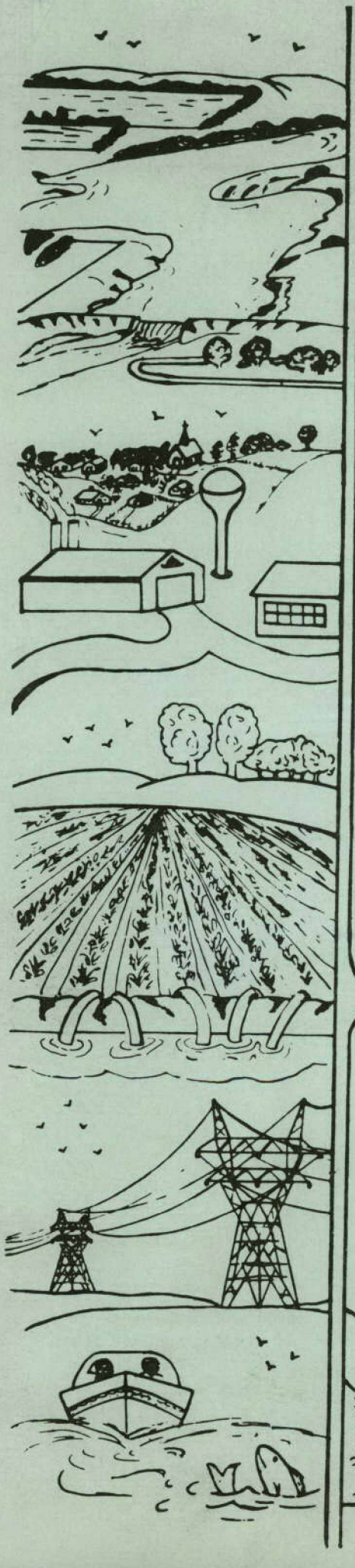

Ground-Water Resources of the Halliday Area Dunn County, North Dakota

North Dakota Ground-Water Studies
No. 78

By
Charles E. Naplin
Ground-Water Geologist

Published By
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Bismarck, North Dakota 58501

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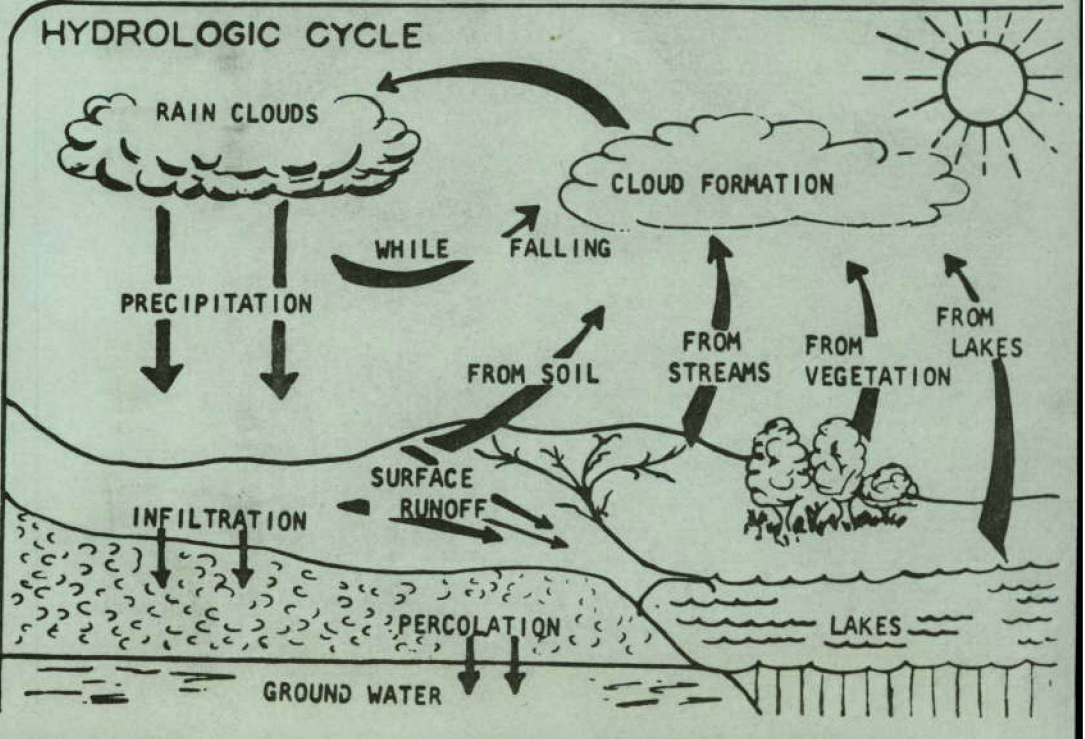

GROUND-WATER RESOURCES OF THE HALLIDAY AREA
DUNN COUNTY, NORTH DAKOTA

NORTH DAKOTA GROUND-WATER STUDIES
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INTRODUCTION

PURPOSE AND SCOPE

A resolution requesting the North Dakota State Water Commission to conduct a ground-water survey for the city was passed by the Halliday City Commission on October 4, 1971. The State Water Commission approved this resolution on October 27, 1971 and the investigation was conducted during October and November of that year.

The geohydrology of the area was determined by test drilling, installation of observation wells and collection of water samples for chemical analysis. Data compiled during the field work and from additional sources was evaluated during February and March of 1972.

ACKNOWLEDGEMENTS

Depths of wells and water levels were obtained from Dunn County well inventory data furnished by Robert Klausing of the U. S. Geological Survey. Elevations were obtained from selected test holes using a Paulin altimeter. Lewis Knutson and Hugh Jacobson accomplished the test drilling using a hydraulic rotary drilling machine. Field work was under direct supervision of the author. Chemical analyses were performed by Garvin Muri, State Water Commission chemist, at the North Dakota State Laboratories Department in Bismarck.

LOCATION AND GENERAL FEATURES

The study area is located in east-central Dunn County and is within the Missouri Slope division of the Missouri Plateau physiographic province of North Dakota (fig. 1). Test drilling, water quality and well inventory data describe a 77 square mile area that includes portions of Tps. 144, 145, and 146 N., Rs. 91 and 92 W. (pl. 1).

Climatological data based on a 73-year period of record at the National Weather Service station located two miles southwest of Dunn Center, North Dakota, shows the average annual temperature to be 40.6°F. Average annual precipitation for the same period of record was 15.46 inches (National Weather Service, 1971).

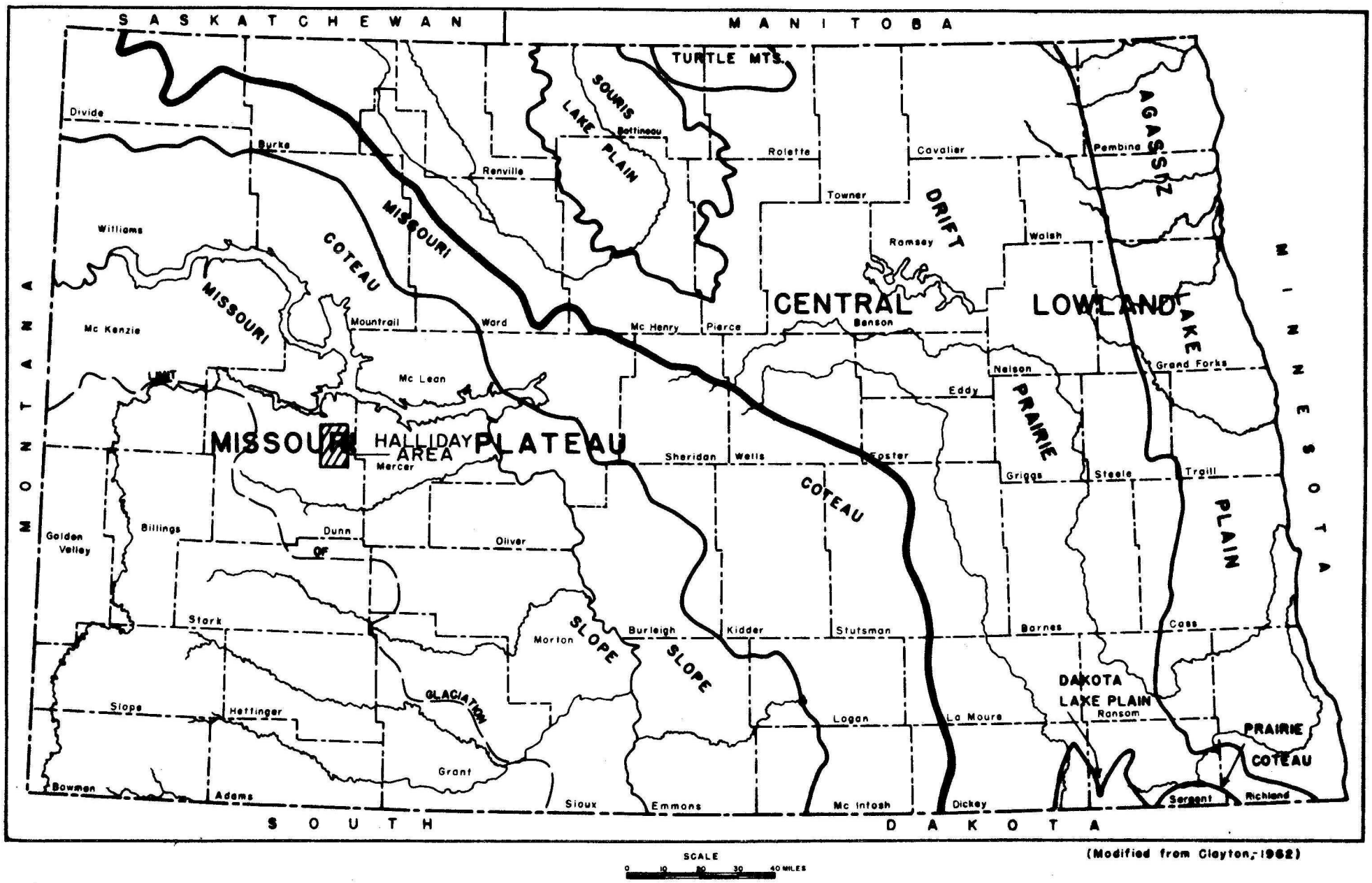
Surface elevations range from about 1,940 feet near Spring Creek to 2,300 feet above mean sea level on the drainage divide between Spring and Hans Creeks north of Halliday. The landscape is typical of western North Dakota where numerous flat-topped buttes and conical-shaped hills remain as erosional remnants of an ancient plateau.

Spring Creek and its associated tributaries form a well established drainage pattern that drains about two-thirds of the area. Hans Creek drains the remaining area and occupies the valley of a former glacial melt-water diversion channel which flowed southeast into the ancestral Missouri River drainage system. It now follows a northwesterly gradient and discharges into Lake Sakakawea.

Halliday (1970 population 413) is an agricultural community. It is served by a branch line of the Burlington Northern Railroad, U. S. Highway 200 and State Highway 8.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report is based upon the location



(Modified from Clayton, 1962)

FIGURE 1--MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE HALLIDAY AREA

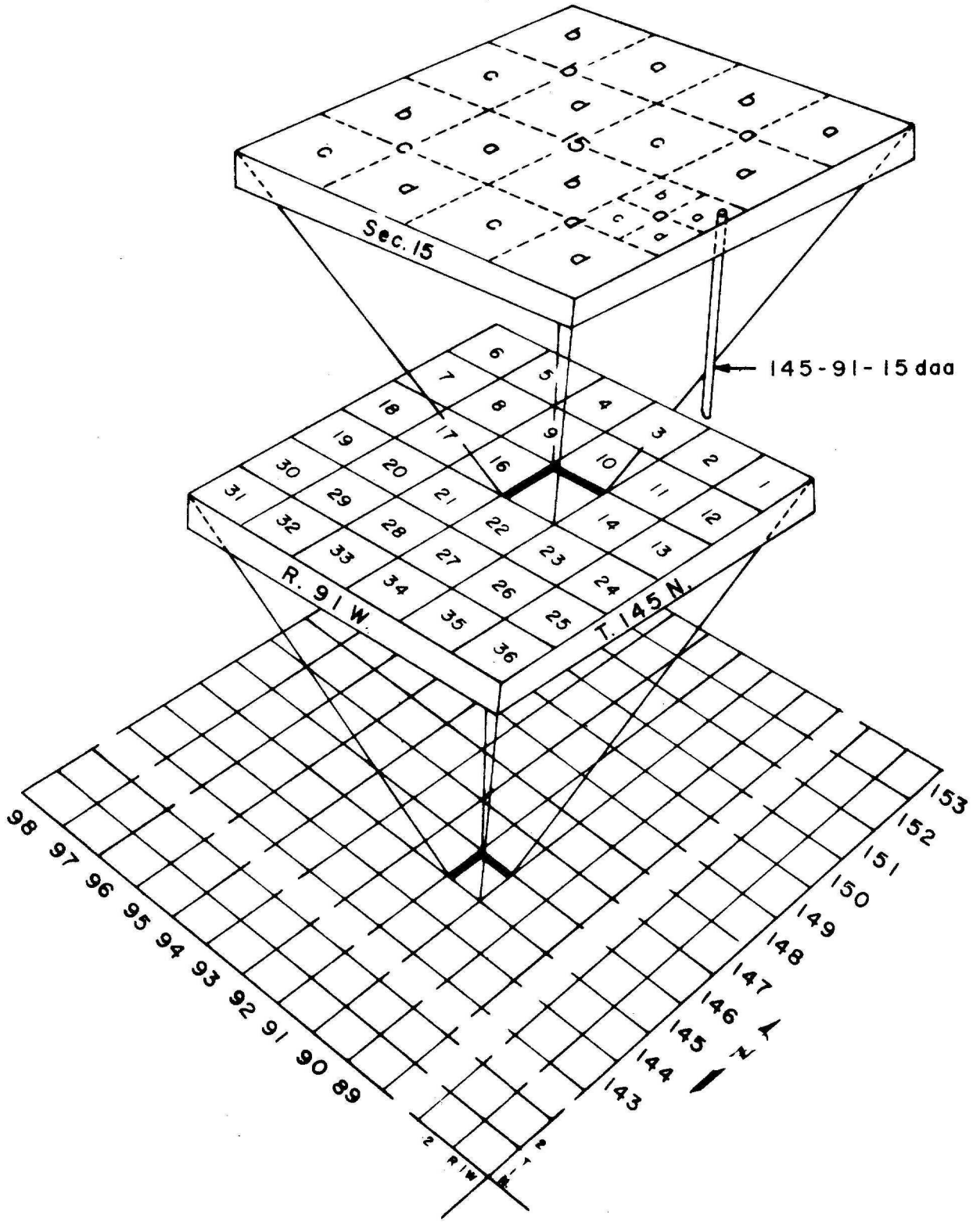


FIGURE 2--SYSTEM OF NUMBERING WELLS, TEST HOLES, AND SPRINGS

of the well in the Federal system of rectangular surveys of public lands (fig. 2). The first number denotes the Township north of the base line that passes laterally through the middle of Arkansas; the second number denotes the range west of the Fifth Principal Meridian; the third number 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 section, quarter-quarter section and quarter-quarter-quarter section (10-acre tract). Consecutive terminal numerals are added if more than one well is located in a 10-acre tract. Thus well 145-91-15daa is in the NE¼NE¼SE¼ sec. 15, T. 145 N., R. 91 W.

PREVIOUS INVESTIGATIONS

Simpson (1929, p. 124-127) discusses in general terms the geology and ground-water resources of Dunn County. His report deals primarily with numerous springs and seeps that issue from lignite seams in the local bedrock. Many springs were developed by local ranchers who piped water to lower elevations for domestic, stock, and the limited irrigation of garden produce.

A study of the geology and ground-water resources of Dunn County was initiated in 1971. This investigation is a cooperative program between the U. S. Geological Survey, North Dakota State Water Commission and the Dunn County Water Management District. Information acquired during this four year study will provide a description of the county's ground-water resources.

PRESENT WATER SUPPLY

The city of Halliday obtains its water supply from a spring located northwest of town (145-92-24bca) near the top of the north valley wall of

Spring Creek (pl. 1). This spring was developed by trenching and installing slotted pipe and then filling the excavation with gravel. Water is pumped from this horizontal well into a storage tank and flows under the influence of gravity throughout the city's water distribution system. The water is chlorinated to prevent bacteria from living in the system. City residents have indicated that the water is hard, has a bad taste and stains plumbing fixtures. Encrustation commonly occurs in pipes and water mains and is probably the result of chemical precipitation of dissolved mineral constituents, especially iron (Fe) and manganese (Mn).

PRINCIPLES OF GROUND-WATER OCCURRENCE

Ground water occurs naturally in rocks at various depths in the upper zone of the earth's mantle. The original source of all ground water is precipitation. Some of the precipitation which falls to the surface of the earth is absorbed into the ground and percolates downward by gravity to a zone of saturation and becomes ground water. Much precipitation is retained for a short time by the soil and then returned to the atmosphere by evaporation and transpiration.

Saturated permeable material that will yield water is called an aquifer. When the water table in an aquifer is free to fluctuate, it is called a water-table aquifer. If the water contained within an aquifer is confined by relatively impermeable material such as clay or shale and under pressure, the reservoir is termed an artesian aquifer.

Ground water moves, under the influence of gravity, from areas of recharge or infiltration to areas of discharge such as streams and springs. Artificial discharge is caused by the pumping of wells. Under natural conditions, the

rates of recharge and discharge are essentially in equilibrium. Ground-water movement is generally very slow and may be only a few feet per year. The rate of movement is governed by the permeability of the deposits through which ground water moves and by the hydraulic gradient. Gravel, well-sorted medium or coarse sand and fractured lignite beds generally are highly permeable. Fine-grained materials such as silt, clay and shale usually have low permeability and act as barriers that impede the movement of ground water into or out of more permeable rocks.

Porosity is the ratio of the volume of open space in a rock to its total volume and is an indication of a material's capacity to store water.

The water level in a well fluctuates in response to recharge to and discharge from an aquifer. Variations in atmospheric pressure and land surface loadings cause minor water-level fluctuations in confined aquifers. Pumping a well causes its water level to be lowered and the water-level surface surrounding the well will resemble a cone referred to as the cone of depression. Water-level drawdown is the difference between static and pumping levels. The amount of drawdown is controlled by the hydraulic properties of the aquifer, the physical characteristics of the well and the rate and duration of pumping. During constant and uniform discharge from a well, the water level declines rapidly at first and then continues to decline at a decreasing rate as the cone of depression expands.

The water level in a pumping well must decline in order for water to flow from the aquifer to the well. However, excessive water-level decline may cause (1) water of undesirable quality to move into the aquifer, (2) a reduction in well yield because of interference from other wells or from aquifer boundaries, (3) excessive pumping lift which may be uneconomical, and/or (4) water level decline below the top of the screen and subsequent screen

damage. When pumping is stopped, the water level recovers in the well and in its vicinity at a decreasing rate until the water level again approaches the static level.

The specific capacity of a well is the rate of discharge of water divided by the drawdown of water level. Generally the specific capacity becomes smaller with time, therefore the duration of pumping should be reported in reference to the specific capacity.

WATER QUALITY

All water occurring on the earth's surface or underground contains dissolved solids. Precipitation begins to dissolve material as it falls to the surface and continues to dissolve solids as it infiltrates into the ground. Dissolved constituents in ground water vary in type and concentration depending primarily upon the composition of rocks with which ground water comes into contact. Other factors such as the duration of contact with rock material, temperature, pressure, and gases in solution also determine the nature and concentration of dissolved material.

The following summary gives the significance of various constituents of water for a domestic or municipal water supply in North Dakota (Schmid, 1965):

Silica (SiO_2)

Silica has no physiological or esthetic significance.

Iron (Fe)

Over 0.3 mg/l (milligrams per liter) iron may cause staining of laundry and fixtures. Over 0.5 mg/l may be tasted by persons not accustomed to water with a high iron content. Iron removal systems are available.

Manganese (Mn)

Manganese produces black staining when present in amounts exceeding 0.05 mg/l.

Calcium (Ca) and Magnesium (Mg)

Calcium and magnesium are the primary causes of hardness. Over 125 mg/l magnesium may have a laxative effect on persons not accustomed to this type of water.

Sodium (Na)

No physiological or esthetic significance results from sodium except for persons on salt-free diets. It does have an effect on the irrigation usage of water.

Potassium (K)

Small amounts of potassium are essential to plant and animal nutrition.

Bicarbonate and Carbonate (HCO_3 and CO_3)

These constituents have no definite significance in natural water; there are, however, certain standards to be maintained in water treatment plants. A water with high bicarbonate content will tend to have a flat taste.

Sulfate (SO_4)

The U. S. Public Health Service limit is set at 250 mg/l for sulfate, however, a survey by the North Dakota Department of Health survey indicates no laxative effect is noticed until sulfates reach 600 mg/l. Sulfate is classified as follows:

0 to 300 mg/l - low

300 to 700 mg/l - high

over 700 mg/l - very high

Chloride (Cl)

Over 250 mg/l chloride may have a salty taste to persons not accustomed to

high concentrations. Humans and animals may adapt to higher concentrations.

Flouride (F)

Flouride helps prevent tooth decay within the limits of 0.9 to 1.5 mg/l in North Dakota. Higher concentrations cause mottled teeth.

Nitrate (NO_3)

Over 45 mg/l nitrate can be toxic to infants. Larger concentrations can be tolerated by adults. Nitrate in excess of 200 mg/l may have a deleterious effect on livestock health.

Boron (B)

Boron has no physiological or esthetic significance.

Total Dissolved Solids

A limit of 500 mg/l of total dissolved solids is set by the U. S. Public Health Service, but persons may become accustomed to water containing 2,000 mg/l or more total dissolved solids. They are classified as follows by the North Dakota State Department of Health:

0 to 500 mg/l - low

500 to 1,400 mg/l - average

1,400 to 2,500 mg/l - high

Over 2,500 mg/l - very high

Hardness

Hardness increases soap consumption but may be removed by a water-softening system. The following is a general hardness scale for North Dakota established by the North Dakota State Department of Health:

0 to 200 mg/l as $CaCO_3$ - low

200 to 300 mg/l - average

300 to 450 mg/l - high

Over 450 mg/l - very high

pH

Should be between 6.0 and 9.0 domestic consumption.

Percent Sodium and Sodium Adsorption Ratio (SAR) indicate the sodium hazard of irrigation water.

Specific Conductance is an electrical indication of total dissolved solids measured in micromhos per centimenter at 25°C. It is used primarily for irrigation analyses.

GROUND WATER IN THE BEDROCK

The Halliday area is located near the center of the Williston Basin. Structural effects due to the presence of the Nesson Anticline cause sediments to dip gently to the northeast (pl. 2). The complete sequence of sedimentary rocks underlying the Halliday area exceeds 12,000 feet in thickness; however, this investigation is concerned only with formations of upper Cretaceous and Tertiary Age that are of importance as potential aquifers for a municipal water supply.

Bedrock aquifers in the study area are divided into the following units: (1) Fox Hills and Hell Creek Formations of Cretaceous Age, and (2) Ludlow-Cannonball, Tongue River and Sentinel Butte Formations of Tertiary age. Data concerning the hydrologic properties of these formations is scarce in the study area. Therefore, information gathered from several sources dealing with upper Cretaceous and Tertiary sediments in western North Dakota was used to interpret and correlate their hydrologic characteristics. Plate 2 illustrates the depositional sequence and generalized lithologies of the upper Cretaceous and Tertiary rocks in the Halliday area. Chemical analyses from the Halliday area are listed in Table 1.

CRETACEOUS SYSTEM

Pierre Formation

The Pierre Formation is the lower-most Cretaceous stratum included in this report and consist of dark gray to grayish black fissile shale. The Pierre is not an aquifer in this area of North Dakota.

Fox Hills and Hell Creek Formations

The sandstone beds of the upper part of the Fox Hills and the lower part of the Hell Creek Formations react as a single hydrologic unit in much of western North Dakota. As a result, they are discussed as a single aquifer in this report.

Electric and radiation logs from oil tests at 145-92-28AA (Dahlen No. 1) and 145-93-25DC (Goetz No. 1) located three and six miles west of Halliday respectively, indicate that the two formations consist of alternating beds of claystone, siltstone, and sandstone. Four sandstone intervals in the Hell Creek and two sandstones in the Fox Hills are recognizable in the subsurface and underlie the Halliday area (pl. 2). The upper Cretaceous sandstones are variable and occasionally pinch out due to nondeposition. The upper sandstone of the Fox Hills thickens to the northeast in the direction of regional dip.

The Fox Hills-Hell Creek contact was picked at a depth of 1480 feet (altitude 565 feet) in a test hole drilled for the city by Mann Drilling Company in 1973 (pl. 2). Seventy-five feet of fine-to medium-grained sandstone was penetrated from 1480 to 1555 feet bls. (below land surface). Stratigraphic correlation indicates this sandstone is the Colgate member of the Fox Hills Formation. The Colgate is an important aquifer in southwestern North Dakota where many domestic and municipal wells tap this unit.

Hydrologic data, interpolated from an adjacent ground-water investigation in Mercer and Oliver Counties, indicates that wells tapping the Fox Hills-Hell Creek aquifer have specific capacities ranging from 0.1 to 0.6 gpm (gallons per minute) per foot of drawdown (Croft, and Wesolowski, 1970 p. B194). Assuming similar hydrologic properties for the aquifer at Halliday, yields of 10 to 60 gpm with 100 feet of drawdown can be anticipated.

Water from the Fox Hills-Hell Creek aquifer in western North Dakota is usually a very soft, sodium bicarbonate type. Water samples from a well (145-91-20aaa$_1$) completed in the aquifer at a depth of 1,450 feet contained up to 1,560 mg/l total dissolved solids, and 3.0 mg/l flouride (table 1). Similar chemical quality should be expected for a well completed in the aquifer at Halliday.

TERTIARY SYSTEM

Cannonball and Ludlow Formations

The Cannonball and Ludlow Formations of Tertiary age lie immediately above the Cretaceous Hell Creek Formation. Because of facies changes and interfingering in the subsurface, these units remain undifferentiated in this report.

Electric logs and drill cuttings show that the Cannonball-Ludlow interval consists primarily of claystone and shale that may be various shades of gray or green in color. Numerous cemented limestone concretions occur throughout the stratigraphic interval along with a few thin beds of sandstone.

The sandstones are quite variable in thickness and probably discontinuous in areal extent. They will probably yield a few gallons per minute to wells, but the Cannonball-Ludlow is not a significant aquifer in this area.

Tongue River Formation

The Tongue River Formation consists of about 500 feet of interbedded medium-to brownish-gray claystones and siltstones, bluish-gray sandstones,

and brownish carbonaceous shales at Halliday. Test hole data indicates that the formation may contain several beds of sandstone that are lenticular and quite discontinuous. Test hole 145-92-25ABA$_2$ penetrated 90 feet of sandstone from 260 to 350 feet bls. and 60 feet of sandstone from 610 to 670 feet bls. The Tongue River-Sentinel Butte contact was picked at the base of the basal Sentinel Butte sandstone at a depth of 160 feet (altitude 1885 feet).

Plate 2 shows that the basal Tongue River sandstone, present in the subsurface at Halliday, pinches out to the northeast. The Tongue River sandstones are characteristically absent locally due to nondeposition.

No wells are known to be completed in the Tongue River Formation within the Halliday area. Consequently, hydrologic data concerning the formation is limited. The specific capacity of a well completed in the basal sandstone probably would not exceed one gpm per foot of drawdown. Well yields of up to 50 gpm may be possible, but the physical characteristics of the formation, well construction and the degree of drawdown are factors which could limit yields considerably.

Water quality data from the basal Tongue River sandstone in the Halliday area is not available. Ground-water investigations in other areas of North Dakota show that the water is usually of the sodium bicarbonate type.

Sentinel Butte Formation

The Sentinel Butte Formation directly overlies the Tongue River Formation and outcrops wherever it is not covered by glacial drift in the area. Subsurface data indicates the formation consists of an interbedded sequence of medium gray claystones and siltstones, brownish-gray carbonaceous shales, and light olive gray to greenish-gray fine-grained sandstones. Concretions of cemented sandstone and seams of lignite are common.

The Sentinel Butte may contain two sandstone beds in the study area but they are variable in thickness, interbedded with claystone, and may be discontinuous due to nondeposition or have been removed by erosion. In the northern portion of the Halliday area the upper Sentinel Butte is very sandy and contains many thin lignites. Precipitation infiltrates directly into the upper sand unit, moves horizontally along numerous lignite beds, and is discharged by springs along valley walls and road cuts. Discharge rates are quite low but the yield of a developed spring at 145-91-14BAD was measured at 20 gpm. Ground-water discharge also occurs near the bottom of coulees where there is usually an abundance of vegetation.

Subsurface and well inventory data indicate that the Sentinel Butte Formation is an important aquifer in the Halliday area. Most wells are completed in lignite seams, but a few wells tap sandstone beds to depths greater than 250 feet in areas of higher elevations. Test hole 8222 (145-92-24bbc) located about one-quarter of a mile west of city well 1 (145-92-24bca) penetrated 10 feet of clayey, fractured lignite from 0 to 10 feet below land surface. City well 1, a developed spring, is probably completed in the same lignite bed. Well yields are generally only a few gallons per minute.

Lignite beds in the Halliday area generally do not extend over a wide area and are usually quite discontinuous. Fractures and joints, along which ground water moves within lignite, may be only a local phenomenon and not a representative physical characteristic of the entire bed.

Water from the Sentinel Butte is generally a sodium sulfate or sodium bicarbonate type. Twelve chemical analyses (table 1) contained dissolved solids ranging from 416 to 4,880 mg/l and averaged 1,822 mg/l. Concentrations of sulfate and hardness average 865 and 550 mg/l respectively. Both iron and manganese may exceed 1.0 mg/l.

GROUND WATER IN THE GLACIAL DRIFT

The Halliday area is covered in most places by glacial drift that ranges in thickness from less than 1 foot to greater than 200 feet in the valley of Hans Creek. The average thickness is about 20 feet. Glacial drift in the study area consists of alluvium, till and buried outwash.

Spring and Hans Creeks are partially filled with very silty, sandy alluvial clay that overlies outwash sand and gravel. The alluvial clays have been altered by oxidation and weathering to a yellowish-brown or dusky-yellow color. The alluvium has thin sand lenses associated with it, but will not readily yield water because it is relatively impervious and most often occurs above the zone of saturation.

Till is the predominant glacial material throughout the area. It consists of very silty sandy pebbly clay which is generally oxidized. Cobbles and boulders are commonly associated with till and are often exposed at land surface. Till covers most of the bedrock surface and is exposed along valley walls and road cuts. It's primary constituents, clay and silt, are relatively impervious and will not readily yield water to wells.

Several thousand years ago glacial meltwaters sorted and deposited varying amounts of sand and gravel in the valleys of Spring and Hans Creeks. Outwash deposits underlying Spring Creek constitute the Halliday aquifer in the study area. The northwest to southeast-trending glacial diversion channel now occupied by Hans Creek is underlain by outwash that is the northwestern extention of the Goodman Creek aquifer (Croft, 1973). The Goodman Creek aquifer has the greatest potential for development in the Halliday area.

QUATERNARY SYSTEM

Halliday Aquifer

Outwash occurring in the valley of Spring Creek constitutes the Halliday

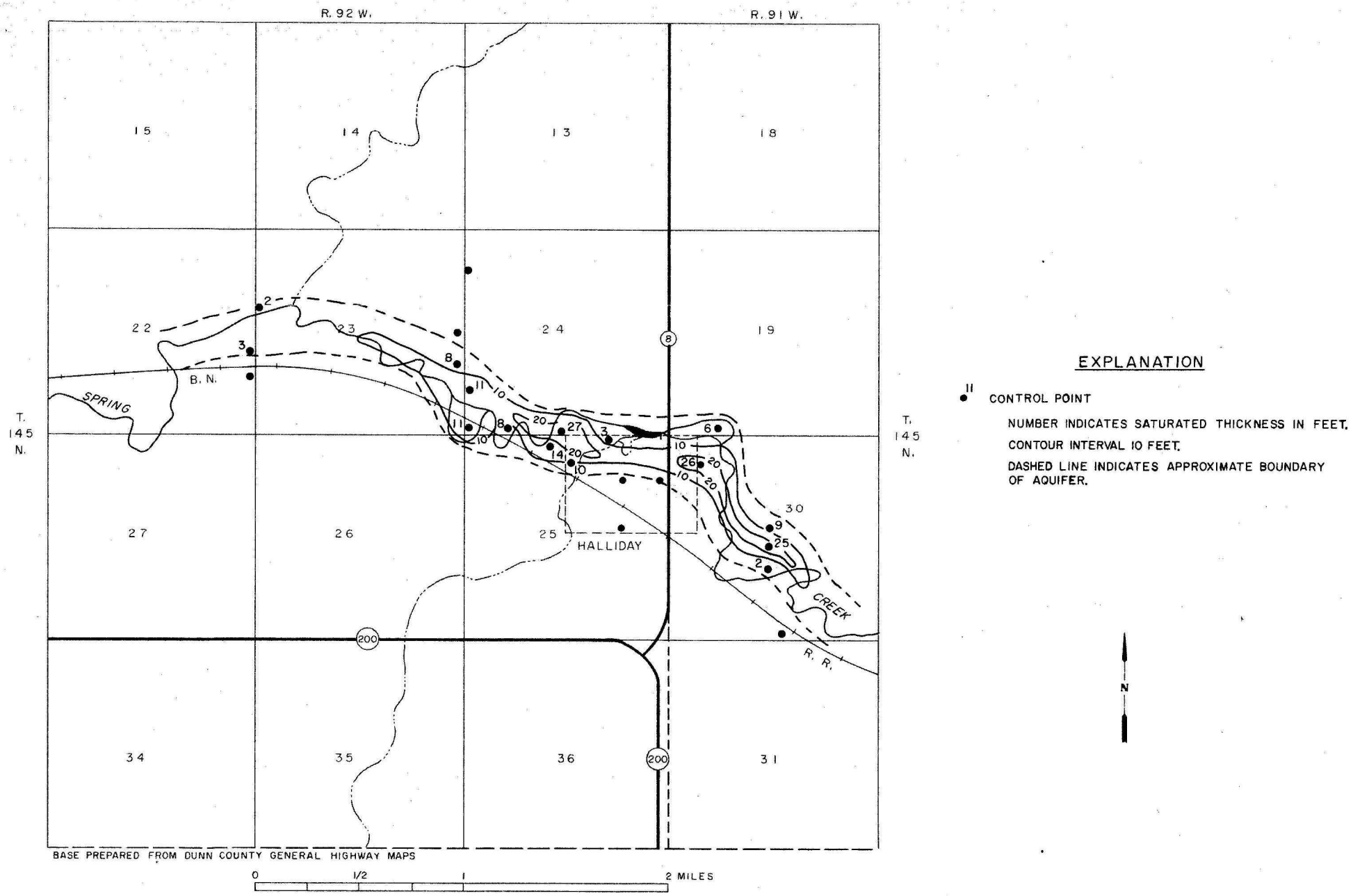


FIGURE 3 -- LOCATION AND THICKNESS OF HALLIDAY AQUIFER

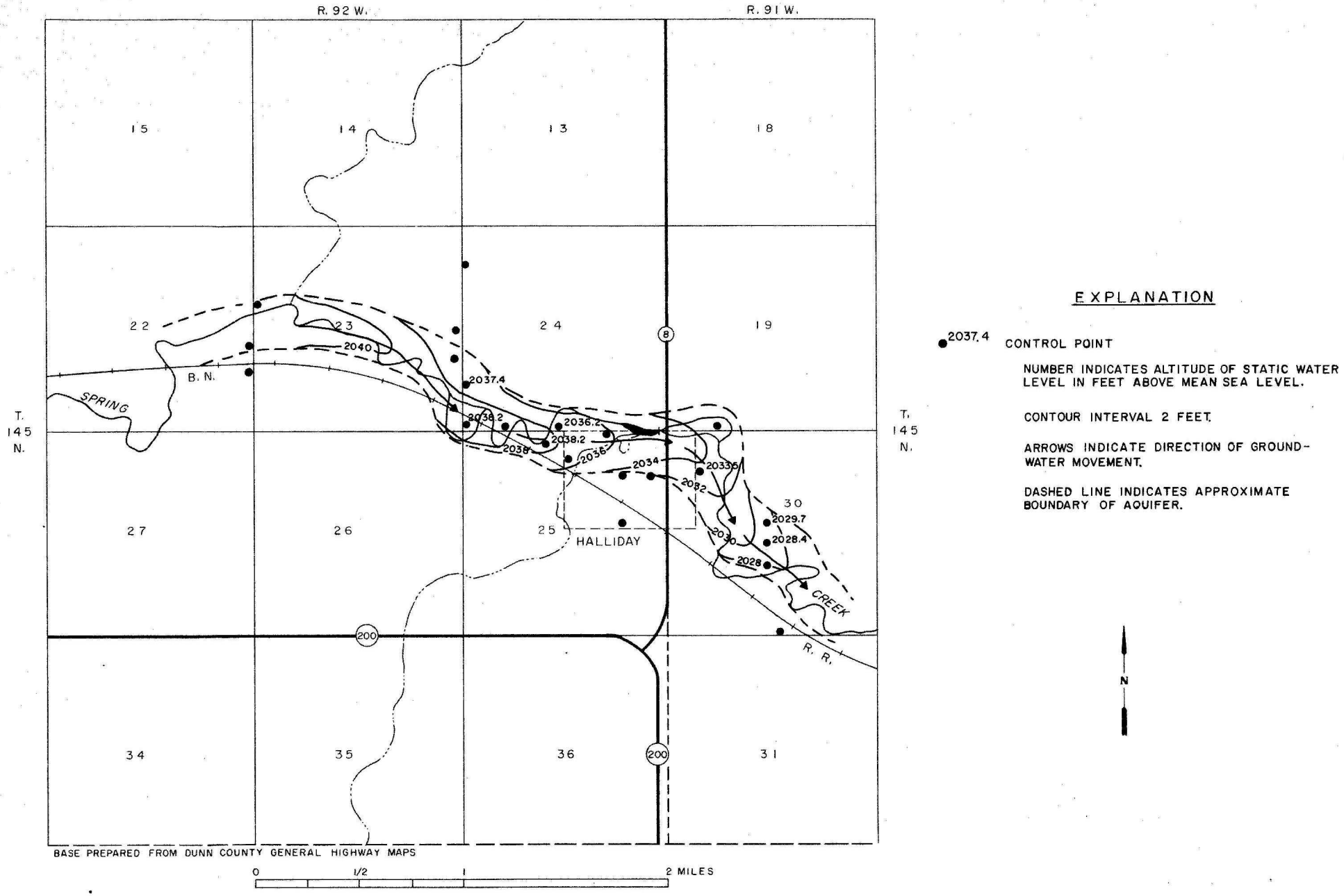


FIGURE 4 -- CONFIGURATION OF THE WATER TABLE IN THE HALLIDAY AQUIFER

aquifer. Characteristics of the aquifer are illustrated in figures 3 and 4. Test drilling indicates that aquifer material range in thickness from 2 to 27 feet with an average thickness of about 10 feet. The aquifer material is predominantly a very fine-to medium-grained moderately well-sorted lignitic sand. However, fine to coarse sandy gravel was encountered in a few test holes (table 2).

Sand and gravel comprising the aquifer generally overlies the Sentinel Butte Formation, except in a small portion of Spring Creek valley where it is underlain by silty clay (pl. 3 Sec.'s A-A' and C-C'). Clay also occurs as lenses and interstitial material within the aquifer. The presence of clay in sand and gravel effectively lowers permeability and may substantially reduce well yields.

Recharge to the Halliday aquifer occurs primarily as precipitation infiltrates through the overlying alluvium. Substantial sodium and sulfate content in water from the Halliday aquifer indicates additional recharge occurs as underflow from the Sentinel Butte Formation. Ground-water movement in the Halliday aquifer is to the southeast (fig. 4).

Existing subsurface data indicate the Halliday aquifer is about a quarter of a mile in width and extends over an area of about one square mile. Assuming a porosity of 30 percent for fine to medium silty sand, an average saturated thickness of 10 feet and an area of one square mile, the aquifer contains about 1,900 acre-feet of water in storage. However, only a portion of this would be recoverable by wells.

Six test holes located in the W½NW¼ Section 30, Township 145 North, Range 91 West were drilled for the city by Mann Drilling Company in 1973. These test holes encountered poorly sorted, clayey, lignitic sand and gravel ranging in thickness from 4 feet to 36 feet. Two test holes that penetrated

the thickest section of the aquifer were temporarily completed as wells. Both wells were 36 feet in depth, completed with either 4-inch or 12-inch diameter casing, screened, and pumped with compressed air. Well yields were estimated at 20 gpm for the 12-inch well and 30 gpm for the 4-inch well, but an excessive amount of drawdown occurred in both wells during pumping. A large degree of drawdown indicates the Halliday aquifer is not capable of large yields in this area due to low permeability.

The chemical quality of water in the Halliday aquifer is of the sodium-sulfate-bicarbonate type. Total dissolved solids content of 8 chemical analyses (table 1) ranged from 1,160 to 3,600 mg/l and averaged 1,827 mg/l. Sulfate ranged from 351 to 1,660 mg/l and averaged 780 mg/l. Hardness ranged from 61 to 1,010 mg/l and averaged 455 mg/l. Concentrations of iron and manganese ranged from 0 to 1.7 mg/l and 0.04 to 0.79 mg/l, respectively. A water sample from a well (145-92-25baa$_1$) contained 129 mg/l nitrate which indicates a local source of contamination, probably from sewage wastes.

Goodman Creek Aquifer

The Goodman Creek aquifer occupies the valley of an ancestral glacial diversion channel and is known to extend into adjacent areas of Dunn and Mercer Counties. The location, thickness, and altitudes of water levels in the Goodman Creek aquifer are indicated on figure 5.

Test drilling indicates that deposition of the valley fill occurred in cycles, as each interval of sand and gravel was overlain by silty clay (pl. 3, Sec. D-D'). The significant thicknesses of clay penetrated suggests that the valley may have been blocked downstream by ice for long periods of time.

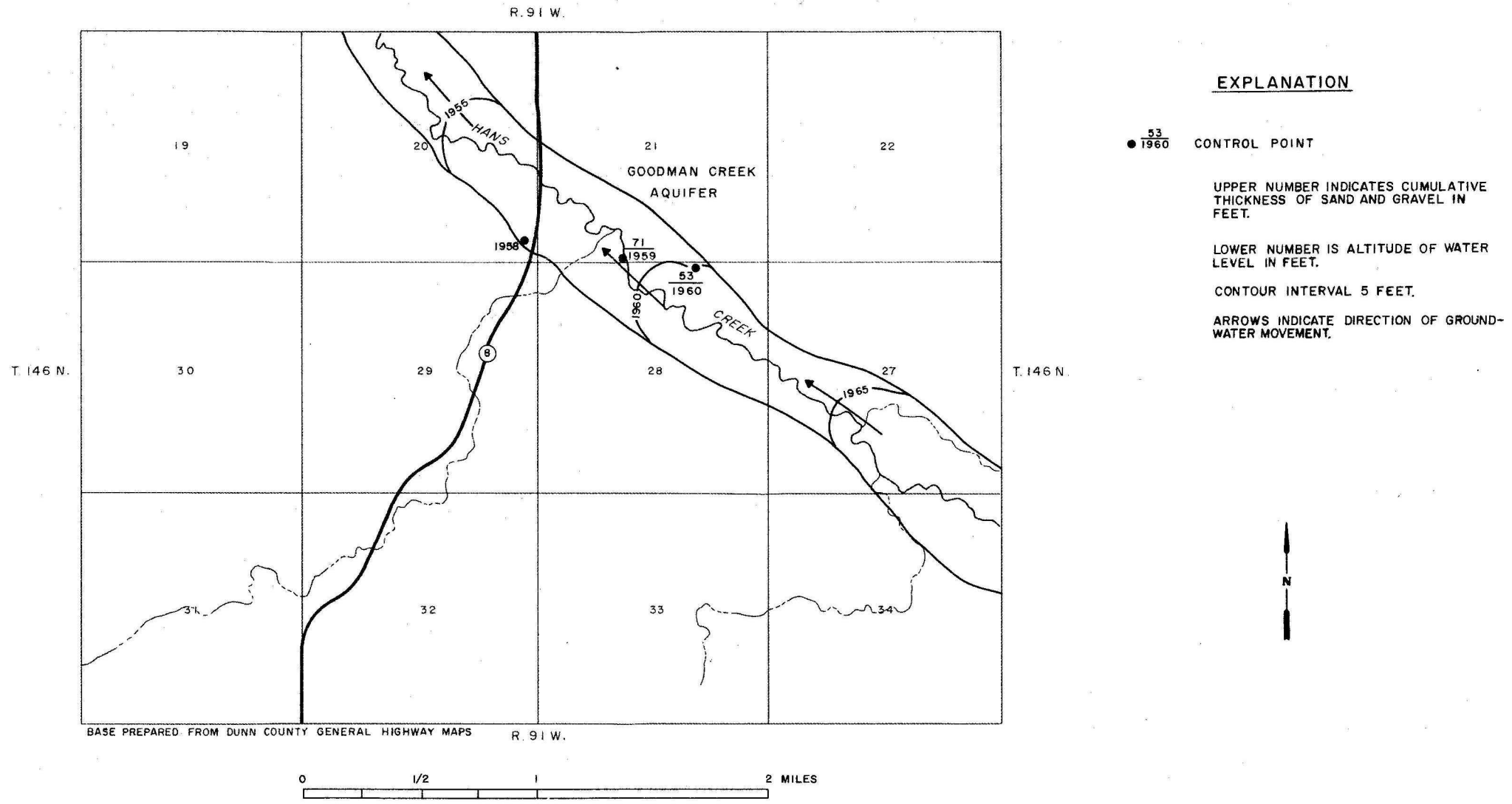


FIGURE 5 -- LOCATION, THICKNESS, AND ALTITUDES OF WATER LEVELS IN GOODMAN CREEK AQUIFER

The buried outwash ranges in aggregate thickness from 53 feet in test hole 8217 (146-91-28aba) to 71 feet in test hole 8216 (146-91-21cdd). The aquifer consists of an upper fine- to medium-grained sand unit and a lower sandy gravel unit in the area of cross section D-D'. Clay occurs as lenses and interstitial material in the vicinity of this section and may also be present within the aquifer.

Direct infiltration of precipitation through overlying alluvial clay and streamflow in Hans Creek provide the majority of recharge to the aquifer. Secondary recharge occurs as underflow from the adjacent and underlying Sentinel Butte Formation.

The Goodman Creek aquifer in the study area is from a quarter of a mile to a half of a mile wide and extends over an area of about 1½ square miles. Assuming a porosity of 30 percent, an average thickness of 50 feet and an area of 960 acres, the Goodman Creek aquifer contains about 14,000 acre-feet of ground water in storage. Potential well yields of up to 500 gpm may be possible at selected locations in the aquifer.

Water quality in Goodman Creek aquifer is generally of the sodium bicarbonate or sodium sulfate type. Total dissolved solids ranged from 514 to 2100 mg/l and average 995 mg/l for 5 samples. Hardness and sulfates averaged 443 and 450 mg/l, respectively, Concentrations of iron ranged from 0 to 1.30 mg/l.

SUMMARY

Geohydrologic data collected and evaluated during this investigation describe a 77-square mile area of Halliday in northeastern Dunn County. The area is situated within the Missouri Slope division of the Missouri Plateau physiographic province of North Dakota. The average annual temperature is 40.6°F. and the average annual precipitation is 15.46 inches. Spring and Hans Creeks drain the area.

The Halliday area is situated near the center of the Williston Basin and is underlain by more than 12,000 feet of consolidated sedimentary rocks. This investigation was concerned only with upper Cretaceous and Tertiary rocks that are potential aquifers at Halliday. Important bedrock aquifers consist of the (1) Fox Hills - Hell Creek Formations, (2) Tongue River Formation, and (3) Sentinel Butte Formation.

The Fox Hills - Hell Creek stratigraphic section contains at least four sandstone beds at Halliday, of which the Colgate member of the Fox Hills has significant potential as a source of water supply for the city. A test hole at 145-92-25ABA$_2$ located within the city limits, penetrated 75 feet of fine- to medium-grained sandstone from 1480 to 1555 feet bls. Data on specific yields for the Fox Hills - Hell Creek aquifer, as interpolated from the Mercer and Oliver County ground-water investigation, suggest that yields of up to 60 gpm with 100 feet of drawdown are possible. Water common to the Fox Hills - Hell Creek aquifer is of the sodium bicarbonate type, is soft, and may contain more than 1,500 mg/l dissolved solids. Concentrations of iron and manganese are within accepted limits, but treatment for flouride may be necessary.

The Tongue River Formation contains two sandstone beds at Halliday, but has not been developed as an aquifer in the area of this investigation. Tongue River water is generally of the soft sodium bicarbonate type.

Test drilling indicates the Sentinel Butte Formation consists of an interbedded sequence of claystone, sandstone, siltstone, carbonaceous shale, and lignite. Sandstone beds and lignites of the Sentinel Butte have been tapped by the majority of domestic and stock wells in the area. Most wells are less than 100 feet in depth and are completed in lignite beds. Halliday obtains it's present water supply from a horizontal well developed in a lignite seam of the upper Sentinel Butte, but the well yields only a few

gallons per minute. Water in the Sentinel Butte aquifer is of the sodium sulfate or bicarbonate type. Sulfate, hardness, iron, and manganese concentrations commonly exceed recommended levels.

Glacial deposits consisting of till, alluvium and buried outwash occur in this area but they are thin and often discontinuous. Spring and Hans Creeks are underlain with buried outwash deposits which constitute the Spring Creek and Goodman Creek aquifers.

The Halliday aquifer, an outwash deposit, is variable in thickness and may be interbedded with silt and clay that can effectively reduce well yields. The deposit is narrow, averages about 10 feet in thickness, and underlies about one square mile of Spring Creek valley in this area. Aquifer materials are mostly fine- to medium-grained sand, but gravel may be encountered locally. Two test wells, completed in the aquifer east of Halliday and pumped at rates of 20 gpm and 30 gpm, had excessive drawdown due to the low permeability of the deposit in this area. Water quality in the aquifer is subject to appreciable change from one location to another and is directly influenced by the underflow of water from the Sentinel Butte Formation. Recharge from the Sentinel Butte is especially significant in contributing to the high concentrations of sodium and sulfate in the Halliday aquifer. Development of the aquifer and the resulting pumpage, may induce additional recharge from adjacent bedrock and thus cause deterioration in water quality. Water in the Halliday aquifer is very hard and should be treated for hardness, and excessive concentrations of iron and manganese.

The Goodman Creek aquifer is located about 6½ miles northeast of Halliday. It consists of more than 70 feet of buried outwash that was deposited in a glacial diversion channel. An upper sand unit and a lower gravel unit comprise

the deposit that underlies an area of about 1½ square miles in the Halliday area. The aquifer also extends into portions of Dunn and Mercer Counties and has the greatest potential for ground-water development in the area. Total dissolved solids average less than 1,000 mg/l and the water is of the sodium bicarbonate or sodium sulfate type. Treatment for iron and manganese may be required.

TABLE 1 -- CHEMICAL ANALYSES

(Analytical results are in milligrams per liter except where indicated)

AQUIFERS Owner or designation	Location	Depth of well (feet)	Temp(°F)	Date of collection	(SiO_2)	(Fe)	(Mn)	(Ca)	(Mg)	(Na)	(K)	(HCO_3)	(CO_3)	(SO_4)	(Cl)	(F)	(NO_3)	(B)	Total dissolved solids	Total hardness as $CaCO_3$	Total hardness Noncarbonate	Percent sodium	S.A.R.	Specific conductance	pH
FOX HILLS - HELL CREEK AQUIFER																									
Oliver Flaget	145-91-20 aaa$_1$	1450	–	1969	–	3.90	–	–	–	647	–	1260	32	1.6	92	–	–	–	1520	11	0	–	–	2370	8.5
Oliver Flaget	145-91-20 aaa$_1$	1450	–	10-10-71	10	0	0.02	4.6	2.1	616	2.4	1530	14	24	60	2.7	1.0	1.80	1560	20	0	98	60	2400	8.3
Oliver Flaget	145-91-20 aaa$_1$	1450	50	2-2-72	9.8	0.48	0.08	4.1	2.2	630	1.9	1570	0	18	68	3.0	1.0	1.60	1510	19	0	98	63	2380	8.1
SENTINEL BUTTE AQUIFER																									
Oliver Flaget	145-91-16 cc	250	–	—	–	0.62	–	–	–	–	–	328	0	1100	19	–	4.0	–	2060	835	–	–	–	2520	7.2
Oliver Flaget	145-91-20 aaa$_2$	190	–	—	–	5.70	–	–	–	12.8	–	478	0	647	8	–	0	–	1480	425	–	60	6.2	2130	7.3
Oliver Flaget	145-91-20 aaa$_3$	125	–	1968	–	7.40	–	–	–	7.4	–	400	0	480	4.4	–	0	0.45	1220	445	0	45	3.5	1630	7.4
Cliff Ferebee	145-92-12 dcc	60	48	7-11-72	20	4.30	0.90	30	24	72	4.2	192	0	179	0	0.8	2.5	0.29	452	173	16	47	2.4	672	7.0
George Ferebee	145-92-14 bdd	Spring	43	11-10-72	16	0.62	0.39	41	30	70	4.2	238	0	175	3.9	0.9	0.1	0.53	416	224	29	40	2.0	712	6.7
Cliff Ferebee	145-92-22 daa	40	46	7-11-72	18	0.20	0.02	6.5	7.3	414	3.8	691	0	372	0	0.9	1.0	1.10	1180	46	0	95	27	1760	7.8
City well 1	145-92-24 bcd	Spring	46	8-4-71	25	1.20	1.10	202	125	132	7.8	286	0	1060	9.1	0.9	1.0	0.53	1830	1020	785	21	1.8	2150	7.5
City well 1	145-92-24 bcd	Spring	46	10-27-71	25	1.40	1.50	244	102	137	7.9	271	0	1040	15	0.7	2.5	0.53	1670	1030	808	22	1.8	2000	6.6
Test hole 72-1	145-92-25 aac	74	50	9-13-72	14	0.70	0.10	415	288	591	12	760	0	2640	47	0.5	0	2.80	4880	2220	1600	37	5.5	5220	7.9
Test hole 72-4	145-92-25 adc	146	49	9-13-72	7.9	0.42	0.04	5.6	4.4	756	3.7	1290	0	624	6.0	4.8	1.0	0.68	2080	32	0	98	58	3030	8.2
Larry Weisz	146-91-21 dcd	60	54	9-28-71	89	0	0.08	27	17	1050	6.4	937	0	1660	4.0	0.8	2.5	0.44	3110	138	0	94	39	4260	8.0
Gust Geleiman	146-91-22 bba	197	50	7-12-72	4.7	0.62	0.03	1.8	0.6	550	2.3	863	62	401	0	0.6	1.0	0.36	1490	7	0	99	90	2200	8.9
HALLIDAY AQUIFER																									
Test hole 72-3	145-91-30 bbd	31	47	9-13-72	20	0.23	0.32	65	48	374	4.2	624	0	539	78	0.7	1.0	0.18	1470	361	0	69	8.6	2120	8.0
Test hole 8242	145-91-30 bdd	25	45	11-10-71	21	1.70	0.79	180	126	321	7.3	581	0	1130	6.1	0.8	1.0	0.44	2030	968	491	42	4.5	2630	7.7
Test hole 8243	145-91-30 caa	35	45	11-11-71	22	0.97	0.27	73	57	339	5.5	647	0	545	37	1.1	1.0	0.62	1350	418	0	63	7.2	2030	7.9
Test hole 8239	145-92-24 ccb	30	45	11-15-71	19	0.0	0.08	13	69	410	2.9	725	0	351	0.9	1.0	1.0	0.66	1160	61	0	93	23	1800	8.1
Test hole 8238	145-92-24 ccc	15	45	11-12-71	22	0.36	0.45	81	56	283	4.3	785	0	375	4.0	1.1	1.0	0.22	1180	432	0	58	5.9	1760	8.0
Test hole 8249	145-92-24 cdd$_2$	35	48	11-12-71	13	0.24	0.06	15	23	633	3.9	948	0	690	9.1	3.4	1.0	0.75	1790	134	0	91	24	2670	8.2
Margaret Bergstedt	145-92-25 baa$_1$	14	52	8-4-71	21	0.0	0.04	92	190	805	6.0	1120	0	1660	75	1.0	129	0.80	3600	1010	91	63	11	4710	8.0
Test hole 8251	145-92-25 baa$_2$	35	45	11-11-71	19	1.10	0.06	44	35	656	5.5	820	0	949	7.6	1.8	0.3	0.35	2040	253	0	85	18	2950	8.1
GOODMAN CREEK AQUIFER																									
Wilfred Schaper	146-91-20 ddd	43	43	8-11-71	11	0.0	0.01	91	37	129	4.5	420	0	322	4.4	0.8	2.5	0.44	806	379	35	42	2.9	1230	7.6
(west well) Test hole 8216	146-91-21 cdd$_1$	93	43	10-27-71	22	0.0	0.55	91	34	46	4.1	423	0	130	1.4	0.7	1.0	0.04	514	366	19	21	1.0	811	7.5
(east well) Test hole 8216-A	146-91-21 cdd$_2$	193	44	10-27-71	25	1.30	0.16	94	27	166	7.0	506	0	287	2.6	0.8	0.3	0.0	870	345	0	51	3.9	1170	7.6
Larry Weisz	146-91-21 ddc	Spring	49	9-28-71	13	0.14	0.02	89	42	75	4.4	298	0	321	2.3	0.8	1.0	0.22	685	396	152	29	1.6	1010	6.8
Test hole 8217	146-91-28 aba	93	45	10-28-71	15	0.0	0.52	149	86	489	5.5	630	0	1190	5.1	0.9	1.0	0.40	2100	728	211	59	7.9	2640	8.1
SURFACE WATER																									
Spring Creek	145-91-30 bbb	–	72	7-11-72	10	0	0.09	78	60	273	6.9	529	0	591	0	0.5	2.5	0.50	1280	441	7	57	5.6	1810	8.2
Spring Creek	145-92-24 ddd	–	48	10-27-71	9	0.32	0.03	129	37	270	8.1	522	0	641	9.1	0.7	1.0	0.66	1410	475	47	55	5.4	1830	7.8

TABLE 2--LOGS OF TEST HOLES

The following test hole logs are a summary of data from driller's logs, geologist's sample descriptions, resistivity, spontaneous potential, and gamma ray electric logs. Color descriptions are of wet samples and are based upon color standards of the National Research Council (Goddard and others, 1948). Grain-size classification is C. K. Wentworth's scale from Pettijohn (1957).

Test holes are called observation wells when they have been completed with 1¼-inch or 2-inch diameter casing and screened at the bottom. Well depths, screened producing intervals, and water levels, with date of measurement, are so designated. Water levels are in feet below land surface. Elevations were obtained for selected test holes using a Paulin altimeter and local U. S. Coast and Geodetic Survey bench mark control.

Explanation of Lithologic Symbols

Sand and gravel

Till

Clay

Sandstone

Siltstone and claystone

Lignite

Shale

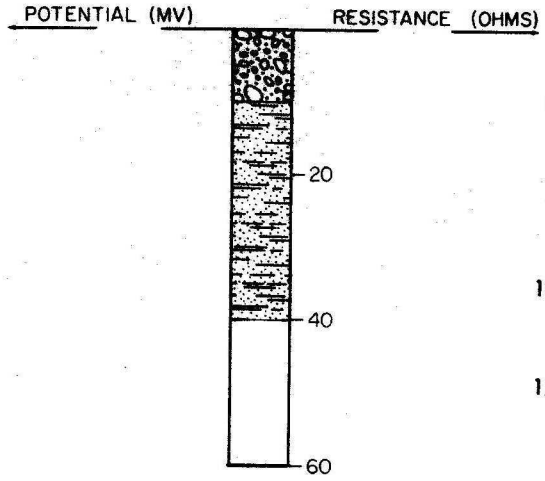
Test Hole 8213

LOCATION: 144-92-5abb

DATE DRILLED: 10-26-71

ELEVATION:
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0 - 1	Topsoil, very silty, sandy, brownish-black.
1 -10	Clay, very silty, sandy, pebbly, dark-yellowish-brown, moderately cohesive, slightly plastic, oxidized (Till).

Sentinel Butte Formation

10 -15	Claystone, moderately silty, moderate-yellowish-brown, oxidized.
15 -40	Claystone, silty, medium gray to light-greenish-gray, thin lignite seams, non-calcareous.

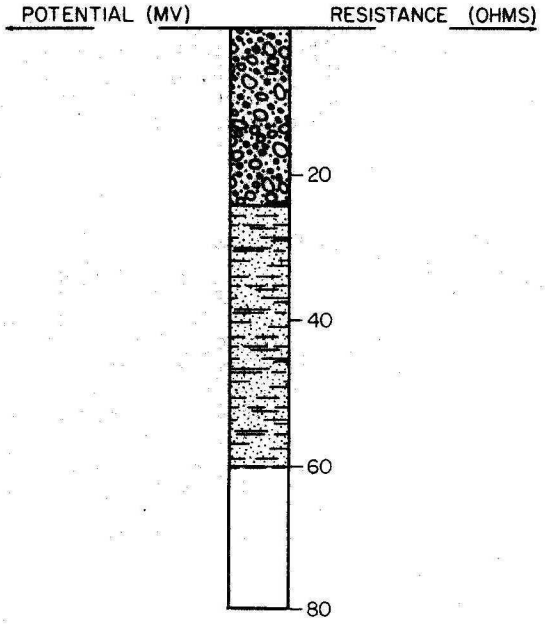
Test Hole 8223

LOCATION: 145-91-5ddd$_1$

DATE DRILLED: 11-2-71

ELEVATION: 2205
(FT, MSL)

DEPTH: 60
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty, clayey, brownish-black.
1-24	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, moderately cohesive, slightly plastic oxidized (Till).

Sentinel Butte Formation

24-30	Claystone, very silty, dusky-yellow, soft, oxidized.
30-40	Claystone, silty, light-brownish-gray to medium gray with pale brown, carbonaceous bedding, non-calcareous.
40-60	Claystone, silty, slightly sandy, light olive gray to light gray, slightly calcareous.

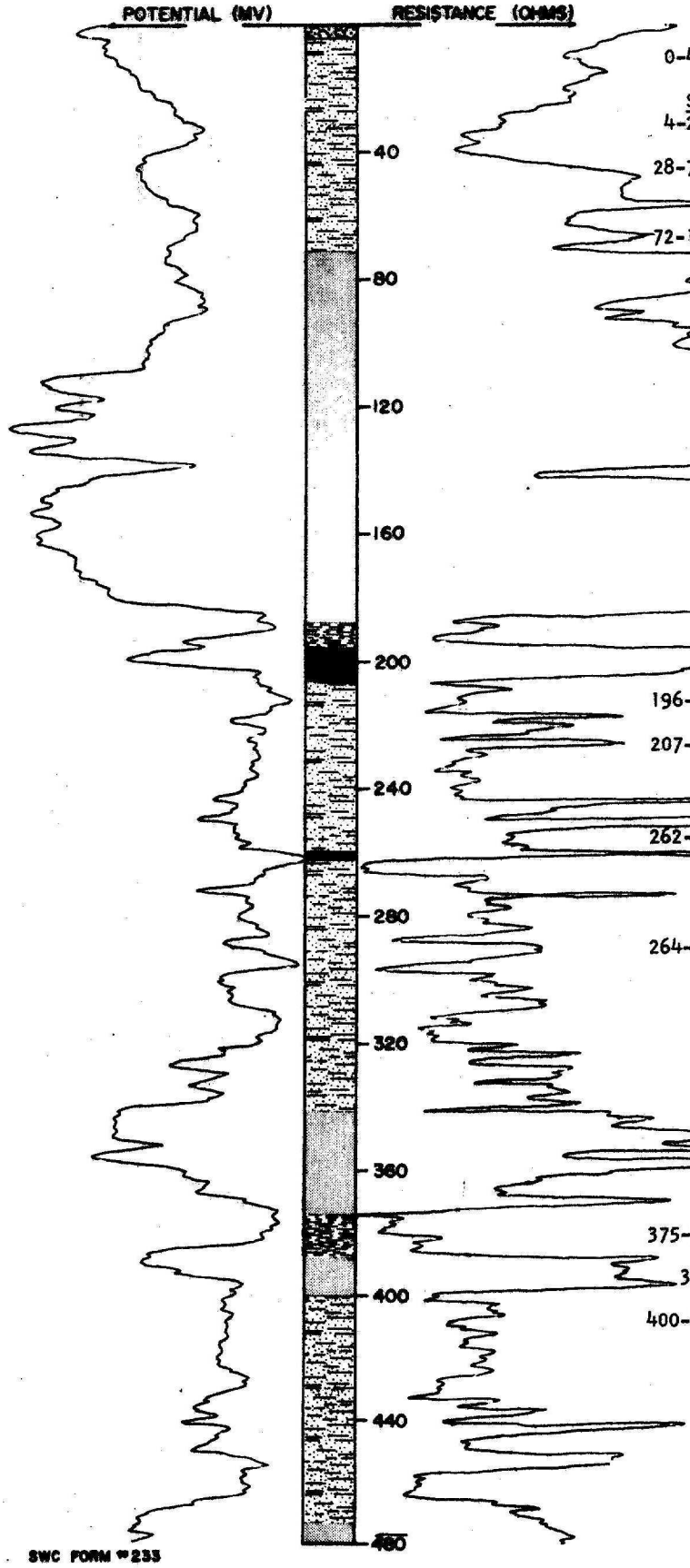
TEST HOLE 4604

LOCATION: 145-91-5DDD2

DATE DRILLED: November, 1973

ELEVATION: 2200 (FT, MSL)

DEPTH: 880 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-4 Clay, silty, sandy, pebbly, olive brown, oxidized (till)

Sentinel Butte Formation

4-28 Siltstone, clayey, sandy, yellowish-gray, oxidized.

28-72 Claystone and siltstone, brownish-gray to light olive gray, carbonaceous, bentonitic.

72-188 Sandstone, very fine to coarse, dark greenish-gray, friable to loose.

188-196 Shale, greenish-gray to dark brown, carbonaceous.

196-207 Lignite, black, hard, shale partings.

207-262 Claystone and siltstone, medium gray, thin lignites at 218, 227, 246, 253, carbonaceous.

262-264 Lignite, black, hard.

264-345 Siltstone, sandy, medium gray to dark gray, carbonaceous shale interbeds, concretions, bentonitic.

345-375 Sandstone, light olive gray to greenish-gray, very fine to fine, silty, shale interbeds.

Tongue River Formation

375-390 Shale, silty, dark brown, carbonaceous.

390-400 Sandstone, light olive gray, carbonaceous.

400-474 Siltstone, clayey, sandy, variagated grays and greens, sandstone concretions, carbonaceous streaks.

SWC FORM #235

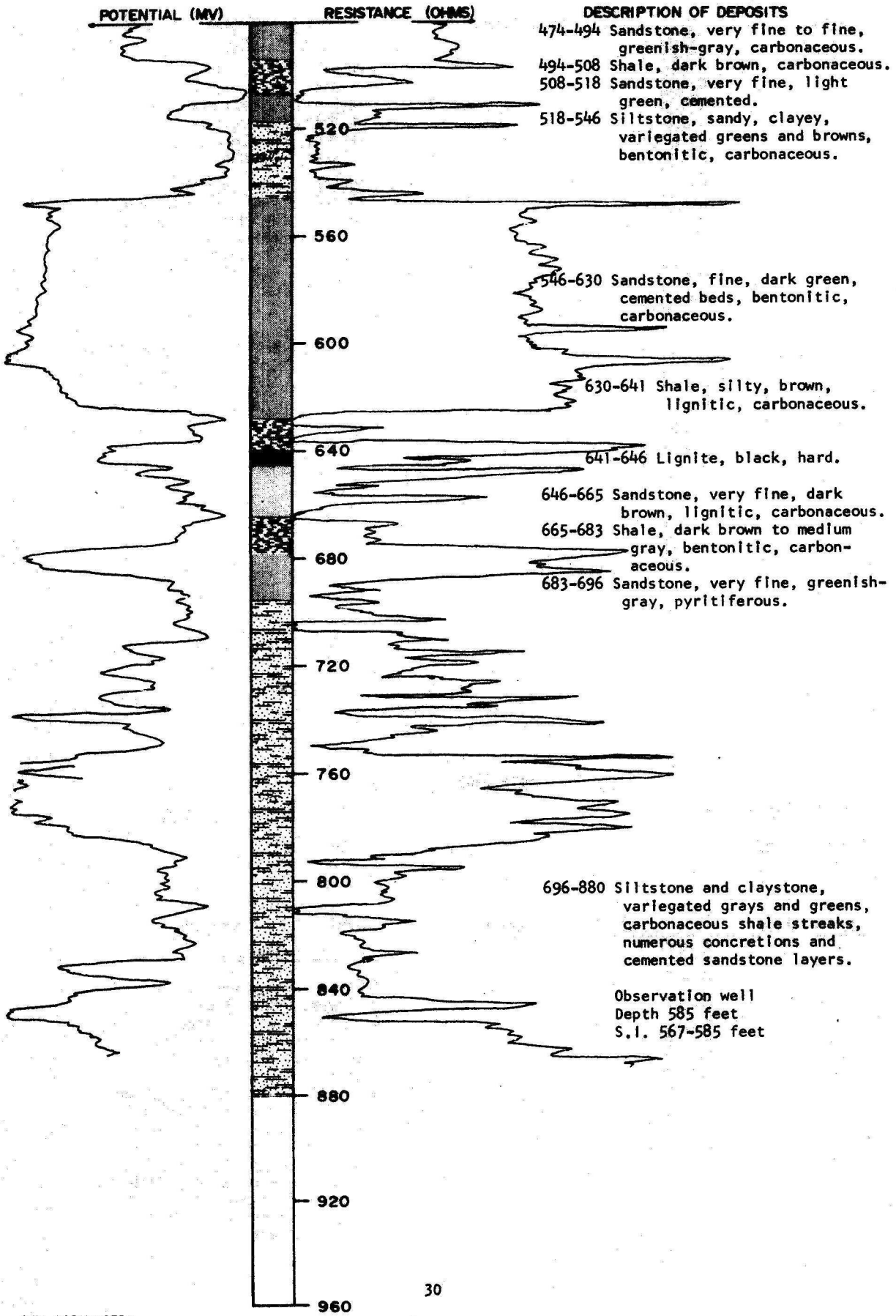
TEST HOLE 4604 (cont.)

LOCATION: 145-91-5DDD2

DATE DRILLED: November, 1973

ELEVATION: 2200
(FT, MSL)

DEPTH: 880
(FT)



DESCRIPTION OF DEPOSITS

474-494 Sandstone, very fine to fine, greenish-gray, carbonaceous.

494-508 Shale, dark brown, carbonaceous.

508-518 Sandstone, very fine, light green, cemented.

518-546 Siltstone, sandy, clayey, variegated greens and browns, bentonitic, carbonaceous.

546-630 Sandstone, fine, dark green, cemented beds, bentonitic, carbonaceous.

630-641 Shale, silty, brown, lignitic, carbonaceous.

641-646 Lignite, black, hard.

646-665 Sandstone, very fine, dark brown, lignitic, carbonaceous.

665-683 Shale, dark brown to medium gray, bentonitic, carbonaceous.

683-696 Sandstone, very fine, greenish-gray, pyritiferous.

696-880 Siltstone and claystone, variegated grays and greens, carbonaceous shale streaks, numerous concretions and cemented sandstone layers.

Observation well
Depth 585 feet
S.I. 567-585 feet

SWC FORM 233A

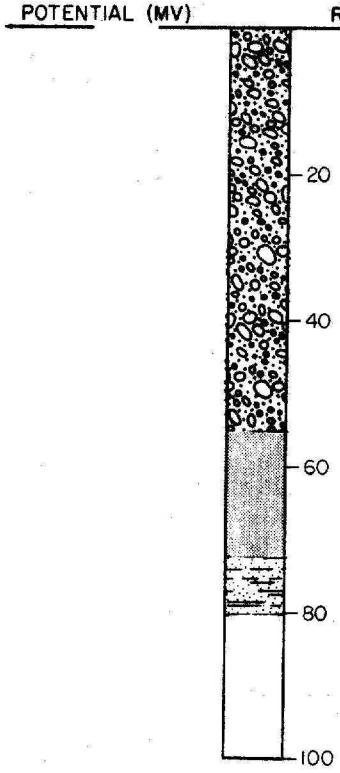
Test Hole 8215

LOCATION: 145-91-17dcc

DATE DRILLED: 10-26-71

ELEVATION: 2184
(FT, MSL)

DEPTH: 80
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty, sandy, brownish-black.
1-55	Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, cohesive, moderately plastic, oxidized (Till).

Sentinel Butte Formation

55-57	Sandstone, fine-grained, medium-bluish-gray with dark-yellowish-brown mottling, cemented, hard, micaceous, calcareous, lignitic.
57-72	Sandstone, very clayey and silty, moderate-yellowish-brown, micaceous, lignitic, well oxidized.
72-80	Claystone, silty, medium-dark-gray with thin brownish-gray, carbonaceous bedding, non-calcareous.

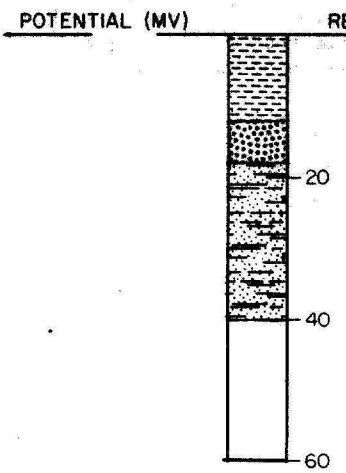
Test Hole 8209

LOCATION: 145-91-19ccd

DATE DRILLED: 10-26-71

ELEVATION: 2040
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, sandy, very silty, clayey, brownish-black.
1-12	Clay, very silty, sandy, dark-yellowish-brown, slightly cohesive, crumbly, oxidized (Alluvium).
12-18	Sand, slightly gravelly, clayey, fine- to coarse-grained, sub-angular to subrounded, fair sorting, lignitic, oxidized.

Sentinel Butte Formation

18-40	Claystone, medium-gray to light-greenish-gray with brownish-gray, carbonaceous bedding, non-calcareous.

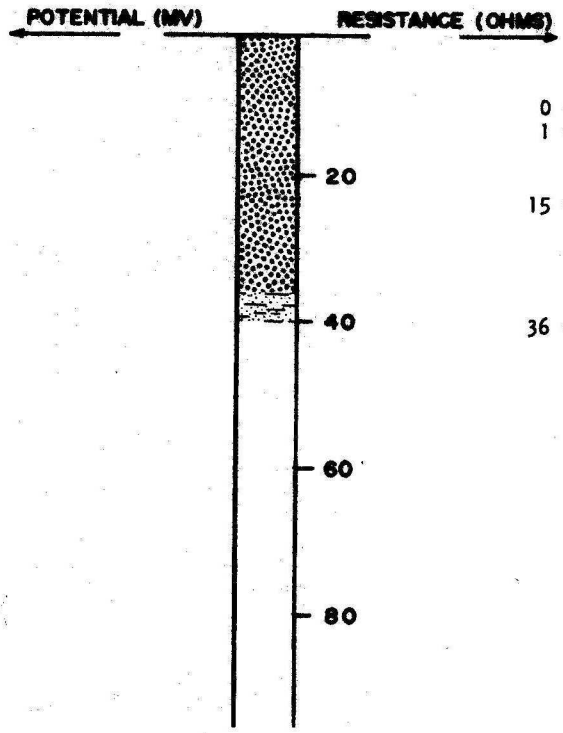
TEST HOLE 72-3

LOCATION: 145-91-30bbd

DATE DRILLED: 8-29-72

ELEVATION: 2043
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0 - 1 Topsoil, sandy loam, dark-brown.

1 - 15 Gravel, sandy, fine to coarse, subrounded, oxidized, mostly carbonates, some silicates and sandstone.

15 - 36 Gravel, slightly sandy, fine to coarse, subrounded.

Sentinel Butte Formation

36 - 40 Claystone, silty, slightly sandy, light-gray to medium-gray, bentonitic.

Observation Well
Depth 31 Feet
Screened Interval 28-31 Feet
Water Level 9.45 Feet
September 13, 1972

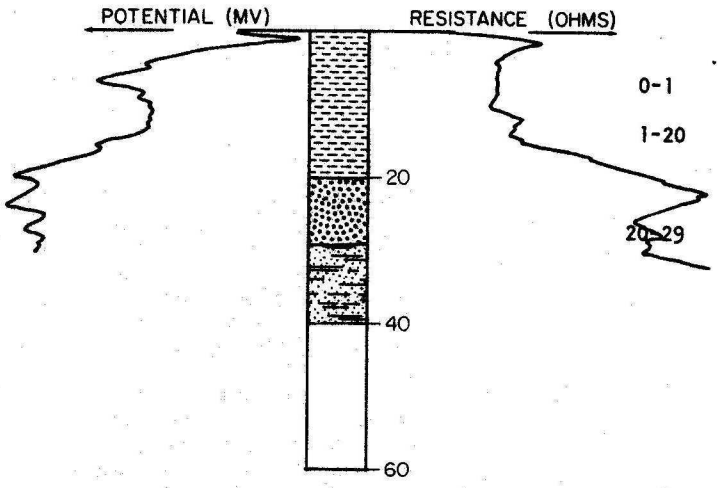
Test Hole 8242

LOCATION: 145-91-30bdd

DATE DRILLED: 11-9-71

ELEVATION: 2041
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, very silty, sandy, clayey, grayish-black.

1-20 Clay, very silty, dark-yellowish-brown, moderately cohesive, slightly plastic, oxidized (Alluvium).

20-29 Gravel, slightly clayey, about 40 percent sand, fine to coarse, angular to well-rounded, fair sorting, about 40 percent brownish, western, siliceous rocks, 20 percent shale, 30 percent local bedrock, 10 percent granitics, carbonates and lignite.

Sentinel Butte Formation

29-40 Claystone, silty, medium-light-gray to medium-gray, calcareous.

Observation Well
Depth 25 feet
Screened interval 22-25 feet
Water level 11.30 feet
February 2, 1972

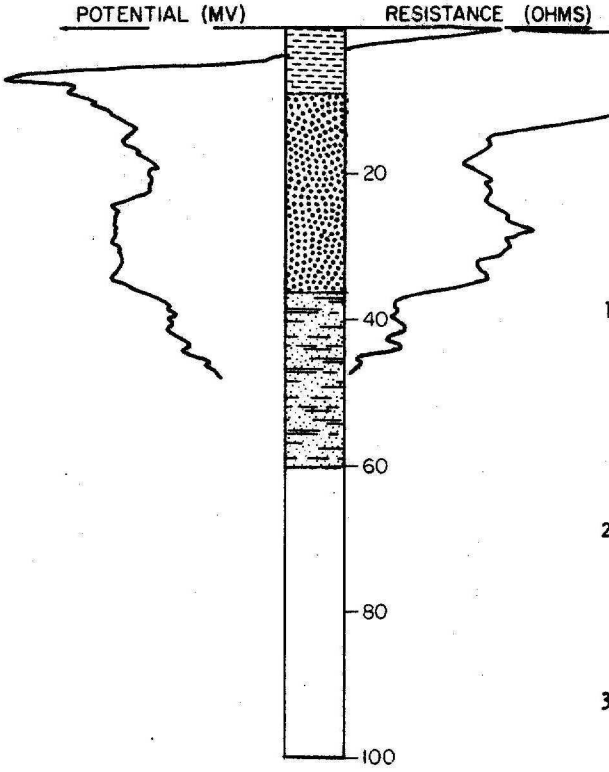
Test Hole 8243

LOCATION: 145-91-30caa

DATE DRILLED: 11-9-71

ELEVATION: 2040 (FT, MSL)

DEPTH: 60 (FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-9	Clay, very silty, dark-yellowish-brown, moderately cohesive, slightly plastic, oxidized (Alluvium).
9-14	Sand, slightly clayey, very fine- to medium-grained, subangular to subrounded, moderately well-sorted, oxidized.
14-20	Gravel, about 30 percent sand, fine to coarse, angular to subrounded, fair sorting, about 30 percent brownish, western, siliceous rocks, 40 percent local bedrock, 20 percent shale, 10 percent granitics, carbonates, lignite, and scoria.
20-36	Sand, silty, moderately clayey, very fine- to medium-grained, subangular to subrounded, moderately well-sorted, very lignitic.
	Sentinel Butte Formation
36-60	Claystone, medium-bluish-gray, slightly calcareous.

Observation Well
Depth 35 feet
Screened interval 33-35 feet
Water level 11.60 feet
February 2, 1972

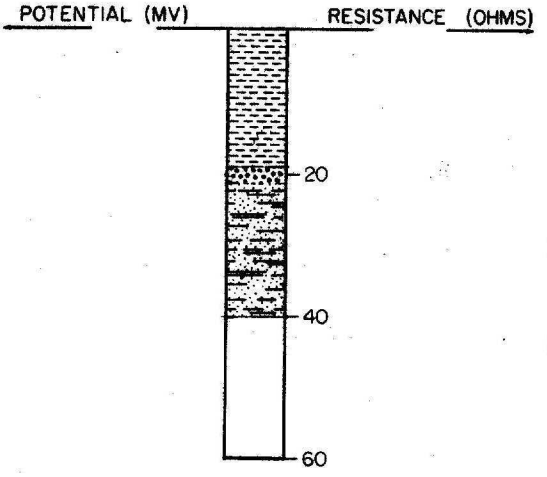
Test Hole 8244

LOCATION: 145-91-30cad

DATE DRILLED: 11-9-71

ELEVATION: 2050 (FT, MSL)

DEPTH: 40 (FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-1	Topsoil, silty, clayey, grayish-black.
1-12	Clay, very silty, slightly sandy, moderate-yellowish-brown to dark-yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).
12-19	Clay, very silty, occasional thin sand layers, olive-gray, moderately cohesive, moderately plastic, calcareous (Alluvium).
19-21	Gravel, slightly sandy, clayey, fine to coarse, angular to rounded, poorly sorted, oxidized.
	Sentinel Butte Formation
21-40	Claystone, moderately silty, medium gray, calcareous.

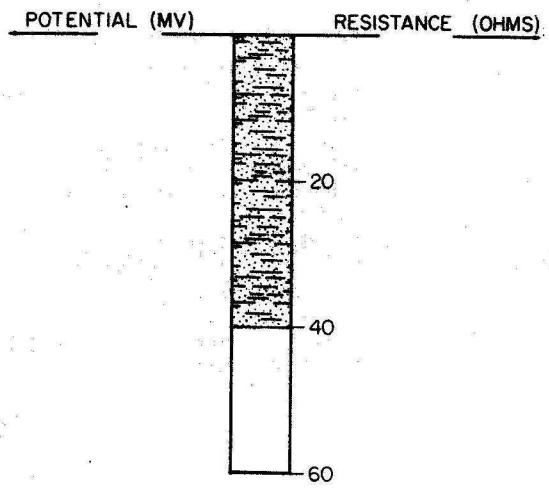
Test Hole 8210

LOCATION: 145-91-30dcc

DATE DRILLED: 10-26-71

ELEVATION: 2070
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

	Sentinel Butte Formation
0-32	Claystone, moderate-yellowish-brown, non-calcareous, thin lignite stringers, oxidized.
32-40	Claystone, medium-gray to light-greenish-gray, a few thin lignite stringers, non-calcareous.

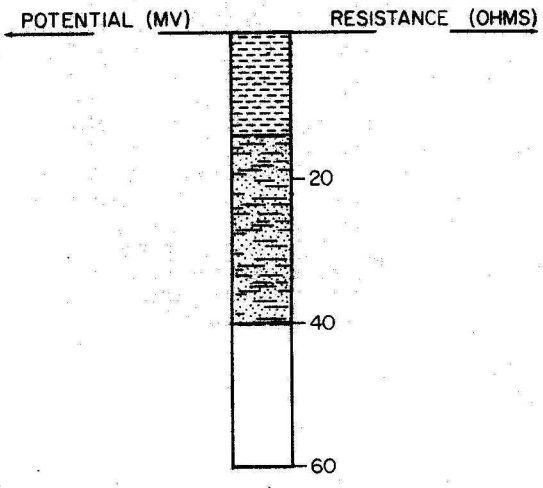
Test Hole 8245

LOCATION: 145-91-33add

DATE DRILLED: 11-10-71

ELEVATION:
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-1	Topsoil, silty, clayey, grayish-black.
1-14	Clay, very silty, slightly sandy, dark-yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).
	Sentinel Butte Formation
14-40	Claystone, silty, medium-gray to medium-bluish-gray, slightly calcareous.

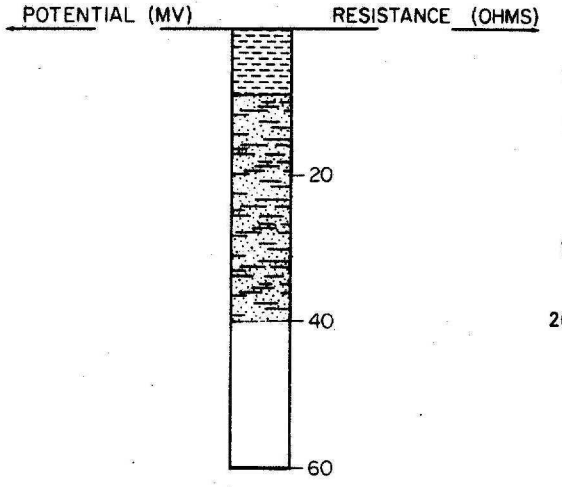
Test Hole 8246

LOCATION: 145-91-34cbc

DATE DRILLED: 11-10-71

ELEVATION:
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-1	Topsoil, silty, clayey, grayish-black.
1-9	Clay, very silty, sandy, dark-yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).
	Sentinel Butte Formation
9-20	Claystone, silty, yellowish-gray, well oxidized.
20-40	Siltstone, clayey, medium-gray, non-calcareous.

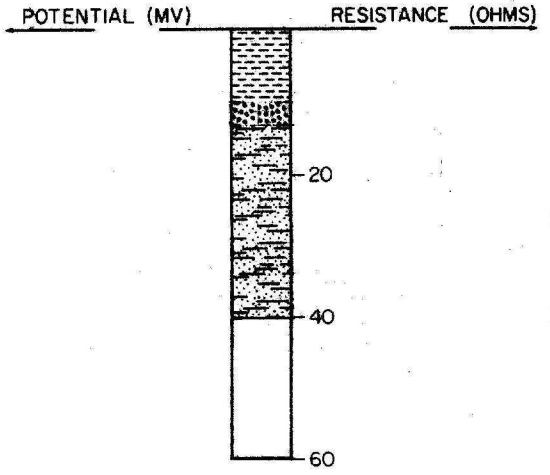
Test Hole 8247

LOCATION: 145-92-22daa

DATE DRILLED: 11-10-71

ELEVATION:
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-1	Topsoil, silty, clayey, grayish-black.
1-10	Clay, very silty, sandy, dark-yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).
10-13	Sand, slightly gravelly, fine- to coarse-grained, subangular, fair sorting, lignitic.
	Sentinel Butte Formation
13-40	Claystone, moderately silty, medium-gray to medium-light-gray, calcareous.

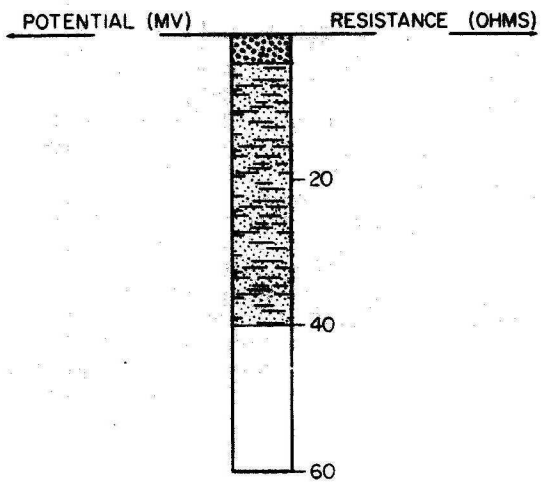
Test Hole 8211

LOCATION: 145-92-22dad

DATE DRILLED: 10-26-71

ELEVATION:
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-1	Topsoil, very sandy, silty, brownish-black.
1-4	Sand, silty, clayey, fine- to medium-grained, subangular, moderately well-sorted, well oxidized.
	Sentinel Butte Formation
4-18	Claystone, moderate-yellowish-brown, well oxidized, bedded, a few thin lignite stringers.
18-40	Claystone, very silty, medium-gray to medium-light-gray, bedded, a few thin lignite stringers and carbonaceous laminae, non-calcareous.

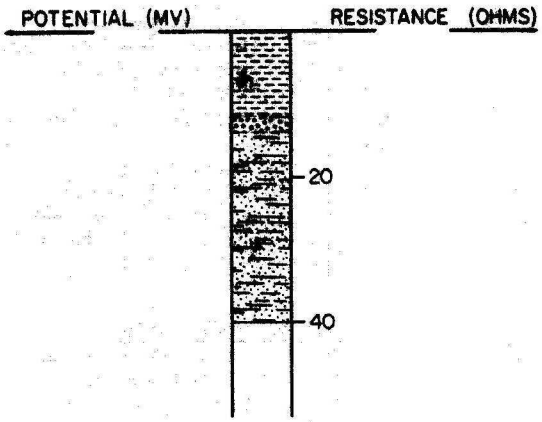
Test Hole 8248

LOCATION: 145-92-23bcc

DATE DRILLED: 11-10-71

ELEVATION:
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-1	Topsoil, silty, clayey, grayish-black.
1-12	Clay, very silty, slightly sandy, dark-yellowish-brown, moderately cohesive, slightly plastic, oxidized (Alluvium).
12-14	Gravel, sandy, fine to coarse, poorly sorted, oxidized.
	Sentinel Butte Formation
14-40	Claystone, moderately silty, medium-light-gray to medium-gray, calcareous.

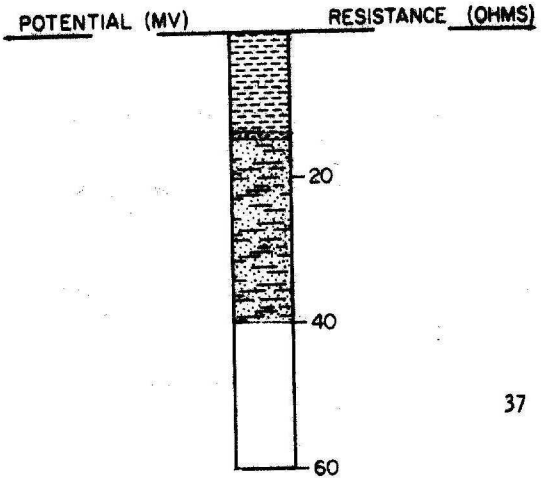
Test Hole 8241

LOCATION: 145-92-23daa

DATE DRILLED: 11-9-71

ELEVATION: 2055
(FT, MSL)

DEPTH: 40
(FT)



37

DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, very sandy, silty, clayey, grayish-black.

1-14 Clay, very silty, sandy, moderate-yellowish-brown to dark-yellowish-brown, slightly cohesive, crumbly, oxidized (Alluvium).

14-15 Gravel, fine to coarse, angular to subrounded, poorly sorted, well oxidized.

Sentinel Butte Formation

15-40 Claystone, moderately silty, medium-gray with brownish-gray bedding, highly calcareous, a few thin lignite stringers.

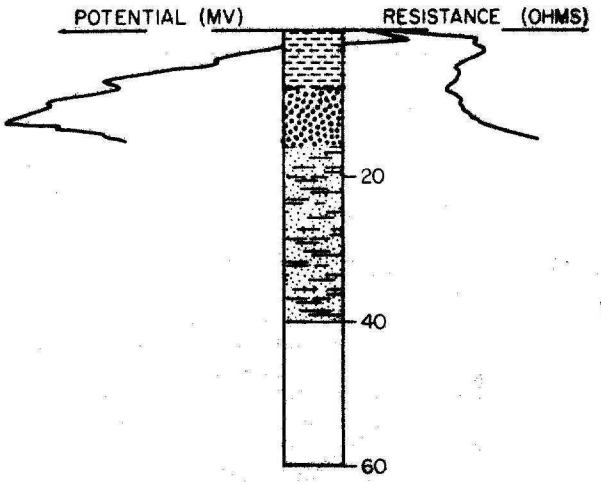
Test Hole 8240

LOCATION: 145-92-23dad

DATE DRILLED: 11-9-71

ELEVATION: 2045
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, silty, very sandy, clayey, grayish-black.

1-8 Clay, very silty, sandy, moderate-yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).

8-12 Sand, very fine- to medium-grained, angular to subrounded, moderately well-sorted, lignitic, slightly oxidized.

12-16 Gravel, about 30 percent, fine to coarse, angular to rounded, fair sorting, about 30 percent shale, 40 percent brownish, western, siliceous rocks, 20 percent carbonates, 10 percent local bedrock, lignitic.

Sentinel Butte Formation

16-40 Claystone, very silty, medium-light-gray to medium-gray, highly calcareous, a few thin lignite stringers.

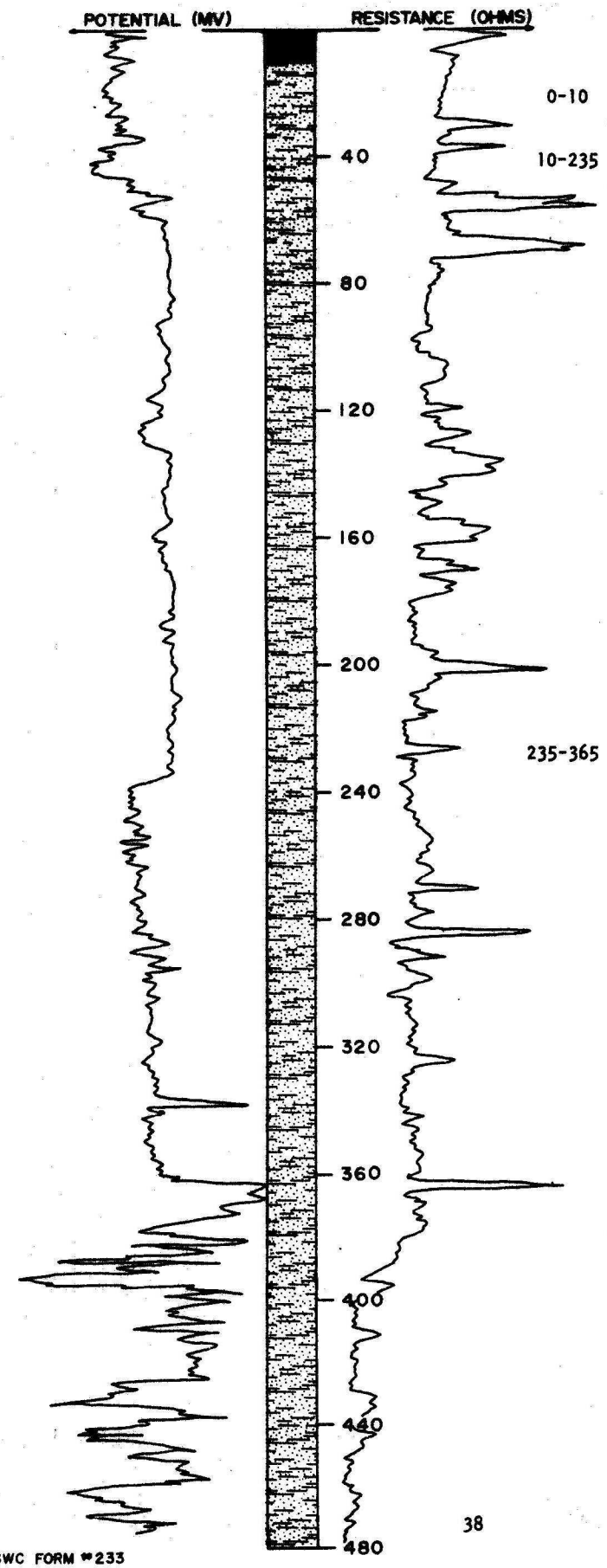
TEST HOLE 8222

LOCATION: 145-92-24bbc

ELEVATION: 2115
(FT, MSL)

DATE DRILLED: 11-2-71

DEPTH: 700
(FT)



DESCRIPTION OF DEPOSITS

Sentinel Butte Formation

0-10 Lignite, black to brownish-black, soft to brittle, some thin carbonaceous shale bedding.

10-235 Claystone and siltstone, medium-gray to medium-bluish-gray, variegated coloration, occasional thin cemeted sandstone concretions and dark-brown to brownish-black, carbonaceous shale beds, a few thin lignite stringers, calcareous.

Tongue River Formation

235-365 Siltstone and claystone, sandy, medium-gray to medium-bluish-gray, variegated coloration, some thin greenish-gray bentonite bedding and cemented sandstone concretions, a few yellowish-gray limonitic nodules, highly calcareous.

SWC FORM #233

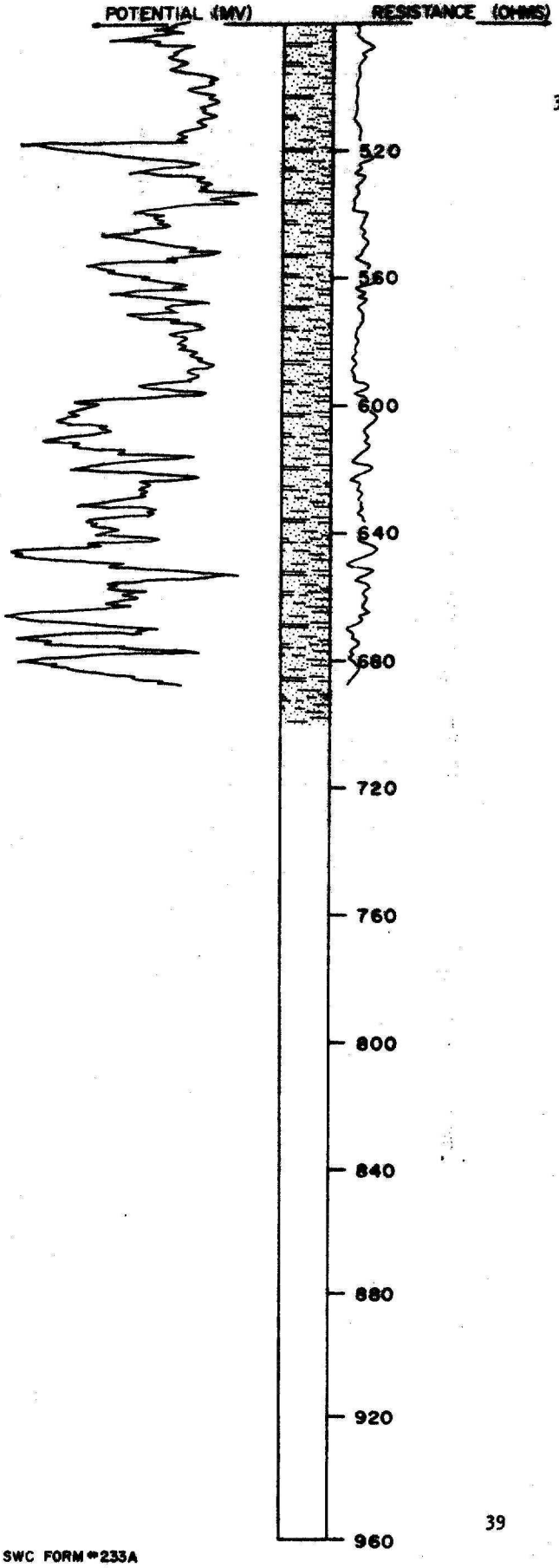
TEST HOLE 8222 Continued

LOCATION: 145-92-24bbc

DATE DRILLED: 11-2-71

ELEVATION: 2115 (FT, MSL)

DEPTH: 700 (FT)



	DESCRIPTION OF DEPOSITS
365-700	Siltstone, medium-light-gray to light-brownish-gray, some thin, brownish-gray carbonaceous shale bedding, a few thin lignite stringers and cemented sandstone concretions, an occasional, greenish-gray bentonitic claystone bed, highly calcareous.

SWC FORM #233A

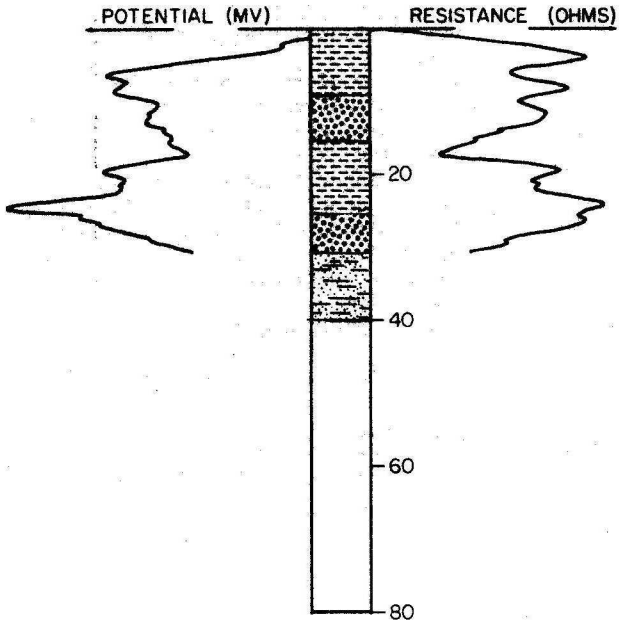
Test Hole 8239

LOCATION: 145-92-24ccb

DATE DRILLED: 11-9-71

ELEVATION: 2045
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty, clayey, grayish-black.
1-9	Clay, very silty, sandy, moderate-yellowish-brown, a few gravelly sand layers, slightly cohesive, plastic, oxidized (Alluvium).
9-15	Sand, slightly clayey, silty, very fine- to medium-grained, subangular to subrounded, well-sorted, slightly oxidized.
15-25	Clay, very silty, sandy, medium-dark gray, moderately cohesive, plastic, lignitic, calcareous, (Alluvium).
25-30	Gravel, about 40 percent sand, fine to coarse, angular to rounded, fair sorting, about 40 percent brownish, western, siliceous rocks, 20 percent carbonates, 30 percent shale, 10 percent local bedrock.

Sentinel Butte Formation

30-40	Claystone, silty, light-gray, calcareous.

Observation well
Depth 30 feet
Screened interval 27-30 feet
Water level 7.60 feet
February 2, 1972

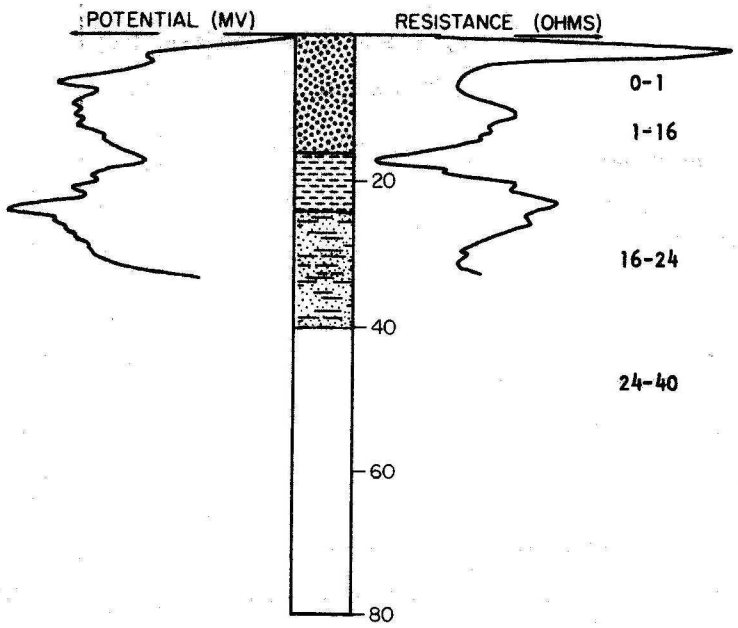
Test Hole 8238

LOCATION: 145-92-24ccc

DATE DRILLED: 11-9-71

ELEVATION: 2044
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty, clayey, grayish-black.
1-16	Sand, slightly clayey, very fine- to medium-grained, sub-angular, moderately well-sorted, lignitic, slightly oxidized.
16-24	Clay, very silty, sandy, a few thin sand layers, medium-dark gray, slightly cohesive, plastic, lignitic (Alluvium).

Sentinel Butte Formation

24-40	Claystone, very silty, medium-gray, calcareous.

Observation well
Depth 15 feet
Screened interval 12-15 feet
Water level 5.80 feet
February 2, 1972

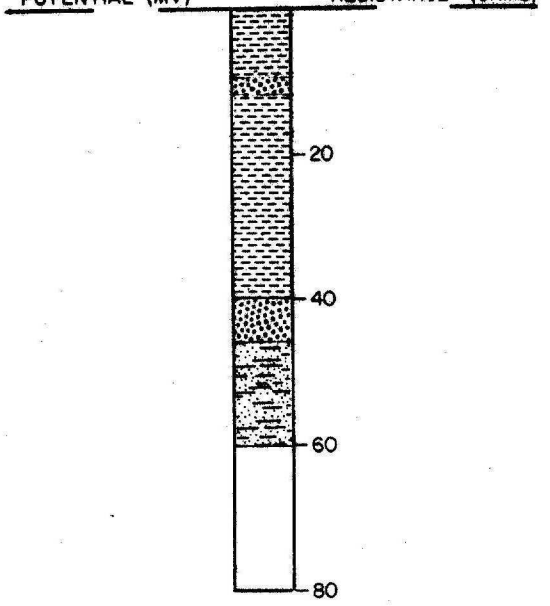
Test Hole 8212

LOCATION: 145-92-24ccd

DATE DRILLED: 10-26-71

ELEVATION: 2042
(FT, MSL)

DEPTH: 60
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty, claley, grayish-black.
1-10	Clay, very silty, sandy, dark-yellowish-brown, slightly cohesive, plastic, well oxidized (Alluvium).
10-12	Gravel, sandy, clayey, fine to coarse, poorly sorted, oxidized.
12-40	Clay, extremely silty, medium-gray, slightly cohesive, highly plastic, very calcareous (Alluvium).
40-46	Sand, slightly clayey, very fine- to medium-grained, moderately well-sorted, much lignite.

Sentinel Butte Formation

46-60	Claystone, medium-gray to light-greenish-gray, non-calcareous.

145-92-24cdd$_1$
City of Halliday (No. 2)
(Log from Layne-Minnesota Co., 1969)

Elevation: 2046

Date Drilled: October, 1969

Depth: 41

Description of Deposits

Glacial Drift

From	To (feet)	
0	15	Clay (Alluvium).
15	37	Sand, fine-grained, shaley, lignitic.
37	41	Sand, fine-grained, gravelly, shaley
41	43	Clay (Alluvium).

Well completed with 34 feet of 10-inch diameter steel casing and 10 feet of 10-inch diameter stainless steel shutter screen and gravel-packed.

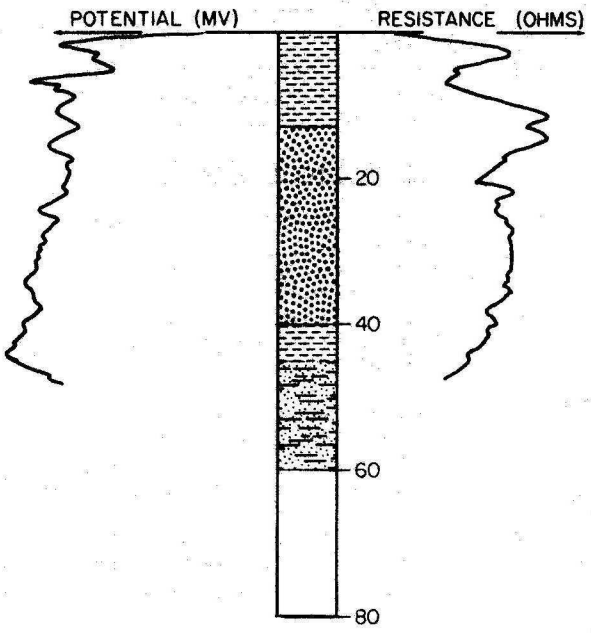
Test Hole 8249

LOCATION: 145-92-24cdd$_2$

DATE DRILLED: 11-10-71

ELEVATION: 2046
(FT, MSL)

DEPTH: 60
(FT)



DESCRIPTION OF DEPOSITS

0-13 **Glacial Drift**
Clay, very silty, dark-yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).

13-40
Sand, slightly clayey, slightly gravelly, very fine- to coarse-grained, subangular to sub-rounded, moderately well-sorted, lignitic.

40-45
Silt, very sandy, slightly clayey, medium-dark-gray, slightly cohesive (Alluvium).

45-60 **Sentinel Butte Formation**
Claystone, very silty, medium-light-gray to medium-gray, calcareous.

Observation well
Depth 35 feet
Screened interval 32-35 feet
Water level 9.70 feet
February 16, 1972

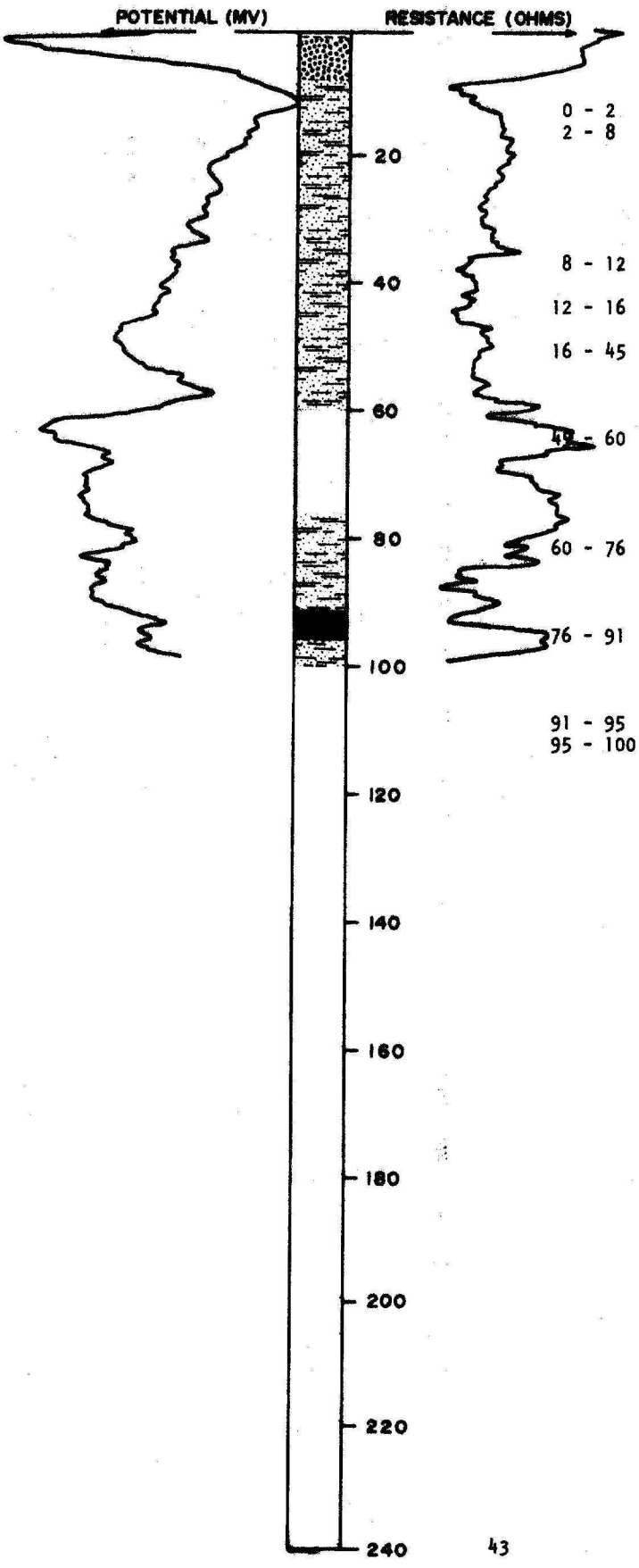
TEST HOLE 72-1

LOCATION: 145-92-25aac

DATE DRILLED: 8-9-72

ELEVATION: (FT, MSL)

DEPTH: 100 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0 - 2 Roadfill.

2 - 8 Sand, gravelly, medium-to coarse-grained, moderately sorted, sub-rounded, oxidized, brown.

Sentinel Butte Formation

8 - 12 Claystone, silty, yellowish-gray, oxidized.

12 - 16 Siltstone, sandy, light-yellowish-gray, oxidized.

16 - 45 Claystone, very silty, slightly sandy, light-gray to medium-light-gray, bentonitic.

45 - 60 Claystone, silty, slightly sandy, medium-gray to dark-greenish-gray with brownish-black carbonaceous shale bedding, thin lignite seams.

60 - 76 Sandstone, clayey, silty, light-greenish-gray to greenish-gray, semi-consolidated to loose, very fine-grained.

76 - 91 Siltstone, clayey, slightly sandy, medium-light-gray to greenish-gray, slightly carbonaceous.

91 - 95 Lignite, black, hard.

95 - 100 Claystone, silty, medium-dark-gray.

Observation Well
Depth 75 Feet
Screened Interval 69-75 Feet
Water Level 8.83 Feet
September 13, 1972

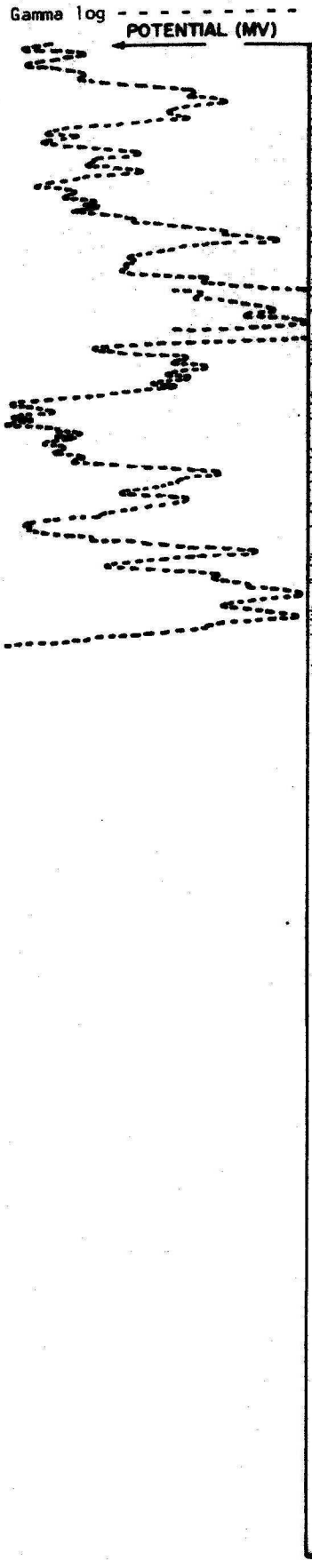
TEST HOLE 72-2

LOCATION: 145-92-25aad

DATE DRILLED: 8-29-72

ELEVATION: (FT, MSL)

DEPTH: 100 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0 - 2	Roadfill.
2 - 7	Sand, slightly gravelly, medium-to coarse-grained, brown moderately well-sorted, oxidized.

Sentinel Butte Formation

7 - 13	Claystone, silty, yellowish-gray, bentonitic, oxidized.
13 - 38	Siltstone, clayey, sandy, light-gray to medium-light-gray to greenish-gray, slightly carbonaceous, thin lignite seams.
38 - 46	Shale, very silty, sandy, brownish-black to black, carbonaceous.
46 - 100	Siltstone, clayey, slightly sandy, light-gray to medium-gray to greenish-gray, thin lignite seams.

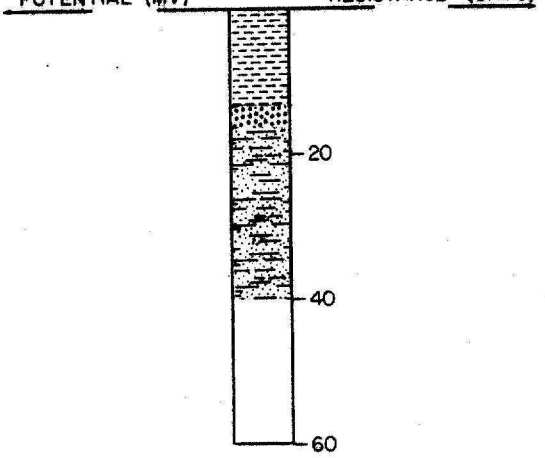
Test Hole 8252

LOCATION: 145-92-25aba1

DATE DRILLED: 11-10-71

ELEVATION: 2040
(FT, MSL)

DEPTH: 40
(FT).



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty, clayey, grayish-black.
1-14	Clay, very silty, olive-gray with dark-yellowish-brown mottling, moderately cohesive, plastic, highly calcareous (Alluvium).
14-17	Gravel, slightly sandy, fine to coarse, angular to rounded, poorly sorted.

Sentinel Butte Formation

17-40	Claystone, silty, medium-light gray to medium-gray, slightly calcareous.

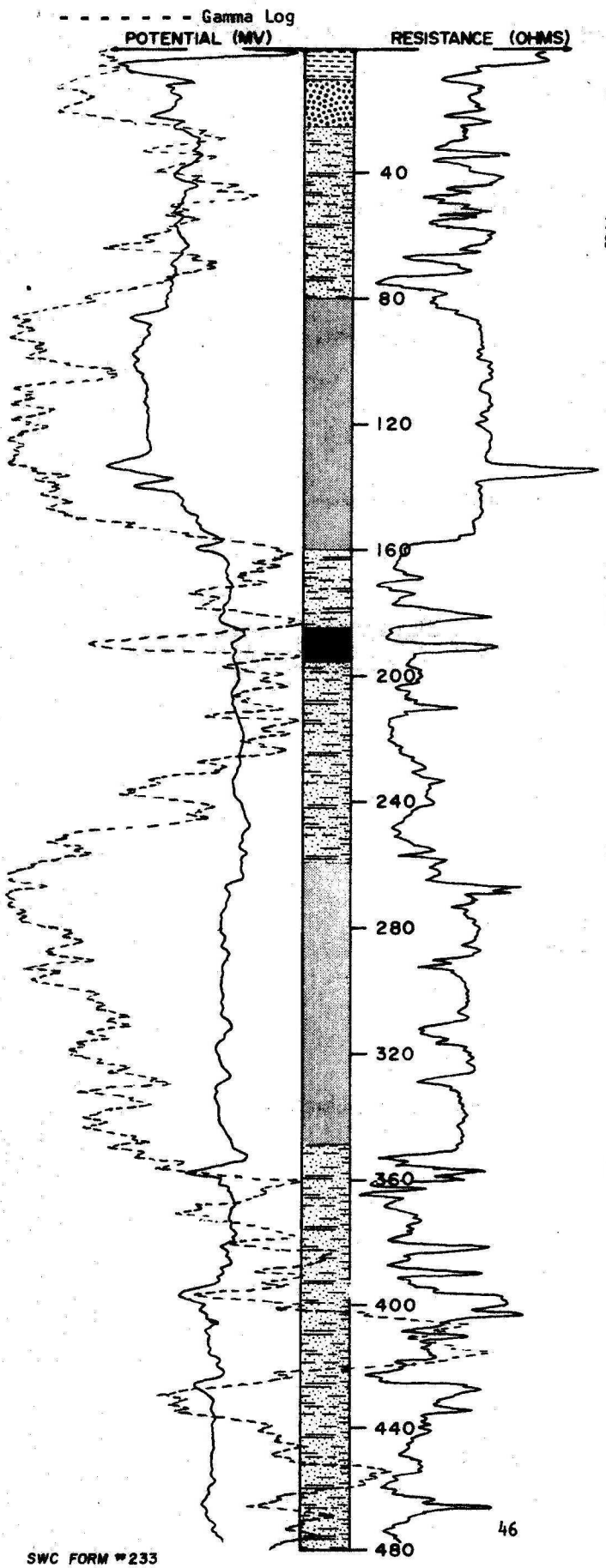
CITY OF HALLIDAY TEST HOLE
(Log from Mann Drilling Co.)

LOCATION: 145-92-25ABA2

DATE DRILLED: October, 1973

ELEVATION: 2045
(FT, MSL)

DEPTH: 1560
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-10 Clay, silty
10-25 Sand, clayey

Sentinel Butte Formation

25-80 Claystone
80-160 Sandstone

Tongue River Formation

160-185 Siltstone, lignite stringers
185-195 Lignite
195-260 Claystone

260-350 Sandstone, claystone bedding

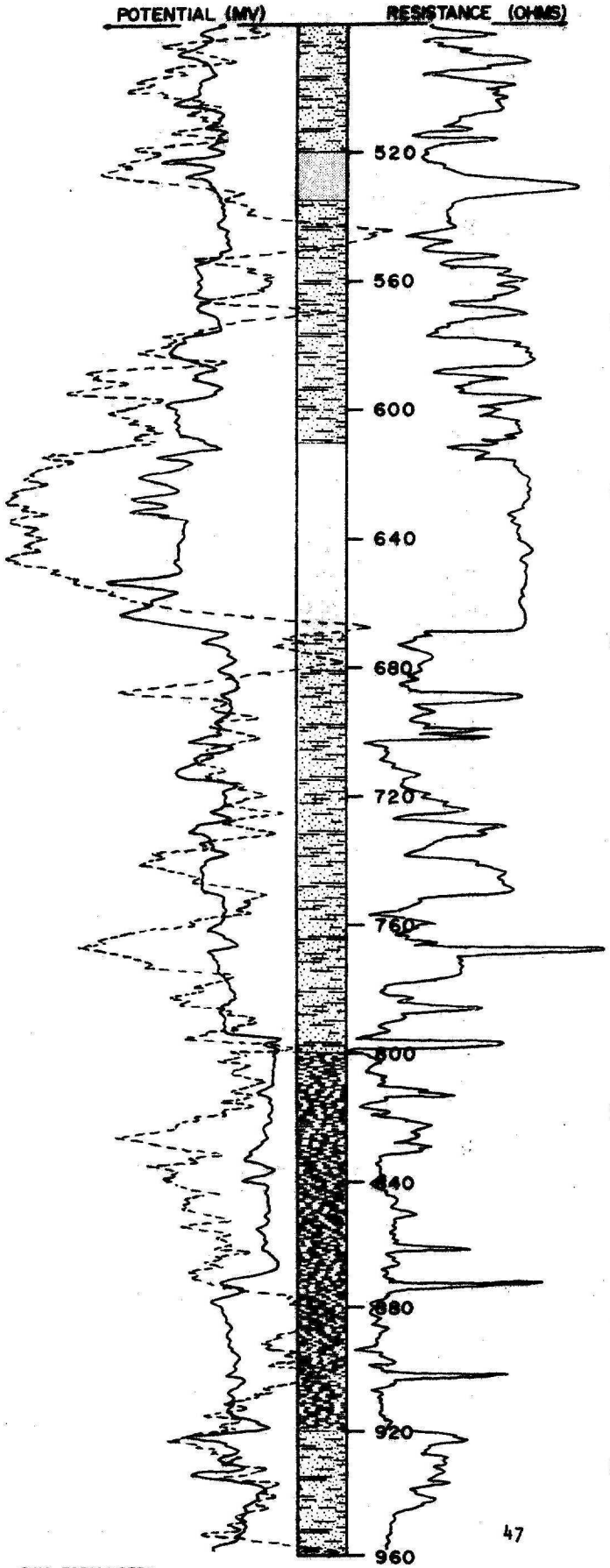
350-520 Siltstone, carbonaceous shale beds, lignite stringers

SWC FORM #233

CITY OF HALLIDAY TEST HOLE
(Log from Mann Drilling Co.) (cont.)

LOCATION: 145-92-25ABA2 — DATE DRILLED: October, 1973

ELEVATION: 2045 (FT, MSL) — DEPTH: 1560 (FT)



DESCRIPTION OF DEPOSITS

520-535 Sandstone
535-580 Siltstone, shale bedding

580-610 Siltstone, sandstone bedding

610-670 Sandstone

Ludlow-Cannonball Formations
670-800 Siltstone, sandstone bedding, limey concretions

800-920 Shale, concretions

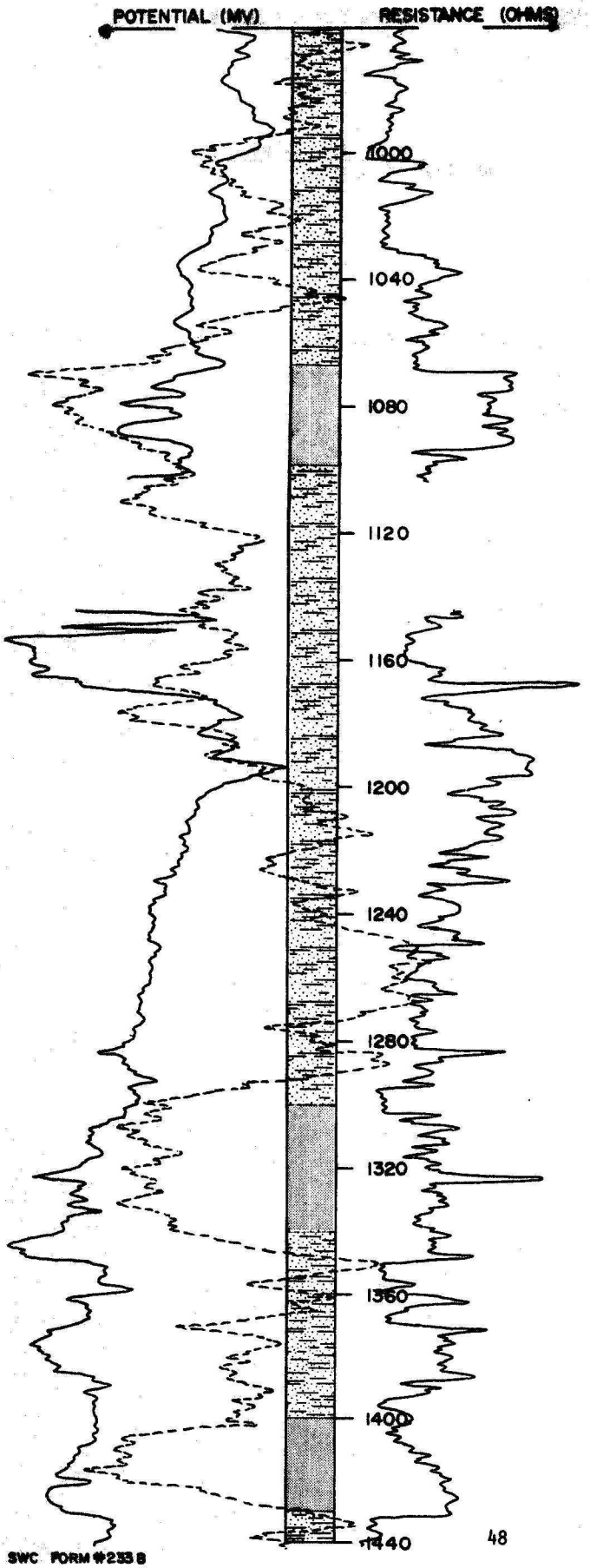
920-1070 Siltstone

SWC FORM #233A

CITY OF HALLIDAY TEST HOLE (cont.)
(Log from Mann Drilling Co.)

LOCATION 145-92-25ABA2 DATE DRILLED October, 1973

ELEVATION 2045 (FT, MSL) DEPTH 1560 (FT)



DESCRIPTION OF DEPOSITS

Heil Creek Formation

1070-1100 Sandstone

1100-1300 Claystone

1300-1340 Sandstone

1340-1400 Claystone

1400-1430 Sandstone

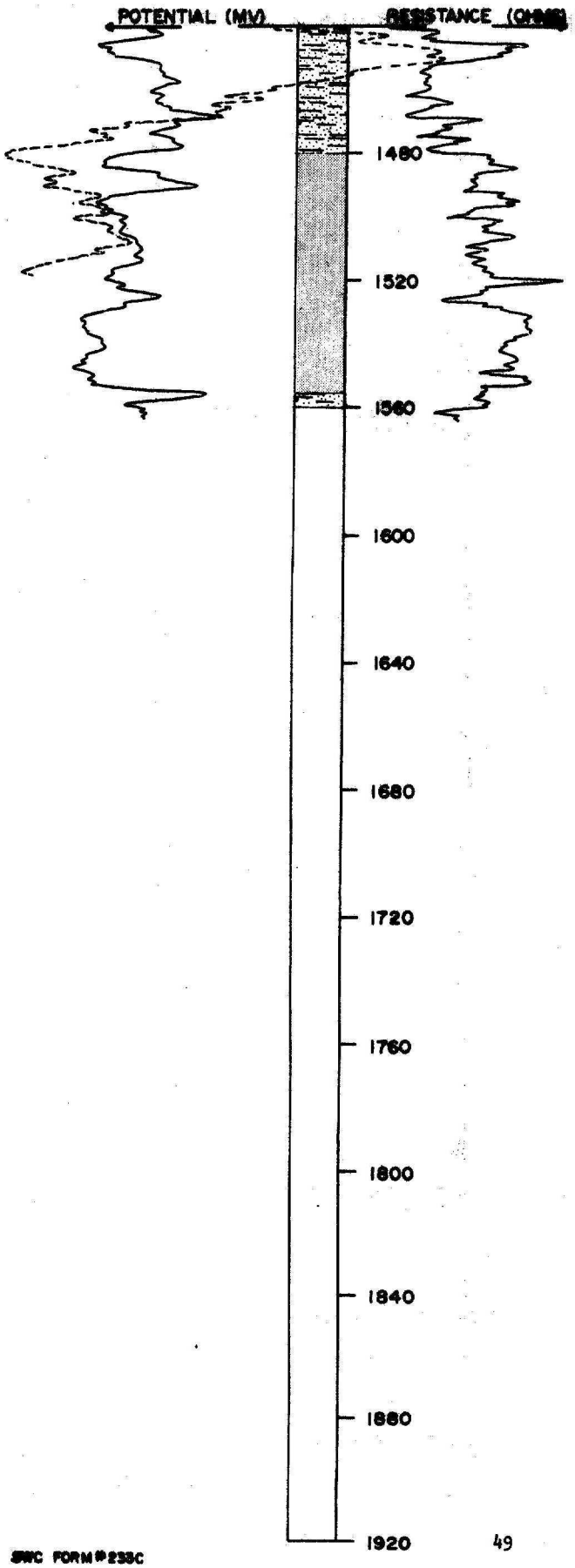
1430-1480 Claystone, sandstone bedding

SWC FORM #233 B

CITY OF HALLIDAY TEST HOLE
(Log from Mann Drilling Co.) (cont.)

LOCATION: 145-92-25ABA2 DATE DRILLED: October, 1973

ELEVATION: 2045 (FT, MSL) DEPTH: 1560 (FT)



DESCRIPTION OF DEPOSITS

Fox Hills Formation

1480-1555 Sandstone

1555-1560 Claystone

SWC FORM #238C

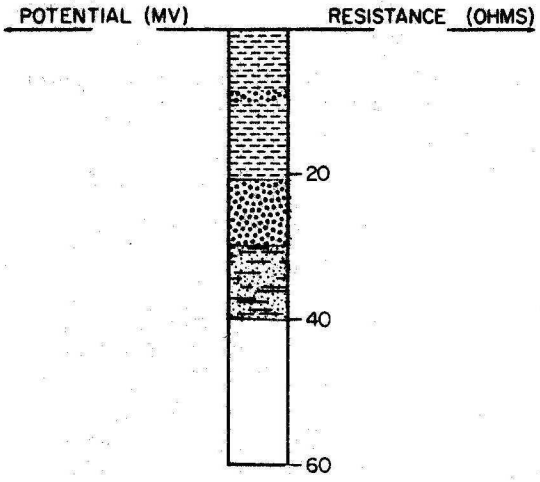
Test Hole 8250

LOCATION: 145-92-25abc

DATE DRILLED: 11-10-71

ELEVATION: 2050
(FT, MSL)

DEPTH: 40
(FT)



	DESCRIPTION OF DEPOSITS
	Glacial Drift
0-1	Topsoil, silty, clayey, black.
1-9	Clay, very silty, slightly sandy, dark-yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).
9-10	Gravel, sandy, fine to coarse, angular to subrounded, poorly sorted, oxidized.
10-15	Clay, very silty, moderate-yellowish-brown, moderately cohesive, plastic, oxidized (Alluvium).
15-21	Clay, very silty, medium-gray, moderately cohesive, plastic, calcareous (Alluvium).
21-30	Sand, moderately clayey, silty, fine- to medium-grained, subangular, moderately well-sorted.
	Sentinel Butte Formation
30-40	Claystone, very silty, brownish-gray with medium-gray bedding, non-calcareous.

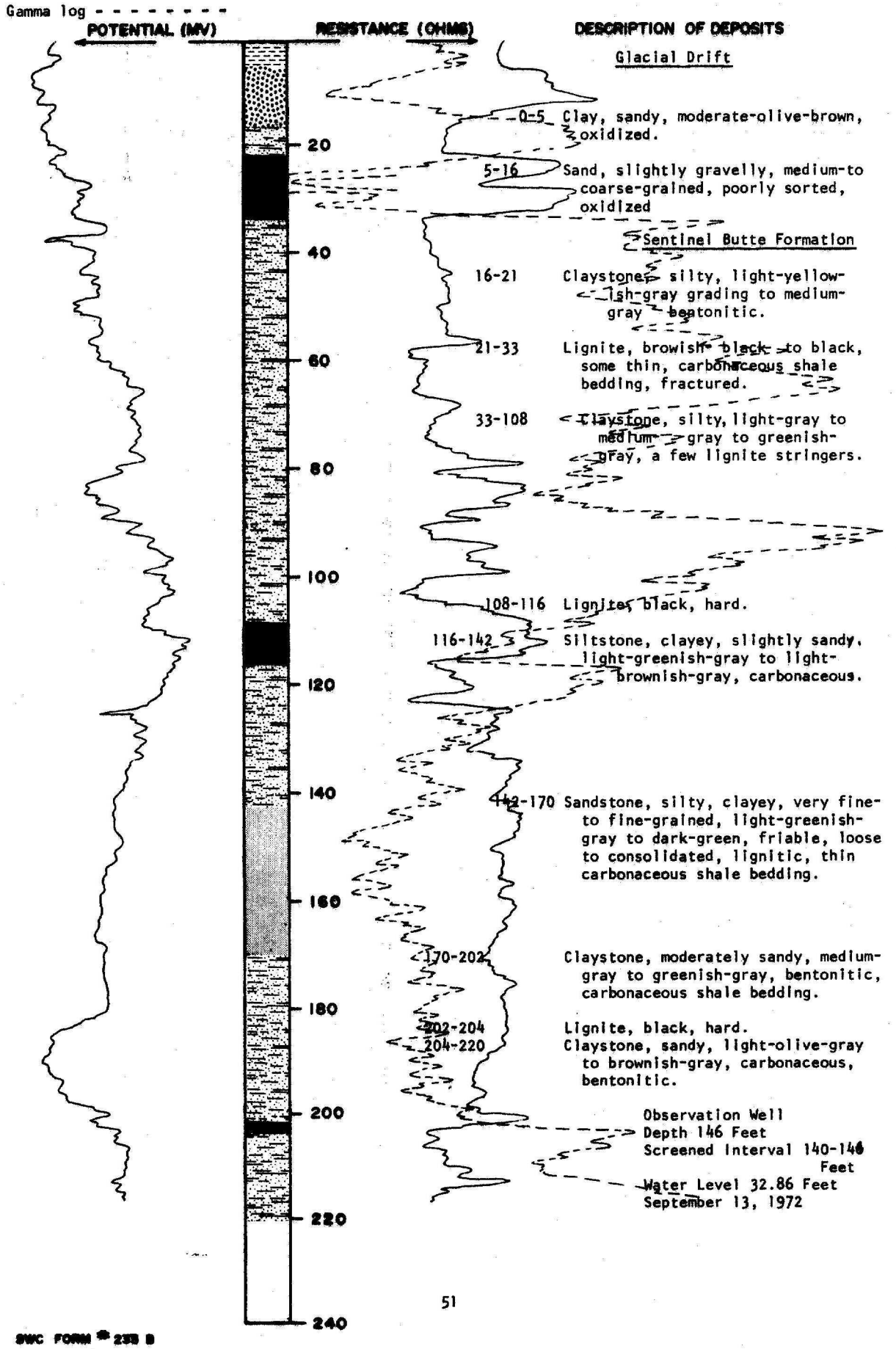
TEST HOLE 72-4

LOCATION: 145-92-25adc

DATE DRILLED: 8-30-72

ELEVATION: (FT, MSL)

DEPTH: 220 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-5 Clay, sandy, moderate-olive-brown, oxidized.

5-16 Sand, slightly gravelly, medium-to coarse-grained, poorly sorted, oxidized

Sentinel Butte Formation

16-21 Claystone, silty, light-yellowish-gray grading to medium-gray bentonitic.

21-33 Lignite, browish-black to black, some thin, carbonaceous shale bedding, fractured.

33-108 Claystone, silty, light-gray to medium gray to greenish-gray, a few lignite stringers.

108-116 Lignite, black, hard.

116-142 Siltstone, clayey, slightly sandy, light-greenish-gray to light-brownish-gray, carbonaceous.

142-170 Sandstone, silty, clayey, very fine- to fine-grained, light-greenish-gray to dark-green, friable, loose to consolidated, lignitic, thin carbonaceous shale bedding.

170-202 Claystone, moderately sandy, medium-gray to greenish-gray, bentonitic, carbonaceous shale bedding.

202-204 Lignite, black, hard.

204-220 Claystone, sandy, light-olive-gray to brownish-gray, carbonaceous, bentonitic.

Observation Well
Depth 146 Feet
Screened Interval 140-146 Feet
Water Level 32.86 Feet
September 13, 1972

SWC FORM # 23B B

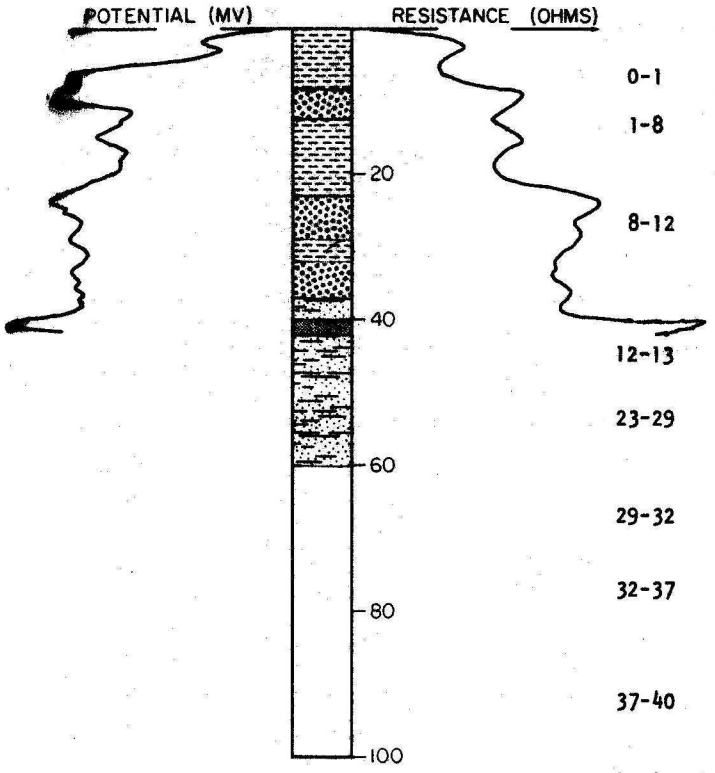
Test Hole 8251

LOCATION: 145-92-25baa

DATE DRILLED: 11-10-71

ELEVATION: 2050
(FT, MSL)

DEPTH: 60
(FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-1	Topsoil, silty, clayey, grayish-black.
1-8	Clay, very silty, slightly sandy, dark-yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).
8-12	Sand, silty, clayey, fine- to medium-grained, subangular to subrounded, moderately well-sorted, oxidized.
12-13	Clay, very silty, medium-dark-gray, moderately cohesive, highly plastic, calcareous (Alluvium).
23-29	Sand, slightly clayey, fine- to medium-grained, subangular to subrounded, moderately well-sorted, very lignitic.
29-32	Clay, very silty, medium-gray, plastic, cohesive, calcareous (Alluvium).
32-37	Gravel, about 30 percent sand, fine to coarse, angular to rounded, fair sorting.
	Sentinel Butte Formation
37-40	Claystone, silty, medium-light-gray, non-calcareous.
40-42	Sandstone, fine-grained, bluish-gray, cemented, hard.
42-60	Claystone, silty, medium-light gray, a few thin lignite stringers.

Observation well
Depth 35 feet
Screened interval 32-35 feet
Water level 9.80 feet
February 2, 1972

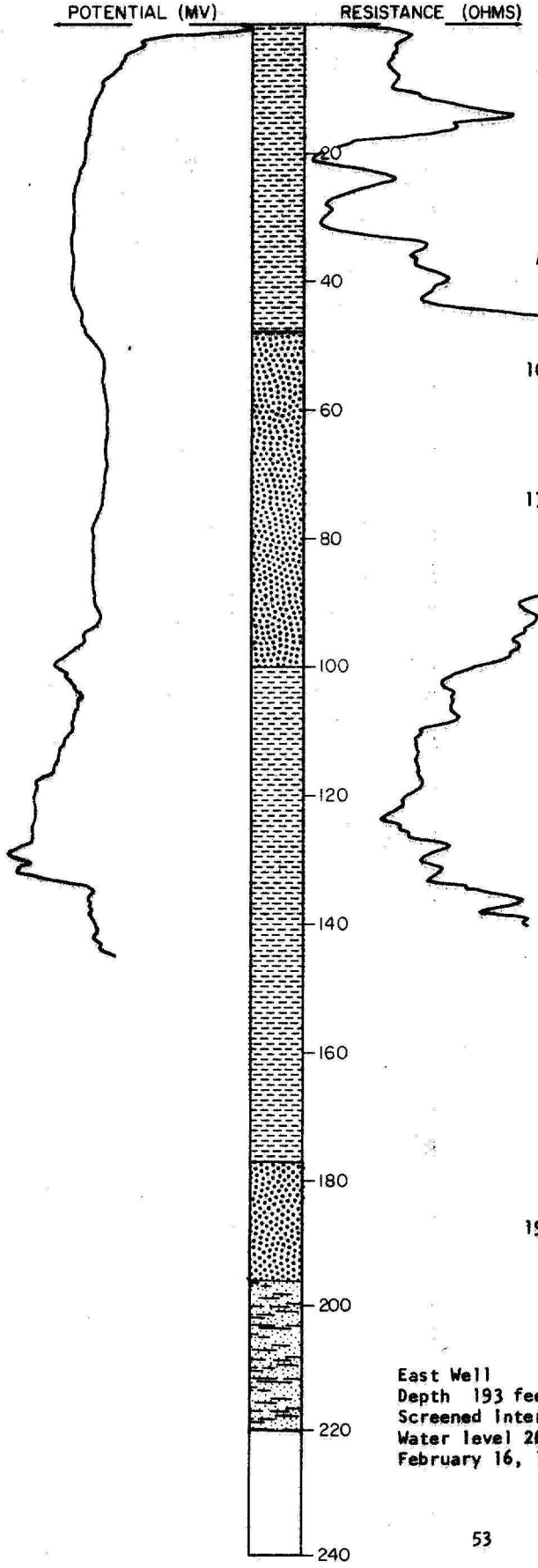
Test Hole 8216

LOCATION: 146-91-21cdd

DATE DRILLED: 10-27-71

ELEVATION: 1977
(FT, MSL)

DEPTH: 220
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, very silty, sandy, brownish-black.

1-48 Clay, very silty, slightly sandy, a few thin sand layers, moderate-yellowish-brown to dark-yellowish-brown with olive-gray mottling, slightly cohesive, highly plastic, oxidized (Alluvium).

48-100 Sand, a few thin clay layers, very fine- to medium-grained, subangular to subrounded, moderately well-sorted, much detrital lignite.

100-177 Clay, very silty, sandy, occasional thin sand layers, olive-gray with light-olive-gray laminae, slightly cohesive, highly plastic, calcareous, much detrital lignite.

177-196 Gravel, about 30 percent sand, fine to coarse, cobbles, angular to well-rounded, fair sorting, about 30 percent brownish, western, siliceous rocks, 40 percent local bedrock, 10 percent granitics, 10 percent dark shale, 10 percent lignite and scoria.

Sentinel Butte Formation

196-220 Claystone, moderately sandy, medium-light-gray, some thin sandstone bedding, highly calcareous to non-calcareous a few thin lignite stringers

Observation Wells

East Well	West Well
Depth 193 feet	Depth 93 feet
Screened interval 187-193 feet	Screened interval 87-93 feet
Water level 26.30 feet	Water level 18.50 feet
February 16, 1972	February 16, 1972

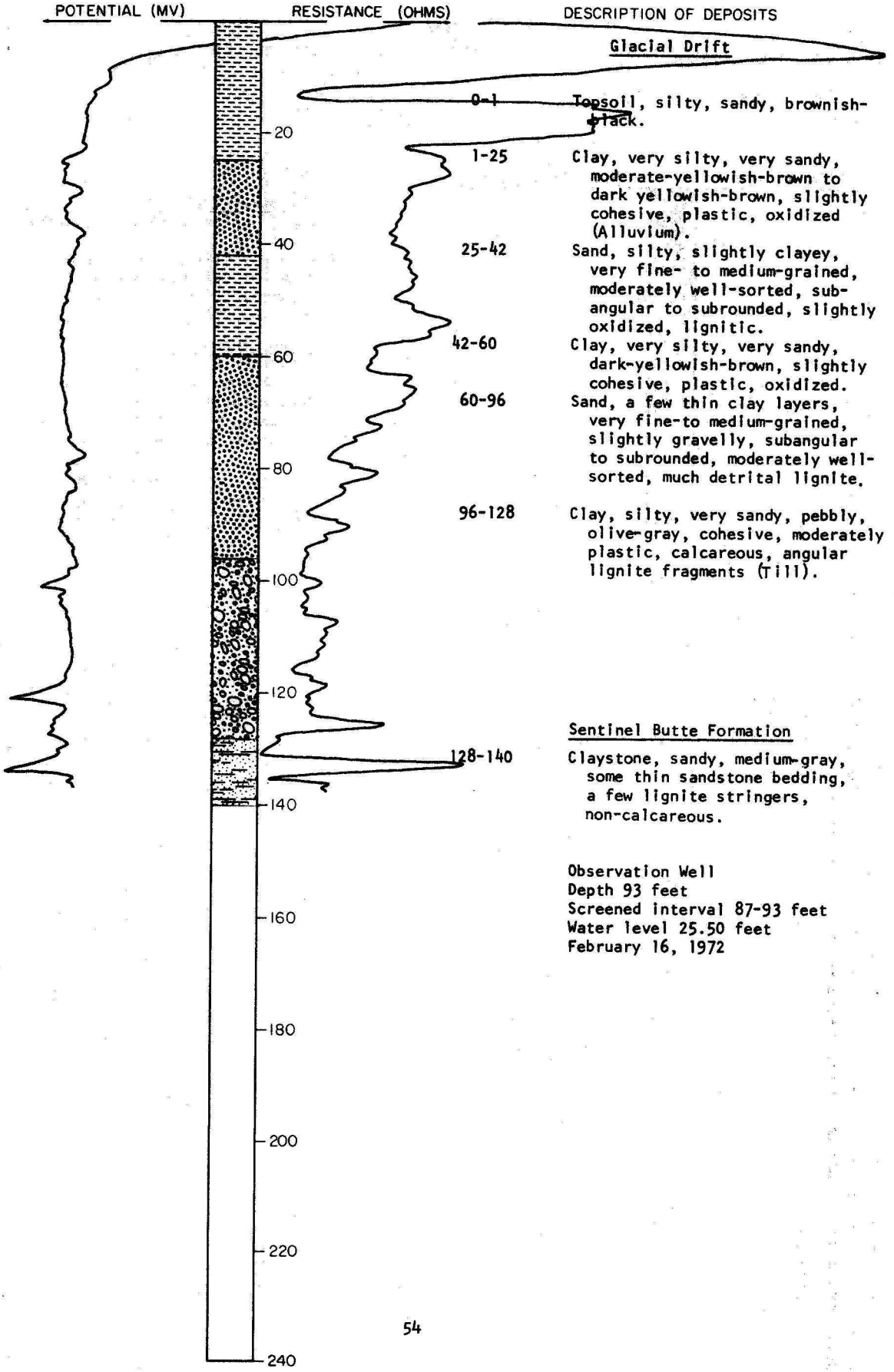
Test Hole 8217

LOCATION: 146-91-28aba

DATE DRILLED: 10-27-71

ELEVATION: 1985 (FT, MSL)

DEPTH: 140 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, silty, sandy, brownish-black.

1-25 Clay, very silty, very sandy, moderate-yellowish-brown to dark yellowish-brown, slightly cohesive, plastic, oxidized (Alluvium).

25-42 Sand, silty, slightly clayey, very fine- to medium-grained, moderately well-sorted, sub-angular to subrounded, slightly oxidized, lignitic.

42-60 Clay, very silty, very sandy, dark-yellowish-brown, slightly cohesive, plastic, oxidized.

60-96 Sand, a few thin clay layers, very fine-to medium-grained, slightly gravelly, subangular to subrounded, moderately well-sorted, much detrital lignite.

96-128 Clay, silty, very sandy, pebbly, olive-gray, cohesive, moderately plastic, calcareous, angular lignite fragments (Till).

Sentinel Butte Formation

128-140 Claystone, sandy, medium-gray, some thin sandstone bedding, a few lignite stringers, non-calcareous.

Observation Well
Depth 93 feet
Screened interval 87-93 feet
Water level 25.50 feet
February 16, 1972

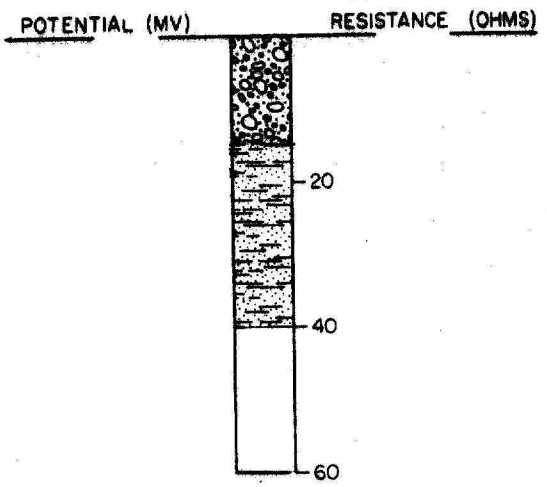
Test Hole 8218

LOCATION: 146-91-28bbb

DATE DRILLED: 10-28-71

ELEVATION: 1980
(FT, MSL)

DEPTH: 40
(FT)



DESCRIPTION OF DEPOSITS

	Glacial Drift
0-1	Topsoil, silty, clayey, brownish-black.
1-15	Clay, very silty, sandy, pebbly, moderate-yellowish-brown, slightly cohesive, plastic, oxidized (Till).
	Sentinel Butte Formation
15-28	Claystone, silty, moderate-yellowish-brown with medium-gray-mottling, slightly calcareous, a few thin lignite stringers, oxidized.
28-40	Claystone, medium-gray to medium-light-gray, non-calcareous, a few thin lignite stringers.

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