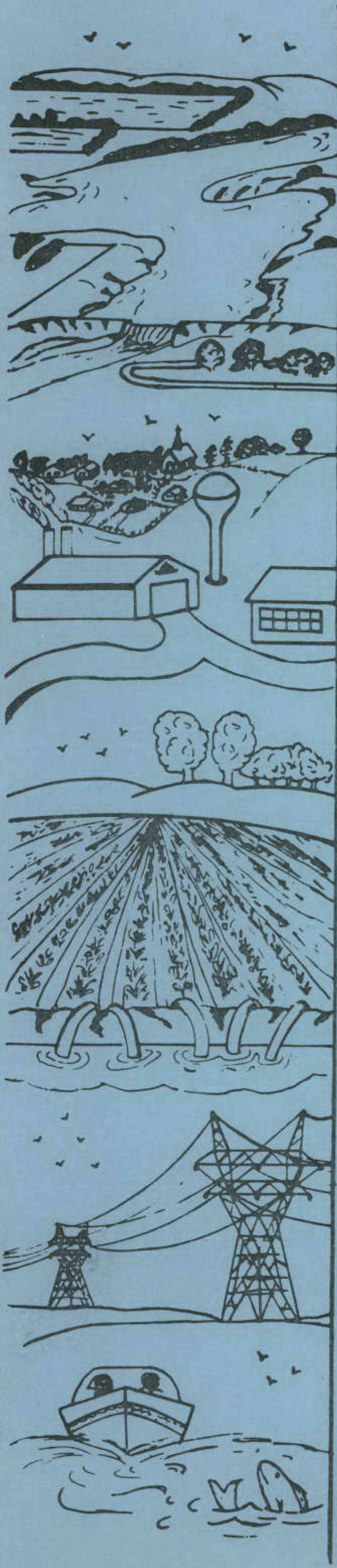


Report of
NORTH DAKOTA STATE WATER COMMISSION
State Office Building
BISMARCK, NORTH DAKOTA
58501

# GROUND-WATER RESOURCES OF THE CATHAY AREA WELLS COUNTY, NORTH DAKOTA



NORTH DAKOTA GROUND-WATER STUDIES

NO. 80

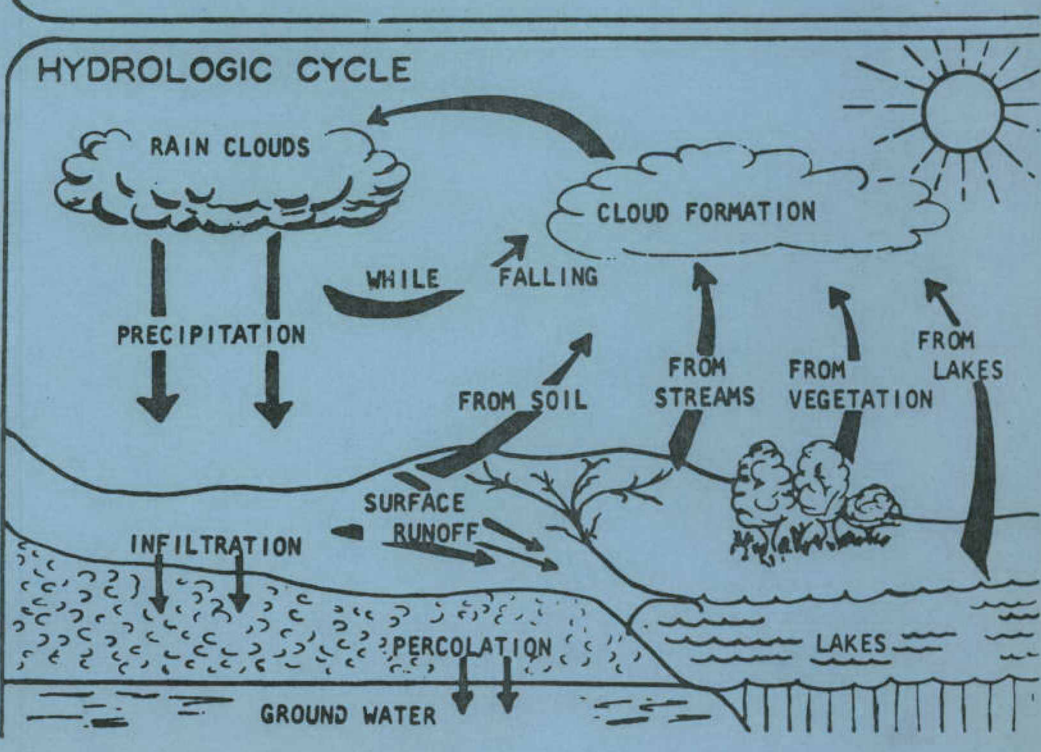
BY

CHARLES E. NAPLIN
GROUND-WATER HYDROLOGIST

NORTH DAKOTA STATE WATER COMMISSION
BISMARCK, NORTH DAKOTA



1975



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# GROUND-WATER RESOURCES OF THE CATHAY AREA

# WELLS COUNTY, NORTH DAKOTA

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## INTRODUCTION

### PURPOSE AND SCOPE

On March 29, 1972 the Cathay City Council passed a resolution requesting the North Dakota State Water Commission conduct a ground-water investigation for the city. The State Water Commission approved the study on April 27, 1972 and field work was completed in early October of that year.

The geohydrology of the Cathay 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 January and February of 1973.

### ACKNOWLEDGEMENTS

The test drilling was accomplished by Lewis Knutson and Wendell Schaan 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. Special acknowledgement is extended to Mayor Harold Lautt for furnishing information concerning shallow wells within the city limits.

## LOCATION AND GENERAL FEATURES

The Cathay area is located in east-central Wells County and is within the Drift Prairie division of the Central Lowland physiographic province of North Dakota (fig. 1). Data collected during this study describe a 36-square mile area located in a portion of Tp. 147 N., Rs. 68 and 69 W.

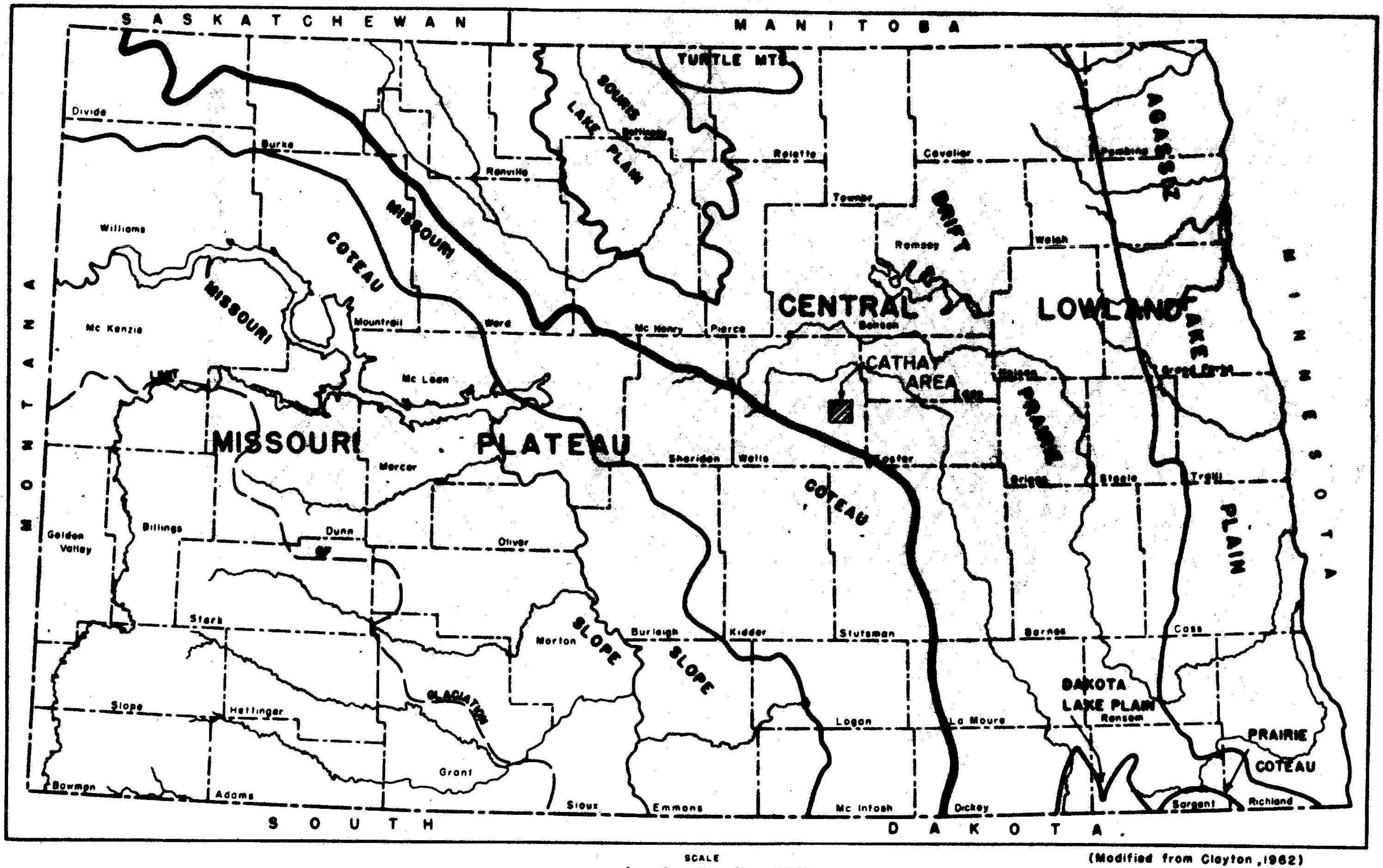
Climatological data based on a 60-year period of record at the National Weather Service station in Fessenden, North Dakota shows the average annual temperature to be 40°F. Average annual precipitation for the same period of record was 17.27 inches (National Weather Service, 1971).

The landscape is characterized by flat to gently rolling topography. Rocky Run and Pipestem Creek are intermittent streams that drain the area from west to east. Potholes and undrained depressions are common. The land surface slopes gently east-northeast, the elevation ranging from 1,560 to 1,634 feet above mean sea level.

Cathay (1970 population 110) is an agricultural community. It is served by the Soo Line Railroad and State Highway 30. The city does not have a municipal water system. Water for drinking and culinary purposes is obtained from shallow wells within the city limits or purchased from local farm residents and hauled into town. Sewage is disposed of through individual septic tanks and drain fields.

## WELL-NUMBERING SYSTEM

Wells and test holes are numbered according to a system based on their location in the public land classification of the United States Bureau of Land Management (fig. 2). The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian and the third numeral denotes the section in which the well is located. The letters A, B, C and D designate, respectively,




(Modified from Clayton, 1962)

FIGURE I -- MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF CATHAY AREA

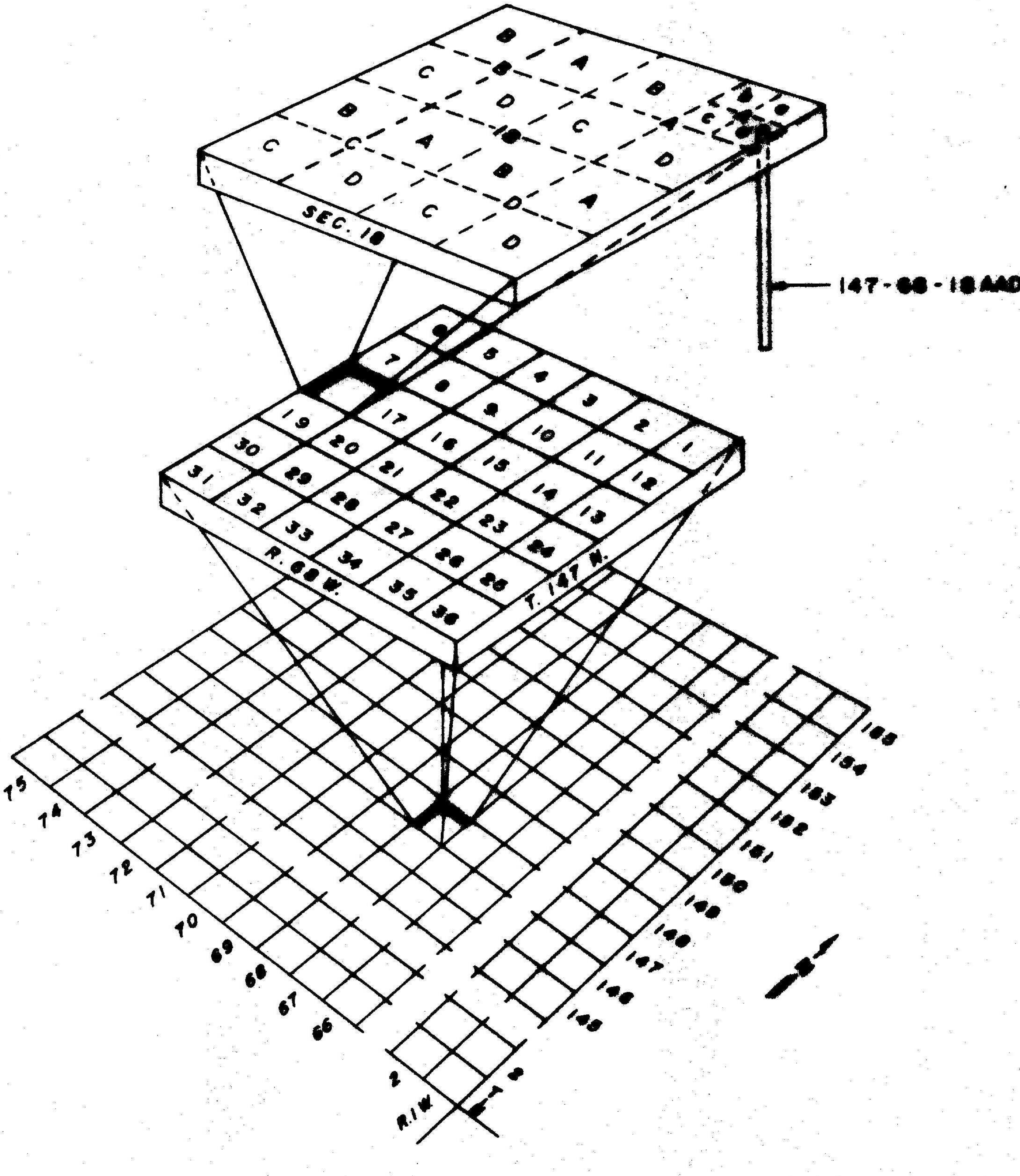



FIGURE 2-- SYSTEM OF NUMBERING WELLS AND TEST HOLES

the northeast, northwest, southwest and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). For example, well 147-68-18 AAD is in the SE¼NE¼NE¼ sec. 18, T. 147 N., R. 68 W. Consecutive terminal numerals are added if more than one well is located in a 10-acre tract.

## PREVIOUS INVESTIGATIONS

The geology and ground-water resources of Wells County were discussed in general terms by Simpson (1929, p. 262-265). His report includes a well inventory and chemical analyses of selected municipal and private wells.

A ground-water survey of Wells County was initiated in 1964 and completed in 1968. The investigation was a cooperative program between the U. S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and the Wells County Water Management District. The report, Geology and Ground-Water Resources of Wells County - County Ground-Water Studies 12, consists of Part 1 - Geology, Part 2 - Basic Data, and Part 3 - Ground-Water Resources. It is a reconnaissance survey of the county's ground-water resources and provides information on geology, geohydrology and water quality.

## PRINCIPLES OF GROUND-WATER OCCURRENCE

All ground water of economic importance is derived from precipitation. After the precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, some runs into streams, and the remainder percolates into the ground. Much of the water that sinks into the ground is held temporarily in the soil and is returned to the atmosphere either by evaporation or by transpiration. The remainder infiltrates downward and becomes ground water.

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. The movement of ground water 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 the water moves and by the hydraulic gradient. Gravel and well-sorted medium to coarse sand are usually very permeable. Fine-grained materials such as silt, clay and shale usually have low permeability, and may act as confining barriers that restrict the free movement of ground water into or out of more permeable rocks. A ground-water reservoir that contains enough saturated permeable material to yield water in sufficient quantity to serve as a source of supply is called an aquifer.

Artesian aquifers are confined by relatively impermeable beds. Ground water contained within these aquifers is under pressure due to the weight of water at higher levels of recharge in the aquifer and to the weight of overlying rocks. The water level in a well completed in an artesian aquifer will be higher than the top of the aquifer.

When water in an aquifer is not confined by impermeable material such as clay or shale, it is called a water-table aquifer. The shape of the upper surface of the zone of saturation is called the water table. It is controlled by gravity and topographic relief.

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 continues to decline at a decreasing rate as the cone of depression expands.

## WATER QUALITY

All natural water occurring on the earth's surface or underground contains dissolved minerals. Precipitation begins to dissolve mineral matter as it falls to the surface and continues to dissolve minerals as it infiltrates into the ground. Dissolved minerals in ground water vary in type and concentration depending primarily upon the composition and solubility of rocks encountered, the length of time the water is in contact with the rocks, and the amount of carbon dioxide and soil acids in the water. Water that has been underground for a long time or that has travelled a long distance from the recharge area, usually contains more dissolved mineral matter than water that has been underground for only a short time and is withdrawn close to a recharge area.

Dissolved mineral constituents are reported in milligrams per liter (mg/l). A milligram per liter is 1 thousandth (0.001) of a gram of dissolved material per liter of solution. Hardness is usually reported in milligrams per liter, but may be converted to grains per U. S. gallon (gr/gal) by dividing milligrams per liter by 17.12. The following summary gives the significance of various constituents of water for a domestic or municipal water supply in North Dakota:

Silica ($SiO_2$)

Silica has no physiological or esthetic significance.

Iron (Fe)

Over 0.3 mg/l 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 ($HO_3$ 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 concentration 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 can 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 for domestic consumption.

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

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

## GROUND WATER IN THE PREGLACIAL ROCKS

The Cathay area is situated on the eastern flank of the Williston Basin and is underlain by approximately 4,000 feet of sedimentary Paleozoic and Mesozoic rocks (Bluemle, et. al., 1967). The rock formations have a regional westerly dip and become thicker toward the northwest. The sediments consist mainly of limestone, dolostone, sandstone and shale. The Cretaceous Pierre Formation directly underlies glacial drift in the Cathay area. Potential bedrock aquifers include the Pierre and certain formations in the underlying Lower Cretaceous Dakota Group, but they are not considered important sources of potable ground water.

## CRETACEOUS SYSTEM

### Dakota Group

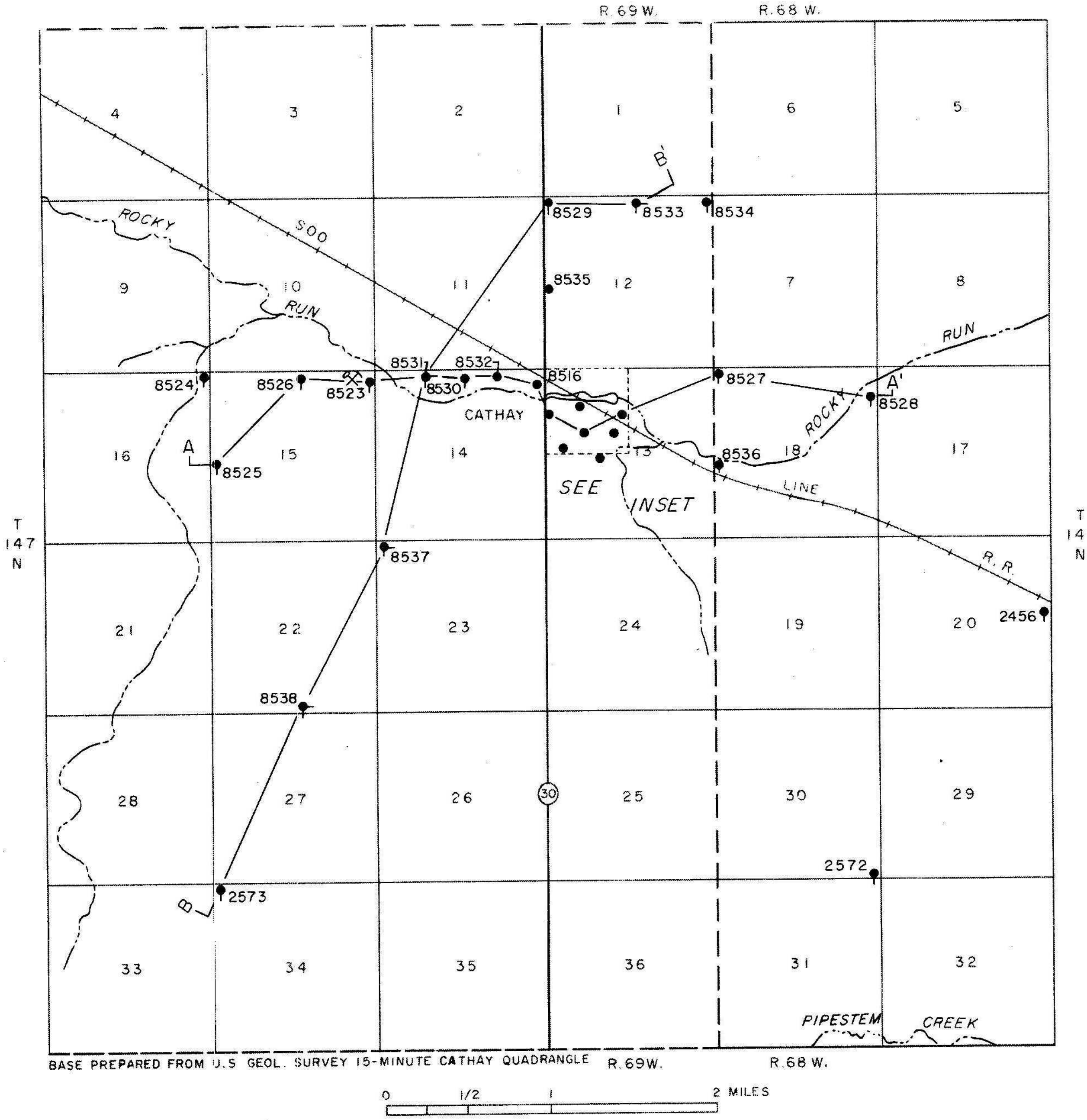
The stratigraphic sequence of rocks comprising the Dakota Group in North Dakota consists of the Lakota, Fuson, Fall River, Skull Creek, Newcastle, and Mowry Formations. Of these, only the Fall River, Lakota, and Mowry Formations are present in the Cathay area (Bluemle, et. al., 1967). The top of the Dakota Group is about 1,800 feet below land surface.

Oil tests indicate the Dakota Group consists of interbedded siltstone, sandstone, limestone, and shale. The sandstone beds have the greatest permeability and are water bearing. Samples indicate they consist of fine- to medium-grained, white, quartzose sandstone. Sandstone may comprise as much as 30 percent of the entire thickness of the Dakota Group. An average cumulative thickness for the Dakota Group at Cathay is about 270 feet (Bluemle, et. al., 1967, p. 3).

Water quality data for the Dakota Group is not available within the Cathay area. However, chemical quality data from wells completed in the Dakota Group in Wells County indicate the water is soft and highly mineralized. It is usually of the sodium sulfate chloride type and is not desirable for domestic use.

### Pierre Formation

Test drilling in the Cathay area indicates the Pierre Formation is a dark gray to grayish-black, moderately hard, brittle, noncalcareous shale (fig. 3). The shale has a very low permeability and the movement of ground water is restricted to openings along cleavage planes and poorly developed joint systems in the upper part of the formation. Ground water enters fractures in the Pierre by infiltration through the overlying glacial drift.




EXPLANATION

● 8522 TEST HOLE AND NUMBER

○ DOMESTIC OR STOCK WELL

A A' GEOLOGIC SECTION

⚒ GRAVEL PIT

MODIFICATIONS USED WITH ABOVE SYMBOL

○- CHEMICAL ANALYSIS IN TABLE 1

♀ LOG IN TABLE 2

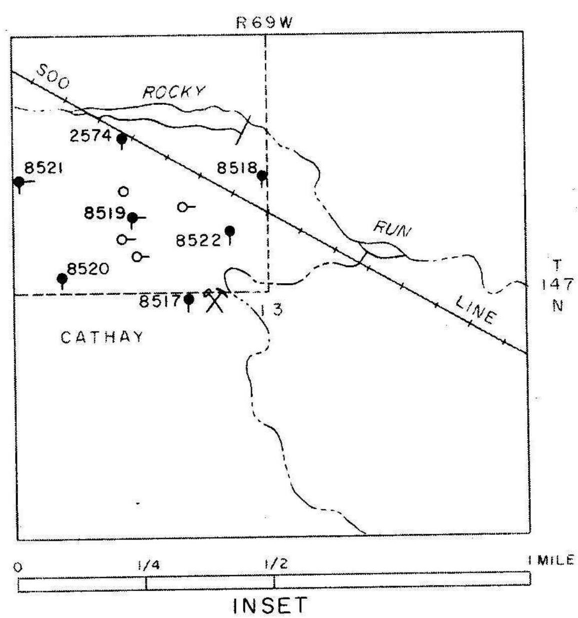


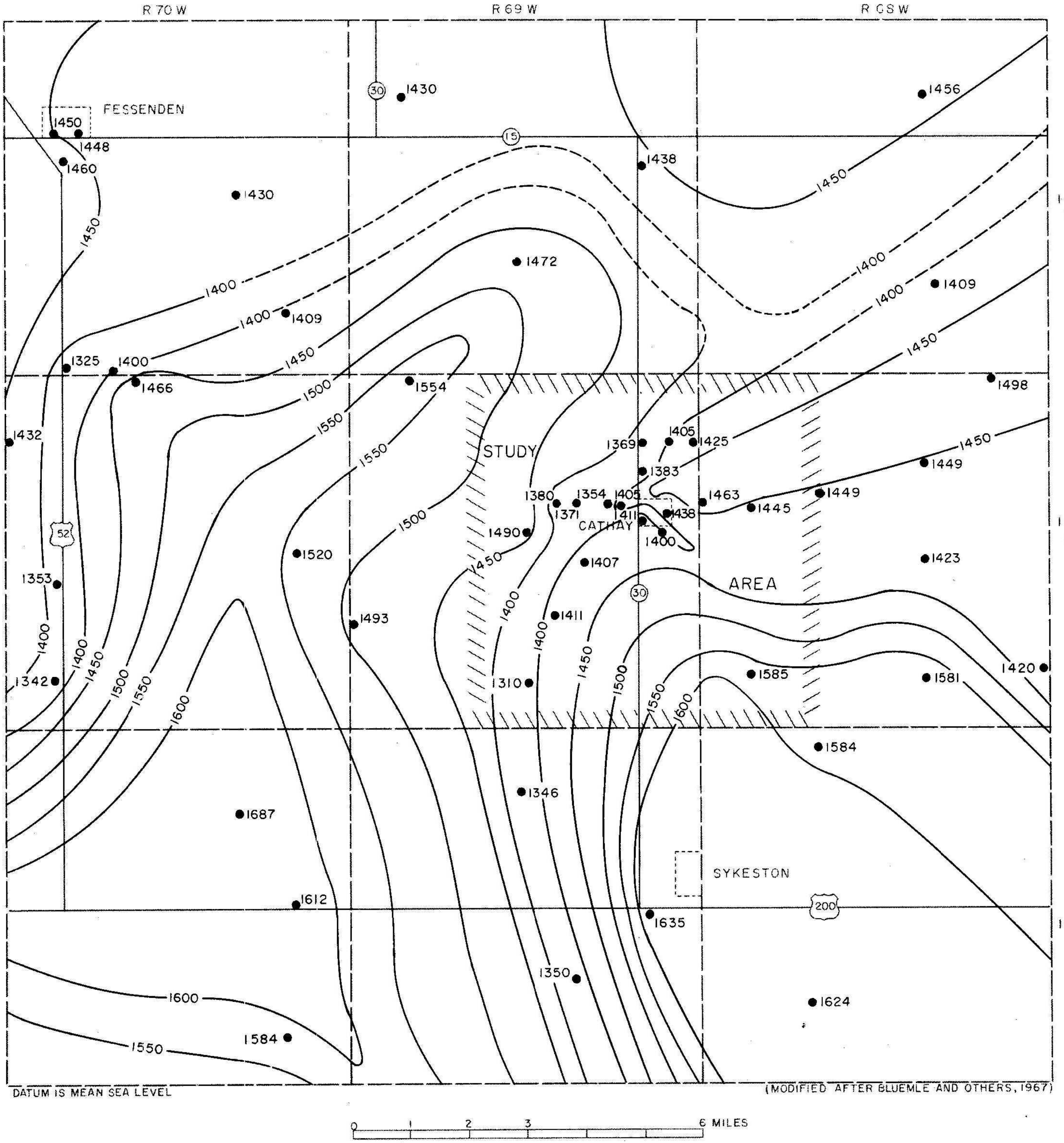

**FIGURE 3 -- LOCATION OF WELLS, TEST HOLES, GEOLOGIC SECTIONS, AND RELATED FEATURES IN THE CATHAY AREA**

There are no known water wells tapping the Pierre Formation in the Cathay area. Water quality data from areas where the Pierre has been developed as an aquifer, indicate the shale generally yields water of the sodium chloride sulphate type. Total dissolved solids may exceed 2,000 mg/l.

## GROUND WATER IN THE GLACIAL DRIFT

Prior to glaciation, drainage in North Dakota generally flowed northeastward from the south and west and eventually discharged into the Lake Winnipeg-Hudson Bay drainage system. Test drilling during this investigation supports the preglacial drainage hypotheses of previous authors (Bluemle, et. al., 1967, p. 5) who suggest that a major preglacial river valley lies buried beneath glacial drift west of Cathay and Sykeston in Wells County, North Dakota. Figure 4 shows the topography of the bedrock surface underlying a portion of eastern Wells County and indicates a probable course of the preglacial Cannonball River.

During the Pleistocene Epoch continental glaciers advanced southward from Canada and overrode the bedrock surface of Wells County. Glacial ice and debris blocked the drainage to the northeast for a period of time, filling the valley with meltwater, and causing a southeasterly diversion of meltwater parallel to the advancing ice front. Eventually, the ice front stagnated and released its sediment load of glacial debris which accumulated on top of the bedrock surface. Consequently, the preglacial valley was filled with varying amounts of silt, sand, gravel and boulder clay, and later on was mantled with ground moraine.




**EXPLANATION**

1687 ● SELECTED CONTROL POINT AND BEDROCK SURFACE ELEV.

CONTOUR INTERVAL 50 FEET -- CONTOURS DASHED WHERE INFERRED

**FIGURE 4 -- BEDROCK CONTOUR MAP OF THE CATHAY AREA IN WELLS COUNTY**

Ground moraine is a glacial landform of low relief and gently rolling topography. It consists primarily of till which is an unsorted mixture of clay, silt, sand, gravel, cobbles and boulders. The deposition of till occurred as glacial debris was let down directly by melting ice with little or no sorting action by water. Drill cuttings of an average section of till in North Dakota reveal that it is usually olive gray in color when encountered below the water table. Above the water table it is yellowish-brown in color indicating that the clay minerals have been oxidized by chemical weathering. Glacial drift ranges in thickness from 12 feet in test hole 2572 (147-68-30 ddd) to 310 feet in test hole 2573 (147-69-34 bbb). It is thickest within the buried river valley. The average thickness of glacial drift penetrated in 24 test holes in the study area is about 170 feet.

Outwash consists of sand and gravel that was washed, sorted and deposited by meltwater streams. Outwash in the Cathay area consists of; (1) surficial gravel deposits along Rocky Run and Pipestem Creeks (2) eskers and linear ice disentegration ridges (3) lenses of sand and gravel within the till and (4) outwash found in the buried preglacial valley.

The most important glacial drift aquifers in the Cathay area are the till-associated sand and gravel deposits and the Cannonball buried outwash, herein called the Cathay aquifer. Most domestic and stock wells are less than 100 feet deep and tap minor till-associated aquifers. There are no known domestic wells completed in the Cathay aquifer.

## TERTIARY SYSTEM

### Till-associated aquifers

Minor drift aquifers associated with till in the Cathay area consist of small, lenticular deposits of sand and gravel. Most domestic wells are completed in till-associated aquifers at depths less than 100 feet, and yield only a few gallons per minute (gpm). Test drilling defined two horizons within the till which have numerous intervals of sand and gravel associated with them. The two horizons are herein designated as; unit 1 - an upper zone that includes all lenses of sand and gravel within the zone of saturation to a depth of 60 feet, and unit 2 - a lower zone that includes all lenses of sand and gravel from a depth of 90 feet to bedrock. Units 1 and 2 are differentiated only within the city limits where sufficient test hole data is available. Cross-section A-A' indicates the stratigraphic sequence of deposits underlying Cathay (pl. 1).

Materials comprising unit 1 were penetrated in four test holes and ranged in cumulative thickness from 3 feet in test hole 8519 (147-69-13 bca) to 12 feet in test hole 8522 (147-69-13 bdd). Lenses of sand and gravel penetrated in test hole 8522 were encountered from 28-33, 48-53, and 58-60 feet below land surface, respectively. Materials ranged in size from fine-grained sand to gravel with cobbles. Most of the city's shallow wells are completed in this unit. Calcium carbonate hardness ranges from 636 mg/l (37 gr/gal) to 2,700 mg/l (158 gr/gal) and dissolved iron and manganese usually exceed recommended limits. Four water samples collected from the city and school wells averaged 1,988 mg/l dissolved solids.

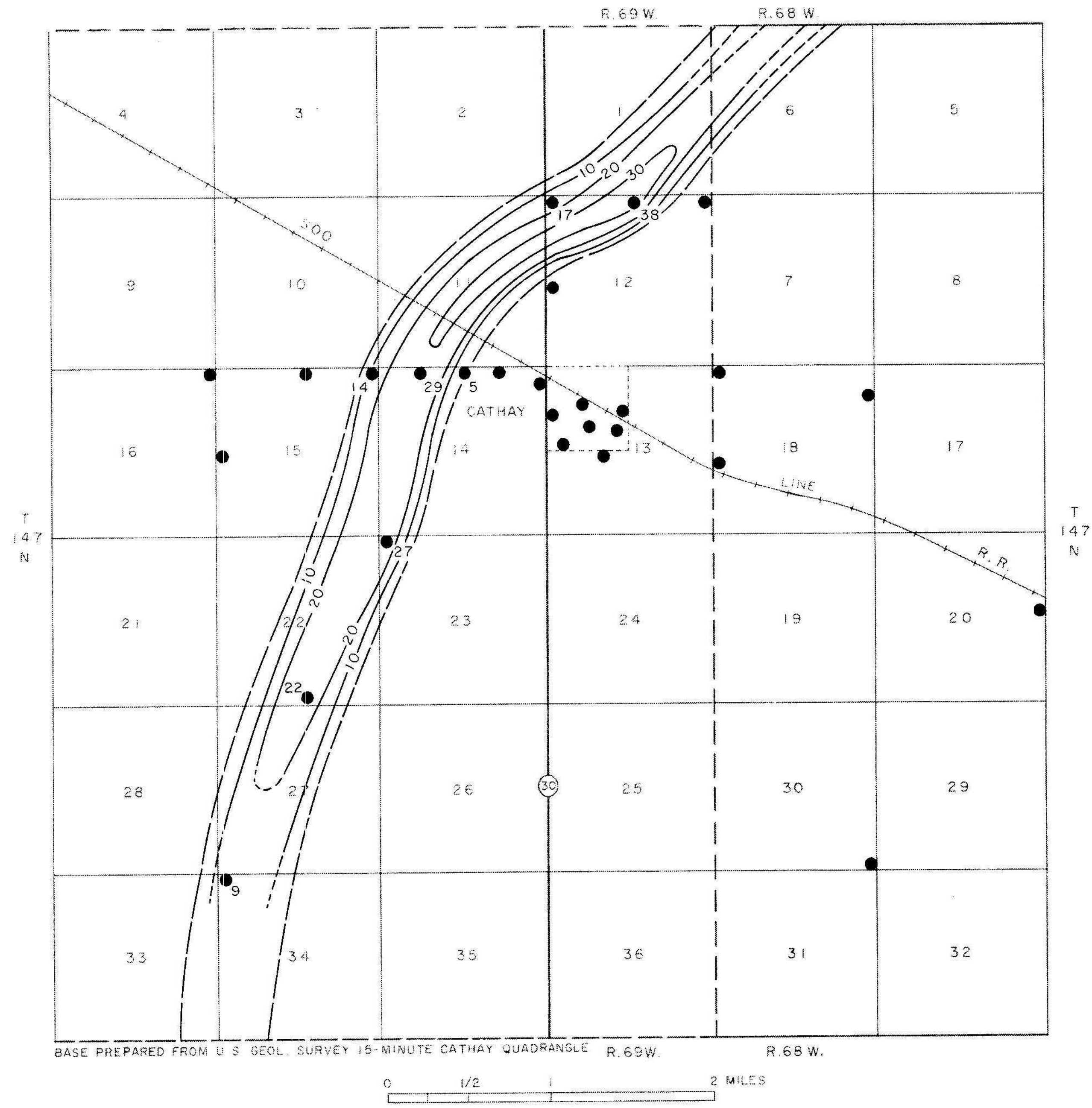
Unit 2 deposits were penetrated in five test holes and ranged in cumulative thickness from 2 feet in test hole 2574 (147-69-13 bbd) to 34 feet in test hole 8519 (147-69-13 bca). Test hole 8519 encountered 34 feet of clean fine-to coarse-grained sand from 94 to 128 feet below land surface. Two small diameter observation wells were completed in unit 2. Water samples from these two wells contain total dissolved solids of 1110 and 1630 mg/l and hardness of 295 mg/l (17 gr/gal) and 639 mg/l (37 gr/gal), respectively. Iron and manganese concentration in both exceed recommended limits.

The till-associated aquifers underlying Cathay are very limited in size and do not extend over an area larger than two or three city blocks. Typically lenses of sand and gravel deposited in conjunction with till have a low degree of hydraulic connection and receive recharge at a very slow rate through the surrounding till. Therefore, these deposits are not capable of large sustained yields.

## Cathay aquifer

The most important glacial drift aquifer in the area is the buried outwash deposit located west of Cathay. It is herein called the Cathay aquifer.

The Cathay aquifer is illustrated on plate 1 and figures 5 and 6. It consists of moderately well-sorted fine sand to coarse gravel and cobbles. Drill samples indicate the sand and gravel is relatively free of clay. However, electric logs show that occasional thin clay layers

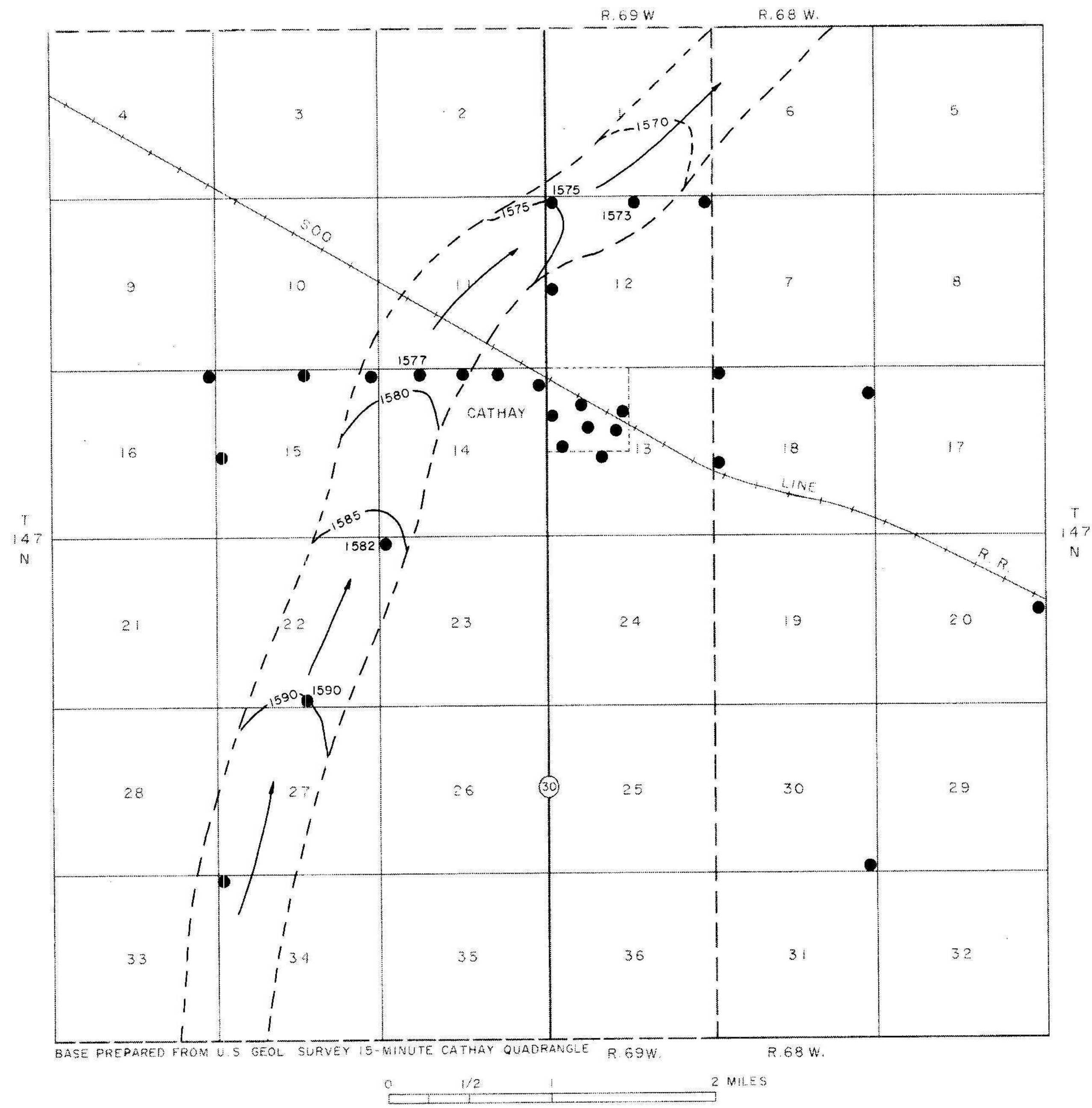



**EXPLANATION**

● 14 CONTROL POINT -- NUMBER INDICATES CUMULATIVE THICKNESS OF SAND AND GRAVEL IN FEET

CONTOUR INTERVAL 10 FEET -- CONTOURS DASHED WHERE INFERRED

FIGURE 5 -- LOCATION AND THICKNESS OF THE CATHAY AQUIFER




**EXPLANATION**

● 590 CONTROL POINT -- NUMBER IS ALTITUDE OF WATER LEVEL IN FEET ABOVE MEAN SEA LEVEL

CONTOUR INTERVAL 5 FEET -- CONTOURS DASHED WHERE INFERRED

ARROWS INDICATE DIRECTION OF GROUND-WATER MOVEMENT

**FIGURE 6-- ALTITUDES OF WATER LEVELS IN THE CATHAY AQUIFER DECEMBER 1972**

occur as interbedded material at some locations. Buried outwash partially fills the preglacial channel and may directly overlie the bedrock surface or till (pl. 1). Brownish-colored siliceous rocks comprise about 20 percent of the aquifer material and suggest a possible western source area. Glacially-derived granite, limestone, and dolostone are also present and indicate that meltwaters washed and resorted the outwash when northeastern drainage was dammed by ice.

Eight test holes penetrated the aquifer in the study area. Sand and gravel ranged in thickness from 5 feet in test hole 8530 (147-69-14 abb) to 38 feet in test hole 8533 (147-69-12 abb). Thirty-eight feet of aquifer material was also penetrated in test hole 8533 from 153 to 191 feet below land surface (fig. 5). The average thickness of the Cathay aquifer was determined to be about 20 feet.

The Cathay aquifer is about half a mile in width and underlies an area of about 3½ square miles (fig. 5). It undoubtedly extends into adjacent areas of Wells County but the scope of this investigation did not allow further evaluation. Assuming a porosity of 30 percent for coarse sand and gravel, and average saturated thickness of 20 feet, and an area of 3½ square miles (2,240 acres), the aquifer contains about 13,400 acre-feet of ground water in storage. However, only about 50 percent of the water in storage, or about 6,700 acre-feet would be recoverable by wells. Yields of 250 gpm may be expected from a properly constructed well.

Water in the Cathay aquifer is confined and water levels in the observation wells range in altitude from 1573 to 1590 feet above mean sea level. Figure 6 shows the water-level gradient slopes to the northeast at about 5 feet per mile. Water levels will fluctuate in response to the infiltration of seasonal precipitation.

Five chemical analyses indicated the water is moderately soft sodium chloride bicarbonate type that contains dissolved solids ranging from 1,390 to 1,510 mg/l and averaging 1,444 mg/l. Iron and manganese generally exceed the recommended limits set by the U. S. Public Health Service and the water may require treatment and removal of these constituents. Sodium-adsorption ratios range from 10 to 16 and specific conductances are above 2,300 micromhos. Therefore, the water has a high salinity and sodium hazard and may require special management if used for irrigation.

## SUMMARY

This investigation consisted of obtaining and evaluating geohydrologic data within a 36-square mile area of Cathay in Wells County. The area is situated within the Drift Prairie division of the Central Lowland physiographic province of North Dakota. The average annual precipitation is 17.27 inches and the average annual temperature is 40°F. Rocky Run and Pipestem Creek drain the area.

Greater than 4,000 feet of westward-dipping siltstone, sandstone, limestone and shale underlie the glacial drift. The pre-Cretaceous rocks contain water that is very highly mineralized and generally not desirable.

Water from sandstones of the Dakota Group is soft, high in dissolved solids and sodium. Dark-gray shale of the Pierre Formation directly underlies the glacial drift but is not a good aquifer because of low permeability and poor water quality.

Glacial drift in the Cathay area consists mostly of ground moraine. Till is the primary glacial material while outwash sand and gravel deposits occur as secondary constituents. Several minor glacial drift aquifers are associated with till in the area. Test drilling indicates two zones of lenticular sand and gravel deposits underlie the city of Cathay. Public and private wells are completed in sand and gravel lenses of the upper zone. Both the upper and lower zones are small in areal extent and very discontinuous. Water in the till-associated aquifers is of the calcium sulfate bicarbonate type, very high in hardness and usually contain excessive dissolved iron and manganese. The till-associated aquifers are not capable of providing an adequate water supply for the city.

A significant buried outwash deposit exists about three quarters of a mile west of the city. This deposit, herein referred to as the Cathay aquifer, is located in a preglacial buried valley. Eight test holes penetrated the aquifer and indications are that it is about one-half mile in width and underlies an area of about 3½ square miles within the study area. Sand and gravel that constitute the aquifer average 20 feet in thickness. The thickest intervals of sand and gravel were penetrated in test holes 8531 (147-69-14 bab) and 8533 (147-69-12 abb) located three quarters of a mile west and one mile north of the city, respectively. Chemical analyses of water from the Cathay aquifer indicate a sodium chloride bicarbonate type with an average dissolved solids content of about 1,440 mg/l. Relatively high sodium adsorption ratios and specific conductivities indicate the water has a salinity hazard for irrigation purposes.

The Cathay aquifer appears to have good hydraulic continuity and the aquifer materials are highly permeable. Interpretation of data obtained during the course of this study indicates the Cathay aquifer can be a reliable source of water supply for the city.

TABLE I -- 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 | SAR | Specific conductance | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TILL - ASSOCIATED AQUIFERS | | | | | | | | | | | | | | | | | | | | | | | | | |
| City of Cathay #1 | 147-69-13 $bca_1$ | 35 | 46 | 10-5-72 | 24 | 0.94 | 1.50 | 178 | 47 | 101 | 8.7 | 611 | 0 | 329 | 35 | 0.2 | 2.0 | 0.17 | 1020 | 636 | 135 | 25 | 1.7 | 1520 | 7.8 |
| Test hole 8519 | 147-69-13 $bca_2$ | 123 | 46 | 10-3-72 | 28 | 1.20 | 1.70 | 163 | 56 | 324 | 14 | 599 | 0 | 612 | 197 | 0.1 | 6.0 | 0.52 | 1630 | 839 | 148 | 52 | 5.6 | 2510 | 7.6 |
| Test hole 8521 | 147-69-13 bcb | 123 | 45 | 10-4-72 | 28 | 1.70 | 0.76 | 71 | 29 | 291 | 12 | 606 | 0 | 203 | 170 | 0.3 | 3.9 | 0.49 | 1110 | 295 | 0 | 67 | 7.4 | 1780 | 8.1 |
| City of Cathay #2 | 147-69-13 $bcd_1$ | 30 | 44 | 10-5-72 | 23 | 0 | 0.44 | 158 | 63 | 33 | 6.2 | 469 | 0 | 279 | 51 | 0.2 | 3.9 | 0 | 882 | 655 | 260 | 10 | 0.6 | 1290 | 7.8 |
| School well | 147-69-13 $bcd_2$ | 70 | 47 | 10-5-72 | 25 | 11.0 | 1.90 | 272 | 93 | 156 | 13 | 579 | 0 | 769 | 135 | 0.2 | 5.9 | 0.30 | 1760 | 1060 | 585 | 24 | 2.1 | 2340 | 7.7 |
| City of Cathay #3 | 147-69-13bdb | 37 | 46 | 7-21-65 | 24 | 1.80 | – | 626 | 277 | 220 | 18 | 362 | 0 | 2300 | 336 | 0.8 | 3.5 | 0.20 | 4290 | 2700 | 2410 | 15 | 1.8 | 4220 | 7.6 |
| CATHAY AQUIFER | | | | | | | | | | | | | | | | | | | | | | | | | |
| Test hole 8533 | 147-69-12 abb | 173 | 45 | 10-10-72 | 26 | 1.30 | 0.49 | 54 | 11 | 485 | 9.0 | 707 | 0 | 240 | 290 | 0.4 | 1.0 | 0.82 | 1440 | 179 | 0 | 85 | 16 | 2390 | 8.1 |
| Test hole 8529 | 147-69-12 bbb | 223 | 45 | 10-9-72 | 26 | 0.04 | 0.41 | 37 | 19 | 518 | 8.6 | 872 | 0 | 51 | 359 | 0.4 | 0.4 | 1.70 | 1420 | 169 | 0 | 86 | 17 | 2460 | 8.2 |
| Test hole 8531 | 147-69-14 bab | 153 | 46 | 10-9-72 | 27 | 0.22 | 0.39 | 54 | 13 | 444 | 9.4 | 683 | 0 | 140 | 350 | 0.5 | 0.2 | 1.20 | 1390 | 186 | 0 | 83 | 14 | 2340 | 8.0 |
| Test hole 8538 | 147-69-22 dcc | 173 | 45 | 10-11-72 | 25 | 1.40 | 0.66 | 78 | 32 | 428 | 12 | 586 | 0 | 364 | 291 | 0.2 | 4.7 | 0.94 | 1460 | 326 | 0 | 73 | 10 | 2440 | 7.7 |
| Test hole 8537 | 147-69-23bbb | 193 | 45 | 10-11-72 | 26 | 0.22 | 0.30 | 52 | 17 | 529 | 11 | 832 | 6 | 158 | 354 | 0.3 | 0.2 | 1.90 | 1510 | 198 | 0 | 84 | 16 | 2600 | 8.3 |
| SURFACE WATER | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rocky Run | 147-69-14 aad | – | 48 | 10-2-72 | 16 | 0.68 | 0.20 | 21 | 30 | 32 | 15 | 191 | 0 | 88 | 5.6 | 0.1 | 14 | 0 | 354 | 175 | 19 | 26 | 1.1 | 518 | 7.0 |

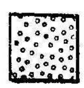
## Table 2 - Logs of Test Holes

The following test hole logs are a summary of data from driller's logs, geologist's sample descriptions and resistivity and spontaneous potential electric logs.

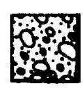
Grain-size classification is C. K. Wentworth's scale from Pettijohn (1957). Color descriptions are of wet samples and are based upon color standards of the National Research Council (Goddard and others, 1948).

Test holes are called observation wells when they have been completed with 1¼-inch diameter plastic casing. Well depths, screened aquifer intervals and water levels are so designated. Water levels are in feet below land surface.

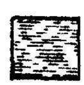
### Explanation of Lithologic Symbols



Sand and Gravel



Till



Silty Clay

Shale

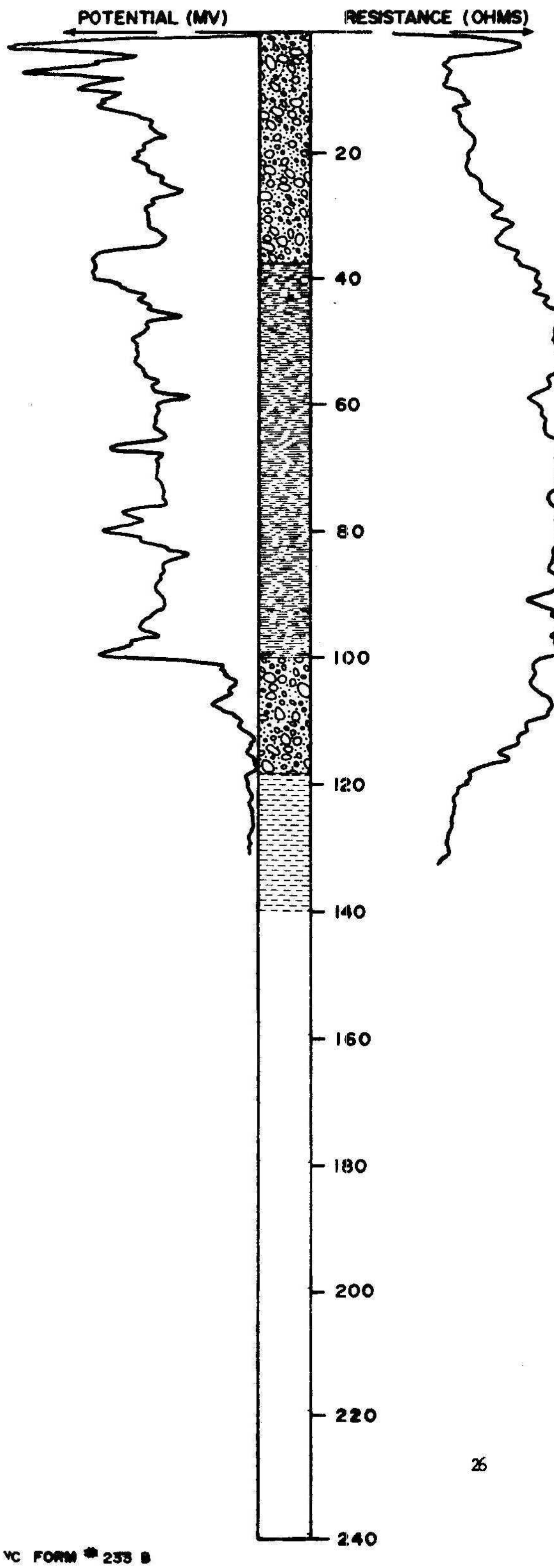
TEST HOLE 8528

LOCATION: 147-68-18aad

DATE DRILLED: 10-5-72

ELEVATION: 1563
(FT, MSL)

DEPTH: 140
(FT)




DESCRIPTION OF DEPOSITS

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty clay loam, brownish-black. |
| 1-10 | Clay, silty, sandy, pebbly, dusky-yellow, slightly cohesive, crumbly, oxidized (Till). |
| 10-37 | Clay, moderately silty, pebbly, a few cobbles, slightly gravelly, olive-gray, moderately cohesive brittle, calcareous (Till). |
| 37-100 | Clay, very silty, slightly sandy, medium-dark-gray, moderately cohesive, crumbly, highly calcareous, occasional thin sand interbeds lower 20 feet. |
| 100-118 | Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, slightly plastic, calcareous (Till). |

Pierre Formation

| | |
|---|---|
| 118-140 | Shale, siliceous, grayish-black, moderately indurated, noncalcareous. |



VC FORM # 233 B

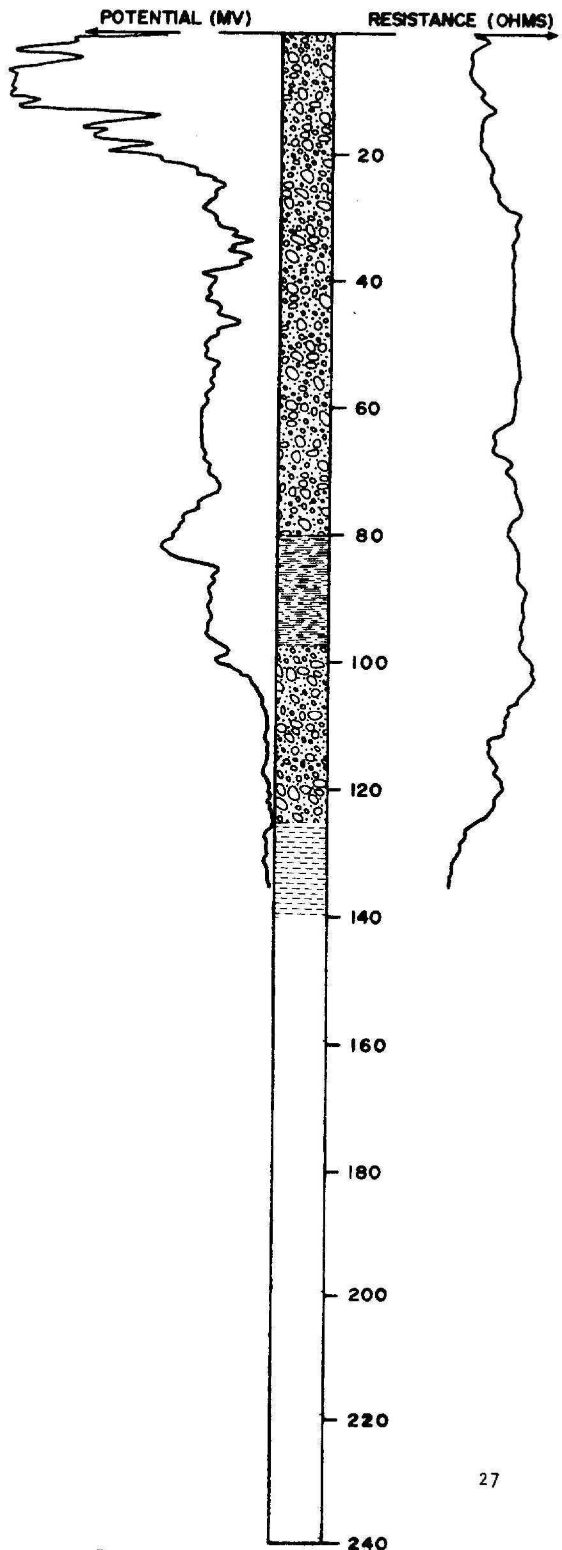
## TEST HOLE 8527

**LOCATION:** 147-68-18bbb

**ELEVATION:** 1588
**(FT, MSL)**

**DATE DRILLED:** 10-5-72

**DEPTH:** 140
**(FT)**




**DESCRIPTION OF DEPOSITS**

Glacial Drift

0-1 Topsoil, silty clay loam, grayish-black.

1-22 Clay, silty, moderately sandy, pebbly, dusky-yellow, slightly cohesiye, crumbly, oxidized(Till).

22-80 Clay, silty, moderately sandy, pebbly, a few cobbles, olive-gray, cohesive, brittle, calcareous (Till).

80-97 Clay, very silty, medium-dark-gray, cohesive, crumbly, highly calcareous (Glaciofluvial deposit).

97-125 Clay, silty, slightly sandy, pebbly, olive-gray, slightly plastic, cohesive (Till).

Pierre Formation

125-140 Shale, siliceous, grayish-black, moderately indurated, non-calcareous.



SWC FORM # 233 B

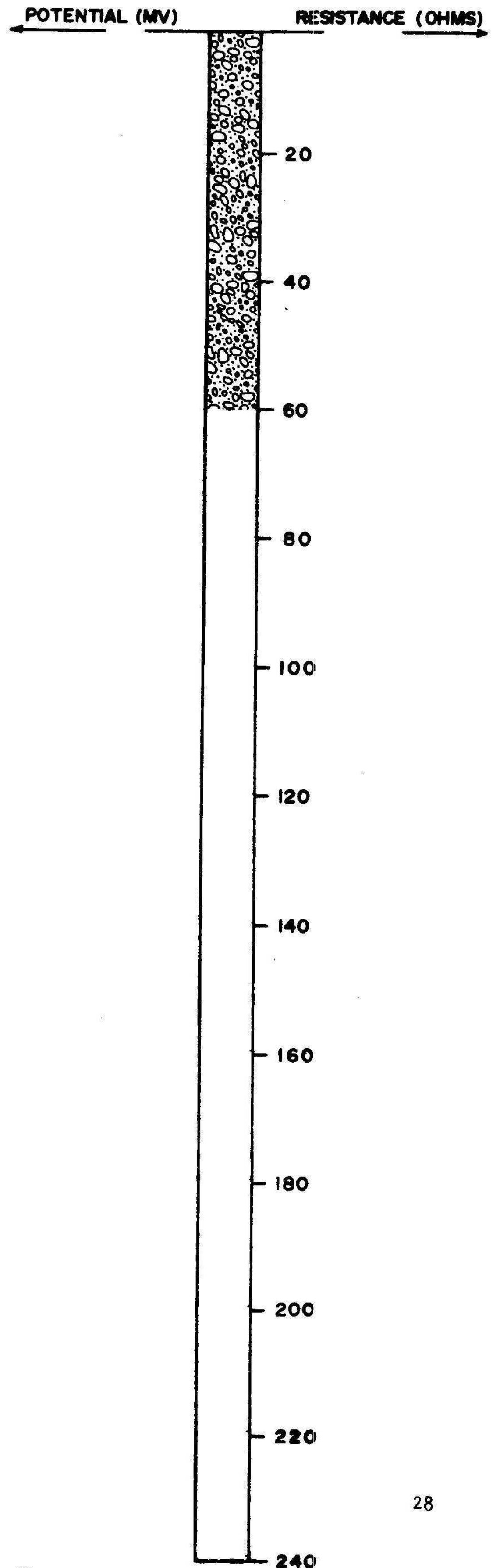
TEST HOLE 8536

LOCATION: 147-68-18cbb

DATE DRILLED: 10-10-72

ELEVATION: 1560
(FT, MSL)

DEPTH: 60
(FT)




DESCRIPTION OF DEPOSITS

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty, pebbly clay loam, grayish-black. |
| 1-11 | Clay, silty, moderately sandy, pebbly, slightly gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till). |
| 11-60 | Clay, moderately silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, brittle, calcareous (Till). |



SWC FORM # 233 B

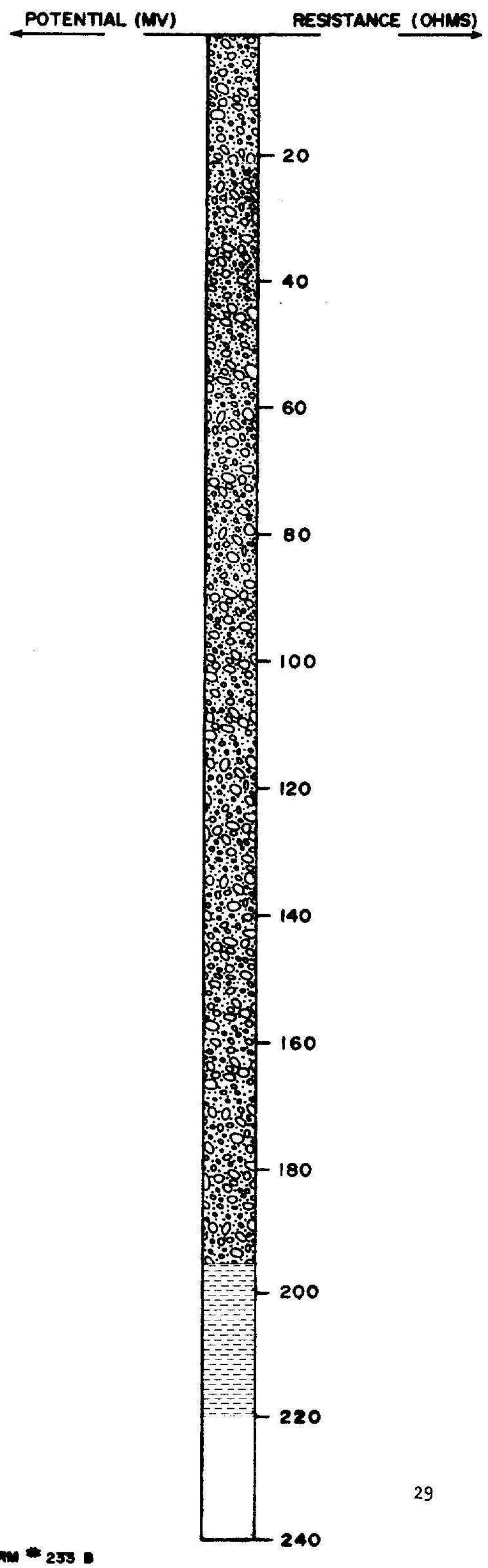
TEST HOLE 2456

LOCATION: 147-68-20add

DATE DRILLED:

ELEVATION: 1580
(FT, MSL)

DEPTH: 220
(FT)




DESCRIPTION OF DEPOSITS

Glacial Drift

| | |
|---|---|
| 0-2 | Topsoil, black. |
| 2-20 | Clay, very sandy, dusky-yellow (Till). |
| 20-21 | Clay, very sandy, olive-gray (Till). |
| 21-22 | Sand. |
| 22-196 | Clay, very sandy, grayish-olive-green, highly cohesive, moderately rocky (Till). |

Pierre Formation

| | |
|---|---|
| 196-220 | Shale, silty, olive-green, highly fissile. |



SWC FORM # 233 B

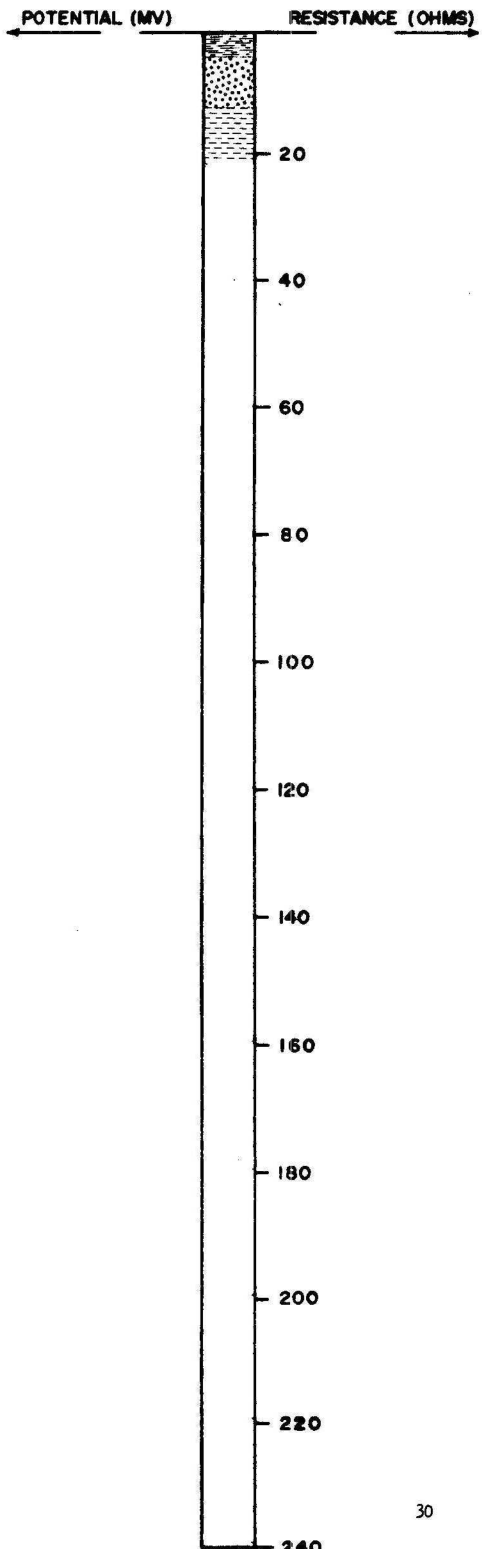
TEST HOLE 2572

LOCATION: 147-68-30ddd

DATE DRILLED:

ELEVATION: 1597
(FT, MSL)

DEPTH: 21
(FT)




DESCRIPTION OF DEPOSITS

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty, dusky-brown. |
| 1-4 | Clay, silty, yellowish-gray. |
| 4-12 | Sand, medium to coarse, gravelly. |

Pierre Formation

| | |
|---|---|
| 12-21 | Shale, olive-black, drills tight. |



SWC FORM # 233 B

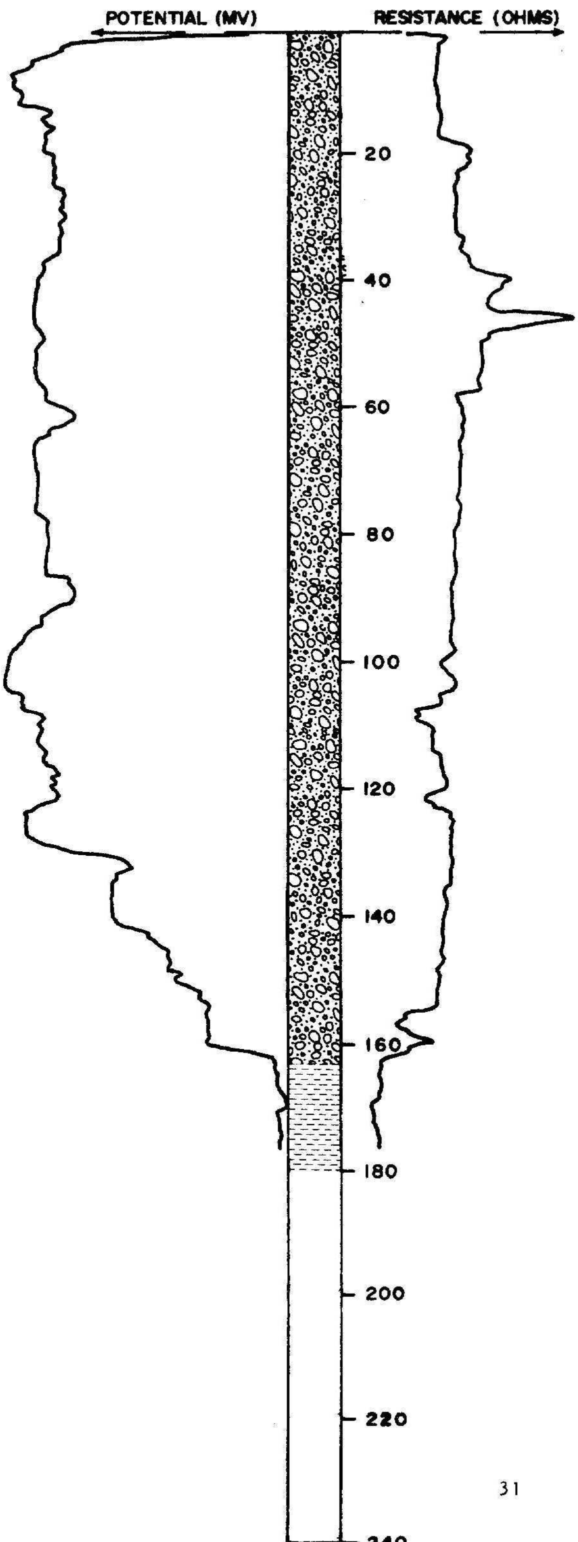
## TEST HOLE 8534

LOCATION: 147-69-12aaa

DATE DRILLED: 10-10-72

ELEVATION: 1588
(FT, MSL)

DEPTH: 180
(FT)




**DESCRIPTION OF DEPOSITS**

Glacial Drift

0-1 Topsoil, silty clay loam, grayish-black.

1-16 Clay, silty, moderately sandy, pebbly, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till).

16-163 Clay, moderately silty, slightly sandy, pebbly, a few thin gravel stringers, cobbles, olive-gray, cohesive, slightly plastic, calcareous (Till).

Pierre Formation

163-180 Shale, siliceous, grayish-black, moderately indurated, non-calcareous.



SWC FORM # 233 B

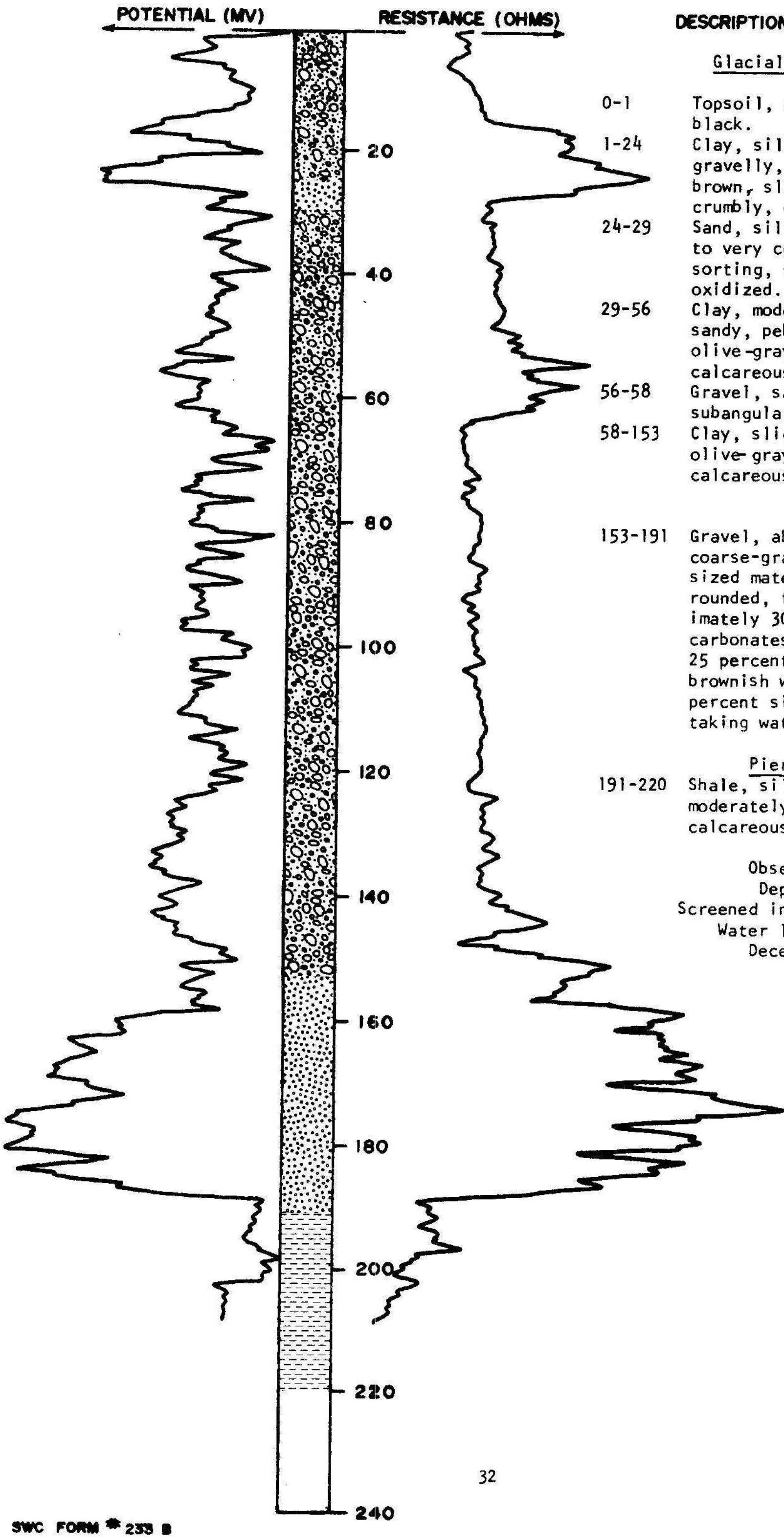
## TEST HOLE 8533

LOCATION: 147-69-12abb

ELEVATION: 1596
(FT, MSL)

DATE DRILLED: 10-9-72

DEPTH: 220
(FT)




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty loam, grayish-black. |
| 1-24 | Clay, silty, moderately sandy, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till). |
| 24-29 | Sand, silty, some clay, fine- to very coarse-grained, fair sorting, subrounded, lignitic, oxidized. |
| 29-56 | Clay, moderately silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, brittle, calcareous (Till). |
| 56-58 | Gravel, sandy, poorly sorted, subangular, loose. |
| 58-153 | Clay, slightly sandy, pebbly, olive-gray, cohesive, sticky calcareous (Till). |
| 153-191 | Gravel, about 40 percent fine- to coarse-grained sand, some cobble-sized material, subangular to rounded, fair sorting, approximately 30 percent buff to tan carbonates, 10 percent granitics, 25 percent dark shale, 20 percent brownish western silicates, 15 percent siltstone and sandstone, taking water, clear. |

Pierre Formation

| | |
|---|---|
| 191-220 | Shale, siliceous, grayish-black. moderately indurated, non-calcareous. |

Observation Well
Depth 173 feet
Screened interval 167-173 feet
Water level 22.60 feet
December 18, 1972

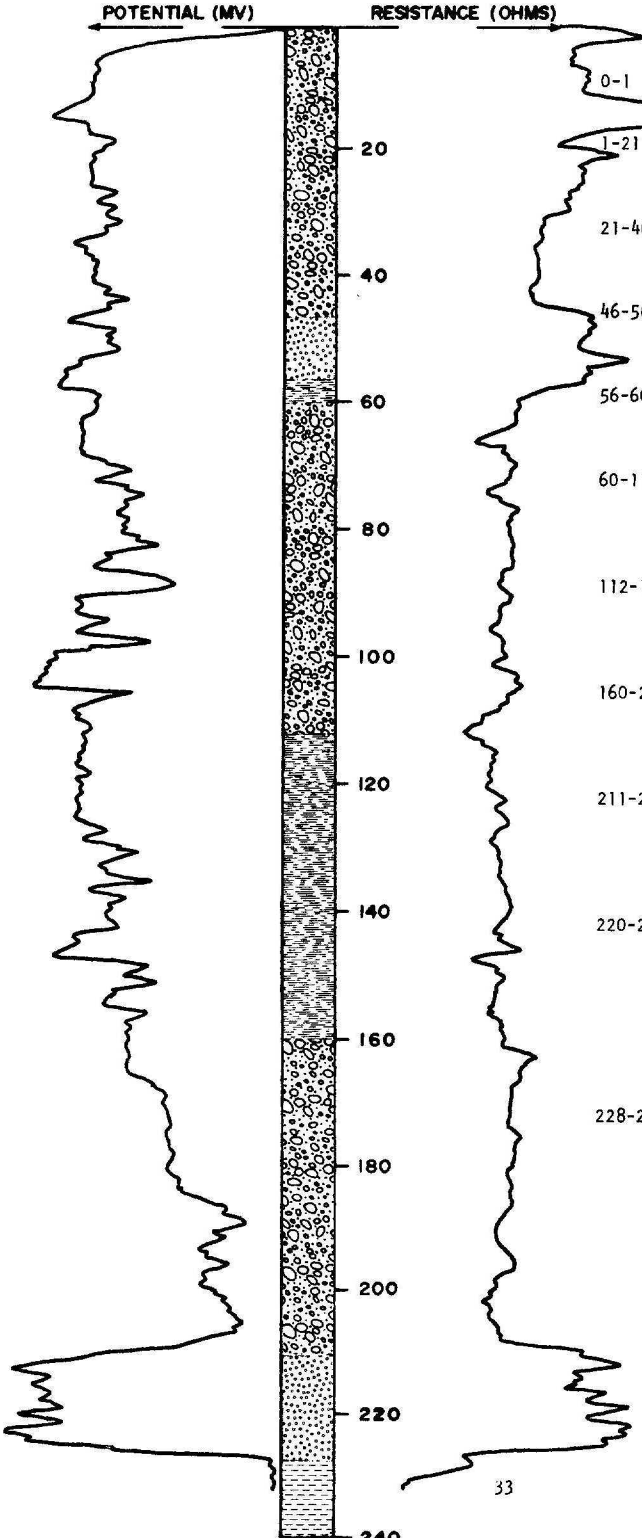


SWC FORM * 233 B

**TEST HOLE** 8529

**LOCATION:** 147-69-12bbb | **DATE DRILLED:** 10-5-72

**ELEVATION:** 1597 **(FT, MSL)** | **DEPTH:** 240 **(FT)**




**DESCRIPTION OF DEPOSITS**

Glacial Drift

0-1 Topsoil, silty clay loam, grayish-black.

1-21 Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till).

21-46 Clay, slightly sandy, pebbly, olive-gray, a few cobbles, slightly plastic, brittle, calcareous (Till).

46-56 Sand, slightly clayey, slightly gravelly, fine- to very coarse-grained, subangular to subrounded, fair to good sorting, clean.

56-60 Clay, very silty, medium-dark-gray, slightly cohesive, slightly plastic, crumbly, highly calcareous (Glaciofluvial deposit).

60-112 Clay, moderately silty, slightly sandy, pebbly, olive-gray, moderately cohesive, slightly plastic, calcareous (Till).

112-160 Clay, very silty, medium-dark-gray, cohesive, moderately plastic, sticky, highly calcareous, (Glaciofluvial deposit).

160-211 Clay, moderately silty, slightly sandy, pebbly, a few cobbles, olive-gray, moderately cohesive, slightly plastic, calcareous (Till).

211-220 Sand, about 30 percent fine to medium gravel, fine- to very coarse-grained, predominantly coarse to very coarse, subangular to subrounded, fair sorting, clean.

220-228 Gravel, about 40 percent sand, fine to coarse, cobbles, angular to subrounded, approximately 25 percent dark gray shale, 40 percent buff to tan carbonates, 15 percent granitics, 20 percent brownish western silicates, taking water, clean.

Pierre Formation

228-240 Shale, siliceous, grayish-black, moderately indurated, non-calcareous.

Observation Well
Depth 223 feet
Screened interval 217-223 feet
Water level 22.40 feet
December 18, 1972



SWC FORM # 233 B

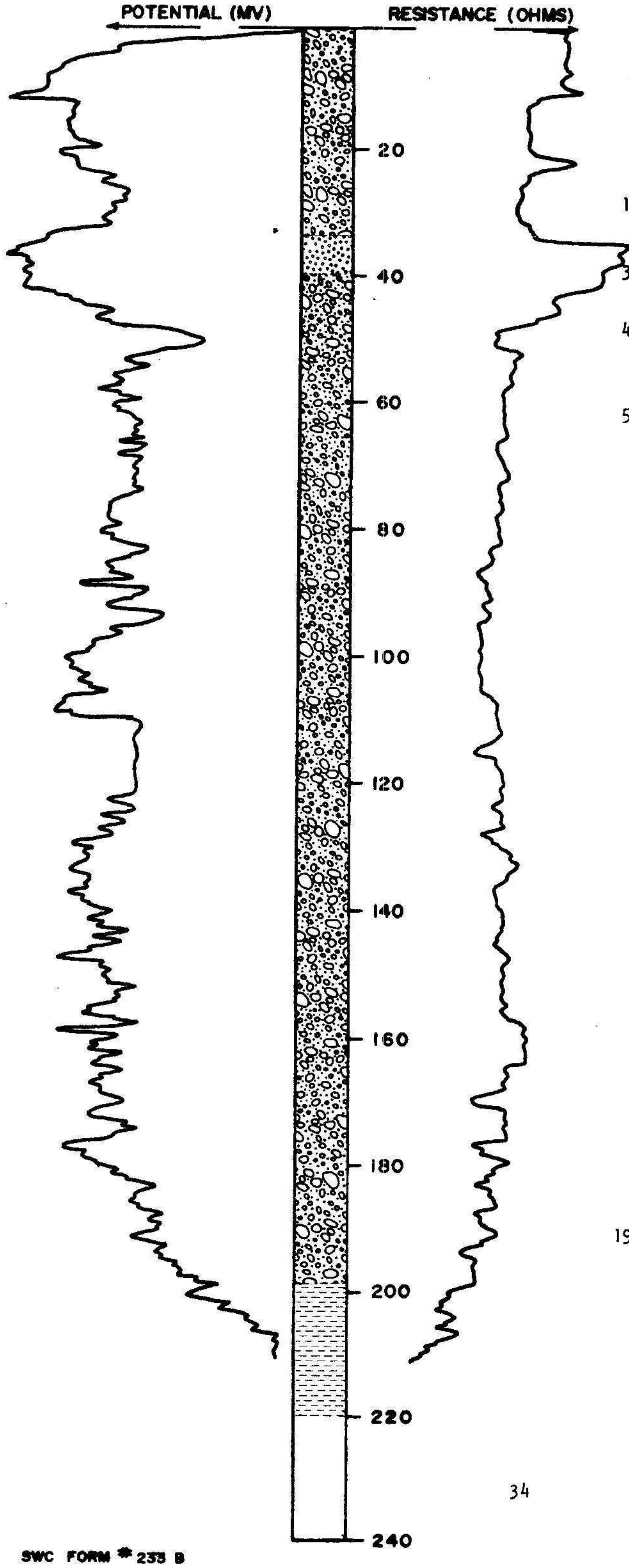
TEST HOLE 8535

LOCATION: 147-69-12cbb

DATE DRILLED: 10-10-72

ELEVATION: 1582
(FT, MSL)

DEPTH: 220
(FT)




DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, silty clay loam, grayish-black.

1-13 Clay, silty, moderately sandy, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till).

13-33 Clay, moderately silty, slightly sandy, a few gravel layers, olive-gray, cohesive, (Till).

33-40 Sand, fine- to very coarse-grained subangular to subrounded, clean.

40-50 Clay, sandy, pebbly, gravel layers olive-gray, moderately cohesive, slightly plastic, calcareous (Till).

50-199 Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, brittle, calcareous (Till).

Pierre Formation

199-220 Shale, siliceous, grayish-black, indurated, non-calcareous.



SWC FORM # 233 B

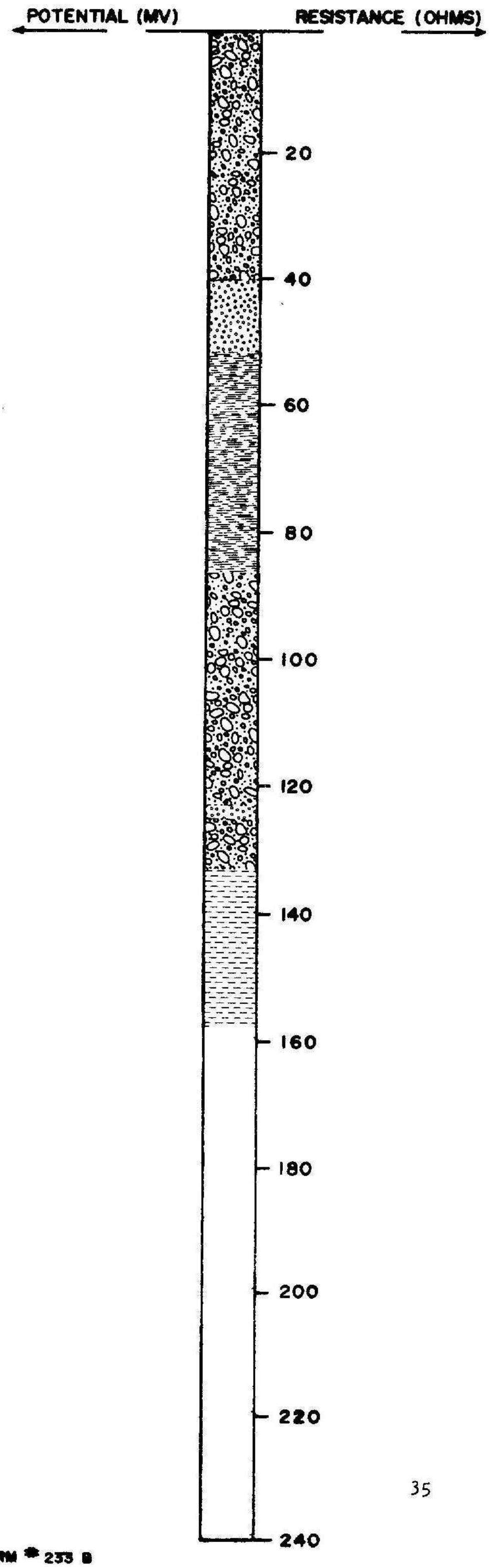
## TEST HOLE 2574

**LOCATION:** 147-69-13bbd

**DATE DRILLED:**

**ELEVATION: (FT, MSL)** 1580

**DEPTH: (FT)** 158




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty, black. |
| 1-23 | Clay, silty, dusky-yellow, oxidized (Till). |
| 23-40 | Clay, silty, olive-gray (Till). |
| 40-51 | Sand, medium to coarse, clayey, consists of shale particles. |
| 51-78 | Silt, sandy, olive-gray, drills tight (Glaciofluvial sediment). |
| 78-86 | Clay, olive-gray, very compact drills tight (Glaciofluvial sediment). |
| 86-123 | Clay, silty, olive-gray (Till). |
| 123-125 | Sand, coarse, gravelly. |
| 125-133 | Clay, silty to gravelly, olive gray (Till). |

Pierre Formation

| | |
|---|---|
| 133-158 | Shale, olive-black. |



SWC FORM # 233 B

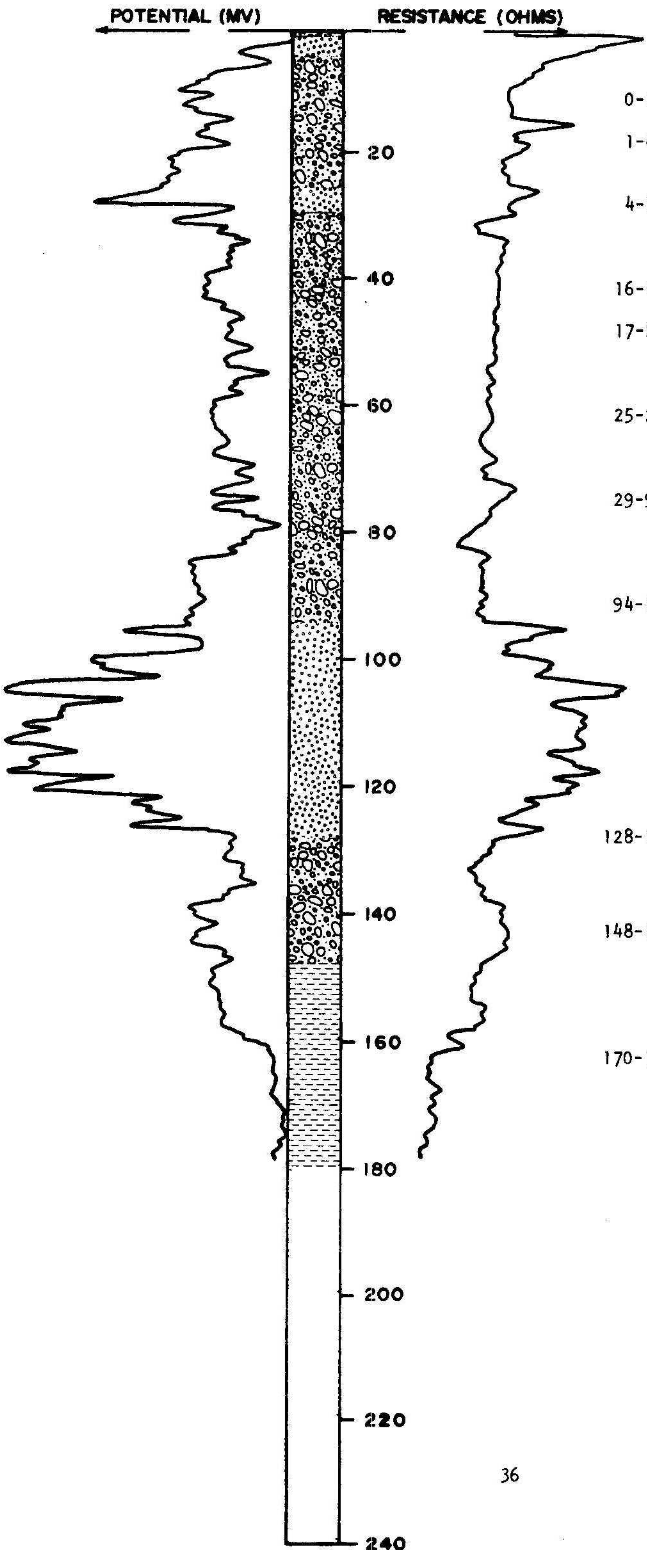
## TEST HOLE 8519

LOCATION: 147-69-13bca

DATE DRILLED: 10-3-72

ELEVATION: 1578
(FT, MSL)

DEPTH: 180
(FT)




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty clay loam, grayish-black. |
| 1-4 | Gravel, clayey, sandy, fine to coarse, subangular, poorly sorted, well oxidized. |
| 4-16 | Clay, silty, moderately sandy, pebbly, slightly gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till) |
| 16-17 | Boulder, granite, greenish-black, very hard. |
| 17-25 | Clay, moderately silty, slightly sandy, pebbly, slightly gravelly, olive-gray, cohesive, crumbly, calcareous (Till). |
| 25-29 | Sand, fine- to very coarse-grained predominantly medium to coarse, subangular to rounded, fair sorting. |
| 29-94 | Clay, moderately silty, slightly sandy, pebbly, a few cobbles, olive-gray, moderately cohesive, slightly plastic, calcareous (Till). |
| 94-128 | Sand, slightly clayey, fine- to coarse-grained, predominantly medium, subangular to rounded, moderately well-sorted, approximately 60 percent quartz, 30 percent shale, 10 percent carbonates, clean-looking. |
| 128-148 | Clay, silty, slightly sandy, pebbly, olive-gray, moderately cohesive, slightly plastic, calcareous (Till). |
| 148-170 | Clay, very silty, medium-dark-gray, cohesive, brittle, crumbly, highly calcareous (Glaciofluvial deposit). |

Pierre Formation

| | |
|---|---|
| 170-180 | Shale, siliceous, grayish-black, moderately indurated, non-calcareous. |

Observation Well
Depth 123 feet
Screened interval 117-123 feet
Water level 18.30 feet
December 18, 1972



SWC FORM # 233 B

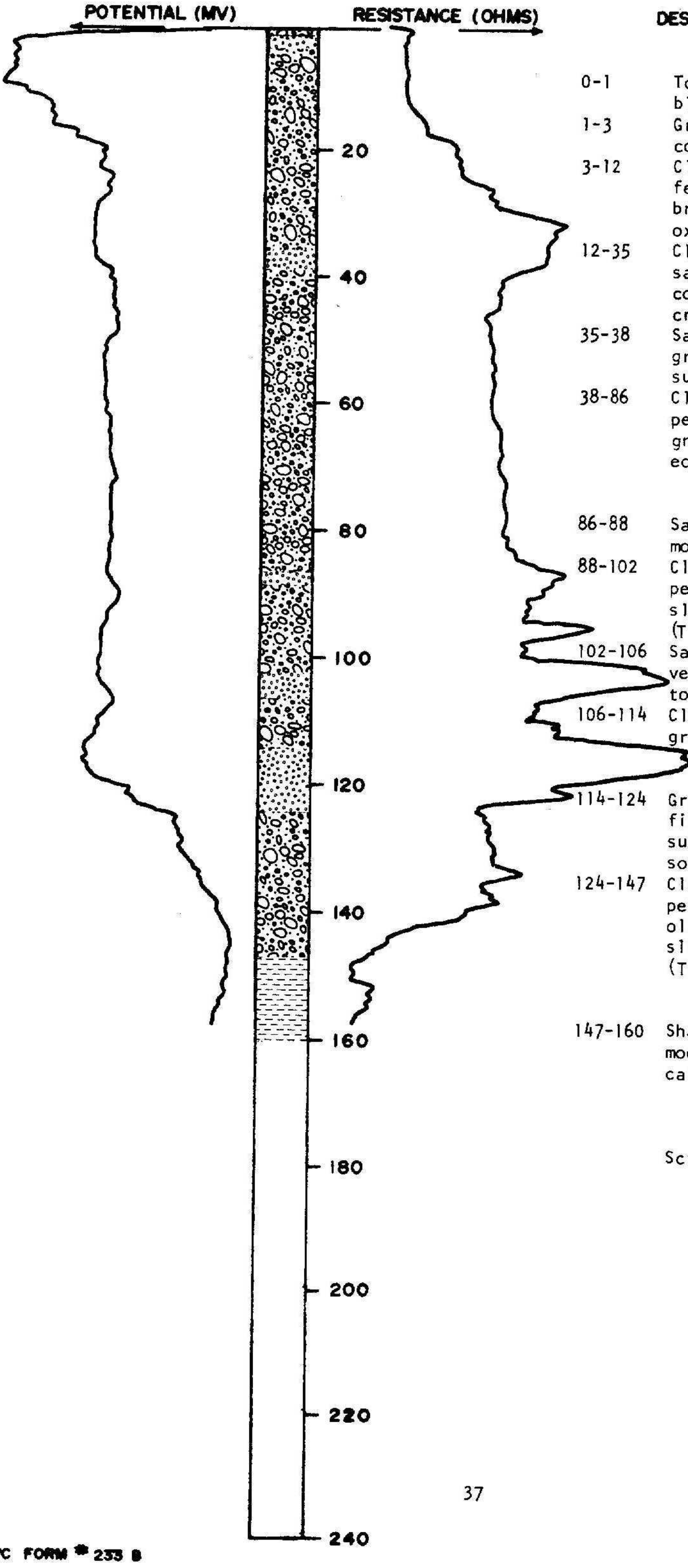
## TEST HOLE 8521

**LOCATION:** 147-69-13bcb

**DATE DRILLED:** 10-3-72

**ELEVATION:** 1580
**(FT, MSL)**

**DEPTH:** 160
**(FT)**




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty clay loam, grayish-black. |
| 1-3 | Gravel, clayey, sandy, fine to coarse, poorly sorted, oxidized. |
| 3-12 | Clay, silty, sandy, pebbly, a few cobbles, moderate-yellowish-brown, slightly cohesive, crumbly oxidized (Till). |
| 12-35 | Clay, slightly silty, slightly sandy, pebbly, gravelly, a few cobbles, olive-gray, cohesive, crumbly, calcareous (Till). |
| 35-38 | Sand, fine- to very coarse-grained, clayey, subangular to subrounded, fair sorting. |
| 38-86 | Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, crumbly, calcareous (Till). |
| 86-88 | Sand, fine to coarse, subrounded, moderately well-sorted. |
| 88-102 | Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, slightly plastic, calcareous (Till). |
| 102-106 | Sand, slightly clayey, fine- to very coarse-grained, subangular to subrounded, fair sorting. |
| 106-114 | Clay, silty, moderately sandy, gravelly, medium-dark-gray, cohesive, crumbly, calcareous (Till). |
| 114-124 | Gravel, about 40 percent sand, fine to coarse, some clay, subangular to rounded, poorly sorted. |
| 124-147 | Clay, silty, moderately sandy, pebbly, gravelly, a few cobbles, olive-gray, moderately cohesive, slightly plastic, calcareous (Till). |

Pierre Formation

| | |
|---|---|
| 147-160 | Shale, siliceous, grayish-black, moderately indurated, noncalcareous, brittle. |

Observation Well
Depth 123 feet
Screened interval 117-123 feet
Water level 7.35 feet
December 18, 1972



SWC FORM # 233 B

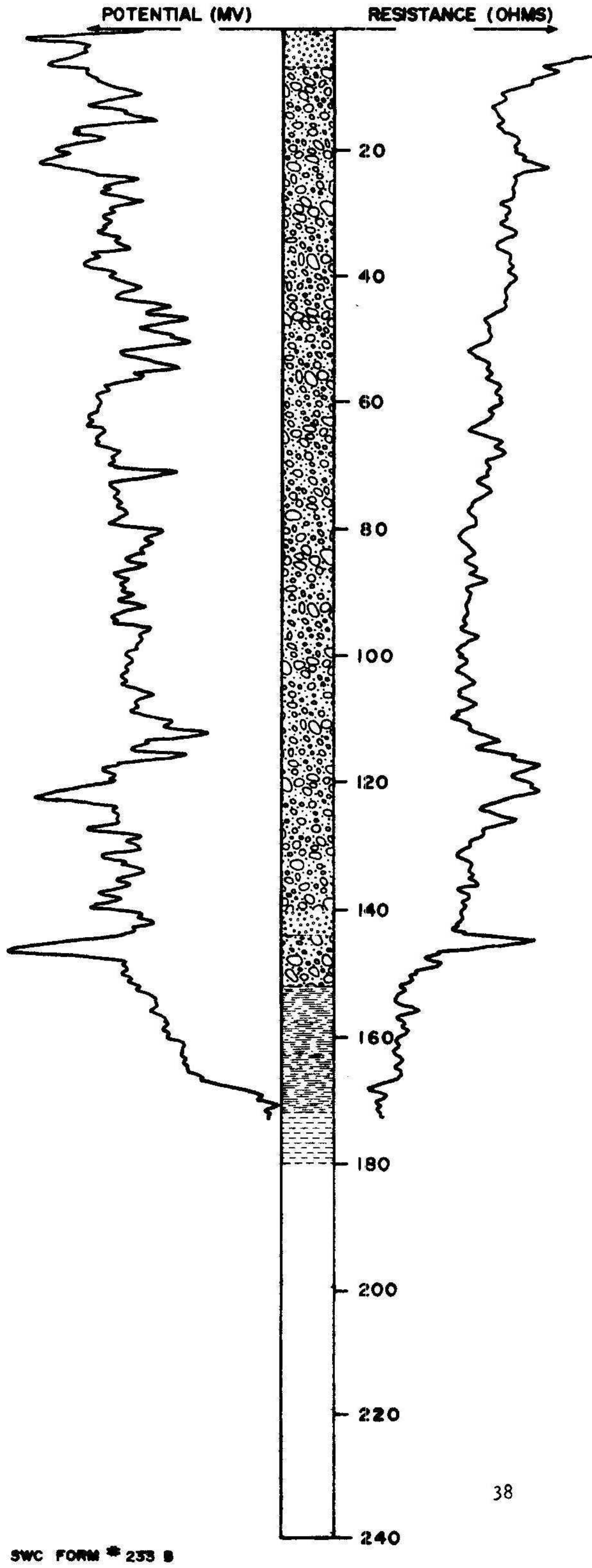
## TEST HOLE 8520

**LOCATION:** 147-69-13bcc

**DATE DRILLED:** 10-3-72

**ELEVATION:** 1583
**(FT, MSL)**

**DEPTH:** 180
**(FT)**




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty, pebbly, clay loam, grayish-black. |
| 1-6 | Gravel, clayey, sandy, fine to coarse, poorly sorted, well oxidized. |
| 6-13 | Clay, silty, slightly sandy, pebbly, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized(Till). |
| 13-140 | Clay, moderately silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, crumbly, calcareous (Till). |
| 140-144 | Sand, clayey, slightly gravelly, fine- to very coarse-grained, predominantly coarse, subangular to subrounded, fair sorting. |
| 144-152 | Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, slightly plastic, calcareous (Till). |
| 152-172 | Clay, very silty, medium-dark-gray, cohesive, brittle, highly calcareous (Glaciofluvial deposit). |

Pierre Formation

| | |
|---|---|
| 172-180 | Shale, siliceous, grayish-black, moderately indurated, non-calcareous. |



SWC FORM # 233 B

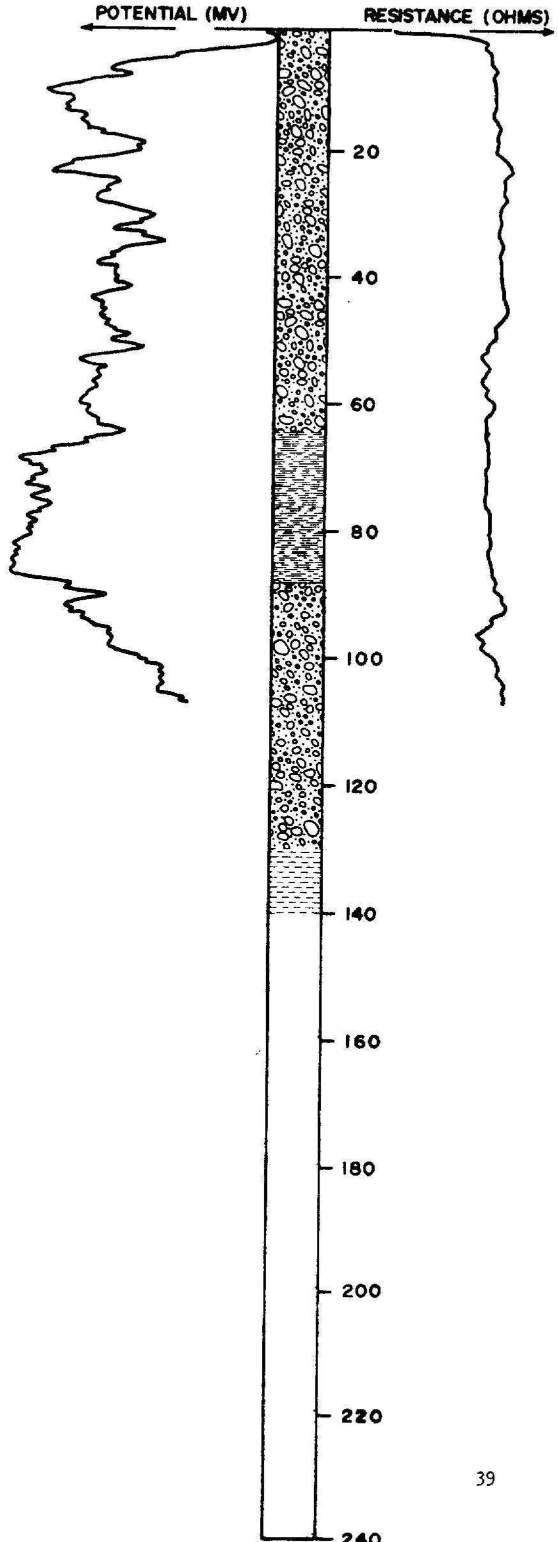
**TEST HOLE** 8518

**LOCATION:** 147-69-13bda

**ELEVATION:** 140
**(FT, MSL)**

**DATE DRILLED:** 10-2-72

**DEPTH:** 140
**(FT)**




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty, loam, grayish-black, |
| 1-15 | Clay, moderately silty, pebbly, gravelly, a few cobbles, moderate yellowish-brown, cohesive, brittle, oxidized (Till). |
| 15-64 | Clay, silty, slightly sandy, pebbly, slightly gravelly, a few cobbles, olive-gray, cohesive, brittle, calcareous (Till). |
| 64-88 | Clay, very silty, medium-dark-gray to dark-greenish-gray, moderately cohesive, crumbly, calcareous (Glaciofluvial deposit). |
| 88-130 | Clay, silty, slightly sandy, pebbly, gravelly, olive-gray, cohesive, brittle, calcareous (Till). |

Pierre Formation

| | |
|---|---|
| 130-140 | Shale, siliceous, grayish-black, moderately indurated, non-calcareous. |



SWC FORM # 233 B

## TEST HOLE 8522

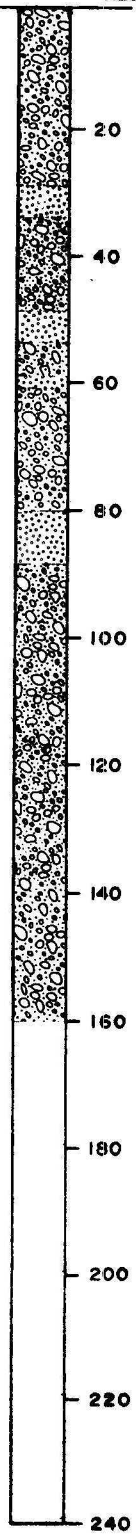
LOCATION: 147-69-13bdd

DATE DRILLED: 10-3-72

ELEVATION: 1578
(FT, MSL)

DEPTH: 160
(FT)

POTENTIAL (MV) RESISTANCE (OHMS)




DESCRIPTION OF DEPOSITS

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty, pebbly clay loam, grayish-black. |
| 1-18 | Clay, silty, sandy, pebbly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till). |
| 18-28 | Clay, slightly sandy, pebbly, gravelly, olive-gray, cohesive, slightly plastic, calcareous (Till). |
| 28-33 | Gravel, slightly sandy, fine to coarse, cobbles, angular to rounded, poorly sorted, loose, predominantly carbonates, caving badly. |
| 33-48 | Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic, calcareous (Till). |
| 48-53 | Sand, fine- to coarse-grained, subangular to rounded, fair sorting. |
| 53-58 | Clay, sandy, moderately silty, pebbly, olive-gray, cohesive, slightly plastic, calcareous (Till). |
| 58-60 | Sand, slightly clayey, fine- to coarse-grained, subangular to rounded, fair sorting. |
| 60-80 | Clay, silty, slightly sandy, pebbly, olive-gray, cohesive, brittle, calcareous (Till). |
| 80-88 | Sand, clayey, fine- to medium-grained, subrounded, moderately well-sorted, dirty. |
| 88-160 | Clay, moderately silty, slightly sandy, pebbly, gravelly, olive-gray, cohesive, slightly plastic, calcareous (Till). |



SWC FORM # 233 B

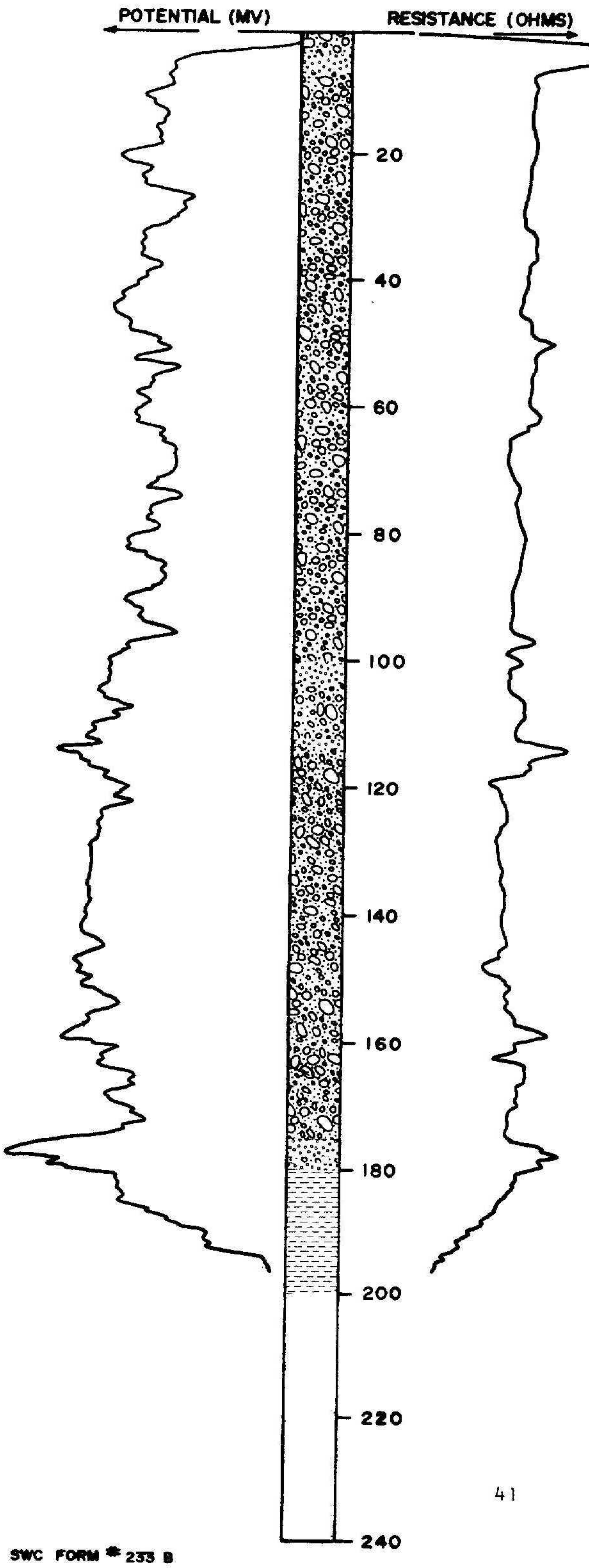
## TEST HOLE 8517

LOCATION: 147-69-13cab

DATE DRILLED: 10-2-72

ELEVATION: 1580
(FT, MSL)

DEPTH: 200
(FT)




**DESCRIPTION OF DEPOSITS**

Glacial Drift

0-3 Clay, very sandy, pebbly, gravelly, dusky-yellow, slightly cohesive, crumbly, oxidized(Till).

3-6 Sand, slightly gravelly medium- to very coarse-grained, subangular to subrounded, fair sorting, well oxidized.

6-9 Clay, silty, sandy, pebbly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized(Till).

9-100 Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, crumbly, calcareous (Till).

100-103 Gravel, clayey, sandy, fine to coarse, subangular to subrounded, poorly sorted, predominantly carbonates and shale.

103-112 Clay, silty, slightly sandy, pebbly, olive-gray, moderately cohesive, slightly plastic, calcareous (Till).

112-113 Gravel, cobbles, fine to coarse, unsorted.

113-175 Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, moderately cohesive, slightly plastic, calcareous (Till).

175-178 Gravel, moderately sandy, fine to coarse, subangular to subrounded, poorly sorted, some clay.

178-179 Clay, silty, sandy, pebbly, olive-gray, cohesive, slightly plastic, calcareous (Till).

179-180 Gravel, clayey, sandy, poorly sorted, subangular.

Pierre Formation

180-200 Shale, siliceous, grayish-black, moderately indurated, slightly calcareous to non-calcareous, brittle.



SWC FORM # 233 B

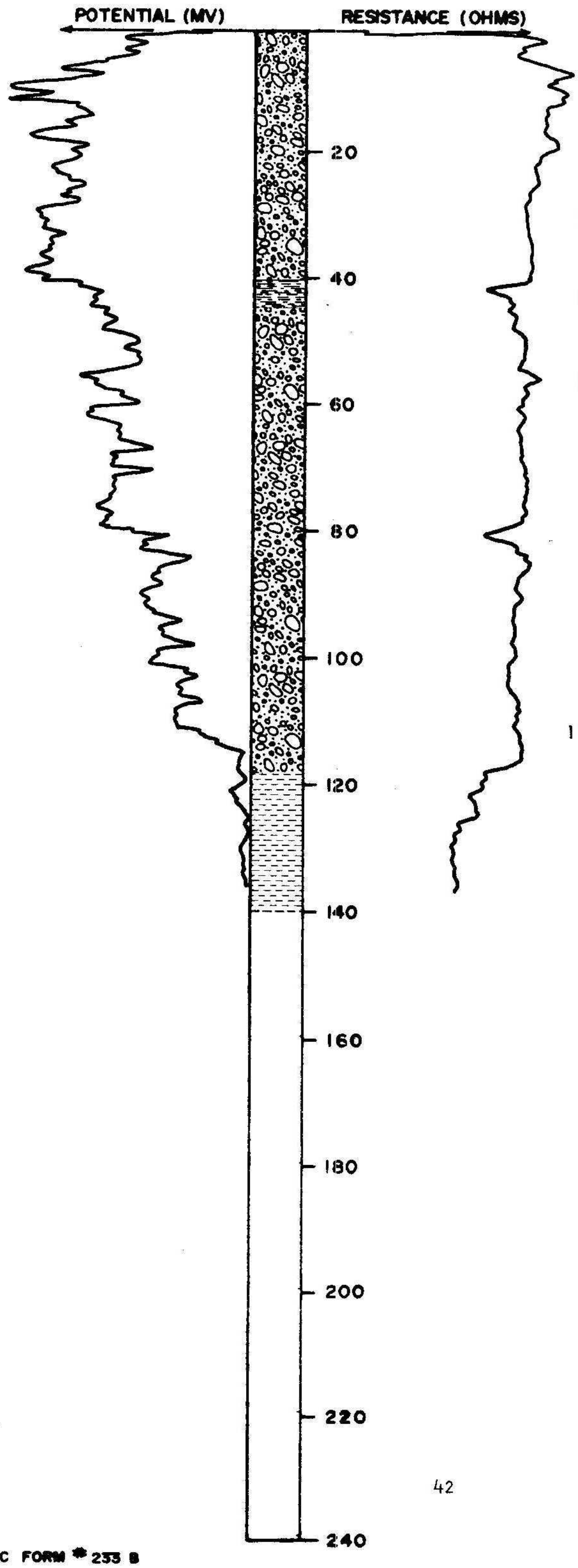
## TEST HOLE 8516

LOCATION: 147-69-14aaa

DATE DRILLED: 10-2-72

ELEVATION: 1575
(FT, MSL)

DEPTH: 140
(FT)




DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, silty, pebbly, clay loam, grayish-black.

1-12 Clay, moderately silty, pebbly, slightly gravelly, moderate-yellowish-brown, cohesive, brittle, oxidized (Till).

12-40 Clay, moderately silty, sandy, pebbly, slightly gravelly, olive-gray, moderately cohesive, crumbly, calcareous (Till).

40-44 Clay, very silty, medium-dark-gray to dark-greenish-gray, very cohesive, plastic, calcareous (Glaciofluvial deposit).

44-118 Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, moderately cohesive, slightly plastic, calcareous (Till).

Pierre Formation

118-140 Shale, siliceous, grayish-black to black, moderately indurated, non-calcareous, brittle.



SWC FORM # 233 B

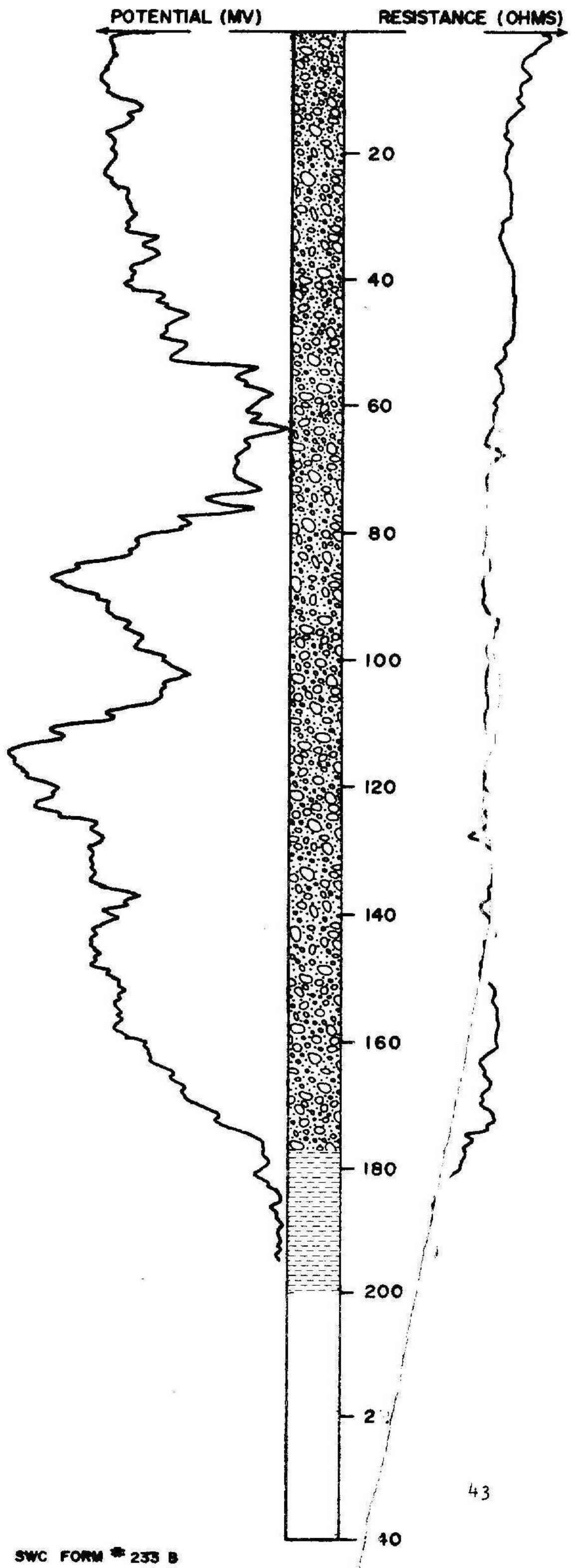
## TEST HOLE 8532

LOCATION: 147-69-14aba

DATE DRILLED: 10-9-72

ELEVATION: 1582
(FT, MSL)

DEPTH: 200
(FT)




### DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, silty clay loam, grayish-black.

1-13 Clay, silty, moderately sandy, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till).

13-112 Clay, moderately silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, moderately plastic, calcareous (Till).

112-177 Clay, very silty, pebbly, medium-dark-gray, cohesive, sticky, calcareous (Till).

Pierre Formation

177-200 Shale, siliceous, grayish-black, moderately indurated, non-calcareous.



SWC FORM # 233 B

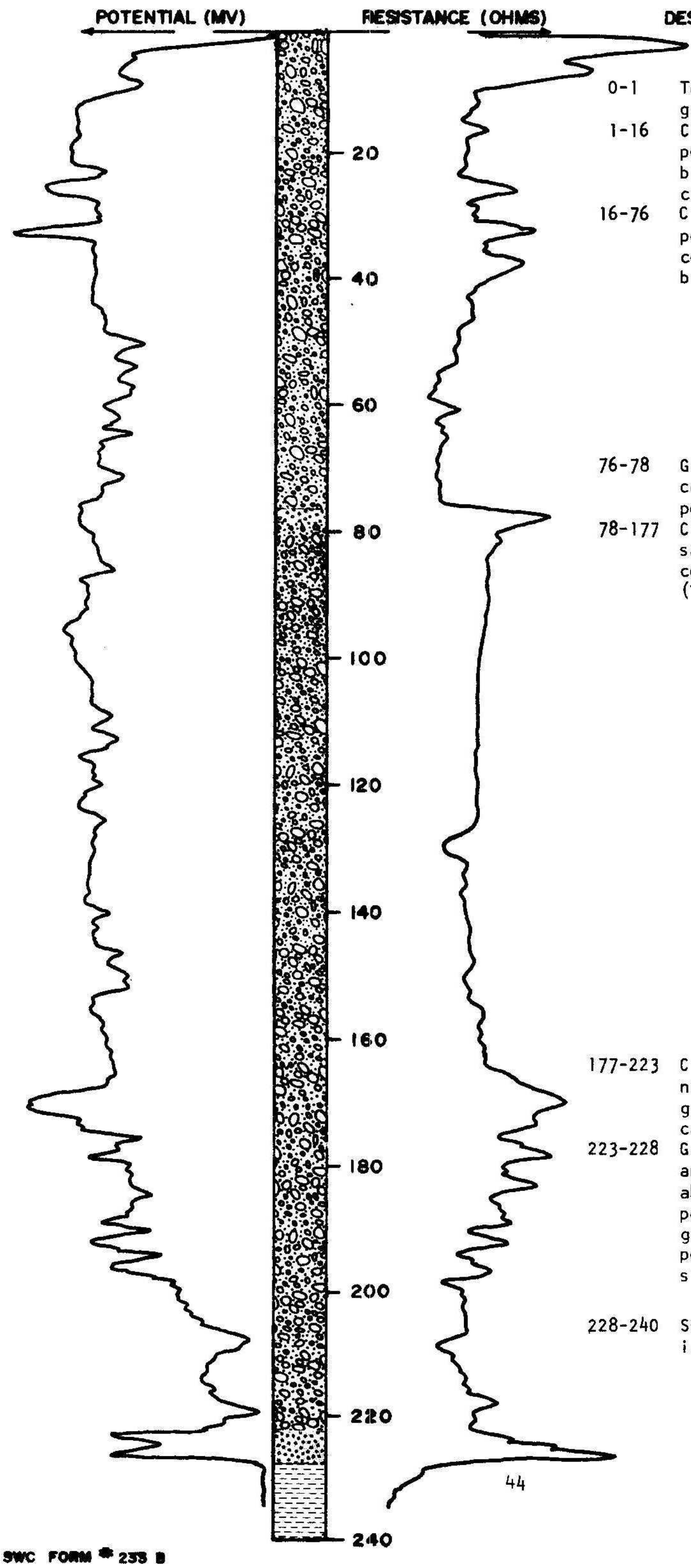
# TEST HOLE 8530

**LOCATION:** 147-69-14abb

**DATE DRILLED:** 10-6-72

**ELEVATION:** 1582
**(FT, MSL)**

**DEPTH:** 240
**(FT)**




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty clay loam, grayish-black. |
| 1-16 | Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till). |
| 16-76 | Clay, silty, slightly sandy, pebbly, a few thin gravel layers, cobbles, olive-gray, cohesive, brittle, calcareous (Till). |
| 76-78 | Gravel, cobbles, medium to coarse, subangular to rounded, poorly sorted. |
| 78-177 | Clay, moderately silty, slightly sandy, pebbly, olive-gray, cohesive, brittle, calcareous (Till). |
| 177-223 | Clay, silty, sandy, pebbly, numerous gravel stringers, olive-gray, slightly plastic, cohesive, calcareous (Till). |
| 223-228 | Gravel, cobbles, fine to coarse, angular to rounded, fair sorting, about 40 percent carbonates, 25 percent dark shale, 15 percent granitics and metamorphics, 20 percent brownish, western silicates. |

Pierre Formation

| | |
|---|---|
| 228-240 | Shale, siliceous, grayish-black, indurated, non-calcareous. |



SWC FORM # 233 B

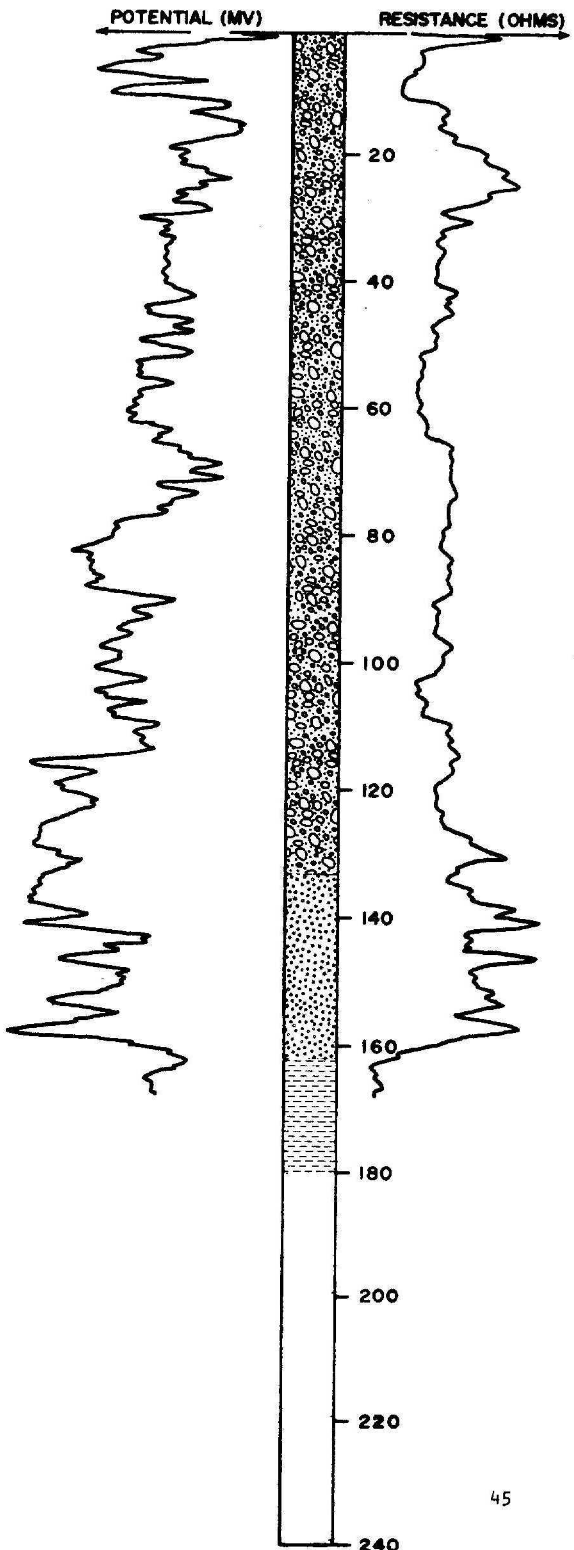
TEST HOLE 8531

LOCATION: 147-69-14bab

DATE DRILLED: 10-9-72

ELEVATION: 1582
(FT, MSL)

DEPTH: 180
(FT)




**DESCRIPTION OF DEPOSITS**

Glacial Drift

0-1 Topsoil, silty loam, grayish-black.

1-13 Clay, silty, moderately sandy, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till).

13-133 Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic, calcareous (Till).

133-162 Gravel, a few clay layers, about 30-40 percent sand, cobbles, subangular to well rounded, fair sorting, approximately 30 percent buff to tan carbonates, 25 percent dark gray shale, 15 percent granitics, 20 percent brownish western silicates, and 10 percent siltstone and sandstone, taking water.

Pierre Formation

162-180 Shale, siliceous, grayish-black, moderately indurated, non-calcareous.

Observation Well
Depth 153 feet
Screened interval 147-153 feet
Water level 5.64 feet
December 18, 1972



SWC FORM # 233 B

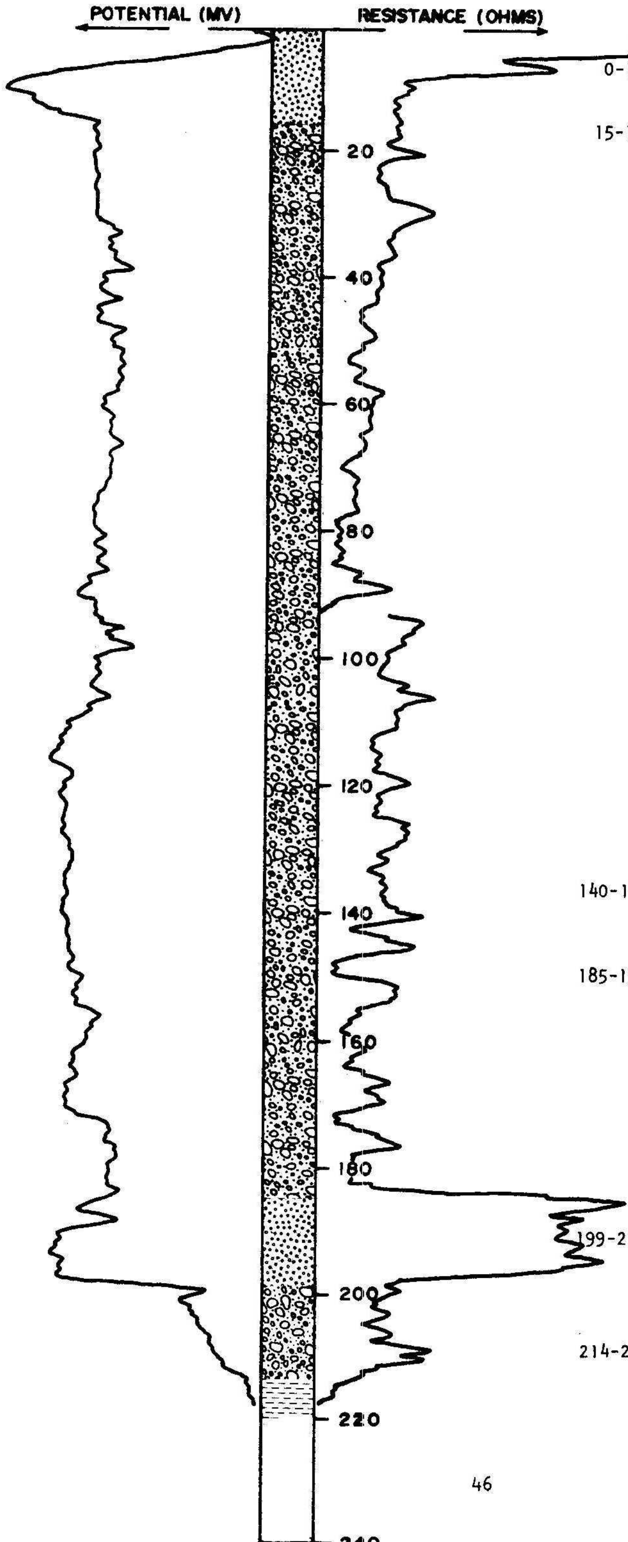
## TEST HOLE 8523

**LOCATION:** 147-69-15aaa

**DATE DRILLED:** 10-4-72

**ELEVATION:** 1585
**(FT, MSL)**

**DEPTH:** 220
**(FT)**




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-15 | Gravel, sandy, clayey, fine to coarse, angular to subrounded, fair sorting, oxidized. |
| 15-140 | Clay, moderately sandy, silty, pebbly, a few cobbles, olive-gray, moderately cohesive, slightly plastic, brittle, calcareous (Till). |
| 140-185 | Clay, silty, slightly sandy, pebbly, medium-dark-gray, cohesive, plastic, sticky, calcareous (Till). |
| 185-199 | Sand, slightly clayey, slightly gravelly, fine- to very coarse-grained, predominantly medium to coarse, subangular to rounded, fair sorting. |
| 199-214 | Clay, silty, pebbly, medium-dark-gray, cohesive, moderately plastic, calcareous (Till). |

Pierre Formation

| | |
|---|---|
| 214-220 | Shale, siliceous, grayish-black, moderately indurated, noncalcareous. |



SWC FORM # 233 B

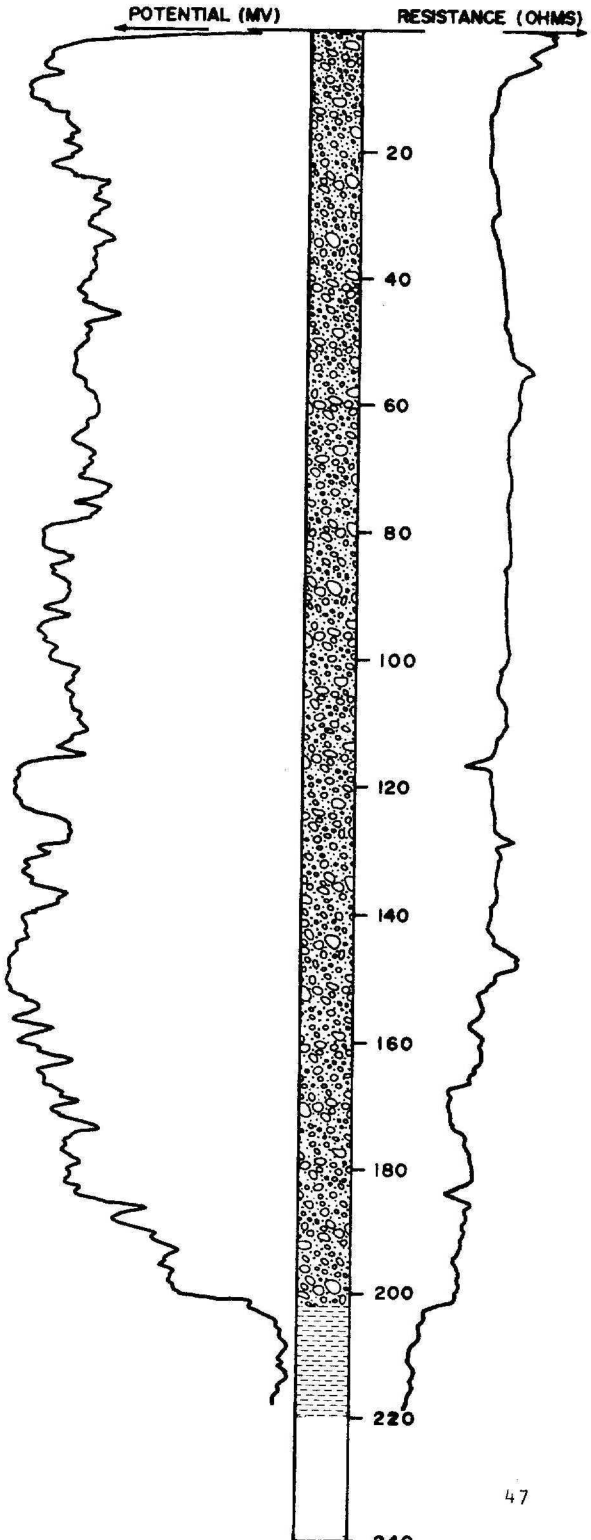
## TEST HOLE 8526

**LOCATION:** 147-69-15abb

**DATE DRILLED:** 10-4-72

**ELEVATION:** 1582
**(FT, MSL)**

**DEPTH:** 220
**(FT)**




**DESCRIPTION OF DEPOSITS**

<u>Glacial Drift</u>

| | |
|---|---|
| 0-1 | Topsoil, silty clay loam, grayish-black. |
| 1-10 | Clay, silty, moderately sandy, pebbly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till). |
| 10-202 | Clay, silty, sandy, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic (Till). |

<u>Pierre Formation</u>

| | |
|---|---|
| 202-220 | Shale, siliceous, grayish-black, moderately indurated, non-calcareous. |



SWC FORM # 233 B

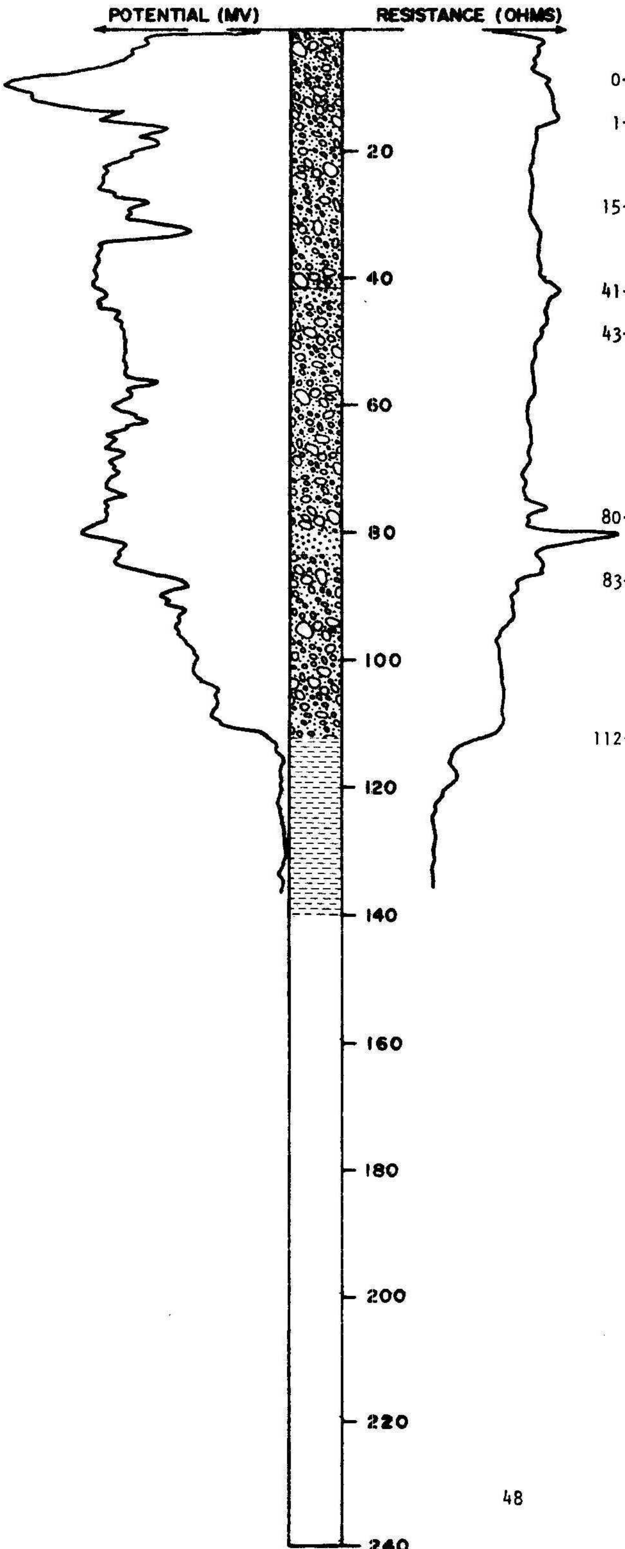
## TEST HOLE 8525

**LOCATION:** 147-69-15cbb

**DATE DRILLED:** 10-4-72

**ELEVATION (FT, MSL):** 1602

**DEPTH (FT):** 140




**DESCRIPTION OF DEPOSITS**

<u>Glacial Drift</u>

| | |
|---|---|
| 0-1 | Topsoil, silty clay loam, grayish-black. |
| 1-15 | Clay, silty, moderately sandy, cobbles, boulders, moderate-yellowish-brown, slightly cohesive, crumbly; oxidized (Till). |
| 15-41 | Clay, slightly sandy, pebbly, a few cobbles, olive-gray, moderately cohesive, crumbly, calcareous (Till). |
| 41-43 | Gravel, sandy, fine to coarse, subangular, poorly sorted. |
| 43-80 | Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, brittle, calcareous (Till). |
| 80-83 | Gravel, sandy, fine to medium, angular to subrounded, poorly sorted. |
| 83-112 | Clay, slightly sandy, moderately silty, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic, calcareous (Till). |

<u>Pierre Formation</u>

| | |
|---|---|
| 112-140 | Shale, siliceous, grayish-black, moderately indurated, noncalcareous. |



SWC FORM # 233 B

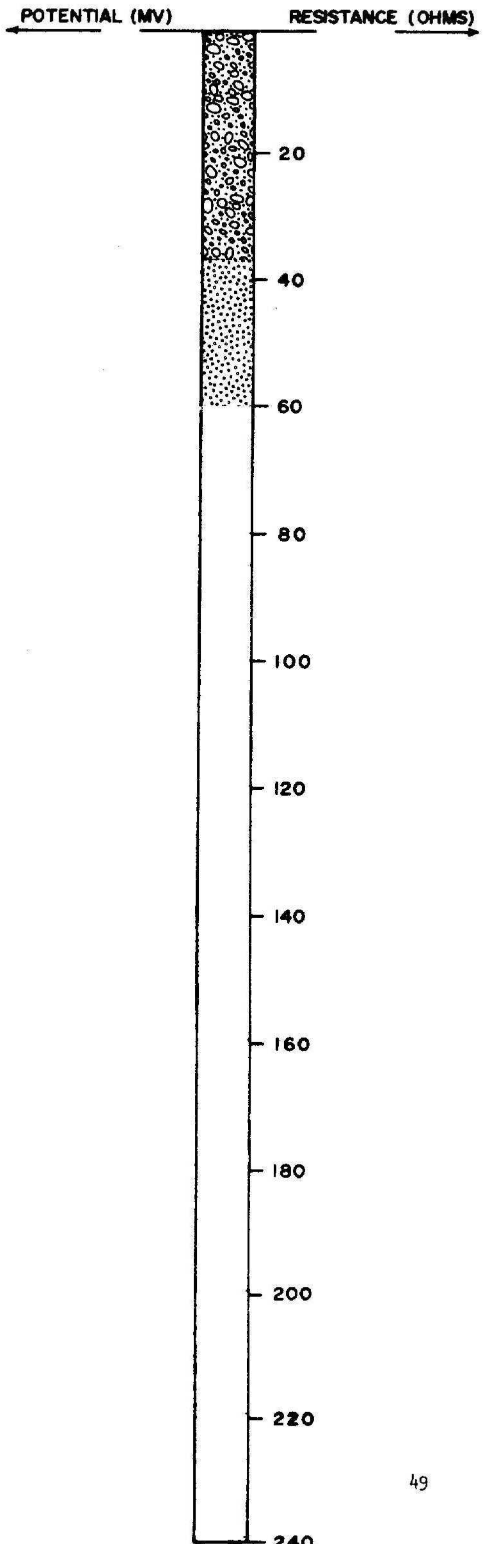
TEST HOLE 8524

LOCATION: 147-69-16aaa

DATE DRILLED: 10-4-72

ELEVATION: 1594
(FT, MSL)

DEPTH: 60
(FT)




DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, silty clay loam, grayish-black.

1-15 Clay, silty, moderately sandy, pebbly, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized(Till).

15-36 Clay, moderately silty, slightly sandy, pebbly, a few cobbles, olive-gray, slightly cohesive, crumbly, oxidized (Till).

36-60 Cobbles, boulders, gravelly, very clayey, poorly sorted, caving badly.



SWC FORM # 233 B

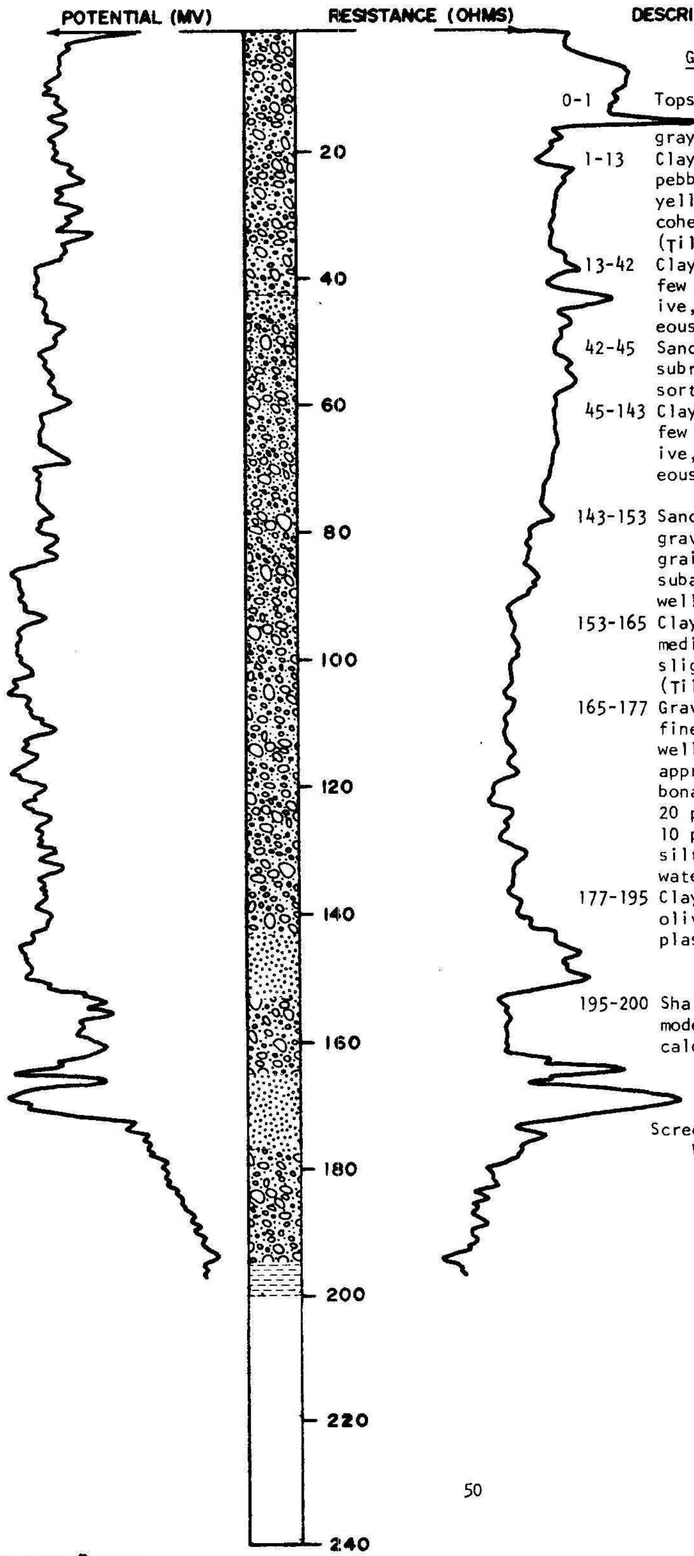
## TEST HOLE 8538

**LOCATION:** 147-69-22dcc

**DATE DRILLED:** 10-11-72

**ELEVATION (FT, MSL):** 1606

**DEPTH (FT):** 200




**DESCRIPTION OF DEPOSITS**

Glacial Drift

0-1 Topsoil, silty clay loam, grayish-black.

1-13 Clay, silty, moderately sandy, pebbly, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till).

13-42 Clay, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic, calcareous (Till).

42-45 Sand, fine- to coarse-grained, subrounded, moderately well-sorted.

45-143 Clay, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic, calcareous (Till).

143-153 Sand, about 30 percent fine gravel, medium- to very coarse-grained, predominantly coarse, subangular to rounded, moderately well-sorted, taking water.

153-165 Clay, slightly sandy, pebbly, medium-dark-gray, cohesive, slightly plastic, calcareous (Till).

165-177 Gravel, about 25 percent sand, fine to coarse, angular to well-rounded, fair sorting, approximately 30 percent carbonates, 30 percent dark shale, 20 percent brownish silicates, 10 percent granitics, 10 percent siltstone and sandstone, taking water.

177-195 Clay, slightly sandy, pebbly, olive-gray, cohesive, slightly plastic, calcareous (Till).

Pierre Formation

195-200 Shale, siliceous, grayish-black, moderately indurated, noncalcareous.

Observation Well
Depth 173 feet
Screened interval 167-173 feet
Water level 17.20 feet
December 18, 1972



SWC FORM # 233 B

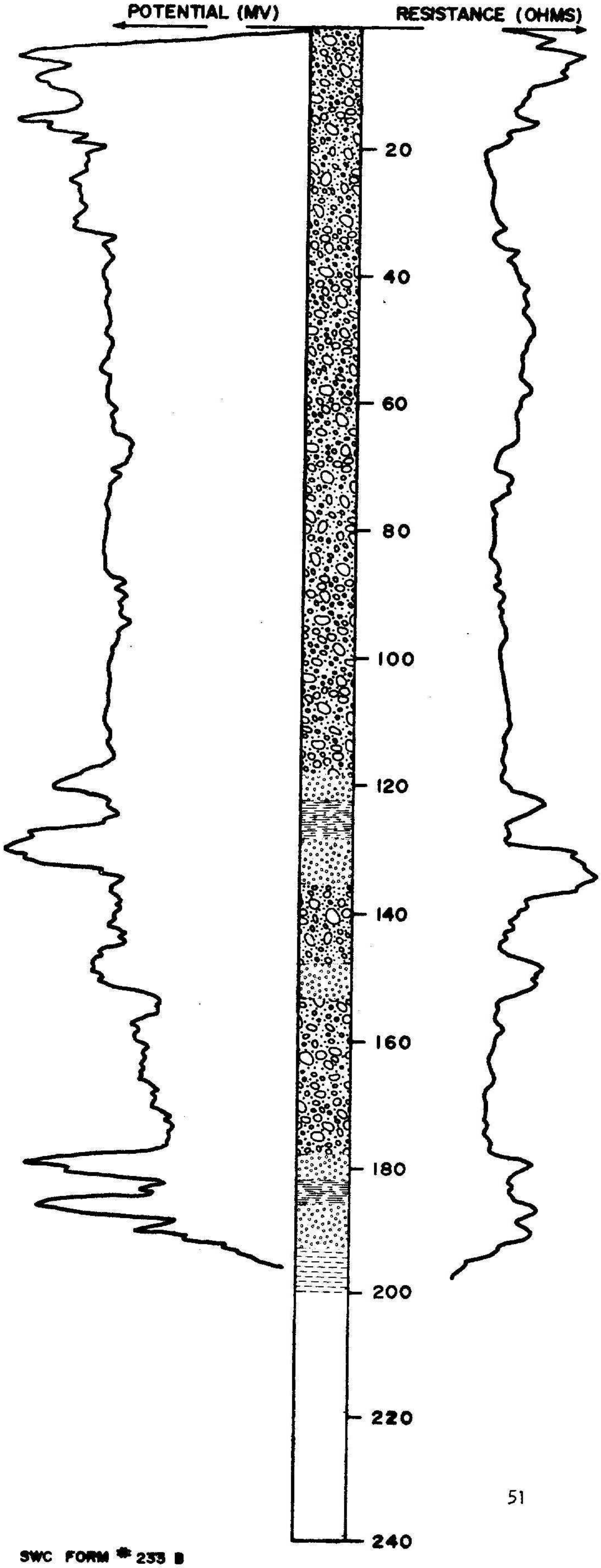
TEST HOLE 8537

LOCATION: 147-69-23bbb

DATE DRILLED: 10-10-72

ELEVATION: 1600
(FT, MSL)

DEPTH: 200
(FT)




DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, silty clay loam, grayish-black.

1-16 Clay, silty, moderately sandy, pebbly, gravelly, moderate-yellowish-brown, slightly cohesive, crumbly, oxidized (Till).

16-118 Clay, silty, slightly sandy, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic, calcareous (Till).

118-122 Gravel, fine to coarse, angular to subrounded, poorly sorted, approximately 40 percent carbonates, 25 percent dark gray shale, 15 percent brownish western silicates, 20 percent granitics and metamorphics.

122-128 Clay, very silty, sandy, medium-dark-gray, cohesive, plastic (Glaciofluvial deposit).

128-135 Sand, slightly gravelly, medium to very coarse-grained, fair sorting, lignitic.

135-148 Clay, pebbly, a few cobbles, olive-gray, cohesive, slightly plastic, calcareous (Till).

148-153 Sand, medium- to very coarse-grained, subangular to rounded, fair sorting, clean.

153-178 Clay, moderately silty, slightly sandy, pebbly, a few cobbles, medium-dark-gray, cohesive, slightly plastic, calcareous (Till).

178-182 Gravel, sandy, fine to coarse, subangular to rounded, fair sorting.

182-186 Clay, very silty, sandy, a few lignite chips, medium-dark-gray, cohesive, plastic, sticky (Glaciofluvial deposit).

186-193 Gravel, about 40 percent sand, fine to medium, fair sorting, subangular to well-rounded, approximately 40 percent carbonates, 30 percent shale, 20 percent granitics and metamorphics, 10 percent brownish western silicates, taking water.

Pierre Formation

193-200 Shale, siliceous, grayish-black, moderately indurated, noncalcareous.

Observation Well
Depth 193 feet
Screened Interval 187-193 feet
Water level 10.55 feet
December 18, 1972



SWC FORM # 233 B

## TEST HOLE 2573

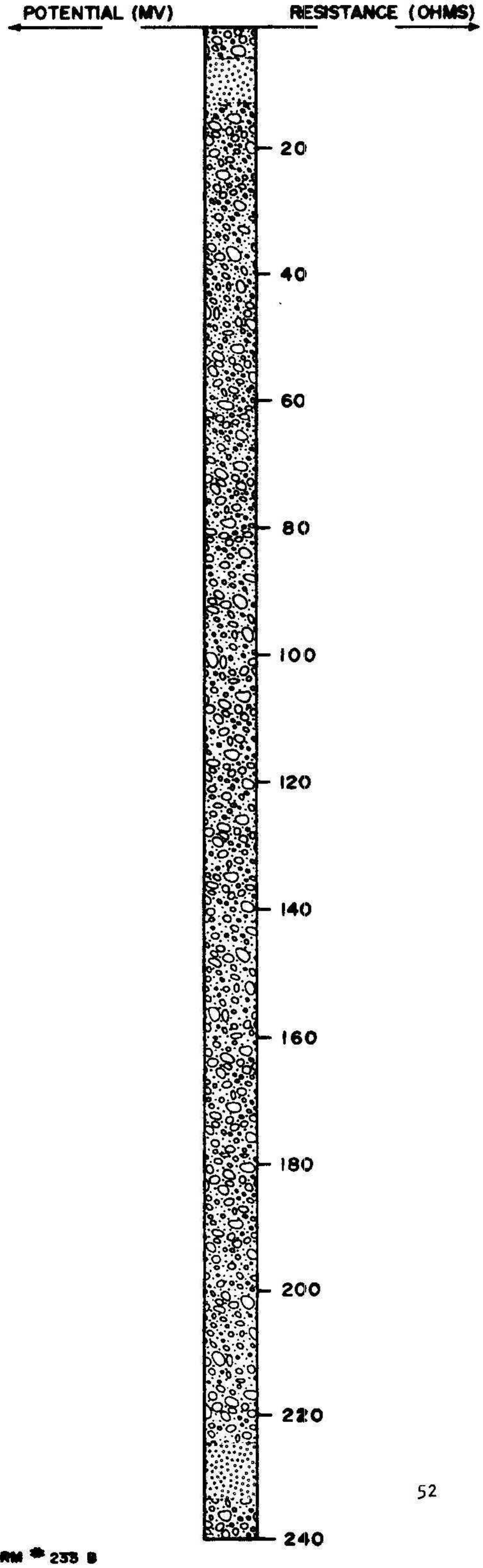
**LOCATION:** 147-69-34bbb

**DATE DRILLED:**

**ELEVATION:** 1620
**(FT, MSL)**

**DEPTH:** 336
**(FT)**

**POTENTIAL (MV)** **RESISTANCE (OHMS)**




**DESCRIPTION OF DEPOSITS**

Glacial Drift

| | |
|---|---|
| 0-1 | Topsoil, silty, black. |
| 1-5 | Clay, silty, dusky-yellow, oxidized (Till). |
| 5-12 | Sand, medium to coarse, gravelly, oxidized |
| 12-18 | Clay, silty, dusky-yellow (Till). |
| 18-166 | Clay, silty, olive-gray,(Till). |
| 166-180 | Clay, olive-gray, with sand and gravel layers (Till). |
| 180-225 | Clay, silty, olive-gray (Till). |
| 225-234 | Sand, coarse to very coarse, clayey. |
| 234-241 | Clay, silty, olive-gray (Till). |



SWC FORM # 233 B

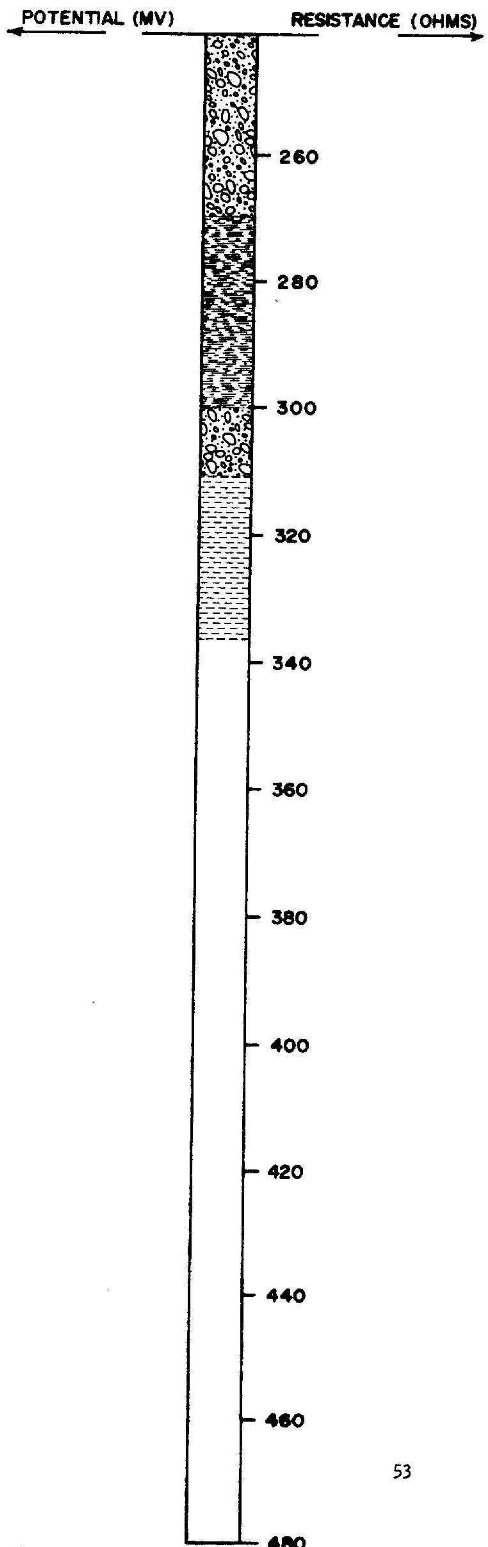
TEST HOLE 2573 (Cont.)

LOCATION: 147-69-34bbb

ELEVATION: 1620
(FT, MSL)

DATE DRILLED:

DEPTH: 336
(FT)




DESCRIPTION OF DEPOSITS

| | |
|---|---|
| | Glacial Drift Cont. |
| 241-251 | Clay, sandy to gravelly, olive-gray (Till). |
| 251-259 | Clay, silty, olive-gray (Till). |
| 259-269 | Clay, gravelly, olive-gray (Till). |
| 269-300 | Silt, olive-gray, laminated (Glaciofluvial sediment). |
| 300-310 | Clay, very silty, (Till). |
| | Pierre Formation |
| 310-336 | Shale, olive-black. |



SWC FORM #233 C

## REFERENCES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