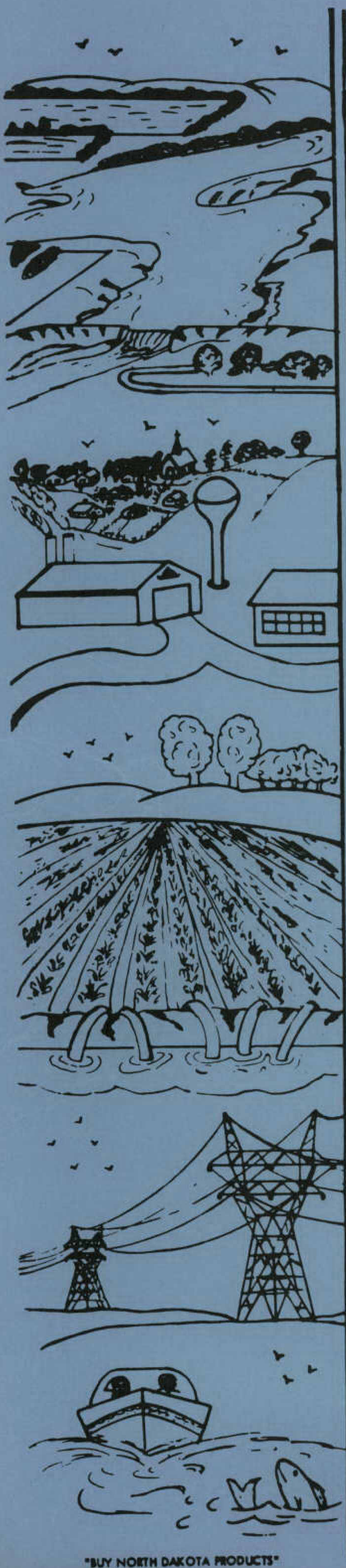


Geohydrology of the Wahpeton Area Richland County, North Dakota

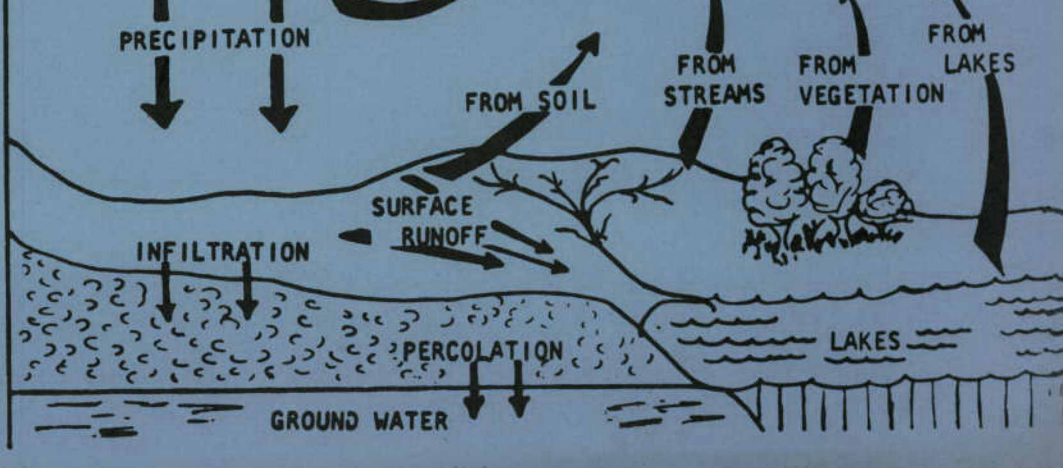
North Dakota Ground-Water Studies
No. 76

By
Larry L. Froelich
Ground-Water Geologist

North Dakota State Water Commission

Bismarck, North Dakota 58501

— 1974 —



"BUY NORTH DAKOTA PRODUCTS"

GEOHYDROLOGY OF THE WAHPETON AREA
RICHLAND COUNTY, NORTH DAKOTA

NORTH DAKOTA GROUND-WATER STUDIES
NUMBER 76

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Published By:
North Dakota State Water Commission
State Office Building
Bismarck, North Dakota 58501

-1974-

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RICHLAND COUNTY, NORTH DAKOTA
State Water Commission Project Number 1518

By
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INTRODUCTION

PURPOSE AND SCOPE

Resolution 343 of the Wahpeton City Council, requesting the State Water Commission perform a ground-water survey to determine the quality and quantity of water available for municipal use and industrial expansion, was adopted on July 7, 1969. On August 12, 1969, the North Dakota State Water Commission approved the Wahpeton ground-water survey.

Fieldwork began in the Wahpeton area on August 20, 1969, and continued throughout September. Test holes were drilled and observation wells installed to determine the geohydrology of the area. A pumping test was performed to define the ground-water hydrology. Data acquired from this fieldwork, and from pre-existing sources, were compiled and examined in March and April of 1970. Additional test drilling, and related work, was completed in May and June of 1970.

ACKNOWLEDGEMENTS

The test drilling was contracted to Empire Irrigation and Drilling Company of Huron, South Dakota in 1969, and Mann Drilling Company of Garrison, North Dakota in 1970. This drilling was accomplished under the direct supervision of the author. The pumping test was performed on a well installed by Frederickson's, Inc. of Fargo under the supervision of R. W. Schmid, Water Commission Hydrologist. Surface elevations of test holes and observation wells were determined by the Water Commission surveying crew supervised by Eugene Sackman. Chemical analyses were performed by Garvin Muri, Water Commission Chemist.

LOCATION AND GENERAL FEATURES

The Wahpeton area, as discussed in this report, comprises about 107 square miles in east-central Richland County (fig. 1). It includes all or parts of Tps. 132, 133, 134, and 135 N. and Rs. 47, 48, and 49 W. Wahpeton (1970 population 7,076) serves as the shopping and trading center to the surrounding farming population and is the home of the North Dakota State School of Science. Federal Highway 81 provides motor transportation to Wahpeton as well as the communities of Abercrombie (1970 population 262) and Dwight (1970 population 93). State Highway 13 provides access from east to west. Rail transportation is furnished from north to south by the Chicago, Milwaukee, St. Paul, and Pacific Railway. Two Burlington Northern branches also traverse the area. The municipal airport is located half a mile south of Wahpeton. The average annual precipitation at Wahpeton was 20.59 inches based on a 79-year period of record (National Weather Service, 1970). The average annual temperature was 43.3° F. during this same period.

The Wahpeton area is in the Agassiz Lake Plain physiographic division of the Central Lowland Province (fig. 1). The plain is practically featureless except for the erosional stream channels containing Red River of the North and its tributaries. The Red River originates at Wahpeton from the confluence of the Bois De Sioux and Ottertail Rivers and is the eastern boundary of the Wahpeton area and North Dakota. The Wild Rice River flows across the western part of the area from south to north, joining the Red River about 8 miles south of Fargo. Maximum topographic relief in the Wahpeton area is about 25 feet.

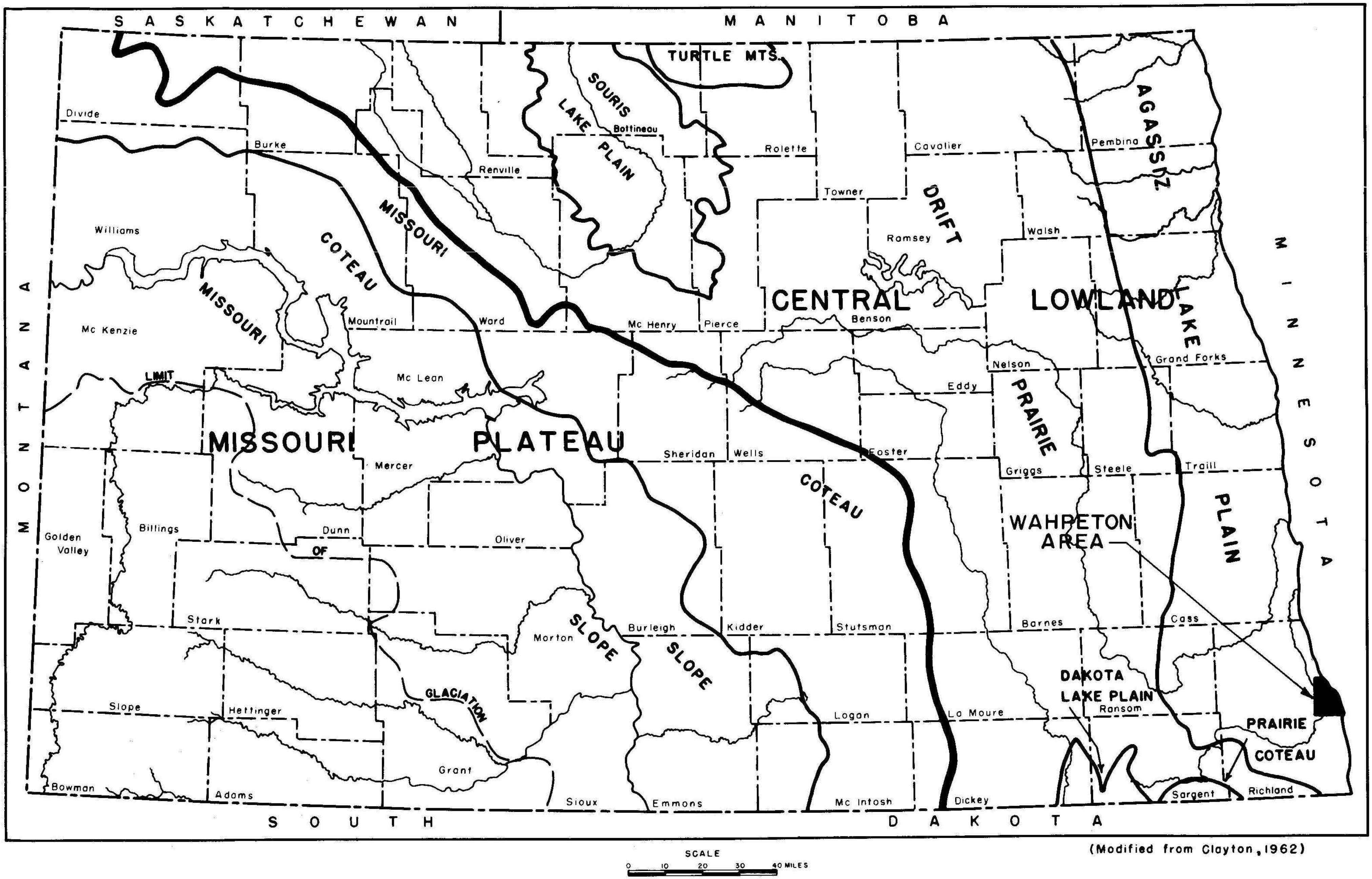


Figure 1 -- Map of North Dakota showing physiographic provinces and location of the Wahpeton Area

PREVIOUS INVESTIGATIONS

The ground-water hydrology of the Wahpeton area had not been studied in detail prior to this survey; however, data of a reconnaissance nature are included in a three-part series on the "Geology and Ground-Water Resources of Richland County" by Baker (1966 and 1967) and Baker and Paulson (1967). Prior investigators of the area are mentioned in Part 1 (Baker, 1967, p. 4) and Part 3 (Baker and Paulson, 1967, p. 1-2).

PRESENT WATER SUPPLIES

Domestic and stock water requirements are supplied primarily by ground water throughout the Wahpeton area. The majority of water wells range from 2 to 4 inches in diameter and 20 to 425 feet in depth. There are no irrigation or industrial wells developed in the area at the present time (1970). The cities of Abercrombie and Wahpeton have installed municipal wells. A well 378 feet in depth was completed at Abercrombie in 1966 (Duane Knudson, oral comm., 1970). Water is pumped to the mains via a 10,000-gallon ground-level storage tank without metering or treatment. An older well is available on a standby basis. Baker (1966, p. 36) lists four municipal wells at Wahpeton ranging from 194 to 420 feet in depth. These wells were abandoned recently in favor of water from Red River.

WELL-NUMBERING SYSTEM

The well-numbering system, illustrated in figure 2, is based upon the location of a well or test hole in the Federal system of rectangular surveys of public lands. The first number denotes the township north and the second number denotes the range west, both referred to the fifth principal meridian and base line. The third number indicates the section in which the well or test hole is located. The letters a, b, c, and d designate, respectively,

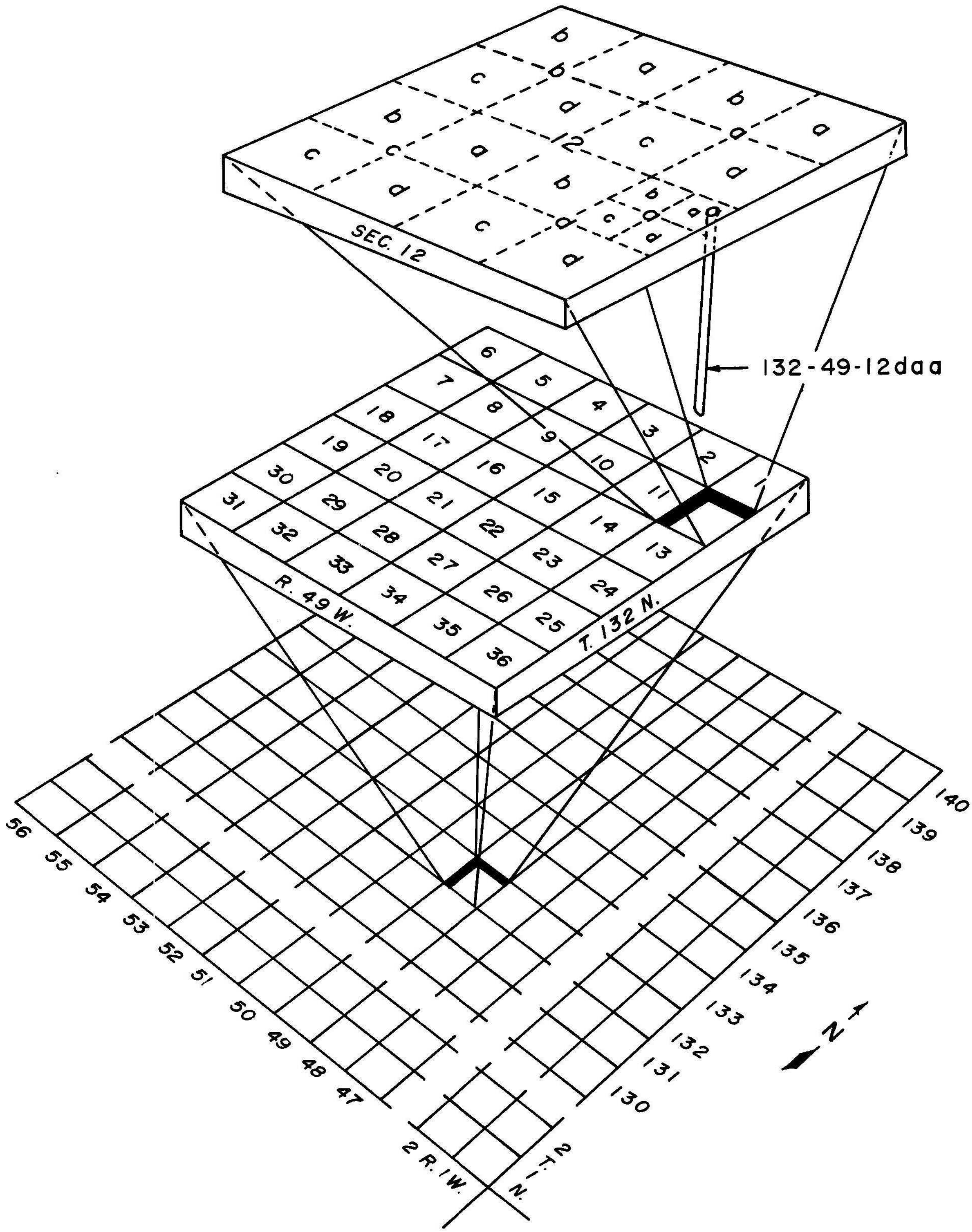


FIGURE 2 -- WELL-NUMBERING SYSTEM

the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). Thus well 132-49-12daa would be located in the NE¼NE¼SE¼ sec. 12, T. 132 N., R. 49 W. Consecutive terminal numerals are added if more than one well is located within a 10-acre tract.

PRINCIPLES OF GROUND-WATER OCCURRENCE

All ground water of economic importance is derived from precipitation. As moisture falls to the earths surface, part is returned to the atmosphere, part is lost to surface runoff, and the remainder infiltrates into the ground. Most of the infiltrating water is retained temporarily in the soil and gradually returned to the atmosphere by evapotranspiration. The remainder percolates downward to become ground water.

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. The rate of movement is governed by the permeability of the sediments through which the water passes and by the hydraulic gradient. Deposits of sorted sand and gravel generally are highly permeable and are called aquifers if they are saturated and of adequate areal extent to yield significant quantities of water to wells. Fine-grained materials such as silt, clay, and shale usually have low permeabilities and function as barriers that impede the movement of ground water.

The water level in a well fluctuates in response to recharge to or discharge from the aquifer. When water is pumped from a well, the amount of drawdown is controlled by the transmissivity and storage 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 in an extensive aquifer, the water level will decline rapidly at first and then continue to lower at a decreasing rate as the cone of depression expands. The area influenced by the cone of depression spreads directly with time and inversely with the storage coefficient. Under artesian conditions the storage coefficient is equal to a small fraction of the aquifer's porosity, and the area of influence spreads rapidly. Artesian conditions exist when the water level in a well penetrating a confined aquifer rises above the aquifer due to hydrostatic pressure. Under unconfined or water-table conditions the storage coefficient, which is much larger than under artesian conditions, is equal to the specific yield, and the area of influence spreads more slowly.

The theoretical shapes and rates of decline of cones of depression in confined aquifers such as buried valleys, are distorted by the effects of relatively impermeable barriers, and rates of decline are increased. Water level decline, therefore, is not only a function of transmissivity and storage, but also of the proximity of aquifer boundaries.

The water level in a pumped well must decline in order that water may flow from the aquifer to the well. However, too great a decline may cause serious problems if (1) it causes water of undesirable quality to move into the aquifer, (2) the yield of the well decreases because of interference from other wells or aquifer boundaries, (3) the pumping lift increases to the point where pumping becomes uneconomical, or (4) the water level declines below the top of the screen. When pumping is stopped, the water level recovers in the vicinity of the well at a decreasing rate until it is at or near the original or static level.

Under natural conditions, over a period of time, the amount of discharge from an aquifer equals the amount of recharge. Under pumping conditions, however, one or more of the following may eventually occur: (1) a decrease in the rate of natural discharge, (2) an increase in the rate of recharge, or

(3) a reduction in volume of ground water in storage. The maximum rate of ground-water withdrawal that can be maintained indefinitely is related directly to the rate of recharge to the aquifer.

CHEMICAL QUALITY OF GROUND WATER

All natural waters contain a certain amount of dissolved minerals. The concentration and nature of dissolved constituents in ground water depends upon the types and solubility of sediments encountered, the duration of contact, temperature, pressure, and gases already in solution. The chemical quality may have as much bearing on the suitability of an aquifer as a source of water supply as the physical factors governing the quantity available.

The suitability of water for domestic use or public supply is commonly judged by standards adopted by the U. S. Public Health Service (1962, p. 7-8). Standards for irrigation water are defined by the U. S. Salinity Laboratory Staff (1954, p. 69-82). Standards on water for livestock consumption have not been established, and industrial standards are determined by the particular processes for which the water is to be used.

The dissolved mineral constituents in water are reported in parts per million (ppm), milligrams per liter (mg/l), or grains per U. S. gallon (gr/gal). One ppm is a unit weight of a constituent in a million unit weights of water. Milligrams per liter are, for all practical purposes, equivalent to ppm. Parts per million may be converted to gr/gal by dividing the ppm by 17.12.

The following summarizes the significance of the various chemical constitutents for a domestic or municipal water supply in North Dakota:

Silica (SiO_2) has no physiological or esthetic significance.

Iron (Fe) may cause staining of laundry and fixtures when present in concentrations exceeding 0.3 mg/l. Over 0.5 mg/l may be tasted by persons unaccustomed to water with a high iron content. Iron removal systems are available.

Manganese (Mn) resembles iron in its general behavior, producing black stains when present in amounts more than 0.05 mg/l .

Calcium (Ca) and Magnesium (Mg) are the primary causes of hardness. Over 125 mg/l magnesium may have a laxative effect on persons unaccustomed to this type of water.

Sodium (Na) has no physiological or esthetic significance, except for persons on salt-free diets.

Potassium (K) is essential, in small amounts, to animal nutrition.

Bicarbonate (HCO_3) and Carbonate (CO_3) 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) is classed as follows:

0 to 300 mg/l - low

300 to 700 mg/l - high

over 700 mg/l - very high

A limit of 250 mg/l is set by the U. S. Public Health Service; however, a North Dakota Department of Health survey indicates no laxative effect is noticed until sulfate reaches 600 mg/ l.

Chloride (Cl) concentrations exceeding 250 mg/l may have a salty taste to persons unaccustomed to it. People may become accustomed to higher concentrations.

Fluoride (F) is believed to 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) concentrations exceeding 45 mg/l 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) has no physiological or esthetic significance.

Total Dissolved Solids are classed as follows:

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

A limit of 500 mg/l total dissolved solids is set by the U. S. Public Health Service; however, persons may become accustomed to water containing 2,000 mg/l or more.

Hardness is classified by the North Dakota Department of Health as follows:

0 to 200 mg/l - low

200 to 300 mg/l - average

300 to 450 mg/l - high

over 450 mg/l - very high

Hardness, which increases soap consumption, may be removed by water softening systems.

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.

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

pH should be between 7.0 and 9.0 for domestic use.

GEOHYDROLOGY

Ground-water availability in any area is directly related to the geology. The interpretation of the geology of the Wahpeton area is based, for the most part, on the logs of test holes. Additional geohydrologic data have been extrapolated from Baker (1966 and 1967). Some of Baker's data have been updated and modified to conform to this report; therefore, certain well and test hole descriptions are slightly different than those included in Baker's reports. Locations of the test holes are shown on plate 1 and individual descriptions are included in table 2 (p.38).

The ground-water resources in the Wahpeton area are described in relation to the geologic units in which they occur. There are two major stratigraphic units underlying the Wahpeton area; (1) bedrock, which consists of rocks of Precambrian and Cretaceous age; and (2) glacial drift of Quaternary age. The glacial drift, which accumulated during the Pleistocene Epoch, is categorized as till, glaciofluvial deposits, or glaciolacustrine deposits.

GROUND WATER IN THE BEDROCK

Plate 2 is a map showing the bedrock units that subcrop beneath the glacial drift, as interpreted from water well and test hole data. The bedrock contours indicate a topographic high, capped by Cretaceous sediments, exists in the south-central part of the area. Adjacent and to the north of the high is a narrow valley incised 150 feet or more into the Cretaceous rocks. Influenced somewhat by the preglacial bedrock topography, this valley formed during the Pleistocene Epoch. A pre-Pleistocene valley, trending east to west, occurs in the Abercrombie area. The stream that eroded the entire Cretaceous section in this area was a tributary to a major drainage system, which occupied the bedrock low in central Richland County discussed by Baker (1967, p. 19).

Plate 3 is a hydrogeologic map showing the location and relationship of existing water wells developed in bedrock aquifers to their particular geologic source. Information on the majority of the wells shown on the map was obtained from table 1 of Baker (1966, p. 7). However, the author has added to or modified data reported by Baker.

Precambrian rocks

The basement rock underlying the Wahpeton area is a Precambrian crystalline rock, commonly referred to as granite. Unaltered Precambrian granite was encountered in test holes 3955 (133-47-7add), 3971 (134-48-32baa), and 3975 (134-48-21bbb) at depths of 348, 350, and 395 feet, respectively (pl. 1, table 2). Drilling is usually stopped at this point because the rock is extremely hard. The composition of the granite is essentially unknown in the Wahpeton area, but probably is similar to certain crystalline rock outcrops found in Minnesota.

Overlying the granite is a regolith or blanket of weathered granite believed to be a product of superficial weathering and subaerial decomposition of the underlying granite. The weathered granite consists of noncalcareous nonplastic talc-like kaolinitic clay. Predominent colors are white, light green, or reddish orange. Crystals of quartz, feldspar, and pyrite are commonly imbedded in the clay matrix and boulders of partially decomposed granite may be encountered several feet above the unaltered granite. Occasionally the clay is interbedded with angular to subangular quartzose sand.

Weathered granite was found to be 7, 24, and 13 feet thick in test holes 3955, 3971, and 3975, respectively; but 33 feet was penetrated in test hole 3978 (135-48-32bbb), which did not encounter unaltered granite. The depth to the weathered granite ranged from 238 feet in test hole 3163

(132-48-10bcc) to 385 feet in test hole 3968 (133-48-2bbc). Taking into account the present land surface elevation, this would indicate a relief of about 160 feet on the Precambrian surface. The irregular surface is undoubtedly due to erosional processes prior to Cretaceous deposition.

Because granite is solidified crystalline rock and weathered granite is composed essentially of clay, it is doubtful that water supplies of any great importance could be developed from the Precambrian rocks. It may be possible, however, to obtain small supplies of water from joints and fractures in the granite or from permeable sand lenses in the weathered material.

Although Precambrian rocks underlie the entire Wahpeton area, hydrologic data are limited to two private water wells owned by the Gunness Brothers (134-48-9dab) and Fritz Schneider (134-48-10bc). The wells were reported to be 390 and 370 feet deep, respectively (Baker, 1966, p. 54), and were drilled in an area where glacial drift directly overlies the Precambrian surface (pl. 3). Because test hole 2309 (134-48-9baa, pl. 1, table 2) penetrated weathered granite from 317 to 326 feet, it is assumed the Gunness and Schneider wells obtain their water supplies from fractures in the unaltered granite. Artesian pressure is sufficient in both wells to cause them to flow. The origin of this pressure head is undetermined.

A water sample was collected from the Gunness well in 1964 as part of the Richland County ground-water study (Baker, 1966). The chemical analysis (table 1, p. 37), indicates the water is very low in hardness and is a sodium bicarbonate type. The water is of suitable quality for domestic and stock use. The percent sodium, which was higher than in any other water analyzed from the Wahpeton area, would restrict its use for irrigation. The flouride content of 0.4 mg/l distinguishes the Precambrian water from Cretaceous water which averages over 3 mg/l.

Cretaceous rocks

Several test holes encountered semiconsolidated fine- to coarse-grained quartzose sandstone unconformably overlying the weathered granite. Baker (1967, p. 15-17) referred to this section as the Cretaceous Dakota Sandstone and, in all probability, it is correlative with the Lakota Formation of the Dakota Group described by Hansen (1955, p. 40). Dakota Sandstone is a general term used by scientists, well drillers, and well owners to portray the lower Cretaceous sandstone of eastern North Dakota. Because the term is generally accepted and entrenched in geologic literature, Dakota(?) Sandstone is retained, although questionably, for use in this report.

Unconformably overlying the Dakota(?) Sandstone throughout much of the area is a sequence of carbonaceous shale, siltstone, and sandstone herein referred to as Cretaceous sediments, undifferentiated. Baker (1967, p. 18) described this section as the Graneros Shale; however, it is probably correlative with the Mowry Formation of the Dakota Group or the Belle Fourche Formation of the Colorado Group.

Dakota(?) Sandstone. -- The Dakota(?) Sandstone was penetrated in test holes 3162 (132-49-12daa), 3955 (133-47-7add), 3968 (133-48-2bbc), 3969 (133-48-3abb), and 3971 (134-48-32baa). Thicknesses encountered were 48, 56, 10, 56, and 31 feet, respectively. The depth to the top of the sandstone ranged from 206 feet in test hole 3162 to 375 feet in test hole 3968, indicating an erosional surface with a relief of at least 185 feet, or 25 feet more than on the Precambrian surface. Unlike the granite, however, the sandstone does not underlie the entire Wahpeton area. It was absent at test holes 2309, 3975, and 3978 in the northern part of the area because of preglacial and Pleistocene erosion and at test holes 2316 and 3163 in the southern part of the area because of lack of deposition (pl. 1 and 3).

The Dakota(?) Sandstone consists essentially of uniformly-sorted medium- and coarse-grained quartz sand that is characteristically white. Infrequent impurities include shale, carbonate pellets, mica, pyrite crystals, and black chips, which are often described as lignite but may be biotite, hornblende, tourmaline, or other dark-colored minerals. In test hole 3162 the Dakota(?) Sandstone appeared buff colored and the sand grains were generally subrounded or rounded, indicating fluvial deposition of material derived from distant areas. In the other four test holes, however, the sand grains were nearly all clear or white quartz and usually subangular, suggesting a more local source area. In test hole 3955 fine-grained sand was interbedded with layers of soft white noncalcareous clay similar in appearance to the underlying weathered granite. It is the author's opinion the Dakota(?) Sandstone formed in place, as a result of wave action washing out the clay from weathered granite, but was supplemented locally by streams transporting sand from source areas to the south and west.

Dakota(?) wells are commonly 2 inches in diameter and screened at the bottom to prevent sand from entering the well casing. The depths of the wells range from 240 to 425 feet. The water in the Dakota(?) Sandstone is under artesian pressure and about half of the wells in the area are flowing (pl. 3). The rate of flow is usually less than 3 gpm (gallons per minute). The potentiometric surface of the remaining wells is at or very near land surface.

The largest single user of Dakota(?) Sandstone water in the area is the city of Abercrombie. A record of water consumption for the city is not maintained, but using an average of 75 gpd (gallons per day) per person, the city would require 20,000 gpd. The only reliable reported pumping yield from the Dakota(?) Sandstone is 35 gpm from the abandoned 420-foot city well at Wahpeton (Baker and Paulson, 1967, p. 14).

Water from the Dakota(?) Sandstone is a sodium bicarbonate type that has an average flouride concentration of about 3 mg/l and less than 1,000 mg/l total dissolved solids. The only exception listed in table 1 was the analysis from the observation well installed in test hole 3162. Water from this well was a sodium sulfate bicarbonate type containing 1,570 mg/l total dissolved solids. Two separate wells were developed at different intervals in this test hole, and it is believed the difference in chemical constituents is the result of mixing of Dakota(?) and glacial-drift water. Because of the low hardness Dakota(?) water may be preferred for laundering, but the high sodium content restricts its use for irrigation. Continuous consumption over a period of time could conceivably cause mottled teeth.

Cretaceous sediments, undifferentiated -- Following a long period of erosion during which the Dakota(?) Sandstone was removed locally, the entire area was inundated by an extensive inland sea. Test drilling indicates the dominant lithology overlying the basal sandstone is a black carbonaceous silty shale, which suggests a shallow-water marine environment of restricted circulation (Baker, 1967, p. 18). Beds of bentonitic clay and fossil remains establish the shale as Cretaceous in age. However, the formation was eroded prior to glaciation and silty to sandy deposits, possibly of Tertiary age, were encountered in the erosional channels during test drilling. Because of this complexity, the entire section is referred to herein as Cretaceous sediments, undifferentiated.

The thickest complete section of Cretaceous sediments penetrated was 131 feet in test hole 2316 (132-47-7bcc) 1 mile west of Wahpeton. The formation consisted essentially of shale and was underlain by weathered granite (table 2). About 1 mile north of Wahpeton, however, test hole 3954 (133-47-28dcb) encountered 151 feet of siltstone and sandstone. Drilling was stopped at a depth of 400 feet without reaching either the Dakota(?) Sandstone or the Precambrian rocks. Cretaceous sediments were encountered as shallow as 134 feet in test hole 3163 (132-48-10bcc) and as deep as 307 feet in test hole 3978 (135-48-32bbb). Geologic cross sections (pl. 4) indicate the undifferentiated Cretaceous sediments are thin or absent in the western and northern parts of the area, but attain thicknesses of 100 feet or more in the southern and eastern parts.

The Cretaceous sediments directly underlie glacial drift in approximately three-fourths of the Wahpeton area (pl. 2). Wells that yield water from these sediments, however, are primarily located on the bedrock high west of Wahpeton (pl. 3). In this area the Dakota(?) Sandstone is absent and only meager ground-water supplies are available from the glacial drift.

Wells developed in the Cretaceous sediments range in depth from 160 to 285 feet, and average about 240 feet deep. Reported water levels usually range from 10 to 50 feet below land surface, but Baker (1966, p. 36) listed a water level of 126.8 feet for the 285-foot Wahpeton city well. This water level reflected a depletion or mining of ground water in storage when the city wells were still in operation. The 265-foot well in Wahpeton was reportedly (Baker and Paulson, 1967, p. 14) pumped at a rate of 50 gpm before being abandoned in favor of surface water from Red River.

Water derived from the undifferentiated Cretaceous sediments is similar in quality to that derived from the Dakota(?) Sandstone. It is low in hardness, high in flouride, and a sodium bicarbonate type. Only 2 analyses are listed in table 1. Both samples were obtained from wells located some distance from wells on the bedrock high. Five specific conductance measurements in the bedrock high area (pl. 3) suggest a much greater variability of the water, as far as total dissolved solids are concerned; however, additional sampling may indicate some of the wells are actually completed in the glacial drift or Precambrian rocks.

GROUND WATER IN THE GLACIAL DRIFT

Initially ice occupied the topographic lows on the bedrock surface as continental glaciers advanced from the north at the onset of the Pleistocene Epoch. The bedrock low in central Richland County probably was a local accumulation area from whence ice gradually moved up the tributary valleys and eventually encroached upon the surrounding highlands as the ice mass expanded. Additional subsurface data substantiate Baker's (1967, p. 10) suggestion that several ice sheets crossed the area. Each ice sheet left deposits of glacial drift, and each succeeding one probably removed, redistributed, and/or added to the deposits of its predecessor. By the time the last glacier retreated from the Wahpeton area, the original bedrock topography was completely masked with glacial drift.

No attempt is made in this report to correlate individual drift sheets in the Wahpeton area to those named and described in other areas. Instead, the discussion of glacial drift is related to three recognizable types of deposits encountered during test drilling within the study area. The three general types include till, glaciofluvial deposits, and glaciolacustrine deposits.

Till

Till is a term describing a heterogeneous mixture of clay, silt, sand, pebbles, cobbles, and/or boulders deposited directly by glacial ice with little or no sorting by running water. Till should not be considered as an aquifer because it is composed predominently of clay and will not readily yield water to wells. However, it is hydrologically significant within the Wahpeton area because it is relatively impervious and acts as a confining layer where it overlies an aquifer -- thus creating artesian conditions.

In the Wahpeton area, glacial till can best be described in relationship to the individual ice sheets that crossed the area. The till has, therefore, been subdivided into "Older Till", "Light-Gray Till", "Intermediate Till", and "Younger Till."

Older Till. -- The initial ice advance in the Wahpeton area overrode a terrain composed essentially of Cretaceous shales. Consequently the Older Till consists of silty clay imbedded with sand grains and pebbles with a notable lack of cobbles and boulders. Drill cuttings are characteristically very stiff, tightly compacted, calcareous, and dark gray or brown to nearly black in color. Blocks of Cretaceous rocks, as well as weathered granite, appear to be an integral part of the mixture. Sand and gravel lenses are uncommon, but where encountered are reddish brown in color and resemble partially decomposed granite.

The Older Till is generally encountered below an elevation of 750 feet msl (mean sea level) in the northern and western part of the Wahpeton area (pl. 4, secs. A-A', C-C') and at an elevation of about 825 feet in the southeastern part (sec. B-B'). As evidenced by the cross sections, the Older Till has been partially or completely removed in certain areas by erosion and probably subsequent glaciation. The average thickness of Older Till, where present, is normally less than 100 feet.

Light-Gray Till. -- A second ice advance and retreat blanketed the Older Till with a very sandy till, herein referred to as the Light-Gray Till. This till sheet is composed of primarily very fine to fine-grained sand with minor amounts of clay and silt. Pebbles are common, but cobbles and boulders are infrequent. Drill cuttings are light olive gray in color, highly calcareous, chunky, and crumble under a slight amount of pressure. Medium-to coarse-grained sand lenses are very common and occasional gravel lenses may be encountered.

The Light-Gray Till usually occupies the interval between 750 and 800 feet msl (pl. 4); however, it has been encountered as high as 860 feet. The average thickness is approximately 50 feet, but it may have been 250 feet thick near Abercrombie (sec. C-C'). The sandy till is missing locally in the southeastern part of the area.

Although no wells are known to recover water from the Light-Gray Till in the Wahpeton area, it is conceivable the sandy till sheet could function as a minor aquifer by transmitting ground water to the more permeable sand and gravel lenses included within the mass. The yield of a well developed in the more permeable lenses, however, would probably be restricted to that of a domestic or stock well.

Intermediate Till. -- The third glacial advance and retreat resulted in the accumulation of silty to pebbly clay, herein referred to as Intermediate Till. Intermediate Till is uniformly olive gray, moderately soft, calcareous, cohesive, and stiff to moderately plastic. Very few lenses of sand and gravel were encountered in test holes penetrating this till sheet.

The Intermediate Till is nearly continuous between 850 and 900 feet msl along cross section A-A' (pl. 4) north of Wahpeton. Following the retreat of the third ice sheet, erosional processes removed the till deposit locally.

Younger Till. -- The fourth and final ice sheet deposited a predominently silty and sandy clay imbedded with numerous pebbles and cobbles, herein referred to as Younger Till. Boulders are rare, but lenses of sand and gravel are very common. It is usually olive gray but, where exposed to oxidation processes, may vary from light or yellowish gray to moderate olive brown. The zone of oxidation normally extends to about 20 feet below land surface. Younger Till probably overlies Intermediate Till in test hole 3967 (133-48-1baa); however, differences in the two lithologies were difficult to determine.

The Younger Till is exposed at the surface north of Wahpeton, but slopes to the northwest and is overlain by 35 feet of lake clay near Abercrombie. The average thickness appears to be about 50 feet.

Glaciofluvial deposits

Glaciofluvial deposition occurs most commonly as a result of streams emerging from, upon, through, underneath, or marginal to melting glacial ice. Deposits from streams originating on or at a stagnant or receding ice front are usually associated with till. Test drilling in the Wahpeton area revealed that, although deposition of this nature did occur during the Pleistocene history of the area, the greatest accumulation of glaciofluvial materials was deposited during interglacial periods by northerly flowing streams. The first major period of glaciofluvial deposition occurred between deposition of the Light-Gray Till and the Intermediate Till and was confined, more or less, to the deep and narrow valley (pl. 2) referred to herein as the Wahpeton buried valley. The interglacial period between the accumulation of the Intermediate and Younger Till deposits witnessed several streams combining to blanket much of the area with the outwash materials that constitute the Wahpeton sand plain.

Because glaciofluvial deposits consist predominantly of porous and permeable sand and gravel, they have the ability to store and transmit ground water. If a significant saturated thickness is present and the deposit is continuous throughout a large area, such as in the Wahpeton buried valley or the Wahpeton sand plain, the potential for developing large volumes of ground water is great. However, if glaciofluvial deposits, such as those associated with till, are local in areal extent and sufficiently enclosed within the till sheet so as to prevent adequate recharge, the sustained pumping rate of a well developed in the deposit will become restricted even though high yields may have been produced initially.

Till-associated deposits. -- Till-associated glaciofluvial deposits are composed essentially of the coarser fraction of the rock material found in the particular till sheet with which they are associated. They are more or less sorted and stratified, but apparently occur as randomly interspersed, irregular-shaped bodies with a limited degree of hydraulic interconnection. Nearly every test hole drilled in the Wahpeton area (table 2) encountered till-associated glaciofluvial deposits of variable thickness at varying depths. It is difficult to correlate the deposits from one test hole to the next, and test drilling is the only reliable means of locating them.

Some wells in the glacial drift have been developed where major aquifers are suspected to be absent. The reported depth of completion suggests these wells probably recover ground water from till-associated glaciofluvial deposits. Most of the wells are located on the bedrock high in the south-central part of the study area and range from 55 to 100 feet in depth (Baker, 1966, p. 36-47). Most of the farms on which these wells are located also have wells in the bedrock. Wells in the glacial drift reportedly are used only for stock watering or have been abandoned. The reason for this is not noted by Baker, but probably is because of an inadequacy of water, poor water quality, or a combination of both. Reported water levels indicate the water in the till-associated deposits is under artesian pressure -- the hydraulic head probably being transmitted through the till from the underlying Cretaceous sediments.

Water quality data are lacking from wells developed in the drift over the bedrock high in the south-central part of the study area. North of Wahpeton, however, observation wells were installed in till-associated deposits in test holes 3773 (133-47-16cad) and 3959 (133-48-$1ddd_2$). Analyses of water samples from the two wells (table 1) indicated the water was of good quality and was of a sodium bicarbonate and calcium bicarbonate type.

Wahpeton buried valley. -- Lack of information precludes a discussion of the origin and history of the ancestral stream that created the Wahpeton buried valley. The course of the former drainage system outside the Wahpeton area is presently undetermined; therefore, the physical characteristics of the valley discussed herein relate specifically to the study area.

The Wahpeton buried valley enters North Dakota from the southeast approximately 2 miles north of Wahpeton (pl. 2) and leaves the study area along U.S. 81 north of Abercrombie, a distance of about 16 miles. Cross sections (pl. 4) indicate the valley was eroded following the deposition of the sandy Light-Gray Till and prior to the accumulation of Intermediate Till deposits. The stream that formed the valley may have incised into as much as 250 feet of Light-Gray Till, Older Till, and/or the underlying bedrock before glacio-fluvial deposition began to occur. The width of the valley was determined by the type of material the ancestral stream eroded. For instance, north of Wahpeton the valley is approximately a quarter of a mile wide where it has been incised into Cretaceous sediments and about 1 mile wide through the overlying less-resistant Older Till (sec. B-B'). Above 775 feet msl the stream appears to have been unconfined, especially to the north. Northwest of cross section B-B' (sec. C-C') the valley has been eroded into Light-Gray Till. Here the valley assumes a broad V-shaped profile probably half a mile wide at the bottom and over 1 mile wide at the top.

The buried valley is filled almost exclusively with well-sorted uniform subangular to subrounded sand. The sand grades transitionally from very coarse grained at the bottom of the valley to very fine grained at the top. This gradation indicates a progressive decrease in stream velocity and, therefore, transporting capacity. Gravel usually occurs as terrace deposits; one notable exception being test hole 3966 (133-48-12baa) in which very coarse-grained materials were penetrated from 89 to 101 and 114 to 231 feet.

The location and thickness of the aquifer contained in the Wahpeton buried valley is shown on plate 5. As presently defined, the aquifer underlies about 16 square miles in the Wahpeton area. Along the central axis of the valley the aquifer has an average thickness of more than 200 feet; however, overall the average thickness may be about 150 feet. It is an artesian aquifer system overlain by 100 to 150 feet of glacial drift and confined essentially by till.

Assuming an area of 16 square miles, an estimated porosity of 35 percent, and an average thickness of 150 feet, the amount of ground water in storage in the study area is about 540,000 acre-feet.

Plate 5 also shows the configuration of the potentiometric surface of the Wahpeton buried valley aquifer. The surface slopes to the north-northwest; therefore, the primary direction of ground-water movement is from the southeast. The amount of water moving through the aquifer cannot be measured directly; however, using a hydraulic gradient of 2 feet per mile, an average width of 1 mile, and hydrologic data relating to the transmissivity and storage properties of the aquifer as determined from an aquifer test, the approximate amount of water passing through a given cross section of the aquifer is about 200,000 gallons per day -- over 0.5 acre-foot. The rate of recharge over a given period of time probably coincides with the amount of water discharged naturally by lateral and upward movement into the surrounding glacial drift.

The aquifer test north of Wahpeton was conducted using a 10-inch diameter test well (133-47-21cbb$_3$). The well is believed to be completed near the central axis of the Wahpeton buried valley, but only partially penetrates the aquifer. An 8-inch nominal, 35-slot screen was set from 230 to 280 feet below land surface. The test began at 0900 on September 24, 1969. The well was pumped at a rate of 1,085 gpm until noon September 27 and recovery was measured through September 30. The rate of flow was measured by a flowmeter coupled to a continuous recorder. Drawdown and recovery were determined by automatic water-level-detector recorders and a chalked steel tape. The water was discharged to Red River via a road ditch.

The location of the test well, the measured observation wells, and the configuration of the cone of depression after 4,500 minutes of pumping are shown in figure 3. The cone of depression was determined by maximum draw-down in each well. Figure 3 shows that the drawdown relative to distance was greatest to the northwest, the primary direction of water movement within the aquifer. Figure 4 is a graphic plot of drawdown and recovery versus time. Total drawdown in the test well was nearly 30 feet. The pumping rate divided by the total drawdown determines the specific capacity of a well. Therefore, the specific capacity of the test well after 4,500 minutes of pumping was 1,085 ÷ 30, or 36 gpm per foot of drawdown. Other technical data acquired during the aquifer test are included in an open-file report (Schmid, 1970), which is available in the North Dakota State Water Commission office in Bismarck.

Water samples were collected for analysis from the test well after 21, 1,500, 3,000, and 4,500 minutes of pumping (table 1). Little change was observed in the quality of the water with the exception of iron content, which was reported at 0.08, 0.98, 1.2 and 0.76 mg/l respectively. In general the hardness of the water was very high, it averaged 657 mg/l total dissolved solids, and was a calcium bicarbonate type. Water samples collected at other locations (table 1) indicate the water is of similar quality throughout the aquifer, although there is a slight variation from calcium bicarbonate to sodium bicar-bonate type.

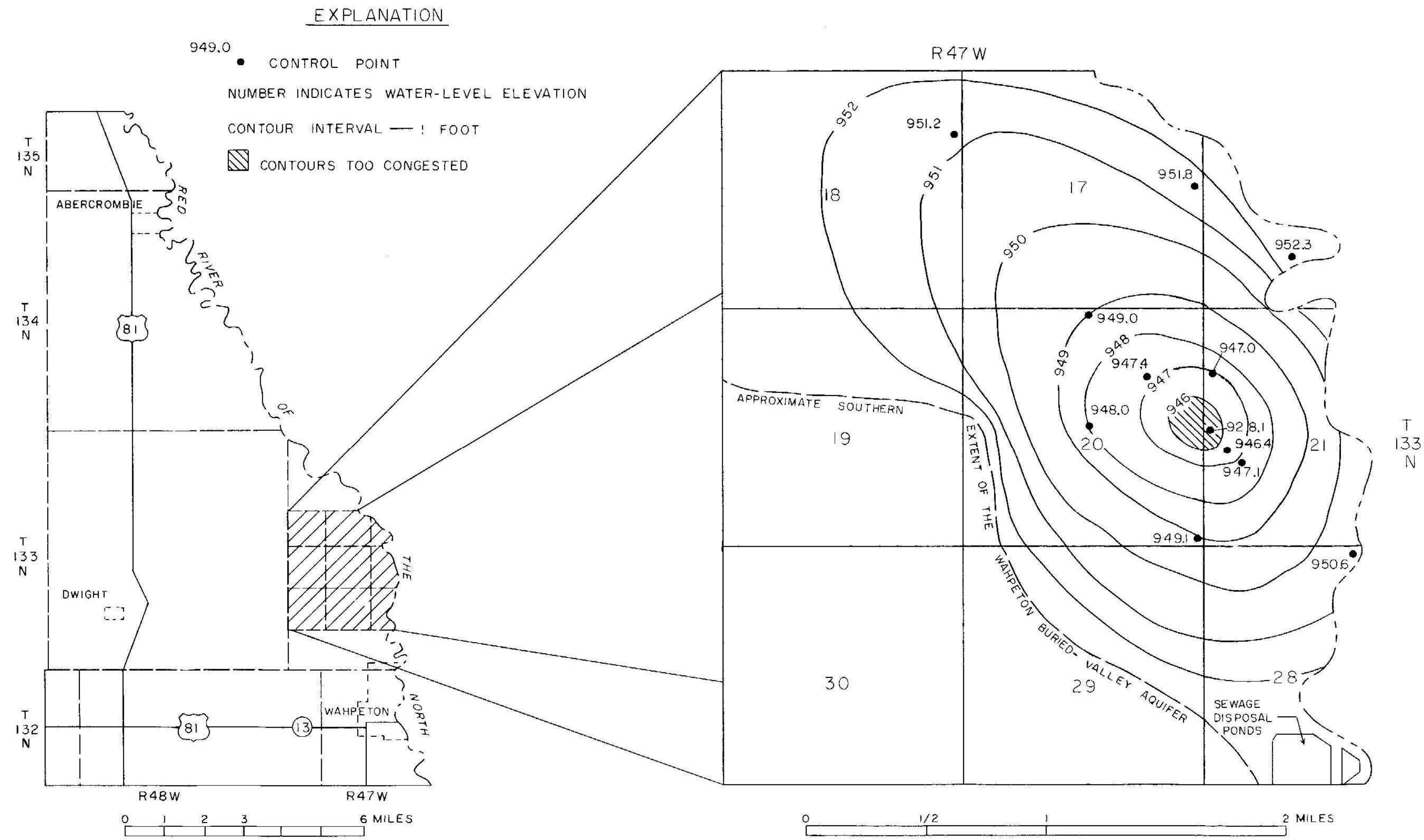


FIGURE 3 --CONFIGURATION OF THE POTENTIOMETRIC SURFACE AFTER 4,500 MINUTES OF PUMPING

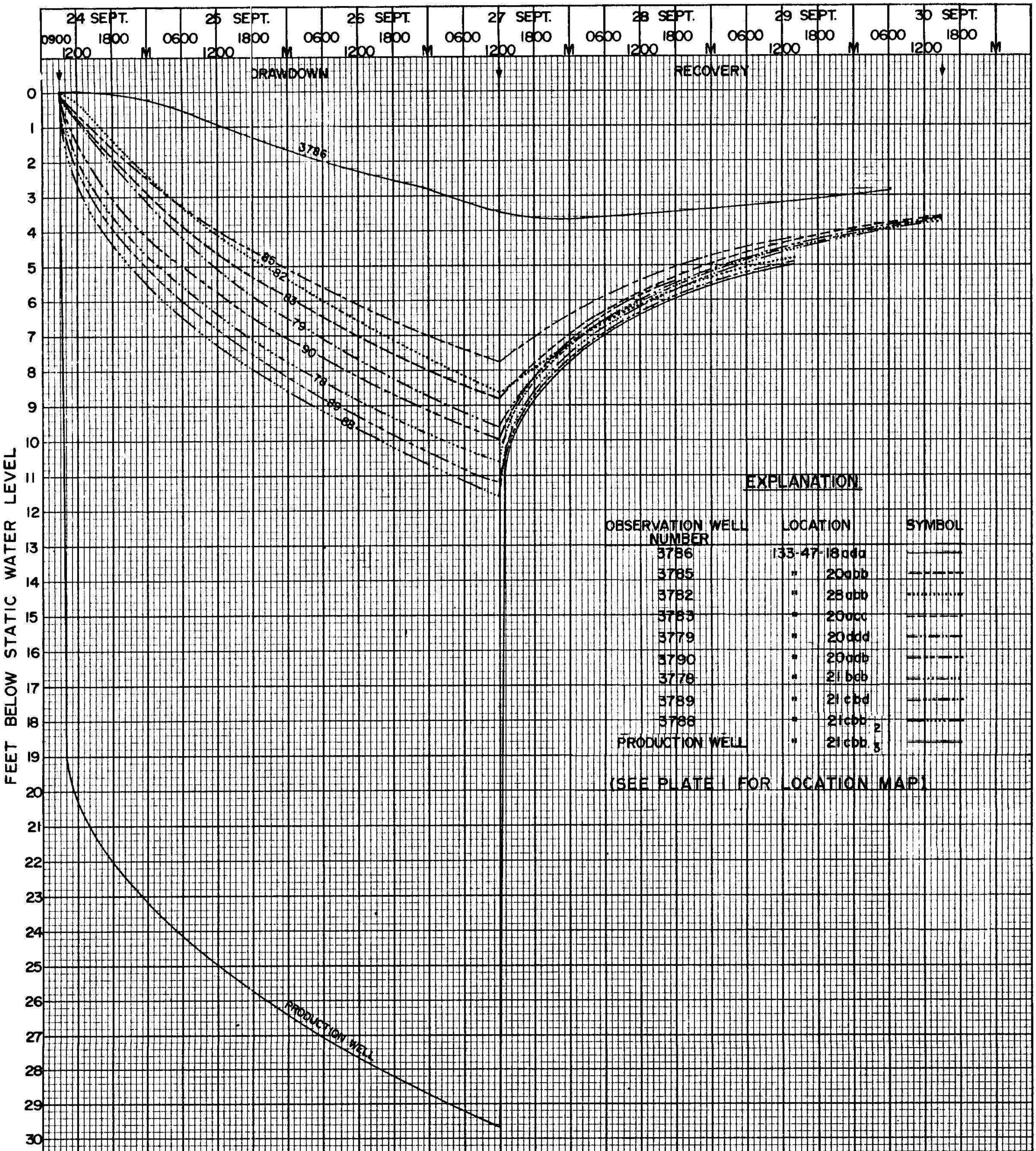


FIGURE 4—GRAPHIC PLOT OF DRAWDOWN AND RECOVERY IN SELECTED WELLS

Presently (1970) the water-yielding potential of the Wahpeton buried valley aquifer is essentially undeveloped. The aquifer is capable of supplying moderate to large municipal and industrial demands without seriously affecting the amount of ground water in storage. High-capacity wells will increase the rate of recharge by increasing the hydraulic gradient in the vicinity of the well field; however, a lowering of the potentiometric surface or pressure head will occur and natural discharge will decrease correspondingly. It can be expected that the several domestic and stock wells developed in the buried-valley aquifer within a radius of 5 or 6 miles of the well field will cease to flow shortly after the high-capacity wells began production. Water quality should not be affected seriously; however, a decrease in hardness and a trend toward sodium bicarbonate type water may result because of induced recharge from the underlying Cretaceous rocks.

Wahpeton sand plain. -- The existence of the Wahpeton sand plain was first suspected during test drilling conducted during this study. After test hole logs were carefully studied, cross sections prepared, and water-well data correlated from Baker (1966, table 1), it became apparent the buried sand plain does exist and could constitute an important source of ground water. However, the test drilling was concentrated on defining the geohydrology of the Wahpeton buried-valley aquifer. As a result, data which could accurately define the geohydrology of the Wahpeton sand plain are lacking throughout much of the area. The following generalized discussion is presented, nevertheless, to familiarize the reader with some of the hydrologic characteristics of the aquifer contained in the Wahpeton sand plain, based on available information and pending additional subsurface exploration.

The Wahpeton sand plain represents an accumulation of glacial outwash that originated during the interglacial period between the occurrence of the Intermediate and Younger Till sheets. The sand plain deposits generally occur in the interval between 875 and 925 feet msl in the southern part of the Wahpeton area (pl. 4, sec. A-A', B-B') to between 800 and 900 feet msl in the northern part (sec. A-A', C-C'). They may be encountered within 20 to 75 feet below land surface; however, there are numerous instances of non-deposition throughout the area because of irregularities on the original surface of the Intermediate Till. In the northern part of the Wahpeton area (sec. C-C') the Intermediate Till has been eroded, and the sand plain deposits directly overlie Light-Gray Till and/or the Wahpeton buried-valley aquifer.

Rapid vertical and lateral changes in lithology suggest that deposition of the Wahpeton sand plain occurred, not as a result of one major stream, as in the case of the Wahpeton buried valley, but as a result of several more or less unconfined streams. Apparently the deposits in the eastern part of the area consist of about equal amounts of silt, sand, and gravel; whereas in the western part coarse-grained sand and gravel predominate.

Plate 6 is a contour map on the potentiometric surface of the artesian aquifer contained in the Wahpeton sand-plain deposits. Much of the water-level data was modified from Baker (1966, table 1). The lack of contours in the southeastern part of the Wahpeton area probably reflects the existence of the till-covered bedrock high. Apparently the elevation on the high was sufficient to cause the streams that deposited the Wahpeton sand plain to be diverted around it. In effect, the high separated the sand plain deposits in the southern part of the Wahpeton area into eastern and western units. The two units probably combine in the northeastern quadrant of T. 133 N., R. 48 W., and function as a single hydrologic unit as they continue north.

The stream or streams that deposited the eastern unit entered the Wahpeton area from the southeast and flowed northwest above, and generally parallel, to the former course of the Wahpeton buried valley. Any map depicting the drainage of western Minnesota shows the Ottertail-Pelican River system as flowing south from its headwaters near Detroit Lakes for a distance of some 30 miles to a point southwest of Fergus Falls. From Fergus Falls the Ottertail River turns and flows west-northwest across the Red River Valley (Agassiz Lake Plain) to its confluence at Breckenridge across the Red River from Wahpeton. It is the author's opinion that the stream or streams that deposited the eastern unit of the Wahpeton sand plain originated at the melting ice front to the north, flowed south in ice-marginal meltwater channels that had been created when the Intermediate Till sheet still occupied the Wahpeton area, and then reversed their flow to the north when the meltwater channels were breached in favor of the topographically lower area that remained after the ice mass had retreated from the area. Because the deposits in the eastern unit are suspected to be the result of an ancestral Ottertail River, they will be referred to herein as the Ottertail unit of the Wahpeton sand plain.

Concurrent with the deposition of the Ottertail unit, streams entered the area from the southwest causing the accumulation of sand and gravel in the western unit. These streams are believed to have originated in much the same manner as those that formed the Ottertail unit, and may reflect the former course of the Wild Rice-Sheyenne River system of eastern North Dakota prior to the advance of the Younger Till sheet. Baker (1967, pp. 21-22) refers to the western unit as the Colfax buried outwash; therefore, the unit is referred to herein as the Colfax unit of the Wahpeton sand plain.

Based on available data, the Wahpeton sand plain underlies about 75 percent of the Wahpeton area. Assuming an area of 80 square miles, an estimated porosity of 30 percent and an average thickness of 40 feet, the amount of ground water in storage is about 610,000 acre-feet.

The amount of daily ground-water recharge to the Wahpeton sand plain aquifer cannot be determined accurately because of the variations in thickness, lithology, and hydraulic gradient. It may be considerably more than that received by the Wahpeton buried valley aquifer.

Ground-water discharge occurs as natural underflow to adjacent areas, to streams and evapotranspiration processes, and to wells. The majority of subsurface discharge, as indicated by the contours on plate 6, is toward the north and northeast; but the depression in the contours paralleling the Wild Rice River in the western part of the area suggests ground water is also being lost to the river. During the summer months, cattails and marsh grasses flourish in natural and artificial depressions in the land surface because of a plentiful water supply created by high water levels. Evaporation and transpiration losses are high under these conditions. Several thousand gallons of water are discharged daily from the numerous wells throughout the area, many of which are flowing.

Recharge conditions apparently play a major role in the determination of water quality in the Wahpeton sand plain aquifer. Table 1 indicates considerable differences in water quality between the Ottertail and Colfax units. Although water from both units is hard and has a high iron concentration, the Ottertail unit contains better quality water because recharge conditions are similar to those of the Wahpeton buried-valley aquifer and, in part, recharge is derived from it. The water is a calcium bicarbonate sulfate type. The Colfax unit is probably recharged by leakage partly from the surrounding till and partly from the underlying Cretaceous rocks (Baker and Paulson, 1967, p. 36). Water from the Colfax unit contains about twice as many total dissolved solids as water from the Ottertail unit and is a sodium sulfate bicarbonate type.

The water-yielding potential of the Wahpeton sand-plain aquifer may be as great as the Wahpeton buried-valley aquifer. Sufficient data are lacking at the present time (1970), however, to prepare a water availability map or estimate anticipated yields from individual wells. The Colfax unit in the western part of the Wahpeton area and the combined Colfax and Ottertail units in the northern part of the area perhaps offer the greatest potential for moderate-to large-scale development of the Wahpeton sand-plain aquifer. The water quality may not be suitable without treatment to certain types of industrial processes, however.

Glaciolacustrine deposits

Glaciolacustrine deposits are essentially, but not always, fine-grained sediments such as clay and silt that accumulate in proglacial lakes. Several test holes in the Wahpeton area encountered isolated buried clay and silt deposits presumably of glaciolacustrine origin. Lake Agassiz deposits, however, blanket the surface of the Wahpeton area nearly in its entirety.

Buried lake deposits. -- The greatest concentration of buried lake deposits appears to be between the Intermediate Till and the Younger Till, however, they were encountered during test drilling at various intervals throughout the glacial drift and occasionally occur immediately above the bedrock. They consist, for the most part, of clay and silt deposits that seldom attain thicknesses of over 20 feet, average perhaps 5 or 6 feet, and appear to be of limited areal extent. The clay is usually smooth, tight, cohesive, stiff to plastic, and dark brown or black owing to large amounts of organic matter derived from decayed vegetation. The silt also contains organic matter, is commonly lighter in color, and often appears in various hues of green. The buried lake deposits are not considered as aquifers because they are essentially impermeable.

Lake Agassiz deposits. -- Surficial deposits on the Agassiz lake plain are separated into two units by Baker (1967, pl. 1). His map describes an L-shaped area, including the western and southern parts of the Wahpeton area, as being underlain by clay and silt that accumulated on the lake floor of glacial Lake Agassiz; and the remainder, essentially that north of State Highway 13 and east of U.S. Highway 81, as mainly lake-washed till.

The lake-floor deposit shows no effect of wave action and consists of uniformly soft dense plastic olive-gray clay. The deposit is usually oxidized to a depth of about 20 feet. The clay in the oxidized zone is primarily yellowish gray. The average thickness ranges from slightly less than 20 feet in the southern part of the area to nearly 40 feet toward the north. The lake-floor deposit does not readily yield water to wells, but does function as a confining layer.

Local concentrations of pebbles and cobbles at the surface in the lake-washed till area mark the highs that existed on the surface of the Younger Till before the till was smoothed by wave action. Cobble-free surfaces are underlain by Lake Agassiz deposits that accumulated in the depressions on the Younger Till. These deposits may consist of clay, silt, sand, or gravel. The texture of the lake-washed till deposits, as well as the degree of sorting, was determined by the intensity of wave and current action. Unlike the uniform blanket of the lake-floor deposit, the lake-washed till deposits vary considerably in thickness and areal extent. Test hole 3774 (133-47-16cda) encountered a deposit of sand and gravel extending from the surface to a depth of 40 feet. The deposit is unique because, along with the sand and gravel, it contains numerous unbroken thumb-nail sized clam shells. It is doubtful the shells could have survived intact in a stream that had sufficient velocity to transport gravel; thus supporting the theory that the deposit is lacustrine in origin.

Water-yielding deposits of glaciolacustrine sand and gravel sporadically underlie the surface of the lake-washed till area. Most of the deposits are of limited extent but would support the demands of a domestic or stock well. The primary source of ground-water recharge to the sand and gravel is by local precipitation and infiltration. A well in the vicinity of test hole 3774 could probably support moderate well yields because additional recharge would be induced from the adjacent Red River. Chemical analyses of water samples (table 1) indicate the water contained in the lake-washed till deposits generally is of good quality, although it is rather hard and high in iron content.

SUMMARY

The Wahpeton area comprises about 107 square miles in east-central Richland County and is in the Agassiz Lake Plain physiographic division of the Central Lowland Province. Maximum topographic relief is about 25 feet. The average precipitation is 20.59 inches and the average temperature is 43.3° F. The area is drained by the north-flowing Red and Wild Rice Rivers and Antelope Creek. The Red River is the present source of municipal water supply for the City of Wahpeton, although ground water has been used periodically in the past. Abercrombie is the only city in the area presently utilizing ground water as a municipal supply. There are no irrigation or industrial wells in the area, but all domestic and stock requirements are met by wells ranging from 20 to 425 feet in depth.

The basement rock underlying the Wahpeton area is Precambrian granite. Its irregular surface is mantled by light-colored clays believed to be a weathered product of the granite. The Dakota(?) Sandstone, which unconformably overlies the Precambrian rocks throughout much of the area, consists of fine- to coarse-grained quartz sand derived mainly from weathered granite as a result of wave action. Undifferentiated Cretaceous sediments were deposited on the eroded surface of the Dakota(?) Sandstone except in the south-central part of the area and other isolated instances where they directly overlie Precambrian rocks. The Cretaceous sediments consist predominently of black carbonaceous shale that is locally silty and sandy.

It may be possible to recover small quantities of water suitable for domestic and stock use from the Precambrian rocks. Several wells penetrating the Dakota(?) Sandstone flow slightly, but pumping rates of 35 gpm or more are possible if significant thicknesses are encountered. The water is considerably softer than glacial-drift water but contains excessive fluorides. The Cretaceous sediments are utilized locally as a source of water only in the absence of other aquifers. The water quality is similar to that from the Dakota(?) Sandstone. All bedrock aquifers contain sodium bicarbonate type water.

The bedrock is overlain by Pleistocene glacial drift with known thicknesses ranging from 134 to 307 feet. Four till sheets were recognized within the study area and include the Older Till, Light-Gray Till, Intermediate Till, and Younger Till. Some glaciofluvial deposition was associated with the individual till sheets, but primarily occured during interglacial periods. The Wahpeton buried valley formed between the retreat of the Light-Gray Till sheet and the advance of the Intermediate Till sheet. The Wahpeton sand plain accumulated between the Intermediate and Younger Till sheets. Isolated instances of glaciolacustrine deposition occur at various depths; however, the deposits of Lake Agassiz constitute the majority of the surficial geology of the Wahpeton area.

Till and glaciolacustrine deposits generally are not considered aquifers because they are essentially impermeable. They do act as confining boundaries, however, thus creating artesian conditions. Porous and permeable till-associated deposits, and certain Lake Agassiz deposits in the lake-washed till area, will adequately support the demand of domestic and stock wells. Small industrial development may be possible locally, depending on the areal extent of the deposits and the degree of hydrologic connection.

The Wahpeton buried-valley aquifer underlies approximately 16 square miles of the Wahpeton area and contains about 540,000 acre-feet of ground water in storage. Yields greater than 1,000 gpm are possible from an individual well. The water quality varies slightly from calcium bicarbonate to sodium bicarbonate type, is hard, and usually contains excessive iron.

The Wahpeton sand-plain aquifer probably underlies 75 percent of the Wahpeton area. Estimated ground water in storage is about 610,000 acre-feet. Water in the Ottertail unit is usually a calcium bicarbonate sulfate type, whereas water in the Colfax unit is a sodium sulfate bicarbonate type. High-capacity wells are possible in certain areas; however, additional geohydrologic investigations should precede development.

TABLE I--CHEMICAL ANALYSES

(analytical results in milligrams per liter except as 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
PRECAMBRIAN ROCKS																									
Gunness brothers	134-48 9 dab	390	56	7-23-64	22	.19	–	6.4	2.9	325	9.0	438	7	217	110	.4	3.0	1.2	918	28	0	95	27	1,380	8.4
DAKOTA(?) SANDSTONE																									
City of Wahpeton	132-47 8 abd	420	50	1-12-65	7.6	.65	–	9.6	5.1	357	13	544	0	245	98	3.8	1.0	.98	1,000	45	0	93	23	1,590	8.0
Test hole 3162	132-49 12 daa1	240	48	9-18-64	21	.34	–	34	10	506	5.8	424	0	558	220	1.9	2.0	1.6	1,570	127	0	89	20	2,420	8.0
Robert Doleshy	133-47 6 cca	350	--	9-19-69	10	.03	.01	32	9.7	208	14	452	0	152	41	3.2	2.5	1.0	696	120	0	77	8.3	1,110	7.8
Test hole 3955	7 add	324	48	6-5-70	11	.00	.04	23	6.9	221	12	452	12	142	37	2.5	1.0	1.2	693	86	0	83	10	1,180	8.3
City of Abercrombie	134-48 4 cbd	378	--	2-8-71	13	.20	.03	25	9.6	251	9.6	319	0	246	100	4.2	3.4	1.2	820	102	0	83	11	1,430	7.7
Jim Walton	25 ccb	365	48	9-19-69	14	5.7	.04	35	12	267	13	352	0	230	144	3.0	0.2	.82	898	135	0	79	10	1,500	7.7
Emila Srnka	26 cda	352	--	9-19-69	17	.24	.01	29	11	277	9.7	397	0	212	131	3.0	2.5	.90	889	118	0	82	11	1,470	7.6
			Average		13.4	1.02	.03	26.8	9.2	298	11.0	420	1.7	255	110	3.1	1.8	1.10	938	105	0	84	13.3	1,530	7.9
CRETACEOUS SEDIMENTS, UNDIFFERENTIATED																									
City of Wahpeton	132-47 8 acb	265	49	1-18-65	8.4	.83	–	8.0	10	380	7.3	734	0	150	104	3.5	1.0	2.2	1,030	63	0	92	21	1,670	8.0
Arnold Styt	133-48 1 ddd1	260	48	9-19-69	9.9	.44	.01	36	11	211	12	456	0	151	43	3.4	3.6	1.0	707	136	0	75	7.9	1,140	7.9
TILL-ASSOCIATED DEPOSITS																									
Test hole 3773	133-47 16 cad	111	51	8-21-69	25	.24	.06	59	11	89	9.6	324	0	106	21	0.3	1.3	.56	483	191	0	49	2.8	768	7.8
Test hole 3959	133-48 1 ddd2	?	–	6-3-70	29	0.0	.04	104	36	68	6.1	500	0	127	19	0.3	0.9	.22	637	406	0	26	1.5	1,010	7.5
WAHPETON BURIED VALLEY																									
Test hole 3775	133-47 16 cdb	155	49	8-26-69	36	.44	.05	70	24	83	14	420	0	103	24	0.7	0.0	.64	563	272	0	38	2.2	893	7.9
Test hole 3771	17 add	155	48	8-21-69	32	.10	.06	78	22	92	10	440	0	120	20	0.9	0.0	.56	593	284	0	40	2.4	925	7.8
Test hole 3960	17 ccc	123	48	6-4-70	31	0.0	.17	85	26	68	5.9	490	0	73	4.0	0.5	0.0	.37	535	320	0	31	1.7	870	8.0
Test hole 3786	18 ada	225	49	9-4-69	29	2.2	.18	124	35	52	6.9	477	0	186	8.0	0.3	1.0	.11	680	454	63	20	1.1	1,020	7.8
Test hole 3785	20 abb	185	49.	9-3-69	28	.46	.18	128	33	52	6.7	478	0	188	7.3	0.4	1.0	.04	680	456	64	20	1.1	1,020	7.8
Test hole 3790	20 aca	264	50	9-5-69	29	.70	.17	125	33	52	6.7	484	0	170	9.7	0.4	2.5	.19	667	448	51	20	1.1	1,020	7.7
Test hole 3783	20 acc	245	50	8-29-69	26	1.1	.13	78	28	68	6.4	369	0	137	15	0.6	1.0	.22	543	309	6	32	1.7	840	7.7
Test hole 3783	20 acc	245	50	9-2-69	30	1.9	.14	87	32	89	6.5	448	0	128	21	0.8	0.2	.30	618	348	0	35	2.1	945	7.7
Test hole 3779	20 ddd	255	51	8-29-69	24	.08	.13	97	33	79	9.3	459	0	167	18	0.9	1.0	.45	656	379	3	31	1.8	1,020	8.2
John J Dietz	21 bad	165	53(?)	8-12-69	17	.36	.06	41	18	132	11	367	0	131	32	0.3	2.3	.56	567	176	0	59	4.2	895	7.7
Test hole 3778	21 bcb	194	49	8-28-69	29	.20	.11	99	28	70	9.7	454	0	143	13	0.7	0	.37	617	364	0	29	1.6	968	7.8
Test hole 3789	21 cba	262	50	9-5-69	30	1.7	.13	114	35	52	6.4	451	0	150	6.2	0.4	0.1	15	618	430	60	21	1.1	942	7.8
Test hole 3787	21 cbb1	262	50	9-4-69	28	.78	.20	132	35	47	6.9	483	0	183	8.1	0.4	0.2	.07	679	474	78	17	0.9	1,020	7.7
Test hole 3788	21 cbb2	252	49	9-4-69	26	2.1	.13	114	31	53	6.2	476	0	133	9.1	0.4	2.5	.07	611	412	22	22	1.1	940	7.7
Production well after 21 minutes	21 cbb3	279	–	9-24-69	30	.08	.16	134	27	51	5.6	486	0	150	10	1.0	1.0	.15	649	444	45	20	1.1	1,020	7.6
Production well after 1,500 minutes	21 cbb3	279	47	9-25-69	30	.98	.18	129	31	50	5.6	486	0	158	10	1.0	1.0	.15	656	448	48	19	1.0	1,020	7.8
Production well after 3,000 min.	21 cbb3	279	47	9-26-69	30	1.2	.14	128	32	50	5.6	488	0	163	10	0.8	1.0	.15	662	452	52	19	1.0	1,020	7.7
Production well after 4,500 min.	21 cbb3	279	–	9-27-69	30	.76	.17	126	33	50	5.6	486	0	162	10	0.8	2.5	.19	660	452	53	19	1.0	1,020	7.8
Test hole 3782	28 abb	181	49	8-29-69	32	.58	.08	79	23	95	10	445	0	121	18	0.8	0	49	599	291	0	40	2.4	952	7.8
Victor Radig	28 ddc	216	–	9-4-69	32	1.4	.13	66	18	102	5.6	461	0	65	23	1.0	0.4	.37	569	238	0	48	2.9	855	7.8
Test hole 3969	133-48 3 abb	120	47	5-28-70	29	0.8	.23	124	36	57	5.6	480	0	191	11	0.4	0.5	0.0	691	457	83	21	1.2	1,060	7.6
Test hole 3966	12 baa	136	50	5-26-70	24	.72	.11	120	40	76	7.1	387	0	310	10	0.4	3	0.0	782	465	148	26	1.5	1,140	7.9
Test hole 3975	134-48 21 bbb	–	48	6-4-70	30	8.9	.23	91	24	117	5.7	426	0	169	53	0.5	0.0	.41	710	327	0	43	2.8	1,080	7.6
			Average		29	1.20	.14	103	29	71	7.3	454	0	152	15.2	0.6	0.9	.26	635	378	34	28	1.7	978	7.8
WAHPETON SAND PLAIN, OTTERTAIL UNIT																									
Test hole 3784	133-47 19 daa	53	49	9-2-69	28	.82	.30	126	35	81	7.1	472	0	239	13	0.5	1.0	.22	765	460	73	27	1.6	1,140	7.7
Test hole 3958	133-48 2 ada	91	47	5-26-70	31	1.4	.11	114	39	62	5.5	469	0	198	11	0.3	0.5	0.0	694	445	60	23	1.3	1,100	7.8
WAHPETON SAND PLAIN, COLFAX UNIT																									
Test hole 3163	132-48 10 bcc	100	–	9-21-64	23	.26	–	172	98	332	10	437	0	1,090	49	.1	14	.70	2,000	835	477	46	5.0	2,630	7.7
Test hole 3162	132-49 12 daa2	80	–	9-18-64	26	1.0	–	69	31	634	15	228	0	1,000	302	1.0	2.0	1.1	2,190	250	63	84	17	3,330	8.9
Lodahl brothers	133-48 17 aaa	81	–	2-8-71	28	.66	.13	88	35	136	6.7	469	0	131	102	0.9	0.7	.80	776	363	0	44	3.1	1,260	7.6
Edwin Larson	18 add	72	50	7-23-64	23	.94	–	25	24	710	17	278	0	1,100	335	5.7	3.0	1.8	2,420	286	58	83	18	3,410	7.9
Test hole 3790	134-48 32 ddd	80	48	6-3-70	28	0.0	.03	94	28	95	6.9	455	0	171	22	0.4	0.5	.41	670	349	0	37	2.2	1,020	7.7
			Average		26	.57	.08	90	43	381	11.1	373	0	698	162	1.6	4.0	.96	1,611	417	120	59	9.1	2,330	8.0
LAKE AGASSIZ DEPOSITS, WAVE-WASHED TILL UNIT																									
Test hole 3772	133-47 16 cba	52	48	8-21-69	27	1.2	.15	179	77	112	10	397	0	663	17	0.5	1.0	.45	1,280	765	439	24	1.8	1,700	7.7
Test hole 3774	16 cda	40	49	8-22-69	29	.72	.11	99	24	111	7.6	363	0	267	29	0.5	0.0	.71	748	348	50	40	2.6	1,100	7.7
Test hole 2313	17 ddd	80	–	9-16-64	24	.31	–	128	63	96	7.1	423	0	246	6.0	0.5	2.0	0.0	694	580	234	3	0.2	1,120	8.0
Test hole 2313	17 ddd	80	49	9-2-69	28	1.2	.10	126	45	59	5.7	438	0	268	10	0.2	2.5	.15	762	500	141	20	1.1	1,110	7.8
			Average		27	.86	.13	133	52	97	7.6	405	0	361	15.5	0.4	1.4	.33	871	548	216	22	1.4	1,260	7.8
SURFACE WATER																									
Red River	132-47 8 aab	–	–	9-4-69	5.5	.96	.01	44	27	9.1	3.7	258	0	28	2.0	0.0	1.0	0.0	248	223	12	8	0.3	428	7.6
Gravel pit	133-47 16 ccd	–	90	8-12-69	15	.44	.01	54	21	18	4.5	176	0	114	3.5	0.3	2.5	.04	320	220	76	15	0.5	516	7.7
Red River	16 cdc	–	84	8-12-69	14	1.1	.01	41	25	8.6	3.6	257	0	14	2.2	0.2	1.0	.04	238	206	0	8	0.3	424	7.5
Red River	16 cdc	–	–	9-4-69	5.4	1.6	.01	49	25	11	3.9	259	0	32	3.0	0.0	2.5	0.0	261	226	14	9	0.3	460	7.5

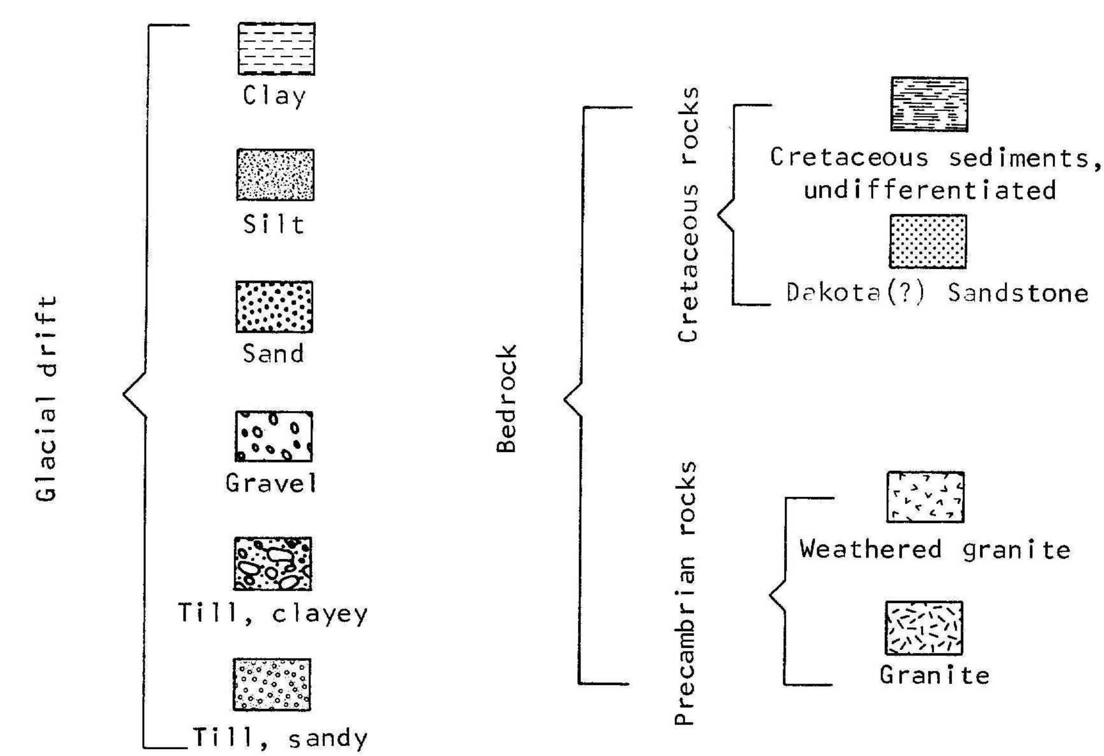
TABLE 2 -- LOGS OF TEST HOLES

The following table is a summary of subsurface data obtained from driller's logs, geologist's sample descriptions, and electrical logs including potential (S.P.), resistance (resistivity), and gamma ray. Grain-size and color classifications are based on accepted standard geologic terminology.

Test holes developed as observation wells are so indicated. All observation wells were completed with $1\frac{1}{4}$-inch plastic casing and screened at the bottom. The depth of the well and the screened or producing interval (S.I.) are indicated along with the water level (below land surface) and date of measurement. Chemical analyses are listed in table 1.

Elevations of observation wells, based on mean sea level datum, were obtained by the State Water Commission surveying crew. Test-hole elevations were interpolated from topographic maps published by the U. S. Geological Survey.

Explanation of Lithologic Symbols



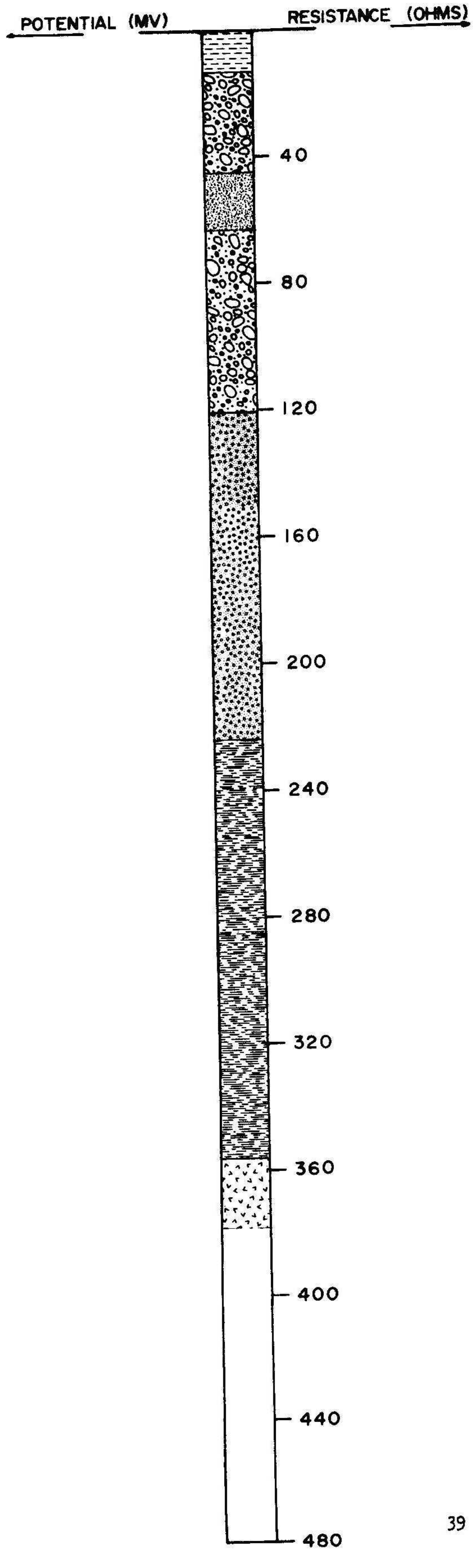
TEST HOLE 2316

LOCATION: 132-47-7bcc

ELEVATION: 958
(FT, MSL)

DATE DRILLED: 9-17-64

DEPTH: 378
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1 Topsoil, black.

1-13 Clay, grayish-orange to dark-yellowish-orange, soft, cohesive.

13-28 Clay, silty to pebbly, moderate-yellowish-brown, soft (Till).

28-45 Clay, silty to pebbly, olive-gray, soft (Till).

45-63 Silt, clayey to sandy, olive-gray, soft, very highly calcareous.

63-121 Clay, silty to pebbly, olive-gray to dark-greenish-gray, moderately compact (Till).

121-225 Clay, very sandy, light-olive-gray, soft, highly calcareous occasional cobble or boulder (Till).

Cretaceous rocks

225-318 Shale, silty, olive-gray to olive-black, compact, non-calcareous.

318-356 Shale, olive-black, very compact, noncalcareous; streaks of fine white sand.

Precambrian rocks

356-378 Clay, pale-bluish-green and light-greenish-gray, soft, nonplastic; contains much angular quartz sand.

Potential and resistance logs in Baker (1966, p. 114).

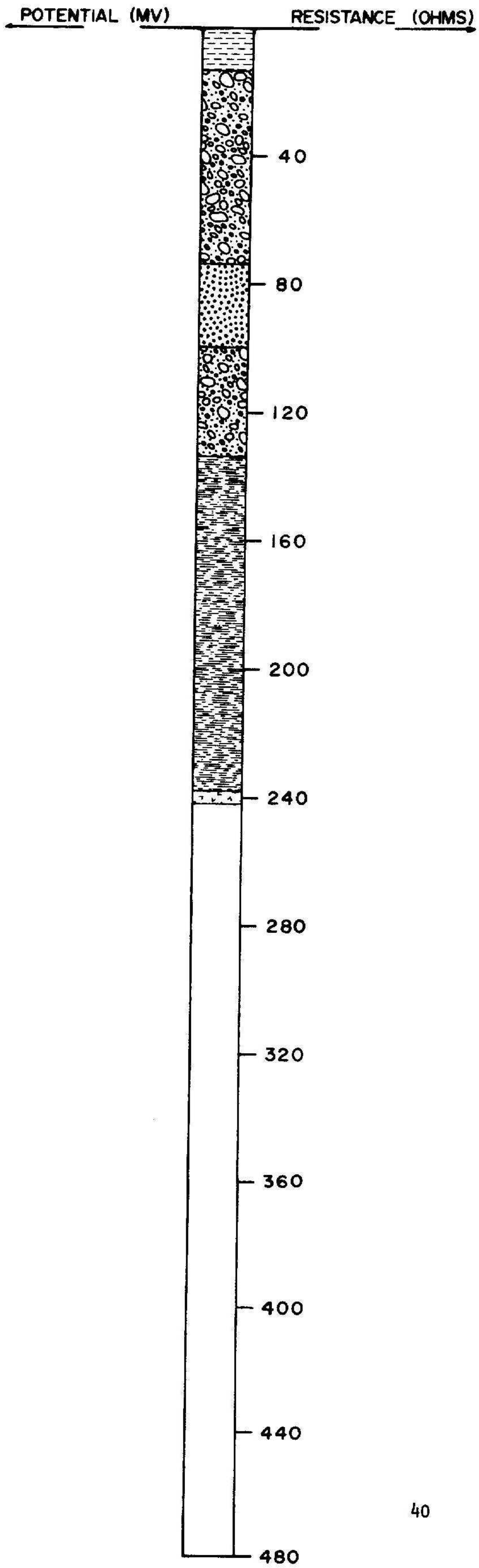
TEST HOLE 3163

LOCATION: 132-48-10bcc

DATE DRILLED: 9-18-64

ELEVATION: 958
(FT, MSL)

DEPTH: 242
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-13	Clay, yellowish-gray to moderate-olive-brown, soft, plastic.
13-22	Clay, silty to pebbly, moderate-olive-brown, moderately cohesive (Till).
22-74	Clay, silty to pebbly, olive-gray, moderately cohesive; thin sand lenses below 50 feet (Till).
74-100	Sand, fine to very coarse, olive-gray, subrounded.
100-134	Clay, silty to pebbly, olive-gray, cohesive (Till).

Cretaceous rocks

134-238	Shale, olive-black, hard, noncalcareous; occasional limey granules; thin layers of light-greenish-gray bentonitic clay; thin beds of limestone and sandstone near base.

Precambrian rocks

238-242	Clay, white, soft, noncalcareous.

Potential and resistance logs in Baker (1966, p.116).

Observation well
Depth -- 100 feet
S.I. -- 80 to 100 feet
Water level -- 9.56 feet
Measured -- 2-9-71

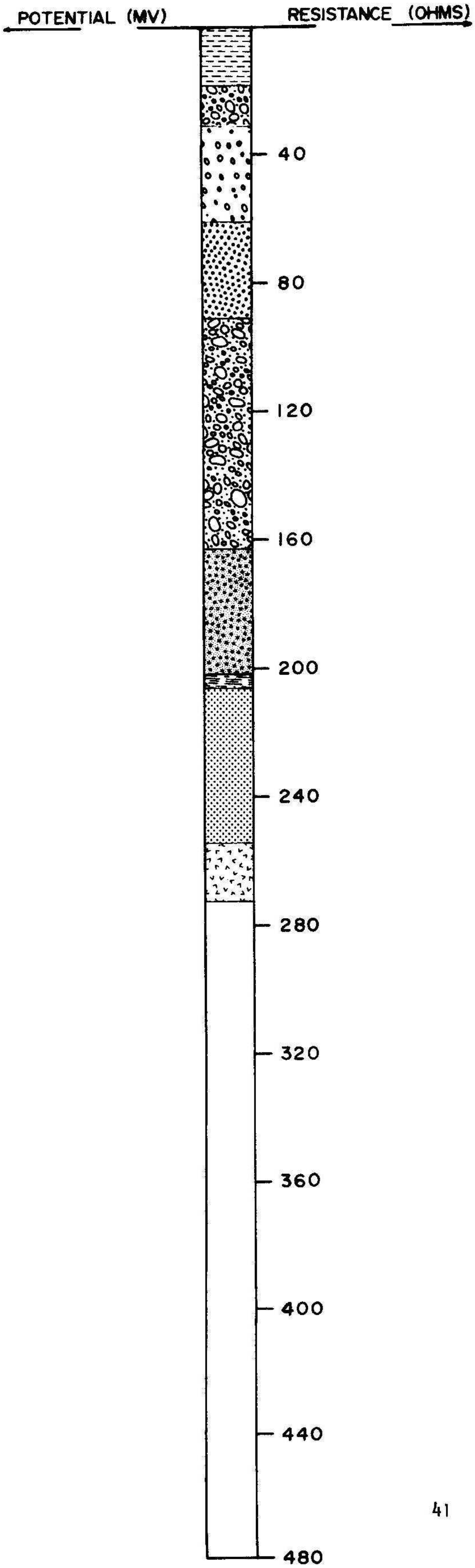
TEST HOLE 3162

LOCATION: 132-49-12daa

DATE DRILLED: 9-16-64

ELEVATION: 961
(FT, MSL)

DEPTH: 272
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2 Topsoil; black silty clay.

2-18 Clay, yellowish-gray, soft, plastic, sticky.

18-31 Clay, silty to pebbly, olive-gray, soft, moderately plastic (Till).

31-61 Gravel, fine to coarse, moderately sorted, subrounded; medium to very coarse sand lenses.

61-91 Sand, medium to very coarse, moderately sorted, subangular to subrounded; fine to coarse gravel lenses.

91-95 Boulder, granite.

95-103 Clay, silty to sandy, olive-gray to olive-black, moderately soft, moderately plastic; numerous pebbles; occasional cobbles (Till).

103-163 Clay, silty to pebbly, olive-gray, soft, slightly plastic; silt and sand lenses (Till).

163-202 Sand, fine and medium, clayey and silty, light-olive-gray, moderately cohesive to crumbly; occasional coarse sand grains, pebbles, cobbles, and boulders (Till).

Cretaceous rocks

202-206 Shale, olive-black, slightly hard, slightly calcareous.

206-248 Sandstone, fine to medium, white to buff, well-sorted, subrounded.

248-254 Sandstone, fine, well-sorted, subrounded; cemented with calcium carbonate.

Precambrian rocks

254-272 Clay, white, soft, talc-like, noncalcareous.

Potential and resistance logs in Baker (1966, p. 116).

Two observation wells

132-49-12daa$_1$
Depth -- 240 feet
S.I. -- 220 to 240 feet
Water level -- 2.3 feet
Measured -- 9-30-64

132-49-12daa$_2$
Depth -- 80 feet
S.I. -- 60 to 80 feet
Water level -- 1.6 feet
Measured -- 9-30-64

TEST HOLE 3955

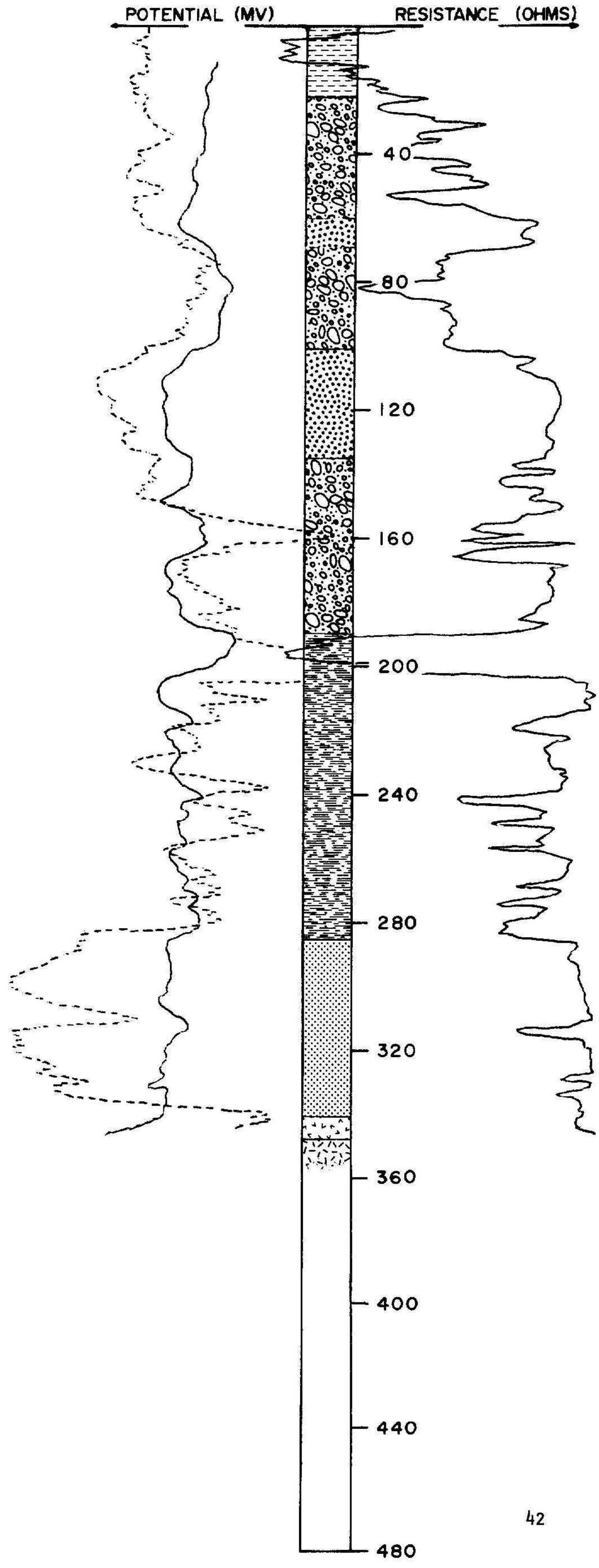
LOCATION: 133-47-7add

DATE DRILLED: 5-21-70

ELEVATION: 955.2
(FT, MSL)

DEPTH: 348
(FT)

----- gamma log



DESCRIPTION OF DEPOSITS

	Glacial drift
0-2	Topsoil; black pebbly silt loam.
2-22	Clay, slightly silty, yellowish- to brownish-gray, soft, moderately plastic; occasional sand grain and pebble.
22-60	Clay, silty to sandy, olive-gray, moderately soft, slightly plastic; coarse sand grains and pebbles; numerous very fine to medium sand lenses (Till).
60-69	Sand, medium, light-olive-gray, well-sorted, subrounded.
69-101	Clay, silty, olive-gray and dark-greenish-gray, moderately soft to slightly hard, smooth; occasional sand grains and pebbles; blocks of Cretaceous(?) sediments (Till).
101-135	Sand, fine and medium, gray, moderately sorted, subangular to subrounded.
135-190	Clay, very silty to pebbly, olive-gray; blocks of white, gray, green, black and brown clay, silt, and sandy clay; lenses of brown angular sand and gravel (Till).
	Cretaceous rocks
190-204	Shale, white, light-green, and light-gray, moderately soft to slightly hard; highly bentonitic.
204-285	Siltstone, white, green, brown, and black, loose to moderately cohesive, smooth to gritty, non- to highly calcareous; interbedded shale and very fine to medium-grained sandstone.
285-341	Sandstone, very fine to very coarse, white, subangular; interbedded white soft crumbly noncalcareous clay.
	Precambrian rocks
341-348	Clay, greenish-white, soft, noncalcareous; occasional quartz grains.
348+	Granite, white, extremely hard; small black (hornblende?) specks.

Observation well
Depth -- 323 feet
S.I. -- 317 to 323 feet
Water level -- land surface

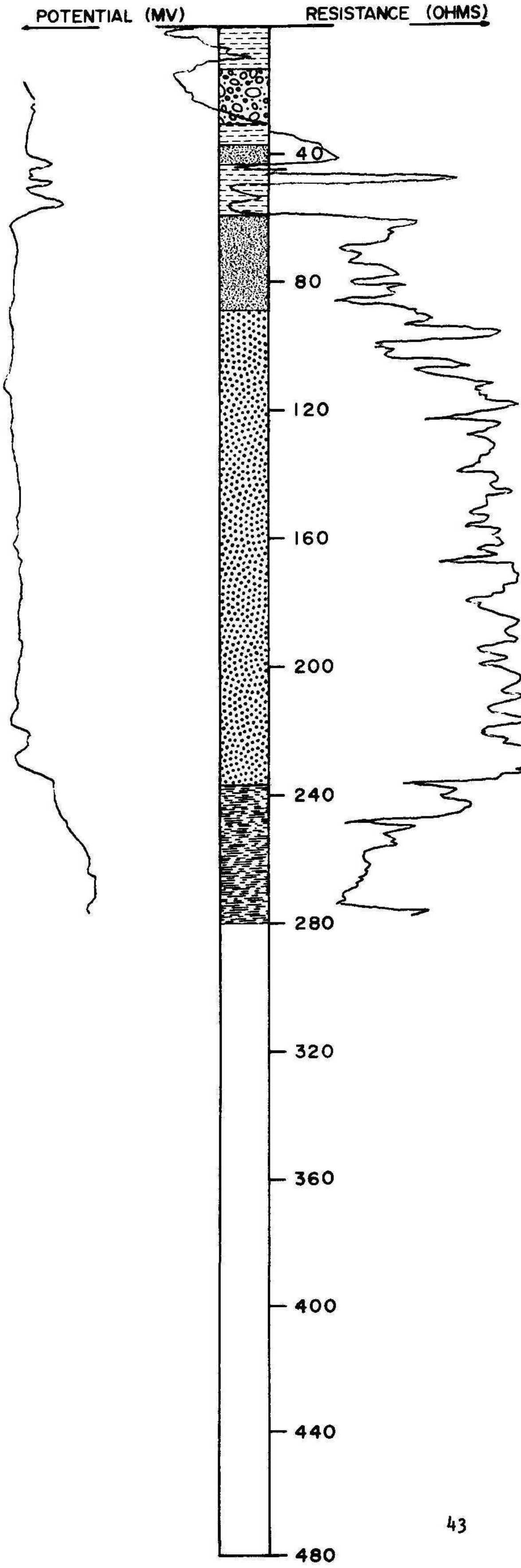
TEST HOLE 3965

LOCATION: 133-47-7cdd

ELEVATION: 957
(FT, MSL)

DATE DRILLED: 5-24-70

DEPTH: 280
(FT)



DESCRIPTION OF DEPOSITS

0-6	Roadfill; brown clay.
	Glacial drift
6-13	Clay, silty to slightly sandy, moderate-olive-brown, moderately soft, moderately plastic; occasional sand grain or pebble.
13-30	Clay, silty to pebbly, olive-gray, moderately soft, plastic; silty clay layers (Till).
30-37	Clay, silty, dark-olive-gray, moderately soft, slightly brittle to moderately plastic, smooth; brown stains.
37-43	Silt, slightly clayey, light-greenish-gray, soft, nonplastic; very fine sand lenses.
43-59	Clay, dark-olive-gray, moderately soft to slightly hard, smooth, slippery; interbedded silt, sand, and till.
59-89	Silt, light-olive-gray to olive-gray, loose to moderately cohesive; brown stains; inter-bedded clay and clayey fine sand.
89-95	Sand, very fine to fine, silty, gray, well-sorted, subrounded.
95-120	Sand, fine to medium, lenticular, subangular and subrounded.
120-169	Sand, medium and coarse, sub-angular to subrounded.
169-200	Sand, coarse to very coarse, subangular to subrounded.
200-237	Sand, as above; fine to medium gravel.
	Cretaceous rocks
237-249	Siltstone, clayey to sandy, brownish-black, moderately soft, slightly friable, carbonaceous, noncalcareous.
249-280	Shale, black, hard, brittle, smooth.

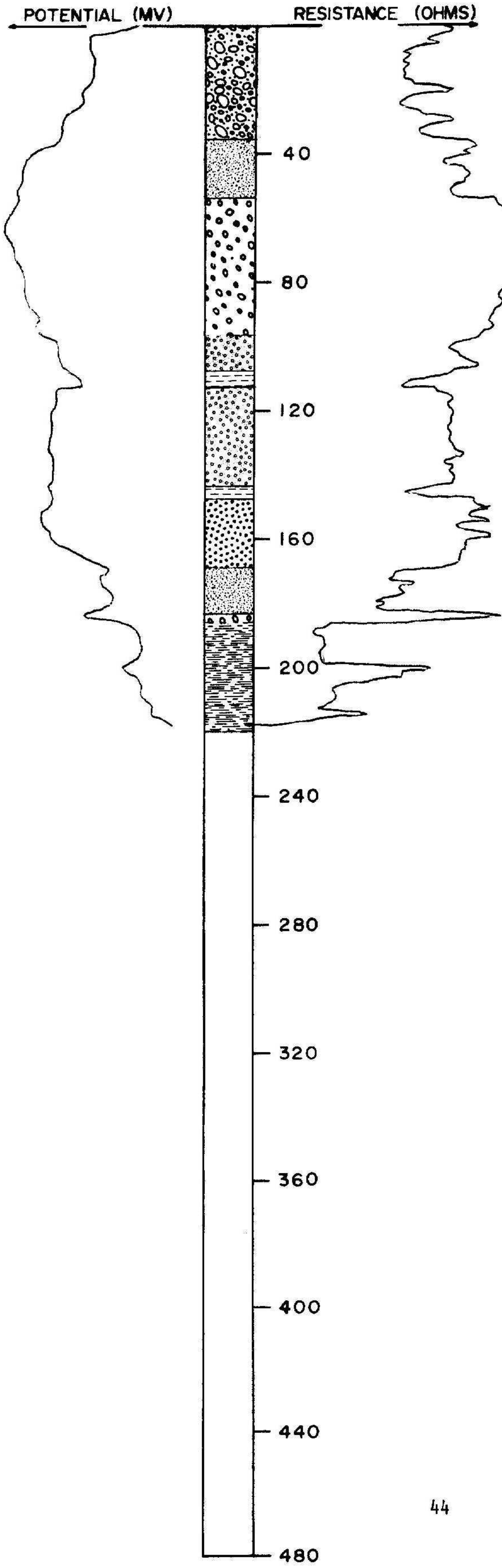
TEST HOLE 3964

LOCATION: 133-47-8cdd

DATE DRILLED: 5-24-70

ELEVATION: 959
(FT, MSL)

DEPTH: 220
(FT)



DESCRIPTION OF DEPOSITS

	Glacial drift
0-2	Topsoil; black pebbly silt loam.
2-17	Clay, silty to pebbly, yellowish-gray to moderate-olive-brown, moderately soft, slightly plastic, iron stained (Till).
17-36	Clay, very silty to pebbly, light-olive-gray to olive-gray, moderately soft; numerous sand and gravel lenses (Till).
36-54	Silt, clayey to sandy, light-olive-gray, soft, slightly crumbly.
54-97	Gravel, fine, sandy; interbedded sandy till.
97-108	Sand, very fine to fine, clayey, light-olive-gray, crumbly, compacted; occasional pebbles (Till).
108-113	Clay, dark-olive-gray, moderately soft, smooth.
113-144	Sand, very fine to fine, clayey, light-olive-gray; occasional pebbles (Till).
144-148	Clay, silty, olive-gray, moderately soft, plastic.
148-169	Sand, fine to coarse, subangular to rounded, lenticular.
169-183	Silt, clayey, light-olive-gray to olive-gray, soft, slightly plastic.
183-186	Gravel, fine, sandy, subangular to subrounded.
	Cretaceous rocks
186-220	Shale, black, hard, brittle, carbonaceous; interbedded brown siltstone and micaceous clayey very fine sandstone.

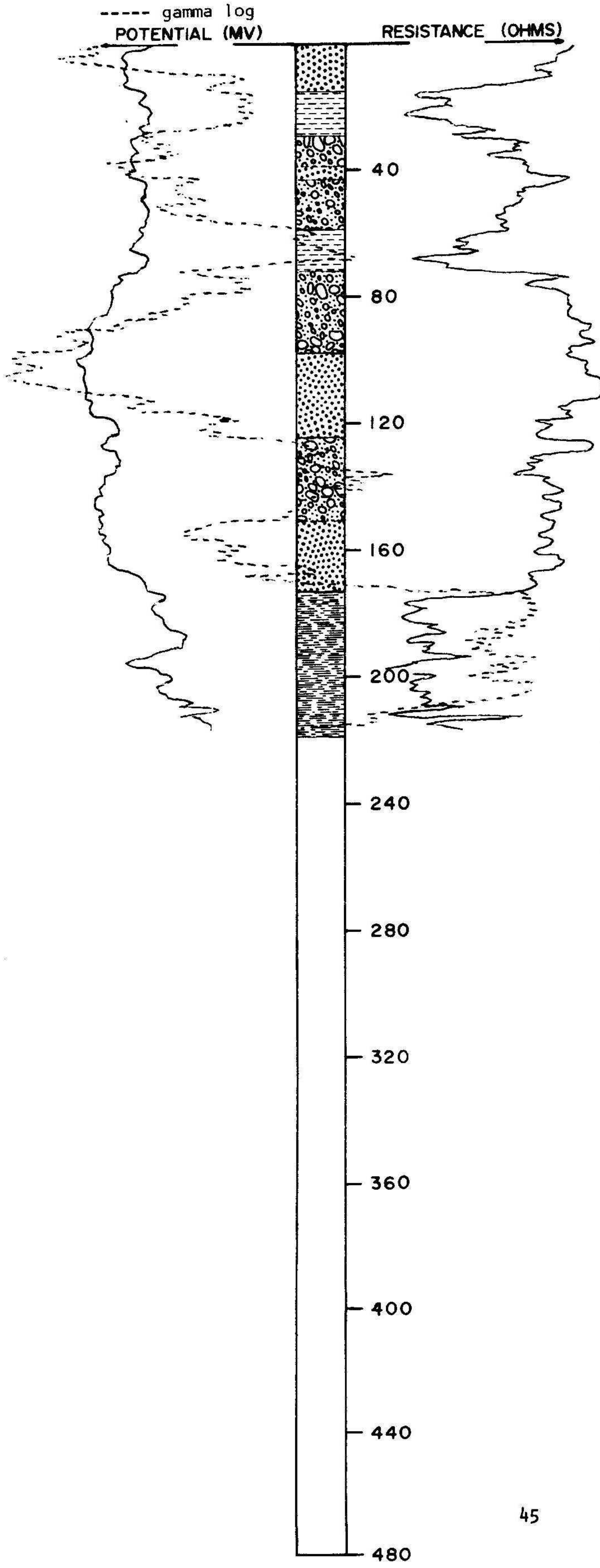
TEST HOLE 3773

LOCATION: 133-47-16cad

DATE DRILLED: 8-21-69

ELEVATION: 951.6
(FT, MSL)

DEPTH: 220
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black sandy clay loam.
2-15	Sand, fine to coarse, yellowish-gray to reddish-brown; fine gravel and soft yellowish-gray clay lenses.
15-29	Clay, light-olive-gray to olive-gray, soft, plastic, sticky; silty clay and very fine sand lenses.
29-39	Clay, silty and sandy, olive-gray, moderately soft, slightly plastic; coarse sand grains, pebbles, and cobbles (Till).
39-43	Sand, coarse to very coarse, sorted, subangular; fine gravel.
43-59	Clay, silty to pebbly, olive-gray, moderately soft, slightly plastic; sand and gravel lenses (Till).
59-72	Clay, olive-gray to dark-olive-gray, moderately soft to slightly hard, smooth, waxy.
72-98	Clay, silty to pebbly, olive-gray; clay, silt, sand, and gravel lenses (Till).
98-112	Sand, coarse, well-sorted, subangular to subrounded.
112-125	Sand, as above; till and fine gravel lenses.
125-151	Clay, silty to sandy, olive-gray; occasional cobbles; very fine sand lenses (Till).
151-158	Sand, fine to medium, light-gray, well-sorted, subangular.
158-174	Sand, as above; very sandy till and fine gravel lenses.

Cretaceous rocks

174-220	Shale, black, hard, stiff, waxy, fossiliferous; soft white highly-calcareous clayey medium-grained sandstone lenses; indurated sandstone in lower 10 feet.

Observation Well
Depth -- 110 feet
S.I. -- 107 to 110 feet
Water level -- 11.78 feet
Measured -- 9-23-69

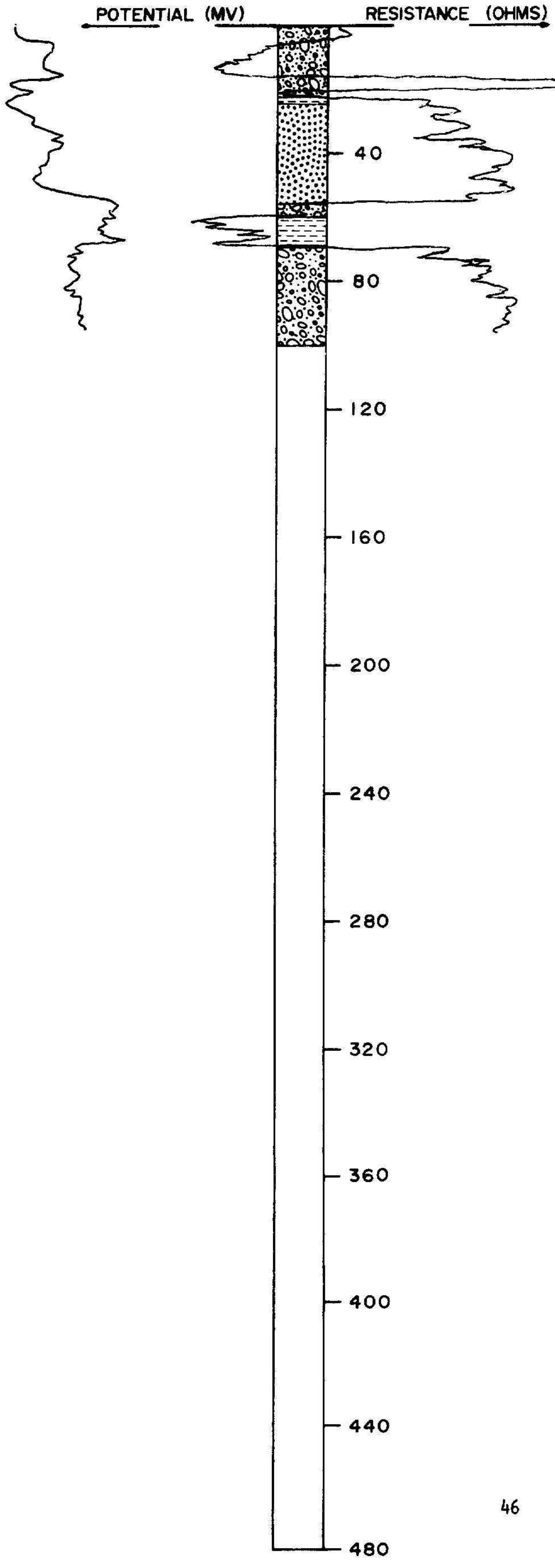
TEST HOLE 3772

LOCATION: 133-47-16cba

DATE DRILLED: 8-21-69

ELEVATION: 957.7
(FT, MSL)

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black pebbly clay loam.
2-19	Clay, silty to pebbly, dusky-yellow to moderate-olive-brown, soft to moderately soft (Till).
19-22	Boulder; indurated pink quartzite.
22-24	Clay, sandy, olive-gray, soft.
24-36	Sand, fine to coarse, lenticular, subangular to subrounded.
36-56	Sand, coarse to very coarse, subangular to subrounded.
56-60	Clay, sandy to pebbly, olive-gray, soft, slightly plastic (Till).
60-69	Clay, olive-gray to olive-black, crumbly, waxy; olive-gray clayey silt lenses.
69-100	Clay, silty to pebbly, olive-gray, soft; sand and gravel lenses (Till).

Observation well
Depth -- 51 feet
S.I. -- 48 to 51 feet
Water level -- 20.64 feet
Measured -- 9-23-70

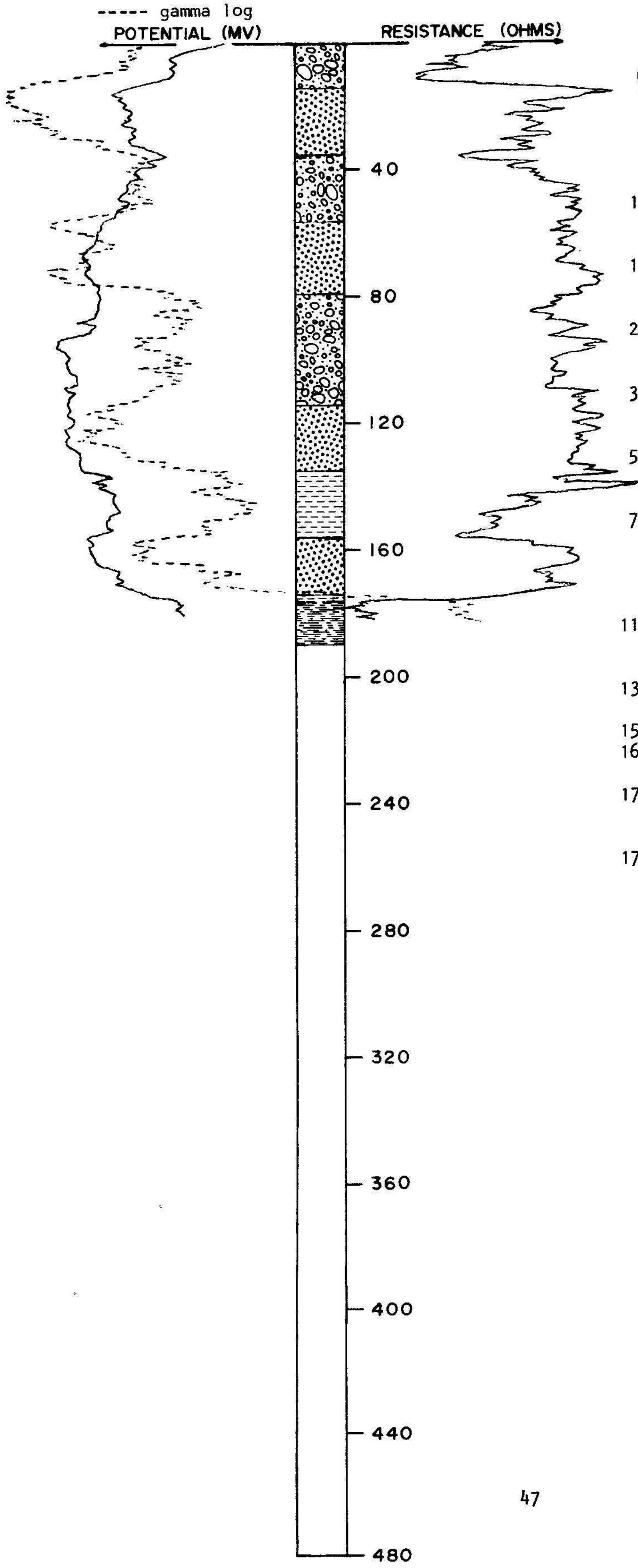
TEST HOLE 3776

LOCATION: 133-47-16ccd

ELEVATION: 962
(FT, MSL)

DATE DRILLED: 8-25-69

DEPTH: 190
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1 Topsoil; black gravelly loam.

1-13 Clay, silty and sandy, yellowish-gray, dusky-yellow, and moderate-olive-brown, soft, slightly plastic; numerous pebbles and cobbles (Till).

13-14 Clay, very sandy to pebbly, olive-gray, soft, slightly cohesive (Till).

14-22 Sand, medium to coarse, brown, well-sorted, subangular to subrounded.

22-35 Sand, medium to very coarse, gray; silt, silty clay, and fine gravel lenses.

35-56 Clay, silty and sandy, olive-gray, moderately soft; pebbles and cobbles (Till).

56-79 Sand, fine and medium, gray; gravelly; light-gray to olive-gray silt and silty clay.

79-114 Clay, silty to very sandy, olive-gray, moderately soft; numerous pebbles and cobbles; sand and fine gravel lenses (Till).

114-135 Sand, fine, light-olive-gray, subangular to subrounded; thin clayey lenses.

135-156 Clay, dark-brownish-gray, slightly hard, smooth.

156-165 Sand, fine, light-olive-gray.

165-174 Sand,fine, silty to clayey, light- to medium-gray.

174-176 Clay, dark-gray, moderately soft, smooth, calcareous.

Cretaceous rocks

176-190 Shale, black, hard, massive, noncalcareous, fossiliferous.

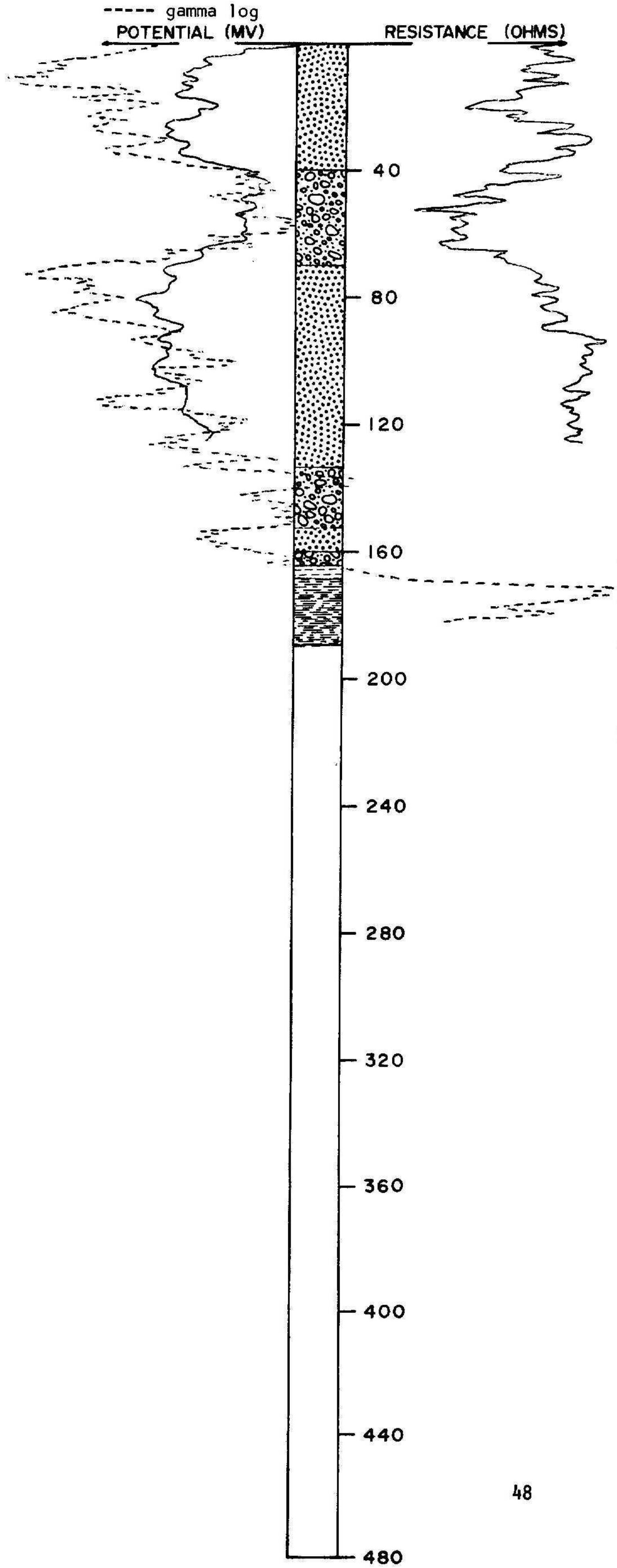
TEST HOLE 3774

LOCATION: 133-47-16cda

DATE DRILLED: 8-21-69

ELEVATION: 948.2
(FT, MSL)

DEPTH: 190
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1 Topsoil; dark-brownish-gray sandy loam.

1-14 Sand, medium to coarse, yellowish-reddish-brown, well-sorted, subangular to subrounded; numerous thumb-nail-sized clam shells.

14-40 Sand, coarse to very coarse, lenticular; fine to medium gravel and cobbles; clam shells.

40-70 Clay, silty to pebbly, olive-gray, moderately soft; cobbles; sand and gravel lenses (Till).

70-91 Sand, medium to very coarse, lenticular, subangular; fine gravel.

91-134 Sand, as above; olive-gray very sandy till lenses.

134-153 Clay, silty to pebbly, olive-gray, moderately soft; lenses of clay, silt, sand, and gravel (Till).

153-160 Sand, fine, light-gray, subangular and subrounded.

160-165 Clay, very sandy to pebbly, olive-gray (Till).

165-169 Clay, silty, olive-gray, moderately soft, plastic, sticky.

Cretaceous rocks

169-190 Shale, black, hard, smooth, waxy, noncalcareous; calcareous medium-grained sand.

Observation well
Depth -- 40 feet
S.I. -- 37 to 40
Water level -- 11.49 feet
Measured -- 9-23-69

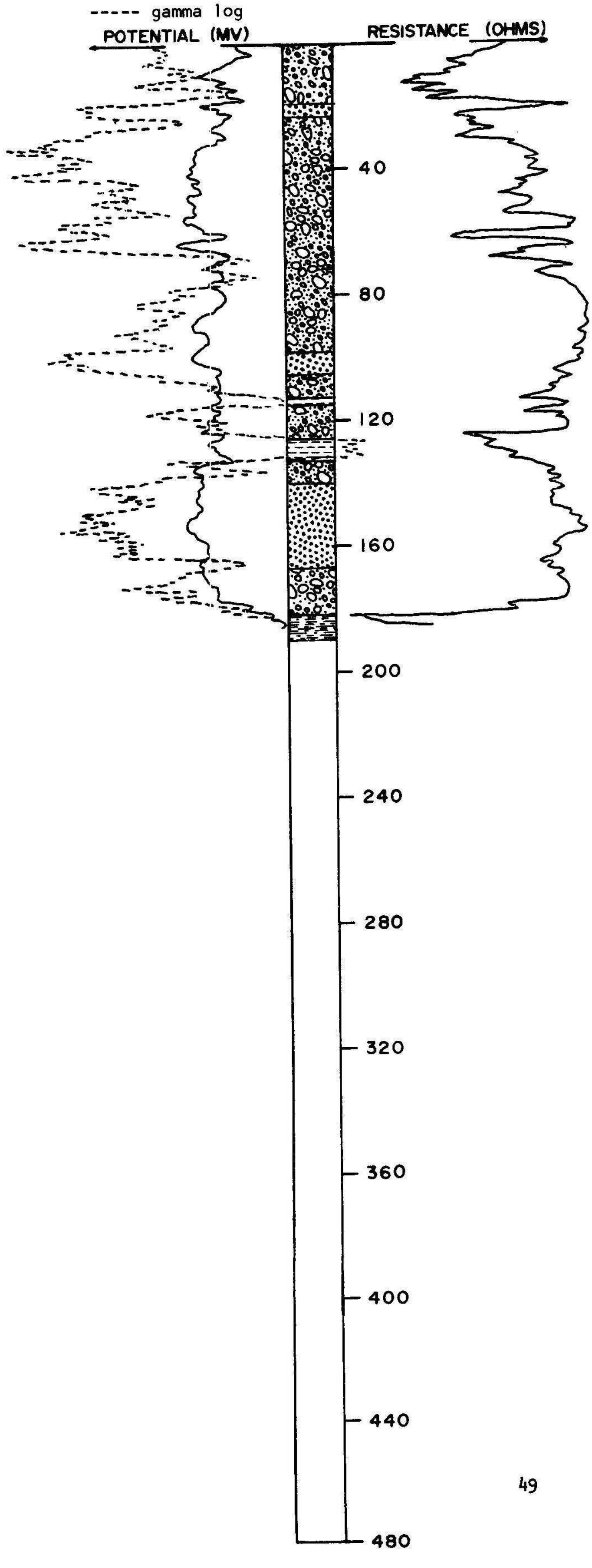
TEST HOLE 3775

LOCATION: 133-47-16cdb

DATE DRILLED: 8-22-69

ELEVATION: 950
(FT, MSL)

DEPTH: 190
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black pebbly sandy clay loam.
2-8	Clay, silty and sandy, yellowish-gray, soft, crumbly; pebbles and cobbles (Till).
8-19	Clay, silty and sandy, moderate-olive-brown, soft to moderately soft; pebbles and cobbles (Till).
19-23	Sand, medium, well-sorted, subangular to subrounded.
23-31	Clay, silty to pebbly, olive-gray, moderately soft, slightly plastic (Till).
31-60	Till, as above; medium to coarse sand and fine to medium gravel lenses.
60-68	Clay, very sandy, olive-gray, soft, slightly cohesive; sandy clay, sand, and gravel lenses (Till).
68-78	Clay, silty and sandy, olive-gray, moderately soft, cohesive; pebbly to rocky (Till).
78-98	Clay, silty to pebbly, olive-gray, moderately soft to slightly hard; thin fine sandy lenses (Till).
98-105	Sand, fine and medium, light-olive-gray, subangular and subrounded.
105-113	Clay, sandy to pebbly, olive-gray, moderately soft (Till).
113-115	Clay, dark-gray, moderately soft, smooth.
115-126	Clay, sandy to pebbly, olive-gray, moderately soft (Till).
126-133	Clay, dark-gray, smooth, waxy.
133-140	Clay, very sandy to pebbly, olive-gray, moderately soft (Till).
140-167	Sand, fine and medium, light-gray, well-sorted.
167-182	Clay, sandy to pebbly, olive-gray, moderately soft; smooth waxy clay and light-gray fine and medium sand lenses (Till).

Cretaceous rocks

182-190	Shale, black, hard, smooth, noncalcareous.

Observation well
Depth -- 155 feet
S.I. -- 149 to 155 feet
Water level -- 6.41 feet
Measured -- 9-24-69

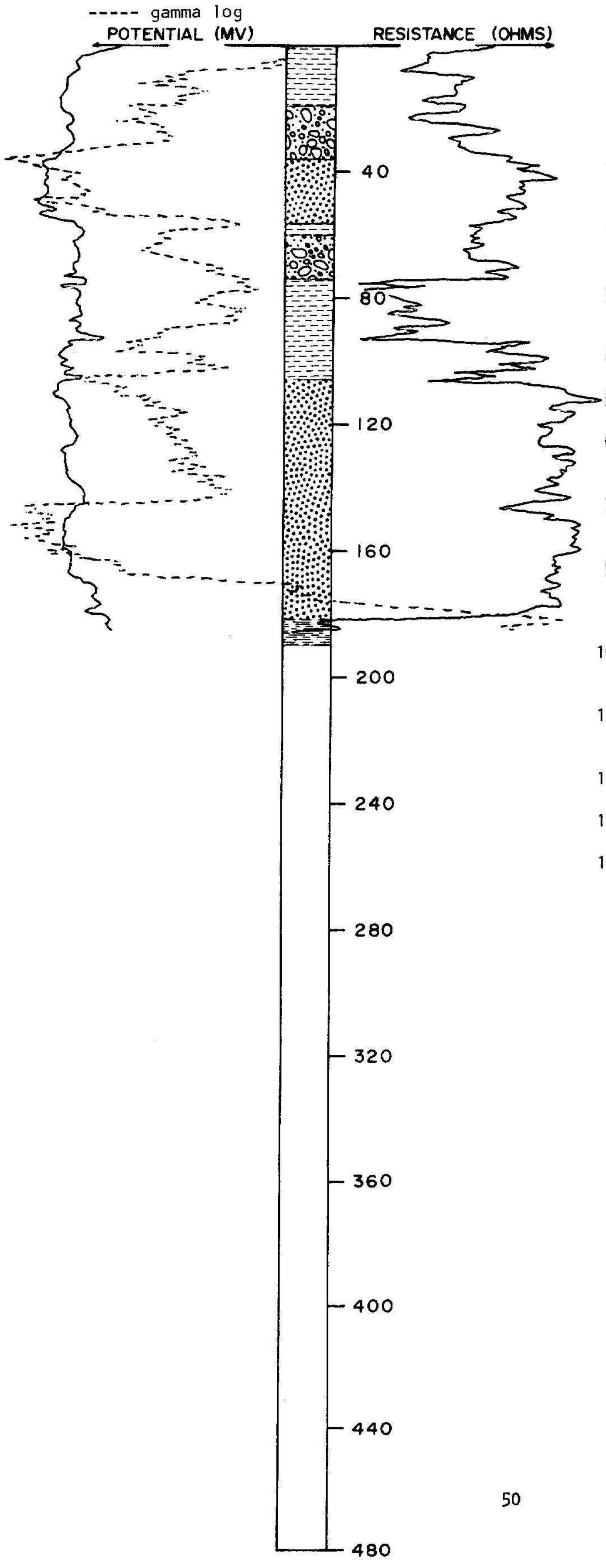
TEST HOLE 3771

LOCATION: 133-47-17add

DATE DRILLED: 8-20-69

ELEVATION: 957.3
(FT, MSL)

DEPTH: 190
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black clayey loam.
2-10	Clay, silty, yellowish-gray and dusky-yellow, soft, laminated.
10-19	Clay, as above; poorly-sorted iron-stained sand and fine gravel lenses.
19-36	Clay, silty and sandy, olive-gray; pebbles and cobbles; sand lenses (Till).
36-42	Sand, coarse and very coarse, moderately sorted, subangular; fine gravel.
42-56	Sand, as above; silty and sandy clay lenses.
56-60	Clay, dark-olive-gray, slightly hard, smooth, waxy.
60-74	Clay, silty, olive-gray, moderately soft; sand grains and pebbles (Till).
74-90	Clay, olive-gray to dark-olive-gray, crumbly to brittle, laminated.
90-106	Clay, as above; friable organic clayey sand, very fine to fine gray sand, and occasional fine gravel.
106-112	Sand, coarse and very coarse, moderately sorted, subangular; fine gravel.
112-146	Sand, as above; soft to moderately soft sandy clay lenses.
146-172	Sand, fine, light-gray, very well-sorted.
172-182	Sand, as above; clayey.

Cretaceous rocks

182-190	Shale, black, hard, stiff.

Observation well
Depth -- 155 feet
S.I. -- 149 to 155 feet
Water level -- 4.56 feet
Measured -- 9-24-69

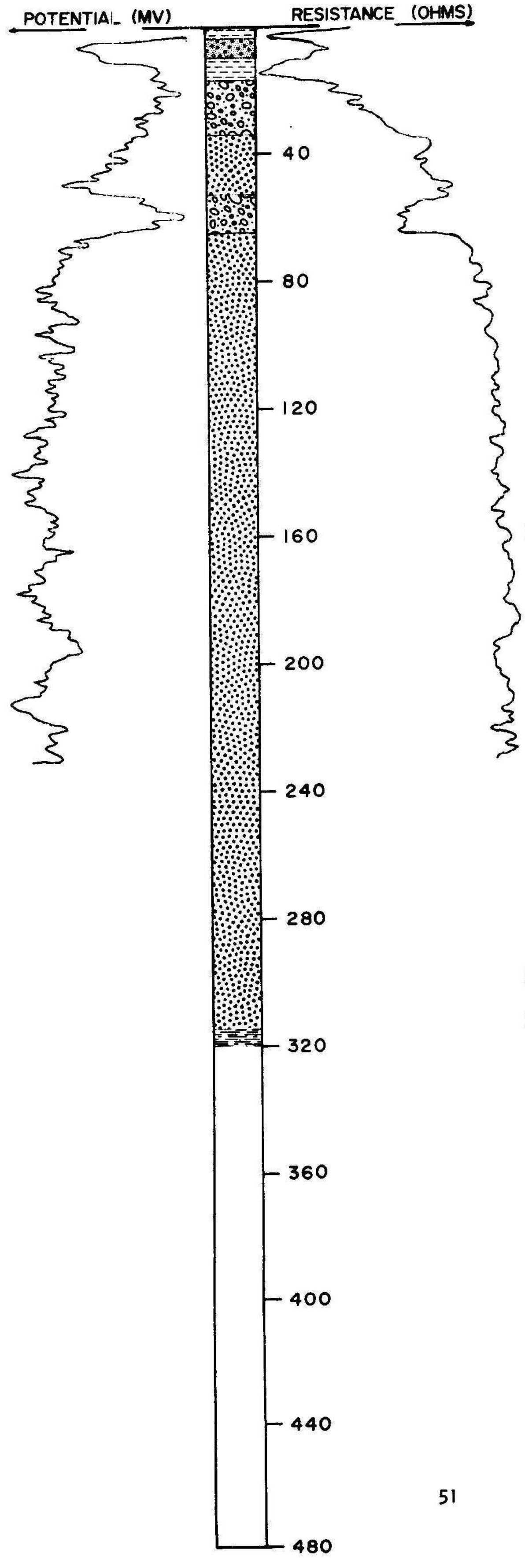
TEST HOLE 3960

LOCATION: 133-47-17ccc

ELEVATION: 958.7
(FT, MSL)

DATE DRILLED: 5-22-70

DEPTH: 320
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black pebbly silt loam.
2-4	Clay, yellow, soft, cohesive, plastic.
4-10	Silt, clayey, yellowish-gray, soft; occasional sand grain and pebble.
10-17	Clay, reddish-brown, soft to moderately soft, slightly plastic.
17-34	Clay, silty to pebbly, olive-gray, moderately soft; sand and gravel lenses (Till).
34-53	Sand, very fine, gray and brownish-black, soft, nonplastic; organic-rich clays and silts.
53-65	Clay, very sandy, olive-gray, moderately soft, compacted; occasional pebbles (Till).
65-80	Sand, very fine to fine, silty, gray, sorted, subrounded.
80-124	Sand, fine to medium, well-sorted, subangular to subrounded.
124-310	Sand, medium to coarse, well-sorted, subangular to subrounded.
310-315	Cobbles; boulders.

Cretaceous rocks

315-320	Siltstone, clayey, brownish-black, soft, noncalcareous; very fine-grained sandstone.

Observation well
Depth -- 121 feet
S.I. -- 118 to 121 feet
Water level -- 2.2 feet
Measured -- 2-8-71

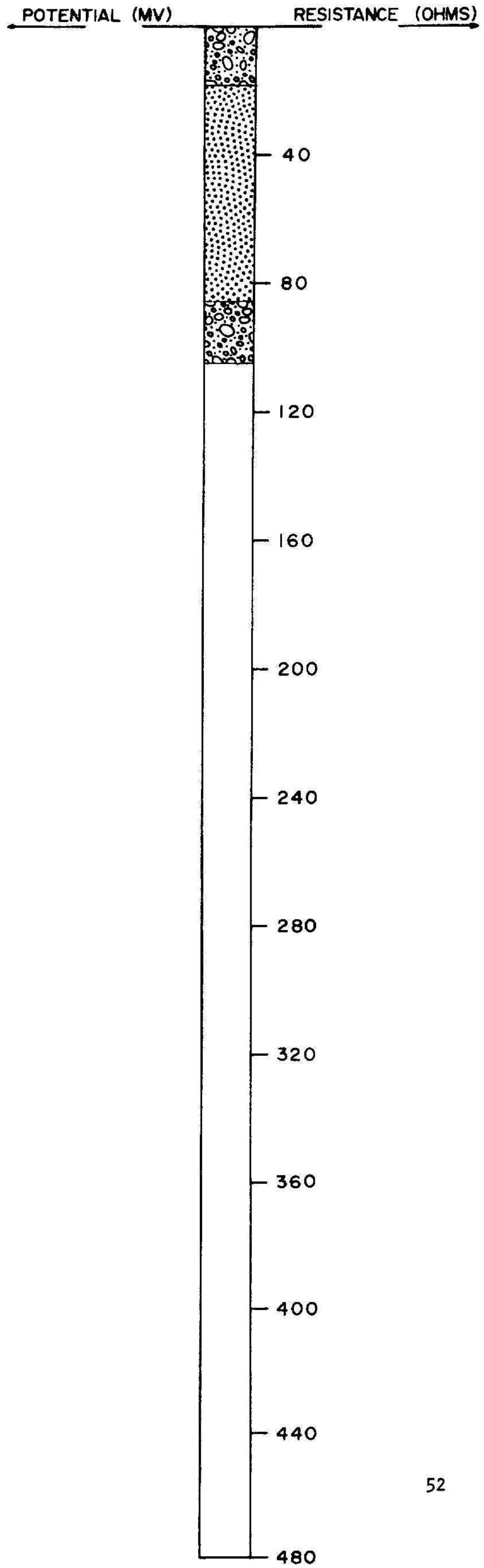
TEST HOLE 2313

LOCATION: 133-47-17ddd

ELEVATION: 964
(FT, MSL)

DATE DRILLED: 9-16-64

DEPTH: 105
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-18 Clay, silty to pebbly, dusky-yellowish-brown to grayish-orange, soft, cohesive (Till).

18-86 Sand, coarse to very coarse, poorly sorted, subangular to subrounded; dark-greenish-gray clay from 60 to 62 feet; fine gravel near base.

86-105 Clay, silty to pebbly, olive-gray, slightly hard, compact (Till).

Observation well
Depth -- 80 feet
S.I. -- 60 to 80 feet
Water level -- 19.57 feet
Measured -- 6-9-65

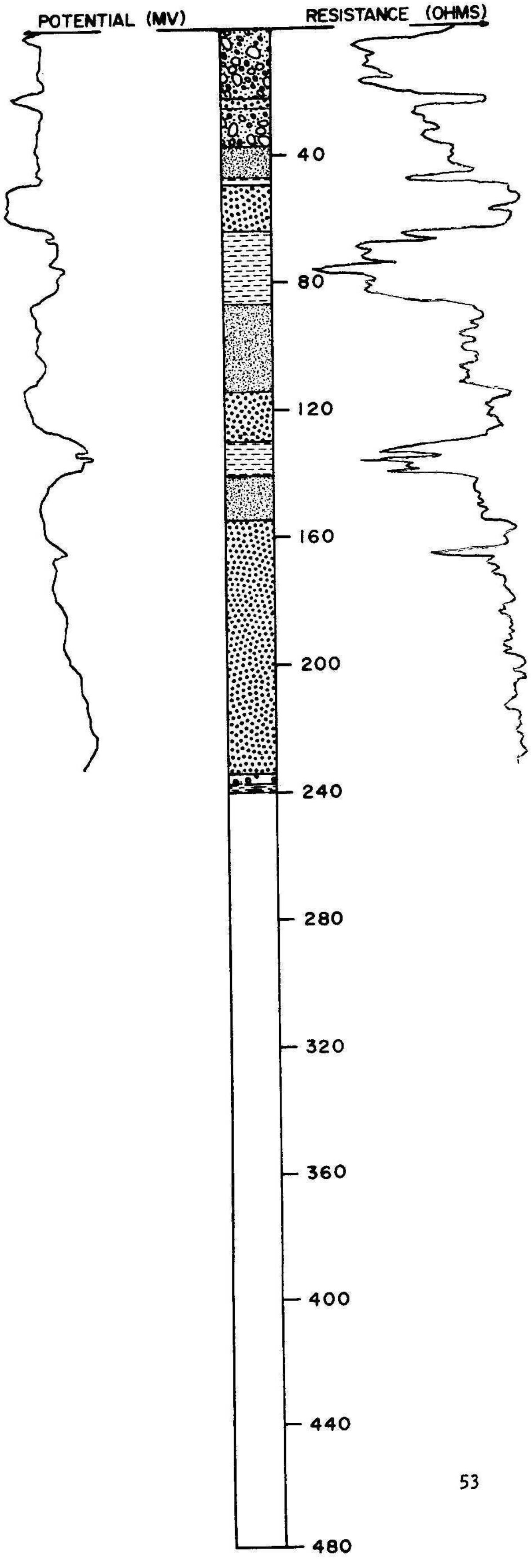
TEST HOLE 3786

LOCATION: 133-47-18ada

ELEVATION: 960.1
(FT, MSL)

DATE DRILLED: 9-3-69

DEPTH: 240
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1½	Topsoil; black sandy clay loam.
1½-4	Clay, silty to pebbly, yellowish-gray, soft, non- to slightly cohesive (Till).
4-17	Clay, silty to pebbly, moderate-olive-brown, soft to moderately soft (Till).
17-22	Clay, silty to pebbly, olive-gray, moderately soft, cohesive (Till).
22-25	Sand, medium, gray, well-sorted, subrounded.
25-37	Clay, silty to pebbly, olive-gray, moderately soft, cohesive (Till).
37-47	Silt, clayey, greenish-gray to light-olive-gray, soft, non-plastic.
47-49	Clay, dark-gray, soft, smooth, sticky.
49-64	Sand, medium to coarse, moderately well-sorted.
64-87	Clay, dark-brownish-gray, slightly hard, smooth, organic rich; light-colored soft silty clay.
87-114	Silt, clayey, light-olive-gray, soft, non- to slightly plastic, lenticular; very fine sand.
114-130	Sand, fine and medium, sorted, subangular and subrounded.
130-141	Clay, silty, medium- to dark-gray, moderately soft to slightly hard, laminated; brown stains.
141-155	Silt, clayey to sandy, light-olive-gray, soft, slightly cohesive, laminated, highly calcareous.
155-198	Sand, fine to medium, light-olive-gray, well-sorted; occasional clay layer.
198-234	Sand, medium and coarse, well-sorted, subangular to subrounded.
234-237	Gravel, coarse.
	Cretaceous rocks
237-240	Sandstone, very fine grained, dark-gray, indurated.

Observation well
Depth -- 225 feet
S.I. -- 219 to 225 feet
Water level -- 5.43 feet
Measured -- 9-24-69

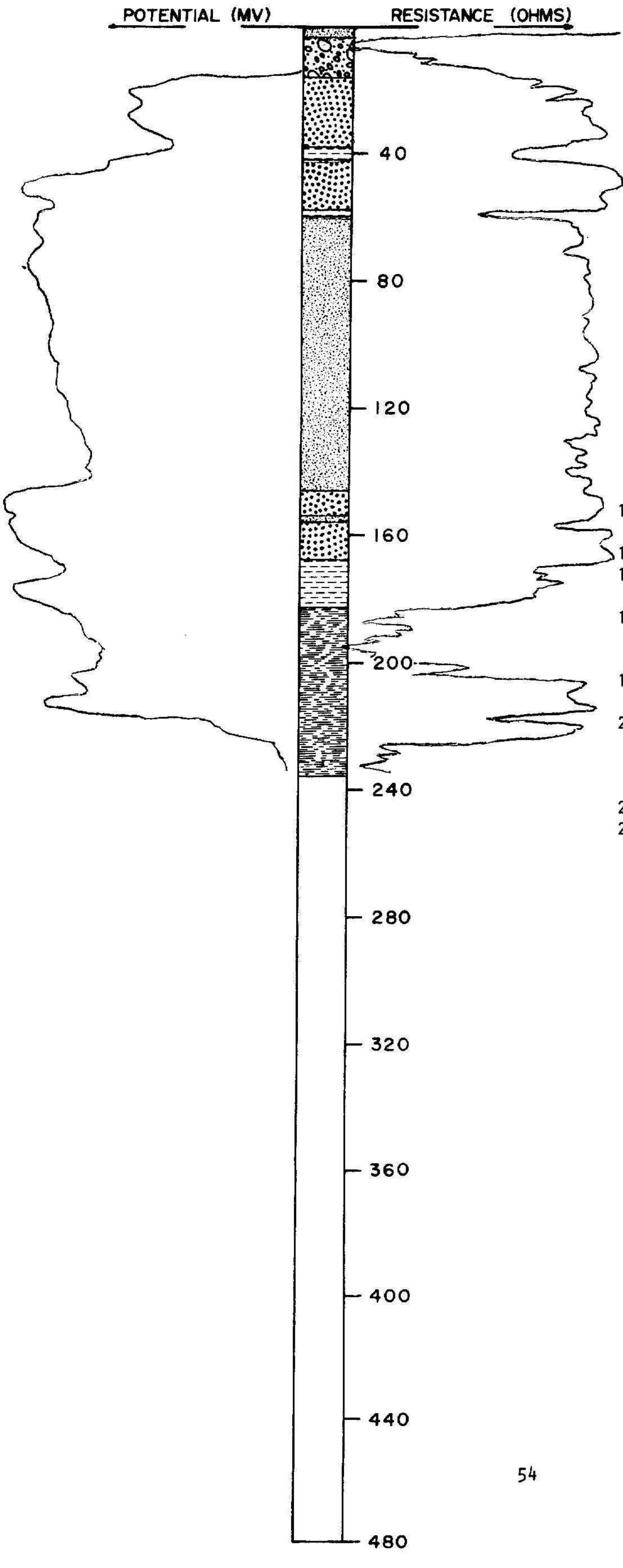
TEST HOLE 3956

LOCATION: 133-47-18bbb

ELEVATION: 955 (FT, MSL)

DATE DRILLED: 5-21-70

DEPTH: 236 (FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1	Topsoil; black pebbly silt loam.
1-3	Silt, clayey, yellowish-gray, soft, crumbly; occasional pebble.
3-16	Clay, silty, dusky-yellow, soft, nonplastic; sand grains and pebbles (Till).
16-38	Sand, medium to coarse, light-olive-gray, moderately well-sorted, subangular to subrounded.
38-42	Clay, greenish-gray to dark-greenish-gray, moderately soft to slightly hard, smooth.
42-58	Sand, medium to very coarse, sorted, subrounded, lenticular; fine gravel.
58-60	Clay, dark-gray, slightly hard, smooth.
60-146	Silt, clayey and sandy, light-olive-gray to olive-gray, soft to moderately soft, crumbly to moderately cohesive, lenticular.
146-154	Sand, very fine, silty, light-olive-gray.
154-156	Silt, olive-gray, soft, crumbly.
156-168	Sand, fine to medium, well-sorted, subrounded.
168-183	Clay, very silty, olive-gray, soft, slightly plastic.

Cretaceous rocks

183-204	Shale, black, hard, smooth, noncalcareous.
204-225	Sandstone, very fine grained, silty to slightly clayey, light-gray to light-green, soft, micaceous.
225-235	Shale, black, hard.
235-236	Sandstone, very fine grained, dark-gray, indurated.

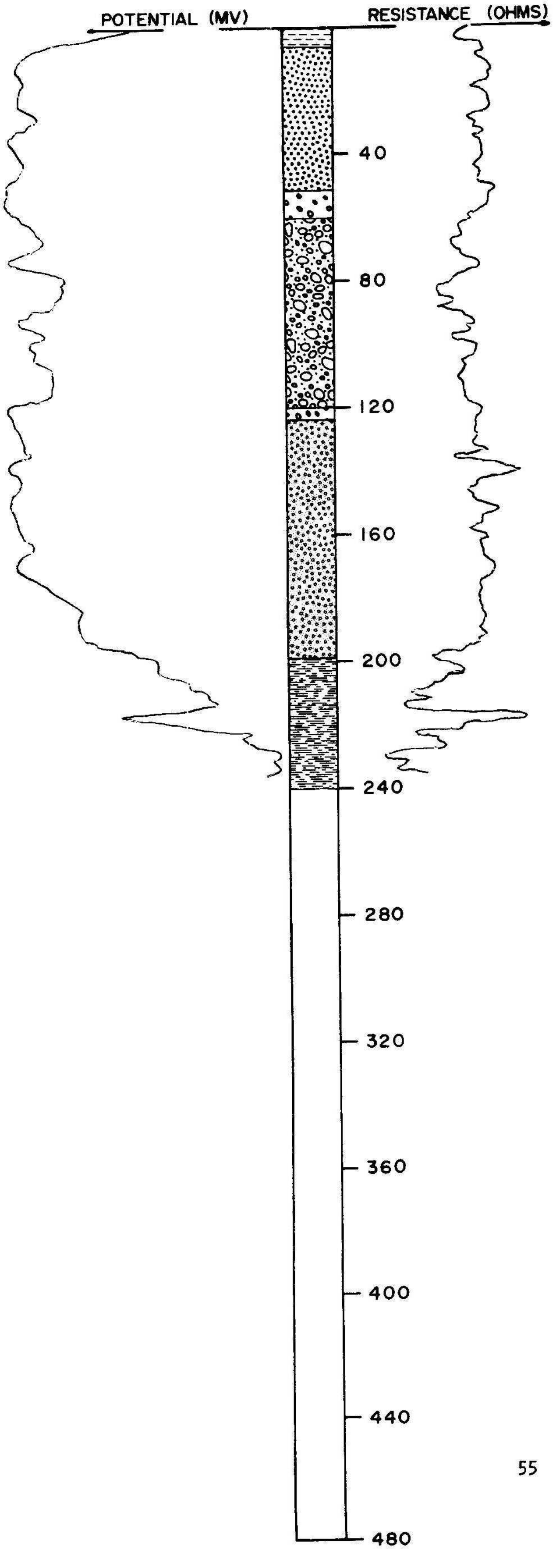
TEST HOLE 3784

LOCATION: 133-47-19daa

ELEVATION: 960.2
(FT, MSL)

DATE DRILLED: 8-29-69

DEPTH: 240
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black sandy clay loam.
2-6	Clay, sandy, yellowish-gray to dusky-yellow, soft, non- to slightly cohesive; occasional pebble or cobble.
6-51	Sand, medium to coarse, well-sorted, subangular to subrounded.
51-60	Gravel, fine and medium, subrounded.
60-120	Clay, silty and sandy, olive-gray to dark-olive-gray, moderately soft to slightly hard; pebbles, cobbles and occasional boulders; smooth brownish-black clay, soft light-brownish-gray silt, and clayey very fine to fine sand (Till).
120-124	Boulders; cobbles.
124-199	Sand, very fine and fine, clayey, light-olive-gray, slightly hard, crumbly; occasional pebbles, cobbles, and boulders (Till).

Cretaceous rocks

199-202	Shale, silty, brownish-black, slightly hard.
202-207	Sandstone, fine, clayey, dark-brownish-green, moderately soft, calcareous.
207-217	Shale, brownish-black, hard, noncalcareous.
217-221	Sandstone, very fine, dark-gray, indurated, highly calcareous.
221-229	Siltstone, shaly, brownish-black, soft, slightly calcareous.
229-240	Shale, brownish-black, hard, carbonaceous.

Observation well
Depth -- 49 feet
S.I. -- 46 to 49 feet
Water level -- 9.42 feet
Measured -- 9-24-69

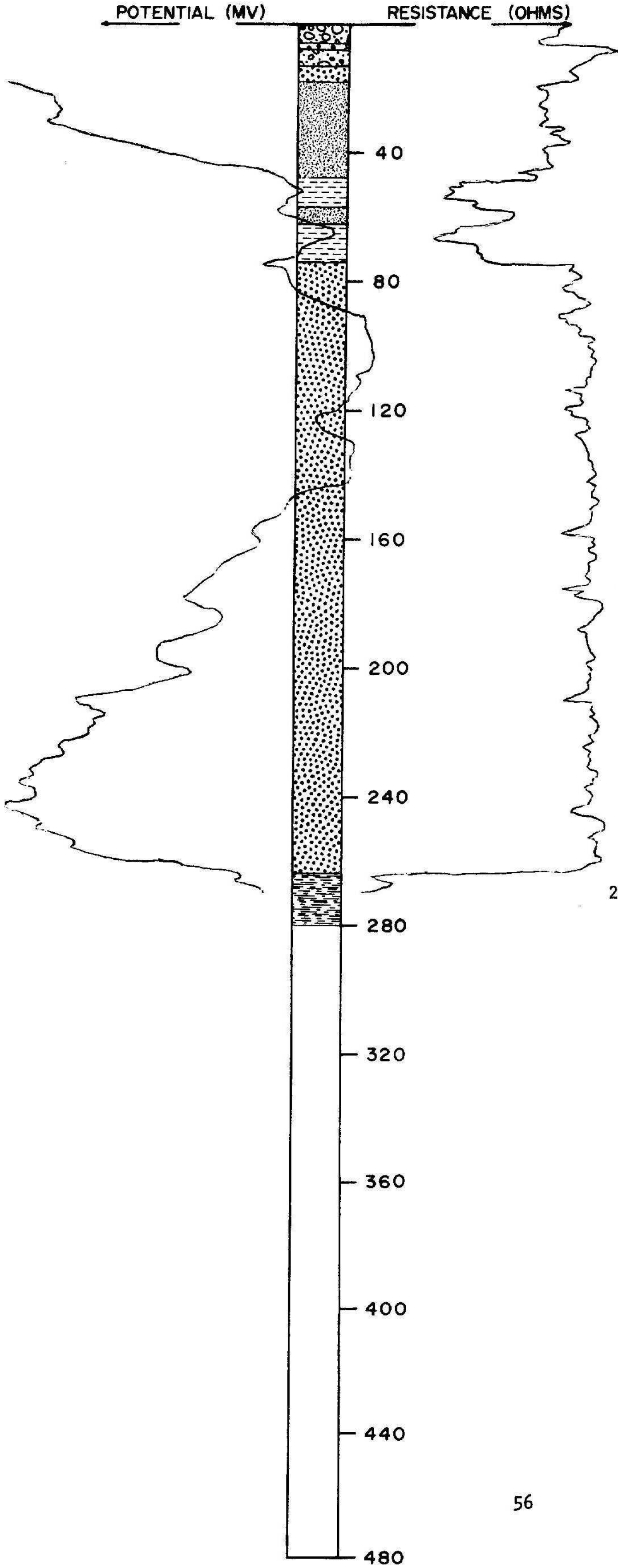
TEST HOLE 3785

LOCATION: 133-47-20abb

DATE DRILLED: 9-2-69

ELEVATION: 964.7
(FT, MSL)

DEPTH: 280
(FT)



DESCRIPTION OF DEPOSITS

	Glacial drift
0-2	Topsoil; black rocky clay loam.
2-6	Clay, silty to pebbly, yellowish-gray, soft, slightly cohesive (Till).
6-8	Gravel, fine and medium, brown, angular to subrounded.
8-13	Clay, silty to pebbly, yellowish-gray to moderate-olive-brown, soft, slightly cohesive; medium to coarse iron-stained sand lenses (Till).
13-18	Sand, medium to coarse, tan, well-sorted, subangular.
18-48	Silt, clayey, gray to brownish-black, soft, slightly cohesive, laminated; very fine sand lenses; occasional coarse sand grain or pebble.
48-57	Clay, very silty, light-olive-gray, moderately hard.
57-62	Silt, light-gray, soft, slightly cohesive.
62-74	Clay, silty to sandy, dark-olive-gray to dark-brownish-gray, slightly hard.
74-264	Sand, very fine, well-sorted, subrounded; progressively coarser with depth; very coarse in lower 20 feet.
	Cretaceous rocks
264-280	Shale, brownish-black, hard, smooth, waxy.

Observation well
Depth -- 185 feet
S.I. -- 179 to 185 feet
Water level -- 7.94 feet
Measured -- 9-24-69

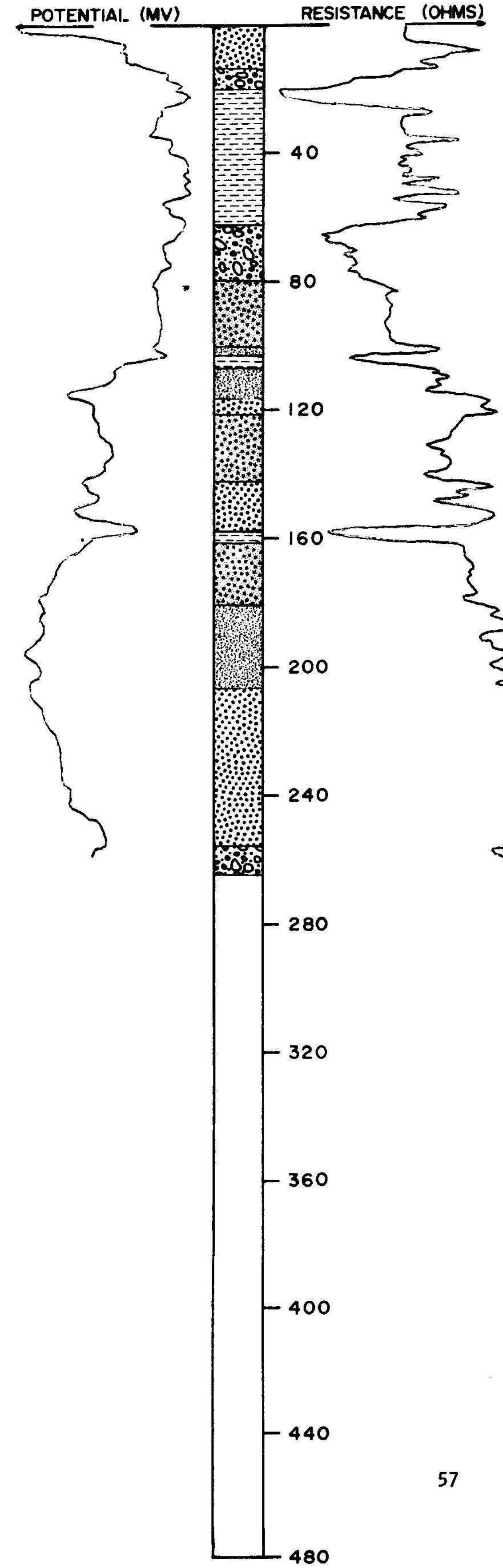
TEST HOLE 3783

LOCATION: 133-47-20acc

ELEVATION: 968.4
(FT, MSL)

DATE DRILLED: 8-28-69

DEPTH: 265
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black pebbly sand loam.
2-6	Sand, fine, clayey, yellowish-gray, loose.
6-14	Sand, medium and coarse, brown, poorly sorted, subangular to subrounded; fine gravel.
14-20	Clay, silty to pebbly, moderate-olive-brown to light-olive-gray, soft to moderately soft (Till).
20-26	Clay, olive-gray to dark-olive-gray, moderately soft, smooth, sticky.
26-62	Clay, silty and sandy, gray and green to brownish-black, soft, slightly cohesive, lenticular.
62-80	Clay, silty, dark-brownish-gray, slightly hard; sand grains, pebbles, and cobbles (Till).
80-100	Clay, very sandy, light-olive-gray, moderately soft, slightly cohesive; occasional pebbles (Till).
100-103	Silt, light-olive-gray, soft, crumbly.
103-107	Clay, olive-gray to dark-olive-gray, moderately soft, smooth.
107-116	Silt, clayey, light-olive-gray, soft, nonplastic.
116-121	Sand, medium, light-gray, sorted, subrounded.
121-142	Clay, very sandy, light-olive-gray to olive-gray, crumbly; occasional pebbles (Till).
142-158	Sand, fine and medium, light-gray, well-sorted, subrounded; sandy till lenses.
158-161	Clay, black, moderately soft, crumbly.
161-181	Silt, clayey to sandy, light-olive-gray to olive-gray, soft, crumbly; pebbles and cobbles (Till).
181-207	Silt, light-gray, compacted; very fine and fine sand lenses.
207-256	Sand, fine and medium, light-gray, well sorted.
256-264	Clay, rocky (Till).
264-265	Boulder; very hard black and white diorite.

Observation well
Depth -- 244 feet
S.I. -- 238-244 feet
Water level -- 11.62 feet
Measured -- 9-24-69

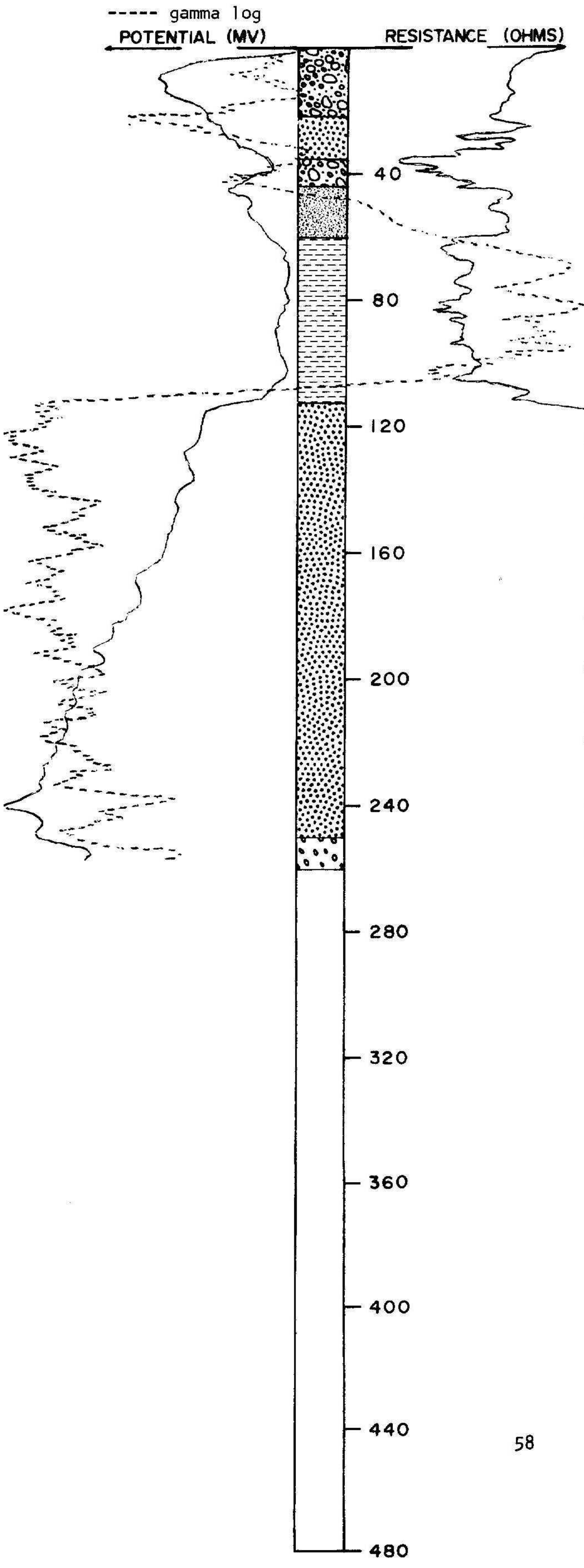
TEST HOLE 3790

LOCATION: 133-47-20adb

DATE DRILLED: 9-4-69

ELEVATION: 971.9
(FT, MSL)

DEPTH: 260
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black cobbly loam.
2-5	Clay, silty and sandy, yellowish-gray, soft, slightly cohesive; pebbles, cobbles, and boulders (Till).
5-16	Clay, silty to sandy, moderate-olive-brown, moderately soft, cohesive; pebbles and cobbles (Till).
16-22	Clay, silty to pebbly, olive-gray, moderately soft to slightly hard (Till).
22-35	Sand, medium to coarse, tan, sorted, subangular; sandy and pebbly till lenses.
35-44	Clay, silty to pebbly, olive-gray; sand and clay lenses (Till).
44-60	Silt, clayey to sandy, greenish-gray, soft, slightly cohesive.
60-104	Clay, dark-gray, smooth, stiff, laminated; light-gray highly calcareous silty clay and dark-olive-gray silty to pebbly till.
104-113	Clay, silty to very sandy, dark-gray to light-gray.
113-250	Sand, fine to medium, well-sorted; progressively coarser with depth.
250-260	Gravel, fine and medium.

Observation well
Depth -- 260 feet
S.I. -- 254 to 260 feet
Water level -- 14.51 feet
Measured -- 9-24-69

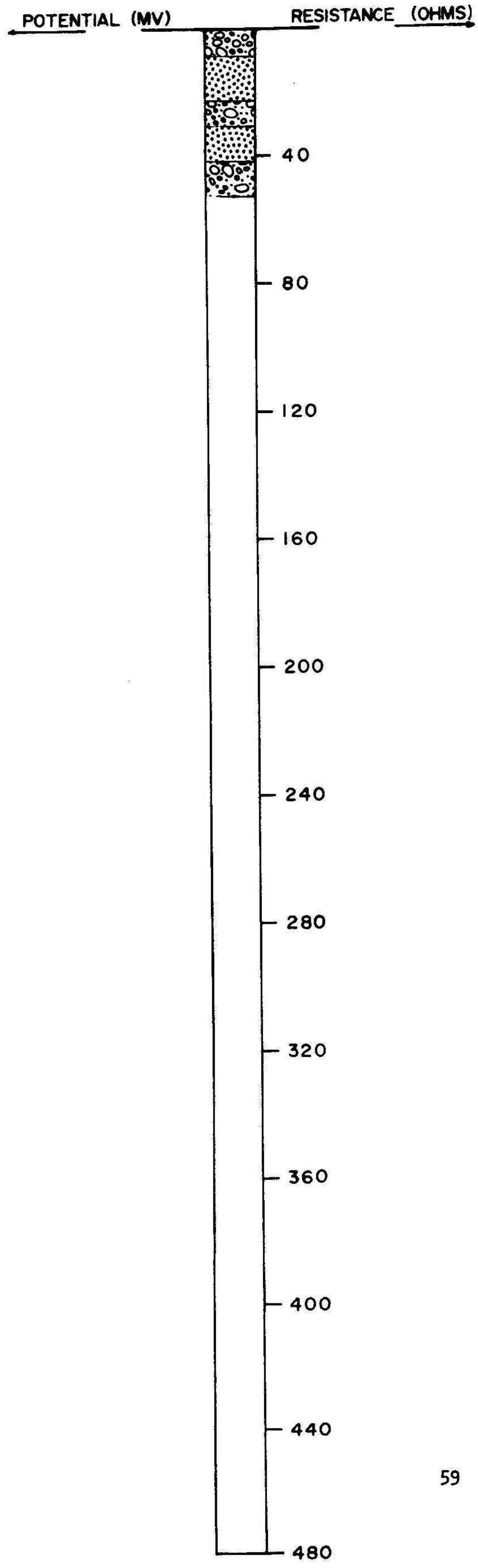
TEST HOLE 2315

LOCATION: 133-47-20bba

DATE DRILLED: 9-17-64

ELEVATION: 966
(FT, MSL)

DEPTH: 53
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-9 Clay, silty to pebbly, soft, cohesive (Till).

9-23 Sand, fine to coarse, olive-gray, lenticular.

23-31 Clay, silty to pebbly, olive-gray, moderately hard (Till).

31-42 Sand, medium to coarse, gray.

42-53 Clay, silty to very pebbly, olive-gray, hard, cohesive (Till).

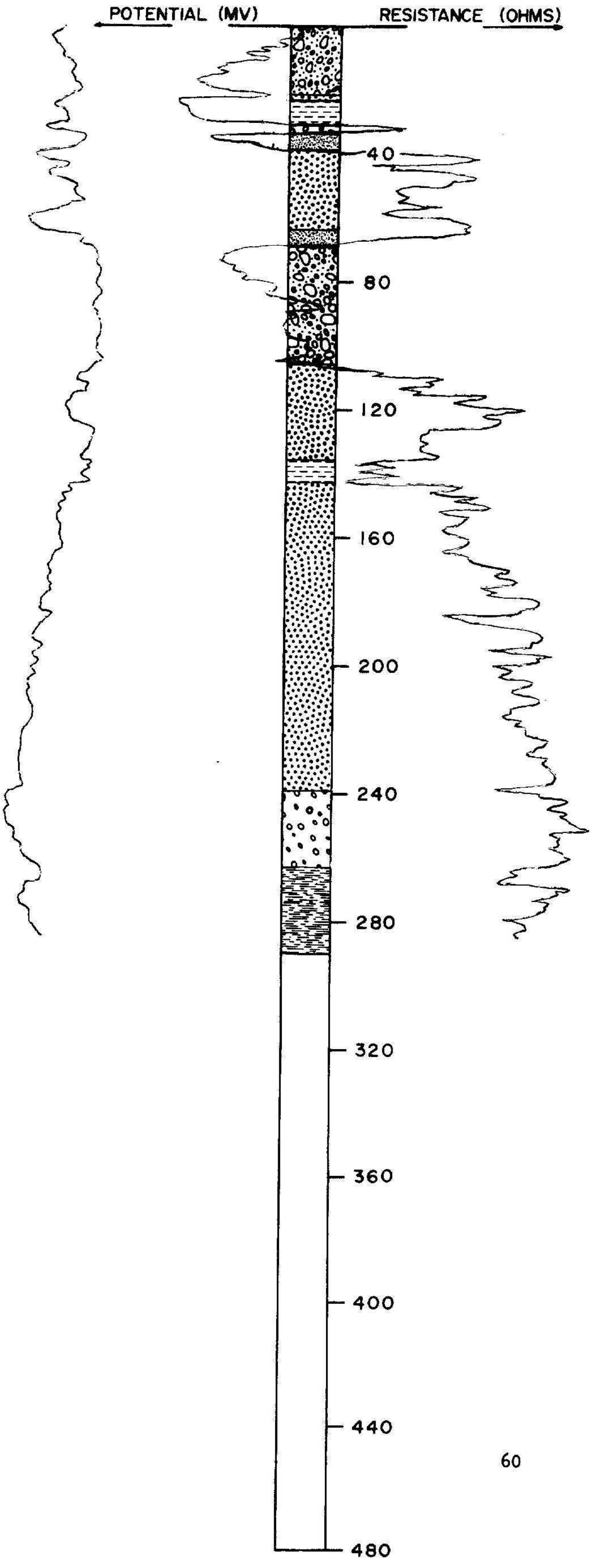
TEST HOLE 3779

LOCATION: 133-47-20ddd

DATE DRILLED: 8-26-69

ELEVATION: 966.7
(FT, MSL)

DEPTH: 290
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black pebbly clay loam.
2-6	Clay, very sandy to pebbly, yellowish-gray, soft (Till).
6-16	Clay, silty to pebbly, yellowish-gray to moderate-olive-brown, moderately soft, cohesive, iron stained (Till).
16-21	Clay, sandy to pebbly, olive-gray, moderately soft, cohesive (Till).
21-23	Sand, fine, gray, well-sorted.
23-31	Clay, olive-gray to dark-brownish-gray, moderately soft to slightly hard.
31-34	Gravel, fine, moderately sorted, subrounded; coarse sand.
34-39	Silt, clayey, light-gray, slightly crumbly.
39-59	Sand, very fine to medium, light-gray; silt and clay lenses.
59-64	Sand, medium, gray, well-sorted, subrounded.
64-69	Silt, clayey, light-olive-gray, crumbly.
69-86	Clay, silty to sandy, olive-gray, moderately soft; pebbles and cobbles (Till).
86-106	Till, as above; very fine to medium sand and fine gravel lenses.
106-114	Sand, fine, gray; light-gray highly-calcareous silt and dark-gray silty clay lenses.
114-125	Sand, medium, light-gray, well-sorted, subrounded.
125-136	Sand, fine, silty.
136-143	Clay, silty, light-gray to olive-gray, laminated.
143-168	Sand, fine, light-gray, well-sorted.
168-239	Sand, medium to coarse, sorted.
239-263	Gravel, fine to medium, subangular to subrounded; sand and cobbles.

Cretaceous rocks

263-268	Shale, silty, dark-brownish-gray, moderately soft, crumbly, carbonaceous.
268-278	Siltstone, sandy, brownish-black, slightly friable, noncalcareous.
278-290	Shale, dark-brown, smooth, crumbly, oily.

Observation well
Depth -- 255 feet
S.I. -- 249-255 feet
Water level -- 8.04 feet
Measured -- 9-24-69

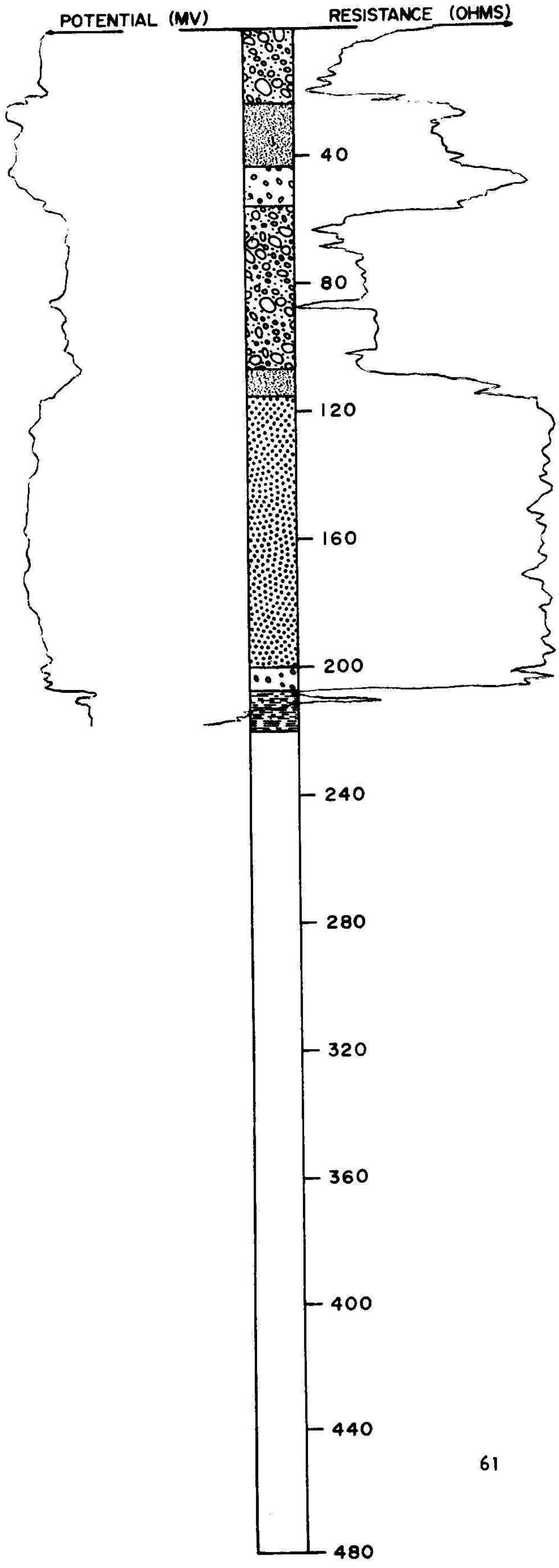
TEST HOLE 3778

LOCATION: 133-47-21bcb

DATE DRILLED: 8-26-69

ELEVATION: 967.1 (FT, MSL)

DEPTH: 220 (FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2 Topsoil; black pebbly clay loam.

2-16 Clay, silty to sandy, yellowish-gray to moderate-olive-brown, soft to moderately soft, iron stained; pebbles and cobbles (Till).

16-24 Clay, silty to sandy, olive-gray, moderately soft; pebbles; gravel lenses (Till).

24-44 Silt, sandy, gray, slightly cohesive, lenticular.

44-56 Gravel, fine to medium, sorted, subangular to subrounded.

56-107 Clay, silty and very sandy, olive-gray, moderately soft to slightly hard; pebbles and cobbles; dark smooth clay, light-gray crumbly silt, fine to medium sand, and occasional gravel lenses (Till).

107-116 Silt, sandy, slightly clayey, light-gray to light-olive-gray, slightly cohesive.

116-200 Sand, medium to coarse, well-sorted, subangular to subrounded.

200-207 Gravel, fine and medium; cobbles.

Cretaceous rocks

207-209 Siltstone, clayey, brownish-gray, moderately soft.

209-211 Sandstone, medium, white; limey clay matrix.

211-220 Shale, black, hard, waxy.

Observation well
Depth -- 195 feet
S.I. -- 189 to 195 feet
Water level -- 9.72 feet
Measured -- 9-24-69

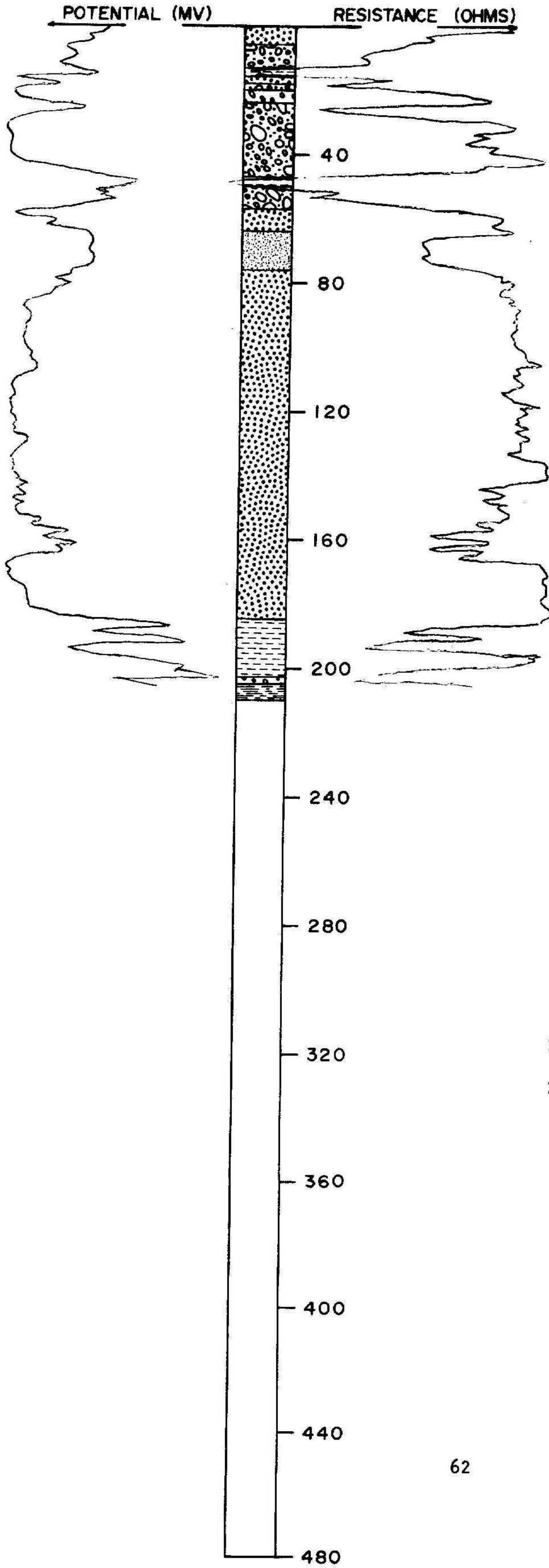
TEST HOLE 3777

LOCATION: 133-47-21bda

DATE DRILLED: 8-5-69

ELEVATION: 960
(FT, MSL)

DEPTH: 210
(FT)



DESCRIPTION OF DEPOSITS

	Glacial drift
0-2	Topsoil; black sandy loam.
2-6	Sand, clayey, yellowish-gray, soft.
6-13	Clay, silty and sandy, yellowish-gray to moderate-olive-brown, moderately soft; pebbles and cobbles (Till).
13-16	Clay, olive-gray, soft, smooth, sticky.
16-18	Sand, fine, light-olive-gray, subrounded.
18-20	Clay, very sandy to pebbly, olive-gray, moderately soft (Till).
20-24	Gravel, fine, well-sorted, subangular to subrounded.
24-28	Clay, very sandy to pebbly, olive-gray, moderately soft (Till).
28-47	Till, as above; medium to very coarse sand and fine gravel lenses; cobbles.
47-50	Clay, dark-gray, moderately soft, cohesive, smooth; light-gray limey mottling.
50-57	Clay, silty to pebbly, olive-gray, cohesive (Till).
57-64	Sand, medium, light-olive-gray, well-sorted.
64-76	Silt, clayey to sandy, light-olive-gray to olive-gray, soft, slightly cohesive, lenticular.
76-134	Sand, fine to coarse, lenticular; fine gravel; light-olive-gray very sandy to cobbly till.
134-141	Sand, medium, light-gray, well-sorted, subrounded.
141-155	Sand, fine to medium; pebbly clay till and clayey sand lenses.
155-165	Sand, as above; dark-gray clay and olive-gray silty clay lenses.
165-185	Sand, medium to coarse, well-sorted.
185-203	Clay, dark-gray, moderately soft, cohesive, smooth; silt, fine to coarse sand, and gravel lenses.
203-205	Boulder.
	Cretaceous rocks
205-210	Shale, black, hard, noncalcareous.

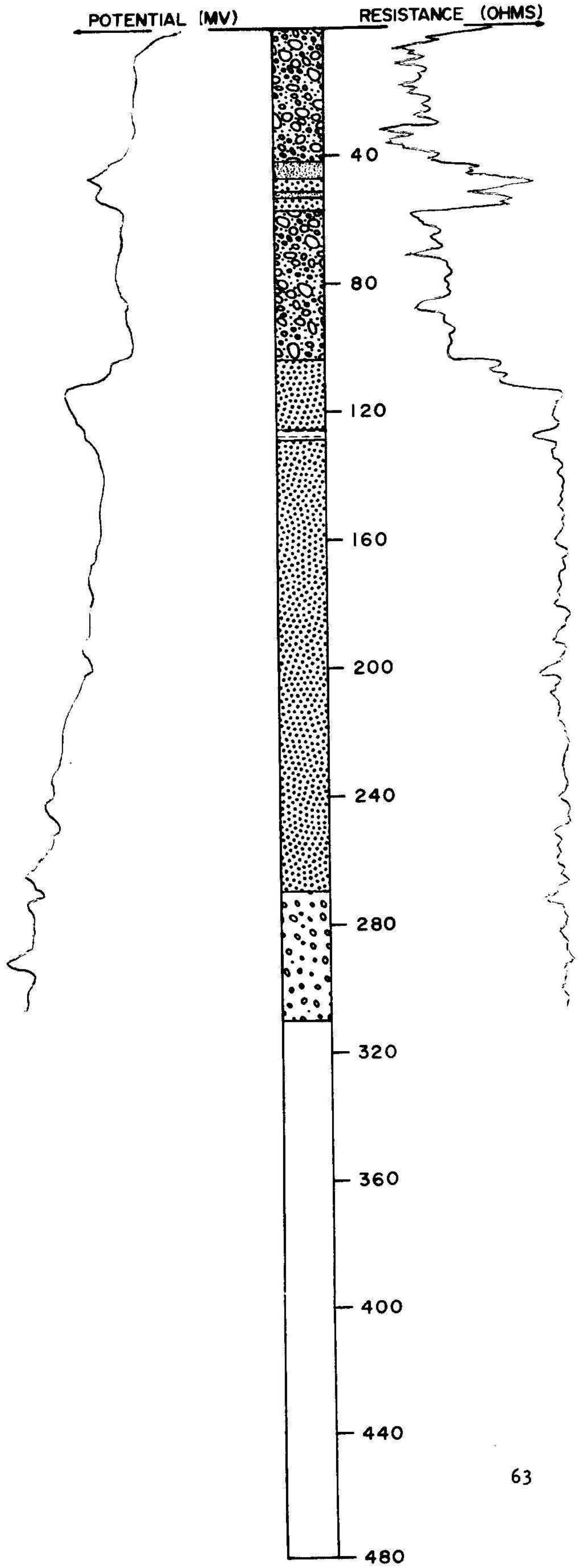
TEST HOLE 3787

LOCATION: 133-47-21cbb1

ELEVATION: 968.2
(FT, MSL)

DATE DRILLED: 9-3-69

DEPTH: 310
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black cobbly loam.
2-5	Clay, sandy, yellowish-gray, soft, slightly cohesive; pebbles and cobbles (Till).
5-17	Clay, silty and sandy, moderate-olive-brown, moderately soft, cohesive; pebbles and cobbles (Till).
17-42	Clay, silty to sandy, olive-gray, moderately soft, cohesive; pebbles and cobbles (Till).
42-47	Silt, clayey to sandy, greenish-gray, soft.
47-51	Sand, medium, well-sorted, subangular.
51-53	Silt, clayey, brownish-gray, soft, slightly cohesive; very fine sand lenses.
53-57	Sand, fine, gray, sorted, subangular to subrounded.
57-104	Clay, silty, olive-gray to dark-olive-gray, moderately soft to slightly hard, stiff; sand grains, pebbles, and cobbles; smooth dark-gray stiff clay lenses (Till).
104-113	Sand, very fine, clayey and silty, light-olive-gray, slightly cohesive, laminated.
113-126	Sand, medium and coarse, tan, well-sorted.
126-129	Clay, sandy, olive-gray, soft, cohesive.
129-160	Sand, medium, tan.
160-220	Sand, coarse, tan, well-sorted.
220-270	Sand, very coarse, tan, well-sorted.
270-310	Gravel, fine, well-sorted.

Observation well
Depth -- 260 feet
S.I. -- 257-260 feet
Water level -- 10.35 feet
Measured -- 9-24-69

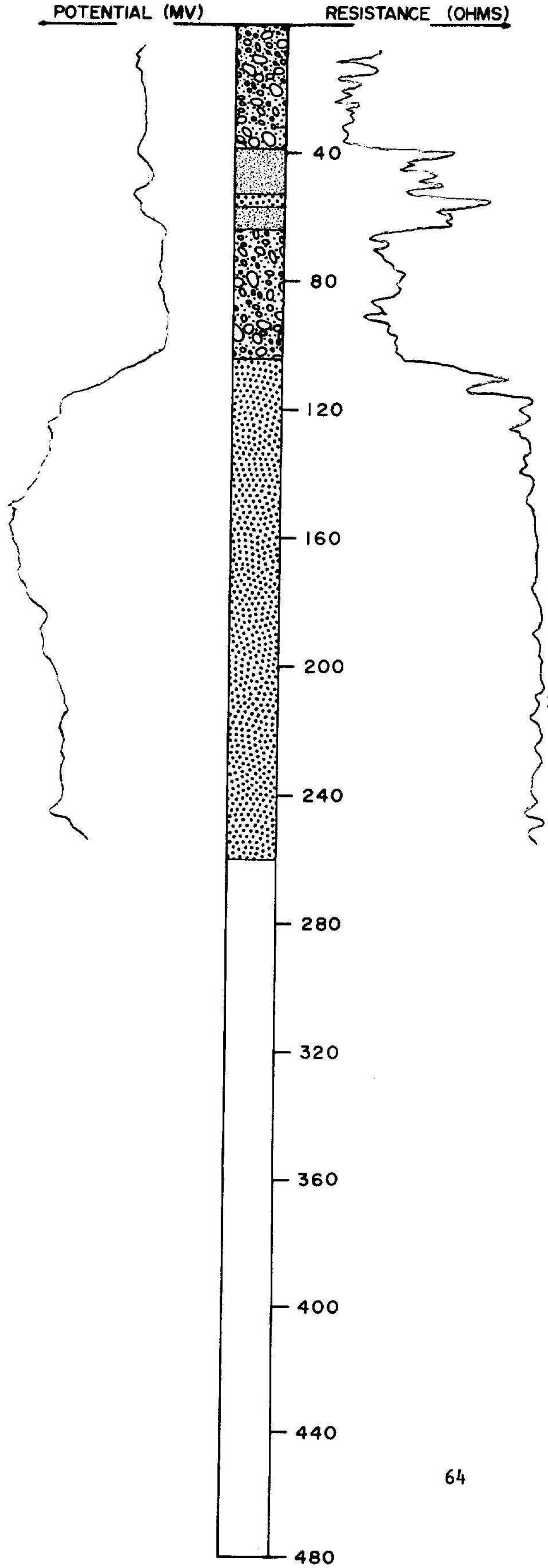
TEST HOLE 3788

LOCATION: 133-47-21cbb2

DATE DRILLED: 9-4-69

ELEVATION: 966.8 (FT, MSL)

DEPTH: 260 (FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black pebbly loam.
2-5	Clay, silty to pebbly, yellowish-gray, soft, slightly cohesive (Till).
5-25	Clay, silty to sandy, moderate-olive-brown, moderately soft, cohesive; pebbles and cobbles (Till).
25-39	Clay, silty to sandy, olive-gray, moderately soft, stiff; pebbles and cobbles (Till).
39-53	Silt, clayey to sandy, greenish-gray to olive-gray, soft, non- to slightly plastic, lenticular.
53-57	Sand, medium to coarse, sorted, subangular.
57-64	Silt, clayey, olive-gray to dark-brownish-gray, soft.
64-105	Clay, silty, olive-gray to dark-olive-gray, stiff; sand grains, pebbles, and cobbles; dark-gray clay layers (Till).
105-116	Sand, clayey to silty, light-gray to medium-gray, loose to slightly cohesive, lenticular.
116-140	Sand, fine, well-sorted.
140-180	Sand, medium, well-sorted.
180-220	Sand, coarse, well-sorted.
220-260	Sand, very coarse, well-sorted.

Observation well
Depth -- 251 feet
S.I. -- 248 to 251 feet
Water level -- 8.79 feet
Measured -- 9-24-69

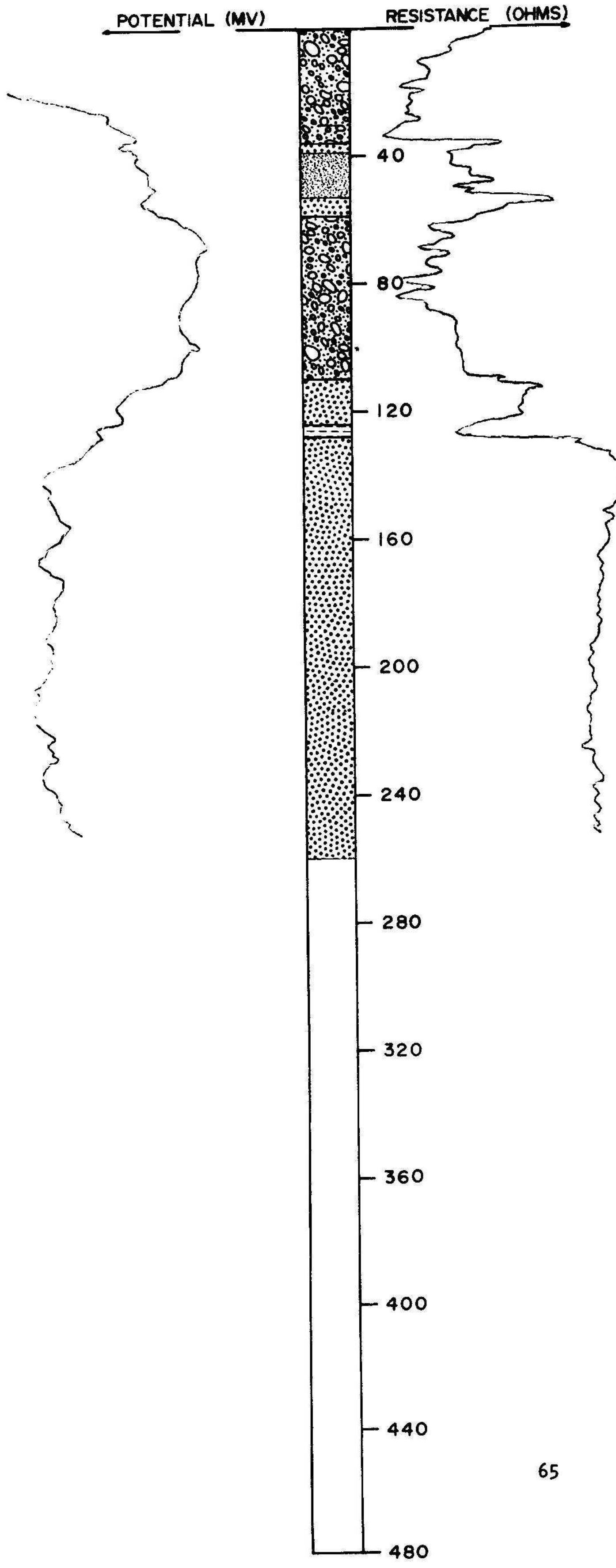
TEST HOLE 3789

LOCATION: 133-47-21cbd

ELEVATION: 964.4
(FT, MSL)

DATE DRILLED: 9-4-69

DEPTH: 260
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black pebbly loam.
2-5	Clay, silty to sandy, yellowish-gray, soft, slightly cohesive (Till).
5-26	Clay, silty, moderate-olive-brown, moderately soft, cohesive; sand grains and pebbles (Till).
26-36	Clay, silty, olive-gray, cohesive, stiff; sand grains, pebbles, and cobbles (Till).
36-39	Sand, medium to coarse, sorted, subangular.
39-53	Silt, clayey to sandy, greenish-gray, soft, slightly cohesive, lenticular.
53-59	Sand, medium to very coarse, moderately sorted, subangular to subrounded; fine gravel.
59-90	Clay, silty, olive-gray, cohesive, stiff; sand grains, numerous pebbles, and occasional cobbles; smooth dark-brownish-gray clay layers (Till).
90-110	Clay, silty and sandy, dark-olive-gray, slightly hard; pebbles and cobbles (Till).
110-124	Sand, very fine and fine, light-olive-gray, loose to slightly cohesive.
124-128	Clay, olive-gray, soft, plastic, smooth.
128-230	Sand, fine and medium, tan, well-sorted.
230-260	Sand, medium to coarse, well-sorted.

Observation well
Depth -- 261 feet
S.I. -- 258 to 261 feet
Water level -- 6.09 feet
Measured -- 9-24-69

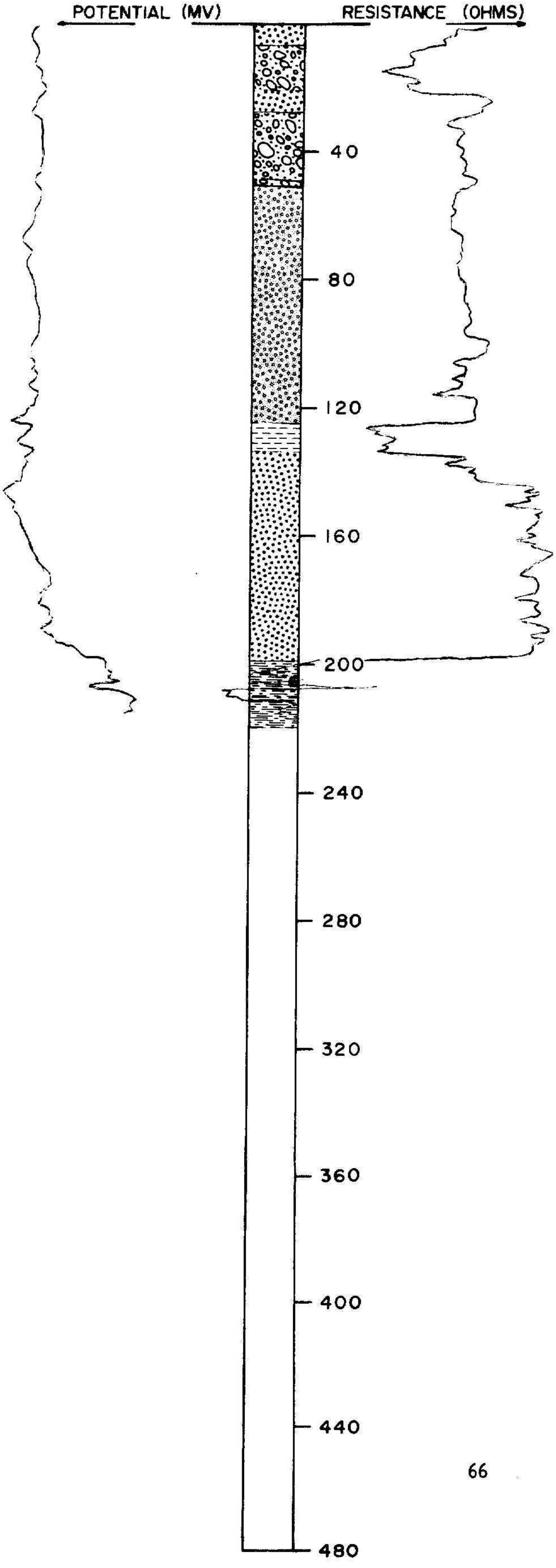
TEST HOLE 3782

LOCATION: 133-47-28abb

DATE DRILLED: 8-28-69

ELEVATION: 952.7
(FT, MSL)

DEPTH: 220
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-3	Topsoil; black very fine sand.
3-7	Sand, very fine to fine, clayey, yellowish-gray, loose.
7-13	Clay, silty to sandy, yellowish-gray and moderate-olive-brown, soft, cohesive; pebbles and cobbles (Till).
13-21	Clay, silty to pebbly, light-olive-gray to olive-gray, soft, cohesive (Till).
21-28	Sand, medium to coarse, light-gray, well-sorted.
28-51	Clay, silty and sandy, olive-gray, moderately soft; pebbles and cobbles; silt and very fine to coarse sand lenses (Till).
51-97	Sand, very fine, clayey and silty, light-olive-gray, compacted; pebbles and occasional cobbles (Till).
97-125	Till, sandy, as above; clay, silt, sand, and gravel lenses.
125-134	Clay, light-gray to olive-gray, moderately soft, laminated.
134-144	Sand, very fine to fine, silty, light-gray, lenticular.
144-199	Sand, fine to coarse, sorted, lenticular.

Cretaceous rocks

199-220	Shale, black, hard, noncalcareous, fossiliferous; sandy lenses.

Observation well
Depth -- 181 feet
S.I. -- 178 to 181 feet
Water level -- +6.51 feet (flow)
Measured -- 9-24-69

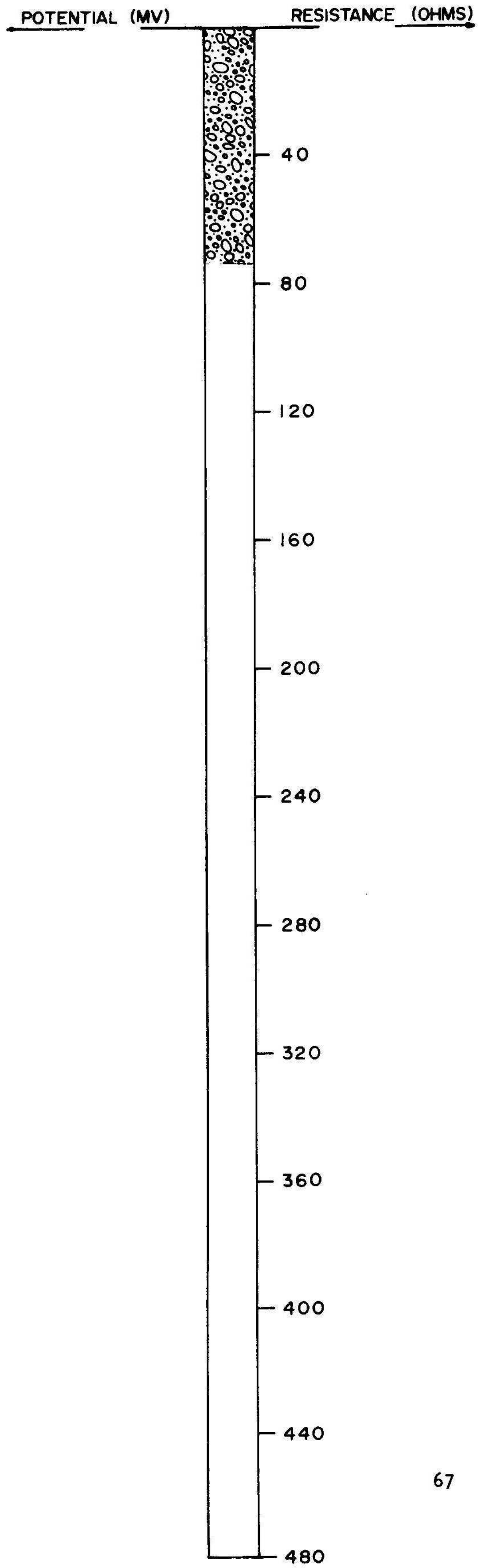
TEST HOLE 2314

LOCATION: 133-47-28bbb

ELEVATION: 967
(FT, MSL)

DATE DRILLED: 9-16-64

DEPTH: 74
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-14 Clay, silty to sandy, grayish-orange to light-brown, firm; pebbles and cobbles (Till).

14-74 Clay, silty to sandy, dark-greenish-gray to olive-gray, compact; pebbles and cobbles; coarse sand lenses from 38 to 40 and 59 to 64 feet (Till).

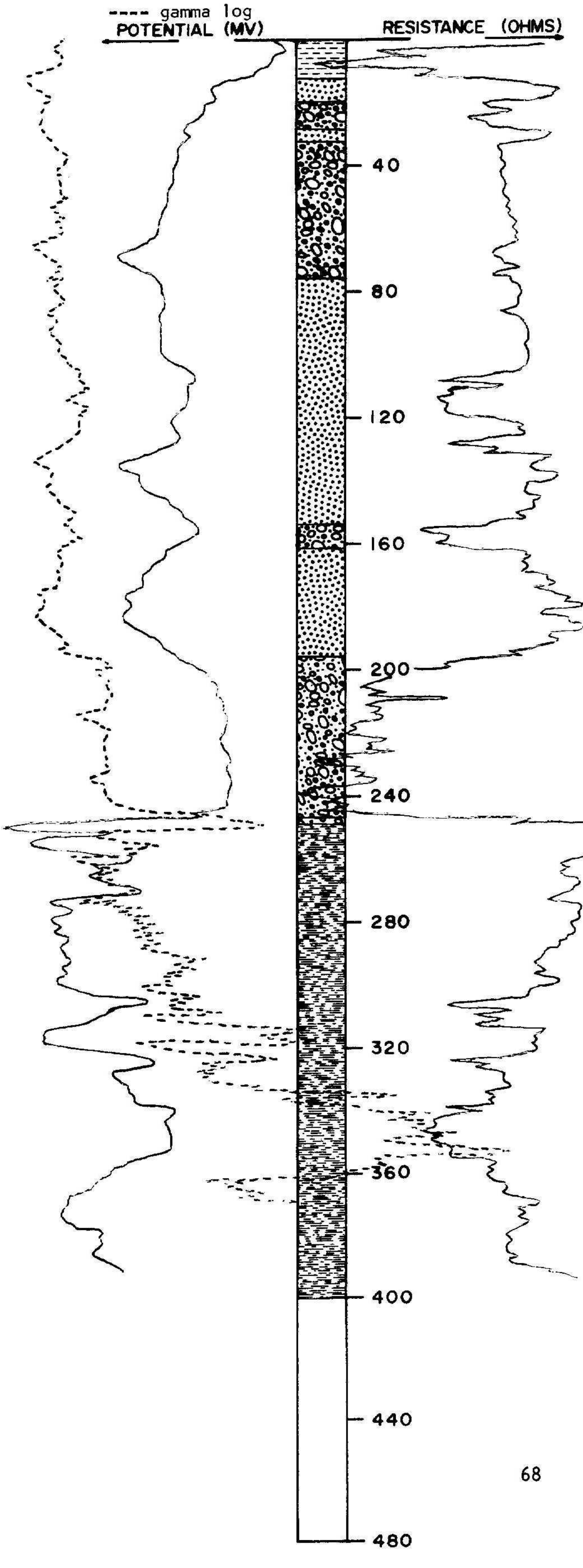
TEST HOLE 3954

LOCATION: 133-47-28dcb

DATE DRILLED: 5-20-70

ELEVATION: 950
(FT, MSL)

DEPTH: 400
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-12	Clay, black and yellow, smooth.
12-19	Sand, fine to coarse, subangular; gravel lenses.
19-28	Clay, silty, light-olive-gray to olive-gray, soft, moderately cohesive; sand grains and pebbles (Till).
28-32	Sand, medium, light-gray, well-sorted, subrounded.
32-76	Clay, very silty to pebbly, olive-gray, moderately soft; sand lenses (Till).
76-106	Sand, fine to medium, gray, well-sorted, subrounded.
106-131	Sand, as above; gray silt and silty clay layers.
131-154	Sand, fine and medium, well-sorted.
154-162	Clay, silty, olive-gray, moderately soft, cohesive; sand grains and pebbles (Till).
162-196	Sand, medium, gray, well-sorted, subrounded.
196-247	Clay, silty, olive-gray; sand grains and pebbles (Till).
247-249	Gravel, sandy, poorly sorted, subangular to subrounded.

Cretaceous rocks

249-253	Sandstone, very fine, gray, indurated.
253-400	Siltstone, clayey to very sandy, varigated, soft to slightly hard, bentonitic, carbonaceous; sandstone and limestone layers; pyrite concentrations.

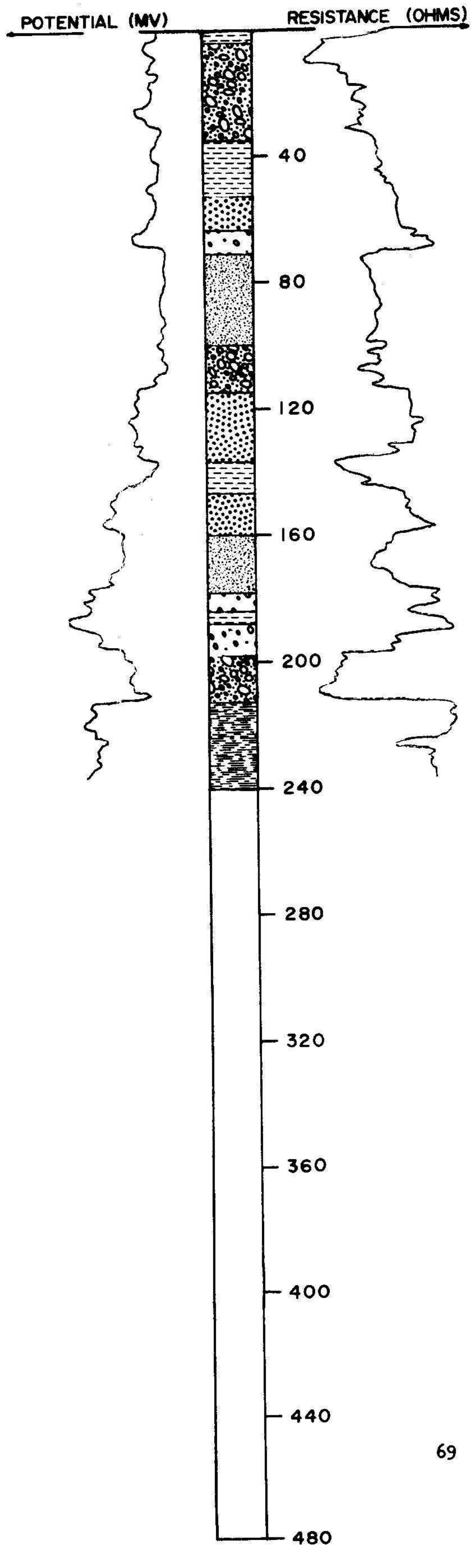
TEST HOLE 3780

LOCATION: 133-47-29bab

ELEVATION: 963
(FT, MSL)

DATE DRILLED: 8-27-69

DEPTH: 240
(FT)



DESCRIPTION OF DEPOSITS

	Glacial drift
0-1	Topsoil; black pebbly loam.
1-4	Clay, silty and very sandy, yellowish-gray, soft.
4-15	Clay, silty, yellowish-gray to moderate-olive-brown, moderately soft, iron stained; sand grains and pebbles (Till).
15-35	Clay, silty to pebbly, olive-gray to dark-greenish-gray, moderately soft, cohesive; sand and gravel lenses (Till).
35-53	Clay, olive-gray, soft, smooth, sticky.
53-64	Sand, very fine, clayey, olive-gray, slightly cohesive.
64-71	Gravel, fine and medium, sorted, subrounded.
71-100	Silt, clayey to sandy, moderately soft, lenticular.
100-115	Clay, silty to pebbly, olive-gray, moderately soft; fine gravel lenses (Till).
115-137	Sand, fine to medium, gray, sorted.
137-147	Clay, olive-gray to dark-gray, cohesive, sticky.
147-160	Sand, fine to coarse, gray, sorted, subrounded, lenticular.
160-178	Silt, clayey to sandy, moderately soft to slightly hard, lenticular.
178-184	Gravel, fine and medium; cobbles.
184-188	Clay, dark-gray, moderately soft.
188-198	Gravel, fine to coarse, assorted; cobbles.
198-213	Clay, silty, dark-brownish-gray, hard, compacted; sand grains and pebbles (Till).
	Cretaceous rocks
213-226	Sandstone, medium, light-gray, well sorted.
226-229	Shale, black, slightly hard, oily, noncalcareous.
229-240	Shale, very silty, medium-light-gray, moderately soft, highly calcareous.

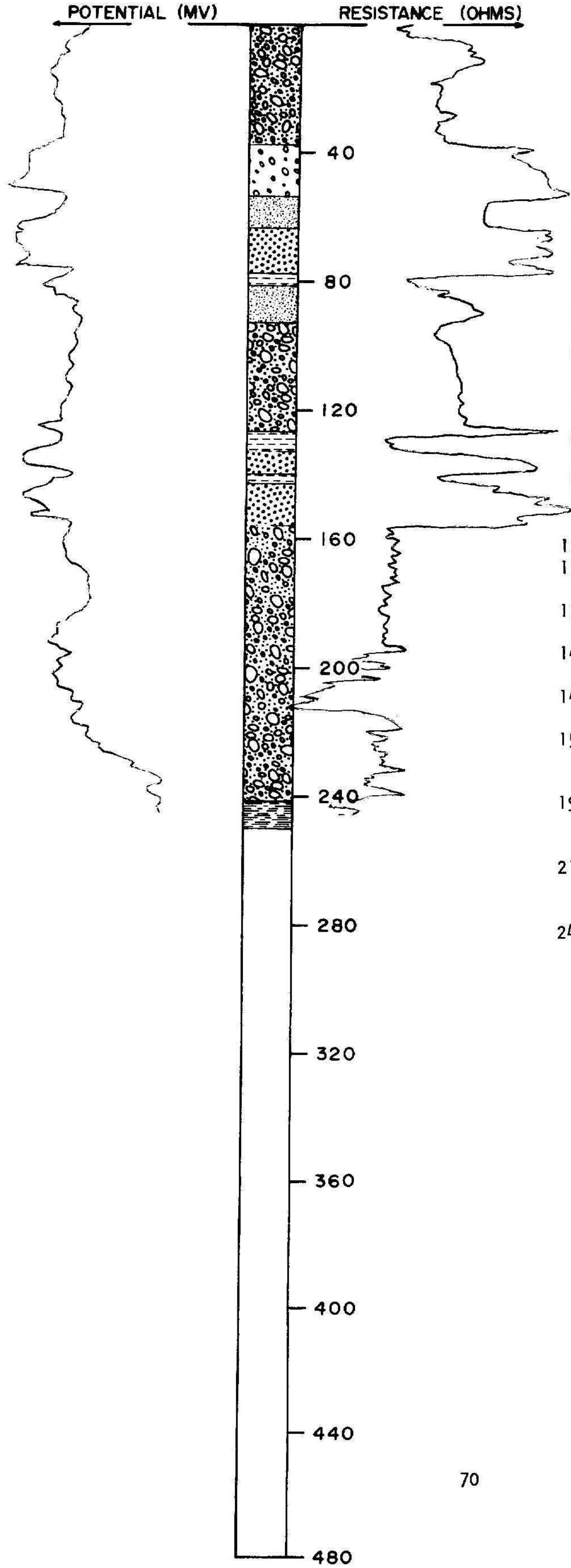
TEST HOLE 3781

LOCATION: 133-47-29daa

DATE DRILLED: 8-28-69

ELEVATION: 965
(FT, MSL)

DEPTH: 250
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black pebbly loam.
2-6	Clay, silty, yellowish-gray, moderately soft; sand grains and pebbles (Till).
6-16	Clay, silty to pebbly, yellowish-gray to moderate-olive-brown, soft, iron stained; sand and gravel lenses (Till).
16-38	Clay, silty to pebbly, olive-gray soft, cohesive (Till).
38-54	Gravel, fine to coarse, sorted, subrounded.
54-64	Silt, sandy, light-gray, soft, nonplastic.
64-78	Sand, fine and medium, sorted, subrounded.
78-82	Clay, olive-gray, soft, smooth, sticky.
82-93	Silt, clayey, light-gray to olive-gray, soft, laminated.
93-125	Clay, silty to pebbly, olive-gray, moderately soft, cohesive; occasional cobbles (Till).
125-127	Boulder; granite.
127-133	Clay, olive-gray, soft, smooth, plastic.
133-140	Sand, medium, light-olive-gray, well-sorted.
140-143	Clay, silty, light-olive-gray, soft.
143-156	Sand, fine to coarse, sorted, subrounded, lenticular.
156-195	Clay, silty to sandy, olive-gray, compacted; pebbles and cobbles (Till).
195-216	Till, as above; smooth dark-gray and brownish-black clay layers.
216-241	Clay, silty to pebbly, olive-gray, stiff, compacted (Till).

Cretaceous rocks

241-250	Shale, black, hard, smooth, waxy.

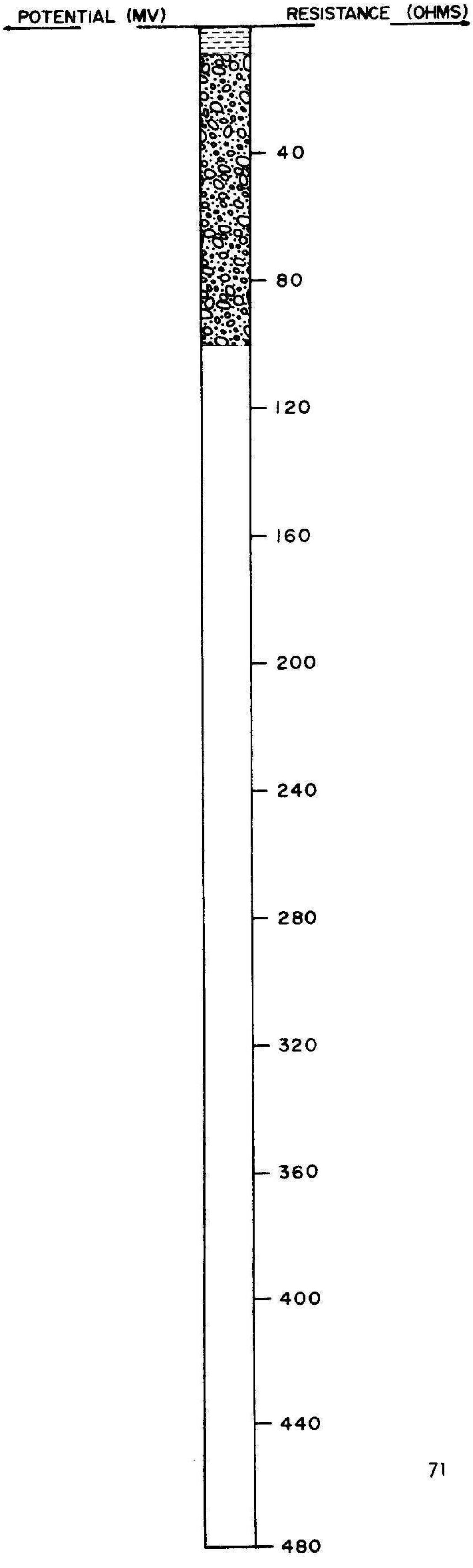
TEST HOLE 3967

LOCATION: 133-48-1baa

DATE DRILLED: 5-29-70

ELEVATION: 951
(FT, MSL)

DEPTH: 100
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-4	Clay, yellow.
4-9	Clay, silty, yellowish-gray, soft; occasional sand grain or pebble.
9-32	Clay, silty to pebbly, reddish-olive-brown, moderately soft (Till).
32-100	Clay, silty to pebbly, olive-gray to dark-olive-gray, compacted; clay and silt layers (Till).

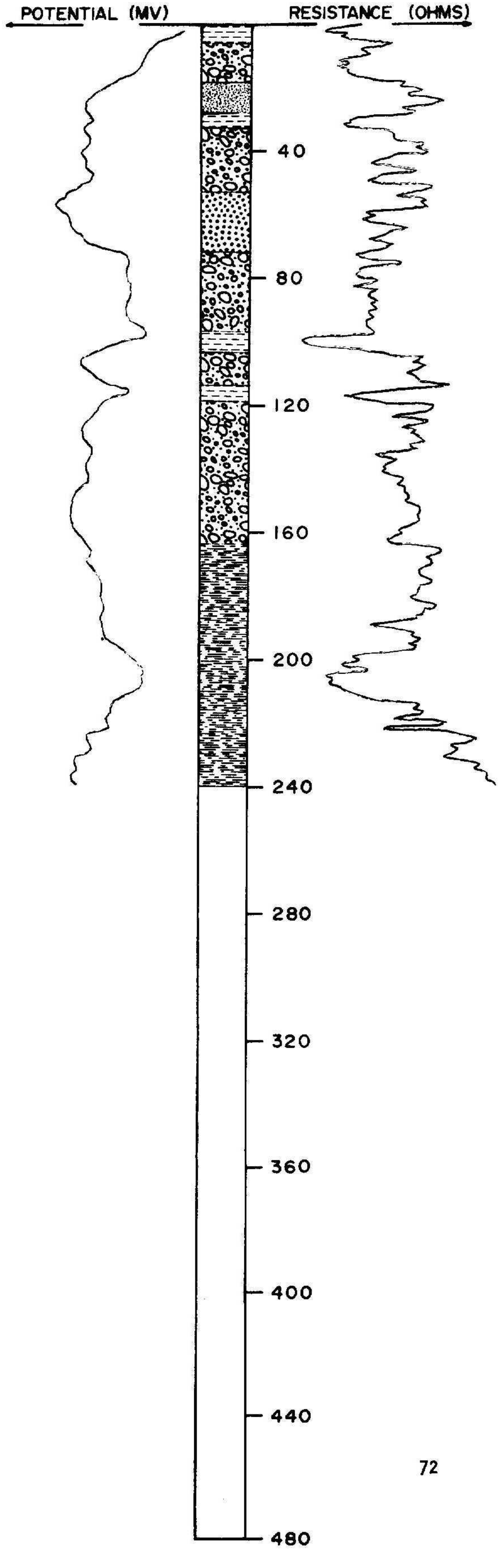
TEST HOLE 3959

LOCATION: 133-48-1ddd

DATE DRILLED: 5-23-70

ELEVATION: 945
(FT, MSL)

DEPTH: 240
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1	Topsoil; black silty loam.
1-6	Clay, yellowish-gray, soft, plastic.
6-18	Clay, silty, yellowish-brown and yellowish-gray, moderately soft; sand grains and pebbles (Till).
18-28	Silt, grayish-green, soft, crumbly.
28-33	Clay, greenish-gray, moderately soft.
33-53	Clay, silty to pebbly, olive-gray to dark-olive-gray, cohesive (Till).
53-72	Sand, very fine to fine, clayey to silty, light-olive-gray, soft, lenticular.
72-97	Clay, silty to pebbly, olive-gray to dark-olive-gray, moderately soft to slightly hard, compacted (Till).
97-104	Clay, dark-brownish-gray, moderately soft, smooth.
104-114	Clay, sandy and pebbly, dark-gray, slightly hard, stiff (Till).
114-119	Clay, dark-brownish-gray to black.
119-164	Clay, very sandy to pebbly, olive-gray to dark-olive-gray, slightly hard, stiff; fine to medium sand lenses (Till).

Cretaceous rocks

164-197	Siltstone, clayey to sandy, light-blue and light-green, moderately soft to slightly hard, micaceous, fossiliferous.
197-212	Shale, silty, brownish-black, hard, brittle.
212-240	Siltstone, varigated, soft to hard; sandstone and shale interbeds.

Test hole flowed on completion. Plugged after collection of water sample.

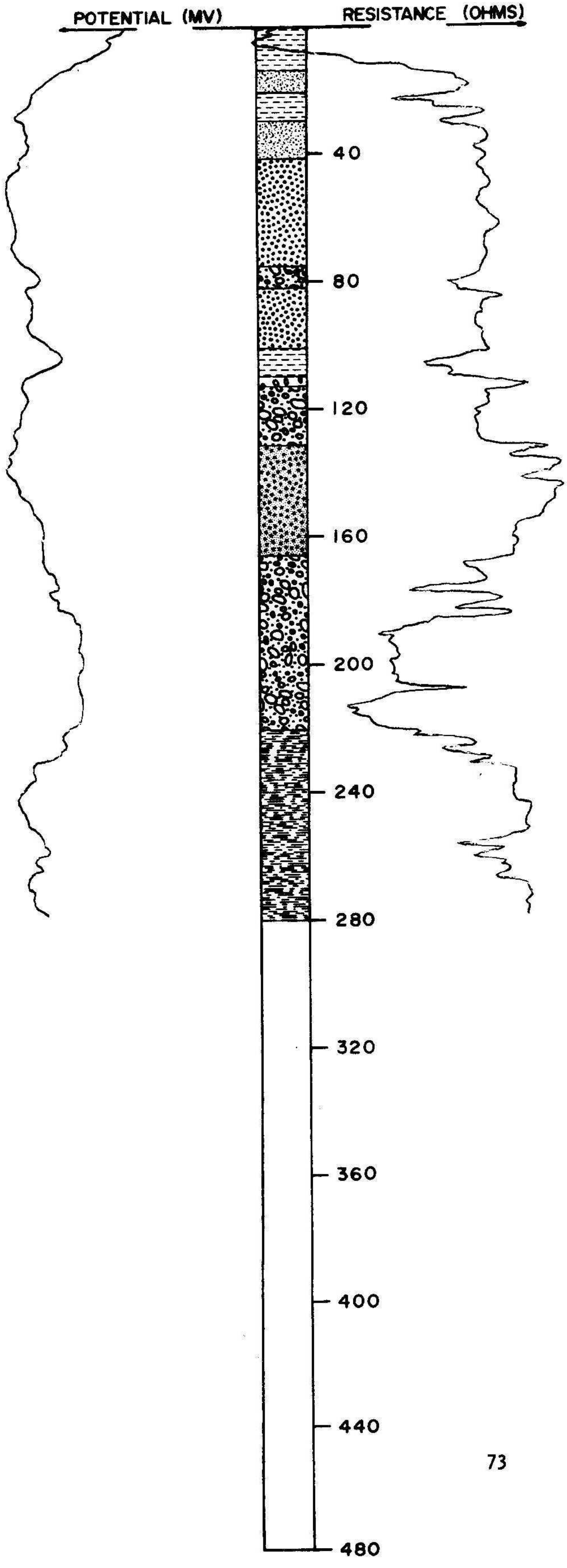
TEST HOLE 3958

LOCATION: 133-48-2ada

ELEVATION: 948.2
(FT, MSL)

DATE DRILLED: 5-21-70

DEPTH: 280
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil, black silty loam.
2-14	Clay, silty, yellowish-gray, soft, smooth.
14-21	Silt, light-olive-gray, soft, crumbly.
21-30	Clay, silty, olive-gray, soft, cohesive.
30-42	Silt, sandy, light-olive-gray to olive-gray, soft, non- to slightly plastic, lenticular.
42-60	Sand, very fine to fine, silty, light-olive-gray.
60-75	Sand, medium to coarse, sorted, subangular to subrounded.
75-82	Clay, silty to pebbly, olive-gray, stiff (Till).
82-101	Sand, coarse, gravelly, moderately sorted.
101-110	Clay, sandy, olive-gray, moderately cohesive.
110-113	Gravel, fine, sandy, subangular.
113-130	Clay, sandy to pebbly, olive-gray, cohesive (Till).
130-132	Boulder; very hard black and white diorite.
132-154	Sand, clayey and silty, light-olive-gray, moderately cohesive; pebbles; sand and gravel lenses (Till).
154-166	Sand, very fine to fine, clayey, light-olive-gray, slightly crumbly; pebbles (Till).
166-186	Clay, silty to pebbly, olive-gray, cohesive; sand and gravel lenses (Till).
186-221	Clay, silty, dark-olive-gray, slightly hard, cohesive; sand grains and pebbles (Till).

Cretaceous rocks

221-280	Siltstone, sandy, dark-brownish-gray to black, soft, friable, micaceous, bentonitic.

Observation well
Depth -- 91 feet
S.I. -- 88 to 91 feet
Water level -- Flow (@1gpm)
Measured -- 5-26-70

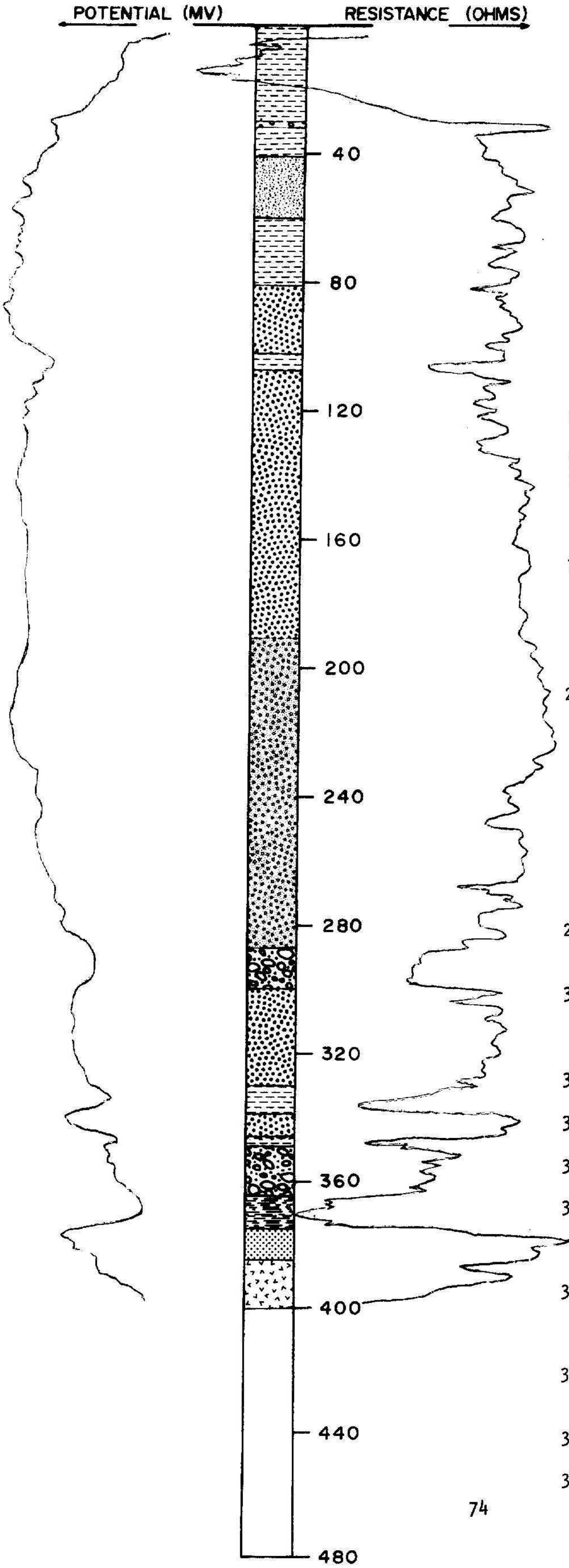
TEST HOLE 3968

LOCATION: 133-48-2bbc

DATE DRILLED: 5-26-70

ELEVATION: 945
(FT, MSL)

DEPTH: 400
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-4	Clay, yellow.
4-18	Clay, silty, yellowish-gray, soft, smooth, plastic; occasional sand grain or pebble.
18-30	Clay, silty, light-olive-gray to olive-gray, soft.
30-32	Gravel, fine, subrounded.
32-41	Clay, silty, dark-greenish-gray, moderately soft.
41-60	Silt, clayey to sandy, gray, soft, lenticular.
60-81	Clay, silty to sandy, light-gray to olive-gray, soft, lenticular.
81-103	Sand, fine and medium, silty, gray, lenticular; wood and shell fragments.
103-108	Clay, silty, olive-gray, soft, cohesive.
108-134	Sand, very fine and fine, gray.
134-191	Sand, fine and medium sorted, subrounded.
191-235	Sand, fine, clayey, light-olive-gray, crumbly; pebbles; sand and gravel lenses (Till).
235-287	Till, sandy, as above; smooth clay and very fine sand lenses.
287-300	Clay, silty to pebbly, olive-gray, slightly hard, cohesive (Till).
300-330	Sand, very fine to medium, gray, lenticular.
330-339	Clay, dark-olive-gray, moderately soft to slightly hard, smooth.
339-346	Sand, fine and medium, sorted, subrounded.
346-349	Clay, olive-gray, moderately soft, cohesive, smooth.
349-365	Clay, silty, dark-brownish-gray, slightly hard; sand grains and pebbles (Till).

Cretaceous rocks

365-375	Shale, sandy, green to dark-green, moderately soft, noncalcareous; calcareous shell fragments.
375-385	Sandstone, coarse, white, subangular.

Precambrian rocks

385-394	Clay, sandy, green and white, soft, crumbly.
394-400	Clay, dark green, smooth, waxy.

Test hole flowed on completion.
Plugged with cement.

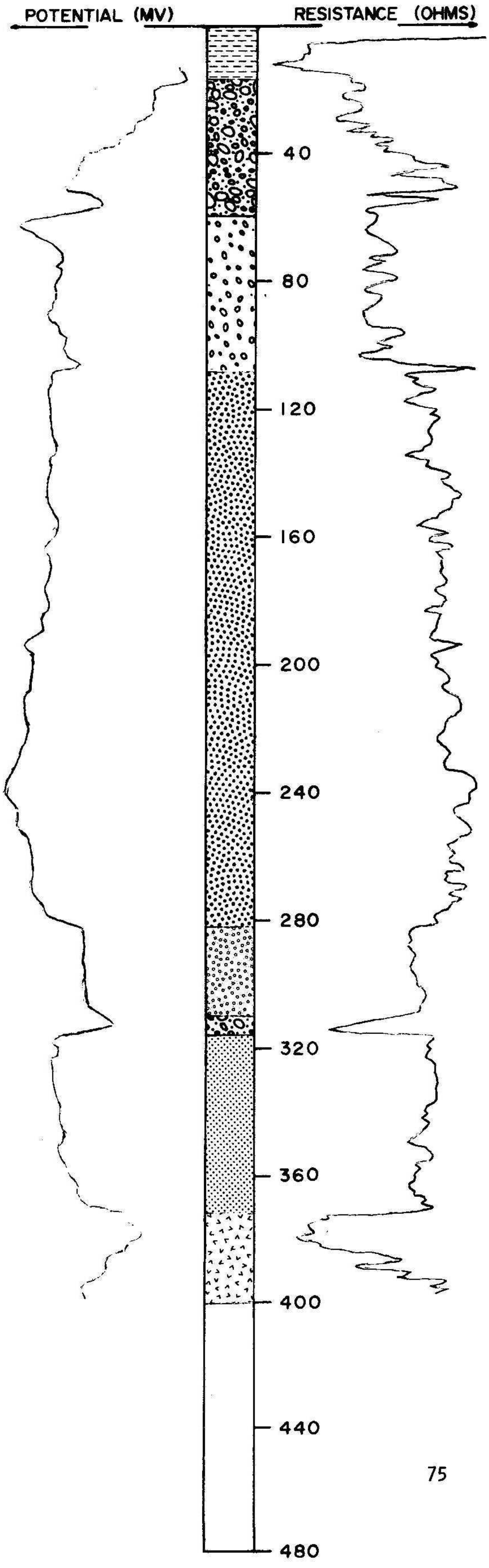
TEST HOLE 3969

LOCATION: 133-48-3abb

DATE DRILLED: 5-26-70

ELEVATION: 944.8
(FT, MSL)

DEPTH: 400
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-6 Clay, yellowish-gray.
6-17 Clay, silty, yellowish-gray to yellowish-olive-brown, moderately soft, cohesive; occasional sand grain or pebble.
17-41 Clay, silty, olive-gray to dark-olive-gray, cohesive; sand grains and pebbles; clay, silt, and fine sand lenses (Till).
41-60 Till, as above; coarse sand and fine gravel lenses.
60-109 Gravel, fine to coarse, sandy, lenticular.
109-196 Sand, fine to coarse, sorted, subrounded, lenticular.
196-282 Sand, medium to very coarse, gravelly, sorted.
282-310 Sand, very fine and fine, clayey, light-olive-gray, crumbly; pebbles (Till).
310-316 Clay, silty, olive-gray to dark-olive-gray, compacted; sand grains and pebbles (Till).

Cretaceous rocks

316-372 Sandstone, medium to coarse, white, sorted, subangular.

Precambrian rocks

372-385 Clay, yellowish-green to dark-green, soft, crumbly, non-calcareous; quartz sand grains.
385-400 Clay, as above; granite boulders.

Observation well
Depth -- 120 feet
S.I -- 100 to 120 feet
Water level -- Flow (@ 20 gpm)
Measured -- 5-28-70

Plugged after collection of water sample.

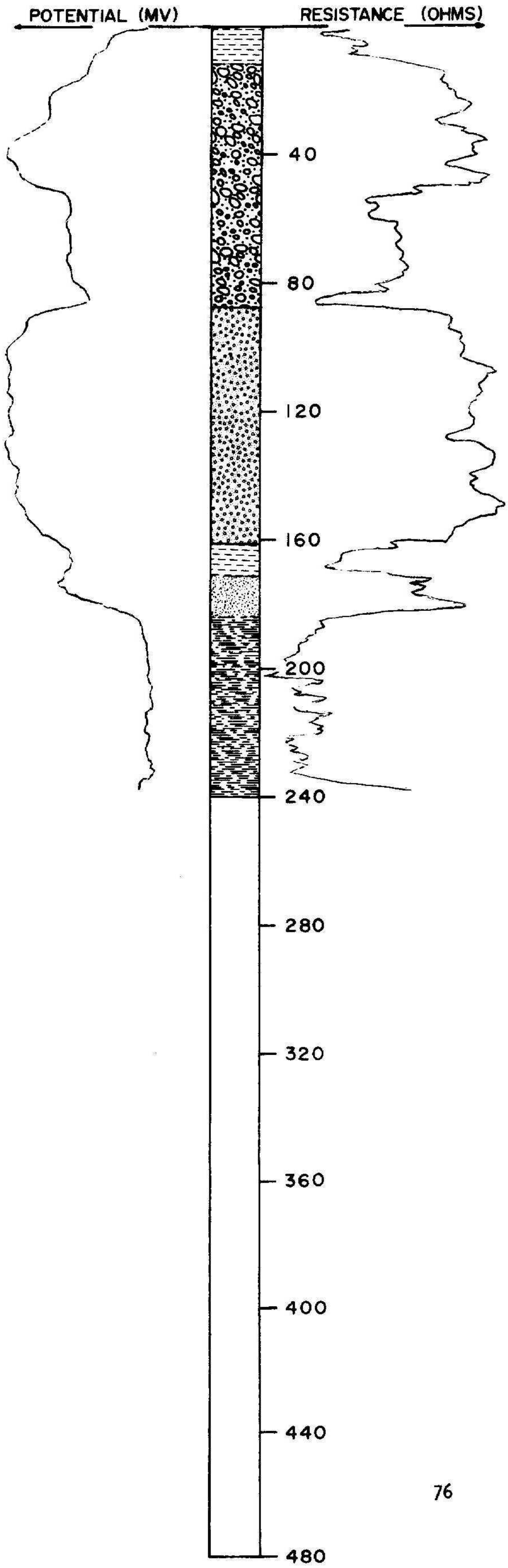
TEST HOLE 3957

LOCATION: 133-48-11ddd

DATE DRILLED: 5-21-70

ELEVATION: 950
(FT, MSL)

DEPTH: 240
(FT)



DESCRIPTION OF DEPOSITS

	Glacial drift
0-1	Topsoil; black silty loam.
1-12	Clay, silty, yellowish-gray, soft, cohesive; occasional sand grain or pebble.
12-49	Clay, very sandy to pebbly, light-olive-gray to olive-gray, moderately soft, cohesive; fine sand lenses (Till).
49-88	Clay, silty to pebbly, olive-gray to dark-olive gray, very cohesive; silt and clay lenses (Till).
88-161	Sand, very fine, clayey, light-olive-gray, slightly crumbly; coarse sand grains and pebbles; fine sand lenses (Till).
161-171	Clay, silty, dark-gray, soft to moderately soft, smooth.
171-184	Silt, sandy, light-olive-gray, soft.
	Cretaceous rocks
184-240	Shale, black, hard, noncalcareous; bluish-white bentonitic clay layers.

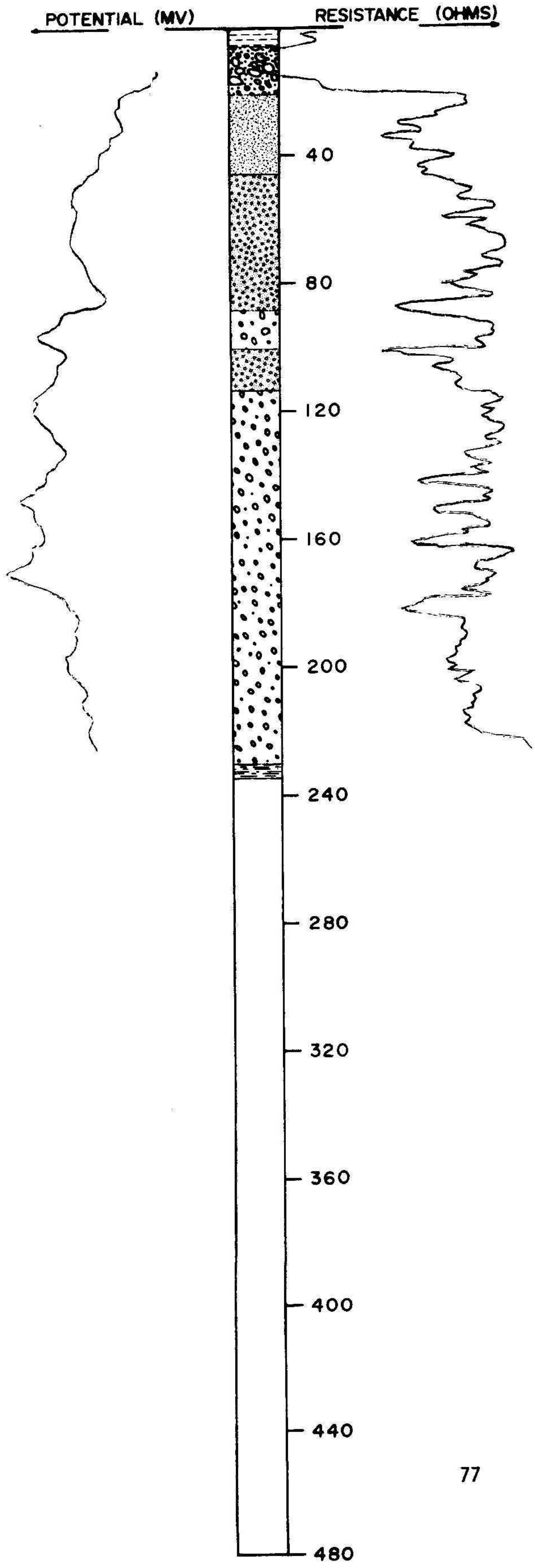
TEST HOLE 3966

LOCATION: 133-48-12baa

ELEVATION: 949.2
(FT, MSL)

DATE DRILLED: 5-24-70

DEPTH: 235
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1	Topsoil; black silty loam.
1-6	Clay, silty, yellowish-gray, soft, cohesive.
6-15	Clay, silty to pebbly, moderate-olive-brown, moderately soft, cohesive (Till).
15-21	Clay, silty to pebbly, olive-gray, moderately soft, cohesive; numerous clay and silt lenses (Till).
21-46	Silt, clayey to sandy, light-olive-gray to olive-gray, soft, lenticular; occasional pebble.
46-89	Clay, very sandy, light-olive-gray, moderately soft; pebbles; sand and gravel lenses (Till).
89-101	Gravel, fine to medium, sorted, subangular to subrounded.
101-114	Clay, very sandy, light-olive-gray, slightly cohesive; pebbles; sand and gravel lenses (Till).
114-184	Gravel, fine to medium, sandy, lenticular.
184-222	Gravel, fine to coarse.
222-231	Gravel, coarse; cobbles.

Cretaceous rocks

231-235	Shale, black, hard, carbonaceous.
235+	Sandstone, very fine, dark-gray, very hard.

Observation well

Depth -- 136 feet
S.I. -- 116 to 136 feet
Water level -- +7 feet (flow)
Measured -- 5-26-70

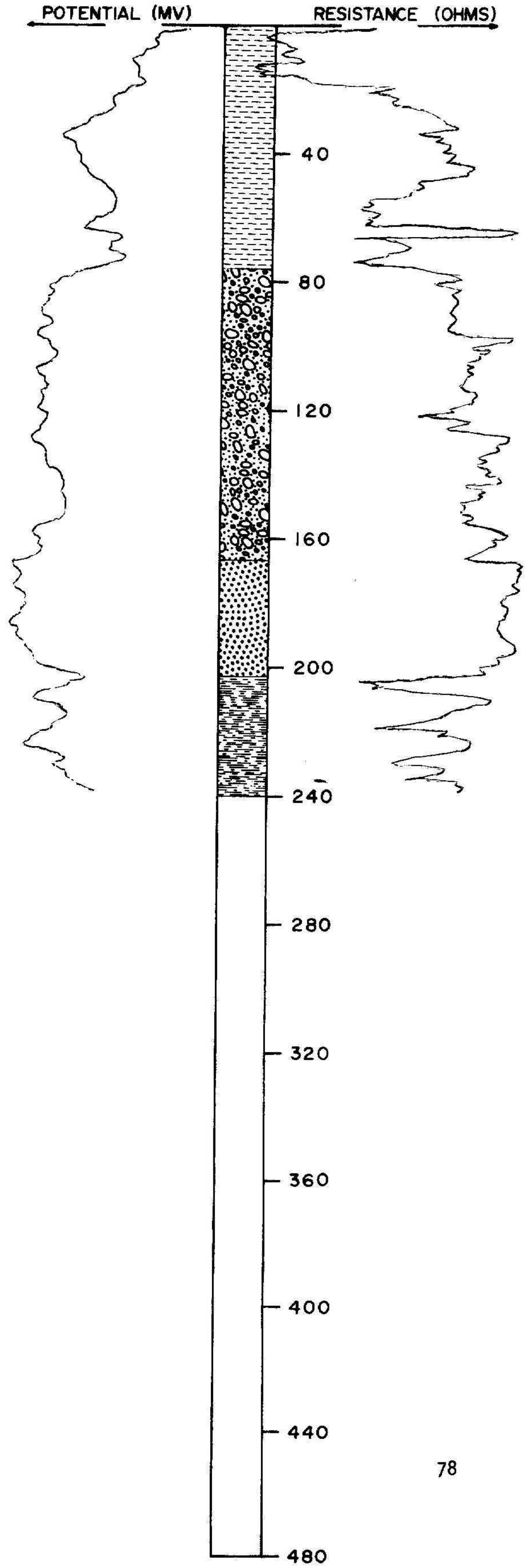
TEST HOLE 3961

LOCATION: 133-48-13add

DATE DRILLED: 5-22-70

ELEVATION: 955
(FT, MSL)

DEPTH: 240
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1	Topsoil; black pebbly loam.
1-18	Clay, silty, yellowish-gray to reddish-brown, moderately soft, smooth; occasional sand grain or pebble.
18-53	Clay, silty and sandy, varigated, soft, lenticular.
53-76	Clay, dark-brownish-gray, moderately soft, cohesive; sand lenses.
76-167	Clay, silty to pebbly, olive-gray to dark-olive-gray, slightly hard; clay, silty, and sand lenses (Till).
167-203	Sand, fine to coarse, light-olive-gray, sorted.

Cretaceous rocks

203-240	Shale, varigated, carbonaceous, bentonitic; micaceous siltstone; fossilifeous fine-grained sandstone.

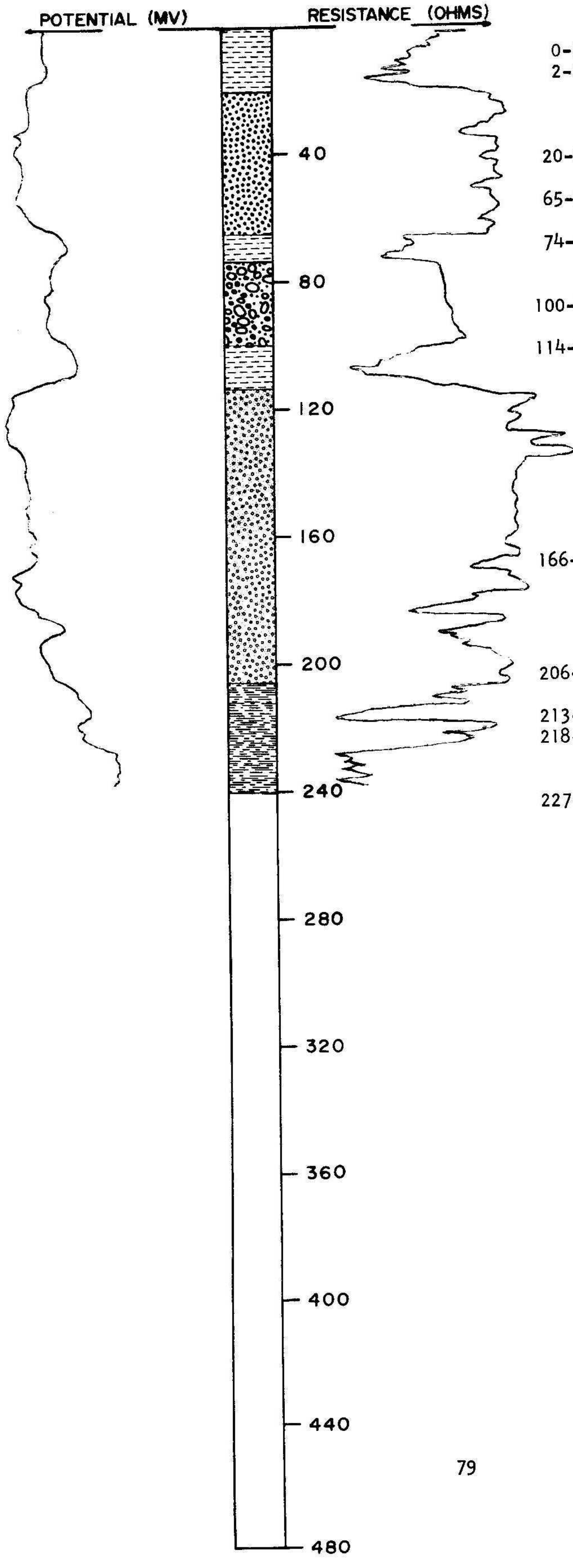
TEST HOLE 3962

LOCATION: 133-48-24abb

DATE DRILLED: 5-23-70

ELEVATION: 957
(FT, MSL)

DEPTH: 240
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black silty clay loam.
2-20	Clay, silty, moderate-olive-brown, soft to slightly hard, cohesive, smooth, iron stained; occasional sand grain or pebble.
20-65	Sand, very fine to medium, silty, gray, lenticular.
65-74	Clay, dark-gray, slightly hard, stiff.
74-100	Clay, silty to pebbly, olive-gray to dark-olive-gray, moderately soft, cohesive (Till).
100-114	Clay, olive-gray to dark-olive-gray, cohesive, laminated.
114-166	Clay, silty to very sandy, light-olive-gray, moderately soft; pebbles; sand lenses (Till).
166-206	Till, sandy, as above; clay and silt lenses.

Cretaceous rocks

206-213	Siltstone, sandy, brownish-black, soft, friable.
213-218	Shale, black, hard, brittle.
218-227	Siltstone, sandy, dark-green to brownish-black, soft, carbonaceous.
227-240	Shale, black, hard, smooth.

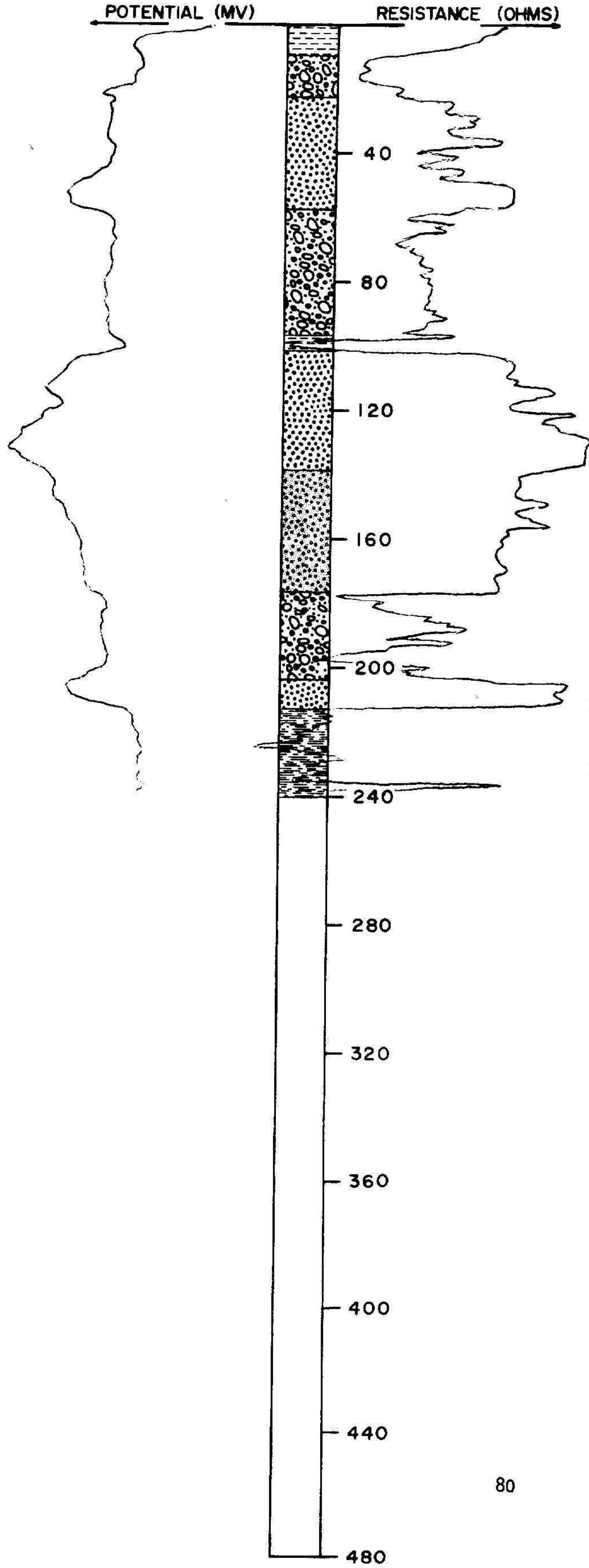
TEST HOLE 3963

LOCATION: 133-48-24ada

DATE DRILLED: 5-23-70

ELEVATION: 960
(FT, MSL)

DEPTH: 240
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black silty loam.
2-10	Clay, silty to sandy, light-gray to yellowish-gray, soft; occasional sand grain or pebble.
10-23	Clay, silty to pebbly, moderate-olive-brown, cohesive (Till).
23-58	Sand, very fine to fine, clayey to silty, varigated, slightly cohesive, lenticular.
58-97	Clay, silty to sandy, olive-gray and dark-olive-gray, slightly hard; pebbles and cobbles (Till).
97-102	Clay, dark-brownish-black, hard, brittle.
102-126	Sand, very fine, clayey, dark-brown, soft.
126-139	Sand, coarse, well-sorted, subangular to subrounded.
139-177	Sand, very fine to fine, silty to clayey, light-olive-gray, crumbly (Till).
177-204	Clay, silty to pebbly, olive-gray, stiff; cobbles and boulders; clay, silt, sand, and gravel lenses (Till).
204-213	Sand, coarse to very coarse, sorted, subrounded.

Cretaceous rocks

213-240	Shale, black, hard, brittle, mottled; sandstone at 237 feet.

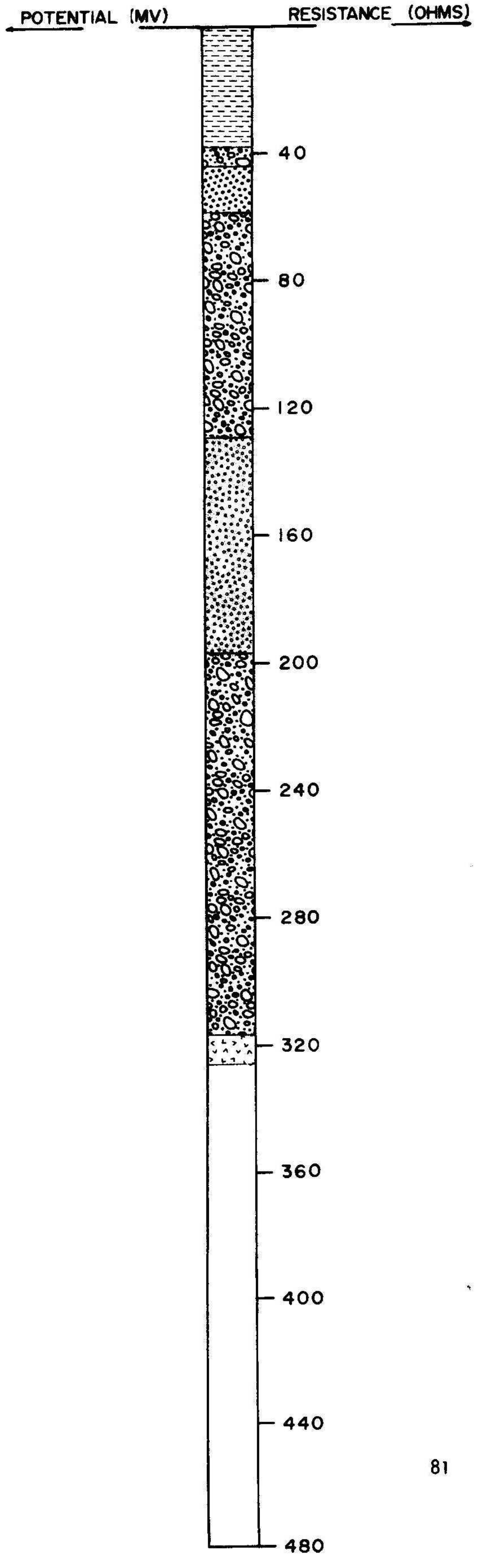
TEST HOLE 2309

LOCATION: 134-48-9baa

DATE DRILLED: 9-15-64

ELEVATION: 940
(FT, MSL)

DEPTH: 326
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-18 Clay, dusky-yellow, soft.

18-38 Clay, dark-greenish-gray to olive-gray, soft, cohesive.

38-44 Clay, silty to pebbly, olive-gray, soft, cohesive (Till).

44-59 Sand, coarse to very coarse, gravelly; wood fragments near base.

59-129 Clay, silty to pebbly, olive-black, hard, cohesive (Till).

129-197 Sand, very fine, clayey and silty, light-olive-gray, moderately soft; pebbles and cobbles (Till).

197-317 Clay, silty to pebbly, olive-black, hard, compacted (Till).

Precambrian rocks

317-326 Clay, light-brownish-gray, soft, crumbly, noncalcareous; pyrite and angular quartz grains.

Potential and resistance logs in Baker (1966, p.131,132).

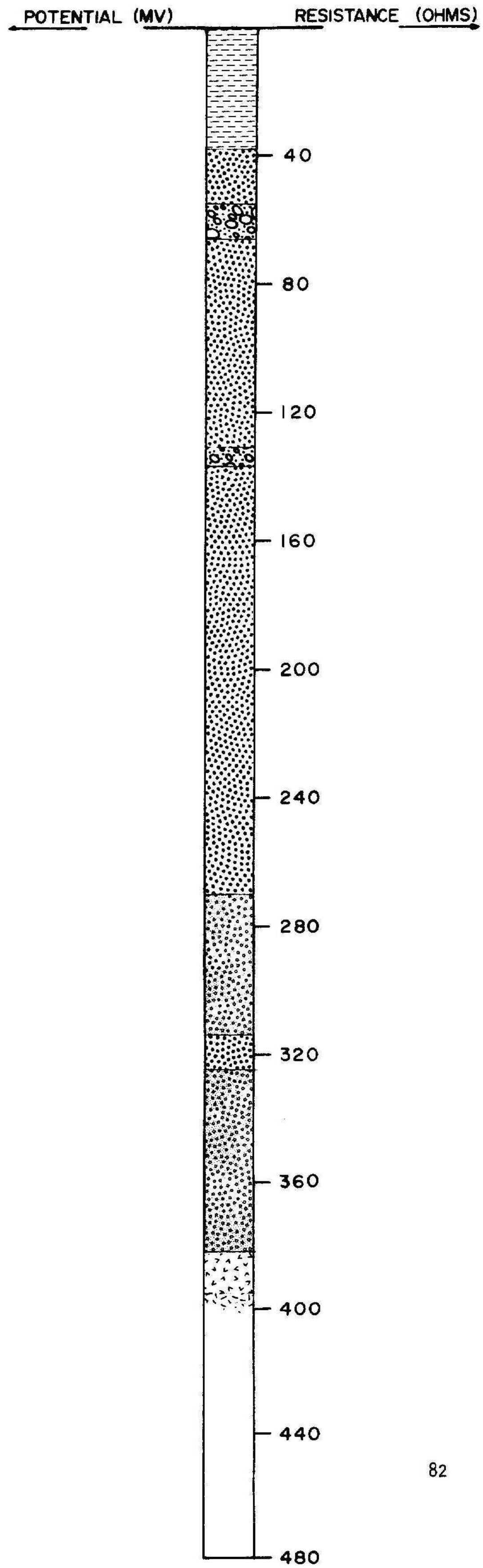
TEST HOLE 3975

LOCATION: 134-48-21bbb

DATE DRILLED: 6-2-70

ELEVATION (FT, MSL): 941

DEPTH (FT): 395



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black clayey loam.
2-9	Clay, yellowish-gray, soft, cohesive, smooth.
9-38	Clay, silty, olive-gray, soft, cohesive, plastic.
38-55	Sand, fine to coarse, subrounded, lenticular.
55-66	Clay, silty to sandy, dark-brownish-gray, cohesive; pebbles (Till).
66-131	Sand, fine to coarse, subangular to subrounded, lenticular; fine gravel.
131-137	Clay, sandy, olive-gray, moderately soft, cohesive; shale pebbles (Till).
137-270	Sand, fine to coarse, lenticular.
270-314	Clay, very sandy, light-olive-gray, crumbly; occasional pebbles (Till).
314-325	Sand, fine and medium, gray, sorted, subrounded.
325-382	Clay, very sandy, light-olive-gray (Till).

Precambrian rocks

382-395	Clay, white to light-greenish-gray, soft, noncalcareous; smears easily; angular quartz sand grains.
395+	Granite, extremely hard.

Test hole flowed on completion (@20 gpm). Plugged after collection of water sample.

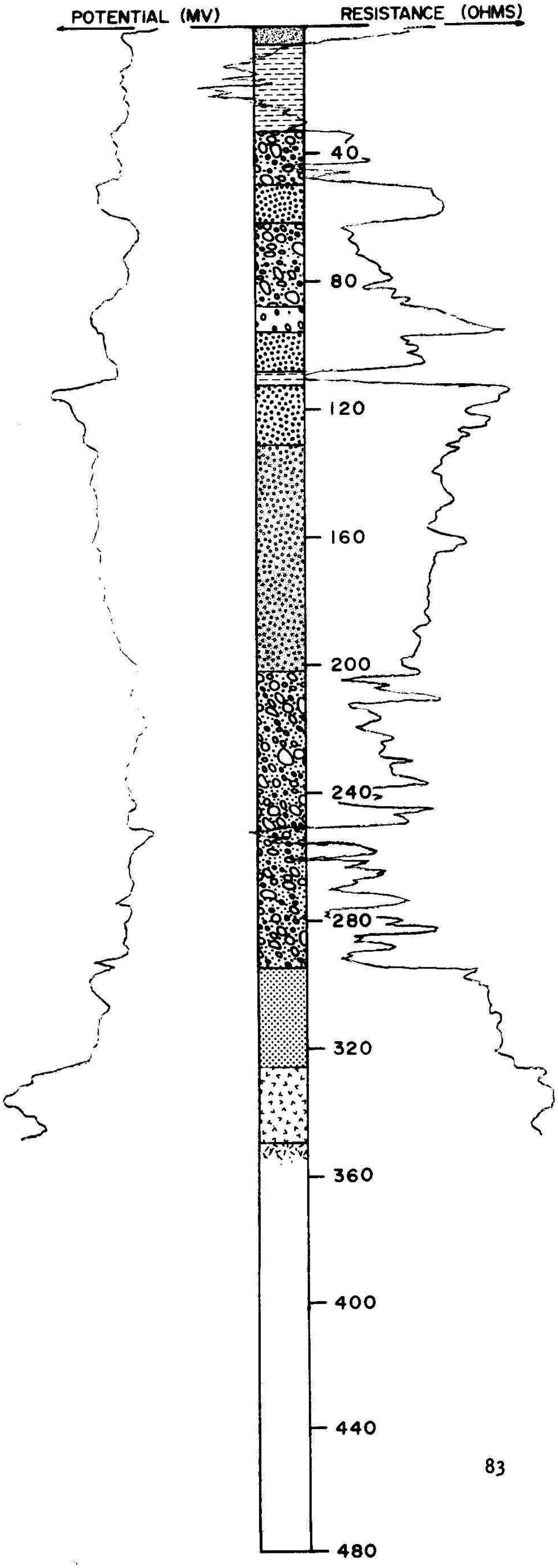
TEST HOLE 3971

LOCATION: 134-48-32baa

ELEVATION: 940
(FT, MSL)

DATE DRILLED: 5-27-70

DEPTH: 350
(FT)



DESCRIPTION OF DEPOSITS

	Glacial drift
0-2	Topsoil; black silty loam.
2-6	Silt, light-gray to yellowish-gray, soft, nonplastic.
6-23	Clay, silty, yellowish-gray, soft, smooth, laminated.
23-33	Clay, silty, olive-gray, soft, plastic.
33-50	Clay, silty to pebbly (Till).
50-62	Sand, fine to coarse, sorted, subangular to subrounded.
62-88	Clay, silty to pebbly, dark-olive-gray, slightly hard, compacted; gravelly in lower part (Till).
88-95	Gravel, fine, sandy, assorted.
95-96	Boulder; granite.
96-109	Sand, fine to medium, sorted, subrounded.
109-113	Clay, dark-gray to dark-brown, slightly hard, brittle.
113-132	Sand, fine to coarse, subrounded, lenticular.
132-202	Sand, very fine to fine, clayey, light-olive-gray, moderately soft; pebbles; sand and gravel lenses (Till).
202-251	Clay, silty to pebbly, olive-gray to dark-olive-gray, cohesive; cobbles; clay, silt, sand, and gravel lenses.
251-256	Clay, silty to sandy, yellowish-green to grayish-brown, moderately soft, partially oxidized (Till).
256-295	Clay, silty to pebbly, dark-brownish-gray to dark-olive-gray, stiff; cobbles; boulders of local bedrock; sand and gravel lenses (Till).
	Cretaceous rocks
295-326	Sandstone, medium to coarse, white, well-sorted, subangular.
	Precambrian rocks
326-350	Clay, white, soft, noncalcareous; occasional granite cobbles or boulders.
350+	Granite, very hard.

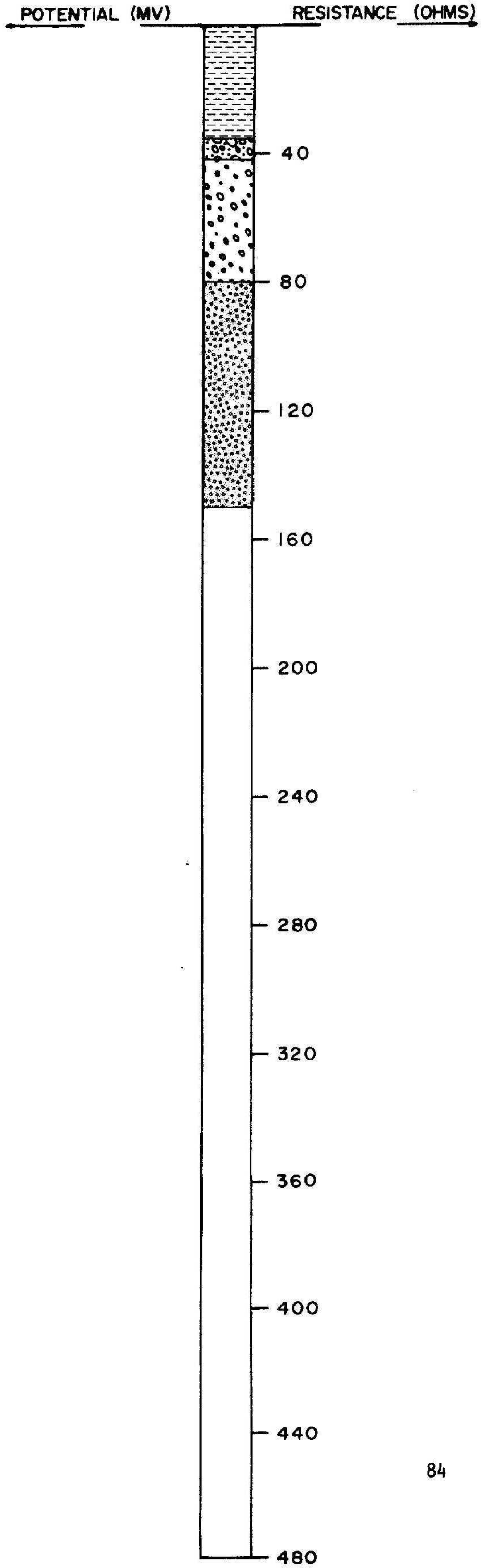
TEST HOLE 3972

LOCATION: 134-48-32bbc

DATE DRILLED: 5-27-70

ELEVATION: 940
(FT, MSL)

DEPTH: 150
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black silty loam.
2-20	Clay, silty, yellowish-gray, soft, smooth; occasional sand grain.
20-35	Clay, silty, olive-gray, soft, smooth, cohesive.
35-42	Clay, silty to pebbly, olive-gray to dark-olive-gray, slightly hard; clay layers (Till).
42-80	Gravel, fine to coarse, sandy, assorted, subangular to subrounded; cobbles.
80-127	Sand, very fine to fine, clayey, light-olive-gray, moderately soft; pebbles; fine to medium sand lenses (Till).
127-150	Till, sandy, as above; less frequent sand lenses.

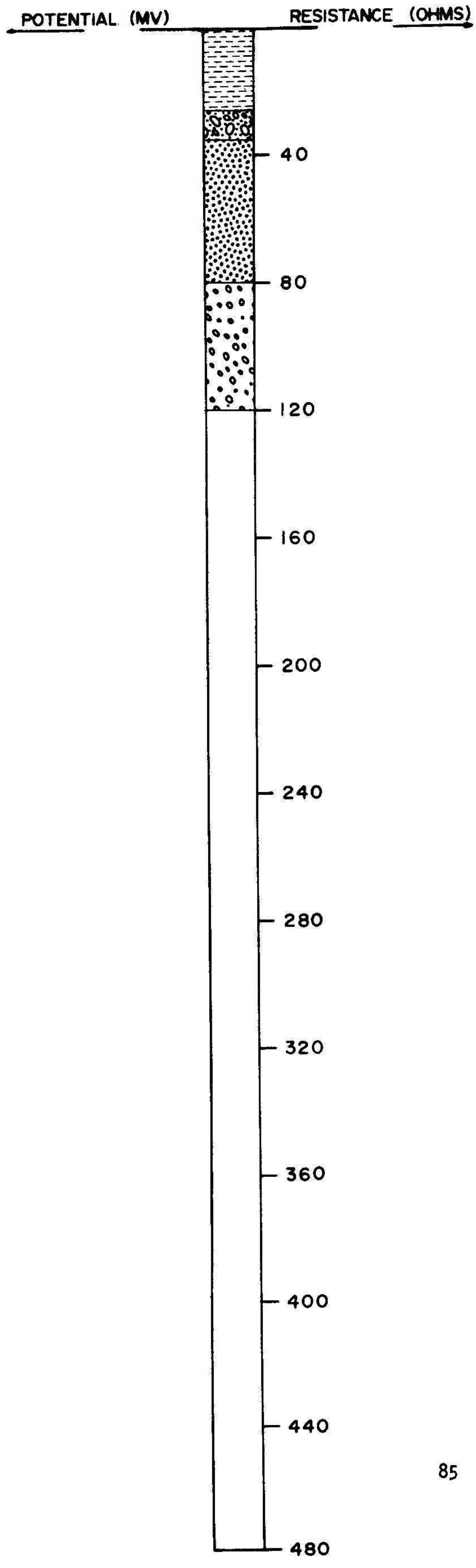
TEST HOLE 3970

LOCATION: 134-48-32daa

DATE DRILLED: 5-26-70

ELEVATION: 940
(FT, MSL)

DEPTH: 120
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1 Topsoil; black silty clay loam.

1-14 Clay, silty, yellowish-gray, soft, cohesive; occasional sand grain.

14-26 Clay, silty, olive-gray, soft, cohesive, plastic.

26-35 Clay, silty to pebbly, olive-gray, moderately soft, cohesive; gravel lenses (Till).

35-80 Sand, medium to very coarse, gravelly, subangular to subrounded.

80-120 Gravel, fine to coarse, slightly sandy, lenticular.

Observation well

Depth -- 80 feet

S.I. -- 60 - 80 feet

Water level -- 5.45 feet

Measured -- 2-8-71

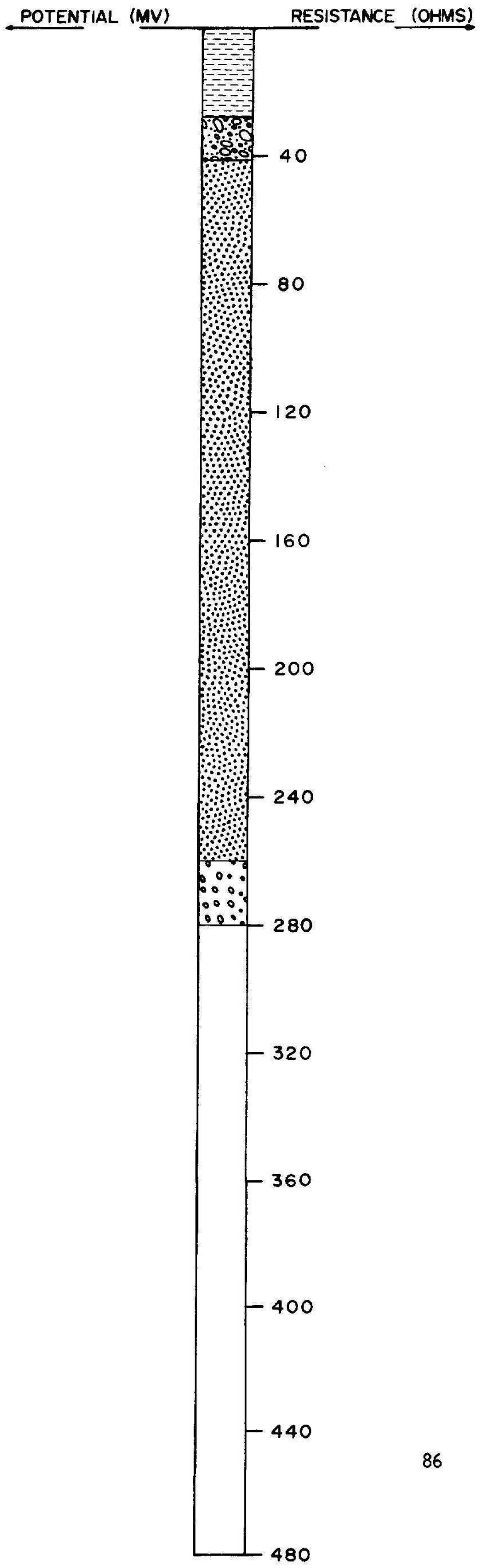
TEST HOLE 3974

LOCATION: 134-48-33aaa

DATE DRILLED: 5-28-70

ELEVATION: 946
(FT, MSL)

DEPTH: 280
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-4	Clay, yellow.
4-16	Clay, silty, yellowish-gray, soft, plastic, smooth.
16-28	Clay, silty, olive-gray, soft, plastic.
28-41	Clay, silty to pebbly, olive-gray to dark-olive-gray, slightly hard, brittle; clay layers (Till).
41-260	Sand, very fine to fine, sorted, subrounded; progressively coarser with depth.
260-280	Gravel, fine, sorted.

Test hole flowed @ 20 to 30 gpm upon completion. Plugged with a post and cement.

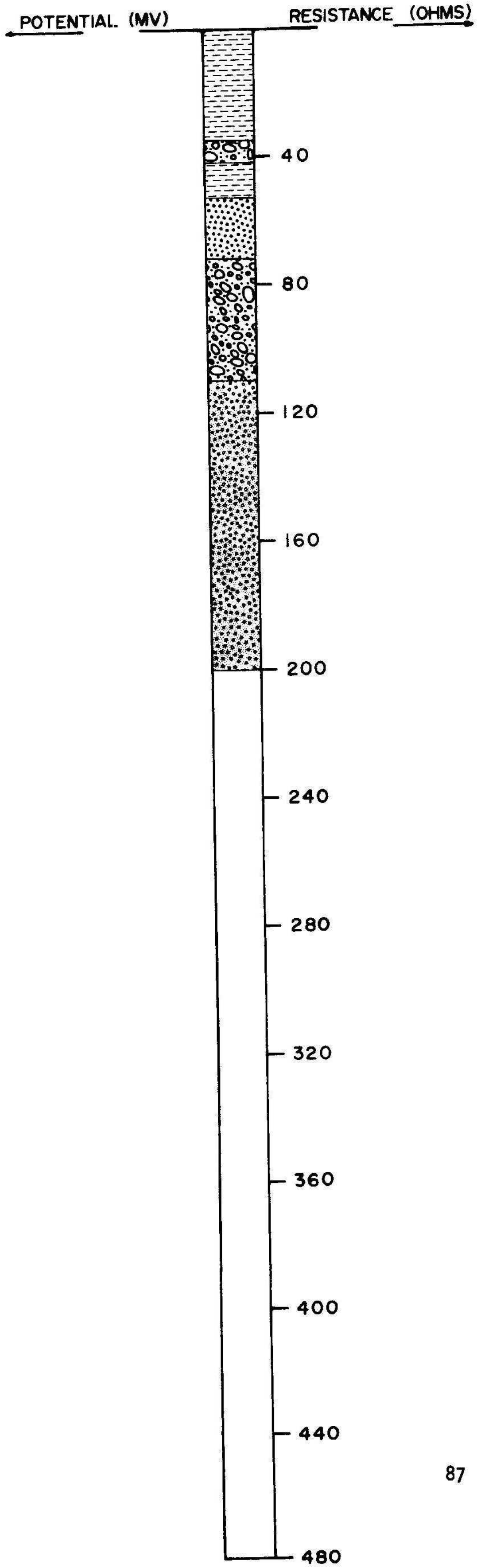
TEST HOLE 3973

LOCATION: 134-48-33bab

ELEVATION: 946
(FT, MSL)

DATE DRILLED: 5-27-70

DEPTH: 200
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black silty clay loam.
2-14	Clay, silty, yellowish-gray, soft, cohesive.
14-35	Clay, silty, olive-gray, soft, plastic.
35-42	Clay, silty to pebbly, olive-gray to dark-olive-gray, slightly hard; smooth dark clay layers (Till).
42-53	Clay, very sandy, dark brown, soft, slightly cohesive; silt and sand lenses.
53-72	Sand, fine to medium, gray, sorted, subrounded.
72-110	Clay, silty to pebbly, dark-olive gray to brownish-gray, slightly hard; organic-rich clay and silt lenses (Till).
110-200	Sand, very fine to fine, clayey, light-olive-gray, moderately soft, crumbly; pebbles; fine to coarse sand lenses (Till).

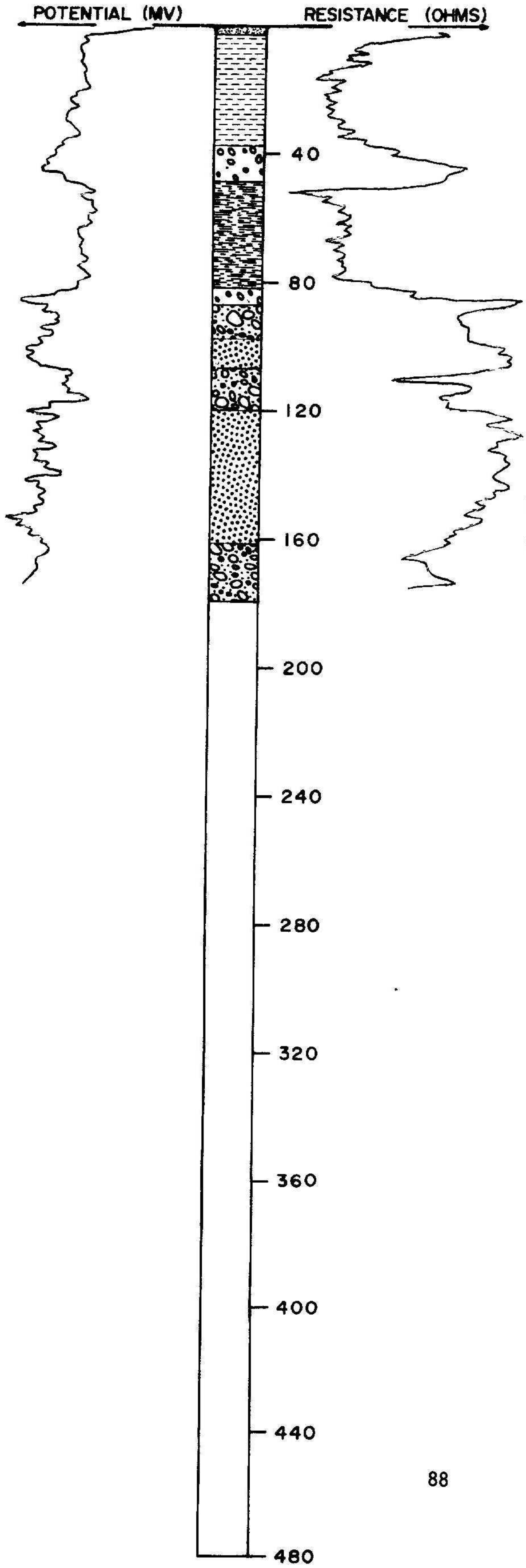
TEST HOLE 3977

LOCATION: 135-48-31dcd

DATE DRILLED: 6-3-70

ELEVATION: 936.3
(FT, MSL)

DEPTH: 180
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1	Topsoil; black silty loam.
1-3	Silt, yellowish-brown, soft.
3-26	Clay, dusky-yellow, soft, cohesive, plastic.
26-38	Clay, yellowish-brown to light-olive-gray, soft, cohesive.
38-49	Gravel, fine and medium, sandy, assorted, iron stained.
49-82	Shale, black, hard, brittle, noncalcareous.
82-87	Gravel, fine and medium, assorted, iron stained.
87-98	Clay, silty to pebbly, brownish-gray, slightly hard, partially oxidized (Till).
98-107	Sand, fine to coarse, brown, sorted, lenticular, iron stained.
107-120	Clay, silty to pebbly, dark-brownish-gray, slightly hard; gravel lenses (Till).
120-162	Sand, fine to coarse, gravelly, brown, assorted, iron stained.
162-180	Clay, silty to pebbly, dark-olive-gray, moderately soft; cobbles and boulders (Till).

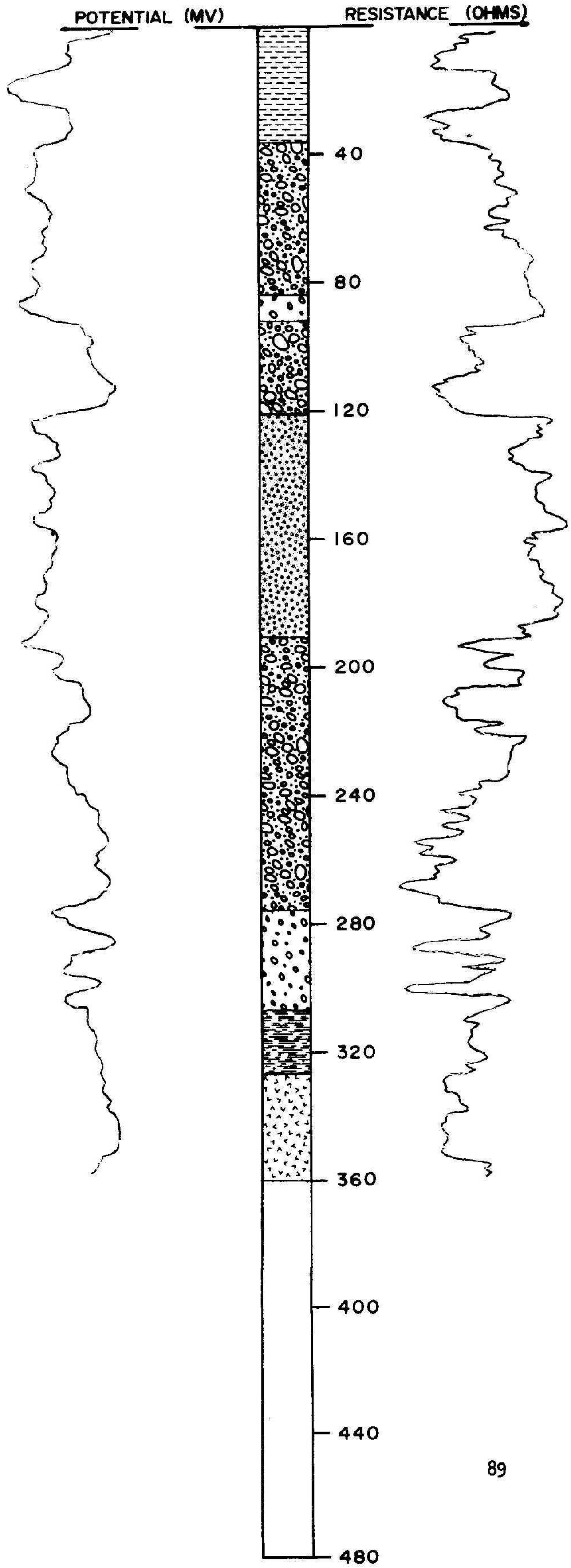
TEST HOLE 3978

LOCATION: 135-48-32bbb

DATE DRILLED: 6-3-70

ELEVATION: 935
(FT, MSL)

DEPTH: 360
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-1	Topsoil; brownish-black silty loam.
1-13	Clay, light-olive-gray to medium-gray, moderately soft.
13-25	Clay, silty, dusky-yellow, soft, cohesive.
25-36	Clay, olive-gray, moderately soft, plastic.
36-84	Clay, silty to pebbly, olive-gray, slightly hard, cohesive; sand and gravel lenses (Till).
84-92	Gravel, fine and medium, sandy, assorted, iron stained.
92-121	Clay, silty to sandy, dark-olive-gray, cohesive; shale pebbles (Till).
121-191	Sand, very fine, clayey, light-olive-gray, moderately soft; crumbly; pebbles; sand lenses (Till).
191-276	Clay, silty to sandy, olive-gray, slightly hard, cohesive; pebbles and cobbles; clay, silt, sand, and gravel lenses (Till).
276-307	Gravel, fine to coarse, assorted, subrounded; clayey till layers.

Cretaceous rocks

307-327	Shale, silty, brownish-black, moderately cohesive, carbonaceous.

Precambrian rocks

327-360	Clay, white to pink, soft, noncalcareous; smears easily; partially decomposed granite boulders in lower 20 feet.

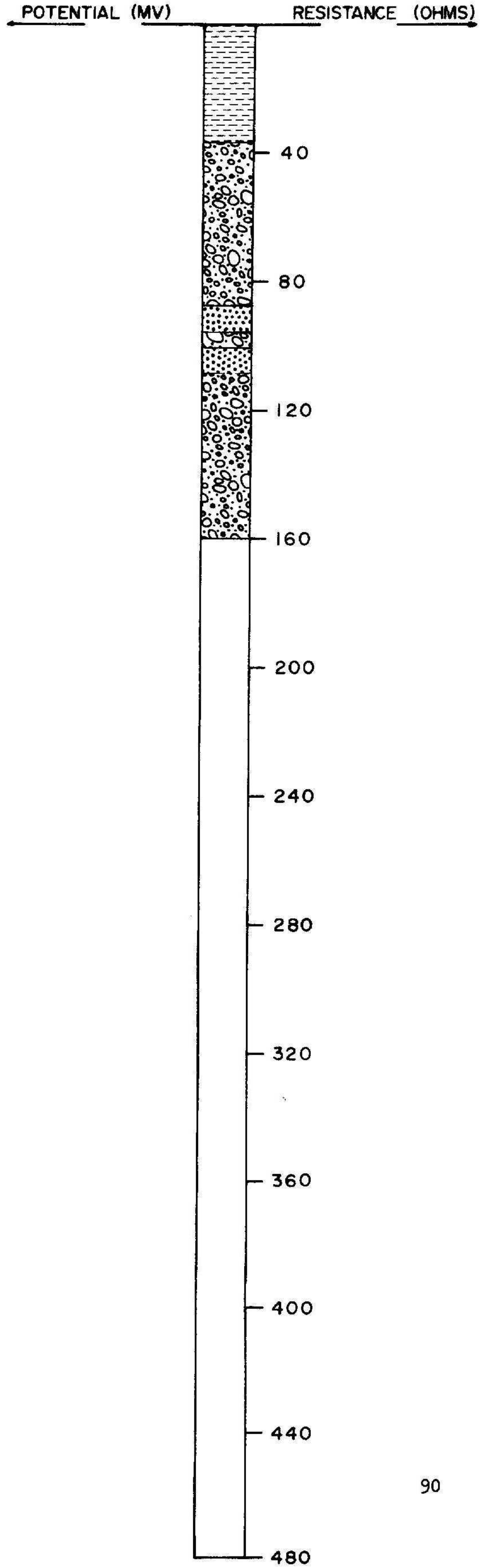
TEST HOLE 3976

LOCATION: 135-48-32ddd

DATE DRILLED: 6-3-70

ELEVATION: 930
(FT, MSL)

DEPTH: 160
(FT)



DESCRIPTION OF DEPOSITS

Glacial drift

0-2	Topsoil; black clayey loam.
2-28	Clay, dusky-yellow, soft, cohesive.
28-37	Clay, olive-gray, soft, plastic.
37-88	Clay, silty to pebbly, olive-gray, slightly hard; iron-stained sand and gravel lenses (Till).
88-96	Sand, fine and medium, brown, moderately sorted, subrounded.
96-101	Clay, silty to pebbly, olive-gray; sand and gravel lenses (Till).
101-109	Sand, fine to coarse, gravelly, brown, assorted, iron stained.
109-160	Clay, silty to pebbly, olive-gray, stiff; sand and gravel lenses (Till).

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