STATE OF MICHIGAN

# PROGRESS REPORT NUMBER SEVENTEEN
# Reconnaissance of the Ground-Water Resources of Chippewa County, Michigan

by

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Prepared cooperatively by the United States Department of the Interior Geological Survey

1958

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## Figures



[Note: See document ____ for tables and plates.]

# INTRODUCTION

## Purpose and Scope of Study

A ground-water reconnaissance of the eastern part of the Northern Peninsula on a county unit basis was begun in 1955 as part of the continuing cooperative agreement between the Michigan Department of Conservation and the U. S. Geological Survey. The objective of the reconnaissance is to determine the general occurrence, availability, quantity, and quality of ground water in the study area. To make the results available to the public with the least possible delay, progress reports are to be released upon completion of each reconnaissance study of an appropriate areal unit. This report is the first of the series of reconnaissance reports, and it summarizes the ground-water data obtained in Chippewa County during the initial phase of the investigation. The data are presented in this manner primarily to aid well drillers, contractors, industrialists, farmers, and the public at large in evaluating the ground-water resources of any given area of Chippewa County. A summary description of the major lithologic units is given, which may have application in future explorations for water or other mineral resources.

Cooperative ground-water investigations by the U. S. Geological Survey in Michigan are directed jointly by A. N. Sayre, Chief of the Ground Water Branch, U. S. Geological Survey, Washington, D. C., and W. L. Daoust, State Geologist, Michigan Department of Conservation, Lansing, Mich., and are under the direct supervision of Morris Deutsch, who succeeded J. G. Ferris, of the Federal Survey, in Lansing.

## Previous Investigations

Various phases of the geology and hydrology of this area are described in numerous reports of detailed and reconnaissance investigations made in the Northern Peninsula of Michigan since 1821. An investigation of flowing-well districts in the eastern end of the Northern Peninsula was made by Frank Leverett (1906). A detailed investigation of the stratigraphy and glacial features of the county was made by W. A. VerWiebe (1928). In 1949, a reconnaissance of the water resources in the eastern end of the peninsula with reference to the probable effect on ground-water levels of a Lake Superior-level canal through the peninsula was made by J. G. Ferris, L. A. Wood, and E. A. Moulder of the U. S. Geological Survey. Many of the data used in this report were collected during that survey. Pertinent data contained in several reports listed in the bibliography (p. 52) were used freely as source material for this project, and appropriate references to them are made in the text,

## Acknowledgment

Special thanks are given to the many well drillers and residents of Chippewa County and to the Federal, State, and county agencies whose wholehearted cooperation made this report possible. Appreciation is expressed also to personnel of the Michigan Geological Survey who furnished much valuable advice and assistance.

## Well-Numbering System

The well-numbering system used in the report indicates the location of the wells within the rectangular subdivisions of the public lands, with reference to the Michigan meridian and base line. The first two segments of a well number designate the township, and range; the third segment designates the section and the number assigned to each well within the section. Thus, well 44N 2W 8-3 is well number 3 in section 8, Township 44 North, Range 2 West. Numbers formerly assigned to wells and test borings included in this report are listed in tables 2 and 3.

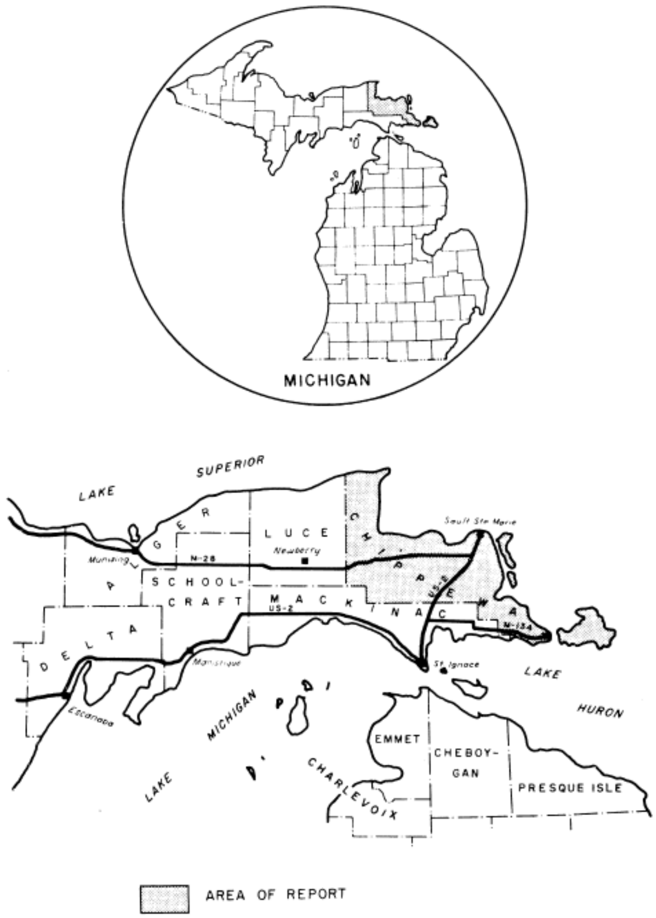


Figure 1. Index map showing location of Chippewa County, Mich.

# GEOGRAPHY

## Location and Extent of Chippewa County

Chippewa County is at the eastern end of the Northern Peninsula of Michigan (fig 1). The county, including Sugar, Neebish, and Drummond Islands and other smaller offshore islands (pl. 1), has an area of about 1,600 square miles. Of irregular shape, it spans a distance of about 100 airline miles from its northwestern corner on the Lake Superior shore to the eastern end of Drummond Island. Including the islands, the county has a shoreline length of almost 400 miles, of which about 180 miles is mainland shoreline. The international boundary with Canada trends in a southeasterly direction and is drawn through a series of waterways including Lake Superior, St. Marys River, and Lake Huron. Sault Ste. Marie, the county seat, is on the south bank of the St. Marys River directly opposite the city of Sault Ste. Marie, Ontario.

## Population

The population of Chippewa County in 1953 was 30,010, compared with 29,206 in 1950 and 27,807 in 1940, as reported by the Bureau of the Census. Commercial and industrial expansion in the Northern Peninsula, with an attendant increase in the rate of population growth, is anticipated after completion of the St. Lawrence Seaway Project and the Straits of Mackinac Bridge. Sault Ste. Marie, the largest city in the county, had an estimated population of 18,500 in 1953. The county-wide population density is about 19 persons per square mile, but if the urban areas are excepted, this figure is reduced to about 6 per square mile.

## Economic Development

### *Agriculture*

The larger tracts of agricultural land are in the eastern part of the county in the Sault Ste. Marie and Rudyard-Pickford areas. In 1949 there were about 1,000 farms averaging about 162 acres in size. The principal farm products are beef cattle, dairy products, and hay.

### *Industry*

The industries of the county are based on the timber, agricultural, mineral, and water resources of the area. The timber industries include woodworking and furniture manufacturing, the production of pulpwood, posts, and several kinds of lumber. The agricultural industries include dairies, meat-processing plants, and leather industries. The mineral industries are primarily quarrying of dolomite, used in the production of flux, road metal, and aggregate. Industries related to water resources include fisheries, recreation and resorts, generation of electricity, production of calcium carbide, which depends upon a ready source of electricity, and maintenance and operation of the Soo Locks and St. Marys River waterway.

### *Recreation*

The many inland lakes and streams, the beach frontage along Lake Superior, Lake Huron, and the St. Marys River; the extensive woodlands; the excellent hunting and fishing; the Soo Locks; the cool summer climate; and one of the lowest pollen counts in the State make Chippewa County an important recreational area.

### *Transportation*

Chippewa County is served by two railroads. The Duluth, South Shore and Atlantic Railroad connects Sault Ste, Marie with St. Ignace and with cities and towns on the south shore of Lake Superior. The Minneapolis, St, Paul and Sault Ste. Marie Railroad connects the cities along the north shore of Lake Michigan and Sault Ste. Marie with principal cities in the Midwest. A railroad bridge across the St. Marys River at Sault Ste, Marie connects the Northern Peninsula with Canada.

One Federal highway and several major State highways serve the area (pl. 1). Auto ferry service is provided to Neebish, Sugar, and Drummond Islands, and to Canada at Sault Ste, Marie.

The St. Marys River and the Soo Locks, which connect Lake Superior to the other Great Lakes, is the busiest waterway in the world. With completion of the St. Lawrence Seaway Project, traffic presumably will increase. The Chicago, Duluth, and Georgian Bay Transit Co, and the Owen Sound Transportation Co, Ltd., provide intercounty, interstate, and international transit service.

Capital and Trans-Canada Airlines provide air transportation for the county through the airport at Kinross.

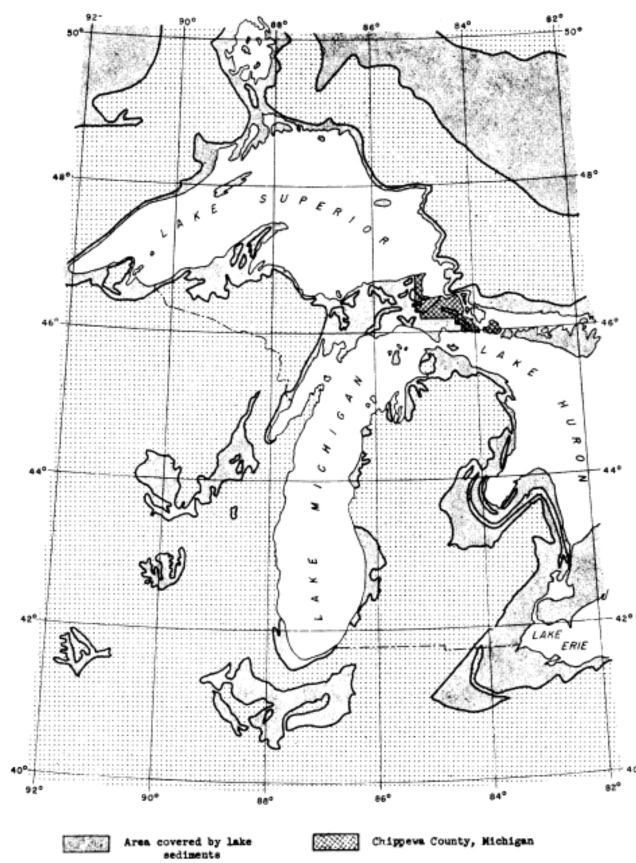


Figure 2. Map of the Upper Great Lakes region showing areas of sediment deposition in glacial Lake Algonquin and other extinct glacial lakes. (After Geol. Soc. America, 1949.)

## Physiography

Chippewa County lies in the glaciated area formerly covered by the waters of glacial Lake Algonquin (fig 2), which was an earlier stage of the present upper Great Lakes system. Deposition in and erosion by the waters of glacial Lake Algonquin and the post-Algonquin non-glacial lakes Nipissing and Algomah (?) produced or altered the physiographic features of the county. The main physiographic units of the county are the lake plains, formed by the deposits of glacial-lake sediments; the morainal highlands, which were modified by lake erosion and deposition; and the Niagara cuesta. The relief of the Niagara cuesta was subdued and the Black River cuesta (pl. 4) was buried by glacial and glacial-lake sediments.

The Niagara cuesta, formed by limestones and dolomites of Early and Middle Silurian age, extends in a broad arc from Wisconsin across the Northern Peninsula and Southern Ontario to New York State. This cuesta, the so-called "backbone" of the Northern Peninsula, forms one of the major highland areas in Chippewa County. The north face of the cuesta (Niagara escarpment) marks the northernmost extent of rocks of Niagaran age in the Michigan Basin. DeTour Passage, which separates Drummond Island from the mainland, and the Pine River are deeply incised into the cuesta.

Most of the western part of the county is an upland formed by a series of moraines (glacial-drift hills) and associated glacial deposits. The upland relief, however, is slight, as the waters of glacial Lake Algonquin leveled the area by eroding the moraines and depositing sediment in the depressions. The areas between and adjacent to the moraines are plains underlain by clayey and sandy lake and glacial-outwash deposits. Moraines in this part of the county are poorly drained, and extensive swamps are located in depressions in the center of the highland and along its edges.

The Kinross moraine (Leverett, 1929) and associated deposits form the only other major highland in the eastern half of the county. This morainic highland probably is an extension of the morainic highland in the western part of the county. It extends southeastward from a point a few miles west of Kinross, across the highland formed by the Niagara cuesta, to Lake Huron a few miles west of DeTour (pl. 3). Other small morainic highlands are in the northeastern part of the county, including a long gravel ridge west of US 2 near Sault Ste. Marie. Elsewhere in the eastern part of the county, the predominant surface features are flat, gently sloping lake plains and till plains, which have been somewhat dissected by streams. This eastern area is poorly drained and contains extensive swamp areas. Bars, beaches, wave-cut shorelines, dune areas, and other minor features associated with glacial Lake Algonquin and post-Algonquin lakes are scattered throughout the county.

### *Relief*

Maximum topographic relief in the county is about 510 feet, between the highest point at McNearny Lake tower (sec, 33, T. 47 N., R. 5 W.), at an elevation of 1,090 feet above mean sea level, and the Lake Huron shoreline, which is at an elevation of about 583 feet (pl. 1). The most prominent relief feature is Mission Hill in T. 47 N., R. 3 W., (elev. 1,045) which is 440 feet above and less than 1 mile distant from Lake Superior. The morainic highland in the western part of the county ranges in altitude from about 800 to more than 1,000 feet. The highest part of the Niagara cuesta is in the western part of the county, where it reaches altitudes exceeding 800 feet. The highland at Kinross, and Larke Hill near Sault Ste. Marie, have altitudes of about 800 feet.

The plains of glacial Lake Algonquin in the eastern part of the county are at an altitude of about 700 feet near Sault Ste, Marie and the Kinross highland, and slope gradually to the bluff marking the shoreline of ancient Lake Nipissing (pl. 3). Streams are entrenched about 40 feet into lake plains above the Nipissing shoreline. The bluff along the Nipissing shoreline is about 40 feet high in the eastern part of the county, although it is generally higher in some places and indistinct elsewhere. Lake plains below the Nipissing shoreline have little relief and slope gradually to Lake Superior and to the St. Mary's River.

### *Drainage*

Chippewa County is drained by a number of major streams, which have a total length of nearly 800 miles and flow into the Great Lakes and associated bodies of water (fig 3). The Betsy and Tahquamenon Rivers flow into Whitefish Bay of Lake Superior. The Waiska River empties into the upper reach of the St, Marys River. The Charlotte, Munuscong, and Little Munuscong Rivers flow eastward into Munuscong Lake. The Pine and Carp Rivers flow southward into Lake Huron. Numerous small streams flow-directly to the waters of the Great Lakes system. Natural drainage in much of the county, however, is in an early stage of development, as shown by the 169 inland lakes and the numerous swamps. Peat deposits in the area provide further evidence of poor drainage during and after the glacial epoch.

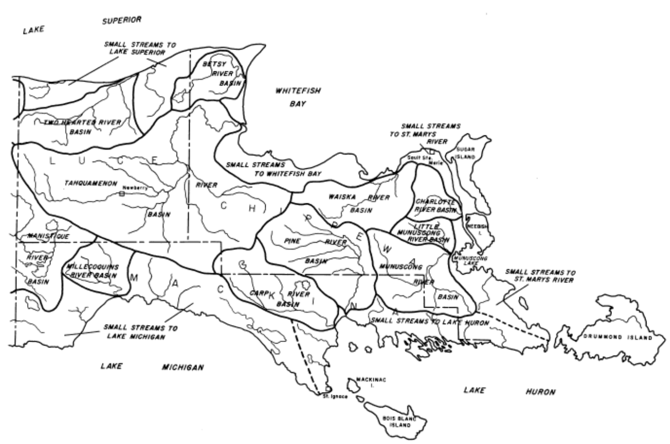


Figure 3. Map of Chippewa, Mackinac, and Luce Counties showing major drainage basins and drainage areas tributary to the Great Lakes system.

## Climate

Temperature in Chippewa County is moderate compared with other interior continental areas in the same latitude. Ranges in temperature are decreased by the Great Lakes, which have a warming influence in winter and a cooling effect in summer. The lakes also provide a source of moisture for precipitation in the area.

Annual precipitation, part of which is snowfall, ranges locally from 28 to 34 inches. The cumulative depth of the snowfall ranges from 73 to 116 inches per year. The mean countywide temperature is about 40°F. At Sault Ste. Marie, records of the period 1921-50 indicate an average annual precipitation of 30.2 inches and an average annual temperature of 39.3°F. The average date of the last killing frost in the spring is May 16 and of the first in the fall is September 30. The period from May 21 to October 14 is normally frost free at Whitefish Point on the Lake Superior shore.

Much of the precipitation in Chippewa County is returned directly to the atmosphere by evaporation. Evaporation is controlled by temperature, humidity, solar radiation, and wind velocity. The average evaporation recorded by the U. S. Weather Bureau at the Germfask Wildlife Refuge in Schoolcraft County during the period June through October is 21.63 inches. The numerous lakes and extensive wetland areas in the county (pl. 6) suggest that the total loss of water by evaporation is a significant percentage of the total precipitation.

# GEOLOGY

Chippewa County is underlain by several sedimentary rock units of Paleozoic age, which lie on Precambrian metamorphic and igneous rocks and are mantled by unconsolidated sediments of Pleistocene glacial and glacial-lake origin. The areal distribution of the formations of consolidated rock is shown in plate 2 and the surficial deposits are shown in plate 3. The lithology and hydrology of the various formations are outlined in table 1 and are described in the section on Ground Water.

## Summary of Geologic History

During the Paleozoic era the lowland area now called the Michigan basin was invaded by a succession of warm, shallow seas in which vast quantities of sediment were deposited. The sediments, which included clastic, organic, and chemical deposits, subsequently were lithified to form the limestones, dolomites, sandstones, shales, evaporites (salt deposits), and other consolidated rocks of the Michigan basin. The rocks deposited in Cambrian and Early Ordovician time are principally sandstones and shales, in contrast to the limestones, dolomites, shales, and evaporites deposited in Middle and Late Ordovician, Silurian, and Devonian time (see table 1). The wide variety of sediments deposited in the Michigan basin is evidence of fluctuating sea levels and oscillating shorelines during each of the periods of the Paleozoic era. The seas of Mississippian and Pennsylvanian time were smaller than the seas of the earlier periods and no evidence indicates that they extended into the Northern Peninsula of Michigan.

Deposition of marine sediments in the Michigan basin ended with the final withdrawal of the sea at the close of the Paleozoic era. A period of erosion followed and lasted throughout the Mesozoic era and during most of the Cenozoic era. During this long interval of geologic time, great quantities of sedimentary rocks of Paleozoic age were removed by erosion. Thus, the rocks of Paleozoic age now cover a smaller area than they did in early Mesozoic time. Rocks of Late Silurian and of Devonian age, which crop out on the St. Ignace Peninsula and on the islands in the Mackinac Straits area, at one time presumably covered a large part of Chippewa County.

Lithology was a major factor in the differential erosion of sedimentary rocks of Paleozoic age. The softer, less competent shales and sandstones and the soluble evaporites were most easily eroded, and buried and submerged valleys mark the traces of pre-Pleistocene exposures of these formations. Cuestas and bedrock-surface highs mark exposures of the more resistant limestones, dolomites, and sandstones. These features, subsequently modified by Pleistocene glaciation, include the Niagara escarpment and the great valleys which now form the basins of the Great Lakes and associated bodies of water. In Chippewa County, tributaries to these major valleys are now filled with glacial drift (pl. 4).

During the Pleistocene epoch, the Great Lakes area was covered by at least four successive continental glaciers. As these ice sheets moved southward from ice-accumulation centers in Canada, they scoured and abraded the land surface, rounding the hills and deepening the valleys. The advancing glaciers transported vast quantities of rock materials of all sorts gouged and torn from the surface over which the ice moved. Melting of the ice resulted in deposition of the transported material (drift) over the Michigan basin. The glacial deposits and features of Chippewa County are predominantly of the last of the four recognized glacial stages, the Wisconsin stage.

In late Wisconsin time, Lake Algonquin, an early stage in the succession of the Upper Great Lakes, covered nearly all of Chippewa County. Figure 2 shows the boundaries of glacial Lake Algonquin. Some of the sediments transported by the glaciers during Wisconsin time were deposited in the waters of this lake. Lake Nipissing (pl. 3) was an important warm water intermediate stage, and Lakes Superior, Huron, and Michigan are the modern stage of this succession. The glacial deposits of Chippewa County were altered by the erosive forces of, and the deposition in, this succession of lakes.

## Structure

The Precambrian surface upon which the sedimentary rocks of Chippewa County are deposited apparently is one of great relief. This is indicated by the log of well 47N 1W 23-1 located south of the city limits of Sault Ste. Marie. This well, drilled to a depth of 850 feet below sea level, did not reach Precambrian igneous and metamorphic rocks, although such rocks crop out at elevations of more than 600 feet above sea level a few miles north and east of Sault Ste. Marie, Ontario. The Precambrian surface presumably slopes southward toward the center of the Michigan basin. Precambrian rocks were not reached in a well drilled to a depth of more than 10,000 feet below sea level in the central part of the basin (Michigan Geological Society, 1954).

The sediments which form the consolidated rocks of the Michigan basin were deposited in nearly horizontal layers, but gradual subsidence and compaction of the beds, which was contemporaneous with deposition and was greatest in the center of the subsiding area, produced a bowl-shaped structure or basin (fig 4). The youngest beds are in the central part of this structure and older rocks crop out in roughly concentric bands. Chippewa County is on the northern edge of the basin, where the oldest sedimentary rocks are exposed (fig 5)'. The regional dip of these rocks in Chippewa County is about 40 feet to the mile southward toward the center of the basin. Most of the strata become thicker toward the center of the basin.

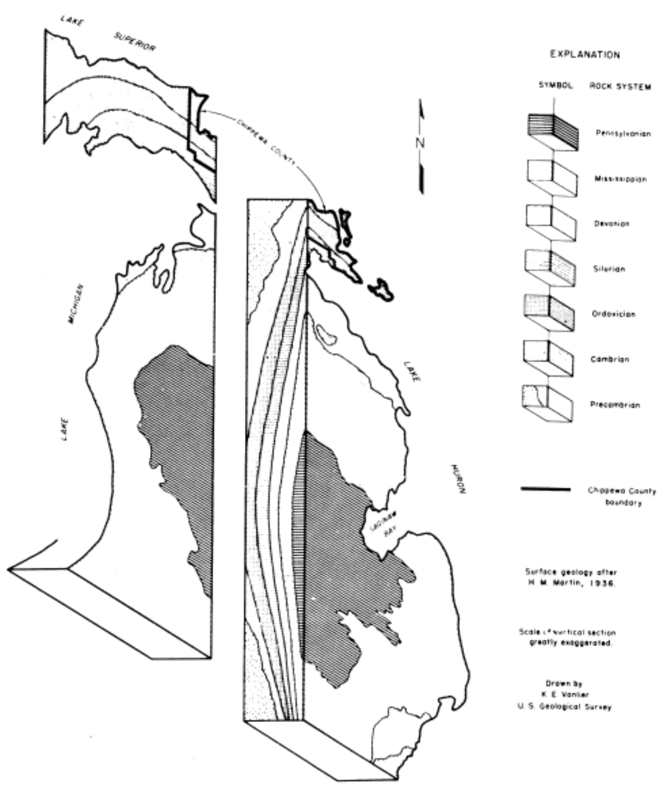


Figure 4. Block diagram showing schematic geologic cross-section through the Michigan basin.

# GROUND WATER

## Occurrence and Availability

A water-bearing formation that yields water in usable quantities is termed an aquifer. In areas where ground water is difficult to obtain, a formation yielding less than a gallon per minute to wells may be classed as a principal aquifer. In other areas where wells may yield several hundred gallons per minute, a rock from which wells obtain less than a few gallons per minute might not be classed as an aquifer.

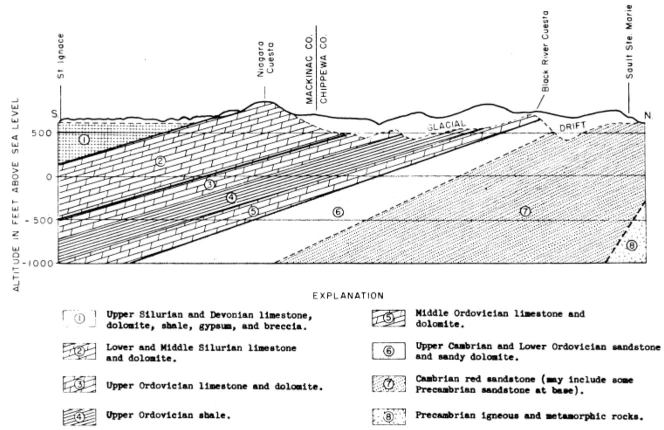


Figure 5. Generalized geologic section through the eastern end of the Northern Peninsula of Michigan.

The amount of water available to a well depends upon the regional and local lithologic and hydrologic characteristics of the aquifer, the climatic conditions in the area, and the hydraulic properties of the soils and subsurface units in the recharge areas.

On the basis of water occurrence, aquifers may be classified as water table or artesian. In a water-table aquifer, ground water is unconfined and the ground-water surface within the aquifer is termed the water table. In an artesian aquifer, ground water is confined under pressure between relatively impermeable strata (strata through which water does not move readily). Under natural conditions, the water in a well finished in an artesian aquifer and tightly cased through the overlying confining bed will rise above the bottom of the overlying confining bed. An artesian aquifer is full of water at all times, even while water is being removed from it. In time, however, enough water may be pumped to draw the water level below the bottom of the overlying confining bed, thus creating water-table conditions locally. The imaginary surface consisting of all points to which water would rise in wells that tap an artesian aquifer is called the piezometric surface. In topographically low areas, the piezometric surface may be higher than the land surface, and wells tapping artesian aquifers in these areas will flow. Such areas in Chippewa County are shown on plate 6.

The aquifers underlying Chippewa County consist of several types of consolidated and unconsolidated rocks. In general, the unconsolidated-rock aquifers (those in the glacial drift and glacial lake deposits) are the most accessible and dependable sources of ground water in the county and have the greatest potential for future development. In areas where the mantle of unconsolidated sediments is thin or lacks permeable zones, the consolidated rock aquifers may be the only source of ground water.

### *Ground Water in Consolidated Rocks*

Precambrian igneous and metamorphic rocks and consolidated sedimentary rocks of Paleozoic age underlie all of Chippewa County. These rocks crop out in many places throughout the Northern Peninsula and in Ontario. Descriptions and names of the formations, members, and other lithologic units in Chippewa County differ considerably among the various authors who have reported on the geology of the Northern Peninsula. Many of the units have been described only in specific localities and work done to date in correlating these units across the Northern Peninsula is incomplete. That facies changes are common is proved by the fact that descriptions of rock units in the out-crop areas differ somewhat from descriptions of the same units in records of deep borings.

The geologic age of most sedimentary rocks is determined from fossils. Intensive and detailed paleontological studies have not been made in Chippewa County, as fossils are scarce in the drill cuttings taken from deep borings. Thus, accurate delineations and regional correlations of the formations, members, and other units of the stratigraphic section in Chippewa County have not been attempted. In this report, therefore, the units used in describing these rocks represent rather broad and basic divisions of geologic time; no attempt is made to describe stratigraphic units smaller than the series, but rather to delineate major hydrologic units.

Several of the consolidated rock units are important aquifers. The sandstones are a source of ground water in Chippewa County and in many places throughout the eastern part of the Northern Peninsula. The limestones and dolomites are important aquifers throughout most of the area where, during preglacial time, permeable zones were developed in the exposed rocks by weathering and solution. Shale beds or units of shale interbedded with layers of limestone and dolomite are of low permeability and will yield little water to wells. They are significant in the hydrologic system, however, because most shales impede vertical movement of ground water and hence retard solution in underlying soluble rocks and act as confining beds in artesian systems,

<u>Precambrian rocks.</u> Precambrian quartzite and other metamorphic and igneous rocks are exposed a few miles northeast of Sault Ste. Marie, Ontario, but are not at or near the surface in Chippewa County. Neither the configuration of the Precambrian surface nor the depth to that surface, except at one point on Neebish Island, is definitely known. Well 45N 2E 34-1, drilled on Neebish Island in 1900, is reported to have entered Precambrian quartzite at a depth of 506 feet below the land surface. However, no other wells or test borings in the county are known to have thin or of low permeability. Where the sandstone and permeable drift are in contact, they constitute a single aquifer. The sandstone appears to be most permeable in the upper part where it is fractured and weathered. Thus, nearly all the wells tapping the sandstone produce water from the upper part of the unit. The low permeability of the sandstone at depth is shown by well 47N 1W 23-1, which was drilled more than 1,400 feet into the sandstone and produced only 8 gpm, and by well 47N 2W 4-5, which was drilled 325 feet into the sandstone and also yielded only a few gallons per minute. Well 47N 1W 11-1, which is the most productive well in the red sandstone known in the county, is 998 feet deep. This well is reported to produce 250 gpm. Most of the water, however, is reported to be produced from the 150- to 200-foot zone. Several wells in the Sault Ste. Marie area produce saline water from the red sandstone (table 7).

<u>Sandstone and sandy dolomite of Late Cambrian and Early Ordovician age.</u> Beds of white and gray fine- to coarse-grained sandstone, dolomitic sandstone, and sandy dolomite underlie all of Chippewa County except the area mapped as red sandstone of Cambrian age on plate 2. In Chippewa County these rocks crop out at Sault Point in sec. 30, T. 47 N., R. 4 W. (VerWiebe, 1928, p. 310) and at the lower falls of the Tahquamenon River (Rominger, 1873, p. 85; VerWiebe, 1928, p. 309). These rocks include the Munising formation of Late Cambrian age and the Hermansville limestone of Late Cambrian and Early Ordovician age (table 1). Their aggregate thickness is about 180 feet in well 45N 2E 34-1, on Neebish Island, and 300 feet in well 45N 1E 18-1, several miles west of Neebish Island. It is believed that these strata are thickest in the western part of the county.

The sandstone beds are permeable and constitute one of the principal aquifers of the Northern Peninsula. The dolomitic layers are less permeable and no wells in Chippewa County are known to have been completed in them. Most of the wells that produce water from the sandstones are in the northeastern part of the county, where the sandstones are mantled only by glacial drift. A few wells are completed in the sandstones where they are overlain by younger consolidated rocks. Assuming that depth and economic considerations make drilling feasible, properly constructed wells tapping these sandstones throughout most of Chippewa County may be expected to yield moderate to large amounts of fresh water; where topographic and geologic conditions are favorable, wells tapping these sandstones may flow. Several deep wells in the Pickford and Rudyard areas, which were drilled in search of oil, produced large flows of fresh water from these sandstones.

<u>Limestone and dolomite of Middle Ordovician age.</u> Rocks of Middle Ordovician age in the Northern Peninsula are represented by a series of limestone and dolomite layers which lie unconformably on the sandstone and sandy dolomite of Early Ordovician age. Thin beds of sandstone and shale are interbedded with the limestone and dolomite. The limestone and dolomite are mostly hard and resistant to erosion, and to drilling.

The Middle Ordovician rock sequence in Chippewa County includes the Trenton and Black River limestones, which are described in detail in the literature (Hussey, 1936; Cohee, 1945b).

In preglacial time, the limestones and dolomites were eroded to form a cuesta having a northward-facing escarpment and a gentle southward dip slope (fig 5). This Black River cuesta (Thwaites, p. 20) trends in a general east-west direction across the northern part of Chippewa County. Glacial deposits of Pleistocene age now mask the cuesta in all but a few places in the county. Rocks of the Trenton and Black River limestones are exposed along the crest of the structure at the rock cut at Neebish Island and along the bank of the Waiska River in sec, 29, T. 46 N., R. 2 W. (Rominger, 1873, p. 63-64; VerWiebe, 1928, p. 311; Hussey, 1952, p. 27, 46). The record of well 45N 1E 14-1 logs rocks of Middle Ordovician age in that vicinity at or near the land surface. At Dafter, these rocks were reported at a depth of 34 feet. The thickness of the Black River-Trenton rocks is reported to be about 210 feet in well 44N 2W 8-7.

Where limestone and dolomite of Middle Ordovician age were exposed in preglacial time (pl. 2) and are now mantled only by glacial drift, openings along fractures and bedding planes have been enlarged by solution. Wells that tap these openings will produce small to moderate supplies of water. As solution must have been greatest in the upper part of the exposed limestone and dolomite, permeability of the rocks probably decreases with depth. Drillers have reported that the solution openings locally have been filled with unconsolidated sediments. These sediments, if permeable, also will yield water to wells. Where overlain by shale of Late Ordovician age, movement of ground water through the limestone and dolomite is impeded, the solution process is retarded, and the rocks remain relatively impermeable. Two wells in the Rudyard area, however, were reported to have produced small flows of sulfurous water from the top of the limestone and dolomite of Middle Ordovician age where they are overlain by shale.

Sandstones and sandy layers associated with the limestones and dolomites in some areas yield small to moderate supplies of water. Well 44N 1E 14-1 produces a flow of water from 30 feet of sandstone inter-bedded with limestone and dolomite of Middle Ordovician age. This sandstone, which produced saline water, was not found in other deep borings in the county.

<u>Shale of Late Ordovician age.</u> Shale of Late Ordovician age is not exposed in Chippewa County, but is described in records of deep wells throughout the Northern Peninsula as a sequence of black bituminous and gray dolomitic shales. The shale is reported to be about 250 feet thick in the county. About 85 feet of shaly dolomite within this sequence was drilled in well 41N 7E 17-1 on Drummond Island. The shale and associated dolomite have very low permeabilities and do not yield water to wells in Chippewa County.

<u>Limestone and dolomite of Late Ordovician age.</u> Limestone and dolomite of Late Ordovician age totaling about 240 feet in thickness overlie the shale of Late Ordovician age. These rocks crop out in the northern part of Drummond Island where, according to VerWiebe (1928), they are dark-gray shaly limestone. According to the records of deep wells in and near Chippewa County, only a small part of the limestone and dolomite drilled contained appreciable quantities of shale. As overlying rocks of Early and Middle Silurian age are also limestone and dolomite, the contact between the rocks of Ordovician and Silurian age cannot be readily determined in deep borings where fossils are absent. Thin beds of red and green gypsiferous shale, which are nearly everywhere near the base of the Silurian system, indicate the proximity of limestone and dolomite of Ordovician age.

In some areas, the limestone and dolomite of Late Ordovician age are permeable and will yield small to moderate amounts of water. Most of these areas are where the rocks were exposed in preglacial time (pl. 2). In these areas, younger rocks of Paleozoic age have been removed by erosion before Pleistocene time and solution openings have developed along fractures and bedding planes in the exposed limestone and dolomite. The permeability of the limestone and dolomite of-Late Ordovician age is primarily the result of such solution. The record of well 44N 2W 8-7 shows that most of the 85 feet of Upper Ordovician dolomite is permeable. A number of flowing wells have been completed in these rocks in areas of low elevation. Well 44N 2W 18-1, near Rudyard, flows at a rate of about 20 gallons per minute.

Where the limestone and dolomite of Late Ordovician age are overlain by shale of Silurian age, the movement of water has been impeded and solution retarded. Upper Ordovician rocks in such areas are of low permeability and will yield little water to wells.

<u>Limestone and dolomite of Early and Middle Silurian age.</u> Rocks of Early and Middle Silurian age are the youngest of the consolidated rocks in Chippewa County. They have an aggregate thickness of more than 500 feet and are primarily hard, resistant limestone and dolomite, but they include some cherty beds and some gypsiferous, calcareous, and dolomitic shales at the base.

Rocks of Early Silurian age are not known to have been tapped for water by any wells in Chippewa County, and hence little is known of their water-bearing characteristics. Where present in the county, they are nearly everywhere overlain by limestones and dolomites of Middle Silurian age which are important sources of water, and most wells are completed before the Lower Silurian strata are reached. The only known exposure of rocks of Early Silurian age in Chippewa County is on the west side of Drummond Island (Cohee, 1948).

Rocks of Middle Silurian age form the Niagara cuesta, which trends in an east-west direction along the southern part of Chippewa County. Numerous exposures of the rock, and several quarries are located along the cuesta. Rocks forming the cuesta are the source of many springs which issue from the north-facing escarpment and also from the dip slope of the cuesta. The water feeding the springs moves in fractures and in crevices along bedding planes, which have been enlarged by solution. Such solution openings are the principal source of water in wells drilled into the limestone of Middle Silurian age in Chippewa County. The amount of solution apparently differs greatly from stratum to stratum, and great ranges in permeability within individual strata are probable. At certain horizons, especially where the rock is composed largely of relatively pure limestone, which dissolves more readily than dolomite, the rock may be very productive over a large area. Solution caves west of Trout Lake in the Fiborn area of Mackinac County have been formed in limestone of Middle Silurian age. In areas where the Middle Silurian limestone and dolomite are exposed at the surface, the strata are fractured and weathered and are very permeable. These areas provide an avenue for direct recharge of ground water.

### *Ground Water in Unconsolidated Deposits*

Most of the Unconsolidated rock in Chippewa County was deposited during the final or Wisconsin stage of the so-called Ice Age (Pleistocene epoch). These deposits, which consist of a heterogeneous mixture of rock debris known as glacial drift, are the most important aquifers in the county and offer the greatest possibility for future development. The general term "glacial drift" embraces all types of rock material deposited by or from glacial ice or its melt waters. Although some of this drift was carried great distances by the ice, much of the material was carried only a short distance. Flint (1947, p, 114) states that "the average distance traveled by a rock fragment from the time it is picked up by the glacier until it is deposited is only a few miles." Thus, the glacial drift may be closely related to the underlying bedrock, especially at the base, and in many wells the contact between the drift and the bedrock cannot be accurately determined.

The glacial deposits of the county consist predominantly of outwash deposited by melt-water streams; till deposited by ice in the waters of glacial Lake Algonquin; and lacustrine sand, silt, and clay deposited also in glacial Lake Algonquin. Minor amounts of windblown sand and till deposited on the land surface also are included within the drift deposits.

In many areas of Michigan, surficial deposits of outwash, till, and lacustrine sediments are readily differentiated by lithologic and topographic expression. Such is not the case in Chippewa County because in some areas both till and outwash deposits were derived from a common source of sandstone composed of well-sorted grains and are physically similar. In addition, the surface features have been greatly modified by the erosive forces of and deposition of sediments in glacial Lake Algonquin and Lake Nipissing. Hence, the map of the surface geology (pl. 3) should be used only as a general aid in locating ground-water supplies. Test drilling is essential to appraise adequately the ground-water resources of the drift aquifers.

The drift has a great range in thickness over the county. Where valleys or channels were cut into the underlying bedrock and subsequently filled with glacial sediments, the drift is as much as 400 feet thick. In areas adjacent to the Niagara escarpment and other bedrock highs, the drift is thin and discontinuous (pl. 5). Well records and seismic data indicate that at least three and possibly four major pre-Pleistocene valleys or channels were cut into bedrock in the eastern part of the county (pl. 4 and table 5).

The drift-filled buried preglacial valleys are some of the best sources of ground water; they coincide roughly with valleys of the present major drainage systems. One bedrock valley extends from Whitefish Bay at Brimley along the course of the Waiska and Pine Rivers to Rudyard and on to Lake Huron. Leverett (1929, p. 15) states that this bedrock channel was the preglacial connection between Lake Superior and Lake Huron. Another bedrock valley leading from Brimley to Neebish Island is in alignment with the present course of the Charlotte River. A third bedrock valley is along the course of the Munuscong River north of the Niagara escarpment. A study of the altitude and locations of the areas of pre-Pleistocene exposures of shale of Late Ordovician age indicates the existence of a fourth valley trending generally along the present course of the Little Munuscong River. However, proof of this valley and its position is lacking at present. In the eastern part of the county, the greatest drift thicknesses and the lowest bedrock elevations are reported in records of wells drilled close to the channels of present-day streams. In the western part of the county, insufficient bedrock data are available to map the trend and configuration of preglacial valleys. However, well records indicate that much of the drift in that area is quite thick,

<u>Moraines.</u> The moraines of Chippewa County (pl. 3) are ridges of glacial till deposited for the most part in the waters of glacial Lake Algonquin along the relatively static front of a glacier which was melting back at approximately the rate of forward movement of the ice sheet. Only a small part of one of the moraines in Chippewa County is known to have been deposited on land. This deposit was mapped by Leverett (1929, pl. 1) in parts of Twps 46 and 47 N., R. 5 W.

The glacial till of which the moraines are composed is a mixture of rock debris transported by ice and deposited by melting of the ice without subsequent transport by wind or water. Commonly the moraines include, and are associated with, deposits of stratified outwash. The nature of the till, however, varies with the sources from which it is derived. Most of the moraines of Chippewa County situated north of the buried Black River escarpment are composed of sandy and gravelly till derived primarily from the sandstone formations of Cambrian and Early Ordovician age described above and to a lesser extent from older igneous and metamorphic rocks of the Canadian Shield. Most of the moraines in Chippewa County composed of clayey till or boulder clay are south of the Black River Escarpment, where the till was derived from shale, limestone, and dolomite of Paleozoic age. Accurate delineation of the various types of till present in the county is beyond the scope of this reconnaissance report.

Much of the land-laid till is unsorted and unstratified, but most of the till in Chippewa County was deposited in glacial Lake Algonquin, and was therefore sorted and stratified to some degree by the lake waters. The degree of sorting of the till ranges greatly. In some areas the sorting is rudimentary. Elsewhere the till is difficult to distinguish from well-sorted outwash or dune deposits, inasmuch as the major source of such till was sandstone composed of well-sorted particles.

The permeability of the morainal deposits varies generally with the degree of sorting, the size of the till particles, and the amount of interbedded outwash material. Large supplies of water may be obtained from moraines which include significant deposits of permeable outwash. Moraines in the western half of the county and in the Kinross area, which are composed largely of sand and gravel, yield moderate supplies of water. In the eastern part of the county, much of the moraines are clayey till and are relatively poor sources of water supply.

<u>Till plains or ground moraines.</u> The till plains or ground moraine of Chippewa County (pl. 3) are plains of glacial till similar in physical character to the morainic deposits. Most of these deposits mantle parts of the Niagara escarpment in the southeastern part of the county, and Drummond Island. In these areas the deposits are thin, and in many places are above the zone of saturation, and hence are not important sources of ground water. Locally within those areas the till may yield small amounts of water.

Throughout much of the county, thin deposits of till which have been covered by wind and lake sediments may yield small quantities of water.

<u>Outwash plains.</u> Outwash plains are plains of stratified sand and gravel deposited by glacial melt-water streams. In Chippewa County, much of the outwash was deposited in the glacial lakes and is deltaic in character. The deposits are closely related to and in places are incorporated within the moraines. The outwash deposits are the most permeable sediments of the glacial drift and yield moderate to large supplies of ground water. The log of well 45N 1W 29-1 (table 4) shows permeable outwash deposits to a depth of 145 feet. Well 46N 4W 28-1 penetrated permeable outwash consisting almost entirely of very fine to coarse sand. Pumping at a rate of 115 gallons per minute in this well lowered the water level 27 feet after 8 hours of pumping. Several areas of outwash and areas where outwash deposits are not differentiated from morainal deposits are shown on plate 4. Subsurface outwash deposits in other areas can be located by test drilling or perhaps by geophysical methods.

<u>Lake plains.</u> Stratified layers of clay, silt, and fine sand deposited by the waters of glacial Lake Algonquin (fig 2) lie at the surface over much of Chippewa County. These sediments are reported to be more than 300 feet thick in some areas. A typical section of lake deposits consists of a thick layer of pebble-free red or gray varved clay underlain by layers of finely laminated silt and fine sand. The silt and fine sand deposits are called "quicksand" by most of the drillers in the area. A typical section is illustrated by the log of well 43N 1E 15-1 (table 4). Locally, beds of coarser sand or gravel outwash are interbedded within the lake-deposited sediments.

Most of the wells drilled in the areas underlain by lake deposits (pl. 3) produce water from outwash or till, which underlies the lake deposits, or from sand and gravel layers within the lake deposits. The Michigan State Highway Department bored test hole 44N 2W 24-1 (table 4) through 56 feet of soft lake clay before reaching water-bearing outwash deposits. The water in this aquifer was under sufficient artesian pressure to flow at the surface. Well 46N 1E 8-4 (table 2) is one of several large-diameter dug wells which produce water from the "quicksand" layers. However, few drilled wells are completed in the lake silt and fine sand, although small yields might be obtained from properly constructed drilled wells.

The lake-clay deposits are of low permeability and yield little water to wells. However, they do act as confining layers, in artesian systems. Most of the flowing artesian wells in the county are in topographically low areas (pl. 6) where the drift and shallow bedrock aquifers are confined by lake clays.

<u>Dunes and beaches.</u> Dunes and beach deposits associated with glacial Lake Algonquin and post-Algonquin lakes are found throughout the county. These sediments consist of permeable windblown (eolian) sand and beach sand and gravel. Most of the dune areas are associated with the beach deposits. Plate 3 shows one large dune area in T. 47 N., R. 3 W., at the northern edge of the county along Whitefish Bay. Other dune and beach areas have not been delineated on the map. Locally, the deposits may yield small to moderate supplies of water to shallow wells. The dune and beach deposits have high infiltration capacities and provide an important avenue of recharge to the underlying ground-water reservoirs.

## Ground-Water Phase of the Hydrologic Cycle

### *Source and Recharge Areas*

The initial source of all fresh ground water in the aquifers of Chippewa County is precipitation. The average annual precipitation over the county exceeds 30 inches. If all the moisture that fell upon the county entered into uniformly distributed permeable aquifers, a bountiful supply, which would more than satisfy any foreseeable needs, would be insured. However, most of this water does not enter the ground-water reservoirs, but is lost by evaporation, by transpiration, and by surface runoff to the Great Lakes drainage system.

The amount of precipitation that does enter the ground-water reservoirs is influenced by a number of factors including the duration, intensity, and type of precipitation, the density and types of vegetation, the topography, and the porosity and permeability of the soil, subsoil, and underlying rock formations. Porosity is the percentage of volume of open or pore space to the total volume of a rock and is indicative of the capacity of a rock or soil to store water. The capacity of a rock to transmit water is a function of its permeability. The coefficient of permeability is a measure of the rate at which a fluid of specified density and viscosity flows through a unit cross-sectional area under a unit hydraulic gradient. Ferris and others (1954) discussed in greater detail the hydrologic cycle as applied to drift and bedrock aquifers in Oakland County, Mich.

In the lake-plain and till-plain areas of Chippewa County the rather impermeable soils promote runoff and hinder recharge to underlying aquifers. Surface drainage courses have developed in these areas. The more permeable moraines of the uplands, the outwash-plain deposits, and the beach and dune sands, however, are able to transmit recharge to the aquifers more rapidly. In areas underlain by these deposits, surface drainage courses are poorly developed or nonexistent.

### *Movement*

The movement of water underground is similar to movement in surface streams, that is, the water moves by gravity from high levels to low levels. The movement of water underground is much slower than the movement of water at the surface, because of friction generated by water in percolating through crevices and interstices in the earth’s crust. Rates of ground-water movement range from a few feet per year to several feet per day. Water may travel great distances underground from regions where recharge is received at the surface to areas down-gradient, where it may once more reach the surface and join the flow of streams, appear as a seep or spring, enter a lake, or escape directly to the atmosphere by evaporation or transpiration.

The general direction of ground-water movement in Chippewa County can be determined from the water-level contours shown on plate 6 (see table 6). Movement of ground water is always in the direction of the hydraulic gradient at right angles to the contours. Unlike surface flow, the gradient may or may not conform to the topographic gradient in any particular area. Where it is undisturbed by man-made diversions the water level of an underground reservoir conforms approximately to the general configuration of the overlying land surface. Water levels in individual wells are given in table 6. It should be clearly understood that the contours shown on plate 6 are generalized and that the actual pattern of flow in any given aquifer is complex. In addition, the contours shown on plate 6, interpolated from all available hydrologic data, represent a combination of the configurations of the water tables and piezometric surfaces in many drift and bedrock aquifers. Where more than one aquifer underlies an area, water will percolate or "leak" from the aquifer having the higher head to the one having lower head. The map does not show the water tables and piezometric surfaces of all the aquifers in the county. The piezometric surfaces of the deeper consolidated rock aquifers may differ from the surface shown on plate 6.

### *Discharge*

Water is discharged from the ground-water reservoirs by evaporation and transpiration (evapotranspiration) and by wells, springs, and drains. The quantity of water lost by evapotranspiration in Chippewa County is not known, but the amount of evaporation from water and wetland surfaces probably is comparable to similar loss in Schoolcraft County (see section on Climate). The amount lost by transpiration on a countywide basis cannot be measured, but is presumed to represent a large percentage of the ground water discharged, inasmuch as most of the county has a shallow water table and is covered by dense forest.

A considerable amount of water is also discharged from the ground-water reservoir by springs. Most of the springs in the county are along the edge of the moraine and outwash highlands and along the Niagara escarpment. The streams issuing from some springs and seeps have eroded into the lake plains.

Pendills Creek, which is supplied from a number of springs in sees. 24, 25, 32, 33, and 34 of T. 47 N., R. 4 W., had a total discharge of about 17,000 gallons per minute on July 17, 1956. Big Spring in the southeast corner of sec. 22, T. 44 N., R. 4 W., flowed at a rate of about 1,600 gallons per minute on July 3, 1956.

The greatest amount of discharge by wells is from aquifers tapped by numerous flowing wells, and it is believed that the perennial flow from these wells greatly exceeds the discharge from pumped wells. The total amount of water discharged by all wells is undoubtedly small compared with the total natural ground-water discharge.

## Fluctuations of the Water Table

### *Seasonal Fluctuations*

Ground-water levels in the county fluctuate with seasonal changes in the rate of recharge to and discharge from the ground-water reservoirs. During the spring thaw, water levels in wells normally rise in response to the infiltration of rain and melting snow. Summer temperatures cause an increase in evapotranspiration, and a reduction in the opportunity for recharge resulting in declines of water levels. Thus, rainfall in the county during the growing season normally has little effect on the rate of decline, as vegetation utilizes most of the available moisture. In the fall, evapotranspiration losses are reduced and precipitation, after restoring depleted soil moisture, may cause rises in water levels. However, the decline in stage common during the summer may continue if precipitation is deficient or if an early general freeze impedes normal infiltration. Recharge to the ground-water reservoir In the winter is negligible because precipitation is predominantly in the form of snow.

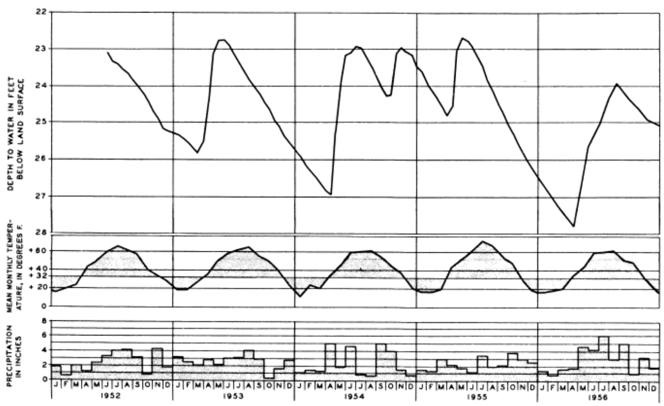

Figure 6. Hydrograph of well 46N 4W 24-1 near Raco compared with graphs of temperature and precipitation recorded at Sault Ste. Marie, 1952-56.

Well 46N 4W 24-1 is the only well in the county in which water-level measurements have been made periodically. This well is relatively shallow and is completed in a glacial-drift aquifer which is under water-table conditions. The hydrograph of this well (fig 6) illustrates the relationship of temperature and precipitation to the water level. Water levels rose during each of the spring seasons for the period of record and declined each summer, fall, and winter, with one exception. A sharp rise in water level during the fall of 1954 is shown on the hydrograph. The rise was caused by an above-average rainfall in September and October. Artesian pressures or water levels in the deeper aquifers may not respond as quickly or to the same extent as levels of the shallow aquifers, for accessibility to sources of recharge and avenues of discharge are not direct,

### *Fluctuations Due to Discharge from Wells*

Generally, ground water is a renewable natural resource because it is intermittently or continually being replaced directly or indirectly by precipitation. If an aquifer is to be developed by means of wells so that a long-term yield can be obtained without dewatering the aquifer, then equilibrium must exist between the rate of recharge to the aquifer and the rate of discharge from the aquifer (Theis, 1940). In any aquifer in its natural state (before it is tapped by wells) an approximate dynamic equilibrium exists between recharge and discharge. When water is withdrawn from an aquifer by a well, a change in the rate of total discharge from the aquifer results. The increase in discharge causes a depressed cone-shaped depression in the water table or piezometric surface around the discharging well. With continued discharge, the cone of depression expands until the resultant lowering of water levels causes a decrease in discharge from the aquifer or an increase in recharge to the aquifer, which restores the aquifer to a state of equilibrium.

Wells within the cone of depression may be affected by the lowering of water levels or artesian pressures. Thus, a well tapping an aquifer is affected by the discharge of other wells that tap the same aquifer. Where several or many wells discharge, a composite cone of depression is formed, which may extend over a large area. The lowering of water levels over a large area may cause a considerable increase in the rate of recharge to or a considerable decrease in the rate of natural discharge from an aquifer. A lowering of the water level, therefore, is necessary in the development of a ground-water reservoir or aquifer. Waste of water by unrestricted flow of wells or by underground leakage from poorly constructed wells or deteriorated well casings results in an unnecessary lowering of the piezometric surface, which may cause some wells to stop flowing, decrease yields, and increase the cost of producing water. The same effects result as the aquifer is further developed by installation of additional flowing wells. Many of the flowing wells in Chippewa County are reported to show the effects of decreased artesian pressure..

## Utilization of Ground Water

Much of Chippewa County is bounded by the waters of the Great Lakes, which provide a potentially unlimited source of fresh water for conveniently located users. Sault Ste. Marie, the largest municipality in the county, obtains its water supply from the St. Marys River. Other towns and villages and nearly all of the farm residences, resorts, motels, and other users tap ground-water sources for supplies.

Brimley is the only municipality that has a public ground-water supply; other villages and towns are supplied by privately owned wells. It is estimated that about 6,000 people residing in the county utilize the ground-water resources. The water is used almost entirely for domestic purposes or for watering stock. The amount used represents only a small fraction of the total resource available.

# QUALITY OF WATER

The chemical composition of the waters in Chippewa County are graphically presented in figure 7, which illustrates the great range in composition of ground and surface waters from several sources. Although a comprehensive program of chemical analysis and geochemical interpretation of the waters of the county was not carried out during this reconnaissance, sufficient data were gathered to reveal the chemical nature of some of the different waters (table 7).

## Fresh Ground Water

Much of the fresh water in the aquifers of Chippewa County is of the calcium magnesium bicarbonate type. Water from the drift or sandstone aquifers is relatively high in calcium bicarbonate compared to water from dolomite or dolomitic limestone or dolomitic sandstone aquifers which is relatively high in magnesium bicarbonate. Thus, a high magnesium-to-calcium ratio indicates that the source aquifer is dolomitic or that some of the water has migrated through dolomitic rocks.

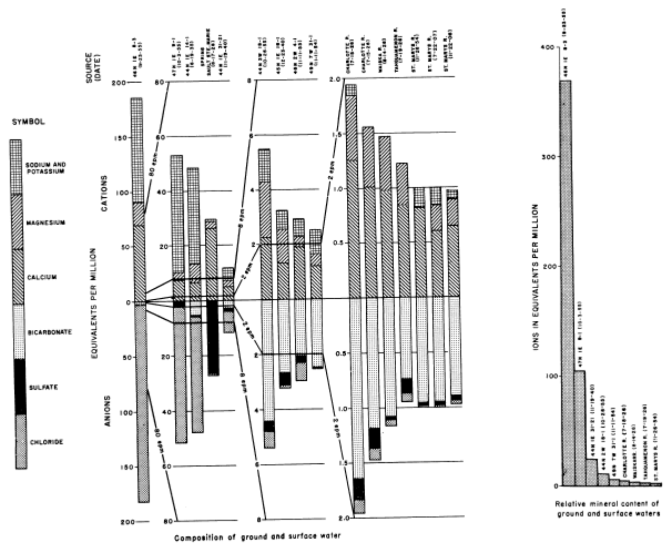

Figure 7. Chemical composition of water in Chippewa County.

The hardness of water samples taken from the glacial drift in the county ranged from 50 to 150 parts per million (ppm). This water is soft compared with water produced from drift aquifers in other areas of the State. The hardness of samples of fresh water from bedrock aquifers ranged from 170 to 365 ppm.

Wells tapping the glacial drift yield water low in chloride and sulfate content, although several drift wells were reported to have yielded "sulfur water" (probably water containing hydrogen sulfide). "Sulfur water" flowed from the limestone of Middle Ordovician age tapped by well 44N 2W 8-7. Oil shows are reported above and below the depth from which the "sulfur water" flowed. Well 44N 2W 7-3 drilled into the same stratigraphic unit also yielded water having an odor of hydrogen sulfide. A possible source of the sulfur in the water is the pyritiferous or other sulfide mineral zones in the limestone and dolomite of Middle Ordovician age.

The iron content of the water samples from the glacial drift ranged from near 0 to 12 ppm. Very high concentrations of iron, which greatly exceed the permissible maximum suggested for drinking water by the U. S. Public Health Service (Michigan Department of Health, 1948), were found in water samples from T. 45 N., Rs. 1 and 2E. (see table 7). A concentration of 16 ppm of iron in the water taken from well 45N 1E 18-1, which was finished in the red sandstone of Cambrian age, indicates that this rock may be the source of the iron in water found in the overlying glacial-drift aquifers.

## Highly Mineralized Ground Water

The aquifers of Chippewa County also yield mineralized water in places. As used herein, and as applied to Chippewa County, mineralized water is defined as water containing more than 1,000 ppm of dissolved minerals. Although the origin of the mineralized water is not definitely known, connate water entrapped at the time of deposition of sediments in the Michigan basin is the probable source. The large variation in mineral concentration in water from the various sources sampled (table 7) is the result of mixing of this connate water with fresh ground water. Wells 46N 1E 8-3, 47N 1E 9-1, 47N 1E 10-1 and 10-2, and 47N 1E 21-2 all produce water containing high concentrations of sodium, calcium, magnesium, and chloride. These wells are aligned along a general north-south-trending axis. The alignment is in conformity with the strike of some of the major faults of the Precambrian shield described by Wilson (1948) and with the faulting at the eastern end of the Lake Superior geosyncline as postulated by Thwaites (1935). A fault zone may provide an avenue of increased permeability along which connate waters within the Michigan basin can migrate. This does not necessarily mean that mineralized waters move only along faults, as wells 44N 1E 14-1, 44N 1E 31-21, and 45N 2E 3-1, which are not in alignment with the wells listed above, produce water of moderately high mineral content.

Extensive pumping from deep wells in the area might reveal the mineralized water in the deeper aquifers throughout the county, as water migrates toward heavily pumped areas within an aquifer. A similar condition could develop if excessive discharges from unrestricted flowing wells caused an extensive lowering of the piezometric surface. A deep uncased well or unplugged test hole may provide an avenue along which mineralized water may flow to the surface or into overlying freshwater aquifers.

An analysis of a sample of water taken from a spring near Sault Ste. Marie (fig 7) revealed unusually high concentrations of calcium and sulfate. At the present time, no other springs or wells in the county are known to yield water of similar chemical quality. The calcium and sulfate concentrations suggest percolation of this water through gypsum-bearing strata along the path of migration, but no such deposits are known in the vicinity of Sault Ste. Marie, although gypsiferous strata are known to be in the southern part of Chippewa County.

## Surface Water

Analyses of surface waters in and bounding Chippewa County and of one spring at Sault Ste. Marie are listed in table 7. Although several of the analyses are somewhat in error, as indicated by the differences in cation-anion totals shown on figure 7, they reveal the mineral constituents and the magnitude of mineralization. Most of the surface waters are of the calcium magnesium bicarbonate type. The analyses show that the mineral content of water in glacial drift is approximately three times greater than the content of the surface-water samples analyzed. The effect of effluent discharge of ground water to the Charlotte, Waiska, and Tahquamenon Rivers is illustrated by the greater mineral content of these waters compared with the mineral content of the St. Marys River, which is the outlet for Lake Superior.

## SUMMARY AND CONCLUSIONS

Small to moderate supplies of ground water suitable for most uses are obtained from wells throughout most of Chippewa County. Locally, properly constructed wells may yield as much as several hundred gallons of water per minute each. In extensive areas of the county, the water in many of the aquifers is under sufficient artesian pressure to cause wells to flow.

The glacial-drift aquifers, which are the most accessible source of ground water and which are tapped by most of the wells in the county, are believed to have the greatest potential for future development. Where drift aquifers are not present or will not yield sufficient water, various bedrock aquifers will yield adequate supplies. However, locally within the Sault Ste, Marie - Sugar Island area, obtaining a potable ground-water supply has been difficult. In other areas in the county where wells have yielded highly mineralized water, it is believed that properly constructed shallow wells will produce potable water.

Ground water sufficient for present needs and for considerable additional development is insured by the humid climate and by the extensive areas favorable for recharge. In some localities, waste of water from unrestricted flowing wells is causing declines in artesian pressure.

Most of the wells in the county are drilled to depths-of less than 200 feet. Some wells were drilled several hundred feet before an adequate supply was obtained. However, application of modern well-construction and development techniques probably would increase the percentage of relatively shallow wells that could produce adequate supplies of water.

The chemical quality of ground water from the several major aquifers in Chippewa County differs considerably, and differences in quality exist also within a single aquifer. Locally, fresh water is hard and contains excessive concentrations of iron. Mineralized water unsuitable for most uses is produced from a few wells, and further data concerning the origin, source, and distribution of the mineral water in the aquifers of the county are needed. However, most of the water, which is of the calcium magnesium bicarbonate type, is of good quality and may be used for many purposes without treatment.

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