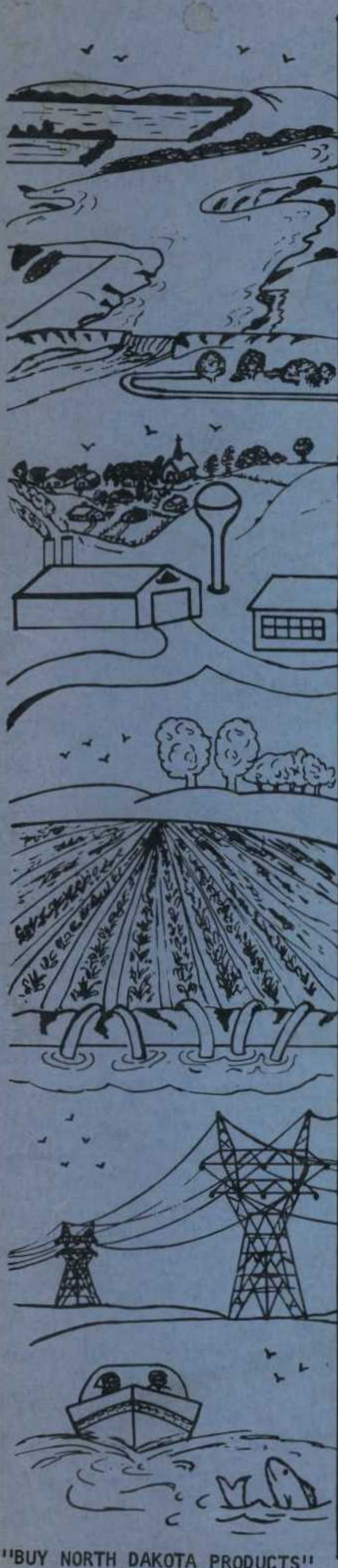


"BUY NORTH DAKOTA PRODUCTS"

GEOLOGY AND GROUND WATER RESOURCES OF THE MINNEWAUKAN AREA BENSON COUNTY, NORTH DAKOTA

By

Saul Aronow and P. E. Dennis, Geologists
and
P. D. Akin, Engineer
Geological Survey
United States Department of the Interior

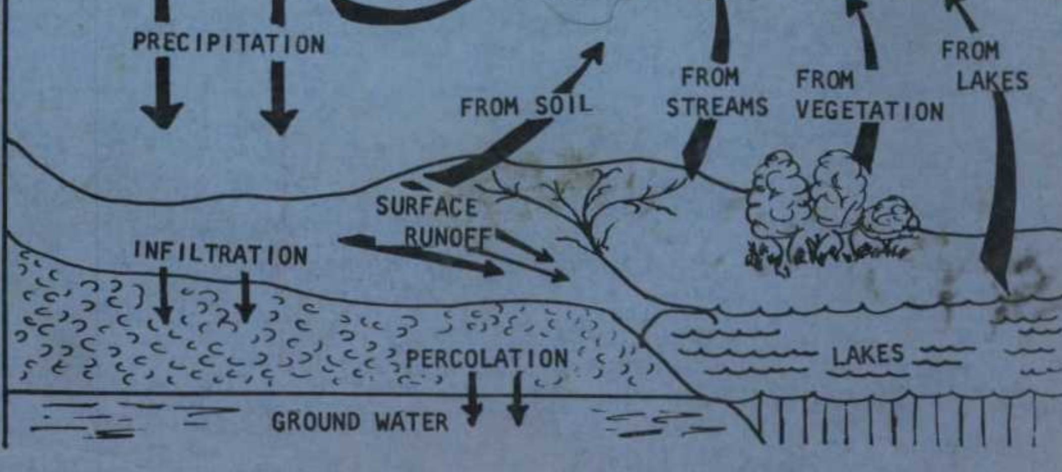
NORTH DAKOTA GROUND WATER STUDIES

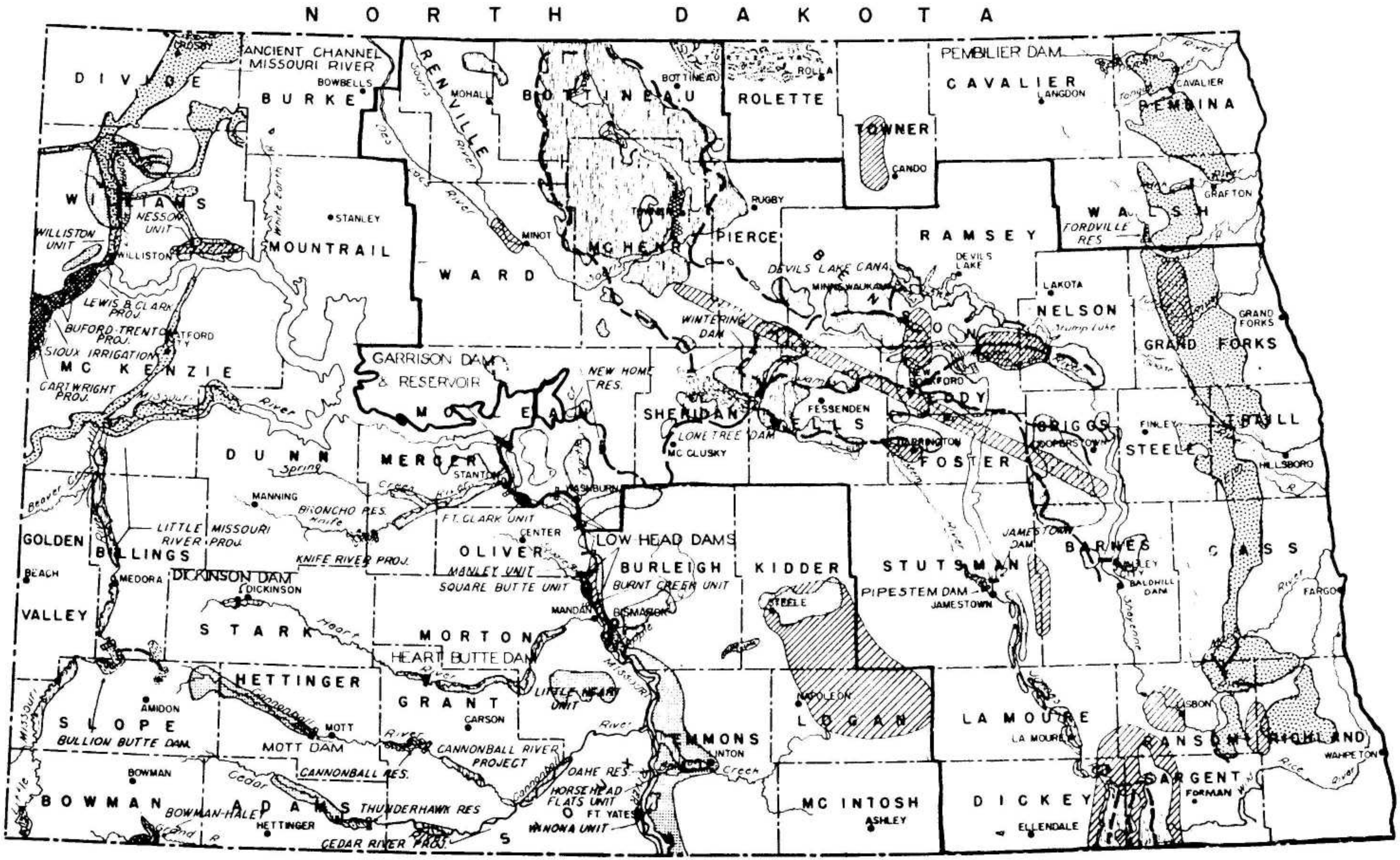
NO. 19

Prepared by the United States Geological Survey in cooperation with the North Dakota State Water Conservation Commission, and the North Dakota Geological Survey

PUBLISHED BY
NORTH DAKOTA STATE WATER CONSERVATION COMMISSION
1301 STATE CAPITOL, BISMARCK, NORTH DAKOTA

Originally published - 1953 Republished - 1962





NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

WATER RESOURCES DEVELOPMENT PLAN

- LANDS UNDER IRRIGATION
- AREAS CONSIDERED IRRIGABLE
- AREAS BEING INVESTIGATED
- PROPOSED FOR INVESTIGATION

DAM & RESERVOIR SITES: EXISTING; UNDER CONSTRUCTION OR PROPOSED

PROPOSED CANALS

GARRISON DIVERSION CONSERVANCY DISTRICT BOUNDARY

GROUNDWATER AQUIFERS

GEOLOGY AND GROUND WATER RESOURCES

OF THE MINNEWAUKAN AREA

BENSON COUNTY, NORTH DAKOTA

by

Saul Aronow and P. E. Dennis, Geologists
and
P. D. Akin, Engineer
Geological Survey
United States Department of the Interior

NORTH DAKOTA GROUND WATER STUDIES
NO. 19

Prepared by the United States Geological Survey in cooperation with the North Dakota State Water Conservation Commission, and the North Dakota Geological Survey

PUBLISHED BY
NORTH DAKOTA STATE WATER CONSERVATION COMMISSION
1301 STATE CAPITOL, BISMARCK, NORTH DAKOTA

Originally published - 1953 Republished - 1962

CONTENTS

CONTENTS - - Continued

ILLUSTRATIONS

GEOLOGY AND GROUND WATER RESOURCES
OF THE MINNEWAUKAN AREA
BENSON COUNTY, NORTH DAKOTA

by

Saul Aronow, P. E. Dennis, and P. D. Akin

ABSTRACT

This is a progress report on the study of the geology and ground water resources of Benson County, N. Dak., being made by the United States Geological Survey in co-operation with the North Dakota State Water Conservation Commission and the North Dakota State Geological Survey. The area discussed in this report comprises about 150 square miles around the city of Minnewaukan.

The geologic formations underlying the area are the glacial drift of Pleistocene age, stream and lake deposits of Recent age, the Pierre shale, Niobrara formation, and Benton shale, all of Late Cretaceous age, and the formations collectively referred to as the "Dakota sandstone." They were studied at their surface exposures and additional data regarding them were obtained from test holes and private wells, as well as from samples obtained from a deep artesian well in the city of Devils Lake. Drill cuttings that may be from an outlier of the Fort Union formation or from Cretaceous formations above the Pierre shale were obtained from one test hole.

The principal surface features in the area are of glacial and lacustrine origin. They include two groups of end moraines (a northern unnamed group and the southern North Viking moraine) which were deposited by ice advancing from the north or northeast. Between the two moraines in the western part of the area is a ground-moraine plain, the relief of which is locally enhanced by washboard morainic topography and by a series of northward-striking ridges, mainly of ice-contact origin. The eastern part of the area between the moraines is occupied by part of the dry bed of Devils Lake, which is circumscribed by two well-defined shore lines; the lower, the "K"

shore, has an altitude of about 1,445 feet and the upper, the "J", about 1,452 feet.

The North Viking moraine is bisected by a northeast-trending kettle chain (referred to as the Long Lake depression), which probably drained Devils Lake in Pleistocene time. South of the North Viking moraine is an outwash apron which, farther south, gives way to a ground-moraine plain. Numerous small ice-contact features also are present throughout the area.

Among the most recent features in the area are a youthful drainage system and ice ramparts in the Long Lake depression.

The glacial, lake, and stream features and their constituent materials generally form poor aquifers because of the clayey composition of the till and the paucity of coarse, sorted material. Among the few deposits that can be considered possible sources of municipal or industrial water supplies are the outwash in the southwestern part of the area and those in the bedrock "low" beneath the dry lake bed east of Minnewaukan. Some deposits in the ground moraine or in the ice-contact deposits west of Minnewaukan may yield supplies large enough to be used for minimum needs of a small community such as Minnewaukan.

The outwash contains at least 30 million gallons of water per square mile in each foot of saturated sand and gravel. The outwash material probably will not support wells having capacities greater than about 50 to 100 gpm (gallons per minute).

The "low" under the lake basin east of Minnewaukan is the first definite evidence discovered so far to indicate that Devils Lake may occupy a preglacial stream valley. The aquifers found in this "low" may be capable of producing water at a rate of several hundred to more than 1,000 gpm.

The quality of water derived from the drift in the Minnewaukan area generally is very poor, as the water contains objectionable amounts of dissolved solids and is hard. In 21 water samples analyzed, dissolved solids ranged from 220 to 10,200 ppm (parts per million) and hardness from 90 to 3,540 ppm. Most of the samples contained objectionable amounts of sulfate and iron.

The Pierre shale, which probably underlies all the glacial drift in the area, is water bearing in its upper hundred feet or more and is capable of supplying less than 10 gpm to individual wells.

A sample of water was taken from one well (153-67-15dab) that is believed to tap aquifers in the Pierre shale. This water contained 5,520 ppm dissolved solids and 270 ppm hardness. The predominant cation was sodium and the predominant anion was chloride. The water contained 2,060 and 2,890 ppm of these elements, respectively.

The "Dakota sandstone" in the Minnewaukan area probably can be tapped at depths between 1,410 and 1,590 feet. In the nearby city of Devils Lake, wells in the "Dakota sandstone" yield more than 300 gpm. The water from the "Dakota sandstone" is very highly mineralized and is not potable.

INTRODUCTION

General studies of the geology and ground-water resources of different counties in North Dakota are being made by the United States Geological Survey in cooperation with the State Water Conservation Commission and the State Geological Survey. These studies are made to determine the occurrence, movement, discharge, and recharge of the ground water, and the quantity and quality of such water available for all purposes, including municipal, domestic, irrigation, and industrial. However, the most critical need at present is for adequate and perennial supplies for numerous towns and small cities that are constructing municipal water-supply systems for the first time. For this reason, the county studies are being started in the vicinity of those towns that have requested the help of the State Water Conservation Commission and the State Geologist. Progress reports are being released as soon as possible in order that the preliminary data may be available for use in the solution of water-supply problems before the general studies can be completed.

Purpose and Scope of the Investigation

The study described in this report is one of the series of county investigations and relates chiefly to that part of Benson County that may be of interest to the city of Minnewaukan in its search for sources of municipal water supply. The investigation was made under the general supervision of A. N. Sayre, chief of the Ground Water Branch, Water Resources Division, of the U. S. Geological Survey. The field work and test drilling were done under the direct supervision of P. E. Dennis, former district geologist, and later under P. D. Akin, district engineer.

Field work in the area was done chiefly in June, July, August, and September, 1946, April and September 1948, and May 1952. It consisted of the following: (1) gathering information on many of the existing wells, including measurements of depths and water levels where possible, (2) mapping geologic features on aerial photographs and topographic maps, 1/ (3) ascertaining altitudes of some test holes and lake strand lines, (4) drilling 53 test holes ranging in depth from 24 to 324 feet, for a total of 4,852 feet, and taking ditch samples and cores of the earth materials, (5) collecting and submitting for chemical analysis samples of water from water-bearing beds penetrated by test holes and existing wells, (6) test pumping of holes and examination of some cuttings from test holes drilled by the city of Minnewaukan.

Laboratory and office work in connection with the investigation was done chiefly in 1947 and during the winters of 1948-49 and 1949-50, and the summer of 1952. It included the following: (1) examination and analysis of the cuttings and cores from the test holes, (2) correlation of well logs, (3) laboratory determination of permeability of some sand samples, (4) interpretation of the chemical analyses of the

1/ Topographic coverage for the geologically unmapped parts of the area was available for only the eastern half of the area. This was the portion in the Grahams Island topographic sheet (see fig. 1).

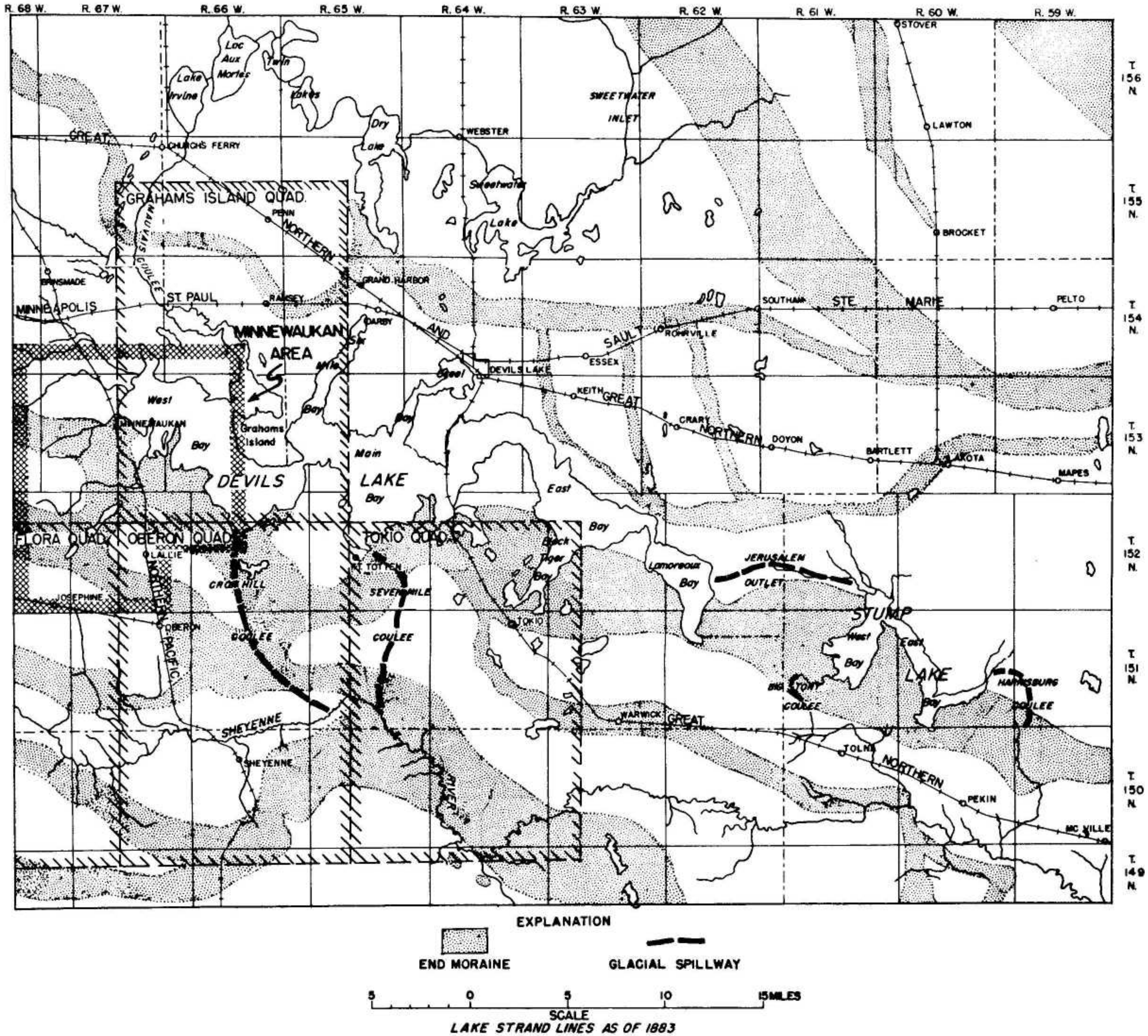


FIGURE 1.— MAP OF DEVILS LAKE-STUMP LAKE REGION, N. DAK., SHOWING MORAINES AND GLACIAL SPILLWAYS.
(AFTER UPHAM AND SIMPSON)

(SEE FIG. 2 FOR INDEX MAP)

water, (5) compilation of well, test-hole, and other data, and (6) preparation of illustrations and writing of a report on the investigation.

A number of questions concerning the geology of the area have been touched on only briefly, if at all, in this report. Among these questions are the origin of Devils Lake, the origin and antiquity of the high strand lines that circumscribe the lake, the possibility of strand lines higher than those discussed in this report, and causes of the recent desiccation of the lake. These questions will be discussed in a later report on a larger investigation now being made in the Devils Lake area.

Possible alternative hypotheses, not discussed in this report, regarding the origin of certain glacial features in the area will be considered in detail in the report on the Devils Lake investigation.

Previous Investigations and Acknowledgments

The geology and ground water resources of the Devils Lake region have been treated very generally by Upham (1896), 2/ Babcock (1902), and Simpson (1912, 1929).

The North Dakota Geological Survey has recently published geologic reports and maps of the Flora, Oberon, and Tokio quadrangles, which are all or partly in the Devils Lake region (Branch, 1947, Tetrick, 1949, and Easker, 1949). (See figs. 1 and 6.) The southern part of the Minnewaukan area overlaps the areas mapped by Branch and Tetrick, and their work has been used freely in the preparation of the present report. Their mapping in some places has been revised as a result of additional field work and interpretations made from aerial photographs.

The present study was facilitated by the ready cooperation of the townspeople and farmers. Thanks are due especially those who permitted measurement of water levels in their wells and test-drilling operations on their land, and to Sigrid Solheim, the local well driller, for information concerning the many wells he has put down in the vicinity.

2/ See references at end of report

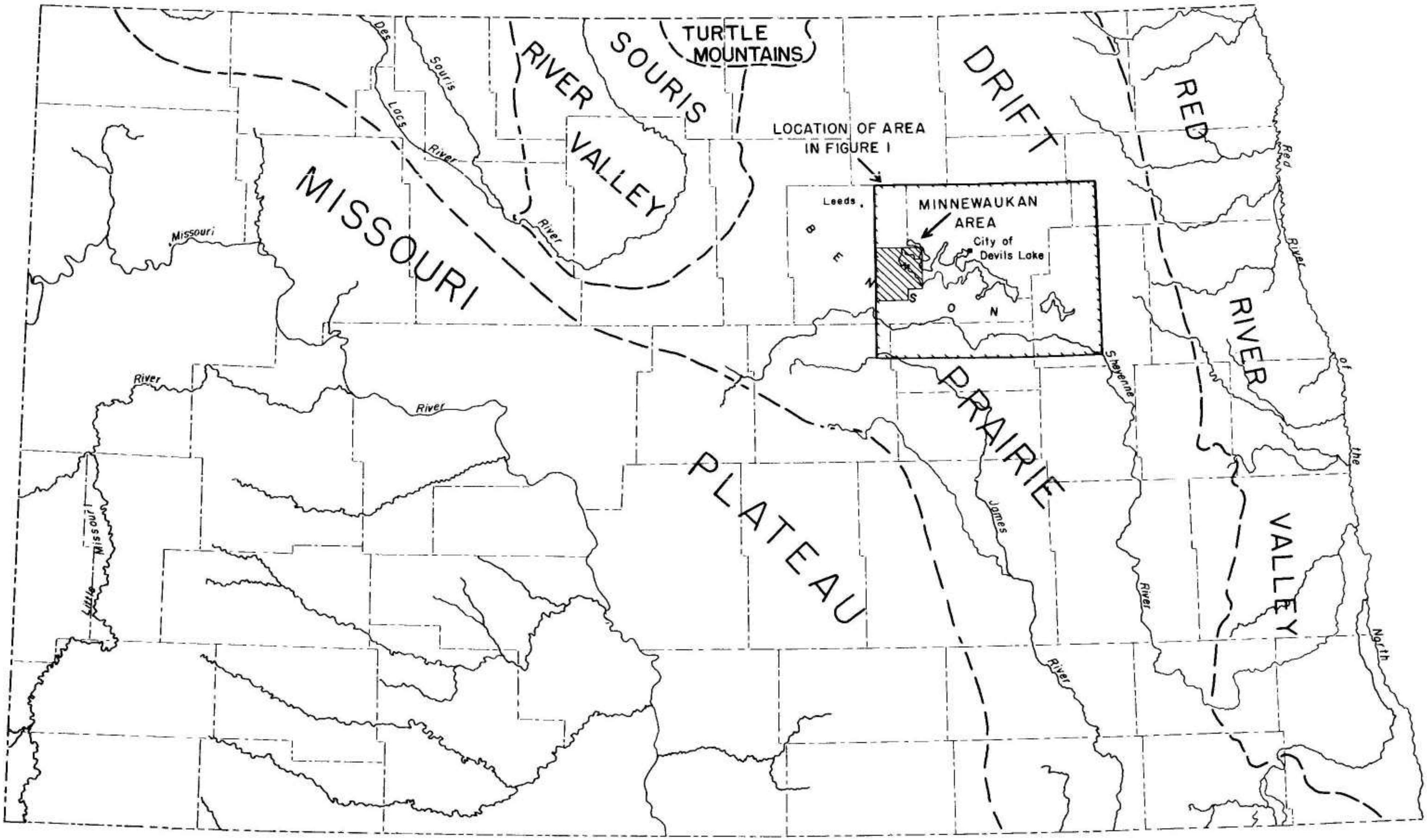


FIGURE 2.— MAP SHOWING PHYSIOGRAPHIC DIVISIONS IN NORTH DAKOTA (MODIFIED AFTER SIMPSON) AND LOCATION OF MINNEWAUKAN AREA

The North Dakota State Department of Health and the State Laboratories Department ran chemical analyses on samples of ground water from the area, and their assistance is gratefully acknowledged.

Location and General Features of the Minnewaukan Area

The Minnewaukan area (see fig. 2) is in the part of the Central lowland physiographic province (Fenneman, 1938, pp. 559-588) that has been called the Drift Prairie by Simpson (1929, p. 5). Most of West Bay, of the former and greater Devils Lake, which occupied the south-central portion of the Devils Lake interior drainage basin in historic time, is included in the northeastern part of the area. The Devils Lake basin includes an area of about 3,500 square miles (Simpson, p. 9) and lies between the drainage basin of the Red River of the North on the north, east, and south, and the Souris River basin on the west (U. S. Weather Bureau, 1949). Not all the interior drainage basin drains into Devils Lake. The poorly developed post-glacial drainage lacks sufficient integration for this to occur, and actually many small individual basins are included in the area between the two river basins.

The more or less distinct physiographic units that make up the principal features of the Minnewaukan area are shown in figure 6. Most prominent of these is the rough, elevated end moraine which crosses the area from the southeast. This was named the North Viking moraine by Branch (1947, p. 6). An unnamed end-moraine group in the northern part of the area, less rugged and less continuous, subparallels the North Viking moraine. The two end moraines are separated by a rolling ground-moraine plain on the west and the dry bed of West Bay on the east. Southwest of the North Viking moraine is a gently undulating outwash plain which gives way to another ground-moraine plain in the extreme southwestern part of the area. In the eastern part of the central ground-moraine plain is a series of northward-striking ridges, generally of ice-contact origin.

The central ground-moraine area and the northeastern parts of the North Viking end moraine are marked by a series of linear and subparallel ridges. The ridges are composed largely of till and grade into and alternate with conspicuous morainal ridges. They give the ground moraine a subdued corrugated appearance and are called "washboard moraines" in this report.

The North Viking end moraine is divided by a southwest-trending chain of kettles occupied by lakes. This kettle chain is referred to hereafter as the "Long Lake depression."

The following climatic data for the Minnewaukan area were assembled from summary tables for the Devils Lake weather station with some interpolation from accompanying maps (Bavendick, 1946). The mean annual average temperature for the area is about 37° F. The annual average temperature ranges from 27° to 48° F. The average annual precipitation is about 17 inches. The growing season averages about 120 days in length, during which time most of the precipitation occurs.

The principal occupation of the area is farming. The main crops are wheat, flax, and hay.

The largest community in the area is the city of Minnewaukan, population 521 (1950 census), which is in the south-central part of Benson County about 21 miles west of the city of Devils Lake. It is the county seat and is the principal trading, shipping, and banking center for the area. The city is served by two important highways, State Highway 19 from the east and west, and U. S. Highway 281 from the north and south. It is located on the branch of the Northern Pacific Railway that connects Jamestown and Leeds.

Present Water Supply and Future Needs

By far the greatest use of ground water in the Minnewaukan area is for farm supplies. Practically all those supplies are obtained from wells in the glacial drift which range in depth from 12 to 200 feet. Most of the water is highly mineralized but is more or less satisfactory for general purposes.

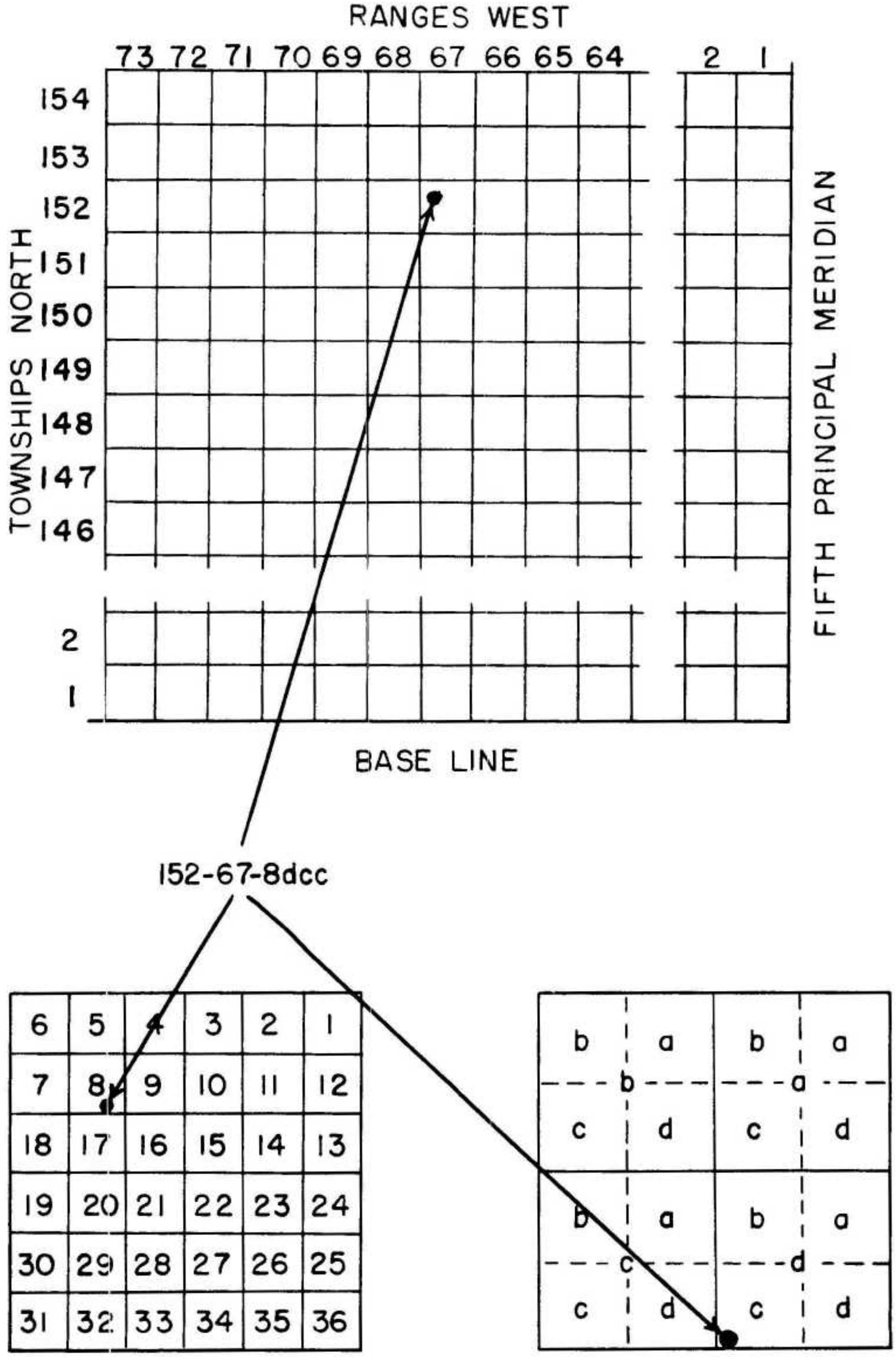


FIGURE 3.– SKETCH ILLUSTRATING WELL-NUMBERING SYSTEM

The city of Minnewaukan has no public water-supply system at the present time. Small supplies of highly mineralized water are obtained from wells in deposits of sand and gravel in the till and from aquifers in the Pierre shale. Because of its high mineralization (see pp. 65-68), the water from these wells is seldom used for drinking and culinary purposes, the principal use being for flushing toilets in private sanitary systems. Occasionally, the well water is used for irrigating lawns and gardens.

Rain water caught from the roofs of buildings and stored in cisterns is used for many domestic purposes, and a considerable amount of water for drinking and culinary use is hauled into the city by private tank truck from a well north of Maddock, N. Dak.

In the future, water supplies for municipal, industrial, and irrigation purposes may be needed in the area. At present, however, the only pressing demand is for an adequate water supply for the city of Minnewaukan. It is estimated that about 50,000 gallons of water a day would be required for a satisfactory municipal water supply for the city, although the present use of water is much less than that amount.

Well-Numbering System

The well-numbering system used in this report is based upon the location of the well with respect to the land-survey divisions used in North Dakota. The first number is the township north of the base line. The second number is the range west of the fifth principal meridian. The third number is the section within the designated township. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter sections, the quarter-quarter sections, and the quarter-quarter-quarter sections (10-acre tracts). If more than one well occurs within a 10-acre tract, consecutive numbers are given to them as they are scheduled. This number follows the letters. Thus, well 152-68-8dcc is in T. 152

N., R. 68 W., sec. 8. It is in the southwest quarter of the southwest quarter of the southeast quarter. Similarly, well 153-67-3aab2 is in the northwest quarter of the northeast quarter of the northeast quarter of sec. 3, T. 153 N., R. 67 W., and is the second well scheduled in that 10-acre tract. Numbers for wells not accurately located within the section may contain only one or two letters after the section number, indicating that the location of such wells is accurate only to the quarter or quarter-quarter section, respectively.

Figure 3 illustrates how the numbering system is applied.

The test holes were given serial numbers in the field. Test holes drilled by the Geological Survey in 1946 and 1948 were designated USGS tests 16-45, inclusive. Those drilled by the Geological Survey in 1952 were designated USGS tests 506-528, inclusive. Test holes drilled for the city of Minnewaukan by Sigrid Solheim, the local driller, were designated Minnewaukan tests 1-9, inclusive. Test holes drilled for the city by the Layne-Minnesota Company were designated Minnewaukan tests 10-16, inclusive. These serial numbers have been retained in the report for purposes of reference and for ease of recognition by local people.

GEOLOGY

The geologic formations provide the framework for the water resources of an area. A fairly good understanding of the geology of an area can furnish many clues concerning the presence and amount of available ground water. The surface formations themselves may locally be water bearing or may suggest the location of deeper aquifers. The glacial and associated lake features and formations of the Minnewaukan area are therefore discussed in some detail in this report because of their relation to the hydrology and the occurrence of ground water.

Stratigraphic Units

Information on the stratigraphic units in the area was obtained from the test holes drilled by the U. S. Geological Survey, from test holes drilled by the city of

Minnewaukan, from private wells, and from surface exposures. For the formations below the Pierre shale, data were obtained from the logs of artesian wells in the communities of Devils Lake (Laird, 1941, pp. 25-27) and Leeds (Simpson, 1929, p. 73). The log of the Devils Lake well was compiled from samples by Virginia H. Kline, while employed by the North Dakota Geological Survey, and the description of these samples and their correlation may be considered accurate. The materials penetrated by the Leeds well are known only from the driller's log. Both Devils Lake and Leeds are about 20 miles from Minnewaukan (see fig. 2). Locations of the test holes are shown in figure 6 and the geologic sections in figure 8; the logs are given on pages 78 to 101.

The following is the stratigraphic section for the Minnewaukan area:

```
Cenozoic
     Quaternary system
          Recent series
               Deposits of intermittent streams
               Lacustrine clay, silt, sand, and gravel
          Pleistocene series
               Wisconsin stage
                    Mankato substage
                         Till and associated glacioaqueous deposits
Cenozoic or Mesozoic (?)
     Cretaceous or Tertiary system(?)
Mesozoic
     Cretaceous system
          Upper Cretaceous series
               Pierre shale
               Niobrara formation
               Benton shale
          Lower Cretaceous series
                                   ( Dakota (?) or Fall River (?) sandstone
               "Dakota sandstone"-( Fuson shale
                                   ( Lakota sandstone
```

The three surface units in the Minnewaukan area are the glacial drift of the Pleistocene series, lake deposits of Recent origin, and thin, patchy stream deposits, also of Recent origin. In the absence of evidence indicating an earlier age, the drift is considered to belong to the Mankato substage of the Wisconsin stage.

The immediately underlying bedrock in practically all places is the Pierre shale of Cretaceous age. A clay from a stratigraphically higher formation was penetrated in USGS test 19 (152-68-35bbc). This material may be of Upper Cretaceous or Tertiary age.

In the lower part of the section, the Dakota sandstone or Fall River sandstone or both, the Fuson shale, and the Lakota sandstone constitute collectively the aquifer generally referred to in North Dakota and possibly elsewhere as the "Dakota sandstone." In this area, neither the total thickness of the "Dakota sandstone" nor the character of the formations below it is known.

Although only the glacial drift, the Pierre shale, and the "Dakota sandstone" are of interest as aquifers in this area, the pages immediately following contain lithologic information on all the units listed in the stratigraphic section. Detailed information on the units as aquifers is given in the hydrology section of the report.

Glacial Drift 3/

The material deposited by glacial ice and its meltwaters is called drift and is derived largely from the local bedrock. It is subdivided into (a) till and (b) stratified drift.

In this area the Pierre shale is the bedrock from which most of the drift is derived. The shale, when weathered or abraded by running water or by glacial ice, breaks down into brittle pebbles and a calcareous clay.

The color of the drift in fresh well cuttings changes from a yellow brown to a blue gray at about 10 to 20 feet below the surface. The depth of the yellow-brown zone at each test hole is indicated in the sections as the bottom of the oxidized

3/ As discussed later in some detail (p.20), the break between the Recent lake sediments and the glacial lake sediments is not clear. Insofar as can be determined from the results of the test drilling and field work, these two units are more or less continuous. For purposes of discussion, therefore, the Recent lake material is considered in this section as part of the glacial drift. The Recent stream deposits are discussed in the section on drainage.

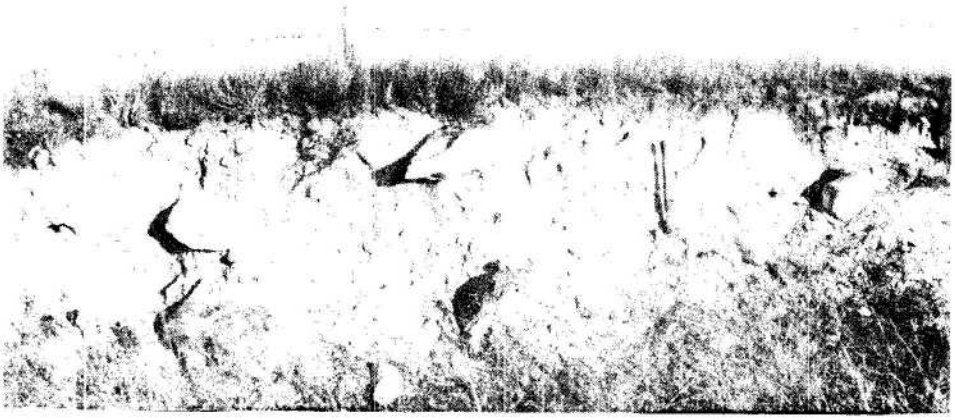


Figure 4.---Bouldery till exposed in road cut in North Viking moraine. Shovel is about 28 inches long.

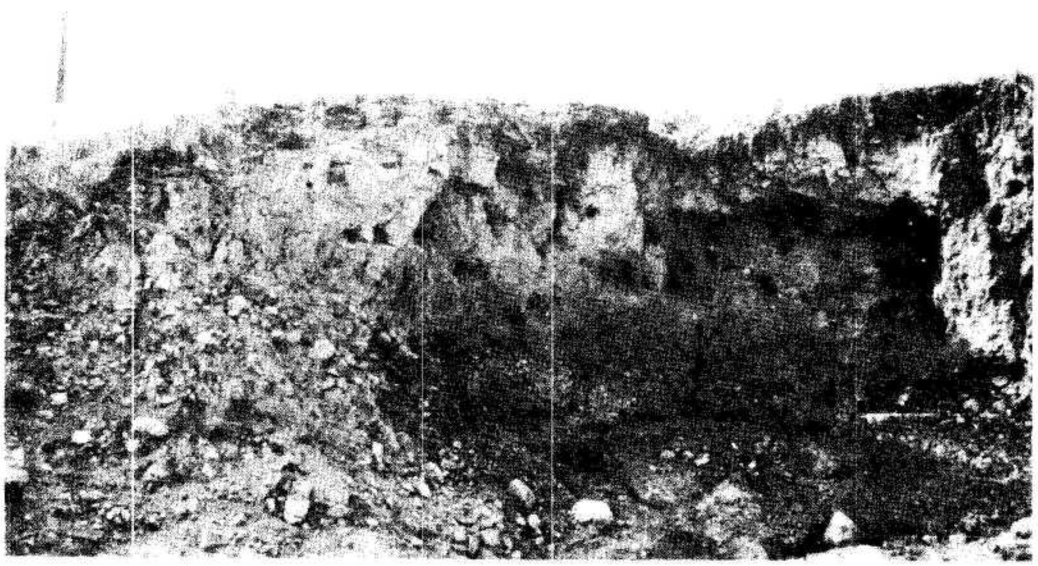


Figure 5.---Road cut through ice-contact feature in SE$\frac{1}{4}$ sec. 29, T. 153 N., R. 67 W., on west side of road. Sorted material at left passes under washed till at right.

zone (see fig. 8). In desiccated samples, such as are examined in the laboratory, the change is from a dull brown or buff to a light or dark gray. The brown is due to oxidation and hydration of the iron-bearing minerals in the drift. The gray is the color of the original Pierre shale.

Till

Till is an unstratified heterogeneous mixture of clay, silt, sand, gravel, and boulders. The till seen at or near the surface in road cuts (see fig. 4) or other exposures in the Minnewaukan area, and in cuttings from test holes, may have some or all of the following characteristics. It may:

Be composed largely of gritty clay and of other materials of all sizes.

Have an over-all color of yellow brown in the oxidized zone near the surface and gray below.

Have a rough, blocky fracture, tending to flakiness when dry.

Be highly calcareous and effervesce in dilute hydrochloric acid.

Contain boulders and pebbles of limestone and dolomite, as well as of shale, granite, and gneiss, which may fall apart at the touch.

Have tiny, distinct red-orange rust flecks.

Contain platy crystals of gypsum, generally less than a quarter of an inch in longest dimension.

Local variations and absence of any of the above characteristics result from particular hydrologic conditions and the lack of certain materials.

The till generally does not yield water to wells, but functions as a confining bed for water contained in associated deposits of sand and gravel.

Stratified drift

Stratified drift is a term applied to material that is layered and, to some extent, sorted. This layering and sorting is due to the action of water. Glacial stream deposits consisting of sorted sand and gravel generally are better aquifers than the glacial-lake deposits, which generally consist of well-sorted silt and clay, but which may contain some sand and gravel. The stratified drift is irregularly distributed and highly variable in its water-transmitting properties, but in the aggregate it constitutes the most important aquifers in the area. (See fig. 5.)

Bedrock

An unidentified deposit of gray gypsiferous, sandy clay about 19 feet thick was penetrated above the Pierre shale in USGS test 19 (see fig. 7). The likelihood of up-hole contamination of the drill cuttings from this test hole renders definite classification of the material difficult, and the material may be till. About the only definite statement that can be made concerning the age of this material is that it may be Upper Cretaceous or Tertiary. Similar well cuttings were obtained from test holes near the village of Maddock, which is 8 miles west of the Minnewaukan area. This material is not water bearing.

The total thickness of the Pierre shale, Niobrara formation and Benton shale in the Devils Lake well is about 1,270 feet. The total thickness in the Leeds well is about 1,640 feet (see p. 10). In the Minnewaukan area it is probably somewhere between these two figures. However, in the absence of detailed correlations for the Leeds well, the thicknesses given in the discussion below are taken, without any interpolation, from the log of the Devils Lake well.

The Pierre shale, a marine deposit, is about 560 feet thick and immediately underlies practically all the drift in this area. As found in the USGS test holes, the shale is a gray compact fissile rock containing occasional thin layers of calcareous material. Bentonitic beds from a few inches to a few feet in thickness were penetrated in some test holes and this may be the material described by local drillers as "soapstone." The log of the Devils Lake well (pp. 98-100) indicates that, in the portions not penetrated by the USGS test holes, the shale is tan in places and contains varying amounts of sand, lignite, gypsum, and sulfur.

The bulk of the shale is not water bearing, but some farm water supplies are obtained from the upper 100 feet or more of the formation in this area as well as in other parts of North Dakota.

The Niobrara formation in this area is about 120 feet thick. It is gray or tan and contains small amounts of gypsum and lignite. It is not an aquifer.

The Benton shale in this area is about 590 feet thick. It is gray and contains varying amounts of pyrite, gypsum, and sulfur. It is not an aquifer.

The Leeds well is thought to have penetrated about 370 feet of the units known as the "Dakota sandstone," the Devils Lake well about 180 feet. The following descriptions and thicknesses given for these units are taken from Kline's log of the Devils Lake well (Laird, 1941).

The Dakota sandstone is about 50 feet thick and consists mainly of gray shale with some sand in its upper and lower portions. It also contains varying amounts of sulfur, pyrite, and gypsum.

The Fuson shale is about 40 feet thick, is gray, and contains varying amounts of gypsum and sulfur.

The Lakota sandstone is about 100 feet thick and contains considerable amounts of shale in the upper part, and varying amounts of pyrite, sulfur, and gypsum throughout.

Simpson (1929, p. 40) notes that, for convenience in his report, "the entire group of water-bearing sandstone beds below the Benton, with the intervening shaly or calcareous beds, is called Dakota sandstone, though it may include earlier Cretaceous rocks, especially in the western part of the State." The Dakota sandstone proper he describes (pp.40-41) as "a gray ferruginous sandstone, very poorly cemented and interbedded with thin layers of clay and shale. In places it includes beds of fine incoherent nearly white sand."

It seems likely that what has been divided into the Dakota (?), Fuson(?), and

Lakota(?) in the log of the Devils Lake well is the Dakota sandstone as used by Simpson in the broad sense.

The screen and gravel packing in the Devils Lake well are so set that the well cannot obtain water from any formation above 1,410 feet--that is, from any formation other than the one called the Lakota.

From Simpson's account (p. 73) it is not clear at what depth in the Leeds well the principal water-bearing formation in the "Dakota sandstone" occurs, but it would appear to be at a depth below 1,640 feet.

The land-surface elevation at the Devils Lake well is about 1,460 feet, and at the Leeds well between 1,500 and 1,510 feet, above sea level. Minnewaukan is about 1,460 feet above sea level. Using these data together with the depths to the "Dakota sandstone" at Devils Lake and Leeds, a simple computation indicates that the water-bearing part of the "Dakota sandstone" in the Minnewaukan area lies somewhere between 1,410 and 1,590 feet below the land surface.

Lake Features

The lakes in the Devils Lake-Stump Lake region are shown in figure 1. The outlines of the lakes shown on this map are those of 1883, the year of the first land survey, from which most subsequent geographic maps have been compiled.

The chain of lakes north of Devils Lake drain one into the other from east to west--that is, from Sweetwater Lake through intermediate lakes to Lake Irvine. Lake Irvine in turn drains into Devils Lake by way of the lower part of Mauvais Coulee, which is a large intermittent stream extending almost to the Canadian border. There is no surface drainage from Devils Lake at the present time, but, perhaps within historic time, water from Devils Lake drained through Jerusalem outlet into Stump Lake. Prehistorically, water from Stump Lake drained through Big Stony Coulee into the Sheyenne River.

Devils Lake itself is divided into several large bays and arms whose relations are also shown in figure 1. Since the 1883 survey, the water level of the lake has undergone a progressive lowering which has caused West and Lamoreaux Bays to dry up, while Main and East Bays have become separated, as have the East and West Bays of Stump Lake. Occasionally in the spring, parts of the various bays of the lake have been filled up to the old 1883 level, temporarily, until the water has drained to the lower portion of the lake. Since about 1940 the lakes have partly refilled but have not approached the 1883 stage.

West Bay of Devils Lake, most of which is in the Minnewaukan area has been more or less dry since about 1910. It generally floods briefly in the spring, but by early summer many of the marshy spots disappear. The extensive but stunted grass cover provides grazing for cattle and sheep, and occasionally crops of flax are grown in the bay area.

Two well-developed strand lines, higher than the 1883 stage, circumscribe the dry lake bed. The strand lines below these are poorly marked and merge into spits, bars, and anomalous irregularities. All of these features are fringed with or are completely covered with trees and brush.

Strand Lines of West Bay

According to Flint (1948, p. 163) a strand line may be defined as "the line traced on shore rocks, either firm or unconsolidated,by erosional or depositional shore features developed at mean sea level or at the level of a lake, whether or not the line is now at mean sea level or lake level." Among the commonest forms developed by stands of water are (1) wave-cut scarps and terraces and (2) beaches.

Wave-cut scarps and terraces are steplike notches, which around West Bay are generally less than 10 feet high (see fig. 7). The scarp is the riser and the terrace is the step. This form is the most prevalent at the two higher strand lines ("J" and

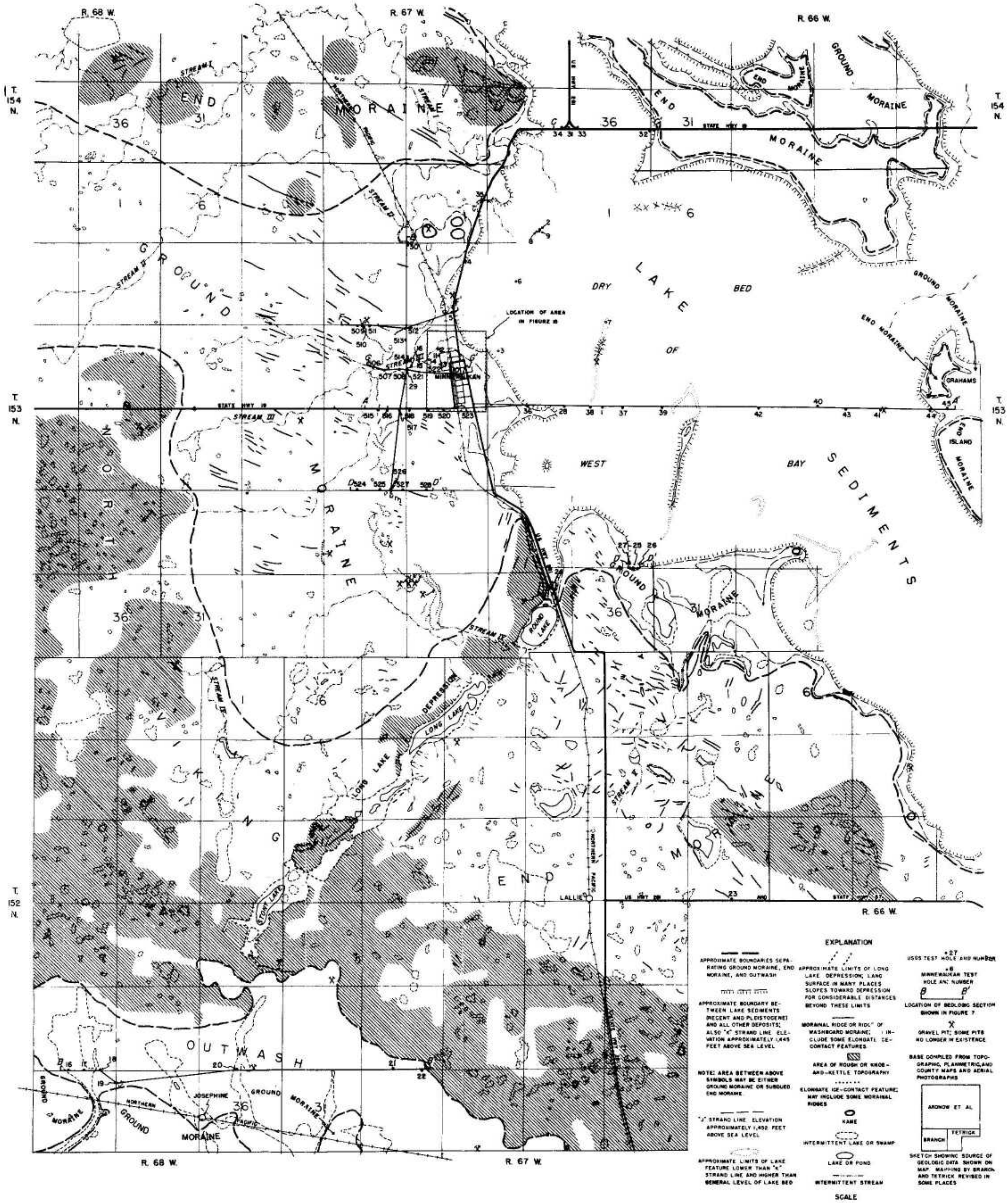


FIGURE 6.- MAP OF MINNEWAUKAN AREA, NORTH DAKOTA, SHOWING GLACIAL GEOLOGY AND LOCATION OF GEOLOGIC SECTIONS AND TEST HOLES.

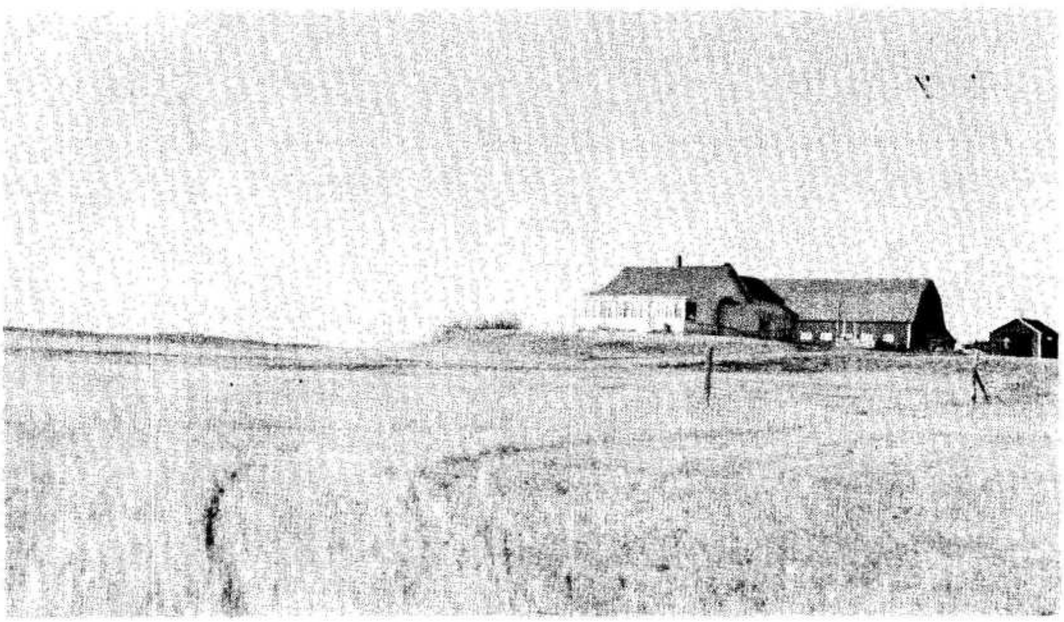


Figure 7.--The "J" strand line, NW¼ sec. 2, T. 153 N., R. 67 W. (looking northeast).

"K") shown on the map (fig. 6). These small scarps are cut into the glacial drift, mostly till, which surrounds and underlies the lake depression. The area between these two strand lines for the most part is underlain by slightly reworked drift and is practically indistinguishable from the drift outside the lake area. The contact between the lake deposits and the surrounding drift is shown at the base of the "K" strand line where a sloping terrace of sand and gravel was built in some places. This contact is not everywhere correctly represented but is satisfactory for a reconnaissance map. Most of the locations for the two upper strand lines were determined from aerial photographs with the aid of a steroscope and topographic maps. They were spot-checked in the field and are believed fairly accurate except for those places indicated with a question mark.

The lower strand lines are developed mostly as beaches and in some places are difficult to distinguish from spits and bars that originated when the water was high enough to carve the upper strand lines.

Partly because the clay till stands up much better than does the lacustrine sand and gravel, the higher strand lines are better developed and preserved than are the lower beaches. Also, the gentle slopes on which the lower beaches rest did not permit waves of sufficient strength to do much cutting.

Simpson (1912) believed that the two upper strand lines were related to the early post-Pleistocene history of Devils Lake and Stump Lake and proposed a theory as to their origin. Simpson's hypothesis depends on the similarity of altitudes of the two upper strand lines to those of certain outlet channels from Devils Lake and Stump Lake. Because (1) the altitudes of Simpson's upper strand lines and those considered in this report are at variance and (2) the area does not include any of the key outlet channels, the reader is referred to Simpson's paper for further details. The two upper strand lines were the ones chiefly studied for this report. Because there apparently is some dispute in regard to their altitudes, a short summary of the literature follows.

Upham (1896, pp. 595-597) leveled the three upper strand lines near Minnewaukan and the city of Devils Lake and recorded their altitudes as 1,451 feet, 1,446 feet, and 1,439 feet above sea level, respectively.

Simpson (1912, pp. 144-148, 152) leveled the strand lines on Devils Lake in two places, near the city of Devils Lake and near Chataugua. Although he did considerable additional leveling, these places are the nearest points to West Bay for which he determined altitudes. He recorded the two upper strand lines at 1,460 feet and 1,453.5 feet respectively.

Easker (1949, pp. 29-30) found three strand lines in the northern part of the Tokio quadrangle. The upper ones were fairly well developed and recognizable at about 1,460 feet and 1,440 feet, respectively. A third, not so well defined as the others, was found 10 to 15 feet below the 1,440-foot strand line. It should be noted that Easker had no opportunity to do any instrumental leveling. His map shows the two upper strand lines on the 1,460-foot and 1,440-foot contour lines, respectively.

Tetrick (1949, p. 12) says, "The highest water mark for Devils Lake is approximately 1,475 feet, as evidenced by wave-cut morainic knobs surrounding the part of Devils Lake in the Oberon quadrangle. The highest remaining beach level is about 1,460." Tetrick, like Easker, did no instrumental leveling. No clear-cut evidence for Tetrick's 1,475-foot Lake level was found in the Minnewaukan area by the authors, though certain obscure features may possibly indicate the previous existence of the lake at approximately this high level.

The authors' leveling around West Bay was confined to the upper strand lines at points along and near Highway 19 from the northeast corner of the area to Minnewaukan. The rod was held at the break in slope at the base of the scarp. The lower strand lines were considered too indistinct for leveling. The leveling indicated the uppermost one, the "J" strand line, to be between 1,451 and 1,452 feet, and the lower one, the "K" 4/ strand line, between 1,444 and 1,445 feet. These are just about the elevations Upham obtained. Simpson did not level strand lines around West Bay and hence the authors' results cannot be directly correlated with his. However, the results of Upham's leveling around the city of Devils Lake, where presumably Simpson also leveled, showed strand lines at the same altitudes as those around Minnewaukan. Simpson, in his report, gave no precise locations of his leveling and it is somewhat difficult to know exactly to what he refers. Subsequently, the authors did some leveling south of the city of Devils Lake which indicated strand-line altitudes about the same as those around West Bay.

Probably the discrepancy between Simpson's results and the authors' may be explained by Simpson's using bench marks whose elevations were inaccurate.

Sediments of the Lake Basin

The term "lake basin" as used here refers to both the topographic depression formerly occupied by West Bay of Devils Lake and the "low" in the bedrock under the dry bed of West Bay.

Upham (1896, p. 170) and Simpson (1929, p. 190) thought that Devils Lake occupied the site of a preglacial river channel. The test drilling has confirmed the existence of a bedrock "low" under West Bay (see fig. 8). Because the extent of glacial deepening of the bedrock "low" is not known it would be difficult to correlate this "low" with other bedrock depressions on the basis of elevations. If not fortuitous, the lesser slope angle on the west side of the "low" suggests that it may extend in a north-northwesterly direction, if it is really a symmetrical channel.

On the basis of well cuttings, it was not possible to make clear distinctions among the Recent and glacial-lake sediments and the drift of other possible

4/ These letters were used to avoid confusion with Simpson's use of the first letters of the alphabet to designate his strand lines.

origins 5/ upon which they rest. For purposes of discussion, distinction is made here between only "surficial" and "underlying" sediments. The section on the surficial sediments includes a description of the more or less shallow lacustrine materials and their surface forms, whereas that on underlying sediments includes a discussion of some deeper, possibly glacial-lake, materials and the underlying and adjacent drift.

Surficial sediments

The surficial sediments and their topographic forms were not studied in any great detail in the field. The principal forms, other than the "J" and "K" strand lines, are shown on the map (fig. 6) in dotted outline. Many smaller ones, some of which contain pits, have been omitted.

A number of factors complicating the geology of the dry lake bed should be noted.

(a) The initial uneven drift surface.

(b) Regressive strand-line deposits which have been reworked and merged into spits and bars deposited originally in relation to higher strand lines.

(c) Probable deepening of West Bay by wind erosion in times of drought.

(d) The annual flooding of West Bay.

Because of these factors no extensive discussion of the significance of the materials and their areal positions will be attempted in this report. Also, there is uncertainty of identification of the uppermost material in USGS tests 38, 39, and 42 (see logs), because stratified coarse and fine material is churned in rotary drilling so that, in some cases, the samples obtained resemble those from till.

The Recent lake sediments are the surficial materials that cover most of the dry bed of West Bay below the "J" strand line (see p.16). The age of the"J" strand

5/ The general term "glacioaqueous" is used in the cross sections (fig.8) for water-sorted material associated with glaciation. Included under it are ice-contact, glacial-stream, glacial-lake, and outwash deposits. It is generally impossible to infer definite origins for much of the subsurface glacial material from an examination of well cuttings.

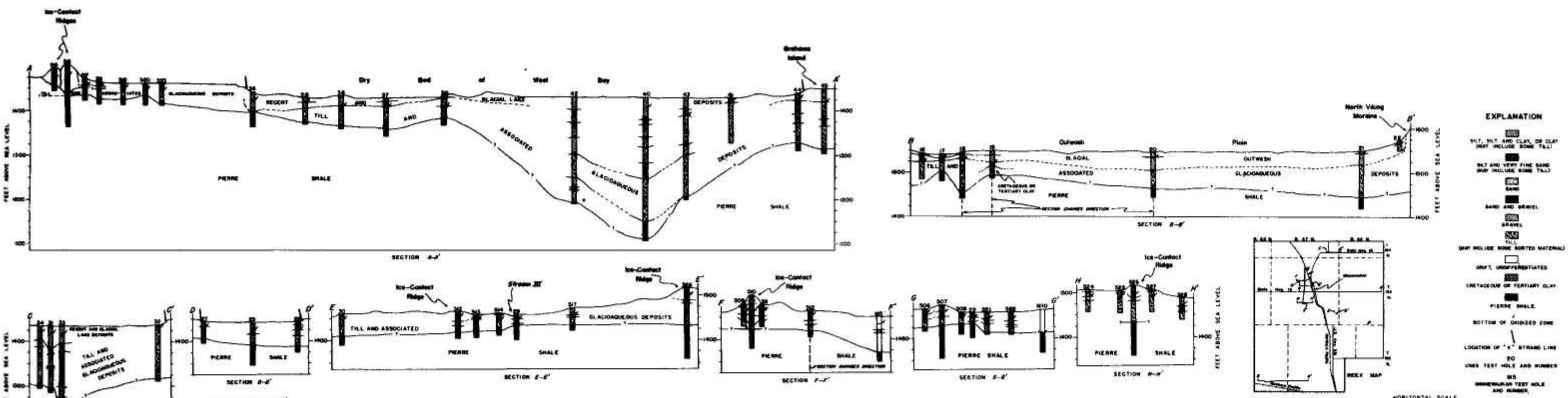


FIGURE 8.— GEOLOGIC SECTIONS IN MINNEWAUKAN AREA
(LOCATION OF SECTIONS AND TEST HOLES SHOWN IN FIGURE 6)

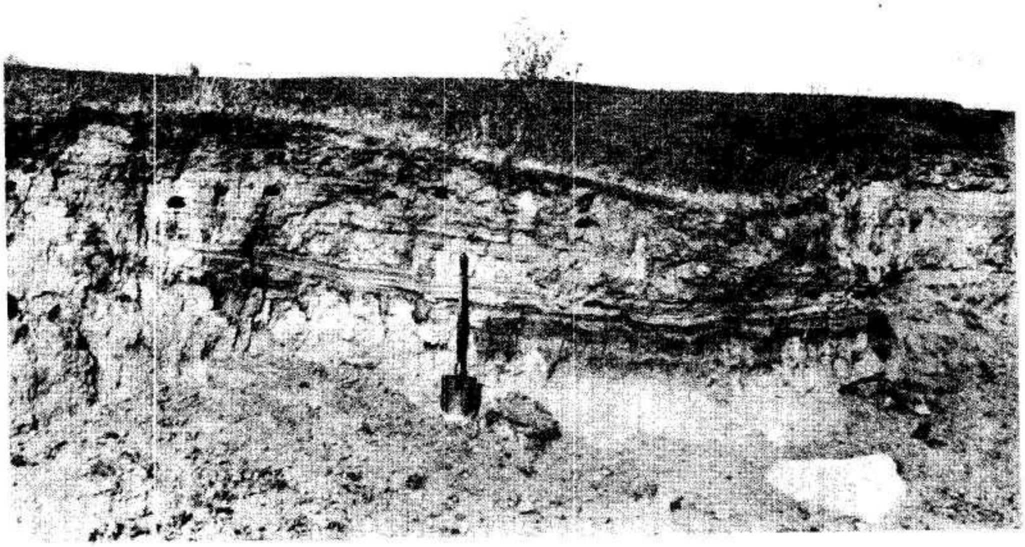


Figure 9.--Stream cut in channel of stream II in dry bed of West Bay, sec. 2, T. 153 N., R. 67 W., showing laminated silt and clay. Note boulder at lower right.

line is not known; it may date back to the Pleistocene, though this is not likely.

In the geologic sections across the dry lake bed (see fig. 8) there is no "discontinuity" in the lake silt and clay that definitely marks the end of the Pleistocene and the beginning of the Recent. Probably sedimentation in the lake bed was continuous from the time the last ice disappeared from the site of the lake bed to the present, although at a diminishing rate. At the present time sedimentation occurs chiefly during brief spring flooding. Therefore, the silt and clay unit in the sections includes glacial-lake sediments below grading into Recent sediments above.

These sediments are shown in figure 8, cross section B-B', to be as much as 50 feet thick. Theoretically, the stratigraphically lower lake sediments should contain a generous amount of ice-rafted material deposited when the ice was near the lake, and the higher beds, deposited when the ice front had withdrawn a considerable distance from the lake, should be relatively free of ice-rafted material. However, examination of the rotary-drill samples did not indicate the presence of these two types of sediments. It is possible that both types do not occur in this area. However, the uppermost lake beds contain coarse material, presumably reworked from spits and bars. Perhaps this upper coarse material became mixed with the cuttings from the beds free of ice-rafted material during the drilling, rendering the samples from these beds practically indistinguishable from those obtained from the lower beds which contained considerable ice-rafted material. This would likely be the case if the beds free of ice-rafted or other coarse material were only a few feet thick. Identification of beds free of ice-rafted material probably could be made from undisturbed cores.

The flat areas of the lake bed seem to be underlain generally be silt, clay, and reworked till. Almost the only good exposures of these finer lake sediments were observed in the lower channel of Stream II where it has incised the lake bed (figs. 9 and 12). As much as 7 feet of laminated clay, silt, and fine sand is exposed. The laminations do not appear to be sufficiently distinct and regular to be varves. In a few other faces of the stream cut are stratigraphically higher intermittent stream deposits like those described in the following section on drainage.

Another exposure, on the east side of U. S. Highway 281 and about 0.6 mile north along the highway from the southern line of sec. 36, T. 153 N., R. 66 W., also shows laminated silt and clay. It is not clear, however, whether the exposed material is of lake or kame-ter-race (ice-contact) origin. This uncertainty applies to the pit north of USGS test 24 as well as to other sand and gravel deposits exposed in road cuts in the immediate vicinity.

Sand and gravel are associated generally with definite topographic forms such as spits, bars, and beaches, but some deposits of these coarse materials occur near the surface of the lake bed and are not associated with recognizable topographic features of this kind. Several small pits have been opened in this material (see fig. 6). The principal difference between the contents of these pits and those in ice-contact deposits is the lack of clay and silt, which gives the lacustrine sand and gravel a cleaner, whiter appearance. There is also some diminution of shale content.

No pebble counts were made but the cursorily observed variations of shale percentages and sizes among the lacustrine pits suggest a residual origin for some of the material. For example, the pit near USGS test 41 (about half a mile west of Grahams Island) contained shale boulders up to 9½ inches in diameter, which disintegrated upon removal from the sides of the pit. This disintegration is probably due to the dry condition of the shale. However, shale is a fragile and easily rounded material which ordinarily will not withstand extensive abrasion and transportation. In the till or ice-contact deposits such large pieces of shale are rare. It is possible that the shale that formed the boulders was incorporated in the glacial ice and deposited by icebergs directly into the lake water without an extensive intermediate reworking by glacial movement. The subsequent immersion in the water may have lessened the tendency to break along planes of weakness and have accentuated the rounding effects initiated by the ice.

The locations of the two north-south bars east of Minnewaukan seem to be controlled to some extent by an initial irregularity in the drift or bedrock surface. The westernmost one (north of USGS test 38), has a number of large boulders, some as much as 3 feet in diameter, scattered around its flanks. A local driller's log (see Minnewaukan test 7, p. 84) for a test hole at the north end of the bar shows 6 feet of clayey sand and gravel which may be till below the top 2 feet of sand and gravel. The material below that is almost certainly till. The bar may have been deposited on a ridge or mound of till which was the starting point for sediment accumulation. The large boulders may be residual from this till "high"or may even have been deposited by stranded icebergs from a nearby ice front.

Similar considerations probably hold true for the bar to the east, near USGS test 39. The "J" strand line in that feature was not visited, but it is fairly certain that it is cut in till. USGS test 39 shows a rise in the bedrock, which also may be a factor in the origin of the feature.

Numerous boulders residual from the till and formerly concentrated as ice ramparts (see p. 44) are found in many places at the bases of the "J" and "K" strand lines. A particularly large accumulation was seen in the SE¼ sec 8 and the NE¼ sec. 17, T. 152 N., R. 66 W.

Underlying sediments

A full discussion of the underlying sediments in the lake basin is given in the hydrology section. Some of the strictly geologic implications of these sediments are noted briefly in this section.

In USGS tests 40, 43, 44, and 45 (see figs. 6 and 8) there are two zones of till separated by sorted materials. In USGS test 42, in which the upper till is missing, and in USGS test 40 the lower till is underlain by sorted material which rests upon the bedrock. The presence of two till zones suggests two glacial advances. The first may have been preceded by an apron of meltwater which deposited the sorted material found in the bottoms of USGS tests 42 and 40. The sorted material between the till sheets may be outwash or other glacial-stream deposits or glacial-lake deposits. Obvious limitations on these speculations are imposed by the fact that neither the glacial scouring of the bedrock nor the amount of drift subsequently eroded is known.

One layer of till enclosed in sorted material in USGS tests 34, 31, and 33 (see fig. 8) may be continuous with the till in the A-A' cross section. This may be associated with the possible deposition of the eastern portion of the northern moraine in the waters of Lake Minnewaukan (the Pleistocene equivalent of Devils Lake, Simpson, 1912, p. 140).

The possibility that the deeper till zone is pre-Mankato in age has, of course, occurred to the authors. However, the well cuttings showed no evidence of buried soils or oxidized zones. In the absence of this kind of evidence it is assumed that the burial of the till zone was an event in Mankato time involving a minor fluctuation of the ice front.

Glacial Features

Glacial geologists use two classifications of glacial features simultaneously: (a) lithology, or of what they are made, and (b) topographic expression, or how they appear. The general lithology of glacial materials has been discussed in the section "Stratigraphic Units." The various and combined topographic expressions of these features will be discussed here.

End Moraine

End moraines are tracts of rough, elevated, and usually pitted topography and on a regional scale are linear in ground plan. The term "knob-and-kettle topography" commonly describes such surfaces because of the juxtaposition of steep-sided hills and depressions. The hills may be rounded and the depressions circular, elliptical, or irregular.

An end moraine marks a place where the glacier halted. This does not mean that it ceased moving, but rather that its edge was melting as fast as the ice was advancing. All sorts of debris picked up by the ice as it moved forward was dumped at the terminus when there was no longer ice to carry the material beyond that point. The longer the edge remained stationary, and the more debris carried by the ice, the more debris was deposited. An advance of the ice front caused a ridging up and overriding of previously deposited debris much as would occur in front of a bulldozer. If the debris was deposited by the ice with little or no water action, till was the result (see fig. 4). However, if considerable meltwater was formed, the deposits became more or less sorted and layered. As the ice front oscillated there was a continuous destruction, disturbance, or burial of meltwater channels and ice-contact features, which produced the complex and more or less confused topography and lithology associated with end moraines.

The locations of the end moraines in the Minnewaukan area are shown in figure 6. They may be classified as well developed or typical where they form a more or less continuous, pitted topographic "high," or as poorly developed or modified where the steep-sided hills are present but no conspicuous steep-sided depressions. Representative of the first type is the North Viking morainal belt, which crosses the area from the southeast corner to the west-central margin. The portions of the moraine that contain knob-and-kettle topography are indicated in figure 6 by a special symbol. Along the southern limit of this moraine, where it fronts on the outwash plain, are ridges which parallel the edge of the moraine, and in some cases form the edge. These ridges are steep sided, and are similar to eskers in appearance. However, the steep sides seem to be due mainly to the numerous boulders that make up most of the materials of these ridges. A very good example can be seen in the SE$\frac{1}{4}$ sec. 24, T. 152 N., R. 68 W. This ridge contains a small gravel pit (see fig. 6).

Sorted material is believed to be a minor component of the ridge, however.

An example of the poorly developed end moraine is an unnamed one in the northern part of the area. The total relief there is approximately 75 feet. This moraine, or group of moraines, is a more or less discontinuous topographic "high". Its eastern parts as well as the eastern limit of the western part are roughly bounded by the "J" strand line of the former Devils Lake (see p.16). The southern boundary of the western part is roughly the southern limit of large isolated hills and rough tracts. This southern boundary is sharply contrasted with boundaries of the eastern part in that it is gradational. A similar contrast is also evident between this southern boundary and the southern boundary of the North Viking moraine.

In general, there are only a few steep-sided depressions in this moraine. About the only conspicuous ones are those in secs. 26,27,34 and 35,T.154 N., R 67 W., and in secs. 25 and 26, T. 154 N., R. 68 W. The appearance of this region suggests a rather halting advance and retreat of the glacier, which paused in no single place on a broad front long enough to build up a continuous moraine. It is also possible that this morainal area is what is left of a better developed moraine that was overridden during a subsequent advance of the ice.

The northern moraine is collinear with Grahams Island, the western edge of which is included in the Minnewaukan area (see fig.1). Grahams Island is a similar topographic high, bounded by lake sediments and without a distinctive morainic character.

Both in the eastern portion of the northern moraine and on Grahams Island the land surface may have been modified by lake waters when the former Devils Lake was possible higher than the "J" strand line (see pp.16-19). The smoothing of the surface by wave erosion and the deposition of thin, patchy, now unrecognizable lake sediments may have contributed to the lack of typical morainal appearance. Another possible explanation is that at least this eastern portion of the moraine and Grahams

Island may have been deposited in lake water. Whether these hypotheses can be applied to the western portion of the moraine can be decided only by further investigation, when the western part of the area has been mapped topographically.

Because this moraine has no knob-and-kettle topography it might be thought to be nothing more than a bedrock "high" thinly mantled with drift. However, figure 8 shows that Grahams Island is not necessarily the reflection of a bedrock high. Also, well data indicate a thickness of drift of more than 150 feet in the northeastern part of the moraine. USGS tests 31-34 immediately west of this part (see fig. 8, geologic section B-B') show the drift to be as much as 185 feet thick.

The morainal belts of the Devils Lake-Stump Lake region were first mapped by Upham (1896, pp. 162, 169-172, 175, 176). The moraines from his plate XVIII are shown in figure 1. The names he used were derived from the presumed correlatives of the morainal belts in Minnesota. Their status as interstate correlations has been revised by later work (Leverett, 1932, pp. 67-78), but they present a fairly accurate picture of the broader relations of the moraines, and are here used in the absence of detailed quadrangle mapping. The recent work by the North Dakota State Geological Survey has given rise to the name "North Viking" for the southern area, and it seems very likely that this name will be retained (Branch, 1947). Because of the indistinct boundaries, the northern morainal group will not be named now.

A cursory comparison of the moraines as shown by Upham (see fig. 1) and in this report (see fig. 6) will reveal several differences. The chief changes made in this report are (1) the addition of the "subdued" northern morainal area, (2) the interpretation of Upham's moraine just west of Minnewaukan as a series of ice-contact features, and (3) the designation of his two elliptical ground-moraine patches in the southeastern part of the area as end moraine. Upham's interpretation, under (2) above, has some validity, as can be seen from the knob-and-kettle topography indicated in figure 6, but the authors prefer to follow Branch's and Tetrick's later quadrangle mapping.

Upham's map does convey, however, the correct impression of the complexity of the moraines in the Devils Lake region. As an experimental start toward determining their relationships, it is thought that indicating the clearly knob-and-kettle type on a map would be of aid. This has been attempted in figure 6, mainly on the basis of data taken from aerial photographs. However, the area described in this report is not large enough for significant general relationships to be recognized.

Ground Moraine and Washboard Moraines

The ground moraine in the Minnewaukan area is shown in figure 6. Topographically it is a flat or gently rolling area, the relief generally not exceeding 30 feet.

Ground moraine may originate from (1) drift overridden and plastered down by moving ice, or (2) rock debris let down from the surface and body of the glacier as the ice thins and melts back. The latter process results in what is called "ablation moraine" and accounts for the sorted material present at or near the surface because of the abundance of meltwater accompanying the wasting of the glacier. Ablation moraine is difficult to identify, except locally. The bulk of the ground moraine is probably of class (1).

Hills in the ground-moraine area are numerous but generally are neither large nor steep sided. Locally, the relief is enhanced by associated ice-contact features and washboard moraines.

The ground moraine may consist of only a thin layer of drift overlying bedrock or it may consist of a very thick layer. For example, in secs. 18 and 20, T. 153 N., R. 67 W., there is a bedrock "low" more than 180 feet deep as indicated by wells that end in the drift at those depths. This low has been filled, or partly filled, with drift by the ice that formed the ground moraine. The lower part may have been filled by an earlier ice sheet.

Lithologically, ground moraine is largely till with pockets and lenses of washed till (till with most of the clay fines removed), silt, sand, and gravel.

The central ground-moraine area and the northeastern parts of the North Viking end moraine are marked by a series of linear and subparallel ridges, very plainly seen on aerial photographs but rather inconspicuous to an observer on the ground. They are composed largely of till and grade into and alternate with conspicuous morainal ridges. The ridges strike approximately northwest. These give the ground moraine a subdued corrugated appearance, which led Upham to include part of them in his end-moraine area west of Minnewaukan. Because of their low relief they have not been designated as end moraine in this report. In the North Viking moraine their occurrence is less systematic and their relief increases as they grade into the better developed parts of the moraine.

Such features have been referred to in the literature as "annual moraines." However, the authors prefer to call them by Mawdsley's (1936) noncommittal term "washboard moraines." On the aerial photographs they show up as white-topped ridges and black swales. The color of the ridge tops is probably due to the partial uncovering of the calcium carbonate-enriched zone by wind and slopewash, but it may be due to a change in the soil type (see Gwynne and Simonson, 1942). Individual ridges are generally less than a mile long. As exposed in road cuts, the ridges exhibit a lithology similar to that of ground moraines; that is, they are made up largely of till, with minor amounts of silt, sand, and gravel, and a few scattered boulders. The relief of these features is generally less than 20 feet.

Similar features have been identified in Finland, Sweden, Canada, and Iowa (see Flint, 1947, p. 130). The ones in Iowa described by Gwynne (1942) seem most like those in the Minnewaukan area. Gwynne identified them from aerial photographs, and mapped them in the way they are mapped here. On a regional scale, in Iowa, they subparalleled the margin of what was then considered the latest Wisconsin (Mankato) ice lobe and seem to mark minor oscillations in the regional retreat of the ice from the area. Gwynne's concept of their origin is that the material was originally laid down in a period of summer melting and ridged up by winter readvances. He thus implies that the ridges are annual.

On the basis of his observations in Canada, Norman (1938) thinks them to be annual and deposited in the water of proglacial lakes. Mawdsley (1936) believes they are in the nature of crevasse fillings, reflecting a fracture pattern in the ice that was parallel to the ice front. The work done in the Minnewaukan area did not throw any light upon their probable mode of origin. They are present in other parts of the Devils Lake region.

Their location in the central ground-moraine area and farther north suggests the possibility that this area was the site of a proglacial lake possibly part of Lake Minnewaukan (the Pleistocene equivalent of Devils Lake; Simpson 1912, p.140). They will be discussed further in the section "Ice-Contact Features."

Ice-Contact Features

Ice-contact features are those formed by meltwater around, in, and under cavernous and fissured ice that temporarily or permanently stopped moving. Ice-contact sediments are distinguished from other types of stratified drift, according to Flint (1947, p. 143), by "extreme range and frequent and abrupt changes in grain size; intimate association with till; and deformation." The specific types of ice-contact features are identified by their shape, lithology, and relation to other features.

The principal types of ice-contact features may be defined as follows: Eskers are sinuous steep-sided ridges deposited generally in tunnels at the base of glaciers. Crevasse fillings are even-crested ridges formed between blocks of ice. Kames are ideally conical, but may be short ridges, flat-topped or wedge-shaped. They may originate as alluvial fans down a steep ice face, or as deposits in openings in the ice. Kame terraces are formed by material deposited between an ice block and a valley wall. In all these, after the retaining walls of ice have melted, the deposits collapse and the materials assume the angle of repose consistent with their size distribution. Most of the above types will be referred to in this section of the report; the kame terraces will be discussed in the section on the Long Lake depression.

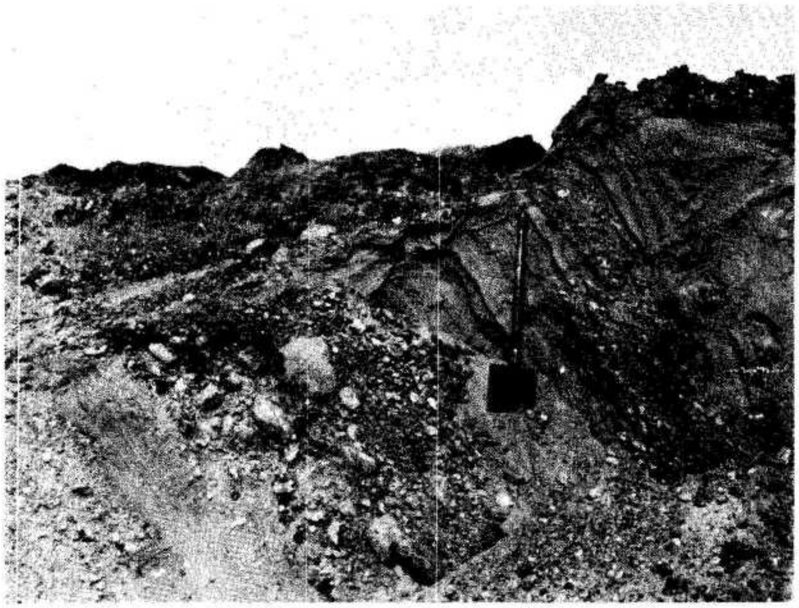
Ice-contact deposits contain sorted material such as gravel, sand, and silt because they are deposited by or in water.

The most prominent group of ice-contact features in the Minnewaukan area is located about a mile and a quarter west of Minnewaukan (see fig 6). This group is a series of elongate hills and ridges about 4 miles long that generally strike north. The individual ridges in the southern part of the group can be traced for longer distances and have a greater degree of parallelism than those in the northern part. The main trend of the group cuts across the general strike of the washboard moraines.

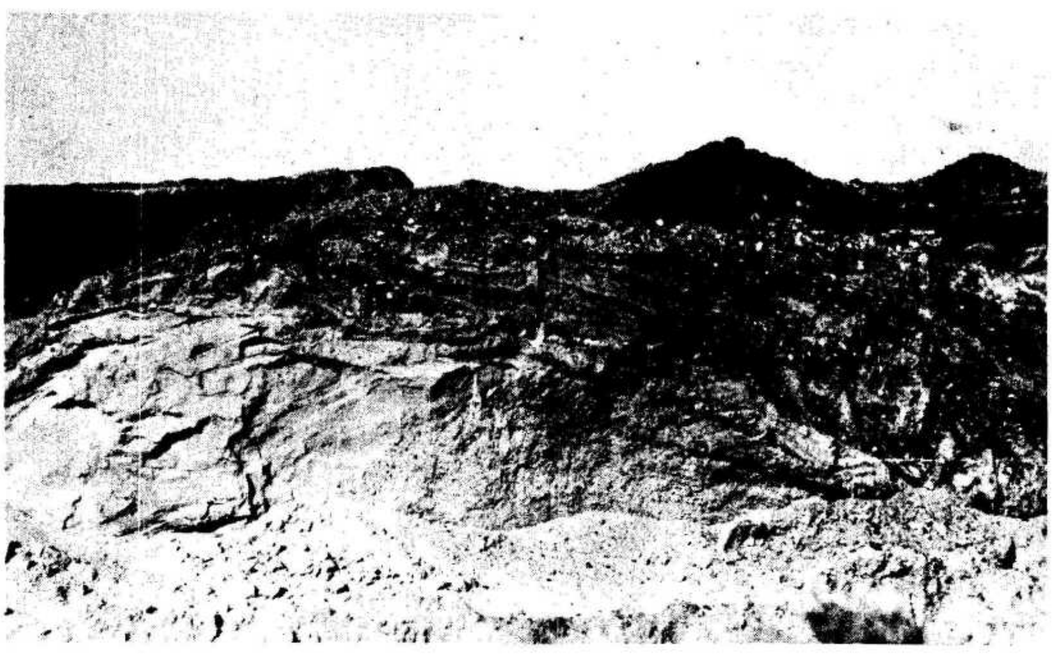
The highest point for which level data are available is the site of USGS test 526, which is 1,517 feet above sea level. The local relief there is about 25 feet (see fig. 8, section H-H'). The local relief near USGS tests 510 and 516 is much greater, about 45 feet (see fig. 8, s. A-A' and F-F'), but the absolute elevations are lower: USGS test 510 is 1,499 feet above sea level and USGS test 516 is 1,503 feet.

The materials in this group were exposed in gravel pits and road cuts. Geologic sections were drilled across the northern part of the group in four places (see figs. 6 and 8).

The material exposed in gravel pits in the northern part of the group is generally poorly sorted gravel with much sand, silt, and clay. The material in the pits at the southern terminus consists largely of gravel with very little silt and clay and only minor quantities of sand and boulders. Here the sorting and bedding



A



B

Figure 10.--Sediments in large ice-contact feature west of Minnewaukan in gravel pit in the NW$\frac{1}{4}$ sec. 34, T. 153 N., R. 67 W. Note disturbed and discontinuous bedding and rapid lithologic changes. Material in lower left of B is sand. Uppermost material in both pictures is spoil.

range from poor to excellent. These deposits show disturbed bedding characteristic of ice-contact materials (see fig. 10). The dip of some of the beds indicates that the depositing water flowed to the southeast. There is little or no till cover at the sites of the gravel pits. Most, if not all, of the material in the pits could have been deposited only by flowing water.

Two road cuts disclosed material entirely different in character and origin from that seen in the pits. Where one of the ridges is crossed by State Highway 19, about 12 feet of silt, clay, and fine sand is exposed. The nature of some of these beds indicates that they were deposited in glacial lakes. In the other road cut, in the northeast corner of sec. 16 and across the road in sec. 15, silt and very fine sand and washed till are exposed in an east-trending ridge.

The locations of four sections drilled across the group are indicated on figure 6, and the geologic sections are shown on figure 8. From north to south these are: F-F', G-G', the west end of section A-A', and H-H'. A north-south section, E-E', was also constructed.

The unravelling of the relationship among the various sorted materials and the till is complicated by the character of the material brought up as drill cuttings from a number of the test holes. 6/ The principal difficulty has been in distinguishing between a pebbly, clayey, very fine sand and silt that was easily recognized in road cuts because of its bedded or laminated character and a silty and sandy till that may have been partly reworked by running water. In the logs at the end of the report (pp. 78-101) the alternative interpretations are given, the more likely one given first. The more likely one is shown also in the geologic sections.

In some of the sections the drilling disclosed a complex relationship among the materials composing the ridges, underlying the ridges, and underlying the flanking lower topography. It was found in some test holes (a) that the sorted material under the ridges (that is, below the total relief of the ridges) was interbedded with

6/ This difficulty was encountered, as noted previously, in the examination of the cuttings from the uppermost parts of test holes drilled across the dry lake bed east of Minnewaukan.

till. In adjacent test holes the sorted material in the ridges was continuous with that underlying the ridges. This relationship may be seen in section F-F' in USGS tests 509, 510, and 511. It was also discovered that (b) the sorted material is not confined to the ridges but also immediately underlies the surface of some of the flatter adjacent topography, as in section F-F', USGS test 512, and in section G-G', USGS tests 508, 29, 521, and 522. (c) Subsurface sorted material in these flatter areas, separated from the surface sorted material by interbedded till, is probably coextensive with sorted material under the ice-contact ridges. A suggestion of this is shown in section F-F', USGS tests 511 and 512. A more definite example occurs in section A-A', USGS tests 516, 517, and 518.

Sorted material composed of very fine sand and silt was found in many test holes in the group and in the flanking lower topography. Wherever found, it is the stratigraphically highest material. In USGS tests 510, 516, 512, and 526 it is the material that makes up the highest parts of the ice-contact ridges. It underlies the flatter topography at the sites of USGS tests 29 and 522. In USGS test 513, about 4 feet of surface clay overlies 4 feet of this sorted material. In the ridges it has a central or "axial" position, goes to depths below the total relief of the ridge, and is flanked, as shown in adjacent test holes, by coarser sorted material or till (see secs. A-A', E-E', F-F', and H-H').

The relation of the very fine sand and silt to the coarser material in the ridge in section F-F' is rather unusual. USGS tests 509, 510, and 511 penetrated gravel and sand arranged in what seems to be a channel above the lowest till. USGS test 511 passed through the axis of the channel and USGS tests 509 and 511, the marginal parts of the channel. The gravel and sand deposits at USGS tests 509 and 511 are overlain by till which in turn is overlain by sorted material. The middle test hole, 511, penetrated mostly very fine sand and silt above the gravel and sand.

Any discussion of the genesis of this group of ice-contact features, in view of the detailed test-hole data, is likely to be lengthy. The following remarks concerning the origin are offered only as tentative suggestions; a more complete discussion will be given in a report on the Devils Lake area.

The group of ice-contact features will be considered from two points of view. The first point of view (a) is the conventional one: that eskers and related features are formed more or less in stagnant masses of ice. The second (b) is that the relation of the group to the washboard moraines suggests that the ice was in some kind of periodic motion. Both views are partly correct.

(a) The variety of the constituent materials in the group indicates a series of changing conditions at a time when the ice was cavernous and perhaps fissured with crevasses open to the sky.

In the northern part of the group, where the test drilling was done, the coarser sorted material, in general, is stratigraphically below and at lower elevations than the finer sorted material. This would indicate that the initial material was deposited by more rapidly moving water than the later, finer material. It suggests that the final episodes in the formation of the northern part of the group must have involved ponded or sluggishly moving water in which the fine material was deposited. The interbedded till, as in section F-F', USGS tests 509 and 511, may be the result of the collapse of ice walls and roofs of the drainageways.

The highest elevation of the very fine sand and silt was found at the site of USGS test 526. This does not mean that the water drained away from this point and toward the north where the material was found at lower elevations. The bedding in the southern part of the group shows that drainage must have been toward the south. Two suggestions may be made regarding the different elevations: (1) The ponds in which the fine material was deposited did not exist simultaneously. (2) The slowly moving water actually may have drained toward the south but the surface of the deposits had no relation to the water levels. The different elevations may be due to subsequent collapse of the material or to deposition in different depths of water.

There is considerable evidence, much of which is outside the Minnewaukan area, that these ice-contact deposits are related to the existence of a large proglacial lake whose waters partly submerged large masses of stagnant ice. The presence of this lake may likewise explain the occurrence of the sand and gravel deposits under the adjacent lower topography.

The southern part of the group contains the most distinctly sinuous forms and the coarsest material. This part probably represents a series of true eskers, which may have been deposited in a group of ice tunnels or as a series of deltas or alluvial fans built up against a wall of collapsing, retreating ice.

The relation between the northern and southern parts of the group, which involves two different modes of deposition, is not clear. The whole group may not have been deposited contemporaneously: that is, the ponding in the northern part may not have been simultaneous with the rapid flow of water in the southern part. The eskers in the southern part may have been formed at the same time as the stratigraphically lower, coarser material of the northern part. The ponding and deposition of the fine material probably were the last events in the history of the group.

(b) The relation of the group of ice-contact features to the washboard moraines presents some supplementary ideas regarding the origin of the group. The varied orientations of the individual ridges making up the northern part of the group may be the result of disturbance by an oscillatory motion of the ice, a condition presumably necessary to the formation of washboard moraines under Gwynne's (1942) hypothesis. The linear persistence of the main trend of the group would require a north-striking fracture system in the ice which was periodically distorted and readjusted as the ice front oscillated. The maintenance of the fracture system in the face of movement would necessitate the continual fluctuating of the thickness of ice around the critical value requisite for movement. It may be noted that the area discussed in Norman's paper (1938) has a similar arrangement of ice-contact features and washboard moraines. The reader is referred to this paper for further discussion.

The interbedding of the till with the sorted material may be partly explained as the result of deposition by moving ice rather than by the collapse of ice walls. The sorted materials underlying the adjacent lower topography may likewise be ice-contact deposits that have been smeared by the oscillating ice.

It is likely that the history of the group of ice-contact features can be written partly in terms of periodic stagnation, during which time the ice-contact features formed, and partly in terms of periodic movement during which some were preserved and some obliterated.

In the southern part of sec. 3, T. 153 N., R. 67 W., are three hills which are probably kames. They lie about in line with the group of ice-contact features and possibly represent a continuation of the group via the north-south ridge in the northern part of sec. 10 (see fig. 6).

The group trends toward the Long Lake depression, the nearest topographic "low," and presumably the water that deposited the ice-contact features drained into the depression.

The other ice-contact features in the Minnewaukan area, with a few exceptions, are small in size, only locally conspicuous, and intermediate in form between the "ideal" ice-contact features defined at the beginning of this section. These were found in the SE$\frac{1}{4}$ sec. 29, T. 153 N., R. 67 W., in the SW$\frac{1}{4}$ sec 35, T. 153 N., R. 67 W., in the NE$\frac{1}{4}$ sec. 35, T. 153 N., R. 67 W., in the SE$\frac{1}{4}$ sec. 13, T. 153 N., R. 68 W., in the NE$\frac{1}{4}$ sec. 24, T. 153 N., R. 68 W., in the NE$\frac{1}{4}$ sec. 25, T. 153 N., R. 68 W., and in the SE$\frac{1}{4}$ sec. 25, T. 154 N., R. 68 W.

In all the ice-contact deposits there is but a small proportion of coarse material of cobble size and larger. Even those that resemble eskers have a paucity of coarse material and thus differ from the usual concept of typical eskers. The absence of coarse material may indicate the absence of swiftly flowing water during the formation of the features. There would have been little, if any, swiftly flowing water if the period of stagnation had been long and the retreat of ihe ice slow and oscillatory. Another factor, believed to be of greater importance in causing a scarcity of coarse material in the ice-contact deposits, may have been the comparative absence of coarse material in the ice. The shale yields very few cobbles and few if any boulders. The coarse material is generally composed of granite, granite pegmatite, gneiss, limestone, and dolomite, a good part of which may have been dropped nearer its source in Canada.

The general absence of these hard rocks is reflected in all deposits of sorted material, regardless of origin, in the Minnewaukan area. The stratified drift, therefore, is not as permeable as it would otherwise be, for sand and gravel deposits composed largely of shale fragments usually contain considerable silt and clay derived from the disintegration of the shale particles.

Outwash

The smooth and gently southward sloping outwash plain (see fig. 6) in the southern part of the area abuts rather sharply against the steep front of the North Viking end moraine. The outwash is composed chiefly of sand and gravel, in part interbedded with and covered by considerable amounts of silt and clay, all deposited by meltwater issuing from the glacial front. Branch (1947, pp. 19-22) has an excellent discussion of the outwash, from which the following quotations are taken. The outwash plain averages "from one to one and one-half miles in width and dividing in the south into a number of distributary channels flowing into the Sheyenne River. Near the surface this belt is composed of fine to coarse sand . . . . From data obtained by drilling and augering it was found that the fine sand commonly gives way to very coarse sand and small pebbles at depths of less than six feet near the axes of the outwash drainage. However, observations made in . . . . sand pits in glacial channels indicate that the fine sand, in places, reaches depths of at least twenty feet. Undoubtedly, the stratification within the outwash will reflect the varying conditions of sedimentation commonly associated with a retreating glacial front."

Long Lake Depression

The term "Long Lake depression" is used here to refer to the whole depression occupied in part by Round Lake, Long Lake, and Stony Lake, as well as to indicate the general shape of the depression. The lakes occupy steep-sided elongate depressions which cut across the North Viking moraine (see fig. 6). The channels connecting the lakes are narrow and more or less V-shaped and, therefore, probably are youthful and fairly recent in origin. The channel between Stony Lake and Long Lake is blocked at the southern end by a ridge, which probably is a beach. According to Branch (1947, p. 24), it is composed of a "finely sorted beach sand with no evidence of gravel or coarse sand on the surface or to a depth of six feet." The channel at the south end of Stony Lake is tortuous and at its terminus in the moraine it still slopes northwestward.

Aerial photographs show traces of several individual subbasins within some of the larger depressions. These are indicated on the map (fig. 6) by lake and swamp symbols. Deposits of sorted material are found in and near the depression. They are indicated on the map by gravel-pit symbols.

Parts of the depression are paralleled by linear patches of knob-and-kettle topography and groups of morainal ridges, which in some places rise above the general level of the area surrounding the depressions. Particularly outstanding is the group in secs. 8, 9, and 17, T. 152 N., R. 67 W.

Water flows intermittently from Long Lake to Round Lake, and a dam has been constructed at the north end of Round Lake to prevent outflow. There appears to be no overflow from Stony Lake at the present time.

There is little, if any, indication of strand lines higher than those almost immediately above the present water level. The shores of all the lakes are lined with numerous boulders, which are presumably residual from the till that eroded from the shores. However, the floor of Stony Lake is covered by a concentration of boulders, and it seems doubtful that these are all resid

The many ice ramparts found along the shores of the lakes in the depression will be discussed in a later section of the report.

The origin of the Round Lake depression involves two questions which may or may not be related to one another, namely, Does the depression occupy a sag or "low" 7/ in the shale bedrock? and What is the glacial history of the Long Lake depression?

In regard to the first question, Branch (1947, pp. 24-25) considered the depression to be the surface reflection of a bedrock "low": "It is interesting to note that the pebble count showing the high percentage of shale was taken on the east valley top of the Stony Lake spillway (SE$\frac{1}{4}$ sec 8, T. 152 N., R. 67 W.) and that rotary drilling (by the U. S. Geological Survey) in the outwash just south of the mouth of the spillway in the outwash belt shows a high count of shale pebbles. This might indicate the presence of the Pierre shale close to the surface and possibly the existence of a preglacial north-south valley now occupied by a chain of lakes or dried lake beds. On the examination of areas to the east of this quadrangle, similar physiographic features appear and indicate that the chain of lakes is a recurring regional phenomenon."

The test drilling done by the U. S. Geological Survey did not give conclusive evidence for or against the Long Lake depression being in a bedrock "low." USGS test hole 24 at the north end of the depression (see fig. 6) penetrated 147 feet of drift, which may indicate the presence of a "low." A possible side of the "low" was encountered in three USGS test holes, 25, 26, and 27, which were drilled just east of USGS test 24, and in which the drift averages only about 50 feet in thickness. These data do not prove the existence of a "low" but do not exclude the possibility of such

7/ The informal term "low" is used here instead of "channel" or some other more definite term in order to avoid a commitment as to the exact nature of the bedrock depression, if such a depression does exist.

an occurrence. Unfortunately, no cross section was drilled in this area. Cross section D-D' was made, however, in the outwash area south of the depression, in hopes of finding thicker outwash material in the presumed southwestward extension of the "low" (see figs. 6 and 8). The thickest outwash found was at USGS test 20 and totaled only 40 feet. There is a possibility that the location of the moraine is due to the presence of an underlying bedrock ridge and that the thick drift found in USGS test 24 indicates a sag in the ridge or the edge of the ridge. It is also possible that the shallower drift in USGS tests 25, 26, and 27 represents a local, isolated bedrock "high."

In regard to the glacial history of the Long Lake depression, an early phase is suggested by the elevated morainal patches and ridges that flank it. Of interest are those at the northern end of the depression and in secs. 8, 9, and 17, T. 152 N., R. 67 W. Three hypotheses regarding them have been considered:

(1) Assuming the existence of a bedrock "low" thinly mantled with drift, this depression may have been entered by the keel of a narrow tongue of active ice which overrode any previously existing stagnant ice in the depression. This occupation may have taken place after the main mass of ice that built the North Viking moraine had either become stagnant or disappeared from the immediate vicinity. This tongue may have had enough lateral movement to build up the various morainal masses surrounding the depression.

(2) A variant of the first hypothesis is the possibility of a single lobe overriding the depression and forming the higher deposits as local end moraines. The continued existence of the depression under this set of circumstances may be explained by its being filled with ice previous to the postulated overriding. Upon the removal of the postulated lobe, the ice melted and exposed the preserved depression.

(3) Without assuming the presence of a bedrock "low," the depression and surrounding high or rough area may be the result of the near confluence of two lobes,

one from the north and one from the northeast. Because it is certain that the depression itself was at one time filled with ice (see below), this bilobation must have occurred after the southern parts of the North Viking moraine were built and the active front had retreated somewhere to the north, leaving the area strewn with large masses of stagnant ice which were surrounded by the two lobes in a pincerlike movement. The details of these hypotheses are not clear and can be settled only by further field work.

Concerning the later phases of the glacial history, Branch (1947, pp. 23-25) believed that this and other similar depressions were glacial spillways "running through the morainic knobs into their respective outwash belts to the south" and, further, "that these channels were glacial spillways through which outwash material was carried, after the ice had retreated a considerable distance to the north and that they were probably flowing at a time somewhat later than that during which the main deposits in their respective terminal outwash belts were laid down. This is most forcefully indicated in the case of the Stony Lake spillway which possesses a valley of considerable width and depth."

The gravel pits around the edges of the depression probably are in kame terraces. Their presence implies that the valley was at one time occupied by ice blocks which were more or less detached from the main mass of ice. Melting of the last remnants of the blocks may have formed the subbasins in the larger depressions. It seems likely that the large amounts of water postulated by Branch to have passed through the valleys would have carved broader channels than the narrow ones observed. There are no notches on the valley walls or other evidence indicating that broad, flat channels existed at higher levels. It appears probable that if any considerable amount of water passed through the depression it was while it was still partly occupied by ice and the water flowed on or in the ice, or both. When the depression was used as a spillway is not clear. However, the sharp change in the outwash from fine to coarse material can be explained, as Branch implies, by assuming that the earlier and coarser material was deposited by short, comparatively steep streams heading in the moraine and that the later and finer material was deposited by water from a proglacial Devils Lake when the ice front stood some distance back of the moraine. The proglacial lake would have acted as a settling basin which removed all but the fine sand, silt, and clay.

The depression was probably the recipient of other drainage, as indicated by the fact that the group of ice-contact features seems to be alined with it. Stream IV (see section on Drainage and fig. 6) drains into the depression through a deeply incised channel and may have been active while ice occupied the depression.

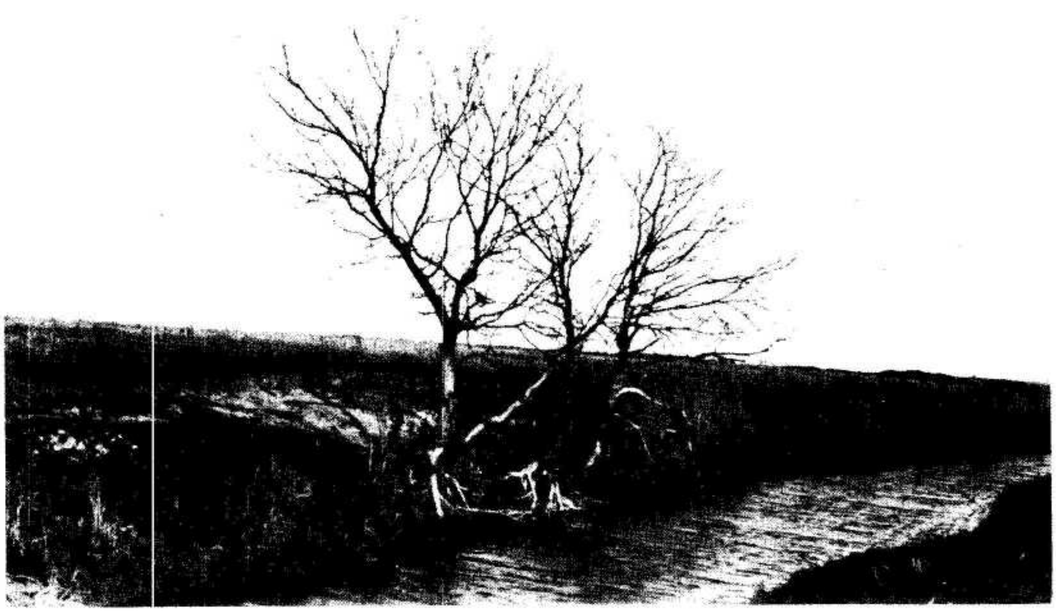
Recent Features

Drainage

Most of the drainage afforded by an integrated stream system in the Minnewaukan area is confined to the western half of the area north of the North Viking end moraine because of the lack of continuous morainic topography there and the general regional slope toward the dry bed of West Bay. The actual area dissected and drained by streams is quite small, but, judging from the state of development of the stream and drainage pattern at the present time, considerably more drainage of the entire area will occur in a geologically short time.

All the streams are intermittent and flow only after the snow melts in the spring or after a heavy rain. They are all physiographically young, their channels being neither broad nor deep. None have cut their own channels over their entire lengths; rather, they have formed them by joining various depressions. The drainage is mostly of post-Pleistocene origin. Some segments of some of the streams may have beeen melt-water channels, though apparently they did not carry any large volume of water for any great length of time.

A. The channel of stream II, sec. 2, T. 153 N., R. 67 W., looking southeast. Note boulders in channel below car.



B. Undercut bank of stream I, looking northeast, SW¼ sec. 35, T. 154 N., R. 67 W. Water present in channel because of dam downstream.

Figure 11.--Recent stream erosion in dry bed of West Bay. Pictures taken October 1948.

That the channels are mainly the result of Recent cutting is indicated by: (a) the V-shaped valleys and (b) the presence in them of large boulders residual from the drift that was removed from the valleys. These boulders, incidentally, are the cause of some rather intricate meanders in the courses of the streams. The cut channels in the Minnewaukan area, outside the lake bed, are as much as 25 or 30 feet deep and may be 30 to 50 feet wide. Good examples of the V-shaped valley, partial boulder fill, and meanders were observed in stream I, 8/ in secs. 29 and 30, T. 154 N., R. 67 W.

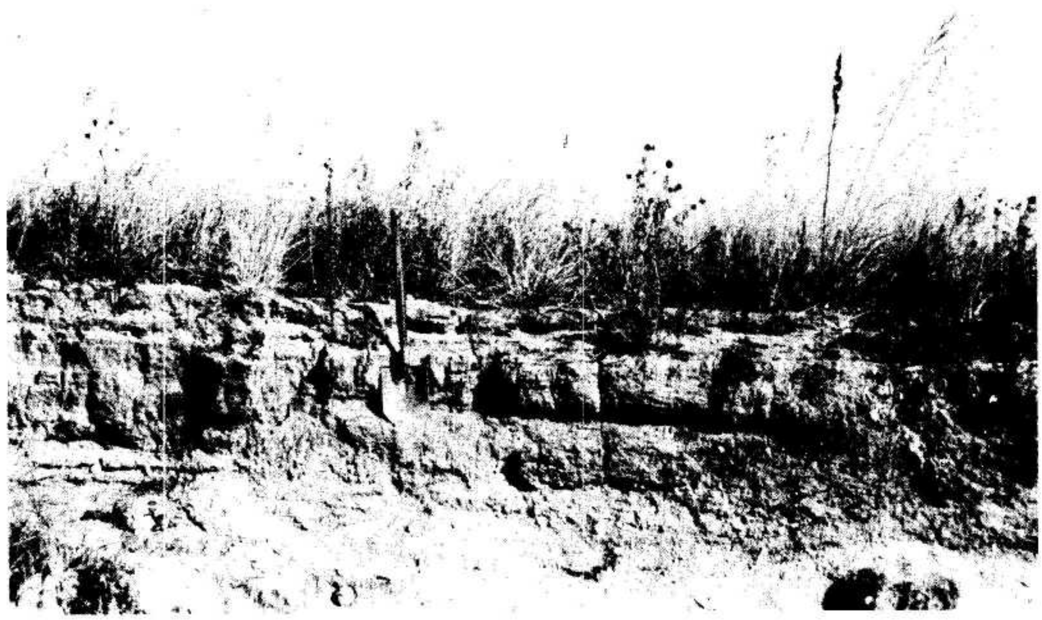
The making of deep V-shaped valleys is the most pronounced activity of the streams before they enter the dry lake bed. However, streams I, II, and III also have incised channels into the lake bed. Streams I and II, observed in greater detail, have cut channels as much as 30 feet wide and 7 feet deep. When visited in the fall of 1948, the channel of stream II contained blocks of lake sediment topped with turf 20 feet or more in length and 4 feet or less in width and thickness (see fig. 11). This channel widening can be expected to continue for a long time if the lake does not refill. It is doubtful if much deepening in the lake-bed area will occur, for the streams are flowing near their base level in the lake bed. It can be expected, however, that in a geologically short time, barring a refilling of the lake, a stream-drainage net will be developed over a considerable part of the dry lake bed.

The only feature resembling a nickpoint is the development in stream IV of a rather deeply incised channel, about 25 or 30 feet deep, within a mile of where it enters the Long Lake depression. Upstream the channel is broader and shallower, suggesting a spillway in appearance, but it is not associated with a clearly marked higher terrace level.

Fluvial sediments consist mainly of boulders and pocketlike accumulations of gravel between the boulders. However, very recent erosion in some places, along streams I and II where the channels have been artificially constricted by bridges,

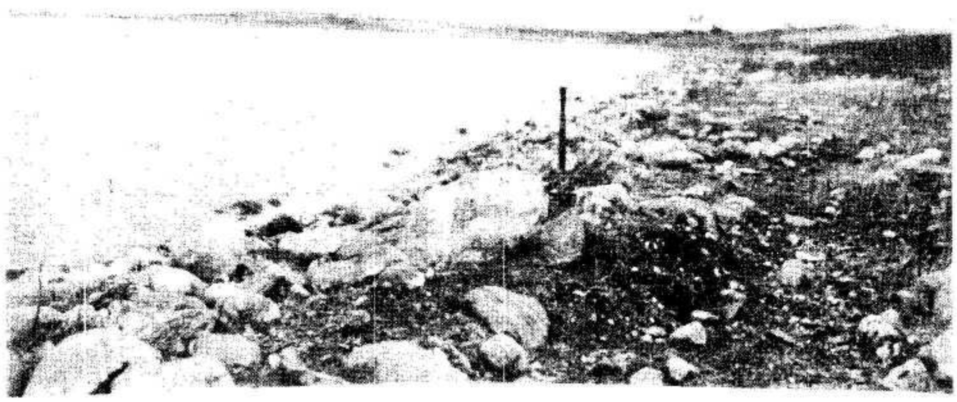
8/ The unnamed streams have been numbered consecutively from north to south.

A. Stream I, NW¼ sec. 34, T. 154 N., R. 67 W., downstream side of bridge.

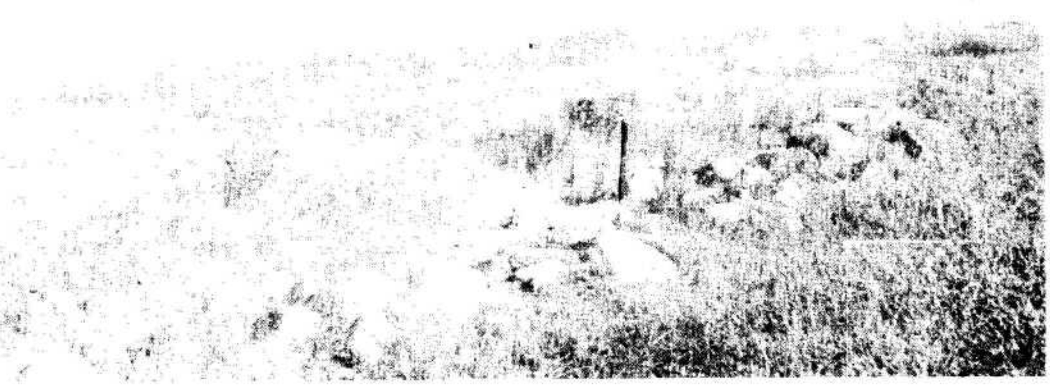


B. Stream II, NW¼ sec. 5, T. 153 N., R. 67 W., downstream side of bridge.

Figure 12.--Stream cuts showing typical intermittent stream deposits of intercalated sand and gravel and fine-grained dark swamp and slope-wash material.



A. Northeast shore of Round Lake, NE$\frac{1}{4}$ sec. 35, T. 153 N., R. 67 W. This rampart consists of turf and boulders. When visited, this feature was in a good state of preservation. It probably was formed in the spring of 1948. Picture was taken in October 1948.



B. Southeast shore of Long Lake, NE$\frac{1}{4}$ sec. 8, T. 152 N., R. 67 W. A very old rampart with interstitial material removed.

Figure 13.--Ice ramparts.

culverts, and dam spillways or in the dry lake bed, has exposed intermittent stream deposits typical of this part of North Dakota. They show alternating layers, less than 6 inches thick, of sand and gravel and dark peaty material (see fig. 12). The sand and gravel presumably are deposited during the times the channels carry water. The peaty material may accumulate from vegetation growing in swampy areas along the stream or from slopewash consisting of soil and associated organic matter. Some of the better exposures were observed (1) under the bridge on the north-south road between secs. 33 and 34, T. 154 N., R. 67 W., (2) at the dam spillway in the NW$\frac{1}{4}$ sec.31 T. 154 N., R.67 W., and (3) under the bridge between secs. 5 and 6, T. 153 N., R. 67 W.

Three test holes in or near the stream channels yielded meager evidence so far as fluvial sediments were concerned. The upper 5 feet of USGS test 35, drilled in the lower reaches of stream II, yielded a yellow sandy and silty till which probably included an extremely thin layer of churned-up fluvial fill. USGS test 30, in a depression near a swamp tributary to stream II, contained little that could be interpreted as fluvial fill. In USGS test 29, in stream III just west of Minnewaukan, the upper 20 feet was sand and gravel that might be fluvial. The stream here, however, is little more than a crease in the topography, and hence it may be that this sorted material was deposited during the formation of the ice-contact features to the west and may be continuous with them. On the other hand, the sorted material may have been deposited as a beach or spit. This latter possibility may mean that the "J" strand line should be shown on figure 6 to enclose the area around the test hole.

The stream deposits cannot be mapped on the scale of the geologic map (fig. 6) and hence are not shown.

Ice Ramparts in the Long Lake Depression

On the shores of Round and Long Lakes there are rough ridges made up of boulders, disturbed and up-ended masses of turf, and mixtures of turf and boulders, generally less than 3 feet in height (see fig. 13). A cursory examination showed that these features are limited to the southeastern shores. They probably are the result of ice-jams in the lakes (Scott, 1921, pp. 56-61) during the late winter or early spring. After stretches of open water appear with the melting of the ice on the lake, a storm may pile up the ice on one shore and force the shore materials into these ridges. The weather station at Devils Lake records a prevailing wind from the northwest, which is almost at right angles to these ice ramparts, and this may explain their areal localization.

Summary of Pleistocene and Recent History

From the scanty information available on the relief of the bedrock, it seems likely that the preglacial land surface was in the stage of early maturity. This is inferred from the rather rough topography indicated by the test-hole and well data.

The area was covered by deposits from an unknown number of glaciations before the last glacial ice moved over the region from the northeast.

The area was last covered with ice which extended probably into South Dakota (Flint, 1947, p. 252). The region south of the Minnewaukan area was uncovered until the ice reached the site of the North Viking moraine. Actually, the front may have retreated to a position indicated by the possible areas of overridden moraine north of of West Bay and then readvanced southward to the site of the North Viking moraine. At any rate, the ice maintained an oscillatory front on the site of the North Viking moraine which it built.

Short, deep streams heading in the glacier and draining into the Sheyenne River deposited the stratigraphically lower parts of the outwash apron south of the moraine. The ice then slowly thinned and its front retreated to the north. A readvance of the ice in the form of one or two small lobes may have made the Long Lake depression on a former rather featureless surface or by modifying an already existing "low" in the bedrock. The ice may have maintained a broad proglacial lake (Lake Minnewaukan) north of the present southern shore of Devils Lake and possibly extending west to the part of the area on which rest the washboard moraines and the north-south alined ice-contact features. During this period of slow retreat water was freed from the mass of ice through the opening marked by the group of ice-contact features. This water, together with water from Lake Minnewaukan, probably drained into the partly ice filled Long Lake depression, and deposited the cover of fine-grained materials over the outwash south of the North Viking moraine. Stream IV may have been supplied with water from isolated masses of ice in the North Viking moraine as well as by the parts of the ice front close to it. The ice may have retreated and thinned more slowly in the northern part of the area, as suggested by the more discontinuous morainal deposits there. Perhaps the eastern parts of this northern moraine were deposited in the waters of Lake Minnewaukan. The ice front probably retreated to the northwest. Subsequent to the retreat of the ice front, the proglacial Lakes Minnewaukan and Wamduska 9/ may have filled to a level from which they drained at the extreme eastern end into the Sheyenne River. At a later time, when large volumes of water were lacking, only the connection between Devils Lake and Stump Lake remained open. Since that time streams I, II, III, and V have connected and integrated the low places, and stream IV has deepened the lower part of its valley.

HYDROLOGY

General Principles

Essentially all ground water is derived from precipitation. The water enters the ground by direct penetration from rain or melting snow, or by percolation from surface-water bodies such as streams and lakes where such bodies are naturally higher than the general water table. In most areas there is lateral movement of ground water from areas of recharge to lower areas of natural discharge.

The amount of water that a rock can hold is determined by its porosity. Unconsolidated material such as clay, sand, and gravel is generally more porous than

9/ Pleistocene equivalent of Stump Lake (Simpson, 1912, p. 140).

consolidated material such as clay, sand, and gravel is generally more porous than consolidated rocks, such as sandstone and limestone, although in some areas the consolidated rocks are highly porous.

If the pore spaces are large and interconnected, as they commonly are in sand and gravel, the water is transmitted freely and the rock is said to be permeable. Where the pore spaces are very small, as in clay, the water is transmitted very slowly or not at all and the rock is said to be impermeable. Furthermore, a deposit of uniformly sized, well-rounded material may be more porous and permeable than a variously sized material because in the latter the smaller particles occupy the interstices between the larger ones.

At various depths in different regions, depending on local conditions, spaces in the rocks are filled with water, and the rocks are said to be saturated. This is true of clay as well as of sand and gravel, but, because of the difference in permeability, it is possible to develop successful wells only in the coarser materials.

Where some part of the water-tramsmitting bed (aquifer) is exposed at the surface or comes in contact with another aquifer so exposed, the water discharged naturally or through wells can be replenished periodically. Where the aquifer is more or less completely surrounded by clay or other relatively impermeable materials, natural recharge may be very slow, and the water taken by wells from storage in the aquifer may not be fully replenished each year. The initial yield of wells in aquifers that are virtually cut off from natural recharge may be as large as that of wells in aquifers having adequate recharge areas, thereby giving an erroneous impression that an abundant perennial water supply is available.

As ground water moves through an aquifer, it dissolves a part of the more soluble mineral constituents of the rock particles. The amount of mineral matter dissolved is determined by the amount of the soluble materials present and the length of time the water is in contact with them. Therefore, in rocks of homogeneous mineral composition, the water that has been underground longest or that has traveled the greatest distance is more highly mineralized than that which is relatively near the recharge area.

Drift Aquifers

The term "drift aquifers" refers to all the water-bearing material found in the unconsolidated glacial and lake material above the bedrock. The discussion here is divided, for the sake of convenience, into the aquifers found in areas occupied by the principal glacial and lake features as discussed previously in the sections on geology. The aquifers are considered from the point of view of their origin, topographic expression, if any, and location.

Aquifers in Ground- and End-Moraine Areas

Most of the wells in the Minnewaukan area obtain their water from aquifers associated with the till in the ground-moraine and end-moraine areas. The wells range in depth from less than 20 feet to as much as 180 feet. Most of them are drilled, but a few are dug. All the wells furnish only relatively small supplies of water for farm or domestic use and many are considered inadequate even for these small demands.

The action of the ice during the formation of the end-moraine areas is believed to have been too chaotic to have permitted the general survival of sorted materials in more than discontinuous pockets. However, in some places the sorted materials of large ice-contact features, outwash deposits, or channel fillings have been buried or partly buried and therefore preserved. These deposits may form important aquifers. Where covered by the relatively impermeable till, they generally are not apparent from an examination of the surface and can be discovered only through a study of well records, by test drilling, or by other methods of exploring the subsurface.

No large aquifers of this type are known to exist in the ground and end moraines in the Minnewaukan area. It is believed that most of the wells obtain their water from small bodies of sand and gravel which may be more or less isolated from each other. Because the till is not entirely impermeable, these small bodies of sorted material may occur in certain areas in sufficient number to make the entire till sheet function as a weak aquifer.

In the poorly drained morainic areas, water from precipitation collects in the kettles, where it is disposed of through evaporation or by percolation into the ground. This is the principal source of recharge to the aquifers in the till but the amount of recharge probably is not great because of the relatively impermeable nature of the kettle bottoms.

Except for the detailed testing that was done in the area just west of Minnewaukan, only three test holes were drilled in the ground-and end-moraine areas because the well inventory did not disclose the presence of significant aquifers there. USGS test 23 was drilled in a sag in the North Viking moraine (see fig. 6) which appeared, on the surface, to be a cutoff remnant of a glacial spillway. However, the Pierre shale bedrock, which was encountered at 75 feet, was overlain by 45 feet of till and about 30 feet of poorly sorted, clayey shale gravel, which would make a poor aquifer. USGS tests 30 and 35 reached shale without penetrating sorted materials in sufficient thickness or depth to yield more than small supplies of water. The detailed drilling in the area just west of Minnewaukan is described in the following pages.

Aquifers in Ice-Contact and Associated Deposits

The sand and gravel in the group of ice-contact deposits just west of Minnewaukan and the sand and gravel deposits associated with them in the flanking lower topography constitute the only aquifer to be discussed under this section that appears to offer any possibility of producing a large amount of water. Judging from the size of the ice-contact features alone, one may expect this aquifer to supply sufficient water for a small town.

Four sections were drilled by the Geological Survey across the group of ice-contact features and the deposits associated with it. The locations of these sections are shown on figure 6 and the geologic sections are shown on figure 8. From north to south the sections are F-F', G-G', the west end of section A-A', and H-H'. A north-south section E-E' was also constructed.

For yielding water, section F-F' contained the best sorted material found. This material was penetrated in USGS tests 509, 510, and 511. The sand and gravel deposits in these tests are 15, 23, and 10 feet thick, respectively, and extended from 22 to 37 feet, 46 to 69 feet, and 26 to 36 feet, respectively. The deposits, in general, are fairly free of clay and consist of a fine to coarse gravel, with some sand. The gravel is about one-third shale. The arrangement of the deposits in USGS tests 509, 510, and 511 suggests the outline of a channel.

USGS test 512 penetrated 23 feet of very fine sand and silt and 9 feet of till. The lowest material above the shale is a very clayey and silty sand, 14 feet thick, from 32 to 46 feet.

With the exception of the lower sorted material in USGS tests 509, 510, and 511, the material found in the test holes in this section probably would yield water only very slowly.

Section G-G' was drilled along the sag in the group of ice-contact features through which stream III flows. In USGS test 506, 11 feet of slightly clayey sand and some fine gravel were penetrated from 13 to 24 feet. In USGS test 29, 10 feet of slightly clayey sand and gravel were penetrated from 10 to 20 feet. In both of these the sand and gravel had a high shale content. Sand and gravel deposits also were found in USGS tests 507, 508, 521, and 522, but all were very clayey. It is likely that all the sand and gravel deposits found in this section are interconnected to some extent, at least hydrologically, so as to form a single aquifer. Tentative correlations are shown on the section.

The west end of section A-A' contains two USGS tests, 515 and 518, in which fairly clean water-bearing materials were found. USGS test 515 penetrated about 25 feet of sorted material that was fairly free of clay. Sand, and some gravel, 19 feet thick was found from 3 to 22 feet. Below this, 6 feet of gravel and sand, from 22 to 28 feet was found. In USGS test 518, 8 feet of a clayey sand was penetrated from 8 to 16 feet. USGS tests 516 and 517 also penetrated sorted material that was either too fine or too clayey to yield much water. USGS tests 519, 520, and 523 penetrated no water-bearing materials of appreciable thickness. The sorted material in USGS tests 515, 516, 517, and 518 is probably more or less continuous, as suggested in the section.

In section H-H' all the test holes contained sorted material which was either too fine, too clayey, or too thin to yield much water.

Section E-E' includes two test holes associated with the group of ice-contact features that were not shown in the other sections: USGS tests 513 and 514. At USGS test 514, a very thin layer of clayey sand and gravel was found at the surface. The drift in the rest of the test hole was till. USGS test 513 penetrated 17 feet of very silty sand and gravel from 9 to 26 feet, which would yield water at a very low rate. Below this, 11 feet of sand and gravel, from 26 to 37 feet, was found. The upper part was fairly free of clay but the clay content increased toward the base. It is likely that the coarser sorted materials in USGS tests 512 and 513 are connected. There was no connection between these and the sorted material at USGS test 29, as indicated by the lack of subsurface sorted material in USGS test 514. A connection may exist, however, outside the plane of the section.

The city of Minnewaukan drilled seven test holes (Minnewaukan tests the lower topography east of the group of ice-contact features. No sampl retained for study by the Geological Survey and hence no first-hand infor cerning the materials penetrated is available. A report rendered to the city by the Layne-Minnesota Co., which did the drilling, indicated that the most permeable material was found in Minnewaukan test 12. Other possible water-bearing materials not quite as good, were reported to have been penetrated in Minnewaukan tests 14 and 15.

In general the test drilling by both the Geological Survey and the city of Minnewaukan has indicated that much of the area west and southwest of Minnewaukan is underlain by numerous thin beds of various types of sorted material. Possible correlations of some of these materials are shown on the sections. The drilling by the Geological Survey was more or less perpendicular to the major strike of the group of ice-contact features, so that little is known about the actual subsurface continuity of materials parallel to the major strike. The extent of surface continuity is, of course, apparent from the orientation and length of the ridges (see fig. 6). However, in view of the mode of origin of these materials, the north-south subsurface continuity is undoubtedly greater than the east-west continuity. The kind of subsurface configuration of the sorted materials might be most simply pictured in terms of the arrangement that would result if the entire group of ice-contact ridges were buried under tens of feet of till and other material. This picture would indicate that connections between the sorted materials are more likely to be found in the direction perpendicular rather than parallel to the plane of the sections. For this reason east-west correlations on the sections must be of a very tentative nature.

The actual amount of contact that one water-bearing deposit has with another in this area probably does not vary too much from place to place. This means that a

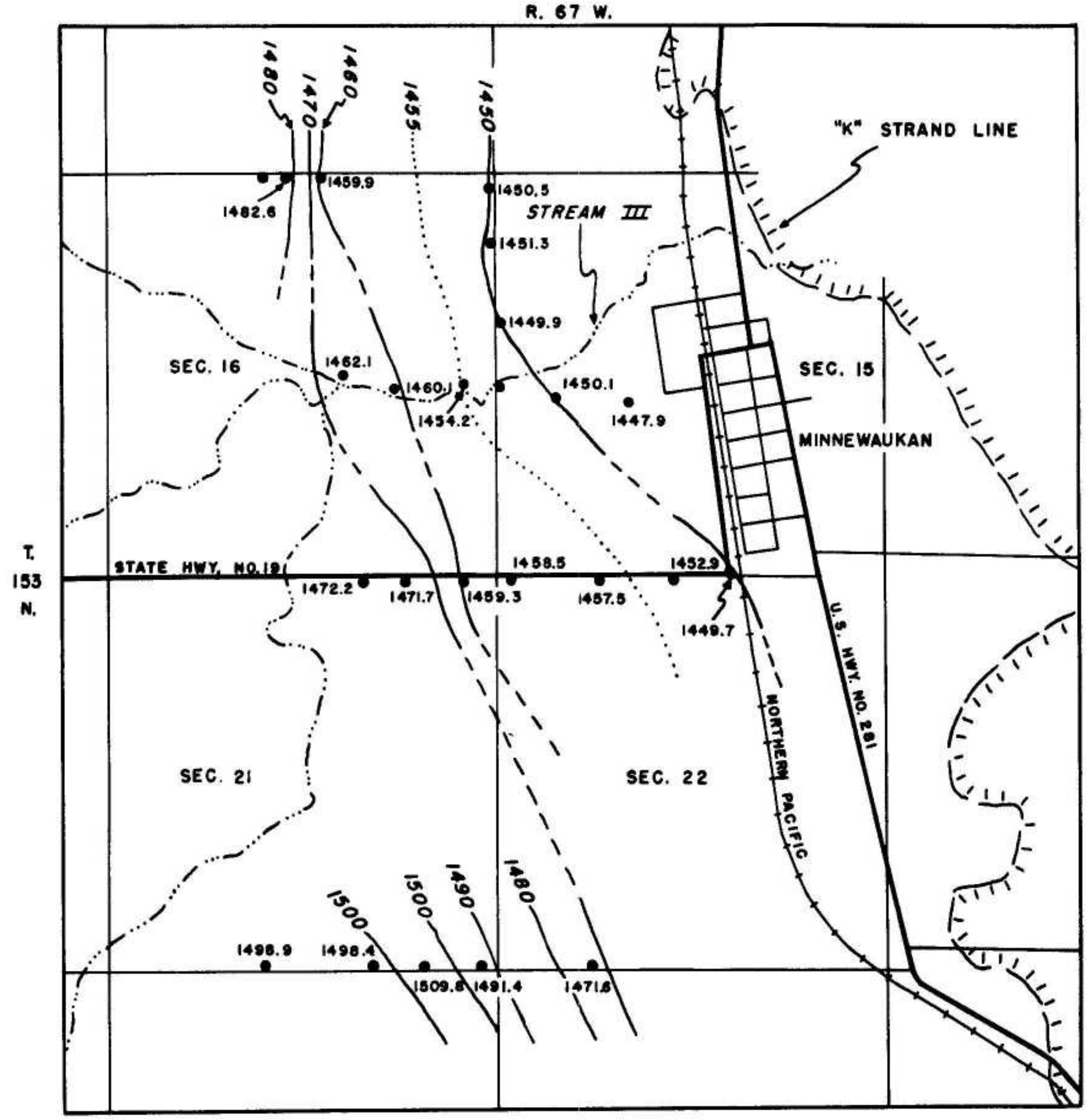


FIGURE 14.— CONTOURS, IN FEET ABOVE SEA LEVEL, ON WATER LEVELS IN UNCASED USGS TEST HOLES IN ICE-CONTACT AND ASSOCIATED DEPOSITS IN AREA WEST OF MINNEWAUKAN

well tapping one deposit would probably eventually draw water from all the neighboring deposits, if not all the deposits in the area. The problem, then, devolves upon locating the well or wells in deposits of the coarsest and "cleanest" material in order to make possible the most rapid rate of infiltration from contiguous deposits. The deposits which contained clay-free, if not coarse, materials were those found in USGS tests 30, 509, 510, 511, and 515.

The total volume of water in storage in these deposits and available to wells can only be guessed at. The total footage of saturated materials considered to be of a water-bearing nature is 152 feet in USGS tests 29 and 506 through 518, inclusive. This is an average of a little more than 10 feet of saturated water-bearing material for each test hole. It seems reasonable to assume that this average figure would be applicable to the entire eastern half of section 16, T. 153 N., R. 67 W. If the average effective porosity of the water-bearing materials is about 20 percent, then nearly 700 acre-feet of water is probably in underground storage in the eastern half of this section.

It would not be possible to recover this entire amount of water through wells. However, the estimated need of 50,000 gpd for the city of Minnewaukan amounts to about 55 acre-feet a year, or only about 8 percent of the estimated water in storage.

Probably the principal recharge to the aquifer occurs from downward percolation of water from the melting snow in the spring and from heavy rains, especially in the fall of the year when evaporation and transpiration losses are at a minimum. Light rains during the summer probably contribute little if any water to the aquifer.

Although the average amount of recharge reaching the aquifer annually is not known, 1 inch is considered to be a conservative figure. One inch of water over the 320 acres in the eastern half of section 16 would amount to about 27 acre-feet of water, or about half the amount estimated to be needed annually by the village of Minnewaukan.

Stream III drains a considerable area (probably about 4 square miles) west of the group of ice-contact features. The south branch of this stream follows the western flank of the group for about a mile in the area just west and southwest of Minnewaukan. The stream then crosses the group in the vicinity of section G-G' (see fig. 6).

Nearly every spring when the accumulated winter snows melt, there is flow of surface water in this stream. Present ground-water levels in the ice-contact deposits are at or a little below the level of the bottom of the stream. It seems likely that at the present time considerable recharge to the aquifer occurs during the period of surface runoff and that additional infiltration might be induced if the water levels were lowered by pumping from wells.

Water-level measurements were made in most of the USGS test holes west of Minnewaukan in May 1952. The test holes were uncased and allowed to fill with water for a few days before measurements were made.

A contour map (fig. 14) of the ground-water surface west of Minnewaukan was drawn from these water-level measurements.10/ The map shows that the water surface slopes to the east and north and that the natural movement of the ground water is to the lake-basin area. The parallelism of the 1,450-foot water-level contour and the "K" strand line probably is an indication that the thick impermeable lake clay and silt near the "K" strand line (see USGS tests 36 and 28, section A-A', fig. 8) forms a barrier to the movement of ground water toward the lake basin. In relation to the group of ice-contact features the water surface slopes north. It seems to be steepest in the vicinity of the group and flatter to the east under the flatter topography.

10/ Water-level measurements in the village of Minnewaukan could not be used in the preparation of this map because (a) the elevations of the wells were not available and (b) most of the measurements were made in 1946.

Probably the nature of the water surface varies from place to place. In some places it may be a piezometric surface and in other places, a water table. This depends on whether sorted material is present above the water level. Where sorted material is present above the water level, water-table conditions exist. Where the subsurface sorted material is overlain by till or more fine-grained sorted material, artesian conditions exist. No doubt in some places where several thin deposits are separated by layers of till, the water level in the test hole is the composite result of artesian conditions and drainage into the hole from "perched" water tables.

The deposits containing the best sorted material, in USGS tests 30, 506, 509, 510 , 511, and 515 are all, with one exception, saturated. In USGS test 515, the better sorted material is found between 3 and 28 feet. The lower part of the material is coarser than the upper. The water level in this hole is about 22 feet below land surface, so that only the lower, coarser part of the sorted material is saturated.

If the city of Minnewaukan should decide to develop this aquifer for a municipal supply, it is likely that more than one well would be required eventually, although it is quite possible that one well could supply the demand for water for at least several years. Such a well probably could be obtained in the locality of USGS tests 509, 510, and 511.

Aquifers in Outwash Deposits

The outwash deposits in the southern part of the area constitute the most extensive single aquifer known in the area. At the present time, only wells for individual domestic and farm supplies are found in this outwash area. Adequate supplies for these purposes generally are obtained from shallow dug or bored wells.

Seven test holes were drilled in the outwash area and the results of this drilling are shown graphically in section D-D' (see figs. 6 and 8). Sufficient gravel to be important as an aquifer was found in only three USGS test holes, 20, 21, and 22. This gravel, ranging in thickness from 16 to 30 feet, is somewhat clayey and contains a large percentage of shale, as is common in the outwash gravels in this part of North Dakota.

The entire area of outwash is underlain with sand or sandy materials, so that there is excellent opportunity for water to percolate into the ground from the surface and recharge the ground-water body. Probably the principal source of recharge is from the infiltration of water from melting snow during the spring and from the heavier rains in the spring and fall when evaporation and transpiration losses are low. The infiltration of water along the drainage channels during periods of surface flow is another important source of recharge, though it appears that such recharge would be more local than that from rainfall and meltwater. In view of the large size of the North Viking moraine and the steep gradient from the moraine to the head of the outwash, it appears likely that a considerable amount of water may enter the outwash by underflow from the moraine.

Much of the water recharging the aquifer is lost through evaporation and transpiration and part is lost by underflow out of the area along the stream channels that are tributary to the Sheyenne River to the south.

The amount of water in transient storage in the outwash is great. It is conservatively estimated that at least 30 million gallons (or about 90 acre-feet) of water is stored in each square mile for every foot of saturated sand and gravel.

It is reported (Branch, 1947, p. 33) that the wells in the outwash have yielded sufficient water for farm purposes during dry years, although the water levels did drop to some extent.

Considering the areal extent of the outwash, its large storage capacity, the thickness of gravels, and the excellent possibilities for receiving recharge, it appears very likely that satisfactory small to moderately large industrial or municipal supplies could be obtained from this aquifer. There are no data in regard to the transmissibility of this aquifer, but, because of the rather clayey character of the gravel found in USGS tests 20, 21, and 22, it seems unlikely that drilled wells would yield more than about 50 to 100 gpm.

This outwash area, because of its permeable subsoil and the widespread occurrence of sorted material, might be of interest as a possible site of small irrigation projects using well water. Should such small-scale projects be desired, this area would be worth investigation in greater detail.

Aquifers in the Lake-Basin Area

None of the surficial lacustrine deposits of sand and gravel, such as the beaches, spits, and bars, is believed to have sufficient extent or thickness to be of importance as aquifers in the Minnewaukan area. In some places where they do not rest on the relatively impermeable lake silt or clay, they may act as recharge conduits to deeper sands and gravels. A good example of such an occurrence is at USGS test 41 where sorted materials extend from the surface to a depth of more than 100 feet (see figs. 6 and 8).

The deeper aquifers found by test drilling in the lake-basin area cannot, as a group, be ascribed to any particular glacial origin. They may be channel fillings, outwash, glacial-lake deposits, or ice-contact deposits, and some may have been modified or partly destroyed by glacial action after deposition. In some places, part of their sorted constituents may have been moved short distances and then redeposited as a very gravelly till. The aquifers are in or associated with till and probably are of the same type as those found in the ground- and end-moraine areas.

Three sections were drilled in the dry bed of West Bay (see fig. 6 for locations). Section A-A' was drilled east of Minnewaukan between the west shore of the dry bed of West Bay and Grahams Island. Section B-B' was drilled across an arm of the dry lake bed north-northeast of Minnewaukan. Section C-C' was drilled across a small reentrant of the lake bed southeast of Minnewaukan.

Eleven test holes were drilled in the lake-basin area in section A-A' (see fig. 8). No aquifers were penetrated in the three test holes (USGS tests 36, 28, and 38) nearest Minnewaukan. Sand was encountered between 8 and 20 feet in USGS test 37, but it is not an aquifer of great importance. About 30 feet of sand and gravel was found in USGS test 39; the Pierre shale bedrock was reached at a depth of 50 feet. The aquifer at this test hole is the nearest one to Minnewaukan that was found in this section to offer any possibility of producing sufficient water for municipal or light industrial use. The upper part of the sand and gravel is quite "dirty" but the lower part is cleaner. It seems likely, however, that a water supply of 25 to 50 gpm could be obtained at this location. The areal extent of the aquifer cannot be determined from present data but it is possible that the sand and gravel deposits in this hole are in some way connected with those found in USGS tests 42 a and 40. Adequate pumping tests on a well constructed at the location of USGS test 39 would help to ascertain whether the aquifer is only local in extent. No sample of the water from this aquifer was obtained for chemical analysis.

Considerable amounts of sand and gravel were found in USGS tests 40, 42, and 43, and it is likely that water supplies satisfactory in quantity for municipal and light industrial purposes could be obtained at these locations. A sample of water for chemical analysis was obtained from the upper aquifer in USGS test 42 (see chemical analyses, p. 68).

The most productive aquifer found in all the test drilling in the Minnewaukan area is that in USGS test 41, where sand and gravel extends from the surface to a depth of more than 100 feet. This hole was cased with approximately 60 feet of 5-inch standard pipe, the lower section of which was slotted with a torch. On August 14, 1948, the hole was pumped for about 6 hours at a rate of about 42 gpm. The initial water level was 7.02 feet below the land surface and the maximum draw-down during this period was 0.90 foot. The well subsequently was pumped for a short time at a rate of about 85 gpm with a maximum drawdown of 2.72 feet. Within 3 minutes after the pump was turned off, the water level had recovered to 7.09 feet below the land surface, or to within 0.07 foot of the water level before pumping began.

In September 1948 the well was again pumped at a rate of about 42 gpm for a period of 24 hours. At this time, the water level before pumping was 4.55 feet below the land surface. The lowest water level recorded was 5.78 feet, which would indicate a drawdown of 1.23 feet. However, 5 minutes after pumping stopped the water level was 4.42 feet below the land surface, or 0.13 foot higher than before pumping began. Approximately 8 hours after pumping stopped the water level was 4.19 feet below the land surface. These water levels, which were higher after pumping than before, probably indicate a natural rise due to recharge. It is believed that the greater part of the drawdown during these pumping periods was due to hydraulic losses from the water entering the well casing from the aquifer rather than to loss in head in the aquifer itself. It is believed that a well capable of producing several hundred to more than 1,000 gpm could be developed at this location. Chemical analyses of two samples of water from this well are given in the table, page 68.

Aquifers of less importance were penetrated by USGS tests 44 and 45, east of USGS test 41.

A fluvial origin of the gravel in USGS test 41 is suggested by the lack of clay in the material. That neither USGS test 43 nor 44 shows a similar amount of gravel suggests an elongation of the deposits, perhaps at right angles to the plane of the section.

The surface of the lake basin is underlain by a relatively impermeable layer of silt or clay and possibly by some till. USGS test 41 is the only one in which the coarser, sorted material persists to the surface. Thus the surface recharge in the area immediately surrounding the test hole is good. The lake basin as a whole collects water in large amounts from direct precipitation, surface runoff, and ground-water inflow from the contiguous high areas. The surface water that does penetrate the relatively impermeable cover enters sorted materials, which in this section are more or less interconnected.

The amount of water in storage in the lake basin as a whole is probably great and, through the probable interconnection of the various aquifers, a good porition of this water would eventually be available to wells near USGS tests 42, 40, 43, 41, and possibly others.

All the holes in section B-B' are below the "J" strand line. The easternmost test hole, USGS test 32, penetrated 120 feet of till above the bedrock. The uppermost material in USGS test 31, 33, and 34 is a relatively impermeable lake silt and clay, which ranges in thickness from about 30 to 50 feet. All these test holes penetrated significant aquifers beneath the cover of lake sediments. The following aquifers seem to be the best: (a) 43 feet of shale gravel above the bedrock in USGS test 31, (b) 79 feet of poorly sorted but clean sand and gravel, from 57 to 136 feet, in USGS test 33, and (c) 63 feet of coarse gravel, from 70 to 133 feet in USGS test 34. All these aquifers are probably interconnected, as they all occur at about the same altitudes in the test holes (see fig. 8).

Direct surface recharge to these aquifers, as to those in section A-A', must penetrate the fairly impermeable lake sediment cover. Large amounts of water flow over the area in the spring as runoff from adjacent areas and as overflow drainage from Mauvais Coulee (see fig. 1). More permeable portions of the aquifers may crop out north of the test holes but the northern extent and altitudes of the aquifers are not known. The western extent of the sorted material likewise is not known but it may be surmised that there is a nearby western till boundary similar to the one at the eastern side (see fig. 8). Recharge, both surface and subsurface, from adjacent areas probably is small.

The aquifers may be connected with the ones penetrated by Minnewaukan tests 2 and 9 and with those found in section A-A'. If this is so, then the movement of ground water probably is toward the southeast because of the bedrock gradient. There is a difference in altitude of about 100 feet between the deepest bedrock in section B-B' and that in section A-A'.

The depth to shale in USGS tests 25, 26, and 27 in section C-C' ranges from about 50 to 60 feet. The surface material in USGS tests 25 and 26 is a comparatively permeable sand. USGS test 25 penetrated 51 feet of sorted material from the land surface to the bedrock. USGS test 27 has 12 feet of till at the surface and below that, 27 feet of sorted material. The sorted materials in USGS tests 25 and 27 should make fairly good aquifers but their areal extent is not known.

The reentrant in which section C-C' was drilled captures a small amount of surface drainage. The gradient from the top of the moraine to the bedrock "low" in the center of the lake basin is fairly steep. Movement of water and recharge should be fairly rapid there if any interconnecting aquifers exist between the moraine and the "low."

In an attempt to locate an adequate supply of water nearer the city than the significant aquifers encountered in the USGS test drilling in the eastern part of the area, the city of Minnewaukan subsequently drilled nine test holes in the lake-basin area. Their locations are shown on figure 6, and logs of all but Minnewaukan test 1 are given at the end of the report. Only a few of the samples from these test holes were examined by Geological Survey personnel; the rest were logged by the driller. No log of Minnewaukan test 1 is available, but it was reported to be a "dry" hole--that is, one penetrating little or no permeable water-bearing material.

A thin aquifer was penetrated between 68 and 71 feet in Minnewaukan test 2. The well was cased with 4-inch pipe and a pumping test was made by the U. S. Geological Survey. Computations based on the pumping test data indicated the coefficient of transmissibility to be about 600 gallons a day per foot, and the coefficient of storage was estimated to be about 0.01. 11/ Later, Minnewaukan test 9 was drilled about 40 feet south of test 2. The well was cased, and another pumping test was made. Although the aquifer in test 9 was thinner than in test 2, the pumping test indicated a coefficient of transmissibility of about 1,400 gallons a day per foot. The coefficient of storage was estimated as about 0.004.

Because of the probably restricted areal extent of these aquifers, it is believed they would not serve as sources for a municipal supply or for even light industrial use. However, if these aquifers were connected in some manner with a much larger aquifer nearby, it is possible that they would yield as much as 10,000 to 20,000 gpd.

Stream Channels

Three test holes (USGS tests 29, 30, and 35) were drilled in Recent stream channels. None of these penetrated any aquifers of fluvial origin that can be considered of importance even for farm supplies. USGS test 29 penetrated 20 feet of sorted material in its upper part, but it is believed that the material is of ice-contact origin.

11/ As used here, the "coefficient of transmissibility" is defined as the number of gallons of water that will pass in 1 day through a vertical strip of the aquifer 1 foot wide under a unit hydraulic gradient (1 foot per foot); or, through a cross section 1 mile wide under a gradient of 1 foot per mile.

The "coefficient of storage" is defined as the amount of water, expressed as a fraction of a cubic foot, that will be released from storage in each vertical column of the aquifer having a base of 1 square foot when the water level falls 1 foot.

Bedrock Aquifers

The only bedrock units that yield water in the Minnewaukan area are the Pierre shale and the "Dakota sandstone" as considered in the broad sense (see pp. 13 - 15.)

Pierre Shale

The water-bearing parts of the Pierre shale are restricted to approximately the upper 100 feet of the unit. Some farm wells in this area, as well as in other areas of North Dakota, obtain water from this part of the shale. It is probable that the wells in the village of Minnewaukan that are more than 50 feet deep end in Pierre shale.

Only a few farm wells are listed as obtaining water from the Pierre shale. However, some of the deeper wells for which no aquifer is listed probably also obtain water from the shale. The test drilling in the Minnewaukan area failed to disclose how the water occurs in this formation. Records of well depths and reports of local drillers in other areas indicate that there are several aquifers in the shale, which occur at specific depths and apparently have an areal extent of several square miles. The presence of brittle calcareous zones in the shale suggests that linear and interconnected solution voids may have developed along fractures. Small solution channels would be extremely difficult to identify by rotary drilling and coring. Local drillers emphasize the fact that water in the shale is found only in the "hardest" shale. This suggests that the openings may be fractures or solution cracks rather than interstices in sand beds. At any rate, the aquifers in the shale seem to be confined to definite zones.

Wells in these aquifers generally yield less than 10 gpm. The yields are large enough for most farm and domestic purposes but probably would be unsatisfactory for municipal supplies.

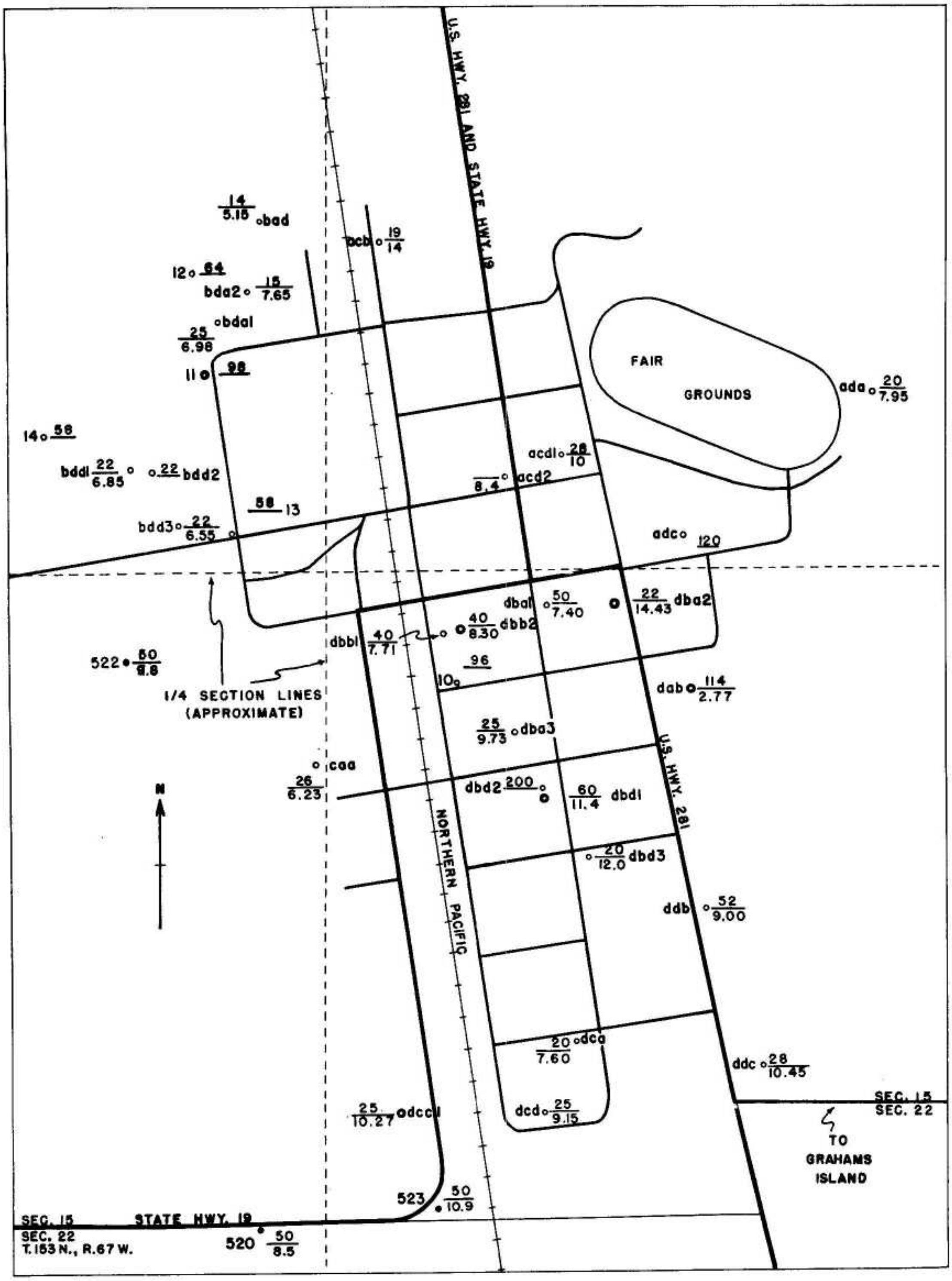
QUALITY OF WATER AND CHEMICAL ANALYSES

In order that the reader may more easily understand the significance of the chemical analyses, following is a partial list of chemical standards established by the U. S. Public Health Service for drinking water on interstate carriers:

Chemical constituent	Maximum concentration permitted (parts per million)
Dissolved solids	500 (1,000 permitted if necessary)
Chloride (Cl)	250
Sulfate (SO_4)	250
Magnesium (Mg)	125
Fluoride (F)	1.5
Iron and manganese (Fe & Mn)	0.3

The presence of excessive amounts of nitrate in ground water may indicate organic contamination. Water containing more than about 10 ppm of nitrate nitrogen (about 45 ppm of nitrate, as listed in the table of chemical analyses, Comly, 1945; Silverman, 1949) should not be used for feeding infants, because of the danger of contributing to infant cyanosis ("blue baby"). The presence of fluoride in drinking water in excess of 1.5 ppm may cause permanent mottling of the enamel of the teeth when the water is used continually by young children, but fluoride in lesser concentrations, up to 1.0 ppm, may be beneficial in the prevention of tooth decay.

Chemical analyses of 22 samples of water from 19 wells and test holes in the Minnewaukan area are given in the table following this discussion. These analyses include 12 from USGS and Minnewaukan test holes, 5 from wells in the city of Minnewaukan, and 5 from domestic and stock wells on farms in the Minnewaukan area. Locations of wells and test holes in Minnewaukan and the



EXPLANATION

$\circ \frac{20}{7.60}$

UPPER NUMBER INDICATES DEPTH OF WELL OR TEST HOLE, FEET. LOWER NUMBER INDICATES WATER LEVEL IN WELL OR TEST HOLE, IN FEET BELOW LAND SURFACE. (SEE WELL TABLES)

∘12

MINNEWAUKAN TEST HOLE AND NUMBER

•522

USGS TEST HOLE AND NUMBER

bad

WELL LOCATION NUMBER IN T. 133 N., R. 67 W., SEC. 15

o

WELL OR TEST HOLE SAMPLED FOR CHEMICAL ANALYSIS. (SEE TABLE OF CHEMICAL ANALYSES)

SEE FIGURE 6 FOR LOCATION OF THIS AREA

SCALE

0 1/4 1/2 MILE

FIGURE 15.–MAP SHOWING LOCATIONS OF WELLS AND TEST HOLES

immediate vicinity are shown in figure 15. Wells and test holes from which water samples were obtained for chemical analysis are indicated.

Only one of the wells sampled(153-67-15dab) is believed to yield water from the Pierre shale. Three other (153-67-15dbb1, 15dbb2, and 25cab) may tap either drift or shale aquifers but are believed to yield water from the drift. The rest of the wells sampled tap drift aquifers.

The dissolved solids in these samples range from 220 to 10,200 ppm and hardness ranges from 90 to 3,540 ppm.

Although there is some similarity in the mineral content of a few of the samples, most of the samples show great divergence either in the degree of mineralization or in the kind of minerals present. If there is any systematic relationship between the location and depth of aquifers and the degree and type of mineralization of the water, the analyses available are not sufficient in number to distinguish it.

Water samples from test holes in the lake-basin area yielded water of several diferent types and degrees of mineralization. USGS tests 41 and 42 yielded relatively hard water (470 to 640 ppm). In the samples from these test holes, the predominant cation is sodium and the predominant anion is sulfate. However, there is sufficient calcium and magnesium present to make a very hard water.

The water obtained from Minnewaukan tests 2 and 9 is relatively soft (90 and 110 ppm). Sodium is the predominant cation. The water contains less sulfate and more chloride than that obtained from USGS tests 41 and 42.

The water obtained from USGS test 33 is very hard (about 360 ppm) but is intermediate in hardness when compared with other supplies in the area. Sulfate is the predominant anion.

All these waters are too highly mineralized to make satisfactory municipal supplies but they could be used for general purposes if no better water were available. The harder waters obtained from USGS tests 41 and 42 could be used for irrigation of lawns and hedges although the percentage of sodium is greater than is desirable for general irrigation.

Water samples from two dug wells in the lake-basin area, the Ward well (153-66-8ddd) and the Knowlton well (153-67-13caa), are considerably different in degree of mineralization. The Ward well yields water containing 2,270 ppm of dissolved solids, and the Knowlton well 730 ppm of dissolved solids. Also, the water from the Ward well is much harder and contains more than 4 times as much sulfate as the water from the Knowlton well. These two wells are similar in depth. The Johnson well (153-67-25cab), on the periphery of the lake basin, is more than twice as deep as either of these two and yields water remarkably similar to that from the Knowlton well. The N. Zacher well (153-67-3dcd), also on the periphery of the lake basin, yields water intermediate in mineralization between that from the Ward well and that from the Knowlton well.

The drift aquifers at Minnewaukan and in the ice-contact and associated deposits just west of Minnewaukan yield water that varies greatly both in mineral composition and in degree of mineralization. The most highly mineralized sample obtained in the area was taken from USGS test 522, on the western edge of Minnewaukan. This sample contained 10,200 ppm of dissolved solids and the hardness was 3,540 ppm. The water contains a high percentage of sodium and the anions are principally sulfate.

The least mineralized water sampled in the area was from USGS test 511 in the ice-contact deposits northwest of Minnewaukan.

The B. M. Knowlton well (153-67-15dab) yields water of a distinctly different character than the other wells sampled and, for that reason, is believed to tap a shale aquifer. The water from this well contains 5,520 ppm dissolved solids and is moderately hard (270 ppm) as compared to other supplies in the area. It contains 2,060 ppm sodium and 2,890 ppm chloride.

D, glacial drift; P, Pierre shale

Location number	Owner or name	Aquifer	Depth of well (ft.)	Date collected	Source of analysis	Iron (Fe)	Calcium (Ca)
153-66-8ddd	R. D. Ward	D	22	9- 1-46	A	1.0	250
153-66-20bab	USGS test 42	D	239	5- 4-48	B	.4	110
153-66-21aab 1/	USGS test 41	D	103	8-17-48	B	1.9	110
153-66-21aab 2/	....do......	D	103	8-17-48	B	1.9	140
153-67-2dca 3/	Minnewaukan test 2	D	72	6-12-47	B	0	25
153-67-2dca 4/	.....do.....	D	72	6-12-47	B	0	25
153-67-2dcb2	Minnewaukan test 9	D	73	9-30-49	B	.2	26
153-67-3dcd	N. Zacher	D	96	9- 1-46	A	43	140
153-67-13caa	B. M. Knowlton	D	18	9- 1-46	A	2.0	130
153-67-15bda3	Minnewaukan test 11	D	98	9-24-51	B	.4	130
153-67-15cab	USGS test 522	D	50	5-14-52	B	.9	280
153-67-15dab	B. M. Knowlton	P?	114	7-12-46	A	9.6	73
153-67-15dba2	H. S. Herman	D	22	7-12-46	A	2.1	440
153-67-15dbb2	City of Minnewaukan	D?	40	7-12-46	A	1.2	420
153-67-15dbd1	Courthouse	D?	60	7-12-46	A	2.8	420
153-67-15dcc1	J. Hager	D	25	7-12-46	A	.4	430
153-67-16abb	USGS test 511	D	50	5- 6-52	B	4.1	54
153-67-19aaa	N. Wentz	D	20	9- 1-46	A	2.0	180
153-67-21aaa	USGS test 517	D	50	5- 9-52	B	.7	95
153-67-25cab	A. Johnson	D?	48	9- 1-46	A	1.1	114
154-67-36bcc 5/	USGS test 33	D	200	5- 4-48	B	3.5	95
154-67-36bcc 6/	.....do.....	D	200	5- 4-48	B	2.3	93

1/ Sample taken after 23 minutes of pumping.

2/ Sample taken after 6 hours of pumping.

3/ Sample taken after 18 hours of pumping.

4/ Sample taken after 6 hours of pumping.

5/ Sample taken after 3 hours of pumping with small air compressor.

6/ Sample taken after 5 hours of pumping with small air compressor.

IN THE MINNEWAUKAN AREA, N. DAK.
million)

A, State Laboratories Department, Bismarck
B, North Dakota State Department of Health, Bismarck

Magnesium (Mg)	Sodium and potassium (Na & K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$	Dissolved solids (sum)	Percent sodium
97	350	0	560	1,160	140	...	....	1,020	2,270	42
47	400	...	590	700	80	0	6.4	470	1,630	65
72	450	...	550	870	150	.03	26.0	570	1,950	63
70	430	...	560	870	150	0	22.0	640	1,960	59
7	750	...	820	400	450	0	....	90	2,040	95
7	740	...	810	390	450	0	....	90	2,010	95
12	830	14	770	370	610	0	10.8	110	2,250	94
36	230	19	440	460	140	...	....	500	1,280	47
35	60	0	410	260	40	...	....	470	730	22
63	59	0	410	300	50	.2	....	580	810	18
690	1,990	0	600	6,570	380	0	....	3,540	10,200	55
22	2,060	38	440	210	2,890	...	....	270	5,520	94
220	930	0	520	3,040	360	...	....	2,000	5,250	50
170	66	48	230	1,300	200	...	....	1,750	2,320	8
97	380	7	350	1,680	160	...	....	1,450	2,920	36
170	110	25	320	1,450	260	...	....	1,780	2,600	11
26	.....	0	250	....	8	.1	0	240	220	...
61	250	0	550	710	30	...	....	700	1,500	44
84	250	0	370	680	86	...	2.1	580	1,380	48
55	95	0	460	310	17	...	....	510	820	29
29	550	...	600	870	110	0	....	360	1,950	77
29	530	...	600	860	110	0	....	350	1,920	76

SUMMARY OF GROUND-WATER CONDITIONS

Most of the wells in the Minnewaukan area are in the ground- and end-moraine areas. These wells range in depth from less than 20 feet to as much as 180 feet. The wells obtain water from sand and gravel lenses or beds situated in and generally completely surrounded by till. The sand and gravel lenses may represent ice-contact or out-wash deposits or channel fillings that were overridden and disturbed by glacial ice and subsequently buried under deposits of till. Where of sufficient areal extent, these sand and gravel deposits may form important aquifers, but no very large deposits of this type are known to occur in the ground and end moraines in the Minnewaukan area (except for surficial ice-contact deposits which are considered separately in this report). The wells furnish only relatively small supplies of water for farm and domestic use, and many yield inadequate supplies for even these small demands.

The principal recharge to the sand and gravel lenses in the till probably is from surface water that collects in the undrained kettles and "potholes" and a part of which percolates into the ground. The rate of recharge probably is not very great because of the relatively impermeable nature of the kettle bottoms and the till itself. Movement of the ground water from the ground- and end-moraine areas is to the lower lake-basin and outwash areas.

A large group of ice-contact deposits alined in a north-south trend occurs in the ground-moraine area west of the city of Minnewaukan. The north end of the group is about half a mile north and about a mile west of the city of Minnewaukan and it extends nearly 4 miles south from there. The deposits in the ice-contact features and in the adjacent flanking topography contain considerable amounts of water-bearing sand and gravel. Only one or two places where it is believed that wells of moderate capacity (say 25 to 50 gpm) could be developed were found by test drilling. However, because of the apparent areal extent of the sand and gravel deposits, it is believed that a water supply adequate for the minimum needs of a small city such as Minnewaukan, or for light industrial use, could be developed from them. Probably three or more wells would be required to supply as much as 30,000 to 40,000 gpd, and they would need to be spaced far enough apart to draw water effectively from a rather large area.

Probably the principal recharge to the deposits is from downward and lateral percolation of water from melting snow and rain in the spring and from heavy rains in the fall. Considerable recharge may also occur through percolation of water from an intermittent stream that flows along the west flank of the group of ice-contact features and crosses it west of Minnewaukan.

The outwash deposits in the southern part of the area constitute the most extensive single aquifer known in the area. At the present time, only wells for individual domestic and farm supplies have been constructed in the area. Adequate supplies for these purposes generally are obtained from shallow dug or bored wells.

There is a large amount of water in storage in the outwash deposits. It has been conservatively estimated that at least 90 acre-feet of water is stored in each square mile for every foot vertically that is saturated. Also, there is excellent opportunity for recharge from downward percolation of rain and water from melting snow. Moreover, it is likely that considerable amounts of water are contributed to the outwash by lateral percolation of water from the adjacent North Viking end-moraine area.

Because of the rather clayey character of the outwash deposits, however, it may not be possible to develop drilled wells of very large capacity in the area. More information is needed in order to evaluate the prospects of obtaining wells of sizable yields.

In the lake-basin area, the only aquifers of importance are in or associated with the till underlying the lake deposits. These aquifers are of the same type as those found in the till of the ground- and end-moraine areas. In the lake-basin area, however, test drilling disclosed the presence of relatively thick and extensive deposits of water-bearing sand and gravel. There is little or no development of water from these aquifers at the present time but it appears likely that relatively large supplies of water might be produced from them.

The only bedrock aquifers in the area are the upper part of the Pierre shale and the "Dakota sandstone." The upper part of the Pierre shale yields water that is too highly mineralized to be suitable for general purposes and the yields of wells tapping the shale generally are less than 10 gpm.

It is estimated that the "Dakota sandstone" would be reached between 1,410 and 1,590 feet below the land surface at Minnewaukan. This aquifer doubtless could furnish supplies on the order of 500,000 to 1,000,000 gpd from several wells for an indefinite period of time. However, the water from this source is highly mineralized and is unsuitable, or at least undesirable, for most purposes.

The chemical quality of water from the drift aquifers varies greatly. The least mineralized sample obtained was from the ice-contact deposits northwest of Minnewaukan. This sample contained 220 ppm dissolved solids and the hardness was 240 ppm (calculated as $CaCO_3$).

Samples of water from the more productive aquifers in the lake-basin area contained 1,630 to 1,960 ppm of dissolved solids and the hardness ranged from 350 to 640 ppm.

Depth to water: Depths given to hundredths or tenths are measured; those given in units only are reported.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date completed
152-67-8dcc	G. Eback	17.1	30	Dug	....
152-67-9baa	Griffith	22.0	36	..do..	1945
152-67-13dcc	USGS test 23	90	5	Drilled	1946
152-67-20cbb	E. Wallace	70	48	Dug	....
152-67-21cdc1	L. Nielsen	37	30	..do..	....
152-67-21dcd2	....do......	48	48	..do..	....
152-67-29bb	W. T. Nelson	70	48	..do..	....
152-67-29cdd	USGS test 21	130	5	Drilled	1946
152-67-29dcc	E. Wallace	40	48	Dug	....
152-67-30abb	M. Christianson	28	48	..do..	1930
152-67-32aba	USGS test 22	24	5	Drilled	1946
152-68-10dcd	Ole Johnson	50	36	Dug	....
152-68-11ddd	Ole Hovde	30	48	..do..	1910
152-68-13acc	Hans Hovde	40	36	..do..	1917
152-68-14b	Lunde	40	36	..do..	1926
152-68-25cdd1	USGS test 20	100	5	Drilled	1946
152-68-25cdd2	E. May	12	60	Dug	....
152-68-26add	L. Hegland	17.8	30	Bored	....
152-68-27add	E. Peterson	12	48	Dug	....
152-68-27ccd	Henry Holey	51	48	..do..	....
152-68-27cdd	USGS test 16	60	5	Drilled	1946
152-68-27dcc	USGS test 17	61	5	..do..	1946
152-68-27ddc	USGS test 18	105	5	..do..	1946
152-68-34baa	H. Lysne	14	36	Dug	1916
152-68-35aa	W. Hokenson	28	36	..do..	....
152-68-35bbc	USGS test 19	61	5	Drilled	1946
153-66-8ddd	R. D. Ward	22	30	Dug	....

Date of measurement: For measured depths to water. For reported depths to water this is date of report, not of measurement.
Use of water: D, domestic; O, observation; S, stock; U, unused.

Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
11.55	7- 5-46	D,S	Water reported good, hard.
11.54	7- 5-46	D,S	Water reported hard, quantity inadequate; aquifer, blue clay.
.....	....	U	See log. Well refilled.
55	7-19-46	D,S	Water reported good, hard.
35.38	7-19-46	D	Water reported hard, quantity inadequate.
31.73	7-19-46	S	Water reported soft, quantity inadequate; aquifer, quicksand.
45.98	7-19-46	D,S	Water reported good, hard; aquifer, gravel.
.....	....	U	See log. Well refilled.
38	7-19-46	D,S	Water reported hard; aquifer, gravel.
23.62	7-19-46	D,S	Water reported very good, hard; aquifer, gravel.
.....	....	U	See log. Well refilled.
.....	....	S	Water reported good, hard; aquifer, clay.
22	8-23-46	S	Water reported good, hard; aquifer, coarse gravel.
18	8-23-46	D,S	Water reported good, hard; aquifer, fine sand.
13	8-23-46	S	Water reported hard; aquifer, clay and gravel.
....	....	U	See log. Well refilled.
5.48	7-19-46	D,S	Water reported hard; aquifer, quicksand.
12.08	7-10-46	D,S	Water reported hard; aquifer, sand.
9.11	7-19-46	S	Aquifer, sand and gravel.
2	7-19-46	D,S	Water reported good, hard.
.....	....	U	See log. Well refilled.
.....	....	U	Do.
.....	....	U	Do.
1	7-19-46	S	Water reported hard, salty, unfit for drinking; aquifer sand.
4.8	7-10-46	D,S	Water reported hard.
.....	....	U	See log. Well refilled.
12.36	9-12-46	S	See chemical analysis.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date collected
153-66-15dcc	USGS test 45	146	5	Drilled	1948
153-66-19bbb	USGS test 39	66	5	..do..	1946
153-66-20bab	USGS test 42	239	5	..do..	1946
153-66-21aab	USGS test 41	103	5	..do..	1948
153-66-21bab	USGS test 43	230	5	..do..	1946
153-66-21bbb	USGS test 40	324	5	..do..	1946
153-66-22bab	USGS test 44	130	5	..do..	1946
153-67-2dca	Minnewaukan test 2	72	4	..do..	1947
153-67-2dcb1	Minnewaukan test 8	90	4	..do..	1949
153-67-2dcb2	Minnewaukan test 9	73	4	..do..	1949
153-67-3aaa1	G. D. LaGrare	30	6	..do..	1917
153-67-3aaa2	....do.......	180	6	..do..	1917
153-67-3abb	W. Hahn	50	42	Dug	1928
153-67-3add	USGS test 35	65	5	Drilled	1946
153-67-3dcd	N. Zacher	96	4	..do..	1943
153-67-4baa	P. Tofsrud	80	6	..do..	
153-67-4cdc	E. Fowler	36	36	Dug	
153-67-10abd	Minnewaukan test 4	94	4	Drilled	1948
153-67-10bbb	USGS test 30	70	5	..do..	1946
153-67-10dcc	Minnewaukan test 5	100	4	..do..	1948
153-67-11bdc	Minnewaukan test 6	79	4	..do..	1948
153-67-12cdd	Minnewaukan test 7	129	4	..do..	....
153-67-13caa	B. M. Knowlton	18	36	Dug	1926
153-67-14bca	Minnewaukan test 3	83	4	Drilled	1948
153-67-15acb	W. Palmer	19	36	Dug	1939
153-67-15acd1	A. Lindstrom	28	24	..do..	1943
153-67-15acd2	Gas Station	...	...	....	....
153-67-15ada	Fairgrounds	20	48	Dug	1935

Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
.....	....	U	See log. Well refilled.
.....	....	U	Do.
.....	....	U	See log and chemical analysis.
7.02	8-14-48	O	Do.
.....	....	U	See log. Well refilled.
.....	....	U	Do.
.....	....	U	Do.
5.38	6-13-47	U	See log and chemical analysis. Well abandoned.
.....	....	U	See log. Well abandoned.
.....	....	U	See log and chemical analysis. Well abandoned.
.....	....	D	Water reported hard, quantity inadequate.
.....	....	S	Water reported salty, alkaline.
.....	....	D,S	Water reported soft, quantity inadequate.
.....	....	U	See log. Well refilled.
.....	....	D,S	See chemical analysis. Water reported good, hard; aquifer in drift.
30	7- 3-46	S	Water reported hard; quantity inadequate.
7.77	7- 3-46	S	Water reported hard, salty, unfit for drinking; aquifer, blue clay.
.....	....	U	Water reported salty. See log. Well abandoned.
.....	....	U	See log. Well refilled.
.....	....	U	See log. Well abandoned.
.....	....	U	Do.
.....	....		Do.
13.60	7- 3-46	D,S	See chemical analysis. Water reported hard, quantity inadequate in dry years; aquifer, gravel; well bottomed in shale (?).
.....	....	U	See log. Well abandoned.
14	7- 3-46	D	Water reported hard, alkaline, not used for drinking; aquifer, sand.
10	7- 3-46	D	Reported unfit for drinking, used only for flushing toilets; aquifer reported as blue clay.
8.4	7- 3-46	U	
7.95	7- 3-46	S	Water reported hard, quantity inadequate, unfit for drinking; aquifer, gravel.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date collected
153-67-15adc	C. F. Plummer	120	8	Drilled	1921
153-67-15bad	A. R. Foss	14	....	Dug	1882
153-67-15bcb	USGS test 514	50	5	Drilled	1952
153-67-15bcc	Minnewaukan test 16	57	...	..do..	1951
153-67-15bcd	Minnewaukan test 15	63	...	..do..	1951
153-67-15bda1	J. H. Archer	25	36	Dug	....
153-67-15bda2	H. Plummer	15	30	..do..	....
153-67-15bda3	Minnewaukan test 11	98	....	Drilled	1951
153-67-15bda4	Minnewaukan test 12	64	...	..do..	1951
153-67-15bdc	Minnewaukan test 14	58	...	..do..	1951
153-67-15bdd1	R. B. Hoffman	22	48	Dug	1928
153-67-15bdd2	....do.......	22	24	..do..	1928
153-67-15bdd3	....do.......	22	24	..do..	1928
153-67-15bdd4	Minnewaukan test 13	58	...	Drilled	1951
153-67-15caa	H. Hanson	26	18	Dug	1910
153-67-15cab	USGS test 522	50	5	Drilled	1952
153-67-15cba	USGS test 521	50	5	..do..	1952
153-67-15cbb	USGS test 29	56	5	..do..	1946
153-67-15dab	B. M. Knowlton	114	6	..do..	1914
153-67-15dba1	Lysne Hotel	50	48	Dug	1936
153-67-15dba2	H. S. Herman	22	30	..do..	1939
153-67-15dba3	F. Rising	25	30	..do..	....
153-67-15dbb1	H. Bily	40	14	..do..	1916

Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
.....	....	D	Water reported hard, quantity inadequate, unfit for drinking or washing, used for flushing toilets.
5.15	7- 2-46	S	Reported good supply, hard, not used for drinking.
9.6	5-20-52	U	See log. Well refilled.
.....	....	U	Do.
.....	....	U	Do.
6.98	7- 2-46	D,S	Water reported hard; quantity inadequate; aquifer, blue clay with a little gravel.
7.65	7- 2-46	S	Reported good supply but hard, unfit for drinking.
.....	....	U	See log and chemical analysis. Well refilled.
.....	....	U	See log. Well refilled.
.....	....	U	Do.
6.85	7- 2-46	S	Water reported hard, quantity inadequate, unfit for drinking; aquifer, blue clay with a little gravel.
.....	....	S	Do.
6.55	7- 2-46	U	Do.
.....	....	U	See log. Well refilled.
6.23	7- 2-46	S	Reported hard, quantity inadequate but fit for drinking; aquifer, blue clay.
9.8	5-20-52	U	See log and chemical analysis. Well refilled.
8.0	5-20-52	U	See log. Well refilled.
.....	....	U	Do.
2.77	7- 3-46	D,S	See chemical analysis. Water reported hard, quantity inadequate.
7.40	7- 3-46	U	Water reported hard, quantity inadequate, unfit for drinking or washing.
14.43	7- 3-46	D	See chemical analysis. Water reported hard, quantity inadequate, unfit for drinking.
9.73	7- 3-46	D	Water reported hard, quantity inadequate; see log.
7.71	7- 3-46	D	Water reported hard, quantity inadequate, unfit for drinking, used for irrigating lawn.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date collected
153-67-15dbb2	City of Minnewaukan	40	10	....	....
153-67-15dbb3	Minnewaukan test 10	96	...	Drilled	1951
153-67-15dbd1	Courthouse	60	...	..do..	....
153-67-15dbd2	....do.....	200	6	..do..	1936
153-67-15dbd3	G. Dickinson, Jr.	20	...	..do..	1919
153-67-15dca	F. Johnson	20	36	Bored	1900
153-67-15dcc1	J. Hager	25	36	Dug	1936
153-67-15dcc2	USGS test 523	50	5	Drilled	1952
153-67-15dcd	S. L. Burgess	25	30	Dug	1900
153-67-15ddc	Johnson	28	36	Bored	1926
153-67-15ddb	W. D. Humphrey	52	24	Dug	1912
153-67-16aaa	USGS test 512	60	5	Drilled	1952
153-67-16aad	USGS test 513	50	5	..do..	1952
153-67-16abb	USGS test 511	50	5	..do..	1952
153-67-16baa1	USGS test 509	50	5	..do..	1952
153-67-16baa2	USGS test 510	120	5	..do..	1952
153-67-16caa	J. Hoffart	50	36	Dug	....
153-67-16daa	USGS test 508	50	5	Drilled	1952
153-67-16dba	USGS test 507	120	5	..do..	1952
153-67-16dbb	USGS test 506	50	5	..do..	1952
153-67-16dcd	USGS test 515	50	5	..do..	1952
153-67-17ccc	Ore White	156	4	..do..	....
153-67-19aaa	N. Wentz	20	30	Bored	....

Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
8.30	7- 3-46	D	See chemical analysis. Water reported fairly good supply, hard; aquifer, blue clay.
.....	....	U	See log. Well refilled.
11.4	7- 1-46	D	See chemical analysis. Water reported hard, unfit for drinking, used for flushing toilets.
.....	....	D	Water reported hard, unfit for drinking, used for flushing toilets.
12.0	7- 3-46	D	Water reported hard, quantity inadequate, unfit for drinking, used for irrigating lawn; aquifer, blue clay.
7.60	7- 3-46	D,S	Water reported hard, quantity inadequate; aquifer, sand.
10.27	7- 2-46	D,S	See chemical analysis. Water reported hard, quantity inadequate; aquifer, gravel.
10.9	5-20-52	U	See log. Well refilled.
9.15	7- 2-46	S	Water reported hard, quantity inadequate; aquifer, blue clay with a little sand.
10.45	7- 2-46	D,S	Water reported hard, quantity inadequate; aquifer, blue clay and sand.
9.00	7- 3-46	D	Water reported hard, quantity inadequate, unfit for washing; aquifer, sand.
14.8	5-20-52	U	See log. Well refilled.
5.6	5-20-52	U	Do.
17.7	5-20-52	U	See log and chemical analysis. Well refilled.
.....	....	U	See log. Well refilled.
16.0	5- 6-52	U	Do.
25.95	7- 3-46	D,S	Water reported good, hard; aquifer quicksand.
4.3	5-20-52	U	See log. Well refilled.
14.9	5-20-52	U	Do.
3.8	5-20-52	U	Do.
22.2	5-20-52	U	Do.
126	7- 4-46	S	Water reported inadequate in quantity, salty, unfit for drinking; aquifer, quicksand.
5	7- 4-46	D,S	See chemical analysis. Water reported good, hard.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date collected
153-67-20abc	T. Sollin	180	5	Drilled	1935
153-67-20acb	....do.....	20	24	Dug	1929
153-67-21aaa	USGS test 517	50	5	Drilled	1952
153-67-21aab	USGS test 516	140	5	..do..	1952
153-67-21cdd	USGS test 524	50	5	..do..	1952
153-67-21dcc	F. Anderson	35	24	Bored	1939
153-67-21ddc	USGS test 526	158	5	Drilled	1952
153-67-21ddd	USGS test 527	50	5	..do..	1952
153-67-22baa	USGS test 520	50	5	..do..	1952
153-67-22bab	USGS test 519	50	5	..do..	1952
153-67-22bbb	USGS test 518	50	5	..do..	1952
153-67-22ccd	USGS test 528	50	5	..do..	1952
153-67-23aaa	USGS test 28	59	5	..do..	1946
153-67-23bab	USGS test 36	80	5	..do..	1946
153-67-23bdd	D. Burgess	22	36	Dug	....
153-67-23dbb1	R. Newcomb	14	60	..do..	1937
153-67-23dbb2	....do......	12	24	..do..	1937
153-67-24abb	USGS test 37	86	5	Drilled	1946
153-67-24bab	USGS test 38	75	5	..do..	1946
153-67-25cab	A. Johnson	48	36	Dug	....
153-67-27ccc1	P. Schmid	30	48	..do..	1929
153-67-27ccc2	....do.......	30	...	..do..	1938
153-67-28aba	USGS test 525	50	5	Drilled	1952
153-67-28bbb	H. Anderson	35	24	Bored	1934
153-67-29aaa	....do.......	23	24	..do..	1943
153-67-34dcc	E. J. Nottestad	48	...	Dug	....
153-67-35aac	USGS test 24	164	5	Drilled	1946
153-67-35dbb	L. Rickansrude	100	6	..do..	1926
153-67-36aab1	USGS test 26	68	5	..do..	1946
153-67-36aab2	USGS test 25	97	5	..do..	1946
153-67-36aba	USGS test 27	49	5	..do..	1946
154-66-31dda	O. Solheim	145	4	..do..	1948

Depth to water (feet below land surface)	Date of measurement	Use of water	Remarks
.....	....	U	Water reported hard, salty, unfit for drinking; aquifer, quicksand.
11.99	7- 3-46	D,S	Water reported hard, quantity inadequate in dry weather.
12.9	5-20-52	U	See log and chemical analysis. Well refilled.
31.3	5-20-52	U	See log. Well refilled.
8.4	5-20-52	U	Do.
18.00	7- 4-46	D,S	Water reported hard, quantity inadequate.
7.6	5-17-52	U	See log. Well refilled.
14.4	5-20-52	U	Do.
8.5	5-20-52	U	Do.
4.1	5-20-52	U	Do.
4.4	5-20-52	U	Do.
16.8	5-20-52	U	Do.
.....	....	U	Do.
.....	....	U	Do.
15.75	7- 5-46	D,S	Water reported hard, quantity inadequate; aquifer, sand.
7.94	7- 5-46	S	Water reported hard, quantity inadequate, unfit for drinking; aquifer, gravel.
6.74	7- 5-46	D	Water reported hard, quantity inadequate.
.....	....	U	See log. Well refilled.
.....	....	U	Do.
24.55	7- 5-46	D,S	See chemical analysis.
15.02	7- 5-46	D,S	Water reported hard, quantity adequate for farm use; aquifer, quicksand.
14.74	7- 5-46	D,S	Do.
5.3	5-20-52	U	See log. Well refilled.
18.07	7- 4-46	S	Water reported hard, quantity inadequate; unfit for drinking; aquifer, gravel.
15.21	7- 4-46	S	Water reported suitable for drinking, but quantity inadequate; aquifer, gravel.
19.40	7- 5-46	D,S	Water reported hard.
.....	....	U	See log. Well refilled.
.....	....	S	Water reported salty.
.....	....	U	See log. Well refilled.
.....	....	U	Do.
.....	....	U	Do.
.....	....	D,S	Aquifer in drift.

Location number	Owner or name	Depth of well (feet)	Diameter (inches)	Type	Date collected
154-67-35add1	USGS test 34	140	5	Drilled	1946
154-67-35add2	USGS test 31	150	5	..do..	1946
154-67-36bcc	USGS test 33	200	5	..do..	1946
154-67-36daa	USGS test 32	126	5	..do..	1946

Depth to water (feet below land surface)	Date of measure-ment	Use of water	Remarks
.....	....	U	See log. Well refilled.
.....	....	U	Do.
.....	....	U	See log and chemical analysis. Well refilled.
.....	....	U	See log. Well refilled.

LOGS OF WELLS AND TEST HOLES IN MINNEWAUKAN AREA, N. DAK.

152-67-13dcc
USGS test 23

Material	Thickness (feet)	Depth (feet)
Till, light-gray, sandy	12	12
Till, gray, sandy	6	18
Sand and gravel, gray	7	25
Till, gray, sandy	20	45
Gravel, coarse, angular, mostly shale	30	75
Pierre shale	15	90

152-67-29cdd
USGS test 21

Sand, brown, medium to coarse, well-sorted	5	5
Gravel, gray, medium to coarse, many shale pebbles.	26	31
Till, gray, silty and sandy	64	95
Sand, fine	10	105
Pierre shale	25	130

152-67-32aba
USGS test 22

Sand, brown, medium to coarse, well-sorted	5	5
Gravel, brown, medium to coarse, well-sorted	19	24

152-68-25cdd1
USGS test 20

Sand, brown, medium to coarse, silty	10	10
Gravel, gray, shale, angular	30	40
Till, gray, sandy and silty	40	80
Pierre shale	20	100

152-68-27cdd
USGS test 16

Material	Thickness (feet)	Depth (feet)
Topsoil, light-brown, silty and sandy	5	5
Gravel, fine, brown, and medium to coarse brown sand	15	20
Till, gray	40	60

152-68-27dcc
USGS test 17

Material	Thickness (feet)	Depth (feet)
Sand, brown, medium to coarse	9	9
Gravel, gray, coarse, angular, with shale pebbles	6	15
Till, gray, silty, sandy	25	40
Pierre shale	21	61

152-68-27ddc
USGS test 18

Material	Thickness (feet)	Depth (feet)
Sand, light-brown, silty, and limestone pebbles	5	5
Gravel, brown, fairly well-sorted	10	15
Till, gray, silty and sandy	70	85
Sand, fine	5	90
Pierre shale	15	105

152-68-35bbc
USGS test 19

Material	Thickness (feet)	Depth (feet)
Sand, brown, medium to coarse, well-sorted	10	10
Silt, light-brown, and limestone pebbles	16	26
Till, gray, silty and sandy	9	35
Cretaceous or Teriary clay, sandy and gypsiferous	19	54
Pierre shale	7	61

153-66-15dcc
USGS test 45

Material	Thickness (feet)	Depth (feet)
Silt, gray, sandy	7	7
Silt, light-brown, clayey	12	19
Silt, brown-gray, clayey	11	30
Till, gray, many shale pebbles	37	67
Gravel and sand, gray, clayey, with shale and limestone-dolomite pebbles	18	85
Till, gray	50	135
Pierre shale	11	146

153-66-19bbb
USGS test 39

Material	Thickness (feet)	Depth (feet)
Clay, light-brown, silty, (till?)	21	21
Gravel and sand, gray, shale	30	51
Pierre shale	15	66

153-66-20bab
USGS test 42

Material	Thickness (feet)	Depth (feet)
Silt and clay, gray, pebbly (till?)	28	28
Sand, gray, fine to medium, well-sorted	29	57
Gravel, gray, fine to medium, with coal and shale pebbles	35	92
Clay and silt, gray	35	127
Till, gray, silty	53	180
Gravel, gray, fine to medium, with shale pebbles	22	202
Sand and gravel, gray, shale	7	209
Gravel, gray, fine to medium	18	227
Gravel, gray, coarse	9	236
Pierre shale	3	239

153-66-21aab
USGS test 41

Material	Thickness (feet)	Depth (feet)
Sand, brown, medium to coarse, well-sorted	5	5
Gravel and sand, gray, angular	6	11
Gravel, gray, coarse, angular, with many large shale pebbles	92	103

153-66-21bab
USGS test 43

Material	Thickness (feet)	Depth (feet)
Clay and silt, light-gray	26	26
Sand, brown, medium to coarse	12	38
Gravel, fine to coarse, with shale pebbles	3	41
Till, gray, silty	65	106
Gravel, gray, fine to coarse, with angular shale fragments	4	110
Gravel, gray, medium to coarse, angular, clayey	20	130
Till, gray, silty	92	222
Pierre shale	8	230

153-66-21bbb
USGS test 40

Material	Thickness (feet)	Depth (feet)
Clay and silt, light-brown	22	22
Caly and silt, gray	29	51
Till, gray	11	62
Gravel, gray, shale	28	90
Till, gray	22	112
Gravel, gray, very coarse, many shale pebbles	36	148
Sand and gravel, gray, clayey, with coal and shale pebbles	35	183
Till or clay, gray	97	280
Sand and gravel, gray, clayey, with coal and shale pebbles	39	319
Pierre shale	5	324

153-66-22bab
USGS test 44

Material	Thickness (feet)	Depth (feet)
Clay and silt, light-brown	4	4
Clay and silt, gray-brown	8	12
Sand, gray, clayey	5	17
Till, gray, with shale and limestone-dolomite pebbles	29	46
Sand and gravel, gray, clayey	9	55
Gravel, gray, coarse, angular, with shale and limestone-dolomite pebbles	13	68
Till, gray	44	112
Pierre shale	18	130

153-67-2dca
Minnewaukan test 2

Material	Thickness (feet)	Depth (feet)
Till, yellow, sandy	7	7
Till, light-brown, sandy	27	34
Gravel, light-brown, coarse, with limestone and granite pebbles somewhat rounded	1	35
Till, gray	1	36
Sand, brown, coarse, with a few pebbles	2	38
Till, gray	30	68
Sand, gray, shale	3	71
Pierre shale	1	72

153-67-2dcb1
Minnewaukan test 8

Material	Thickness (feet)	Depth (feet)
Clay, yellow	14	14
Gravel; contained some water	2	16
Clay, gray (till?)	65	81
Sand, gravel, some coal, water-bearing	2	83
Gravel, shale	5	88
Pierre shale	2	90

153-67-2dcb2
Minnewaukan test 9

Material	Thickness (feet)	Depth (feet)
Clay, yellow, sandy	8	8
Clay, gray	1	9
Sand, coarse	4	13
Quicksand	2	15
Clay, gray, sandy (till?)	27	42
Sand, water-bearing	2	44
Clay, gray (till?)	5	49
Gravel	2	51
Clay, gray, and sand (till?)	6	57
Pebbles	1	58
Clay, gray, and sand (till?)	11	69
Sand, shaly	4	73

153-67-3add
USGS test 35

Material	Thickness (feet)	Depth (feet)
Till, light-brown, sandy and silty	5	5
Till, gray	40	45
Gravel, gray, clayey, mostly shale	5	50
Pierre shale	15	65

153-37-10abd
Minnewaukan test 4

Clay, sand, and gravel, mixture of, brown (till?)	24	24
Sand	7	31
Clay, gray	11	42
Clay, gray, and sand	9	51
Hardpan (till?)	1	52
Sand	2	54
Clay, blue, pebbly (till?)	37	91
Pierre shale	3	94

153-67-10bbb
USGS test 30

Till, light-brown, silty	12	12
Till, gray, silty, with angular shale pebbles	38	50
Pierre shale	20	70

153-67-10dcc
Minnewaukan test 5

Clay, yellow, pebbly (till?)	16	16
Clay, gray	13	29
Sand	8	37
Clay, blue, pebbly (till?)	42	79
Pierre shale	21	100

153-67-11bdc
Minnewaukan test 6

Material	Thickness (feet)	Depth (feet)
Clay, yellow, silty	14	14
Clay, gray, silty	18	32
Till, gray	26	58
Pierre shale	21	79

Note: Depths from driller; samples examined by U. S. Geological Survey

153-67-12cdd
Minnewaukan test 7

Material	Thickness (feet)	Depth (feet)
Sand and gravel	2	2
Clay, brown, pebbly (till?)	6	8
Till, gray	40	48
Clay, gray, silty	28	76
Sand, gray, very fine	13	89
Gravel, gray, mostly coarse, subrounded, silt	1	90
Limestone boulder	1	91
Sand, gray, fine to coarse, some small quartz and shale pebbles	1	92
Sand, gray, mostly coarse, silty	1	93
Till, gray	18	111
Sand, gray, mostly fine	1	112
Sand, gray, very fine to coarse, some shale gravel	2	114
Sand and gravel, gray shale	5	119
Gravel, gray, coarse, very clayey	5	124
Shale, gray	5	129

Note: Depths from driller; samples from 8 feet to 119 feet examined by U. S. Geological Survey.

153-67-14bca
Minnewaukan test 3

Material	Thickness (feet)	Depth (feet)
Clay, brown	25	25
Sand	1	26
Clay, gray	23	49
Sand, medium to coarse	1	50
Clay, blue	11	61
Clay, blue, and coarse gravel (till?)	13	74
Pierre shale	9	83

153-67-15bcb
USGS test 514

Topsoil, black	1	1
Clay, sandy and gravelly, gray	1	2
Sand and gravel, very clayey, gray	2	4
Till, light-brown	10	14
Till, gray	25	39
Pierre shale, gray	11	50

153-67-15bcc
Minnewaukan test 16

Topsoil	1	1
Gray clay	3	4
Yellow sandy clay	5	9
Blue sandy clay	15	24
Sand	2	26
Blue clay	12	38
Sand	2	40
Blue sandy clay	8	48
Blue clay (shale?)	9	57

153-67-15bcd
Minnewaukan test 15

Material	Thickness (feet)	Depth (feet)
Topsoil	2	2
Yellow sandy clay	6	8
Blue sandy clay	14	22
Sand	4	26
Blue sandy clay	10	36
Sand	5	41
Blue sandy clay	15	56
Blue clay, sticky (Pierre shale?)	7	63

153-67-15bda3
Minnewaukan test 11

Fill	3	3
Sandy clay	9	12
Blue sand and clay	18	30
Sand and gravel	4	34
Sand and gravel	4	38
Blue clay (Pierre shale?)	56	94
Shale	4	98

153-67-15bda4
Minnewaukan test 12

Clay	4	4
Yellow sand (shells)	8	12
Blue sand and clay	29	41
Sand and gravel	2	43
Blue clay (Pierre shale?)	21	64

153-67-15bdc
Minnewaukan test 14

Topsoil	2	2
Yellow sand clay	10	12
Blue sandy clay	16	28
Sand	6	34
Blue clay (sand streaks)	22	56
Blue clay (Pierre shale?)	2	58

153-67-15bdd4
Minnewaukan test 13

Material	Thickness (feet)	Depth (feet)
Yellow clay	13	13
Blue sandy clay	3	16
Sand	2	18
Blue sandy clay	8	26
Sand and gravel	2	28
Blue sandy clay	18	46
Blue clay (Pierre shale?)	12	58

153-67-15cab
USGS test 522

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, sandy and gravelly	2	3
Silt and very fine sand, clayey and gravelly, light-brown (till?)	11	14
Silt and very fine sand, clayey and gravelly, gray (till?)	6	20
Till, gray	8	28
Sand, fine to very coarse, very clayey, gray; some of coarser material, shale	6	34
Till, gray	12	46
Pierre shale, gray	4	50

153-67-15cba
USGS test 521

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Sand, very fine to very coarse, clayey, light-brown	4	5
Till, silty, light-brown, or silt and very fine sand, clayey and gravelly	8	13
Till, gray	4	17
Sand, very coarse, and gravel, fine, very silty and clayey, gray	9	26
Till, gray	20	46
Pierre shale, gray	4	50

153-67-15cbb
USGS test 29

Material	Thickness (feet)	Depth (feet)
Silt, light-brown, with shale pebbles	10	10
Sand and gravel, gray, with angular shale pebbles	10	20
Till, gray	5	25
Pierre shale	31	56

153-67-15dba3
F. Rising

Topsoil	1	1
Clay, yellow	9	10
Clay, blue	12	22
Gravel	3	25

153-67-15dbb3
Minnewaukan test 10

Topsoil	2	2
Sandy clay	26	28
Sand and gravel	1	29
Blue clay with rocks	22	51
Blue clay, sticky (Pierre shale?)	40	91
Shale, hard	5	96

153-67-15dcc2
USGS test 523

Topsoil, black	3	3
Clay, sandy and gravelly, gray	2	5
Till, silty, light-brown	11	16
Sand, medium to very coarse, and gravel, fine, clayey, gray	2	18
Till, gray	26	44
Pierre shale, gray	6	50

153-67-16aaa
USGS test 512

Material	Thickness (feet)	Depth (feet)
Silt and very fine sand, clayey and gravelly, light-brown	11	11
Silt and very fine sand, clayey and gravelly, gray	12	23
Till, gray	9	32
Sand, very fine to medium, very clayey and silty, gray; coarser material, shale	14	46
Pierre shale, gray	14	60

153-67-16aad
USGS test 513

Topsoil, black	1	1
Clay, sandy and gravelly, gray	4	5
Silt and very fine sand, clayey and gravelly, light-brown	4	9
Sand and gravel, very silty, gray (or very sandy and gravelly till)	17	26
Sand, medium to very coarse, and gravel, fine, fairly free of clay at top, more clayey toward bottom, gray; about one-fourth shale	11	37
Pierre shale, grey	13	50

153-67-16abb
USGS test 511

Topsoil, black	1	1
Sand, medium to very coarse, and gravel, fine to medium, very clayey, light-brown	8	9
Till, light-brown	5	14
Till, gray	12	26
Gravel, fine to coarse, and some sand; very little clay; finer gravel, shale	10	36
Till, gray	14	50

153-67-16baa1
USGS test 509

Material	Thickness (feet)	Depth (feet)
Sand, fine to very coarse, light-brown, clayey...	5	5
Till, silty, light-brown, or silt and sand, very fine, clayey and gravelly.....................	12	17
Till, sandy and gravelly, gray..................	5	22
Gravel, fine to medium, and some sand, very little clay; about one-third shale............	15	37
Till, gray......................................	13	50

153-67-16baa2
USGS test 510

Topsoil, light-brown to black, silty............	1	1
Clay and silt, pebbly, light-brown..............	2	3
Sand, very fine to medium, and silt, light-brown, clayey......................................	9	12
Sand, very fine to fine, light-brown............	7	19
Silt and very fine sand, gravelly and clayey, light-brown, or till..........................	16	35
Silt and sand, very fine, gravelly and clayey, gray, (till?)................................	11	46
Gravel, fine to medium, and some sand, very coarse, fairly free of clay, gray; about one-third shale..................................	23	69
Till, gray......................................	8	77
Pierre shale, gray..............................	43	120

153-67-16daa
USGS test 508

Topsoil, black..................................	3	3
Sand and gravel, very clayey, light-brown........	3	6
Till, light-brown, sandy and gravelly...........	3	9
Till, gray......................................	18	27
Pierre shale....................................	23	50

153-67-16dba
USGS test 507

Material	Thickness (feet)	Depth (feet)
Topsoil, dark-brown	2	2
Sand and gravel, very clayey, light-brown	2	4
Till, light-brown	8	12
Gravel, fine to medium and sand, very coarse, very clayey, light-brown; about one half shale.	4	16
Gravel, fine to medium, and sand, very coarse, very clayey, gray; about one-half shale	11	27
Till, gray	19	46
Pierre shale, gray	74	120

153-67-16dbb
USGS test 506

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Till, gray	2	4
Till, light-brown	4	8
Till, gray	5	13
Sand, medium to very coarse, and some fine gravel, slightly clayey, gray; coarser material, shale.	11	24
Till, gray	17	41
Pierre shale, gray	9	50

153-67-16dcd
USGS test 515

Material	Thickness (feet)	Depth (feet)
Silt, clay and sand, very fine, light-brown	3	3
Sand, fine to very coarse, and some gravel, fine to coarse, slightly clayey, light-brown	19	22
Gravel, fine to medium, and sand, medium to very coarse, slightly clayey, gray; gravel about one-third shale	6	28
Sand, medium to very coarse, and gravel, fine to medium, very clayey, gray; coarse material is shale	8	36
Till, gray	14	50

153-67-21aaa
USGS test 517

Material	Thickness (feet)	Depth (feet)
Till, silty, light-brown, or silt and sand, very fine, clayey and gravelly	15	15
Sand, medium to very coarse and some gravel, fine, very clayey, gray; about one-third shale.	5	20
Till, gray	18	38
Pierre shale, gray	12	50

153-67-21aab
USGS test 516

Material	Thickness (feet)	Depth (feet)
Silt and very fine sand, clayey and gravelly, light-brown	25	25
Silt and very fine sand, clayey and gravelly, gray; more gravel toward bottom	40	65
Till, gray, sandy and gravelly, or very clayey sand and gravel	7	72
Pierre shale, gray	68	140

153-67-21cdd
USGS test 524

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Clay, sandy and gravelly, gray	4	5
Till, silty, light-brown, or silt and sand, very fine, clayey and gravelly	10	15
Sand, very fine to medium, clayey, gray	10	25
Till, gray	25	50

153-67-21ddc
USGS test 526

Material	Thickness (feet)	Depth (feet)
Topsoil, black	1	1
Silt and very fine sand, clayey and gravelly, light-brown	18	19
Silt and very fine sand, clayey and gravelly, gray	8	27
Sand, very coarse, and gravel, fine, very clayey, gray; mostly shale	7	34
Till, gray	18	52
Gravel, fine, and sand, very coarse, very clayey, gray; mostly shale	2	54
Till, gray	29	83
Pierre shale, gray	75	158

153-67-21ddd
USGS test 527

Topsoil, black	2	2
Clay, sandy and gravelly, gray	2	4
Till, light-brown	9	13
Sand, fine to very coarse, very clayey, light-brown	2	15
Till, gray	35	50

153-67-22baa
USGS test 520

Topsoil, black	1	1
Clay, sandy and gravelly, gray	1	2
Till, light-brown	9	11
Till, gray	17	28
Pierre shale, gray (till?)	22	50

153-67-22bab
USGS test 519

Material	Thickness (feet)	Depth (feet)
Topsoil, light-brown	1	1
Clay, sand and gravelly, gray	1	2
Till, silty, light-brown	10	12
Till, gray	24	36
Pierre shale, gray	14	50

153-67-22bbb
USGS test 518

Material	Thickness (feet)	Depth (feet)
Topsoil, gray	1	1
Till, silty, light-brown or silt and sand, very fine, gravelly and clayey	7	8
Sand, fine to coarse, clayey, gray; mostly shale	8	16
Till, gray	22	38
Pierre shale, gray	12	50

153-67-22ccd
USGS test 528

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Clay, sandy and gravelly, gray	1	3
Till, light-brown	13	16
Till, silty, gray, or silt and sand, very fine, clayey and gravelly	4	20
Sand, medium to very coarse, and gravel, fine, very clayey, gray mostly shale	12	32
Till, gray, sandy, and gravelly	18	50

153-67-23aaa
USGS test 28

Material	Thickness (feet)	Depth (feet)
Silt, light-brown	10	10
Clay, gray, with fresh-water gastropod	15	25
Till, light-brown	30	55
Pierre shale	4	59

153-67-23bab
USGS test 36

Material	Thickness (feet)	Depth (feet)
Silt, light-brown	18	18
Silt, gray	27	45
Pierre shale	35	80

153-67-24abb
USGS test 37

Material	Thickness (feet)	Depth (feet)
Silt and clay, light-brown	8	8
Sand, brown, fine to medium, well-sorted	12	20
Till, gray, many shale pebbles	50	70
Pierre shale	16	86

153-67-24bab
USGS test 38

Material	Thickness (feet)	Depth (feet)
Clay and silt, light-brown (till?)	23	23
Till, gray, silty, with shale pebbles	45	68
Pierre shale	7	75

153-67-28aba
USGS test 525

Material	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Clay, sandy and gravelly, gray	3	5
Till, silty, light-brown, or silt and very fine sand, clayey and gravelly	4	9
Till, silty, gray, or silt and very fine sand, clayey and gravelly	5	14
Till, sandy and gravelly, gray	11	25
Till, gray	25	50

153-67-35aac
USGS test 24

Material	Thickness (feet)	Depth (feet)
Silt, gray	5	5
Silt, light-brown	10	15
Silt, gray	15	30
Till, gray, silty, with some limestone pebbles	117	147
Pierre shale	17	164

153-67-36aab1
USGS test 26

Material	Thickness (feet)	Depth (feet)
Sand, brown	7	7
Till, light-brown, sandy and silty	11	18
Gravel, gray, coarse, angular, and shale	14	32
Till, gray	25	57
Pierre shale	11	68

153-67-36aab2
USGS test 25

Material	Thickness (feet)	Depth (feet)
Topsoil, gray, silty	5	5
Sand, light-brown, silty	12	17
Sand, gray, fine to medium	9	26
Gravel, gray, coarse, angular	25	51
Pierre shale	46	97

153-67-36aba
USGS test 27

Material	Thickness (feet)	Depth (feet)
Till, light-brown, silty	12	12
Sand and gravel, gray, fairly well sorted, with shale pebbles	18	30
Sand and gravel, gray, poorly sorted, with some weathered shale	9	39
Shale	10	49

154-67-35add1
USGS test 34

Material	Thickness (feet)	Depth (feet)
Clay and silt, light-brown	14	14
Clay and silt, gray	16	30
Till, gray	17	47
Gravel, gray, angular shale	23	70
Gravel, gray, very coarse, angular	20	90
Gravel, gray, shale with some coal	43	133
Pierre shale	7	140

154-67-35add2
USGS test 31

Material	Thickness (feet)	Depth (feet)
Silt, very light-gray	5	5
Silt, light-brown	13	18
Clay and silt, gray	33	51
Sand and gravel, gray, shaly, clayey	14	65
Till, gray	25	90
Clay, gray, silty	9	99
Gravel, gray, shale, angular	42	141
Pierre shale	9	150

154-67-36bcc
USGS test 33

Material	Thickness (feet)	Depth (feet)
Silt, light-brown with a few shale pebbles	18	18
Silt, gray	22	40
Till, gray, with shale pebbles	5	45
Gravel and sand	2	47
Till, gray, with shale pebbles	10	57
Sand and gravel, gray, clean, angular, poorly sorted, with some shale pebbles	79	136
Gravel, gray, shale, with some clay	8	144
Gravel, gray, shale, coarse, round	16	160
Sand and gravel, gray, with some shale pebbles and coal, clayey	25	185
Pierre shale	15	200

154-67-36daa
USGS test 32

Material	Thickness (feet)	Depth (feet)
Till, yellow, silty	8	8
Till, gray	112	120
Pierre shale	6	126

Devils Lake Well

(from Laird, 1941, pp. 25-27)

Formation	Material	Thickness	Depth
Pleistocene			
	Drift	10	10
	Coarse sand	10	20
	Fine gravel	30	50
Cretaceous			
Pierre (shale)			
	Shale with silt and gravel	20	70
	Shale with sand and gravel	10	80
	Soft tan shale	10	90
	Sand and shale	20	110
	Soft gray shale with shell fragments and gypsum	80	190
	Dark-gray shale, lignite with sulphur and gypsum	10	200
	Light-gray shale with gypsum and shells	100	300
	Dark-gray shale with lignite, gypsum	20	320
	Light-gray shale with lignite	10	330
	Dark-gray shale with lignite, sulphur, gypsum	20	350
	Light-gray shale with lignite	10	360
	Dark-gray shale	10	370
	Light-gray blocky shale, gypsum, lignite	10	380
	Light-gray shale and lignite	10	390
	Blocky and tan shale, little lignite. Satinspar and prisms, gypsum and spherules	110	500
	Dark-gray shale with selenite	10	510

Devils Lake Well - - Continued

Formation	Material	Thickness	Depth
	Gray and tan shale, rare prisms and selenite......................	10	520
	Gray and tan shale with gypsum and sulphur........................	20	540
	Gray and tan shale with gypsum, sulphur rare, satinspar............	10	550
	Light and dark-gray shale with selenite and satinspar.............	40	590
	Light-gray to black shale with abundant sulphur and gypsum, prisms rare......................	10	600
	Medium gray shale..................	10	610
Niobrara (formation)			
	Gray and tan shale with lignite, selenite and abundant fossils......	50	660
	Soft gray shale, less fossils, much gypsum..........................	10	670
	Dark and light-gray shale...........	10	680
	Soft gray shale, some gypsum and lignite........................	20	700
	Dark-gray shale, abundant selenite, fossils rare......................	30	730
Benton (shale)			
	Soft light-gray shale...............	130	860
	Light to medium gray shale..........	40	900
	Blocky medium gray shale with abundant selenite, pyrite, fossils, rare...........................	20	920
	Flaky gray shale with granular gypsum..........................	60	980
	Gray shale with sulphur and selenite.	10	990
	Flaky gray shale with a little pyrite	10	1,000
	Flaky gray shale with selenite and pyrite..........................	20	1,020
	Gray shale, abundant prisms and gypsum..........................	10	1,030
	Flaky medium gray shale, selenite, fossils.........................	50	1,080
	Medium gray shale, fossils, sulphur, prisms..........................	20	1,100
	Flaky gray shale, prisms and fossils.	10	1,110

Devils Lake Well - - Continued

Formation	Material	Thickness	Depth
.	Gray shale with prisms, fossils, pyrite	30	1,140
	Flaky gray shale	20	1,160
	Gray shale	10	1,170
	Flaky gray shale	50	1,220
	Light to dark-gray shale	10	1,230
	Flaky gray shale, few fossils	20	1,250
	Gray shale	10	1,260
	Flaky gray shale	10	1,270
	Gray shale with prisms	20	1,290
	Flaky gray shale	30	1,320
Dakota (sandstone)			
	Gray shale and coarse sand	10	1,330
	Dark-gray shale, sulphur, selenite	10	1,340
	Dark-gray shale and sand, pyrite	10	1,350
	Gray sandy shale with gypsum and sulphur	20	1,370
Fuson (shale?)			
	Flaky gray shale with gypsum	30	1,400
	Dark-gray shale, gypsum and sulphur	10	1,410
Lakota (sandstone?)			
	Sand and shale with little gypsum and pyrite	10	1,420
	Sand and shale with sulphur	10	1,430
	Coarse sand with pyrite	81	1,511

Leeds Well

(From Simpson, 1929, p.73)

Material	Thickness (feet)	Depth (feet)
Drift	100	100
Hard shale and streaks of limestone	1,637	1,737
Sandrock streaks in shale	55	1,792
Shale	30	1,822
Sandstone, good	10	1,832
Shale	3	1,835
Sandstone	25	1,860
Soft sand and shale	30	1,890
Streaky sandstone	220	2,110

Geologic interpretation of log by Simpson is given below:

Pleistocene drift	100
Pierre, Niobrara, and Benton shales (Upper Cretaceous)	1,637
Dakota sandstone (basal Upper Cretaceous) and other beds	373
	2,110

REFERENCES

Babcock, E. J., 1902, Water resources of the Devils Lake region: North Dakota Geol. Survey, 2d Bienn. Rept., pp. 208-250.

Bavendick, F. J., 1946, Climate and weather in North Dakota: North Dakota State Water Cons. Comm.

Branch, J. H., 1947, The geology of the Flora quadrangle: North Dakota Geol. Survey Bull. 22.

Comly, H. H., 1945, Cyanosis from nitrates in well water: Am. Med. Assoc. Jour., vol. 129, pp. 112-116.

Easker, D. G., 1949, The geology of the Tokio quadrangle: North Dakota Geol. Survey Bull. 24.

Fenneman, N. M., 1938, Physiography of the eastern United States: New York, McGraw-Hill Book Co., Inc.

Flint, R. F., 1947, Glacial geology and the Pleistocene epoch: New York, John Wiley & Sons, Inc.

__________, 1948, Glacial geology and geomorphology, in Boyd, L. A., The coast of northeast Greenland with hydrographic studies in the Greenland Sea: Am. Geog. Soc. Special Pub. 30, pp. 91-210.

Gwynne, C. S., 1942, Swell and swale pattern of the Mankato lobe of the Wisconsin drift in Iowa: Jour. Geology, vol. 50, pp. 200-208.

Gwynne, C. S., and Simonson, R. W., 1942, Influence of low recessional moraines on soil type pattern of the Mankato drift plain in Iowa: Soil Sci., vol. 53, pp. 461-466.

Laird, W. M., 1941, Selected deep well records: North Dakota Geol. Survey Bull. 12.

Leverett, Frank, 1932, Quaternary geology of Minnesota and parts of adjacent States: U. S. Geol. Survey Prof. Paper 161.

Mawdsley, J. B., 1936, The washboard moraines of the Opawica-Chibougamau area, Quebec: Royal Soc. Canada Trans., 3d ser., vol. 30, pp. 1-8.

Norman, G. W. 1938, The last Pleistocene ice-front in Chibougamau district, Quebec: Royal Soc. Canada Trans., 3d ser., vol. 32, pp. 69-86.

Scott, I. D., 1921, Inland lakes of Michigan: Michigan Geol. and Biol. Survey Pub. 30.

Silverman, L. B., 1949, Methemoglobinemia: Report of two cases and clinical review: Journal-Lancet, vol. 69, pp. 112-116.

Simpson, H. E., 1912, Physiography of the Devils-Stump Lake region, N. Dak.: North Dakota Geol. Survey 6th Bienn. Rept., pp. 101-157.

__________, 1929, Geology and ground-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598.

Tetrick, P. R., 1949, Glacial geology of the Oberon quadrangle: North Dakota Geol. Survey Bull. 23.

Upham, Warren, 1896, The glacial Lake Agassiz: U. S. Geol. Survey Mon. 25.

U. S. Weather Bureau, 1949, River basin maps showing hydrologic stations: map 30, Red River of the North Basin.