STATE OF MICHIGAN
DEPARTMENT OF CONSERVATION
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PROGRESS REPORT NUMBER NINETEEN RECONNAISSANCE OF THE GROUND-WATER RESOURCES OF MACKINAC COUNTY, MICHIGAN

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

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ABSTRACT

The principal aquifers of Mackinac County, Mich., are limestone and dolomite strata of the Niagara series of Silurian age. Other important aquifers include sandstone units of Cambrian age; limestone, dolomite, and breccia of Late Silurian and Middle Devonian age; and sand and gravel deposits of Pleistocene age.

The water-bearing Munising sandstone of Cambrian age is tapped at depths of about 1,000 feet by two wells in the northwestern part of the county, where, locally, water of good quality has not been obtained from shallower aquifers. Many wells tap the Burnt Bluff, Manistique, and Engadine formations of the Niagara series. These rocks form the bedrock surface over most of the county and are sources of relatively large quantities of fresh water. Wells in these rocks obtain water from solution openings along joints and bedding planes.

On the St. Ignace Peninsula, the Salina formation and the Mackinac breccia are important sources of ground water, although the rocks are of low permeability and yields are commonly small. Locally, these formations will not yield water in sufficient quantity even for domestic use. The Mackinac breccia and the St. Ignace and Bois Blanc formations are believed to be potential sources of water to wells on the islands in the Straits of Mackinac.

The glacial drift which mantles the bedrock formations is another important source or potential source of ground water over much of the county. In composition and thickness the drift mantle varies widely, however; in many areas it is thin, impermeable, or situated above the regional water table, and in such areas, of course, it is not a source of water.

Conditions are favorable for ground-water recharge in large areas of the county where the surface is directly underlain by sand and gravel or permeable consolidated rocks.

Ground water in Mackinac County is used mainly for domestic supply. The total amount used is only a small fraction of the total available.

The quality of the ground water varies with the lithology and depth of the aquifers. Limestone and dolomite strata and the glacial drift deposits generally yield water of the calcium magnesium bicarbonate type. Water of the calcium sulfate type is present in the formations underlying the St. Ignace Peninsula, which contain appreciable quantities of gypsum or are connected hydraulically to gypsum-bearing strata. Some of the sulfate waters are too highly mineralized for most uses. The deeply buried Cambrian sandstones produce fresh water which have higher concentrations of sodium and chloride than water from shallow fresh-water aquifers. Highly mineralized water of the sodium chloride type has been produced from the Trenton and Black River limestones of Ordovician age.

INTRODUCTION

Purpose and Scope of Study

A ground-water reconnaissance survey of the Northern Peninsula on a county-unit basis was begun in 1955 as part of the continuing cooperative investigation by the Michigan Department of Conservation and the U. S. Geological Survey. The objective of the reconnaissance is to gather sufficient information from an inventory of wells, water-sampling program, geologic field check, and study of the literature, and from review of existing hydrologic, topographic, and geophysical data, to determine the source, occurrence, availability, and geochemistry of ground water in the Peninsula. To make the results available to the public with the least possible delay, progress reports are to be released upon completion of the reconnaissance of an appropriate areal unit. This is the second county report of this series and it summarizes ground-water resources data obtained in a brief survey of Mackinac County made during the 1956 field season. Because of the limitation of time, the reconnaissance was not extended to the major islands of the county. The first county report of the present series covered the field reconnaissance of Chippewa County made in 1955 (Vanlier and Deutsch, 1958).

The mode of presenting the data obtained is designed primarily as a general aid to well drillers, contractors, industrialists, farmers, and the public at large in evaluating the ground-water resources of any area of Mackinac County. A summary description of the major lithologic units is presented, since this type of information 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, and W. L. Daoust, State Geologist, Michigan Department of Conservation, and are under the direct supervision of Morris Deutsch, district geologist of the U. S. Geological Survey at Lansing.

Previous Investigations

Various phases of the geology and hydrology of Mackinac County are described in numerous reports which relate the results of detailed and reconnaissance investigations made in the Northern Peninsula of Michigan since 1821. An investigation of flowing-well districts in the eastern part of the Northern Peninsula was made by Frank Leverett (1906). During the period 1934 to 1936 the Michigan Department of Conservation, in cooperation with the Civilian Conservation Corps, delineated areas of shallow ground-water supplies that might be tapped by future fire-control wells. Some of the unpublished data gathered during the course of that project have been included herein. In 1943, an investigation of the geology of the Mackinac Straits region was made by K. K. Landes, G. M. Ehlers, and G. M. Stanley (1945). Many of the geologic concepts and much of the geology of the Mackinac Straits area expressed herein are based on the report of that investigation. In 1949, a reconnaissance of the water resources in the eastern part 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 for the Corps of Engineers. Many of the basic data used in this report were collected during that survey. Pertinent data contained in a number of the reports listed in the bibliography (p. 60) were used freely as source material for this project; where appropriate, references to specific reports are made in the text.

Acknowledgments

Special thanks are given to the many well drillers and residents of Mackinac County and to personnel of various Federal, State, county, and municipal agencies whose wholehearted cooperation made this report possible. Appreciation is extended 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 both the section and the well within the section, its serial number being assigned arbitrarily. Thus, well 44N 12W 7-1 is the first well listed in section 7, Township 44 North, Range 12 West. Numbers formerly assigned to some of the wells and test borings included in this report are listed in table 2.

GEOGRAPHY

Location and Extent of Area

Mackinac County is at the eastern end of the Northern Peninsula of Michigan along the northern shores of Lake Michigan, the Straits of Mackinac, and Lake Huron (fig. 1). The land area of the county, including Bois Blanc and Mackinac Islands as well as other smaller islands, is 1,014 square miles. The irregularly shaped county spans an east-west distance of about 85 miles and a north-south distance of about 23 miles (pl. 1). The County is bounded on the west by Schoolcraft County and on the north and east by Luce and Chippewa Counties. It has a total shoreline length of about 225 miles, of which about 150 miles is along the mainland. St. Ignace, the largest city in the county and the county seat, is at the southern tip of the St. Ignace Peninsula. The city is the northern terminus of the Mackinac Bridge.

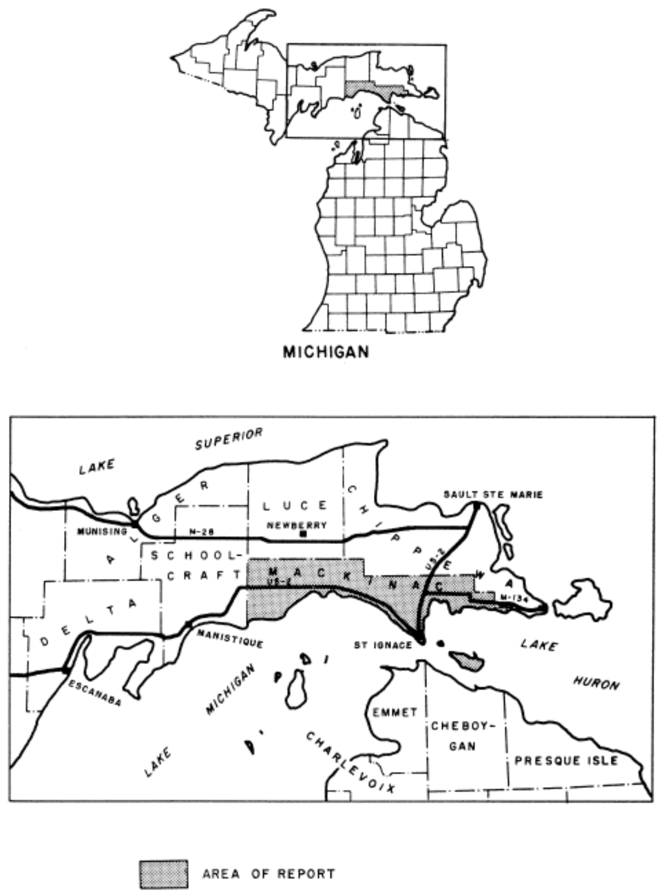

Figure 1. Index map showing location of Mackinac County, Mich.

Population and Economic Development

The population of the county was 8,750 in 1953, 9,287 in 1950, and 9,438 in 1940, as reported by the Bureau of the Census. The population of the City of St. Ignace for the same years was reported as 2,860, 2,960, and 2,669.

The economy of Mackinac County is closely related to its natural resources. Industries include commercial fishing, production of timber and timber products and of sand and gravel, and quarrying of limestone. The wildlife, the natural scenic beauty, the many inland lakes, and the extensive beach frontage on Lakes Michigan and Huron provide for a thriving tourist industry. Less than 10 percent of the county is farmed. About 22 percent of the area of the county is included in the Marquette National Forest and 32 percent is State owned.

U. S. Highway 2, which is connected to highways of the Southern Peninsula by the Mackinac Straits Bridge, and several major State highways serve the area. The county is served also by the Duluth, South Shore and Atlantic Railroad and the Minneapolis, St. Paul and Sault Ste, Marie (M., St. P., and S. Ste. M.) Railroad. Rail connection between the two peninsulas is provided by a ferry between St, Ignace and Mackinac City. Several interstate and international shipping companies operating on the Great Lakes provide passenger and freight service in and to the Straits of Mackinac area.

Physiography

Mackinac County is in the area that was glaciated during the Pleistocene epoch. Much of the county was covered by the waters of glacial Lake Algonquin and other extinct glacial lakes (fig. 2).

The main physiographic feature in the northern part of the county is a north-facing cuesta formed by rocks of the Niagara series. This cuesta, which is known widely as the "Niagaran escarpment", trends in a broad arc from eastern Wisconsin across the Northern Peninsula and southeastern Ontario to New York State. It is formed by strata of hard, resistant limestone and dolomite. In Mackinac County these rocks dip gently southward and are truncated to form a steeper north-facing escarpment. The relief of the cuesta has been subdued by Pleistocene glaciation. The cuesta is breached at the Pine River near U. S. Highway 2 in T. 43 N., Rs. 2 and 3 W.

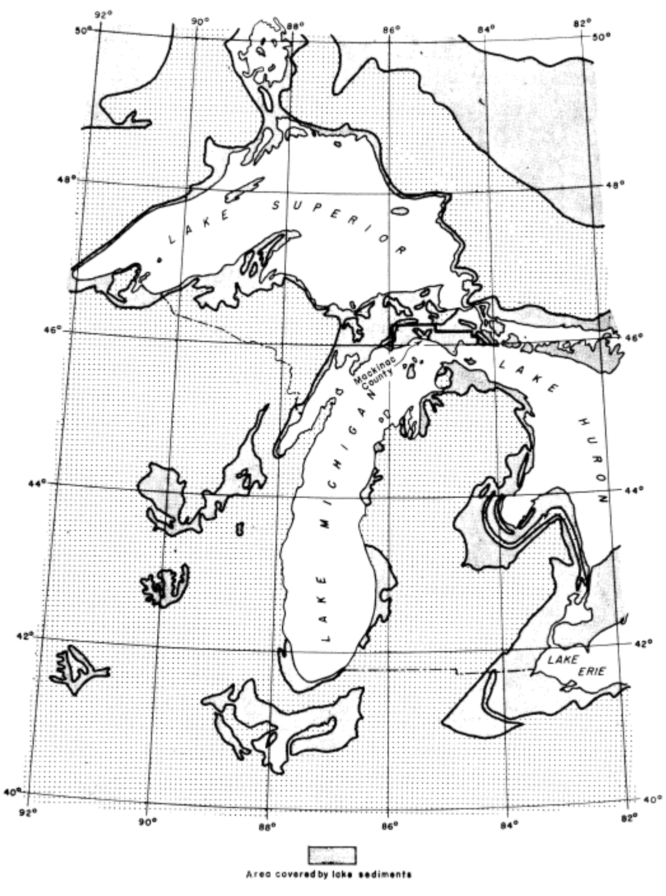

Figure 2. Map of the Upper Great Lakes region showing areas of sediment deposition in glacial Lake Algonquin and other extinct glacial lakes. (After Geol. Soc. America, 1949.)

The highland formed by the Niagara cuesta is mantled in many places by morainal and related glacial deposits which form extensive and rather flat highlands. Most of the lowland areas of the county have been mantled by sand and smaller amounts of silt and clay deposited in the glacial lakes which at various times extended over most of the county. Many of these lake-plain areas are poorly drained and contain extensive swamps and wetlands. Throughout the county, bars, beaches, dunes, and wave-cut benches mark the many shorelines of the extinct glacial lakes.

The soft shales, dolomites, limestones, and evaporites of the Salina formation are less resistant than the underlying Niagara rocks, and valleys generally mark the areas where the Salina forms the bedrock surface. These valleys are a part of the basins of Lakes Michigan and Huron in the Mackinac Straits region. The Salina rocks in this region, however, were not everywhere deeply eroded, as is evidenced by the presence above the modern lake level of the St. Ignace Peninsula, most of which is underlain by the Salina formation. Where the Peninsula is underlain by the soft shales, limestones, and dolomites of the Salina formation, topographic relief-is low. In the southern part of the St. Ignace Peninsula remnants of the more indurated and resistant Mackinac breccia-form small highlands. Mackinac-Island also is a remnant of resistant breccia. Round Island and Bois Blanc Island are formed from hard, resistant limestones and dolomites of the St. Ignace and Bois Blanc formations.

A group of elongate hills (drumlins) which are composed of glacial till deposited beneath moving ice sheets, are present along the shore near Hessel and Cedarville at the eastern end of the county. The Les Cheneaux Islands are part of the same group of drumlins, which are partially submerged in Lake Huron (Russell, 1905, p. 69-71).

Relief

The highest areas within Mackinac County are along the rim of the glaciated Niagara cuesta. In the central part of the county this highland locally reaches altitudes greater than 950 feet. In the western part of the county the highland is generally above 800 feet. The lowest areas in the county are along the shorelines of Lakes Michigan and Huron at an altitude of about 580 feet.

Drainage

Mackinac County is drained by a number of streams which flow into the Great Lakes (fig. 3). Most of the streams flow directly into Lakes Huron and Michigan; however, part of the county lies in the Tahquamenon drainage basin, which drains into Lake Superior, and part lies in the Munuscong drainage basin, which empties into Munuscong Bay. Most of the streams flow southward, down the dip slope of the Niagara cuesta. Tributaries of the Munuscong, Tahquamenon, Manistique, and Pine Rivers, however, flow down the escarpment of the cuesta. Parts of the valleys of the Carp, Pine, and Munuscong Rivers have developed parallel to the strike of the Paleozoic rocks. These strike valleys and the Pine River where it crosses the Niagara cuesta traverse drift-filled valleys in the bedrock surface. Hence, these bedrock valleys are reflected in the present drainage system.

Climate

Owing to the effect of the Great Lakes, the annual temperature range in Mackinac County is moderate in comparison to that of other interior continental areas at the same latitude. At Rexton the average annual precipitation is 29.7 inches and average annual temperature is 40.1° F. The estimated average date of the last killing frost in the spring is May 28, and of the first killing frost in the fall, September 23.

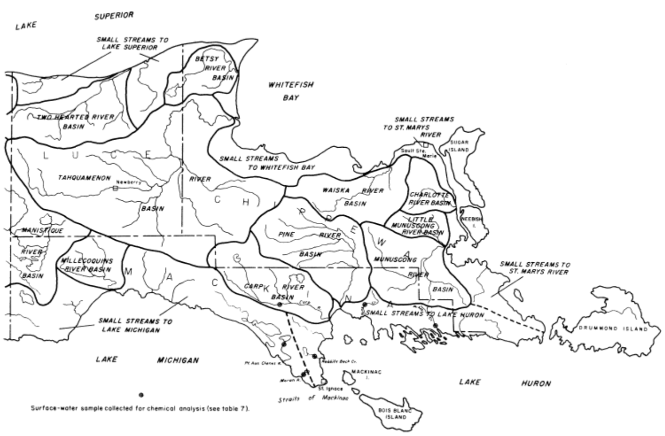

Figure 3. Map of Luce, Chippewa, and Mackinac Counties showing major surface drainage basins and drainage acres tributary to the Great Lakes.

GEOLOGY

Mackinac County is underlain by sedimentary rocks of Paleozoic age which are mantled discontinuously by glacial deposits of Pleistocene age. The areal distribution of the Paleozoic rocks is shown in plate 2 and of the surficial deposits, in plate 5. The lithology and hydrology of the various rock units underlying the county are outlined in table 1 and are described in the section on "Ground Water." Data concerning the depth, surface configuration, and nature of the Precambrian igneous and metamorphic rocks underlying Mackinac County are not available.

Summary of Geologic History

The Paleozoic rocks that underlie Mackinac County consist of limestone, dolomite, shale, sandstone, breccia, and evaporites. These rocks were deposited in the shallow seas which covered the Michigan basin during most of the Paleozoic era. The wide diversity of the sediments deposited is evidence of fluctuating sea levels and oscillating shorelines during that era.

A significant geologic event of the Paleozoic era with respect to the Mackinac Straits region was the leaching and removal by percolating ground water of large volumes of salt from the Salina formation of Late Silurian age. The interval of intense leaching is believed to have been limited to Middle Devonian time (Landes, Ehlers, and Stanley, 1945), but it is possible that the leaching process began as early as Late Silurian time. The removal of the salt resulted in the aggregation of a unique formation, the Mackinac breccia. The character of that formation and the effect on the structure of the Salina and superjacent formations deposited during and prior to the removal of the salt are outlined below in the sections on "Structural Geology" and "Ground Water in Consolidated Rocks."

During the Mesozoic and most of the Cenozoic eras, the Paleozoic sedimentary rocks were being subjected to erosion, which resulted in the creation of some of the major physiographic features of Michigan. These features, later modified by Pleistocene glaciation, include the Niagara escarpment and the major valleys which are now part of the basins of the Great Lakes.

A period of glaciation (the Pleistocene epoch) followed the long interval of erosion. During this epoch, ice migrated southward from accumulation centers in Canada during at least four major glacial stages. The glaciers scoured and abraded the surface and transported vast amounts of material torn from it. With melting of the ice sheets, this material was deposited over the eroded Paleozoic rocks.

At the close of the Pleistocene epoch glacial Lake Algonquin (fig. 2) covered nearly all of Mackinac County. Post-glacial uplift of the land mass which had been depressed by the ice changed drainage patterns, lake elevations, and shoreline positions (Leverett and Taylor, 1915, chaps. 21-25). The result of these changes was a succession of postglacial Upper Great Lakes. Lakes Superior, Huron, and Michigan represent the modern stage of this succession. Bars, beaches, wave-cut terraces, and dunes, which are present throughout the county, mark the shorelines of this succession of lakes.

Structure

The Precambrian surface upon which the sedimentary rocks of Mackinac County were deposited slopes generally southward toward the center of the Michigan basin. The Paleozoic 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 basin, produced a bowl-shaped structure (fig. 4). The youngest beds are exposed at the surface in the central part of this structure and the formations crop out in roughly concentric bands, Mackinac County is near the northern edge of the basin, where older sedimentary rocks are exposed. The regional dip of these formations in Mackinac County is to the south at about 45 feet per mile. The formations tend to become thicker toward the center of the basin.

Major alteration of the structure of Upper Silurian and Middle Devonian strata of the Michigan basin has occurred in the so-called collapse area in the Straits of Mackinac region (Landes, Ehlers, and Stanley, 1945). In this area (fig. 5) the dissolution of thick salt beds of the Salina formation created large caverns. Strata of the Salina, St, Ignace, and Bois Blanc formations collapsed into the voids, producing a zone of faulted and brecciated rock. Near St. Ignace and on Mackinac Island these formations are so extensively faulted and brecciated, and fragments of all are so completely intermixed, that boundaries of the individual formations cannot be delineated. On Bois Blanc Island and in that part of the Southern Peninsula within the collapse area, however, the formations maintain some stratigraphic continuity and can be identified, despite the faulting and brecciation.

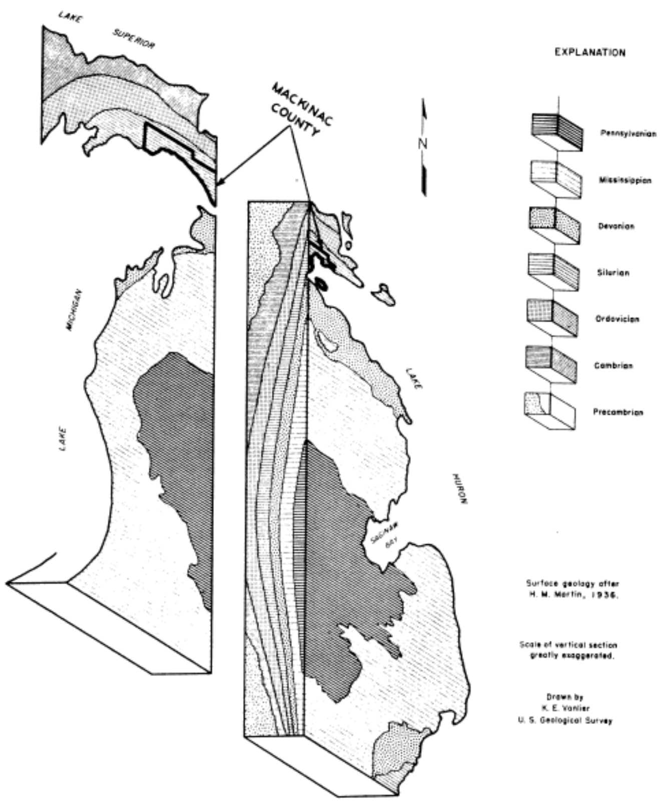

Figure 4. Block diagram showing schematic geologic cross section through the Michigan basin.

GROUND WATER

Occurrence and Availability

A rock formation, part of a formation, or group of formations 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 a well may be classed as a principal aquifer. In other areas where wells may yield several hundred gallons per minute, a formation from which wells obtain less than a few gallons per minute may be classed as nonproductive.

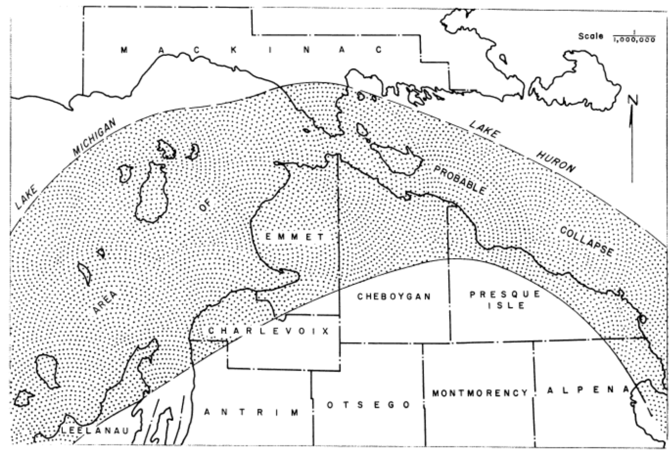

Figure 5. Map of the Straits of Mackinac region showing areas of probable collapse of Upper Silurian and Middle Devonian strata into voids created by leaching of salt from the Salina formation (after Landes, Ehlers, and Stanley, 1945).

The amount of water available to a well depends upon the regional and local geologic 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.

The imaginary surface consisting of all points to which water would rise in wells tapping an aquifer is called piezometric surface. 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 water table may be considered the piezometric surface of that aquifer. In an artesian aquifer, ground water is confined under pressure between relatively impermeable strata (strata through which water does not readily move). Under natural conditions, the water in a well that is finished in an artesian aquifer and that is tightly cased through the overlying confining bed will rise above the bottom of that bed, and therefore, the piezometric surface is above the top of the aquifer. An artesian aquifer is full of water at all times even when water is being removed from it. Eventually, however, enough water may be pumped to draw the water level below the bottom of the overlying confining bed, thus locally creating water-table conditions.

In topographically low areas, the piezometric surface of an artesian aquifer may be higher than the land surface. Wells tapping artesian aquifers in such areas will flow at or above the land surface.

Ground water in Mackinac County is contained in consolidated-rock aquifers ranging in age from Cambrian to Silurian, in brecciated-rock aquifers of Silurian and Devonian age, and in unconsolidated glacial drift and associated sediments of Pleistocene age. The most important and widespread aquifers of the county are the limestones and dolomites of Middle Silurian age. In scattered areas throughout the county shallow glacial deposits will yield adequate supplies of water. Brecciated-rock aquifers are tapped for water in the St. Ignace Peninsula. In one area in the northwestern part of the county very deep drilling to Cambrian sandstone may be necessary to develop a ground-water supply.

Most areas in Mackinac County are underlain by two or more aquifers. Many of the geologic units described in the following pages may constitute important sources of ground-water supplies in one or more of the areas described in the section of this report entitled "Occurrence of Ground Water by Areas."

Ground Water in Consolidated Rocks

Sedimentary rocks of Paleozoic age which include a number of important aquifers underlie all of Mackinac County. The depth to the surface of the Precambrian rocks underlying the Paleozoic rocks has not been determined at any location in the county. Future development of Precambrian rocks as a source of water supply is unlikely because of their great depth and probably low permeability, and because of the poor quality of water they might contain.

Munising Sandstone of Late Cambrian Age

The Munising sandstone as used herein may include strata of the Hermansville limestone of Cambrian and Ordovician age, which locally is very similar in lithology to the Munising and difficult to distinguish solely on the basis of deep-well logs. Because of the lack of distinguishing characteristics between the formations, delineation of the Munising and Hermansville formations has not been attempted in this report. The Munising is a white to gray locally dolomitic fine- to medium-grained sandstone. The sand grains generally are rounded and frosted. The Hermansville, which is similar lithologically to parts of the Munising, contains greater quantities of dolomite. In some areas it is described as sandy dolomite (Bergquist, 1936a). The thickness of the Munising sandstone in Mackinac County has not been determined, although more than 200 feet of the formation has been penetrated by deep wells.

The Munising, which is often called the "St. Peter sandstone" by drillers, is tapped by two wells (44N 12W 10-1 and 26-1) in the northwestern part of the county, where water of good quality is not present in overlying formations. In this area and along the northern boundary of the county, the Munising sandstone is reached at depths of about 1,000 feet; in the southern part of the county, it is at greater depth (pl. 3).

It is believed that the sandstone is permeable throughout the eastern part of the Northern Peninsula, and may prove to be a useful source of ground water if drilling is economically feasible. In the northwestern part of the county, water from the Munising sandstone is potable and generally of good quality (table 7), but its quality elsewhere in the county is not known.

Black River and Trenton Limestones of Middle Ordovician Age

The Black River and Trenton limestones consist of a thick sequence of gray, buff, and brown limestone and dolomite which overlies the Munising sandstone as defined in the preceding section. The Black River and Trenton are treated as a unit because of the difficulty in distinguishing between them on the basis of drilling records. The limestone and dolomite are generally hard and resistant, but they include some beds of shale and shaly limestone or dolomite. Logs of wells 44N 12W 26-1 and 44N 12W 17-2 indicate that the unit is about 250 feet thick in the northwestern part of the county.

The Black River and Trenton limestones are not a source of fresh ground water in Mackinac County. They did, however, yield mineral water from well 44N 9W 17-2. Mineral water zones within these rocks should be sealed off in wells drilled through them to avoid contamination of fresh water both in the underlying sandstones and in the overlying rocks.

Collingwood Formation and Richmond Group of Late Ordovician Age

<u>Shale unit</u>. The Black River and Trenton limestones are overlain by a thick sequence of Upper Ordovician shale, limestone, and dolomite strata. The lower part of this sequence includes gray and black dolomitic and bituminous shales of the Collingwood formation, overlain by the basal shale beds of the Richmond group. The total thickness of this shale sequence in Mackinac County is about 240 feet. Because of the similarity of hydrologic and lithologic characteristics the total shale sequence is treated herein as a single unit. This shale unit is of low permeability and is not a source of ground water in the county.

<u>Limestone and dolomite of the Richmond group</u>. The upper part of the Richmond group consists of about 160 feet of gray limestone and dolomite. These rocks have not been tapped for water in Mackinac County, as they are nearly everywhere overlain by the limestone and dolomite of the Niagara series, which are excellent sources of ground water. In the northeastern part of the county where the limestone and dolomite of the Richmond group form the bedrock surface (pl. 2), wells have been completed in overlying permeable glacial drift. Well 43N 9W 11-2 at Gilchrist, which was drilled to a depth of 1,111 feet, is believed to have produced water from limestone and dolomite of the Richmond. However, water was encountered also in the overlying Niagara rocks. Water in the Richmond probably occurs in fractures and openings along bedding planes, which generally have been enlarged by solutional activity of ground water.

The limestone and dolomite of the Richmond group are sources of water to many wells in the Rudyard-Pickford area of Chippewa County (Vanlier and Deutsch, 1958). These rocks may be productive also in the adjacent areas of Mackinac County.

Cataract Formation of Early Silurian Age

The Cataract formation is composed predominantly of alternate beds of limestone, dolomite, and shale. The shale is characteristically gypsiferous, calcareous, or dolomitic. The formation is about 210 feet thick in Mackinac County. In the northwestern corner of the county and near the Pine River and at Pickford in the northeastern part of the county, it is mantled by glacial drift. In these areas, the Cataract formation was exposed at the surface in preglacial times, and locally shale beds have been weathered or removed by erosion, allowing increased circulation of ground water. The limestone and dolomite beds may have greater permeability as a result of the development of solution openings along joints and bedding planes. Well 43N 1W 13-2 near Pickford produced a flow of water from dolomite and limestone strata 185 to 200 feet deep. Throughout most of the county, the Niagara rocks overlie the Cataract formation, and limestone and dolomite strata within the Cataract probably are of low permeability because movement of ground water, which normally results in solutional activity, is impeded by shale near the top of the formation. Because adequate water supplies are obtained by most wells drilled into the limestone and dolomite of the Niagara series, the Cataract formation generally has been penetrated only by oil-test wells and is not an important aquifer in Mackinac County.

Niagara Series of Middle Silurian Age

Limestone and dolomite rock strata of the Niagara series, which form the bedrock surface in about 75 percent of Mackinac County, are the most important source of fresh ground water within the county. Each of the formations (Burnt Bluff, Manistique, and Engadine) of the Niagara series is important as an aquifer in large areas of the county. Many wells drilled into carbonate rocks of the Niagara obtain water from openings formed largely by solution and weathering when the rocks were at the surface. Permeable zones have developed also at depth through the solutional activity of percolating ground water moving through joints and minute openings along bedding planes. Solution of the carbonate rock adjacent to these openings permitted an increase in the volume moving through them, consequently increasing the rate of solution. Solution was probably greatest along beds of high-calcium limestone, which is more soluble than high-magnesium dolomite. Many wells in the county tap such deep permeable zones. Not all beds of high-calcium limestone have been made permeable by solutional activity, however. Development of solution openings in some strata probably was blocked by the initial impermeability of the bed or by restriction of ground-water flow in adjacent strata of low permeability.

Generally, permeable zones in rocks of Niagara age are thin and are separated by relatively thick beds of low permeability. Thus the yield of a well that has tapped one permeable zone will not increase significantly until the next permeable zone is reached. This contrasts with the yield of a well tapping a rock such as sandstone, which will increase roughly with the amount of the formation penetrated.

Permeable zones are important avenues of circulation in the carbonate rocks and commonly are areally extensive (pl. 4). Equally extensive beds of low permeability form very efficient confining layers which allow practically no natural vertical leakage from artesian zones within the Niagara series. Hence, in topographically low areas, many wells tapping the formations of the Niagara series are under sufficient artesian pressure to cause a flow of water at or considerably above the land surface (table 2).

Burnt Bluff formation. The Burnt Bluff formation, the oldest of the Niagara series, crops out or is covered only by glacial drift in the northern part of Mackinac County. The formation is composed of light-gray, gray, and brown dolomite and limestone strata including some beds of high-calcium limestone. The strata are jointed and range from thinly bedded to massive. In Mackinac County the formation is more than 200 feet thick. Beds of high-calcium limestone in the Burnt Bluff formation are quarried at the Hendricks Quarry northwest of Rexton, at the Fiborn Quarry northeast of Rexton, and at the Inland Lime and Stone Quarry near Huntspur. Near the Fiborn Quarry, caves have developed in some of the high-calcium limestone beds.

The Burnt Bluff formation is an important aquifer in much of the county. Generally, it is tapped by wells only in the area where it would be exposed if the glacial-drift mantle were removed, or in adjacent areas where the overlying Manistique dolomite is nonproductive. In the area where the Burnt Bluff is mantled by the younger Manistique and Engadine dolomites, it generally is not utilized as a source of ground-water supply, for water can be obtained at shallower depths. There is no evidence to show, however, that the Burnt Bluff would not be productive at depth in the southern part of the county where it is overlain by younger formations.

Manistique dolomite. The Manistique dolomite consists of high-magnesium limestone and buff to light-brown cherty dolomite. The formation crops out in a number of places in the northern part of the county. The hard and resistant limestone and dolomite strata are cliff formers, and in many localities the outcrop area of the Manistique is marked by a steep escarpment. The formation is about 200 feet thick in Mackinac County.

Moderate to large supplies of water can be obtained from the Manistique dolomite throughout much of the county. The occurrence of water in the limestone and dolomite of the Manistique is similar to that in the other formations of the Niagara series. In many places water in the formation is confined under artesian pressure sufficient to cause it to flow at the surface. Artesian pressures in some of the wells tapping the Manistique dolomite at Naubinway are great enough to cause water levels to rise as much as 85 feet above the land surface (table 2).

Engadine dolomite. The Engadine dolomite is a hard crystalline massive white, buff, and light-gray dolomite. In places the escarpment and dip slope of the Niagara cuesta are formed on resistant layers of Engadine dolomite. The area where the Engadine would be exposed if the glacial-drift mantle were removed (pl. 2) covers a major portion of the county.

The Engadine is, as are the other formations of the Niagara series, an important aquifer in Mackinac County. Moderate supplies of fresh water are produced from the more permeable zones which have developed largely as a result of solutional activity. Solution features are evident where the Engadine is exposed at the surface. Reports from drillers indicate that in the eastern part of the county some sandstone beds are included in the Engadine dolomite. These sandstones also may be a source of water to wells. Much of the water in the Engadine is under artesian pressure. Relatively impermeable beds within the formation commonly form confining layers, but in many places water in the aquifer is confined under artesian pressure by the mantle of glacial drift.

The solution features that developed where the Engadine dolomite is exposed, or was exposed in preglacial time, are significant as they provide a direct avenue for recharge. South of Could City, solution caves and sinks have formed in the jointed and weathered surface of the Engadine.

Salina and St. Ignace Formations of Late Silurian Age

Salina formation. The Salina formation, which crops out on the St. Ignace Peninsula, consists of green and red shale and shaly dolomite and thin beds and irregular masses of gypsum. Thick beds of salt also were deposited within the formation, but these beds were subsequently removed by leaching. The log of well 40N 3W 7-1 shows a thin bed of salt at 400 feet. The leaching of the salt beds in the Salina formation produced large caves into which the overlying rock strata collapsed. Thus, much of the Salina is broken and faulted into blocks ranging in size from small fragments to slabs several hundreds of feet in horizontal dimension. As a result of the faulting and brecciation due to collapse, it is generally impossible to correlate strata of the Salina formation on the basis of well logs.

Wells tapping the formation generally produce water from the thin dolomite beds, or in some places from beds of shaly dolomite. The water in the Salina Formation occurs along joints and bedding planes, and the permeability of the formation in some areas probably has been increased as a result of brecciation. In some areas fragments of the broken formation have been recemented by carbonate minerals carried in solution by percolating ground water which has resulted in filling the void spaces and lowering the permeability of the aquifer. Because of the great range in permeability within the Salina formation, test drilling to locate permeable zones or detailed geologic information concerning a specific locality is needed to insure obtaining an adequate water supply. The presence of gypsum, resulting in mineralization of ground water within the formation, adds to the difficulty of obtaining a water supply of good quality.

St. Ignace formation. The St. Ignace formation is the youngest of the formations of Silurian age that crop out in Mackinac County. This formation also is broken and faulted as a result of collapse of the underlying Salina formation. On the St, Ignace Peninsula and Mackinac Island, these rocks are present only as large segments of strata intermixed within the Mackinac breccia. No attempt was made to delineate segments of the St. Ignace formation within the breccia in the above areas, and hence those areas are mapped as Mackinac breccia (pl. 2). Relatively intact strata of the St. Ignace formation are present on Round Island and in the northern part of Bois Blanc Island. The St. Ignace formation consists of layers of light-buff and light-gray dolomite and includes several thin layers of varicolored shale. Landes, Ehlers, and Stanley (1945, P. 53-73) published a detailed description of the lithologic character of the formation. They estimated the thickness of the St. Ignace formation to be about 250 to 300 feet.

Little is known of the water-bearing characteristics of the St. Ignace because the present reconnaissance investigation was limited to the mainland portion of the county. It is believed, however, that these rocks may be a source of ground water on Round and Bois Blanc Islands.

Bois Blanc Formation of Middle Devonian Age

The Bois Blanc formation is the youngest of the Paleozoic sedimentary rock units in the Northern Peninsula of Michigan. This formation also is brecciated as a result of collapse. Fragments and faulted blocks of the Bois Blanc formation are present in the Mackinac breccia underlying Mackinac Island and part of the St. Ignace Peninsula. In those areas, however, the formation is too extensively brecciated and intermixed with older rocks to permit delineation of the formation as a stratigraphic unit. Within Mackinac County, the formation is mappable as a stratigraphic unit in the southern two-thirds of Bois Blanc Island. The upper portion of the formation is present also along the northern tip of the Southern Peninsula.

Landes, Ehlers, and Stanley (1945, p. 80-109) described the lithology of the formation in detail. The lower part of the formation, which is estimated to be about 75 feet thick, crops out on Bois Blanc Island and consists of interbedded chert and dolomite. Light-gray to light-buff cherty limestone of the middle part of the formation forms the bedrock surface under the south shore of the island. The upper part of the formation, which consists predominantly of limestone, is present only under the water and along the south shore of the Straits of Mackinac.

Little is known of the water-bearing characteristics of the Bois Blanc formation in Mackinac County. It may be a source of ground water on Bois Blanc Island.

Mackinac Breccia of Devonian and Silurian Age

The Mackinac breccia is composed predominantly of angular blocks of limestone and dolomite and admixtures in varying amounts of chert, shale, and gypsum from the Salina, St. Ignace, and Bois Blanc formations. The Mackinac breccia was formed as a result of collapse of the Salina, St, Ignace, and Bois Blanc into voids formed as a result of leaching of thick salt beds of the Salina. Although many large blocks of the separate formations of which the Mackinac breccia is composed can be recognized, the boundaries of these blocks generally cannot be delineated. Brecciation and other collapse features are recognized over a large area (fig. 5); however, the Mackinac breccia as described in this report is limited to the area where the rocks show no stratigraphic continuity because fragments and blocks from the different formations are jumbled together at random.

Locally, the blocks and fragments composing the Mackinac breccia are indurated (cemented) into resistant, coherent, and generally impermeable masses. These resistant masses of rock form many of the prominent physiographic features of the St. Ignace Peninsula and Mackinac Island. Excellent examples of resistant breccia masses are St. Anthonys Rock and Castle Rock in the St. Ignace area, and Arch Rock and Sugar Loaf on Mackinac Island. Other hills near St, Ignace and on Mackinac Island mark areas underlain by masses of resistant breccia. Most of the breccia, however, is nonindurated or incompletely indurated, and, hence, the permeability of the breccia mass varies widely both vertically and laterally.

The occurrence of water within the Mackinac breccia is as complex as the breccia itself. Just as there is a complete lack of stratigraphic continuity in the breccia, there is a lack of continuity between water-bearing horizons. Much of the permeability of the breccia may be the result of openings along faults and other fractures. These openings may or may not be filled with precipitated calcium carbonate, which forms the cement of the resistant breccia. Thus, masses of impermeable breccia may occur in direct contact with masses of permeable breccia- The masses of impermeable rock may have horizontal and vertical dimensions of hundreds of feet or only a few feet. Some wells drilled only a few tens of feet from productive wells will not yield water. The water produced from the Mackinac breccia generally is hard and high in mineral content.

Although the Mackinac breccia is an important aquifer at the southern end of the St. Ignace Peninsula, specific capacities of wells tapping the formation are generally very low (table 6). Well 40N 4W 5-3 tapping this aquifer yielded 50 gpm with 2 feet of drawdown. Other localities of similar or perhaps greater yields might be located by test drilling, but wells drilled into indurated breccia may yield no water.

Ground Water in Unconsolidated Deposits

Most of the unconsolidated rocks in Mackinac County were 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 important aquifers in some parts of the county. The general term "glacial drift" embraces all types of morainal and associated glacial lake and beach, meltwater-stream, and windblown deposits. The drift generally is closely related in lithology to the underlying bedrock, especially at the base of the drift section, and in many wells the contact between the drift and the bedrock cannot be accurately delineated.

The glacial deposits of the county consist of stratified gravel, sand, silt, clay, and unstratified rock debris (till). Stratified sand and gravel deposits generally are more permeable than the unstratified deposits and in most areas will yield more water to wells. In many areas of the State, stratified drift can readily be differentiated from the unstratified drift by areal geologic mapping. Such is not the case in Mackinac County, as here surface features have been modified by erosion and masked by glacial-lake deposits. Hence, the map of the surficial deposits (pl. 5) should be used only as a general aid in locating ground-water supplies. Test drilling is essential in order to appraise adequately the ground-water resources of the drift aquifers in the county.

The drift has a great range in thickness in the county. At the Pine River near Chippewa County the drift is as much as 300 feet thick. In this area it fills a deep preglacial valley eroded into the bedrock surface extending from St. Martin Bay on Lake Huron to Whitefish Bay on Lake Superior. In large areas of the county, however, the drift mantle is thin or discontinuous. In such areas, underlying bedrock formations are the best sources of ground water.

Morainal Deposits

The moraines of Mackinac County (pl. 5) are ridges of glacial till which was deposited for the most part in the waters of glacial Lake Algonquin along the relatively static front of glaciers melting back at approximately the rate of movement of the ice sheet. Only two deposits of land-laid morainal till have been described in Mackinac County. These deposits were mapped by Leverett

(1929, pl. 1) in T. 43N., R. 4 W., and in Tps. 42 and 43 N., R. 1 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. Accurate delineation of the various types of morainal till in the county, however, is beyond the scope of the present reconnaissance report.

Land-laid till tends to be unsorted and unstratified, but most of the till in Mackinac County was deposited in water or later reworked and sorted or stratified to some degree by lake waters. The degree of sorting of the till varies greatly. In some areas the sorting is rudimentary; elsewhere the till is difficult to distinguish from well-sorted outwash deposits. Moraines in the western half of the county, which are composed largely of sand, may yield moderate supplies of water. Those in the eastern part of the county generally are composed of clayey till, which is a relatively poor source of water. The clayey morainal deposits, however, include some small lenses of stratified sand and gravel that will yield small amounts of water to wells. Well 42N 1W 3-1 (table 4) penetrated several layers of permeable sand within the moraine.

Till

The till plains of Mackinac County are underlain by glacial till similar in physical character to that described above in the section entitled "Morainal Deposits." Most of the till is now thin and discontinuous as a result of wave-washing by the glacial lakes, which at various times covered much of the county. Till-plain areas are not shown on plate 5, as the deposits generally form only a veneer over the bedrock surface. In many places the till deposits are above the zone of saturation, although locally they yield small amounts of water to shallow wells. In general, however, the till-plain deposits are not important sources of water to wells in Mackinac County.

Outwash

Outwash is composed of stratified sand and gravel deposited by glacial melt-water streams. In Mackinac County, much of the outwash was deposited as deltas in glacial lakes and is composed mainly of sand. The outwash deposits are closely related to, and in places are incorporated within, morainal deposits. They are permeable and generally yield small to moderate supplies of ground water. Several areas of such deposits are shown on plate 5. Subsurface outwash deposits in other areas may be located by test drilling or, perhaps, by geophysical methods.

Glacial-Lake Deposits

Stratified clay, silt, and fine sand deposited in the waters of glacial Lake Algonquin and other extinct glacial lakes mantle much of Mackinac County. These sediments can be divided into two major types: The clayey lake-plain deposits, which are composed mainly of pebble-free red and gray varved clay, and the sandy lake-plain deposits, which are composed of fine sand and silt.

The clayey lake deposits are of low permeability and are not a source of water to wells; they act as confining layers in some artesian systems. The sandy lake deposits may yield small amounts of water to wells.

Dune Sand and Beach Deposits

Dune sand and beach deposits associated with glacial Lake Algonquin and post-Algonquin lakes are found throughout the county. These sediments consist of permeable windblown sand and beach-deposited sand and gravel. Most of the dune areas are associated with the beach deposits. Dune and beach areas have not been delineated on plate 5. Locally, these deposits may yield small to moderate supplies of water to wells. They have high infiltration capacities and, where situated above the water table, they 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 nearly all the ground water of Mackinac County is precipitation, which averages about 30 inches annually. If all the moisture that fell upon the county entered into uniformly distributed permeable aquifers, a bountiful supply, more than enough to satisfy any foreseeable needs, would be insured. However, much of this water does not enter the ground-water reservoirs, but is lost by evaporation, by transpiration, and by direct runoff to the Great Lakes drainage system.

The amount of precipitation that enters the aquifers 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. Ferris and others (1954) discuss the hydrologic cycle in greater detail, particularly as applied to drift and rock aquifers in Oakland County, Mich.

In Mackinac County, areas of small recharge are the clayey lake and till plains which have soil and subsoil of low permeability. In the lake-plain areas, where the soils promote runoff, complex surface drainage features have developed. Areas of high recharge are in the permeable morainal, outwash-plain, sandy lake- and till-plain, and dune and beach deposits. In these areas, surface drainage courses are poorly developed or nonexistent. Some rock highlands which are permeable because of fracturing and solution also are major areas of high recharge.

Movement

The movement of ground water is somewhat similar to that of surface streams in that the water moves by gravity from high to low levels. Percolation of water through the interstices between rock particles below the surface involves a great amount of friction and hence is much slower than flow of water upon the surface. Rates of ground-water movement range widely from a few feet per year to many feet per day.

Water may travel great distances underground from recharge areas to areas downgradient 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 and transpiration. Where undisturbed by man-made diversions, the piezometric surface of an aquifer near the surface conforms generally to the configuration of the overlying land surface. In the deeper artesian aquifers, however, the piezometric surface may differ considerably from the overlying land surface, and locally its gradient may be in a direction opposite to the slope of the land surface. Where more than one aquifer underlies the same area, water will migrate or leak from an aquifer of high head to an overlying or underlying one of lower head. In this way, water will leak slowly through the confining beds of an artesian system. Artesian pressures in the Naubinway area, where water levels more than 75 feet above the land surface are not uncommon, are evidence of efficient confining beds which allow relatively little natural vertical leakage from the aquifer.

Many areas of Mackinac County are underlain by two or more aquifers differing considerably in water level, and some natural seepage or leakage occurs between them. The greatest leakage between aquifers in some areas, however, takes place through wells that are open to more than one aquifer. Where considerable interaquifer leakage occurs, it may be difficult to define the piezometric surface of an individual aquifer.

Discharge

Water is discharged from the ground-water reservoirs by evaporation and transpiration and through wells, springs, and drains. Because much of the county is covered by dense growths of forest and swamp vegetation, the amount lost by evapotranspiration is presumed to represent a large percentage of the total discharge. A considerable amount of water is also discharged from the ground-water reservoir through springs. Most of the springs in the county are along the edge of the moraine and outwash highlands and along the Niagara escarpment.

The greatest amount of discharge by wells is that from aquifers tapped by numerous flowing wells, the perennial flow from these wells greatly exceeding the discharge from pumped wells. The total discharge by all wells, however, is small compared with the total natural ground-water discharge.

Fluctuations of the Water Table

Climatic Influences

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 resulting decrease in recharge and decline in water levels. Rainfall during the growing season normally has slight effect on the rate of decline, as vegetation in the county utilizes most of the available moisture. In the fall, evapotranspiration losses are reduced and precipitation may be adequate to replenish soil moisture and then to cause rises in water levels. However, the decline in stage common during the summer may be continued during the fall if precipitation is deficient or if there is an early general freeze which tends to impede normal infiltration.

The relation of climate to ground water is illustrated by the fluctuation of water level in well 42N 2W 7-1, which is compared with the average of the daily precipitation at Kinross in Chippewa County and at Brevort and with the range in average monthly temperature at Kinross (fig 6). The water level in this well, which taps the Engadine dolomite, rose rapidly in response to rainfall during the last part of June and early part of July 1956. Much of the rain that fell during this period entered the ground-water reservoirs, as the soil-moisture and plant requirements had been supplied by snowmelt and earlier spring rains.

The rapid rise in water level in response to rainfall shows the accessibility of the Engadine dolomite to recharge from precipitation. Solution openings along joints provide direct access to the aquifer. Precipitation during later summer months, however, had very little effect on the water level in the well. All available moisture during the hot months was utilized by plants or went to replenish soil moisture which had been depleted by plant use. During the summer months the water level declined gradually as water within the aquifer was slowly discharged to springs and seeps. The use of water by plants declined in the fall, and during these months precipitation caused a slight rise in the water table. During the winter, when precipitation fell as snow, little or no recharge took place and the water level slowly declined.

Fluctuations Due to Discharge from Wells

Generally, ground water is a renewable natural resource, as 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 substantially dewatering the aquifer, then equilibrium must exist between the rate of recharge to the aquifer and the rate of discharge from it (Theis, 1940). Any aquifer in its natural state (before it is tapped by wells) is in approximate dynamic equilibrium. When water is discharged from an aquifer by means of a well, a temporary change in the rate of total discharge from the aquifer results. The increase in discharge causes a cone-shaped depression in the 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, restoring the aquifer to a state of equilibrium.

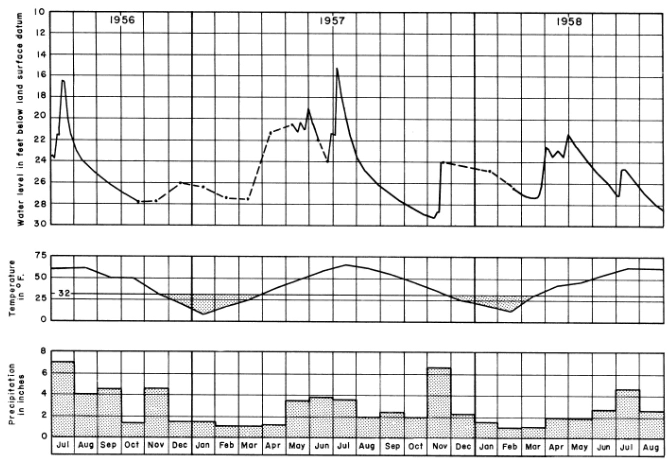

Figure 6. Hydrograph of well 42N 2W 7-2 compared with the average monthly temperatures and monthly precipitation at Kinross.

Wells within the cone of depression are affected by the lowering of water level. Thus, a well tapping an aquifer is affected by the discharge of other nearby wells that tap the same aquifer. If there are several or many discharging wells, a composite cone of depression results, 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 the aquifer. A lowering of the water level, therefore, is necessary in the development of a ground-water reservoir. Waste of water, however, as from unrestricted flowing 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 Mackinac County are reported to show effects of decreased artesian pressures, and in the Engadine area many wells have stopped flowing.

Utilization of Ground Water

Much of Mackinac County is bounded by the waters of the Great Lakes system, which provide a practically unlimited source of fresh water, St. Ignace, the largest municipality in the county, obtains its water supply from Lake Huron. Other towns and villages and nearly all the farm residences, resorts, motels, and other users tap ground-water sources.

Utilization of the ground-water resources of the county has been limited for the most part to domestic purposes and watering of stock, and the amount used represents an insignificant fraction of the total resource available. Engadine is the only municipality that has a public ground-water supply. Other villages and towns are supplied by privately owned wells. The tourist industry, which is one of the important users of ground water during the vacation season, does not require such large quantities of water as would be needed in industrialized areas or in irrigated agricultural areas. Comparatively minor amounts of ground water are used by other industries in the county, and no water is known to be used for air conditioning.

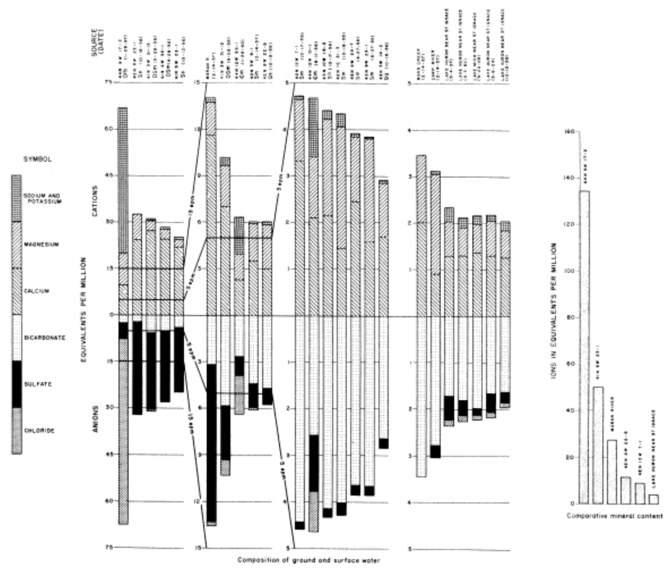

Figure 7. Diagrams showing chemical quality of water in Mackinac County.

QUALITY OF WATER

A listing of chemical analyses and records of various physical properties of the waters of Mackinac County is provided in table 7. Despite the fact that it was not possible to engage in a comprehensive program of chemical analysis of the waters of the county and geochemical interpretation during the present reconnaissance, sufficient data were gathered to reveal the general nature of the water from each of the major aquifers.

Figure 7 is a graphic presentation of the chemical quality of the waters in Mackinac County, which illustrates the great range in mineral content of ground and surface waters from various sources. Fresh water, as defined herein, is water containing less than 1,000 parts per million (ppm) of dissolved minerals. This concentration represents the maximum that should be permitted in drinking water, according to the U. S. Public Health Service (Michigan Department of Health, 1948). However, the dissolved-solids content of water of good chemical quality should not exceed 500 ppm. All waters containing more than 1,000 ppm of dissolved mineral matter are referred to in this report as "mineralized." The source of the dissolved solids present in the mineralized ground waters in Mackinac County is believed to be connate water entrapped at the time of deposition of sediments in the Michigan basin, and formations containing soluble minerals, which are being dissolved and removed in solution by percolating ground waters. Variations in mineral content result from the mixing of mineralized and fresh waters in various proportions, the solubility of mineral constituents in the aquifer, and the quantity of fresh ground water moving through the aquifer.

The waters in the aquifers of Mackinac County are of two predominant types: calcium magnesium bicarbonate and calcium sulfate. Waters from the glacial drift, sandstone, and limestone aquifers are relatively high in calcium bicarbonate, compared to waters from dolomite and dolomitic limestone aquifers, which are relatively high in magnesium bicarbonate. Thus, a high magnesium-to-calcium ratio generally indicates that the source aquifer is dolomite or that some of the water has migrated through dolomitic rock. Water high in calcium sulfate content commonly indicates that gypsum is present in the source aquifer. Water of the sodium chloride type in the Munising sandstone and Trenton and Black River limestones may represent connate water migrating from the interior of the Michigan Basin. Water from the Salina formation locally may contain sodium chloride dissolved from residual salt beds present within the formation (see log of well 40N 3W 7-1, table 4).

Fresh Ground Water

Supplies of fresh ground water varying widely in chemical quality are present in the glacial drift and most of the bedrock formations of Mackinac County.

The Munising sandstone of Late Cambrian age yields potable water in the northwestern part of Mackinac County and in adjacent areas of Schoolcraft and Luce Counties. The type, source, and occurrence of the water in this aquifer within Mackinac County are not fully known. Wells 44N 12W 10-1 and 44N 12W 26-1 both yielded water of the calcium bicarbonate type. However, water from the latter well contained 92 ppm of chloride, compared to 30 ppm in the former well. In general the chloride content is believed to increase from north to south, or downdip. The chloride content of fresh water from all other aquifers sampled in the county was less than 18 ppm. The chloride is believed to indicate greatly diluted connate water migrating from the interior of the Michigan basin. The calcium bicarbonate probably represents calcium carbonate taken into solution by ground water percolating from the recharge area through glacial drift or overlying bedrock formations.

The aquifers within the Niagara series each yield water of the calcium magnesium bicarbonate type. Water from the Engadine dolomite, which is composed predominantly of that mineral, has a relatively high magnesium-to-calcium ratio. Most of the water taken from the Manistique and Burnt Bluff formations is of the calcium bicarbonate type, indicating that these formations are composed predominantly of limestone. Dolomite or dolomitic limestone also is present within the formations and results in local increases of the magnesium-to-calcium ratio. The hardness of water sampled from the formations of the Niagara series ranged from 191 ppm in the Manistique to 335 ppm in the Engadine.

The Salina, St. Ignace, and Bois Blanc formations and the Mackinac breccia lie at the surface or directly beneath the drift in the St. Ignace Peninsula and the islands in the Straits of Mackinac and St. Martins Bay. These rocks which are important or potentially important aquifers contain gypsum and, in general, yield hard water of the calcium sulfate type. The sulfate content varies greatly, and water from wells tapping these aquifers is highly mineralized locally. In areas where glacial drift overlies these gypsum-bearing formations the drift may yield water of the calcium sulfate type. Chemical analyses of water supporting this assumption were not available at the time of the preparation of this report.

The glacial drift mantling much of the county contains relatively large-percentages of limestone and dolomite fragments which are important sources of constituents causing hardness. Water taken from the drift is hard and of the calcium magnesium bicarbonate type; the hardness of samples analyzed ranged from 142 to 360 ppm and was comparable to that of water produced from drift aquifers in other parts of the State.

The iron content of water samples from most of the fresh-water aquifers of the county generally was less than 1 ppm. Well 43N 11W 21-2, tapping the Manistique dolomite, yielded water containing 2.8 to 3.0 ppm of iron, or about 10 times the maximum concentration of iron and manganese suggested by the U. S. Public Health Service for drinking water (Michigan Department of Health, 1948).

Mineralized Ground Water

Several of the aquifers of Mackinac County yield mineralized water. A sample of water was taken from the Black River and Trenton limestones during the drilling of well 44N 9W 17-2. The very high sodium and chloride content of this sample (table 7) indicates that connate water from within the Michigan Basin is percolating through the aquifer in the area of the well, for salt strata are not present in the Black River and Trenton limestones. The source, direction of movement, and extent of mineralization of ground water in the Black River and Trenton, however, are not fully known.

Wells 42N 6W 22-1 and 41N 3W 23-1 tapping the Salina formation yield water high in sulfate. Water of similar chemical quality was taken from wells 41N W 36-1 and 41N 3W 31-13, which tap the Mackinac breccia. The presence of sulfate in the water results from the solution of gypsum in these formations. In the Mackinac Straits area (fig. 5), the Salina, St. Ignace, and Bois Blanc formations have been undermined by the removal of salt from the Salina formation and have collapsed into the voids previously occupied by the salt strata. The absence of significant quantities of sodium and chloride in water taken from the breccia demonstrates the difference in solubility between gypsum and salt. Nearly all the salt was removed in Devonian time and the amount still present is insufficient to increase materially the chloride content of the water. The gypsum that was deposited with the salt in the Salina formation has dissolved very slowly, and large quantities are still present in the Salina formation and the Mackinac breccia.

The distribution of mineralized water in the Mackinac breccia and brecciated portions of the Salina formation is very complex. Locally, water having high concentrations of sulfate is present at or near the surface, but in nearby areas wells of considerable depth yield fresh water. The extensive brecciation of the strata rules out the possibility of correlating reports of gypsum in wells spaced more than a few tens of feet apart. Thus reliable prediction of the occurrence of high-sulfate water in various portions of the aquifer cannot be made. In general, however, it may be assumed that the likelihood of obtaining mineralized water will increase with depth. Because of the random but widespread distribution of gypsum, extensive pumping of fresh water from wells tapping the brecciated rocks may induce migration of mineralized water into the fresh-water-bearing portions of the aquifers. Pumping of fresh water from aquifers hydraulically connected with the breccia may result in a similar condition.

The occurrence of mineralized water in Chippewa and Mackinac Counties suggests that highly mineralized water from the interior of the Michigan basin is migrating along undetermined paths through the deeper formations underlying Mackinac County. Extensive pumping from deep wells or deep test drilling might reveal that mineralized water is widespread in the deeper aquifers.

The existence of highly mineralized water in the various aquifers of the county necessitates caution in well drilling and water utilization to avoid contamination of nearby fresh-water aquifers. A deep uncased well or unplugged test hole may provide a conduit along which mineralized water may flow to the surface or into fresh-water aquifers above or below aquifers containing mineralized water.

Surface Water

Analyses of water from some of the streams in the county and from Lake Huron and the Straits of Mackinac are listed in table 7. Water from the Great Lakes in the Straits area is of the calcium magnesium bicarbonate type. The maximum dissolved-solids content noted was 146 ppm, and the hardness ranged from 92 to 130 ppm. Water from the Carp River, Nuns Creek, and McKay Creek, which are fed in part by ground water from the glacial drift and the Niagara series, is of the calcium magnesium bicarbonate type and contains approximately one-third more mineral matter than water from the Great Lakes. The Pointe Aux Chenes River is lower in mineral content than any other water sampled in the area. Most of the water taken at the time of sampling probably represents direct runoff from precipitation.

The effects of effluent discharge of ground water to a stream are well illustrated by comparison of the mineral content of water from the Salina formation, the Mackinac breccia, and the Moran River into which water from these formations is discharged (fig. 7). The river water at the sampling point is high in calcium sulfate, as is water from wells 42N 6W 22-1 and 41N 5W 23-1.

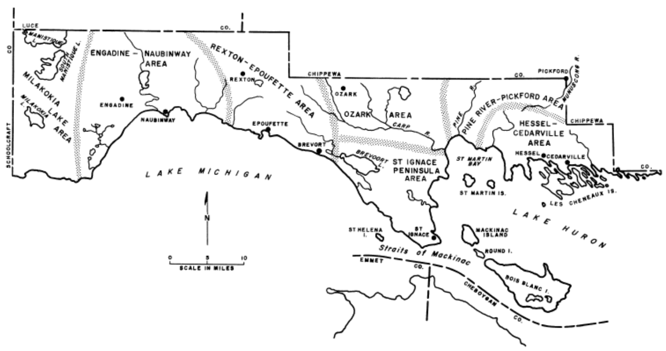

Figure 8. Map of Mackinac County showing ground-water areas.

OCCURRENCE OF GROUND WATER BY AREAS

The following section summarizes briefly the general occurrence of water in the areas shown on figure 8.

Milakokia Lake Area

Most of the wells in the Milakokia Lake area are completed in the glacial drift or in limestones of the Burnt Bluff formation. The wells tapping the drift aquifers are generally less than 75 feet deep and produce small to moderate supplies of water. The wells tapping the Burnt Bluff are generally less than 150 feet deep, although a few wells in the limestone are deeper than 170 feet. The Burnt Bluff formation in this area is believed to be capable of yielding large supplies of ground water. Generally, the water from the drift and from the limestones of the Burnt Bluff is of good quality, although moderately hard. In topographically low areas, water in the bedrock and drift aquifers is under sufficient artesian pressure to flow.

In the northwestern corner of this area, near the Manistique Lakes, at least two wells (44N 12W 10-1 and 26-1) tap the Munising sandstone at a depth greater than 1,000 feet. In this vicinity the Burnt Bluff formation is not present and locally the drift is of low permeability;

hence the only source of fresh ground water may be the Munising sandstone (pl. 3), which produces water of good quality. The sandstone throughout most of the Milakokia Lake area contains water under sufficient artesian pressure to flow above the land surface.

Engadine-Naubinway Area

Most of the wells in the Engadine-Naubinway area are completed in the limestone and dolomite of the Niagara series. The rest are completed in glacial drift. Wells tapping the glacial drift generally will provide sufficient quantities of water for domestic uses or the demands of small resorts. The bedrock aquifers are capable of yielding large amounts of water, from rather thin but areally extensive weathered zones along fractures and bedding planes. One permeable zone, which is about 190 feet below the level of Lake Michigan, can be traced for many miles (see pl. 4).

Nearly all the wells in this area are less than 250 feet deep and most are less than 200 feet deep. Wells tapping the glacial drift are generally less than 60 feet deep. Many wells in this area flow. In general, the deep aquifers are under greater artesian pressure than the shallow aquifers, and many wells are drilled through one or more water-producing zones in search of a zone under sufficient artesian pressure to provide an adequate flow. Thus, the depth of wells in this area does not indicate the depth to the most accessible source of ground water. Shallow permeable zones also are present, but many of these zones have not been developed extensively as a source of supply because the water is not under sufficient pressure to flow. In many wells where the upper permeable zones are not sealed off, interaquifer leakage (leakage from an aquifer under high pressure to one under lower pressure) occurs. As a result of this leakage, the artesian head of water in wells ending in the same permeable zone varies widely throughout the area. The loss of pressure and related decline in flow of many of the wells is a result of such leakage. Subsurface leakage may increase gradually in a well as the result of solutional enlargement of openings in the vicinity of the well. An example of the amount of water that can be lost by underground leakage was shown at well 43N 10W 26-3. This well would not flow at the surface until a permeable zone in the upper part of the well was sealed off. After this zone was sealed, the well had sufficient artesian pressure to raise the water 55 feet above the land surface, and it flowed in excess of 75 gallons per minute (gpm). Thus the loss by subsurface leakage before the upper permeable zone was sealed was in excess of 75 gpm. A similar loss of water by subsurface interaquifer leakage occurs in many wells in the area. The amount of subsurface leakage may exceed the amount of uncontrolled surface flow.

Although it is believed that considerable loss of artesian pressure has resulted from subsurface flow in the Engadine area, only a small change in artesian pressure has been observed near Naubinway. Well 43N 9W 29-7, which has the highest artesian pressure measured in any well in Mackinac County, shows little or no decline in pressure from the time when the well was drilled in 1948. As new wells are drilled, however, the artesian pressure in the Naubinway area also may decline eventually, unless the wells are properly maintained and are shut off when water is not needed.

Rexton-Epoufette Area

Most of the wells in the Rexton-Epoufette area are completed in glacial drift. Generally, these wells are less than 40 feet deep. At Epoufette, however, wells tapping the drift are considerably deeper. The drift generally yields small to moderate supplies of water of good quality.

A large part of this area is underlain by sandy outwash deposits (pl. 5), which are a source of water to many wells. At Brevort (fig. 8) and Epoufette some wells are completed in dune sands along the Lake Michigan shoreline. Difficulties in developing and maintaining wells tapping fine sand may be overcome by the use of properly constructed gravel-packed wells. Springs, a few of which have been improved and utilized for water supplies, issue from drift deposits.

Water is produced also from the Niagara series and Salina formation, which underlie the area. The water from wells tapping these rocks is generally of poorer quality than that from the glacial drift. Water from the Salina formation is especially hard and high in sulfate content. The depths of wells tapping the bedrock aquifers vary considerably in the area. Wells 42N 7W 2-2 and 2-3 at Epoufette, which tap aquifers in the Niagara series, were drilled to depths of 338 and 288 feet respectively and are the deepest known wells in this area.

Ozark Area

Wells in the Ozark area generally are less than 110 feet deep and are completed in limestone and dolomite of the Engadine dolomite. Bedrock in this area, which marks the crest of the Niagara cuesta, is at or near the surface. Permeable zones probably are present at depth in all the formations of the Niagara series in this area. The Engadine dolomite, however, yields water of good quality in sufficient quantity for most present and anticipated needs, and it has been unnecessary to drill to the older Niagara rocks for additional supplies of ground water.

Pine River-Pickford Area

The Pine and Munuscong Rivers mark the position of valleys in this area which were eroded into the underlying bedrock in preglacial time, and which are now filled with glacial sediments. Much of the fill in these valleys is glacial-lake clay (pl. 5). Wells produce small to moderate supplies of water of good quality from permeable drift which mantles the bedrock along these buried valleys. Most of these wells will flow above land surface. Wells along the Pine River generally are 150 to 200 feet deep. At Pickford along the Munuscong River, those wells are generally less than 150 feet deep.

St. Ignace Peninsula

The St. Ignace Peninsula is in the area of collapse (fig. 5), and wells in this area that tap the Salina formation and Mackinac breccia differ greatly in depth, in specific capacity, and in quality of the water they produce.

Test drilling is necessary to determine whether the Salina formation and the Mackinac breccia of the St. Ignace Peninsula will yield a supply of water suitable in quantity and quality at a specific site. Specific capacities of wells drilled into these rocks are generally low (table 6), and in some areas the rocks are almost impermeable. One area of "impermeable" rocks is at the approach of the Mackinac Straits Bridge. Wells 40N 3W 19-2, 19-3, and 19-4, which were drilled into the Mackinac breccia, did not yield an appreciable quantity of water. Other scattered areas of varying size where the breccia is impermeable have been found throughout the St. Ignace Peninsula.

The drift mantle of the St. Ignace Peninsula generally is thin and discontinuous. Locally, however, the sandy lake deposits and the gravel of some of the till plains yield small supplies of water to shallow wells. Large-diameter gravel-packed wells equipped with screens may provide sufficient water for domestic or resort uses in areas where conventional wells-have not proved satisfactory. In many places on the peninsula, the drift is composed largely of clay derived from the shale of the underlying Salina formation. Where the drift contains large quantities of clay, it will not yield significant quantities of water to wells.

The limestone and dolomite of the Niagara series, which are important aquifers throughout most of Mackinac County, underlie the Salina formation and the Mackinac breccia of the St. Ignace Peninsula. The Niagara rocks are exposed north of the St. Ignace Peninsula, dip to the south, and are about 600 feet below the surface at St. Ignace (pl. 3). The records of wells 41N 3W 31-15 and 40N 3W 7-1 near St. Ignace, which were drilled into rocks of Niagara age, are incomplete, but they furnish evidence that water of good quality may be produced locally from these rocks underlying the St. Ignace Peninsula. Good water was reported from well 41N 3W 31-15 in the Niagara rocks at a depth of 575 feet. This well is also reported to have yielded "sulfur" water (water containing hydrogen sulfide) at a depth of 681 feet (Michigan Geological Survey, 1901, p. 228). Test drilling of the Niagara rocks is needed in areas where water of good quality cannot be obtained at shallower depths, to determine the quality of water and the hydrologic characteristics of the aquifers within the Niagara series.

To date the Niagara series underlying the St. Ignace Peninsula has not been developed as a major source of fresh water. Its future utilization will depend on the outcome of exploration for fresh-water supplies, the need for additional supplies in the peninsula, and the economic feasibility of deep drilling. The depth to the Niagara in the peninsula decreases northward and everywhere would be considerably less than the depth to the Munising sandstone in the northwestern part of the county.

Cedarville-Hessel Area

The Cedarville-Hessel area is underlain by limestone and dolomite of the Niagara series. Most of the wells in the area produce adequate supplies of water from the Engadine dolomite, which forms the bedrock surface. The wells tap weathered zones near the bedrock surface, where solution openings are common. A few wells tap deep permeable zones which occur along distinct horizons. The areal extent of these permeable zones has not been determined because of the lack of topographic maps. Some wells are completed in the morainal or outwash deposits that mantle the Niagara rocks in the northern part of the area, and others are completed in the shallower drift deposits at Hessel and Cedarville.

Most wells of the Cedarville-Hessel area are less than 100 feet deep, although many are as much as 200 feet deep and a few exceed that depth.

The Les Cheneaux Islands south of Cedarville and Hessel are glacial drumlins (streamlined drift deposits) which are partly submerged by Lake Huron. The glacial drift may be rather thick, but its water-bearing properties have not been determined.

Islands in the Straits of Mackinac

Little is known of the occurrence of ground water on the major islands in the Straits of Mackinac, because the reconnaissance was not extended beyond the mainland. As a result, well records which .would provide details concerning the hydrologic characteristics of the Mackinac breccia and the St. Ignace and Bois Blanc formations were not obtained for Mackinac, Round, and Bois Blanc Islands.

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SYSTEM	SERIES		STRATOGRAPHIC UNIT	THICKNESS (feet)	HYDROLOGY	NAMES USED BY THE MICHIGAN GEOLOGICAL SURVEY		
						SERIES	GROUP	FORMATION
QUATERNARY	Pleistocene	Wisconsin stage	Glacial Drift Undifferentiated (Qgd); Sand (Qs); Gravel (Qg); Sand and gravel (Qsg) Heterogeneous assemblage of unsorted to slightly stratified clay, sand, gravel, and boulder till, principally waterlaid; stratified sand and gravel outwash ;stratified clay, silt, and sand lake deposits; sand and gravel beach deposits; windblown sand.	0 to 300	Locally important source of ground water. Best yields from sand and gravel outwash deposits. Moderate yields from morainal sand and gravel deposits, and from sand and gravel lenses interbedded with lake clay and silt. Small yields might be obtained from properly constructed wells tapping fine sand and silt lake deposits. Poor yields from clayey till. Layers of clay till and lake clay may be confining beds in artesian system.	GLACIAL DRIFT (Wisconsin)		
DEVONIAN AND SILURIAN	Middle Devonian and Upper Silurian		Mackinac Breccia (DSm) Assemblage of limestone and dolomite fragments ranging in size from powder to rock slabs measuring hundreds of feet in maximum dimension. Chert, shale, and gypsum blocks are present within the brecciated mass. Cementation of the breccia by calcium carbonate varies widely, and various gradations between completely nonindurated to indurated breccia are present. Brecciation due to collapse of Salina, St. Ignace, and Bois Blanc strata overlying caverns formed by dissolution of salt in the Salina formation.	0 to 400?	Source of water to some wells in the St. Ignace area. Nonindurated or poorly indurated breccia is permeable, but the distribution of relatively impermeable indurated breccia is exceedingly complex. Test drilling is necessary to determine the presence of permeable zones. Water-bearing zones are discontinuous and difficult to correlate from well to well. Much of the water yielded by the breccia is very hard.			MACKINAC BRECCIA
DEVONIAN	Middle Devonian		Bois Blanc formation (Db) Gray to light-gray and buff cherty dolomite and limestone. This formation is brecciated and faulted as a result of collapse of strata overlying caverns in the Salina formation.	250±	Possible source of water to wells on Bois Blanc Island.	ULSTERIAN	ONESQUETHAW	BOIS BLANC
SILURIAN	Upper Silurian		St. Ignace formation (Si) Light-colored, even-bedded dolomite and some thin shale beds. This formation is brecciated and faulted as a result of collapse of strata overlying caverns in the Salina formation.	250 to 300	Possible source of water to wells on Bois Blanc and Round Islands.	CAYUGAN	BASS ISLAND	ST. IGNACE
			Salina formation (Ss) Red and green shale interbedded with limestone and dolomite and thin beds and masses of gypsum. The formation is brecciated and faulted as a result of collapse after removal of vast quantities of salt from the formation. Some thin salt beds may remain at depth.	500 to 600	Important aquifer in the St. Ignace Peninsula. Wells produce water from permeable limestone and dolomite beds. These beds often lack continuity as a result of collapse faulting. Much of the water is very hard and is high in sulfate. Locally may yield mineralized water from deep wells.		SALINA	SALINA (PT. AUX CHENES)

	Middle Silurian	Niagara series (Sn)	Engadine dolomite (Se) Hard, resistant white commonly crystalline dolomite, and interbedded limestone. Locally very sandy and cherty.	100 to 175	Important aquifer in large part of county. Permeable where solution openings have developed along fractures and bedding planes. Very permeable where exposed at the surface. Solution caves formed in Engadine south of Gould City.	NIAGARAN	LOCKPORT	ENGADINE
			Manistique dolomite (Sm) Hard, resistant gray to light-gray high-calcium limestone and dolomite. Locally very cherty.	150 to 275	Important aquifer throughout much of the county. Permeable as result of solution along fractures and bedding planes. Very permeable where exposed at surface. Water confined locally under considerable pressure.		CLINTON	MANISTIQUE
			Burnt Bluff formation (Sb) Hard, resistant gray to light-gray lithographic limestone and dolomitic limestone. Some beds of high-calcium limestone.	248	Important aquifer throughout much of the county. Permeability is result of solution along fractures and bedding planes. Locally produces flows under moderate pressure. Very permeable where exposed at surface. Caves in Burnt Bluff near Fiborn Quarry, northeast of Rexton.			BURNT BLUFF
	LOWER SILURIAN		Cataract formation (Sc) Alternate beds of dolomite and greenish-gray shale, with gypsum.	210±	Locally these rocks may yield water to wells where they are directly mantled by glacial drift. Probability of low permeability where covered by younger consolidated rocks.	ALBION	CATARACT	MAYVILLE CABOT HEAD MANITOULIN
ORDOVICIAN	Upper Ordovician	Richmond group and Collingwood formation	Limestone and dolomite of the Richmond group (Or) Hard gray and brown limestone and dolomite, interbedded with shale and shaly limestone and dolomite.	170 to 200	Source of water to deep well at Gilchrist. Wells tapping limestone and dolomite in Rudyard-Pickford area of Chippewa county indicate that these rocks may be productive in adjacent areas of Mackinac County	CINCINNATIAN	RICHMOND	QUEENSTOWN? BIG HILL STONINGTON BILLS CREEK
			Shale unit (Orc) Basal shale beds of the Richmond group underlain by gray dolomitic and black bituminous shale of the Collingwood formation.	240	Permeability low. Will not yield significant amounts of water to wells.			LORRAINE? UTICA? COLLINGWOOD
	Middle Ordovician		Trenton and Black River limestones (Otb) Blue, gray, brown, and buff limestone and dolomite. Unit includes some shaly and sandy beds.	260	Yields mineralized water in the northwestern part of the county. Yields "sulphur" water at Rudyard in Chippewa County. Poor potential source of fresh water in Mackinac County.	MOHAWKIAN	TRENTON BLACK RIVER	TRENTON BLACK RIVER
CAMBRIAN	Upper Cambrian		Munising sandstone (Єm) White and gray medium- to fine-grained sandstone. Sand grains generally rounded and frosted; locally dolomitic. May include some strata of the Hermansville limestone of the Ordovician.	250±	Important aquifer in the northwestern part of Mackinac County and in adjacent areas in Schoolcraft and Luce Counties. Yields water of relatively good quality in this area. May yield water moderately high in mineral content in other areas of the county.		HERMANSVILLE? MUNISING	

Table 1. Lithology and hydrology of the major geologic units underlying Mackinac County.