GEOLOGY AND GROUND WATER RESOURCES OF TIOGA AND HOFFLUND FLATS AREAS WILLIAMS AND MOUNTRAIL COUNTIES, NORTH DAKOTA

By
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and
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Geological Survey
United States Department of the Interior

NORTH DAKOTA GROUND WATER STUDIES

NO. 43

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

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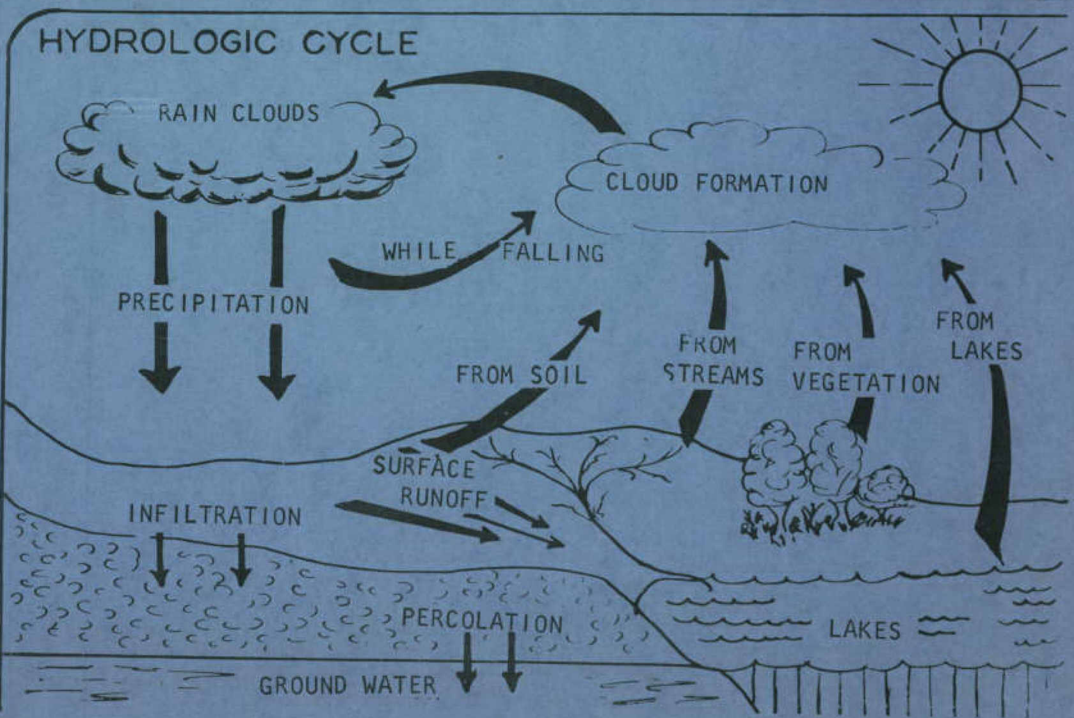

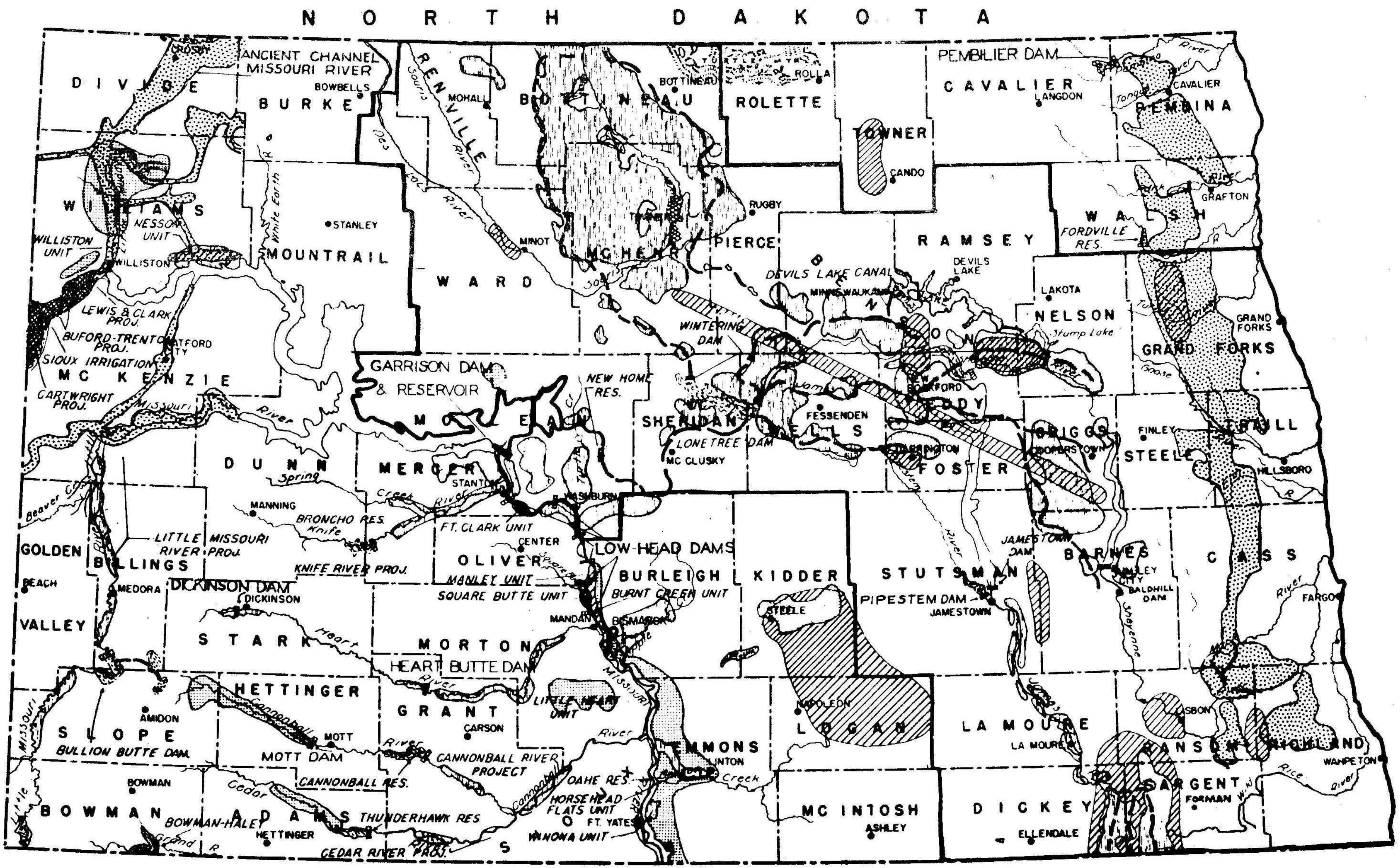

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ABSTRACT

This report is concerned mainly with the ground-water resources of an area of about 107 square miles surrounding the city of Tioga in Williams and Mountrail Counties in northwestern North Dakota. In addition, about 25 square miles adjacent to the Missouri River and locally known as the Hofflund Flat area, was examined in less detail. The geologic units that crop out in the areas consist of the Fort Union Formation of Paleocene (early Tertiary) age, glacial drift of Wisconsin age, and alluvium and slopewash of Recent age.

The Fort Union Formation contains soft beds of fine-grained sandstone that yield adequate supplies of ground water for oil-well drilling purposes as well as domestic and stock purposes.

The glacial drift consists of end moraine, ground moraine, glacial lake deposits, and outwash. Small quantities of ground water, generally adequate for domestic and stock purposes are obtainable from sand and gravel deposits in the glacial drift. Thin beds of water-bearing sand and gravel occur in buried bedrock channels that trend east and north from Tioga. The municipal water supply for Tioga is obtained from wells that tap these beds and yield from 20 to 150 gallons per minute.

An area of glacial outwash and alluvium lies along the north edge of the Missouri River about 15 miles south of Tioga. Test drilling indicates that the deposits are permeable and could support wells yielding as much as 1,000 gallons per minute.

The alluvium and slopewash deposits are generally too thin to be of importance as aquifers.

Nine water samples from aquifers in the Fort Union Formation contained dissolved solids ranging from 317 to 3,680 ppm (parts per million) and averaging 1,623 ppm. Six samples from glacial-drift aquifers contained dissolved solids ranging from 207 to 1,590 ppm and averaging 837 ppm. Ground water from most sources in the area is very hard. Much of the ground water in the Tioga area, because of high salinity and high percent sodium, probably is not suitable for irrigation.

INTRODUCTION

Location and General Features of the Area

Tioga is in the eastern part of Williams County in northwestern North Dakota (fig. 1). In 1950 the population of the city was 456. In early 1951, however, oil in commercial quantity was discovered about 9 miles south of Tioga. As a result of the discovery and development of a major oil field in the area, the city had a population of 2,087 in 1960.

Two areas in the vicinity of the city of Tioga are discussed. The Tioga area is approximately 107 square miles in Williams and Mountrail Counties. In addition, a reconnaissance study was made in an area of about 25 square miles along the Missouri River, called the Hofflund Flat, which is about 15 miles south of Tioga.

Tioga, the only city in the area, is served from the east and west by the Great Northern Railroad and from the north and south by State Highway 40. U.S. Highway 2 crosses the area in an east-west direction 3 miles south of Tioga. The city serves as a shopping, trading, and industrial center for eastern Williams County and western Mountrail County.

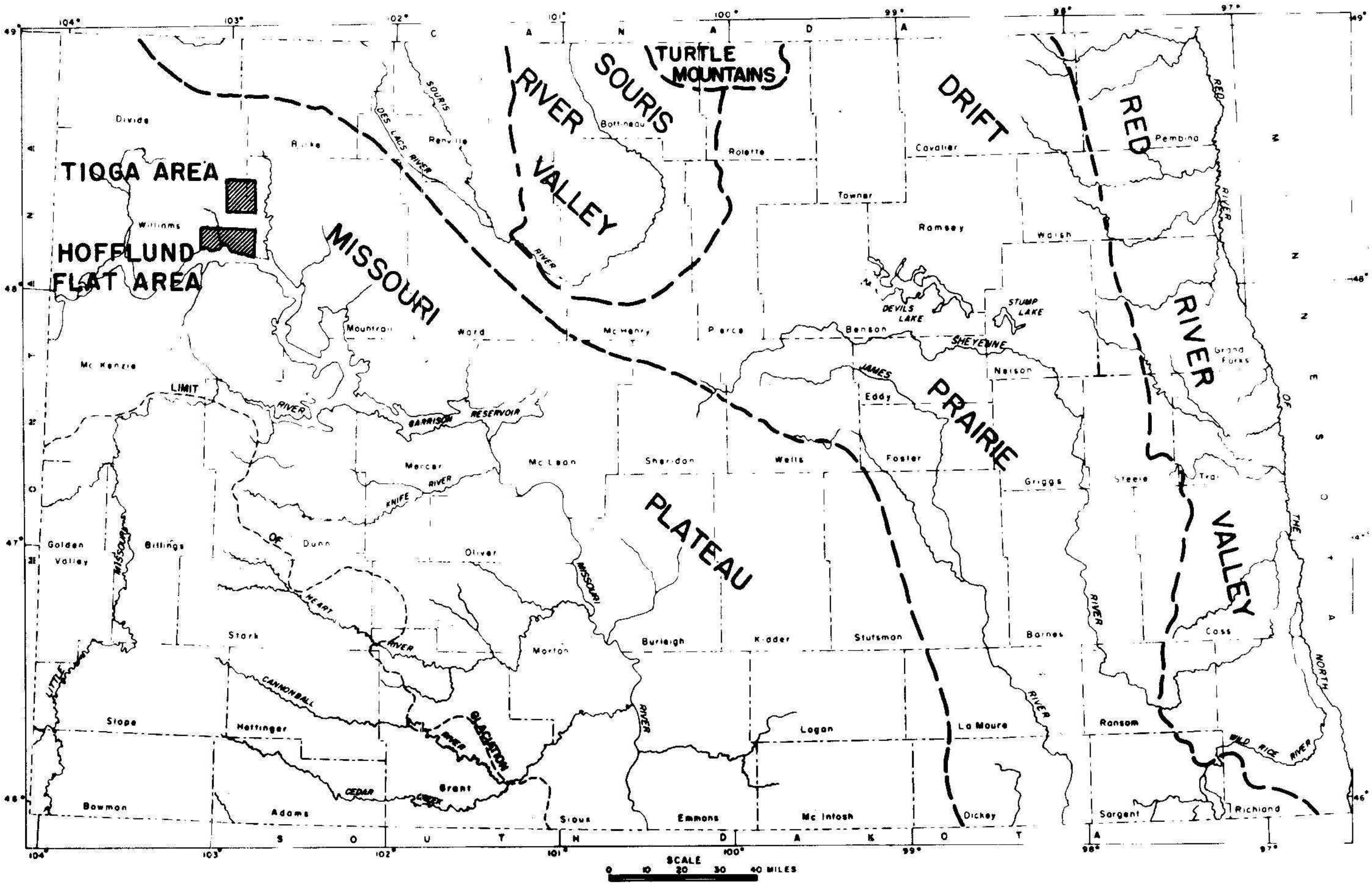

FIGURE 1--MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES (FROM SIMPSON, 1929) AND LOCATION OF THE TIOGA AND HOFFLUND FLAT AREAS

The average annual precipitation recorded by the United States Weather Bureau (1961) from 1878 to 1960 at Williston, about 35 miles southwest of Tioga, was 14.68 inches. Most of the precipitation falls as rain during the growing season. The mean annual temperature for the period was 41.3°F. Oil exploration and development and farming are the principal occupations in the area. The main crops are wheat and flax.

Purpose and Scope of the Investigation

This ground-water investigation is one of a series being made by the United States Geological Survey in cooperation with the North Dakota State Water Conservation Commission and the North Dakota Geological Survey. The purpose of these investigations is to determine the surface and subsurface geology, to relate the geology to the occurrence, movement, discharge, and recharge of ground water, and to determine the quantity and quality of ground water available for municipal, domestic, industrial, and irrigation purposes. One of the most critical needs in the State is for adequate and perennial water supplies for the many small towns and cities that are attempting to install water-supply systems or are expanding present facilities. Because of this need, many North Dakota ground-water studies are begun in the vicinities of towns that have requested aid from the State Water Conservation Commission and the State Geologist. Where feasible, and, as new data become available, the town studies are incorporated into countywide studies.

The fieldwork consisted mainly of mapping the geologic features with the aid of aerial photographs (1:20,000), inventorying water wells in the area, making pumping tests to determine the hydraulic properties of the aquifer, test drilling by use of a hydraulic rotary rig owned by the North Dakota State Water Conservation Commission, and collecting water samples for chemical analyses.

Office and laboratory work consisted of examination and analysis of cuttings and cores from the test holes, correlation of well logs, interpretation of chemical analyses of water samples, interpretation and correlation of well-inventory data, analysis of aquifer-test data, and preparation of illustrations and a written report of the investigation.

Previous Investigations and Acknowledgments

A general study of the geology and ground-water resources of Mountrail and Williams Counties was made by Simpson (1929, p. 174-177, 265-268), who included in his report records and chemical analyses of several wells in the Tioga area. The geology and physiography of western North Dakota were described by Alden (1932), and the geologic structure of southeastern Williams County was described by Dove (1922). Abbott and Voedisch (1938, p. 88) made an investigation of the municipal water supplies of North Dakota, and their report includes the well description and chemical analysis of water from a Tioga city well. Howard (1960) made a reconnaissance of the glacial geology in a large part of northwestern North Dakota and northeastern Montana that includes the Tioga area.

The cooperation of the residents of the Tioga area was of great help during the field investigation. Valuable assistance was given by members of the city council. Thanks are given C. A. Simpson and Sons, well drillers, who supplied logs and considerable information concerning the physical description and performance of municipal wells in the area.

Well-Numbering System

The well-numbering system used in this report is illustrated in figure 2 and is based upon the location of the well in the federal system of rectangular surveys of the public lands. The first numeral denotes the township north, the second numeral denotes the range west, both referred to the fifth principal meridian and base line; the third numeral denotes the section in which the well is located. The letters a, b, c, and d designate respectively the northeast, northwest, southwest, and southeast quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections (10-acre tract), as shown on figure 2. Consecutive terminal numerals are added when more than one well is shown in a given 10-acre tract. Thus, well 156-95-11bab is in the NW$\frac{1}{4}$NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 11. T. 156 N., R. 95 W.

Physiographic Features

The area is in the glaciated part of the Missouri Plateau section of the Great Plains Province (fig. 1) according to the U.S. Geological Survey map of physical divisions of the United States (1946). Surface deposits consist largely of glacial drift deposited during one or more stades of the Wisconsin Glaciation of the Pleistocene Epoch. Three main types of glacial landforms occur in the area; these are end moraine, lake basin, and ground moraine.

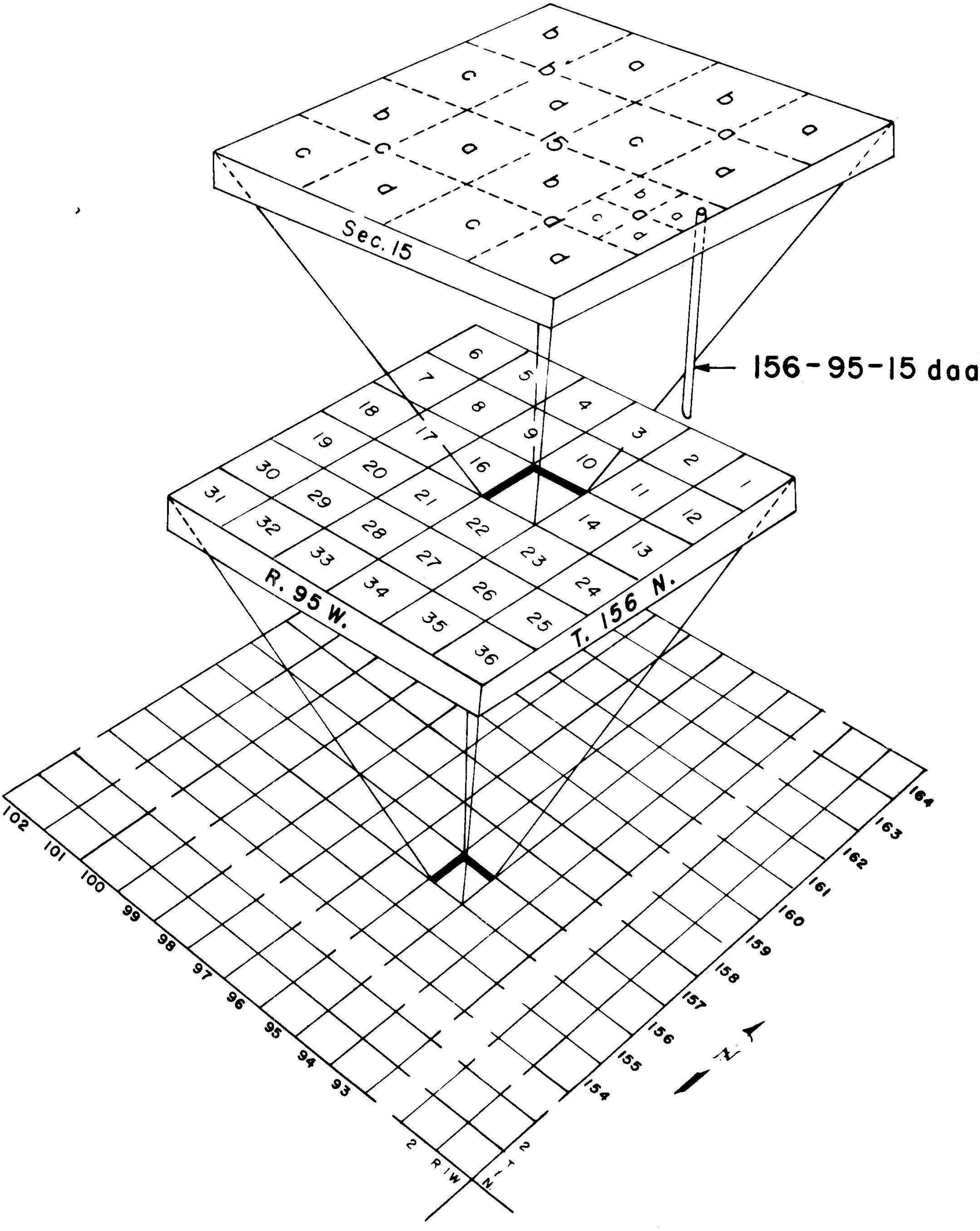

FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES

End moraine is the predominant landform of the area and is particularly well developed north of Tioga, where it exhibits a knob-and-kettle topography. Local relief in the end moraine areas usually is about 50 feet, but is as much as 100 feet at some places. Surface drainage is poorly developed and there are numerous small ponds and marshes. The surface elevation of the moraine increases to the north because of a northward increase in altitude of the bedrock surface. The land-surface altitude is 200 feet higher 5 miles north of Tioga than in Tioga. Aerial photographs show that the end moraine trends in a northeast direction across the area.

A glacial-lake basin entirely surrounded by end moraine is present in the western part of the area. The basin is elongate in a northeast direction and has an area of about 7 square miles.

The area classed as ground moraine is east and southeast of Tioga. Here deposits of glacial drift are much thinner, and the configuration of the underlying bedrock surface is more evident than in other parts of the area. In the extreme eastern part of the area the glacial drift has been removed by erosion and surface deposits consist of buff-colored Fort Union Formation of Paleocene (early Tertiary) age.

The major drainage feature is an eastward-trending valley that heads in the vicinity of Tioga and extends for 7 miles to its junction with the White Earth River valley. The floor of the valley is 50 to 100 feet below the surrounding drift prairie. At some places erosional remanents of former terraces are 20 to 40 feet above the valley floor. The terraces are composed of coarse sand and gravel and probably represent the level of the stream during an earlier stade of Wisconsin Glaciation. The bed of the present-day intermittent stream is incised approximately 5 feet below the valley flood plain.

GEOLOGY AND OCCURRENCE OF GROUND WATER

Principles of Occurrence of Ground Water

Virtually all ground water is derived from precipitation. Rain or melting snow enters the ground by direct penetration or by percolation from streams and lakes that lie above the water table. Ground water generally moves downward and laterally from areas of recharge to areas of natural discharge.

Ground-water discharge occurs by seepage into streams, lakes, and ponds, transpiration from plants, evaporation from the land surface in areas where the ground-water level is near the land surface, and by discharge from wells and springs.

Any rock formation or stratum that will yield water in sufficient quantity to be important as a source of supply is called an "aquifer" (Meinzer, 1923, p. 52). Water moving in an aquifer from recharge to discharge areas may be considered to be in "transient storage."

The amount of water that a rock can hold is determined by its porosity. Unconsolidated material such as clay, sand, and gravel generally is more porous than consolidated rocks such as sandstone and limestone; consolidated rocks in some areas, however, are highly porous.

The capacity of an aquifer to yield water may be much less than is indicated by its porosity because part of the water is held in the pore spaces by molecular attraction between the water and the rock particles, the smaller the pores, the greater the proportion of water that will be held. The amount of water, expressed as a fraction of a cubic foot, that will drain by gravity from 1 cubic foot of an aquifer is called the "specific yield" of the aquifer.

If the water in an aquifer is not confined by overlying impervious strata, the water is said to be under water-table conditions. Under these conditions, water can be obtained from storage in the aquifer by gravity drainage; that is, by lowering the water level as in the vicinity of a pumped well.

Water is under artesian conditions if it is confined in the aquifer by an overlying impermeable stratum. Under these conditions, hydrostatic pressure will raise the water in a well penetrating the aquifer above the top of the aquifer, and water is yielded as the water level in the well is lowered by pumping or by natural flow. The aquifer remains saturated; however, and the yield of water from storage occurs because the water expands slightly and the aquifer is compressed as the head is decreased. Gravity drainage does not occur as long as the water level in the well remains above the top of the aquifer. The water-yielding capacity of an artesian aquifer is called the "coefficient of storage" and generally is very much smaller than the specific yield of the same material under water-table conditions. The coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

The frictional resistance to the movement of water through pore spaces that are relatively large, as in coarse gravel, is not great and the material is said to be permeable. The resistance to the movement of water through small pore spaces, however, as in clay or shale, may become very great, and the material then is said to be relatively impermeable or to have low permeability. The coefficient of permeability is expressed quantitatively, for field use, as the number of gallons of water per day that will pass through a cross-sectional area of 1 square foot under unit hydraulic gradient at the local temperature of the ground water.

The "coefficient of transmissibility" is convenient to use in ground-water studies because it indicates a characteristic of the aquifer as a whole rather than of a small section. It is the average field coefficient of permeability of the aquifer multiplied by its thickness, in feet, and is expressed in gallons per day per foot.

The suitability of an aquifer as the source of a water supply is governed by its permeability, volume, capacity to store and release water, and access to recharge. Recharge to the aquifer must be adequate if the water supply is to last indefinitely, because even a small rate of withdrawal will eventually deplete the water in storage unless there is equal or greater recharge. Aquifers that are highly permeable but small in areal extent and completely enclosed in relatively impermeable material can be pumped nearly dry in a comparatively short time. The rather high initial yield of a well may give an erroneous impression that a great volume of water is available from the aquifer indefinitely. Thus, before a ground-water development is made, sufficient test drilling, aquifer tests, and related studies should be made to determine the capabilities and recharge conditions of the aquifer being considered.

Residents of the Tioga area depend almost exclusively upon wells for domestic, farm, and industrial water supplies (table 5). Where necessary, ground-water supplies for livestock are augmented by surface water obtained from prairie potholes or from manmade reservoirs in the smaller stream valleys. Shallow, large-diameter dug wells range in depth from 15 to 20 feet, whereas small-diameter drilled wells are occasionally as much as 600 feet deep. In 1958 the Tioga municipal water system was supplied by 6 wells.

General Stratigraphic Relations

Information regarding the stratigraphy in the Tioga area was obtained in part from 53 test holes and in part from published data. Locations of the test holes are shown on figure 3, and the logs are listed in table 6. The test holes were drilled with a hydraulic-rotary drilling machine. Depths of the test holes ranged from 25 to 600 feet, and samples were taken of each 5-foot interval. Four test holes, 775, 776, 777, and 778 were drilled in the Hofflund Flat area approximately 15 miles south of Tioga (fig. 4). These test holes were drilled to determine the extent and water-bearing properties of deposits of glacial outwash and alluvium in that area.

The following table shows the general stratigraphic relations of the Cretaceous and younger rocks in the Tioga area as determined from test drilling, geologic mapping, and published data.

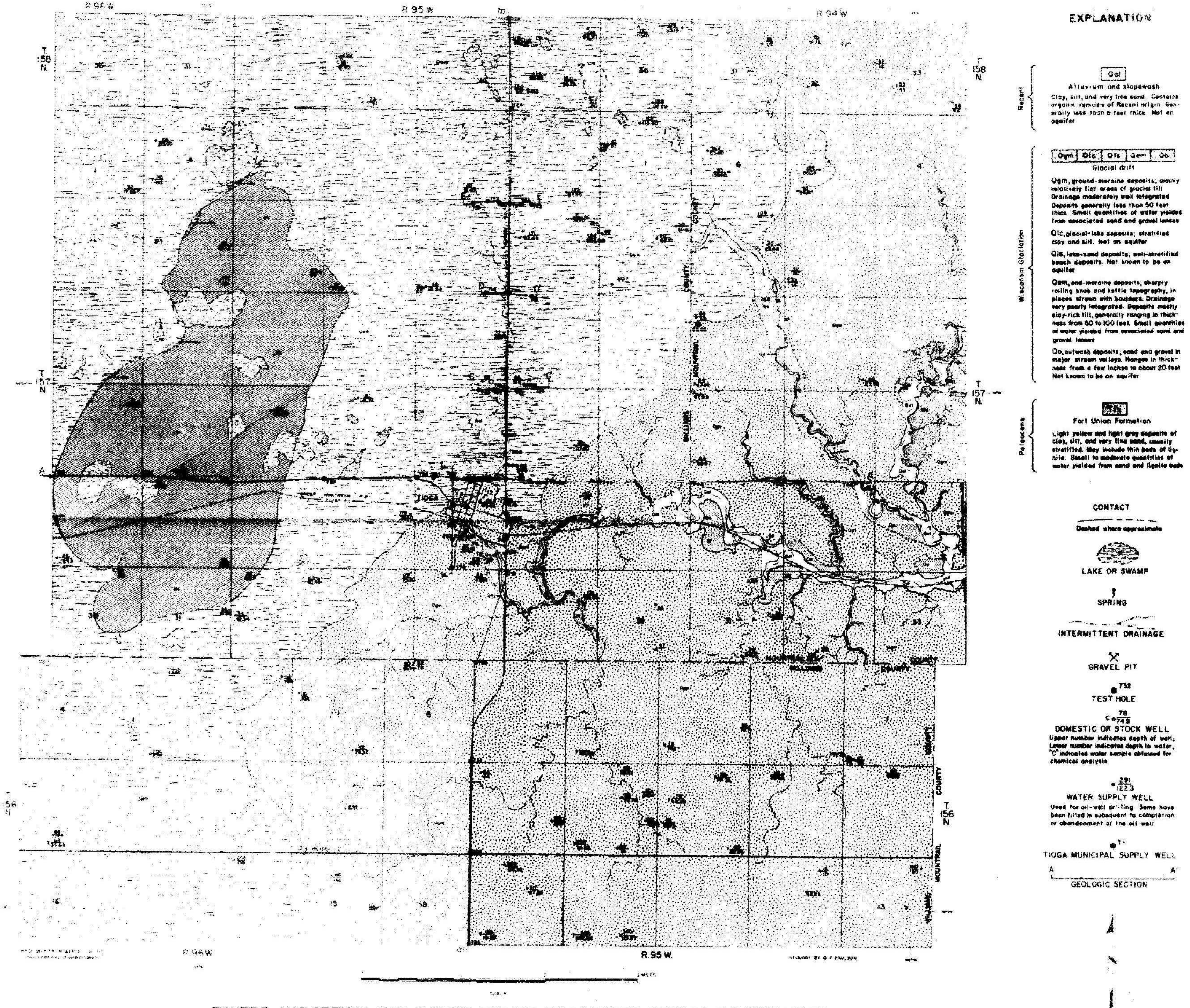

FIGURE 3--MAP OF TIOGA AREA SHOWING GEOLOGY AND LOCATIONS OF WELLS AND TEST HOLES

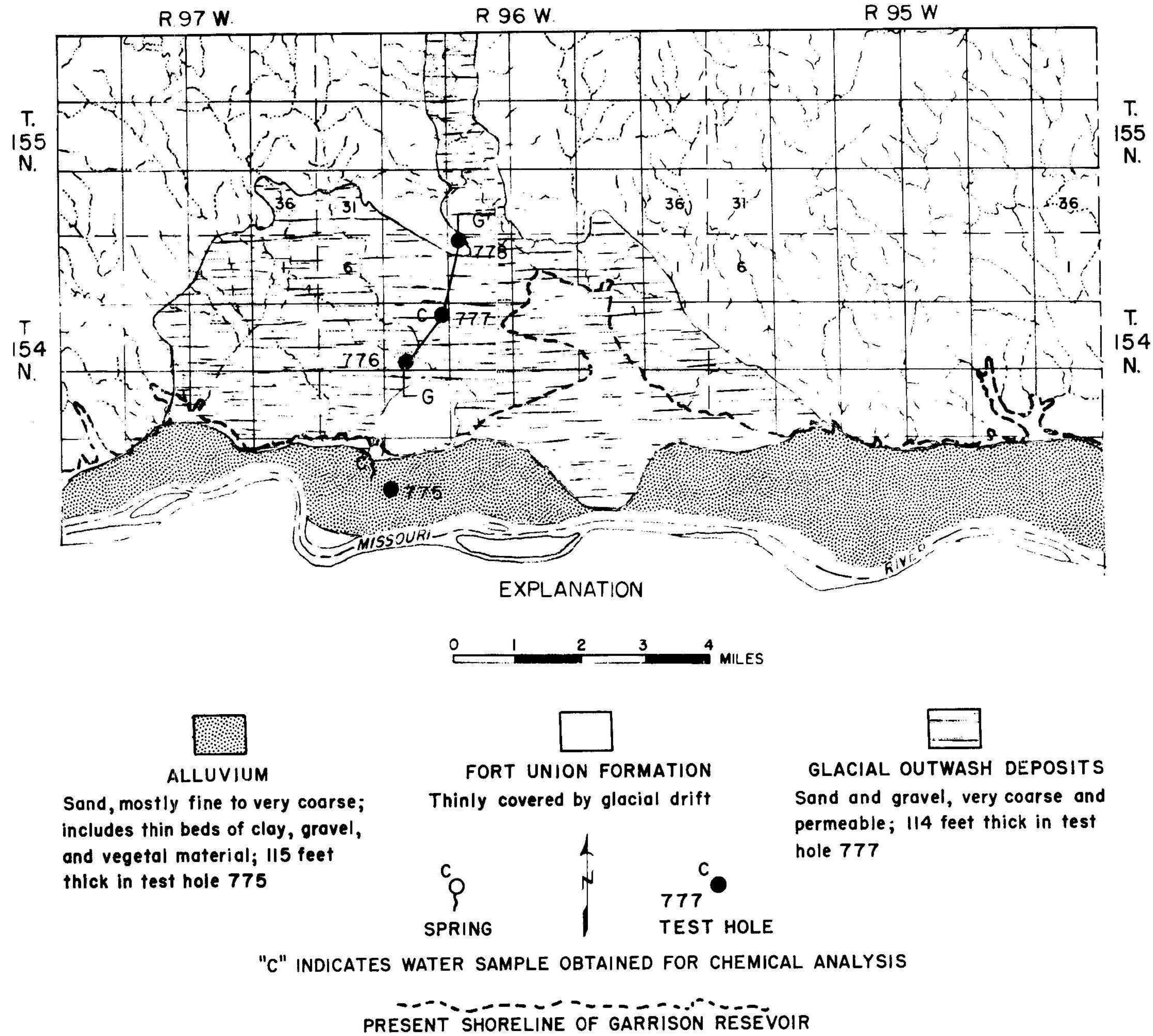

FIGURE 4--MAP OF HOFFLUND FLAT AREA SHOWING GEOLOGY AND LOCATIONS OF TEST HOLES, SPRING, AND SECTION G-G′

Table 1.--Cretaceous, Tertiary, and Quaternary stratigraphy in the Tioga area

- Cenozoic Era
  - Quaternary System
    - Recent Series
      - Alluvium
    - Pleistocene Series
      - Glacial drift of Wisconsin age
  - Tertiary System
    - Paleocene Series
      - Fort Union Formation

- Mesozoic Era
  - Cretaceous System
    - Upper Cretaceous Series
      - Hell Creek Formation
      - Fox Hills Sandstone
      - Pierre Shale
      - Niobrara Formation
      - Greenhorn Formation
      - Dakota Sandstone

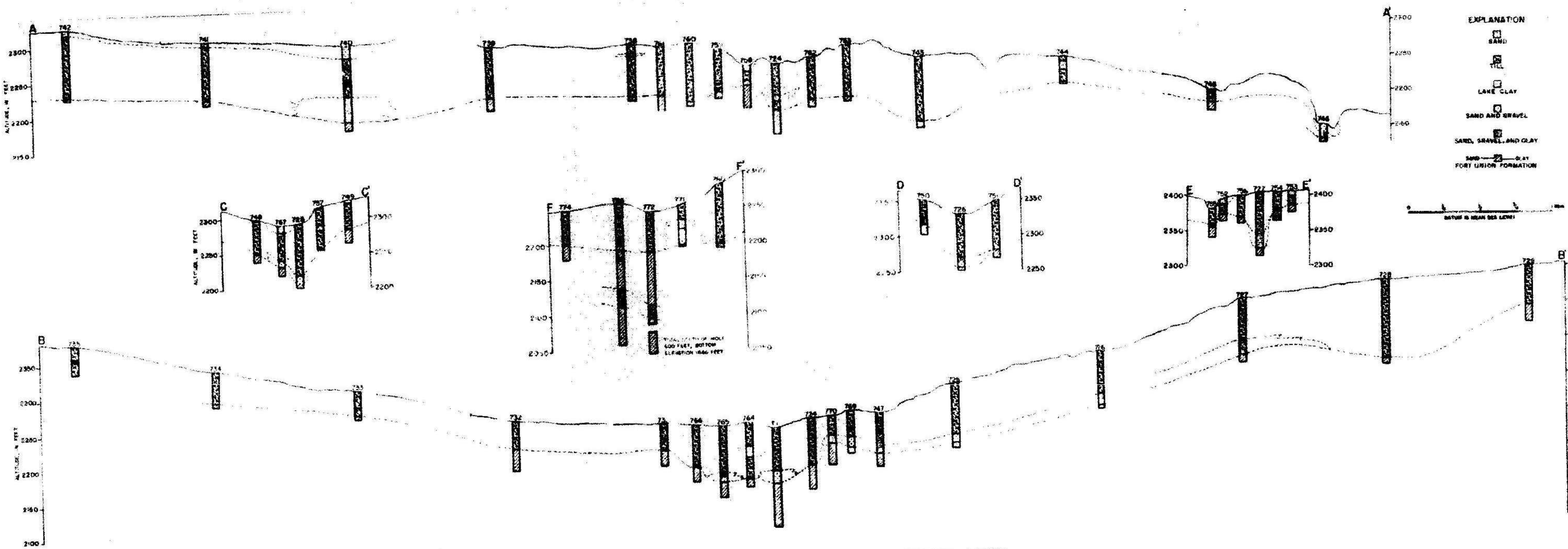

FIGURE 5--LITHOLOGIC SECTIONS IN THE TIOGA AREA

Bedrock Formations

Cretaceous and older rocks.--The total thickness of sedimentary rocks underlying the Tioga area exceeds 14,000 feet at some locations. Granite of Precambrian age has been reached by 4 Amerada Petroleum Corp. oil-test holes drilled in the southern half of the report area. The total thickness of sedimentary rocks at the sites of the 4 test holes ranged from 13,614 to 14,828 feet and averaged 14,260 feet. (Personal communication, S. B. Anderson, North Dakota Geological Survey, 1958).

Few data are available concerning the water-bearing properties of the Cretaceous and older rocks of the area. Lithologic and electric well logs indicate that the Cretaceous rocks, at least, contain several probable aquifers. Water in these aquifers probably is highly mineralized. However, important advances have been made in desalinization of mineralized waters in recent years, and some of these deeper aquifers may become economically important in the future; the following discussion of Cretaceous formations underlying the Tioga area is included for this reason.

The Dakota Sandstone of Late Cretaceous age is the base of the Cretaceous System in the report area. It was penetrated at a depth of 4,543 feet below the land surface in the Bakken No. 1 oil-test well in SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 12, T. 157 N., R. 95 W. The Dakota Sandstone yields large amounts of highly mineralized water to wells in other parts of the State, notably the southeast and south-central.

A thick sequence of shale of Cretaceous age overlies the Dakota Sandstone in the Tioga area. The Greenhorn and Niobrara Formations were penetrated at 4,090 and 3,390 feet, respectively. The top of the Pierre Shale, which overlies the Niobrara Formation, was penetrated at 1,960 feet. The total thickness of shale of Cretaceous age penetrated in the Bakken No. 1 test well was 2,455 feet. The shale is not considered to be sufficiently permeable to yield significant amounts of water to wells.

The Fox Hills Sandstone was reached at a depth of 1,635 feet. According to the log the formation is 325 feet thick at that location and is composed of gray to olive-gray quartzose sandstone and siltstone. As it is marine in origin, aquifers contained within the Fox Hills Sandstone probably are more uniform and widespread than those in overlying formations.

In the California Kamp test well, which was drilled 9 miles south of the southern boundary of the Tioga area, the Hell Creek Formation of Late Cretaceous age was reportedly penetrated from 800 to 910 feet below the land surface. It is composed of gray fine-grained sandstone and gray shale and minor amounts of lignite (Laird, 1946, p. 13). In Morton County, where it is well exposed, the Hell Creek Formation is composed largely of gray and brown bentonitic and limonitic shale, sand, and sandstone containing limonitic concretions and small amounts of lignitic shale (Laird and Mitchell, 1942, p. 9-10).

Fort Union Formation.--The Fort Union Formation of Paleocene (early Tertiary) age overlies the Hell Creek Formation. It consists of interbedded light-gray to yellow clay, sand, siltstone, and lignite. The beds, with the exception of those consisting of lignite, are not continuous but tend to grade into one another. As it appears in the drill cuttings at some locations, the formation is similar in lithology to glacial till.

The complete thickness of the Fort Union Formation in the report area is not known. The deepest test hole, 772 (157-95-27bdd), was drilled to a total depth of 600 feet of which all but the first 56 feet was in the Fort Union Formation. The many oil-test wells, which have been drilled in the area, have completely penetrated the Fort Union Formation. However, no identification was made of rocks younger than the Pierre Shale.

A rough estimate of the thickness of the Fort Union Formation may be made as follows: the log of the Bakken No. 1 test well indicates that a comparatively small amount of lignite occurs deeper than 1,200 feet below the land surface (Anderson, 1953). In addition, bentonitic shale was noted in the samples from rocks below that depth. Lignite is common in the Fort Union Formation, and bentonitic shale is common in the underlying Hell Creek Formation. Thus, the Fort Union is about 1,200 feet thick.

Aquifers in the Fort Union Formation supply most wells in the Tioga area. Most of the wells are drilled and are less than 6 inches in diameter. Numerous water wells have been drilled into the Fort Union Formation for oil-well drilling operations. Generally these wells range in depth from 100 to 350 feet and are not completed at any particular horizon. The lack of correlation in regard to well depths in the comparatively small area involved indicates that the aquifers are discontinuous and probably consist of lenticular zones containing above-average proportions of sand. Common practice is to drill the well through several sand beds and set perforated casing opposite each. By this method, small to moderate quantities of water can be obtained even though the sand beds are fine grained and have low permeability.

Glacial Drift

With the exception of a small area in the eastern part where bedrock is exposed and those small areas where alluvium and slope-wash of Recent age are present in the drainage courses, the Tioga area is covered with glacial drift of Wisconsin age. Older drift also may be present in parts of the area, but sufficient evidence to warrant its classification as such was not available. Generally, the drift is thickest in the northern and western parts and thinnest in the southern and eastern parts of the area. The thickest deposit of glacial drift, 109 feet, was penetrated by test hole 728 (158-95-35ccc) near the northern edge of the area (fig. 5).

Most of the glacial drift deposits in the Tioga area consist of till. The till is composed of heterogeneous materials ranging in size from clay to large boulders. It was deposited directly from the ice and was subjected to little or no subsequent sorting by wind or water. Because the till is largely unsorted and composed mainly of fine-grained material it does not yield water to wells readily.

Small bodies of sand and gravel are present within the till at many locations. These deposits range greatly in thickness and in areal extent. They were deposited by glacial melt water and commonly are well sorted and stratified. However, their occurrences are erratic and generally impossible to predict from surface evidence.

Wells of rather high initial yield might be developed in larger deposits of this type. The yield of wells penetrating aquifers completely surrounded by dense till, however, would decrease rapidly as the aquifers become unwatered. Recharge through the glacial till to aquifers of this type is slow, and pumping rates must be kept moderate if production is to be maintained.

The glacial drift in the area has been divided into deposits of end moraine, outwash, glacial lake, and ground moraine. These units are nearly contemporaneous, and the following order of discussion is not based on their relative ages.

End moraine deposits.--Deposits of end moraine cover approximately half the Tioga area (fig. 3). They are composed mainly of till but include lenses of water-bearing sand and gravel of varying thickness and extent. Wells in the end moraine range in depth from 12 to 507 feet and average 118 feet. Most of them tap sand and gravel lenses in the till. Generally they have small yields but are adequate for farm and domestic needs. Test drilling did not indicate any major aquifers in the end-moraine deposits.

Outwash deposits.--Outwash deposited by streams of melt water issuing from glacial ice occurs in the valleys of the major drainage courses. The outwash deposits in the Tioga area range in thickness from a few inches to a known maximum of 20 feet and consist of very coarse sand and gravel. In places, the outwash deposits are 5 to 40 feet above the valley floors and probably are remanents of stream terraces laid down during one or more glacial stages.

More extensive deposits of glacial outwash border the Missouri River flood plain in the Hofflund Flat area approximately 15 miles south of Tioga. The deposits underlie a relatively flat plain, the surface of which is approximately 50 feet above the present flood plain of the Missouri River. The area of the outwash deposits was estimated from air-photo index sheets to be at least 25 square miles (fig. 4). The deposits are roughly rectangular, approximately 8 miles long by 3 miles wide. Three test holes, 776, 777, and 778 were drilled to determine the thickness and water-bearing properties of these deposits. The thicknesses in each test hole, respectively, were 81, 114, and 37 feet (fig. 6). Test hole 777 probably was drilled near the central and thickest part of the deposits.

The deposits range in texture from medium to coarse sand at the top to very coarse gravel near the bottom. The coarse gravel near the bottom is composed largely of well-rounded quartzite, flint, and other siliceous-rock pebbles. As glacial outwash usually contains a large percentage of limestone and granitic-rock fragments the coarse gravel near the bottom of the deposits probably is preglacial alluvium, possibly reworked Flaxville Formation of late Miocene or Pliocene age, rather than glacial outwash.

Most wells in the Hofflund Flat area are shallow dug wells, which extend only a short distance below the water table. None are known to penetrate the deeper coarse gravel. However, the test drilling indicated the deposits have a high permeability, and a properly designed and constructed well penetrating the full thickness of the deposits probably would yield as much as 1,000 gpm.

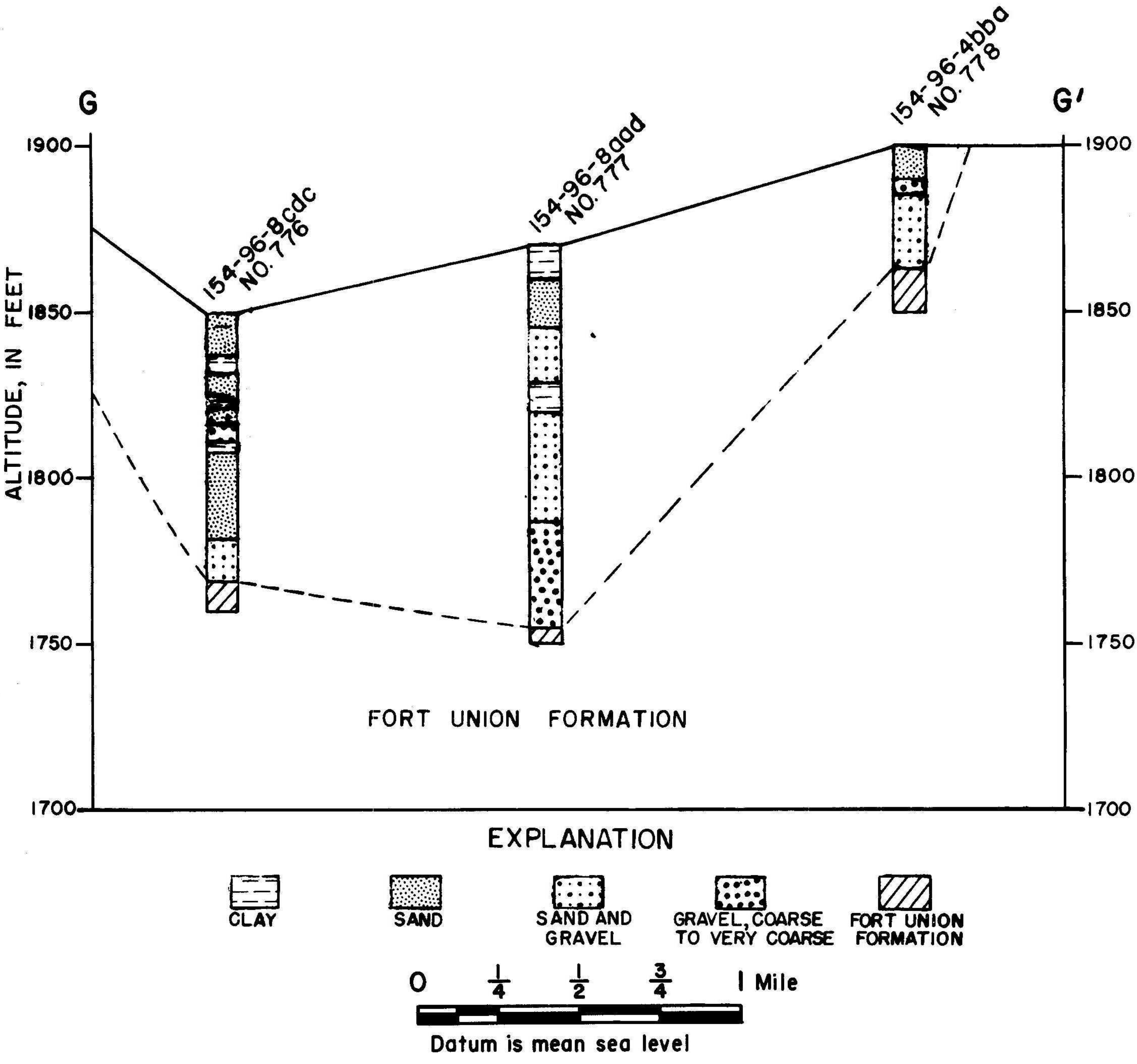

FIGURE 6--LITHOLOGIC SECTION G-G′ IN HOFFLUND FLAT AREA
(LOCATION OF TEST HOLES SHOWN IN FIGURE 4)

Glacial lake deposits.--A glacial lake basin occupies an area of approximately 7 square miles in the western part of the Tioga area (fig. 3). The surface of the basin is gently concave and nearly featureless; it has a north-south orientation and at its greatest dimensions is approximately 5 miles long and $2\frac{1}{2}$ miles wide. Thin deposits of lake clay and silt cover most parts of the basin; they were penetrated by test holes 740 and 741. At these locations the deposits were 19 and 6 feet thick, respectively. Low beach ridges consisting of well-sorted and stratified sand extend intermittently along the western edge of the basin. The beach deposits have a maximum thickness of 15 feet but generally are thinner. The lack of shore features along the east edge of the basin indicates that this edge of the basin was confined by ice during much of the lake's existence. Similar glacial lake basins have been reported in the Stanley area, approximately 15 miles east of the eastern limit of the Tioga area (Paulson, 1954, p. 12).

Ground moraine deposits.--The southeastern and eastern parts of the Tioga area are covered with deposits of ground moraine (fig. 3). Lithologically, ground moraine is similar to end moraine in that it is composed largely of glacial till. However, the ground moraine is flatter than end moraine, its surface is gently rolling, with relief seldom in excess of 25 feet. The deposits are thin as compared to the end moraine deposits and probably do not average over 30 feet in thickness. Because of the thinness of the deposits, surface configuration probably is controlled to a large extent by irregularities in the bedrock surface.

Drainage in the ground moraine is relatively well integrated, as compared to that in the end moraine. This probably is due to the thinness of the ground moraine, which results in the present drainage following the earlier drainage courses established in the underlying Fort Union Formation.

An additional factor that may account for the advanced drainage pattern in the ground moraine area is the possibility that the deposits of ground moraine originated during an earlier glacial stade and are thus older and more eroded than the deposits in the end moraine area. However, no distinguishable characteristics were found in the deposits that would allow a differentiation on the basis of age.

The ground moraine of the Tioga area is too thin to be of importance as an aquifer.

Bedrock channels.--The maximum bedrock relief in the Tioga area as determined from logs of test holes is approximately 230 feet. This relief is in the eastern part of the area where a bedrock channel extends east from the city of Tioga to a junction with the White Earth River valley, a distance of about 7 miles. The bedrock channel underlies a valley, which is about 1 mile wide and is incised to a depth of about 50 feet. The bedrock surface slopes toward the channel from the north and south at about 50 feet per mile. The slopes extend for about 4 miles on either side of the channel (sec. B-B', fig. 5). West of the city of Tioga the channel, if present, is masked by thick deposits of end moraine and has no surface expression. The channel is well developed in the vicinity of the city and probably extends for some distance west.

A similar bedrock channel extends north from Tioga for a known distance of 3 miles and probably considerably farther. The channel is incised to a depth of about 50 feet into the bedrock and ranges in width from one-fourth to one-half mile (sections C-C', D-D', and E-E', fig. 5). At some locations the course of the north-south channel is followed by the valley of an intermittent stream. At other locations the channel is masked by deposits of glacial drift and has no surface expression. The north-south channel is considerably smaller than the east-west channel and probably was tributary to, rather than a part of, the main east-west channel.

The occurrence in the bedrock channels of sand and gravel containing a high percentage of limestone and dolomite suggests a glacial rather than a preglacial origin. The sand and gravel is relatively thin in the immediate vicinity of Tioga. It constitutes an important aquifer, however, and is tapped by 5 of the 6 wells that supply the Tioga municipal water system (fig. 3). These wells yield from about 20 to 150 gpm (table 2).

Table 2.--Depths, approximate production rates, and dates of completion of Tioga municipal wells.

Well No.	Depth (feet)	Approximate production (gpm)	Date completed
T1	-	20	June 1955
T2	90	20	May 1953
T3	110	20	November 1953
T4	116	150	August 1954
T5	93	40	August 1956
T6	98	40	April 1957

Wells T2 through T6 obtain water from zones of sand or gravel associated with the bedrock channels, but well T1 may produce from a sand bed in the Fort Union Formation of Paleocene age.

The sand and gravel in the north-south bedrock channel north of Tioga ranges in thickness from 10 to 20 feet. North of test hole 725 (157-95-15ddd), which is about 1 mile north of Tioga, the deposits probably are not water bearing as they occur above the zone of saturation.

Additional test drilling is needed to determine the thickness and water-bearing characteristics of the sand and gravel in the main bedrock channel extending east from the city. Aquifer tests utilizing wells T4, T5, and T6 were made during August 1954, August 1956 and May 1957, respectively.

Table 3.--Results of aquifer tests on three Tioga municipal wells.

Well No.	Depth (feet)	Length of screen (feet)	Pumping rate (gpm)	Drawdown after 24 hrs. pumping (feet)	Average coefficient of trans-missibility gal/day/ft	Average coefficient of storage
T4	116	14	200	27.7	17,000	------
T5	93	32	85	22.2	10,000	.00014
T6	100	5	75	19.7	11,000	.00004

Average coefficients of transmissibility and storage (table 3) were determined by use of the Theis (1935) formula. Because no observation well was available at the time of the test on well T4, the coefficient of storage for the aquifer at that location was not determined. The average coefficient of transmissibility for the test was based upon drawdowns and recoveries observed in the pumped well. The coefficients of storage obtained from the tests on wells T5 and T6 are typical for aquifers in which ground water is under artesian head. Specific capacities for wells T4, T5, and T6, obtained by dividing the pumping rates in gallons per minute by the respective drawdowns in feet, are 7, 4, and 4 gallons per minute per foot of drawdown, respectively.

Alluvium and Slopewash

Deposits of alluvium and slopewash of Recent age are present in the major drainage courses of the area. The deposits consist of clay, silt, and very fine sand, together with considerable organic matter. Generally the material is less than 5 feet in thickness and is not considered to be an aquifer.

QUALITY OF THE GROUND WATER

Ground water dissolves a part of the soluble mineral constituents of the rock particles as the water moves into and through an aquifer. The amount of mineral matter dissolved depends mostly upon the amount of soluble materials in the aquifer, the length of time the water is in contact with them, and the amount of carbon dioxide in the water. Water that has been stored underground a long time or that has traveled a long distance from the recharge area generally is more highly mineralized than water that has been stored a short time and recovered relatively near the recharge area.

The quality of water for public supply and domestic use commonly is evaluated in relation to standards of the U.S. Public Health Service for drinking water. The standards, adopted in 1914 to protect the health of the traveling public, were revised several times in subsequent years. The latest revisions by the U.S. Public Health Service (1961), approved by the Secretary of Health, Education, and Welfare, are, in part, as follows:

Constituent	Maximum concentration ppm
Iron (Fe)	0.3
Manganese (Mn)	.05
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.7*
Nitrate (NO_3)	45
Dissolved solids	500

* Based on annual average of maximum daily air temperatures at Tioga.

Water samples were collected from 14 wells and 1 spring in the Tioga and Hofflund Flat areas. The wells range in depth from 30 to 217 feet. Five wells and the spring tap aquifers in the glacial drift and nine wells tap aquifers in the Fort Union Formation. Chemical analyses of the samples are given in table 4. The analyses show a wide range in degree of mineralization and in the relative proportions of dissolved constituents. Recommended maximums of some chemical constituents were exceeded in each of the samples. However, water having more than the recommended maximums for some constituents has been used in parts of North Dakota for many years without apparent ill effects.

Dissolved solids in water from the glacial drift, ranged from 207 to 1,590 ppm (parts per million) and averaged 837 ppm. Water from the Fort Union Formation ranged in dissolved solids from 317 to 3,680 ppm and averaged 1,623 ppm. Water from most wells, particularly those producing from the Fort Union Formation, contained large amounts of bicarbonate and sulfate. Seven of the 15 samples contained nitrate in excess of the recommended limit, and in samples 157-94-7add and 157-95-1bcb1 the concentration of nitrate was very high. High concentrations of nitrate in ground water may be due to decaying organic matter in the well, in the aquifer, or on the ground surface in the vicinity of the well. It also may be due to such inorganic material as mineral fertilizers. Water containing more than about 45 ppm of nitrate may cause cyanosis in infants when used in feeding formulas and for drinking. (Comly, 1945, p. 112-116; Silverman, 1949, p. 94-97).

The consumption of water containing fluoride in concentrations of 0.8 to 1.5 ppm during the calcification of the teeth may lessen the incidence of tooth decay. However, the consumption of water containing concentrations higher than about 1.5 ppm may cause mottling of tooth enamel (Dean, 1936). Fluoride concentrations were below the recommended maximum in all but one of the samples.

Most ground water contains at least small amounts of hardness-causing minerals. Hardness in water is caused principally by calcium and magnesium and to a lesser extent by iron, aluminum, strontium, barium, zinc, and free acid. Hardness in water is undesirable, especially if the water is used for cleaning, because it causes increased soap consumption as well as soap scum. Hardness of water from the glacial drift ranged from 154 to 764 ppm and averaged 468 ppm, and hardness of water from the Fort Union ranged from 16 to 2,890 ppm and averaged 626 ppm.

Water having a high concentration of sodium relative to the total cation concentration (high percent sodium) is unsuitable for irrigation because it may cause soils to become impermeable. The relative proportion of sodium expressed as a percentage, may be calculated using the following equation:

$$\text{Percent Na} = \frac{\text{Na} \times 100}{\text{Ca} + \text{Mg} + \text{Na} + \text{K}}$$

where the concentrations of all cations are in equivalents per million.

The continued use of irrigation water in which the percent sodium is in excess of 50 may cause damage to the soil. The amount of damage to the soil that will result from the continued use of a particular type of water also depends on other factors, such as salinity of the water, porosity of the soil, drainage, irrigation practices, and crop management. In general, the higher the percent sodium the less suitable the water is for irrigation. Among the samples tested, the water from the Fort Union Formation was generally less suitable for irrigation than water from the glacial drift. The average percentage of sodium for the 9 samples from the Fort Union aquifers was 53, whereas it was 31 for the 6 samples from the glacial drift aquifers.

In the Tioga area the surface deposits consist largely of clay. Subsurface drainage is slow in this type of soil, and caution should be used in applying water having a high percent sodium and a high dissolved-solids content.

SUMMARY OF GROUND-WATER CONDITIONS

Most wells in the Tioga area obtain water from aquifers in the Fort Union Formation of Paleocene (early Tertiary) age, which constitutes the bedrock. Generally the wells are drilled, are 6 inches or less in diameter, and are from 50 to 350 feet deep. They supply small to moderate amounts of moderately to highly mineralized water for farm and domestic use. Larger amounts of water for oil-well drilling operations are obtained by continuing wells through two or more aquifers and perforating the casings at these depths.

Aquifers probably occur in formations older and deeper than the Fort Union, but few data are available concerning them. The water in these deeper aquifers is probably highly mineralized.

Aquifers in the glacial drift supply water to about one-third of the wells in the Tioga area. Most of these wells are in the end moraine and lake basin parts of the area. Wells penetrating glacial drift deposits supply small amounts of water, which usually are adequate for individual farm and domestic users.

Relatively large supplies of ground water probably are available from glacial outwash and alluvial deposits in the Hofflund Flat area, which is about 15 miles south of Tioga. The deposits, which consist of sand and gravel, have an area of about 25 square miles and a maximum known thickness of 115 feet. A properly constructed well penetrating the full thickness of these deposits probably would yield as much as 1,000 gpm.

The municipal supply for Tioga is obtained from wells that penetrated thin deposits of sand and gravel associated with a bedrock channel. The channel trends eastward toward the White Earth River valley and has a branch extending north from the vicinity of the city. A major valley marks the location and trend of the main bedrock channel. Additional cross sections should be drilled across the valley east of the city to determine the full extent, thickness, and water-bearing characteristics of the sand and gravel associated with the channel.

Recharge to aquifers in the glacial drift is derived from water falling upon or passing over the surface of the area. Recharge to bedrock aquifers probably is derived partly from water percolating downward from the glacial drift aquifers and partly from water moving laterally into the area.

The regional movement of ground water appears to be southeastward. The movement is controlled locally by bedrock channels, surficial features, and by local differences in the transmissibility of the aquifers.

Fifteen samples of ground water were collected in the Tioga area. Chemical analyses of the samples show them to have a wide range in degree of mineralization and in the relative proportions of dissolved constituents. In general, ground water from most parts of the report area is very hard and has relatively high concentrations of sulfate, nitrate, bicarbonate, and iron. Among the samples analyzed, dissolved solids averaged higher for the Fort Union Formation than for the glacial drift. Much of the ground water in the Tioga area, because of high salinity and high percent sodium, probably is not suitable for irrigation use.

Aquifer: FU, Fort Union Formation
D, Glacial drift

Analyses by State Laboratories, Bismarck, N. Dak.

Location No.	Owner or name	Date of collection	Aquifer	Depth of well (feet)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
154-96								
8aad	Test hole 777	7-25-53	D	120	0.6	55	50	240
19aaa	W. T. Crawford	7-28-53	D	Spring	.48	146	53	60
157-94								
7add	Henry Rohde	6-18-53	D	30	.08	181	76	70
19ccb	George Neset	6-11-53	FU	96	.19	49	51	252
31add	Lawrence Myers	6-11-53	D	39	.38	18	26	3
157-95								
1bcb1	Arnold Ives	5-30-53	FU	70	.48	366	481	80
11aac	Oscar Bakken	5-30-53	FU	71	.7	56	36	250
22daa	Test hole 747	6-13-53	D	58	.48	161	80	118
27cad	Test hole 786	8-11-53	FU	200	.2	37	90	270
27ddc	T6, Tioga Supply	5-57	FU	100	.9	51	43	29
158-94								
33cbd	Carl C. Locken	7-30-53	D	59	.35	18	47	195
33dd b	Marvin Tande	7-30-53	FU	133	....	31	20	215
158-95								
33bcd1	Eilert Haakenson	6- 1-53	FU	200	6.5	0	4	924
35bca1	Thrond Lalim	6- 1-53	FU	118	.38	35	259	45
158-95								
35dda	W. E. Benson	6- 2-53	FU	217	.24	0	4	830

analyses of ground water

Results in parts per million except as indicated

Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids calculated	Hardness as $CaCO_3$	Percent sodium	pH
7.8	357	38	454	11	0.0	34	1,070	344	60	8.5
4.5	394	38	89	4	.0	58	647	582	18	8.0
4.0	266	29	396	32	.0	673	1,590	764	16	8.1
7.0	393	67	428	4	.0	35	1,090	331	61	8.7
2.0	123	19	......	23	.0	55	207	154	4	8.4
8.8	240	41	2,210	106	.4	266	3,680	2,890	6	8.2
5.8	564	88	238	14	.0	21	987	290	64	8.5
4.5	460	0	......	8	.0	2	600	728	26	7.7
14	482	56	532	11	.0	8.4	1,260	465	55	8.2
4.0	330	0	26	0	.2	0	317	302	17	7.5
3.8	266	61	387	11	.1	52	906	239	63	8.7
4.2	387	34	268	123	.0	48	934	162	74	8.4
4.2	1,040	194	1,040	23	1.7	71	2,770	18	98	8.8
8.5	374	0	749	10	.0	34	1,320	1,150	8	7.8
10	894	158	764	20	1.3	41	2,270	16	98	9.0

Depth of well and depth to water: Measured depths given in feet and tenths or hundredths; reported depths given in feet.

Type: Dr, drilled; Du, dug; Spr, spring.

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed	Depth to water below land surface (feet)
154-96						
4bba	Test hole 778	50	5	Dr	.....	......
8aad	Test hole 777	120	5	Dr	.....	......
8cdc	Test hole 776	90	5	Dr	.....	......
19aaa	W. T. Crawford	...	..	Spr	.....	Flow
20ccb	Test hole 775	120	5	Dr	.....	......
156-95						
1ccc	Tom Heen	85	24	Dr	.....	75
1ccd	..do....	82	6	Dr	.....	72
2dd	Ole Baaken	...	..	..	.....	72.69
3ccb	Vacant	78	20	Dr	.....	74.97
3daa	Inga Hersel	90	24	Dr	.....	75.71
4cc	Robert Shelton	...	6	Dr	.....	158.90
5bbb	Test hole 732	70	5	Dr	5-22-53	6.56
6bab1	Ernest Olson	110	24	Dr	.....	81.77
6bab2	..do....	93	4	Dr	.....	78
6ddd	Test hole 733	40	5	Dr	5-25-53	16.39
7ddd	Test hole 734	50	5	Dr	5-25-53	11.08
8bbb	Ernest Davidson	64	24	Dr	1937	44
8dab	..do....	303	6	Dr	1952	200 +
9abb	Vacant	80	24	Dr	.....	52.43
9acb	..do....	331	6	Dr	.....	77.70
9ada	..do....	91	36	Dr	.....	81.04
9cc	Dena Svore	250	6	Dr	1952	111.20
9da	..do....	291	6	Dr	1952	122.30
9dcc	Elwood Svore	90	4	Dr	.....	16
10ab	Vacant	79	24	Dr	.....	70.84
10bc	Inez Pierson	70	6	Dr	1952	69.50
10cbc	Peter Wallentinson	65	18	Dr	.....	60.73
10ddc	Marvin Nylander	80	24	Dr	.....	55.40
11bab	Vacant	101	24	Dr	.....	68.66

and test holes

Use: D, domestic; Irr, irrigation; N, none; PS, public supply; S, stock; T, test hole.

Elevation of land surface determined by spirit level.

Date of measurement	Use	Aquifer	Elevation of land surface (feet above mean sea level)	Remarks
....	N	.....	1,870	See log.
....	N	.....	1,844	See log; chemical analysis.
....	N	.....	1,861	See log.
....	D,S	.....	.....	See chemical analysis.
....	N	.....	.....	See log.
6-11-53	S	Bedrock	.....	
6-11-53	D	Sand	.....	Soft; adequate supply.
6-10-53	...	.....	.....	
6-10-53	N	.....	.....	
6-10-53	D,S	.....	.....	Adequate supply.
6-11-53	N	.....	.....	Abandoned oil-well location.
5-26-53	T	.....	2,256	See log.
6- 9-53	D,S	.....	.....	Hard.
6- 9-53	D	.....	.....	Hard; reddish color.
5-26-53	T	.....	2,304	See log.
5-25-53	T	.....	2,337	..Do....
6-11-53	D,S	.....	.....	Hard; adequate supply.
7-14-53	N	.....	.....	Oil-well location.
6-11-53	...	.....	.....	
7-16-53	N	.....	.....	Abandoned oil-well location.
6-10-53	...	.....	.....	
7-14-53	N	.....	.....	Oil-well location.
7-16-53	N	.....	.....	Oil-well location; see log.
6-10-53	D,S	Lignite	.....	Hard; reddish color, adequate supply.
6-10-53	N	.....	.....	
7-16-53	N	.....	.....	Oil-well location.
6-10-53	D,S	.....	.....	Temperature 48°F., adequate supply.
6-11-53	D,S	.....	.....	Adequate supply.
6-10-53	S	.....	.....	

TABLE 5.--Records of wells

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed	Depth to water below land surface (feet)
156-95 (Cont.)						
12baa	Jack Joyce	93	24	Dr	.....	87.48
13aa	Leholm Arne	190	6	Dr	.....	130
14aac	Elmer Moe	18	...	Dr	.....	10
14ac	..do....	...	...	Dr	1952	48.25
16cc	State of North Dakota	306	6	Dr	1952	295.30
16dc	..do....	300 +	6	Dr	1952	110.97
17ac	Anna J. Nelson	317	6	Dr	1953	187.50
17ba	E. C. Davidson	200	6	Dr	1953	145.78
17cc	A. M. Peterson	139	6	Dr	.....	119.20
18ddd	Test hole 735	40	5	Dr	5-25-53	13.38
156-96						
1bcc	Carl Lind	110	24	Dr	.....	104
1dcd	E. A. Anderson	112	4	Dr	.....	76.32
2aaa	Ben Iverson	113	24	Dr	.....	106
3abd	Carl Swanson	220	4	Dr	1923	......
3cdd	Olaf Skistad	255	4	Dr	1947	220
9cdc1	Carl Swanson	64	6	Dr	.....	35.69
9cdc2	..do....	86	4	Dr	1932	71.57
12acc	Bertha Fries	235	2½	Dr	.....	......
13bad	Albert M. Peterson	180	...	Dr	.....	146
13daa	Nils Anderson	110	24	Dr	1905	100 +
14baa	Carl Moe	253	6	Dr	1910	225
157-94						
5ca	O. C. Lokken	156	6	Dr	1953	66.04
5cc	..do....	65	6	Dr	.....	54.60
6bcd	Esther Knoshaug	169	6	Dr	.....	155.60
6aa	Willard Hanson	153	6	Dr	.....	133.60
7aa	Henry Rohde	108	6	Dr	.....	......
7add	..do....	30	24	Dr	.....	26.55
8ccb1	John Arnstad	32	24	Dr	1908	14
8ccb2	..do....	32	6	Dr	.....	20
17dd	Rudoff Rice	40	24	Du	1907	23.10
18aaa	Test hole 768	35	5	Dr	7- 9-53	......
18bbc1	Clifford Syverson	43	5	Dr	1949	38

and test holes -- Continued

Date of measurement	Use	Aquifer	Elevation of land surface (feet above mean sea level)	Remarks
6-11-53	N	.....	.....	
6-11-53	D,S	.....	.....	Soft; adequate supply.
6-10-53	D,S	Gravel	.....	Hard.
6-11-53	N	.....	.....	Abandoned oil-well location.
7-16-53	N	.....	.....	Oil-well location.
6-11-53	N	.....	.....	..Do....
7- 9-53	N	.....	.....	..Do....
6-11-53	N	.....	.....	..Do....
6-11-53	N	.....	.....	..Do....
5-25-53	T	.....	2,377	See log.
6-10-53	...	.....	.....	
6-10-53	D,S	.....	.....	Hard.
6-10-53	S	.....	.....	
6-10-53	D	Lignite	.....	
6-10-53	D,S	Sand	.....	Soft.
6-10-53	D	.....	.....	Hard.
6-10-53	S	.....	.....	Hard; brownish color.
6-10-53	D,S	.....	.....	Soft.
6-11-53	D,S	Lignite	.....	Soft.
6-11-53	D,S	Lignite	.....	Hard.
6-11-53	D,S	Sand	.....	Soft; salty.
7-15-53	N	.....	.....	Oil-well location.
7- 9-53	N	.....	.....	..Do....
7-15-53	N	.....	.....	Oil-well location; see log.
7- 8-53	N	.....	.....	Oil-well location.
7- 9-53	N	.....	.....	Oil-well location; see log.
6-18-53	D,S	.....	.....	Hard; see chemical analysis.
6-18-53	S	.....	.....	Hard.
6-18-53	D	Sand	.....	..Do....
6-18-53	D	.....	.....	..Do....
....	T	.....	.....	See log.
6-11-53	D	Lignite	.....	Soft.

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed	Depth to water below land surface (feet)
157-94 (Cont.)						
18bbc2	Clifford Syverson	58	24	Dr	1942	55.35
18ccc	John Hoass	64	24	Dr	1914	37.67
19bbb	Clarence Swanson	...	3	Dr	1908	27.95
19ccb	George Neset	96	4	Dr	1943	65.57
20ccc	Test hole 745	30	6	Dr	6- 8-53	......
25dbb	Test hole 779	50	5	Dr	7-13-53	......
29aab	Test hole 746	25	5	Dr	6-12-53	......
30bbb	Test hole 744	40	5	Dr	6- 6-53	......
31ab	Lawrence Myers	37	36	Du	1944	......
31add	..do....	39	24	Dr	1944	25.01
31dcc	Martin Tande	29	24	Dr	.....	24.07
32cd	Vacant	66	24	Dr	.....	......
32cdd	Robert Joyce	108	24	Dr	.....	88.44
157-95						
1baa	Arnold Ives	155	...	Dr	.....	110.90
1bcb1	..do....	70	4	Dr	1952	51
1bcb2	..do....	70	4	Dr	1941	50
2dcd	Oscar Bakken	132	6	Dr	1952	84.50
3dcc	Vacant	40	24	Dr	.....	15.40
3ddc	Test hole 752	30	5	Dr	6-19-53	......
3ddd	Test hole 756	40	5	Dr	6-30-53	......
6abd	Vacant	74	18	Dr	.....	Dry
6bc	..do....	156	6	Dr	.....	155.00
6ccb	Oscar Stenborg	145	4½	Dr	1945	80
7add	Vacant	84	16	Dr	.....	68.13
7dd	J. A. Simon	147	6	Dr	1915	80
8dda	Lloyd Langager	84	4	Dr	1940	50
9ccc	Vacant	111	24	Dr	.....	77.60
10abb	Test hole 755	40	5	Dr	6-30-53	......
10ccc1	John Swanesund	36	24	Dr	1943	18.92
10ccc2	..do....	30	7	Dr	1939	20
10ddc	Test hole 750	50	5	Dr	6-17-53	......
11aac	Oscar Bakken	71	6	Dr	1924	55.20
11ada1	Henry and Harry Bakken	482	7½	Dr	.....	224.00
11ada2	..do....	70 +	...	Dr	1953	......

and test holes -- Continued

Date of measurement	Use	Aquifer	Elevation of land surface (feet above mean sea level)	Remarks
6-11-53	S	Lignite	.....	Hard.
6-11-53	D,S	Sand	.....	..Do....
6-11-53	D,S	.....	.....	..Do....
6-11-53	D,S	Lignite	.....	Hard; see chemical analysis.
....	T	.....	2,200	See log.
....	T	.....	2,090	..Do....
....	T	.....	.....	..Do....
....	T	.....	2,250	..Do....
6-11-53	D	.....	.....	Soft.
7-30-53	D,S	.....	.....	Hard; see chemical analysis.
7-30-53	D,S	.....	.....	
6-11-53	N	.....	.....	
7-30-53	D,S	.....	.....	
7-14-53	N	.....	.....	Oil-well location.
5-29-53	D	.....	.....	See chemical analysis.
5-29-53	S	.....	.....	
5-30-53	N	Lignite	.....	Abandoned oil-well location.
6-10-53	N	.....	.....	
....	T	.....	2,394	See log.
....	T	.....	2,400	..Do....
6- 1-53	N	.....	.....	
6- 2-53	N	.....	.....	Abandoned oil-well location.
6- 2-53	S	Lignite	.....	Temperature 43°F., brownish-color.
6- 1-53	N	.....	.....	
6-10-53	D,S	.....	.....	Soft.
6-11-53	S	Lignite	.....	Hard; brownish color.
6-10-53	N	.....	.....	
....	T	.....	2,381	See log.
6-11-53	S	Clay	.....	Hard; adequate supply.
6-11-53	D	Clay	.....	Hard.
....	T	.....	2,353	See log.
5-30-53	D	Lignite	.....	Soft; temperature 44°F., see chemical analysis.
5-29-53	N	Clay	.....	Soft; see log.
5-29-53	N	.....	.....	

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed	Depth to water below land surface (feet)
157-95 (Cont.)						
11bab	Test hole 753	30	5	Dr	6-19-53	......
11bba	Test hole 754	40	5	Dr	6-29-53	......
11bbb	Test hole 727	90	5	Dr	5-19-53	34.58
11bc	Vacant	171	6	Dr	1952	92.60
11ccc	Test hole 726	80	5	Dr	5-19-53	12.37
12aac	Vacant	50	6	Dr	......	20.90
12ac	R. G. McGuiness	50	6	Dr	......	48.10
12bcb	Henry and Harry Bakken	68	4	Dr	1945	......
12cc	Clifford Syverson	507	7	Dr	......	......
14bba	Test hole 751	80	5	Dr	6-17-53	......
14ccd1	Lawrence Pederson	62	24	Dr	1920	37.80
14ccd2	..do....	31	24	Dr	1944	2.90
14cdc	Test hole 749	60	5	Dr	6-16-53	......
15add	Peter Braaten	32	6	Dr	1923	20.35
15dcd	Sever Breckey	85	24	Dr	1915	67.22
15ddd	Test hole 725	90	5	Dr	5-18-53	5.12
17cad	Francis Ostlund	32	...	Dr	1947	......
19ccc	Test hole 741	90	5	Dr	6- 2-53	......
19cdc	Vacant	75	20	Dr	......	71.39
20bda	..do....	88	4	Dr	......	85.00
21ba	..do....	152	6	Dr	......	118.74
22aab	Test hole 767	70	5	Dr	7- 8-53	......
22aba	Test hole 748	60	5	Dr	6-15-53	......
22ccc	Test hole 738	80	5	Dr	5-27-53	......
22ccd	Test hole 761	90	5	Dr	7- 3-53	......
22cdd	Test hole 760	90	5	Dr	7- 2-53	......
22daa	Test hole 747	75	5	Dr	6-13-53	......
22dad	Test hole 769	60	5	Dr	7- 9-53	......
22dda	Test hole 770	70	5	Dr	7-11-53	......
22ddd	Test hole 724	100	5	Dr	5-18-53	33.78
23bbb	Test hole 757	60	5	Dr	7- 2-53	......
23ccc1	Asbjorn Haustveit	35	6	Dr	1943	20
23ccc2	..do....	75	4	Dr	1945	40
23da	Vacant	195	6	Dr	......	127.80

and test holes -- Continued

Date of measurement	Use	Aquifer	Elevation of land surface (feet above mean sea level)	Remarks
....	T	.....	2,403	See log.
....	T	.....	2,404	..Do....
5-21-53	T	.....	2,404	..Do....
7-14-53	N	.....	.....	
5-21-53	T	.....	2,331	..Do....
6-29-53	N	.....	.....	Temperature 43°F.
7- 8-53	N	.....	.....	Oil-well location.
6-30-53	D	.....	.....	Hard.
....	D	.....	2,364	See log; oil-well location.
....	T	.....	2,348	See log.
6-10-53	D,S	.....	.....	Hard.
6-10-53	D,S	Gravel	.....	..Do....
....	T	.....	2,325	See log.
6-10-53	D,S	Gravel	.....	Hard; adequate supply, temperature 43°F.
6-10-53	D,S	Gravel	.....	Hard; temperature 43°F.
5-22-53	T	.....	2,293	See log.
6-11-53	D,S	.....	.....	Hard; adequate supply.
....	T	.....	2,304	See log.
6- 1-53	N	.....	.....	
6-11-53	N	.....	.....	
6-11-53	N	.....	.....	Oil-well location.
....	T	.....	2,291	See log.
....	T	.....	.....	..Do....
....	T	.....	2,282	..Do....
....	T	.....	2,278	..Do....
....	T	.....	2,282	..Do....
....	T	.....	2,254	See log; chemical analysis.
....	T	.....	2,258	See log.
....	T	.....	2,252	..Do....
5-21-53	T	.....	2,249	..Do....
....	T	.....	2,316	..Do....
8- 6-53	D	Gravel	.....	Hard; inadequate supply; temperature 44°F.
8- 6-53	S	Gravel	.....	Soft; adequate supply; temperature 45°F.
7-15-53	N	.....	.....	Oil-well location.

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed	Depth to water below land surface (feet)
157-95 (Cont.)						
25bbb	Test hole 743	100	5	Dr	6- 6-53	......
26aac	Signal Oil And Gas	150	10	Dr	1953	80
26abb	Test hole 763	80	5	Dr	7- 6-53	......
26bab	Test hole 762	70	5	Dr	7- 6-53	......
26bcc	Test hole 764	90	5	Dr	7- 7-53	......
27aab	Test hole 758	60	5	Dr	7- 1-53	......
27abb	Test hole 759	70	5	Dr	7- 2-53	......
27acb	T3, City of Tioga	...	...	..	.....	......
27abd	T2, City of Tioga	...	...	Dr	1951	43.44
27ada	T1, City of Tioga	90	10	Dr	1953	41.10
27bda	Test hole 771	60	5	Dr	7-11-53	......
27bdd	Test hole 772	600	5	Dr	7-14-53	......
27cad	Test hole 786	200	5	Dr	8-11-53	......
27cdd	Test hole 774	70	5	Dr	7-22-53	......
27daa	Test hole 765	100	5	Dr	7- 7-53	......
27db	T4, City of Tioga	116	5	Dr	1954	52.75
27dca	T5, City of Tioga	93	5	Dr	1956	38.00
27dda	Test hole 766	80	5	Dr	7- 8-53	......
27ddc	T6, City of Tioga	100	5	Dr	1957	43.16
28add	Edward Fredricson	178	5	Dr	1920	70.40
28bbb	Test hole 739	90	5	Dr	5-28-53	......
30aaa	Test hole 740	120	5	Dr	5-29-53	......
30bbb	Stella Schmidt	191	4	Dr	1944	96.07
30ddd	Vacant	30	4	Dr	.....	13.35
31add	..do....	34	20	Dr	.....	14.29
32aaa	Andrew Folden	113	4	Dr	1941	92.46
32bab	Wilfred Stone	65	4	Dr	1947	41.17
32cbb	Vacant	34	20	Dr	.....	10.34
33aaa	C. R. Cole	122	4	Dr	.....	70.74
34aab	Glans Estate	53	24	Dr	1918	43.95
35ad	LeRoy Nelson	175	6	Dr	1952	165.60
35bbb	Test hole 731	60	5	Dr	5-22-53	......
36ac	Amerada Petroleum Corp.	65	...	Dr	.....	......
36dc	..do....	47	...	Dr	.....	......

and test holes -- Continued

Date of measurement	Use	Aquifer	Elevation of land surface (feet above mean sea level)	Remarks
....	T	.....	2,255	See log.
7-30-53	Irr	Lignite	.....	
....	T	.....	2,274	..Do....
....	T	.....	2,258	..Do....
....	T	.....	2,245	..Do....
....	T	.....	2,249	..Do....
....	T	.....	2,273	..Do....
....	...	.....	.....	No data available.
8- 6-53	PS	.....	.....	See log; chemical analysis.
5-13-53	PS	.....	.....	See log.
....	T	.....	.....	..Do....
....	T	.....	2,245	..Do....
....	T	.....	.....	..Do....
....	T	.....	2,249	..Do....
....	T	.....	2,242	..Do....
8-11-54	PS	.....	.....	..Do....
8-21-56	PS	.....	.....	..Do....
....	T	.....	2,244	..Do....
5-22-57	PS	.....	.....	See log; chemical analysis.
6- 6-53	S	Lignite	.....	Hard.
....	T	.....	2,284	See log.
....	T	.....	2,293	..Do....
6- 8-53	D,S	.....	.....	Hard.
6- 9-53	...	.....	.....	
6- 9-53	N	.....	.....	
6- 9-53	D,S	Lignite	.....	..Do....
6- 9-53	D,S	Sand	.....	Soft.
6- 9-53	N	.....	.....	
6- 8-53	D	Lignite	.....	Hard.
6- 9-53	D,S	Sand	.....	Soft.
7-16-53	N	.....	.....	Oil-well location.
....	...	.....	2,248	See log.
7-16-53	N	.....	.....	Oil-well location.
7-16-53	N	.....	.....	..Do....

TABLE 5.--Records of wells

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed	Depth to water below land surface (feet)
157-96						
1ddd	Vacant	30	18	Dr	.....	17.86
24aad	..do....	61	18	Dr	.....	46.68
25ccc	Charles Hartsoch	65	24	Dr	.....	24.68
26aaa	Test hole 742	100	5	Dr	6- 3-53	......
36aba	Charles Hartsoch	132	4	Dr	.....	100
158-94						
31abd	Philip Eraas	36	30	Dr	1918	18
32add	Andrew Hulberg	32	24	Dr	1933	12
32bac	Odell Knoshaug	85	4	Dr	1932	73
32cac	Synsteby Estate	92	9	Dr	1914	.....
33cbd	Carl C. Locken	59	...	Dr	.....	45
33ddb	Marvin Tande	133	4	Dr	1949	63
158-95						
33bcd1	Eilert Haakenson	200	4	Dr	.....	......
33bcd2	..do....	18	18	Du	.....	12.40
33cdd	Vacant	23	36	Dr	.....	11.94
34aaa	Test hole 729	80	5	Dr	5-21-53	14.98
34dac	Harold Borstad	130	4	Dr	.....	......
35aa	Thrond Lalim	126	6	Dr	1952	99.21
35bca1	..do....	118	2	Dr	1904	85
35bca2	..do....	110	5	Dr	1928	85.09
35caa	Adolph Borstad	114	6	Dr	.....	90.65
35cca1	Morris Borstad	135	2	Dr	1917	......
35cca2	..do....	120	6	Dr	1952	50
35ccc	Test hole 728	120	5	Dr	5-20-53	22.28
35dbd	Harold Borstad	150	2	Dr	.....	95.76
35dda	W. E. Benson	217	6	Dr	1921	150
36aaa	Vacant	176	...	Dr	.....	113.14
36baa	N. D. C. B. #3	12	6	Dr	.....	11.40
36dcc	Vacant	158	6	Dr	.....	112.20

and test holes -- Continued

Date of measurement	Use	Aquifer	Elevation of land surface (feet above mean sea level)	Remarks
6- 2-53	S	.....	.....	
6- 2-53	N	.....	.....	
6- 8-53	N	.....	.....	
....	T	.....	2,326	See log.
6- 8-53	D,S	.....	.....	Soft.
7-30-53	D,S	.....	.....	Hard.
7-30-53	D,S	.....	.....	..Do....
7-30-53	S	.....	.....	..Do....
7-30-53	D,S	Sand	.....	..Do....
7-30-53	D,S	Sand	.....	Hard; see chemical analysis.
7-30-53	D,S	.....	.....	..Do....
6- 1-53	S	Lignite	.....	Soft; see chemical analysis.
6- 1-53	D	Gravel	.....	Hard; see chemical analysis.
6-10-53	N	.....	.....	Temperature 41°F.
5-22-53	T	.....	2,450	See log.
6- 9-53	D,S	Lignite	.....	Hard.
6- 1-53	N	.....	.....	Oil-well location.
6- 1-53	S	Sand	.....	Hard; see chemical analysis.
6- 1-53	D	Sand	.....	Hard.
7-14-53	N	.....	.....	
6- 1-53	D,S	Sand	.....	Hard.
6- 1-53	Irr	Gravel	.....	..Do....
5-21-53	T	.....	2,430	See log.
6-10-53	N	Sand	.....	
6- 2-53	D,S	Lignite	.....	Soft; adequate supply, brownish color. See chemical analysis.
7-15-53	N	.....	.....	Abandoned oil-well location.
7-14-53	N	.....	.....	
7- 8-53	...	.....	.....	Oil-well location.

TABLE 6.--Logs of wells and test holes*

154-96-4bba
Test hole 778

Formation	Material	Thickness (feet)	Depth (feet)
Glacial outwash:			
	Sand, coarse........................	10	10
	Gravel, medium......................	5	15
	Sand and gravel.....................	22	37
Fort Union Formation:			
	Clay, sandy, light-gray.............	13	50

*Note: The term "till" used in many of these logs refers to a heterogeneous mixture of clay, silt, sand, gravel, and boulders. Generally clay and till are the predominant constituents.

154-96-8aad
Test hole 777

Formation	Material	Thickness (feet)	Depth (feet)
Glacial outwash:			
	Clay, yellowish-gray................	10	10
	Sand, medium to coarse..............	10	20
	Sand, mostly very coarse............	5	25
	Gravel, coarse, and sand, very coarse	17	42
	Clay; medium-gray...................	7	49
	Sand, very coarse, and gravel, coarse	36	85
	Gravel, very coarse. Many of the gravel particles are rounded; some are polished; composed mostly of hard rock materials such as quartzite and flint................	29	114
Fort Union Formation:			
	Clay, light-gray....................	4	118
	Lignite and clay; black.............	2	120

TABLE 6.--Logs of wells and test holes -- Continued

154-96-8cdc
Test hole 776

Formation	Material	Thickness (feet)	Depth (feet)
Glacial outwash:			
	Sand, fine to medium.................	13	13
	Clay, sandy, yellowish-gray..........	5	18
	Sand, very fine to fine..............	2	20
	Sand, mostly medium, clean, light-brown.............................	7	27
	Clay, medium gray....................	2	29
	Clay, carbonaceous, black............	1	30
	Sand, medium to coarse, clean........	4	34
	Gravel, fairly well rounded..........	5	39
	Silt and clay, carbonaceous, black...	3	42
	Sand, mostly coarse..................	26	68
	Sand, coarse to very coarse. Large amount of gravel composed of lignite	13	81
Fort Union Formation:			
	Clay, very sandy, light-gray.........	9	90

154-96-20ccb
Test hole 775

Formation	Material	Thickness (feet)	Depth (feet)
Alluvium and glacial outwash:			
	Clay and sand, very fine.............	15	15
	Sand, very fine to fine..............	5	20
	Sand, coarse, clean..................	5	25
	Sand, very coarse....................	5	30
	Sand, medium.........................	5	35
	Sand, fine...........................	5	40
	Sand, fine to very coarse. Considerable amounts of carbonized wood fragments............................	10	50
	Sand, mostly fine to medium..........	20	70
	Sand. Samples show much contamination due to difficulty in maintaining circulation........................	10	115
Fort Union Formation:			
	Lignite..............................	1	116
	Clay, light-gray.....................	4	120

TABLE 6.--Logs of wells and test holes -- Continued

156-95-5bbb
Test hole 732

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: sandy, yellowish-gray.........	38	38
Fort Union Formation:			
	Clay, sandy, yellowish-gray..........	26	64
	Clay, sandy, gray....................	6	70

156-95-6ddd
Test hole 733

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	33	33
Fort Union Formation:			
	Clay, yellowish-gray.................	7	40

156-95-7ddd
Test hole 734

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: sandy, weathered, yellowish-gray	44	44
Fort Union Formation:			
	Clay, light-gray.....................	6	50

156-95-9da
Dena Svore water well No. 2
Log furnished by Amerada Petroleum Corp.

Material	Thickness (feet)	Depth (feet)
Sand................................	35	35
Coal and sand.......................	80	115
Sand................................	25	140
Coal................................	10	150
Sand................................	50	200
(Not known).........................	65	265
Coal and sand.......................	30	295
Shale...............................	40	335
Sand................................	35	370
Coal................................	16	386

156-95-18ddd
Test hole 735

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: yellowish-gray................	17	17
	Sand................................	4	21
	Till: sandy, yellowish-gray.........	19	40

157-94-6bcd
Esther Knoshaug water well No. 1
Log furnished by Amerada Petroleum Corp.

	Material	Thickness (feet)	Depth (feet)
	Clay, gray..........................	102	102
	Clay, yellow........................	39	132
	Clay, gray, gravel with water.......	19	151
	Clay, gray..........................	18	169
	Coal................................	2	171
	Clay, gray..........................	33	204
	Sand with water.....................	6	210

157-94-7aa
Henry Rohde water well No. 1
Log furnished by Amerada Petroleum Corp.

	Material	Thickness (feet)	Depth (feet)
	Gravel and sand.....................	10	10
	Clay, yellow........................	64	74
	Coal................................	2	76
	Clay, sandy.........................	46	122
	Clay, sandy, gravel with water......	33	155
	Clay, white.........................	3	158

157-94-18aaa
Testhole 768

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Sand, fine to medium................	9	9
	Till(?): Samples are mostly very coarse sand. Drilled hard, like till..............................	18	27
Fort Union Formation:			
	Clay, very light-gray...............	8	35

TABLE 6.--Logs of wells and test holes -- Continued

157-94-20ccc
Test hole 745

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: yellowish-gray................	4	4
	Sand................................	4	8
	Till: light-gray....................	9	17
Fort Union Formation:			
	Clay, very sandy, light-gray.........	13	30

157-94-25dbb
Test hole 779

Formation	Material	Thickness (feet)	Depth (feet)
Alluvium:			
	Sand, fine, clayey..................	26	26
	Clay, dark-gray, soft...............	12	38
	Sand, clayey........................	6	44
Fort Union Formation:			
	Clay, very light-gray...............	6	50

157-94-29aab
Test hole 746

Formation	Material	Thickness (feet)	Depth (feet)
Alluvium:			
	Sand and gravel.....................	11	11
	Till: yellowish-gray................	8	19
Fort Union Formation:			
	Clay, light-gray....................	6	25

157-94-30bbb
Test hole 744

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	8	8
	Sand, fine to coarse................	11	19
	Till: weathered, yellowish-gray.....	7	26
	Till: gray..........................	11	37
Fort Union Formation:			
	Clay, very sandy, light-gray.........	3	40

TABLE 6.--Logs of wells and test holes -- Continued

157-95-3ddc
Test hole 752

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Sand and gravel......................	8	8
	Till: weathered, yellowish-gray.....	14	22
Fort Union Formation:			
	Clay, very sandy, yellowish-brown....	2	24
	Clay, light-grayish green............	6	30

157-95-3ddd
Test hole 756

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: yellowish-gray................	28	28
Fort Union Formation:			
	Clay, light-gray.....................	8	36
	Clay, sandy, yellowish-gray..........	4	40

157-95-10abb
Test hole 755

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: yellowish-gray................	23	23
	Sand................................	3	26
Fort Union Formation:			
	Clay, sandy, yellowish-gray..........	7	33
	Clay, light-gray.....................	7	40

157-95-10ddc
Test hole 750

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	35	35
Fort Union Formation:			
	Clay, alternating layers of light-gray and yellow....................	15	50

TABLE 6.--Logs of wells and test holes -- Continued

157-95-11adal
Henry and Harry Bakken
Log furnished by Wm. Bruton
Well driller, Tioga, N. Dak.

Formation	Material	Thickness (feet)	Depth (feet)
	Glacial drift	70	70
	(Not known)	164	234
	Clay	6	240
	Quicksand	83	323
	Sandy clay	27	350
	Clay, gray	90	440
	Coal, water-bearing	2	442
	Clay, gray	23	465
	Clay, sandy	17	482

157-95-11bab
Test hole 753

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Sand	7	7
	Till: yellowish-gray	12	19
Fort Union Formation:			
	Clay, sandy, yellowish-gray	11	30

157-95-11bbb
Test hole 754

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray	26	26
Fort Union Formation:			
	Sand, clayey, yellow, very fine	9	35
	Clay	5	40

TABLE 6.--Logs of wells and test holes -- Continued

157-95-11bbb
Test hole 727

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	58	58
	Gravel, fine, may have considerable clay..............................	17	75
	Gravel, medium, some clay in samples.	5	80
Fort Union Formation:			
	Clay, yellowish-gray.................	6	86
	Lignite and carbonaceous clay........	4	90

157-95-11ccc
Test hole 726

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	19	19
	Till: sandy, light-gray.............	40	59
	Gravel, may be slightly silty........	6	65
	Gravel, mostly fine..................	9	74
Fort Union Formation:			
	Clay, sandy, very light-gray, also some dark-purple (carbonaceous) clay....	6	80

TABLE 6.--Logs of wells and test holes -- Continued

157-95-12cc
Clifford Syverson water well No. 1
Log furnished by Amerada Petroleum Corp.

Material	Thickness (feet)	Depth (feet)
Gravel	27	27
Boulder	2	29
Clay	5	34
Gravel	15	49
Shale, soft	47	96
Coal	8	104
Boulder	2	106
Sand	100	206
Coal	12	218
Sand	43	261
Coal	3	264
Sand	7	271
Boulders	2	273
Sand	19	292
Coal	4	296
Shale	4	300
Coal	16	316
Shale	19	335
Sand	5	340
Boulder	3	343
Sand	40	383
Coal	13	396
Sand	10	406
Coal	7	413
Shale	25	438
Pyrite	2	440
Boulder	5	445
Sand	5	450
Boulder	4	454
Sand	28	482
Limerock	25	507

157-95-14bba
Test hole 751

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	45	45
	Till: gray..........................	24	69
Fort Union Formation:			
	Clay, light-gray....................	10	79
	Clay, yellowish-gray................	1	80

157-95-14cdc
Test hole 749

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Sand................................	4	4
	Till: weathered, yellowish-gray.....	20	24
	Till: gray..........................	15	39
Fort Union Formation:			
	Clay, sandy, gray...................	4	43
	Clay, sandy, yellowish-gray.........	17	60

157-95-15ddd
Test hole 725

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: gravel, weathered, light-yellow	17	17
	Till: light-gray....................	27	44
	Till: weathered, yellowish-gray.....	8	52
	Till: very gravelly, light-gray.....	20	72
	Gravel, fine to medium..............	11	83
Fort Union Formation:			
	Clay, sandy, light-gray.............	7	90

157-95-19ccc
Test hole 741

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Clay, yellowish-gray................	6	6
	Till: yellowish-gray................	64	70
	Till: medium-gray...................	13	83
Fort Union Formation:			
	Clay, sandy, gray...................	7	90

TABLE 6.--Logs of wells and test holes -- Continued

157-95-22aab
Test hole 767

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Sand and gravel	9	9
	Till: medium-gray	30	39
	Till: weathered white, highly calcareous	1	40
	Till: yellowish-gray	7	47
	Sand, coarse	9	56
Fort Union Formation:			
	Clay, gray	2	58
	Clay, yellowish-gray	9	67
	Clay, light-gray	3	70

157-95-22aba
Test hole 748

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray	19	19
	Till: gray	29	48
Fort Union Formation:			
	Clay, very sandy, light-gray	12	60

157-95-22ccc
Test hole 738

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: yellowish-gray	13	13
	Sand	4	17
	Till: yellowish-gray	10	27
	Till: sandy, medium-gray	47	74
Fort Union Formation:			
	Clay, sandy, medium-gray	6	80

157-95-22ccd
Test hole 761

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray	38	38
	Till: medium-gray	30	68
Fort Union Formation:			
	Clay, sandy, gray	22	90

TABLE 6.--Logs of wells and test holes -- Continued

157-95-22cdd
Test hole 760

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray......	47	47
	Till: light-gray.....................	36	83
Fort Union Formation:			
	Clay, sandy, medium-gray.............	7	90

157-95-22daa
Test hole 747

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray......	8	8
	Sand, medium to coarse................	8	16
	Till: weathered, yellowish-gray......	8	24
	Sand and gravel. Much clay...........	21	45
	Sand and fine gravel, some clay.......	5	50
	Gravel, fairly clean, fine............	8	58
Fort Union Formation:			
	Clay, sandy, light-gray...............	17	75

157-95-22dad
Test hole 769

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray......	23	23
	Sand and gravel.......................	2	25
	Till: gray............................	10	35
	Sand and gravel.......................	16	51
Fort Union Formation:			
	Clay, sandy, gray.....................	6	57
	Clay, yellowish-gray..................	3	60

TABLE 6.--Logs of wells and test holes -- Continued

157-95-22dda
Test hole 770

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	8	8
	Sand................................	4	12
	Till: weathered, yellowish-gray.....	5	17
	Till: gray..........................	11	28
	Sand, clayey, mostly coarse, poorly sorted............................	11	39
Fort Union Formation:			
	Clay, sandy, gray...................	11	50
	Clay, sandy, yellowish-gray.........	16	66
	Clay, sandy, light-gray.............	3	69
	Lignite.............................	1	70

157-95-22ddd
Test hole 724

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: sandy, yellowish-gray, becoming gray toward the bottom.............	31	31
	Till: very gravelly, yellowish-gray.	13	44
	Till: very gravelly, gray...........	9	53
	Till: gravelly, bright yellow (distinctly oxidized)..............	13	66
Fort Union Formation:			
	Clay, light-gray....................	30	96
	Lignite.............................	2	98
	Clay, light-gray and brown..........	2	100

157-95-23bbb
Test hole 757

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Sand, mostly very coarse............	25	25
	Gravel, fine........................	7	32
	Till: yellowish-gray................	25	57
Fort Union Formation:			
	Clay, sandy, yellow.................	3	60

TABLE 6.--Logs of wells and test holes -- Continued

157-95-25bbb
Test hole 743

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	70	70
	Till(?): mostly very coarse sand, weathered........................	21	91
Fort Union Formation:			
	Clay, sandy, light-gray..............	9	100

157-95-26abb
Test hole 763

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	42	42
	Till: gray.........................	30	72
Fort Union Formation:			
	Clay, light-gray....................	8	80

157-95-26bab
Test hole 762

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	48	48
	Till: gray.........................	11	59
Fort Union Formation:			
	Clay, sandy, medium-gray............	11	70

157-95-26bcc
Test hole 764

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered,yellowish-gray......	32	32
	Sand and gravel. Samples contain considerable amounts of clay.......	15	47
	Till: weathered, yellowish-gray.....	21	68
	Till: sandy, gray..................	9	77
Fort Union Formation:			
	Clay, sandy, light-gray.............	13	90

TABLE 6.--Logs of wells and test holes -- Continued

157-95-27aab
Test hole 758

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Sand, coarse..........................	9	9
	Till: weathered, yellowish-gray......	8	17
	Till: gray...........................	4	21
	Sand, coarse..........................	7	28
Fort Union Formation:			
	Clay, sandy, yellowish-gray...........	32	60

157-95-27abd
City of Tioga No. 2
Log furnished by C. A. Simpson & Son
Bisbee, No. Dak.

	Soil..................................	1	1
	Clay, yellow..........................	27	28
	Clay, sandy, gray.....................	21	49
	Clay, sandy, yellow...................	5	54
	Clay, sandy, gray.....................	11	65
	Clay, sandy, brown....................	7	72
	Sand and gravel, clayey...............	18	90
	Clay, sandy, gray.....................	12	102
	Clay, very sandy, gray................	20	122
	Clay or shale, light-gray.............	8	130
	Clay or shale, medium gray............	10	140
	Coal..................................	1	141
	Shale, gray...........................	24	165

157-95-27abb
Test hole 759

Glacial drift:			
	Till: weathered, yellowish-gray......	50	50
	Gravel, may be silty..................	5	55
	Till: weathered, yellowish-gray......	6	61
Fort Union Formation:			
	Clay, light-gray......................	5	66
	Clay, sandy, medium-gray..............	4	70

TABLE 6.--Logs of wells and test holes -- Continued

157-95-27bda
Test hole 771

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray......	6	6
	Till: light-gray....................	5	11
	Till: weathered, yellowish-gray......	11	22
	Sand, medium to coarse...............	13	35
	Sand and gravel......................	22	57
Fort Union Formation:			
	Clay, light-gray.....................	3	60

157-95-27bdd
Test hole 772

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray......	56	56
Fort Union Formation:			
	Clay, light- greenish-gray...........	34	90
	Clay, sandy, light-gray..............	41	131
	Sand, clayey, mostly fine to medium...	18	149
	Clay and fine sand...................	41	190
	Clay, sandy, gray....................	16	206
	Lignite..............................	2	208
	Clay, sandy, light-gray..............	117	325
	Lignite..............................	2	327
	Clay, light-gray.....................	116	443
	Clay, very light-gray................	25	468
	Lignite..............................	1	469
	Clay, very light-gray................	11	480
	Clay, light-gray.....................	28	508
	Lignite..............................	2	510
	Clay, very light-gray................	90	600

TABLE 6.--Logs of wells and test holes -- Continued

157-95-27cad
Test hole 786

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	33	33
	Sand and gravel.....................	5	38
	Till: weathered, yellowish-gray.....	9	47
	Clay, sandy, yellowish-gray.........	14	61
	Sand and gravel, clayey.............	3	64
Fort Union Formation:			
	Clay, light-gray....................	12	76
	Sand................................	3	79
	Clay, light-gray....................	8	87
	Clay, sandy, light-gray, (very poor samples).........................	33	120
	Sand................................	24	144
	Clay, sandy, light-gray (poor samples)	56	200

157-95-27cdd
Test hole 774

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	29	29
	Clay, yellowish-gray................	6	35
	Clay, sandy, light-gray.............	11	46
	Sand, coarse........................	4	50
Fort Union Formation:			
	Clay, yellowish-gray................	14	64
	Clay, sandy, light-gray.............	6	70

TABLE 6.--Logs of wells and test holes -- Continued

157-95-27daa
Test hole 765

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	41	41
	Clay, sandy, yellowish-gray..........	11	52
	Clay, sandy, gray....................	13	65
	Sand and gravel, clayey..............	5	70
	Sand and gravel, fairly clean........	8	78
Fort Union Formation:			
	Clay, sandy, light-gray..............	8	86
	Clay, light-gray.....................	11	97
	Clay, yellowish-gray.................	3	100

157-95-27db
City of Tioga No. 4
Log furnished by C. A. Simpson & Son, Bisbee, N. Dak.

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Topsoil..............................	1	1
	Clay, hard, gravelly, yellow.........	4	5
	Clay, yellow.........................	40	45
	Clay, sandy, blue....................	23	68
	Clay, sandy, yellow..................	17	85
	Sand, clayey, gray with lignite pebbles..........................	7	92
	Clay, sandy, blue....................	10	102
	Sand, clayey, medium fine............	4	106
	Clay, gravelly, blue.................	4	110
	Gravel, coarse.......................	5	115
Fort Union Formation:			
	Sand, clayey, fine...................	3	118
	Gravel...............................	1	119
	Clay, gravelly.......................	3	122
	Sand, clayey, fine with lignite pebbles..........................	22	144
	Shale, gray..........................	6	150

TABLE 6.--Logs of wells and test holes -- Continued

157-95-27dca
City of Tioga No. 5
Log furnished by C. A. Simpson & Son, Bisbee, N. Dak.

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Topsoil	1	1
	Gravel, coarse, clayey	2	3
	Clay, hard, yellow	9	12
	Clay, sandy, yellow	34	46
	Clay, very sandy, yellow with little water	10	56
	Clay, sandy, gray	5	61
	Sand, fine, gray with coal pebbles and some water	3	64
	Clay, sandy, light-gray	12	76
	Sand, silty, with some water	4	80
	Clay, sandy, with little water	10	90
	Sand, gravelly, coarse	1	91
	Clay, gravelly	1	92
Fort Union(?) Formation:			
	Clay or shale, sandy, light-gray, caving	31	123
	Lignite	1	124
	Shale, gray	2	126

157-95-27dda
Test hole 766

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray	33	33
	Till: sandy, weathered, yellowish-gray. Samples from here down appear to be sandier than those of the overlying till	26	59
Fort Union Formation:			
	Clay, sandy, light-gray	19	78
	Clay, grayish-black. Lignite	2	80

TABLE 6.--Logs of wells and test holes -- Continued

157-95-27ddc
City of Tioga No. 6
Log furnished by C. A. Simpson & Son, Bisbee, N. Dak.

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Topsoil	1	1
	Gravel, coarse	1	2
	Clay, yellow	15	17
	Clay, sandy, yellow	39	56
	Clay, gray, with coal particles	40	96
	Gravel, sandy	2	98
	Clay, blue	2	100

157-95-28bbb
Test hole 739

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray	18	18
	Till: medium-gray	54	72
Fort Union Formation:			
	Sand, silty, very fine	11	83
	Clay, sandy, medium-gray	7	90

157-95-30aaa
Test hole 740

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Clay (lake deposits), yellowish-gray	18	18
	Sand	1	19
	Till: light-gray	29	48
	Sand	3	51
	Till: weathered, grayish-brown	21	72
	Sand, very fine to fine, gray, probably becomes coarser toward the bottom	30	102
	Sand, coarse to very coarse, brown	6	108
Fort Union Formation:			
	Clay, gray	12	120

TABLE 6.--Logs of wells and test holes -- Continued

157-95-35ad
LeRoy Nelson water well No. 1
Log furnished by Amerada Petroleum Corp.

Formation	Material	Thickness (feet)	Depth (feet)
	Clay and sand	10	10
	Sand	80	90
	Sand and coal	47	137
	Coal	15	152
	Coal and sand	32	184
	Sand and clay	30	214
	Sand and gravel	77	291
	Shale, hard	1	292
	Sand and gravel	18	310
	Coal streaks	20	330
	Gravel	38	368
	Shale, gravel	32	400
	Clay, sand, and gravel	15	415
	Sand and coal streaks	170	585

157-95-35bbb
Test hole 731

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray	37	37
Fort Union Formation:			
	Clay, sandy, yellowish-gray	20	57
	Clay, light-gray	3	60

157-96-26aaa
Test hole 742

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Clay, yellowish-gray	7	7
	Sand, coarse	5	12
	Till: yellowish-gray	4	16
	Till: medium-gray	81	97
Fort Union Formation:			
	Clay, light-gray	3	100

TABLE 6.--Logs of wells and test holes -- Continued

158-95-34aaa
Test hole 729

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	56	56
Fort Union Formation:			
	Clay, sandy, yellowish-gray..........	24	80

158-95-35ccc
Test hole 728

Formation	Material	Thickness (feet)	Depth (feet)
Glacial drift:			
	Till: weathered, yellowish-gray.....	34	34
	Till: medium-gray..................	6	40
	Till: weathered, contains considerable rock alteration fragments. Highly calcareous.........................	30	70
	Till: hard, light-gray.............	39	109
Fort Union Formation:			
	Clay, sandy, light-gray.............	2	111
	Lignite.............................	3	114
	Clay, carbonaceous, dark-gray........	6	120

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