" "	Basalt Unit	20
85	" "	Basalt Unit	15
86	" "	Basalt Unit	40
87	" "	Basalt	65
88	" "	Basalt	55
89	" "	Ophite	70
90	" "	Basalt	55
91	" "	Basalt	80
92	" "	Basalt	80
93	" "	Basalt	80
94	" "	Basalt	80

West of Tofte the progress is down the sequence to flow 73 at the Lake County line. It is not certain, in fact improbable, that flow 73 at the county line is the same flow as flow 73 on the shore east of Tofte at Black Point in Sec. 11, T. 60 N., R. 2 W. The sequence of flows, the rock type, and the estimated thickness from Grand Portage Bay to the highest flow at Tofte are given in Table 6. The thickness of individual flows ranges from a few feet, doubtless a flow-unit in most cases, to a maximum estimate of 550 feet for a basalt flow (No. 7) and 735 feet for a rhyolite flow (No. 49).

Some of the estimated thicknesses may seem excessive, but on Keweenaw Point, on the south side of Lake Superior syncline, basic flows hundreds of feet thick have been cut by many diamond drill holes (Lane, 1911; Butler and Burbank, 1929). The Greenstone flow has a maximum thickness of 1300 feet in Keweenaw County, Michigan. Rhyolite flows, in accord with the viscosity of a highly siliceous lava, tend to be thick and many lens out in short distances along the strike.

The total estimated thickness of the 94 flows from Grand Portage to Tofte is 17,543 feet. Although several calculations have been made by different individuals at different times, the results have not varied greatly.

Diabase dikes totaling a width of 1593 feet, the Hovland diabase sill with an estimated thickness of 1700 feet, another sill or irregular diabase intrusion near Hovland of 1000 feet, an irregular diabase intrusion east of the Reservation River with an estimated thickness of 3400 feet, and the Duluth gabbro with a thickness at the shore of 3500 feet were all eliminated in calculating the thickness of the flows. In addition interflow sediments, mainly very lenticular and not all cropping out at the shore, aggregated 500 feet in thickness and these too were not used in obtaining the total for the flows.

One of the significant features of the assemblage of flows is the occurrence of rhyolite flows in the midst of a great series of dominantly basalt flows. The rhyolites are high in silica and alkalies (see Table 5). In the tabulating of flows and thicknesses, rhyolites aggregate 4752 feet or about 27 per cent of the total. This figure, however, is somewhat misleading because the rhyolites tend to form thick lenticular masses as previously noted. It therefore seems that an estimate of 10 to 15 per cent rhyolite and 85 to 90 per cent basaltic types would be more realistic.

Regional Relations of the Flows. The flows exposed in Cook County are an integral part of the Keweenawan flows of the Lake Superior district but they by no means represent the major part, even with the great thickness shown by the tabulation.

As previously stated (and as shown on Plate 5), the sequence of flows is reversed west of Tofte. At the Cook-Lake county line, flow 73 is exposed on the shore of Lake Superior. As previously noted, it is not certain that this correlates with flow 73 east of Tofte but it is the twenty-second flow down in the sequence from the highest, Number 94 near Tofte.

Calculations show that the 22 flows aggregate 1244 feet, which compares with 1143 for the first 22 flows east of the top flow, i.e., Number 94. This is a surprisingly good agreement in view of all of the problems involved in estimating thickness.

An inventory of the flows from Tofte to the base of the Keweenawan at Duluth has not been completed because of difficulties in determining the sequence and thickness in eastern Lake County, but the major part has been completed and shows that there are many more flows in the western sequence and the estimated thickness is also greater. Following are the pertinent data:

	Number of Flows	Estimated Thickness in Feet
Sandberg (1938): Duluth to Two Harbors	209	20,539
Grogan (1940): Two Harbors to Split Rock River	70	2,565
Grout, Schwartz (unpublished): Cook-Lake county line to Split Rock River	20±	?
Grout (this report): Cook-Lake county line to Tofte ..	22	1,244
Total	321±	25,000+

Thus the number of flows recognized from the base at Duluth to the highest flow at Tofte is 321±, more than three times the number from Tofte to the base at Grand Portage although the estimated thickness is only one and a half times greater. The greater number of flows to the west possibly indicates that the source of the flows may have been in that area but this is speculative to say the least.

Another significant fact regarding the flows on the Minnesota coast is that only the lower part of the sequence is exposed, the upper part lying beneath Lake Superior. On Keweenaw Point the reverse is true; there the flows are interbedded with extensive conglomerates and the series grades upward through more and more sediment and fewer flows until only sediment is found deposited. The lower sequence of flows on Keweenaw Point is downthrown out of sight by the great Keweenaw Fault. The alternation of flows and conglomerates is exposed on the north limb of the Lake Superior syncline at Isle Royale. The scarcity of conglomerate and sandstone in the Minnesota sequence suggests that the flows of the Minnesota coast are stratigraphically below those of Isle Royale and Keweenaw Point which further enlarges the number of Keweenawan flows and their thickness. It should be emphasized that none of the estimates of thickness should be taken to mean that the flows actually piled up to anywhere near the estimated thicknesses. The lenticular nature of the flows is evidence that this is not so.

Duluth Gabbro Complex

Distribution. The Duluth gabbro complex extends at the surface as a crescent-shaped mass from Duluth to Hovland in Cook County. In Cook County the rocks of the complex occupy most of the west central and north central part of the county, forming a great sill-like mass which breaks up into two main irregular sills extending eastward past Brule Lake (Plate 2). The area underlain by the gabbro complex is approximately one third of the total area of the county.

The base of the mass is fairly regular and has a general eastward trend from the west county line at Gabimichigami Lake to a point near the center of T. 64 N., R. 3 E. where the northern sill ends. The south border is irregular and its trend varies greatly as shown on Plate 2, nevertheless from R. 2 W. the upper contact trends nearly due east to a point about five miles northwest of Hovland, where it swings southeast to intersect the shore of Lake Superior at Hovland.

Structure. The general shape of the Duluth gabbro complex as a whole is that of a great sill which dips gently southward. At its base the contact, insofar as can be determined, dips generally southward at angles ranging from 10 to 40 degrees. From the west county line eastward the gabbro at its base intruded and metamorphosed Knife Lake metasediments, Gunflint formation, and Rove formation. At the extreme east end of the north tongue the gabbro intruded the Puckwunge formation and lava flows of the Keweenawan.

The upper contact of the sill-like mass is poorly exposed over much of its length in Cook County, but available evidence indicates that it intruded mainly lava flows, both basalt and rhyolite. The same is true of the long area between the tongues from Brule Lake eastward.

Although a great deal of geologic work has been done on the Duluth gabbro complex in Cook County, particularly with reference to the titaniferous magnetites, it is far from completely mapped or understood. There are at least three primary reasons for this situation: (1) the very large area in a country practically devoid of roads and covered with an extremely thick growth of brush and trees; (2) the complexity of the rocks in many parts; and (3) a cover of glacial drift in some of the critical areas, particularly of the upper part.

The present treatment, therefore, is largely descriptive and does not pretend to explain the origin of the mass as a whole. It is a safe inference that detailed mapping of some of the complex areas will lead to even further subdivision in the classification of the rocks.

Gabbro Facies. The most important rock facies in the gabbro complex, at least from a quantitative point of view, is properly called gabbro. A detailed petrographic study of the variations of the gabbro has not been made for the Cook County area, but it is known that there are many varieties as is well shown by the titaniferous magnetite. There are all gradations from a normal type of olivine gabbro to almost 100 per cent magnetite-ilmenite.

The principal minerals of the gabbro facies are labradorite, augite, hypersthene, olivine, and minor amounts of hornblende, biotite, apatite, magnetite, and ilmenite. The principal variations are a result of changes in the proportions of the essential minerals plus magnetite-ilmenite. The most abundant facies is a gray, medium to coarse grained, granitoid rock consisting of a high proportion of labradorite and augite and small amounts of olivine and magnetite.

Some rocks in the gabbro mass have a high content of plagioclase and correspondingly less olivine and pyroxene. Such rocks are called feldspathic or anorthositic gabbro unless plagioclase makes up 90 per cent or more of the rock, in which case it is called anorthosite. There are limited bands of anorthosite and some inclusions evidently brought in with the gabbro magma. Most of the highly feldspathic rocks in the gabbro in Cook County, however, are properly called anorthositic gabbro.

The plagioclase feldspar ranges from labradorite to bytownite. Augite is abundant in the most widespread variety of gabbro while olivine is abundant mainly in the gabbro near the magnetite segregations and along the base of the mass.

Secondary minerals are common, though as a rule not abundant. They include biotite, hornblende, chlorite, actinolite, serpentine, leucoxene, and zoisite.

Many varieties of gabbro were recognized and described by N. H. Winchell and his co-workers (1900). The most detailed descriptions in recent times are by Grout (1950), in a study of cores from the test drilling of some of the titaniferous magnetites. The following descriptions are based on about 110 thin sections of drill cores from drill holes near Tucker Lake in T. 64 N., R. 3 W. and Smoke Lake in T. 63 N., R. 4 W., and abstracted from the report by Grout. The descriptions refer to the gabbro near the titaniferous magnetite deposits, and the rocks are somewhat more basic than for the gabbro mass as a whole.

At least 60 per cent of the rock is olivine gabbro and about 20 per cent more has abundant olivine. Some 10 per cent is gabbro without olivine. The normal olivine gabbro carries plagioclase, augite, olivine, and titaniferous magnetite. As one or the other of these four minerals ranges to high or low extremes, the rock name may be modified. If augite is absent, the rock is a troctolite, and 5 or 10 per cent of the cores near Tucker Lake are of this character. If plagioclase falls below 5 per cent, the rock is a peridotite, and again, 5 or 10 per cent of the cores near Tucker Lake are of this character. Similar rocks carry titaniferous magnetite at Poplar Lake and near Thomas Lake in Lake County. A few cores in this work proved to have abundant augite with no more than traces of olivine and feldspar; they are pyroxenites. Such rocks occur near magnetite at Poplar Lake and near Thomas Lake in Lake County. Any of these rocks that has as much as 40 to 60 per cent of iron ore minerals may be classed as a cumberlandite. Nearly 5 per cent of the cores consist of recrystallized fragments of older slates, lavas, and iron formations, altered by the heat of the gabbro and by reaction with the gabbro magma. These altered rocks, called hornfels, are sugary grained, finer than the gabbro, but commonly carry much the same minerals.

Mineral Descriptions. Plagioclase is labradorite or bytownite and is commonly fresh and euhedral to subhedral. It may enclose apatite in rather large euhedral grains, and at a few places does enclose rounded olivine grains. The twinning bands are wide, and are crossed by a second set of bands in only a few grains. A bending of bands as if deformed at high temperature was noted in perhaps 5 per cent of the sections. Along the contacts of plagioclase with ores, olivine, and augite, there are local rims or coronas — wormy intergrowths of the two minerals of the major contact. These are perhaps most conspicuous when the intergrowths are with opaque minerals, so that the pattern is in black and white. Probably one rock out of ten will show such intergrowths with plagioclase, but the same pattern appears with other minerals.

Most of the plagioclase shows only traces of alteration to sericite, kaolinite, zoisite, or carbonate. Some chlorite replacement occurs but is rare.

The pyroxene is commonly augite but there are, in the cores of this set, several containing orthorhombic pyroxenes besides augite. Some 5 or 10 per cent of the pyroxene shows a herringbone structure. Some of the augite grains are very large and enclose euhedral plagioclase, but the plagioclase is so abundant that it seems to divide the very large augites into several medium-sized grains. In three of 110 sections the pyroxene shows the extra "diallage" parting diagonal to the two common cleavages. There are a variety of inclusions (schiller in a few), and a few large grains of the iron minerals, which may be subhedral and, rarely, even euhedral. A few of the rocks rich in magnetite-ilmenite have a notably pink augite, suggesting that even the pyroxene carries considerable titanium, though it is not useful as an ore. Alteration attacks the pyroxene, producing amphiboles, chlorites, and other secondary minerals.

Olivine in the Duluth gabbro has been tested both chemically and optically, showing that it is highly ferruginous (hortonolite); the weathered grains, perhaps iddingsite, look like limonite in the hand specimen. The grains, having formed early, may be euhedral to slightly rounded, and enclosed in any of the other abundant minerals. Coronas are common along the olivine-plagioclase contacts. Olivine shows more variety of alteration products than the other minerals — serpentine, talc, iddingsite, carbonate, and fine-grained secondary magnetite.

The magnetite-ilmenite is nearly all later to crystallize than the plagioclase and olivine, and about simultaneous with the augite. It is clearly earlier than biotite, which commonly forms a reaction rim between magnetite and plagioclase. In one thin section the magnetite, euhedral in the coarse augite, had ilmenite inclusions in a lattice intergrowth and segregated in grains in or along the edges of the magnetite.

The proportion of magnetite and ilmenite may increase in any of the rocks named above, until there is enough to consider an ore. The rich ores commonly carry only traces of plagioclase, olivine, biotite, and alteration products.

Apatite occurs in small amounts in many sections. It may be euhedral or subhedral, and is associated with magnetite and less commonly with plagioclase. Several scattered spots near Poplar Lake and south of Tucker Lake seem to have more than 10 per cent of apatite. It is in coarse grains, and amounts to 20 per cent of the rock in only one or two of the sections. The apatite-rich rocks may not all be rich in titanium and iron — some are lean magnetite gabbro.

Sulfides are readily noted in more than four fifths of the rocks examined under the microscope. A few pyrite grains occur in magnetite grains, but most of the sulfides, including pyrrhotite and chalcopyrite, are alteration, or introduced vein-minerals, associated with hydrothermally altered rock minerals. Other introduced and shear-zone minerals include green and brown hornblende, actinolite, chlorite, serpentine, talc, zoisite, epidote, sericite, kaolinite, leucoxene, iddingsite, carbonates, and sphene.

The hornfels in fresh cores is typically banded and fine-grained, about like granulated sugar. Many grains are .1 mm. in diameter, many .2 to .3 mm., but the most common have .5 mm. grains dominant. Hornfelses carry anhedral pyroxene, with or without olivine, and magnetite-ilmenite in a colorless background of feldspar, which under crossed nicols proves to be in grains of about the size of the darker minerals. Rarely some large crystals enclose the sugary grains poikilitically. There are secondary chlorite and some scattered sulfides in nearly every hornfels studied. The hornfels from Gunflint formation may carry quartz, cordierite, fayalite, hyperthene, and a variety of amphiboles.

One of the hornfels specimens from near Gaskans Lake of the "Middle Range" shows a texture very much like that of the "granules" in taconite, slightly different from the common "sugary" hornfels, but the minerals have been changed by the heat of the gabbro in which it lies.

In petrographic summary, it should be noted that much of the gabbro area where no magnetite segregations are known shows a rather monotonous uniformity for a distance of one to several miles. In contrast, the rock near the magnetite segregations is conspicuously variable, and has hornfels, iron formation, pegmatites, troctolite, and the several extremes of gabbro varieties in rapid alternation. The difference suggests that the gabbro has been locally contaminated, but it is probable that a good deal of variety resulted from normal differentiation, even if there was no contamination.

Layering is characteristic of much of the gabbro complex (Grout, 1918a) and is conspicuous in Cook County, particularly in the area of magnetite bodies. The layering is responsible for a distinct linear topography as shown by the lakes in the gabbro complex of T. 64 N., Rs. 1 to 5 W. (Plate 2).

Intermediate Rocks. Within the Duluth gabbro complex there are many narrow zones which are intermediate in composition and other characteristics between the typical olivine gabbro and granophyre. Daly

(1917, p. 424), in his discussion of the geology of Pigeon Point, used the descriptive term "intermediate rock" for similar rock and this convenient term has been used in mapping the gradation between granophyre and gabbro in Cook County.

The intermediate rock is characteristically a mixture of dark gabbro and red patches which are somewhat irregularly distributed in the dark facies. A detailed study of this gradational material has not been made, but in part it seems to represent late-stage granophyric material in the gabbroic rock. At places granophyre clearly cuts the gabbro in the upper part of the intrusions, but some of the granophyre seems to have been present during crystallization or soaked into the gabbro. There are also rocks that have less calcic feldspars than the usual gabbro and perhaps classify as diorite. At Duluth, Taylor (1957, p. 57) found that some of the intermediate rock corresponded to granodiorite and allied species of rocks.

An important question regarding the Cook County exposures in the gabbro complex is whether the intermediate rock represents a physical mixture of rather typical gabbro and granophyre or a chemical gradation expressed by variations in composition of the feldspars, pyroxene, etc. This can be determined only by very detailed petrographic and chemical work. The field evidence to date suggests much physical mixing and possibly some alteration of gabbro in contact with later granophyre.

Granophyre. An important part of the Duluth gabbro complex consists of a red granite or granophyre, often called "red rock." This descriptive term is objectionable because there are red rocks in Cook County and elsewhere in the Keweenawan rocks of Minnesota which are of two distinct origins. The granophyre is a coarse-grained intrusive rock whereas the other common red rock is a fine-grained lava flow properly called "rhyolite," or to use a more general term, "felsite," but there are also red basaltic lava flows formed by the oxidation of iron-bearing minerals.

The granophyre of the Duluth gabbro complex in Cook County is abundant and widely distributed. For reasons which are not evident, granophyre is more abundant in proportion to gabbro than it is in the complex in Lake and particularly St. Louis counties. In general the granophyre occurs at and near the top (south side) of the main intrusion and the sills which extend eastward from Brule Lake. The intrusion is more or less one continuous mass in Rs. 4 and 5 W. from T. 61 N. to T. 65 N. (Plate 2), but the structure from T. 61 to 63 N. is complex, and only very detailed work will determine the exact relations, assuming that key outcrops can be found where necessary. It seems fairly clear, however, that the division of the complex into two main sills begins near the west county line as a belt of granophyre branches off from a very large area of the same rock in T. 63 N., R. 5 W. and trends northeast into the north side of T. 63 N., R. 4 W., and thence slightly north of east to the terminus of the sill in T. 64 N., R. 3 E. Throughout this distance (Plate 2 and township maps) the gabbro occupies the greater part of the sill except at the east end where the granophyre is approximately equal in outcrop area to that of the gabbro. Across T. 63 N., Rs. 4 and 5 W. the northern granophyre belt occupies a narrow and probably discontinuous belt not over a quarter mile in width, but in T. 64 N., R. 3 W. it expands at places to the width of a half mile and in R. 2 W. is fully a mile wide at the Misquah Hills. It is not as wide and has been mapped in less detail across Rs. 1 and 2 E., but in T. 64 N., R. 3 E. around Devil Fish Lake the granophyre is fully one and a half miles wide and is somewhat wider than the gabbro facies. The reason for this concentration at the east end of the sill is obscure, but the granophyre is known to have solidified late in the history of the gabbro complex and perhaps there was a tendency for the molten phase to work eastward as cooling of the main mass took place.

The granophyre belt of the south sill of the gabbro complex extends from the complicated area southwest of Brule Lake nearly due east from R. 3 W. to R. 3 E. where it lenses out in contrast to the expansion of granophyre in the north sill described above.

Granophyre by definition is a porphyritic granite that has a ground-mass with micrographic texture. In Minnesota and elsewhere large diabase or gabbro intrusions are commonly accompanied by a characteristic red granite which has irregular fine-grained intergrowths of quartz and feldspar.

The granophyre of the Duluth gabbro complex has been described many times. Material collected in the area and presented by Grout (1918a) has provided the basis for later descriptions and has been recently supplemented by Taylor (1957). The available descriptions of the granophyre in Cook County reveal little difference from those of the Duluth area.

The granophyre is characteristically red, as previously noted. This is caused by minute inclusions of red iron oxide in the feldspar. Clay minerals also cloud the feldspar in most specimens. The red color and granophyric ground-mass of intergrown quartz and feldspar are characteristic of the granites associated with the gabbro and diabase intrusions and serve to distinguish them from the numerous granites of other origins in Minnesota.

The feldspar is usually an intergrowth of orthoclase and albite which is variable in the different occurrences. Plagioclase is a constituent of many samples, particularly those that contain augite. The principal ferro-magnesian mineral is hornblende but, as a rule, this is badly altered to epidote, chlorite, and other secondary minerals. Specimens have been described which contained augite (Winchell, 1900, pp. 486, 481). Biotite has been noted but is relatively rare. Magnetite is a common accessory mineral and is normally more abundant than in ordinary granites. Miarolitic cavities lined with quartz crystals are fairly common in the granophyre, a minor characteristic in which they differ from ordinary granite.

Anorthosite in Gabbro. There are two different groups of occurrences of anorthosite in Cook County. The most extensive occurrences are in the Duluth gabbro complex; others, notably at Carlton Peak, consist of foreign blocks in the diabase intrusions above the gabbro (see pp. 55–56).

The most extensive and continuous occurrence of anorthosite is in a belt across T. 63 N., R. 3 W., south of Brule Lake from Sec. 26 to Sec. 30. There are, however, many widely scattered outcrops of anorthosite and anorthositic gabbro from the west county line eastward as far as T. 64 N., R. 1 W. The principal occurrences mapped are listed below, but there are doubtless many more.

Sections	Township
9, 16, 19, 20, 22, 29, 34	T. 64 N., R. 5 W.
1, 2, 3, 5, 8, 11, 12	T. 63 N., R. 5 W.
7, 8, 17, 18, 19, 20	T. 62 N., R. 5 W.
36	T. 64 N., R. 4 W.
1, 4	T. 63 N., R. 4 W.
8	T. 62 N., R. 4 W.
26, 27, 28, 29, 30	T. 63 N., R. 3 W.
1, 22	T. 64 N., R. 2 W.
15	T. 63 N., R. 2 W.
7, 18, 19	T. 64 N., R. 1 W.

Contact Metamorphism. It has long been recognized that the large mass of gabbro had a profound effect on the rocks which it intruded, particularly those which were engulfed. In fact many of the metamorphosed rocks were altered to resemble the gabbro so much that N. H. Winchell (1900, p. 71) was of the opinion that the gabbro was formed by "metamorphism carried to fusion and intrusive action." It was recognized, however, by Winchell (1900, p. 67) and his co-workers that muscovado (muscovadyte) represented pre-existing rocks of several kinds. The term "muscovado" (also spelled "muscovadyte") was used by Winchell and others to designate the fine- to medium-grained rocks which resulted from the metamorphism of greenstone, slate, graywacke, etc. The word was originally a name for brown sugar, which the metamorphosed rocks resembled, at least superficially. The modern term for these rocks is "hornfels." There are many descriptions of the metamorphosed rocks, but those by Schwartz (1924) and Grout (1933) are somewhat more detailed and apply to the entire gabbro mass, not Cook County alone.

In Cook County the Duluth gabbro is in contact along its base with Knife Lake metasediments, Gunflint iron formation, and Rove formation. The upper contact is with basalt and rhyolite lava flows which also form the country rock between the two eastward projecting sills (Plate 2).

The effects of gabbro metamorphism are best shown along the base where the gabbro is not complicated by the granophyre facies. The zone over which contact effects are recognizable ranges widely but, as a rule, does not exceed half a mile in width. Within a hundred feet of the contact the invaded rocks are completely recrystallized to a granoblastic texture.

The rocks of the Knife Lake group are in contact with the gabbro only near Gabimichigami Lake, for a distance of two miles; much of this area is water, however, so exposures are limited. The slates and associated rocks have been converted to granular aggregates of quartz, feldspars, chlorite, biotite, muscovite, magnetite, and traces of many other minerals.

The Gunflint formation is intruded by the gabbro along a distance of six miles (Plate 2.) Near the contact the iron formation has been recrystallized to a texture coarser than that found at a distance from the contact. The changes have been described in detail by Zappfe (1912). The important type of metamorphosed iron formation is termed a "cordierite-magnetite" rock by Zappfe, although it contains more fayalite than cordierite. Other minerals include bronzite, hedenbergite, grunerite, quartz, pyrrhotite and several others in minor amounts.

The metamorphism of the Rove formation has been described in detail by Grout and Schwartz (1933) and is only summarized here. The Rove formation is in contact with the base of the gabbro over a distance of 35 miles from the Gunflint district to the valley of the Stump River.

The first sign of change in the slate on approaching the gabbro contact, is the appearance of small siliceous seams that weather out as little ridges on the outcrops. Microscopic examination shows that the rock has been somewhat recrystallized. Within a few feet of the contact the rock is completely recrystallized to a granular texture with grains 0.05 to .7 mm. in diameter. Inclusions of slate and diabase at the contact have been recrystallized to the extent that recognition in the field is difficult. The minerals of the argillite, where metamorphism is mild are: quartz, biotite, graphite, chlorite, feldspar, pyrite, magnetite, hornblende, and sericite. Close to the gabbro, augite, hypersthene, and olivine appear and the feldspars have been cleared of alteration products. Cordierite occurs locally.

The lava flows at the upper contact of the Duluth gabbro complex are poorly exposed because of the cover of drift prevalent in that part of the county; moreover, the upper part of the gabbro grades into granophyre over most of its length. The metamorphic effect of the granophyre magma is much less pronounced and of a different character from that found at the contact with gabbro magma. This is a result of the fact that gabbro magmas are hotter than the acidic magma which formed granophyre; acidic magma is different in composition and gives off more water on solidifying. Where the lava flows at the upper contact consist of rhyolite, little effect can be noted. Basalt flows are reddened, and altered to a confusion of primary and secondary products. No detailed study of the changes was attempted due to the poor exposures.

A very complicated problem of alteration by the gabbro intrusion exists in the narrow belt of flows and associated rocks between the two gabbro tongues extending eastward from Brule Lake. At Brule Lake on both shores and islands there is an exceedingly complicated belt of basalt and rhyolite flows plus many intrusions of diabase, some highly porphyritic (see map of T. 63 N., R. 3 W.). In T. 63 N., R. 2 W. this belt narrows rapidly eastward to a simple narrow belt of basalt in Secs. 1 and 2 but farther eastward it widens; all the rock types noted above occur, though outcrops are sparse. In general the lava flows are not intensely altered within the belt. There are numerous basalt and diabase dikes and sills which intrude granophyre as well as the flows and are therefore of later origin. For some unknown reason the intrusions seem most abundant in the granophyre.

Inclusions in Gabbro. Inclusions of finer-grained rocks in the coarse-grained gabbro were examined by the geologists who first worked in the area, and the similarity to the rocks at the contacts of the intrusive mass was observed. Winchell (1900) recognized that the inclusions resembled the rocks at the contact which he called "muscovadyte" but, for the inclusions, he used the name "granulitic gabbro" or "norite." He considered the inclusions as transition stages toward the complete fusion which resulted in the gabbro (1900, p. 71).

In the field work leading to the present report the hornfels inclusions were mapped whenever observed. The significance of the inclusions in connection with the magnetic deposits was recognized by Broderick (1917, p. 670), and particular attention was paid to them in all subsequent field work (Grout, 1950).

One of the most striking facts about the inclusions is their distribution throughout so much of the gabbro. Most of these are so modified to hornfels by the gabbro magma that they resemble fine-grained gabbro. The sugary texture, grains .5 mm. in diameter, is characteristic of contact metamorphism of a complex mixture of minerals and ordinarily serves to identify the inclusions. Some of the older rocks are so completely different from gabbro that even long heating in the gabbro does not suffice to completely change the minerals. Thus, the cherts of the Gunflint iron-bearing rocks after inclusion in the gabbro recrystallize to quartz, which is a rare mineral in the gabbro. Cordierite and hypersthene also suggest altered sediments. It happens, however, that some of the Gunflint rocks are thin-bedded and the cherts are mixed with slaty and carbonate layers so that no free quartz remains in the hornfels included in the gabbro. The sugary-textured dark rocks contain a variety of silicates, and if the original rock carried much iron, the hornfels has abundant sugary-textured magnetite, some of it titaniferous.

The abundance of hornfels fragments (including these from iron formation) in the gabbro is very noteworthy. Along the lower (north) margin of the gabbro a careful mapping showed that an area two miles wide was nearly 15 per cent hornfels, containing fragments that were some hundreds of feet across. Near some of the magnetite inclusions the gabbro itself may be enriched in magnetite by contamination (Broderick, 1917, pp. 673–75).

One of the remarkable features of the hornfels inclusions is the fact that they are widely distributed, with concentrations in certain localities. A notable example is in the southern part of T. 63 N., R. 3 W., where extensive areas of hornfels associated with more or less magnetite occur across the township from Sec. 25 to Sec. 30 and westward for over a mile in T. 63 N., R. 4 W. There are also widespread occurrences over the entire township.

Some of the hornfels were derived from sedimentary rocks, as shown by well-preserved bedding. Some beds were iron-bearing and now exist as magnetite lenses. Much of the hornfels was probably slate, perhaps with beds of ferruginous slate, and represents a belt of either Gunflint and Rove formations or some other beds of unknown correlation. If the former, a mass of sedimentary rocks was lifted up by the gabbro intruding below as a sill-like mass.

Logan Intrusions

Throughout northeastern Minnesota, including Cook County, there are abundant intrusions of basic igneous rocks with some acidic differentiates at places. The abundant rock is diabase and gabbro, and it has been the custom to refer to the intrusions (except the Duluth gabbro), in a general sense, as diabase. These intrusions were examined by all of the early geologists, and there are many descriptions in the publications of the Minnesota and United States geological surveys.

There has been no single proper name used for these intrusions, which are most abundant in the Keweenawan and Animikie rocks both in Minnesota and adjacent areas in Ontario. The problem was discussed long ago by Lawson (1893b), and he was the first to definitely recognize the intrusive character of the sills. Lawson proposed that they be called the "Logan sills" in honor of Sir William E. Logan, a pioneer Canadian geologist. Actually the intrusions consist of sills, dikes and irregular bodies (Fig. 3) and therefore the term "Logan intrusions" is more precise.

Distribution. The Logan intrusions are abundant throughout Cook County except within the area occupied by the Duluth gabbro complex and the Saganaga granite mass.

Small but rather continuous diabase sills intrude the Gunflint formation from Sec. 35, T. 65 N., R. 5 W., eastward to Gunflint Lake (Plate 3). In the eastern part of T. 65 N., R. 5 W., where the Gunflint formation is exposed over a width of one and a half miles, two principal diabase sills are recognized.

The sills in the Gunflint formation are closely related, and possibly are continuous with some in the Rove formation in Sec. 25, T. 64 N., R. 4 W. From Sec. 25 eastward there is a continuous series of diabase sills and lesser dikes in the Rove formation to Pigeon Point, a distance of sixty miles. To the north of Pigeon Point the intrusions continue eastward in Canada to Port Arthur and beyond. From Gunflint Lake eastward to

North and South Fowl lakes the diabase occurs mainly as sills with numerous irregularities. In the Grand Portage area (Rs. 5, 6, and 7 E.), however, the intrusions become more irregular, and dikes as well as sills are important. There are also examples of one passing into the other along the strike. The diabase intrusions in the Rove formation are described in Minnesota Geological Survey Bulletin 24, to which reference should be made for greater detail.

The greater part of west central Cook County is occupied by the Duluth gabbro complex. In general this excludes the diabase sills and dikes which are actually closely related bodies, and locally there are basic dikes which cut the gabbro and related granophyre. At Brule Lake the gabbro divides into two east-trending sill-like tongues. Between these tongues from Brule Lake eastward is a belt of flows and numerous porphyritic diabase intrusions, mainly sill-like. These are well shown on the maps of T. 63 N., Rs. 2 and 3 W. The eastward extension of this belt contains some diabase, but it is much less abundant than to the west. The north finger of gabbro ends in T. 64 N., R. 3 E., and the area of lava flows and associated diabase intrusions expands to cover the area from Lake Superior to the belt of Rove formation and intrusions noted above. In that area small and large diabase dikes and sills as well as irregular intrusions are numerous and have a conspicuous control of the topography (Figs. 12 and 13). One particularly large diabasic gabbro mass extends nearly five miles along shore from the Reservation River eastward (Plate 2).

South of the Duluth gabbro and associated with rocks at the west side of the county, a belt of lava flows and associated diabase intrusions extends to the shore of Lake Superior, a distance of 15 miles. This broad belt narrows eastward to end where the south finger of gabbro reaches Lake Superior at Hovland (Plate 2). Part of this area consists mainly of lava flows, but at other places diabase, porphyritic diabase, and associated intrusive rocks are abundant. The township maps show the details of distribution.

Topographic Expression. The diabase and associated intrusive rocks are generally massive and fairly resistant to erosion, and therefore tend to form prominent ridges or hills. Good examples are the "saw-tooth" ridges between the lakes from Gunflint Lake to Pigeon Point, Hat Point, and Mt. Josephine between Grand Portage Bay and Wauswaugoning Bay, Carlton Peak, and Leveaux mountain. Carlton Peak is a mixture of diabase and huge anorthosite inclusions.

Diabase sills form ridges that follow the strike of the rocks which have been intruded, whereas ridges formed by dikes may trend in any direction, often at right angles to the strike of the country rock. In the area between the Reservation River and Grand Portage Bay, Gryc (1942) described three prominent parallel ridges formed by dikes which strike northeasterly. One starts as an offshoot of the large sill east of the Reservation River, has been traced for ten miles to the Pigeon River, and is known to extend beyond into Canada. Near the south line of Sec. 36, T. 63 N., R. 5 E. this dike splits into a sill to the north and a dike to the south (Grout and Schwartz, 1933, Pl. 20). The dike lenses out a mile and a half to the east and the other leg becomes the sill which continues into Canada.

Dikes are responsible for some waterfalls, notably the High Falls and Partridge Falls of the Pigeon River. The sills dip southward in conformity to the regional structure of the Lake Superior syncline; hence the sill ridges usually have a steep bluff on the north and a gentle dip-slope to the south, resulting in the "saw-tooth" effect so conspicuous in several parts of the county. Columnar and blocky jointing is well developed in many sills, and erosion is partly controlled by the fractures. A good example is the point on the east side of Grand Marais harbor.

Petrography. The rocks of the Logan intrusions consist predominantly of diabase, porphyritic diabase, and gabbro, but there are lesser amounts of basalt, granophyre, and rocks which are intermediate between diabase and granophyre. In addition there are inclusions of anorthosite distributed erratically in the intrusive rocks. Most of the diabases between Gunflint Lake and Grand Portage are remarkably uniform, but the Pigeon Point sill is differentiated into several rock types.

The texture of the rocks in the sills and dikes ranges from glassy and spherulitic at the borders of small masses to coarse diabasic and granular in the larger intrusions. The fabric in most of the intrusions is ophitic, that is, crystals of plagioclase feldspars are surrounded by pyroxene, dominantly as large single grains, and on weathered surfaces this results in a mottled effect. Probably 80 per cent of all the Logan intrusions in Minnesota are diabase and of those only 10 per cent have phenocrysts. Near the top of some of the larger sills are accumulations of phenocrysts of plagioclase up to six inches in length. These rocks are properly called "porphyritic diabase" but, for convenience, are often called simply "porphyry." On the maps the letter P is used in conjunction with the diabase symbol for the porphyritic diabase. Many porphyritic diabase sills have a trachytic structure formed by long plagioclase crystals oriented in a general way parallel to the long dimensions of the sill.

In a few of the porphyritic diabase sills there is a remarkable increase in feldspar phenocrysts near the top, and in extreme cases the diabasic matrix may make up only 10 per cent of the rock. The phenocrysts are nearly euhedral and in extreme cases form rock which is essentially anorthosite.

The essential minerals of the intrusions are, in order of importance, basic labradorite (60 per cent), augite, magnetite, ilmenite, olivine; locally, in the absence of olivine, there may be feldspars, quartz, biotite, and hornblende. Small amounts of interstitial quartz seem characteristic of many diabases. Accessory minerals include apatite, sulfides, and zircon; secondary minerals are chlorite, uralite, serpentine, talc, epidote, sericite, hematite, kaolinite, leucoxene, and carbonates.

The labradorite is commonly uniform as euhedral crystals in the diabase and the porphyritic diabase. In the granophyres the outer zones of plagioclase are more silicic. Augite (pigeonite) ranges from colorless to pink and purple, is rarely euhedral, but usually encloses the labradorite in an ophitic or diabasic fabric as noted above. Diallage also occurs in several of the intrusions.

The opaque minerals consist of magnetite and ilmenite except where the latter has been altered to leucoxene. Some dark gray diabases have an abnormal amount of magnetite and are partly granophyric groundmass.

In the granophyres and intermediate stages from typical diabase to granophyre, the silicic feldspars intergrown with quartz are probably variable. They are commonly red from minute inclusions of hematite, and dark owing to minute inclusions of clay minerals. The silicic feldspar that formed in continuity with zoned plagioclase is a potash-bearing oligoclase. Both albite and orthoclase occur in the typical red granophyres.

About half of the diabase specimens examined contain olivine and most of the others contain some quartz although a few have neither. In the coarser-grained diabase and gabbro both olivine and graphic intergrowths of quartz and alkalic feldspar occur in the same rock.

The larger dikes and sills usually show at least small areas in which quartz and alkalic feldspar occur as blotches or patches in the diabase or gabbro. A thin section of a typical example from a dike in Sec. 28, T. 63 N., R. 3 E. shows about 30 per cent basic plagioclase, 40 per cent augite as large, somewhat distorted crystals, and about 20 per cent granophyric material.

Detailed studies of the variations in the diabase are needed. Except for the Pigeon Point sill only one chemical analysis of the diabases in Cook County is available (Table 7). This is from a diabasic porphyry collected on Vance Lake, which is in the complex of flows and sills between the two arms of the Duluth gabbro.

TABLE 7. ANALYSIS OF DIABASIC PORPHYRY *

Constituent	Per Cent	Constituent	Per Cent
SiO_2	52.76	H_2O+	.93
Al_2O_3	19.15	H_2O-	.04
Fe_2O_3	3.75	CO_2	Tr.
FeO	5.70	TiO_2	2.38
MgO	2.35	P_2O_5	.32
CaO	7.96	MnO	.11
Na_2O	4.13		
K_2O	1.03	Total	100.61

* Fresh porphyry from SW¼ SW¼ Sec. 4, T. 63 N., R. 2 W. on shore of Vance Lake at mouth of creek. Analyst, J. J. Ivan.

Reservation River Diabase. There is an unusually large, coarse-grained diabase that extends along the shore from the Reservation River eastward for at least five miles (Plate 7). For convenience this is called the Reservation River diabase. This is a sill-like mass, but clearly cuts across the general strike of the flows. It was once thought to represent an eastern extension of the Duluth gabbro, but mapping for this report indicates that there is no direct connection. The rock is a black, medium-grained, diabasic gabbro. Plagioclase (labradorite) makes up about 50 per cent, and titanaugite fills in between the plagioclase grains. Magnetite-ilmenite is relatively abundant and chlorite, biotite, sericite, and leucoxene are alteration products. There is a local basic pegmatitic facies along shore in the northwest quarter of Sec. 35, T. 63 N., R. 5 E. which contains augite crystals over a foot long and plagioclase crystals up to six inches in length.

Pigeon Point Sill. Probably the largest of the many Keweenawan sills in Minnesota forms Pigeon Point in Lake Superior, at the extreme eastern tip of the state. This sill is about 500 feet thick but may locally reach 700 feet. It altered the adjacent rocks and was segregated into several distinctive kinds of rocks. For this reason it has become a classic locality to study and infer the processes responsible for the rock complex. There are many descriptions of the rocks but the most comprehensive are by Bayley (1893), Daly (1917), Grout (1928), and Grout and Schwartz (1933).

Pigeon Point is from four to six miles long, depending on the viewpoint, but the exposures of the sill extend six miles from the east side of Wauswaugoning Bay to the tip of the point in Lake Superior. The width of the point ranges from about 500 feet at Little Portage Bay to more than a mile at the base; the exposed part of the sill has a maximum width of half a mile.

The Pigeon Point sill is intruded into the sedimentary rocks of the Rove formation, which here consists of quartzite and argillite (slate). At the top the sill locally transgresses the quartzite beds, but the general structure is that of a sill as is well shown by the map. (See T. 64 N., R. 7 E.). The general dip is to the south at about 15°. There are minor intrusions, particularly at the top, but investigators have agreed that the several rocks of the sill are an intrusive unit.

The components of the sill from the roof down are as follows:

1. Chilled diabase containing at places phenocrysts of labradorite and small masses of anorthosite.
2. Granophyre (granite, locally called "red rock").
3. Intermediate rock.
4. Diabasic gabbro (main unit).
5. Chilled diabase.

1. The chilled upper facies consists of medium-grained diabasic gabbro. Labradorite is the feldspar and locally there are abundant phenocrysts,

some several inches long, and also masses of anorthosite. This unit grades downward into anorthosite and is broken by later granophyre.

2. Generally beneath the chilled zone, but cutting across it and intruding the quartzite above, is a sodic granite that contains abundant intergrowths of feldspar and quartz and thus is properly called a granophyre.

3. The granite grades downward into a narrow zone which is a mixture of the constituents of the gabbro and the granophyre. This is a hybrid but is best classified as granodiorite. It contains two feldspars, red and gray. Daly (1917) believed the rock ranges chemically from a monzonitic to a dioritic composition.

4. The main diabasic gabbro consists of labradorite, augite (diallage), olivine, and magnetite-ilmenite. In short it is a typical gabbroic rock. The texture is generally medium-grained and small lath-shaped feldspars are embedded in augite.

The floor of the sill is poorly exposed but the diabase near the floor is somewhat finer-grained, suggesting a chilling effect of the floor. Locally in the diabase intrusions there are exposures of rocks which seem intermediate, between diabase and granophyre. Commonly these consist of diabase with patches and interstitial granophyres (quartz and alkalic feldspar). In general the granophyre crystallized later than plagioclase and pyroxene, but there is a lack of clear intrusive relations in many occurrences. Locally there are pegmatitic and aplitic dikes and stringers, and these impregnate the diabase at the contacts.

Detailed studies of the petrographic variations in many of these rocks must be made before a complete understanding of their exact composition and origin is reached.

Anorthosite Inclusions. Inclusions of anorthosite, a rock composed of approximately 95 per cent plagioclase feldspar, occur in the Logan intrusions. These are conspicuous, especially at Carlton Peak and westward in Lake County. Lawson (1893) gave an early description, and they were described in more detail by Grout and Schwartz (1939).

The largest occurrences in Cook County are at and near Carlton Peak, but there are sporadic occurrences as far east as Wauswaugoning Bay, where rounded inclusions of anorthosite occur in a coarse-grained diabase on the shore in the southwest quarter of Sec. 25, T. 64 N., R. 6 E.

Carlton Peak is a huge rounded hill of anorthosite and diabase overlooking the surrounding area which rises gently from the shore of Lake Superior a mile to the south. There are outlying anorthosite masses in the lowland as shown by the map of T. 59 N., R. 5 W.

The peak consists of several large masses of anorthosite, clearly separated by diabase. Quarrying in recent years for the breakwater at Taconite Harbor has furnished additional evidence of the fact that large masses of anorthosite are surrounded on all sides by diabase. Since the several anorthosite masses vary somewhat in character, it is clear they were not derived by fragmentation of a single block. A tunnel about 100 feet long, on the south side at the base of the hill, encountered only diabase.

Other scattered inclusions are well exposed; one east of Caribou Lake is about 800 feet east of the north quarter corner of Sec. 1, T. 60 N., R. 3 W., possibly north of the line in Sec. 36. The inclusion is about thirty feet in diameter and occurs at the crest of a hill known as Caribou Lookout. A knob of anorthosite fifty feet across is surrounded by low outcrops of weathered anorthosite in Sec. 15, T. 59 N., R. 4 W.

A ten-foot diabase dike occurs on the shore of Lake Superior in SE¼ Sec. 14, T. 64 N., R. 1 E. and contains inclusions of both anorthosite and red granite.

A question arises as to whether xenoliths of anorthosite in the diabases of the Rove area are analagous to those found at Carlton Peak. In any event, on the east shore of Moss Lake in Sec. 33, T. 65 N., R. 1 W., rounded masses of anorthosite and anorthositic diabase up to several feet across occur in porphyritic diabase. Rounded anorthosite and slaty xenoliths, also several feet across, occur on a high hill in Sec. 13, T. 64 N., R. 3 E. Others have been mapped north of Pine Lake in the south half of Sec. 31, T. 65 N., R. 2 E. and on a high hill in Sec. 27, T. 65 N., R. 1 E.

The anorthosite inclusions in the diabases are obviously foreign, picked up by the magma on the way to its present position where it solidified to form diabase.

One occurrence of anorthosite inclusions in an ophitic flow was observed on the shore east of Grand Marais in Sec. 9, T. 61 N., R. 2 E.

Anorthosite also occurs in the Duluth gabbro complex and is described in the section on the gabbro (see p. 47).

Granite and Granodiorite in Western Cook County

In the midst of the Duluth gabbro complex in T. 63 N., Rs. 4 and 5 W. of western Cook County there is a particularly confused mass of gabbro, granophyre, granite, granodiorite, diorite, anorthosite, basalt and diabase dikes, metamorphosed basalt and rhyolite flows, hornfels of various kinds, and titaniferous magnetite (Figs. XXII and XXIII). In this area there are three main bodies of coarse-grained rocks which appear to be later than the gabbro and associated granophyre.

The largest is in the central part of T. 63 N., R. 5 W., around Wine Lake. For convenience this will be referred to as the Wine Lake intrusion. A much smaller intrusion is separated from the Wine Lake intrusion by zones of gabbro about a mile wide. This lies in Secs. 4 and 5 T. 63 N., R. 5 W. around the north and east sides of Dent Lake and extends east to the shore of Mesaba Lake. It is named the Dent Lake intrusion. The third is in the southern part of T. 63 N., R. 4 W. and forms a long, somewhat irregular belt of outcrop from the north end of Smoke Lake in Sec. 33 through the southeast corner of Sec. 27, thence east across Secs. 27 and 26. This is known as the Smoke Lake intrusion.

The Wine Lake Intrusion. This intrusion covers an area of about seven square miles with a length of four and a half miles and a width ranging up to two miles. It is irregular in outline and extremely complex, which results from a mixture of earlier inclusions and later intrusions. It contains many inclusions of recrystallized rhyolite and basalt. The main rock ranges from granite to diorite but is probably largely granodiorite. It is surrounded by gabbro and granophyre, mainly gabbro on the west and north sides and granophyre on the east. The south end is largely covered by drift and is poorly known. Locally there are granophyre stringers in the granodiorite and less commonly larger irregular intrusions of granophyre. In the SE SW Sec. 16 and in SW SE Sec. 17, T. 63 N., R. 5 W. inclusions resembling the granodiorite occur in gabbro. The evidence, while not clear on the basis of the limited work done to date, suggests that the Wine Lake intrusion is earlier than the gabbro and certainly is earlier than the granophyre. Late basalt dikes intrude all other rocks.

Detailed work will be required to unravel the complex relations in the Wine Lake area.

The Dent Lake Intrusion. This mass is about two miles long and ranges up to half a mile in width. It has a curved shape, narrow at Dent Lake and trending northward, thence curving eastward across Sec. 4, T. 62 N., R. 5 W. (Fig. XXII) to the west bay of Mesaba Lake. Its exact shape is somewhat uncertain owing to a lack of detailed mapping and covered areas. It is apparently separated from the Wine Lake intrusion by only a mile, presumably mainly gabbro. It is possible that it may physically connect with the Wine Lake mass but detailed work in a heavily wooded area will be necessary before this can be determined.

Hornfels crops out along the south side of the mass in Sec. 4 and on the south end of Dent Lake. Gabbro and anorthosite occur on the west side of the intrusion on the east shore of Dent Lake; and gabbro on the west shore.

The rock ranges from quartz diorite to granodiorite and closely resembles the principal rock of the Wine Lake area. The granodiorite contains inclusions of anorthosite such as are common in diabase at many places in Cook and Lake counties. Some rocks of the complex assemblage at the northeast end of Dent Lake grade from granodiorite to quartz diorite; the former has about 20 per cent quartz, the latter only 5 per cent.

The Smoke Lake Intrusion. This intrusion extends from the north end of Smoke Lake over three miles northeast to the Temperance River in Sec. 26, T. 63 N., R. 4 W. The greatest width is half a mile (Fig. XXIII). A striking feature of the area is the zone of titaniferous magnetite bodies which occur in the gabbro along the west and north sides of the intrusion with essentially a parallel trend. There seems little doubt that the structure of the gabbro had a controlling influence on the shape of the later granite which is intruded into gabbro on all sides. It is a sill-like body, as would be expected from its long narrow shape and general conformity with the structure of the gabbro, and is obviously later than the gabbro as small dikes cut the gabbro, and in the SW NE Sec. 26, T. 63 N., R. 4 W. the granite transgresses the banding of the gabbro and the titaniferous magnetite layers. Diamond drill holes (Fig. 25) in Sec. 32, T. 63 N., R. 4 W., a quarter mile north of the southeast corner, clearly show the sill-like nature of the rock which is there a hornblende granite underlain by titaniferous magnetite bodies in gabbro. Inclusions of gabbro occur in the intrusion, leaving little doubt that the granite is later than the gabbro and therefore apparently later in age than the Wine Lake and Dent Lake intrusions. Because of the similarity of the rock in the three intrusions this conclusion seems questionable. It is possible that the gabbro in the Dent Lake area is of a different age from that of the Smoke Lake area. Much detailed work will be required to ascertain the relations in this rock complex.

Most of the rock in the Smoke Lake intrusion is a hornblende microgranite. Quartz is abundant in all specimens, and hornblende ranges from 15 to 25 per cent. Orthoclase is the dominant feldspar, and the plagioclase is all within the oligoclase range.

Basalt Dikes. Small dikes of basalt occur at widely scattered places in Cook County. Some are doubtless related to the pouring out of the sequence of flows and the incidental intrusion of dikes in earlier flows. Many of the dikes, however, were formed later, and these intrude all of the other formations. Whether these dikes are related to the Logan intrusions or represent a still later period of intrusion is difficult to determine. Fine-grained diabase or basalt dikes later than the main facies of the Duluth gabbro are fairly common at places. Specific examples of small diabase dikes occur on the south shore of Brule Lake and of Juno Lake in Sec. 22, T. 63 N., R. 3 W. To the east in Sec. 23 diabase clearly has a chilled border next to the gabbro, proving that the gabbro was relatively cool before the diabase was intruded. Some of the dikes are so fine-grained that they were mapped as "trap," a term used for very fine-grained dark-colored igneous rocks.

In Sec. 7, T. 63 N., R. 3 W. a remarkable number of dikes and sill-like masses of diabase intrude a large area of granophyre. These evidently were intruded along fractures which strike roughly N. 70° E.

At Red Rock Point, in Sec. 25, T. 63 N., R. 5 E., a number of basaltic dikes about thirty feet wide cut a rhyolite porphyry flow. About 1200 feet southwest of Red Rock Point a basaltic dike thirty-five feet wide contains many inclusions of the rhyolite porphyry.

In the complex of rocks around Frederick Lake, in Sec. 14, T. 63 N., R. 5 W., basalt dikes cut all other rocks, including the Dent granodiorite, and the typical granophyre associated with the gabbro. Thus the basalt dikes are the latest known igneous rocks in the district.

3. GLACIAL GEOLOGY

In the Wisconsin period, two separate ice lobes invaded Cook County (Sharp, 1953b). It seems unlikely that this region could have escaped glaciation during some of the pre-Wisconsin stages, but the evidence of earlier ice sheets has not been found.

The earlier lobe, termed the Rainy Lobe (Elftman, 1898, p. 108), moved into the county from the north and extended southward beyond the north shore of Lake Superior. It left extensive deposits of brown sandy till and associated glacifluvial accumulations as well as numerous striations and other bedrock erosional features showing the direction of flow (Plate 1). The exact age of this advance is not known, but it is unquestionably Wisconsin, most likely about middle Wisconsin (Cary).

The later lobe, called the Superior Lobe (Leverett, 1929, p. 7), came from the east-northeast. It followed the Lake Superior trough and covered only a narrow strip of land along the southern edge of Cook County, where it left red clay till. The age is presumed to be late Wisconsin (Mankato or Valders). Leverett attributed all drift in the county to the Superior Lobe, but this is clearly refuted by the field evidence. From striations and glacial deposits it is judged that the Superior Lobe did not extend more than five and a half miles north of the present Lake Superior shore. Its red clay till is clearly superimposed upon the brown sandy till of the Rainy Lobe. Credit for initial recognition of this stratigraphic relation should go to Franklin B. Hanley, whose work on Cook County glacial deposits was brought to an end by his untimely death in 1944. One of his lantern slides now at the University of Minnesota is labeled as showing red till on brown till in Cook County.

Both Elftman and Leverett mapped several end moraines extending east-northeasterly across Cook County. Upon investigation all these features proved to be bedrock ridges thinly mantled with till, or accumulations of glacifluvial material, including eskers, developed in association with isolated bodies of stagnant ice. During the work of 1947–48 not a single undoubted end moraine was found in Cook County.

FEATURES OF GLACIAL EROSION

The principal features of glacial erosion in Cook County are small markings on ice-scoured rock outcrops such as polish, striations, grooves, chatter marks, and various types of friction cracks; and larger forms constituting visible features of the landscape such as *roches moutonnées*, glaciated bedrock hills and ridges, and excavated rock basins and valleys.

Glacial striations are locally abundant, but they are neither so abundant nor so widespread as one might anticipate from the extensive bedrock exposures. This scarcity of striations is due principally to destruction by postglacial weathering, and they are preserved only on resistant rock or under a protecting mantle. Most Rainy Lobe striae bear within 30° on either side of south (Plate 1). Divergences are caused chiefly by local topographic influence on the direction of flow. Superior Lobe striae show movement west-southwestward down the Lake Superior trough with a slight tendency to fan out to the northwest onto the adjacent upland (Plate 1). All intersecting striations, such as those near Tom Lake north of Hovland, are attributed to changes in direction of flowage within a single ice body, rather than to superimposition of the two ice lobes. Of the several types of friction marks described by Harris (1943), only crescentic fractures were found in this area, a fine display being on an outcrop of Northern Light gneiss in the northeastern arm of Saganaga Lake just north of Cook County.

Most rock outcrops have been rounded and smoothed by the glaciers. Many of the larger hillocks and ridges show scouring on one side and the top, though the opposite side is precipitous and ragged owing to the removal of rock by glacial plucking. Carlton Peak near Tofte displays a marked asymmetry of this origin.

The Glacial Tills

Rainy Lobe Till. Brown sandy till laid down by the Rainy Lobe is the most extensive glacial deposit in Cook County. Good exposures can be seen along the Sawbill Trail (T. 60 N., R. 4 W.), along the Gunflint Trail south of Swamper Lake (T. 64 N., R. 1 E.), and along the abandoned right of way of the old logging railroad east and west of the Sawbill Trail (Ts. 61 and 62 N., Rs. 4 and 5 W.).

Brown colors dominate with local gradations to gray, black, and red. The till is stony with a sandy matrix, and along the abandoned railroad it is so sandy that it can be distinguished from a glacifluvial deposit only by the lack of bedding. Less than 5 per cent of the till has a matrix of clay or silt, possibly obtained by incorporation of lake deposits. Boulders are composed of granophyre, intermediate rock, gabbro, diabase, taconite, jasper, iron formation, greenstone, granite, porphyritic granite, syenite, gneiss, schist, amygdaloid, felsite, rhyolite, basalt, basalt porphyry, argillite, graywacke, sandstone, and quartz-pebble conglomerate. Some attain a diameter of 15 feet. The till shows many compositional varieties, depending upon the nature of the underlying or nearby bedrock. Near areas of the Rove formation, as along the road just south from McFarland Lake, it consists predominantly of fragments of argillite, quartzite, graywacke, and diabase. On or near belts of red granophyre, it is composed of boulders of granophyre set in a sandy matrix of ground-up granophyre.

The brown till is loose and uncemented in most exposures, displays considerable oxidation, and shows some decomposition-disintegration of

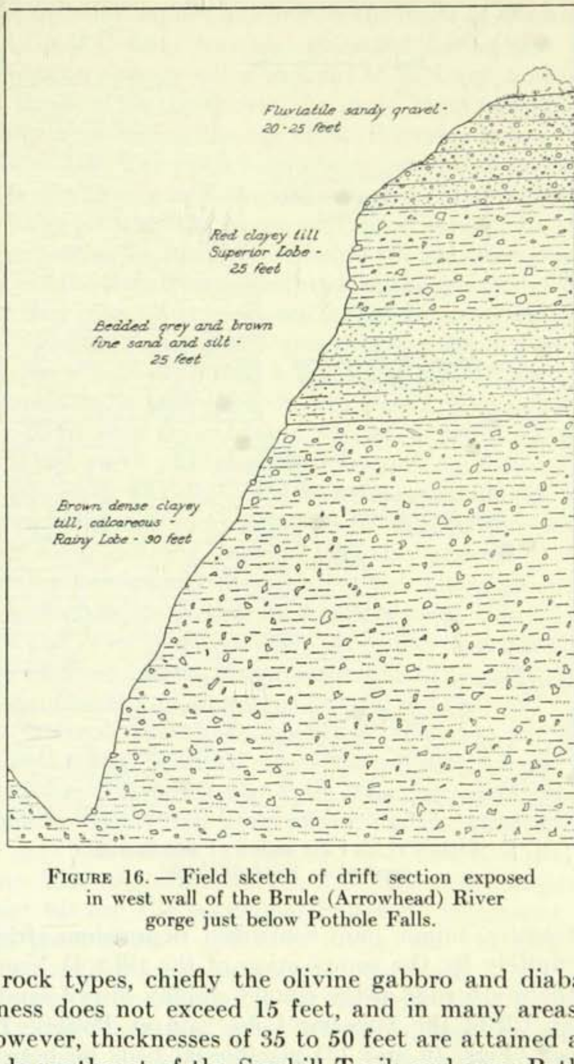

FIGURE 16. — Field sketch of drift section exposed in west wall of the Brule (Arrowhead) River gorge just below Pothole Falls.

susceptible rock types, chiefly the olivine gabbro and diabase. The average thickness does not exceed 15 feet, and in many areas it is only a few feet. However, thicknesses of 35 to 50 feet are attained along the old railroad grade northeast of the Sawbill Trail; and near Pothole Falls on the Arrowhead River is 93 feet of brown calcareous clay till beneath sandy silts and Superior Lobe till (Fig. 16). It is possible that this brown clay till is older than the Rainy Lobe.

Leverett (1932, p. 51, Plates 1 and 3) attributes the brown sandy till to the Superior Lobe, although Elftman (1898, pp. 92–109) had earlier (and correctly, according to the interpretation offered here) recognized it as a product of the Rainy Lobe. The evidence is as follows: (1) The glacial striations (Plate 1) related to the brown sandy till trend within 30° of north and south. That the movement was southward is shown by

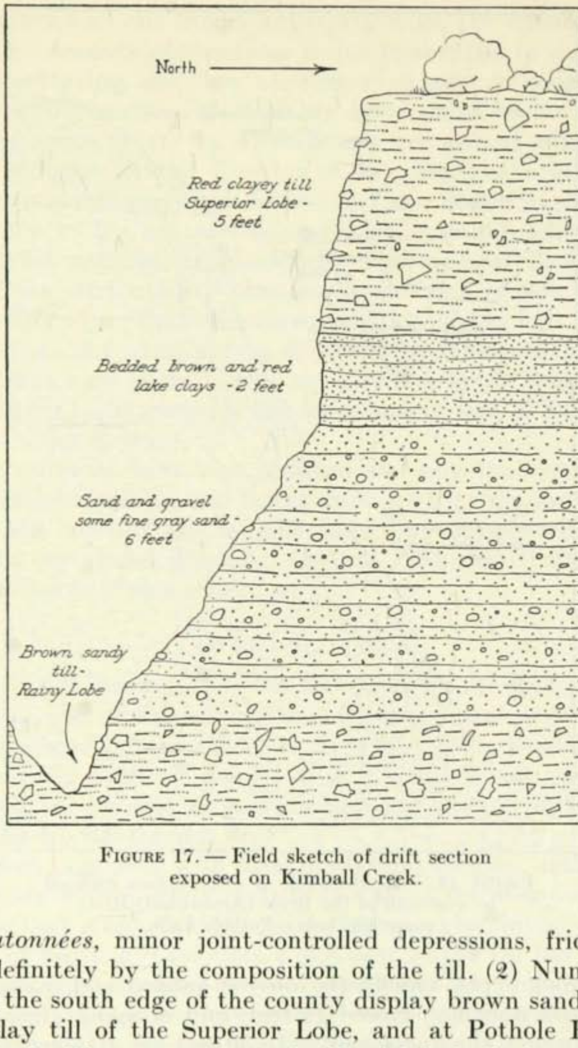

FIGURE 17. — Field sketch of drift section exposed on Kimball Creek.

roches moutonnées, minor joint-controlled depressions, friction cracks, and most definitely by the composition of the till. (2) Numerous exposures along the south edge of the county display brown sandy till underlying red clay till of the Superior Lobe, and at Pothole Falls and on Kimball Creek (Figs. 16 and 17) glacifluvial beds lie between the two tills. It is clear that the brown and red tills are two distinct and separate deposits, and that the brown till was formed by a southward-moving ice mass.

The age of the brown sandy till cannot be fixed with exactness. The abundant lakes, the freshness of the glacial forms, especially those displayed by associated glacifluvial deposits, and the lack of deep or extensive weathering preclude an age older than Wisconsin, and strongly favor mid-Wisconsin or younger. Although northeastern Minnesota may have been covered by ice in both the Iowan and Tazewell sub-stages of the

Wisconsin, the distribution of Cary drift in the State of Wisconsin strongly suggests that Cook County was also glaciated during this sub-age. For this reason the brown sandy till is thought to be Cary, and probably late Cary, in age. Reasons for discounting an early Mankato age are given in the subsequent discussion on the age of the Superior Lobe.

Superior Lobe Till. The Superior Lobe moved west-southwestward in the Lake Superior trough and shoved outward three to five and a half miles beyond the present lake shore in Cook County. In the course of this study, the northern limit of its red clay till has been traced from the western border of the county east-northeast to the vicinity of Mineral Center (Plate 1). Red clay till is best seen in the broad open valleys of the Coastal Hills (Plate 1) and good exposures are located along Caribou Lake Road in Sec. 11, T. 60 N., R. 3 W., along U.S. Highway 61 at Poplar Cemetery, one and a half miles west of Grand Marais, along the road east of Poplar River near the center of Sec. 21, T. 60 N., R. 3 W., and on the Gunflint Trail north of Grand Marais in Secs. 9 and 10, T. 61 N., R. 1 E. Red lake clay was deposited in many parts of the area covered by the Superior Lobe, and every exposure of red clay-rich material raises the problem of distinguishing between lake clay and till.

Tills of this hue are usually described as red, although most are actually pink. Near its base and along its northern edge, this till sheet is also brownish pink and even brown in some exposures owing to incorporation of brown lake clays or brown Rainy Lobe till. In its most typical form, Superior till is compact and contains 60 to 80 per cent red clay. In addition to a clay matrix, discrete fragments of lake clay are also incorporated. Sandy and stony facies are rare. Most stones are one half to four inches in diameter, although some may attain two feet. Common rock types are rhyolite, basalt, red granophyre, diabase, greenstone, granite, gneiss, white and red arkosic sandstone, and conglomerate. There is a little limestone. The only differences in lithology of the stones from those in Rainy Lobe till are the occasional limestone fragments, pieces of a dense uniform greenstone of unknown origin, and the greater amounts of Keweenawan sandstone, conglomerate, and lava.

At Big Bay and on the Poplar River, Superior Lobe till is calcareous. Its clay matrix also displays a "nutty" structure, breaking out, when dry, in angular fragments one half to one inch in size. The weathered profile is mostly 16 to 18 inches thick and consists of 6 to 12 inches of dark humic soil at the top, underlain by brownish leached and oxidized material. This modest depth of alteration is attributed more to impermeability of the till than to a short period of weathering. Where calcareous the till is leached to a depth of two and a half feet on the crest of a well-drained ridge.

In most exposures the Superior Lobe till is 5 to 15 feet thick, but locally as much as 25 feet has been seen. The Poplar River flows in a deep rock gorge in Sec. 21, T. 60 N., R. 3 W., and red clay till is exposed on the east wall up to 250 feet above the floor of the gorge (Fig. 18). This relation and remnants of high terrace gravel suggest the possibility that a preglacial rock gorge was filled to a depth of 200 or more feet with red clay till.

The lack of prominent topographic features within this till sheet is probably due to its thinness and to the high clay content which gives the material great mobility when wet and permits it to spread into low inconspicuous forms. The topography and deposits a few miles northwest of Grand Marais (Sec. 15, T. 61 N., R. 1 W.) are faintly suggestive of an end moraine.

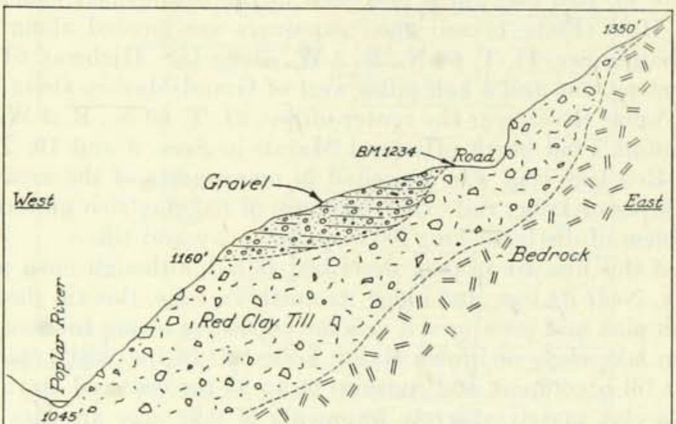

FIGURE 18. — Interpretative sketch of relations on the Poplar River suggesting a thick till filling of a preglacial rock gorge.

Dating of this Superior Lobe till from local relations is at best approximate and depends largely upon more extended studies by Leverett (1932, p. 65) and Wright (1955). It has earlier been assigned to the Mankato sub-stage of the Wisconsin period (Sharp, 1953b, p. 866), but Wright (1955, p. 409) now regards it as Valders. The relation between Mankato and Valders deposits in the upper Midwest is still a matter of debate (Leighton, 1957; Wright, 1955) to which the work in Cook County does not at present materially contribute.

Elftman (1898, p. 108) and Leverett (1929, pp. 7, 20, 28) conceived the Superior and Rainy lobes as occupying northeastern Minnesota contemporaneously and effecting a junction in the area north of Lake Superior. However, the fact that meltwater from the Superior Lobe deposited red clay over areas formerly occupied by the Rainy Lobe, for example on the Stump River (T. 64 N., R. 3 E.), indicates that the Rainy Lobe had withdrawn from parts and perhaps all of Cook County before the Superior Lobe appeared on the scene. Even though the Rainy and Superior lobes were not exactly contemporaneous, the time interval between their respective occupations of Cook County need not have been great since the Rainy Lobe represents the waning phase of one Wisconsin sub-age and the Superior Lobe the waxing phase of the succeeding sub-age.

Glacial Lake Deposits

Parts of Cook County were occupied by lakes lying along the margins of the ice lobes, from which they received meltwater and debris. Their existence is demonstrated primarily by beds of red clay, locally calcareous, and beds of brown non-calcareous clay, silty clay, and silt, in all instances older than or locally interbedded with the basal red clay layers. Such lake beds are exposed principally in the valleys of the Stump, Swamp, and Pigeon rivers, in the Mineral Center area, in the lower valleys of the Poplar, Onion, and Temperance rivers, and in the land bordering Lake Superior (Plate 1).

In the broad flat valley of the Stump River (T. 64 N., R. 3 E.) one to two feet of red clay rests with sharp contact on brown clay layers interbedded with silts. Around the margin of this basin the brown beds rise to an elevation of 1415 feet above sea level, but the red clay extends only to 1385 feet.

The Stump River deposits have been attributed to glacial Lake Omimi by Elftman (1898, p. 104) and to glacial Lake Duluth by Leverett (1929, Plate 2). The interpretation favored here is that there are deposits of two separate lakes, the brown beds being supplied by Rainy Lobe meltwater, and the red beds by Superior Lobe meltwater at a somewhat later date. Red clays attaining an altitude of 1385 feet on the Swamp River (Ts. 63 and 64 N., R. 4 E.) and its tributaries are related to an arm of the younger of the two lakes flooding the Stump River Valley. Exposures and excavations are too shallow to show whether these red clays are underlain by brown beds.

Much of the Pigeon River–Grand Portage region is covered by lake deposits. Not all parts of this region shown on the map (Plate 1) as lake deposits have been explored in detail, but their elevation, appearance on air photographs, and relation to areas known to be underlain by lake beds make lake deposits probable. About an eighth of a mile south of the Pigeon River on U.S. Highway 61, at 980 feet altitude, 20 feet of red clay overlies with sharp contact 30 feet of brown silty clay. Southward along U.S. Highway 61 the red clay decreases in thickness and rises to 1400 feet. As on the Stump River, the brown silty clays are thought to be composed of debris from the Rainy Lobe, and the red clay is attributed to waters from the Superior Lobe. The exceptional thickness of the red deposits near the Pigeon River may be due to superimposition of deposits from a succession of lakes marginal to the Superior Lobe, including Lake Duluth and its successors.

Mineral Center (T. 63 N., R. 5 E.) is situated in a broad basin covered with red lake clays at least seven feet thick. These clays are massively to poorly bedded, and contain calcareous nodules as well as occasional stones and patches of sand. A stony veneer suggests the possibility of a thin till cover, but this could not be confirmed. The upper limit of these beds is 1350 feet. Since this is above any known level of Lake Duluth (Sharp, 1953a, p. 116), they are assigned to a somewhat older lake held at a higher level along the margin of the Superior Lobe. The water body at Mineral Center appears to have been independent of the lakes on the Stump and Pigeon rivers.

In the southwestern part of the county, lake beds are exposed in the valleys of the Poplar, Onion, and Temperance rivers on the northern side of the Coastal Hills (Plate 1). For the most part these accumulations are thin and consist entirely of red clay, but at Oxbow Camp on the Temperance River (Sec. 33, T. 60 N., R. 4 W.) is at least fifty feet of red clay with interbeds of fine brownish sand and silt near the top. The upper limit of lake beds is 1309 feet on the Poplar River, 1250 feet on the Onion River, and 1240 feet on the Temperance River. These elevations are above the known shorelines of Lake Duluth at these places, so the beds are ascribed to marginal lakes formed when the valley mouths were dammed by the Superior Lobe. Meltwater carried red debris north into those lakes that formed after some recession of the ice had occurred, for the beds lie largely in areas formerly covered by the Superior Lobe. The brown sand and silt near the top of the Temperance River section were probably secondarily derived from Rainy Lobe drift.

The land immediately bordering Lake Superior was submerged by Lake Duluth and its successors, and within this area are scattered deposits of red lake clay, usually one to ten feet thick.

The high content of red lake clay in the Superior Lobe till indicates that the ice moved over areas mantled by lake beds, and on Kimball Creek is an exposure (Fig. 17) showing two feet of red and brown clay beneath red clay till. Clay-rich phases of the Rainy Lobe till also suggest incorporation of earlier lake beds, and brown silty clays are exposed beneath Rainy Lobe till along the Gunflint Trail just south of Devils Track River.

Knob and Kettle Drift

Accumulations of glacifluvial material, displaying a striking knob and kettle topography interlaced with numerous short ridges lacking consistent trend or pattern, were deposited in association with Rainy Lobe ice in the central and northern parts of Cook County. These deposits are prominent in the landscape and on air photographs because of their topographic peculiarities.

The materials range in grain size from sand to boulders, and the rocks are the same as those in the brown sandy till. Bedding, sorting, and rounding of particles are moderate to poor, but for the most part the deposits are clearly water-laid. In topographic setting they favor lowlands, especially in the vicinity of Leo, Hungry Jack, Aspen, Flour, West Bearskin, and Clearwater lakes where they lie in valleys between diabase ridges. Similar accumulations along the Sawbill Trail between Honeymoon Road and Plouff Creek, at the west end of Devils Track Lake, and in the vicinity of Elbow Lake (T. 62 N., R. 1 E.) are less obviously situated in lowlands but with respect to the surroundings they certainly do not stand high.

The constitution and diversified form of these deposits and the location in lowlands can be attributed to accumulation upon, around, and perhaps to some degree under masses of stagnant ice which subsequently wasted away *in situ*. Active ice does not produce glacifluvial deposits with these features, nor can the topography be explained by burial of large ice masses floated out from the glacier front (Thwaites, 1926, p. 315).

Eskers

Sixteen clearly defined eskers have been mapped in Cook County (Plate 1). One group is strung out along an east-northeast line through the center of the county, and a second group lies farther north near Aspen, Clearwater, and Bearskin lakes. Those in the south trend mostly in directions nearly at right angles to the direction of ice flowage, and in general topographic configurations have controlled the trend of these eskers more than direction of ice flowage. No eskers related to the Superior Lobe were found.

Insofar as exposed, Cook County eskers are composed of glacifluvial material in which gravel is the major constituent, but there is abundant sand in the matrix and in individual beds. Occasional boulders two to four feet in diameter are embedded within the eskers, and numerous boulders of up to fifteen feet are scattered about the surface. Stones in the esker debris are the same as in the brown sandy till, largely local rocks. Bedding, sorting, and rounding are mostly poor. The internal "anticlinal" structure displayed by many eskers is well shown in some instances in Cook County.

Most of these eskers are 20 to 30 feet high, some attain 50 feet, and a few are 80 to 90 feet high. Lengths of one half to three miles are usual. Twin Lake esker is at least ten miles long (Fig. 19), and Devils Track esker can be traced with confidence for twenty miles (Fig. 20). Slide slopes are mostly about 30 degrees, but range from 20 to 35 degrees depending upon material.

Most Cook County eskers are irregular in plan. Neither the nearly straight two- to three-mile stretch of Pancore esker nor the symmetrical meandering curves at the north end of Twin Lake esker (Fig. 19) are typical. Single-esker ridges occasionally give way to a braided and reticulated network of ridges or to glacifluvial masses with knob and kettle topography. The Sawbill assemblage, consisting of an irregular arrangement of short, sub-parallel esker ridges of north-south and east-west trend, is best described as an esker complex. In topographic setting, Cook County eskers show a preference for lowlands.

Nearly every esker close to a major road has been worked for gravel. Much of the ballast for the old logging railroad came from eskers along the right of way. Roads and trails have been laid out along esker crests, for they provide good foundations, are less densely timbered than the surrounding country, and raise no problems of drainage, water crossings, or of finding suitable road material.

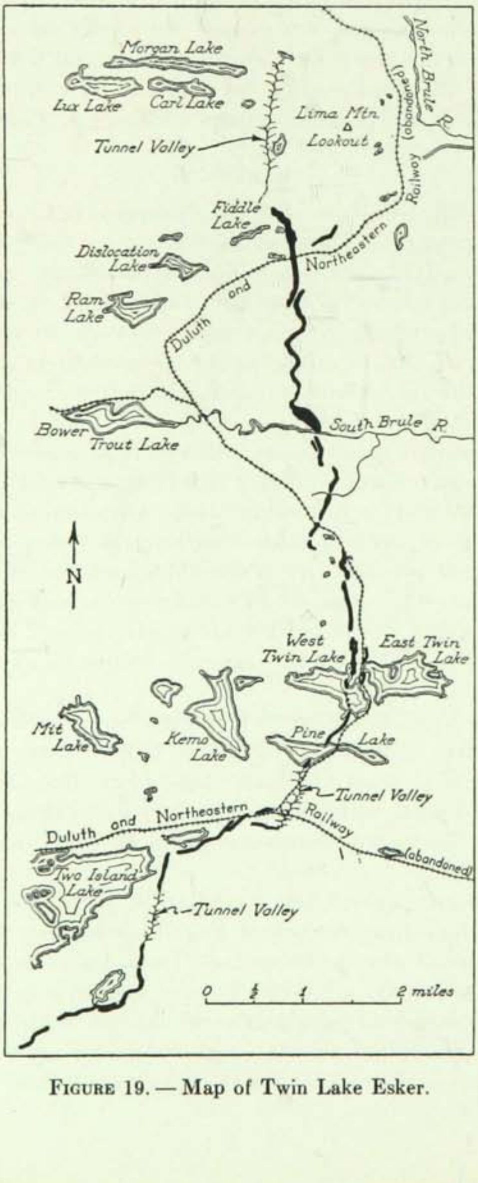

FIGURE 19. — Map of Twin Lake Esker.

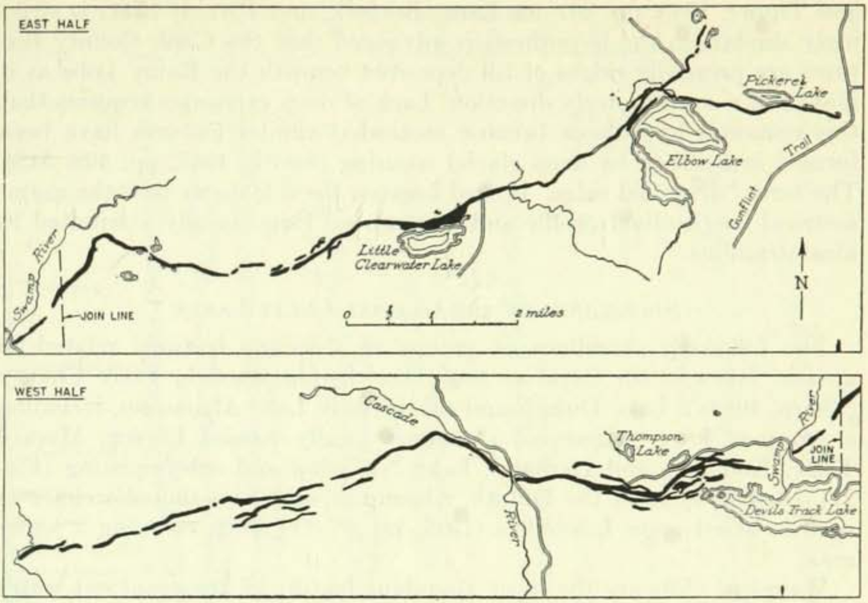

FIGURE 20. — Map of Devils Track Esker.

It is generally agreed that eskers are the product of fluvial deposition in intimate association with glaciers. Such deposition may occur at the mouth of a glacier stream debouching into ponded water, in subglacial streams flowing beneath inactive ice, in englacial channels, or in ice-walled gorges open to the sky. Most features of Cook County eskers can be explained by deposition in subglacial stream channels, but the internal anticlinal structure is puzzling except insofar as it is formed by slumping as the confining ice walls melted.

DRUMLOID RIDGES

In westernmost Cook County in T. 59 N., R. 5 W. is a series of short parallel ridges trending about N. 45° W. They are 10 to 25 or more feet high, one half to three quarters of a mile long, a quarter mile wide, round-topped, equally blunt at both ends, and separated by wide swales. These features occupy a broad lowland along the Cross River where brown sandy till is the only material seen, but exposures are shallow. The possibility that the ridges are bedrock thinly mantled with till and that their orientation reflects a structural control was considered, but discarded. They are discordant with known structural trends in this part of the county, and discovery of glacial striations bearing S. 35° E., roughly parallel to the axes of the drumloid ridges a few miles farther east, suggests that the ridges are of glacial origin.

Air photos show that drumlinized landscape in Canada (Armstrong and Tipper, 1948, pp. 287–93; Lang, Bostock, and Fortier, 1947) is strikingly similar, so the hypothesis is advanced that the Cook County features are primarily ridges of till deposited beneath the Rainy Lobe as it moved in a southeasterly direction. Lack of deep exposures requires that this remain a hypothesis because somewhat similar features have been formed in bedrock by deep glacial scouring (Smith, 1948, pp. 508, 513). The term "drumloid ridge" is used because these features lack the asymmetrical longitudinal profile and streamlined form usually attributed to ideal drumlins.

Shorelines of the Glacial Great Lakes

The following shorelines or groups of shoreline features related to ancient lakes in the Superior basin are distinguished in Cook County (Sharp, 1953a): Lake Duluth and sub-Duluth; Lake Algonquin, including a group of lower Algonquin shorelines locally named Lutsen, Marais, Tofte, Kodonce, and Deronda; Lake Nipissing and sub-Nipissing (Fig. 21). Identification of the Duluth, Algonquin, and Nipissing shorelines as such is based upon Leverett's (1929, pp. 57–71) work covering a wider area.

Wave-cut cliffs are the most abundant feature of these ancient water planes. Most cliffs are twenty to thirty feet high, but some attain fifty feet. They are cut largely in bedrock and red clay till. Abandoned beach ridges are also easily identified and provide convincing evidence of former lake levels. In this county the ridges are largest and most numerous along the lower shorelines, specifically the Deronda, Nipissing, and sub-Nipissing.

Most beach ridges are composed of fine pebbly gravel, but some are bouldery. Heights of five to eight feet above the surroundings are average, and one at Deronda Bay attains nine feet. Beach ridges form best on gently sloping shores where abundant loose debris is subjected to strong wave action. These conditions prevailed at Deronda Bay where twenty beach ridges are distinguishable in the first fifty feet above present lake level. Good ridges were also formed near Grand Portage, at Wauswaugoning and Horseshoe bays, and at Paradise Beach.

Some of the previously described "lake terraces" in Cook County are actually slightly modified gravel-mantled dip slopes on Keweenawan lavas and intrusives. Genuine terraces can be seen both above and below the Nipissing cliff east of Grand Marais; near Tofte at the base of a cliff along the Kodonce shoreline; and at Thomasville.

Elevations of the ancient water planes were measured to the base of wave-cut cliffs or to the crests of beach ridges. In this area it can be shown that elevations along a beach ridge or wave-cut cliff may differ from place to place by as much as ten feet owing to variations in the conditions under which they formed. Within short distances of the present shore or near bench marks, measurements were by hand leveling. The ma-

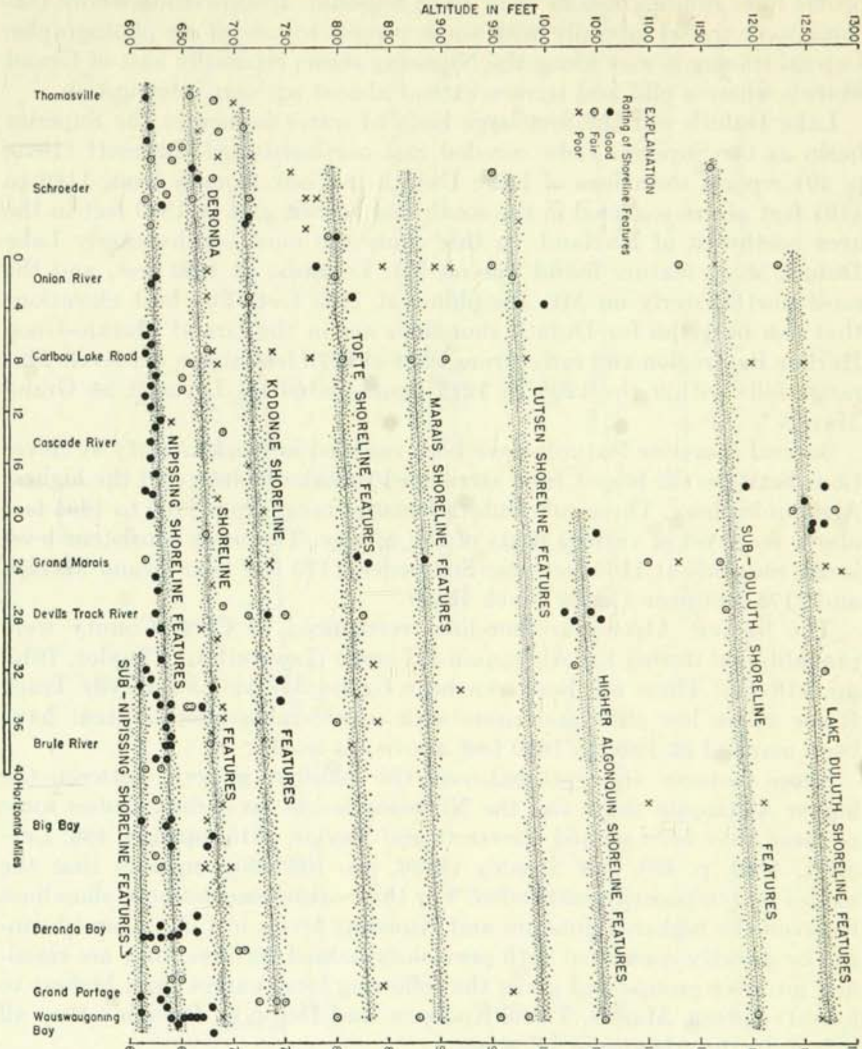

FIGURE 21. — Profile plots of shoreline features in Cook County.

jority of other elevations were by barometer and are believed to be accurate within ten feet at the higher levels and within two or three feet at the lower shorelines. This degree of accuracy was obtained by repeated measurements, often on different days, to the same feature and by frequent checks to the level of Lake Superior or to bench marks.

Owing to dense vegetation and to the obscurity of the ancient shore features, previous studies in Cook County have been almost solely along profile lines running inland from Lake Superior. In this study, shore features were traced laterally with some success by use of air photographs. Lateral tracing is easy along the Nipissing shore, especially east of Grand Marais where a cliff and terrace extend almost without interruption.

Lake Duluth was the first large body of water formed in the Superior basin as the Superior Lobe receded east-northeastward. Leverett (1929, p. 59) reports shorelines of Lake Duluth in Cook County from 1126 to 1191 feet above sea level in the southwest corner, and to 1300 feet in the area northwest of Hovland. In this study the most southwesterly Lake Duluth shore feature found was on Mt. Leveaux, at 1225 feet, and the most northeasterly on Mt. Josephine, at 1265 feet. The best elevations that can be given for Duluth shorelines are in the Grand Marais–Good Harbor Bay region and range from 1240 to 1270 feet above sea level. This range falls within the 1206 to 1275 figures cited by Leverett at Grand Marais.*

Several shoreline features have been mapped in Cook County at elevations between the lowest level attributed to Lake Duluth and the highest Algonquin shore. These sub-Duluth features range from 1100 to 1205 feet above sea level in various parts of the county. The most consistent level is one recorded at 1160 feet near Schroeder, 1170 feet near Grand Marais, and 1175 feet near Devils Track River.

The highest Algonquin shorelines recognized in Cook County were probably cut during the Algonquin III stage (Leverett and Taylor, 1915, pp. 413–15). These are best seen near Grand Marais and Devils Track River where low cliffs and risers with considerable lateral extent have been mapped at 1020 to 1050 feet above sea level.

Shore features are scattered over the 400-foot interval between the higher Algonquin shore and the Nipissing levels. In earlier studies some of these have been named (Leverett and Taylor, 1915, pp. 433, 436; Leverett, 1929, p. 68), but Stanley (1936, pp. 1933–60) suggests that the names be temporarily suspended. For this reason, and because shorelines between the higher Algonquin and Nipissing levels in Cook County cannot be directly connected with previously named features, they are classified into five groups and given the following local names from highest to lowest: Lutsen, Marais, Tofte, Kodonce, and Deronda. Probably they all belong to the Algonquin IV stage.

The best elevations for the Lutsen shoreline are 975 to 985 feet. The features at this level are small and not easily discerned. Features of the Tofte shoreline are seen at a number of places but are most clearly evident near Grand Marais, at 820 to 830 feet, and at Gervais airport near Tofte. The Kodonce shoreline has an extensive riser at Kodonce Creek and a continuous cliff, with broad terrace, at Tofte with an elevation of 712 to 715 feet. The Deronda shoreline is represented by many beaches,

* No traces were found of Leverett's Duluth shorelines at or near 1224 feet on the Poplar River, or at 1300 feet northwest of Hovland; the latter was seemingly determined on the basis of "wave-washed slopes," a doubtful criterion.

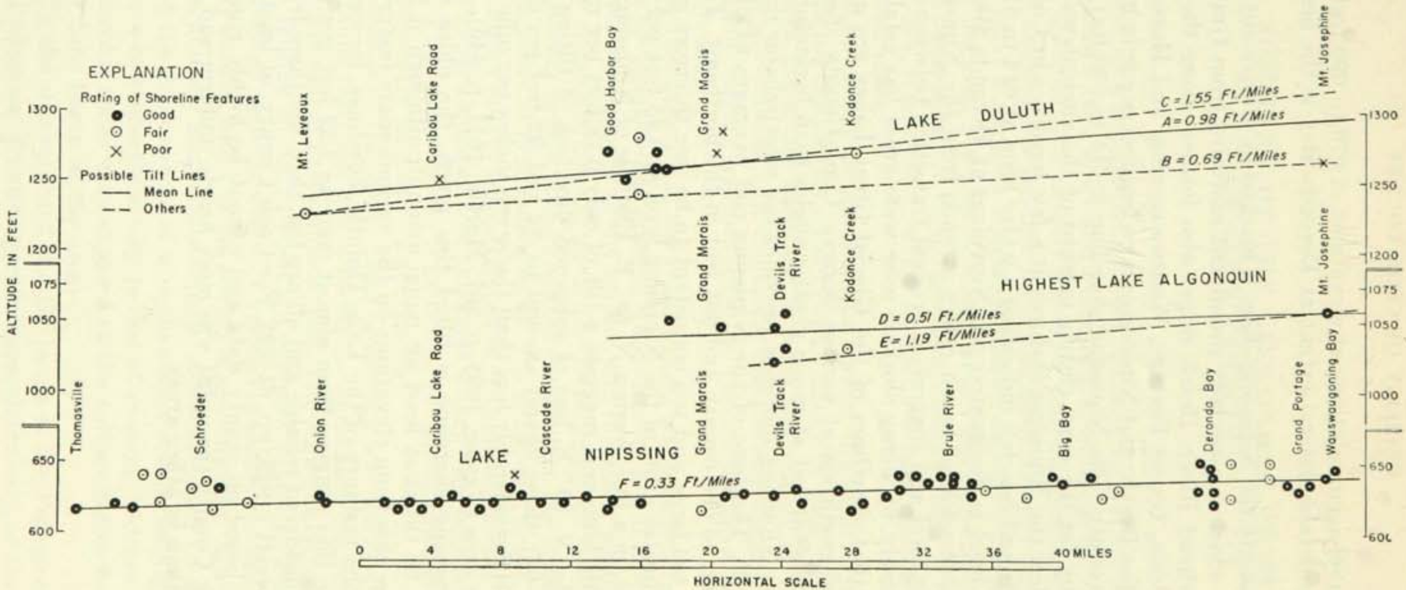

FIGURE 22. — Possible angles of tilt for Lake Duluth, highest Lake Algonquin, and Lake Nipissing shorelines.

cliffs, and gravel accumulations at elevations of 670 to 690 feet. A broad beach of considerable lateral extent at Deronda Bay is the best of these features.

In Cook County the Nipissing shore is marked by a wave-cut cliff, 15 to 30 feet high, which is especially prominent eastward from Grand Marais to the Arrowhead River. Beach ridges also formed along the Nipissing level at Deronda, Grand Portage, Wauswaugoning, and Horseshoe bays and at Paradise Beach; and Nipissing shore features occur in many other parts of the county. The Nipissing shoreline is 615 to 640 feet above sea level and is by far the most clearly marked of the ancient water planes.

A little below the Nipissing features at a few localities in Cook County are small cliffs and beaches indicating a water level at 612 to 614 feet elevation. This level is designated sub-Nipissing; at Deronda Bay a nearly continuous succession of beach ridges extends from the Nipissing to the sub-Nipissing level and suggests a gradual transition between them.

Previous study by many workers over wide areas has established beyond doubt that shorelines of the Glacial Great Lakes are up-tilted to the north and northeast at various degrees. Cook County shorelines are affected by this tilt but at much gentler angles than heretofore reported (Fig. 22). The Nipissing shoreline provides the most reliable data for calculation of tilt. The base of the Nipissing cliff averages 617 feet in the southwest part of the county and 635 feet in the northeast. This 18-foot difference is too large and too consistent to be due to errors in measurements. It indicates a tilt of the Nipissing level at 0.25 feet per mile up to the northeast on a line bearing N. 68° E. Plotting of Nipissing shore features in profile however, suggests a tilt of only 0.18 feet per mile. Recalculated to the N. 30° E. line of supposed direction of tilting (Leverett, 1929, pp. 61–62), these figures amount to .32 and .22 feet per mile respectively. This is considerably less than the seven inches per mile previously cited for this area (Taylor, 1895, p. 307; Martin, 1911, p. 449).

If the Nipissing shoreline is tilted this much, the older and higher shores must be tilted at least an equal amount, although it is not possible to prove this from elevations on the various shore features in Cook County. In the instance of the Lake Duluth shorelines, for example, one can calculate tilts ranging from almost none to 1.52 feet per mile. None of these is considered reliable and all are less than the three feet per mile cited by Leverett (1929, pp. 61–62). For Cook County, at least, his calculations were based on scanty data and cannot be highly regarded. Perhaps in Cook County the uplift was more nearly uniform and with a less marked tilt than in other areas.

4. SUMMARY OF THE GEOLOGICAL HISTORY OF COOK COUNTY

The oldest rock recognized in Cook County is the Ely greenstone, a group of basaltic lava flows and lesser tuffaceous material which has altered to a chloritic rock usually having a grayish green color. Thus the first known event in the geologic history of Cook County was the pouring out of extensive lava flows which are known to have extended far westward in Minnesota. For the most part these flows probably poured out from great fissures rather than volcanoes because there is only a minor amount of ash, bombs, etc., which normally accompany flows from the craters of volcanoes.

After the flows had accumulated to a great thickness, a large mass of magma invaded the earth's crust in the vicinity of what is now Sea Gull and Saganaga lakes and solidified to form the granite of the Saganaga batholith which extends into Canada a considerable distance. The intrusion of the hot magma recrystallized the greenstone near the contact to a hornblende schist.

Following the intrusion of the granite there was a long period of erosion as is shown by the fact that granite, which forms only at a depth of thousands of feet, was exposed at the surface and furnished pebbles and boulders to the conglomerates of the Knife Lake group of rocks. While the granite was being eroded there was accumulating in the adjacent lowland a very thick series of muds, lava flows, volcanic tuffs, sands, gravels, etc. Professor Gruner (1941) has estimated that these sediments in Cook and Lake counties accumulated to a thickness somewhere between 11,500 and 21,000 feet. This accumulation is known as the Knife Lake group of rocks and was apparently formed in a geosyncline.

The deposition of the Knife Lake sediments was followed by another period of granite intrusion and deformation, probably the greatest mountain building period of Precambrian time. The Knife Lake sediments were folded and faulted in an exceedingly complex manner. The muds and other fine-grained sediments were converted to slates, the sands to quartzite and graywackes, and the gravels to conglomerates. Near the granite contacts hornblende and biotite schists were developed on a large scale.

Following the great events of what has been called the Algoman Revolution there was evidently a long period of erosion, because the granites and metamorphic rocks were exposed at the surface before sedimentation of Animikie time began in the area.

Eventually the seas returned and the sands of the Pokegama formation were deposited on the granites, greenstones, slates, etc., of the older rocks.

In Cook County the quartzite is thin, showing that the deposition of sand did not last long but was succeeded by the deposition of chemical iron-bearing sediments which form the Gunflint formation. Since the deposition of chemical sediments is normally a slow process, this episode must have lasted a relatively long time in order to deposit a thickness of over 300 feet of iron-bearing material.

The deposition of chemical sediment ended with a change in the sea, resulting in the deposition of muds and impure sands to form the thick series of beds of the Rove formation, estimated to total at least 3000 feet.

At the end of the deposition of the Rove sediments a period of erosion of unknown length set in, but it is evident that the sediments were consolidated before being exposed at the surface. Eventually deposition again set in, starting with pebbles of quartz and of underlying rocks but these promptly gave way to the deposition of a relatively pure quartz sand which now forms the sandstone of the Puckwunge formation, the basal member of the Keweenawan group of formations. The deposition of sand did not last long, as such events go, not exceeding the 200 feet of sandstone which now forms the Puckwunge. In any event, the first flows of the great outpourings which characterized the Keweenawan time on both the north and south shores of Lake Superior in Cook County lie directly on the Puckwunge sandstone. The flows piled up in great numbers and assumed an imposing thickness. Only the flows of the lower part are exposed in Cook County, the upper part being under Lake Superior.

Following extrusion of the flows the magma from below forced its way into the pre-existing rocks, including the lava flows, and formed the Duluth gabbro and the sills, dikes, and irregular masses of the Logan intrusions in the Rove formation and other rocks. This period of intrusion ends the history of the rocks exposed in Cook County, but across Lake Superior on Keweenaw Point and on the Wisconsin shore a great thickness of sand accumulated before the end of the Keweenawan period of geologic history.

With the closing of the Keweenawan period deposition of sediments and igneous activity largely ceased in the Lake Superior area, which for a long period of time was subject to erosion; such sediments as were deposited later disappeared as a result of erosion.

In any case the tremendous events of Paleozoic and Mesozoic time, as shown by the record elsewhere on the continent, left little or no trace in Cook County or adjacent areas. In fact the record is missing for Cenozoic time until the beginning of glaciation of the northern part of the continent. Cook County lay in the path of the glaciers as they crept forward to cover large areas to the south. How many glaciers invaded Cook County is not known with certainty because the later advances of the ice tended to destroy the evidence of the earlier ice sheets. There is evidence that two ice lobes invaded Cook County in Wisconsin time, the latest of the subdivisions of the glacial period (see page 59).

The Rainy Lobe advanced from the north and presumably overrode the entire county. Later a lobe extended along the depression of Lake Superior, moving in from the northeast and eventually extending southwestward to the Mille Lacs area of central Minnesota.

The physiographic features of Cook County as we see them today were fashioned by stream erosion preceding glaciation and then modified greatly by glacial erosion and deposition. It is thought that the actual basin of Lake Superior was largely scoured out by a succession of glacial lobes which occupied the basin.

The elongated lakes, a conspicuous feature of the northern part of the county, presumably owe their origin to stream erosion controlled by rock structure plus modification and damming by ice erosion and deposition of till when the ice melted.

The end of glaciation, about ten thousand years ago, allowed vegetation to re-establish itself, forests developed, peat was deposited in the bogs, and the glacial lakes which occupied the Superior basin disappeared with the opening of drainage to the St. Lawrence River. Thus Lake Superior attained its present level, the development of shore features began, and Cook County became the country we know today.

5. ECONOMIC GEOLOGY

Cook County comprises a large area of many kinds of rocks which belong to several Precambrian formations. Elsewhere, particularly in Minnesota, Michigan, and Canada, rocks of the same types contain many ore deposits of great value. It has thus been a considerable disappointment that the county has to date produced essentially no ore. There are, however, deposits which have been examined and explored over a period of about seventy-five years. There is reason to expect that some of these deposits will eventually be productive but perhaps not in the immediate future.

The principal deposits consist of the Gunflint iron-bearing district and the titaniferous magnetites of the Duluth gabbro complex. Prospects have been found which contain small amounts of copper, nickel, and cobalt. Small amounts of vanadium occur in the titaniferous magnetites. Barite occurs in small veins on Pigeon Point and on Susie Island. Gravel, anorthosite, and other rock deposits are locally useful.

PRINCIPAL DEPOSITS

The Gunflint Iron-Bearing District

The Gunflint district in Minnesota is the area in Ts. 65 N., Rs. 4 and 5 W. which is underlain by the Gunflint iron formation. The formation continues eastward for a long distance into Canada and the district may thus be considered to include an area extending nearly to Port Arthur. Westward from Gunflint Lake, where the iron-bearing rocks have been most explored, the surface consists of gentle slopes to the south broken by steep northward-facing cliffs, some 100 feet or more in height, which are capped by diabase sills or the more resistant cherty beds of the iron formation. Dips of 45° to 60° to the south are common at the western end of the district but dips of 10° to 12° are more characteristic near Gunflint Lake and the abandoned Paulson Mine. The first published reference to iron ore in Minnesota is in a report by David Dale Owen (1852), United States geologist, whose assistants visited the Gunflint area.

The district received considerable attention at an early date before all the implications of the geologic relations were understood. The Gunflint district resembles the East Mesabi district in many respects, as it has the large gabbro intrusion along the south side which recrystallized the iron formation so that oxidation and leaching to form high grade ore is almost lacking. According to Grant (1899), test pits were sunk in the iron-bearing rocks, particularly in Sec. 28, T. 65 N., R. 4 E., prior to 1892 when the railroad from Port Arthur was extended into that section. Shallow shafts from 75 to 105 feet in depth were sunk and some ore was reported. The work was abandoned in 1893. Available data make it fairly certain that the so-called ore consisted simply of thin beds of rich taconite which were sorted and shipped. This obviously was not an economic procedure when the rich Mesabi ore became available at about the same time. Interest in the area continued, however, and considerable diamond drilling was done about 1907. Available records indicate that a total footage of 809 feet in the Gunflint formation averaged 22.1 per cent iron, which is lower than the iron content of the taconite of the East Mesabi district. Two of the several holes penetrated an unusual thickness of iron formation, but thirteen holes which bottomed in greenstone had an average of 24 feet of iron formation that contained 24.1 per cent iron. One hole reported 257 feet of iron formation which leads to the suspicion that it may have followed down steeply dipping beds as no such true thickness of iron formation is known in the Gunflint district.

An early attempt to obtain an average for the formation indicated an iron content of 25.22 per cent (Table 8).

TABLE 8. CHEMICAL COMPOSITION OF IRON-BEARING GUNFLINT FORMATION *

Constituent	Per Cent	Constituent	Per Cent
SiO_2	61.51	K_2O	.00
Al_2O_3	1.20	H_2O	Tr.
Fe	25.22	P_2O_5	.05
MgO	.52	S	.59
CaO	.67	MnO_2	.92
Na_2O	.00		

* Average of an analysis of 245 feet of drill core and of a surface sample across the width of the formation (Van Hise and Lath, 1911).

About 1942 a series of 24 samples were collected from outcrops scattered over a length of four and one half miles from Secs. 24 to 30, T. 65 N., R. 4 W. These were mainly from the Lower Slaty member of the Gunflint formation, and tests by the Mines Experiment Station, University of Minnesota, show that at −200 mesh the iron recovery by magnetic separation is less than 20 per cent of the sample and the concentrates averaged 59.39 per cent iron. It required about 3.3 tons of crude to make one ton of concentrate. The iron in the non-magnetic tailings averaged 21.87 per cent, which is mainly tied up in silicate minerals. The best results were obtained from material of the Upper Cherty member, and the poorest results from the Upper Slaty member.

It doubtless would be possible to improve recovery by finer grinding or other means, but the overall situation is not favorable to the large investment necessary to conduct operations. Probably the most serious difficulty in the possible development of the Gunflint district for concentrating ore is the lack of large tonnages, readily available. As shown by Plate 3 the

Gunflint formation occurs as a relatively narrow band from Secs. 22 and 27 westward. The dips are from 20° to 45° to the south, so that a relatively small amount of the formation is available to open pit excavation within a reasonable depth. In Secs. 23, 24, and 25, immediately west of Gunflint Lake, the dips are gentle although two diabase sills interrupt the continuity. Faults and folds also complicate the situation. Drill records are not available to estimate closely the amount of taconite present, but it is not large compared to the East Mesabi district.

Titaniferous Magnetite

The earliest prospectors in Cook County recognized the black magnetite deposits which occur widely scattered in the Duluth gabbro (Plate 2). The principal deposits occur along the northern border of the gabbro near Gabimichigami, Tucker, Iron, Portage, and Poplar lakes and over a wide area south and southwest of Brule Lake. The following township maps show the location of the principal deposits: Figures III, XI–XIV, XXIII, XXIV, XXXII, XXXIII.

Because of their highly magnetic character, black color, metallic luster, and resistance to weathering these deposits have been a continual object of interest, prospecting, and exploration.

The most important fact about these deposits is that the black metallic material consists of two minerals, magnetite (Fe_3O_4) and ilmenite ($FeTiO_3$) as shown in Figure 23. The ratio of iron to titanium ranges widely, but typical samples average around 35 per cent iron and 10 per cent titanium. The presence of titanium is objectionable in iron ore, and prevented utilization of titaniferous magnetite anywhere in the United States until the demand for titanium made it possible, at one plant in New York State, to separate the ilmenite and market the magnetite concentrate which, however, still contains a considerable percentage of titanium.

A detailed report (Grout, 1950) on the titaniferous magnetites of Minnesota was published by the Office of the Commissioner of Iron Range Resources and Rehabilitation, and the reader is referred to that report for greater detail than is given below. The general nature and origin of the deposits was earlier described by Broderick (1917). Shorter descriptions of many of the deposits occur in widely scattered publications, particularly of the Minnesota Geological and Natural History Survey.

Origin. The only detailed discussion of the origin of the titaniferous magnetite in the gabbro mass is given by Broderick (1917). He recognized the following four classes: (1) Inclusions of banded Gunflint iron formation; (2) Banded segregations of the gabbro; (3) Irregular bodies of titaniferous magnetite; (4) Dike-like bodies of titaniferous magnetite.

Inclusions of banded Gunflint formation are abundant near the base of the gabbro, particularly to the west of Cook County in Lake County, but some occur at, and east of, Gabimichigami Lake in Cook County.

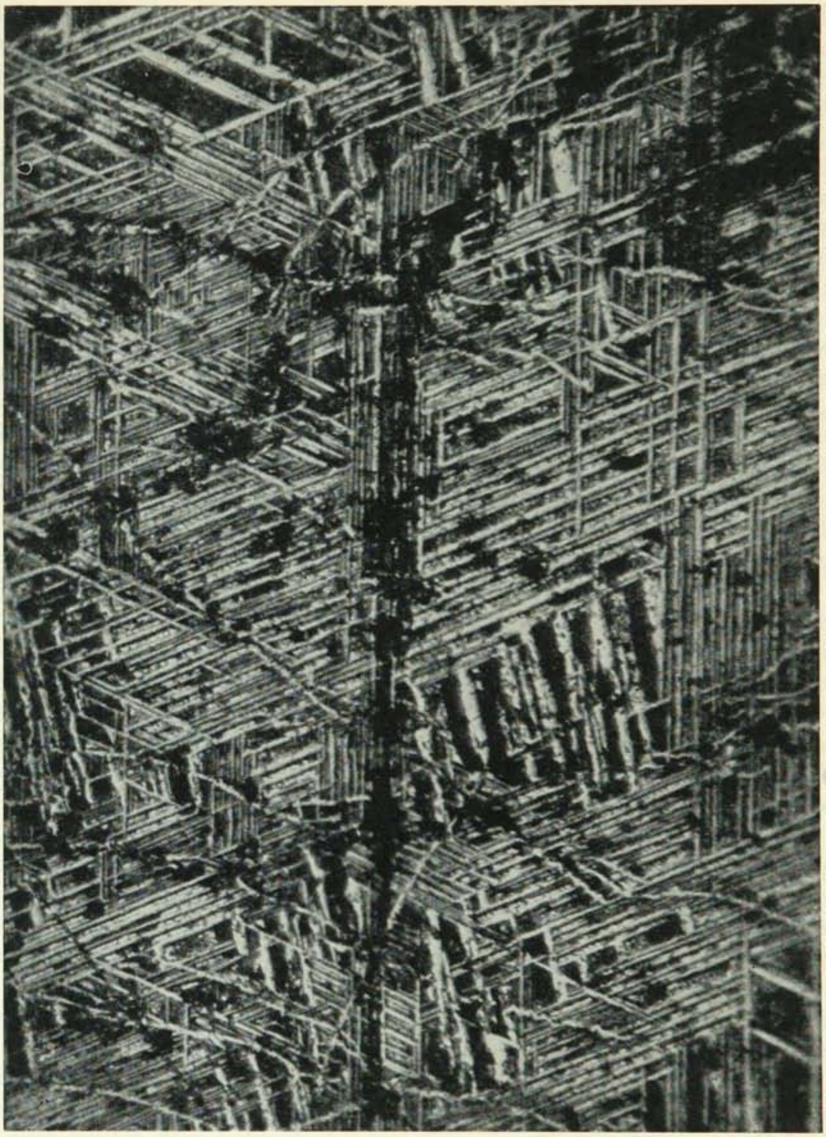

FIGURE 23. — Microphotograph of polished and etched titaniferous magnetite. Ilmenite (white) laths mainly along three octahedral planes in magnetite. Magnification 320 X.

The inclusions are recognizable not only by the preservation of the sedimentary banding but by the presence of abundant quartz, not a normal constituent of the gabbro proper. The inclusions are also associated with hornfels rock developed from inclusions of Rove slate. In general this type of occurrence is characterized by great variability, especially in the titanium oxide content which ranges from less than 1 per cent to as high as 25 per cent. It is thought that the titanium was added to the inclusions by the gabbro as the amount of titanium in the Gunflint formation is very small. Small amounts of sulfides occur in about three fourths of the drill cores examined.

The banded segregations in the gabbros do not contain quartz but consist of the normal minerals of gabbro: plagioclase feldspar, augite, and olivine, in addition to magnetite and ilmenite.

The banded segregations occur in gabbro which is also banded due to variation in the mineral composition. There is more or less gradation from nearly pure titaniferous magnetite to gabbro with only a low percentage of magnetite and ilmenite (Figs. 24 and 25). The beds range up to about five feet in thickness. The titanium content of the banded segregations is much higher than in the inclusions.

The irregular bodies of titaniferous magnetite occur throughout the area of titaniferous deposits and consist chiefly of olivine and pyroxene in addition to the magnetite and ilmenite. They cut across the banding of the gabbro in contrast to the banded deposits. The titanium content is variable but higher than in either the inclusions or banded segregations, averaging around 15 to 17 per cent. The origin of these irregular deposits is uncertain, although Broderick (1917) was of the opinion that they represent extreme metamorphism of included Gunflint formation.

The dike-like bodies of titaniferous magnetite are generally more nearly pure magnetite and ilmenite than the other types, and the principal associated minerals are olivine and pyroxene. They are generally small, being traceable for a length of only a few feet. Many of them finger out into hornfels or have an irregular branching form. Some cut across the contact of the gabbro and the hornfels and are truly dike-like. They are thought to form by fusion of inclusions and injections of the liquid into the adjacent rocks.

Size. The deposits of titaniferous magnetite in Cook County are small compared to most of the commercial iron ores of the Mesabi, Vermilion, and Cuyuna districts. The deposits are interbedded with gabbro and are notably discontinuous along their length as is well shown by the township maps referred to above. This discontinuity in outcrop has been verified by detailed magnetic work. In 1947 the Office of the Commissioner of Iron Range Resources and Rehabilitation provided funds to check the thickness and continuity of typical deposits and thus determine their size. The results of 10 drill holes are given in detail by Grout (1950).

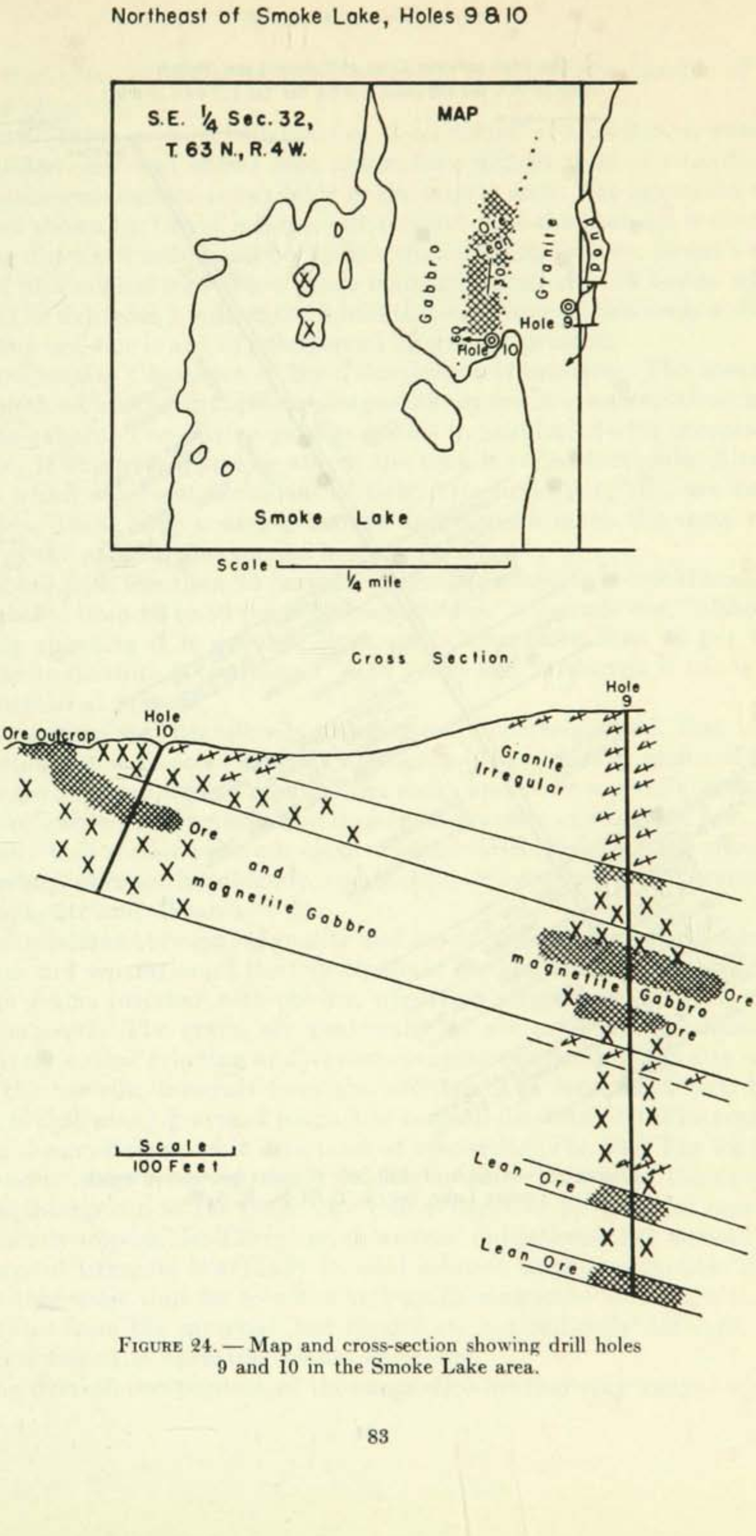

FIGURE 24. — Map and cross-section showing drill holes 9 and 10 in the Smoke Lake area.

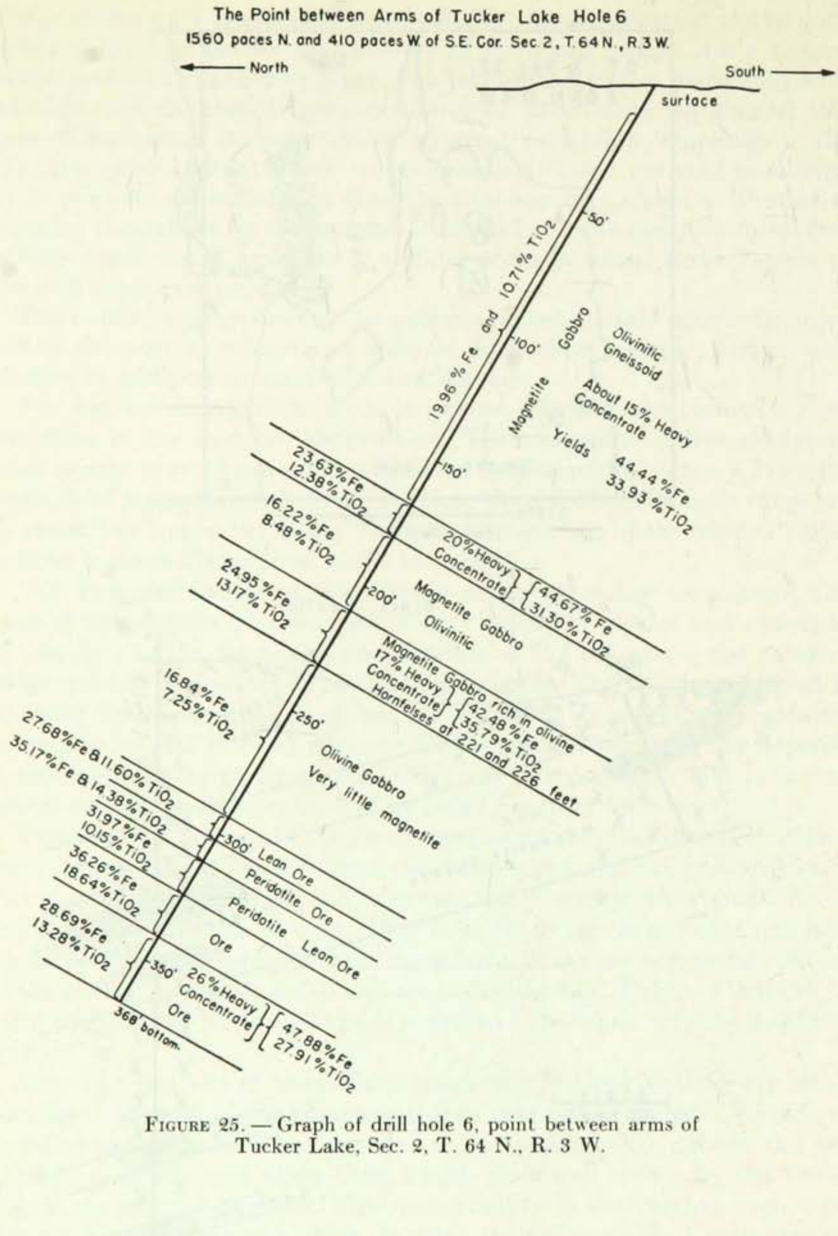

FIGURE 25. — Graph of drill hole 6, point between arms of Tucker Lake, Sec. 2, T. 64 N., R. 3 W.

Hole 6 of this drilling is included herewith as a typical example of the results (Fig. 25).

Grout (1950) gives calculations of the amount of titaniferous rock in the drilled area and shows that about four million tons of titaniferous magnetite concentrate is available in the largest area. The aggregate tonnage as shown by Grout is large, but the fact that the tonnage is divided among dozens of individual bodies is a discouraging feature. Grout's estimated 81.6 million tons of low grade material occurred in 14 bodies which ranged in size from 1 million to 19 million tons. None of this rock is direct shipping ore, nor is any of commercial interest at present.

Petrographic Character of the Titaniferous Magnetites. The common rock with which the titaniferous magnetite occurs in concentrations is an olivine gabbro. The olivine gabbro grades to peridotite with increase in olivine. If augite is sparse or absent the rock is called troctolite. Altered rocks which represent inclusions of slate, iron formation, etc., are called hornfels. These have a sugary texture and contain much the same minerals as the gabbro, plus quartz in some varieties.

Gabbro with less than 20 per cent magnetite-ilmenite is called magnetite gabbro; from 20 to 40 per cent magnetite is "low grade ore," although strictly speaking it is not ore. Rock containing more than 40 per cent magnetite-ilmenite is considered "high grade ore," although it too is not commercial at present.

The gabbro and titaniferous magnetite are coarse-grained, that is, all important minerals occur as readily recognizable grains. The grains of feldspars are long and thin in many of the rocks and show a parallel arrangement or gneissoid structure. The magnetite-ilmenite crystallized late, and in many thin sections there is clear evidence of corrosion of the silicates. Secondary silicates, hornblende, and biotite are common at the boundary of magnetite and silicates.

The relations between magnetite and ilmenite are important in concentration and separation of the two minerals. Both minerals occur partly as coarse grains together with olivine, pyroxene, plagioclase, and less common minerals. The grains are practically all above .5 mm. in diameter; relatively coarse grinding and various magnetic processes serve to separate the metallic minerals from the silicates. The important fact, however, is that many grains of magnetite contain ilmenite plates intergrown along the crystallographic directions of magnetite (Fig. 24). The ilmenite inclusions range from extremely minute to those visible to the eye. All are so intergrown in the magnetite that separation by physical means is practically impossible. There are, moreover, indications that a small percentage of titanium is actually in solid solution in the magnetite. It has been impossible thus far to make high grade magnetite and ilmenite concentrates from the material, but results are not radically different from those obtained in operating plants elsewhere.

The over-all composition of the magnetite-bearing rock ranges widely.

The analysis given by Grout (1949, p. 28) and reproduced here in Table 9 is typical.

TABLE 9. ANALYSIS OF TITANIFEROUS MAGNETITE GABBRO *

Constituent	Per Cent	Constituent	Per Cent
SiO_2	8.86+	H_2O+	.26
Al_2O_3	5.51	TiO_2	20.27
Fe_2O_3	22.50	P_2O_5	.02
FeO	35.68	Cr_2O_3	.19
MgO	4.23	MnO	.31
CaO	.99	V_2O_3	.30
Na_2O	.62		
K_2O	.20	Total	100.05+
		Total Fe	43.47

* Sample from Sec. 1, T. 64 N., R. 2 W. Medium grade of feldspathic magnetite-ilmenite segregation. Analyst, Lee C. Peck, Rock Analysis Laboratory, University of Minnesota.

Data regarding the assays and tests of the core of the diamond drilling in 1947 are given in Table 10.

MINOR DEPOSITS

COPPER-NICKEL SULFIDES

Sporadic occurrences in Cook County of copper, nickel, and, less commonly, other sulfides have been known for a long time. The most conspicuous vein is on Susie Island in Lake Superior, which was explored in 1882 to 1884 and again in 1905 to 1907. The ore was a mixture of chalcopyrite, bornite, chalcocite, and pyrite in a calcite gangue. A small amount of barite occurred with the calcite. The nature of the ore has been described in detail by Schwartz (1928). The veins were small, however, and no work has been done since 1907. When last visited in 1953 there was very little evidence of the ore at the surface.

Several occurrences of sulfides led to the detailed mapping of the area of the Rove slate from Gunflint Lake to Pigeon Point (Grout and Schwartz, 1933), but no deposits of economic size were found. Because of its unusual mineral composition, one prospect was described in detail by Schwartz (1924a, 1925a). A list of occurrences, largely repeated from Bulletin 24, page 61, is given in the Appendix (see Table C).

In 1948 copper-nickel sulfides were discovered in Lake County near the base of the Duluth gabbro intrusion (Schwartz and Davidson, 1952). This immediately created interest in the possibility of similar occurrences along the base of the gabbro in Cook County, where the base extends for nearly fifty miles (Plate 2). A considerable amount of field work and some drilling have been done in the past by private companies, but such activities have been largely discontinued. If exploration in Lake County is successful, there will no doubt be a renewal of interest in Cook County.

TABLE 10. ANALYSES AND TEST DATA ON CORES FROM THE 1947 DRILLING OF TITANIFEROUS MAGNETITE DEPOSITS *

Site and Depth in Feet	% Fe	% TiO_2	Approx. % Gravity Conc.	Grade of Concentrate % Fe	Grade of Concentrate % TiO_2
	Tucker Lake Area				
Hole 1					
5–40	21.05	5.58	7	45.36	21.56
40–54	32.20	9.60	20	51.94	21.89
161–170	26.98	14.39	20–	46.66	30.86
Hole 2					
7–20	21.68	7.92	10		
20–22	37.43	24.99	30		
22–32	19.73	6.69			
72–82	19.96	4.80	15		
82–90	31.35	10.04	25		
91–104	20.82	7.25	30		
155–181	26.04	9.48	24	42.30	19.15
181–201	26.36	12.50	24	48.57	27.80
Hole 3A					
57–67	24.48	22.98	35+		
151–170	33.06	19.41	40	46.96	28.89
206–265	14.35	4.91	10–	46.66	31.63
265–270	31.81	13.28	50+		
270–290	20.43	6.69	8	48.04	24.52
Hole 4					
87–107	26.59	12.05	22	48.57	26.16
107–114	17.31	6.58	10		
190–200	14.82	7.92	10		
497–507	26.98	10.82	20+		
Hole 5					
8–23	22.30	10.26	13+	46.20	30.54
23–34	27.92	13.50	10		
34–54	24.17	13.39	15	43.91	34.56
54–97	18.87	11.16	15	42.07	35.68
97–108	27.84	17.85	35		
108–145	22.46	11.05	15	46.89	31.19
145–170	26.28	18.41	20–	41.84	38.96
170–182	22.61	11.38	15		
182–210	29.32	13.95	20	42.27	29.77
210–256	21.52	10.93	10	44.75	34.70
256–264	26.75	12.61	40–		
264–303	18.25	6.69	10		
Hole 6					
12–156	19.96	10.71	15	44.44	33.93
156–175	23.63	12.38	20	44.67	31.30
175–209	16.22	8.48	10		
210–231	24.95	13.17	20–	42.28	35.79
231–294	16.84	7.25	5		
294–302	27.68	11.60			
302–310	35.17	14.39	20+		

* From Grout, 1950. Data from selected parts of cores, tested at the University of Minnesota, Mines Experiment Station. Concentrates derived by using gravity methods (tabling) on 40-mesh powder. The drilling was supported by funds from the Office of the Commissioner of Iron Range Resources and Rehabilitation.

TABLE 10 — *Continued*

Site and Depth in Feet	% Fe	% TiO_2	Approx. % Gravity Conc.	Grade of Concentrate % Fe	Grade of Concentrate % TiO_2
		Tucker Lake Area			
Hole 6					
310–325	31.97	10.15	20		
325–342	36.26	18.64			
342–368	28.69	13.28	25	47.88	27.91
Hole 7					
72–86	22.77	21.42	15		
118–124	21.05	12.94	30+		
124–150	14.04	8.03	10	43.83	35.57
Hole 8					
38–43	15.75	6.47	5		
43–49	16.22	9.15	15		
49–64	27.14	24.10	25	37.48	43.78
64–79	24.64	22.32	20	37.71	44.77
79–84	14.30	7.55	10		
124–130	20.51	9.04	10+		
130–141	33.53	19.41	25+		
141–146	24.28	14.89	15+		
157–168	30.14	16.53	20		
		Smoke Lake Area			
Hole 9					
126–136	21.11	11.93	20		
180–186	16.45	7.33	5		
186–206	14.99	6.13	11	50.25	27.03
206–230	27.46	12.02	15	53.24	22.55
230–253	21.88	8.54	23	51.78	22.55
253–262	17.75	6.35	10		
262–268	32.66	13.90	30+		
268–289	23.94	9.85	10		
304–311	19.89	7.77	13		
408–414	25.17	9.30	15		
414–423	24.02	8.97	10		
478–498	23.86	8.32	18	53.61	21.67
Hole 10					
57–63	15.68	4.82			
63–69	26.01	9.19			
69–74	29.68	9.85			
74–80	22.26	7.22			
80–150	10.79	3.39			

COBALT

At an early date a shallow shaft was sunk at the head of a small bay at the west end of Loon Lake on a vein which was explored for gold. In recent years, in this same area, Mr. R. E. Blankenberg and associates have explored along the strike of the same vein by test pit and diamond drill. The veins lie at or near the contact of diabase and slate and contain abundant arsenopyrite. The arsenopyrite contains cobalt in addition to iron, arsenic, and sulphur. Thus far the veins discovered are narrow and the tonnage insufficient for a mining operation, although the cobalt content is as much as 3 per cent.

Anorthosite

Plagioclase feldspar occurs as nearly pure masses called anorthosite. There are two types of occurrence, one confined mainly to Carlton Peak (Fig. 26) and vicinity and the other to more widespread occurrences in the Duluth gabbro. There have been many suggestions for use of this feldspar rock and an extensive investigation of the deposits in Lake County and at Carlton Peak was made by the Minnesota Geological Survey (Grout and Schwartz, 1939).

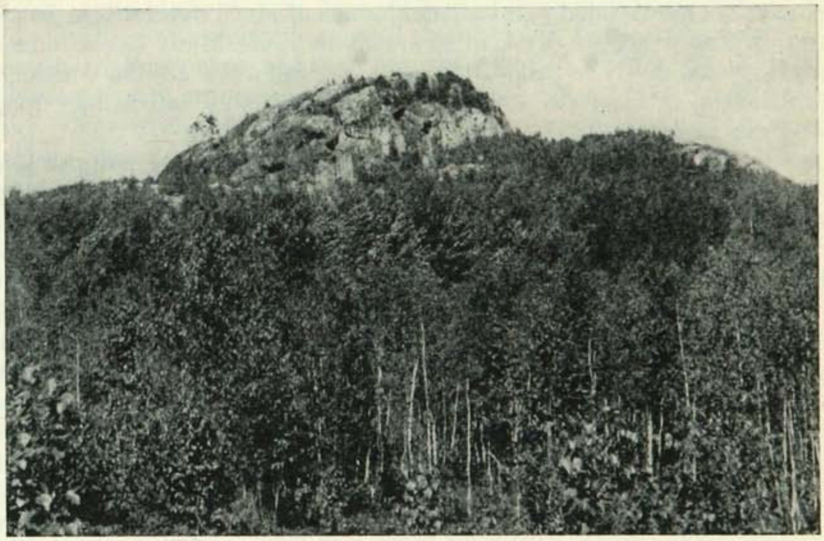

FIGURE 26. — Carlton Peak near Tofte. Huge anorthosite masses in diabase resisted erosion.

Recently the Erie Mining Company opened a quarry in Carlton Peak to obtain large blocks to face the breakwater of Taconite Harbor. The anorthosite is ideal for the purpose, being tough and breaking in large blocks, but not particularly difficult to drill.

No other practical use for anorthosite has been found to date. It is a potential source of aluminum, but under present conditions it is not practical to use it because of the difficulty of separating the aluminum from the other elements present, that is, calcium, sodium, silicon, and oxygen. Future technological developments may make anorthosite suitable as a source of aluminum when readily available sources of bauxite are exhausted.

Gravel and Sand

Gravel is the most abundant non-metallic geological resource of Cook County. It has been used chiefly for railroad ballast in former years and more recently for road materials, concrete and asphaltic aggregates, and minor special purposes. Reserves are good, and material suitable for roads is widely distributed. Quartzite cobbles in gravel were tested in 1943 as a substitute for imported flints, when flints were hard to get from western Europe.

The qualities desired in a gravel depend primarily upon the specific use. Since most Cook County gravel is used on roads, its exact composition and nature are secondary matters. Proximity is the first consideration and quantity the second. A thickness sufficient to yield ample volume without widely extended excavation, absence of much overburden, and a situation permitting gravity loading are all desirable. Many Cook County gravels are too sandy to be ideal for road use, and a few are too bouldery. Nevertheless, in most parts of the county reasonably satisfactory road gravel can be located.

For use in ball mills, quartzite cobbles must be of fairly uniform size and well recrystallized, like those of the Rove formation accumulated on the beaches of Wauswaugoning Bay. Before loading for shipment it would be necessary to hand-sort this gravel to remove perhaps 20 per cent of other rocks, such as diabase.

For use in concrete and asphaltic aggregates a good degree of sorting is required, and lithology of the particles is important. Rock fragments of high porosity, disintegrated by weathering, loosely aggregated, lacking resistance to wear, containing much clay, consisting of chert, or with a marked fissility are all undesirable. Usually, virgin gravel has to be screened, and in some instances crushed, to produce material suitable for aggregates. Most rocks in Cook County gravels are lithologically satisfactory, the principal undesirable constituents being slate from the Rove formation, chert and iron formation from the Gunflint, some Keweenawan lava of exceptional porosity or fissility, and minor amounts of weathered diabase, gabbro, and lava. Fragments of these rocks are abundant only in proximity to their bedrock sources. The major disqualifying feature of Cook County gravels for use in aggregates is the abundance of sand.

Four types of gravel accumulation are distinguished on a genetic basis: (1) shoreline gravels, (2) stream gravels, (3) glacial gravels, and (4) disintegrated bedrock. Subdivisions within the principal classes are possible, as for example in shore gravels which can be further subdivided into beaches, deltas, and shore platform veneers. Beach gravels form ridges a few to 10 feet high, hundreds to thousands of feet long, and 20 to 75 feet wide. This includes beaches of the present Lake Superior shore as well as abandoned beaches of ancient glacial lakes. Sorting in beach gravels is good, and the constituents have been subjected to extended wear with elimination or reduction of less resistant fragments. The cleanest pebble and cobble gravels in the county are in beaches, which consequently provide the best source for aggregates. Pebbles an eighth to one inch in diameter compose 80 to 90 per cent of some beach deposits, and 95 per cent of the beach gravel in Sec. 26, T. 62 N., R. 3 E. is estimated to consist of stones three eighths to three inches in diameter. Cobble and boulder beach deposits are also available. Particle size in beaches increases toward river mouths, so one may select material of almost any desired coarseness by moving laterally along a beach. Most beach deposits are not more than 10 feet thick, but their extent and outline are easily determined, and the total volume can be quickly estimated. Modern beaches and abandoned beach ridges at Deronda Bay and in Sec. 26, T. 62 N., R. 3 E., close to shore, have been worked by drag lines from barges.

Deltaic deposits along abandoned shorelines of the Superior coast have been more widely exploited than beaches. Most of the large gravel pits in the coastal area are in ancient deltas near stream mouths, probably because the gravels have greater volume and coarseness than elsewhere. Deltaic deposits are 15 to 25 feet thick and cover a wider belt than beaches. For the most part they contain too much sand to be ideal. The Cascade delta near Cascade Lodge consists predominantly of sand.

Shore platform veneers have been worked for gravel, but this appears to be chiefly a matter of proximity rather than desirability. Platform gravels are reasonably well sorted, but they are likely to be overly sandy and only 3 to 10 feet thick. Locally, as near Thomasville, a beach ridge superimposed on a platform veneer produces a desirable gravel deposit.

Stream gravels compose alluvial terraces extending upstream from the heads of abandoned deltas. The Temperance, Cascade, and Arrowhead rivers display such deposits. Gravel terraces, or more commonly gravel-capped terraces, also occur farther inland, as along the east side of the Temperance River, in T. 60 N., R. 4 W., where several gravel pits have been opened in a terrace 20 feet above river level. Most of these deposits are 10 to 20 feet thick, but along the Gunflint River are gravels fully 110 feet thick. These are classed as stream gravels, although they were probably deposited as glacial outwash in the valley of this river. Stream gravels are comparatively well sorted and are usually suitable for road use, although sandy.

Glacifluvial accumulations, such as eskers and the knobby, pitted deposits formed in association with stagnant ice, are the principal sources of glacial gravel. Sandy facies of the Rainy Lobe till have also been used for road gravel. Esker deposits are 20 to 30 feet thick, easily worked, and have better than average sorting for a glacial accumulation. A few, like Wampus esker, are too sandy, and the surficial layers of some are too bouldery. Esker reserves are large, easily evaluated, and constitute the best source of glacial gravels (Plate 1).

Glacifluvial gravels formed in association with stagnant ice are closely allied to eskers in character and distribution. They are not as well sorted as eskers and are locally too sandy, or have too many large boulders to be ideal. However, partly because of their wide distribution and availability, they have been freely used for railroad ballast and road gravel. In and near areas underlain by the Rove formation they contain too much slate to make suitable aggregates. Thicknesses are 20 to 30 feet, locally up to 50 feet, and reserves are large. The extent is determined with moderate ease from topographic form.

Glacifluvial materials also compose broad outwash plains and valley trains. Outwash debris, although better sorted than the knobby accumulations left by stagnant ice, is also richer in sand. It contains fewer large boulders than other glacifluvial deposits.

Sandy facies of Rainy Lobe till have been worked for railroad ballast and road gravel along the old logging railroad northeast of the Sawbill Trail. This material is poorly sorted, too rich in sand, and too bouldery to be ideal, but in lieu of anything better close at hand, it has been used. Till has also been sparingly used for gravel in other parts of the county.

At least a dozen pits have been developed in disintegrated bedrock. This material has a limited use on roads and in yards around homes for surfacing of walks, driveways, and parking areas. It is desirable because of its small and uniform particle size. Rocks weathering to this type of debris are ophitic diabase, amygdaloidal lavas, and a coarse, almost pegmatitic, facies of the Duluth gabbro. The thickness of such disintegrated material is 5 to 15 feet, but this usually includes some cores of firm rock. Small pits in this material are scattered over the Coastal Hills, several have been developed in diabase ridges south and southeast of Mineral Center, and the largest is in gabbro near the west end of Loon Lake (SE¼ of NW¼, Sec. 32, T. 65 N., R. 3 W.).

A total of 154 gravel pits have been located, although less than a quarter of these are active, and a number have been worked out. Considerable deposits of sand are available but have not been widely worked. Good thicknesses are exposed in the Cascade deltaic deposits near Cascade Lodge. Much of the glacifluvial material along the grade of the old logging railroad is rich in sand. Wampus and other eskers consist largely of sand, and much sand occurs in beach ridges and in hillocks among the knobby glacifluvial deposits of the interior. Along Gunflint Trail in the Gunflint River valley are exposures of fine sand 7 to 8 feet thick. Many gravel deposits are so rich in sand that screening would yield two good products. Beach sands along the north coast of Lake Superior are known to contain modest amounts of ilmenite, hematite, garnet, and spinel.

Soils

McMiller (1947, pp. 45–46) classifies the soils of Cook County in two major groups or associations. The Ontonagan soils of the first group are gray or light grayish-brown clay loams and silt loams developed on heavy red lake clays and red clay till. This group is limited to the area covered by the Superior Lobe. Most of the suitable farm land lies on the lakeward slope of the Coastal Hills and on the floors of the intervening broad longitudinal drift-filled valleys. The second group of soils is the Milaca-Cloquet association developed in areas where Rainy Lobe deposits mantle the surface. The coarse nature of this drift makes the soils too stony to have much use for agriculture. Their principal value is for silviculture, seemingly the best possible means of exploitation at present. Minor peat soils are widespread, but not likely to be much used.

Building Stone

Large exposures of rocks of many varieties have been described in Chapter 1, the general part of this report. Many of these rocks would make excellent crushed rock for concrete work, but the abundance of gravel makes this use of solid rock unnecessary. Likewise many varieties yield blocks suitable for construction, and some local use has been made of them.

The distance to market has discouraged investigation of the igneous rocks as a source of commercial granite. In general these rocks are dark gray to black; the demand for them is small and likely to be limited to the immediate area of occurrence.

OTHER RESOURCES

Water Supply

The area of Cook County along the shore of Lake Superior has access to perhaps the world's finest water supply. The total hardness of the lake water is 54 parts per million, and at depth the year-round temperature is close to the point of greatest density of water, 4°C. or 39.2°F. Because of a growing population along shore and use of the lake for navigation, the water needs some treatment for domestic use.

Surface water from lakes and streams is abundant over most of the county. The water is generally of low hardness but may have considerable organic material in solution.

In general the bedrock formations of the county are not good sources of water. Many of the rocks are lacking in porosity and permeability. The porous tops of lava flows frequently supply water, but in some cases the water has a high mineral content and if sulfates are present this is particularly objectionable.

The best sources of ground water are the sand and gravel deposits which occur at many places. The glacial drift is normally sandy and gravelly, and shallow wells yield water copiously. Near the shore of Lake Superior many springs have been utilized as a source of domestic water. Most of the springs probably result from water which flows along the top of the rock surface to emerge at favorable points, mainly near Lake Superior.

At places the porous tops of lava flows dip toward the lake, and water entering inland builds up a head as it moves toward the lake. Grand Marais has long utilized the water from a group of springs near the Gunflint Trail, about a mile from town and at a considerable elevation above Lake Superior.

Water Power

For the most part, the streams of Cook County have a large flow in the spring and a small flow in late summer, fall, and winter. Data are given by Follansbee (1912) and by reports to the U.S. House of Representatives (1932). Over the years, interest in water power has given rise to sporadic proposals for the development of sites, but with present-day efficient generation of power by steam and diesel units, it seems doubtful whether any water power site in Cook County would prove more economical.

Forest Resources

The basic natural resource of Cook County is its forests. The Office of Iron Range Resources and Rehabilitation of Minnesota has published an inventory of the forest resources of the county (1955) to which reference should be made for detailed information. A few of the most important facts are summarized herewith for convenience.

Out of a total forest land area of 897,900 acres, commercial forest land accounts for 722,800 acres; non-commercial forest land, 144,500 acres; other land areas, 30,600 acres.

Distribution by ownership is as follows: national forest, 593,900 acres; Indian trust, 42,900 acres; state, 137,300 acres; county and municipal, 18,900 acres; farm (1950 census), 700 acres; other private ownership, 97,900 acres.

The allowable annual cut of sawtimber is 38,460 board feet; of pulp wood, 147,830 cords. Though not equally applicable to all ownerships nor to all types of timber, the present annual cut is approximately one half of that allowable, so that at the moment the county as a whole is building up reserves. That forest resources will long continue to play an important role in the economic life of Cook County is a foregone conclusion.

6. DESCRIPTIONS OF TOWNSHIPS

TOWNSHIP 66 NORTH, RANGE 5 WEST
(FIGURE I)

Little is known of the Pleistocene deposits in this township from first-hand observation. Air photographs and a few hasty traverses indicate that most of the area is bedrock, bare or in places thinly mantled by till. The till cover is more extensive in the western part of the township, south of the southwest arm of Saganaga Lake, and around Red Rock Lake. The lake shores and exposures of granite show glacial striations running southeast.

The bedrock in many scattered exposures is Saganaga granite. The structures plotted are based on a great many exposures and a high degree of uniformity in the plunge of elongated minerals, quartz, hornblende, and others. A few aplite and pegmatite dikes in cross joints all indicate that at a late magmatic stage there were minor amounts of magma injected into the cooling batholith — much of it in the Canadian parts of the mass. A detailed study of the structures plotted suggests that an intrusive domed up its greenstone roof and was later eroded and largely covered by Knife Lake sediments ranging from sand to gravel. The late sediments were folded, faulted, and metamorphosed so that it is clear that the intrusive complex, as well as the sediments, was eroded in Pre-cambrian time (Grout, 1933a). The interpretation of well-exposed formations is clear at most places. The Knife Lake meta-sediments near the granite are perhaps best exposed on the Canadian shores of Saganaga Lake, but they are clearly folded and probably faulted metamorphosed sediments. Gruner (1941) suggested a "buttress" of granite deformed at considerable depth, but the evidence is not clear.

In this township the plunge of linear structures in the granite ranges from 10° east near the contact, to 40° or 50° east a few miles east of the contact.

TOWNSHIP 66 NORTH, RANGE 4 WEST
(FIGURE II)

Rock exposures in this township are extensive, and the glacial deposits are chiefly localized accumulations in lower areas between outcrops. Most of the glacial material is thought to be bouldery Rainy Lobe till, rich in debris derived from the Saganaga granite.

The main area is underlain by a portion of the Saganaga granite mass which also contains a long lamprophyre dike extending from Sec. 7 to Sec. 30, and it also continues northwestward in T. 66 N., R. 5 W.

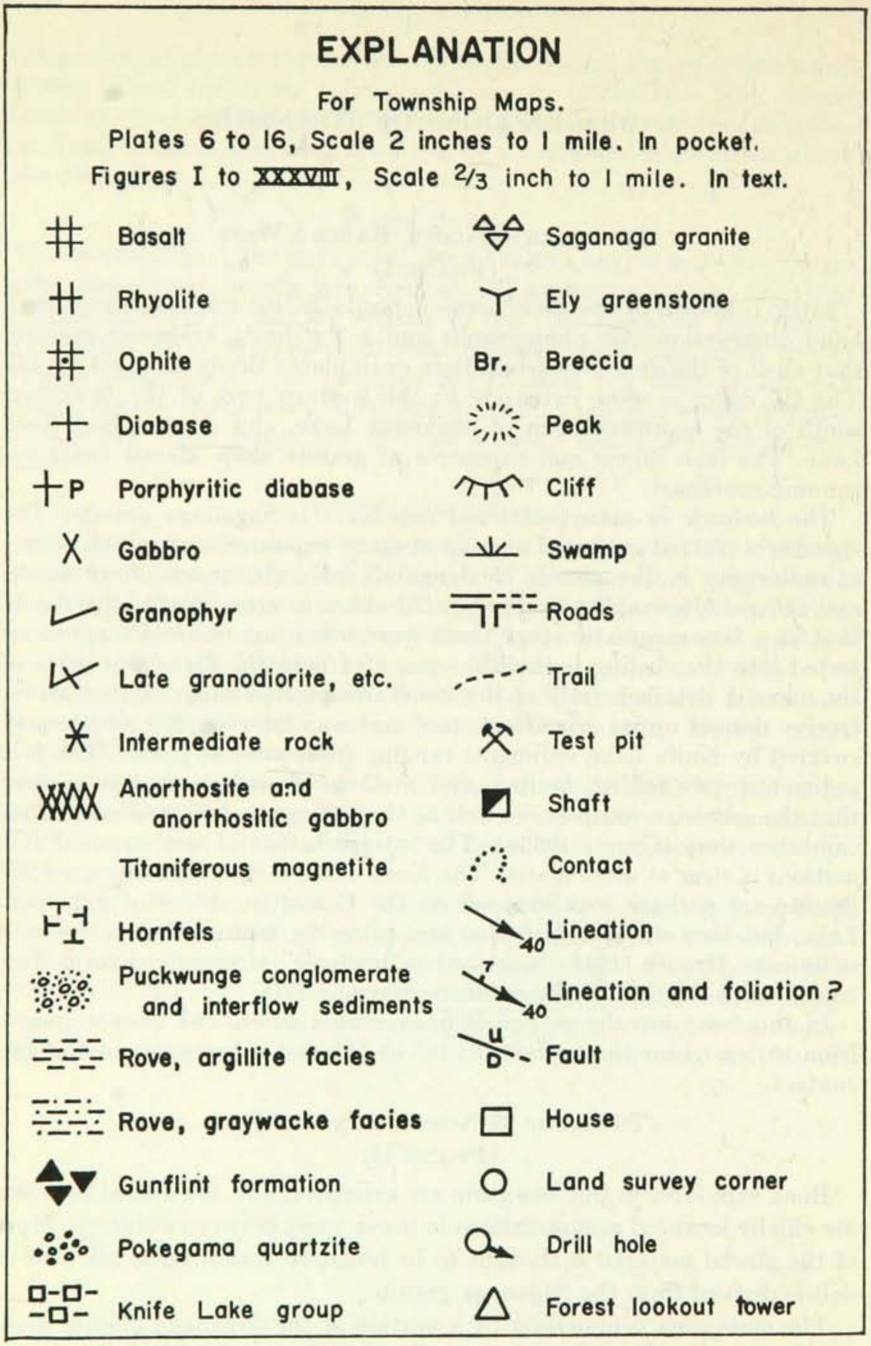

FIGURE 27. — Explanation for township maps.

The fraction in T. 67 N., R. 4 W. included here consists of several islands, not more than half a mile across, near the mainland in T. 66 N. East of the boundary river, the fairly well-exposed granite and related igneous rocks have been studied in Canadian areas for approximately ten miles.

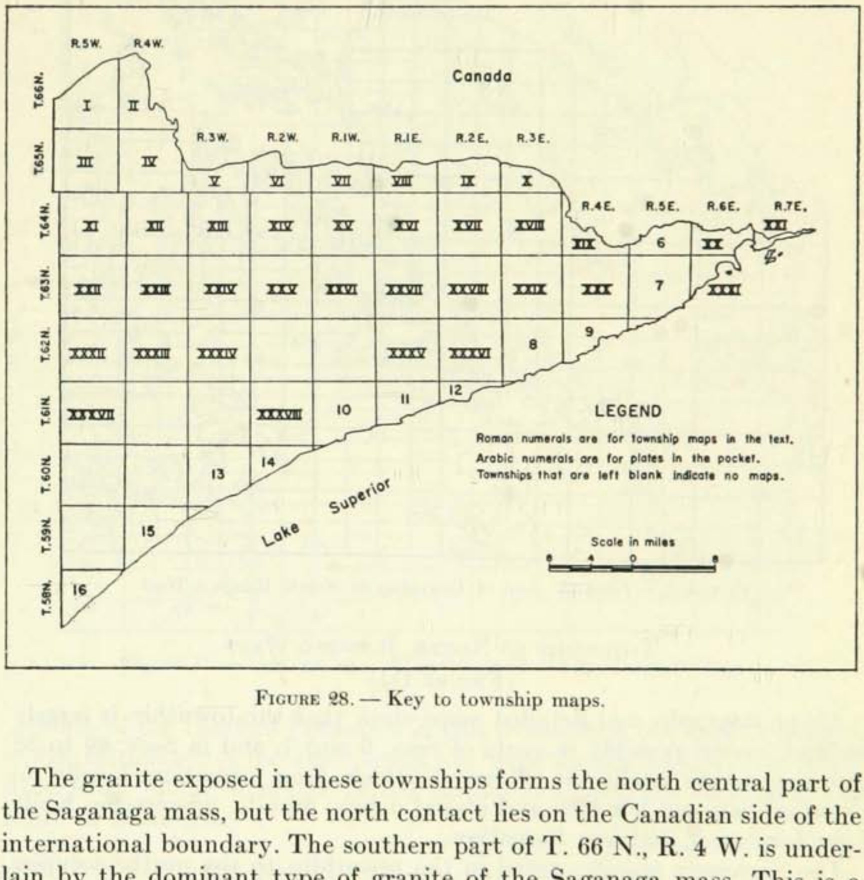

FIGURE 28. — Key to township maps.

The granite exposed in these townships forms the north central part of the Saganaga mass, but the north contact lies on the Canadian side of the international boundary. The southern part of T. 66 N., R. 4 W. is underlain by the dominant type of granite of the Saganaga mass. This is a sodic hornblende granite with conspicuous large grains of quartz (one eighth to one half inch across).

In the northern part of the map area the outcrops consist of hornblendic border facies, which grades locally into hornblende syenite but for the most part is a simple granite that contains more hornblende and less quartz than the granite farther south. Two large lamprophyre dikes on the islands of Secs. 1 and 12 may be much later than the Saganaga granite mass.

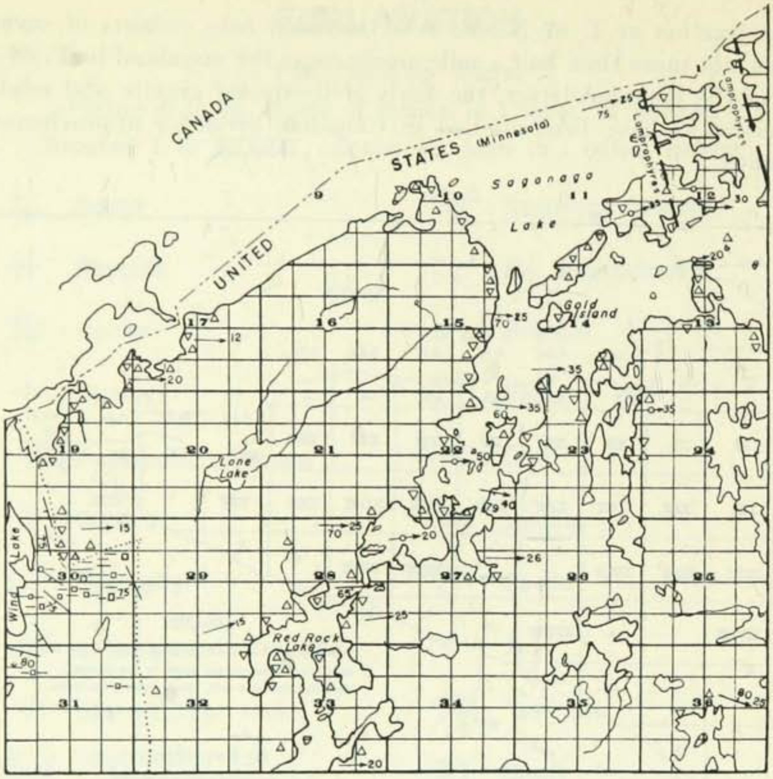

FIGURE I. — Geologic map of Township 66 North, Range 5 West.

TOWNSHIP 65 NORTH, RANGE 5 WEST
(FIGURE III)

Air photographs and detailed maps show that the township is largely bedrock except possibly in parts of Secs. 6 and 7, and in Secs. 29 to 32 inclusive, where locally the till may be thick. Four formations locally resisted erosion and left hills and glacial debris; granite, greenstone, Knife Lake formation, and iron formation.

The Saganaga granite, noted in the townships to the north, occupies about one third of the township at the northeast. The older Ely greenstone and the younger, overlying Knife Lake sediments are highly folded and metamorphosed, and extend east and west across the township. It is likely that the greenstone and younger beds were folded into an anticline, as Knife Lake beds occur both north and south of the greenstone.

The Gunflint iron formation in this township is a continuation of a long series of exposures to the northeast, cut off by the gabbro at the west side of Sec. 34, with only small exposures occurring farther west across Lake County.

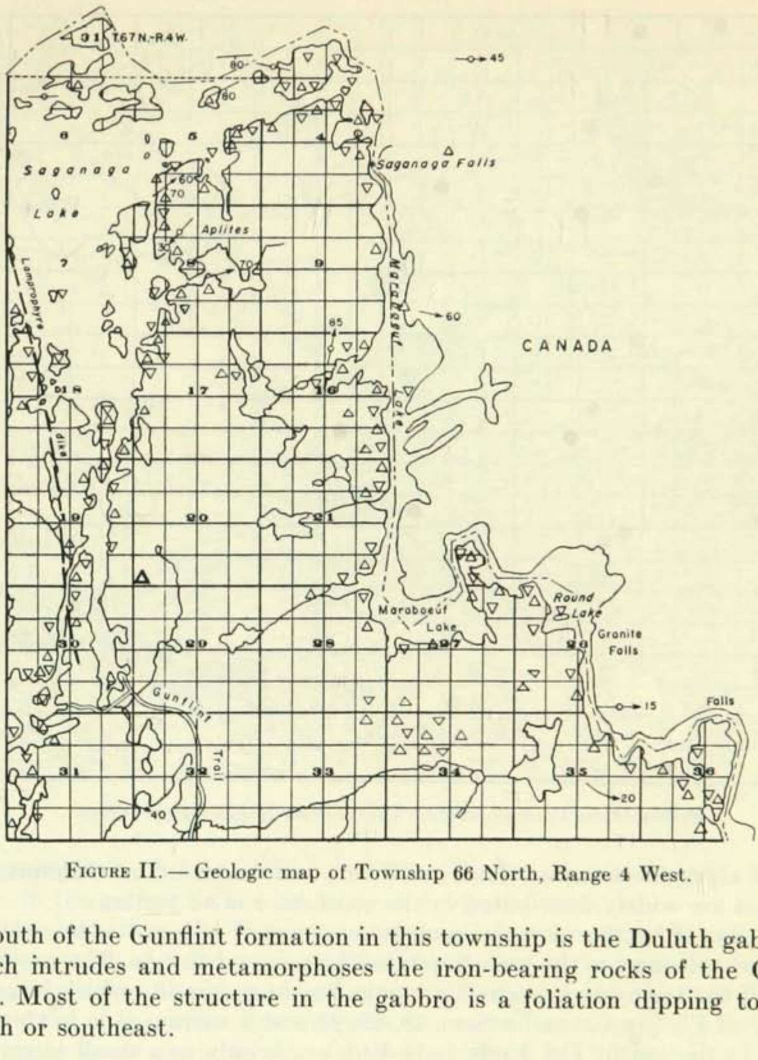

FIGURE II. — Geologic map of Township 66 North, Range 4 West.

South of the Gunflint formation in this township is the Duluth gabbro, which intrudes and metamorphoses the iron-bearing rocks of the Gunflint. Most of the structure in the gabbro is a foliation dipping to the south or southeast.

TOWNSHIP 65 NORTH, RANGE 4 WEST (FIGURE IV)

Throughout much of this township rock outcrops are numerous. The glacial deposits are thin and patchy, and consist largely of Rainy Lobe till and localized accumulations of bouldery glacifluvial gravel; the latter appear to be especially abundant in Secs. 17 and 18 and in the northern parts of Secs. 19 and 20. Along the Gunflint River in Sec. 26 are deposits of sandy gravel at least 110 feet thick, with localized areas of limonitic and calcareous cement. Fine sand deposits, possibly water-laid, are ex-

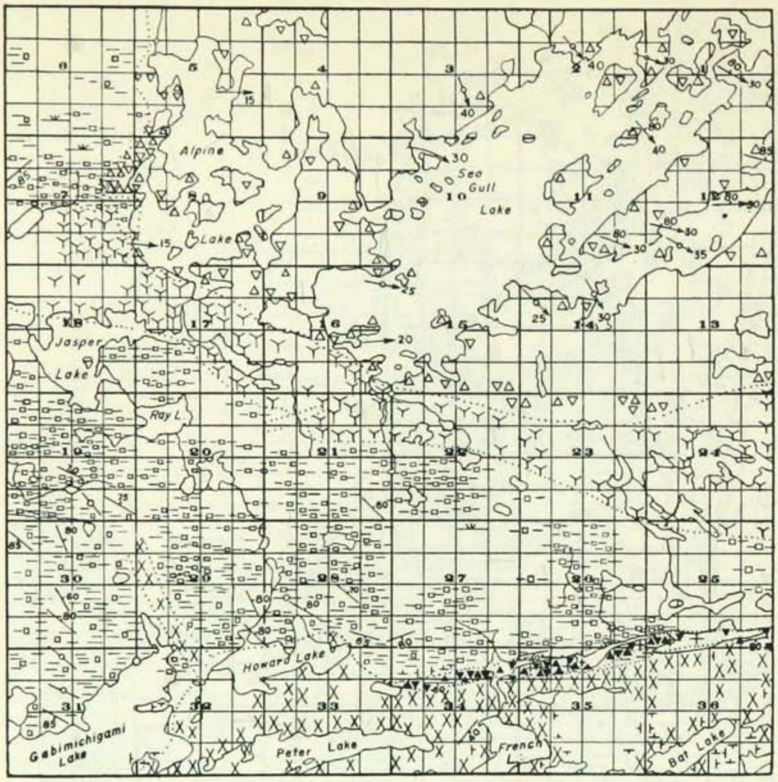

FIGURE III. — Geologic map of Township 65 North, Range 5 West.

posed along the Gunflint Trail in Sec. 25; and fragments of Gunflint formation are widely distributed in the southern row of sections.

As shown by the map the geology is arranged in more or less clearly defined belts across the township in an east-west direction. The northern half of the township is underlain by the Saganaga granite which intrudes a belt of Ely greenstone in Secs. 19, 20, 21 and a narrow zone in the sections to the south. The Knife Lake beds occur only as a small tongue in Sec. 30. Unconformably overlying the older formations noted above is a belt of Gunflint iron formation which extends across the township. In Secs. 22, 23, and 24 is a narrow belt of Pokegama quartzite which overlies the granite unconformably and underlies the Gunflint formation. Diabase sills intrude the Gunflint formation and complicate the problem of utilization as a material for concentration.

In Sec. 25 a narrow tongue of Rove formation extends into the township from the large area to the east.

The north border of the Duluth gabbro mass extends along the southern two tiers of sections. As a result there has been considerable contact

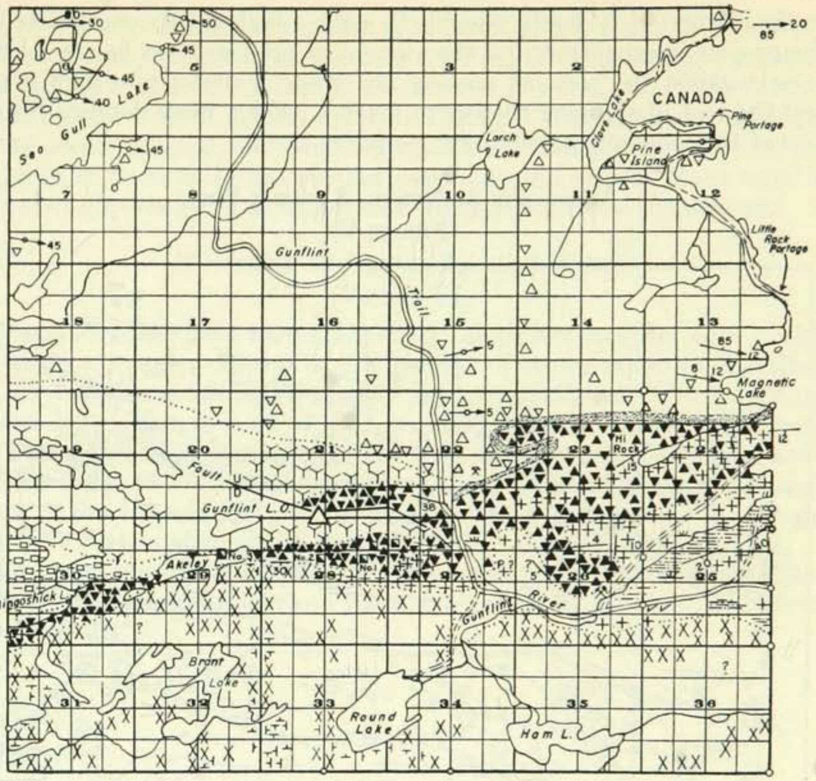

FIGURE IV. — Geologic map of Township 65 North, Range 4 West.

metamorphism of the Gunflint and Rove formations, and hornfels inclusions in the gabbro, in Sec. 33, represent engulfed material.

From early days the Gunflint iron formation was recognized as a prospective source of iron ore along the Hudson Bay route from Grand Portage, long before the Mesabi iron range was known and correlated. Flints from some of the rock exposures were known and used by the earliest explorers to ignite gunpowder in flintlock muskets; hence the name "Gunflint Lake" and later the term "Gunflint iron formation."

Several explorations in T. 65 N., R. 4 W. have led to drilling, shaft-sinking, and careful analyses and metallurgical tests. The iron formation was explored in early years by opening shafts of moderate depths and by drilling some 75 holes. There was a railroad from a harbor in Canada, but modern methods of concentrating ore had not been developed. Three deep holes explored to underlying rock were largely in Ely greenstone schist altered by granite. Active work was abandoned in 1893.

In 1950 more careful explorations were undertaken, using modern methods of testing iron ores, and a general summary has been made available to the Survey. It is clearly possible to make a high grade concentrate but the process is expensive, and the amount of ore produced has to be balanced against the costs of making low grade material into high grade, and the cost of shipping the ore to market. (For a more detailed discussion of the economic possibilities, see pages 78–80.)

Township 65 North, Range 3 West
(Figure V)

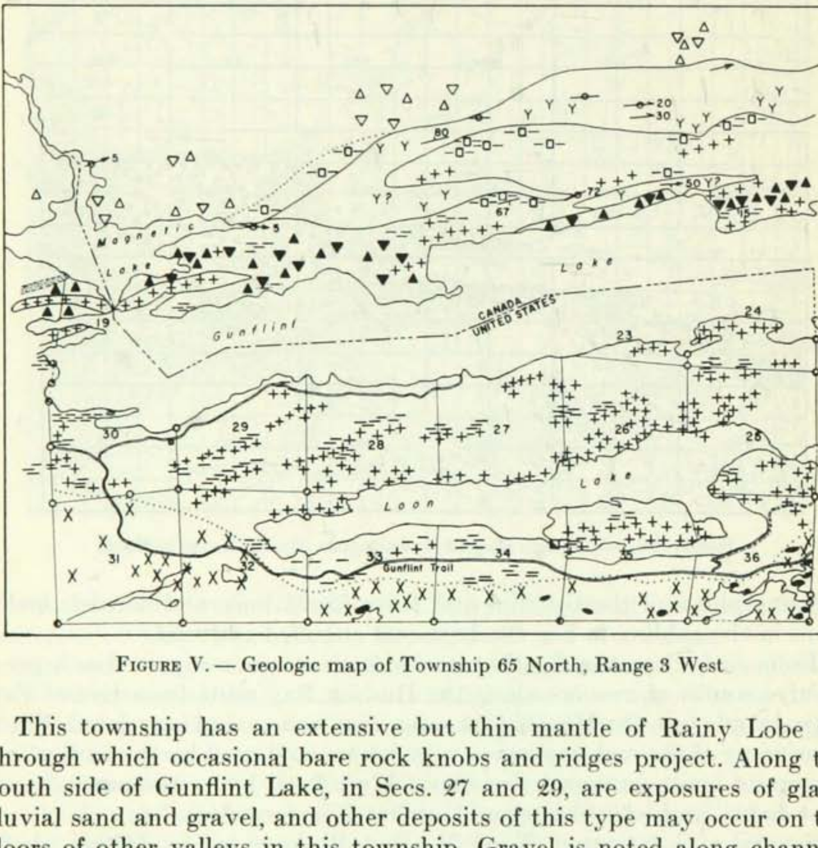

Figure V. — Geologic map of Township 65 North, Range 3 West

This township has an extensive but thin mantle of Rainy Lobe till through which occasional bare rock knobs and ridges project. Along the south side of Gunflint Lake, in Secs. 27 and 29, are exposures of glacifluvial sand and gravel, and other deposits of this type may occur on the floors of other valleys in this township. Gravel is noted along channels between some of the lakes. At the west end of Gunflint Lake, according to Zumberge (1952), sandy deltaic deposits laid down by the Gunflint River have been reworked into a sandy beach and a low bar.

The geologic sequence is well shown near Gunflint Lake. North of Magnetic Bay there are outcrops of Saganaga granite which continue eastward into Canada across the map. Around the eastern shores of Magnetic Lake are small outcrops of Ely greenstone and Knife Lake slates; northwest of the entrance to Magnetic Bay is a bed of Pokegama quartzite one to ten feet thick, and Gunflint iron formation is found in somewhat deformed beds. As shown on the map the beds of the Gunflint formation and the Rove slate are intruded by diabase sills and dikes, and farther south by the Duluth gabbro near the Gunflint Trail. Titaniferous magnetite occurs as scattered small segregations in the gabbro south of the highway in Secs. 32 to 36. Further details on the area of Rove slate in this township are given in Minnesota Geological Survey Bulletin 24.

Township 65 North, Range 2 West
(Figure VI)

Glacial deposits have been studied only along the southern edge of this township where they appear as thin patches of brown sandy till scattered among bedrock outcrops. Grout and Schwartz (1933, p. 72) report that glacial drift is thin in most of the township except in parts or all of Secs. 19, 20, 25, and 26. An esker extending from the east end of Gunflint Lake through Secs. 19, 20, and 21 to the west end of North Lake suggests that much of this thicker drift may be glacifluvial material formed in association with masses of stagnant ice.

The main topographic feature of the township is a ridge between Gunflint, North, and South lakes on the north, and Crab, Mayhew, and Birch

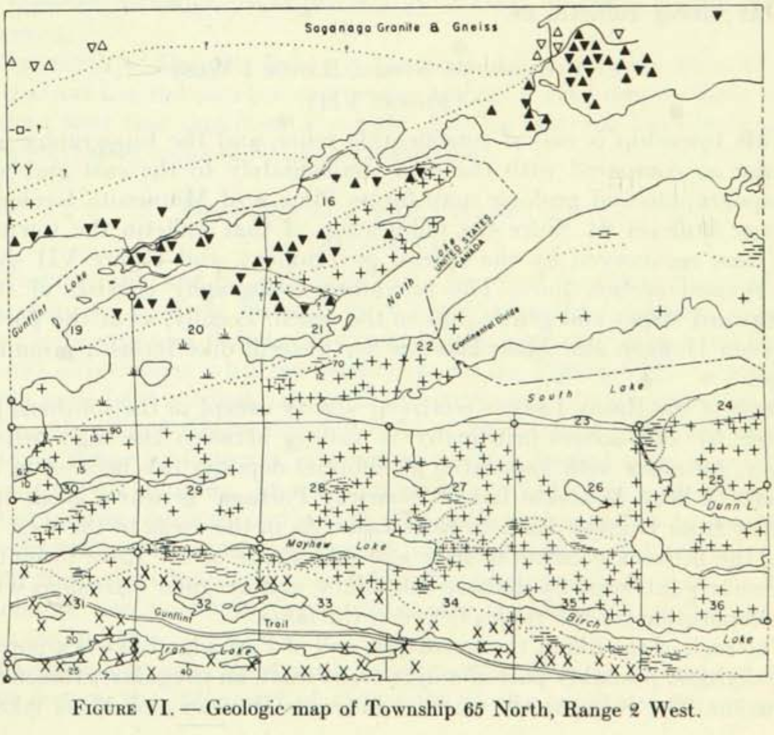

FIGURE VI. — Geologic map of Township 65 North, Range 2 West.

lakes on the south. The east-west trend of the lakes coincides with the strike of the slate and diabase sills. There is a marked difference in elevation of the two chains of lakes, the water surface of South Lake, for example, is approximately 1552 feet whereas Mayhew is 1850 feet above sea level.

The Continental Divide between North and South lakes is a very low ridge which rises scarcely 20 feet above the water level on either side, but nevertheless deflects the drainage partly toward the north to Hudson Bay, and partly toward the east to the Pigeon and St. Lawrence rivers.

The Gunflint formation trends across the area along the international boundary. To the south the rocks of the Rove formation, intruded by diabase sills, form a belt about two miles wide. In the southern tier of sections the base of the Duluth gabbro lies on and metamorphoses the argillites and graywackes of the Rove formation.

It is reported that early hunters using the Grand Portage canoe route found the best flints for their guns in the low bluffs of Secs. 16, 17, 20, and 21.

Titaniferous magnetite deposits of limited extent occur in Secs. 31 and 33 near Iron Lake, in Sec. 32 near West Pope Lake, and also on the north shore of Iron Lake.

Further details regarding this township are given in Minnesota Geological Survey Bulletin 24.

Township 65 North, Range 1 West
(Figure VII)

This township is one of considerable relief, and the topography is irregular as compared with the areas immediately to the east and west. A topographic and geologic map forms Plate 4 of Minnesota Geological Survey Bulletin 24. Since the publication of that bulletin the township has been resurveyed by the federal government, and Figure VII shows the revised section lines. The prevailing topography consists of steep northward slopes and gentle dips to the south. Locally, as at the portage between Duncan and Moss lakes, a north-south dike forms a prominent ridge.

Drift of the Rainy Lake is relatively scanty except in the southern part of Sec. 31 and occurs principally in valleys between the high bedrock ridges. An esker with associated glacifluvial deposits can be seen in Sec. 36 east of West Bearskin Lake. "Stairway Portage" is near a small creek flowing from Duncan Lake to Rose Lake. As in the areas to the west and east, the bedrock consists of slate and graywacke of the Rove formation, extensively intruded by diabase sills, dikes, and irregular intrusions which are responsible for the ridges between the lakes.

The rock of the hill at the southwest end of Partridge Lake is a porphyritic diabase, probably part of a dike or, at least, an irregular, crosscutting intrusion. The ridge at the portage between Duncan and Moss lakes is

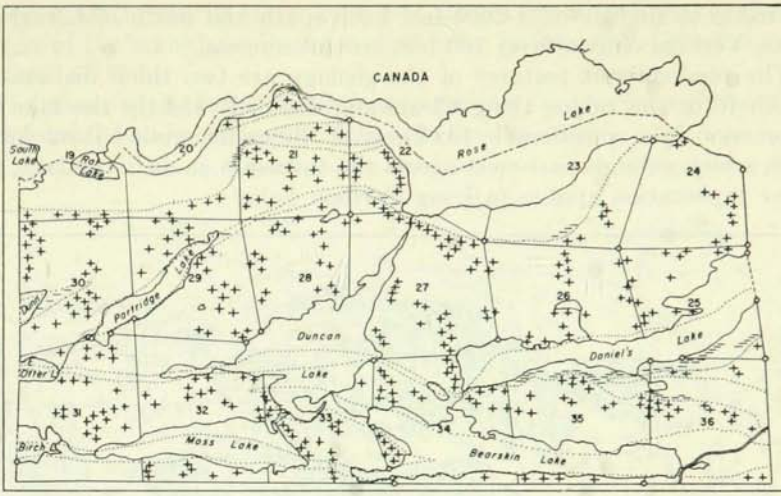

FIGURE VII. — Geologic map of Township 65 North, Range 1 West.

formed by a porphyritic diabase dike. Near the shore of Moss Lake a coarse-grained diabase grades into anorthosite. Many anorthosite blocks are rounded, although single crystals up to three inches in length may be observed.

Just north of Daniel's Lake, on the section line between Secs. 25 and 26, diabase has red patches and grades toward a granophyre. This is the farthest west that significant amounts of acidic material have been noted in the intrusive rocks of the Rove formation.

TOWNSHIP 65 NORTH, RANGE 1 EAST
(FIGURE VIII)

A topographic and geologic map and a more detailed description of this township are given in Bulletin 24 of the Minnesota Geological Survey. Since publication of Bulletin 24 the township has been resurveyed by the federal government with the results shown on Figure VIII. Glacial deposits have been studied only in the western part of this township along the north side of Clearwater Lake. The area is principally one of high bedrock ridges and narrow intervening valleys floored with glacial drift consisting of bouldery, brown, sandy Rainy Lobe till and patches of pitted glacifluvial sand and gravel. The drift is thought to be somewhat thicker and more extensive in Secs. 19, 27, 30, and 32 (Grout and Schwartz, 1933) than elsewhere in the township. Air photographs suggest an esker extending north-easterly from Clearwater to Mountain Lake through Secs. 22 and 27.

The township has considerable relief, ranging from an altitude of about 1489 feet on the little part of Pine Lake at the southeast corner of the township to slightly over 2000 feet both south and north of Clearwater Lake. Vertical cliffs of over 100 feet are not unusual.

The predominant features of the geology are two thick diabase sills which form the ridges along Clearwater Lake. Evidently the lake is a depression in a considerable thickness of the easily eroded Rove formation, which extends east-west across the township as does the lake. The same explanation applies to Long Caribou Lake.

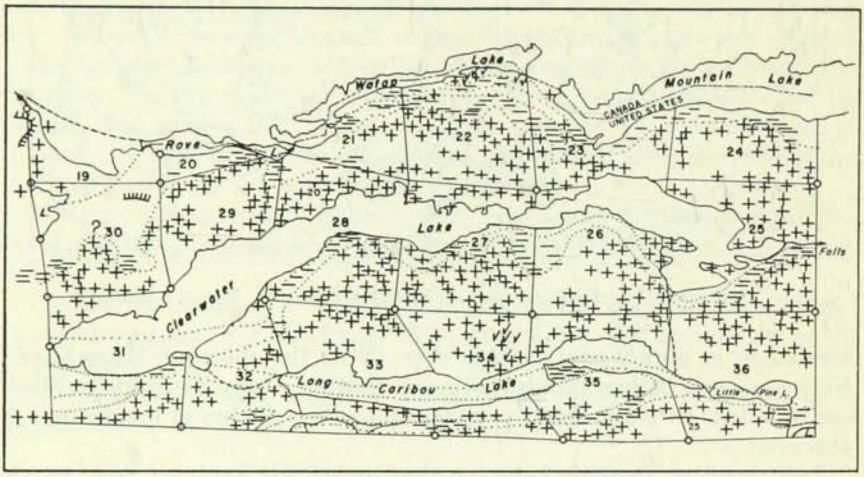

FIGURE VIII.— Geologic map of Township 65 North, Range 1 East.

The large sill south of Clearwater Lake has plagioclase phenocrysts and anorthositic patches near the top. One patch of granophyre occurs in Sec. 34, a rather small occurrence for such a large sill.

The large exposures of slate and graywacke along the bluff overlooking Rove Lake were the source of the name "Rove formation," introduced by Clements (1903) as "Rove slate."

TOWNSHIP 65 NORTH, RANGE 2 EAST (FIGURE IX)

A map and a more extended description of this township are given in Bulletin 24 of the Minnesota Geological Survey. The general east-west trend of the ridges between lakes is continuous with those to the west. In the northeast sections (23 to 26), however, a rather broad somewhat dissected plateau is believed to result from hinge faults near a bluff.

Glacial deposits are thin over most of the area. The lowlands contain some thin deposits of brown sandy till and possibly local accumulations of related glacifluvial material. The general effect of the glacier was to scour off the diabase ridges and, to some extent, dump the material in the valleys.

The south border of the township is formed by Pine Lake, by far the largest of the many east-west trending lakes in the area of the Rove formation.

The major geologic feature of the township is the two large diabase sills that form the main east-west ridges between the lakes.

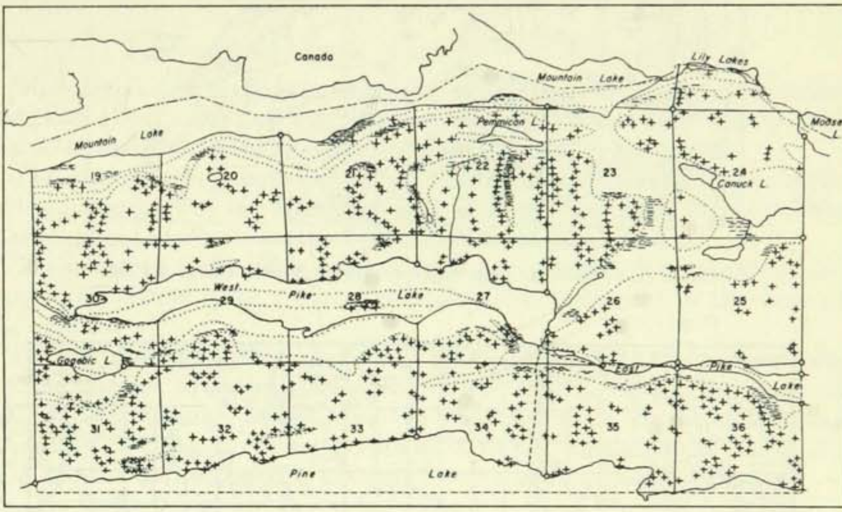

FIGURE IX. — Geologic map of Township 65 North, Range 2 East.

Near Pine Lake anorthosite patches are numerous in the porphyritic diabase. Phenocrysts up to three inches in length were observed. It is noteworthy that the large sill between West Pike and Mountain lakes is not at all porphyritic.

TOWNSHIP 65 NORTH, RANGE 3 EAST
(FIGURE X)

A map and a more detailed description of this township are given in Bulletin 24 of the Minnesota Geological Survey. Glacial deposits are scanty and occur chiefly in the valleys and hollows between the bare rock ridges. The drift is probably till deposited by the Rainy Lobe. The western part of the township is essentially a continuation of the topography to the west, but to the east North and South Fowl lakes cut abruptly across the trend. As the international boundary passes through the lake the township is cut off at Secs. 26, 27, and 35. The presence of a lake with its length running north and south is unusual in the area of the Rove formation and seems to be accounted for by a well-defined change in the strike of the rocks from east-west to northwest-southeast.

The diabases of the area are normal in character, as are the slate and graywacke of the Rove formation. At the bluff on the west shore of John

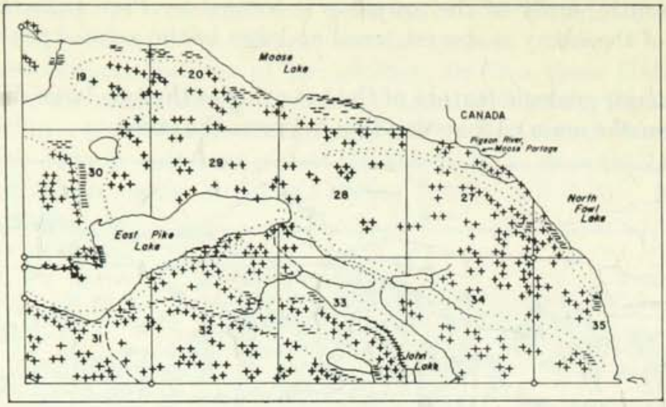

FIGURE X. — Geologic map of Township 65 North, Range 3 East.

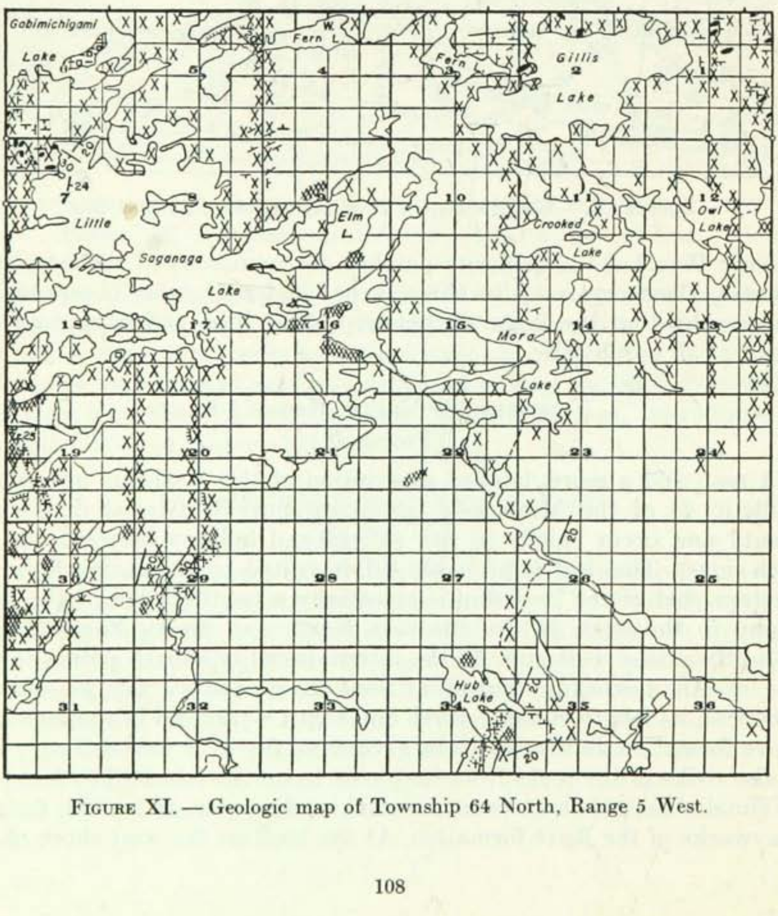

FIGURE XI. — Geologic map of Township 64 North, Range 5 West.

Lake is an exposure of about 165 feet of slate, the greatest thickness observed at any one place.

On a bluff overlooking North Fowl Lake a vertical fault with a throw of at least 40 feet was observed. Another minor fault is exposed in a cliff near the center of Sec. 30. These serve to verify the inference of faulting as a cause of the breakup in the plateau surface noted above.

Township 64 North, Range 5 West (Figure XI)

The glacial debris consists largely of gabbro, boulders, and finer material; and about one fourth of the township at the south is almost concealed by debris of gabbro and other rocks.

This township lies almost wholly within the area underlain by the rocks of the lower part of the Duluth gabbro complex. The base of the gabbro mass is about one mile north of the north town line.

The island in Gabimichigami has exposures of rocks that probably belong to the Knife Lake group and represent a re-entrant in the base of the gabbro.

Diabase dikes, probably later than the gabbro, occur in Secs. 19 and 34.

A small area of Animikie iron formation is exposed on the shore of Gabimichigami Lake, but most of the small exposure is west of the west boundary of Cook County. From Sec. 9 to the south side of T. 64 N., R. 5 W., the Duluth gabbro has many outcrops of anorthosite.

Township 64 North, Range 4 West (Figure XII)

Little is known from direct observation concerning glacial deposits in this township. Air photographs and traverses show extensive areas of bare or almost bare bedrock with only a thin patchy veneer of glacial debris, but the south central part has an extensive veneer of drift.

This township is in the midst of the Duluth gabbro, the base being from one to one and a half miles to the north of the town line. Three minerals have been segregated locally: titaniferous magnetite in the northern part near Tuscarora and Dawkins lakes; anorthosite in Sec. 36; and some copper in the gabbro exposures in the general area of Secs. 9, 10, and 15.

Further details regarding the titaniferous magnetite are given by Grout (1950). It is noteworthy that hornfels rock occurs with the titaniferous magnetite, suggesting that they may represent masses of Gunflint formation rather thoroughly digested by the gabbro.

A zone of granophyre in gabbro is somewhat persistent from Sec. 31 northeastward to Sec. 16, beyond which it was not observed.

Township 64 North, Range 3 West (Figure XIII)

Glacial deposits in this township have not been thoroughly studied but are extensive in the central part where outcrops are sparse. Thin, disconnected deposits of till occur in low places between numerous gabbro

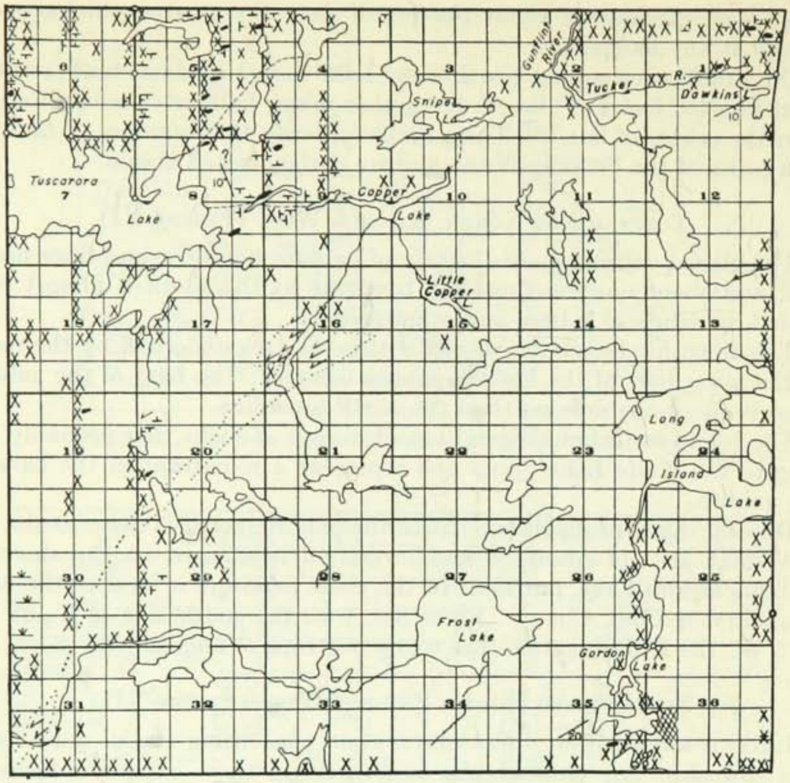

FIGURE XII. — Geologic map of Township 64 North, Range 4 West.

knobs and prominences, along both the north and south rows of sections. Gravel occurs near the Gunflint Trail and is evidence of glacifluvial deposits.

The northern part of the township (Sec. 1 to Sec. 6) has been explored for titaniferous magnetite at intervals since 1883. Additional field work and drilling near Tucker Lake in 1947 added much information as to the exact nature of the deposits. The detailed results, including logs of the drillings, are given by Grout (1949). The extensive deposits are in Secs. 1 to 6. Grout (1950, p. 83) gives an estimate of six million tons of "inferred" ore in Sec. 2.

This township lies in the midst of the north arm or sill-like projection of the gabbro mass. The gabbro along the north side of the township is therefore typical of the lower part of the gabbro complex, and the outcrops along the southern tier of sections include intermediate rock and granophyre characteristic of the upper part of the sill.

Because of difficulty of access and the information that outcrops were largely lacking, the central part of the township was not examined.

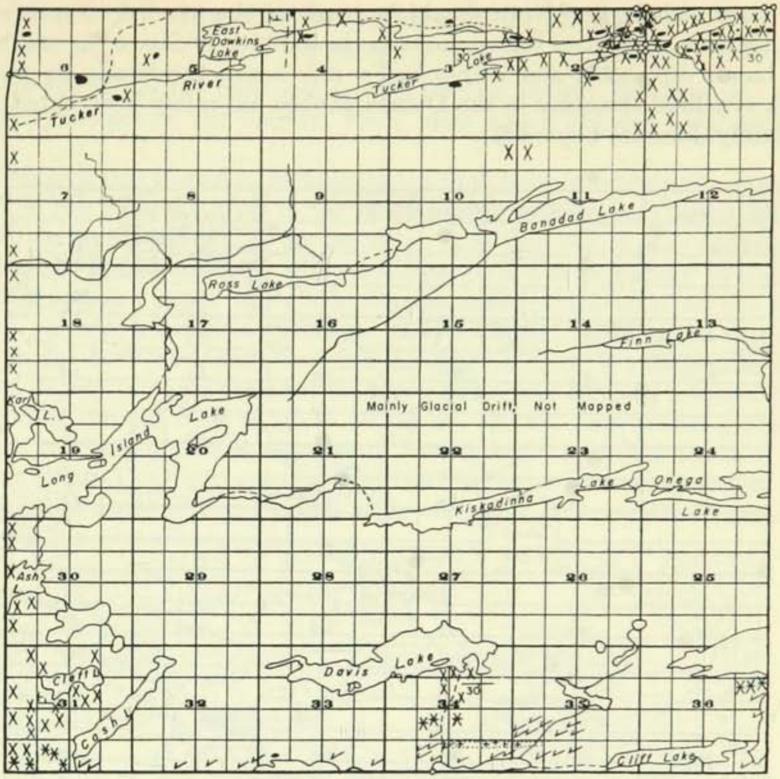

FIGURE XIII. — Geologic map of Township 64 North, Range 3 West.

TOWNSHIP 64 NORTH, RANGE 2 WEST (FIGURE XIV)

Glacial deposits were studied only in the northeastern corner of this township. Here they consist of a thin patchy veneer of brown sandy till scattered among bare rock knobs and ridges. Air photographs suggest that this is the general situation throughout most of the township, although the high bedrock ridges of the Misquah Hills south of Winchell Lake dominate the southern and southeastern part.

The entire township is underlain by various facies of the Duluth gabbro complex. Gabbro, plus some titaniferous magnetite, occupies the northern two thirds, but south of Winchell Lake intermediate rock and granophyre form the Misquah Hills.

Titaniferous magnetites are exposed at many points in this township, notably near Poplar Lake in Secs. 1 and 2. This area is along the same zone as the Tucker Lake deposits in the next township west. Careful study of the surface outcrops shows many small bodies, though few if any large rich bodies. Note should be made of the banded structure resulting from magnetite segregations in the gabbro. In Sec. 2 the northern ore bands dip south, and within half a mile south the bands dip north. Such synclinal structure in the Duluth gabbro has rarely been noted and probably does not extend far.

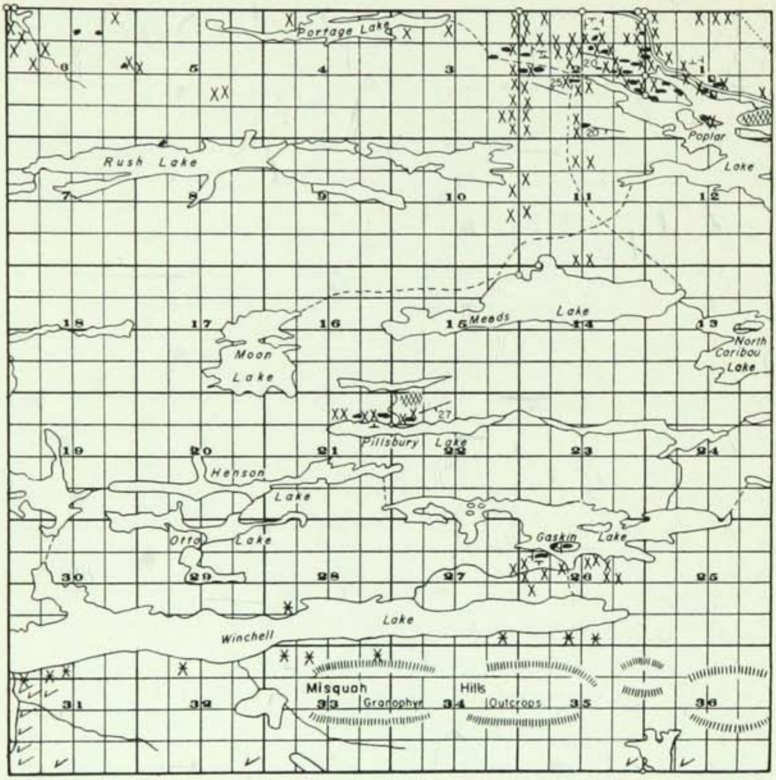

FIGURE XIV. — Geologic map of Township 64 North, Range 2 West.

Other exposures of titaniferous magnetite have long been known, but only a few have been carefully mapped. Small exposures occur north of Pillsbury Lake and in the islands and on the south shore of Gaskin Lake in Sec. 21, 22, and 26. The fact that these are about three miles south of the Poplar Lake belt, and even farther northeast of the prospects at Smoke Lake, has led to these deposits being referred to as the "Middle Range." Grout (1950) lists the following sections as having some magnetite: 1, 2, 3, 4, 6, 8, 21, 22, 25, and 26. Although an estimate of one million tons of "inferred" ore is given for Sec. 6, such scattered deposits are unlikely to be of interest in the near future.

Township 64 North, Range 1 West
(Figure XV)

The township has been resurveyed by the federal government, with drastic changes in the original town plots which showed ideal section lines.

Although this township includes much high bare country rock, particularly in the Misquah Hills in the southern tier of sections (highest point in Minnesota, 2232 feet above sea level, is in Sec. 32), it also contains a variety of glacial deposits. Most widespread is a thin patchy veneer of bouldery brown sandy till which, despite earlier statements to the contrary, nowhere appears to constitute an end moraine. Glacifluvial deposits are particularly abundant and can be seen in Secs. 4 and 5 near Leo Lake; in Sec. 10 along the road to Aspen Lake; and forming a broad area extending through Secs. 8, 10, 15, 17, 20, 21, and 22. This township is also rich in eskers, with Wampus esker in Secs. 1 and 2 affording the best example (Plate 1). Others occur at Leo Lake in Sec. 5, near the pond on the section line north of Sec. 21, and along the north shore of East Bearskin

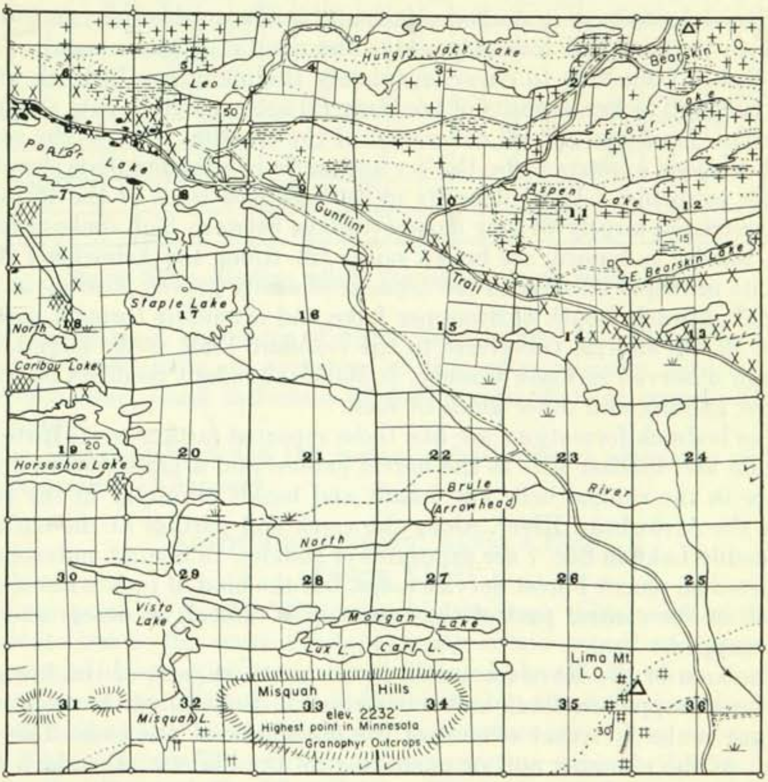

Figure XV. — Geologic map of Township 64 North, Range 1 West.

Lake in Sec. 12. In general the central part of the township has a fairly heavy cover of glacial drift.

A little more than a mile north of the North Brule (Arrowhead) River on the Gunflint Trail, the road passes over a very marked boulder bed. This is apparently an old stream channel and the outline of the valley may be seen on both sides of the road. Presumably the stream washed away the fine silt and pebbles, but was unable to move the large boulders which are chiefly of granophyre.

The major divisions of bedrock in the township are (1) the northern Rove formation plus diabase sills and dikes; (2) the Duluth gabbro in a central belt, with anorthosite masses at the west and titaniferous magnetite near Poplar Lake; and (3) a few flows of rhyolite and basalt at the south.

Magnetite deposits are noted by Grout (1949) for sections 5, 6, 7, 8, and 18.

Township 64 North, Range 1 East (Figure XVI)

Glacial deposits were studied principally in the southeastern and southwestern parts of this township where the mantle of brown sandy till of the Rainy Lobe fails to cover completely the many low bedrock knobs and ridges. Thicker deposits of bouldery till are exposed in cuts along the Gunflint Trail, and the till cover west of the Gunflint Trail in the southwest sections appears to be thicker and more continuous than elsewhere in the township. Glacial deposits in the northern third of the township are restricted largely to long narrow valleys between high diabase ridges and, insofar as known, are brown sandy till. Along the Arrowhead River and its principal tributaries are deposits of sandy gravel, possibly in part glacial outwash. South of Swamper Lake and extending through parts of Secs. 19, 20, and 29, transverse to the Gunflint Trail, is the largest rock stream observed in Cook County. It shows abundant boulders of granophyre, gabbro, and other kinds of rock.

The bedrock formations are like those reported farther west: Rove formation and diabase sills in the north; gabbro and a gradation to granophyre in the central belt; and basalt and basalt porphyry in the south near the Arrowhead River. Along the creek and portage at the outlet of Crocodile Lake in Sec. 7 are exposures of sulfides. In Sec. 25, outcrops are reported on recent Forest Service maps, but the kind of rock is not shown. Much of the central part of the township is difficult of access and was not mapped.

The area of the Rove formation in the northern part of the township has been mapped in detail and is described in Bulletin 24. A conspicuous feature is the fact that several of the lakes fork at the ends. This is a result of the pinching out, or narrowing, of the diabase sills which form the ridges that divide the bays and lakes. The diabase sills are mainly

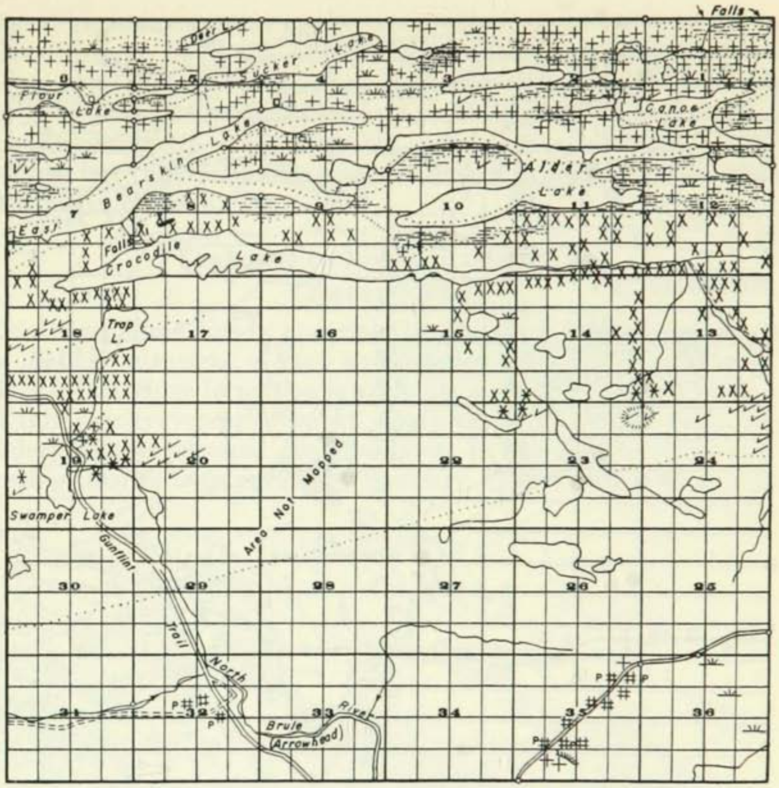

FIGURE XVI. — Geologic map of Township 64 North, Range 1 East.

of a normal type, but south of Alder Lake in Sec. 10 and on the north shore of Canoe Lake are exposures of granophyre; locally, on the point in Alder Lake, small inclusions of anorthositic diabase occur with the granophyre.

The Duluth gabbro and the metamorphosed slates along the contact are generally well exposed.

TOWNSHIP 64 NORTH, RANGE 2 EAST
(FIGURE XVII)

In the northern third of this township, bedrock ridges and lakes predominate but to the south the topography is less rugged and there is a thin patchy covering of brown sandy Rainy Lobe till. Nowhere does the till appear to exceed 10–15 feet in thickness, but the cover becomes more general southward. Local deposits of gravel were seen along stream valleys. The numerous bedrock exposures projecting through the till in the south display many glacial striations. There is a striking contrast be-

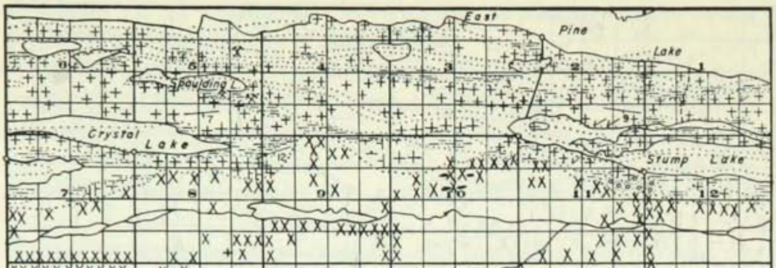

FIGURE XVII. — Geologic map of Township 64 North, Range 2 East.

tween the long narrow lakes of the area in the Rove formation to the north, and the large irregular Greenwood Lake in the gabbro area. In general the Duluth gabbro forms a high plateau-like area, with a northward-facing bluff along the south border of the Rove area.

The sequence of bedrock formations, from the Rove formation at the north to Keweenawan flows and breccias at the south, with Duluth gabbro and its differentiates between, is much the same as the sequence east and west of this township.

One noteworthy effect of late deformation (probably related to gabbro injection) is that some basic flows and sills near Greenwood Lake show cleavage, apparently a result of closely spaced fractures rather than recrystallization.

The granophyre facies of the gabbro is well developed in a belt across the township from Secs. 18 and 19 eastward past Greenwood Lake.

The Rove area is characterized by relatively small diabase sills alternating with graywacke and slate. The result is fewer and smaller lakes than in many other parts underlain by the Rove formation. Small outcrops of granophyre occur at the top of sills in Secs. 1, 2, and 11 on the shores of Stump Lake. The Old Spaulding Mine, as it was called locally, consists of a series of pits and shallow shafts on the south shore of Spaulding Lake (also known as Miranda Lake). The work was done along a brecciated zone cemented by quartz and carbonate. A little pyrite was observed, but there is no dependable evidence of mineral content of any real value in the area.

Township 64 North, Range 3 East (Figure XVIII)

This township is largely underlain by the Rove formation and associated diabase intrusions. A map and detailed description of the part underlain by the Rove formation is available in Bulletin 24.

A thin patchy veneer of brown sandy till of the Rainy Lobe, locally bouldery, is the principal glacial deposit. In the southwest part of the township this till is exceptionally bouldery. Glacifluvial sand and gravel

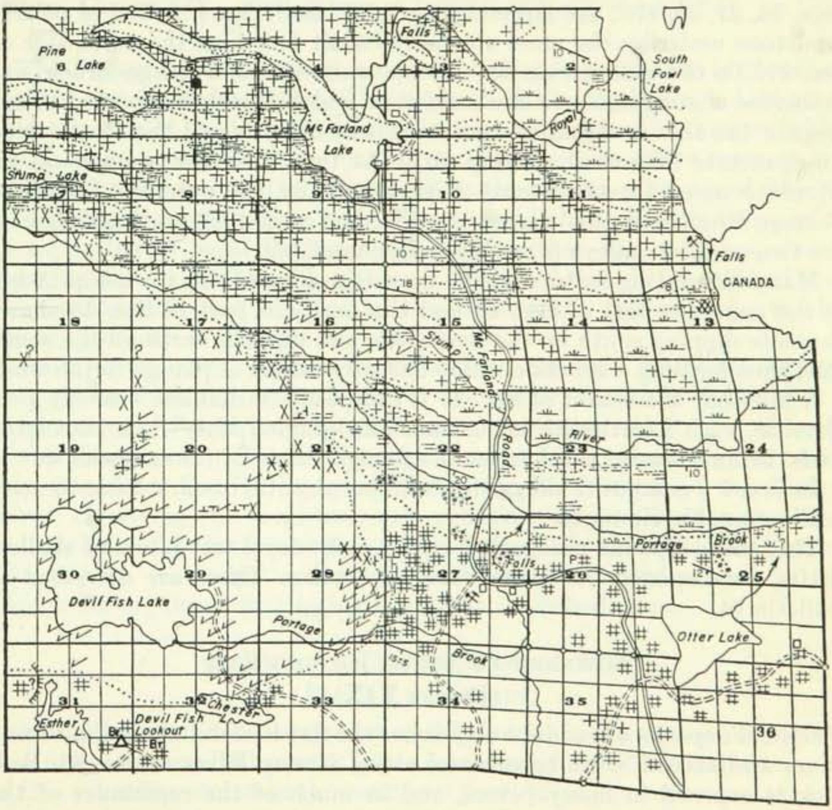

FIGURE XVIII. — Geologic map of Township 64 North, Range 3 East.

derived from the Rainy Lobe are abundant locally, as in Sec. 33 and along parts of Portage Brook in Sec. 27. In the Stump River lowland, brownish clay-silt lake beds are overlain by younger red clay lake deposits. The brown silts rise to 1415 feet elevation, and the red beds only to 1385 feet.

The simple east-west trending saw-tooth ridges, which are characteristic of the area to the west, break up east of Pine and McFarland lakes, although one major sill continues to the outlet of South Fowl Lake and beyond into Canada. This sill backs up the waters of South and North Fowl lakes and also is responsible for the rapids and falls in the Pigeon River below the outlet.

The Duluth gabbro reaches its eastern limit in Secs. 21, 27, and 28. It seems probable that the upper granophyric differentiate generally known as "red rock" may have continued to inject the flows for a time after the gabbro reached its limit, because this eastern tip has a very large amount of granophyre in comparison with the amount of gabbro. See, for example, the large area that exists around Devil Fish Lake. To the east, in Secs. 26, 27, 35, etc., are large exposures of basalt flows. A bed of pebbly sandstone underlies the most northerly basalt flow near the north side of Sec. 27. To the east in Sec. 25, on the south side of Portage Brook, are exposures of conglomerate and sandstone which Winchell reported to aggregate 144 feet in thickness and from which he named the Puckwunge conglomerate (Winchell, 1899, p. 517). At that time Puckwunge was an alternate name for the Stump River. Actually the outcrops are along Portage Brook but this was very wild country in 1899 and confusion of the two parallel valleys is readily understandable.

Many interesting features make up the geology of this township. A hill in the southern part of Sec. 10 and the northern part of Sec. 15 shows the slate dipping south on the north side and dipping north on the south side, thus forming a syncline which has a low angle of plunge to the west.

A hill near the center of Sec. 13 is composed of diabase, coarsely porphyritic, with anorthosite inclusions. Fine-grained slaty rock associated with the anorthosite emphasizes the foreign origin of the inclusions.

In Sec. 7 a composite sill grades from porphyritic to dark basic to more acidic granophyric rock.

This township was prospected in the early days; test pits and shallow shafts were opened but none were productive. These are described in Bulletin 24.

Township 64 North, Range 4 East
(Figure XIX)

Glacial deposits of red lake clay cover the flat lowland along the Pigeon River and extend south (upstream) along Swamp River in Sec. 33. Bedrock is exposed in many places, and in much of the remainder of the township it is thinly mantled by brown sandy till.

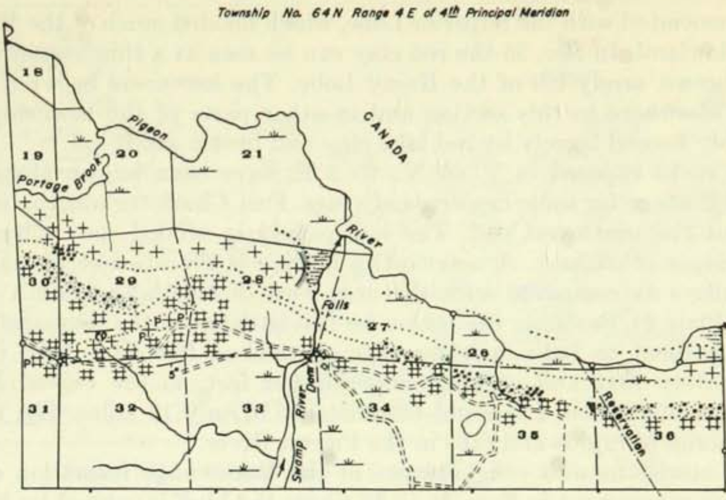

FIGURE XIX. — Geologic map of Township 64 North, Range 4 East.

The Pigeon River has cut a broad flat valley, presumably in the slaty beds of the Rove formation. The contact of the Puckwunge formation with the beds of the Rove formation is nowhere exposed in this township, but there is no reasonable doubt that an unconformity exists between the two. In the dip slope of the diabase sill, in the northeast corner of Sec. 30, an outcrop of conglomerate rests directly on diabase. This is believed to be an outlier of basal Puckwunge formation that has not been eroded from the dip slope of the sill. Although it is not definitely established that the conglomerate was intruded by the diabase, the regional relations indicate that such is the case.

South of the river, in Secs. 28, 29, and 30, the rock bluffs are held up by a diabase sill at the south side of the valley. South of the bluff is a narrow zone of Puckwunge conglomerate, sandstone, and basal sediments of the Keweenawan. The Puckwunge extends eastward across the township and, from Sec. 27 eastward, forms the bluff south of the Pigeon River. Overlying the sandstone and primarily responsible for the bluff are the lowest of the Keweenawan basalt flows of this area. The Swamp (Kameskeg) River has eroded a broad valley at right angles to the Pigeon River, thus interrupting the bluffs described above.

TOWNSHIP 64 NORTH, RANGE 5 EAST
(PLATE 6, IN POCKET)

A map and detailed description of this township is given in Minnesota Geological Survey Bulletin 24. Little is known of the Pleistocene deposits in this township except in the southeast part. Here the exposures are primarily red clays deposited partly in Lake Duluth and partly in an older lake, associated with the Superior Lobe, which flooded much of the Pigeon River lowland. In Sec. 35 the red clay can be seen as a thin veneer overlying brown sandy till of the Rainy Lobe. The low areas between rock ridges elsewhere in this section and in other parts of the township are probably floored largely by red lake clay and brown sandy till.

The rocks exposed in T. 64 N., R. 5 E. have been known along the Grand Portage for some hundreds of years. Fort Charlotte was the settlement at the northwest end. The low valleys in eroded slate, alternate with ridges of diabase. A noteworthy feature is the absence of lakes in the valleys as compared with the area west of North and South Fowl lakes (Plate 2). Probably the reason for this situation is the comparatively steep gradient to Lake Superior. The altitude at Partridge Falls is approximately 1310 and at Lake Superior 602 feet, so the Pigeon River drops are 700 feet in a straight-line distance of only 12 miles. The result is the series of rapids and falls in the Pigeon River.

The sandstone and conglomerate of the Puckwunge formation occur along an escarpment in Secs. 31 to 33 where the bluff is capped by basalt lava flows. A broad swamp lies north of the escarpment and suggests a valley eroded at some earlier time by a stream of considerable size.

The greater part of the township is underlain by the Rove formation and its accompanying intrusive diabases. Some of the east-west ridges have steep northward facing bluffs and are clearly a result of the erosion of sills. Other ridges are steep on both sides and are obviously dikes.

Many dikes trend with the strike of the beds of the Rove formation while others are transverse to the prevailing structure. The highest point is on the diabase hill at the south quarter corner of Sec. 36, where a barometer reading indicates an approximate altitude of 1720 feet above sea level or 1100 feet above Lake Superior.

A series of test pits in Sec. 35 showed some evidence of copper and nickel sulfides (Schwartz, 1925). Excavation from time to time, however, failed to show any continuity in the occurrence and no further work was done. Several other small occurrences are described in Bulletin 24.

Township 64 North, Range 6 East
(Figure XX)

This township is also mapped and described in Bulletin 24. Lowlands between almost mountainous bedrock ridges are floored or partly filled with glacial drift of various types. On U.S. Highway 61, in Sec. 28 near the Pigeon River bridge, are the thickest exposures of lake beds known in Cook County. An older brownish silt-clay series attributed to a lake associated with the Rainy Lobe is overlain by younger red clay beds deposited in lakes associated with the Superior Lobe. Beds of red lake clay, probably of similar age and origin, are widespread in the lowlands of this township and extended up to altitudes of 1400 feet at the maximum. Along the Pigeon River red clays overlie dark bluish-gray argillaceous

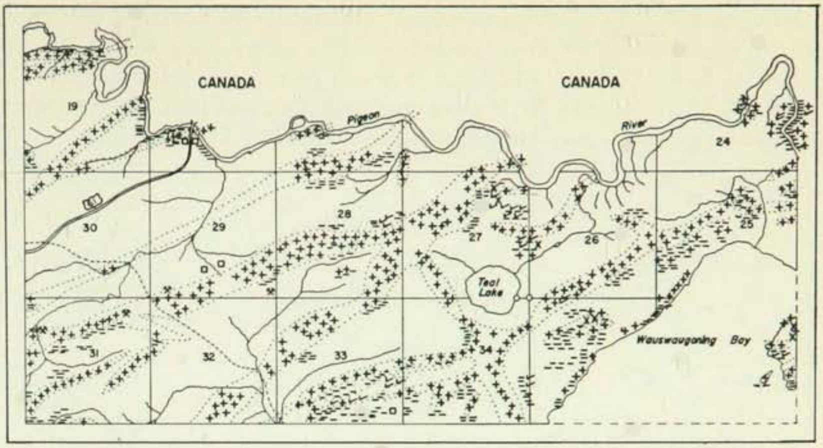

FIGURE XX. — Geologic map of Township 64 North, Range 6 East.

till, possibly derived from the Rainy Lobe. Along the shores of Wauswaugoning Bay gravel beaches of some of the younger glacial Great Lakes are well shown.

Beds of the Rove formation are cut by dikes and sills of diabase which generally trend about N. 30° E. A major cross dike west of Teal Lake trends northwest-southeast at right angles to the prevailing trend of the beds and sills. The amount of granophyre associated with the diabase sills is somewhat greater than in the sills to the west but nowhere near the amount in the Pigeon Point sill to the east. The exposures in Sec. 27 most closely resemble the occurrences on Pigeon Point. Diabase is overlaid or grades into an intermediate rock which is in turn overlaid by granophyre and it in turn by slate and quartzite. Near the east quarter corner of Sec. 18, and in Sec. 24 and elsewhere, late veins carry copper, lead, and zinc sulfides, more or less weathered.

There are several calcite veins, some containing sulfides, but to date none has been found of a size to justify active mining. A complete list is given in the Appendix (see Table C).

Townships 63 and 64 North, Range 7 East (Figure XXI)

These partial townships consist of Pigeon Point — a long projection between Lake Superior on the south and the Pigeon River and Pigeon Bay on the north — and the islands south of the point which lie partially in T. 63 N. The geology is described in some detail in Bulletin 24 and has been the subject of detailed studies by Bayley (1893), Daly (1917), and Grout (1928).

Much of the area is bare rock with only a scattering of glacial drift in hollows between bedrock ridges and knobs. In Secs. 29 and 30 is a broad lowland mantled by surficial materials the nature of which is not known because of the cover of bog vegetation. The entire area was submerged by glacial Lake Duluth, and local deposits of red lake clay occur in the low spots. The east shore of Wauswaugoning Bay displays emerged shorelines of the glacial Great Lakes younger than Lake Duluth.

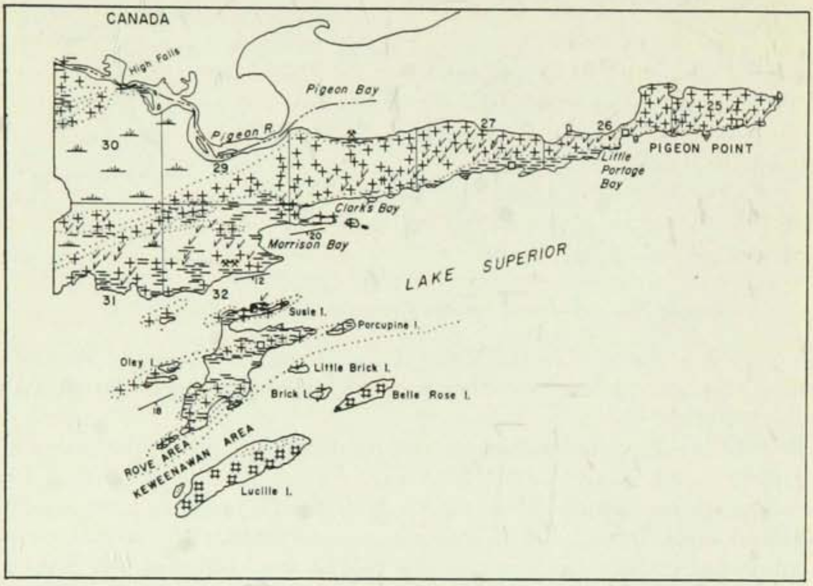

FIGURE XXI. — Geologic map of Townships 63 and 64 North, Range 7 East.

Pigeon Point extends about four miles east beyond the mouth of Pigeon River, and though very narrow, rises nearly 300 feet above the lake. The north side is characteristically a bluff or cliff, whereas the south shore dips gently under the lake. This topography is a result of the sill of igneous rock that forms most of the point. For a detailed description of this area reference should be made to Bulletin 24. The point is a result of the resistance to erosion of a large diabase sill with associated granophyre and other related rocks. Slate and quartzite of the Rove formation are exposed both above and below the igneous sill.

The islands immediately south of the point consist of slate and small sills. The southerly islands (Lucille, Belle Rose, Brick, Little Brick), however, are composed of Keweenawan rocks. Along the north side of Lucille Island the Puckwunge sandstone is well exposed, overlain by the lowest basalt flows of Keweenawan age.

Both Brick and Little Brick islands are composed of granophyre doubtless related to the larger exposures to the north on Pigeon Point.

The unconformity between the Animikie and Keweenawan rocks lies beneath the waters between Lucille and Susie islands. A few pebbles attached to the dip-slope surface of the slate on Susie Island indicate that this dip-slope is very close to the surface of the unconformity.

Township 63 North, Range 5 West
(Figure XXII)

Rock exposures are abundant and drift thin in the northern and eastern parts of the township but all of the area southwest of a line from Secs. 18 to 35 is covered with glacial drift except for a few rock exposures.

The bedrock geology is extremely complicated and only partially understood. The northern two tiers of sections are largely underlain by gabbro with inclusions of anorthosite.

There appear to be two gabbros, one north, the other south of Kelso Tower. The main area of granophyre, presumably a differentiate of the gabbro, occurs in Secs. 26, 35, and 36. Between the granophyre and the main area of gabbro in the northern sections is a complex of later granite, basalt on an island in Wine Lake, rhyolite on the north shore of Frederick Lake, plus various areas of diabase, hornfels, and rocks which

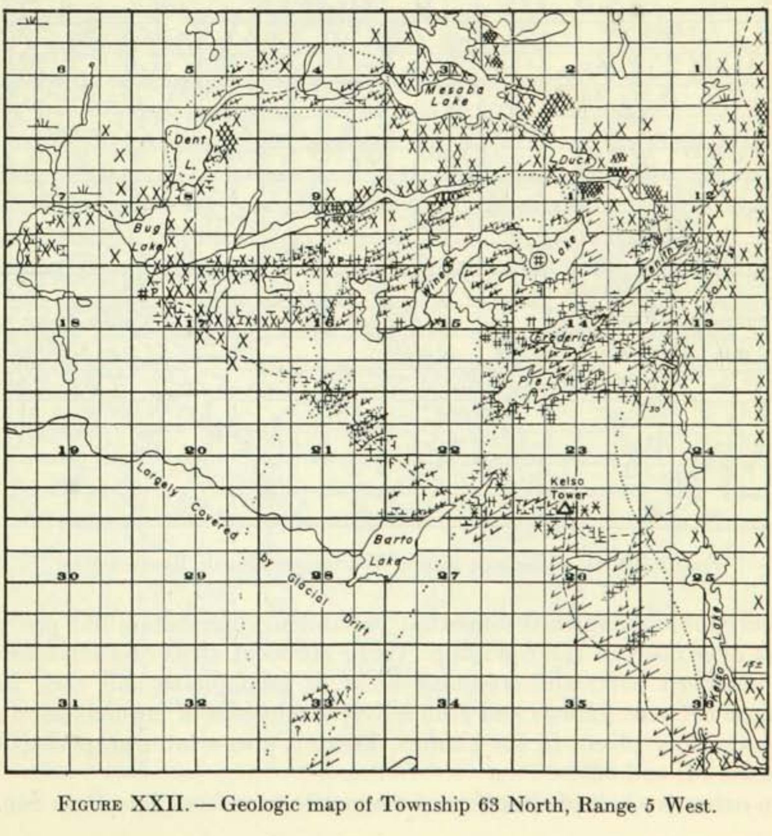

Figure XXII. — Geologic map of Township 63 North, Range 5 West.

are intermediate between gabbro and granophyre. The determination of the exact relations of these rocks will require very detailed work far beyond that possible during the mapping of Cook County.

Township 63 North, Range 4 West
(Figure XXIII)

This township is characterized by unusually extensive exposures of bare rocks, mainly gabbro. Drift occurs in the depressions between rock ridges and in rather large areas in Secs. 30, 31, and 32.

Figure XXIII. — Geologic map of Township 63 North, Range 4 West.

The gabbro complex is somewhat variable in composition but predominates over most of the township. There are local areas of anorthosite in the northern part, and irregular areas of granophyre and rock intermediate between gabbro and granophyre. Inclusions of hornfels are abundant at many places in the gabbro. There is also a later granodiorite in Secs. 26, 27, and 33.

An extensive belt of titaniferous magnetite runs from Sec. 25 to Sec. 32.

Some magnetite is also found in Secs. 20 and 21. The main belt of titaniferous magnetite has been mapped in considerable detail, magnetic surveying being used to connect the exposed masses. Also, in 1947 (Grout, 1950) the Office of the Commissioner of the Iron Range Resources and Rehabilitation sponsored the drilling of two diamond drill holes in the southeast quarter of Sec. 32, which proved that the magnetite continued beneath the sill-like Smoke Lake granodiorite (Fig. 25).

Township 63 North, Range 3 West (Figure XXIV)

The topography of this township is dominated by Brule Lake which extends from Sec. 18 eastward into T. 63 N., R. 2 W. Although the lake is very irregular, its trend is determined by the general distribution of the rocks in east-west belts.

From observations in the southeastern part, and from air photos, it appears that this township has about three east-west belts of bouldery brown sandy till, alternating with prominent bare rock knobs, hills, and

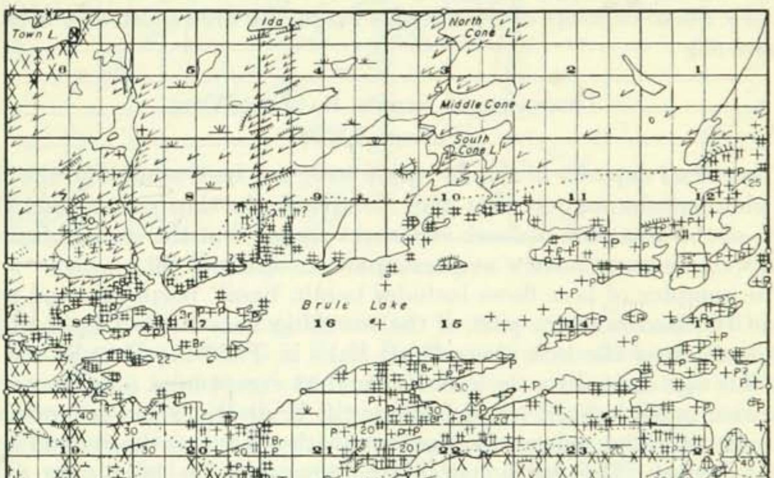

Figure XXIV. — Geologic map of Township 63 North, Range 3 West.

ridges. The drift covering may be somewhat more complete in the southern parts and in low spots.

The rock outcrops in the northern part of the township are largely the granophyric upper facies of the northern branch of the Duluth gabbro. This can be clearly seen in Plate 2. An east-west belt of miscellaneous extrusive and intrusive rock is probably responsible for the ease of erosion of the rocks that produced the basin of Brule Lake. Here basalt, rhyolite, and diabase occur, with extremely confused relations between the different rocks.

In this township the southern belt of the Duluth gabbro is clearly separated from the northern belt. From Brule Mountain, in Sec. 25, two irregular belts run west; one is the anorthosite and anorthositic gabbro from Sec. 26 to Sec. 30; and the other a belt gabbro containing numerous hornfels fragments and associated titaniferous magnetites in Secs. 27, 31, 32, and 33. Most of the rocks dip south and the granophyre at the south edge of the township seems clearly the uppermost differentiate of the great gabbro complex. Some of the rocks are intermediate in composition between gabbro and granophyre and may represent a gradation between the two. Small deposits of titaniferous magnetite are reported in Secs. 31, 32, and 33.

Township 63 North, Range 2 West (Figure XXV)

The glacial deposits of this township have not been studied in the field. Air photographs suggest that they are relatively thin and sparse. Over much of the area bare bedrock exposures prevail, but the east-central and southwestern parts have a more complete covering of till.

The complex of lava flows includes basalt, basalt porphyry, and rhyolite in the northwestern part of the township near Brule Lake and is a continuation of the belt along Brule Lake in T. 63 N., R. 3 W. To the east this belt ends abruptly in Secs. 9 and 13 except for a possible narrow extension noted in Secs. 1 and 2. Along the Brule River and around Swan Lake are extensive exposures of gabbro, with a few anorthosite and hornfels inclusions. The south half of the township has been only partly mapped, but appears to contain two belts of granophyre separated by a tongue of gabbro. The granophyre forms the prominent rock hill called Eagle Mountain.

This township deserves detailed work to establish the exact relations of the gabbro, granophyre, and intermediate facies as well as the relation of the gabbro to the lava flows which were intruded by the gabbro around Brule Lake. This was beyond the scope of the present county-wide work but should receive attention in the future. Outcrops are much more numerous than those shown on Fig. XXV, which are based on widely spaced traverses.

Lean magnetite gabbro is exposed in Sec. 12, and strong magnetic effects

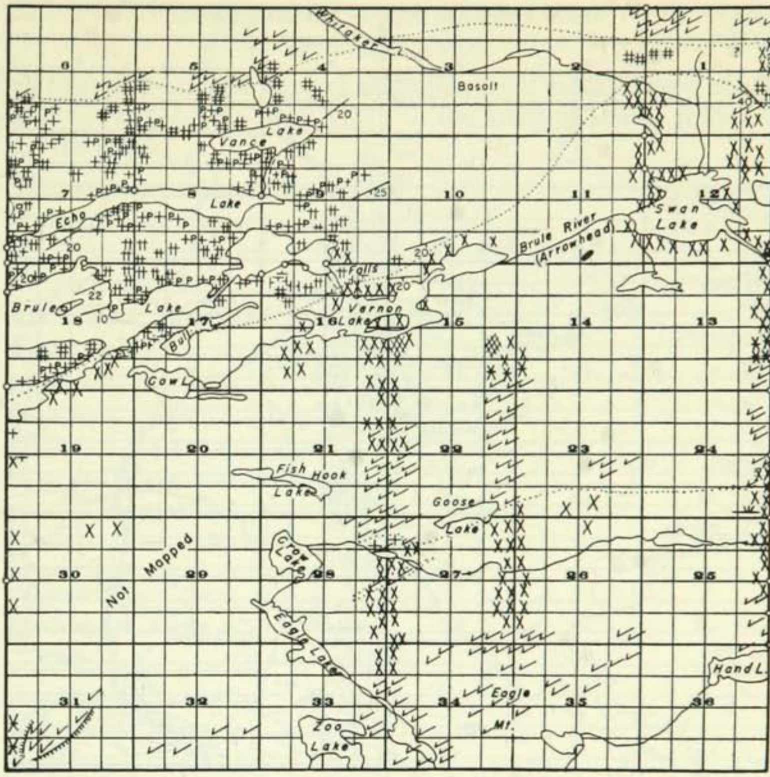

FIGURE XXV. — Geologic map of Township 63 North, Range 2 West.

suggest that more and possibly better deposits are concealed. During the field operations in Sec. 7, R. A. Ranta carried on detailed work supplemented by a laboratory study of thin sections (Ranta, 1939). There, on a conspicuous hill north of Brule Lake, a rhyolite porphyry lava flow has been intruded below by an olivine diabase porphyry sill. The rhyolite within twenty feet of the contact has been recrystallized to yield large crystals of feldspar and large aggregates of quartz. The texture is granoblastic, and the feldspars show good twinning in contrast to the rhyolite away from the contact where twinning is not visible. Much of the quartz seems to have recrystallized into larger clear grains. Ranta (1939, p. 29) concluded that the rhyolite was recrystallized but not melted by the heat of the diabase magma.

TOWNSHIP 63 NORTH, RANGE 1 WEST (FIGURE XXVI)

This township displays a patchy cover of brown sandy till of the Rainy Lobe which is most complete in the east central part, especially in Secs.

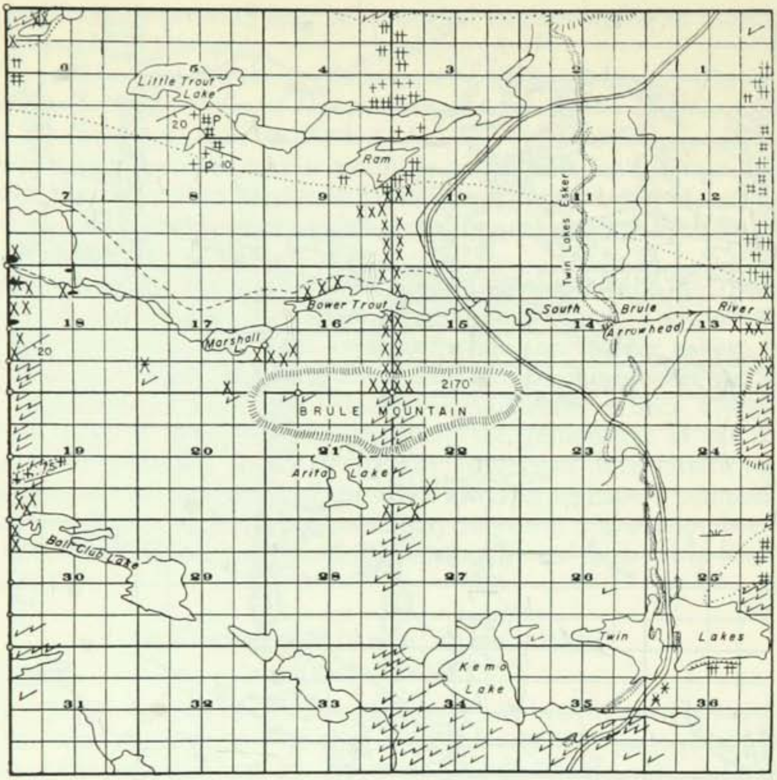

Figure XXVI. — Geologic map of Township 63 North, Range 1 West.

11, 12, 13, 14, 23, and 24. Much of the southern and western part is higher and more rugged, with considerable areas of gabbro and granophyre. Running north-south from Sec. 2 to Sec. 35 entirely across the township is Twin Lakes esker, and associated with it throughout this length are pitted glacifluvial sand and gravel. Twin Lakes are in Secs. 25, 26, 35, and 36, and are nearly equal in size.

In common with the township to the west, east-west zones of lava flows, gabbro, and granophyre are characteristic of this township. The belt of granophyre is particularly well developed in the south half of the area. Brule Mountain owes its prominence to the resistance of granophyre to erosion. The distribution of outcrops as shown on the map is a result of north-south traverses along the range lines and through the center of the township; the areas between are poorly known but presumably similar to the area where more detail was secured.

Some lean titaniferous magnetite rock is exposed in Sec. 7 near the west line. Scattered zones of high magnetic effects suggest the possibility of ore at places in Sec. 18.

Township 63 North, Range 1 East
(Figure XXVII)

This township is in the zone of transition from areas of very abundant outcrops toward the west and north to the areas of heavy glacial cover toward the south.

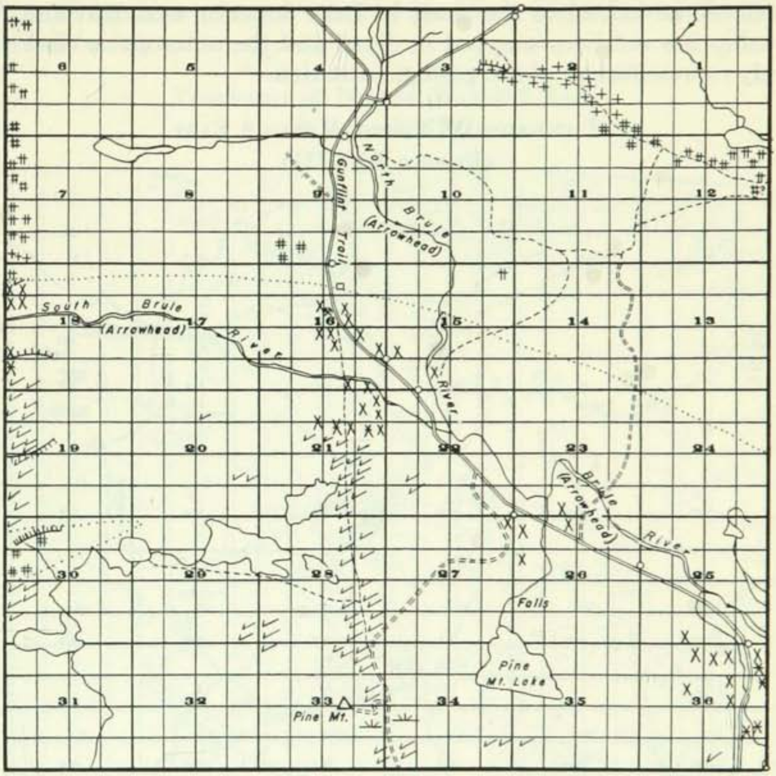

Figure XXVII. — Geologic map of Township 63 North, Range 1 East.

The glacial drift in this township is extensive and varied, but it has all been deposited by, or derived from, the Rainy Lobe. Brown sandy till and glacifluvial sand and gravel are the principal materials. The drift cover is nearly continuous in the northern half of the township, but rugged bedrock ridges rise above the general level in the southwest and the drift mantle is more patchy there. An esker extends south from the Gunflint Trail to Pine Mountain Lake through Sec. 26, and another is well exposed in a large gravel pit on the Gunflint Trail in Sec. 16. Pitted glacifluvial deposits were mapped along the line between Secs. 23 and 24. Also noteworthy are high level glacifluvial gravels among the bedrock ridges in Secs. 27 and 33. Some of these were probably deposited in glacial spillway channels. Along the Arrowhead River and its various branches accumulations of sand and gravel are abundant.

The southwest quarter of this township has abundant exposures of granophyre. Pine Mountain, used as a forest lookout station, is located on a high ridge of granophyre. The gabbro belt across the central part of the township is a narrow eastward extension of the southern finger, which is believed to extend to the shore of Lake Superior near Hovland. The township has not been mapped in detail and the outcrops as shown are merely representative of the geologic situation.

Township 63 North, Range 2 East
(Figure XXVIII)

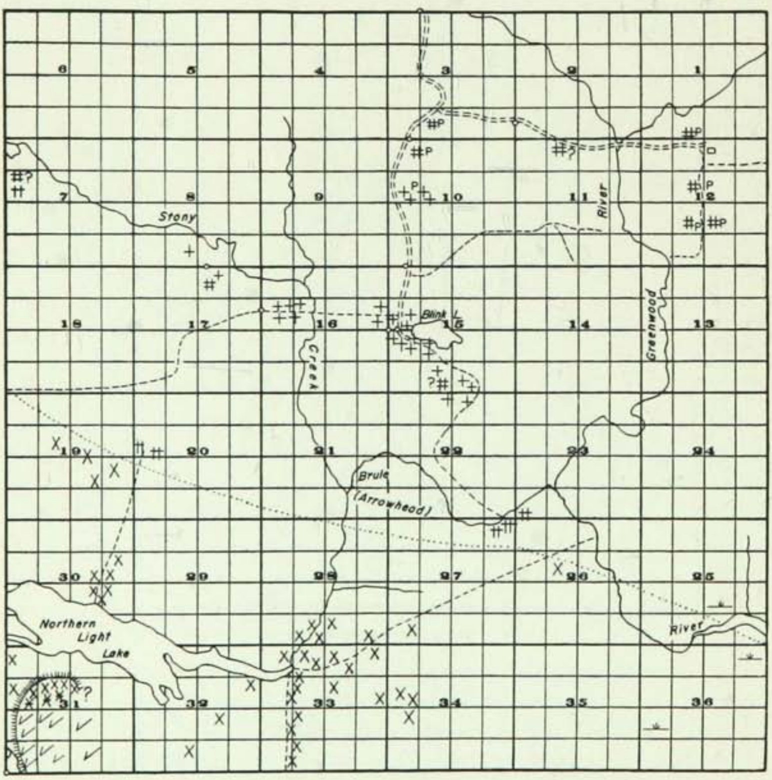

Figure XXVIII. — Geologic map of Township 63 North, Range 2 East.

Glacial deposits have been studied at first hand only along the road leading to Blink Lake. The principal material is a thin patchy veneer of bouldery till of the Rainy Lobe, through which many glaciated rock outcrops project. In Sec. 3 is a considerable accumulation of pitted and hummocky glacifluvial sandy gravel, and similar material extends into Secs. 10 and 15.

The northern part of the area is underlain by basalt flows which have been intruded by diabase and diabase porphyry. The southern part is mainly occupied by a belt of gabbro, but outcrops are sparse and the area has been only partially mapped so that the geology is incompletely known. The gabbro mapped south of Northern Light Lake may in fact be a diabase intrusion.

Township 63 North, Range 3 East
(Figure XXIX)

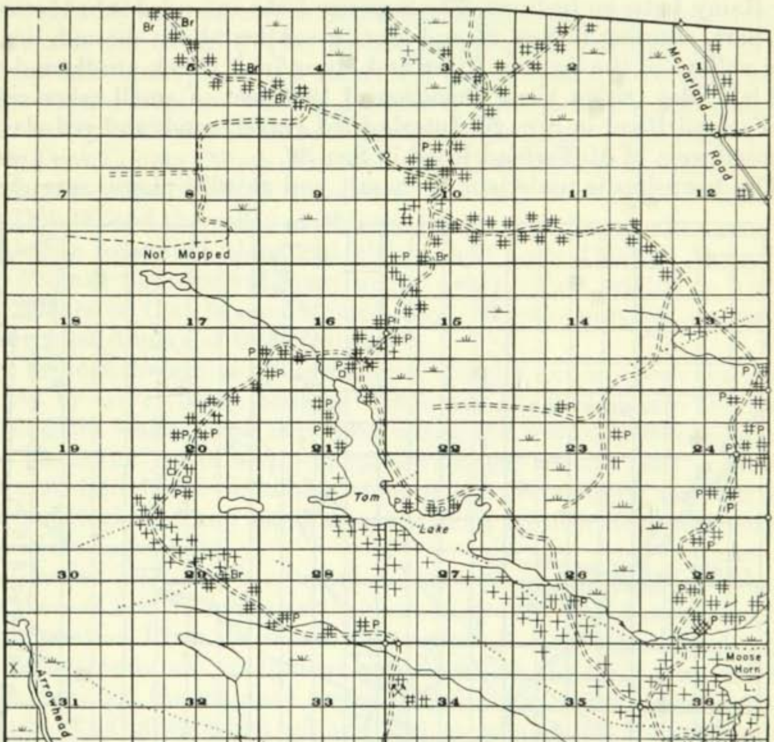

Figure XXIX. — Geologic map of Township 63 North, Range 3 East.

A thin patchy covering of bouldery brown sandy till deposited by the Rainy Lobe is the principal glacial deposit. Red clay till of Superior Lobe origin appears only in the southern parts of Secs. 33 and 34. Thin localized accumulations of glacifluvial deposits alternate with large swamps.

The bedrock basaltic and porphyritic flows of the main part of the township give way at the south to a diabase sill which extends across the township south of Tom Lake. A few outcrops in the southwestern part of the township, particularly along the Arrowhead River, are believed to be part of a long eastward extension of Duluth gabbro.

The northwestern part of the township is largely difficult of access and was not mapped. Some outcrops were examined, mainly near the various logging roads.

Township 63 North, Range 4 East
(Figure XXX)

Most of this township has a thin patchy veneer of brown sandy till of the Rainy Lobe on bedrock. The Superior Lobe extended into the southern part, entering in Sec. 24 and leaving southwesterly through Sec. 32. The valleys of the Swamp River and lower Irish Creek are floored with red lake clay, rising to an elevation of 1385 feet. A small esker crosses McFarland Road in Sec. 20. Interbedded gravel, sand, and red clay are exposed west of McFarland Road in Sec. 32.

The township is underlain by basalt and rhyolite flows, sparsely ex-

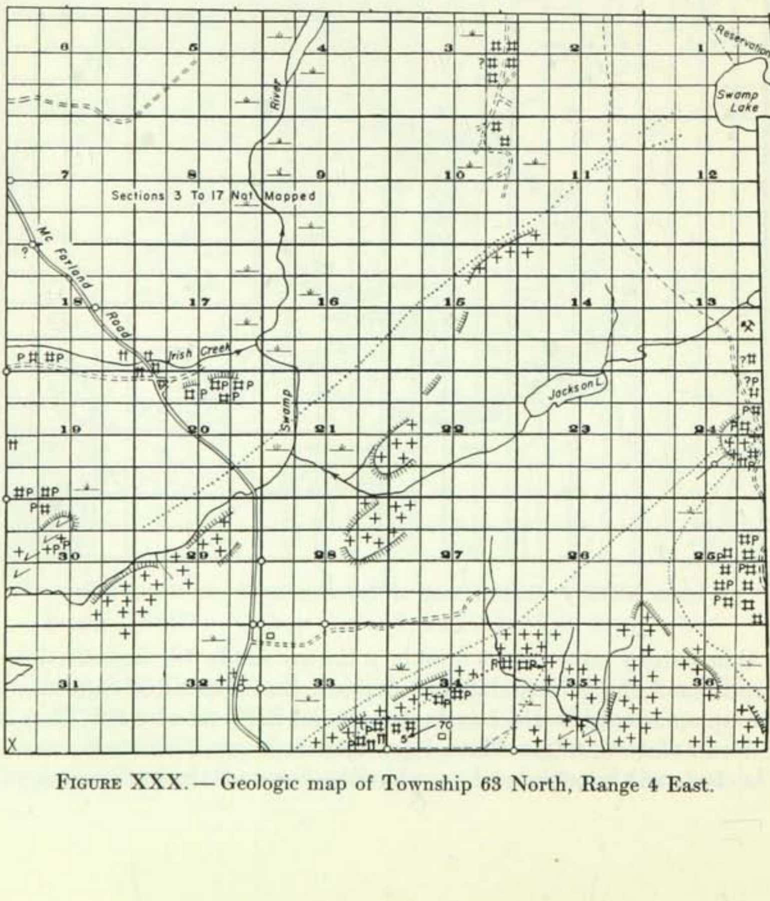

Figure XXX. — Geologic map of Township 63 North, Range 4 East.

posed because of the rather heavy glacial drift. Diabase intrusions into the flows form somewhat higher ridges and are better exposed, particularly in the southeast corner of the township. The predominantly northeastward trend of the exposures, particularly the diabase, indicates that the general structures have the same trend, which is at a considerable angle to the eastward trend of the rocks in eastern Cook County.

The areas difficult of access were not examined because of the scarcity of outcrops.

Township 63 North, Range 5 East (Plate 7, in pocket)

Lowlands between numerous bare rock ridges in this township contain considerable glacial drift. The contact between the red clay till of the Superior Lobe and the brown sandy till of the Rainy Lobe runs west-southwestward from the vicinity of Mineral Center. In Sec. 9 deposits of brown sandy drift show the best depositional glacial topography to be seen in Cook County. Much of the red clay till in the southern part of the township is capped by a thin veneer of red clay, probably deposited in Lake Duluth, and the valley at Mineral Center once harbored a marginal glacial lake somewhat older and higher than Lake Duluth. Along the shore of Lake Superior are many gravel beach ridges related to higher water planes in that basin. Deronda Bay (Sec. 25) provides an exceptionally good display of these features.

The bedrock geology of this township is complex and has been described in detail by Gryc (1942). Striking features of the geology are the large diabase dikes which trend northeast across the township into adjacent areas. The main type of rock is an olivine diabase which locally grades to an intermediate facies containing more or less granophyric material between the plagioclase and augite crystals. There are also dikelets of granophyre in the main mass.

The largest intrusion is a mass of coarse-grained diabase or gabbro along shore in Sec. 34 and inland in Secs. 31 and 32. This has been called the Reservation River diabase in this report. It was originally thought that this intrusion was continuous westward with the main mass of Duluth gabbro, but the mapping undertaken for this report indicates that this mass is an independent sill and that an arm of the Duluth gabbro actually touches Lake Superior near Hovland. The mass is a black medium-grained diabase gabbro and, locally in Sec. 27, is more or less gneissoid.

The basalt flows along the contact of the larger dikes and sills have been metamorphosed to finely granular hornfels.

In Secs. 1 and 2 there is a north-facing bluff capped by basalt flows overlying the sandstone and conglomerate of the Puckwunge formation. Along the town line in the same sections a diabase dike intrudes the Rove formation.

The glacial drift of the small remnant of T. 62 N., R. 5 E. is chiefly a thin patchy deposit of red clay till of the Superior Lobe, locally overlain by sands and gravels along the shores of the glacial lakes that occupied the Superior basin. Just west of the Reservation River on U.S. Highway 61 a dark clay-rich till of uncertain age (probably Rainy Lobe material) underlies the red clay till. Emerged deltaic sands and gravels at the mouth of the Reservation River have been worked for road material.

The bedrock in Sec. 6 is composed partly of rhyolite flows but dominantly of diabase sills and dikes. A part of the large Reservation River diabase intrusion occupies Secs. 4 and 5, and is somewhat coarser grained than the usual diabase.

Township 63 North, Range 6 East (Figure XXXI)

This township also has many bare rock ridges, with the lower areas between bearing a mantle of Pleistocene deposits, largely of the red clay till of the Superior Lobe, and more local overlying deposits of red clay deposited in Lake Duluth or its successors. Along the shores of Grand Portage Bay and southwestward are many gravel beach ridges formed in post-Duluth stages of the glacial Great Lakes.

Grand Portage Bay is the deepest indentation in the Minnesota coast of Lake Superior, and the harbor is protected by Grand Portage Island. The bay is evidently a result of ease of erosion of the argillites of the Rove formation in contrast to the more resistant dike of Hat Point and

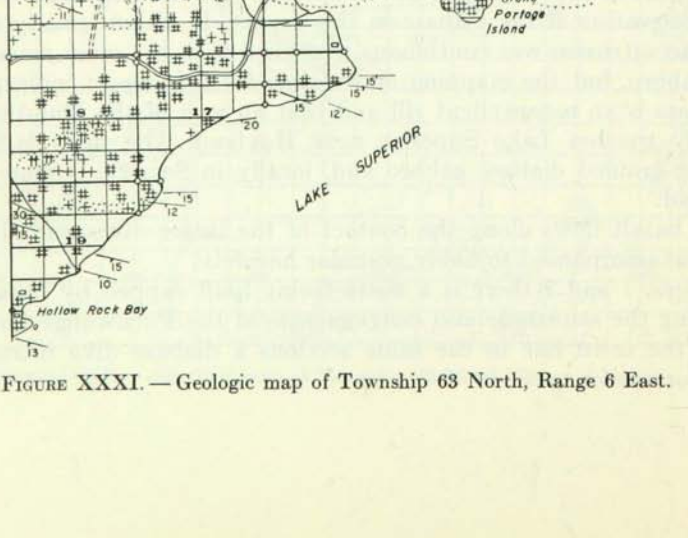

Figure XXXI. — Geologic map of Township 63 North, Range 6 East.

the basalt flows of the southwest headland. This was the site of the earliest settlement in Minnesota (Buck, 1923).

From Sec. 8 southward the area is underlain by basalt flows, with at least one thin rhyolite flow and several small diabase intrusions. The northern part of the area is underlain by the sedimentary rocks of the Rove formation, intruded by diabase dikes and sills. This part of the township is described in Bulletin 24.

Grand Portage Island has the Puckwunge formation exposed at the northeast corner, where fourteen feet of sandstone and conglomerate are overlain by basalt (Thiel, 1947, p. 98).

Township 62 North, Range 5 West (Figure XXXII)

In general, glacial deposits are fairly continuous and thick at places in the southern half of the township and rather thin and discontinuous over the northern half. The glacial deposits can be identified as till deposited by the Rainy Lobe. West of the creek in Sec. 33 it is very thick and con-

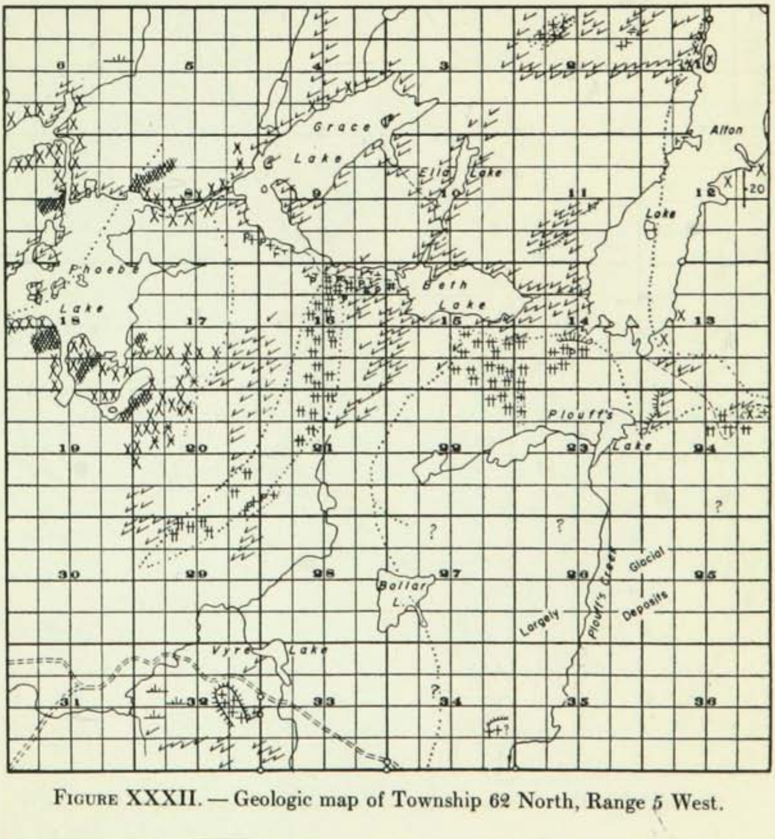

Figure XXXII. — Geologic map of Township 62 North, Range 5 West.

tains a considerable amount of red granophyre. Gravels occur on both sides of Plouff's Creek, and eskers occur in Secs. 33 and 34.

The Duluth gabbro along the west side of Cook County is exposed at many places from Little Saganaga Lake (T. 64 N.) to Phoebe Lake in Sec. 19, T. 62 N., R. 5 W. Along the west side of the township exposures are neither numerous nor large, but a few outcrops in the southern half of the township suggest belts of gabbro together with differentiates of gabbro extending nearly three miles south and southwest. As indicated by the map the geologic situation around Phoebe, Grace, and Beth lakes is a complex of lava flows, gabbro, granophyre, anorthosite, and related rocks, granophyre being the predominant rock variety. Confusion is increased by the presence of considerable areas of rhyolite, which on metamorphism resembles granophyre. There are areas of anorthositic gabbro in the vicinity of Phoebe Lake but probably no large ones have more than 90 per cent plagioclase feldspar.

Diabase dikes occur at several places and some, at least, are clearly later than all of the associated rocks.

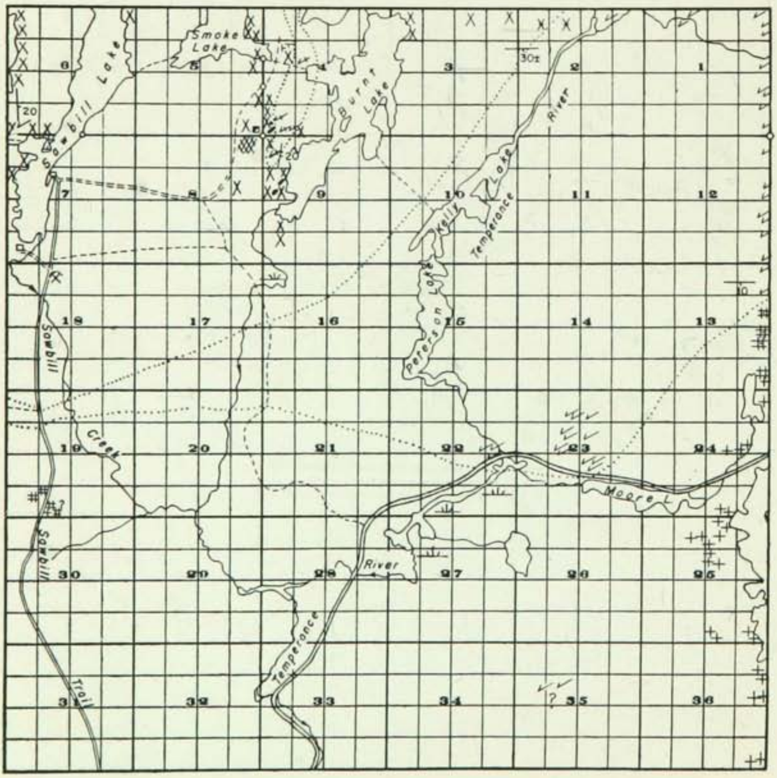

FIGURE XXXIII. — Geologic map of Township 62 North, Range 4 West.

Township 62 North, Range 4 West
(Figure XXXIII)

This township has an extensive, at places unusually thick, cover of Rainy Lobe till. Areas of rock project through the drift, but along the road in Secs. 28 and 33, near the Temperance River, are some of the thickest exposures of Rainy Lobe deposits in the county. Much of this till is more sandy than usual and is distinguished from a glacifluvial deposit only by its lack of stratification.

There are few outcrops in the southern half of the township. In the northwest, however, some gabbro, anorthosite, granophyre, and many small segregations of titaniferous magnetite occur near Smoke and Burnt lakes, all a part of the Duluth gabbro complex.

Outcrops of basalt, diabase, and a few other rocks are mapped in the eastern section but the exposures are not good. The upper contact of the Duluth gabbro complex trends east-west across the township from Sec. 23 and is located only in a general way by occasional outcrops so few in number that much of the township was not examined in detail.

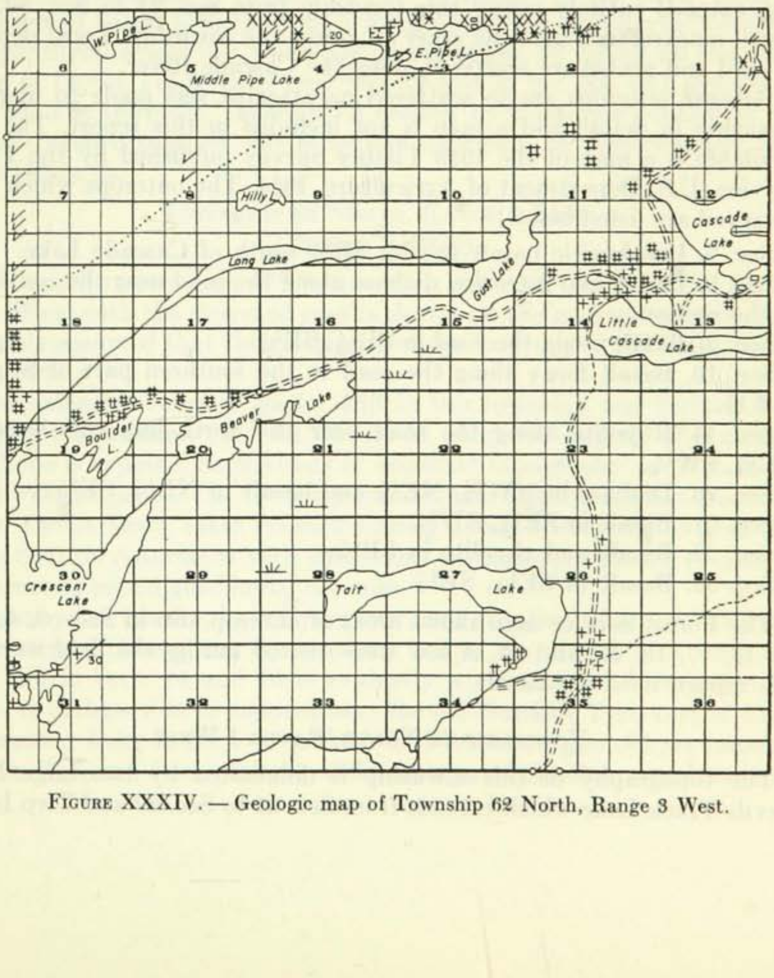

Figure XXXIV. — Geologic map of Township 62 North, Range 3 West.

Township 62 North, Range 3 West (Figure XXXIV)

This township has a thin veneer of Rainy Lobe till which is exceptionally bouldery in Sec. 26 east of Tait Lake. Bedrock is locally exposed or lies close to the surface, but outcrops are sparse over much of the area. Some of the sections are rather inaccessible and not all of the exposures have been mapped.

The top of the granophyre of the Duluth gabbro complex extends across Secs. 2, 3, 4, and 5, and abundant granophyre is fairly well exposed. The remainder of the township is underlain by basalt and rhyolite flows, locally intruded by diabase. Not much detail is available, nor is it likely that more work would change the general geologic picture because of the scattered nature of the outcrops.

Township 62 North, Range 2 West

This township has an extensive cover of brown sandy till deposited by the Rainy Lobe, with only occasional projecting bedrock knobs. The Devils Track esker (Fig. 19), with associated ridges of glacifluvial material, extends entirely across this township from Sec. 25 to Sec. 30, and a well-marked trail uses the esker all across the township. Local deposits of sand and gravel are scattered along the Cascade River.

Because outcrops are so scattered no attempt was made to map the township in detail, and a map is not included in this report. The best available is a map of the 1948 Timber Survey published by the Forest Service, U.S. Department of Agriculture, 1954. The outcrops which were observed are listed below.

Sec. 7. Porphyritic basalt in S½, SE¼ south of Cascade Lake.

Sec. 8. Basalt and intrusive diabase along the road near the south line of the section.

Sec. 9. Basalt along the road in SE¼, SE¼.

Sec. 10. Basalt flows along the road in the southern part of Secs. 10 and 11.

Sec. 14. Rhyolite along the road near the north line and basalt in NE¼, SW¼.

Sec. 23. Diabase in NW¼, NE¼ and basalt in NE¼, SE¼.

Sec. 31. Basalt in SE¼, SW¼.

Sec. 32. Basalt and rhyolite in SE¼.

Sec. 33. Basalt in SE¼, SE¼.

The Forest Service map shows areas of outcrop also in Secs. 3, 4, 5, 6, 13, 15, 17, 18, 22, and 24. A few were visited during the field work for this report; most are basalt.

Township 62 North, Range 1 West

The topography of this township is dominated by two large lakes, Devils Track Lake which extends from Sec. 25 to Sec. 29 and Two Island

Lake in Secs. 4, 5, 8, and 9. The area is largely covered by glacial drift and outcrops are sparse. Because the area has not been mapped in detail no map is included in this report, but noteworthy outcrops are listed below. The best map of the township is that published by the Forest Service in 1954.

The southern end of Twin Lakes esker (Twin Lakes are in T. 63 N., R. 1 W.) extends almost to the center of this township (Fig. 19); and Devils Track esker (Fig. 20) extends entirely across it in an east-west direction from Sec. 24 to Sec. 30. Both eskers have associated knob and kettle glacifluvial deposits which are especially abundant in Secs. 3, 20, 29, and 30. An independent area of glacifluvial materials featuring deep pits and reticulated ridges exists in Sec. 18. A thin mantle of Rainy Lobe till covers much of the remainder of the township.

The following are the principal outcrops: northern part of Secs. 2 and 3, ophitic and porphyritic basalts; north of Two Island Lake in Secs. 2 and 5, granophyre of the upper part of the Duluth gabbro; west and south of Two Island Lake in Secs. 7, 9, 15, and 16, several outcrops of basalt flows and one of rhyolite in Sec. 9, diabase in the SE¼, Sec. 15; diabase and basalt near the trail in Secs. 15 and 16; porphyritic basalt in Sec. 21; rhyolite near Sec. 9 and SW corner of Sec. 22; basalt on the south shore of Devils Track Lake near Sec. 22 and in Sec. 35; and rhyolite in Sec. 36. The township, therefore, is crossed by the upper contact of the Duluth gabbro complex but is mainly underlain by Keweenawan lava flows (Plate 2).

Township 62 North, Range 1 East
(Figure XXXV)

The southwestern part of the township was resurveyed by the federal land office, with the distorted results shown on the geologic map. It may be safely assumed that the remainder of the township is far from regular as shown.

The extensive cover of glacial drift in this township was derived from the Rainy Lobe except in Secs. 35 and 36 where red clay till of the Superior Lobe is exposed. Suggestions of drumloid topography are seen in the northwestern part of the township from Elbow Lake to Little Clearwater Lake. Devils Track esker extends entirely across the township from Sec. 12 to Sec. 19. Associated with this esker, particularly in Secs. 17 and 20, are areas of pitted glacifluvial deposits.

Outcrops of basalts, basalt porphyry and rhyolite, plus some diabase, are scattered throughout the southern half of the township. A large diabase hill in Secs. 24 and 25 is evidently a sill which has intruded the flows. A diabase dike is exposed near the old Gunflint Trail east of Little Clearwater Lake in Secs. 17 and 21. The scattered granophyre outcrops in Secs. 3, 4, and 5 are probably differentiates of the Duluth gabbro complex.

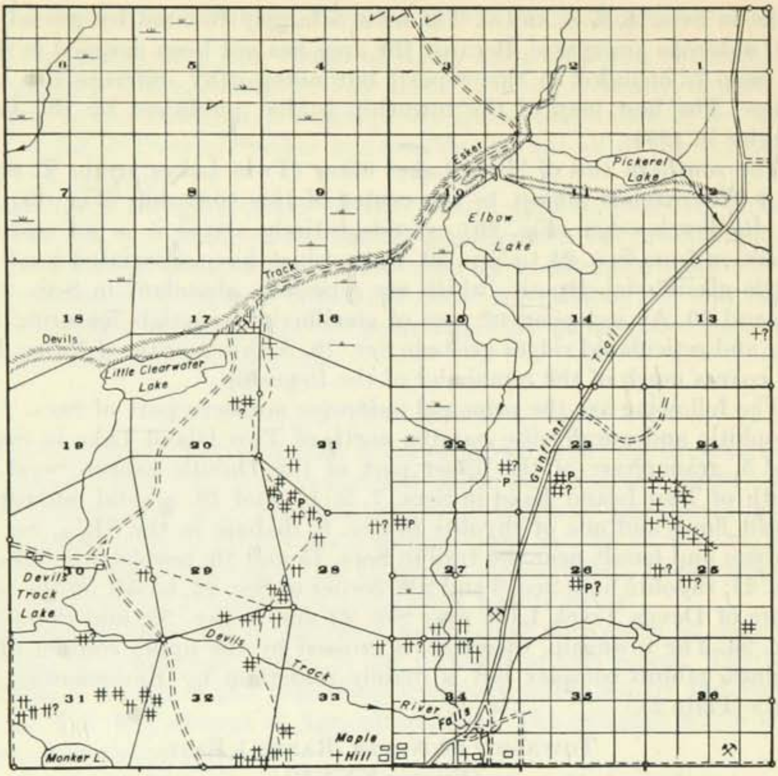

FIGURE XXXV. — Geologic map of Township 62 North, Range 1 East.

Much of the isolated area in the northwestern corner was not examined and because of the sparse outcrops other areas were not mapped in detail. Doubtless a few scattered outcrops exist which were not found.

Township 62 North, Range 2 East (Figure XXXVI)

The northern edge of the Superior Lobe extended diagonally west-southwest across this township so that brown sandy till of the Rainy Lobe is exposed at the surface in the northwestern two thirds, and red clay till of the Superior Lobe forms the surface material in the southeastern third. There are many rock exposures in the northern part of the township, but the drift mantle is thicker and more continuous farther south, particularly in the middle part of the township. An informative section of drift is exposed at Kimball Creek (south edge of Sec. 28). Here red clay till rests on red and brown lake clays, which overlie sand and gravel resting on Rainy Lobe till. In cuts along the road east from Kimball Creek, red clay till can be seen overlying brown sandy till, with de-

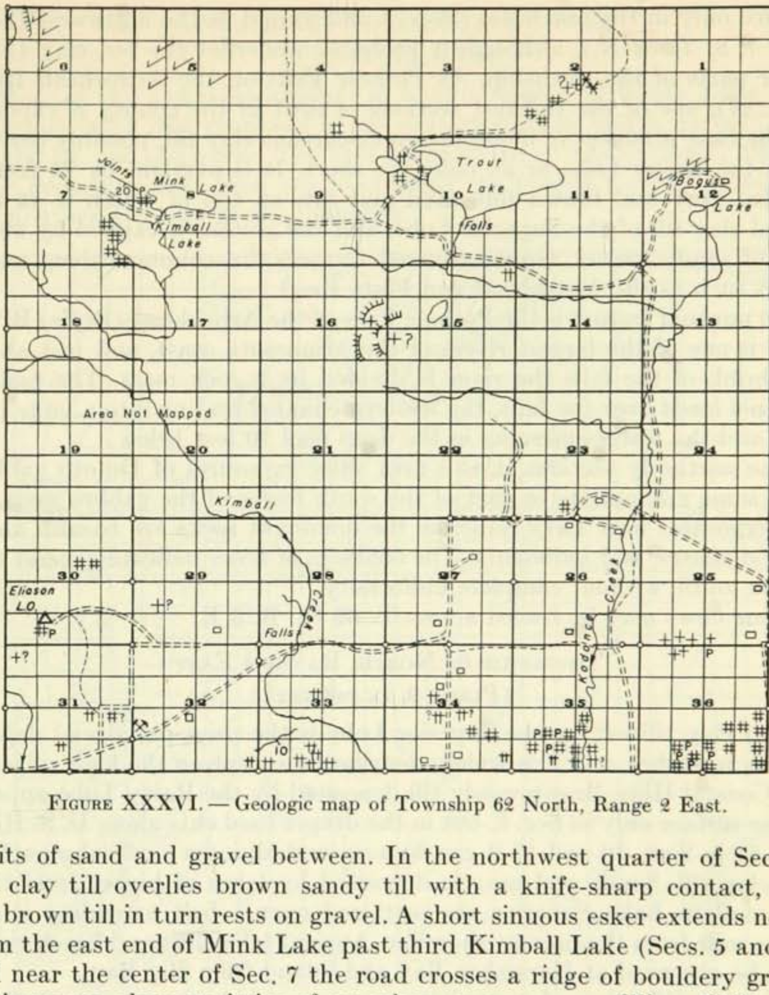

FIGURE XXXVI. — Geologic map of Township 62 North, Range 2 East.

posits of sand and gravel between. In the northwest quarter of Sec. 25 red clay till overlies brown sandy till with a knife-sharp contact, and the brown till in turn rests on gravel. A short sinuous esker extends north from the east end of Mink Lake past third Kimball Lake (Secs. 5 and 8), and near the center of Sec. 7 the road crosses a ridge of bouldery gravel having some characteristics of an esker, or a crevasse filling. Cliffs and gravel deposits mark the Lake Duluth and Algonquin beaches in Sec. 34.

In Secs. 5, 6, and 12 the granophyre outcrops are believed to be the upper parts of the southern gabbro sill or finger of the Duluth gabbro complex (Plate 2). Outcrops of basalt, basalt porphyry, and rhyolite occur particularly in the southern tier of sections but are too scattered to permit outlining individual flows.

TOWNSHIPS 61 AND 62 NORTH, RANGE 3 EAST

(PLATE 8, IN POCKET)

Red clay till of the Superior Lobe is the principal glacial material in these townships. Brown sandy till of the Rainy Lobe is exposed on the surface only in the northeast (Secs. 1 and 2) and in the northwest (Secs. 5, 6, 7, 8, T. 62 N.), although it probably underlies the red clay till in other parts of the township. At Pothole Falls on the Arrowhead River (Sec. 27), one of the thickest sections of drift in the county is exposed. At the base is 90 feet of dense brown calcareous clay till, possibly derived from the Rainy Lobe or an older ice sheet. It is overlain by 25 feet of bedded gray and brown fine sand and silt, on top of which is 25 feet of red clay till of the Superior Lobe, and the section is capped by 20–25 feet of sandy gravel. Gravel-covered terraces are common along major rivers such as the Arrowhead and Flute Reed.

An unusual feature is the Pothole Falls of the Arrowhead (Brule) River. This is one of the largest rivers of the Minnesota coast, and just above the brink of the falls the river is divided by a rock mass. The eastern channel leads over the falls, the western channel leading into a large pothole and the water emerging in the deep pool 70 feet below.

The northerly sections in this area show exposures of Duluth gabbro, with some granophyre in part of the south finger of the gabbro mass. In the exposures near Lake Superior the dominant rocks are basalts, rhyolites, diabases, and sediments. The contacts of flows indicate general dips to the south, without complete uniformity.

Four flows may be traced across T. 62 N., R. 3 E.

Township 62 North, Range 4 East
(Plate 9, in pocket)

Red clay till left by the Superior Lobe is the principal glacial deposit of this township, and it is widely distributed except on the high ridges of the Coastal Hills. Brown sandy till deposited by the Rainy Lobe appears at the surface only in Sec. 6, but in the deeper road cuts along U. S. Highway 61 in Secs. 10 and 16 it can be seen underlying a surficial mantle of red clay till. Sands and gravels deposited by lakes of higher level than the modern Lake Superior are scattered over a belt extending inland half a mile from the present shoreline. Ancient lake cliffs and beach ridges may be observed at Horseshoe Bay and inland from Big Bay.

The identification of several igneous masses where not very well exposed is tentative. The gabbro at Hovland (from Chicago Bay to Horseshoe Bay) has been mapped as Duluth gabbro. This is partly distinguished by its petrographic character (fairly constant though complex) all the way from Duluth; and partly by the continuity of the belt along the Arrowhead River — until that stream turns sharply south in T. 62 N., R. 3 E. (Plate 8).

In the eastern part of the township a complex of sills and dikes cuts across the basalts and rhyolites along the slopes down to Lake Superior. The prominent diabase ridge in Secs. 2 and 3 is doubtless a large dike which trends at right angles to the prevailing strike of the flows along shore.

Township 61 North, Range 5 West
(Figure XXXVII)

Most of this township appears to have a mantle of Rainy Lobe drift, although much rock crops out in the western sections and in parts of Secs. 13 and 24, and elsewhere. The best information on the nature of Pleistocene deposits comes from the road along the former logging railroad in the southeast corner of the township.

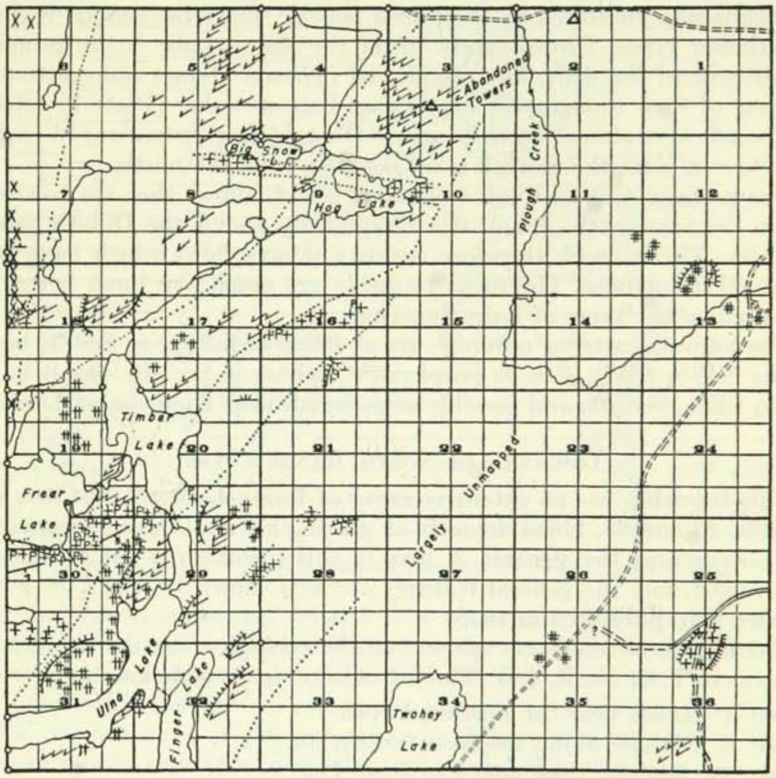

Figure XXXVII. — Geologic map of Township 61 North, Range 5 West.

The till has a matrix rich in sand. At Twohey Lake (Sec. 34) thick exposures of fine glacifluvial sand are found interbedded with coarse sand and pebble gravel.

The Duluth gabbro is exposed in a narrow belt from the northwest corner of the area to Frear Lake four miles to the south. The granophyre related to gabbro crops out from Sec. 3 to Sec. 18, and in some scattered areas farther south, but occurs in a confusion of lavas and diabases of several varieties. The eastern side of the township is largely drift-covered, but there are basalts, diabases, and, locally, granophyres.

It is difficult to distinguish granophyre related to the gabbro from several red rhyolites, especially in the forested areas along the old railroad in the eastern part of the township.

There appears to be a belt of porphyritic diabase from Sec. 16 to Sec. 30, T. 61 N., R. 5 W.

Township 61 North, Range 4 West

This township has so very few outcrops that no map is necessary. The township map published by the Forest Service shows the general features and timber types. Brown sandy till of the Rainy Lobe is the principal constituent of the drift, but glacifluvial deposits attract more attention because of their topographic expression. Pancore esker (Plate 1) extends west-southwest almost entirely across the township from Sec. 13 to Sec. 31, where it joins the Sawbill esker complex from the north.

The geologic map of Cook County (Plate 2) shows that the township lies in the area south of, and stratigraphically above, the Duluth gabbro complex. The bedrock therefore consists of lava flows which have been intruded by diabase. The rocks probably are much like those better exposed along the shore of Lake Superior.

The known scattered outcrops are as follows: diabase in Sec. 1; basalt in the NW¼ SW¼, Sec. 8; porphyritic diabase in Sec. 18; basalt in the SW¼ SE¼, Sec. 33; and possibly some basalt near Honeymoon Lookout.

Township 61 North, Range 3 West

This township has an extensive cover of Rainy Lobe till, but it is thin in Secs. 29 and 33. Local deposits of gravel and sand (some surprisingly fine) occur near the streams. A map of this township is not included in this report, but the general features are well shown by the U.S. Forest Service map published in 1953.

The known outcrops are sparse and the geologic situation is much the same as in T. 61 N., R. 2 W. The list of outcrops is as follows:

Sec. 1. Basalt near the northeast corner.

Sec. 6. Diabase along the west section line.

Sec. 29. Diabase dike near Christine Lake.

Sec. 33. Diabase, granophyre and basalt in the NW¼.

Sec. 36. Diabase and anorthosite fragments at the forest lookout south of Caribou Lake.

Township 61 North, Range 2 West
(Figure XXXVIII)

The southeastern fifth of this township is covered by red clay till of the Superior Lobe, except in the channel of the Cascade River. Much of the remainder of the township is covered with brown sandy till of the Rainy Lobe; in places so thin and patchy that bedrock knobs protrude. At the east end of Pike Lake (Sec. 15) is an accumulation of glacifluvial

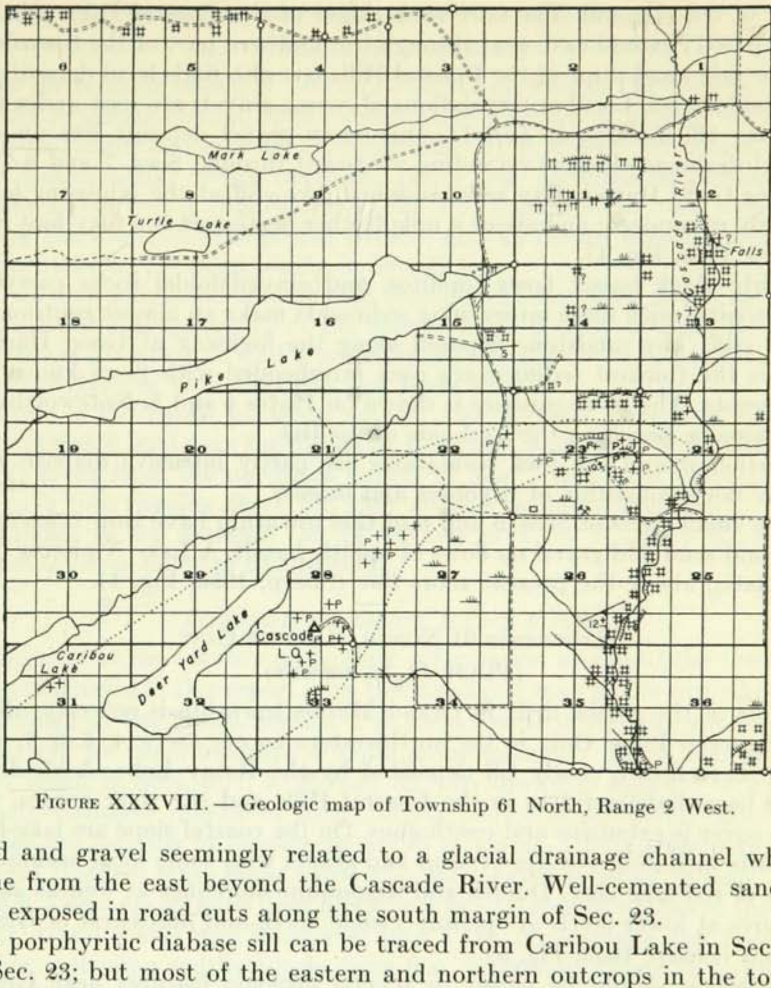

FIGURE XXXVIII. — Geologic map of Township 61 North, Range 2 West.

sand and gravel seemingly related to a glacial drainage channel which came from the east beyond the Cascade River. Well-cemented sand is also exposed in road cuts along the south margin of Sec. 23.

A porphyritic diabase sill can be traced from Caribou Lake in Sec. 31 to Sec. 23; but most of the eastern and northern outcrops in the township are basalt, rhyolites, and volcanic breccias. About fifteen flow units were counted along the Cascade River in Sec. 25, and the extensive outcrops of basalt flows along the channel of the river show that the prevailing bedrock consists of basaltic lava flows, with some rhyolite flows and diabase intrusions. A sandy bed occurs along the Cascade River in Sec. 12.

Much of the western part of the township was not investigated because of the scarcity of outcrops and relative inaccessibility.

TOWNSHIPS 60 AND 61 NORTH, RANGE 1 WEST
(PLATE 10, IN POCKET)

Masses of the Rainy Lobe brown sandy till are widely distributed over the northern half of this township. The southern half has a more patchy cover of red clay till. The bare rock ridges of the Coastal Hills (Sharp, 1953, p. 857) extend east-west through the southern part of the township. On the lakeward slope of the Coastal Hills one also finds local deposits of lake-laid gravel. Local accumulations of coarse gravels are seen under the red clay till in Secs. 13 and 14, and many gravel deposits line an old glacial drainage channel extending westward through Secs. 7 and 8.

Near Good Harbor Bay an abandoned lake cliff at the Nipissing level is easily recognized; and about a mile farther northwest is a fifty-foot cliff (Sharp, 1953, Fig. 4).

Fairly thick basalt flows (ophites, and amygdaloidal rocks carrying thomsonite) with some intervening sediments make an almost continuous shore cliff. The sandstone exposed along the highway at Good Harbor Bay is the thickest sedimentary rock interbedded with flows known in Minnesota. The flow sequence is shown on Plates 4 and 5. Noteworthy is Thomsonite Beach on the west side of the bay.

Farther inland the rock formations are partly intrusive diabase and partly flows consisting of rhyolites and basalts.

The small parts of Secs. 5 and 6 of this township have thin veneers of lake-laid sand and gravel on flows of ophitic basalt. A Lake Nipissing cliff is isolated above the present shore line (Sharp, 1950, Fig. 4).

TOWNSHIP 61 NORTH, RANGE 1 EAST
(PLATE 11, IN POCKET)

Most of the glacial drift in Grand Marais township is red clay till of the Superior Lobe. Only in the northwestern corner (Secs. 4, 5, 6, 7, and 8) is there brown sandy till deposited by the Rainy Lobe. Aside from large bare diabase ridges in the Coastal Hills and the river gorges, the drift cover is extensive and continuous. On the coastal slope are lake-laid deposits including veneers of sand and gravel with some local accumulations of red lake clay. Duluth and Algonquin shorelines as well as shore features at lower levels are plainly visible north and northwest of Grand Marais (Sharp, 1953, Fig. 5).

Attention should be called to several geologic features near Grand Marais: (1) Exposures on the shore of Lake Superior in Sec. 14, indicate that certain beds are overturned. (2) It seems certain that some diabase magma was intruded in a complex involving rhyolite flows, so that the irregular areas of rhyolite are matched as shown by the shaded pattern on the map. (3) The Devils Track River gorge has been cut much more steeply than most of the rivers, largely as a result of the extensive jointing of the rhyolite. (4) The harbor at Grand Marais is formed by the junction of a resistant diabase sill, with the bay in the more easily eroded rhyolite flow.

Because of the heavy cover of glacial drift much of the northern part of the township was not mapped in detail.

Parts of Townships 61 and 62 North, Range 2 East
(Plate 12, in pocket)

In the fraction shown of Township 61, red clay till of the Superior Lobe is the principal deposit. The coastal slope also has a patchy veneer of lake-laid sands and gravels. The Nipissing cliff is almost continuous along the southern edge of this township, and a large Deronda beach ridge extends across Sec. 1 (Sharp, 1953, Fig. 7). Gravels have been deposited along the lower courses of the streams and as deltaic accumulations at higher lake levels, particularly in Sec. 10.

The rock succession is somewhat confused by the steep slopes on tilted beds, by the irregular dip of the stream beds, and by possible faulting. There are from east to west a probable sequence of seven flows that intersect the shore of Lake Superior (see Plate 4).

West of the basalt porphyry in Sec. 1 at the east, there is a rhyolite flow in Sec. 2, and near the mouth of Kimball Creek. Exposures along the short creek from the northeast corner of Sec. 3 suggest a succession of three or four rhyolite flows, but they are not easily distinguished.

Inland, in the southern tier of sections in T. 62 N., R. 2 E., glacial deposits cover much of the bedrock.

Township 60 North, Range 5 West

Because of the scarcity of geologic information a map of the township is not included in this report. The best available map of the township was published by the Forest Service, U.S. Department of Agriculture, in 1953.

Except for small outcrops of granophyre in Secs. 1 and 8, and diabase and basalt in Secs. 6, 7, 9, 33, and 35, this township appears to have a nearly complete mantle of drift, largely brown sandy Rainy Lobe till. There are deposits of glacifluvial origin at places. Direct observations of glacial features were made along the old logging railroad in Secs. 3, 8, and 9. Three eskers have been identified; one extending westward through Secs. 1 and 2 and then northwest into T. 61 N.; another, the Fourmile esker, extending southwesterly from Sec. 2 through Fourmile Lake into Secs. 10, 9, and 8; and a third extending west from the southwest tip of Richey Lake in Sec. 20 into Sec. 19.

Diabase crops out in Secs. 19 and 20 and there are small outcrops in Secs. 33 to 35.

Township 60 North, Range 4 West

Because of a scarcity of outcrops this township was not mapped in detail and a map is not included in this report. The U.S. Forest Service map of 1953 is the best available. The best-known Pleistocene deposits of this township are found along the Sawbill road and the Temperance River. Most of the township has a uniform mantle of bouldery Rainy Lobe till, with the usual brown sandy matrix; but in Secs. 8 and 17 there is an exceptional richness of boulders; and locally through Secs. 5, 8, 17, and 20 the matrix contains considerable brownish clay.

Red clay deposited in a lake marginal to the Superior Lobe and occupying the lower part of the Temperance River valley is exposed in Sec. 33, T. 60 N., R. 4 W. About 50 feet of red clay with interbeds of brown silt and sand is exposed in a river bank at the well-known Oxbow campground.

A low gravel terrace along the Temperance River has been worked for gravel in Secs. 7 and 20. A higher belt of rolling country is mapped as a swamp through Secs. 14, 21, 22, 23, 27, and 28. Lake gravels are spread in scattered patches over the coastal slope up to 200 feet above Lake Superior, and beaches of ancient lakes are numerous within 50 feet of the plane.

A high bluff of diabase faces northwest toward the Temperance River, at about the center of Sec. 33, and there probably are smaller outcrops for a mile or two east. The west facing bluffs in Secs. 4 and 9, T. 59 N., R. 4 W., may be related.

The Forest Service map shows extensive rock outcrops in the west half of Sec. 13 and the southeast quarter of Sec. 14.

Townships 59 and 60 North, Range 3 West (Plate 13, in pocket)

The northern third of Township 59 has chiefly a mantle of Rainy Lobe till. The southern two thirds was covered by the Superior Lobe and has much red clay till. On the Poplar River in the southern part of Sec. 21 is an exceptionally thick deposit of red clay till in a preglacial rock gorge. Dense red lake clays, deposited in a lake marginal to the Superior Lobe, extend over the Rainy Lobe till of the Poplar River in Secs. 3, 4, 5, 9, and 10.

The Poplar River has about five distinct falls in Sec. 33, and three falls occur farther north in Secs. 15, 16, and 20.

On the coastal slopes there is a porphyritic diabase sill which strikes northeast and dips southeast at angles of 10 to 25 degrees. The rocks that crop out abundantly within a mile or two from Lake Superior are nearly all basalt flows.

This small fraction of T. 60 N., R. 3 W. has a rocky shore, local thin accumulations of lake-laid sand and gravel, and some cliffs of lower Algonquin and Nipissing age. The exposed rocks are all basalt lava flows. Some are porphyritic and others ophitic. The detail of the flows along shore in both townships is shown on Plate 5.

Township 60 North, Range 2 West (Plate 14, in pocket)

The drift in this township is principally Superior Lobe red clay till. Much basalt is exposed on the ridges of the Coastal Hills, and Keweenawan sediments are interbedded. Near the Superior shore are deposits of lake-laid sand and gravel, and west of the Cascade River mouth are emerged deltaic deposits of considerable thickness, rich in sand. The Nipissing lake cliff extends with only minor interruptions slightly inland from the Superior shore throughout most of this township.

There is an almost continuous exposure of basaltic lava flows. The detailed inventory along shore is shown on Plate 5. A total of 19 flows were recognized along the river from its mouth to the north line of Sec. 35, T. 61 N., R. 2 W.

An arkosic conglomerate occurs along the Cascade River in the NW¼ of Sec. 1. There is some green copper stain, and the locality was once known as Mayhew's copper prospect.

An extensive exposure of tuff and arkose occurs along shore near Black Point in Sec. 11, and similar material is also exposed a short distance inland on a secondary road and also on Highway 61. Another exposure of arkosic material occurs farther west, in Sec. 16 along Trout Creek. None of these sedimentary deposits interbedded with the flows can be traced far along the strike, and it is a reasonable inference that they are patches of material deposited on top of flows.

Township 59 North, Range 5 West

A map of this township is not included here, but Secs. 25, 26, 31, 35, and 36 are on an insert in Plate 16. The U.S. Forest Service map of 1953 shows the general features and timber types.

This township has an extensive cover of drift, except for a few small exposures of flows, sills, and dikes in the southeast along the Cross River. Sharp (1953, Fig. 2) shows that the glacial drift cover is largely in drumloid belts running northwest.

The large exposures of flows near Lake Superior continue north along the Cross and Two Island rivers for about two miles into this township (see Plate 16). The rocks are largely basalt flows, some of them ophitic or porphyritic.

Other known outcrops occur as follows: Sec. 4, diabase near the north line; Sec. 18, rhyolite, granophyre, and diabase complex; Sec. 28, basalt near Two Island River in the southeast corner; Sec. 34, basalt in NW¼ SW¼.

Township 59 North, Range 4 West (Plate 15, in pocket)

The principal Pleistocene deposits of this township are red clay till of the Superior Lobe, red lake clay, and sand and gravel deposits formed chiefly along shorelines of the Pleistocene Great Lakes. Brown sandy Rainy Lobe till is known at the surface in Sec. 6. Rainy Lobe till is also exposed in cuts along the Sawbill Trail in Secs. 8 and 17, but here it is mantled by red lake clay. Mass movements on slopes have locally mixed this red clay and brown sandy till to give a product strongly resembling a phase of the Superior Lobe till.

Red clay Superior Lobe till covers large areas to the northwest of the Coastal Hills (Sharp, 1953, p. 857). This till extends northeasterly across the township from Sec. 18 to Sec. 3, and is also exposed at places in the Coastal Hills. Red lake clay is the principal surface material along the Temperance River in Sec. 5 and along the Onion River in Secs. 1 and 2, showing that these valleys were in existence before glacial Lake Duluth.

Gravels and sands form terraces along the Temperance River, and near its mouth deltaic deposits are extensive. Some are seen south of Leveaux Mountain in Sec. 11, and at the airport north of Tofte in Sec. 22. Just west of Tofte and north of the highway is one of the best cliff and terrace relations in Cook County along the old shore, now about 110 feet above the level of Lake Superior. Cliffs also occur along the abandoned lower Algonquin and Nipissing shores. The higher ridges of the Coastal Hills have exposed much bare bedrock on the coastal slope.

The rocks along shore reveal a practically continuous sequence of lava flows; inland there are extensive ridges of diabase, mainly sills intruded into flows which are very poorly exposed. The lava flow just west of Tofte is the highest in the sequence of flows on the north shore; that the strike is essentially parallel to the shore is clearly shown by the map.

Carlton Peak is described in the section on anorthosite (see p. 89). The prominent diabase ridge, cut by the Onion River Valley, has a conspicuous porphyritic texture.

TOWNSHIP 58 NORTH, RANGE 5 WEST (PLATE 16, IN POCKET)

The Pleistocene deposits of this township are principally Superior Lobe red clay till and overlying accumulations of shoreline and river gravels. Rainy Lobe till forms the surface mantle only in the northwest corner. A high rock ridge with thin scattered spots of red clay till crosses southwesterly through about the center of the land area. Pleistocene deposits on the coastal slope of this ridge are chiefly sand and gravel of shore or near-shore origin. An area of pitted glacifluvial deposits lies north of Dyers Lake in Secs. 4 and 5.

With the exception of a small diabase hill near the southeast corner of Sec. 8, all the outcrops in this township consist of basalt flows. As shown on Plate 5 the flows to the northeast lie above those to the southwest. Flow units are conspicuous on the point at Sugarloaf Bay (Fig. 15) and also in a railroad cut at Taconite Harbor. The near-parallelism of the strike of the flows to the coastline is conspicuous in this township.

Sugar Loaf Bay is an active shipping point for logs from the surrounding forests. The projecting point, which guards the harbor from the west wind, shows a series of wave-washed flows, many of which are two to ten feet thick. Near the tip of the point a thick flow guards the smaller ones; and a group of "4 units" shows a complex structure, apparently a synclinal group plunging gently down into the lake but still not quite concordant with other main flows and units.

APPENDIX, REFERENCES, AND INDEX

APPENDIX

TABLE A. THE LARGE LAKES OF COOK COUNTY, LOCATED BY TOWNSHIP AND RANGE

Name	Location	Name	Location
Agnes	60:3W	Maraboeuf	66:4W
Alpine	65:5W	Moose	65:3E
Alton	62:5W	Mountain	65:1E,2E
Birch	65:2W	North	65:2W
Brule	63:3W	North Fowl	65:3E
Caribou	60:3W,65:1E	Otter	64:3E
Cascade	62:2W	Phoebe	62:5W
Cherokee	63:4W	Pike	61:2W
Clearwater	65:1E	Pine	64,65:2E
Daniels	65:1W	Pine	62:3W
Devilfish	62:3E	Poplar	64:1W,2W
Devils Track	62:1W,1E	Rose	65:1W
Duncan	65:1W	Saganaga	65,66:4W,5W
East Bearskin	64:1E	Sawbill	62,63:4W
East Pike	65:3E	Sea Gull	65:5W
Fourmile	60:5W	South	65:2W
Gabimichigami	64,65:5W	South Fowl	64:3E
Gaskin	64:2W	Staple	64:1W
Grace	62:5W	Tom	64:6E
Greenwood	64:2E	Tomash	63:3E
Gunflint	65:3W	Tucker	64:3W
Hungry Jack	64:1W	Tuckarora	64:4W,5W
Iron	65:2W	Two Island	62:1W
Jasper	65:5W	Ulna	61:5W
Little Saganaga	64:5W	West Bearskin	65:1W
Long Caribou	65:1E	West Caribou	64:1W,2W
Long Island	64:3W	West Pike	65:2E
Loon	65:3W	Winchell	64:2W

TABLE B. THE SMALL LAKES OF COOK COUNTY, LOCATED BY SECTION, TOWNSHIP, AND RANGE

Name	Location	Name	Location
Ada	16:63:4W	Cliff	36:64:3W
Afton	26:64:5W	Cone	3:63:3W
Alder	11:64:1E	Copper	10:64:4W
Allen	23:64:2W	Cow	17:62:2W
Alpha	18:64:2W	Crab	30:65:2W
Anderson	2:61:4W	Crocodile	7–11:64:1E
Arc	18:65:4W	Crooked	11:64:5W
Arita	21:63:1W	Crow	28:63:2W
Ash	30:64:3W	Crystal	6:64:2E
Aspen	11:64:1W	Cucumber	23:64:1E
Auk	26:64:4W	Davis	34:64:3W
Axel	28:63:3W	Dawkins	6:64:3W
Ball Club	16:63:1W	Deer	4:64:1E
Banadad	11,12:64:3W	Deeryard	32:61:2W
Barker	7:60:3W	Dent	5,8:63:5W
Barto	27,28:63:5W	Devilfish	29,30:64:3E
Bat	5,6:60:5W	Dick	7:62:1W
Bat	36:65:5W	Digest	3:61:1W
Bean	18:64:2E	Doe	13:64:4W
Bear Cub	13:64:1W	Dollar	27:62:5W
Beaver	20:62:3W	Dot	24:64:1W
Beaver	7,9:64:2E	Duck	11:63:5W
Beaver	33:65:2W	Dunn	25:65:2W
Bench	6:64:2E	Dunn	30:65:1W
Benning	1:64:3W	Dutchman	6,7:63:6E
Beth	15:62:5W	Dyers	9:58:5W
Big Sand	9:61:5W	Eagle	28,33:63:2W
Bingoshick	30:65:4W	East Dawkins	5:64:3W
Blink	15:63:2E	East Pipe	3:62:3W
Blueberry	2:61:1W	East Otter	31:65:1W
Bogus	12:62:2E	Elbow	31:61:5W
Boulder	19:62:3W	Elbow	10,15:62:1E
Bow	15:64:1W	Ella	10:62:5W
Bower Trout	16:63:1W	Elm	9:64:5W
Brule Bay	9:63:2W	Esther	31:64:3E
Buck	21:59:5W	Everett	29:65:4W
Bug	8:63:5W	Fern	3:64:5W
Bull	17:63:2W	Finger	5:60:5W
Bunga	36:64:2W	Finger	32:61:5W
Burnt	4:62:4W	Finn	13:64:3W
Burt	23:64:4W	Fishhook	21:63:2W
Byre	33:62:5W	Flame	4:62:4W
Cam	7:63:3W	Florence	35:64:5W
Canoe	1:64:1E	Flower	1:64:1W
Caribou	13:64:2W	Flying	31:65:4W
Carl	34:64:1W	Fool	11:64:4W
Carrot	17:64:2E	Fox	11:60:5W
Cash	31,32:64:3W	Frear	19:61:5W
Cedar	22:60:5W	Fredrick	14:63:5W
Celery	20:64:2E	French	35:65:5W
Center	11:63:5E	Frost	27:64:4W
Chase	29:64:4W	George	17:64:3W
Christine	29:61:3W	Gillis	2:64:5W
Chub	20:65:4W	Gneiss	26:66:4W
Chub	34:65:5W	Goose	22:63:2W
Circle	29:63:1E	Gordon	36:64:4W
Clam	23:63:4W	Gotter	32:65:4W
Clara	8:61:3W	Grandpa	35:66:5W
Cleft	31:64:3W	Gulf	24:66:5W

TABLE B — *Continued*

Name	Location	Name	Location
Gull	30,31:66:4W	McFarland	4,5,9:64:3E
Gust	11:62:3W	Meeds	14,15:64:2W
Ham	35:65:4W	Mesaba	3:63:5W
Hand	36:63:2W	Mid Cone	3:63:3W
Henson	20,21:64:2W	Middle Pipe	4,5:62:3W
Hilly	8:62:3W	Mina	21:64:5W
Hog	9:61:5W	Mink	8:62:2E
Homer	34,35:63:3W	Misquah	32:64:1W
Horn	14:62:4W	Missing Link	4:64:4W
Horseshoe	19:64:1W	Missouri	13:61:4W
Howard	28:65:5W	Mit	33:63:1W
Hub	34:64:5W	Monker	6:61:1E
Hug	11:63:5W	Moon	16:64:2W
Ida	4:63:3W	Moon	5,32,33:64,65:1E
Iowa	1:61:4W	Moore	23:62:4W
Iris	21:64:4W	Moosehorn	36:63:3E
Ivy	16:64:2W	Mora	14:64:5W
Jack	35:63:4W	Morgan	27:64:1W
Jackson	23:63:4W	Moss	32:65:1W
Jake	28:64:1W	Muckwa	21:63:1E
Jap	24:65:5W	Mulligan	12:63:3W
Java	17,19:63:4W	Muskeg	21:64:2W
Jay	30:64:3W	Musquash	29:63:1E
Jerry	14:64:5W	North Caribou	13:64:2W
Jim	26:64:1E	North Java	7:63:4W
John	33:65:3E	North Shady	22:64:2E
Juniper	15:64:4W	North Temperance	12,13:63:4W
Juno	20–22:63:3W	Northern Light	30–32:63:2E
Kelly	10:62:4W	Omega	19:64:2W
Kelso	25:63:5W	Omega	24:64:3W
Kemo	34:63:1W	One Island	4:64:2W
Kimball	8:62:2E	Onion	23:64:1E
Kishadinna	23:64:3W	Osprey	28:63:1W
Larch	10,11:65:4W	Otto	25,26:64:3E
Leah	2:63:5W	Otto	29:64:2W
Leo	5:64:1W	Owl	12:64:5W
Lilly	12:63:3W	Pancore	22:61:4W
Little Caribou	36:65:1E	Parsnip	13:64:1E
Little Cascade	13:62:3W	Partridge	29:65:1W
Little Capper	15:64:4W	Pendent	36:62:1W
Little Iron	36:65:3W	Peter	33:65:5W
Little Mayhew	30:65:2W	Peterson	15:62:4W
Little Sand	8:61:5W	Petit	24:62:4W
Little Trout	5:63:1W	Pickeral	11,12:62:1E
Locket	30:64:1E	Pie	14:63:5W
Lone	20:66:5W	Pillsbury	21,22:64:2W
Long Lake	9:62:3W	Pine	35:63:1W
Long Lake	1,2:64:2E	Pine Mountain	35:63:1E
Lower George	12:64:4W	Pipe	6:62:3W
Lujenida	24:63:5W	Poe	10:63:5W
Lum	9:64:2W	Poet	19:62:5W
Lux	33:64:1W	Pope	32,33:65:2W
Magnetic	18,19:65:3W	Portage	4:64:2W
Many Moon	13:61:4W	Potato	20:64:2E
Mark	8:61:2W	Prout	34:64:4E
Marsh	22,27:62:4W	Quiver	15:64:1W
Marshall	17:63:1W	Ram	9:63:1W
Mayhew	33:65:2W	Ranger	3:63:4W
McDonald	12:62:2W	Rat	19:65:1W

TABLE B — *Continued*

Name	Location	Name	Location
Rattle	6:64:5W	Table	6:64:2E
Ray	20:65:5W	Tait	27:62:3W
Red Rock	22,23:62:5W	Teal	27,34:64:6E
Red Rock	33:66:5W	Temperance	26,27:62:4W
Rice	11,12:61:4W	Thelma	17:64:4W
Richey	20:60:5W	Third Kimball	8:62:2E
Rock	14:63:1E	Timber	20:61:5W
Rock	31:65:4W	Tomash	6:62:2W
Rocky	3:64:1E	Tote	13:63:2W
Ross	16:64:3W	Town	6:63:3W
Round	33,34:65:4W	Trap	17:64:1E
Rove	19,20:65:1E	Trap	31:64:2W
Royal	3:64:3E	Trout	30:61:2W
Rudy	12:64:1W	Trout	10:62:2E
Rush	8:64:2W	Turnip	24:64:1E
Section Ten	10:63:2E	Turtle	8:61:2W
Shoe	30:64:2E	Twin Lakes	10,15:61:3W
Shoko	14:64:1W	Twin Lakes	25,26:63:1W
Smoke	5:62:4W	Twohey	34:61:5W
Smoke	32:63:4W	Vance	4,5,8,9:63:2W
Snipe	3:64:4W	Vern	32,33:63:3W
South Cone	10:63:3W	Vernon	16:63:2W
South Temperance	13:63:4W	Virgin	5:64:5W
Spaulding	5:64:2E	Vista	29:64:1W
Speckled Trout	7:65:5E	Watap	21,22:65:1E
Spud	25:64:2W	West Fern	4:64:5W
Squash	19:64:2E	West Pipe	6:62:3W
Star	25:63:3W	Whitaker	3,4:63:2W
Stony	12:64:1E	White Pine	19,30:61:3W
Stump	12:64:2E	Wigwam	7:60:5W
Sunfish	26:64:2E	Williams	4:61:3W
Swamp	12:62:1W	Wills	34:62:3W
Swamp	16,21:62:2W	Wind	30:66:5W
Swamp	17:64:1W	Wine	10,11,15:63:5W
Swamp	7:64:5E	Wonder	23:62:5W
Swamper	19:64:1E	Zenith	12:63:5W
Swan	12:63:2W	Zoo	33:63:2W

TABLE C. LOCATION AND DESCRIPTION OF MINERAL VEINS IN COOK COUNTY

1. Calcite Veins
   - SW¼ SW¼ Sec. 33, T. 65 N., R. 1 W. Pit.
   - NE¼ NW¼ Sec. 3, T. 64 N., R. 3 E. Outcrop.
   - SE¼ Sec. 12, T. 64 N., R. 3 E. Outcrop.
   - NE¼ SW¼ Sec. 35, T. 64 N., R. 5 E. Pit.
   - NW¼ SE¼ Sec. 21, T. 64 N., R. 5 E. Outcrop.
   - NE¼ NE¼ Sec. 28, T. 64 N., R. 5 E. Outcrop.
   - SE¼ SE¼ Sec. 35, T. 64 N., R. 5 E. Outcrop.
   - NE¼ SW¼ Sec. 35, T. 64 N., R. 5 E. Pit.
   - SE¼ NE¼ Sec. 19, T. 64 N., R. 6 E. Outcrop.
   - SE¼ NW¼ Sec. 31, T. 64 N., R. 6 E. Outcrop.
   - NE¼ NE¼ Sec. 31, T. 64 N., R. 6 E. Outcrop.
   - Shore of Lake Superior, Sec. 31, T. 64 N., R. 7 E. Outcrop.
   - Shore of Lake Superior, Sec. 32, T. 64 N., R. 7 E. Outcrop.
2. Calcite-Barite Veins
   - Shore of Pigeon Bay, Sec. 28, T. 64 N., R. 7 E. Outcrop.
   - Shore of Lake Superior, Sec. 27, T. 64 N., R. 7 E. Pit.
   - SE¼ Sec. 32, T. 64 N., R. 7 E. Pit.
   - Small island west of Lucille Island.
   - Southern end of Susie Island and small island off point.
3. Calcite-Sulfide Veins
   - E½ Sec. 24, T. 64 N., R. 6 E. Outcrop.
   - SE¼ SE¼ Sec. 31, T. 65 N., R. 2 E. Pits.
   - SW¼ SW¼ Sec. 32, T. 65 N., R. 2 E.
4. Calcite-Barite-Sulfide Veins
   - Susie Island, Lake Superior. Shafts.
   - Near Shore on Pigeon Point, Sec. 28 (from Winchell). Shaft.
5. Quartz Veins
   - SE¼ Sec. 5, T. 64 N., R. 2 E. Pits.
   - NW¼ NW¼ Sec. 5, T. 64 N., R. 3 E. Shaft.
   - Sec. 9 and 10, T. 64 N., R. 3 E. (from Winchell). Outcrops.
   - SE¼ SW¼ Sec. 4, T. 63 N., R. 3 E.
6. Xonotlite-Prehnite-Sulfide Vein
   - SW¼ SE¼ Sec. 35, T. 64 N., R. 5 E. Pit.
7. Sulfide Diabase
   - NE¼ SE¼ Sec. 36, T. 64 N., R. 5 E. Outcrop.
   - NE¼ SW¼ Sec. 35, T. 64 N., R. 5 E. Pits.
   - NE¼ NE¼ Sec. 31, T. 64 N., R. 6 E. Outcrop.
   - SW¼ SW¼ Sec. 29, T. 64 N., R. 6 E. Outcrop.
   - SW¼ SE¼ Sec. 35, T. 64 N., R. 5 E. Pits.
   - SW¼ NE¼ Sec. 6, T. 63 N., R. 6 E. Outcrop.
   - SE¼ SE¼ Sec. 29, T. 64 N., R. 6 E. Pit.
   - SE¼ NE¼ Sec. 28, T. 64 N., R. 6 E. Outcrop.
   - SE¼ SE¼ Sec. 16, T. 62 N., R. 4 E.
8. Graphite
   - SE¼ Sec. 32, T. 64 N., R. 7 E. Pits.
   - NW¼ NE¼ Sec. 36, T. 64 N., R. 5 E. Outcrop.
9. Copper-Stained Rocks
   - NW¼ Sec. 1, T. 60 N., R. 2 W.
   - NW¼ SE¼ Sec. 31, T. 60 N., R. 3 W. Test pits.
   - NW¼ NW¼ Sec. 13, T. 59 N., R. 4 W. In conglomerate.
   - NE¼ NE¼ Sec. 34, T. 60 N., R. 3 W. In amygdaloidal basalt.
   - NW¼ NE¼ Sec. 25, T. 60 N., R. 3 W. In basalt on shore.
10. Miscellaneous
    - SE¼ NW¼ Sec. 35, T. 61 N., R. 2 W. Test pits.
    - SW¼ SE¼ Sec. 35, T. 63 N., R. 4 W. "Old Silver Mine"?

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