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GEOLOGY AND GROUND WATER RESOURCES OF THE RICHARDTON AREA STARK COUNTY, NORTH DAKOTA

BY
J. E. POWELL
AND
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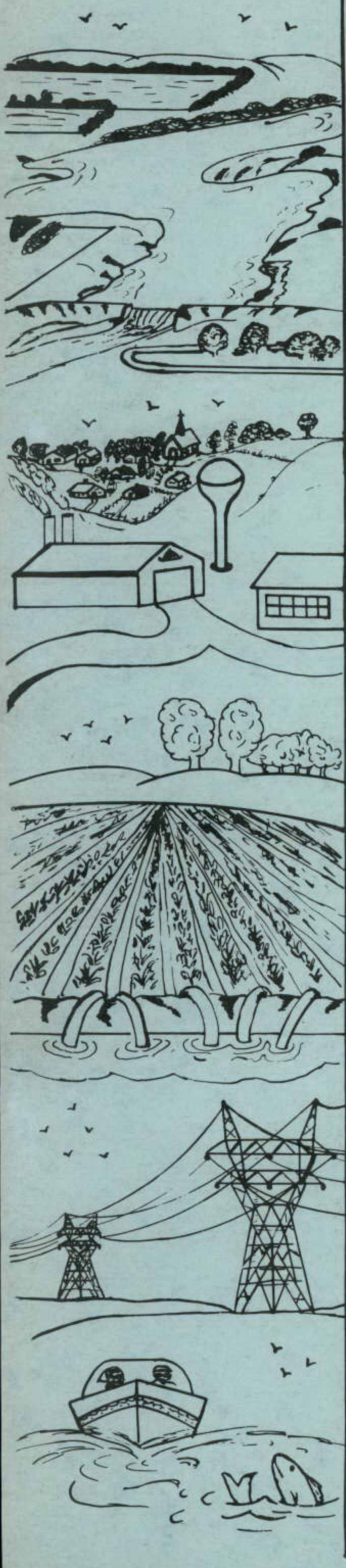
GEOLOGICAL SURVEY
UNITED STATES DEPARTMENT OF THE INTERIOR



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NO. 29

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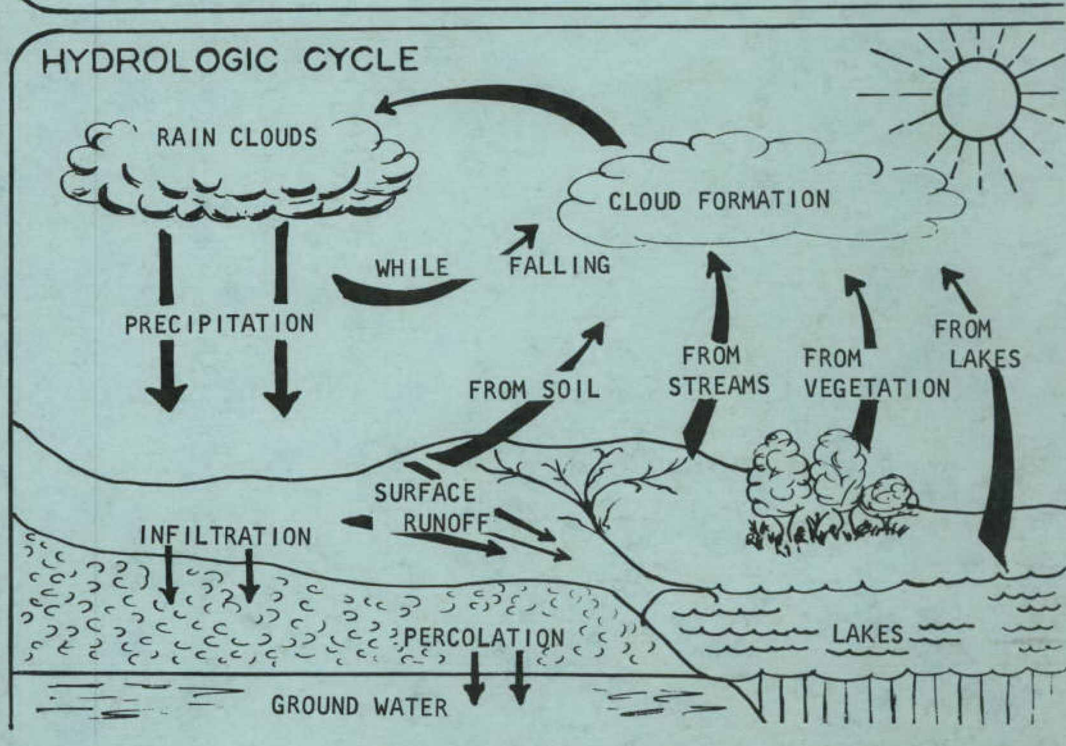

NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

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- LANDS UNDER IRRIGATION
- AREAS CONSIDERED IRRIGABLE
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GEOLOGY AND GROUND-WATER RESOURCES OF THE RICHARDTON AREA
STARK COUNTY, NORTH DAKOTA

J. E. Powell
and
Q. F. Paulson

ABSTRACT

The area described in this report is in Stark County in southwestern North Dakota and includes 144 square miles in the vicinity of the city of Richardton.

The geologic units that underlie the area are as follows, from land surface down: Widely scattered patches of thin Pleistocene deposits which consist of glacial till and scattered boulders; shale, clay, lignite, and sand and gravel of Tertiary age; and shale, sand, lignite, and sandstone of Cretaceous age.

The surface rock in the entire area, with the exception of the thin Pleistocene deposits in the extreme north, is the Tongue River member of the Fort Union formation of Paleocene age. The member is approximately 500 feet thick and, with the possible exception of the aquifer tapped by the new well drilled by the city of Richardton in 1959, is the source of all ground water used in the area.

The water from wells that penetrate aquifers in the Tongue River member varies considerably in hardness and in degree of mineralization. In the 2-square-mile area in the vicinity of Richardton, in which water samples were collected, hardness ranged from 445 to 3,050 ppm (parts per million) and concentrations of dissolved solids ranged from 635 to 5,720 ppm.

Results of test drilling indicate that the Cannonball member of the Fort Union formation probably underlies the Tongue River member. In other parts of western North Dakota the Cannonball member is a source of ground water, and it is considered to be a potential aquifer in the Richardton area.

Rocks of the Fort Union formation are underlain by the Hell Creek formation and the Fox Hills sandstone of Late Cretaceous age. These in turn are underlain by a thick sequence of Cretaceous rocks which includes the Pierre shale, the Niobrara formation, and the Greenhorn limestone. The Dakota sandstone underlies the Greenhorn limestone and is the base of the Cretaceous system in the report area.

Only the Fox Hills sandstone and Dakota sandstone of the above-mentioned Cretaceous formations are considered to be potential sources of ground water in the report area. The Dakota sandstone, however, occurs much below the economic drilling depth for water wells. The Fox Hills sandstone, although it occurs approximately 3,000 feet above the Dakota sandstone, probably is also too deep (1,400 to 1,500 feet below the land surface) for practical water-well development under current economic conditions.

INTRODUCTION

Location and General Features of the Area

Richardton, population 792 (1960 census), is in the northeastern part of Stark County. The area covered by this report is approximately 144 square miles and includes Tps. 139 and 140 N., Rs. 92 and 93 W. Taylor, population 215 (1960 census), also is in the area and is about 5 miles west of Richardton. Both cities are served from the east and west by the Northern Pacific Railroad and by U.S. Highway 10. Richardton is served from the north and south by State Highway 8.

The average annual precipitation recorded by the U.S. Weather Bureau station at the Richardton Abbey from 1891 to 1959 was 17.16 inches. Most of the precipitation occurs during the growing season. The mean annual temperature for the same period was 42.4°F.

The principal occupation in the area is farming and the main crops are wheat, flax and hay. Cattle and sheep grazing are extensive, especially north of the drainage divide upon which the city of Richardton is situated; this part of the area is characterized by rugged topographic features and is less suited to cultivation than is the area south of the drainage divide.

Purpose and Scope of the Investigation

A study of the geology and ground-water resources of Stark County, North Dakota, is being made by the U.S. Geological Survey in cooperation with the North Dakota State Water Conservation Commission and the North Dakota Geological Survey as part of a series of investigations in the State. The purpose of these studies is to determine the occurrence, movement, discharge, and recharge of the ground water, and the quality and availability of ground water for municipal, domestic, irrigation, and industrial use. The most critical current need is for adequate and perennial water supplies for many towns and small cities throughout the State. For this reason, countywide studies are begun in the vicinities of towns that request the help of the State Water Conservation Commission and the State Geologist to locate suitable ground-water supplies. Reports such as this one, are prepared before the completion of the general studies so that current data may be available for use in connection with immediate problems.

The fieldwork for this report was done during 1951-52 and consisted of a study of the surface geology of the area, an inventory of the wells in the area, test drilling, the collection and chemical analysis of water samples, and a study of the available data.

Previous Investigations and Acknowledgments

A general study of the geology and ground-water resources of Stark County was made by Simpson (1929, p. 225-228). In his report he included the record and chemical analysis of water from a well in the Richardton area. Abbott and Voedisch (1938, p. 78-79) made an investigation of the municipal water supplies of North Dakota, and their report includes analyses of water and physical descriptions of two wells in the Richardton area.

The cooperation of the residents of the Richardton area was of great help in the present investigation. Valuable assistance was given by members of the city council, one of whom, Mr. John W. Schulz, contributed considerable time and effort, which greatly facilitated the fieldwork.

Physiographic Features

The Richardton area is a part of the Missouri Plateau section of the Great Plains physiographic province (Fenneman, 1938, p. 599). In general, the altitude of the Missouri Plateau is 500 to 600 feet greater than that of the drift prairie to the east. Numerous buttes and mesas stand above the irregular surface of the plateau as erosional remnants of extensive beds of sandstone and shale that formerly existed in the area.

Evidence of glaciation is found only at scattered locations in the northern half of the area. A thin layer of weathered till overlies the Fort Union formation about 4 miles north of Taylor and a few glacial boulders were discovered near the northern limit of the area. The present topography in the Richardton area is largely the result of wind and water erosion and it is unlikely that ice action played more than a minor role.

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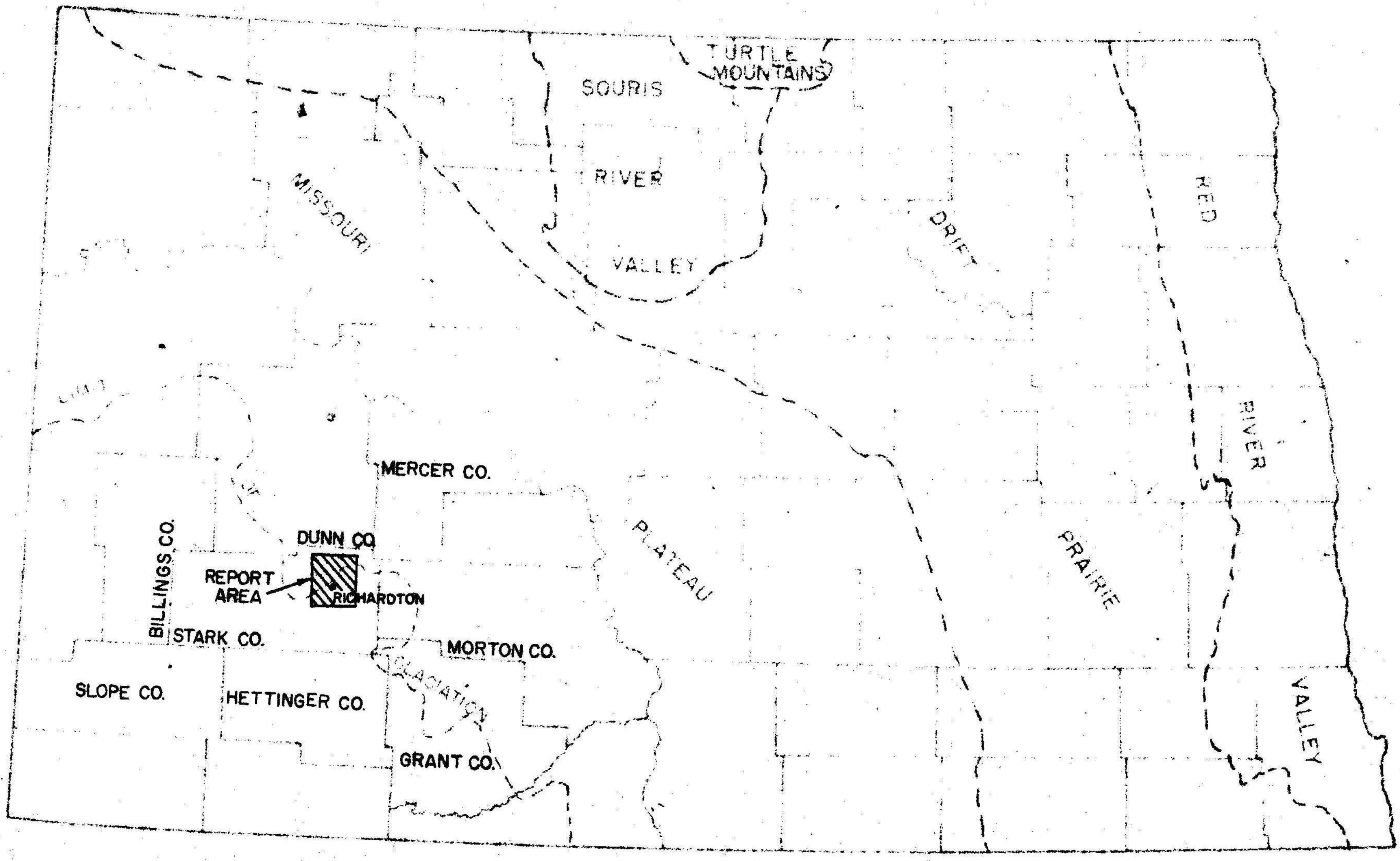
NORTH DAKOTA GROUND WATER
STUDIES NO. 29
FIGURE 1



PHYSIOGRAPHIC PROVINCES IN NORTH DAKOTA AND LOCATION OF THE RICHARDTON AREA

(MODIFIED FROM SIMPSON, 1929)

The southern half of the area is an erosional plain that slopes gently south-southeastward toward the Heart River. The divide between the Heart and Knife River drainage basins roughly bisects the area in an east-west direction. Both streams are tributary to the Missouri River. (See fig. 1.) North of the drainage divide, the

---

Figure 1. Physiographic provinces in North Dakota and location of the Richardton area (modified from Simpson, 1929)

---

erosional plain ends abruptly where it is broken by an irregular northward-facing escarpment which has been considerably dissected by erosion. Numerous water-bearing beds of sand and lignite crop out in the escarpment. The water that seeps from these beds collects in springs which contribute water to intermittent streams tributary to the Knife River.

The area north of the escarpment is a cup-shaped basin dissected by numerous small valleys. A modified type of badland topography prevails over the eastern part of the basin where shale, sandstone, and lignite of the Fort Union formation are exposed on the sides of small cone-shaped buttes.

The highest altitude, 2,715 feet, is the summit of Young Mans Butte in the eastern part of the area; the lowest altitude, less than 2,100 feet, are in the creek bottoms in the extreme northern part of the area. The total relief therefore exceeds 600 feet.

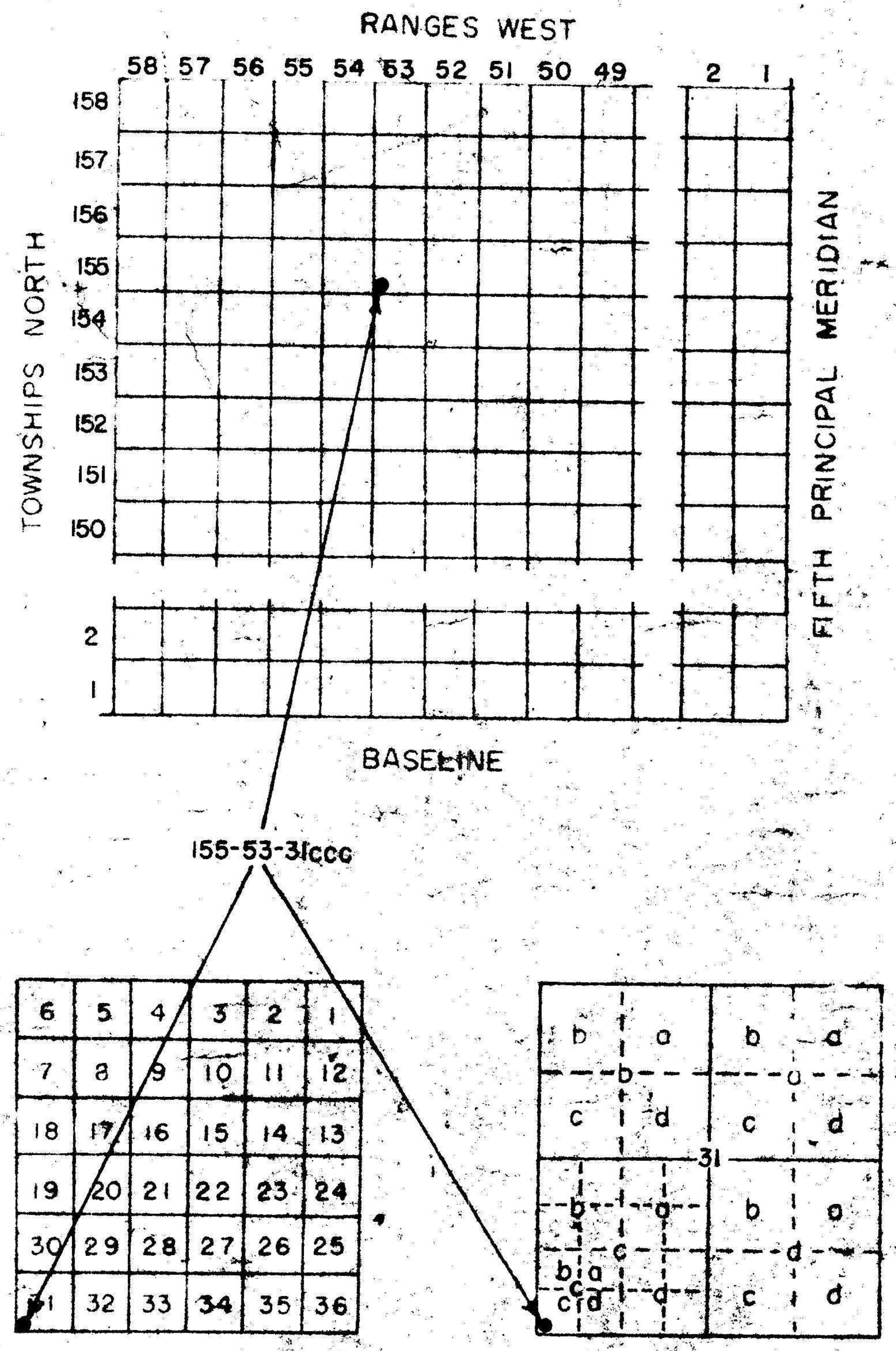


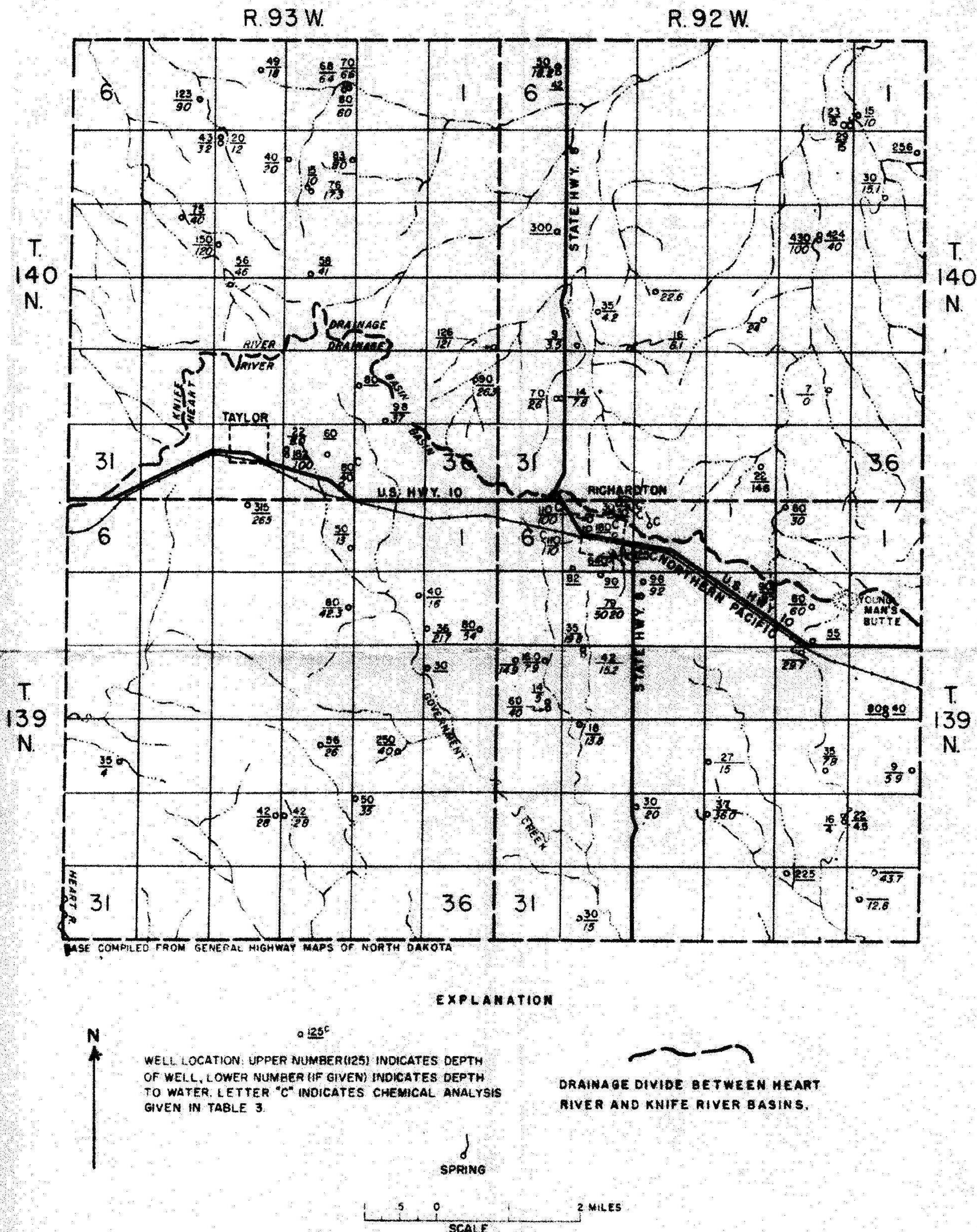
Figure 2 --Sketch illustrating well-numbering system.

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 within the public

Figure 2. Sketch illustrating well-numbering system.

land classification of the U. S. Bureau of Land Management. The first numeral denotes the Township north of the base line, the second numeral the range west of the fifth principal meridian, and the third 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 tracts). Consecutive terminal numerals are added if more than one well is recorded within a 10-acre tract. Thus, well 139-93-22acb is in the NW¼SW¼NE¼ sec. 22, T. 139 N., R. 93 W. Similarly, well 140-92-12cdd is in the SE¼SE¼SW¼ sec. 12, T. 140 N., R 92 W.



GURE 3 — MAP OF RICHARDTON AREA SHOWING PHYSIOGRAPHIC FEATURES AND LOCATIONS OF WELLS AND SPRINGS.

(SEE DETAIL FOR SEC. 5, T. 135 N., R. 92 W. IN FIGURE 3)

Water Supply

The water supply for the city of Richardton is obtained from a 30-foot-deep dug well at the bottom of which are three radiating shafts having an aggregate length of about 200 feet. The shafts penetrate laterally into the aquifer, which is a lignite bed in the Fort Union formation. This collection system, together with a similar one recently acquired by the city from the Northern Pacific Railroad, provides approximately 122,000 gpd (gallons per day). During periods of peak demand, it is estimated that 150,000 gpd is needed. In 1959, a new well was drilled by the city to a depth of 640 feet. The well is reported to produce 50 gpm (gallons per minute) or about 72,000 gpd of soft, turbid water.

Elsewhere in the area, individual water supplies are obtained largely from drilled wells. (See fig. 3) However, along the edge

Figure 3. Map of the Richardton area showing physiographic features and locations of wells and springs.

of the escarpment north of the drainage divide some springs have been developed for domestic and farm use.

GEOLOGY AND OCCURRENCE OF GROUND WATER

Principles of Occurrence of Ground Water

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

Ground water is discharged by evaporation from lakes and ponds into which the water seeps, by transpiration by plants, by evaporation from the land surface in areas where the water table is near the surface, by seepage into streams, by pumping from wells, and by discharge from 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 rock such as sandstone and limestone; however, consolidated rocks in some areas are highly porous.

The ability of an aquifer to yield water by gravity drainage 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 saturated water-bearing material is called the "specific yield" of the material.

If the water in an aquifer is not confined by overlying imperious strata, the water is 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 between overlying and underlying relatively impermeable strata. Under these conditions, hydrostatic pressure will raise the water in a well, or other conduit that penetrates the aquifer, above the top of the aquifer. When water is yielded from the well, the aquifer remains saturated and water is yielded because the water expands and the aquifer is compressed as the pressure is decreased. Gravity drainage does not occur under artesian conditions. The water-yielding ability 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 such material is said to be permeable. However, the resistance to the movement of water through small pore spaces, as in clay or shale, may be very great and such material 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 permeability of the aquifer multiplied by its thickness, in feet.

The suitability of an aquifer as the source of a water supply is governed by its permeability, its volume, and its capacity to store and ability to release water. Recharge to the aquifer also must be adequate if the water-supply development 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 that are surrounded by relatively impermeable material can be depleted 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 any substantial ground-water development is made, sufficient test drilling, aquifer tests, and related studies should be undertaken to determine the capabilities and recharge conditions of the aquifer being considered.

An attempt was made to make an aquifer test and thereby determine the water-bearing characteristics (coefficients of transmissibility and storage) of the aquifer penetrated by test hole 321. However, because of equipment failure, the attempt was abandoned.

General Stratigraphic Relations

Stratigraphic information was obtained from a study of samples from 3 test holes drilled in the Richardton area, from field study of bedrock exposures in the area, from examination of logs of oil-test borings in nearby areas, and from published information. Locations of test holes drilled in the area are shown on figure 4.

Figure 4. Map of Richardton vicinity
showing locations of test holes

The test holes were drilled with a hydraulic-rotary drilling machine owned by the North Dakota State Water Conservation Commission. The depths of test holes ranged from 130 feet to 854 feet. Samples were taken of each 5-foot interval. Information regarding older Cretaceous formations were obtained from a study of the logs of two deep oil-test borings made in nearby areas. They were the Northwest Oil Drilling Co., Walter Hamann No. 1 (149-91-8dac), approximately 4 miles north of the northern limit of the Richardton area, which was logged only from the top of the Pierre shale, and the F. F. Kelly-Plymouth Oil Co. Fritz Lentz No. 1 (142-89-28aba), approximately 15 miles northeast of the northeast corner of the Richardton area, which was logged only from the top of the Fox Hills sandstone.

Table 1 shows a stratigraphic section of the area based largely upon the Quaternary and Tertiary rocks exposed on the slopes of Young Mans Butte.

Table 1. General Quaternary and Tertiary stratigraphy in the Richardton area

System	Series	Formation	Description	Thickness (feet)
Quaternary	Recent	Alluvium	Thin alluvium along the larger creek bottoms	0-1/2
	Pleistocene	Pre-Wisconsin (?) glacial deposits	Glacial erratics and thin patches of stony, much weathered till in northern part of area.	0-10
Tertiary	Oligocene	White River	White limestone, forming cap rock on Young Mans Butte; light - colored calcareous clay, sand-stone and conglomerate; continental Not Water bearing.	80
	Eocene	Golden Valley	Probably present in Young Mans Butte but not exposed; continental deposits; not water bearing. Generally consists of two members Upper member - light-buff, un-consolidated, micaceous sand; light-gray sandy shale, few thin beds of lignite. Lower member - white to purplish-gray clay and shale, commonly stained bright orange on surface forming prominent marker bed.	100±
	Paleocene	Fort Union	Tongue River member - Buff and light-gray sandy clay and shale; few sand beds of lignite which are a source of water to many wells and several springs; con-tinental deposits. Top of Tongue River member occurs about 50 to 100 feet higher than the elevation at Richardton.	500-550
			Ludlow member - Usually consists of dark-colored shale, sandstone and thin lignite beds, non-marine. Possibly underlies Richardton at depths greater than 500 feet but cannot be distinguished from Cannonball member on basis of drill cuttings. Cannonball member-Uniformly gray to dark-gray sand, clay, and shale; sand beds are relatively thick, with fine sand, and constitute important aquifers in the Richardton area; marine deposits	325±

Following is a section showing the Cretaceous stratigraphy in the Richardton area.

Cretaceous system
- Upper Cretaceous series
  - Hell Creek formation
  - Fox Hills sandstone
  - Pierre shale
  - Niobrara formation
  - Greenhorn limestone
  - Dakota sandstone

Deposits of the Pleistocene Epoch

Thin patches of glacial till and scattered boulders constitute the Pleistocene deposits in the Richardton area. These glacial features are confined largely to the northernmost part of the area and are too thin and discontinuous to be a potential source of ground water.

Bedrock

White River formation.--The youngest Tertiary rocks in the area are those of the White River formation of Oligocene age. The only occurrence of this formation in the report area is on Young Mans Butte, where it forms the caprock. The formation in this exposure is approximately 80 feet thick and consists of white siliceous limestone underlain by beds of light-colored calcareous shale, sandstone, volcanic ash, and conglomerate. None of the beds except the limestone are well exposed. The formation is continental in origin and at this location is not an aquifer.

Golden Valley formation.--The Golden Valley formation of Eocene age is divided into an upper and lower member, both of which are exposed on the slopes of an unnamed butte (140-91-2) about 8 miles northeast of Young Mans Butte. At this location, the upper unit consists of about 66 feet of fine micaceous loosely consolidated buff sand, and the lower unit consists of about 34 feet of purple-gray shale and white kaolinitic clay. At the outcrops, the kaolinitic clay of the lower unit is oxidized to a bright orange, which makes it useful as a marker bed.

The only known outcrop of the Golden Valley formation in the Richardton area is a small patch of gray shale of the lower unit exposed on the drainage divide 1 mile west of Taylor. White clay and purple-gray shale of the lower unit crops out below the White River formation on the slopes of Antelope Butte just east of the report area. A test hole drilled in connection with an investigation by the North Dakota Geological Survey penetrated clay and shale of the lower unit of the Golden Valley formation beneath the White River formation at Young Mans Butte (Hansen, 1953, p. 13,29).

The upper unit of the Golden Valley formation is not an aquifer because of its limited extent and high topographic position. The lower unit, chiefly clay and shale, also is of limited extent and is not sufficiently permeable to be an aquifer.

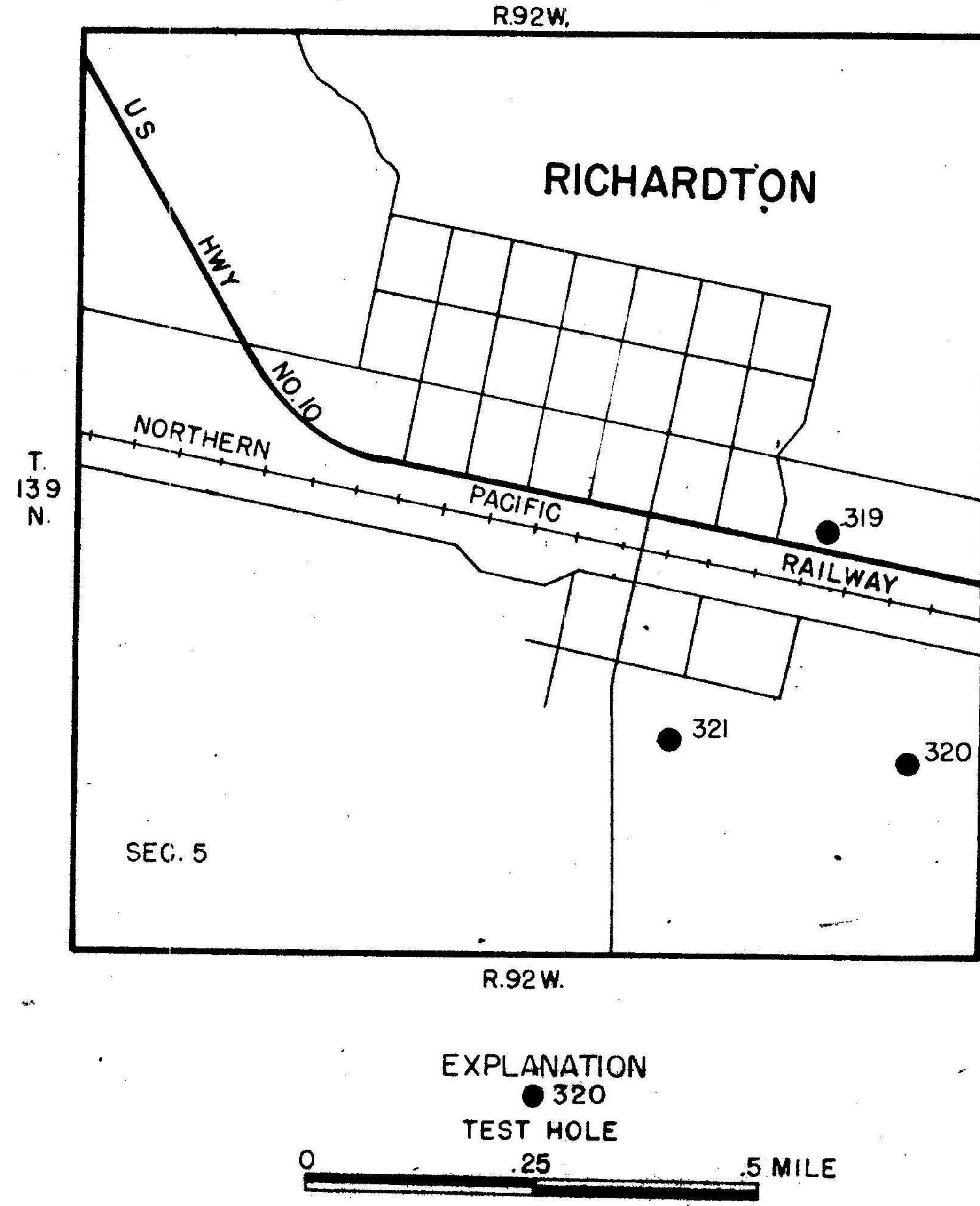


FIGURE 4--MAP OF RICHARDTON VICINITY SHOWING LOCATIONS OF TEST HOLES.

Fort Union formation.--Three test holes (table 4) were drilled near the city of Richardton to investigate the water-bearing characteristics of the Fort Union formation of Paleocene age. Locations of test holes are shown on figure 4 and their logs are shown on pages 35-38.

The Sentinel Butte member, which is the top of the Fort Union formation in southwestern North Dakota, probably is not present in the Richardton area. However, the lower part of the member is reported to underlie the city of Dickinson 20 miles to the west, where it is tapped by wells and is a source of municipal water supply (McLaughlin and Greenlee, 1946, p. 14).

The Tongue River member of the Fort Union formation of Paleocene age is the uppermost bedrock unit in the Richardton area. There are numerous exposures of this member in the stream-dissected area north of the drainage divide. The exposed beds consist of light - to dark-gray clay and shale, fine to coarse gray or buff sand, and lignite which locally contains silicified logs and stumps. The shale and clay constitute 65 to 70 percent of the materials in the member and may be plastic when they occur immediately above or below water-bearing lignite beds. Locally the constituent particles of the shale and clay may be cemented with $CaCO_3$ (calcium carbonate) or FeO (ferrous oxide).

The Tongue River member is not completely exposed in the report area. However, the member immediately underlies the soil zone and was completely penetrated at a depth of 550 feet at test hole 319 (139-92-5daba), and a depth of 528 feet at test hole 321 (139-92-5dca). Most of the wells listed in table 3 obtain small supplies of water from sand and lignite in the Tongue River member.

The basal, or Ludlow, member of the Fort Union formation may underlie the Richardton area at depths greater than about 500 feet below the land surface. However, the Ludlow, which is continental in origin, interfingers with the Cannonball member, which is marine, and it is difficult to distinguish between the two solely on the basis of drill cuttings.

Either the Cannonball member of the continental Ludlow member was probably penetrated at a depth of 550 feet in test hole 319 and at a depth of 528 feet in test hole 321. A very resistant rock stratum that ranges from 1 to 3 feet was penetrated at these depths; the rocks below the resistant stratum are distinguishable from those of the Tongue River member on the basis of lithology and color. The drill cuttings of the Tongue River member consist primarily of light- to medium-gray sandy clay and lignite; the cuttings of rocks below the resistant stratum are gray to dark gray and contain a much higher proportion of sand. Another significant difference is that the lignite beds are thinner and less numerous below the resistant stratum than above. Although positive identification was not possible, the character of the rocks that underlie the Tongue River member indicates that they are of marine rather than continental origin. These rocks, therefore, are probably the Cannonball member of the Fort Union formation. The Cannonball member is a source of ground water in other parts of western North Dakota (Abbott and Voedisch, 1938, p. 33) and is considered to be a potential aquifer in the Richardton area.

In March 1959, a new municipal well was completed at Richardton at a depth of 640 feet. The 8-inch well is reported to produce 50 gpm of soft turbid water. The aquifer penetrated by the well is not positively identified but is probably the Cannonball member of the Fort Union formation.

Hell Creek formation.--The Hell Creek formation of Cretaceous age probably underlies the Fort Union formation in the Richardton area. The closest known outcrop of the Hell Creek is about 70 miles southeast of Richardton, where it is well exposed along the bluffs that border the flood plain of the Missouri River. At this location it consists predominantly of calcareous gray sand and brown to black lignitic shale. Brown limonitic concretionary zones are common throughout the formation. The sand is medium to fine, is commonly crossbedded, and generally contains considerable amounts of clay. Generally, two types of shale are present -- lignitic and bentonitic. The lignitic shale is brown and thin bedded and commonly contains plant fragments at the bedding surfaces. The bentonitic shale is lighter in color more resistant to erosion, and, as a consequence, more massive than the lignitic shale. The beds of bentonitic shale commonly exceed 10 feet in thickness (Laird and Mitchell, 1942, p. 9-11). Thin lignite beds occur locally throughout the formation and are common near its base.

The Hell Creek formation, because of its high clay content, lenticular bedding, and sharp gradations in texture, is not generally considered to be a productive aquifer in North Dakota and probably is not an important aquifer in the report area.

Fox Hills sandstone.--Stratigraphic information available from logs of oil-test wells indicates that the Fox Hills sandstone underlies the Hell Creek formation in the Richardton area. The nearest known outcrop of this sandstone is in a stream cut in the valley of Little Beaver Creek (132-106-7) about 88 miles southwest of Richardton. The following description of the outcrop was given by Leonard (1908, p. 43-44):

	(feet)
Sandstone, light-greenish-gray, massive.........	50
Sandstone, ledge, yellow........................	10
Clay, sandy, finely laminated...................	25

In general, the Fox Hills is a brown to light-gray weakly cemented fine-grained sandstone containing numerous limonitic concretions.

In southwestern North Dakota the Fox Hills is an important aquifer. It is the source of municipal water supply for the cities of Marmarth, Bowman, and Hettinger. It is questionable, however, if this formation lies within economical drilling depths in the Richardton area. The log of the F.F. Kelly-Plymouth Oil Co. Fritz Lentz No. 1 (hereafter referred to as the Fritz Lentz No. 1) lists the top of the Fox Hills sandstone as 1,460 feet below the land surface, or 824 feet above sea level. The altitude of the land surface at the Northern Pacific Railroad station in Richardton is 2,470 feet above sea level. Inasmuch as the regional dip of the Fox Hills sandstone is not known, it would be difficult to predict the depth accurately in the report area. However, a rough approximation based upon the above altitudes indicates that the sandstone would be penetrated within the depth range of 1,500 to 1,700 feet below the land surface in the vicinity of Richardton.

No information is available in regard to the quality or the quantity of water available from the Fox Hills sandstone in the report area. However, the city of Hettinger, approximately 63 miles south-southeast of Richardton, obtains an ample supply (about 100 gpm) of potable water from this source. At Hettinger the Fox Hills sandstone is about 900 feet below the land surface; water in the sandstone is under sufficient artesian head to cause it to rise to within 320 feet of the land surface (Robinove, 1956, p. 10).

Older Cretaceous rocks.--A thick sequence of Cretaceous rocks underlies the Fox Hills sandstone in the report area. According to the log of the Fritz Lentz No. 1, the Pierre shale underlies the Fox Hills sandstone at a depth of 1,960 feet below the land surface. Underlying the Pierre shale are the Niobrara formation, 3,390 feet below the land surface, and the Greenhorn limestone 3,940 feet below the land surface. The total thickness of Cretaceous rocks at the site of this test well is 2,740 feet. The Cretaceous rocks are largely shale and are not sufficiently permeable to yield significant amounts of water to wells; they are not considered to be a source of ground water in the report area.

The Dakota sandstone, which represents the base of the Cretaceous system in the Richardton area, yields large amounts of highly mineralized water to wells in other parts of the State, notably the southeastern and south-central parts. However, it is too deep (4,740 feet at the Fritz Lentz No. 1. well) to be a practical source of ground-water supply in the report area.

Recharge, Movement, and Discharge of Ground Water

Aquifers above the Pierre shale in the Richardton area probably are recharged in part by downward percolation of water that falls upon or passes over the land surface. However, a large part of the water in the aquifers probably has percolated laterally into the area, inasmuch as the clayey surficial deposits are not conducive to downward percolation of water.

The regional movement of ground water appears to be southeastward in the area south of the drainage divide and northeastward in the area north of the divide. The local direction of movement is controlled by streams, small valleys, and depressions, which are areas of ground-water discharge, and by local differences in the transmissibility of the aquifers.

QUALITY OF THE GROUND WATER

Ground water dissolves a part of the soluble mineral constituents of the rock particles as it moves into and through an aquifer. The amount of mineral matter dissolved depends principally on the amount of soluble materials in the aquifer and the length of time the water is in contact with them. Therefore, in any aquifer, water that has been stored underground a long time or 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.

Chemical-quality data available for the Richardton area consist of analyses of water from 1 spring and from 6 wells 30 to 180 feet deep. The Tongue River member of the Fort Union formation is the source of water for all the samples. The analyses (table 2) indicate that the waters differ in degree of mineralization and in chemical type; concentrations of dissolved solids ranged from 635 to 5,720 ppm (parts per million), and the 8 analyses represent water of 3 different types--magnesium calcium sulfate, sodium sulfate, and sodium bicarbonate. Chemical analyses of the water from the Cannonball member of the Fort Union formation or from older formations in the Richardton area are not available. However, results of investigations in other parts of the State indicate that water from the Cannonball member is likely to have high concentrations of sodium and chloride (Akin, 1951, p.30-31).

No information is available on the quality of the water from the Fox Hills sandstone or the Dakota sandstone in the Richardton area.

The U.S. Public Health Service (1946) has established standards for drinking water used on common carriers in interstate traffic. These standards have been adopted by the American Water Works Association and are useful to evaluate public and domestic supplies. Listed below are the recommended maximum limits for some of the mineral constituents commonly present in drinking water.

Constituent	Recommended maximum limit (ppm)
Iron (Fe plus manganese (Mn)	0.3
Magnesium (Mg)	125
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.5 a/
Dissolved solids	500 b/

a/ Mandatory limit.

b/ Dissolved-solids concentrations of 1,000 ppm are permitted if water of better quality is not available.

The chemical analyses of ground water in the Richardton area given in table 2 show that the recommended concentration limits of some chemical constituents are exceeded in water from most of the wells sampled. However, water that contains certain chemical constituents in excess of the recommended concentrations, has been used in some areas, including North Dakota, for many years without noticeable ill effects.

High concentrations of nitrate in ground water may be caused by decaying organic matter in the well, in the aquifer, or on the ground surface in the vicinity of the well. It may be caused also by such inorganic material as mineral fertilizers. Water that contains more than about 44 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).

Consumption of water that contains fluoride in concentrations of about 1 ppm by children during the period of calcification of teeth lessens the incidence of tooth decay. However, consumption by children of water that has concentrations higher than about 1.5 ppm may cause mottling of tooth enamel (Dean, 1936, p. 1269-1272).

Nearly all ground water contains minerals that cause hardness. Hardness of water is caused principally by calcium and magnesium and to a lesser extent by iron, aluminum, manganese, copper, strontium, barium, zinc, and free acid. Hard water is generally undesireable, especially if the water is used for cleansing, because it increases soap consumption and forms soap scum. Water that has a hardness of about 100 ppm generally is considered to be moderately hard; water that has a hardness of 200 ppm or more is considered to be very hard and requires softening to be satisfactory for most uses.

According to residents and well drillers, water of good quality for domestic use is difficult to find in the report area. Data in table 2 seem to substantiate these reports and indicate that in some places the water is highly mineralized and very hard (hardness ranged from 320 to 3,050 ppm, and concentrations of dissolved solids were as high as 5,720 ppm). Concentrations of iron were much in excess of the U. S. Public Health Service recommended limit in most of the samples, and concentrations of nitrate were in excess of the suggested limit of 44 ppm in 3 out of the 5 samples analyzed for nitrate.

The concentrations of sulfate were higher than the recommended limit in all but 1 of the 8 samples, and the concentrations of magnesium were higher than the recommended limit in 3 of the 8 samples. Consequently, some of the water may have the cathartic effect of Epsom salts on people who drink it.

Water used for irrigation should be of such quality that continued use of the water will not adversely affect the productivity of the land. The suitability of water for irrigation can be evaluated from the dissolved-solids content and the precent sodium, which is the ratio, expressed as a percentage, of sodium to the sum of calcium, magnesium, sodium, and potassium--all ions being expressed in equivalents per million. Unless good drainage is provided, use of water that has a high dissolved-solids content may cause an accumulation of salts in the root zone and may thereby cause the soil to become unproductive. According to the U.S. Salinity Laboratory Staff (1954, p. 70), "Nearly all irrigation waters that have been used successfully for a considerable time have conductivity values of less than 2,250 micromhos per centimeter (which is equivalent to a dissolved-solids concentration of about 1,500 ppm or less)." Although water that has a higher dissolved-solids concentration is used in some places with apparent success, the crops grown are salt tolerant, good drainage is provided, or special measures for salinity control are practiced. Use of water that has a percent sodium of more than 50 may cause the soil to become relatively impermeable to the moisture and to the air needed by plants for healthy growth. The higher the percent sodium, the greater the chances of damage to the soil.

Data in table 2 indicate that some of the water is sufficiently low in dissolved-solids concentration that its use probably would not cause an accumulation of salts in the soil if drainage were reasonably good. Also, the data indicate that some of the water has a sufficiently low percent sodium that its use probably would not cause damage to the soil texture. The surface deposits in the Richardton area are mainly silt and clay and subsurface drainage is slow; consequently, caution should be used in developing ground water for irrigation supplies. Not only should the chemical quality of the water to be used be determined, but other factors such as drainage, porosity of the soil, and salt tolerance of the crops to be grown should be carefully studied.

SUMMARY OF GROUND-WATER CONDITIONS

Aquifers in the Tongue River member of the Fort Union formation supply most of the ground water used in the Richardton area. These aquifers, which are made up of sand and (or) lignite, generally are of small areal extent and yield only small to moderate amounts of water to individual wells. However, supplies are usually adequate for farm or domestic use. The 77 wells in the area that obtain their supplies from aquifers in the Tongue River member range from 7 to 430 feet in depth and average 74 feet.

Eight chemical analyses were made from water samples from wells and a spring that penetrate aquifers in the Tongue River member; results of analyses indicate that the water is rather highly mineralized and very hard. U.S. Public Health Service recommend limits for certain mineral constituents were exceeded in water from all wells sampled.

Information from logs of oil-test holes and general information from other areas is available concerning the occurrence and water-bearing characteristics of rocks below the Tongue River member. With the exception of the new municipal well (139-92-5db) drilled at Richardton in 1959, which may produce from the Cannonball member, no water wells in the Richardton area are known to be deep enough to tap aquifers in formations older than the Tongue River member.

The Cannonball member of the Fort Union formation, which probably underlies the Tongue River member in the report area, is a source of ground water in other parts of the State and is a potential aquifer in the report area. The member may have been penetrated in test hole 319 at a depth of 550 feet and in test hole 321 at a depth of 528 feet.

The Fox Hills sandstone is a source of potable water in southwestern North Dakota and is a potential aquifer in the Richardton area. However, it is estimated to lie 1,500 to 1,700 feet below the land surface at Richardton and may be too deep to be a practical source of supply. Aquifers in rocks older than the Fox Hills sandstone are beyond economical drilling depths for water wells under present conditions.

TABLE 2.--CHEMICAL

Results in parts per million except as indicated

Location No.	Owner or name	Depth of well (feet)	Date of collection	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
139-92-4bca 1/	Northern Pacific Railroad	Spring	11-24-50	2.3	57	74
139-92-5aab 1/	City of Richardton (untreated supply_	30	12- 4-50	2.0	102	75
Do	City of Richardton (treated supply)	30	11-24-50	.25	64	75
139-92-5acd 1/	Paul Aman	180	11-24-50	2.1	465	460
139-92-5dac 1/	John Herman	125	1-19-51	.35	297	252
139-92-5 2/	L. Braulick	110	....	1.1	63	37
139-92-5 2/	A. F. Mischel	110	....	2.2	64	51
140-93-34d 3/	H. R. Hutchinson	80	6-24-21	.80	429	415

1/ North Dakota State Department of Health, Bismarck, N. Dak.

2/ Abbott, G. A., and Voedisch, F. W., 1938 The municipal ground-water supplies of North Dakota: North Dakota Geol. Survey Bull. 11, p.79

3/ Simpson, H. E. 1929, Geology and ground-water resources of North Dakota: U.S. Geol. Survey Water-Supply Paper 598, p.300.

ANALYSES OF GROUND WATER

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	Dissolved solids	Percent sodium
82	..	275	376	6.0	..	...	445	711	28
136	..	340	420	6.4	.1	...	562	856	34
151	..	339	391	4.0	..	...	468	804	41
840	..	1,140	3,130	230	..	434	3,050	5,720	37
1,250	..	1,070	2,740	250	..	520	1,790	5,460	60
150	..	460	240	10	..	12	320	635	51
230	..	450	440	11	..	53	380	973	57
	424	593	2,990	8.0	..	2.8	2,780	4,980	25

Depth of well and depth to water: measured depths are given in feet and tenths; reported depths are given in feet.
Type of well: Dr, drilled; Du, dug; Dv, driven.

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed
139-92					
2bbb	Steven Schnell	60	...	Dr.	....
4bca	Northern Pacific Railroad	Spring	...	...	....
5	L. Braulick	110	...	...	....
5	A. F. Mischel	110	...	...	....
5aab1	City of Richardton	30	...	...	....
5aab2	Do	30	...	...	....
5acd	Paul Aman	180	...	...	....
5ccd	Julius Zimmerman	82	2	Dr	1947
5daba	Test hole 319	570	5	Dr	1950
5dac	John Herman	125	...	...	....
5db	City of Richardton	640	8	Dr	1959
5dca	Test hole 321	854	5	Dr	1950
5dda	Test hole 320	130	5	Dr	1950
5ddb	Ewald Albert	79	18	Dr	1925
8abb	John Erdle	90	24	Dr	1914
9bbb	Zeno Muggli	98	....	...	1894
10aad	Roy Gress	90	18	Dr	1919
11acc	Unknown	80	6	Dr	1947
11dcc	Frank Hoff	55	6	Dr	1919
13dcc1	C. F. Wahlers	40	6	Dr	1948
13dcc2	Do.	80	3	Dr	1947
14bab	John Barth	...	...	Dr	1941
17bab1	John Kopp	35	24	Dr	1946
17bab2	Do	42	40	Du	....
18abd	Anton Sattler	16	50 x 50	Du	....
18bac	Henry Hunke	...	40	Du	....
18ddb1	Carl Rummel	14	...	Du	....
18ddb2	Do.	60	...	Dr	....
20bab	Jacob Palm	18	24	Du	1941

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

Depth to water below land surface (feet)	Date of measurement	Use of water	Aquifer	Remarks
30	8- 3-49	D,S	.....	Water adequate, hard.
10	....	D,PS	.....	See chemical analysis
100	....	D	.....	Do.
10	....	D,PS	.....	Do.
...	....	PS	.....	Do.
...	....	PS	.....	Do.
...	....	...	.....	Do.
...	8- 8-49	D,S	.....	Water adequate, hard.
...	6-17-50	N	.....	See log.
...	....	...	.....	See chemical analysis.
...	6-30-60	PS	Sand	Water adequate, soft.
...	7-15-50	N	.....	See log.
...	7-10-50	N	.....	Do.
50.24	12- 8-49	D,S	Sand and coal	Water adequate
...	8- 8-49	D,S	Clay	Water adequate, hard.
92	8- 8-49	D,S	.....	Water unfit for drinking. alkaline, inadequate.
65	8- 5-49	D,S	.....	Water adequate, hard.
60	8- 5-49	S	.....	Water adequate, soft.
...	8- 5-49	D,S	Coal	Water adequate, hard.
...	8- 5-49	S	.....	Do.
...	8- 5-49	S	.....	Do.
29.7	8- 5-49	D,S	.....	Do.
19.8	8- 8-49	D	.....	Do.
15.2	8- 8-49	S	.....	Slow recharge, water hard.
7.9	8- 8-49	D,S	.....	Water adequate, hard.
14.9	8- 8-49	D,S	.....	Water adequate, soft.
5	8- 8-49	S	.....	Water adequate, hard.
40	8- 8-49	D,S	.....	Water adequate, soft.
13.8	8- 8-49	D,S	.....	Water adequate, hard.

TABLE 3.--RECORDS OF WELLS

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed
139-92 (Continued)					
22cbb	Lee Senn	27	...	Du	....
23dbd	Joe Mischel	35	18	Dr	....
24dad	Unknown	9	36 x 36	Du	....
26ada1	Anthony Rixen	22	36	Du	1885
26ada2	Do	16	18	Dr	1933
27bcb	Mike Melchiel	37	...	Du	....
28bbc	Fred Rummel	30	...	...	....
32cad	Lee Senn	30	...	Du	....
35bba	Peter Baer	225	...	Dr	1947
36baa	Martin Boehm	...	18	Dr	....
36bcd	Mike Boehm	...	18	Dr	....
139-93					
3dad	Arthur Marcusen	50	3	Dr	1943
4abb	Adam Gabe	315	2	Dr	1948
10add	Spencer Bobb	80	18	Dr	....
11ada	Peter Pflepsen	40	...	...	....
12ccb	Spencer Bobb	36	...	Du	1890
12ddb	Henry Hunke	80	...	Dr	....
13bcb	Herman Leatz	30	6	...	....
19dab	Harold Stanger	35	40	Du	....
22acb	Ray Marcusen	56	18	Dr	....
23acd	Jasper Jasperson	250	...	Dr	....
26bbb	William Jasperson	50	...	...	....
27bcb	Marcusen	42	...	...	....
28ada	Do	42	...	...	....
140-92					
1ccb	Nick Messer	15	...	Du	....
2ddd1	Tom Messer	23	8	Du	1949
2ddd2	Do	29	...	Dr	1918
6aab1	Julius Gress	50	12	Dr	1942

AND TEST HOLES -- Continued

Depth to water below Land surface (feet)	Date of measurement	Use of water	Aquifer	Remarks
15	8- 8-49	...	.....	Water adequate hard.
7.8	8- 5-49	D,S	Coal	Do.
5.9	8- 5-49	...	.....	....
4.5	8- 5-49	D	Coal	Water adequate, hard.
4	8- 5-49	S	.....	Do.
36.0	8--8-49	D,S	.....	Do.
20	8- 8-49	S	.....	Water adequate, hard. Unfit for drinking.
15	8- 8-47	D,S	....	Water inadequate in winter, hard.
...	8-5-45	D,S	Sand	Water Adequate, soft
43.7	8- 5-49	S	.....	Water adequate, hard.
12.8	8- 5-49	N	.....	Abandoned.
13	8- 6-49	D,S	.....	Water adequate, hard.
265	....	D,S	Sand	Water adequate, soft.
42.3	8- 6-49	...	.....	Vacant farm.
16	8- 8-49	D,S	.....	Water adequate, soft.
21.7	8- 8-49	D	.....	Do.
54	8- 8-49	D,S	.....	Do.
...	8- 8-49	D,S	.....	Do.
4	8- 8-49	D,S	.....	Do.
26	8- 8-49	D,S	.....	Do.
40	8- 8-49	D,S	Sand	Do.
35	8- 8-49	D,S	.....	Do.
28	8- 8-49	D,S	.....	Water adequate, unfit for drinking, alkaline.
28	8- 8-49	D,S	.....	Do.
10	8-3-49	D,S	.....	......
15	8- 3-49	D,S	.....	Water adequate, soft.
15	8- 3-49	D,S	.....	Do.
18.2	8- 3-49	D,S	.....	Do.

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed
140-92 (Continued)					
6aab2	Julius Gress	42	12	Dr	1945
12ada	Nick Forster	256	2	Dv	1928
12cdd	John Miller	30	14	Du	.....
14acc1	Emil Hoff	424	4	Dr	1950
14acc2	Do	430	2	Dr	1928
18add	Joe Gress	300	5	Dr	....
20acc	Anton Feller	35	18	Dr	1945
20ccd	Val Hoerner	9	40	Du	1942
20ddd	Unknown	16	30	Du	....
21bac	Albert Hoff	...	11	Dr	1945
22dab	Frank Messer	....	1	Dr	....
26dba	Emil Hoff	7	40	Du	....
30dad1	Jake Forster	14	42	Du	1946
30dad2	Do	70	18	Dr	1945
34dab	Richard Lehman	22	36	Du	....
140-93					
3adc1	Seb Elis	80	18	Dr	1947
3adc2	Do	70	...	Dr	1909
3adc3	Do	68	...	Dr	....
4abd	Harry Vendersloot	49	18	Dr	1919
5dab	Sebastian Bernhardt	123	18	Dr	1940
9bbb1	Cris Stoxen	20	18	Dr	1919
9bbb2	Do	43	...	Dr	....
10add	Herman Jurgens	83	18	Du	1904
10bcc	Mrs. Reka Tammen	40	16	Dr	1939
10cdb1	Louis Gullickson	15	...	Du	1934
10cdb2	Do	76	18	Dr	1918
15cdd	Frank Kolar	58	...	....	....
16cbb	Emil Stoxen	150	...	Dr	1916
17abc	H. A. Myrun	75	18	Dr	....
21bab	George Heidt	56	18	Dr	1947

Depth to water below land surface (feet)	Date of measurement	Use of water	Aquifer	Remarks
...	8- 3-49	D	.....	Water adequate, soft.
...	8- 3-49	D,S	.....	Do.
15.1	8- 3-49	D,S	.....	Water adequate, hard.
40	3-16-50	D,S	Sand	Water adequate, see log.
100	8- 3-49	D,S	.....	Water adequate, soft.
...	8- 3-49	D	.....	Water alkaline, unfit for drinking
4.2	8- 3-49	D,S	.....	Water adequate, medium soft.
3.5	8- 3-49	S	.....	Water inadequate,alkaline, unfit for drinking.
8.1	8- 4-49	...	.....	Water black color.
22.6	8- 4-49	N	.....	Water alkaline.
24	8- 3-49	D,S	.....	Water inadequate, hard.
.0	8- 3-49	D,S	.....	Water adequate, soft.
7.8	8- 3-49	S	.....	Water soft, unfit for drinking.
26	8- 3-49	D,S	.....	Water inadequate, brown coal color.
14.6	8- 3-49	D,S	.....	Water adequate, soft.
60	8- 5-49	D,S	Sand	Water inadequate,hard.
66	8- 5-49	S	Sand	Water adequate, hard.
64	8- 5-49	D	.....	Do.
18	8- 5-49	D,S	.....	Water inadequate, hard.
90	8- 4-49	S	.....	Water adequate, yellow.
12	8- 4-49	D	.....	Water adequate, hard.
32	8-4-49	...	.....	Do.
80	8- 5-49	D,S	Sand	Do.
20	8- 5-49	D,S	Sand	Do.
10	8- 5-49	D	.....	Do.
17.3	8- 5-49	S	Coal	Water adequate, hard. Tastes bitter.
41	8- 5-49	S	.....	Water inadequate, alkaline, hard. Unfit for drinking.
20	8- 4-49	D,S	.....	Water adequate, alkaline, hard.
40	8- 4-49	S	Sand	Water inadequate, soft, alkaline unfit for drinking.
46	8- 4-49	D,S	.....	Water adequate, alkaline.

TABLE 3.--RECORDS OF WELLS

Location No.	Owner or name	Depth (feet)	Diameter or size (inches)	Type	Date completed
140-93 (Continued)					
24ddd	Frank Forster	126	6	Dr	1909
25adb	William Forster	90	14	Dr	....
26bcc	Ivan Sievers	80	...	...	....
26cdd	Martin Sieverson	98	...	Dr	....
34acc	Frank Zimmerman	60	...	Dr	....
34bcc1	H. G. Larson	22	24	...	....
34bcc2	Do	162	...	...	1948
34d	H. R. Hutchinson	80	18	Dr	....

Depth to water below land surface (feet)	Date of measurement	Use of water	Aquifer	Remarks
121	8- 4-49	D,S	Sand	Water adequate, hard.
26.3	8- 4-49	S	.....	Water inadequate, hard,alkaline, unfit for drinking
...	8- 4-49	S	.....	Do.
37	8- 4-49	D,S	.....	Water adequate, hard.
...	8- 4-49	S	.....	Water adequate, alkaline.
6.0	8- 5-49	N	.....	....
100	8- 5-49	D,S	Clay	Water adequate, soft.
40	....	S	Clay	Water adequate.

TABLE 4.--LOGS OF WELLS AND TEST HOLES

139-92-5daba
Test hole 319

Material	Thickness (feet)	Depth (feet)
Clay, highly calcareous, buff to gray.................	4	4
Clay, buff, numerous rust colored streaks and pockets	34	38
Clay, light-gray....................................	12	50
Clay, or shale, hard.................................	5	55
Clay, or shale, plastic, carbonaceous and very hard, dark-brownish-purple..........................	5	60
Clay and silt, mostly very light-gray, clay and thin bands of buff silt (core from 60 to 70 feet, about 50% complete).....................................	10	70
Clay, silt and very fine sand, light-gray to gray......	24	94
Lignite (core from 90 to 100 feet, about 70% complete)	7	101
Clay, sandy, light-gray, micaceous, very fine; contains poorly preserved leaves and carbonized wood (core from about 100 to 110 feet)......................	5	106
Clay, gray, contains numerous poorly preserved leaves and carbonized wood fragments. About ½ foot of lignite at bottom..............................	4	110
Clay, gray...	15	125
Lignite..	3	128
Clay, gray and brown.................................	20	148
Lignite..	2	150
Clay, gray and brown.................................	4	154
Lignite..	3	157
Clay, carbonaceous, brown............................	3	160
Clay, gray; some brown clay..........................	40	200
Shale, light-gray....................................	30	230
Clay, light-gray.....................................	38	268
Clay, green..	2	270
Clay, light-gray.....................................	30	300
Clay, carbonaceous, dark-brown. Sand, fine.............	10	310
Clay, gray, sandy, and thin beds of very fine sand (core from 330 to 340 feet) very similar to material in 100 to 110 feet, not as micaceous and contains a greater percentage of sand. Small bits of partly carbonized wood scattered throughout core.........	39	349
Lignite..	2	351
Clay, light-gray.....................................	29	380
Clay, sandy, light-gray..............................	9	389
Clay, greenish-gray (?), not apparent in samples.......	13	402
Lignite..	3	405
Clay, gray (core from 430 to 440 feet, about 60% complete and badly disturbed and broken in places during process of extracting from barrel)................	25	430

139-92-5daba
Test hole 319 - continued

Material	Thickness (feet)	Depth (feet)
Clay, light-gray	3	433
Clay, carbonaceous and lignite, brown, Many plant impressions	2	435
Clay, sandy, micaceous, plant fragments, light olive-gray	4	439
Clay, plastic, purple	½	439½
Lignite	½	440
Clay, sandy, light olive-gray	5	445
Clay, gray	43	488
Lignite	2	490
Clay, gray	35	525
Clay, not very sandy, micaceous, light greenish-gray, (core from 530 to 540 feet, about 75% complete).	25	550
Very hard rock, requiring the use of rock bit, no sample obtained	3	553
Sand reported by drillers, no sample	6	559
Clay, dark-gray	11	570

139-92-5dca
Test hole 321

Material	Thickness (feet)	Depth (feet)
Topsoil,brown	2	2
Clay, highly calcareous, light-olive	12	14
Clay, light-gray, with ferrugineous concretions	28	42
Lignite and carbonaceous clay	1	43
Clay, very light-gray to white	38	81
Lignite	7	88
Shale, carbonaceous	2	90
Clay, light-gray	12	102
Lignite interbedded with gray clay	18	120
Clay, gray	8	128
Clay, carbonaceous, black	2	130
Clay, gray	6	136
Lignite	1	137
Shale, green and gray, interbedded	23	160
Clay, light-gray	18	178
Clay, carbonaceous, black	2	180
Clay, light-gray	6	186
Clay, brown	8	194

139-92-5dca
Test hole 321 - continued

Material	Thickness (feet)	Depth (feet)
Clay, dark-gray	17	211
Shale, grayish-white	6	217
Clay, dark-gray	13	230
Clay, fairly hard, light-gray	32	262
Clay, light-green	6	268
Clay, soft, dark-gray	34	302
Lignite	1	303
Clay, interbedded with brown carbonaceous clay, soft, gray	9	312
Lignite	4	316
Clay, gray	10	326
Siliceous rock	1	327
Clay, sandy, light-gray	12	339
Lignite	2	341
Shale, light-gray, hard drilling. Lost about 440 gallons of drilling fluid	39	380
Clay, light-brown	4	384
Clay, dark-brown	4	388
Shale, gray. Several thin layers of carbonaceous clay, and lignite	12	400
Clay, greenish-gray	10	410
Shale, light-gray	15	425
Clay, light greenish-gray. Siliceous rock at 455 feet	35	460
Clay, silt and sand, very fine, light-gray quartzitic, and some mica present	22	482
Clay, calcareous, light-gray to white	34	516
Clay, light-brown	2	518
Clay, greenish-gray	10	528
Indurated rock, hard drilling	1	529
Shale, hard, dark-gray. Contains fairly abundant pelecypod shell fragments	41	570
Sand, fine, silty, light-gray. Drilled easily	47	617
Lignite	½	617½
Clay, dark-gray	70½	688
Lignite and carbonaceous shale	7	695
Clay, or shale, gray	7	702
Sand, fine, gray. Samples show considerable clay and silt	38	740
Clay, gray	33	773
Sand, fine	5	778
Shale, gray	76	854

TABLE 4.--LOGS OF WELLS AND TEST HOLES -- Continued

139-92-5dda
Test hole 320

Material	Thickness (feet)	Depth (feet)
Clay, buff to gray	8	8
Shale, carbonaceous, brown	2	10
Lignite	3	13
Clay, light-gray, limonitic nodules	8	21
Clay, buff	6	27
Shale, light-gray	7	34
Shale, carbonaceous, black	1	35
Clay, light-gray to gray	23	58
Clay, carbonaceous, brown to black	5	63
Lignite	1	64
Clay, light-gray	3	67
Lignite	1	68
Clay, very light-gray	18	86
Drillers report dark gray slate rock	2½	88½
Clay, light-gray	12½	101
Lignite and clay, interbedded. Samples show mostly lignite	16	117
Clay, light-gray	13	130

140-92-14acc1
Emil Hoff 1/

Material	Thickness (feet)	Depth (feet)
Surface soil	1	1
Clay and sandy streaks	63	64
Blue clay	30	94
Gravel, very little water	1	95
Brown clay	59	154
Carbonaceous clay	2	156
Coal	4	160
Blue sandy clay, fairly tight	34	194
Blue clay	40	234
Coal	2	236
Blue clay	28	264
Coal	4	268
Blue clay	76	344
Blue limestone, a little sandy, hard	30	374
Water sand, lots of good water and definite water crystals	50	424

1/ Log furnished by R. E. Sylvester, Midwest Well and Pipe Co., Mandan N. Dak. Water rose to within 40 feet of the ground surface. Eight-inch hole with 4-inch casing packed within 10 feet of surface with pea-size gravel and top 64 feet cemented off.

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