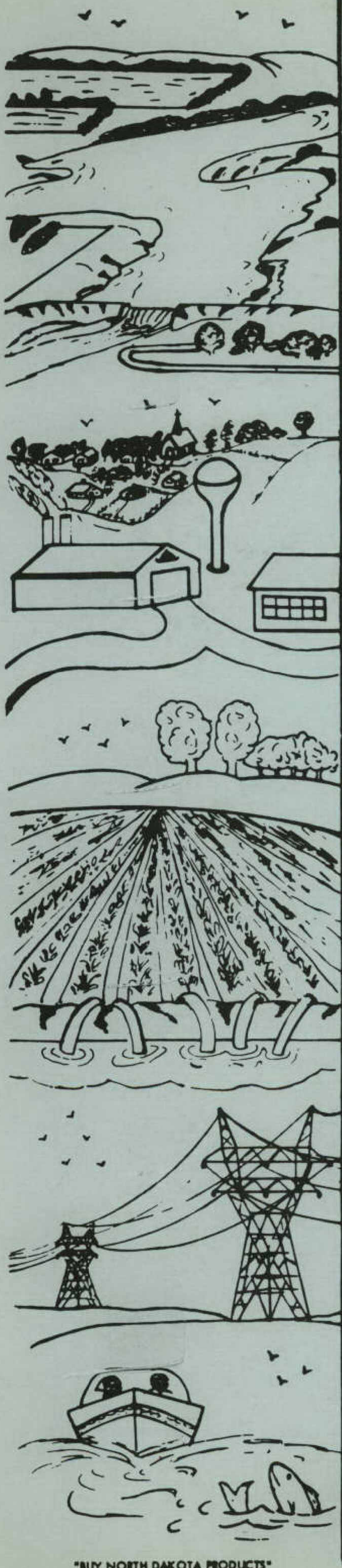


GROUND-WATER RESOURCES

of the

CROSBY AREA

DIVIDE COUNTY, NORTH DAKOTA

NORTH DAKOTA GROUND-WATER STUDIES

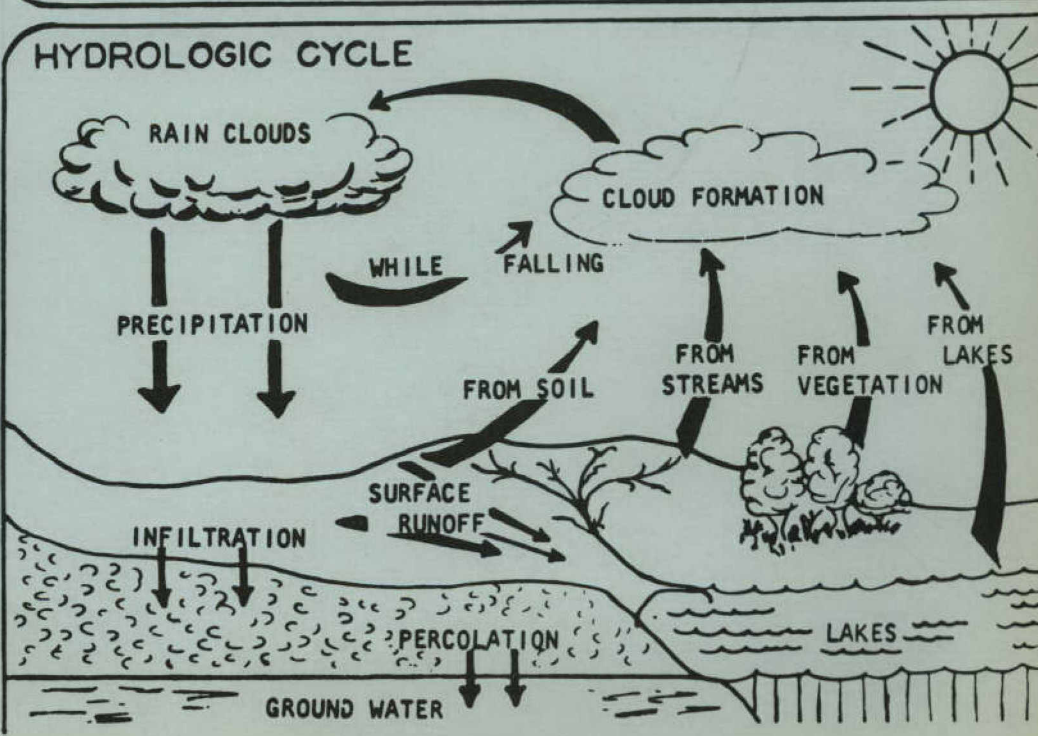
NUMBER 79

By
Larry L. Froelich
Ground-Water Geologist

Appendix
By
Alan Wanek
Hydrologist

North Dakota State Water Commission
Bismarck, North Dakota 58505

1983



GROUND-WATER RESOURCES OF THE CROSBY AREA

DIVIDE COUNTY, NORTH DAKOTA

NORTH DAKOTA GROUND-WATER STUDIES

NO. 79

By

Larry L. Froelich
Ground-Water Geologist

With Appendix By

Alan Wanek
Hydrologist

Published By

North Dakota State Water Commission
State Office Building
Bismarck, North Dakota

-1983-

CONTENTS

ILLUSTRATIONS

(plates in pocket)

TABLES

GROUND-WATER RESOURCES OF THE CROSBY AREA
DIVIDE COUNTY, NORTH DAKOTA

INTRODUCTION

Purpose and Scope

In November, 1971, the Crosby City Council approved a motion authorizing the drafting of plans and specifications for a half-million dollar water system improvement project. Proposed for the project was a treatment plant, a 500,000 gallon storage facility, a well and a water transmission line from the well to the plant. Although there was a general consensus that adequate underground water was available to support a municipal supply, the City Council, at the suggestion of their consulting engineer, requested the North Dakota State Water Commission to conduct a ground-water study of the area. The Crosby Ground-Water Survey was approved on December 2, 1971, and field work began immediately.

The purpose of this investigation was to evaluate the quantity and quality of ground water in the Crosby area. The principal objective was to locate the most suitable site for the proposed municipal well.

Field work consisted of drilling test holes and installing observation wells. Water samples were obtained from the wells to determine chemical characteristics of the water. Water level fluctuations were determined by periodic measurements. Actual pumping conditions were observed at the existing municipal well (City Well #3).

A total of 22 test holes were drilled in December before inclement weather forced a shutdown of operations. Drilling was resumed in May 1972; however, extremely wet conditions seriously affected the location of test hole sites. Nineteen additional test holes were drilled in May and June.

ACKNOWLEDGEMENTS

The test drilling was accomplished by Lewis Knutson using the State Water Commission hydraulic-rotary drilling machine and by Tony Mann, Mann Drilling Company of Garrison, North Dakota, using a hydraulic-rotary drilling machine. Field work was under direct supervision of Milton O. Lindvig, Chief of the Hydrology Division, State Water Commission. L. L. Froelich and C. E. Naplin, State Water Commission geologists, logged the test holes. Chemical analyses were performed by G. O. Muri, State Water Commission chemist.

LOCATION AND GENERAL FEATURES

Divide County is in extreme northwestern North Dakota. Crosby, the county seat and largest city (1970 population 1,542), is located in the northeastern part of the county. The Crosby area, as described in this report, includes approximately 92 square miles (all or portions of) in Townships 162, 163, and 164 North, Ranges 96 and 97 West.

The Crosby area, for the most part, lies within the Drift Prairie section of the Central Lowlands physiographic province (fig. 1). It is characterized by a northeastward sloping glacial plain of low relief. The Missouri Escarpment occupies the southeastern corner of the report area. It represents the steep north-facing slope of the Coteau Du Missouri which extends through Divide Coungy in a southeasterly direction across the state into South Dakota. The escarpment is interrupted southwest of Crosby where a large re-entrant into the Coteau marks the buried valley of the Yellowstone River, which flowed north prior to glaciation.

Maximum topographic relief approximates 250 feet. The highest altitude (2,130 feet msl, mean sea level) occurs on the Coteau in the extreme southeast corner of the area. The lowest altitude (1880 feet msl) is in the Long Creek

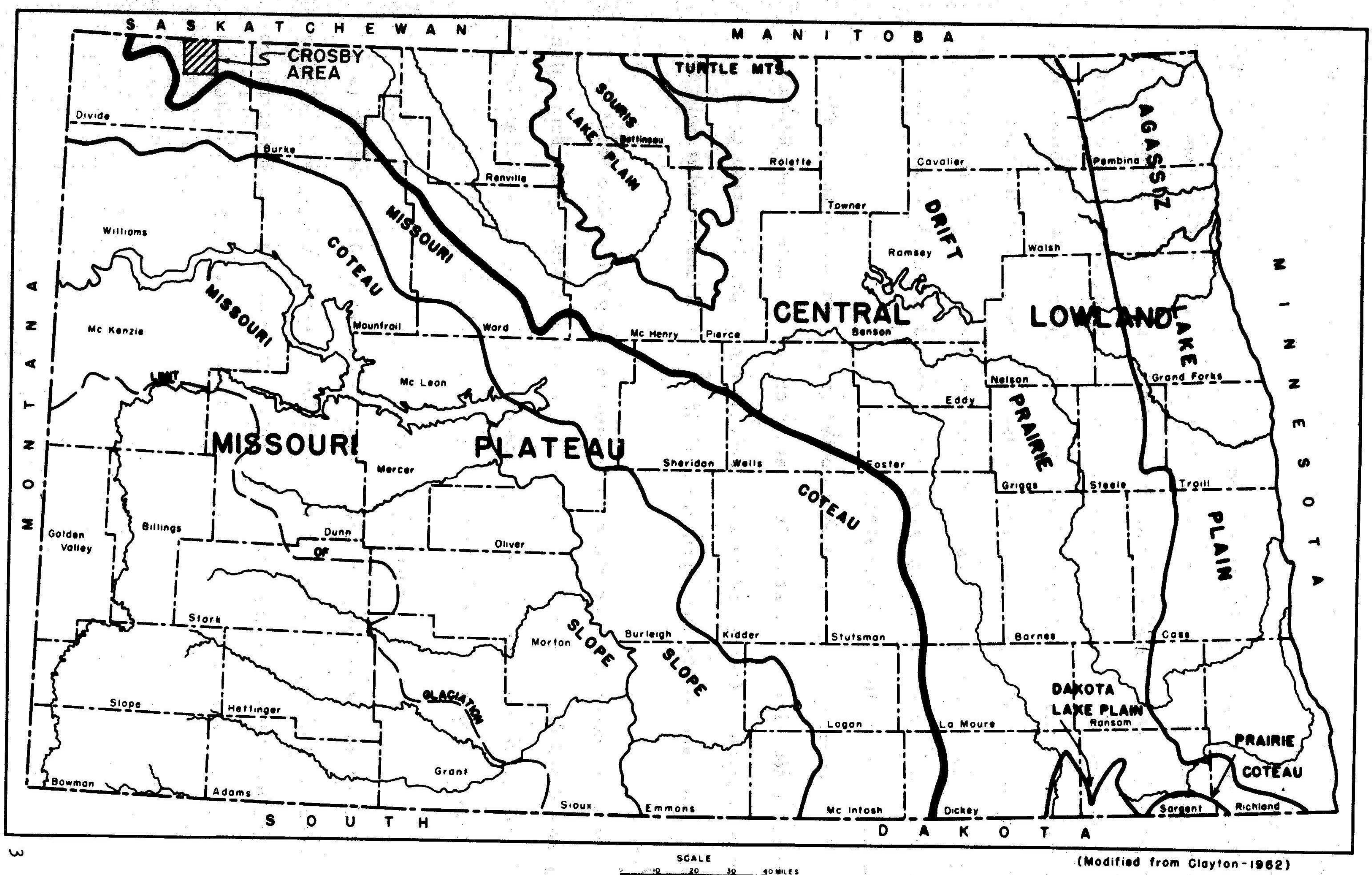


FIGURE I -- MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE CROSBY AREA.

channel where it leaves the area. Local relief in the Drift Prairie section rarely exceeds 20 feet.

Drainage from the Missouri Escarpment is toward an unnamed intermittent stream channel at the base of the Coteau which formerly contained Long Creek and which effectively drained a large post-glacial lake that occupied the re-entrant southwest of Crosby. Chains of perennial and intermittent lakes and sloughs in the central part of the Crosby area also represent former ice-marginal courses of Long Creek. Present day Long Creek drains the northern part of the area from west to east. Between the present and former stream channels drainage in nonintegrated and characterized by numerous undrained depressions of various size and shape.

The economy of the Crosby area is based largely on agriculture. The climate is semi-arid. Climatological data recorded at the National Weather Service station at Crosby indicate the average annual precipitation to be 13.36 inches and an average temperature of 38.9° F (National Weather Service, 1971).

Motor transportation to the area is provided by North Dakota State Highways 5 and 42. Crosby is the western terminus of a spur of the Burlington Northern Railroad (formerly Great Northern Railroad). The municipal airport is located one-half mile north of the city at an altitude of 1945 msl.

PREVIOUS INVESTIGATIONS

A study of the geology and ground-water resources of Divide County is included in a series of three reports published as County Ground Water Studies 6 of the North Dakota State Water Commission. The investigation was performed as a cooperative effort of the State Water Commission, North Dakota Geological

Survey, United States Geological Survey and the Divide County Board of Commissioners. In his report, Hansen (1967, p. 2) discusses contributions by authors of publications relating to the geology of Divide County. Armstrong (1967, p. 3) includes prior investigators concerned with the ground water resources of Divide County. Supplemental county-wide ground-water studies include Williams County (County Ground Water Studies 9) and Burke and Mountrail Counties (County Ground Water Studies 14).

The general geology of the Crosby Quadrangle was mapped by Townsend (1954). His report contains a special section in which ground-water resources of the quadrangle are discussed by LaRocque. Naplin (1969) described the ground-water survey of the Columbus area. Columbus is located 25 miles east of Crosby in Burke County.

AREA WATER SUPPLIES

Early settlers of the Crosby area experienced little difficulty in locating shallow ground water to supply hand dug wells. Because surface water supplies were limited and subject to climatic variations, water wells became the major source of public, domestic, and stock requirements. However, the ease with which the shallow waters became polluted, along with the generally high dissolved mineral content of the water, forced many persons to have wells bored to greater depths in search of more suitable supplies. When it was discovered that flowing artesian wells could be obtained throughout much of the area, small diameter drilled wells began replacing the larger diameter dug and bored wells. Armstrong (1965, table 1) lists wells ranging from 16 to 562 feet in depth and 2 to 60 inches in diameter throughout the Crosby area. Water levels are commonly less than 30 feet bls (below land surface), but range from flowing to a reported 140 feet below land surface.

Simpson (1929, p. 120) described the public supply at Crosby as "furnished by an artesian well 622 feet deep and 5 inches in diameter at the top and 1¼ inches at the bottom." Flow from the well was reported at one gpm (gallon per minute). Simpson also mentioned a shallow (30 feet in depth) well used for public supply near Main Street and the Great Northern Railway, but warned of the danger of pollution. In his report, Simpson discusses a group of wells about one mile west of Crosby and states, "The waters...represented by these wells are unquestionably the best waters in this vicinity, not only for domestic use, but everything considered, for city supply." Apparently Crosby residents followed Simpson's suggestion because Armstrong (1967, p. 49) reports that prior to 1941 the city obtained its water supply from two wells developed in the deposits of the abandoned Long Creek channel to the west of the city. Armstrong estimates 50,000 to 100,000 gpd (gallons per day) were pumped from the wells.

Presumably the drought of the late 1930's caused a serious decline in water levels in the area because in 1941 the city drilled a flowing well, 296 feet in depth, about two miles southeast of Crosby. The well is 12 inches in diameter and reportedly will yield 74 gpm for a few hours (Armstrong, 1967, p. 51). In 1949 city well #2 was drilled a short distance from the 1941 city well #1. The well is six inches in diameter and 390 feet deep. It was used as a standby supply until 1964 when its use was discontinued. The present municipal supply is obtained from city well #3 located in the NW¼ Section 35, Township 163 North, Range 97 West, along the Burlington Northern right-of-way. The 12-inch well was drilled in 1957 to a depth of 310 feet. It originally flowed, but approximately 30 feet of artesian pressure head has been lost since its installation and the present static water level is about 10 feet bls within the immediate vicinity.

In December, 1971, city well #3 was being pumped at a rate of 260 gpm and had a measured drawdown of 84 feet. Average municipal use approaches 5,000,000 gallons monthly.

WELL NUMBERING SYSTEM

Wells and test holes listed in the tables are numbered according to a system based on the location in the public land classification of the United States Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral denotes the section in which the well is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10 acre tract). For example, well 163-97-35ADD is in the SE¼SE¼NE¼ Section 35, Township 163 North, Range 97 West. Consecutive terminal numerals are added if more than one well is recorded 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 earth's 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.

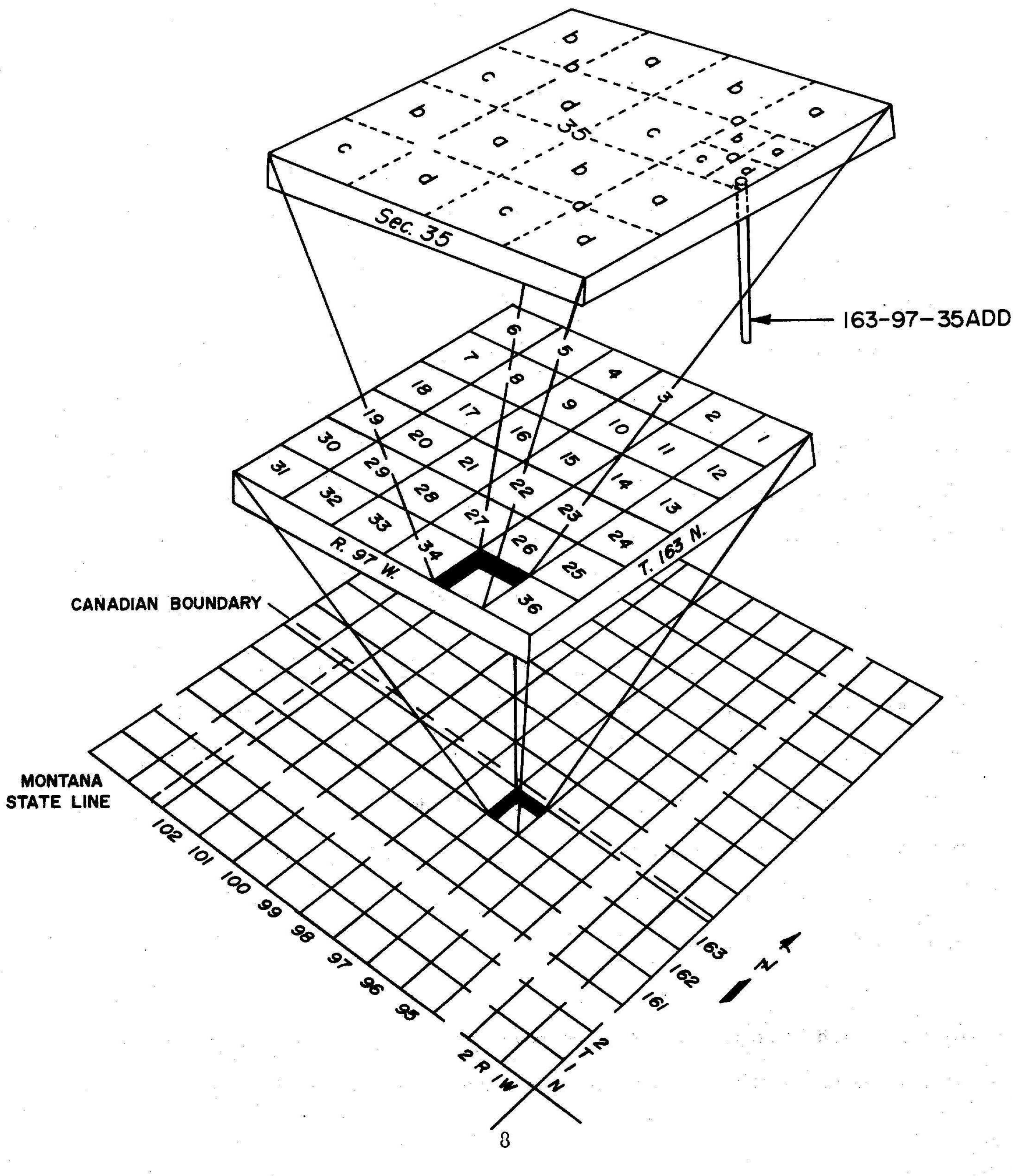


FIGURE 2 WELL-NUMBERING SYSTEM

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 boundary conditions.

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 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. In general, ground water withdrawn near a recharge area will be less mineralized than that which occurs at the discharge area.

The dissolved mineral constituents in water are reported in parts per million (ppm), milligrams per liter (mg/1), or grains per U. S. gallon (gr/gal).

One part per million is a unit weight of a constituent in a million unit weights of water. Milligrams per liter are, for all practical purposes, equivalent to parts per million. Parts per million may be converted to grains per gallon by dividing the ppm by 17.12.

The following summary gives the significance of the various constituents determined by chemical analysis as they apply to a domestic or municipal water supply in North Dakota (Schmid, 1965):

Silica (SiO_2)

Silica has no physiological or esthetic significance.

Iron (Fe)

Over 0.3 mg/l may cause staining of laundry and fixtures. Over 0.5 mg/l may be tasted by persons unaccustomed to water with a high iron content. Iron removal is economically feasible.

Manganese (Mn)

Manganese is similar to iron, producing black stains when present in amounts over 0.05 mg/l.

Calcium (Ca) and Magnesium (Mg)

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

Sodium (Na)

Sodium has no physiological or esthetic significance except for persons on salt-free diets. It eventually affects soils if high-sodium waters are used for irrigation without proper additives.

Potassium (K)

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

Bicarbonate (HCO_3) and Carbonate (CO_3)

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

Sulfate (SO_4)

A North Dakota Department of Health survey indicates a noticed laxative effect when sulfates reach 600 mg/l. Sulfates are classified as follows:

0 to 300 mg/l - low
300 to 700 mg/l - high
Over 700 mg/l - very high

Chloride (Cl)

Over 250 mg/l chloride may have a salty taste to persons not accustomed to it. Humans and animals can adapt to higher concentrations.

Fluoride (F)

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

Nitrate (NO_3)

Over 45 mg/l nitrate may be toxic to infants. Higher concentrations may be tolerated by adults. In excess of 200 mg/l it may have a deleterious effect on livestock.

Boron (B)

Boron has no physiological or esthetic significance.

Total Dissolved Solids

Persons may become accustomed to water containing 2,000 mg/l or more total dissolved solids. They are classified by the State Department of Health as follows:

0 to 500 mg/l	- low
500 to 1,400	- average
1,400 to 2,500	- high
Over 2,500	- very high

Hardness

Hardness increases soap consumption but may be removed by a water softening system. The State Department of Health classifies hardness as follows:

0 to 200 mg/l	as $CaCO_3$		- low
200 to 300 mg/l	"	"	- average
300 to 450 mg/l	"	"	- high
over 450 mg/l	"	"	- very high

pH

The pH should be between 6.0 and 9.0 for domestic consumption.

Percent Sodium; Sodium Adsorption Ratio (SAR); Specific Conductance

These are factors used in determining irrigation feasibility.

OCCURRENCE OF GROUND WATER

Ground-water occurrence in any area is directly related to the geology. The interpretation of the geology of the Crosby area is based, for the most part, on the logs of test holes. Additional geohydrologic data have been extrapolated from Hansen (1967) and Armstrong (1965, 1967). Locations of test holes are shown in Plate 1 and individual descriptions are included in table 3 at the conclusion of this report.

The economically recoverable ground-water resources are described in relation to the geologic units in which they occur. There are two major stratigraphic units underlying the Crosby area; (1) bedrock, which consists of Mesozoic rock of Cretaceous age and Cenozoic rock units of Paleocene age; and (2) glacial drift of Quaternary age.

GROUND WATER IN THE BEDROCK

The Crosby area overlies the northern flank of the Williston Basin, a structural basin containing a thick sequence of sedimentary rocks. The rock units that overlie Precambrian rocks were deposited during the Paleozoic, Mesozoic and Cenozoic Eras (Hansen, 1967, p. 11). During the time span which includes Cambrian through Cretaceous age, sediments were deposited chiefly in a marine environment; non-marine rocks were deposited during the late Cretaceous and Early Tertiary. The total thickness of sedimentary rocks at Crosby may be as great as 12,000 feet (Basement Rock Projects Committee, 1967).

Only the Mesozoic and Cenozoic rock units above the Pierre Formation of Late Cretaceous age are considered in this report. Certain formations below the Pierre, notably the sandstone and carbonate rocks, could possibly yield very large supplies of water, however, the water is so highly mineralized that it would not be suitable for most purposes without highly technical and expensive methods of treatment. The Pierre Formation is a thick shale sequence that is too fine grained to transmit significant quantities of water to wells. Depth to the Pierre Formation at Crosby probably is 1,400 to 1,500 feet.

CRETACEOUS ROCKS

The Fox Hills Formation conformably overlies the Pierre Formation. It consists of slightly more than 250 feet of interbedded marine shale and sandstone. The Fox Hills in turn, is overlain by slightly less than 250 feet of non-marine Hell Creek sediments. The contact probably is gradational. The Hell Creek Formation is the youngest Cretaceous formation in the Crosby area and consists chiefly of carbonaceous siltstone and claystone or shale with interbedded fine-grained sandstone.

There are no water wells developed in either the Fox Hills or Hell Creek Formations in the Crosby area. In other parts of the state where development has taken place, the two formations function essentially as a single hydrologic system. Investigations by Croft (1973) have revealed apparent geohydrologic differences between the lower and upper Hell Creek, however.

The sandstone beds in the Fox Hills and Hell Creek Formations may yield small quantities of ground water. The sands are generally poorly sorted which results in low transmissivity and reduces the specific capacity of a well to $\frac{1}{4}$ to $\frac{1}{2}$ gallon per minute per foot of drawdown. The water level or potentiometric surface is undetermined at present (1973), but flowing wells are a possibility. The closest sources of recharge are the Brockton and Scobey areas of northeastern Montana where the formations are exposed at the surface. Ground-water discharge is to areas to the north and east of Crosby. The water contained in the sandstone beds can be expected to be a soft sodium bicarbonate type with total dissolved solids in the 1,500 to 2,000 mg/l range.

PALOCENE ROCKS

The Ludlow Formation overlies the Hell Creek at a gradational contact. It consists of non-marine carbonaceous shale and bentonitic claystone with thin beds of siltstone, fine-grained sandstone, and lignite. The formation may be 250 to 300 feet thick in the Crosby area. Both Hansen (1967, p. 21) and Armstrong (1967, p. 18) refer to this section as the Ludlow-Cannonball Formations, undifferentiated; however, data are insufficient to suggest the marine sediments of the Cannonball Formation exist in the Crosby area. If the Cannonball is present, a combined thickness of 450 feet is possible for the Ludlow-Cannonball. Hansen (1967, p. 23) indicates the Ludlow subcrops beneath the glacial drift throughout much of the Crosby area; Armstrong (1967, p. 18) disagrees. In any event, the Ludlow is very difficult to distinguish in the subsurface from the overlying Tongue River Formation.

The Tongue River, the youngest bedrock formation in the Crosby area, is composed of nearly horizontal, but lenticular, non-marine beds of lignite, claystone, siltstone, and sandstone. If Hansen's Ludlow subcrop theory is correct the Tongue River ranges from absent to perhaps 500 feet thick. Test holes drilled in connection with this study usually encountered sandstone deposits at various intervals beneath the glacial drift. Some of these sandstones may be correlative with the basal or "lower Tongue River aquifer" described by Croft (1973, p. 37).

There are no known wells developed in the Ludlow Formation in the Crosby area, although it is possible the municipal artesian well described by Simpson (1929, p. 120) may have recovered water from the Ludlow. The scarcity of wells may suggest only meager water supplies are available from the Ludlow and that the water quality is unsuitable for most purposes. Numerous wells have been developed in the Tongue River Formation and usually yield small but dependable supplies from the sandstone and/or lignite beds. Many of the wells flowed originally; some still do. Discharge results from pumping or flowing wells, upward and lateral seepage to the overlying glacial drift, and natural underflow to the north. The water is generally high in sodium, bicarbonate and total dissolved solids. The water is normally satisfactory for stock water, but not recommended for human consumption if better quality water is available.

GROUND WATER IN THE GLACIAL DRIFT

The bedrock topography, the base of the glacial drift in the Crosby area, has the approximate configuration shown on Plate 2. This form is an interpretation based on the surface elevations of the bedrock as determined from test drilling and, to some extent, available information on water wells.

Test drilling revealed the thickness of glacial drift in the Crosby area ranges from 45 to over 575 feet (table 3), and is greatest over buried valleys. The largest vertical accumulation of drift overlies the preglacial valley which contained the northeasterly flowing Yellowstone River (Plate 2). More than 450 feet of drift may overlie the Columbus buried valley, created when the Yellowstone River was diverted eastward by continental glaciation. The Crosby buried valley contained a northeasterly flowing stream tributary to the Columbus valley. It probably formed during one of the earlier interglacial periods of the Pleistocene Epoch and is now filled and overlain by about 400 feet of drift. The divides between the former drainage systems consist of buttes and ridges capped by the least thickness of glacial drift. The buried bedrock topography is undoubtedly more complex than indicated on Plate 2 and probably similar in appearance to that now developed on the exposed Tertiary rocks of western North Dakota.

Glacial drift can be separated into three groups of clastic lithologies based on differences in texture and bedding. The groups include: 1) clay and silt, 2) sand and gravel, and 3) till. The stratigraphic relationship of the lithologic groups are illustrated in cross sections A-A', B-B', and C-C' (pl. 3).

Clay and silt occur on the land surface and at depth throughout the Crosby area. They represent the depositional phase of proglacial lakes created by the impoundment of meltwater. These glaciolacustrine sediments occur as thick extensive and generally continuous deposits or as thin narrow lenses. The clays are olive gray to olive black in color and the silts usually light olive gray. Both are commonly laminated and interbedded. Clay and silt do not readily yield water to wells and are, therefore, not considered aquifers.

Extensive stratified glaciofluvial deposits of sand and gravel commonly constitute the fill of the major buried valleys and, in most instances, directly overlie bedrock. Less extensive deposits occur as long narrow interglacial channel fills or as randomly interspersed pockets of indeterminable size and shape associated with glacial till. Surficial sand and gravel deposits are contained in the former and present-day courses of Long Creek. Generally, the sand and gravel varies considerably in grain size, sorting and type of bedding. The ability of these deposits to yield large quantities of ground water depends on their transmissivity, areal extent and the amount of recharge they receive.

The majority of glacial drift is composed of till, a heterogenous mixture of clay, silt and sand with pebbles, cobbles and/or boulders. This debris is a result of 4, or possibly 5, separate glacial advances that overrode the Crosby 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. No attempt is made in this report to correlate the individual drift sheets. Till is relatively impermeable and yields little water to wells.

YELLOWSTONE BURIED VALLEY AQUIFER

The Yellowstone buried valley was eroded in Late Tertiary time by the ancestral Yellowstone River. Originally, the river flowed north from Williston, past Crosby, to its confluence with the preglacial Missouri River near Estevan, Saskatchewan (Armstrong, 1967, p.26). The valley enters the southwest corner of the Crosby area and continues north-northeast into Canada (plate 2).

Two major periods of erosion are believed to exist in the Yellowstone valley. The main valley, approximately 1½ miles wide, formed during an early erosional sequence. Perhaps as a result of regional uplift an inner valley, approximately ¼ mile wide, incised as much as 100 feet below the floor of the main valley. This narrow valley-in-valley became filled with gravel, presumably during the interglacial period following the initial glacial advance in the area, and was subsequently overridden by ice. Any fill which may have been deposited in the larger main valley, however, was essentially redistributed and incorporated into the debris of the second glacial advance. The fill in the main valley now consists primarily of till.

Glaciofluvial gravel, believed to represent the inner valley fill, was encountered from 540 to 575 feet in depth in test hole 4445 (163-97-15BCC, plate 1). The deposit was not completely penetrated, however. If this gravel, which is apparently highly permeable and porous, is continuous with the inner valley throughout the Crosby area the potential for development could be substantial. Assuming the gravel deposit is present and continuous, it is referred to herein as the Yellowstone buried valley aquifer.

Test hole 8289 (163-97-22CCC) and a Missouri Basin test hole (163-97-33CCC) are suspected to have been drilled on or near the axis of the Yellowstone buried-valley aquifer. However, they were abandoned in the glacial drift at depths of 332 and 521 feet, respectively. Other test holes, including numbers 3024, 4442, 4443, 4444, 8283, 8286, 8287, and 8288 (plate 1) penetrated the fill of the main Yellowstone valley but encountered no recognizable aquifers of significance.

A two-inch observation well, screened from 546 to 558 feet, was installed in test hole 4445 (163-97-15BCC). Following development, in June 1972, the measured water level in the well casing was 36.43 feet bls (table 2). By August, the water level had recoevered to 14.48 bls. In January, 1973, the water level measured 11.54 feet bls and stayed fairly consistent. This indicates the Yellowstone buried valley aquifer is under artesian conditions with hydrostatic head about 500 feet above the top of the aquifer.

The chemical analysis of a water sample from the observation well (table 1) indicates the water is low in hardness and a sodium-bicarbonate type. Iron content exceeded the recommended limit. The 90 percent sodium, which is higher than all other analyzed glacial drift waters in the Crosby area, would restrict its use for irrigation.

The chemical quality of the water in the Yellowstone buried valley aquifer suggests the majority of recharge is being transmitted from the underlying Paleocene rocks. Discharge is to the north and laterally within the confines of the buried valley. Some upward leakage to the overlying drift may also occur. Recharge to the aquifer equals discharge over a given period of time.

Development of the aquifer consists of one farm well (163-97-22CDC$_3$, Armstrong, 1965, p. 47) throughout the entire Crosby area. Future development will depend primarily on locating the aquifer by means of test drilling. Difficult drilling conditions can be expected.

COLUMBUS BURIED VALLEY AQUIFER

The Columbus buried valley is a generally west-to-east trending valley formed as a result of the ancestral Yellowstone River being dammed by ice and glacial drift. The damming of the river may have occurred during the second major interglacial period at which time the Yellowstone valley to the south of the Crosby area was filled with runoff water from the melting ice. Apparently the resulting lake was short-lived and eventually the water was diverted to the east, in front of the ice margin, and created the Columbus valley. The narrowness and depth of the valley indicates a considerable quantity of water was involved and erosion was very rapid. The valley can be traced from the Crosby area to the Columbus area (Naplin, 1969) where it was initially identified by test drilling. From Columbus the valley trends eastward across northern Burke County (Armstrong, 1971, pl. 3).

North of Crosby (plate 2) near the confluence of the Yellowstone and Columbus valleys, another valley, time equivalent to the Columbus valley, is inferred to have entered from the northwest. This valley is believed to have contained water diverted from the ancestral Missouri River. The diversion of the Missouri probably occurred several miles north of Ambrose, North Dakota, in southern Saskatchewan.

Additional subsurface exploration would be required to accurately delineate the boundaries and historical sequence of events concerning the Columbus valley in the Crosby area. However, test hole 4429 (163-97-24BBB) is believed to reasonably represent the aquifer contained in the Columbus buried valley.

As indicated in geologic section C-C' (pl. 3) gravel and cobbles occupy the lower part of the valley fill at a depth of 414 to 440 feet, and presumably directly overlie bedrock. The gravel deposit was not completely penetrated because of lost circulation of the drilling fluid, but extends to at least 457 feet based on the log of a nearby Missouri Basin test hole (163-97-13CCC). In test hole 4429, 38 feet of coarse sand overlies the basal gravel. This sand and gravel, and its extension to the east and west within the confines of the valley, constitutes the Columbus buried valley aquifer. The aquifer is overlain by 37 feet of silty clay, suggesting the valley during its latter stage was blocked at some point downstream and the stream was ponded. The lithologic section above the lake deposits consists essentially of till.

Test hole 4437 (163-97-24AAA) also encountered the Columbus buried valley aquifer. The position of the test hole along the line of section B-B' (pl. 3) however, creates the illusion the Columbus valley is trending upgradient to the southwest. Actually the sands southwest of test hole 4437 represent the depositional cycles in the Crosby buried valley (plate 2) and will be discussed in the following section dealing with the Crosby buried valley aquifer.

Observation wells were installed in test holes 4429 and 4437. Well 4429 was screened from 420 to 432 feet bls and well 4437 from 399 to 411 feet bls. The measured water levels on December 13, 1973 (table 2) were 50.91 and 55.29 respectively, indicating artesian conditions prevail. Converting the water level measurements to elevation above mean sea level, the potentiometric surface at well 4429 was 1864.09 feet and 1863.71 feet at well 4437. Therefore the hydraulic gradient is decreasing to the east at a rate of .38 feet per mile. The Columbus aquifer at wells 4429 and 4437, however, is being influenced by the Crosby buried valley aquifer because of direct hydrologic connection. Therefore, although the slope of the hydraulic gradient may remain fairly constant in the Columbus aquifer as it leaves the Crosby area to the east, an increase in gradient slope could be expected toward the west where the aquifer enters the area.

Test holes 4443, 4444, and 4445 (plate 1) were drilled in the approximate area the Columbus valley was believed to have intersected the Yellowstone valley (plate 2). The Columbus aquifer could not be identified in any of the tests, however. It is assumed, therefore, the aquifer passes just south of test hole 4445. The Columbus valley west of the junction with the Yellowstone valley may be relatively narrow, possibly in the neighborhood of 1,500 feet wide. It can be identified only by additional test drilling.

Data are insufficient to determine the average depth, width, thickness, and hydrologic properties of the Columbus aquifer within the Crosby area. An estimate of ground-water storage would be conjectural at best. However, based on field sample examination, drilling characteristics, and electric logs from test holes 4429 and 4437, and interpolating results from an aquifer test in the Columbus area (Armstrong, 1971, pp. 31-36), the following estimates seem reasonable. The transmissivity of the aquifer should be about 10,0000 ft^2/day. The specific capacity of properly constructed wells should approximate 25 gpm per foot of drawdown. Yields of over 500 gpm are possible from individual wells, however, a lesser rate may prove more practical if sustained pumping is to be maintained.

East and west of test holes 4429 and 4437, where the aquifer is assumed to be more confined and influenced less by the Crosby buried valley aquifer, considerable drawdown may result because of the effect of boundary conditions. Drawdown would continue as the cone of depression spreads up and down the buried valley until it nullifies the effects of the lateral boundaries and recharge equals discharge from the aquifer. A 30 to 40 foot loss of head may result if very large withdrawals are introduced. The aquifer would remain saturated but there may be a noticeable decrease of specific capacity under actual pumping conditions.

Water samples from wells 4429 and 4437 indicate the water contained in the Columbus aquifer is a sodium bicarbonate type with sulfate and chloride concentrations within acceptable limits. The water at well 4429 was somewhat softer and contained less total dissolved solids than well 4437, 240, and 1,380 mg/l as compared to 255 and 1,530 mg/l. Well 4437 contained water of exceptionally high iron concentration as compared to well 4429, 3.3 mg/l to 0.87 mg/l respectively; both exceed recommended limits. Percent sodium (81), SAR (14), and temperature (10°C or 50°F) was consistent at both locations.

Water quality suggests the Columbus aquifer is being recharged principally by underflow from the Paleocene rocks in which the Columbus buried valley is incised. Lateral recharge from the Crosby aquifer and direct infiltration of precipitation through the overlying glacial drift also contribute, but the proportion from each source is unknown. Development of the aquifer would undoubtedly induce more recharge from the glacial drift. Water level measurements indicate the aquifer is essentially in a state of equilibrium (recharge = discharge) at the present time. The Columbus aquifer in the Crosby area is, for all practical purposes, undeveloped.

CROSBY BURIED VALLEY AQUIFER

The Crosby buried valley formed as a major tributary to the Columbus valley. It enters in the south-central part of the Crosby area and joins the Columbus valley near the central part of the area (plate 2). The sequence and distribution of sediments in the valley (plate 3) suggest three cycles of deposition occurred. The first depositional cycle covered the valley floor with glaciofluvial deposits, principally sand and gravel. The second depositional cycle formed as a result of a glacial advance which blocked the drainage of the Columbus valley creating a proglacial lake in both the Columbus and Crosby valleys. Approximately 40 feet of lacustrine clays were deposited in portions of the valleys unoccupied by ice. Till defines the remainder of the area overlain by the glacier prior to recession of the ice. The third depositional cycle was confined to the Crosby valley and that portion of the Columbus valley east of their confluence and is represented primarily by fluvial sand. The Columbus valley west of the confluence was filled with till during the second depositional cycle. Meltwater which formerly followed the course of the western portion of the Columbus valley apparently was diverted elsewhere during the third cycle.

The Crosby buried valley aquifer is divided into two zones that are separated by clay and/or till. The lower zone, representing the first depositional cycle, is usually encountered from 320 to 390 feet below land surface. It averages 40 feet in thickness, but may be 80 or more feet thick. The upper zone, representing the third depositional cycle, generally is 230 to 310 feet below land surface and averages about 30 feet in thickness. The probable extent of the Crosby aquifer, and its relationship to the Columbus aquifer, are indicated on figure 3. Although thinner the upper zone of the Crosby aquifer appears to be more extensive laterally than the lower zone. The cumulative thickness of both zones is shown on figure 4.

Aquifer characteristics have been determined from the following test holes which penetrated one or both zones of the Crosby aquifer; they are test hole numbers 4423, 4424, 4425, 4428, 4432, 4433, 4438, 4446, 4447, 4450, 8290, 8291, 8292, and 8293 (plate 1). Observation wells were developed in the upper zone in test hole numbers 4423A, 4450, 8292, and 8293 and in the lower zone in numbers 4423, 4428, 4446, and 8291.

Estimates of aquifer constants were interpreted from four pumping tests which include city well #3, two test wells drilled by C. A. Simpson & Son in 1972; and the new, city well #4 drilled in 1973 also developed by the Simpson Drilling firm. All four pumping tests produced water from the upper zone of the Crosby aquifer. Water samples were collected for chemical analyses from all the wells.

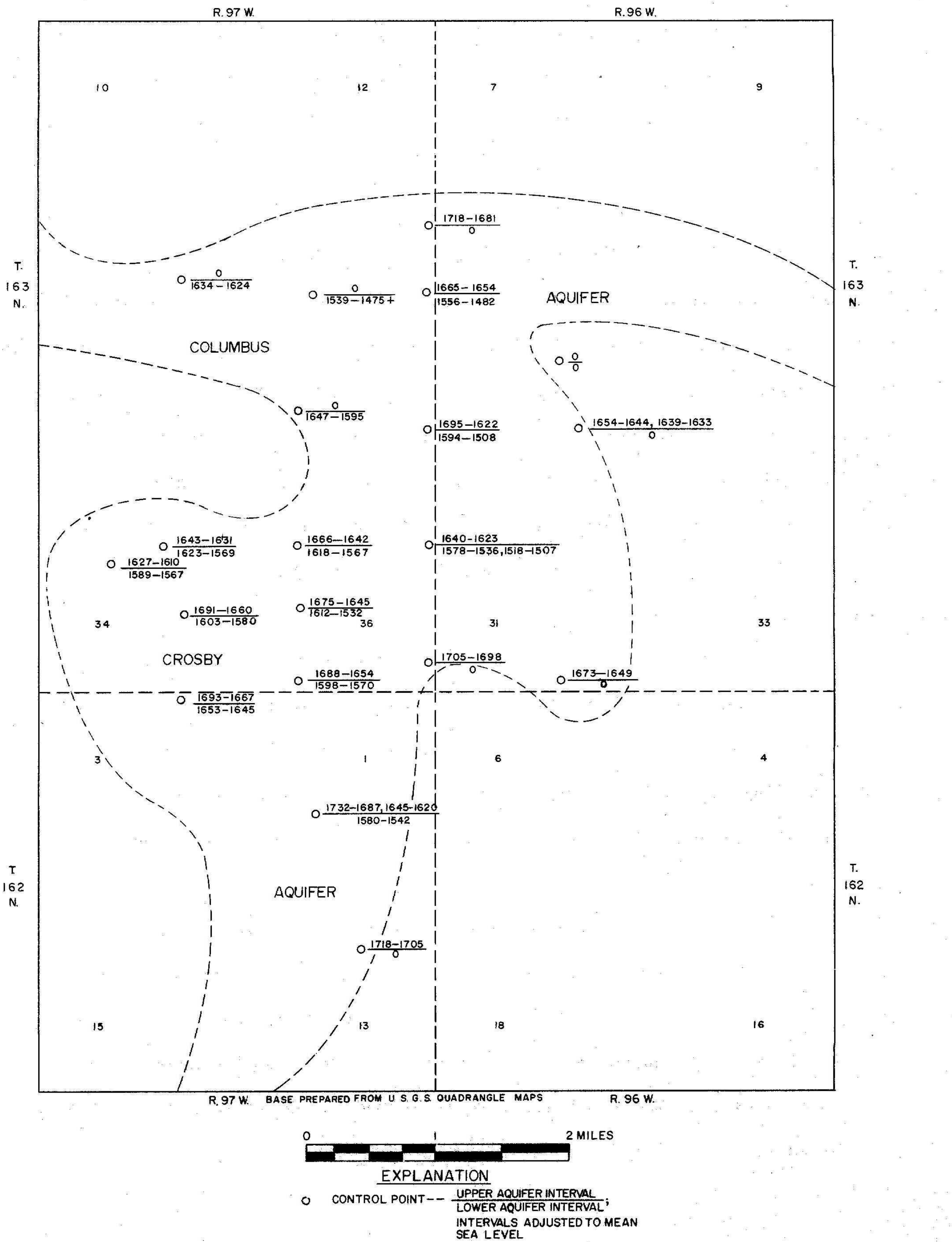
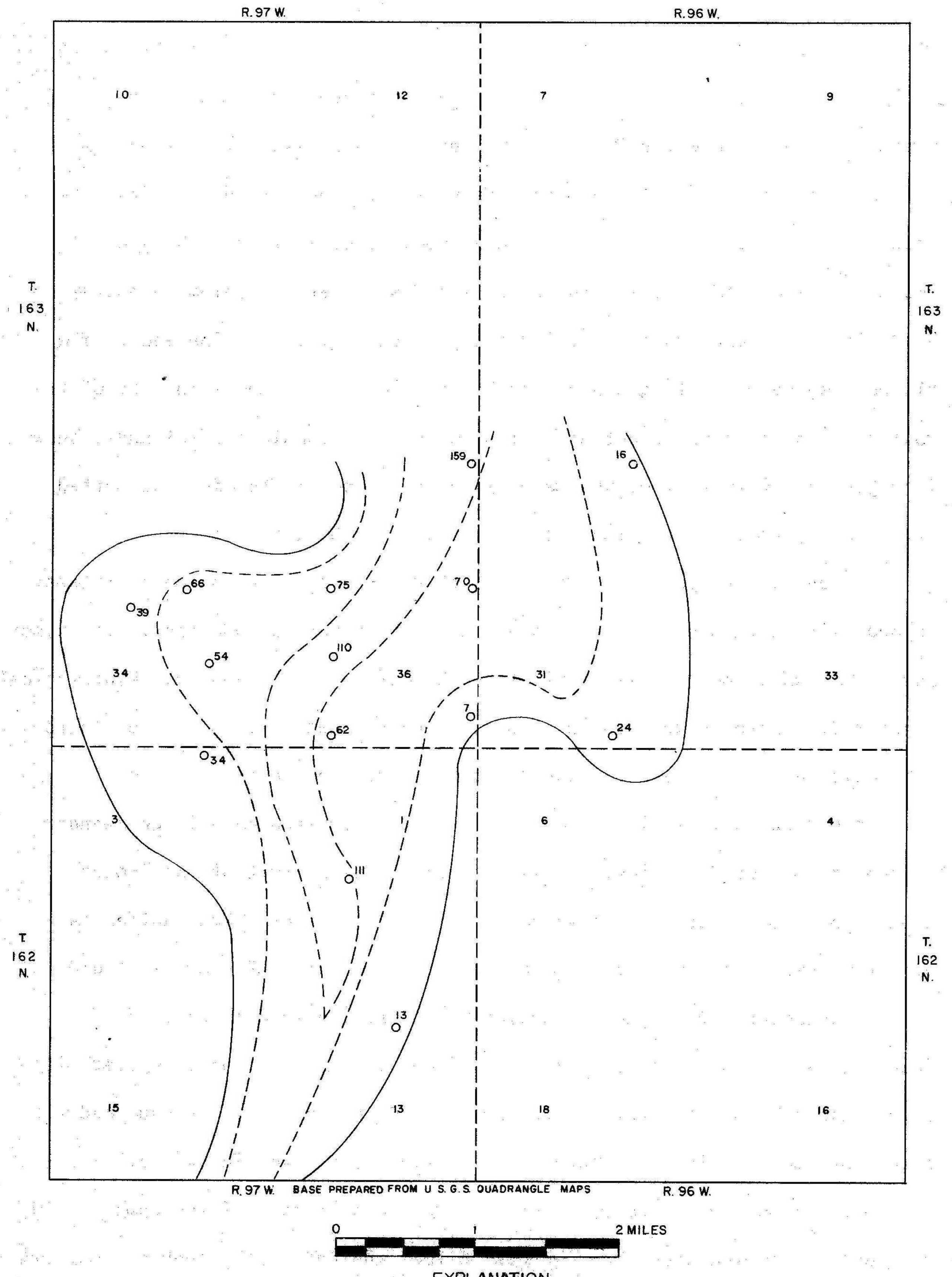


FIGURE 3--PROBABLE EXTENT OF THE COLUMBUS AND CROSBY BURIED VALLEY AQUIFERS



EXPLANATION

○70 CONTROL POINT-- NUMBER INDICATES TOTAL SATURATED THICKNESS.

CONTOUR INTERVAL--50 FEET.

FIGURE 4--CUMMULATIVE THICKNESS OF THE CROSBY BURIED VALLEY AQUIFER

Test drilling establishes the water bearing deposits in the Crosby buried valley as glaciofluvial in origin. Typical of glaciofluvial deposition, the materials are in no way uniform in thickness, grain size, or sorting. A general indication of thickness and grain size may be interpreted from the cross sections (pl. 1). The lower zone commonly consists of nearly equal amounts of sand and gravel. The upper zone is primarily medium to coarse sand with minor amounts of gravel but significant silt and fine sand. The highest degree of sorting appears to be associated with the main part of the valley which conforms essentially with the greater cumulative thickness shown in figure 4. Outward from the main valley the deposits become less sorted with lenticularity increasing proportionately to the distance.

Because of the variable lithology, there is also a variation in lateral permeability within each zone. This variation is more pronounced in the upper zone. The water bearing materials in each zone, nevertheless, are hydrologically connected. There is substantial proof, however, that a definite hydrologic separation exists between the upper and lower aquifer units.

The Crosby well field is located in what is apparently a large meander in the Crosby buried valley. It is near the western limit of the Crosby aquifer but both upper and lower zones are still present. The aquifer is absent within ½ to 1 mile to the north, west, and south of the well field.

In December, 1971, pumping cycles were observed on city well #3 (Schmid, 1972). The well casing is 12 inches in diameter and completed with 6 inch diameter shutter screen from 295 to 310 in depth. It is equipped with a turbine pump. Prior to pumping, the static water level in the well was 9 feet bls (below land surface). The well pumped at a rate of 260 gpm for 110 minutes. Total measured drawdown was 86 feet indicating the specific capacity of the well is about 3 gpm per foot of drawdown. Based on available and assumed data, Schmid concluded the well was operating at 20% efficiency. In 1957 Layne-Minnesota Company, after completing and developing city well #3, obtained a specific capacity of 2.52 gpm/ft dd (F. W. Voedisch, written comm.). At that time (1957) the static water level was 11½ feet above land surface with a pumping level of 100 feet bls. The well was pumped at 281 gpm for 19 hours.

In 1972, C. A. Simpson and Son drilled and pumped two 6 inch test wells. Well 72-1 (163-97-35bdd) was located ¼ mile southeast of city well #3 near the main channel of the Crosby aquifer. Screen was set from 306½ to 324 feet bls and after development the static water level was about 10½ feet bls. After pumping 80 gpm for 4½ hours this well had a specific capacity of approximately 20 gpm/ft dd. Well 72-2 (163-97-34daa) was drilled slightly more than ¼ mile southwest of city well #3. Screen was set from 287 to 309 feet bls. Static water level in the well was 14 feet bls. Specific capacity of this well was about 6 gpm/ft dd after 6½ hours of pumping at a rate of 328 gpm.

In July, 1973, C. A. Simpson and Son drilled a 6-inch test well at the proposed site of the new city well (163-97-34add). The well was screened from 272 to 303 feet bls and after 5 hours of pumping 30 gpm the calculated specific capacity was 10 gpm/ft dd. The casing and screen were recovered and the hole enlarged to accommodate 12 inch casing. Twelve inch nominal screen was then set from 277 to 307 feet bls. In September the State Water Commission and Mr. Fred Simpson performed a pumping test on the production well. Data from this test are included in a Water Commission open-file report (Schmid, 1974). The well was pumped at a rate of 450 gpm for 3000 minutes; however, concurrent with the test, city well #3 was also pumped continuously at 150 gpm. The specific capacity of the production well was determined to be 7.4 gpm/ft dd. Schmid concluded that transmissivity of the aquifer in the immediate vicinity of the Crosby well field was 2,700 ft^2/day with a storage coefficient of 5×10^{-5}. He also noted that excessive drawdown in observation well 8293 (163-97-35DDD) as compared to the theoretical drawdown was due to a non-contributing impermeable boundary to the east. A significant fact illustrated during the pumping test is that little if any drawdown was observed in observation wells developed in the lower zone of the Crosby aquifer.

Recharge to both zones of the Crosby aquifer is principally by underflow from adjacent Paleocene rocks. Direct infiltration of precipitation on the glacial drift overlying the aquifer also contributes to recharge. The pressure head or potentiometric surface relates directly to the abrupt increase in elevation to the south. Discharge is primarily natural underflow toward the Columbus buried valley aquifer. Water pumped from the upper zone of the Crosby aquifer during the past 25 years has resulted in a 20 foot lowering of the static water level in the vicinity of the well field and a cone of depression has developed. Beyond the area of influence of the city wells, water level measurements (table 2) indicate fluctuations in the potentiometric surface relate to seasonal variations and suggest the aquifer is essentially in a state of equilibrium.

An estimate of ground water in storage in the Crosby aquifer has been made assuming an average thickness of 30 feet for the upper zone and 40 feet for the lower zone. As delineated on figure 3, the Crosby aquifer underlies approximately 10 square miles or 6,400 acres. Conservatively assuming an overall porosity of 30 percent there should be over 130,000 acre-feet of water in storage within the Crosby area. Approximately 60 percent of this water could be recovered by wells, however, large scale pumping would in turn induce considerable recharge. It is therefore conceivable that a combination of both zones of the Crosby aquifer could adequately support several properly spaced wells pumping continuously at a rate of 500 gpm.

The lower and upper zones of the Crosby aquifer can be easily differentiated on the basis of water quality as evidenced by Table 1. Water contained in the lower zone is characteristically a sodium-bicarbonate type and closely resembles ground water contained in the Paleocene rocks into which the Crosby buried valley is incised. Noticeably, the total dissolved solids are usually over 1,000 mg/l and the percent sodium, sodium adsorption ratio (SAR) and pH average 82, 15, and 8 respectively. Water in the upper zone is also typically a sodium-bicarbonate type, but approaches or becomes a calcium-bicarbonate type near the central, more permeable part of the valley. Total dissolved solids in the upper zone generally are less than 1,000 mg/l and comparatively, the percent sodium, SAR and pH average about 5.0, 4.5 and 7.6, respectively. Fluoride and chloride concentrations are somewhat higher in the lower zone, however, both constituents are still within acceptable limits for a municipal supply. Sulfates in either unit are variable and apparently relate to the near proximity of glacial till or recharge therefrom. Increased sulfate concentrations are correlative with increased hardness of the water. Iron content for the most part is unpredictable.

UNDIFFERENTIATED GLACIAL-DRIFT AQUIFERS

Associated with the glacial drift, but separate from the aquifers contained in the Yellowstone, Columbus, and Crosby buried valleys, are water bearing deposits of sand and gravel that could or do support the requirements of domestic and stock wells. These deposits occur at the surface and at depth and may range from small isolated pockets or lenses to narrow but relatively lengthy channel fills. Surficial channel fill deposits occupy the present and former drainage courses of Long Creek and are easily traceable, however, test drilling is the only reliable means of locating the subsurface deposits.

Permeable surficial deposits normally contain very good quality water because of recharge by local precipitation and infiltration. However, water levels are extremely sensitive to climatic variations and there is the danger of contamination. Surficial aquifers in the Crosby area are therefore not highly recommended as a source for municipal supply.

The subsurface deposits, exclusive of the major aquifers, are characterized by generally poor quality water with total dissolved solids ranging from 1,500 to over 3,000 mg/l. These small aquifers contain calcium-sulfate type water when recharged exclusively by the surrounding glacial drift or sodium bicarbonate type water when recharge is derived primarily from the underlying bedrock. Well yields from the minor aquifers in general are limited and not capable of supplying the sustained pumpage required for a municipal water supply system.

SUMMARY

The Crosby area, as described in this investigation, includes approximately 92 square miles in northeastern Divide County. The area lies within the Drift Prairie section of the Central Lowlands physiographic province of North Dakota. The average annual precipitation is 13.36 inches and the annual temperature is 38.9^{o}F. Long Creek and an unnamed intermittent stream channel, the ancestral Long Creek, drain the area.

The Crosby area overlies the northern flank of the Williston Basin and is underlain by as much as 12,000 feet of consolidated sedimentary rocks. The test holes in this investigation terminated in bedrock, except where difficult drilling conditions existed. One test hole penetrated the Fox Hills Formation of Late Cretaceous age, the remainder were completed in the Tongue River Formation of Paleocene age.

Test drilling revealed the thickness of glacial deposits consisting of till and buried outwash ranges from 45 feet to over 575 feet, and is greatest over buried valleys. Extensive stratified glaciofluvial deposits of sand and gravel commonly constitute the fill of the major buried-valley aquifers: the Yellowstone, Columbus, and Crosby. In most instances they directly overlie bedrock.

The Yellowstone buried valley aquifer, approximately 1½ miles wide, enters the southwest corner of the Crosby area and continues north-northeast into Canada. Water-bearing material consists of glaciofluvial gravel in an approximately ¼ mile wide valley-in-valley. The gravel was encountered from 540 to 575 feet, but was not completely penetrated. A chemical analysis indicates the water is low in hardness and a sodium-bicarbonate type. Iron content exceeded the recommended limit. Chemical quality suggests recharge is from the underlying Paleozoic rocks.

The Columbus buried valley aquifer trends west-to-east and resulted from damming of the ancestral Yellowstone River. Water bearing material consists of coarse sand, gravel, and cobbles, and may be as much as 80 feet thick. Data are insufficient to determine the average depth, width, thickness, and hydrologic properties within the Crosby area. Analyses indicate the water is a sodium bicarbonate type and is being recharged by the underlying Paleocene rocks. The Columbus aquifer is practically undeveloped.

The Crosby buried valley aquifer which underlies approximately 10 square miles of the Crosby area is divided into two zones. The lower zone consisting of glaciofluvial sand and gravel is usually encountered from 320 to 390 feet and averages 40 feet in thickness. The water is a sodium-bicarbonate type similar to ground water in the underlying Paleocene rocks. The upper zone, represented primarily by medium to coarse fluvial sand, is generally encountered 230 to 310 feet below land surface and averages 30 feet in thickness. The water is typically a sodium-bicarbonate type but approaches or becomes a calcium-bicarbonate type near the central, more permeable part of the valley. The Crosby city well #4 was developed in the upper zone. Ground water in storage in the Crosby aquifer (both zones) is estimated to be over 130,000 acre-feet and should adequately support several properly spaced wells pumping continuously at a rate of 500 gpm.

Associated with the glacial drift, but separate from the Yellowstone, Columbus, and Crosby buried valley aquifers, are water bearing deposits of sand and gravel. These deposits occur at the surface and at depth and range from small isolated pockets or lenses to narrow relatively lengthy channel fills. In general, well yields from minor aquifers are limited for a municipal water supply system.

TABLE 1 -- CHEMICAL ANALYSES

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

AQUIFERS Owner or Designation	Location	Depth of Well (feet)	Temp(°C)	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
YELLOWSTONE BURIED-VALLEY AQUIFER																									
T.H. 4445	163-97-15bcc	558	10	6-16-72	27	1.0	.11	29	7.9	472	4.8	789	0	136	267	.9	1.0	.75	1320	105	0	90	20	2160	8.1
COLUMBUS BURIED-VALLEY AQUIFER																									
T.H. 4427	163-97-23ddd	335	--	12- 6-71	19	1.6	.10	27	12	435	6.1	1160	0	9.1	75	1.7	1.0	.44	1220	117	0	88	17	1880	8.1
T.H. 4437	163-97-24aaa	411	10	5-31-72	25	3.3	.07	50	31	523	6.8	1420	0	79	75	.9	1.0	2.3	1530	255	0	81	14	2330	8.2
T.H. 4429	163-97-24bbb	432	10	12-21-71	27	.87	.08	55	25	490	7.3	1380	0	107	80	.9	.9	.58	1380	240	0	81	14	2300	7.9
CROSBY BURIED-VALLEY AQUIFER; UPPER ZONE																									
T.H. 4423A	162-97-1ccc$_2$	264	--	12- 3-71	25	2.0	.24	212	74	182	9.5	802	0	506	43	.5	2.0	.13	1450	836	178	32	2.7	2010	7.6
T.H. 4450	162-97-2bbb	294	8	6-17-72	24	4.9	.57	51	27	238	5.1	814	0	6.4	46	.8	1.0	.07	872	236	0	68	6.7	1310	8.0
T.W. 73-1	163-97-34add$_1$	301	--	4- 6-73	24	.69	.16	52	36	209	6.7	825	0	24	47	.4	1.0	.43	944	280	0	61	5.4	1350	7.5
City Well #4(73-D)	163-97-34add$_2$	307	9	9-12-73	26	2.4	.04	72	24	220	5.5	847	0	7.4	47	.8	1.0	.39	866	280	0	63	5.7	1350	7.6
T.W. 72-2	163-97-34daa	309	--	9- 6-72	25	1.1	.06	68	24	221	5.7	793	0	6.2	44	.5	7.6	.52	830	267	0	64	5.9	1320	7.3
T.H. 4425	163-97-35add	283	--	12- 5-71	25	6.3	.16	174	67	120	7.5	847	0	238	38	.7	1.0	.49	1090	708	14	27	2.0	1650	7.7
City Well #3	163-97-35bca	310	--	12- 6-71	27	2.0	.14	91	36	186	7.1	878	0	24	46	.9	1.0	.09	872	376	0	51	4.2	1410	7.6
T.H. 8292	163-97-35bcc	300	7	12-23-71	27	1.1	.09	67	25	227	5.7	834	0	13	46	.7	.9	.40	831	271	0	64	6.0	1340	7.8
T.W. 72-1	163-97-35bdd	324	--	8-27-72	24	2.9	.20	121	48	161	6.4	937	0	35	44	.4	1.0	.21	940	498	0	41	3.1	1480	7.5
T.H. 8293	163-97-35ddd	283	--	1-11-72	27	2.2	.08	107	49	152	7.7	783	0	90	44	.4	1.0	--	869	471	0	41	3.0	1410	7.5
CROSBY BURIED-VALLEY AQUIFER; LOWER ZONE																									
T.H. 4423	162-97- 1ccc$_1$	411	--	12- 8-71	18	3.0	.18	58	30	596	7.8	1470	0	288	58	1.5	1.0	.09	1780	269	0	82	16	2710	8.0
T.H. 4428	163-97-25aaa	390	--	12- 7-71	25	.0	.10	60	28	475	8.0	1370	0	135	56	1.7	1.0	.49	1470	266	0	79	13	2280	8.0
T.H. 4446	163-97-26ddd	369	9	6-16-72	24	2.8	.10	30	15	396	6.3	1090	0	8.7	53	1.1	1.0	.11	1090	136	0	86	15	1720	7.9
T.H. 8291	163-97-34abb	378	10	12-22-71	20	3.9	.08	42	20	418	7.4	1210	0	11	66	1.2	1.6	.31	1230	187	0	82	13	1900	7.9
UNDIFFERENTIATED GLACIAL DRIFT AQUIFERS																									
T.H. 8285	162-97-12aaa	153	7	12- 2-71	24	.28	.45	97	49	375	6.9	1120	0	242	49	.8	1.0	.13	1430	445	0	64	7.7	2140	7.7
T.H. 4443	163-97-15abb	244	8	6-13-72	26	2.0	1.10	410	155	291	16	406	0	1960	20	.2	1.0	.36	3310	1660	1330	27	3.1	3420	7.4
T.H. 4440	163-97-19aaa	288	8	6-17-72	19	.08	.07	37	21	557	8.9	1440	37	38	79	.9	1.0	.61	1540	178	0	86	18	2260	8.3
T.H. 4438	163-97-25ddd	124	8	5-31-72	22	8.8	.59	315	88	107	11	571	0	888	2.6	.4	1.0	.71	1790	1730	682	17	1.4	2220	8.0
T.H. 8288	163-97-27ccc	263	--	12- 7-71	27	.0	1.60	418	198	163	13	719	0	1540	21	.8	1.0	.53	2940	1860	1270	16	1.6	3160	7.6

TABLE 2 -- WATER-LEVEL RECORDS OF OBSERVATION WELLS
Depth to Water in Feet Below Land Surface

162-97-1ccc$_1$

Date	Water Level	Date	Water Level
Jan. 11, 1972	18.48	Mar. 12	21.47
Feb. 8	18.59	Jun. 4	20.06
Mar. 14	18.42	Aug. 8	23.40
Apr. 4	18.38	Aug. 14	23.67
May 24	Frozen	Sep. 12	24.29
Jun. 17	18.63	Sep. 17	24.77
Jul. 12	18.11	Oct. 31	24.21
Aug. 9	19.40	Dec. 13	24.01
Jan. 18, 1973	18.87		

162-97-1ccc$_2$

Date	Water Level	Date	Water Level
Jan. 11, 1972	14.68	Mar. 12	18.06
Feb. 8	14.83	Jun. 4	18.96
Mar. 14	14.92	Aug. 8	25.53
Apr. 4	15.25	Aug. 14	26.57
May 11	15.55	Sep. 12	25.03
May 24	15.22	Sep. 17	27.43
Jun. 17	15.85	Oct. 31	22.17
Jul. 12	18.13	Dec. 13	18.21
Aug. 9	16.69		
Jan. 18, 1973	15.76		

162-97-2bbb

Date	Water Level	Date	Water Level
Jun. 17, 1972	25.19	Aug. 14	37.05
Aug. 9	26.22	Sep. 12	35.38
Jan. 18, 1973	27.63	Sep. 17	39.26
Mar. 12	28.59	Oct. 31	31.59
Jun. 4	28.91	Dec. 13	33.12
Aug. 8	37.10		

162-97-12aaa

Date	Water Level	Date	Water Level
Jan. 11, 1972	12.47	Jun. 17	12.50
Feb. 8	12.52	Jul. 12	12.75
Mar. 14	12.36	Aug. 9	12.74
Apr. 4	12.47	Jan. 18, 1973	12.68
May 24	12.54	Mar. 12	Abandoned

162-97-15abb

Date	Water Level	Date	Water Level
Jun. 17, 1972	10.01	Sep. 12	10.78
Aug. 9	9.85	Sep. 14	10.88
Jan. 18, 1973	10.16	Sep. 17	10.88
Mar. 12	10.17	Oct. 31	10.79
Jun. 4	10.31	Dec. 13	10.73
Aug. 8	10.78		

163-97-15bcc

Date	Water Level	Date	Water Level
Jun. 17, 1972	36.43	Sep. 12	11.27
Aug. 9	14.48	Sep. 14	11.48
Jan. 18, 1973	11.54	Sep. 17	11.44
Mar. 12	11.38	Oct. 31	11.25
Jun. 4	11.20	Dec. 13	11.28
Aug. 8	11.47		

163-97-23ddd

Date	Water Level	Date	Water Level
Jan. 11, 1972	18.20	Jan. 18, 1973	18.37
Feb. 8	18.51	Mar. 12	21.49
Mar. 14	18.45	Jun. 4	18.39
Mar. 21	17.09	Aug. 8	18.86
Apr. 4	18.21	Sep. 12	18.86
May 24	18.07	Sep. 14	18.95
Jun. 17	18.02	Sep. 17	18.97
Jul. 12	18.18	Oct. 31	19.03
Aug. 9	18.16	Dec. 13	19.00

163-97-24aaa

Date	Water Level	Date	Water Level
Jun. 17, 1972	55.20	Sep. 12	55.29
Aug. 9	55.10	Sep. 14	55.39
Jan. 18, 1973	53.36	Sep. 17	55.42
Mar. 12	51.25	Oct. 31	55.31
Aug. 8	56.35	Dec. 13	55.29

163-97-24bbb

Date	Water Level	Date	Water Level
Jan. 11, 1972	50.88	Mar. 12	50.76
Feb. 8	51.17	Jun. 4	50.72
Mar. 14	47.79	Aug. 8	51.08
Apr. 4	50.89	Sep. 12	50.95
May 24	50.84	Sep. 17	51.11
Jun. 17	50.73	Oct. 31	50.98
Jan. 18, 1973	50.74	Dec. 13	50.91

163-97-25aaa

Date	Water Level	Date	Water Level
Jan. 11, 1972	46.17	Aug. 8	48.09
Feb. 8	47.09	Sep. 12	47.98
May 24	47.55	Sep. 14	48.10
Jun. 17	47.54	Sep. 17	48.13
Jul. 12	47.56	Oct. 31	47.97
Aug. 9	47.94	Dec. 13	47.95
Jan. 18, 1973	47.82		
Mar. 12	48.06		

163-97-25ddd

Date	Water Level	Date	Water Level
Jun. 17, 1972	8.84	Sep. 12	9.76
Aug. 9	8.62	Sep. 14	9.85
Jan. 18, 1973	9.08	Sep. 17	9.84
Mar. 12	9.32	Oct. 31	9.89
Jun. 4	9.42	Dec. 13	9.82
Aug. 8	9.84		

163-97-26ddd

Date	Water Level	Date	Water Level
Jun. 17, 1972	Flow	Mar. 12	Flow
Aug. 9	Flow	Jun. 4	Flow
Jan. 18, 1973	Flow	Aug. 8	Flow

163-97-27ccc

Date	Water Level	Date	Water Level
Jan. 11, 1972	5.74	Jan. 18, 1973	6.04
Feb. 8	7.38	Mar. 12	5.95
Mar. 14	6.06	Jun. 4	5.59
Apr. 4	6.31	Aug. 8	5.95
May 24	6.08	Sep. 12	5.76
Jun. 17	6.14	Sep. 17	6.27
Jul. 12	6.30	Oct. 31	5.72
Aug. 9	6.05	Dec. 13	5.65

163-97-34abb

Date	Water Level	Date	Water Level
Jan. 11, 1972	2.10	Jan. 18, 1973	2.71
Feb. 8	2.18	Mar. 12	2.64
Mar. 14	2.13	Jun. 4	3.00
Apr. 4	2.10	Aug. 8	5.12
May 24	2.22	Sep. 12	5.86
Jun. 17	2.21	Sep. 17	6.26
Jul. 12	2.51	Oct. 31	6.45
Aug. 9	2.55	Dec. 13	5.79

163-97-35bcc

Date	Water Level	Date	Water Level
Jan. 11, 1972	11.66	Jan. 18, 1973	13.55
Feb. 8	12.83	Mar. 12	13.94
Mar. 14	10.60	Jun. 4	16.51
Apr. 4	12.55	Aug. 8	25.89
Jun. 17	14.16	Sep. 17	28.85
Jul. 12	19.32	Oct. 31	19.34
Aug. 9	14.27	Dec. 13	15.60

163-97-35ddd

Date	Water Level	Date	Water Level
Jan. 12, 1972	5.53	Mar. 12	8.14
Feb. 8	5.83	Jun. 4	10.91
Mar. 14	5.29	Aug. 8	19.44
May 11	7.05	Aug. 14	22.10
May 24	6.41	Sep. 12	17.75
Jun. 17	7.28	Sep. 17	21.38
Jul. 12	8.15	Oct. 31	13.75
Aug. 9	8.43	Dec. 13	13.67
Jan. 18, 1973	7.09		

TABLE 3 - LOGS OF TEST HOLES

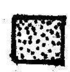
The following test hole logs are a summary of data from driller's logs, geologist's sample descriptions, resistivity, spontaneous potential, and gamma ray logs. Test hole elevations were interpolated from topographic maps published by the U. S. Geological Survey. Color descriptions are of wet samples and are based upon color standards (Goddard and others, 1963). Grain-size classification is C. K. Wentworth's scale from Pettijohn (1957).

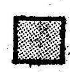
Test Holes developed as observation wells are so indicated. Observation wells deeper than 300 feet were completed with 2-inch diameter steel casing; and wells shallower than 300 feet were completed with $1\frac{1}{4}$-inch diameter plastic pipe. Observation well depths and screened producing intervals (S.I.) are indicated. Water-level records of observation wells are in Table 2 and chemical analyses are in Table 1.

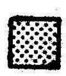
Explanation of Lithologic Symbols

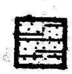
 Clay

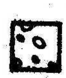
 Shale

 Silt

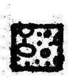
 Siltstone

 Sand

 Sandstone

 Gravel

 Lignite

 Till

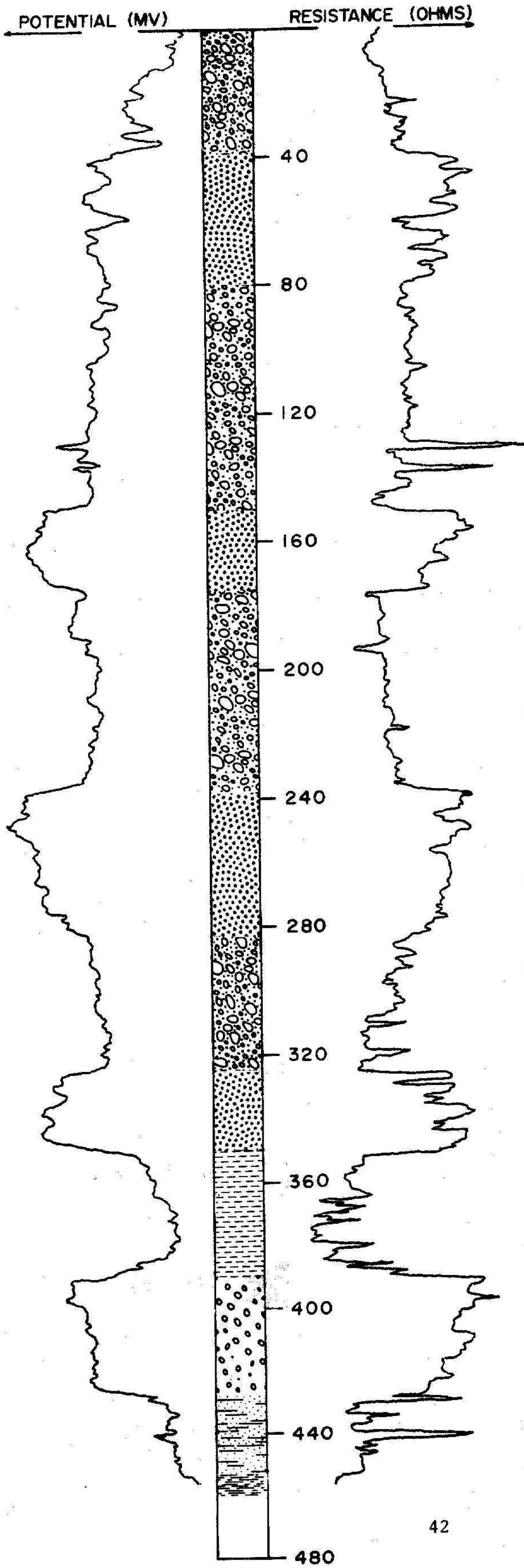
TEST HOLE 4423

LOCATION: 162-97-1ccc

ELEVATION: 1970 feet
(FT, MSL)

DATE DRILLED: 12-1-71

DEPTH: 460 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly clay loam, dark brown.
1-13	Clay, silty, sandy, pebbly, dusky reddish yellow, soft to moderately soft, cohesive, moderately plastic, oxidized (Till).
13-28	Clay, silty, slightly sandy, numerous pebbles and occasional cobbles, reddish brown to moderate olive brown, moderately soft, cohesive, slightly plastic, oxidized (Till).
28-39	Clay, silty to slightly sandy, pebbly, occasional cobbles and boulders, olive gray, moderately soft, slightly stiff and brittle (Till).
39-80	Sand; very fine to fine, thin silty to clayey lenses, light olive to olive gray but partially oxidized in upper few feet, loose to slightly cohesive, predominantly quartz laminated with fine lignite particles and carbonaceous material.
80-150	Clay, silty, sandy, pebbly, granite boulders at 130 and 137 feet, olive gray, cohesive, tough (Till).
150-175	Sand, predominantly fine, medium in upper part, very fine in lower part, well-sorted and uniform, quartzose, subrounded, loose, clean.
175-238	Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, tight (Till).
238-283	Sand, coarse to very coarse, some fine gravel, moderately well-sorted, subangular to rounded, loose, clean.
283-308	Clay, silty, sandy, pebbly, occasional cobbles, olive gray, moderately soft, cohesive, fairly stiff (Till).
308-325	Clay, silty, sandy, pebbly, and cobbles, olive to dark olive gray, slightly hard, tightly compacted, stiff and moderately brittle (Till).
325-350	Sand, very fine to fine, slightly clayey, light gray to light olive gray, moderately soft, chunky, crumbly, calcareous (Till?); occasional thin layers of marl-like clay.
350-365	Clay, silty, slightly sandy, occasional pebbles, olive gray with green and white, soft, sandy bedrock clays (Till?).
365-390	Clay, varigated greens and grays with black carbonaceous material, occasional sand grains and pebbles, soft to moderately soft (Till?); predominantly reworked bedrock.

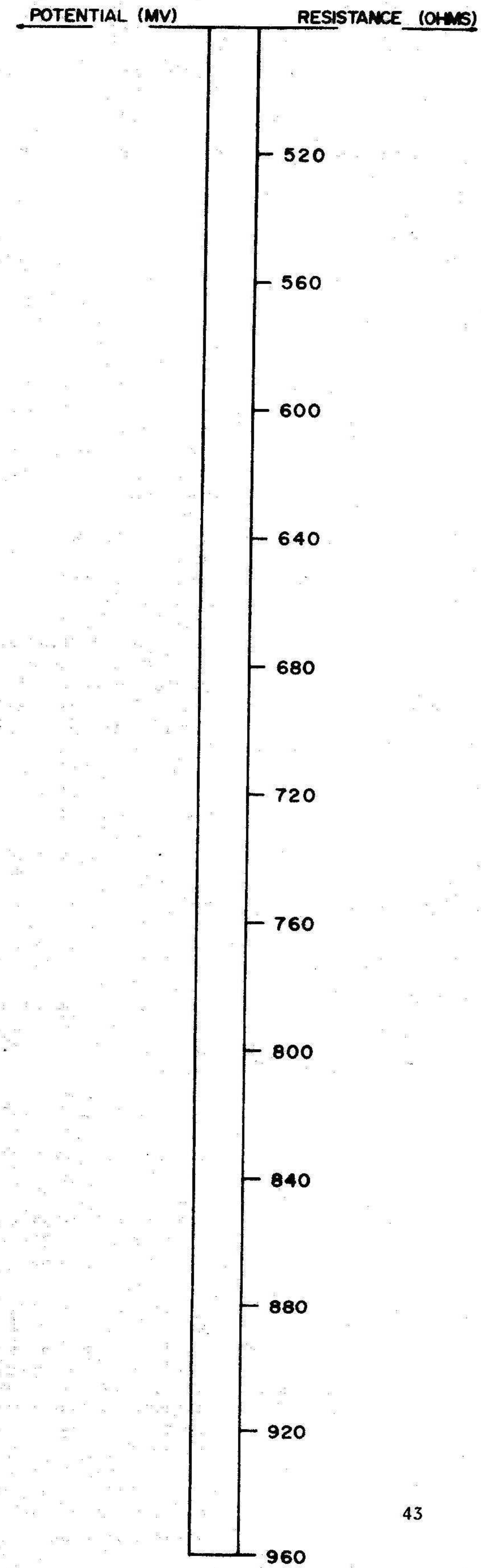
TEST HOLE 4423 (Cont.)

LOCATION: 162-97-1ccc

DATE DRILLED: 12-1-71

ELEVATION: 1970 feet
(FT, MSL)

DEPTH: 460 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift (Cont.)

390-428 Gravel, medium to very coarse with cobbles, very little sand, generally subrounded, sorted, dark brown, mostly silicates with carbonates and a few granitics; poor sample return, rough drilling.

Tongue River Formation

428-453 Sandstone, very fine, clayey, light green to greenish gray, moderately soft, chunky, slightly friable; interbedded with indurated sandstone and carbonaceous siltstone and shale.

453-460 Shale, dark green and black, hard, smooth, waxy, very tight (bit sample).

2 Observation Wells

Obs. Well 4423 (2-inch steel)
Depth: 411 feet
S. I.: 399 to 411 feet

Obs. Well 4423 A (1¼-inch plastic)
Depth: 264 feet
S. I.: 258 to 264 feet

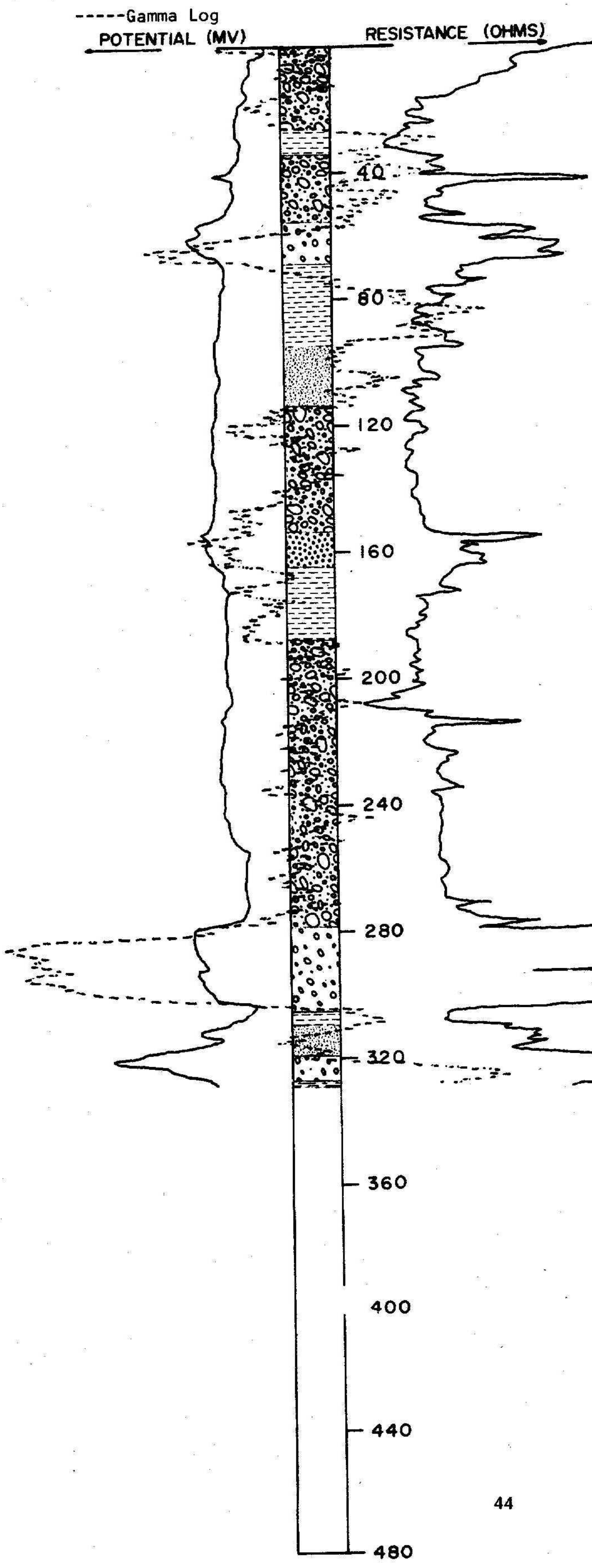
TEST HOLE 4450

LOCATION: 162-97-2bbb

ELEVATION: 1975
(FT, MSL)

DATE DRILLED: 6-16-72

DEPTH: 329
(FT)



DESCRIPTION OF DEPOSITS
Glacial Drift

0-1 Topsoil, pebbly silt loam, black.

1-16 Clay, very silty and sandy, occasional pebbles and sand lenses; dark brown; soft, moderately cohesive, sticky (washed till?).

16-26 Clay, silty to sandy, pebbly, yellowish gray with moderate olive brown, moderately soft, cohesive, slightly plastic, oxidized (Till).

26-34 Clay, silty, with coarse sand grains, moderate olive brown with varigated laminations, slightly hard.

34-41 Clay, silty, sandy, pebbly, light olive gray, moderately soft, cohesive, slightly plastic, partially oxidized (Till).

41-44 Cobbles, mostly carbonates and granitics; rough drilling.

44-56 Clay, silty, sandy, pebbly cobbles, olive gray, moderately soft to slightly hard, cohesive, compacted, stiff, slightly brittle (Till).

56-69 Gravel, fine to coarse, sandy, sorted but lenticular, iron-stained, subrounded, mostly carbonates with granitics with black siliceous shale and a little detrital lignite.

69-95 Clay, silty, sandy, occasional pebble or cobble, olive gray, soft to moderately soft, cohesive to slightly crumbly, laminated, fairly tight.

95-114 Silt, clayey, light olive and olive gray, soft, moderately cohesive, very slightly plastic.

114-154 Clay, silty, sandy, pebbly, occasional cobbles, olive gray, slightly hard, very cohesive, stiff (Till).

154-165 Sand, very fine to medium, light olive gray, lenticular, silty and clayey, loose to slightly cohesive.

165-188 Clay, sandy, pebbly, olive to dark olive gray, soft, moderately cohesive, slightly plastic to slightly crumbly, organic laminae.

188-279 Clay, silty, sandy, pebbly, cobbles and occasional boulders, olive gray, slightly hard, tightly compacted, stiff, tight (Till).

279-305 Gravel, sandy, yellow-brown, clay layer at 293 feet.

305-309 Clay, dark gray, moderately hard, smooth, very stiff, tight.

309-319 Silt, clayey to sandy, interbedded, soft and moderately soft, slightly to moderately cohesive.

319-327 Gravel and cobbles, dark brown, sorted subrounded; mostly dark brown iron-stained silicates with carbonates; rough drilling.

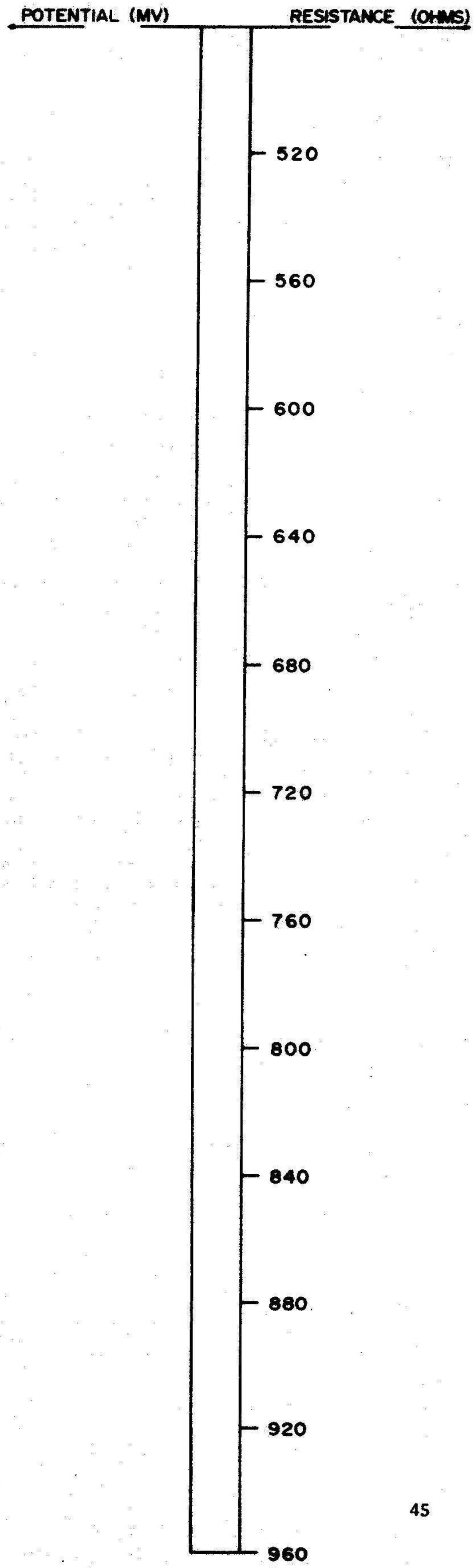
TEST HOLE 4450 (Cont.)

LOCATION: 162-97-2bbb

DATE DRILLED: 6-16-72

ELEVATION: 1975
(FT, MSL)

DEPTH: 329
(FT)



DESCRIPTION OF DEPOSITS

Tongue River Formation

327-329 Shale, extremely silty with very fine sand, light gray, indurated, chalky.

Observation Well

Depth: 294 feet
S. I.: 288 to 294 feet

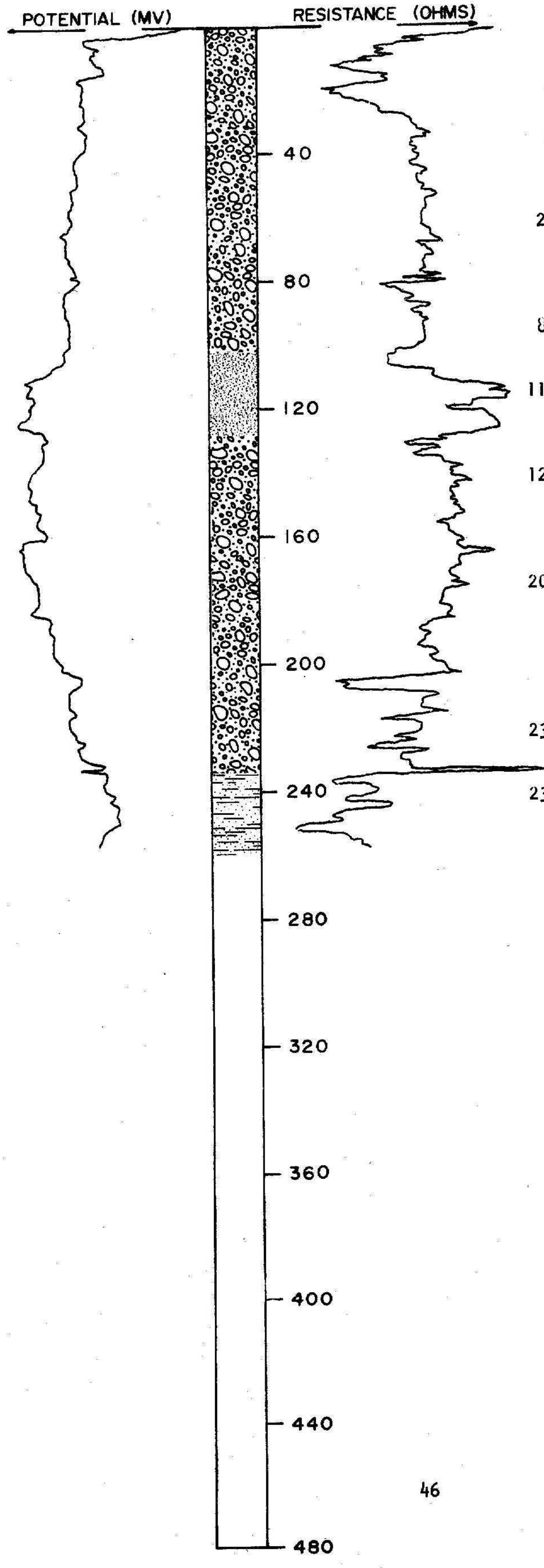
TEST HOLE 4422

LOCATION: 162-97-3ccc

ELEVATION: 1978 feet (FT, MSL)

DATE DRILLED: 12-1-71

DEPTH: 260 feet (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2	Topsoil, pebbly loam, dark brownish gray.
2-29	Clay, silty, sandy, pebbly, dark yellowish and reddish brown, moderately soft, cohesive, stiff, oxidized (Till).
29-80	Clay, silty, sandy, pebbly, occasional cobbles, olive gray, moderately soft to slightly hard, very cohesive, tight (Till).
80-112	Till (as above); interbedded with blocks of green shale and sandstone.
112-128	Silt, light olive and olive gray, moderately soft, chunky, friable, laminated; some very fine and fine sand.
128-204	Clay, very silty, sandy, pebbly, occasional cobbles and boulders, olive gray, moderately soft to slightly hard, very cohesive, stiff and tight (Till).
204-234	Till (as above); frequent blocks of soft, green and gray shale and sandstone.

Tongue River Formation

234-235	Sandstone, very fine-grained, dark greenish gray, indurated, pyritiferous.
235-260	Sandstone, very fine-grained, clayey, light grayish green; slightly hard, slightly friable; interbedded with brownish gray, moderately carbonaceous siltstone and shale.

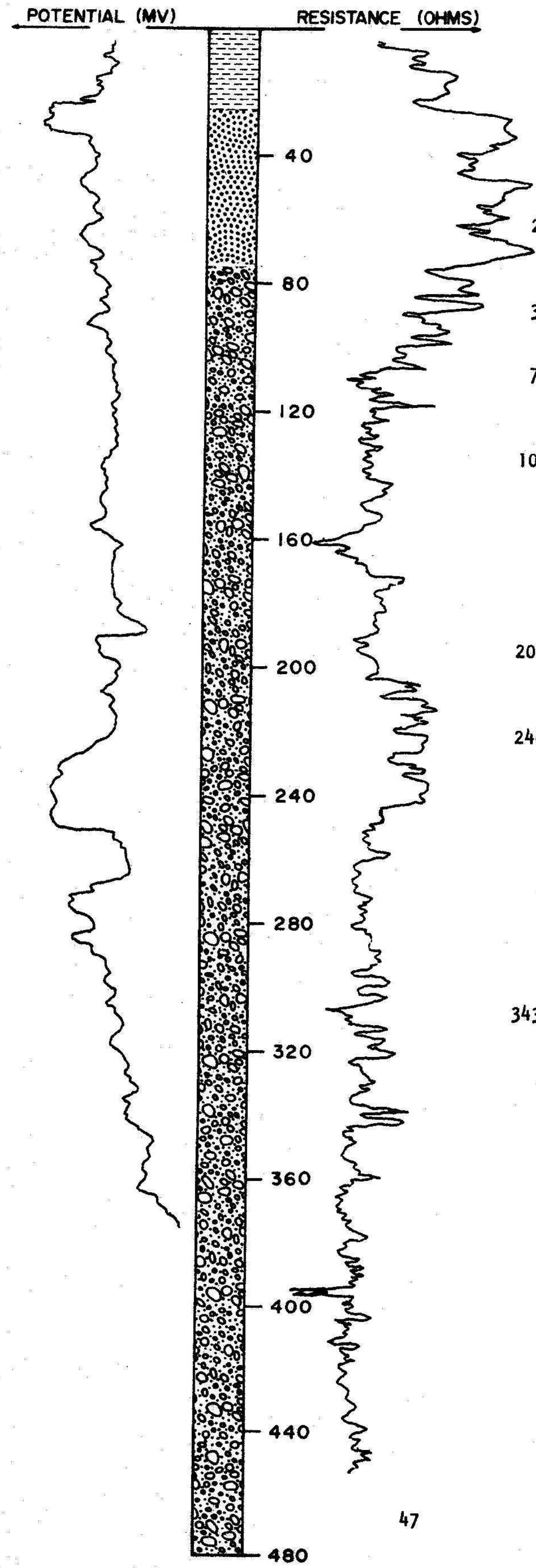
TEST HOLE 8286

LOCATION: 162-97-5ccc

DATE DRILLED: 12-1-71

ELEVATION: 1960 feet
(FT, MSL)

DEPTH: 580 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay, brownish black.
1-26	Clay, very silty, slightly sandy, dark yellowish brown; moderately cohesive, slightly plastic, oxidized.
26-38	Sand, fine to medium, subangular to subrounded, moderately well-sorted, slightly lignitic, slightly oxidized.
38-74	Sand (as above); interbedded with gravel and thin lenses of clay or clayey till, lenticular.
74-107	Clay, silty, moderately sandy, gravel lenses and occasional cobbles, moderately soft, cohesive, slightly lignitic (Till).
107-204	Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, tightly compacted, stiff (Till).
204-244	Clay, very silty, sandy, sand and gravel lenses, olive gray, moderately soft, cohesive (Till).
244-343	Clay, silty, sandy, pebbly, occasional cobbles, olive gray, slightly hard, very cohesive and compacted, stiff (Till).
343-547	Clay, silty, sandy, pebbly, cobbles, and boulders, occasional gravel lenses, olive gray, very cohesive, stiff and tough (Till).

TEST HOLE 8286 (Cont.)

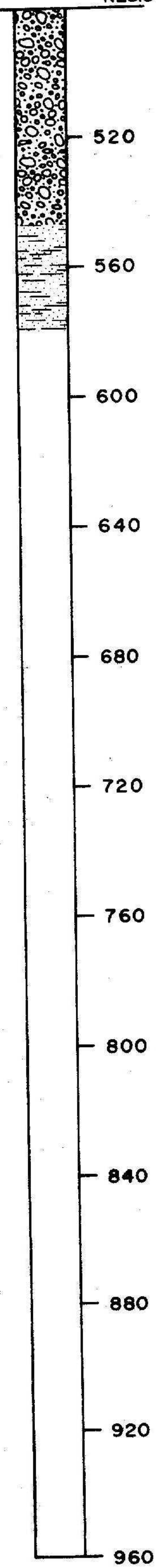
LOCATION: 162-97-5ccc

ELEVATION: 1960 feet
(FT, MSL)

DATE DRILLED: 12-1-71

DEPTH: 580 feet
(FT)

POTENTIAL (MV) RESISTANCE (OHMS)



DESCRIPTION OF DEPOSITS

Fox Hills Formation

547-580 Sandstone, very fine-grained, slightly clayey, medium bluish gray, noncalcareous, micaceous.

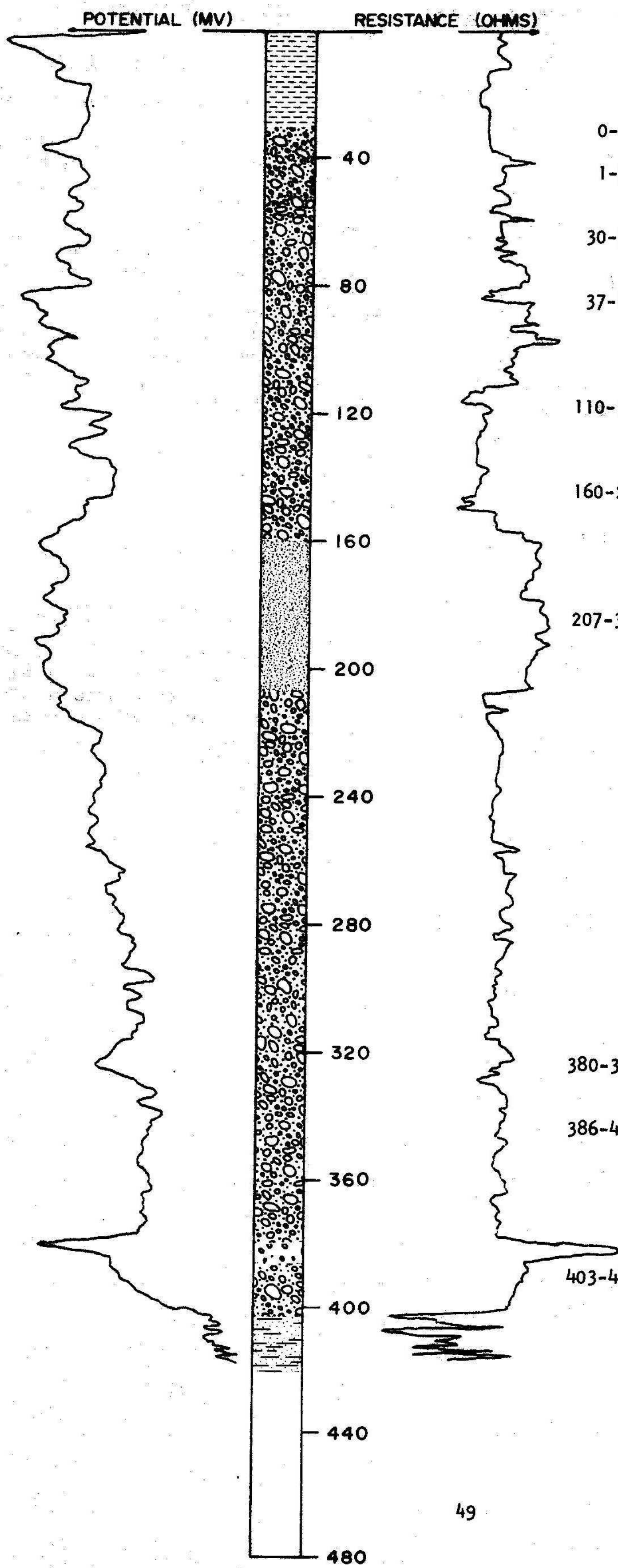
TEST HOLE 8283

LOCATION: 162-97-8aaa

DATE DRILLED: 11-30-71

ELEVATION: 1980 feet
(FT, MSL)

DEPTH: 420 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay; brownish black.
1-30	Clay, silty, sandy, dark yellowish brown, soft, slightly cohesive, oxidized.
30-37	Clay, silty, sandy, pebbly, olive gray, moderate soft, moderately cohesive (Till).
37-110	Clay, silty, sandy, pebbly, cobbles and boulders, numerous interbedded sand and gravel lenses, olive gray, cohesive, moderately stiff (Till).
110-160	Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, tightly compacted, stiff (Till).
160-207	Silt, clayey to sandy, interbedded and laminated, olive gray, soft, loose to slightly cohesive; detrital lignite.
207-380	Clay, silty, sandy, pebbly, cobbles and thin gravel lenses, olive gray, cohesive, compacted, stiff (Till).
380-386	Gravel, cobbles, boulders, sorted, subrounded, mostly carbonates; rough drilling.
386-403	Clay, sandy, pebbly, cobbles, olive gray, hard, stiff, brittle, tightly compacted (Till).

Tongue River Formation

403-420	Sandstone, very fine-grained, slightly clayey, medium bluish-gray, moderately soft and friable, micaceous; thinly interbedded with brownish black to medium dark gray, moderately indurated, noncalcareous, carbonaceous shale.

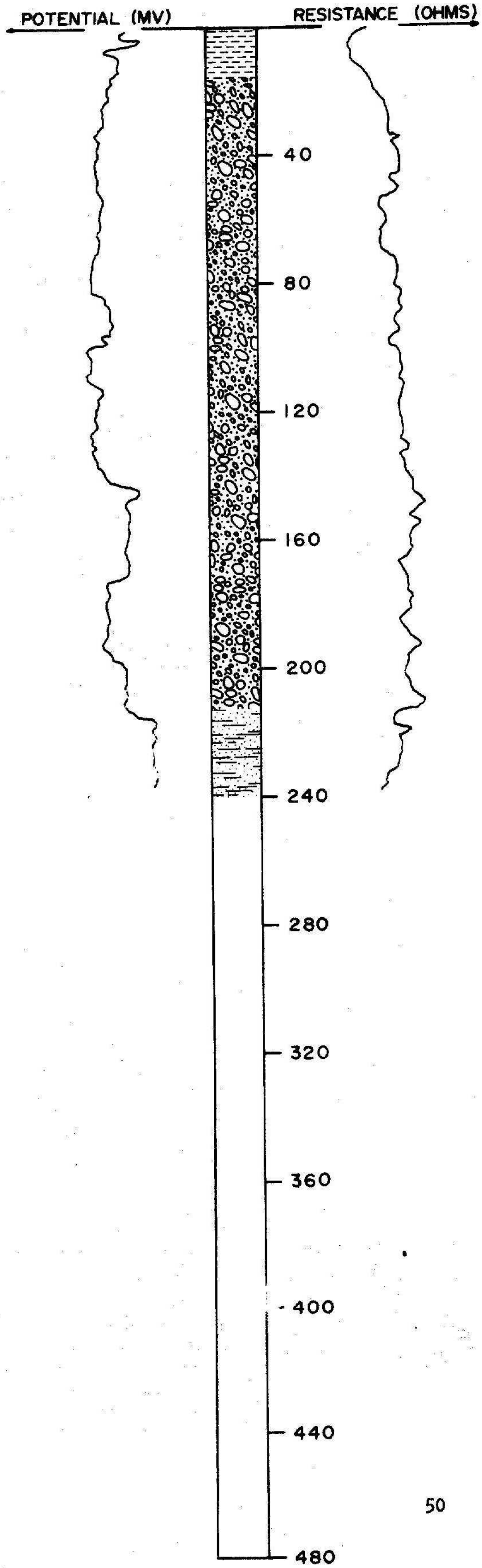
TEST HOLE 8284

LOCATION: 162-97-11bbb

ELEVATION: 1980 feet
(FT, MSL)

DATE DRILLED: 12-1-71

DEPTH: 240 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay, brownish black.
1-16	Clay, very silty to slightly sandy, dark yellowish brown, moderately cohesive, slightly plastic, oxidized.
16-46	Clay, silty, sandy, pebbly, dark yellowish brown, cohesive, slightly plastic, oxidized (Till).
46-213	Clay, silty, sandy, pebbly, cobbles, and occasional gravel lenses, olive gray, moderately soft to slightly hard, cohesive, stiff (Till).

Tongue River Formation

213-240	Sandstone, very fine-grained, slightly clayey, micaceous, noncalcareous; interbedded with thin, medium gray shale beds.

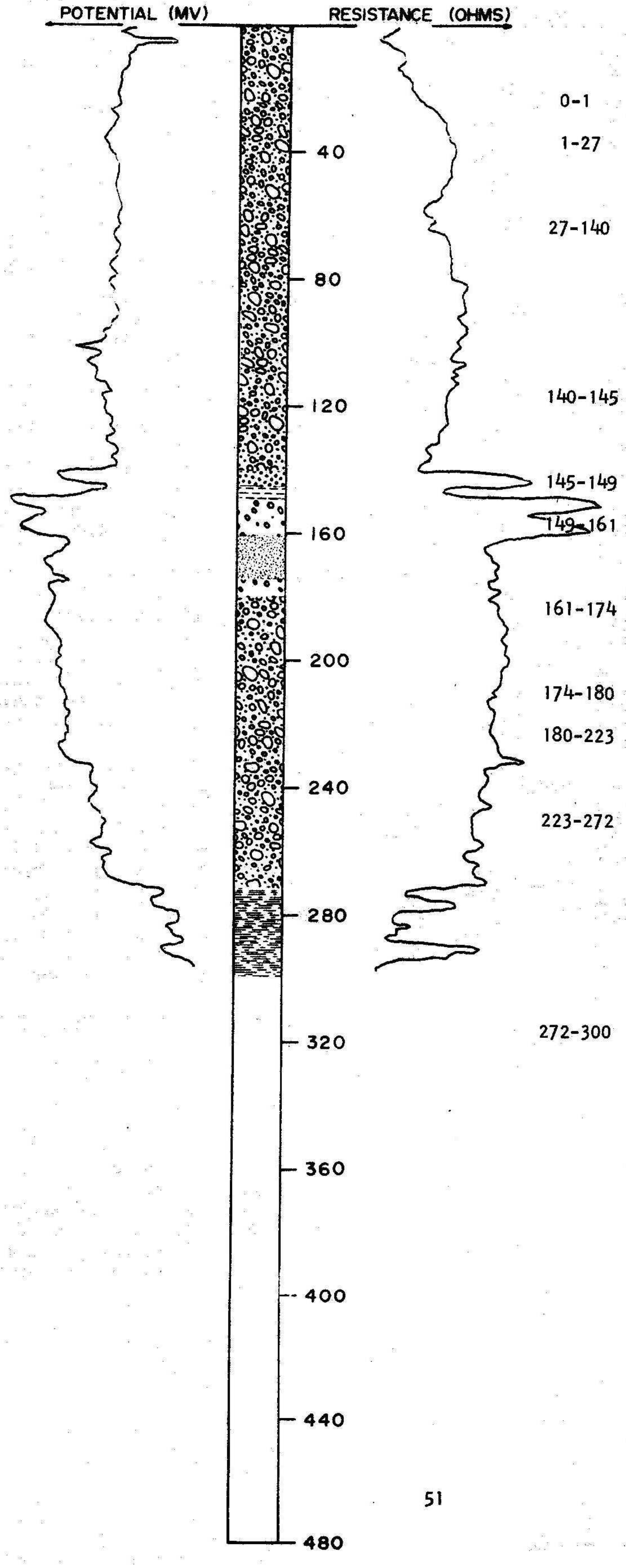
TEST HOLE 8285

LOCATION: 162-97-12aaa

DATE DRILLED: 12-1-71

ELEVATION: 1958 feet (FT, MSL)

DEPTH: 300 feet (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly clay loam, brownish black.
1-27	Clay, silty, sandy, pebbly, dark yellowish brown, moderately cohesive, oxidized (Till).
27-140	Clay, silty, sandy, pebbly, cobbles, gravel lenses, olive gray, moderately soft, cohesive (Till).
140-145	Sand, medium to coarse, slightly clayey, moderately well-sorted, subangular to subrounded.
145-149	Clay, silty, olive gray, moderately soft, smooth, sticky.
149-161	Gravel, fine to coarse, clayey, sorted but lenticular, subangular to rounded; about 50% dark brown silicates, rough drilling.
161-174	Silt, clayey to very sandy, interbedded gravel lenses, moderate yellowish brown, slightly cohesive, oxidized.
174-180	Gravel, fine to coarse, clayey and sandy, poorly sorted.
180-223	Clay, silty, sandy, pebbly, thin gravel lenses, olive gray, moderately soft to slightly hard, cohesive, stiff (Till).
223-272	Clay, very silty, sandy, pebbly, gravel lenses, and sandy detrital lignite, medium-light to light-bluish gray, soft to moderately soft, slightly cohesive, crumbly, very calcareous (Till).

Tongue River Formation

272-300	Shale, light greenish gray, moderately well-indurated, noncalcareous, interbedded with lignite and medium-bluish gray, fine-grained sandstone.

Observation Well

Depth: 153 feet
S. I.: 147 to 153 feet

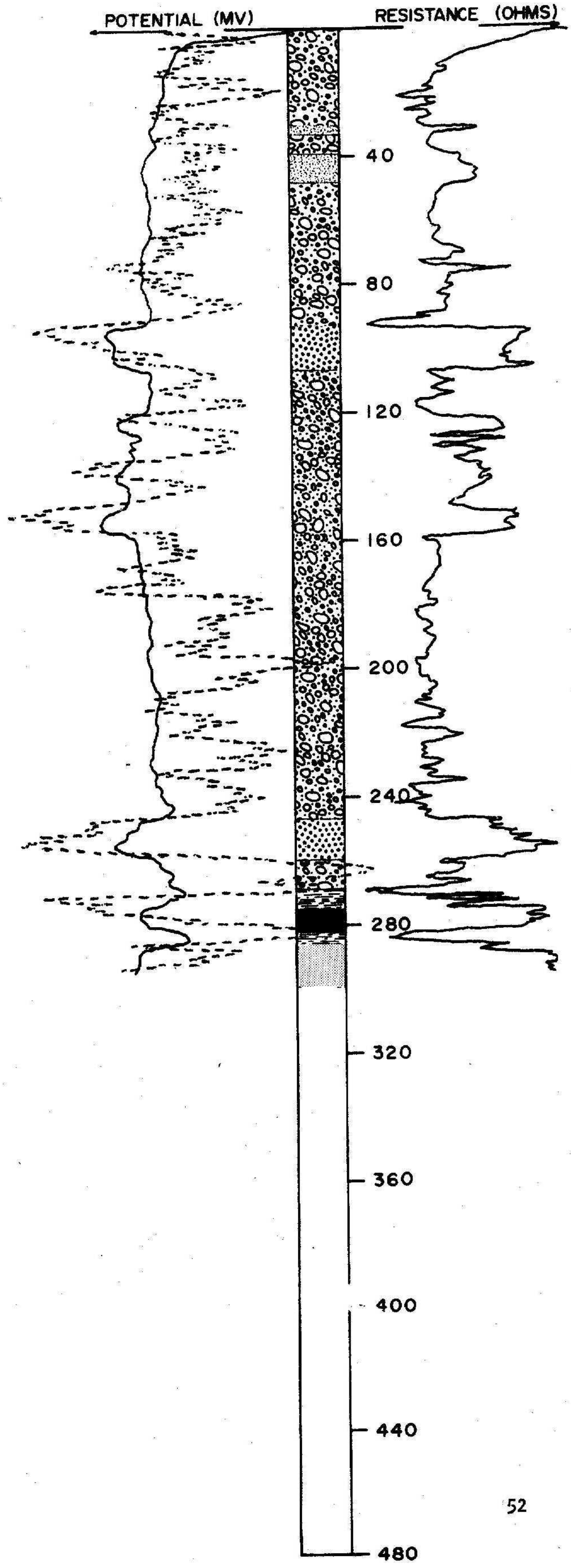
TEST HOLE 4432

LOCATION: 162-97-12cdd

ELEVATION: 1965
(FT, MSL)

DATE DRILLED: 5-23-72

DEPTH: 300
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly silt loam, black.
1-5	Clay, very silty, pebbly, dusky yellow, soft, slightly cohesive, oxidized (Till).
5-30	Clay, silty, sandy, pebbly, cobbles, moderate olive brown, moderately soft, moderately cohesive, oxidized (Till).
30-33	Silt, slightly clayey, yellowish gray, soft, crumbly.
33-39	Clay, silty, pebbly, light olive gray, moderately soft, chunky, slightly friable (Till).
39-48	Silt, clayey, sandy, soft, very slightly cohesive.
48-93	Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft to moderately hard, cohesive to friable (Till).
93-107	Sand, very fine to fine, some medium, light gray, sorted, subrounded, loose.
107-158	Clay, silty, sandy, pebbly, slightly hard, tight (Till); interbedded with layers of clay, silt, and sand; occasional gravel and detrital lignite.
158-247	Clay, very silty, sandy, pebbly, occasional cobbles, olive gray, slightly to moderately hard, very cohesive, compacted (Till).
247-260	Sand, medium to coarse, clayey in upper part, well-sorted.
260-269	Clay, silty, sandy, pebbly, olive gray, slightly hard, slightly brittle, compacted (Till); thin sandy lenses.

Tongue River Formation

269-271	Shale, silty, light gray, hard, brittle.
271-275	Shale (as above); grayish brown; interbedded lignite.
275-283	Lignite, black, hard; possibly fractured.
283-286	Shale, silty, brownish black, hard, smooth, carbonaceous.
286-300	Siltstone, varigated grays and browns to black, hard, porous, carbonaceous.

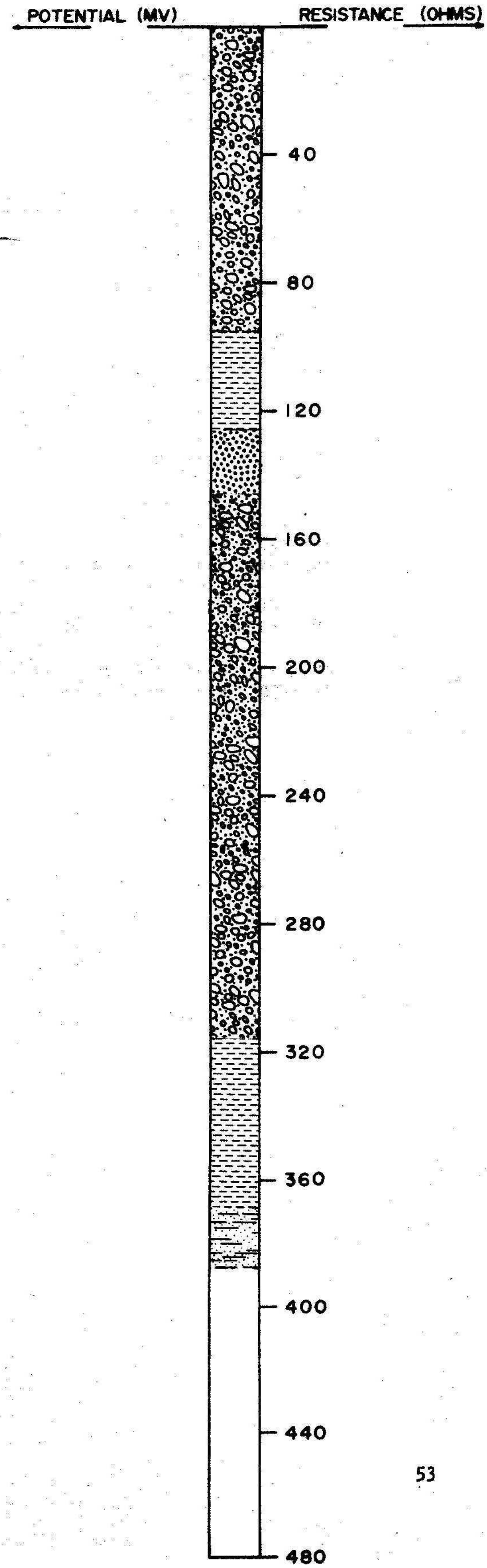
TEST HOLE 1532

LOCATION: 162-97-14ddd

DATE DRILLED: 6-4-59

ELEVATION: 1990 feet
(FT, MSL)

DEPTH: 378 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-4 Topsoil, clayey loam, brownish black.

4-21 Clay, sandy, pebbly, yellowish to brownish orange, mottled, oxidized (Till).

21-95 Clay, silty, sandy, pebbly, lignitic sand and gravel lenses, occasional cobbles, olive gray, moderately soft, cohesive (Till).

95-126 Clay, silty, olive to dark olive gray, moderately soft, cohesive, moderately stiff, laminated.

126-146 Sand, very fine and fine, clayey and lignitic, dark gray, interbedded or lenticular.

146-316 Clay, silty, sandy, pebbly, cobbles and boulders, occasional gravel stringers, olive gray, cohesive, stiff, tough (Till).

316-369 Clay, silty, dark gray, moderately soft to slightly hard, very cohesive, smooth, slightplastic to stiff and brittle.

Tongue River Formation

369-378 Sandstone, fine-grained, clayey, greenish gray, slightly hard, chunky, friable.

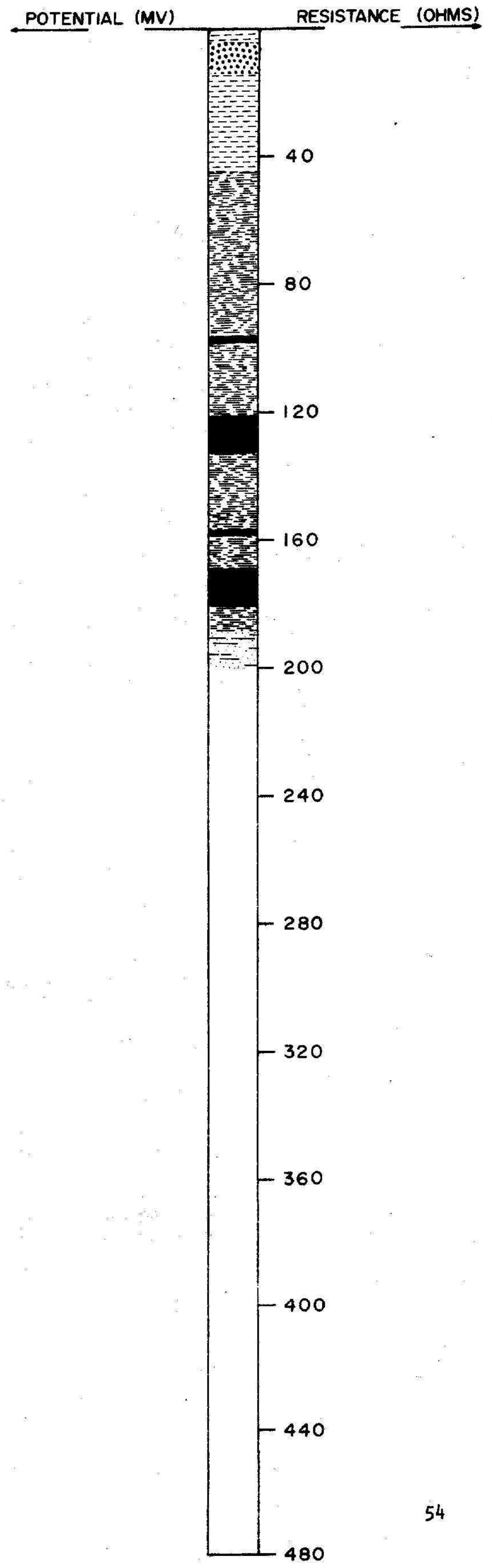
TEST HOLE MB

LOCATION: 163-96-5aaa

DATE DRILLED: 1947

ELEVATION: 1881 feet
(FT, MSL)

DEPTH: 200 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-3	Topsoil.
3-4	Clay, gray.
4-14	Gravel.
14-45	Clay, silty, gray.

Tongue River Formation

45-71	Clay, sandy, blue, with fine sand.
71-75	Clay, gray, with lignite.
75-82	Clay, brown, tight, with strips of light gray clay and lignite.
82-86	Clay, blue and gray.
86-96	Clay, gray, with strips of lignite.
96-99	Lignite, with strips of gray clay.
99-121	Clay, gray.
121-133	Lignite, hard and soft in strips, some clay.
133-157	Clay, gray, strips of lignite.
157-159	Lignite.
159-169	Clay, gray, tight, stips of lignite.
169-181	Lignite, with some clay.
181-189	Clay, sandy, gray, strips of lignite.
189-192	Sandstone, gray, hard.
192-200	Sand, gray, compact.

TEST HOLE 4435

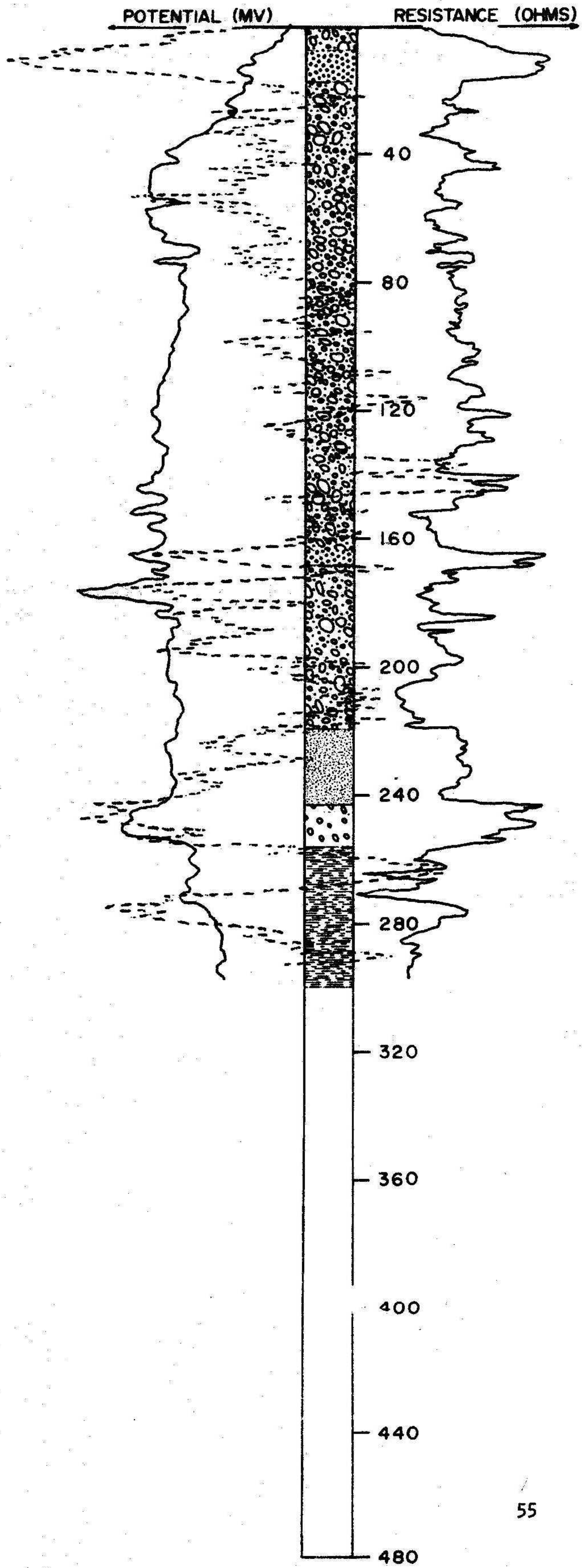
LOCATION: 163-96-8ccc

DATE DRILLED: 5-24-72

ELEVATION: 1913
(FT, MSL)

DEPTH: 300
(FT)

-----Gamma Log



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, clayey silt loam, black.
1-7	Clay, very silty, sandy, pebbly, dark brown, soft, moderately cohesive, organic (washed till?).
7-17	Sand, fine to coarse, reddish brown, sorted, subrounded, clean, oxidized.
17-32	Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, oxidized (Till).
32-39	Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft, slightly friable, oxidation stains (Till).
39-79	Clay, very silty, sandy, pebbly, occasional cobbles, dusky yellow to moderate olive brown, moderately soft to slightly hard, cohesive, slightly brittle, oxidized (Till); numerous silt and clayey fine sand lenses.
79-134	Clay, silty, sandy, pebbly, cobbles, moderate olive brown, slightly hard, tightly compacted, oxidized (Till).
134-164	Clay, silty, sandy, pebbly, moderate olive brown and olive gray intermixed (Till).
164-169	Sand, coarse to very coarse with fine and medium gravel, sorted, subrounded, clean.
169-206	Clay, very silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive, stiff (Till); lenticular sand and gravel.
206-219	Clay, silty, sandy, pebbly, dark olive gray, hard, tightly compacted (Till).
219-243	Silt, clayey with very fine sand, light olive to olive gray, soft, slightly cohesive.
243-256	Gravel, fine to coarse, sandy with possible clay or till layers, poorly sorted.

Tongue River Formation

256-300	Shale, varigated grays and browns, hard, tight; interbedded with greenish gray and dark greenish gray, moderately soft, friable, carbonaceous sandstone.

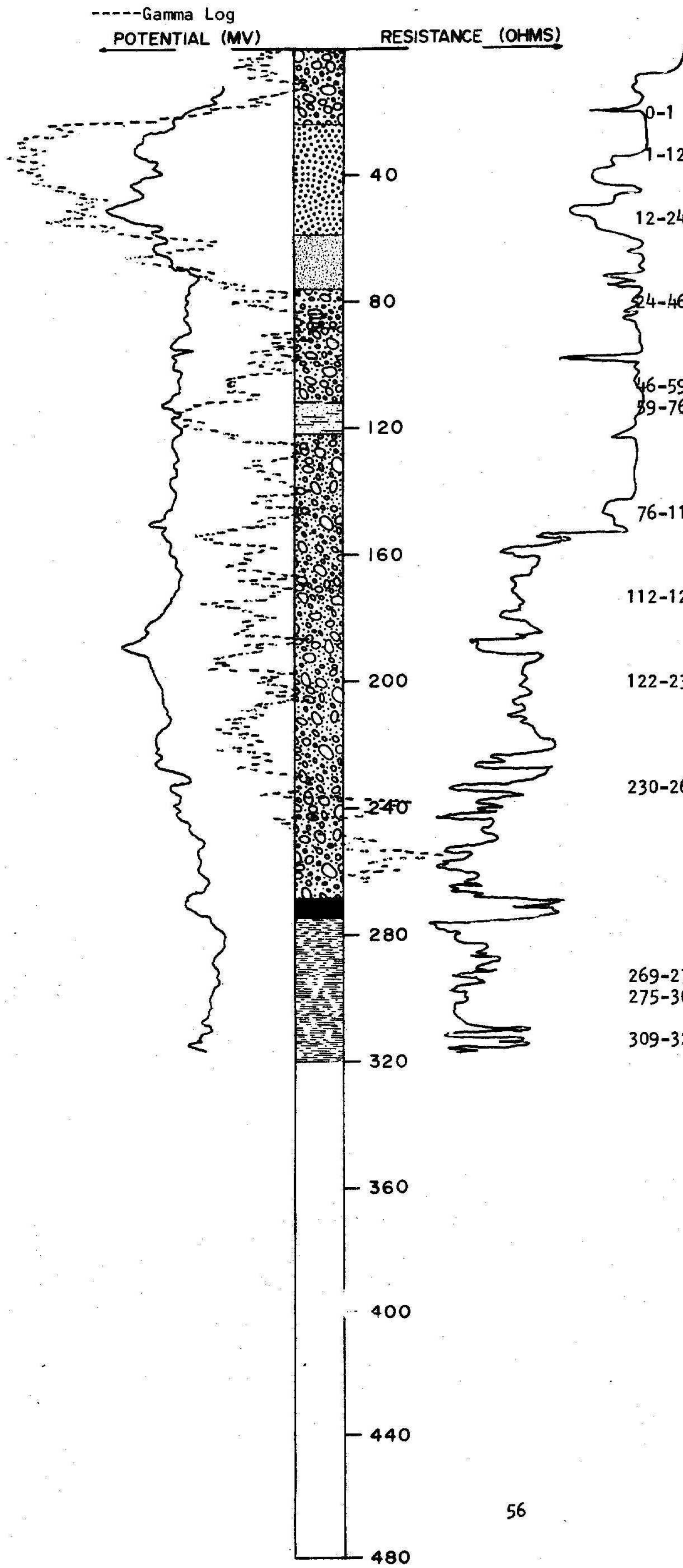
TEST HOLE 4448

LOCATION: 163-96-17ada

DATE DRILLED: 6-15-72

ELEVATION: 1910 (FT, MSL)

DEPTH: 320 (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, sandy silt loam, black.
1-12	Clay, very silty, sandy, pebbly, dark brown, soft, sticky (washed till?).
12-24	Clay, silty, sandy, pebbly, moderate olive brown, soft, cohesive, moderately plastic, oxidized (Till).
24-46	Sand, medium to coarse, light olive gray, well-sorted and uniform, clean, subrounded, lignitic.
46-59	Sand (as above); olive gray.
59-76	Silt and clayey sand, light olive gray and olive gray, laminated, soft, slightly to moderately cohesive; interbedded sand lenses.
76-112	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive and compacted (Till).
112-122	Sandstone, fine-grained, light greenish gray, moderately soft slightly friable, slightly lignitic.
122-230	Clay, silty, slightly sandy, pebbly, olive gray, slightly hard, cohesive, stiff (Till); numerous lignitic sand and gravel lenses.
230-269	Till (as above); very clayey and sticky, gravel lenses.

Tongue River Formation

269-275	Lignite, hard, black, fissile.
275-309	Shale, silty, varigated, carbonaceous and lignitic.
309-320	Shale, sandy, varigated, slightly lignitic with indurated sandstone or pyritiferous concretions.

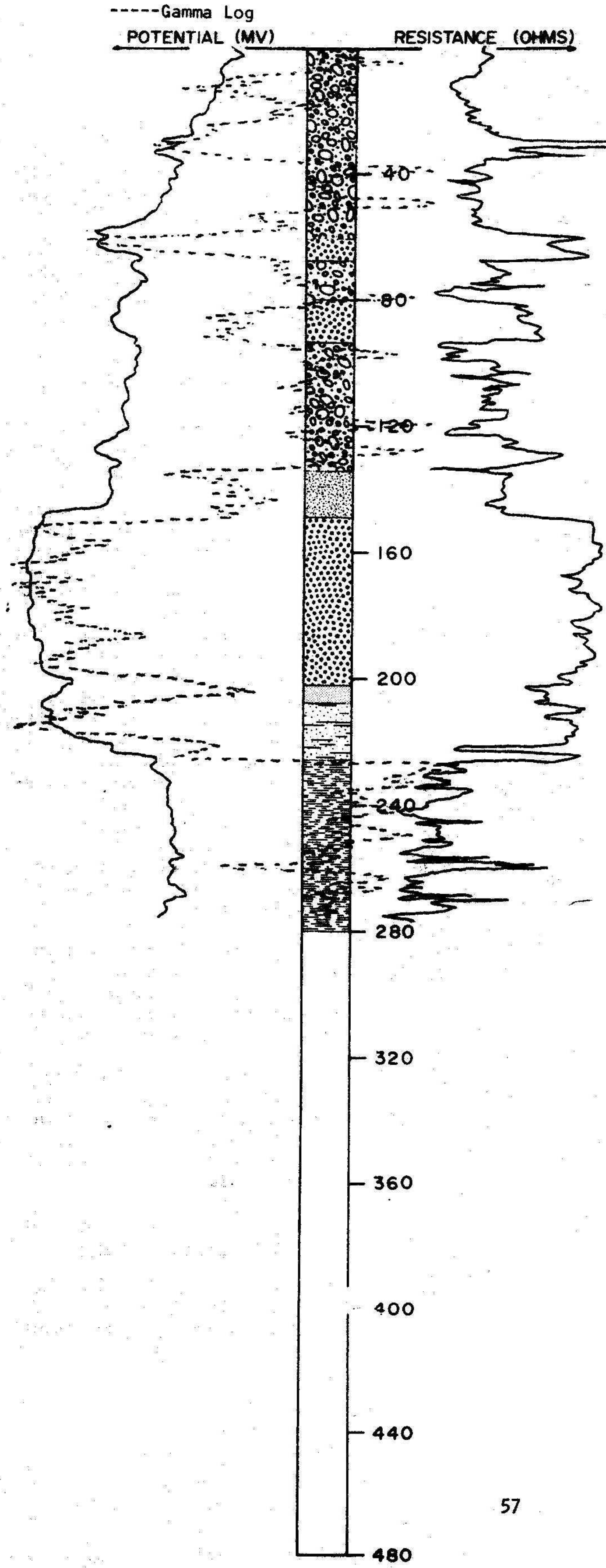
TEST HOLE 4434

LOCATION: 163-96-19daa

DATE DRILLED: 5-24-72

ELEVATION: 1922
(FT, MSL)

DEPTH: 280
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, clayey silt loam, black.
1-35	Clay, very silty, slightly sandy, pebbly, cobbles, moderate to dark olive brown, soft to moderately soft, slightly crumbly to moderately cohesive, oxidized (Till); boulders at 30 and 34 feet.
35-60	Clay, silty, sandy, pebbly, olive gray, moderately soft, stiff (Till); clay layers.
60-67	Sand, medium to coarse, yellowish-brown, loose, sorted, subrounded.
67-80	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard (Till).
80-93	Sand, very fine, silty and moderately clayey, olive gray, soft, slightly cohesive, nonplastic.
93-134	Clay, silty, sandy, pebbly, varigated bedrock boulders containing lignite, slightly hard, compacted, stiff (Till).
134-149	Silt, slightly clayey with very fine sand, light olive gray with brownish tint, chunky, crumbly, nonplastic.
149-202	Sand, very fine to fine, some medium in upper part, becoming siltier with depth, loose to slightly cohesive.

Tongue River Formation

202-208	Siltstone, brownish gray, slightly hard, chunky, slightly friable, carbonaceous.
208-226	Sandstone and siltstone, greenish and brownish gray, slightly hard, moderately friable, slightly carbonaceous and lignitic, thin waxy shales.
226-280	Shale, silty and sandy, varigated greens and grays, hard, brittle, carbonaceous and lignitic.

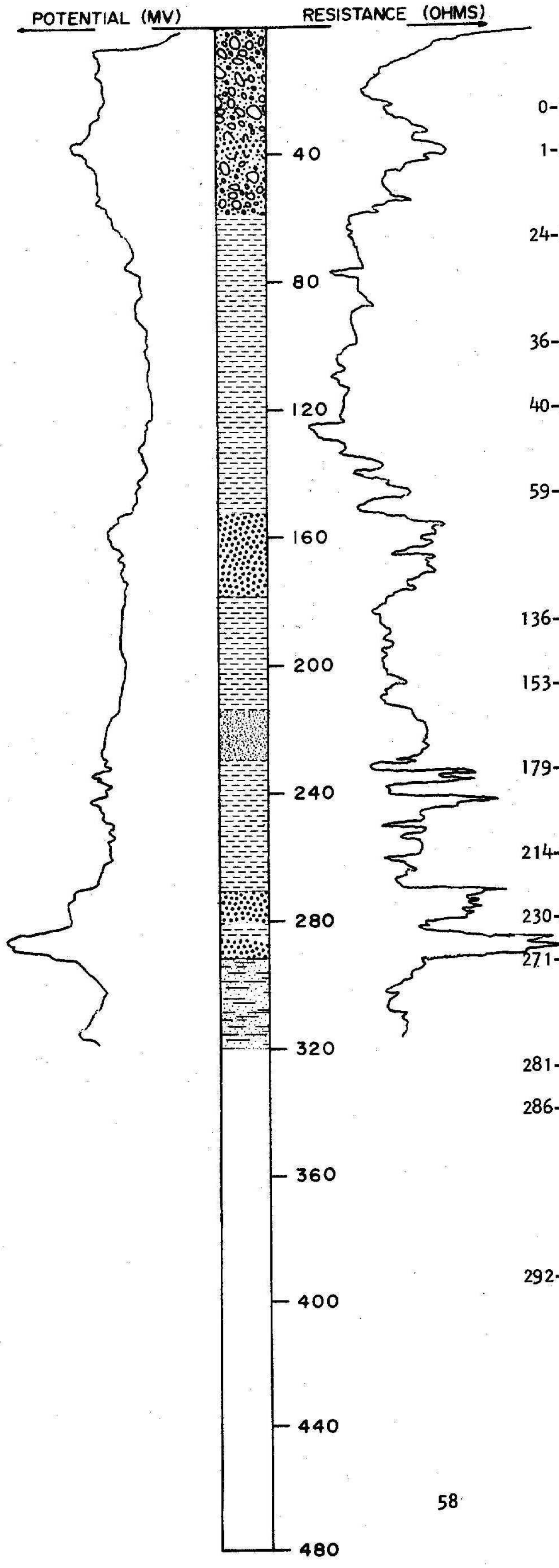
TEST HOLE 8290

LOCATION: 163-96-29bbb

ELEVATION: 1925 feet
(FT, MSL)

DATE DRILLED: 12-20-71

DEPTH: 320 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly clay loam, grayish black.
1-24	Clay, moderately silty, slightly sandy, pebbly, moderate yellowish brown, moderately cohesive, oxidized (Till).
24-36	Clay, silty, sandy, pebbly, numerous fine to coarse sand lenses, dark yellowish brown, loose to moderately cohesive, oxidized (Till).
36-40	Sand, medium to coarse, well-sorted, subrounded, partially oxidized.
40-59	Clay, silty, sandy, pebbly, sand and gravel lenses, cobbles, olive gray, moderately soft, cohesive (Till).
59-136	Clay, silty, sandy, interbedded, medium gray to medium dark gray with very light gray mottling and laminations, soft to moderately soft, moderately cohesive, slightly plastic.
136-153	Clay (as above), dark gray, interbedded with fine and medium, sorted, subrounded sand.
153-179	Sand, fine to coarse, thinly interbedded with clay and silty clay lenses, light olive gray, quartzose and lignitic.
179-214	Clay, silty, olive gray, moderately soft, very cohesive, slightly plastic to stiff, smooth, laminated.
214-230	Silt, slightly clayey to sandy, light olive gray, soft chunky, crumbly, uniform.
230-271	Clay, silt, and sand (as above); thinly interbedded or lenticular.
271-281	Sand, fine and medium, light olive gray to slightly grayish-orange, well-sorted, subrounded, mainly quartz and carbonate rocks.
281-286	Clay, silty, dark olive gray, slightly hard, smooth, tight.
286-292	Sand, medium and coarse, some gravel and detrital lignite, moderately sorted, subangular to subrounded, mostly quartz and feldspars.

Tongue River Formation

292-320	Sandstone, very fine-grained, slightly clayey, medium bluish gray, micaceous, noncalcareous; thin shaley streaks.

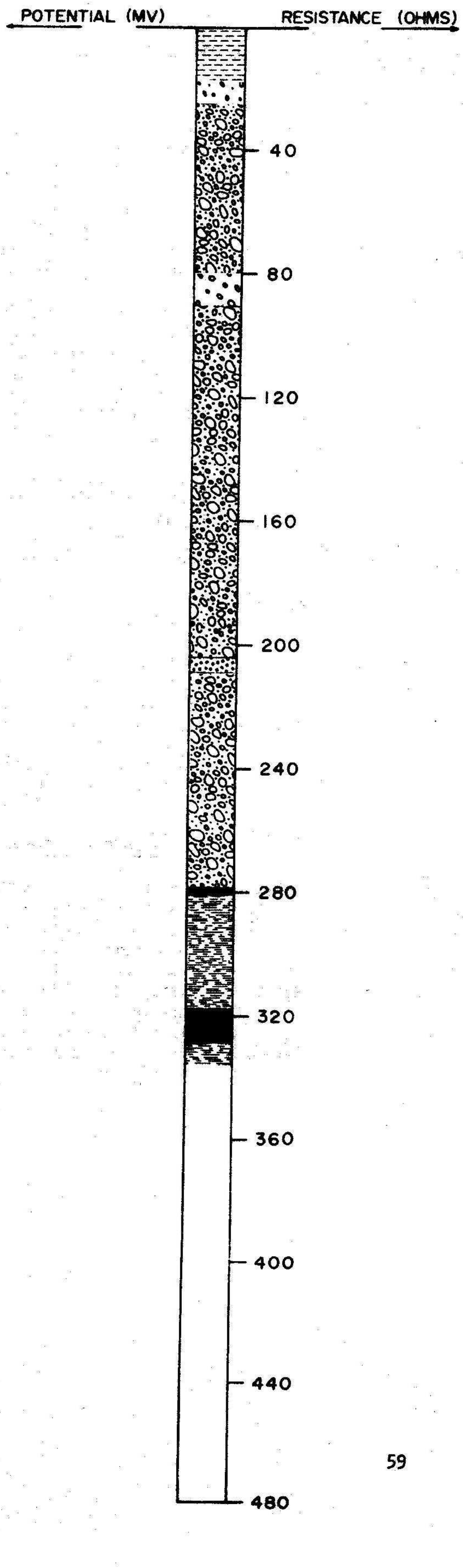
TEST HOLE MB

LOCATION: 163-96-29ddd

DATE DRILLED: 1947

ELEVATION: 1905 feet
(FT, MSL)

DEPTH: 336 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2	Soil.
2-13	Clay, yellow, gypsiferous.
13-17	Clay, sandy, gray.
17-18	Boulder, limestone.
18-25	Gravel, interbedded with yellow clay.
25-36	Clay, pebbly, yellow (Till).
36-62	Clay, sandy with pebbles, gray (Till).
62-63	Rock.
63-80	Clay, sandy with pebbles, gray (Till).
80-91	Gravel, fine, sandy.
91-204	Clay, sandy with pebbles, cobbles and boulders, gray (Till).
204-209	Sand, fine, lignitic, thinly interbedded with gray clay.
209-266	Clay, sandy with pebbles, boulders and lignite fragments (Till).
266-279	Clay, pebbly, gray (Till).

Tongue River Formation

279-281	Lignite.
281-318	Clay, gray, interbedded with lignite.
318-329	Lignite, soft and hard.
329-336	Clay, sandy, brown, carbonaceous and lignitic.

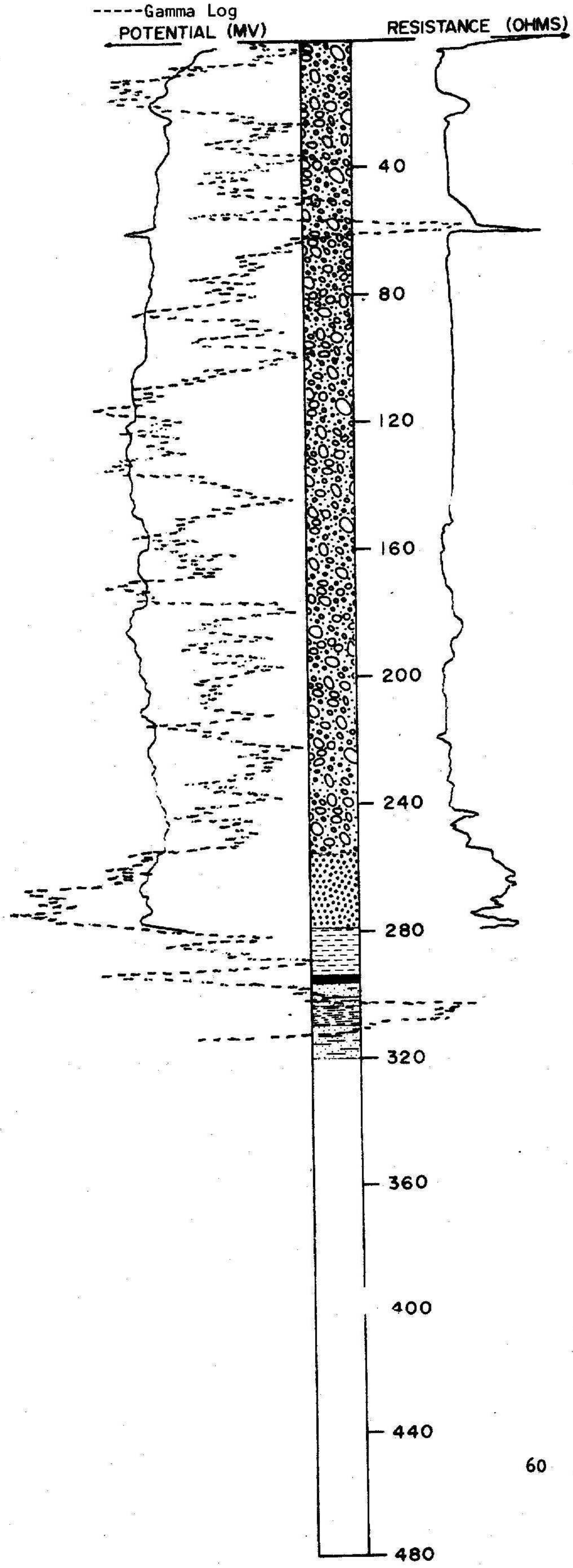
TEST HOLE 4433

LOCATION: 163-96-31ddd

ELEVATION: 1928
(FT, MSL)

DATE DRILLED: 5-23-72

DEPTH: 320
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay loam, black.
1-35	Clay, silty, sandy, pebbly, yellowish gray to moderate olive brown, soft to moderately soft, moderately cohesive, oxidized (Till); interbedded laminated silt and sandy clay layers.
35-150	Clay, moderately silty, sandy, pebbly, olive gray, moderately soft to slightly hard, cohesive, slightly plastic to stiff and brittle, tightly compacted (Till); granite boulder at 58 feet.
150-255	Clay, silty, slightly sandy, pebbly, cobbles, olive gray, slightly hard, very stiff (Till); thin lignitic sand and carbonate gravel lenses.
255-266	Sand, fine, silty, light olive gray, sorted, subrounded, loose.
266-279	Sand, medium to very coarse, sorted, subangular to subrounded, loose, clean.
279-294	Clay, silty to sandy, dark gray, smooth, tight, sticky; interbedded with fine to coarse, dark brown, heavily iron-stained silicate gravel.

Tongue River Formation

294-296	Lignite, black, hard.
296-304	Sandstone, very fine to fine-grained, greenish gray, moderately soft, friable, micaceous; macerated shell fragments.
304-310	Shale, light gray, hard, fissile, smooth, very tight; possibly bentonitic.
310-320	Sandstone (as above), clayey and lignitic.

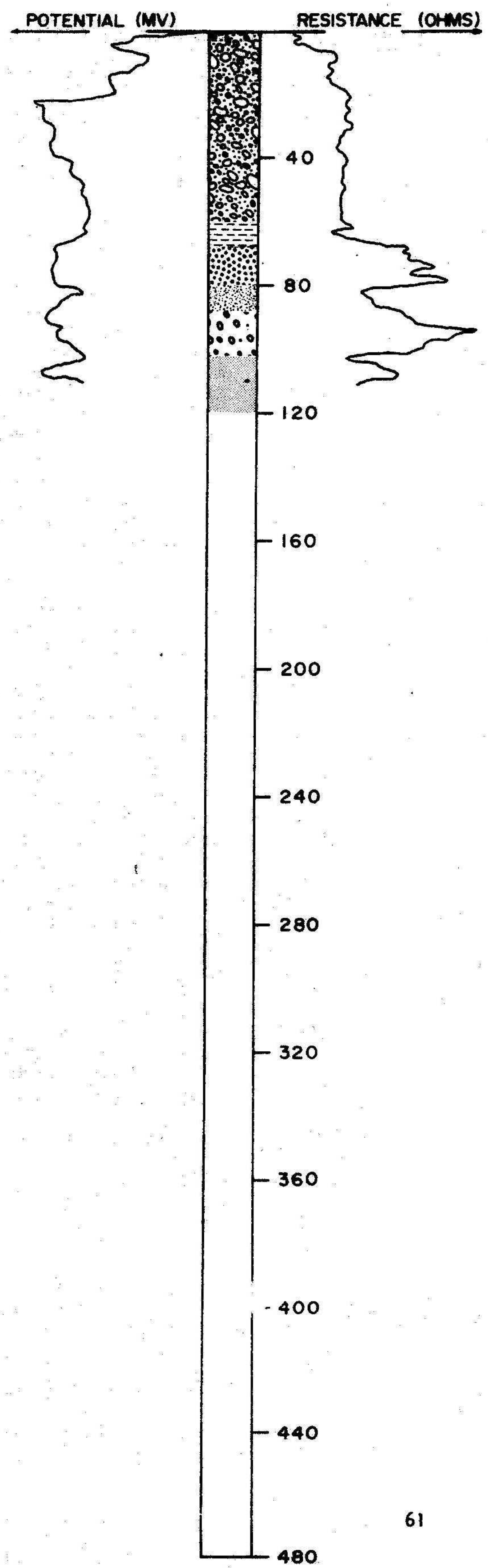
TEST HOLE 3023

LOCATION: 163-96-33ccc

DATE DRILLED: 6-25-63

ELEVATION: 1927 feet
(FT, MSL)

DEPTH: 120 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2	Topsoil.
2-6	Clay, silty, pebbly, yellowish gray, moderately soft, cohesive, oxidized (Till).
6-18	Clay, silty, pebbly, thin, fine to coarse, lignitic sand stringers, dark yellowish orange to moderate olive brown, moderately soft, loose to cohesive, oxidized (Till).
18-41	Clay, silty, sandy, pebbly, cobbles, and boulders; interbedded lignitic sand lenses, dark greenish gray to olive gray, moderately soft to slightly hard, cohesive, stiff (Till).
41-60	Clay, silty, sandy, pebbly, abundant lignite fragments, olive gray, moderately hard, chunky, slightly brittle (Till).
60-68	Clay and silt, interbedded, olive gray, laminated, lignitic, soft, slightly to moderately cohesive, non-to slightly plastic.
68-80	Sand, medium to very coarse, some gravel, interbedded, sorted, subangular to subrounded, lignitic; contains "scoria" and dark brown silicates.
80-88	Silt, clayey, greenish gray, laminated, lignitic and micaceous, soft, calcareous.
88-102	Gravel, fine to coarse, slightly sandy, dark brown, sorted, subrounded.

Tongue River Formation

102-120	Siltstone, varigated very light gray to medium dark gray, lighter material very limey, darker material carbonaceous and non-calcareous, hard, tight.

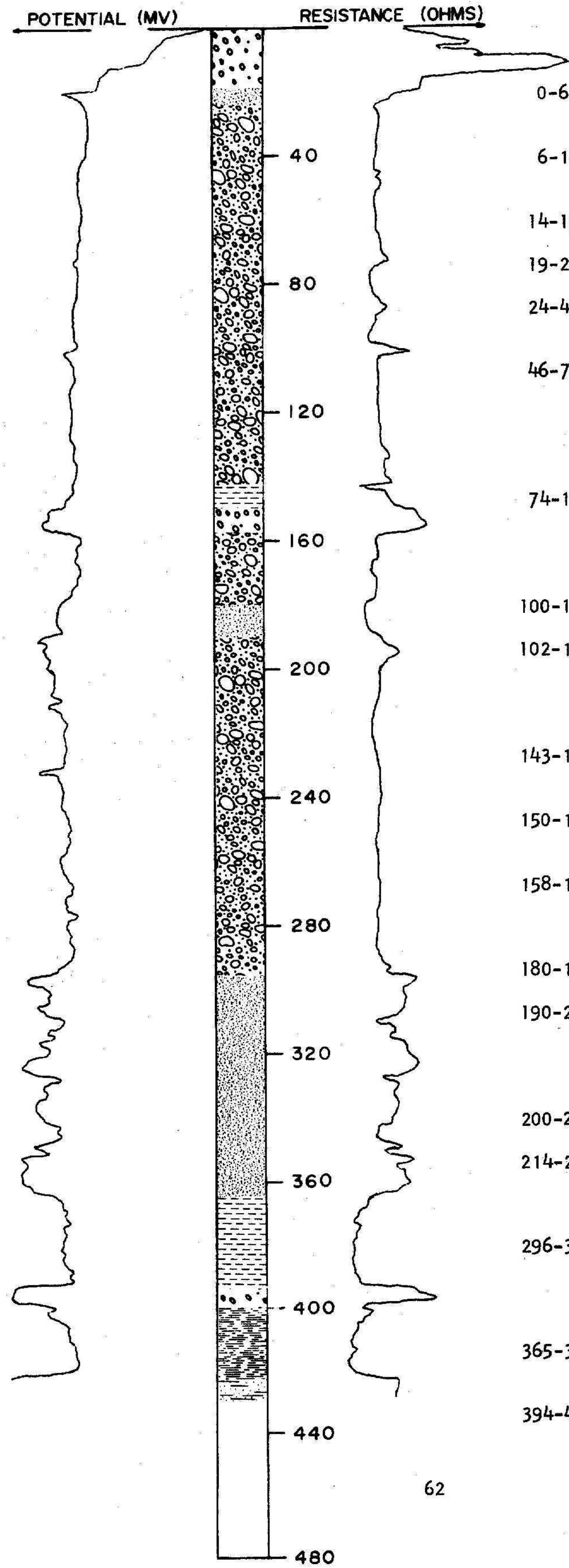
TEST HOLE 3024

LOCATION: 163-97-3adb

ELEVATION: 1890 feet
(FT, MSL)

DATE DRILLED: 6-26-63

DEPTH: 430 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-6	Gravel, sandy, assorted, subangular to subrounded, highly oxidized.
6-14	Gravel (as above), interbedded with grayish-orange, crumbly, oxidized silt.
14-19	Gravel (as above), silty, less oxidized.
19-24	Silt, olive gray, moderately cohesive, calcareous.
24-46	Clay, silty, sandy, pebbly, lignite fragments, olive gray, moderately soft, cohesive (Till).
46-74	Clay, silty, sandy, pebbly, dark yellowish orange to moderate yellowish brown; moderately soft, crumbly to slightly brittle, oxidized (Till); possibly jointed or fractured.
74-100	Clay, silty, sandy, pebbly, occasional cobbles or gravel lenses, dusky yellow to light olive gray, moderately soft, partially oxidized (Till).
100-102	Gravel, granular, sandy, subrounded, oxidized.
102-143	Clay, silty, sandy, pebbly, cobbles, boulders, moderate to dark yellowish brown, slightly hard, compacted cohesive, oxidized (Till).
143-150	Clay and silt, moderate yellowish brown, soft, crumbly, laminated, oxidized.
150-158	Gravel, granular, well-sorted, subangular to subrounded, partially oxidized.
158-180	Clay, silty, sandy, pebbly, dark yellowish brown with olive gray blocks, hard tightly compacted, oxidized (Till).
180-190	Silt, moderate yellowish brown, hard, oxidized.
190-200	Clay, silty, sandy, pebbly, cobbles, and gravel lenses, moderate yellowish brown, hard, tightly compacted, oxidized (Till).
200-214	Till (as above), no gravel lenses.
214-296	Clay, silty, sandy, pebbly, cobbles, and boulders, dark greenish gray, hard, cohesive, tightly compacted, stiff, (Till).
296-365	Silt, clayey, sandy (very fine and fine), olive gray to black, soft to moderately soft, loose to slightly cohesive, laminated, lignitic.
365-394	Clay, slightly silty, dark greenish gray, hard, smooth, stiff, tight.
394-400	Gravel, granular, sandy, moderately well-sorted, subrounded.

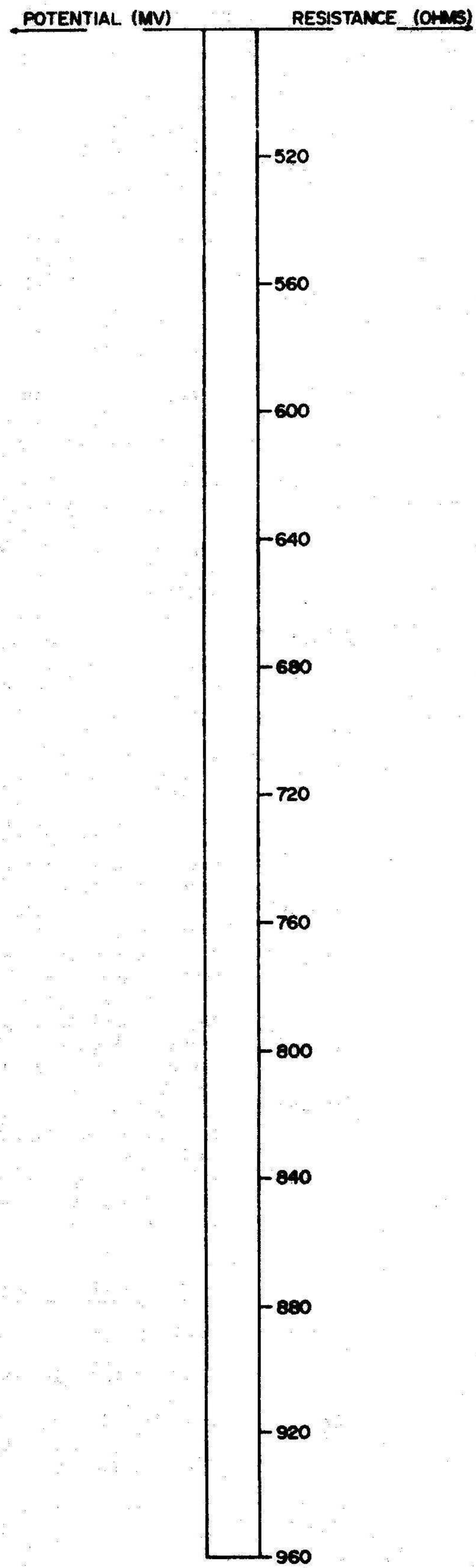
TEST HOLE 3024 (Cont.)

LOCATION: 163-97-3adb

DATE DRILLED: 6-26-63

ELEVATION: 1890 feet
(FT, MSL)

DEPTH: 430 feet
(FT)



DESCRIPTION OF DEPOSITS

Tongue River Formation

400-423 Shale, silty, varigated light olive and greenish gray to brownish black, hard, brittle, tight, carbonaceous and lignitic.

423-430 Sandstone, very fine-grained, light bluish gray, chunky, micaceous, calcareous.

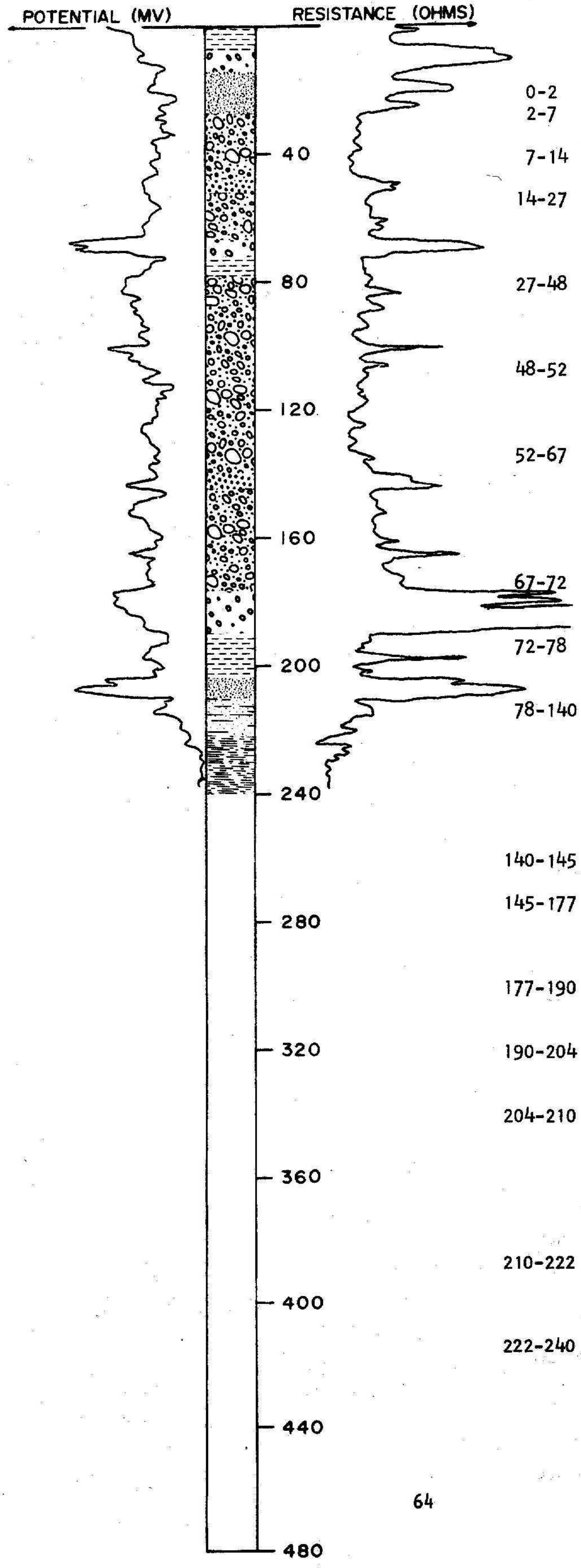
TEST HOLE 3019

LOCATION: 163-97-4daa

ELEVATION: 1890 feet
(FT, MSL)

DATE DRILLED: 6-16-63

DEPTH: 240 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2	Topsoil, very gravelly.
2-7	Clay, very silty, dark yellowish orange, soft, oxidized.
7-14	Gravel, fine and medium, angular to rounded, oxidized.
14-27	Silt, clayey to very sandy, dusky yellow to light olive gray, soft, loose to slightly cohesive, partially oxidized.
27-48	Clay, silty, sandy, pebbly, dark greenish gray, moderately soft, cohesive, slightly plastic (Till).
48-52	Sand, very fine and fine, light olive gray, loose, well-sorted, subrounded, quartzose, lignitic, and micaceous.
52-67	Clay, silty, slightly sandy, pebbly, dark greenish gray or olive gray with moderate yellowish or greenish brown inclusions, hard, cohesive, tightly compacted (Till).
67-72	Gravel, fine, sandy, well-sorted, subangular to subrounded, mostly carbonate rocks.
72-78	Clay, silty, olive gray, moderately soft, cohesive, slightly plastic, smooth.
78-140	Clay, silty, sandy, pebbly, cobbles, and boulders, occasional thin sandy gravel lenses, frequent blocks or boulders of oxidized till, dark greenish gray, moderately hard, cohesive, tight, (Till).
140-145	Sand, medium to coarse, well-sorted, loose, clean.
145-177	Clay, very silty, sandy, pebbly, cobbles and occasional boulders, olive to dark greenish gray, hard, cohesive, compacted (Till).
177-190	Gravel, slightly sandy, cobbles, sorted, generally subrounded; very rough drilling.
190-204	Clay and silt with thin gravel lenses, olive gray, moderately soft to slightly hard, stiff.
204-210	Silt, very sandy (fine), light olive gray, soft, loose to slightly cohesive.

Tongue River Formation

210-222	Sandstone, very fine-grained, clayey, greenish gray, possibly oxidized in upper few feet, noncalcareous.
222-240	Shale and siltstone, sandy and lignitic, hard, brittle, tight, noncalcareous.

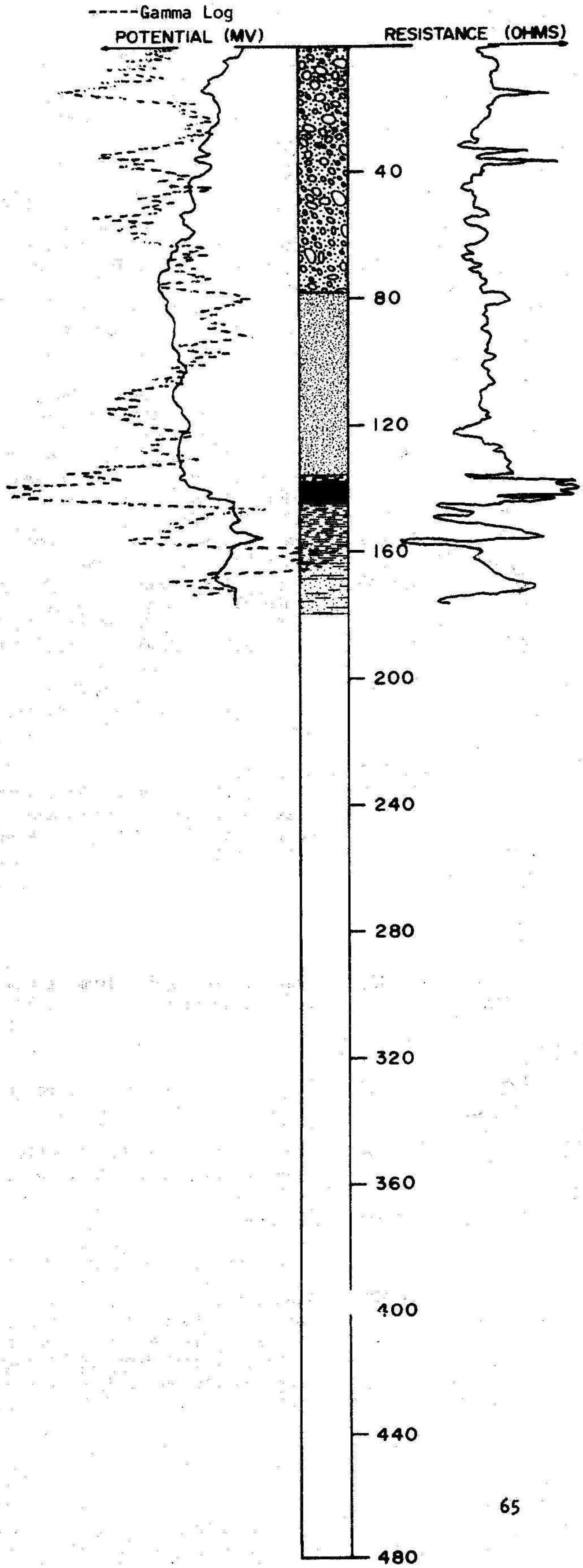
TEST HOLE 4441

LOCATION: 163-97-5ccc

ELEVATION: 1929
(FT, MSL)

DATE DRILLED: 6-1-72

DEPTH: 180
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty loam, black.
1-18	Silt, clayey, sandy, pebbly, yellowish gray to moderate olive brown, soft, cohesive, moderately plastic, slightly sticky, oxidized (Till).
18-41	Clay, very silty, sandy, pebbly, moderate olive brown with olive gray, moderately soft, cohesive, slightly plastic, partially oxidized (Till); boulders at 33 and 36 feet.
41-78	Clay, very silty, sandy, pebbly, olive gray, soft, cohesive, plastic, sticky (Till).
78-136	Silt, clayey, occasional sand grain or pebble, olive gray, soft, cohesive, plastic, smooth.

Tongue River Formation

136-138	Shale, medium gray, slightly hard, slightly brittle, smooth, tight.
138-145	Lignite, hard, brittle; probably fractured.
145-158	Shale, silty to sandy, varigated browns to black, slightly to moderately hard, oily, carbonaceous and lignite, tight.
158-164	Shale, silty, green with brown stains, moderately soft, smooth.
164-180	Sandstone, very fine-grained, clayey, greenish gray with brown, soft, moderately friable, carbonaceous.

Flowing Test Hole
Plugged

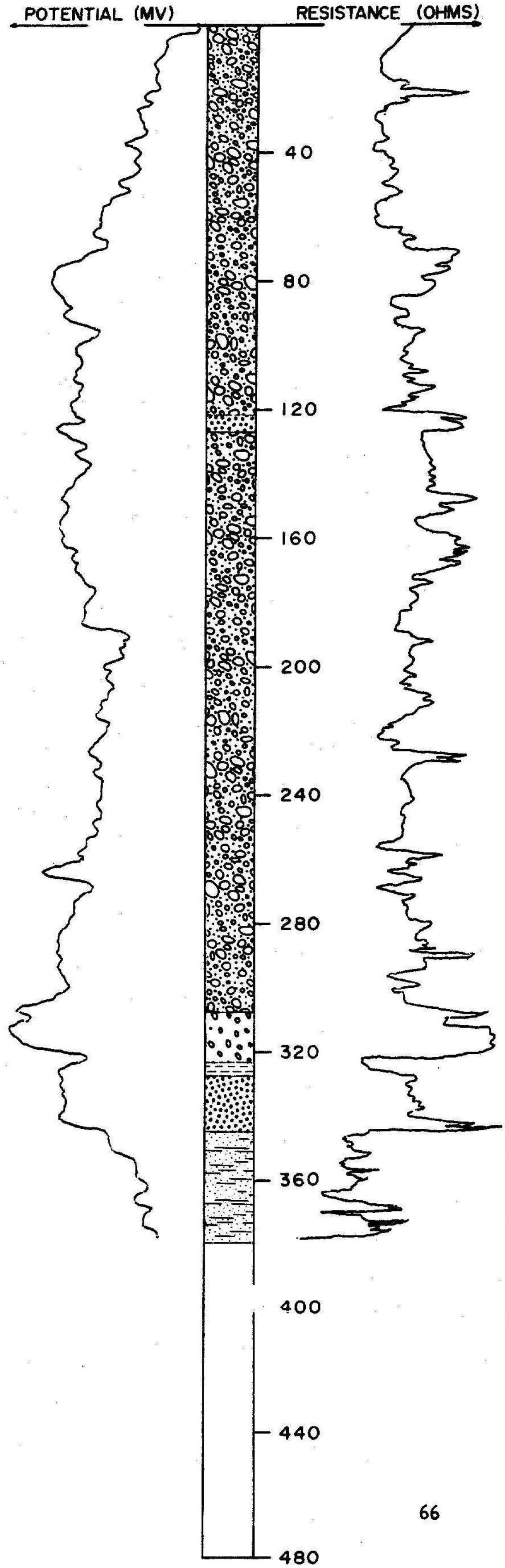
TEST HOLE 4442

LOCATION: 163-97-10bcb

ELEVATION: 1922
(FT, MSL)

DATE DRILLED: 6-1-72

DEPTH: 380
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2	Topsoil, clayey silt loam, black.
2-18	Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, iron-stained, oxidized (Till).
18-27	Till (as above); very gravelly.
27-39	Clay, silty, sandy, pebbly, light olive to olive gray, slightly hard, cohesive, compacted, oxidized (Till).
39-70	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, slightly plastic (Till).
70-85	Silt, clayey, sandy, pebbly, dusky yellow, soft, slightly cohesive, oxidized (Till).
85-122	Clay, silty, sandy, pebbly, cobbles, moderate olive brown, moderately soft, cohesive, stiff, oxidized (Till).
122-127	Sand, coarse, sorted, subangular and subrounded, iron-stained.
127-189	Clay, silty, sandy, pebbly, moderate olive brown, slightly hard, stiff, slightly brittle, oxidized (Till); medium to coarse sand and fine gravel lenses.
189-227	Clay, silty, sandy, pebbly, light olive gray, hard, stiff, compacted, partially oxidized (Till).
227-230	Cobbles.
230-308	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, cohesive, stiff (Till).
308-323	Gravel, fine and medium, sandy, lenticular, subrounded, loose.
323-327	Clay, dark olive gray, moderately soft, cohesive, stiff, smooth, tight.
327-342	Sand, fine, silty to slightly clayey, laminated grays, soft, crumbly.
342-345	Cobbles.

Tongue River Formation

345-380	Sandstone, very fine, clayey, varigated grays, greens, and browns, moderately soft, friable, micaceous, carbonaceous; interbedded siltstone and sandy shale.

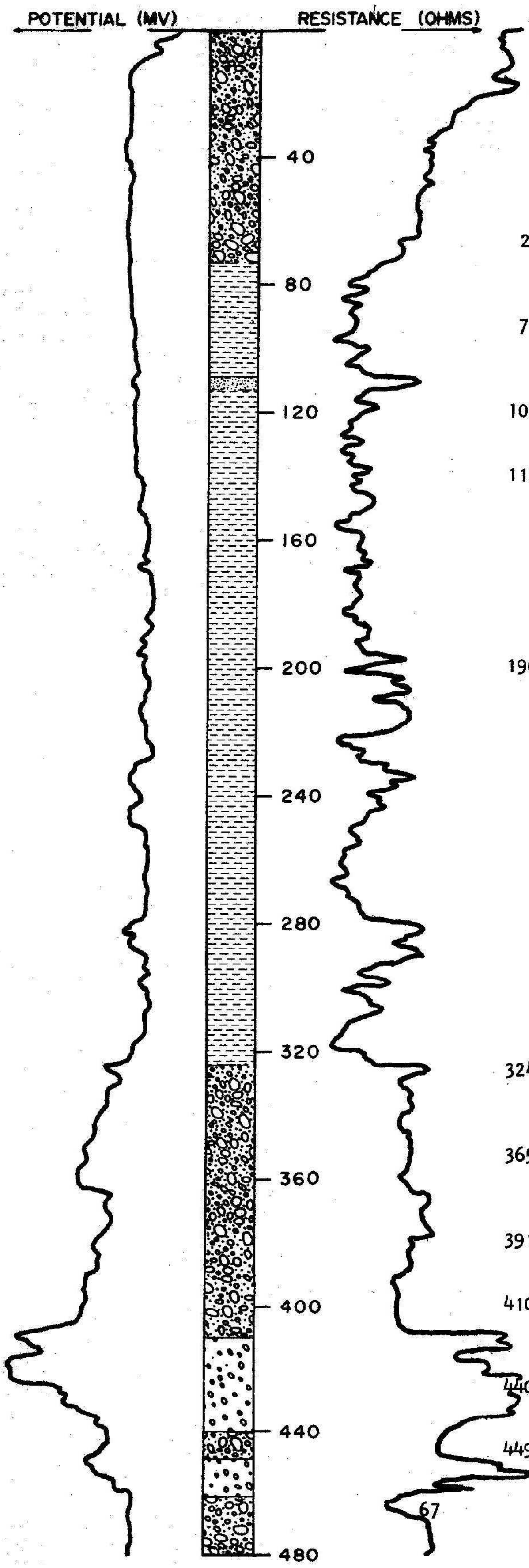
TEST HOLE 4444

LOCATION: 163-97-10cac

DATE DRILLED: 6-6-72

ELEVATION: 1920
(FT, MSL)

DEPTH: 540
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly, silty loam, dark brown.
1-20	Silt, clayey, very sandy, pebbly, numerous sand and gravel lenses, yellowish gray to reddish brown, soft moderately cohesive, oxidized (washed till).
20-73	Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, slightly plastic to stiff (Till).
73-109	Clay and silty clay, olive to dark olive gray, moderately soft to slightly hard, moderately stiff and brittle.
109-113	Silt, slightly clayey to very sandy, dusky yellow, soft, friable, laminated, oxidized.
113-196	Clay and silty clay, olive or dark olive gray, occasional white, green, or brown, moderately soft to slightly hard, cohesive, tight, stiff, brittle, smooth.
196-324	Clay, olive gray, soft to moderately soft, cohesive, plastic, sticky; interbedded with silt and silty clay, some fine lignitic sand, frequent coarse sand and gravel lenses, occasional cobbles.
324-365	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, cohesive, compacted, (Till); sand lenses.
365-391	Silt, clayey to very sandy, pebbly, dusky yellow, moderately soft, moderately cohesive, oxidized (Till).
391-410	Clay, silty, sandy, pebbly, moderate olive brown, slightly hard, stiff, compacted, oxidized (Till).
410-440	Gravel, fine to coarse, sandy, sorted but lenticular, subangular to subrounded; interbedded with oxidized sandy till.
440-449	Silt, clayey, very sandy, pebbly dusky yellow, soft, moderately cohesive, oxidized (Till).
449-461	Gravel (as above), sandy, "dirty".

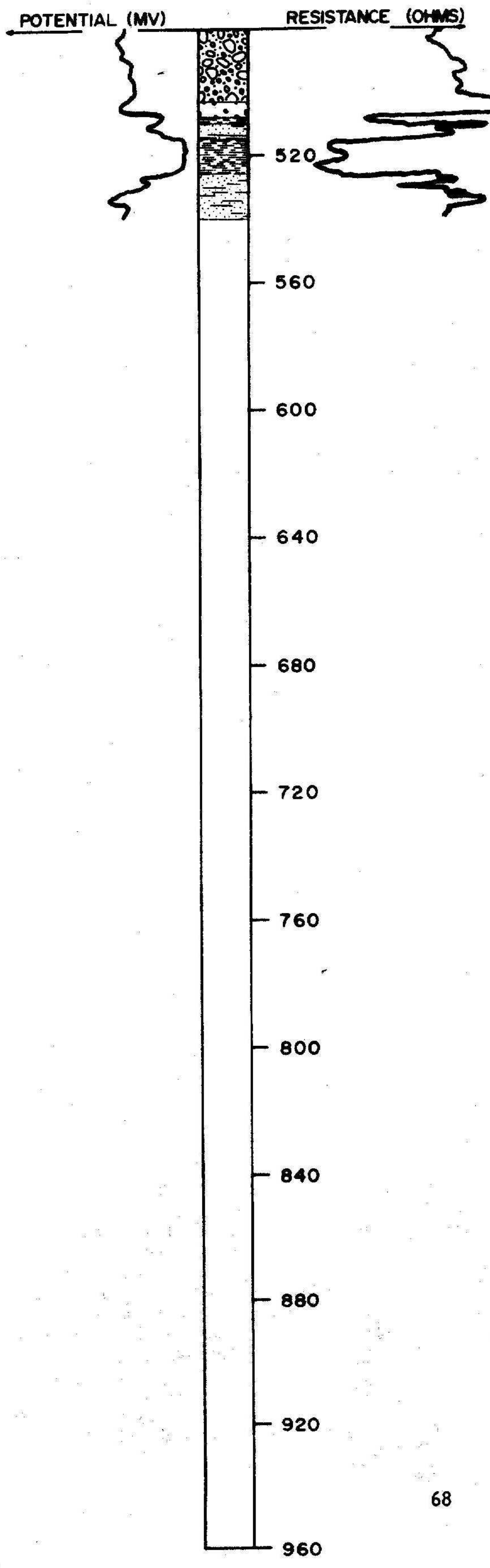
TEST HOLE 4444 (Cont.)

LOCATION: 163-97-10cac

ELEVATION: 1920
(FT, MSL)

DATE DRILLED: 6-6-72

DEPTH: 540
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift (Cont.)

461-503	Clay, extremely silty to moderately sandy, pebbly, cobbles, and frequent sandy gravel lenses, olive gray, cohesive, stiff (Till).
503-508	Gravel, coarse, many cobbles.

Tongue River Formation

508-510	Shale, silty, medium dark gray, smooth, hard, brittle.
510-515	Sandstone, very fine-grained, light grayish green, moderately soft, slightly friable.
515-526	Shale, silty, varigated grays and browns, hard, smooth carbonaceous.
526-540	Sandstone, very fine-to fine-grained, grayish green, moderately soft, moderately friable, chunky, micaceous.

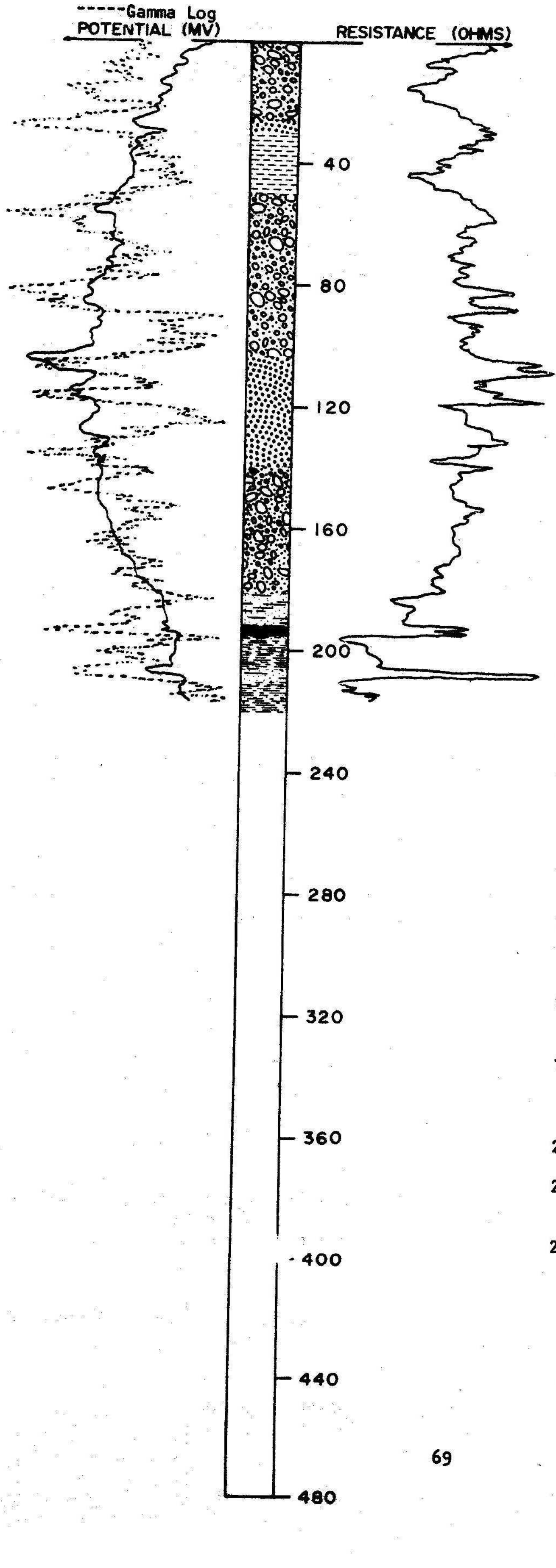
TEST HOLE 4430

LOCATION: 163-97-12ccc

DATE DRILLED: 12-22-71

ELEVATION: 1925 feet
(FT, MSL)

DEPTH: 220 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly silt loam, black.
1-26	Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, slightly plastic to slightly crumbly, oxidized (Till).
26-30	Sand, coarse, varies from medium sand to fine gravel, generally rounded, heavily iron-stained carbonates with granitics, little shale, no lignite.
30-50	Clay and silt, occasional sand grain or pebble, moderate olive brown, yellowish gray, and light olive gray, soft and moderately soft, plastic to crumbly.
50-104	Clay, very silty and sandy, pebbly, cobbles, numerous lenses of medium to coarse sand and fine to medium gravel, also blocks or boulders of greenish brown oxidized till, moderately soft to slightly hard, very cohesive and tough to crumbly (Till).
104-140	Sand, medium to very coarse, gravelly, interbedded with olive gray clayey till.
140-182	Clay, very silty, sandy, pebbly, olive gray, slightly hard, very cohesive and tough (Till).

Tongue River Formation

182-192	Sandstone, very fine-grained very clayey, light grayish green, moderately soft, slightly friable.
192-195	Lignite, black, hard, brittle; thinly interbedded with carbonaceous shale.
195-206	Shale, very silty, varigated greens, grays, and browns, hard, smooth, tight, carbonaceous.
206-207	Clay, sandy, white, soft, chalky.
207-210	Sandstone, very fine-grained, greenish gray, moderately indurated, $CaCo_3$ cement.
210-220	Shale, very silty to sandy, varigated, hard, tight, brittle, carbonaceous and lignitic.

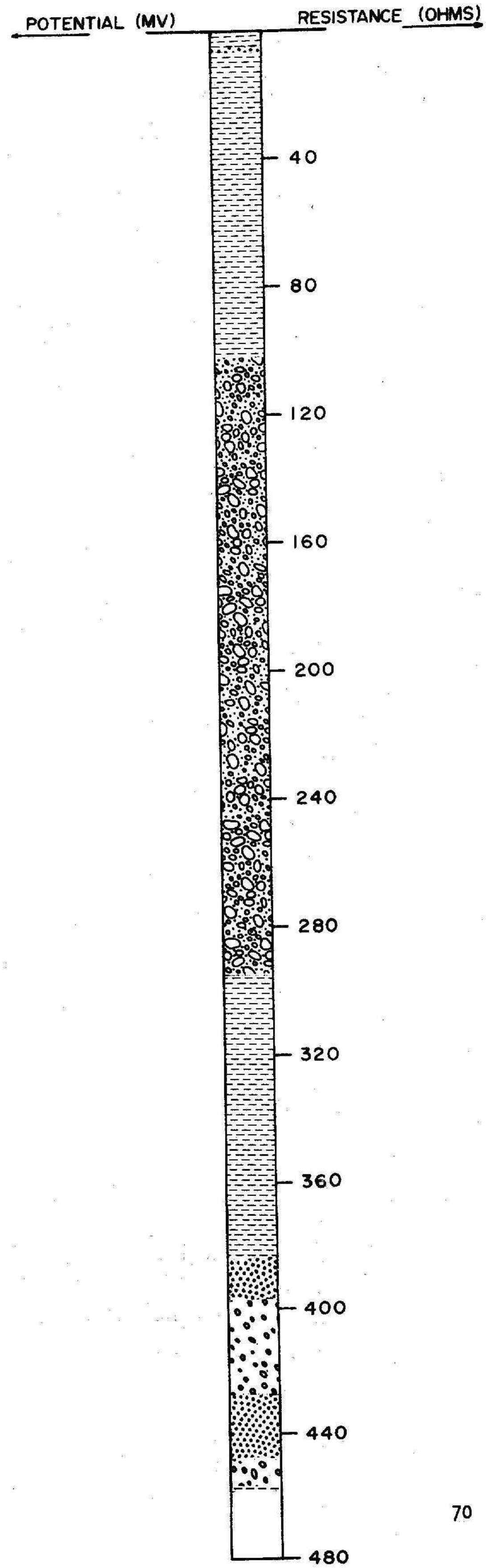
TEST HOLE MB

LOCATION: 163-97-13ccc

ELEVATION: 1915 feet
(FT, MSL)

DATE DRILLED: 1947

DEPTH: 459 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Soil
1-5	Clay, sandy, gray.
5-7	Sand, fine, some gravel.
7-10	Clay, yellow.
10-33	Clay, blue.
33-45	Clay, yellow and gray.
45-46	Rock.
46-61	Clay, gray, with fine sand.
61-102	Clay, silty, gray.
102-240	Clay, gray with some gravel and lignite fragments (Till).
240-295	Till, as above, interbedded with fine sand.
295-384	Clay, gray.
384-397	Sand, fine, gravel and lignite fragments.
397-428	Gravel and fine sand.
428-448	Sand, fine, with gravel and gray clay.
448-457	Boulders.
457-459	Clay, gray.

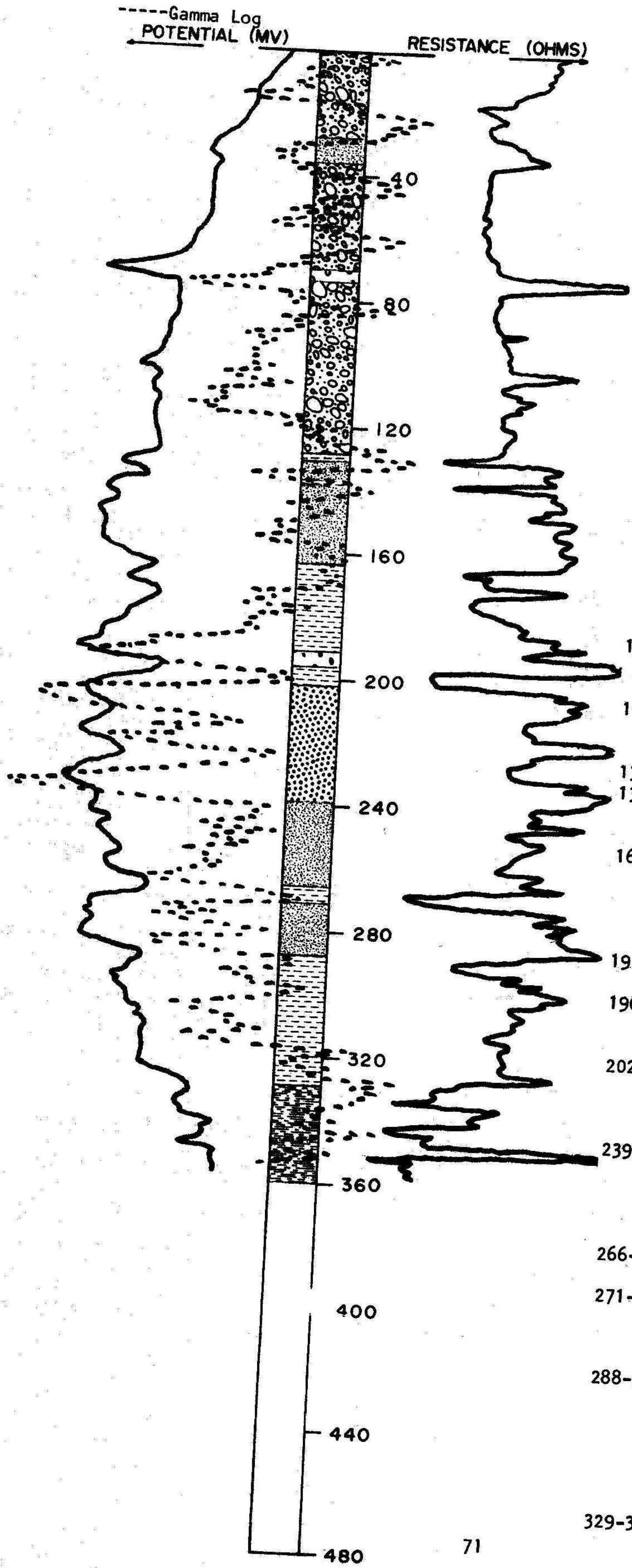
TEST HOLE 4436

LOCATION: 163-97-13daa

ELEVATION: 1920
(FT, MSL)

DATE DRILLED: 5-24-72

DEPTH: 360
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, clayey silt loam, black.
1-16	Clay, very silty, sandy, pebbly, dark brown, soft, moderately cohesive, slightly sticky (washed till?).
16-28	Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, slightly stiff, oxidized (Till).
28-36	Silt, slightly clayey to sandy, dusky yellow, soft, slightly cohesive, nonplastic, oxidized.
36-70	Clay, silty, slightly sandy, pebbly, olive gray, moderately soft, very cohesive (Till).
70-74	Gravel, fine with medium, slightly sandy, well-sorted, subrounded, clean.
74-129	Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, very cohesive, stiff, tightly compacted (Till); silt and gravel lenses.
129-131	Clay, dark gray, moderately soft, moderately plastic, smooth.
131-137	Silt, sandy (very fine), light olive to olive gray, soft, slightly cohesive, nonplastic.
137-139	Clay (as above) dark, smooth.
139-164	Silt, slightly clayey to very sandy, olive gray, laminated and interbedded.
164-191	Clay and silty clay, silt, and fine sand, thinly interbedded, varigated grays, soft to moderately soft, loose to cohesive.
191-196	Gravel, fine, sandy, generally subrounded, loose, sorted.
196-202	Clay, dark gray, slightly to moderately hard, brittle, stiff, tight.
202-239	Sand, very fine to medium, loose, laminated; interbedded with silty clay, silt, detrital lignite.
239-266	Silt, clayey to sandy, interbedded and laminated, soft to moderately soft, loose to moderately cohesive, non-to moderately plastic.
266-271	Clay, dark olive gray, slightly hard, stiff, smooth.
271-288	Silt, sandy (fine and medium), sorted but interbedded, generally light olive gray, soft.
288-329	Clay, silty, sandy, varigated grays, soft to hard; blocks of local bedrock, boulder pavement at the base.

Tongue River Formation

329-360	Shale, silty to sandy, varigated grays with green, black and brown, hard, very tight, carbonaceous.

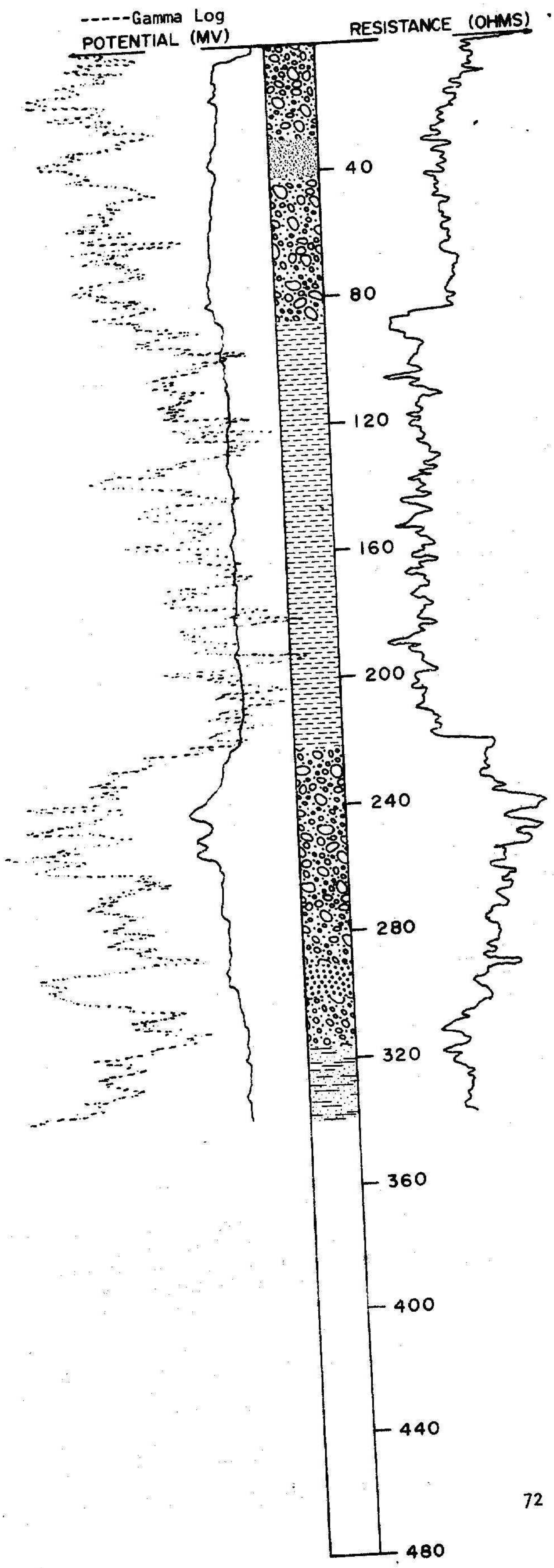
TEST HOLE 4431

LOCATION: 163-97-14ccc

ELEVATION: 1925 feet
(FT, MSL)

DATE DRILLED: 12-23-71

DEPTH: 340 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1 Topsoil, pebbly silt loam, black.

1-30 Clay, silty, sandy, pebbly, cobbles, moderate olive brown to greenish brown, moderately soft to slightly hard, cohesive to slightly crumbly (Till); contains blocks and lenses of clay, silt, and sand, oxidized.

30-42 Silt, slightly clayey, light olive gray, moderately soft, slightly cohesive, laminated; contains sand grains.

42-88 Clay, silty, slightly sandy, pebbly, olive gray, slightly hard, stiff (Till).

88-222 Clay and silty clay, predominently olive gray but varies from light gray to nearly black, limey to organic, soft to moderately soft, cohesive, slightly crumbly to plastic, smooth.

222-237 Clay, silty, sandy, pebbly, olive to dark olive gray, slightly hard, very cohesive and compacted, stiff and tough (Till).

237-260 Till (as above) interbedded with sandy, fine and medium, carbonate gravel; rough drilling.

260-291 Till (as above) without the gravel.

291-301 Sand, gravelly, assorted, generally subrounded, loose, "dirty"; mostly carbonates with silicates and granitics.

301-317 Clay, silty, sandy, pebbly, olive gray, cohesive, compacted, tough, (Till).

Tongue River Formation

317-340 Sandstone, very fine to fine-grained, clayey, light greenish gray, moderately soft, slightly friable, micaceous, noncalcareous; interbedded with carbonaceous shale and thin indurated sandstone stringers; possibly lignitic near base.

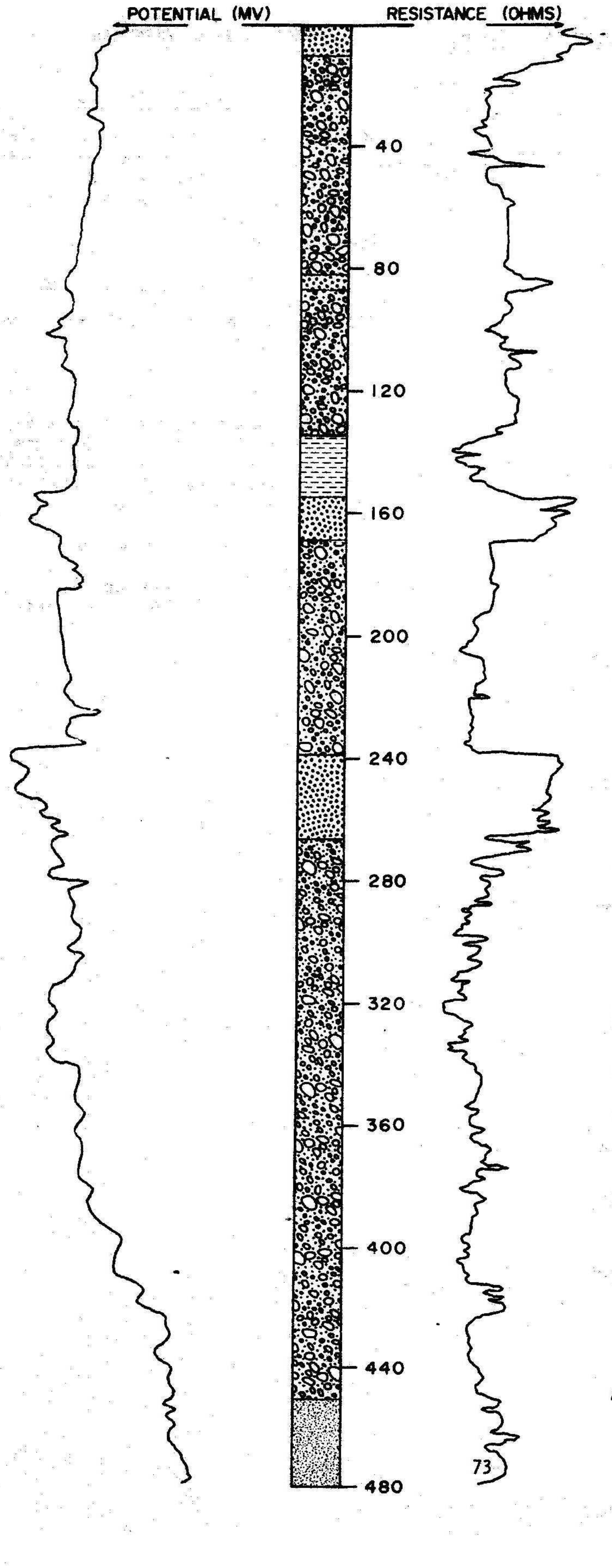
TEST HOLE 4443

LOCATION: 163-97-15abb

ELEVATION: 1910
(FT, MSL)

DATE DRILLED: 6-2-71

DEPTH: 540
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, sandy loam, dark brown.
1-10	Sand, medium to very coarse, gravelly, assorted, generally subrounded, loose, iron-stained, oxidized.
10-22	Silt, clayey, sandy, pebbly, yellowish gray, soft, slightly cohesive, laminated, oxidized (Till?).
22-69	Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, very cohesive, stiff, tightly compacted (Till).
69-82	Clay, silty, sandy, pebbly, moderate olive brown, moderately soft, slightly crumbly to slightly brittle, partially oxidized (Till).
82-87	Sand, coarse, reddish brown, sorted, generally subangular, loose, ironstained.
87-102	Clay, very silty and sandy, pebbly, dusky yellow, soft to moderately soft, slightly crumbly, compacted, oxidized (Till).
102-135	Clay, silty, sandy, pebbly, cobbles, occasional coarse sand lenses, olive gray, mod-soft, cohesive, moderately stiff (Till).
135-155	Clay, silty, olive gray, slightly hard, cohesive, stiff, smooth, tight.
155-169	Sand, fine and medium, light brown, sorted, subrounded, loose; thin clay layers.
169-224	Clay, silty, sandy, pebbly, cobbles, varigated but predominantly moderate olive brown, moderately soft, cohesive to slightly crumbly, oxidized to partially oxidized (Till).
224-239	Clay, silty, sandy, pebbly, olive gray, slightly hard, cohesive, stiff (Till).
239-266	Sand, medium and coarse, very gravelly, lenticular.
266-289	Clay, silty, sandy, pebbly, olive gray, moderately soft, very cohesive, stiff (Till); sand and gravel lenses.
289-362	Clay, silty, sandy, pebbly, cobbles and sandy gravel lenses, olive gray, moderately soft, cohesive (Till).
362-451	Clay, very sandy, pebbly, sand lenses, olive gray, soft to moderately soft, moderately cohesive, compacted (Till).
451-484	Silt, sandy (very fine and fine) olive gray, laminated, soft, loose to slightly cohesive.

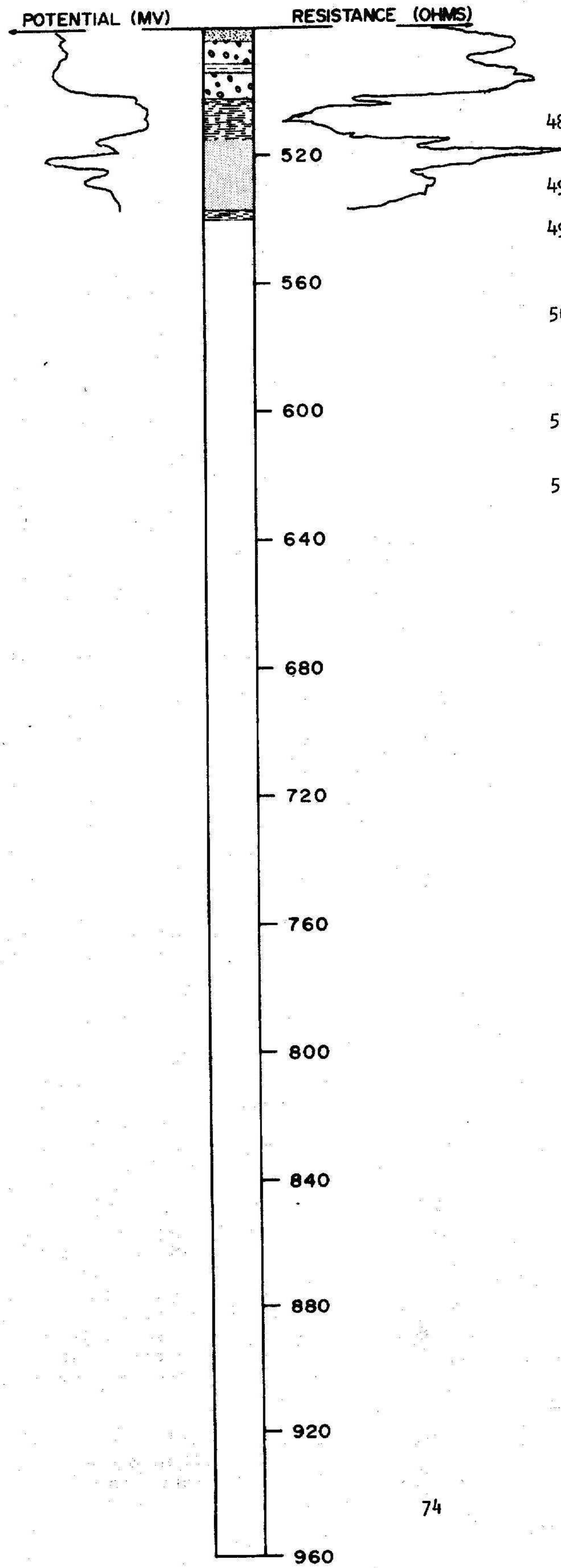
TEST HOLE 4443 (Cont.)

LOCATION: 163-97-15abb

DATE DRILLED: 6-2-71

ELEVATION: 1910
(FT, MSL)

DEPTH: 540
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift (cont.)

484-491	Gravel, fine to coarse, sandy, assorted, subrounded, loose, clean, iron-stained.
491-494	Clay, sandy, white, soft, chalky.
494-502	Cobbles.

Tongue River Formation

502-515	Shale, silty varigated grays, hard, brittle.
515-537	Siltstone, clayey to sandy, buff to tan with light greenish gray laminations, friable.
537-540	Shale, dark gray, hard brittle, possibly bentonitic.

Observation Well

Depth: 244 feet
S. I.: 238 to 244 feet

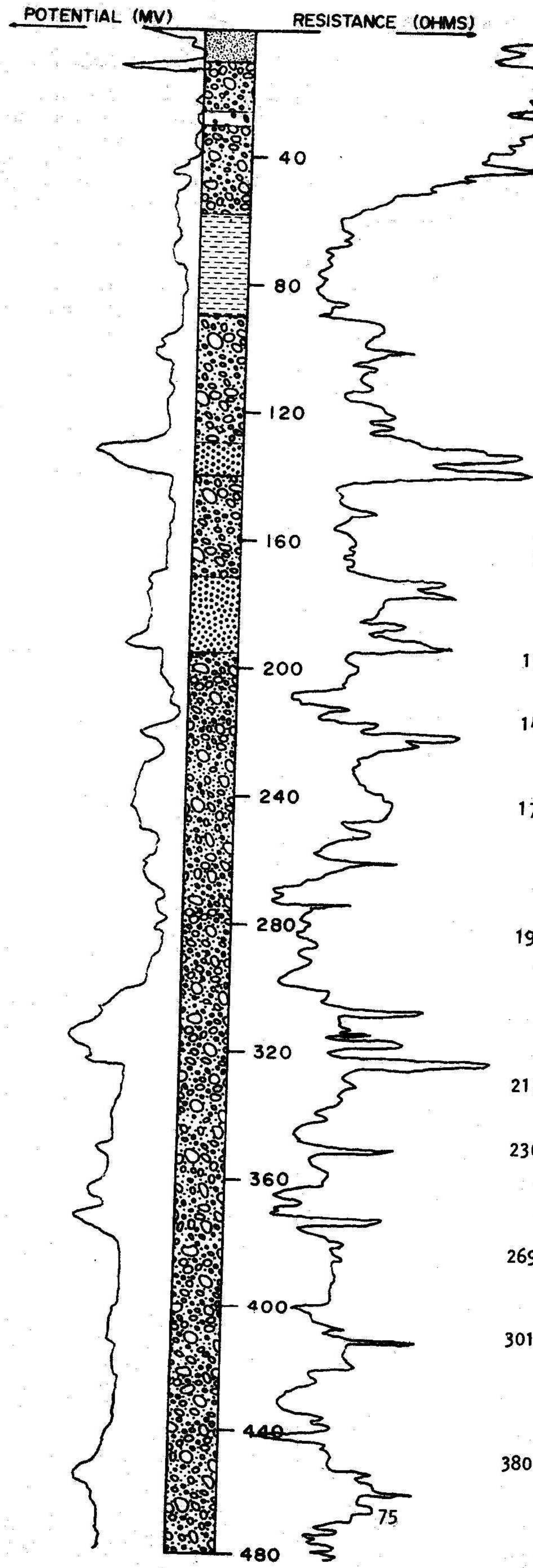
TEST HOLE 4445

LOCATION: 163-97-15bcc

DATE DRILLED: 6-7-72

ELEVATION: 1915
(FT, MSL)

DEPTH: 575
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2	Topsoil, silty loam, black.
2-10	Silt, clayey, sandy, dark brown, laminated, soft, sticky, oxidized.
10-26	Clay, very silty and sandy, pebbly, sand and gravel, lenses, moderate olive brown, soft to moderately soft, moderately cohesive, slightly plastic, oxidized (Till).
26-30	Gravel with cobbles, iron-stained.
30-58	Clay, silty, sandy, pebbly cobbles, moderate olive brown with olive gray, soft to moderately soft, cohesive, slightly stiff (Till); sand and gravel lenses in upper part.
58-90	Clay silty, olive to dark olive gray, moderately soft, smooth, slightly crumbly.
90-130	Clay, very silty and sandy, pebbly cobbles, dusky yellow to moderate olive brown, slightly hard, tightly compacted, oxidized (Till).
130-140	Sand, medium to very coarse, yellowish brown, sorted but lenticular, subangular, loose.
140-172	Clay, silty, sandy, pebbly, olive gray, slightly hard, very cohesive, partially oxidized (Till).
172-195	Sand, medium to very coarse with gravel, moderately sorted, lenticular, subangular and subrounded, oxidized; interbedded with silty clay or till.
195-217	Clay, silty, sandy, pebbly, moderate olive brown moderately soft, moderately cohesive to slightly crumbly, oxidized (Till); blocks or layers of dark brown, waxy, smooth clay.
217-230	Clay, silty, sandy, pebbly, cobbles, olive gray (Till); sand and gravel lenses.
230-269	Clay, silty, sandy, pebbly, cobbles, sandy gravel lenses, moderate olive brown, moderately soft, cohesive, oxidized (Till).
269-301	Clay, silty, sandy, pebbly, cobbles, moderate olive brown, slightly hard, stiff, compacted, oxidized (Till).
301-380	Clay, silty, sandy, pebbly numerous cobbles, yellowish gray, dusky yellow, moderate olive brown, and light olive gray, moderately soft, cohesive, oxidized (Till).
380-540	Clay, silty, sandy, pebbly, cobbles, boulders, blocks or layers of clay, silt sand, and gravel; poor sample return.

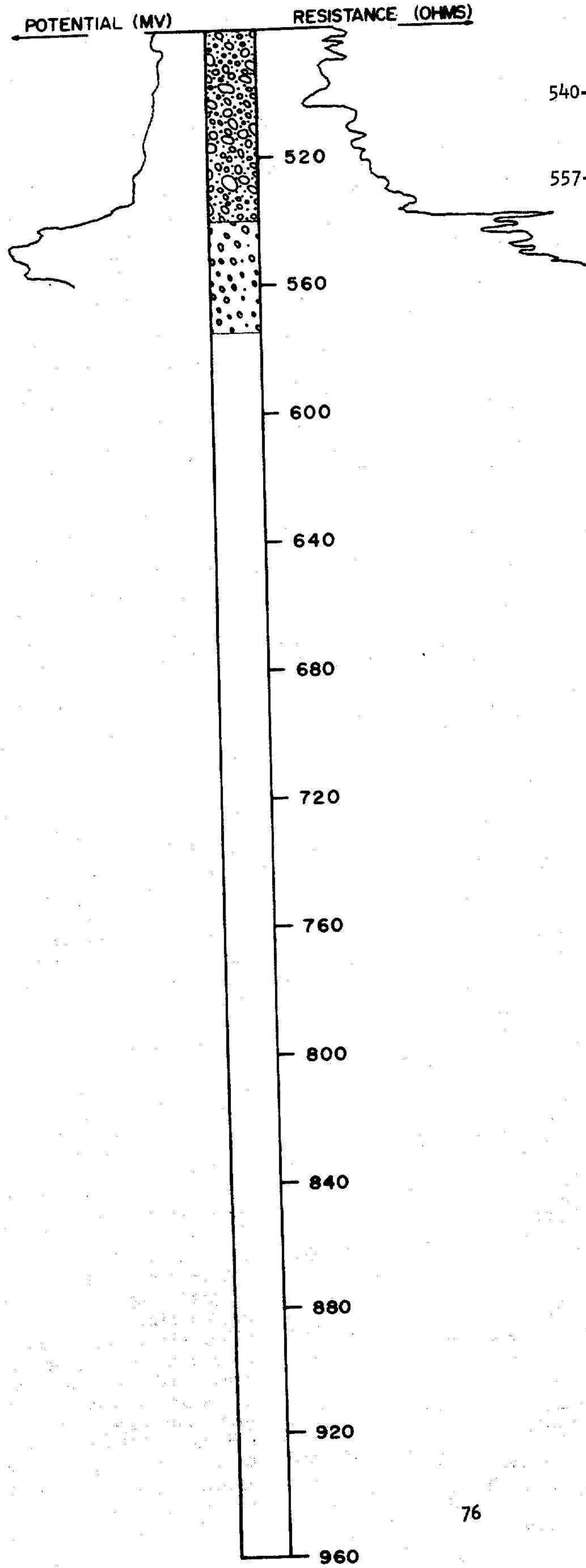
TEST HOLE 4445 (Cont.)

LOCATION: 163-97-15bcc

ELEVATION: 1915
(FT, MSL)

DATE DRILLED: 6-7-72

DEPTH: 575
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift (Cont.)

540-557 Gravel, fine to very coarse, coarse sand and cobbles, moderately sorted, subangular to subrounded, loose, clean.

557-575 Gravel, cobbles, and boulders; very difficult drilling.

Observation Well

Depth: 558 feet
S. I.: 546 to 558 feet

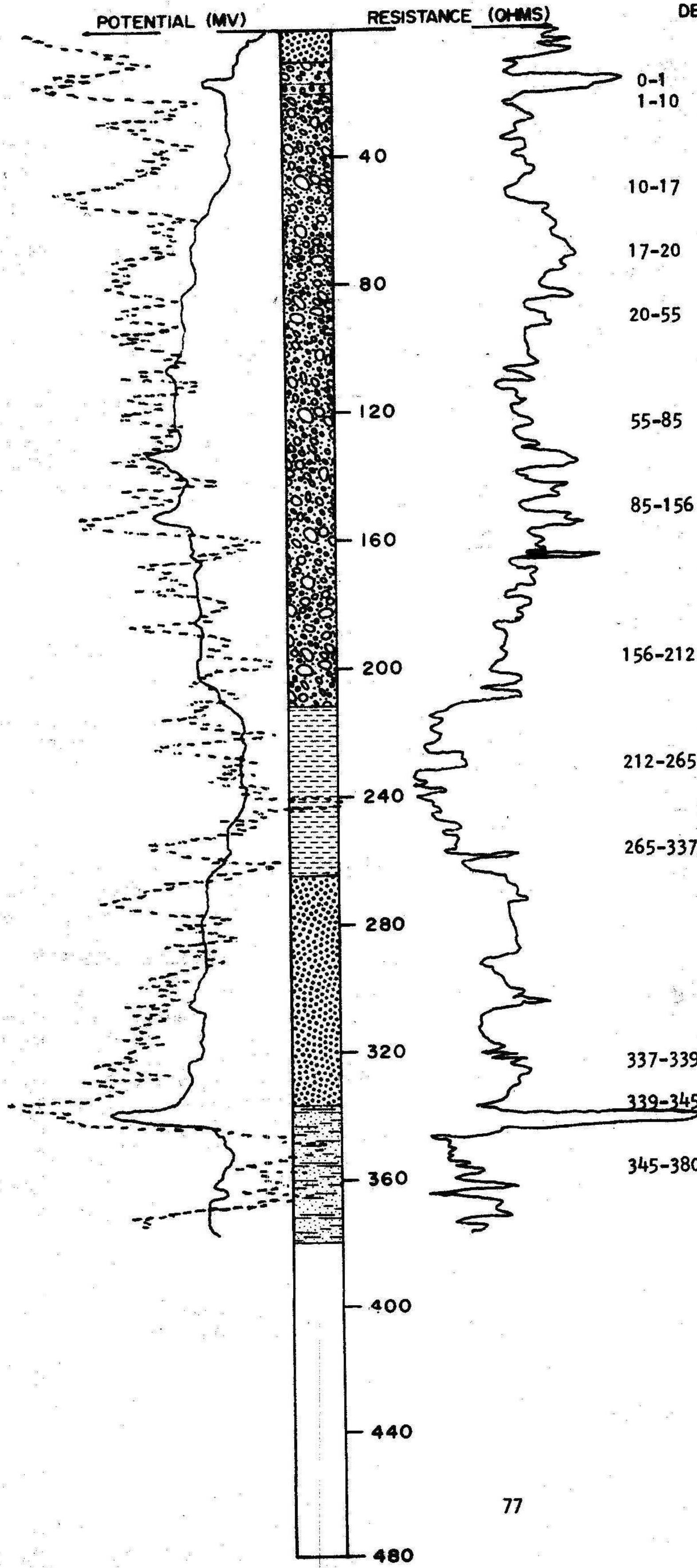
TEST HOLE 4439

LOCATION: 163-97-16ccc

ELEVATION: 1935
(FT, MSL)

DATE DRILLED: 5-31-72

DEPTH: 380
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil; silty loam, black.
1-10	Sand; fine and medium; yellowish gray, subrounded, sorted, loose; interbedded soft, oxidized clays.
10-17	Clay, silty, sandy, moderate olive brown, moderately soft, cohesive, oxidized (Till).
17-20	Sand, coarse with fine gravel, moderately sorted, subrounded, loose, iron-stained.
20-55	Clay, silty, sandy, pebbly, cobbles, moderate olive brown to light olive gray, slightly hard and brittle, tightly compacted (Till).
55-85	Silt, clayey, sandy, pebbly, dusky yellow, moderately soft, moderately cohesive, oxidized (Till).
85-156	Clay, silty, sandy, pebbly, cobbles, moderate olive brown, moderately soft to slightly hard, cohesive to slightly brittle, compacted, oxidized (Till); iron-stained sand lenses.
156-212	Clay, silty, sandy, pebbly, cobbles, moderate olive brown and light olive gray, slightly hard, very cohesive, stiff, partially oxidized (Till).
212-265	Clay, olive gray, soft, to moderately soft, cohesive, plastic, smooth, sticky; interbedded silt and sand lenses.
265-337	Sand, very fine to coarse, clayey and silty with gravel stringers, loose to moderately cohesive, thinly interbedded.

Tongue River Formation

337-339	Clay, sandy, white, soft, chalky.
339-345	Sandstone, fine-grained, dark greenish gray, indurated, $CaCO_3$ cement.
345-380	Sandstone, very fine-to fine-grained; predominantly greenish gray but varigated, moderately soft, friable; interbedded with light gray and tan siltstone and light to medium gray shale, occasionally carbonaceous.

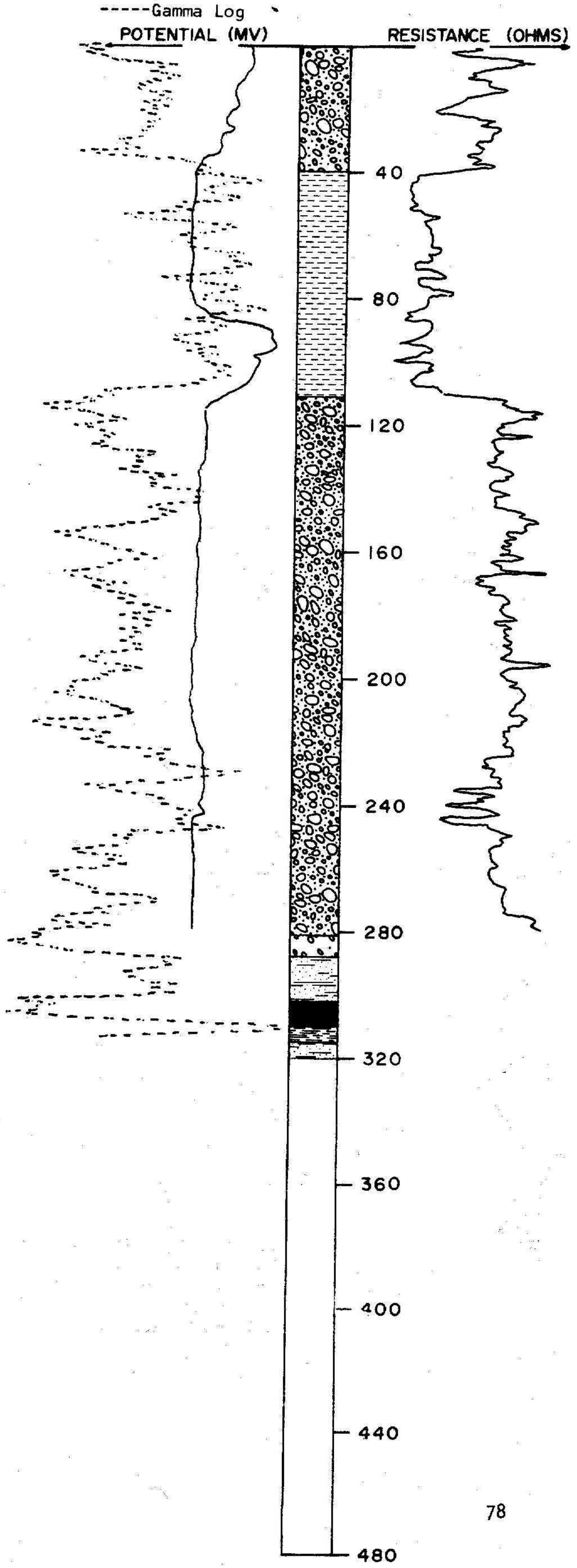
TEST HOLE 4440

LOCATION: 163-97-19aaa

DATE DRILLED: 5-31-72

ELEVATION: 1950
(FT, MSL)

DEPTH: 320
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil; silty clay loam, black.
1-21	Clay, very silty, sandy, pebbly, moderate olive brown, moderately soft, cohesive, iron-stained, oxidized (Till); interbedded silt and sand lenses.
21-40	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, stiff (Till).
40-111	Clay, silty, dark olive gray, moderately soft, cohesive, sticky, tight.
111-223	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, very cohesive, stiff (Till); medium to coarse sand lenses.
223-281	Clay, silty, sandy, pebbly, light olive and olive gray, moderately soft, cohesive, slightly plastic to moderately stiff (Till); varigated gray and black clay lenses.
281-288	Gravel, fine and medium, sandy, dark brown, subangular and subrounded, sorted, loose.

Tongue River Formation

288-302	Sandstone, very fine-grained, light greenish gray, moderately soft, slightly cohesive, chalky.
302-310	Lignite, black, hard, brittle; possible carbonaceous shale partings.
310-315	Shale, silty, medium gray, hard, tight, bentonitic.
315-320	Sandstone, very fine-grained, clayey, grayish green, carbonaceous.

Flowing Test Hole

Plugged with cement after obtaining water sample

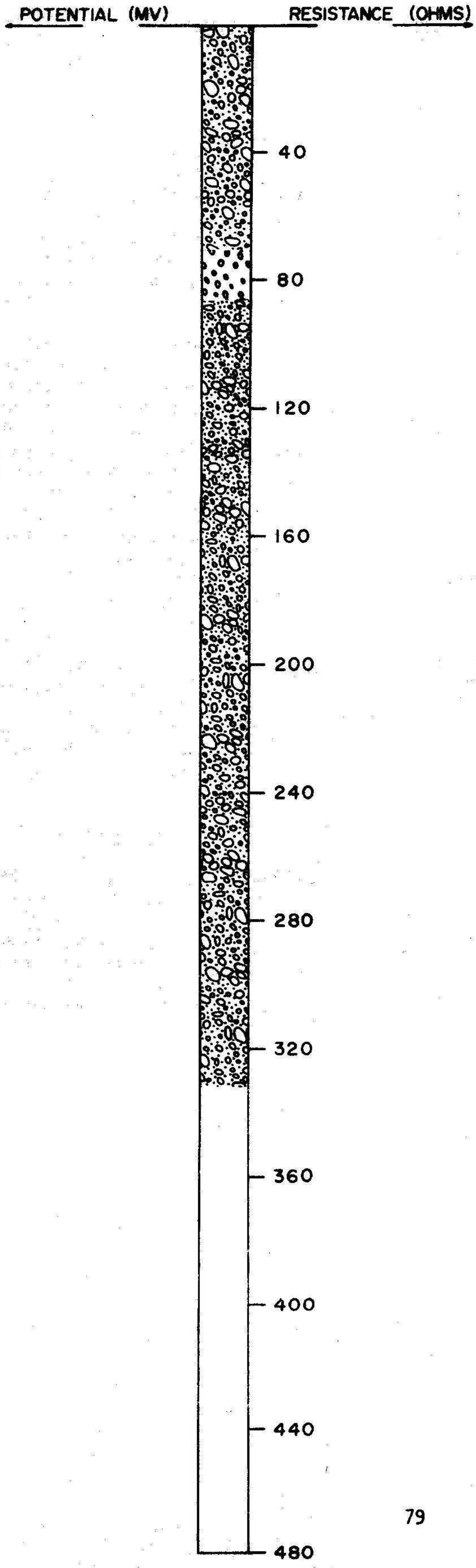
TEST HOLE 8289

LOCATION: 163-97-22ccc

DATE DRILLED: 12-6-71

ELEVATION: 1943 feet (FT, MSL)

DEPTH: 332 feet (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay, brownish black.
1-34	Clay, silty, sandy, pebbly, moderate yellowish brown, moderately cohesive, slightly plastic, oxidized (Till).
34-71	Clay, silty, sandy, pebbly, cobbles, thin sandy gravel stringers, olive gray, slightly hard, cohesive, stiff (Till).
71-86	Gravel, slightly sandy with cobbles, moderately sorted, angular to subrounded, mostly carbonate rocks; occasional clay or clayey till lenses.
86-332	Clay, silty, sandy, pebbly, cobbles, and boulders, interlensed with sand and gravel, olive gray, cohesive, compacted, stiff (Till); rough drilling.

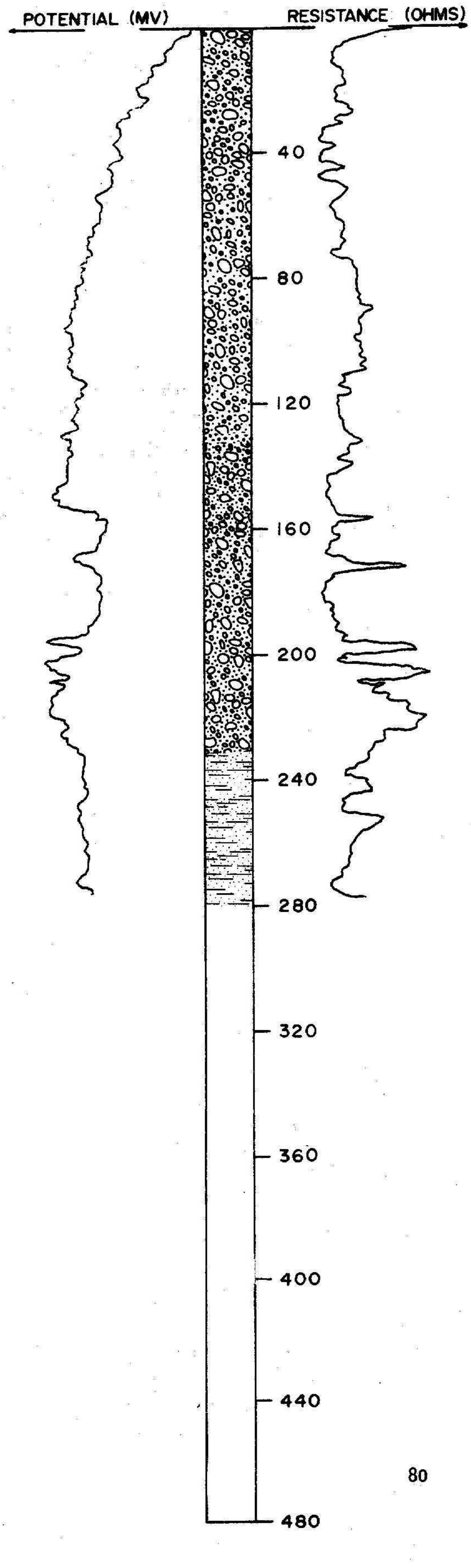
TEST HOLE 4426

LOCATION: 163-97-23ccd

DATE DRILLED: 12-4-71

ELEVATION: 1947 feet (FT, MSL)

DEPTH: 280 feet (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly loam, black.
1-30	Clay, silty, sandy, pebbly, dusky yellow to moderate olive brown, moderately soft, cohesive, slightly plastic, oxidized (Till).
30-74	Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, slightly plastic to slightly stiff (Till).
74-130	Clay, silty, slightly sandy (very fine), contains coarse sand grains and carbonate pebbles, moderate olive brown, moderately soft, cohesive, compacted, oxidized (Till).
130-132	Sand, medium to very coarse, buff-colored, sorted, subrounded, loose.
132-155	Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, compacted, moderately stiff (Till).
155-196	Clay, slightly silty, sandy, pebbly, gravel stringers, olive gray, slightly hard, cohesive, very stiff and tough (Till); rounded lignite fragments.
196-232	Till (as above), very gravelly, cobbles and boulders; moderately rough drilling.

Tongue River Formation

232-280	Sandstone, very fine-grained, light grayish green to greenish gray, soft to moderately soft, chunky, friable, carbonaceous, calcareous; interbedded with thin, white, marly or soft limestone layers.

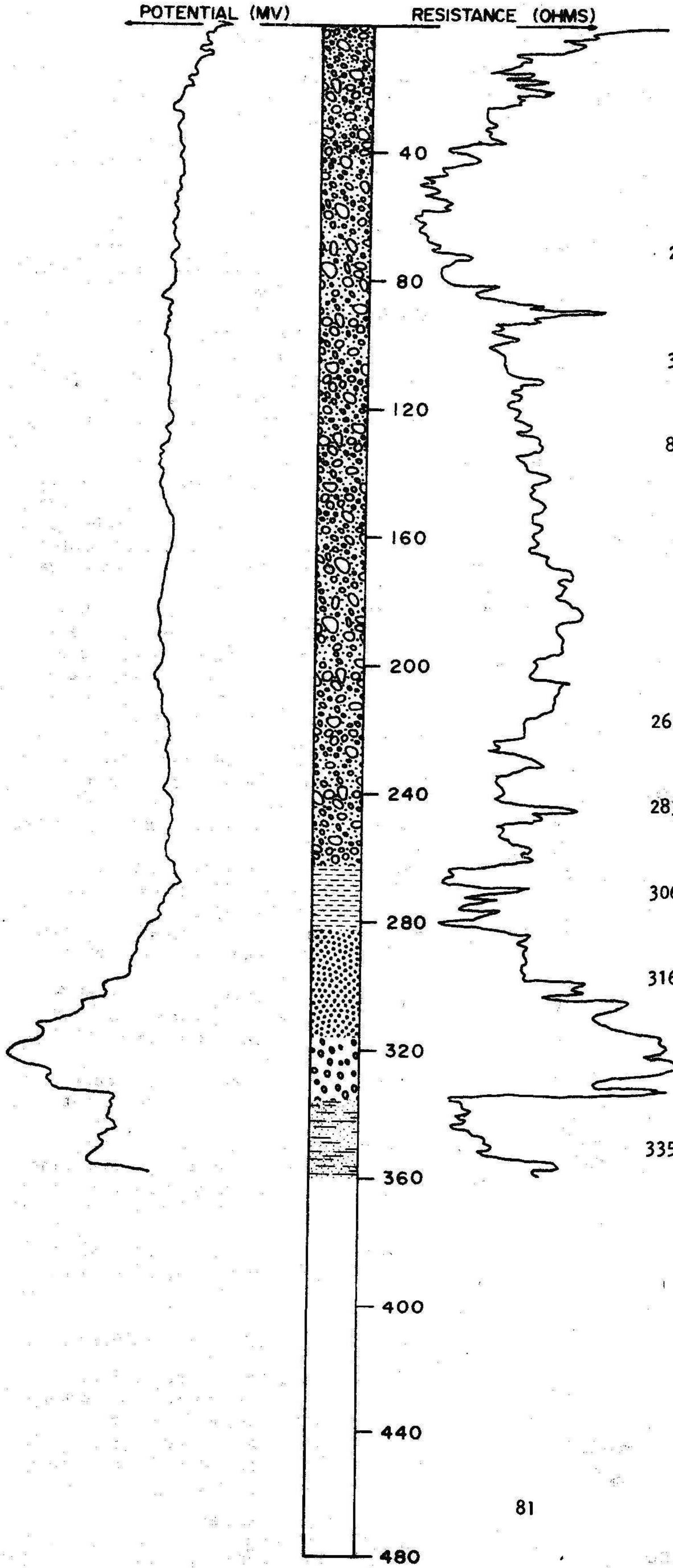
TEST HOLE 4427

LOCATION: 163-97-23ddd

DATE DRILLED: 12-5-71

ELEVATION: 1930 feet
(FT, MSL)

DEPTH: 360 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly silt loam, black.
1-20	Clay, silty, slightly sandy, pebbly, dusky yellow, moderately soft, cohesive, slightly to moderately plastic, oxidized (Till).
20-38	Clay, silty, sandy, pebbly, moderate olive green, slightly hard, slightly brittle to slightly crumbly, partially oxidized (Till).
38-80	Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive and tough (Till).
80-263	Clay, very silty, sandy, pebbly, carbonate cobbles and boulders, olive gray, moderately soft to slightly hard, tightly compacted, stiff (Till); interbedded with blocks of clay, silt, sand and fine carbonate gravel.
263-283	Clay, very silty, dark gray, laminated, slightly hard, smooth, tight, waxy, very stiff.
283-306	Sand, very fine to fine with medium, dark gray, sorted, subrounded, loose, highly lignitic.
306-316	Sand, medium to very coarse, moderately well-sorted, subrounded, mostly carbonate rocks.
316-335	Gravel, fine to coarse, sandy, cobbles, assorted or sorted, very lenticular, mostly carbonate rocks.

Tongue River Formation

335-360	Sandstone, very fine-grained, slightly clayey to silty, light grayish green, moderately soft, friable, micaceous, occasionally carbonaceous.

Observation Well

Depth: 327 feet
S. I.: 315 to 327 feet

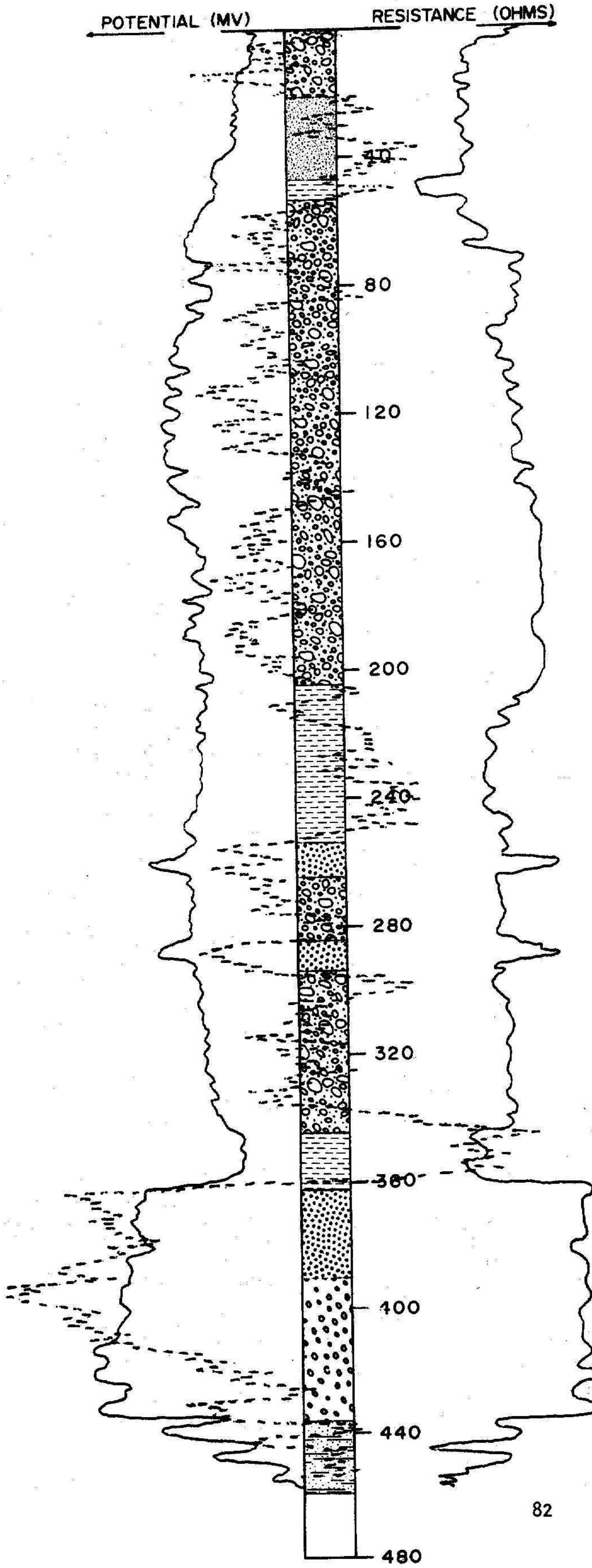
TEST HOLE 4437

LOCATION: 163-97-24aaa

ELEVATION: 1919
(FT, MSL)

DATE DRILLED: 5-25-72

DEPTH: 460
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay loam, black.
1-4	Clay, silty, sandy, dark brown, soft, slightly cohesive, crumbly (Till).
4-13	Clay, silty, sandy, pebbly, dark brown, soft, moderately cohesive, slightly sticky (Till).
13-21	Clay, silty, sandy, pebbly, yellowish gray to moderate olive brown, moderately soft, cohesive, oxidized (Till).
21-35	Silt, clayey, sandy, dusky yellow, soft, slightly cohesive, oxidized.
35-47	Silt, very clayey to sandy, light olive gray, soft, slightly to moderately cohesive, non-to slightly plastic.
47-53	Clay, olive gray, moderately soft, cohesive, smooth, tight.
53-71	Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive, stiff (Till).
71-205	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, moderately plastic (Till); occasional layer of clay, silt, sand, and fine gravel.
205-254	Clay and silty clay with fine sand, olive gray, soft to moderately soft, smooth, sticky.
254-265	Sand, medium, lignitic, sorted, loose.
265-285	Clay, very silty, sandy, pebbly, olive gray, stiff, tight (Till).
285-294	Sand, fine and medium, gray, subrounded, sorted, loose, clean.
294-345	Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, moderately stiff (Till).
345-363	Clay, dark gray to nearly black, hard smooth, tight, sticky.
363-391	Sand, medium and coarse, light olive gray, subangular and subrounded, sorted, lenticular; fine sand and silt stringers.
391-437	Gravel, fine to coarse, moderately sorted, subrounded, loose.

Tongue River Formation

437-460	Sandstone, fine-grained, nearly white to light greenish gray, moderately soft, friable, chalky; interbedded with varigated, noncarbonaceous shales.

Observation Well
Depth: 411 feet
S. I.: 399 to 411 feet

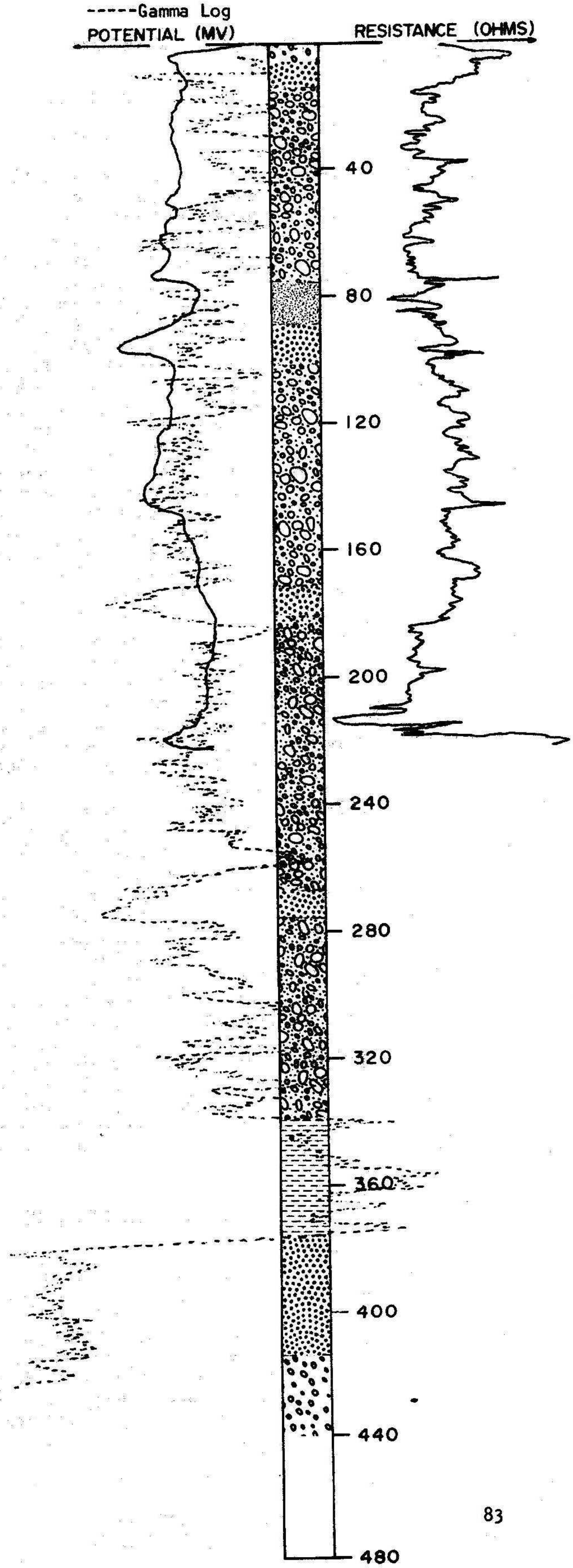
TEST HOLE 4429

LOCATION: 163-97-24bbb

ELEVATION: 1915 feet
(FT, MSL)

DATE DRILLED: 12-20-71

DEPTH: 440 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2	Topsoil, clayey loam, black.
2-6	Gravel, fine, sandy, assorted, subangular and subrounded, mostly heavily iron-stained carbonate rocks and granitics.
6-14	Sand, very fine, very silty to clayey, dusky yellow to yellowish gray with limonitic stains, soft, slightly cohesive, laminated, oxidized.
14-76	Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, slightly plastic to moderately stiff (Till).
76-89	Silt, clayey to slightly sandy, laminated light and dark grays, soft, crumbly to slightly plastic.
89-101	Sand, very fine and fine, silty to slightly clayey, light olive and olive gray, soft, nonplastic.
101-172	Clay, silty, sandy, carbonate pebbles, olive gray, moderately soft to slightly hard, very cohesive and compacted, tough (Till); occasional blocks of lacustrine clays and silts with thin streaks of medium and coarse sand.
172-180	Sand, medium and coarse, moderately well-sorted, subrounded, loose, mostly carbonates and quartz.
180-268	Clay, silty, sandy, pebbly, cobbles, olive gray, (slightly lighter than till above), highly calcareous, tough (Till).
268-276	Sand, medium to very coarse with some fine gravel, well-sorted, subrounded with subangular, loose, mostly carbonate rocks.
276-339	Clay, very silty, sandy, pebbles, and interbedded medium to very coarse sand and gravel stringers, generally olive gray, stiff (Till).
339-376	Clay, silty, olive and dark olive gray, soft and moderately soft, moderately cohesive, smooth.
376-414	Sand, medium to very coarse with gravel, sorted but lenticular, subrounded, loose, clean, mainly granitics and carbonates.
414-440	Gravel, sandy with cobbles and boulders; lost circulation, 15 bags of bentonite.

Observation Well

Depth: 432 feet
S. I.: 420 to 432 feet

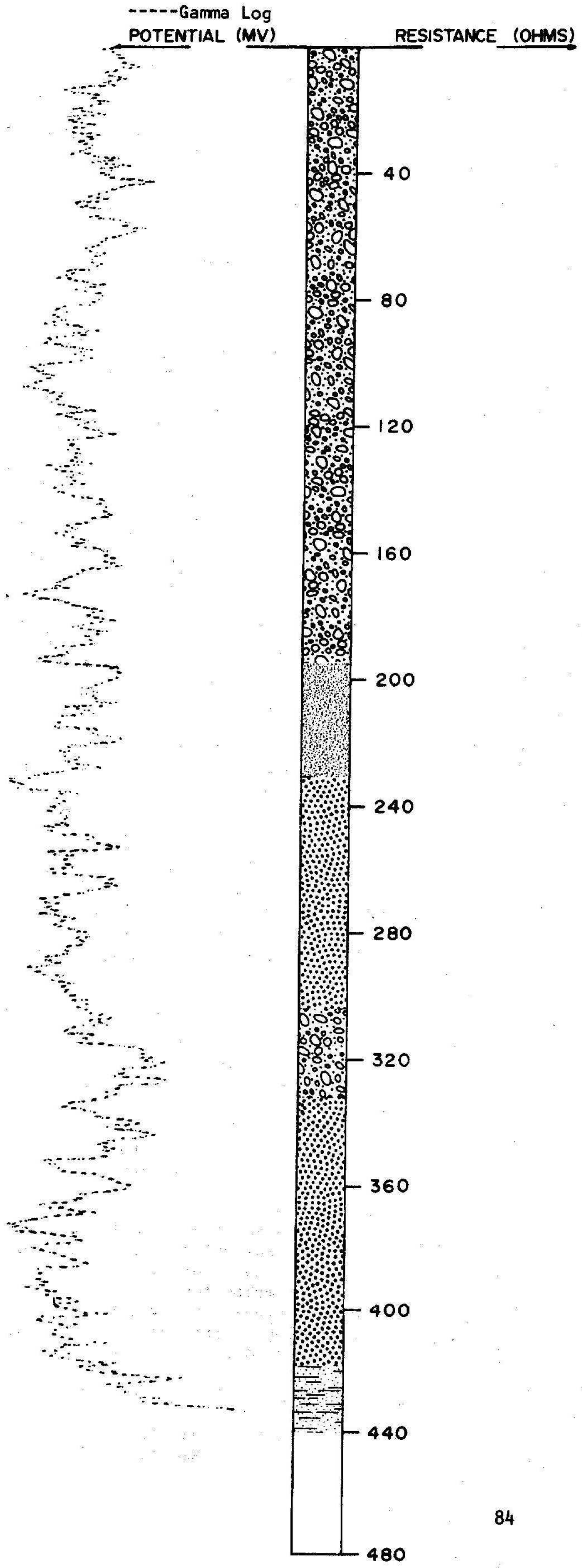
TEST HOLE 4428

LOCATION: 163-97-25aaa

ELEVATION: 1926 feet
(FT, MSL)

DATE DRILLED: 12-6-71

DEPTH: 440 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly silt loam, black.
1-34	Clay, silty, sandy, pebbly, dusky yellow to moderate olive brown, moderately soft, cohesive, slightly plastic to slightly stiff, oxidized (Till)
34-50	Clay, silty, sandy, pebbly, moderate olive green, moderately soft, cohesive, slightly stiff to slightly crumbly, partially oxidized (Till).
50-70	Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive, tightly compacted (Till).
70-195	Clay, silty, sandy, numerous carbonate pebbles and cobbles, boulders and thin sandy gravel lenses, olive gray, slightly hard, cohesive, very stiff, tight and tough (Till).
195-231	Silt, very sandy (very fine) to clayey, generally olive gray, laminated with light gray, carbonate silty clay and black detrital lignite streaks, soft to moderately soft, slightly cohesive to crumbly.
231-267	Sand, very fine to fine, silty and lignitic, soft, crumbly, laminated.
267-304	Sand, medium, some fines, lignitic, well-sorted and uniform, subrounded, streaks of fine to medium gravel.
304-332	Clay, silty, sandy, pebbly, cobbles, and boulders, interbedded with carbonate gravels, olive gray, cohesive (Till).
332-370	Sand, very fine to medium, occasionally coarse, well-sorted but lenticular, laminated, quartzose and lignitic.
370-418	Sand, medium to very coarse with interbedded gravel, sorted, subrounded, sand mainly quartz and carbonates, gravel mostly dark brown silicates and carbonates.

Tongue River Formation

418-420	Clay, sandy, white, soft, crumbly highly calcareous.
420-422	Sandstone, very fine-grained, indurated, $CaCO_3$ cement.
422-440	Sandstone, very fine and fine, silty to slightly clayey, light grayish green, moderately soft, chunky, friable; interbedded with dark green and black waxy shales.

Observation Well

Depth: 390 feet
S.I. : 378 to 390 feet

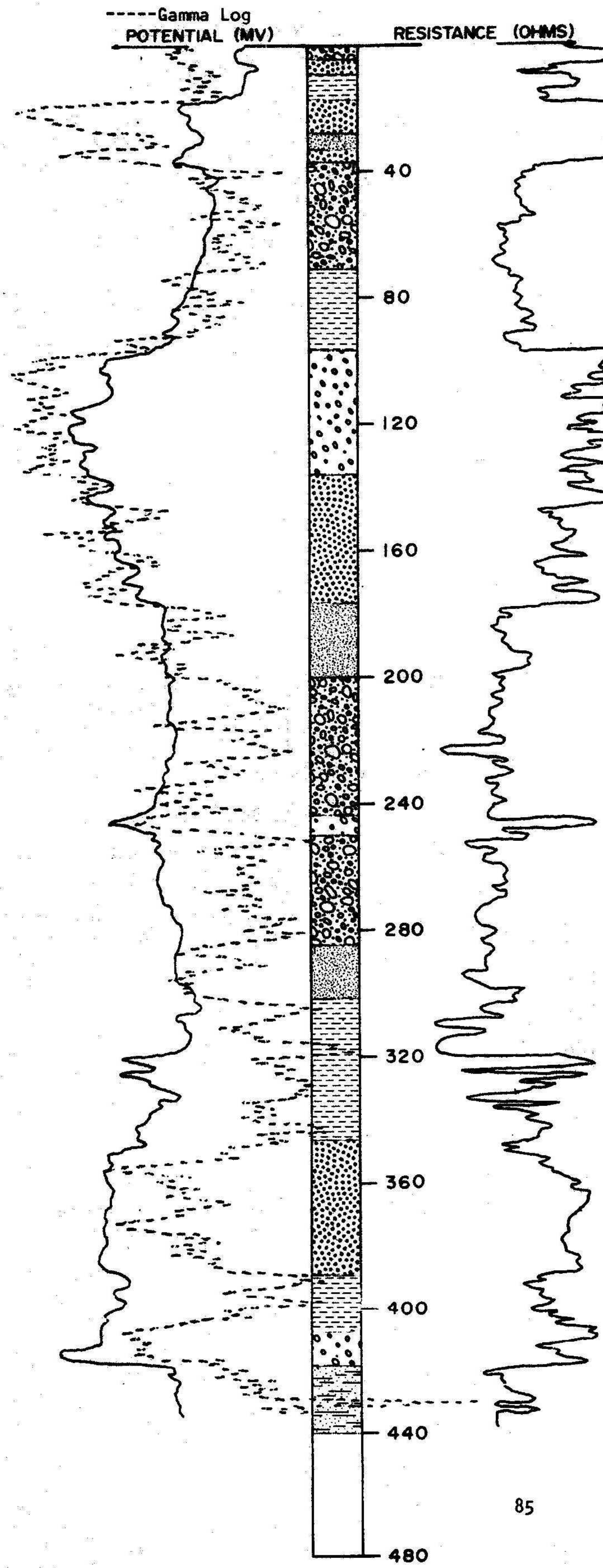
TEST HOLE 4438

LOCATION: 163-97-25ddd

ELEVATION: 1925
(FT, MSL)

DATE DRILLED: 5-30-72

DEPTH: 440
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

Depth (ft)	Description
0-1	Topsoil, pebbly very fine sandy loam dark brown.
1-4	Clay, silty, sandy, pebbly, yellowish brown, soft, moderately cohesive, oxidized (Till).
4-9	Sand, coarse, fine gravel, reddish brown, sorted, generally subangular, heavily iron-stained, oxidized.
9-17	Clay, extremely silty, sandy, moderate olive brown, moderately soft, moderately cohesive, oxidized.
17-28	Sand, fine to medium, dusky yellow, well-sorted, subrounded, loose, oxidized.
28-33	Silt, clayey, dusky yellow, soft, slightly cohesive, oxidized.
33-37	Sand, fine, dusky yellow, oxidized.
37-71	Clay, very silty to slightly sandy, pebbly, cobbles, dark olive gray, slightly hard, very cohesive, stiff, compacted (Till).
71-97	Clay, silty to very silty with very fine sand, olive gray, thinly interbedded, soft to moderately soft, slightly to moderately cohesive.
97-136	Gravel, fine and medium, sandy, sorted, interbedded, subrounded, loose.
136-177	Sand, fine to coarse; interbedded with clay, silt, gravel and detrital lignite.
177-200	Silt, clayey to sandy (very fine and fine), olive gray, soft, slightly to moderately cohesive, lenticular.
200-244	Clay, very silt, sandy, pebbly, olive gray, soft, cohesive, slightly plastic (Till); blocks or layers of clay, silt, sand, and gravel.
244-250	Gravel, fine to coarse; clayey streaks.
250-285	Till, as above; silty and sandy clay lenses.
285-302	Silt, very sandy, light olive gray, soft, slightly cohesive.
302-347	Clay, silty to sandy (fine to coarse); very lenticular.
347-389	Sand, very fine and fine, silty, olive gray, sorted, loose.
389-407	Clay, silty to sandy, olive gray, laminated, soft to moderately soft, slightly to moderately cohesive.
407-418	Gravel, fine to coarse; cobbles and boulders.

Tongue River Formation

Depth (ft)	Description
418-440	Sandstone, very fine, clayey, light greenish gray to grayish green, moderately soft, slightly friable, marly; thin bentonitic clay layers.

Observation Well

Depth: 134 feet
S.I.: 128 to 134 feet

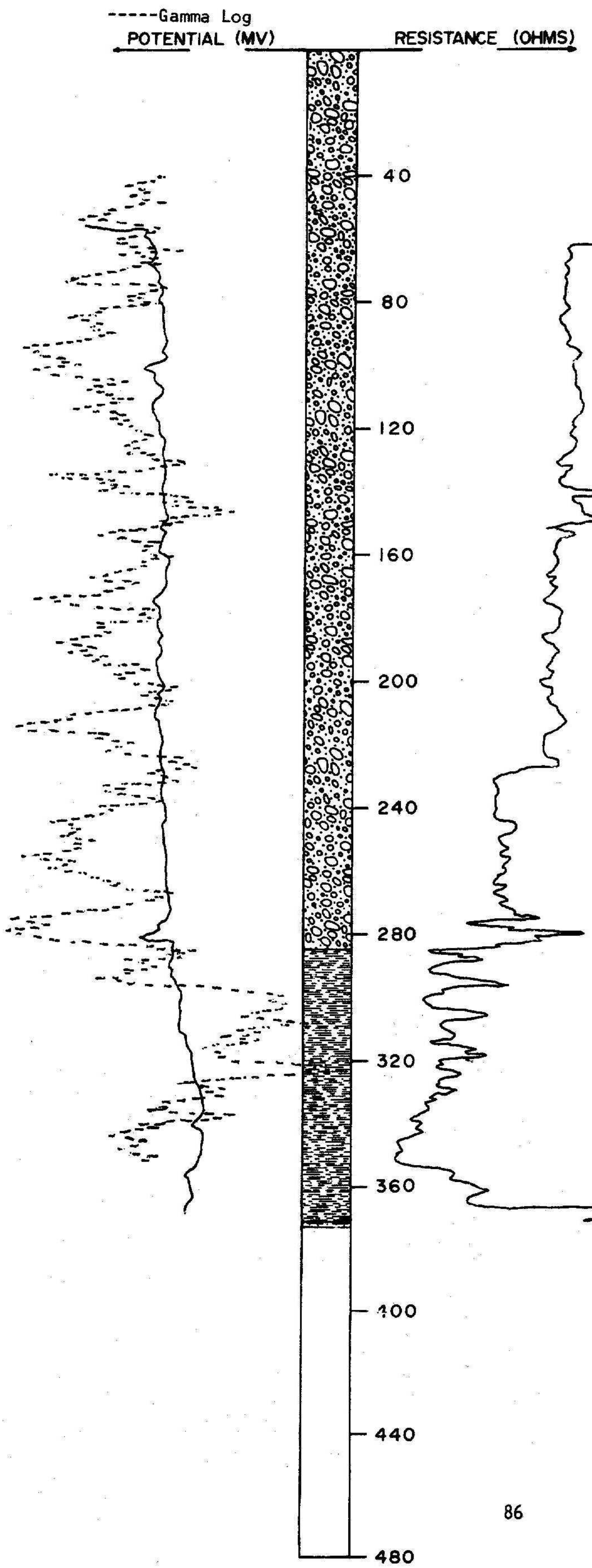
TEST HOLE 4449

LOCATION: 163-97-26add

DATE DRILLED: 6-16-72

ELEVATION: 1936
(FT, MSL)

DEPTH: 373
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-2 Topsoil, silty loam, black.

2-22 Clay, very silty, sandy, pebbly, dark olive brown, soft, cohesive, sticky, oxidized (Till).

22-40 Clay, silty, sandy, pebbly, moderate olive brown, soft to moderately soft, cohesive, slightly plastic, oxidized (Till).

40-225 Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, cohesive, slightly plastic to stiff (Till).

225-285 Clay, silty, sandy, pebbly, olive gray, slightly hard, cohesive, stiff, brittle, tightly compacted (Till); occasional gravel lenses.

Tongue River Formation

285-299 Shale, silty and sandy, varigated, smooth, tight; thin indurated layers.

299-372 Shale and sandstone, interbedded, varigated, moderately soft to indurated.

372-373 Sandstone, very fine-grained, dark green, indurated.

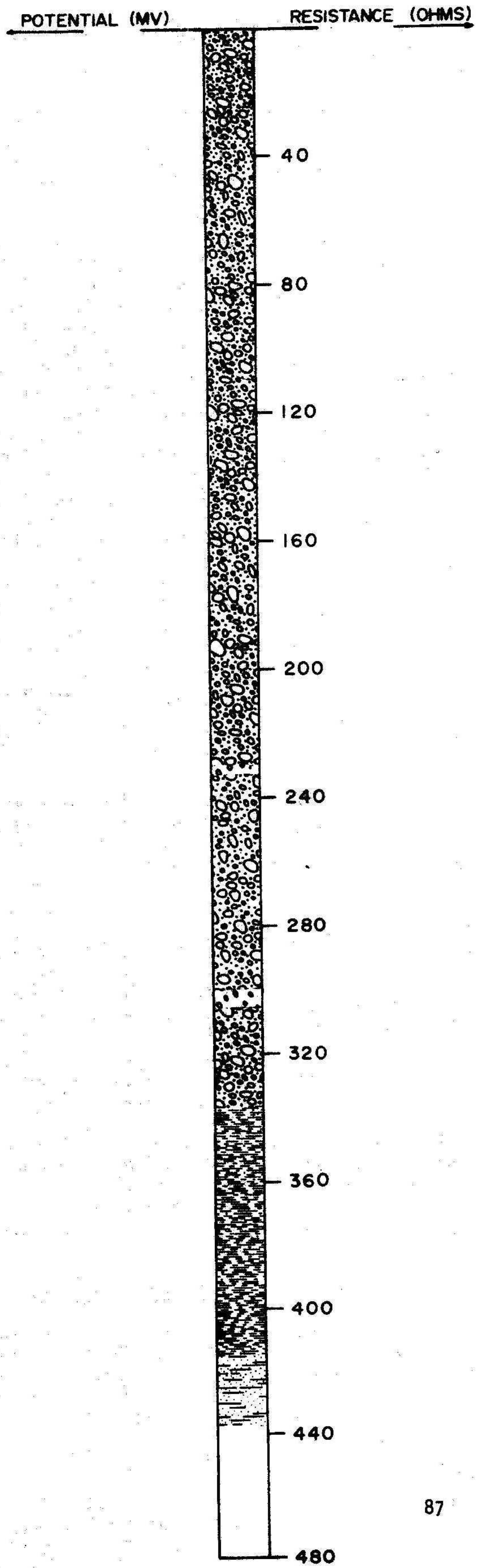
TEST HOLE MB

LOCATION: 163-97-26bbb

ELEVATION: 1944 feet
(FT, MSL)

DATE DRILLED: 1947

DEPTH: 438 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-4	Soil
4-18	Clay, pebbly, yellow (Till).
18-69	Clay, sandy with pebbles, gray (Till).
69-85	Clay, sandy with pebbles, yellow (Till).
85-194	Clay, sandy with pebbles and cobbles, brown (Till).
194-230	Clay, sandy with pebbles, blue (Till).
230-233	Gravel, sandy, lignitic.
233-300	Clay, sandy with pebbles and cobbles, gray (Till).
300-306	Gravel, mostly carbonate rocks.
306-337	Clay, sandy with pebbles and cobbles, lignitic, gray (Till).

Tongue River Formation

337-375	Clay, sandy, lignitic, gray.
375-415	Clay, sandy, gray.
415-416	Rock.
416-430	Clay, sandy, gray.
430-438	Sand, fine.

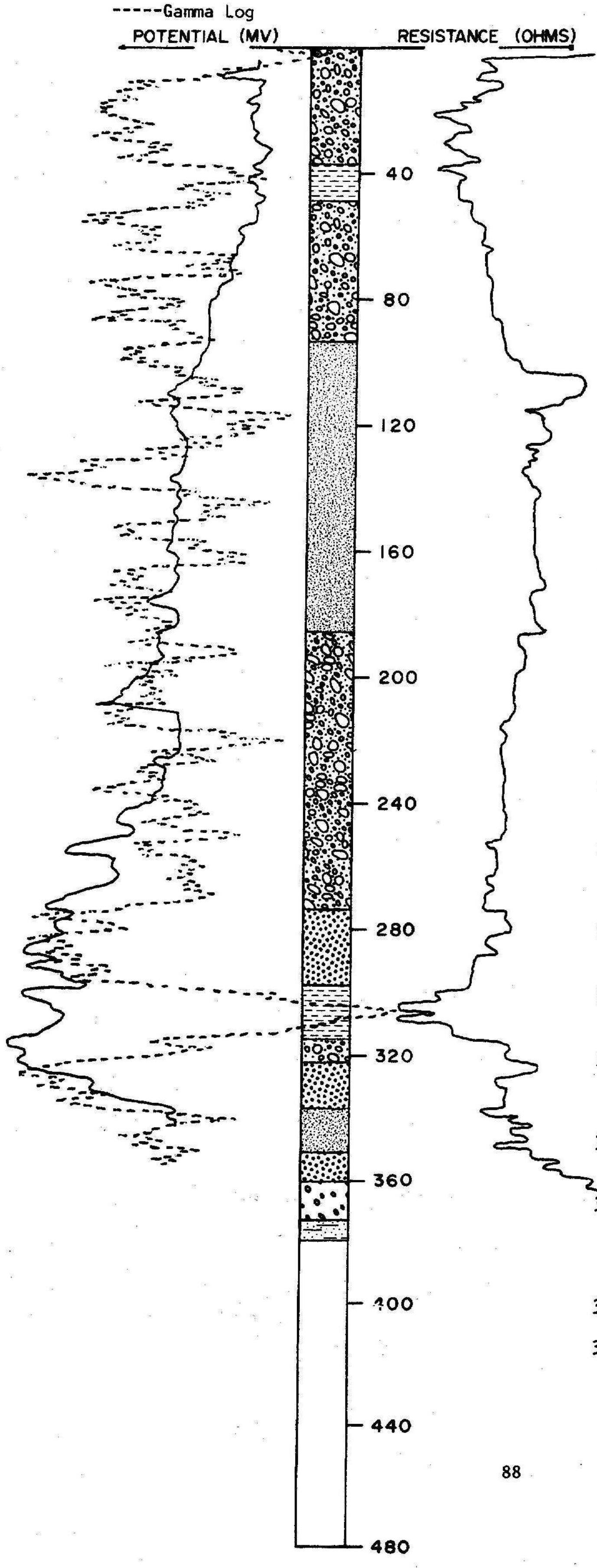
TEST HOLE 4446

LOCATION: 163-97-26ddd

DATE DRILLED: 6-14-72

ELEVATION: 1940
(FT, MSL)

DEPTH: 380
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly silty loam, black.
1-10	Clay, silty, sandy, pebbly, dark brown, moderately soft, very cohesive, slightly plastic, oxidized (Till).
10-37	Clay, silty, sandy, pebbly, moderate olive brown to light reddish brown, soft to moderately soft, moderately cohesive, oxidized (Till); lenses of loose, medium grained sand.
37-49	Clay, silty to sandy, dark olive gray, moderately soft, slightly friable, laminated.
49-94	Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, stiff, brittle, compacted (Till).
94-103	Silt, clayey, sandy, light olive gray, moderately soft, slightly cohesive to friable, laminated, partially oxidized.
103-186	Silt, clayey to very sandy, gravel lenses, light olive and olive gray to light brown, laminated, soft and slightly cohesive to loose.
186-274	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, stiff (Till); gravel lenses.
274-298	Sand, very fine to medium, interbedded silt and sandy clay, loose to slightly cohesive.
298-315	Clay and silty clay, olive to dark olive gray, moderately soft to slightly hard, stiff, brittle, smooth, tight.
315-322	Clay, very silty, sandy, pebbly, cobbles, olive gray, slightly hard, stiff, compacted (Till).
322-337	Sand, medium to very coarse, yellowish brown, sorted but lenticular, subrounded, loose.
337-351	Silt, clayey, very sandy, olive gray, laminated, soft to moderately soft, slightly cohesive; interbedded with fine gravel.
351-360	Sand, medium to coarse, brown, subangular and subrounded, sorted, loose, clean.
360-373	Gravel, slightly sandy with cobbles, dark brown.

Tongue River Formation

373-375	Sandstone, very fine-grained, dark greenish gray, indurated.
375-380	Sandstone, very fine-grained, clayey, greenish gray, moderately soft, slightly friable, chalky.

Observation Well

Depth: 369 feet
S. I.: 357 to 369 feet

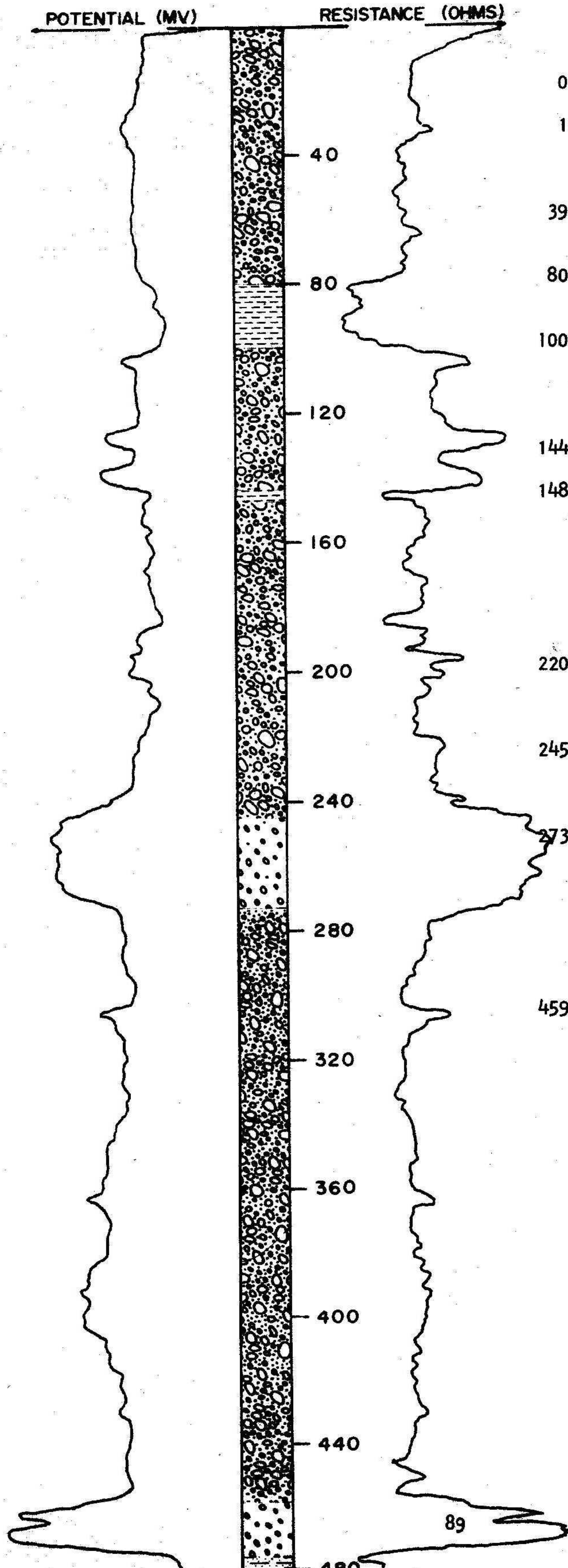
TEST HOLE 8288

LOCATION: 163-97-27ccc

ELEVATION: 1962 feet
(FT, MSL)

DATE DRILLED: 12-3-71

DEPTH: 500 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay, brownish-black.
1-39	Clay, moderately silty, sandy, pebbly, dark yellowish brown, moderately cohesive, oxidized (Till).
39-80	Clay, very silty, sandy, pebbly, cobbles, olive gray, cohesive, slightly plastic (Till).
80-100	Clay, very silty, sandy, medium dark gray, slightly plastic to crumbly.
100-144	Clay, very sandy, pebbly, much interbedded fine sand and occasional gravel lenses, moderate yellowish brown, soft, crumbly oxidized (Till).
144-148	Clay, silty, light olive gray, cohesive, moderately plastic.
148-220	Clay, silty, sandy, pebbly, cobbles, numerous blocks or lenses of clay, silt, and sand, occasional gravel stringer, moderate yellowish brown with olive gray mottling, moderately soft and cohesive, partially oxidized (Till).
220-245	Clay, very silty, sandy, pebbly, olive gray, moderately soft, compacted, stiff to slightly friable (Till).
245-273	Gravel, fine to coarse, sandy, moderately sorted, angular to subrounded, mostly carbonates, some dark brown silicates.
273-459	Clay, silty, sandy, pebbly, cobbles, occasional boulders, frequent sand and gravel lenses, olive gray, slightly hard, cohesive and compacted, stiff and slightly brittle (Till).
459-476	Gravel, fine to coarse, slightly sandy, clay bed at 466 feet, cobbles near base, angular to subrounded, mostly carbonates and silicates.

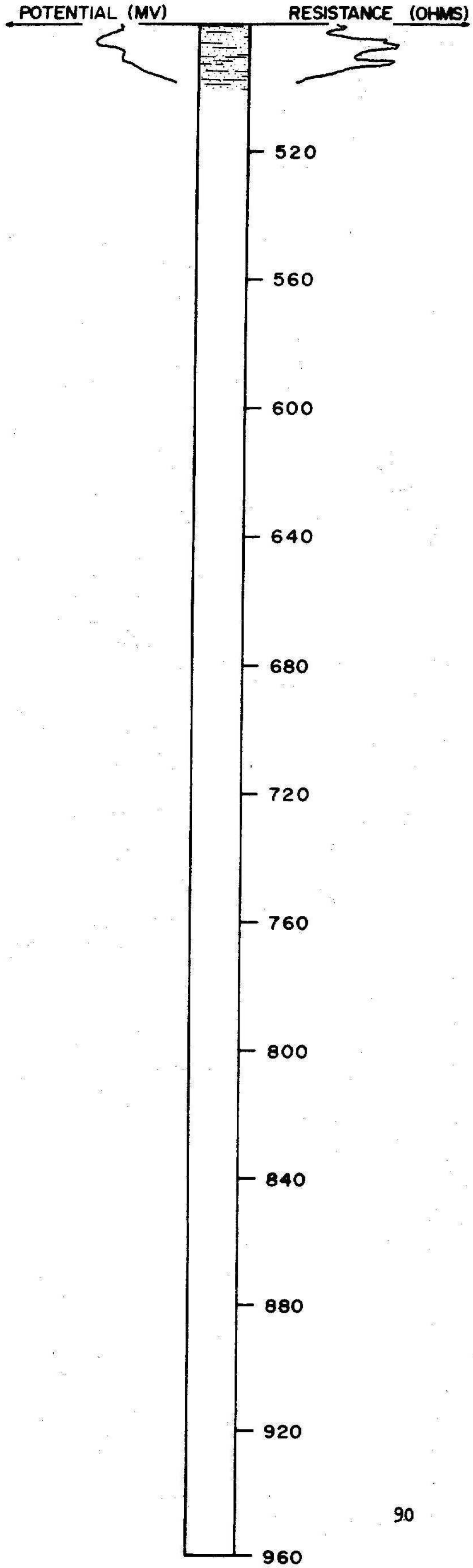
TEST HOLE 8288 (Cont.)

LOCATION: 163-97-27ccc

DATE DRILLED: 12-3-71

ELEVATION: 1962 feet
(FT, MSL)

DEPTH: 500 feet
(FT)



DESCRIPTION OF DEPOSITS

Tongue River Formation

476-500 Sandstone, fine-grained, slightly clayey, medium bluish gray, friable, noncalcareous; interbedded with medium gray shale.

Observation Well

Depth: 264 feet
S. I.: 258-264 feet

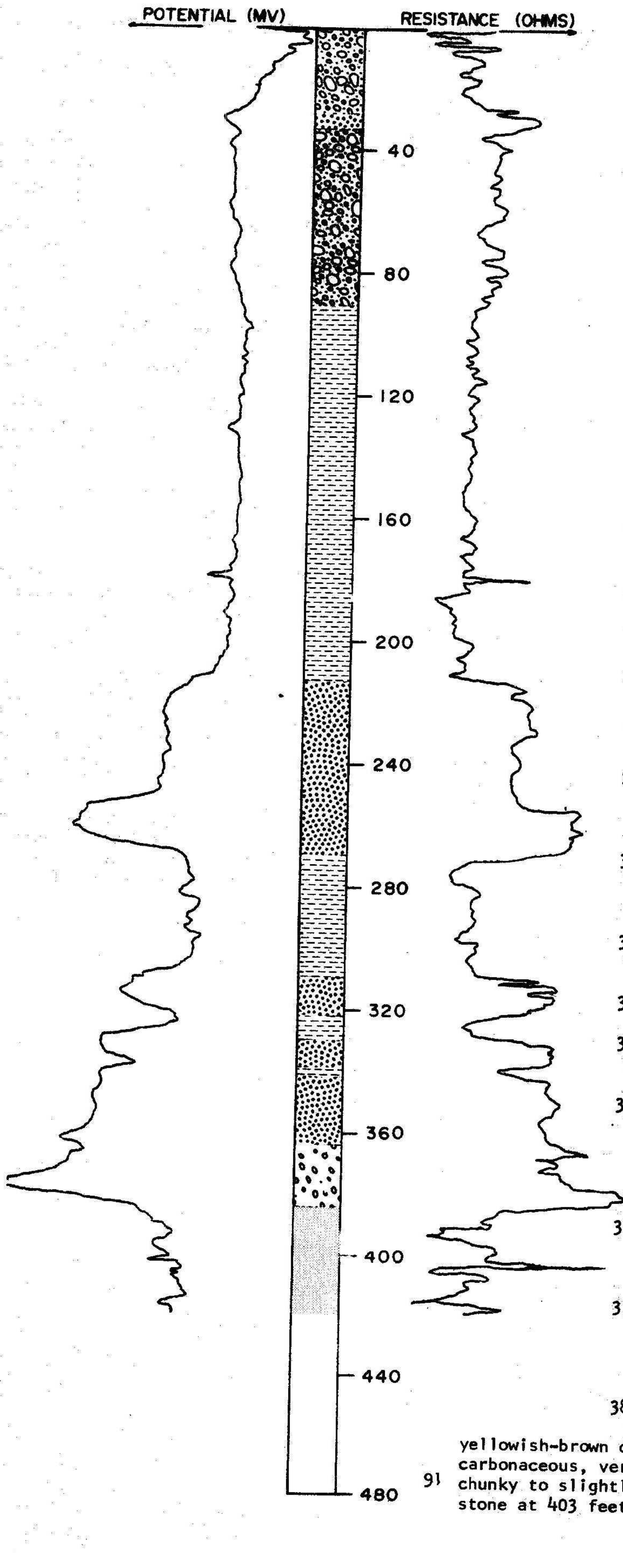
TEST HOLE 4424

LOCATION: 163-97-27ddd

DATE DRILLED: 12-2-71

ELEVATION: 1953 feet
(FT, MSL)

DEPTH: 420 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, pebbly silty loam, black.
1-28	Clay, silty, sandy, pebbly, yellowish brown, moderately soft, cohesive, slightly plastic, oxidized (Till).
28-33	Sand, fine, dusky yellow, loose, well-sorted, subrounded, oxidized.
33-64	Clay, silty, slightly sandy, numerous carbonate pebbles, moderate olive brown to moderate olive green, moderately soft, cohesive, slightly plastic to slightly stiff, partially oxidized (Till).
64-91	Clay, silty, sandy, pebbly, olive gray, moderately soft to slightly hard, very cohesive and compacted (Till).
91-185	Clay, olive to dark olive gray, soft to slightly hard, smooth, tight, waxy, stiff, laminated, sticky.
185-213	Clay, dark to very dark gray, slightly hard, very tightly compacted, smooth, tight.
213-255	Sand, very fine and fine, slightly silty and clayey, light olive and olive gray, laminated, fairly uniform.
255-270	Sand, coarse and very coarse, some gravel, moderately sorted, generally subrounded, loose, clean, mostly carbonates with granitics and silicates.
270-310	Clay, silty, olive and olive gray, laminated, smooth, slightly hard and brittle, tightly compacted.
310-322	Sand, medium to very coarse with thin lenses of silty sandy clay, sorted, lenticular, subrounded; wood fragments.
322-330	Clay, silty, olive gray, slightly hard, very cohesive, tight, stiff, smooth.
330-339	Sand, coarse, well-sorted, subrounded, loose, clean.
339-342	Clay, sandy (very fine), light olive gray, soft, slightly cohesive.
342-364	Sand, medium to very coarse with some gravel, moderately sorted, subangular and subrounded, yellowish-brown, loose, mostly carbonates and silicates.
364-379	Gravel, fine to coarse with sand lenses, sorted, lenticular, subangular and subrounded, brown.
379-384	Gravel, coarse, very little sand, numerous cobbles, generally subrounded, dark brown, mostly silicates.

Tongue River Formation

384-420	Siltstone and silty shale, varigated but primarily yellowish-brown or light gray, some greens, occasionally carbonaceous, very tight, slightly to moderately hard, chunky to slightly fissile; indurated laminated siltstone at 403 feet.

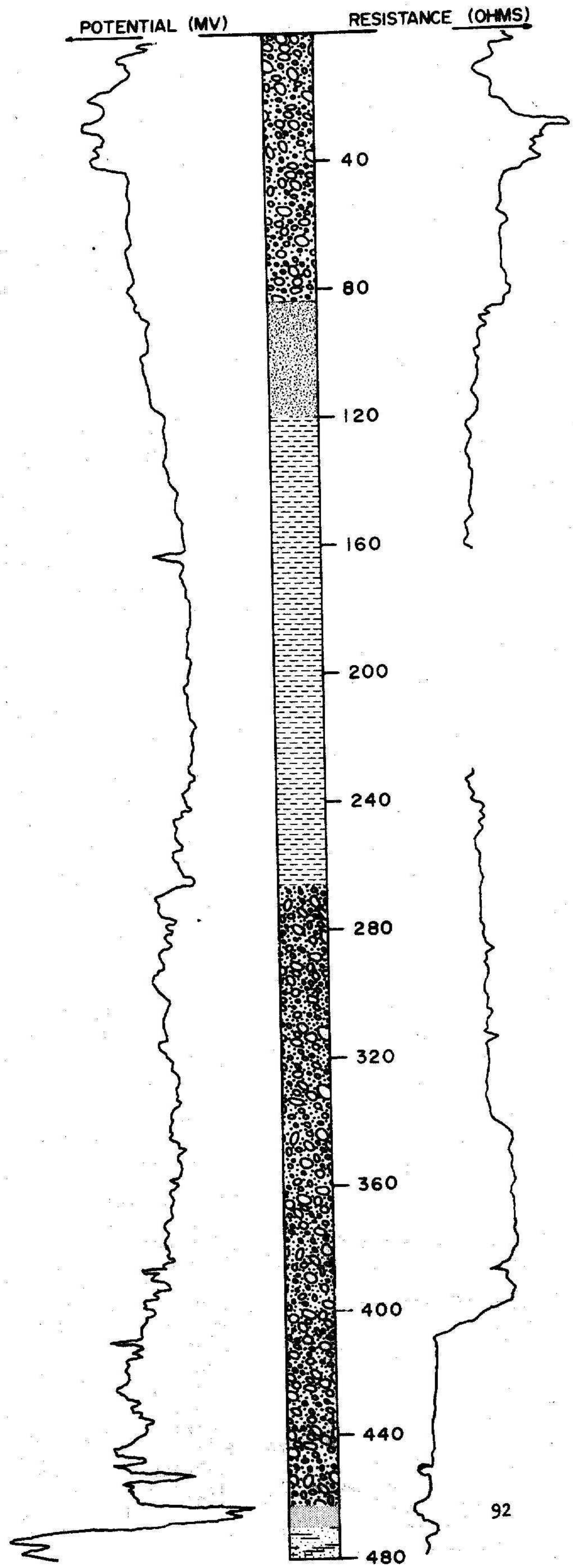
TEST HOLE 8287

LOCATION: 163-97-28cdb

ELEVATION: 1950 feet
(FT, MSL)

DATE DRILLED: 12-2-71

DEPTH: 500 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, very silty clay, brownish black.
1-21	Clay, very silty, moderately sandy, pebbly, dark yellowish brown, moderately cohesive, oxidized (Till).
21-43	Clay, silty, sandy, pebbly, sand and gravel lenses, cobbles, olive gray, loose to moderately cohesive (Till).
43-84	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive (Till).
84-120	Silt, clayey with very fine sand, olive gray, soft, slightly cohesive, laminated.
120-241	Clay, silty, slightly sandy, medium gray with light gray laminae and dark greenish gray mottling, very cohesive, stiff to slightly brittle, smooth, tight.
241-266	Clay, very silty, olive gray, soft, chunky, moderately plastic, smooth.
266-276	Clay, silty, sandy, pebbly, gravel stringers, yellowish brown, slightly cohesive, crumbly, oxidized (Till).
276-409	Clay, silty, sandy, pebbly, cobbles, sandy gravel lenses, olive gray, slightly hard, cohesive, stiff (Till).
409-463	Clay, sandy, numerous pebbles, cobbles, and boulders, dark olive gray, hard, very tightly compacted, brittle (Till).

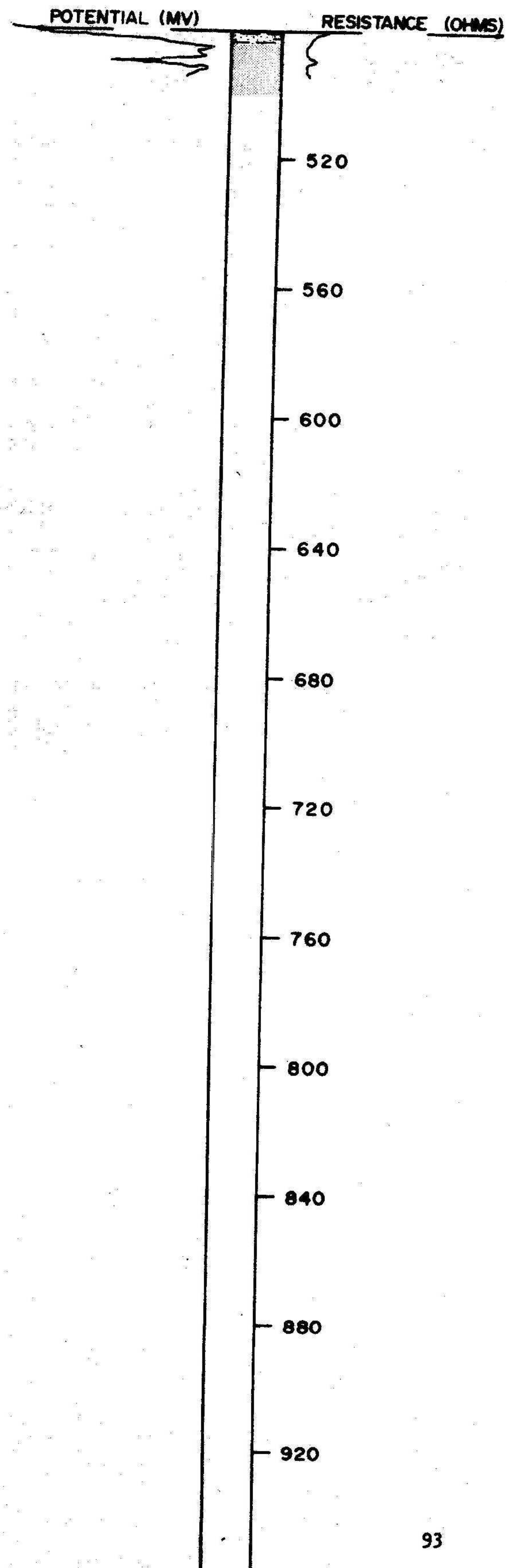
TEST HOLE 8287 (Cont.)

LOCATION: 163-97-28cdb

ELEVATION: 1950 feet
(FT, MSL)

DATE DRILLED: 12-2-71

DEPTH: 500 feet
(FT)



DESCRIPTION OF DEPOSITS

Tongue River Formation

463-470 Siltstone, clayey, light bluish gray, moderately indurated, noncalcareous.

470-484 Sandstone, fine-grained, medium bluish gray, moderately soft, micaceous.

484-500 Siltstone, as above, moderately to highly indurated.

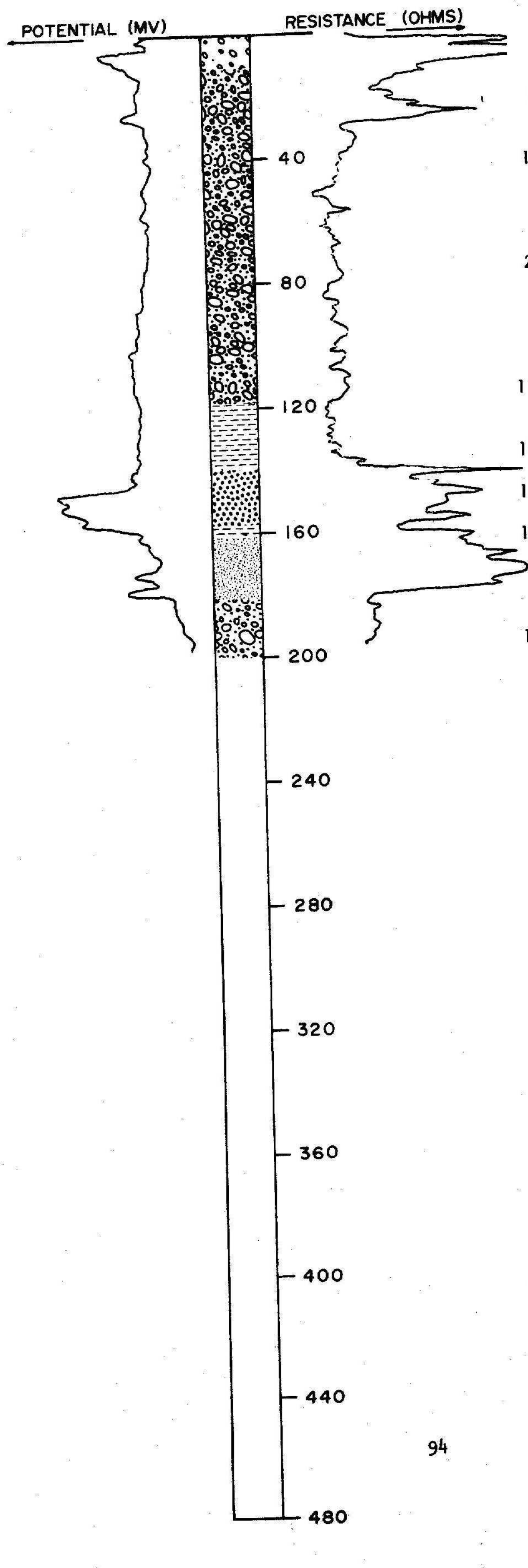
TEST HOLE 3017

LOCATION: 163-97-30abb

ELEVATION: 1955 feet
(FT, MSL)

DATE DRILLED: 6-15-63

DEPTH: 200 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-10	Gravel, sandy, assorted, subangular and subrounded, oxidized.
10-28	Clay, very silty, sandy, shale and carbonate pebbles, moderate yellowish brown to dark greenish gray (Till); numerous sand and gravel lenses.
28-119	Clay, silty, sandy, pebbly, cobbles, boulders, olive gray to dark greenish gray, slightly hard, very cohesive (Till); blocks of bedrock shale and clayey sandstone.
119-140	Clay, silty, slightly sandy, dark greenish gray, smooth, tight.
140-158	Sand with gravel and silty layers, sorted, lenticular.
158-161	Clay, very silty, olive gray, moderately soft, smooth.
161-181	Silt, extremely sandy (very fine and fine), olive gray to black, laminated, soft, loose to very slightly cohesive, lignitic.
181-200	Clay, silty, sandy, pebbly, cobbles, boulders, light olive to olive gray, slightly hard, tightly compacted (Till).

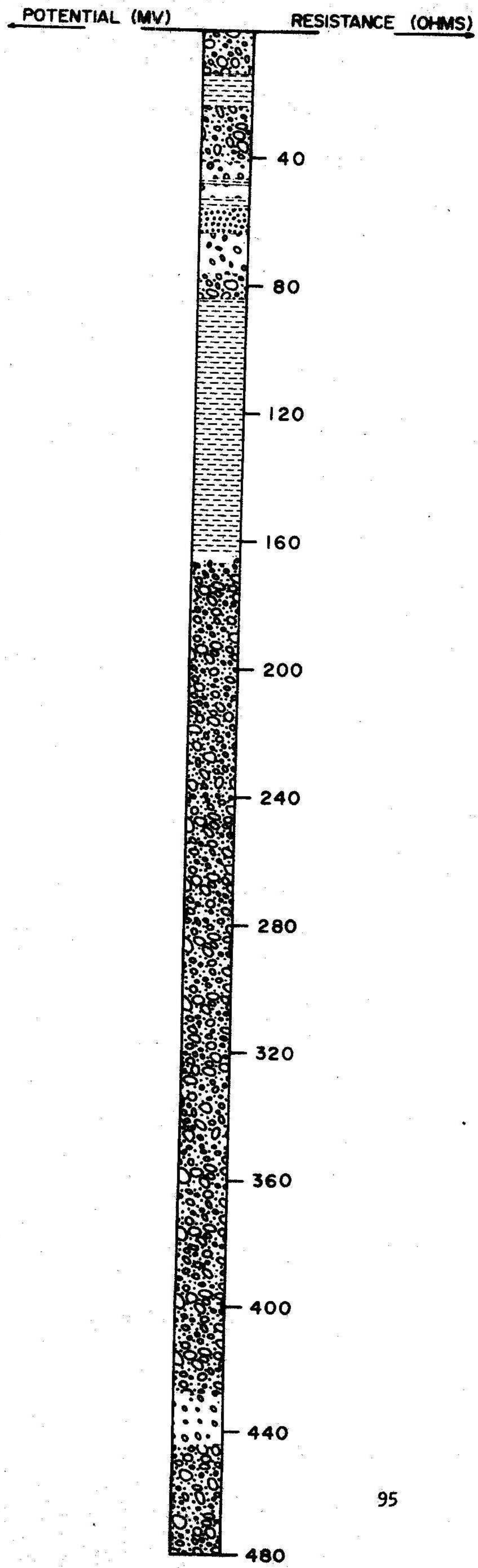
TEST HOLE MB

LOCATION: 163-97-33ccc

ELEVATION: 1977 feet
(FT, MSL)

DATE DRILLED: 1947

DEPTH: 521 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-13	Clay, sandy with pebbles, yellow (Till).
13-24	Clay, dark yellow.
24-41	Clay, sandy with pebbles, gray (Till).
41-46	Gravel.
46-48	Clay, gray.
48-52	Gravel.
52-56	Clay, sandy, gray.
56-64	Sand, interbedded gray clay, gravel, and detrital lignite.
64-71	Gravel, fine, lignitic.
71-76	Gravel, interbedded gray clay and boulders.
76-84	Clay, sandy with pebbles, gray (Till).
84-165	Clay, sandy, gray.
165-167	Gravel.
167-326	Clay, sandy with pebbles, gray (Till); interbedded sandy gravel lenses.
326-366	Clay, sandy with pebbles and cobbles, gray (Till).
366-428	Clay, sandy with pebbles, gray, lignitic (Till).
428-444	Gravel, interbedded clay and detrital lignite.
444-445	Boulder, sandstone, hard.
445-496	Clay, sandy with pebbles and lignite fragments, gray (Till).

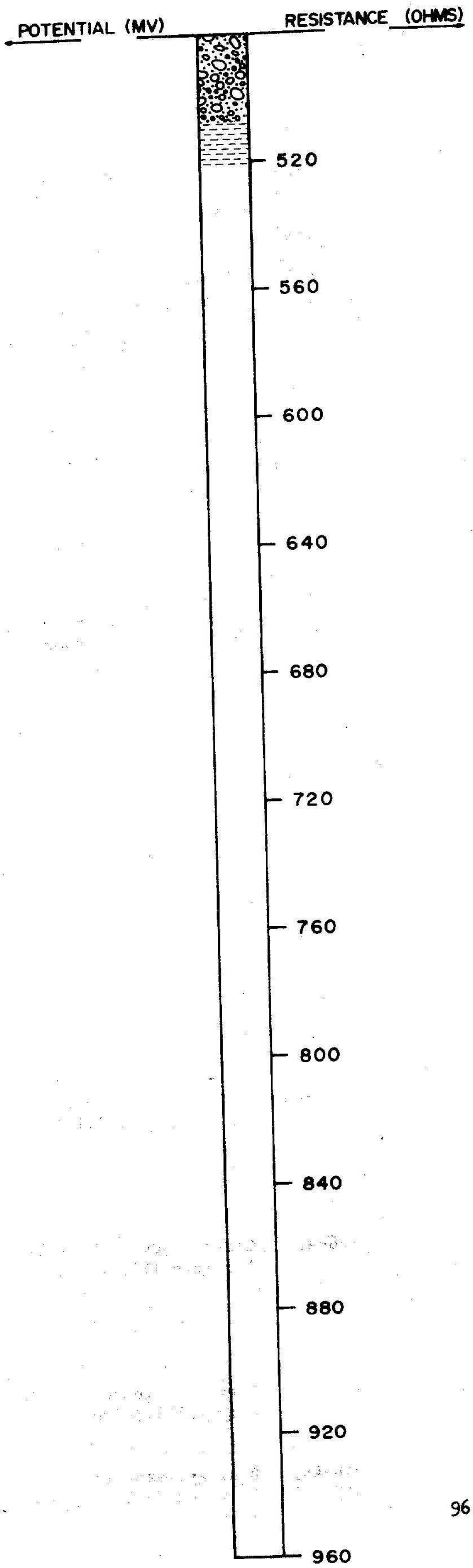
TEST HOLE MB (Cont.)

LOCATION: 163-97-33ccc

ELEVATION: 1977 feet
(FT, MSL)

DATE DRILLED: 1947

DEPTH: 521 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift (Cont.)

496-497	Rock.
497-521	Clay, sandy, gray.

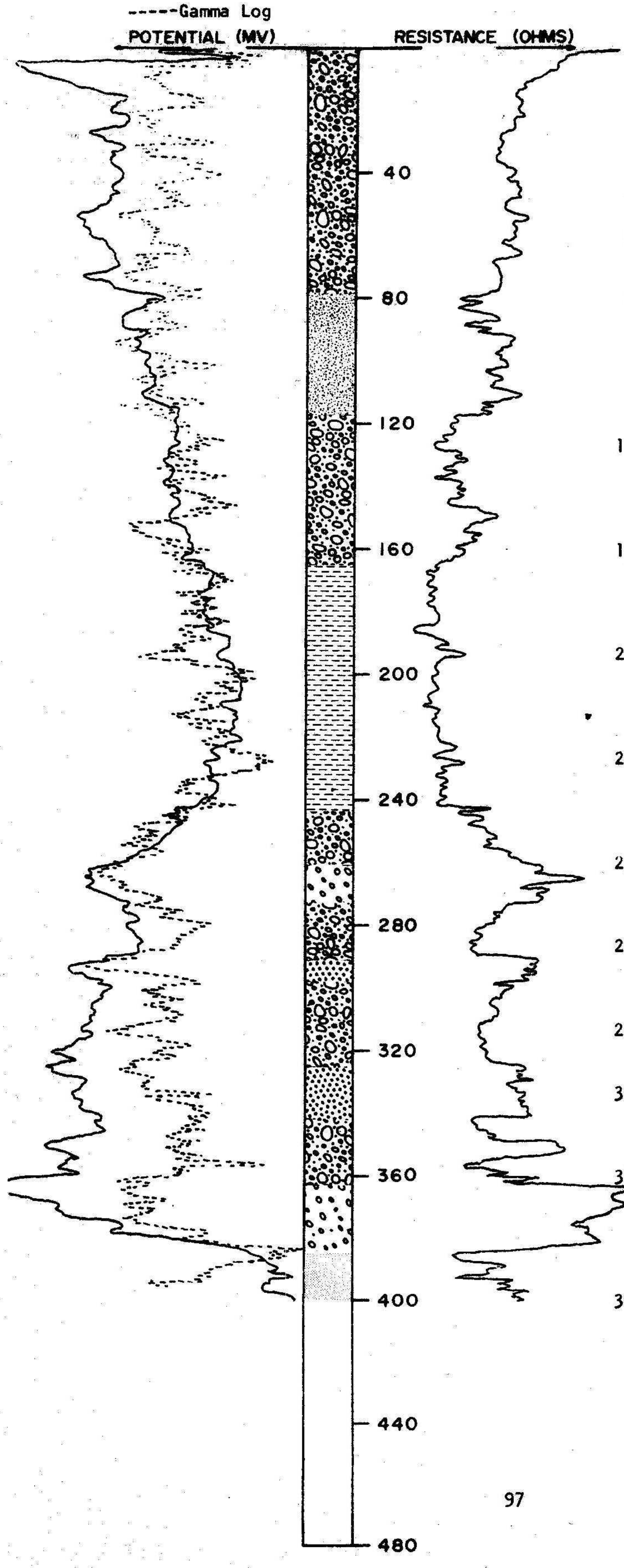
TEST HOLE 8291

LOCATION: 163-97-34abb

DATE DRILLED: 12-20-71

ELEVATION: 1952 feet (FT, MSL)

DEPTH: 400 feet (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay, brownish black.
1-27	Clay, silty, sandy, pebbly, dark yellowish brown, slightly cohesive to crumbly, oxidized (Till).
27-78	Clay, silty, sandy, pebbly cobbles, olive gray, moderately soft, cohesive (Till).
78-117	Silt and silty clay, slightly sandy (very fine to fine), medium dark gray with light gray laminae and mottling, thinly interbedded, moderately cohesive, slightly plastic; thin layers of fine gravel.
117-165	Clay, silty, sandy, pebbly, occasional cobble or boulder, olive gray, moderately soft to slightly hard, cohesive, stiff (Till).
165-243	Clay, silty, medium dark gray with very light gray mottling, cohesive, slightly plastic to slightly brittle, smooth, tight, laminated.
243-261	Clay, silty, moderately sandy, pebbly, cobbles, sandy gravel lenses, olive gray, moderately soft to slightly hard, chunky, crumbly (Till).
261-273	Gravel, medium to coarse, slightly sandy, cobbles, clay layers, sorted, highly lenticular, subrounded, loose, mostly carbonate rocks.
273-291	Clay, silty, sandy, pebbly, cobbles, olive gray, slightly hard, cohesive and compacted, stiff (Till).
291-298	Sand, medium to coarse, moderately well-sorted, subrounded, loose, clean, mostly quartz and carbonate rocks.
298-325	Clay, very silty, sandy, pebbly, slightly hard, chunky, brittle, compacted (Till).
325-342	Sand, fine and medium, slightly silty, thinly interbedded, fairly uniform, loose to very slightly cohesive.
342-363	Clay, very silty and sandy, pebbly, sandy gravel lenses, olive to dark olive gray, slightly hard, cohesive and compacted, stiff and brittle (Till).
363-385	Gravel, fine to coarse, slightly sandy, cobbles, poorly sorted angular to subrounded, mostly brown silicates and carbonates, some granitics and lignite; rough drilling.

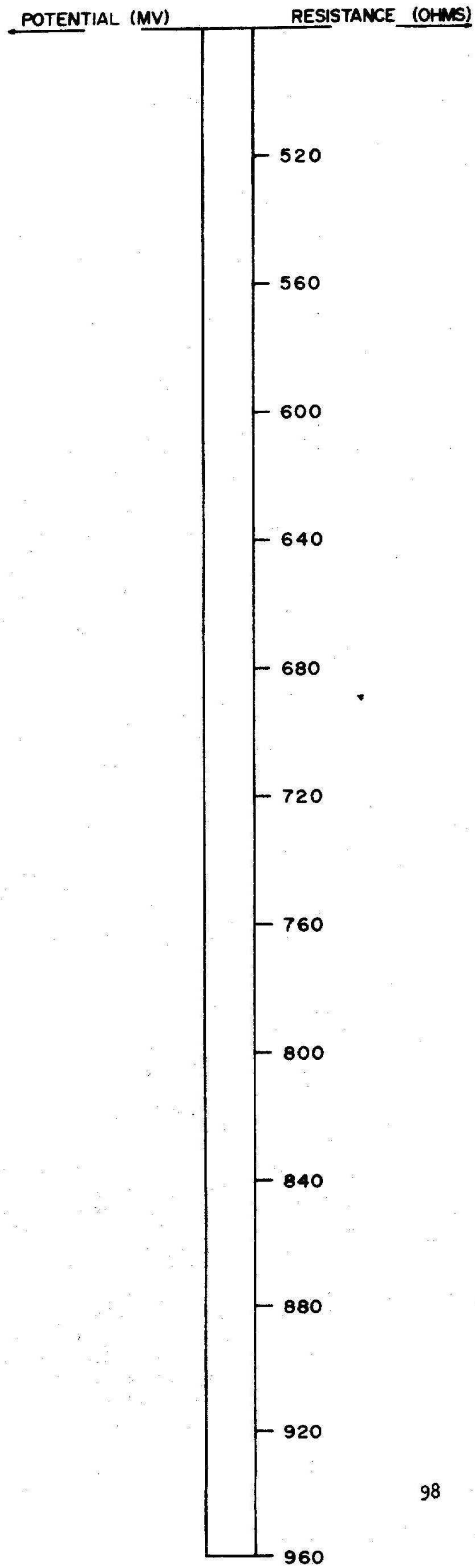
TEST HOLE 8291 (Cont.)

LOCATION: 163-97-34abb

DATE DRILLED: 12-20-71

ELEVATION: 1952 feet
(FT, MSL)

DEPTH: 400 feet
(FT)



DESCRIPTION OF DEPOSITS

Tongue River Formation

385-400 Siltstone, clayey, medium light gray, moderately well-indurated, bedded, soapy, slightly calcareous.

Observation Well

Depth: 378 feet
S. I.: 366 to 378 feet

CITY WELL #4 (T.H. 73-1)

(Log from C. A. Simpson & Son)

LOCATION: 163-97-34add1

DATE DRILLED: (#4) 7-5-73
(73-1) 4-6-72

ELEVATION: 1963
(FT, MSL)

DEPTH: 325 feet

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:	Topsoil	1	1
	Clay, slightly sandy, yellow ----	15	16
	Clay, yellow, rock at 31 feet ---	29	45
	Clay, blue, some rocks ----------	30	75
	Gravel --------------------------	1	76
	Clay, sandy, blue ---------------	39	115
	Clay, some sand, blue -----------	120	235
	Clay, very sandy, blue ----------	5	240
	Clay, sandy, gray ---------------	34	274
	Sand, medium --------------------	33	307
	Clay, pebbly, blue --------------	18	325

City Well #4 (12-inch steel casing)
Depth: 307 feet
S. I.: 277-307 feet (12-inch nominal screen)

Test Hole 72-2

(Log from C. A. Simpson & Son)

LOCATION: 163-97-34daa

DATE DRILLED: 10-24-72

ELEVATION: 1964 feet
(FT, MSL)

DEPTH: 322 feet

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:	Topsoil -------------------------	1	1
	Clay, yellow, rock at 32 --------	31	32
	Clay, sandy, pebbly, gray -------	79	111
	Sand, clayey --------------------	3	114
	Clay, sandy, light-gray ---------	17	131
	Clay, very little sand, blue ----	15	146
	Clay, very sandy, gray ----------	11	157
	Clay, some gravel, blue ---------	32	189
	Gravelly hardpan, rock ----------	2	191
	Gravel and clay -----------------	5	196
	Rock ----------------------------	2	198
	Clay, gravelly, blue ------------	11	209
	Rock ----------------------------	1	210
	Clay, gravelly, blue ------------	2	212
	Rock ----------------------------	1	213
	Clay, very sandy, blue ----------	12	225
	Clay, slightly sandy, gray ------	25	250
	Clay, gravelly, pebbly, gray ----	30	280
	Clay, sandy, gray ---------------	12	292
	Sand, fine to coarse, clayey ----	17	309
	Clay, gravelly, detrital lignite, gray -------------------------	13	322

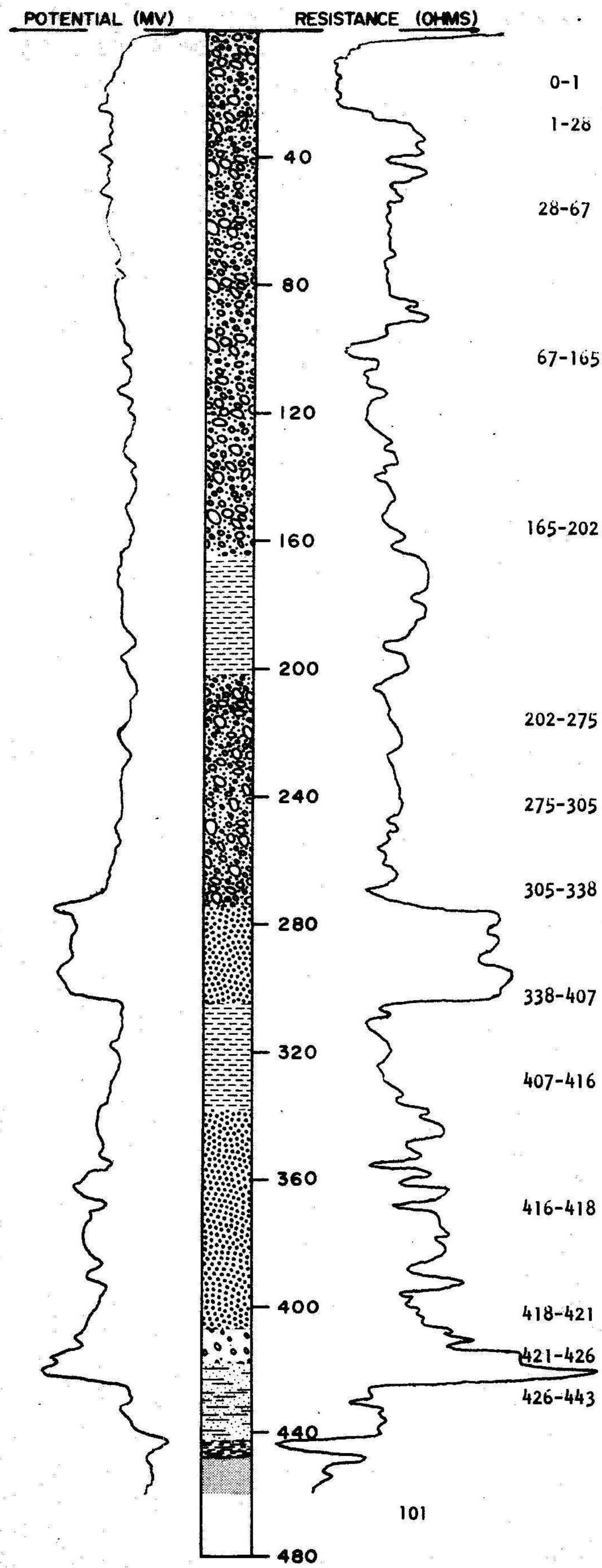
TEST HOLE 4425

LOCATION: 163-97-35add

DATE DRILLED: 12-4-71

ELEVATION: 1950 feet (FT, MSL)

DEPTH: 460 feet (FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil pebbly clay loam, black.
1-28	Clay, silty, sandy, pebbly, moderate olive brown, slightly hard, very cohesive, slightly brittle, tight, oxidized (Till).
28-67	Clay, silty, sandy (very fine), numerous carbonate pebbles, moderate olive green, moderately soft to slightly hard, cohesive, slightly plastic to slightly brittle, partially oxidized (Till).
67-165	Clay, silty, sandy (very fine), pebbly, olive gray, moderately soft to slightly hard, very cohesive, slightly plastic to slightly brittle (Till); thin layers of carbonate sand and fine gravel, blocks of clay and silty clay.
165-202	Clay, silt, and sandy clay, predominantly olive gray, laminated with light and dark grays to black, thinly interbedded, soft to moderately soft, slightly to moderately cohesive, non- to slightly plastic to very crumbly; usually dry and powdery.
202-275	Clay, silty, sandy, pebbly, olive gray, moderately soft, cohesive, slightly plastic (Till).
275-305	Sand, fine to coarse, clean and uniform, well-sorted, subrounded, loose, mostly carbonate rocks.
305-338	Clay, silty, olive and dark olive gray with black lignite flakes, laminated, moderately soft to slightly hard, compacted; rounded lignite pebbles.
338-407	Sand, very fine to very coarse, thinly interbedded with clay, silt, and gravel; erratic drilling.
407-416	Gravel, fine to very coarse with cobbles, subangular to rounded, assorted, "dirty", clay layers, mostly carbonate rocks with brown silicates and granitics.
416-418	Boulders.

Tongue River Formation

418-421	Clay, very sandy, white soft, crumbly, highly calcareous.
421-426	Sandstone, very fine-grained. indurated, $CaCO_3$ cement.
426-443	Sandstone, very fine-grained, grayish green, moderately soft, friable.

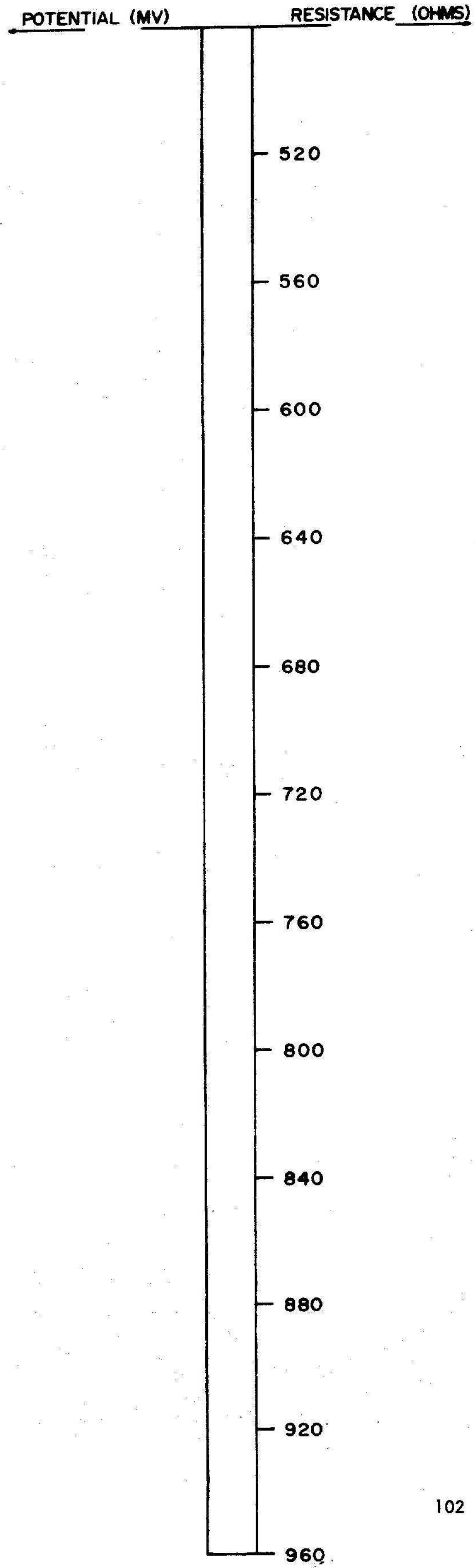
TEST HOLE 4425 (Cont.)

LOCATION: 163-97-35add

ELEVATION: 1950 feet
(FT, MSL)

DATE DRILLED: 12-4-71

DEPTH: 460 feet
(FT)



DESCRIPTION OF DEPOSITS

Tongue River Formation (Cont.)

443-448 Shale, very light gray, hard, moderately brittle, smooth, tight, possible bentonitic.

448-460 Siltstone, clayey to sandy, light gray with brown carbonaceous stains, moderately hard, tight.

Observation Well

Depth: 283 feet
S. I.: 277 to 283 feet
Plugged: 12-22-71

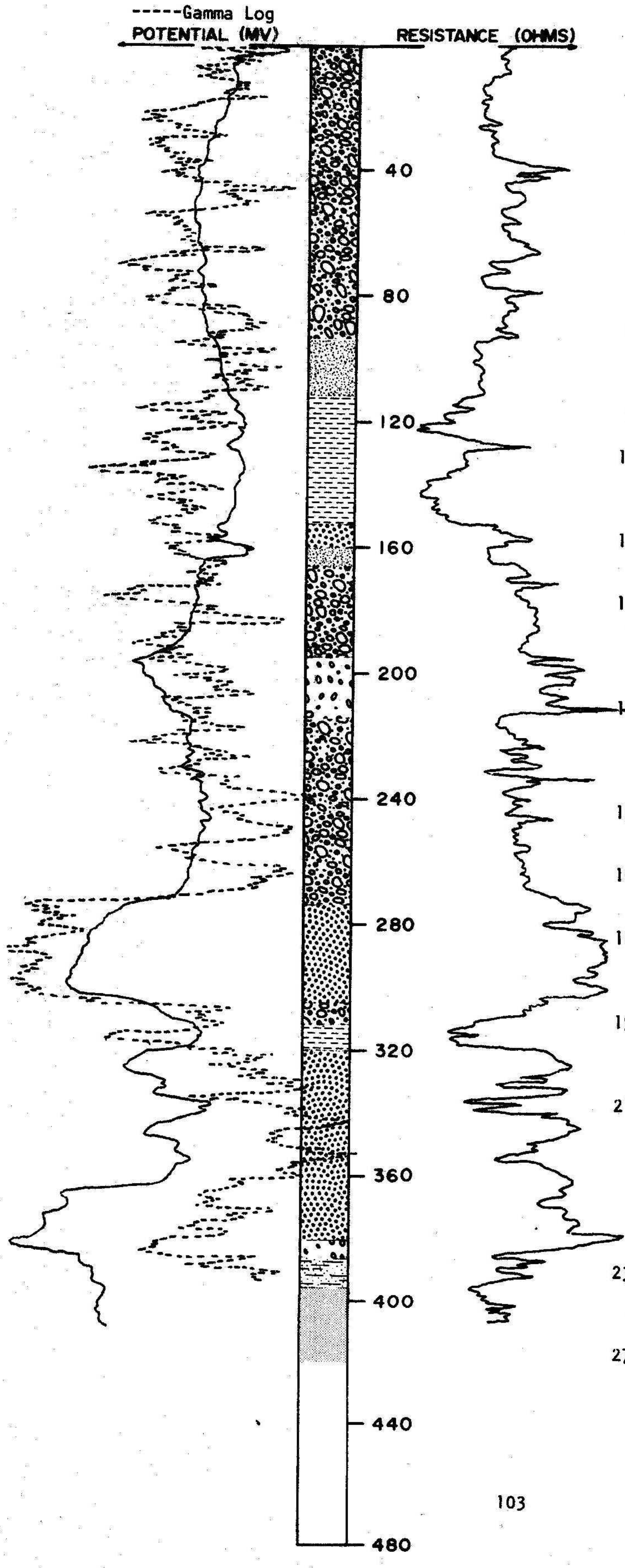
TEST HOLE 8292

LOCATION: 163-97-35bcc

DATE DRILLED: 12-22-71

ELEVATION: 1965 feet
(FT, MSL)

DEPTH: 420 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay, brownish black.
1-38	Clay, silty, moderately sandy, pebbly, dark yellowish brown, slightly cohesive. slightly plastic, oxidized (Till).
38-69	Clay, very silty, sandy, pebbly, sand and gravel lenses, occasional cobbles, loose to slightly cohesive, iron-stained, oxidized (Till).
69-94	Clay, very silty, sandy, pebbly, sand and gravel lenses, olive gray, moderately soft, cohesive, moderately stiff (Till).
94-112	Silt, light olive gray, soft, chunky, crumbly.
112-121	Clay and silty clay, light olive to olive gray, laminated, soft to moderately soft, cohesive, slightly plastic.
121-124	Clay, dark gray to black, slightly hard, cohesive, smooth, stiff, very tight, organic.
124-138	Clay and silty clay, slightly sandy, interbedded, light and medium gray to brownish gray, soft, cohesive; mostly reworked bedrock shales.
138-153	Clay to silty clay, dark greenish gray to medium dark gray, slightly hard to moderately soft, brittle to slightly plastic, smooth, tight.
153-160	Sand, very fine and fine, silty, gray, loose, subrounded, soft, lignitic.
160-166	Silt, clayey to slightly sandy, light olive gray, soft, friable, laminated.
166-195	Clay, very sandy, pebbly, cobbles, boulders, thin gravel stringers, olive gray, cohesive, stiff (Till).
195-214	Gravel, fine to coarse, sorted, thinly interbedded with sandy clay till as above, cobbles and boulders.
214-237	Clay, silty, moderately sandy, pebbly, cobbles, boulders, blocks of bedrock shale and clayey sandstone, greenish, brownish, and medium grays, slightly to moderately hard, cohesive, stiff and tough (Till).
237-274	Clay, silty, sandy, carbonate pebbles, cobbles, slightly hard, very cohesive and compacted, stiff (Till).
274-305	Sand, medium and coarse, interbedded clayey and gravelly lenses, sorted, lenticular, subangular to subrounded, slightly lignitic.

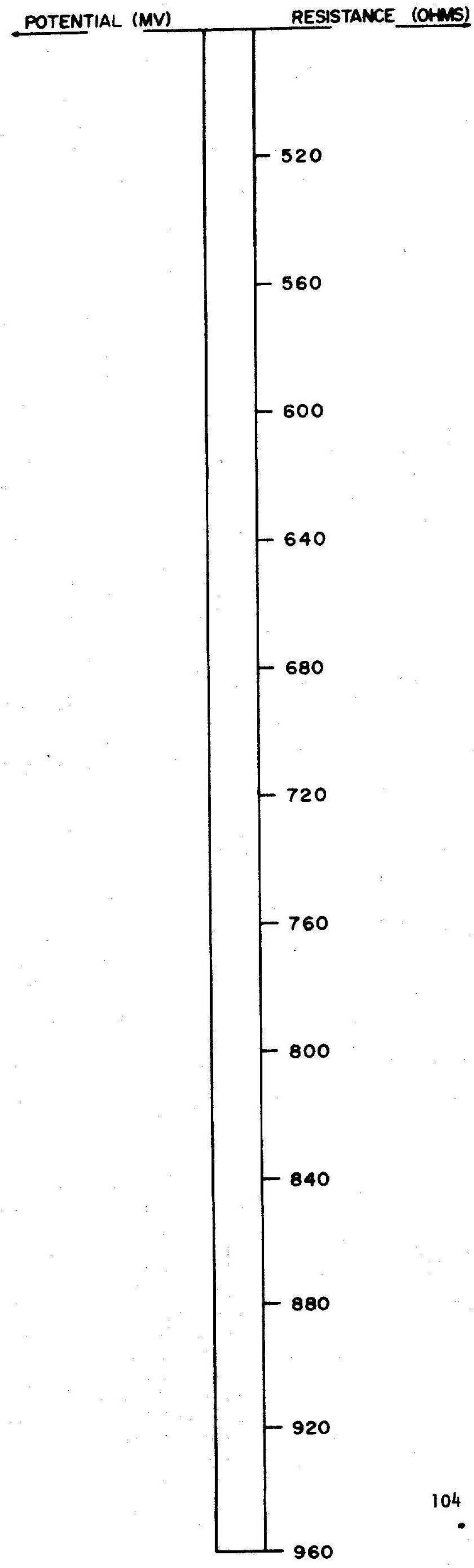
TEST HOLE 8292 (Cont.)

LOCATION: 163-97-35bcc

ELEVATION: 1965 feet
(FT, MSL)

DATE DRILLED: 12-22-71

DEPTH: 420 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift (Cont.)

305-312	Clay, silty, very sandy, pebbly, sand lenses, moderate yellowish brown with olive gray mottling, moderately cohesive, oxidized (Till).
312-320	Clay, silty, light olive to dark olive gray, slightly hard, smooth, stiff, tight.
320-362	Sand, fine to coarse, sorted, thinly interbedded silty clay or clayey till lenses, loose, subangular and subrounded.
362-380	Sand, medium, moderately well-sorted and uniform, loose, clean, subrounded, quartzose, slightly lignitic.
380-385	Gravel, fine to coarse, slightly sandy, cobbles, assorted, angular to subrounded, mostly carbonate rocks, small amount of brown silicates and lignite.

Tongue River Formation

385-395	Sandstone, clayey, moderately soft to indurated, medium bluish gray.
395-420	Siltstone, clayey, medium light gray, moderately indurated, tight.

Observation Well

Depth: 300 feet
S. I.: 294 to 300 feet

Test Hole 72-1

(Log from C. A. Simpson & Son)

LOCATION: 163-97-35bdd

DATE DRILLED: 8-30-72

ELEVATION: 1960 feet
(FT, MSL)

DEPTH: 330 feet

Formation	Lithology	Thickness (feet)	Depth (feet)
Glacial Drift:	Topsoil -------------------------	1	1
	Clay, yellow --------------------	34	35
	Clay, sandy, blue, some rocks ---	266	301
	Clay, sandy ---------------------	6	307
	Sand, medium, slightly clayey ---	3	310
	Sand, medium to coarse, gravelly-	15	325
	Clay, blue ----------------------	5	330

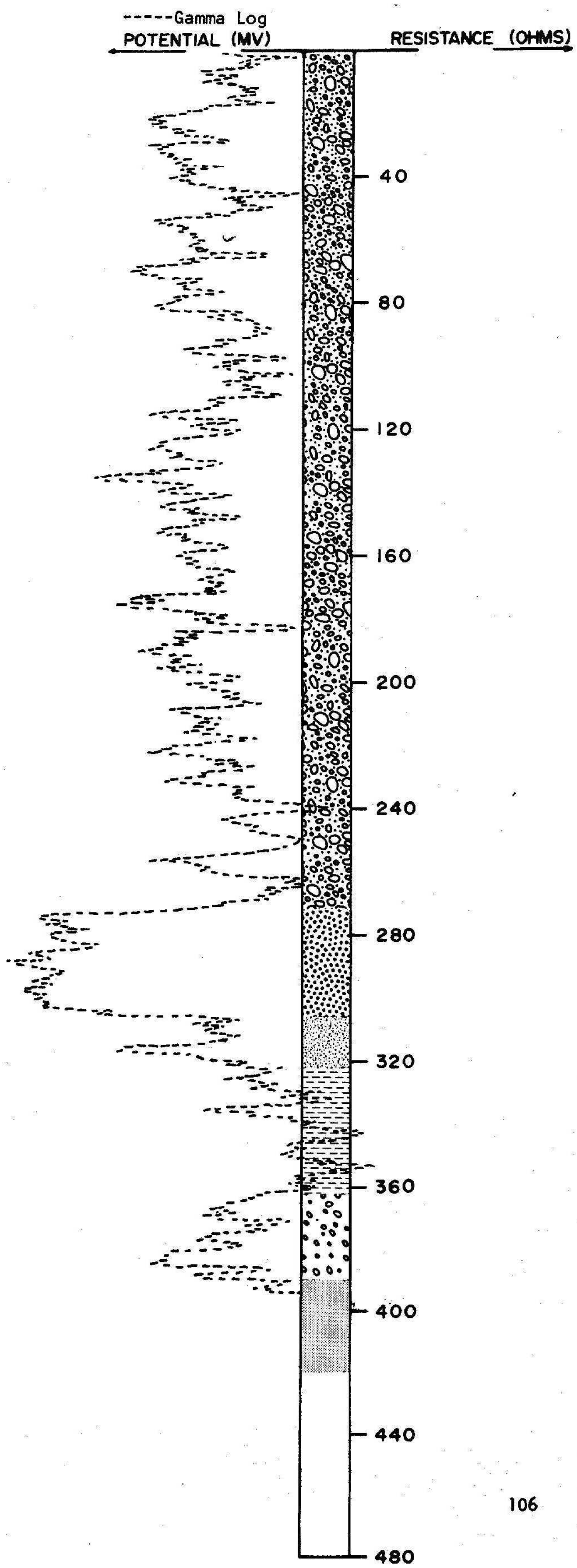
TEST HOLE 8293

LOCATION: 163-97-35ddd

DATE DRILLED: 12-23-71

ELEVATION: 1960 feet
(FT, MSL)

DEPTH: 420 feet
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty clay, brownish black.
1-18	Clay, silty, slightly sandy, pebbly, moderate yellowish brown, slightly cohesive, slightly plastic, oxidized (Till).
18-29	Clay, silty, sandy, pebbly, cobbles, dark yellowish brown to light olive gray, moderately soft, cohesive, partially oxidized (Till).
29-272	Clay, silty, sandy, pebbly, cobbles, occasional boulder, lenses or blocks of clay, silt, sand, and gravel, generally olive gray, moderately soft to slightly hard, cohesive and compacted, slightly plastic to very stiff and tough, calcareous (Till).
272-306	Sand, medium and coarse, well-sorted and uniform, subangular to subrounded, loose, clean, mostly quartz and feldspar with carbonates and some lignite.
306-322	Silt, slightly clayey to very sandy, some fine gravel, lenticular and laminated, soft, loose to very slightly cohesive.
322-362	Clay, very silty to slightly sandy, interbedded sand lenses, lenticular and laminated, soft, loose to slightly cohesive, crumbly, calcareous.
362-390	Gravel, fine to coarse, sandy, cobbles, interbedded clayey streaks, angular to subrounded, poorly sorted, mostly carbonate rocks.

Tongue River Formation

390-420	Siltstone, clayey, medium gray to light greenish gray, moderately indurated, brittle, tight, noncalcareous; some interbedded bluish green sandstone.

Observation Well

Depth: 283 feet
S. I.: 277 to 283 feet

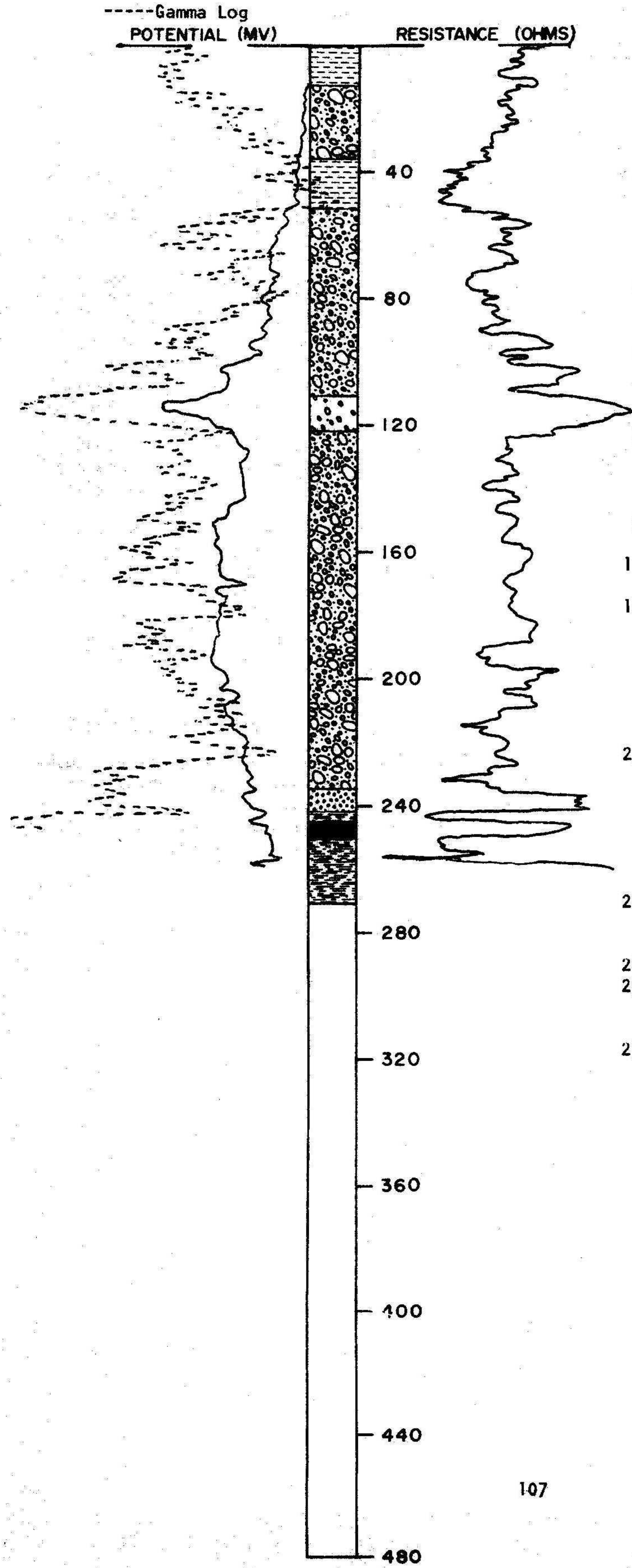
TEST HOLE 4447

LOCATION: 163-97-36dda

DATE DRILLED: 6-15-72

ELEVATION: 1940
(FT, MSL)

DEPTH: 271
(FT)



DESCRIPTION OF DEPOSITS

Glacial Drift

0-1	Topsoil, silty loam, black.
1-13	Clay, very silty, sandy, pebbly, yellowish gray with dark brown, soft, cohesive, plastic, sticky.
13-27	Clay, silty, sandy, pebbly, dusky yellow with moderate olive brown, soft, cohesive, moderately plastic to slightly stiff, oxidized (Till).
27-36	Clay, very silty, sandy, pebbly, olive gray, moderately soft, cohesive (Till).
36-52	Clay, silty, olive gray with light gray laminations, moderately soft, very cohesive, smooth, slightly sticky, tight.
52-91	Clay, very silty, sandy, pebbly, cobbles, olive gray, moderately soft, cohesive, slightly plastic to stiff (Till).
91-111	Till, as above, interbedded with layers of sandy gravel.
111-122	Gravel, fine and medium, sandy, assorted, subrounded, loose.
122-235	Clay, silty, sandy, pebbly, cobbles, olive gray, moderately soft to slightly hard, cohesive, tightly compacted (Till); blocks or layers of clay and sandy clay, sand and gravel lenses.
235-242	Sand, very fine and fine, light olive gray, sorted, lenticular, loose; detrital lignite.

Tongue River Formation

242-245	Shale, very silty, light gray, moderately soft, smooth, bentonitic.
245-250	Lignite, black, hard, fissile.
250-270	Shale and lignite; interbedded with varigated siltstone and sandstone.
270-271	Sandstone, very fine-grained dark greenish gray, indurated, calcareous.

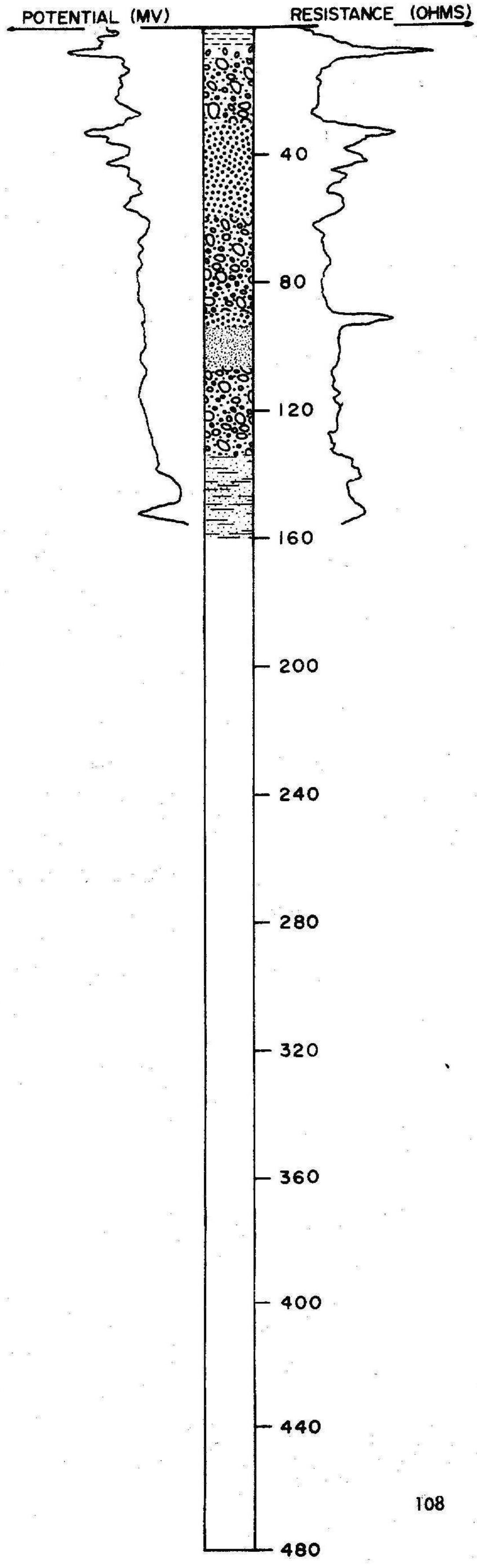
TEST HOLE 3018

LOCATION: 164-97-31daa

ELEVATION: 1890 feet
(FT, MSL)

DATE DRILLED: 6-15-63

DEPTH: 160 feet
(FT)



DESCRIPTION OF DEPOSITS

0-6	Fill
	Glacial Drift
6-10	Gravel, fine, sandy, rounded, iron-stained, oxidized.
10-13	Clay, silty, sandy, pebbly, dark yellowish orange, cohesive, oxidized (Till).
13-30	Clay, silty, sandy, pebbly, dark greenish gray, moderately soft, cohesive (Till).
30-60	Sand, very fine to coarse, sorted, interbedded, silty clay or clayey till lenses, subangular to subrounded, quartzose and lignitic.
60-90	Clay, silty to sandy, pebbly, dark greenish gray, moderately soft, cohesive, sticky (Till); poor sample return.
90-94	Sand, medium, gray, sorted, subrounded, quartzose.
94-107	Silt, light olive gray, soft, chunky, friable.
107-135	Clay, silty, sandy, pebbly, olive gray, moderately hard, compacted, stiff (Till).
	Tongue River Formation
135-142	Sandstone, fine, clayey, dusky yellow, soft, friable, oxidized.
142-160	Sandstone, fine, clayey, bluish gray, noncalcareous.

REFERENCES

Armstrong, C. A., 1965, Geology and ground-water resources of Divide County, Part 2, Basic Data: North Dakota State Water Comm. County Ground-Water Studies 6, 112 p.

----- 1967, Geology and ground-water resources of Williams County, Part 2, Basic Data: North Dakota State Water Comm. County Ground-Water Studies 9, 129 p.

----- 1967, Geology and ground-water resources of Divide County, Part 3, Ground-Water Resources: North Dakota State Water Comm. County Ground-Water Studies 6, 56 p.

----- 1969, Geology and ground-water resources of Williams County, Part 3, Hydrology: North Dakota State Water Comm. County Ground-Water Studies 9, 82 p.

----- 1969, Geology and ground-water resources of Burke and Mountrail Counties, Part 2, Basic Data: North Dakota State Water Comm. County Ground-Water Studies 14, 282 p.

----- 1971, Geology and ground-water resources of Burke and Mountrail Counties, Part 3, Ground-Water Resources: North Dakota State Water Comm. County Ground-Water Studies 14, 86 p.

Basement Rock Projects Committee, 1967, Basement map of North America, between latitudes 24° and 60° N.: U. S. Geological Survey.

Croft, M. G., 1973, Ground-water resources of Mercer and Oliver Counties, North Dakota, Part 3: North Dakota State Water Comm. County Ground-Water Studies 15, 81 p.

Freers, T. F., 1970, Geology and ground-water resources of Williams County, Part 1, Geology: North Dakota State Water Comm. County Ground-Water Studies 9, 55 p.

----- 1973, Geology of Burke County, North Dakota: North Dakota County Ground-Water Studies 14, Part 1, 32 p.

Goddard, E. N. and others, 1963, Rock-Color Chart: Geol. Society of America.

Hansen, D. E., 1967, Geology and ground-water resources of Divide County, Part 1, Geology: North Dakota State Water Comm. County Ground-Water Studies 6, 90 p.

Naplin, C. E., 1969, Ground-water survey of the Columbus area, Burke County, North Dakota: North Dakota State Water Comm. Ground-Water Studies No. 73, 59 p.

National Weather Service, 1971, Climatological data, North Dakota: Annual Summary 1971, V. 80, No. 13.

Pettijohn, F. J., 1957, Sedimentary rock: New York, Harper and Brothers, p. 15-51.

Schmid, R. W., 1965, Water quality explanation: North Dakota State Water Commission unpublished report, file number 989.

----- 1972, Crosby city well #3 efficiency: North Dakota State Water Commission, Open-File Report.

----- 1974, Crosby aquifer test: North Dakota State Water Commission, Open-File Report.

Simpson, H. E., 1929, Geology and ground-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598, 312 p.

Townsend, R. C., 1954 b, Geology of the Crosby quadrangle, North Dakota: U. S. Geol. Survey Geol. Quad. Map GQ-46.

Voedisch, F. W., 1972, written communication, in Schmid, R. W., 1972, Crosby city well #3 efficiency: North Dakota State Water Commission, Open-File Report.

APPENDIX

The report preceeding this appendix was written in 1973 by L. L. Froelich. The appendix was written in 1982 by Alan Wanek, State Water Commission hydrologist.

MUNICIPAL WATER SUPPLY

In July 1973 a 12-inch diameter, 307 feet deep municipal well was installed by C. A. Simpson and Son Drilling. The well is located in the SE¼, NW¼ Section 34, Township 163 North, Range 97 West. The well provides part of the present water supply for the city of Crosby. A log of the well is included in Table 3 and is labeled "city well #4."

WATER LEVEL FLUCTUATIONS: 1972-1980

Since the original manuscript was written in 1973 water levels in nine observation wells in the Crosby area have been monitored by the U. S. Geological Survey. Hydrographs illustrating these data are included in Table 2. Note that the vertical scale varies between hydrographs depending on the magnitude of the water level fluctuations.

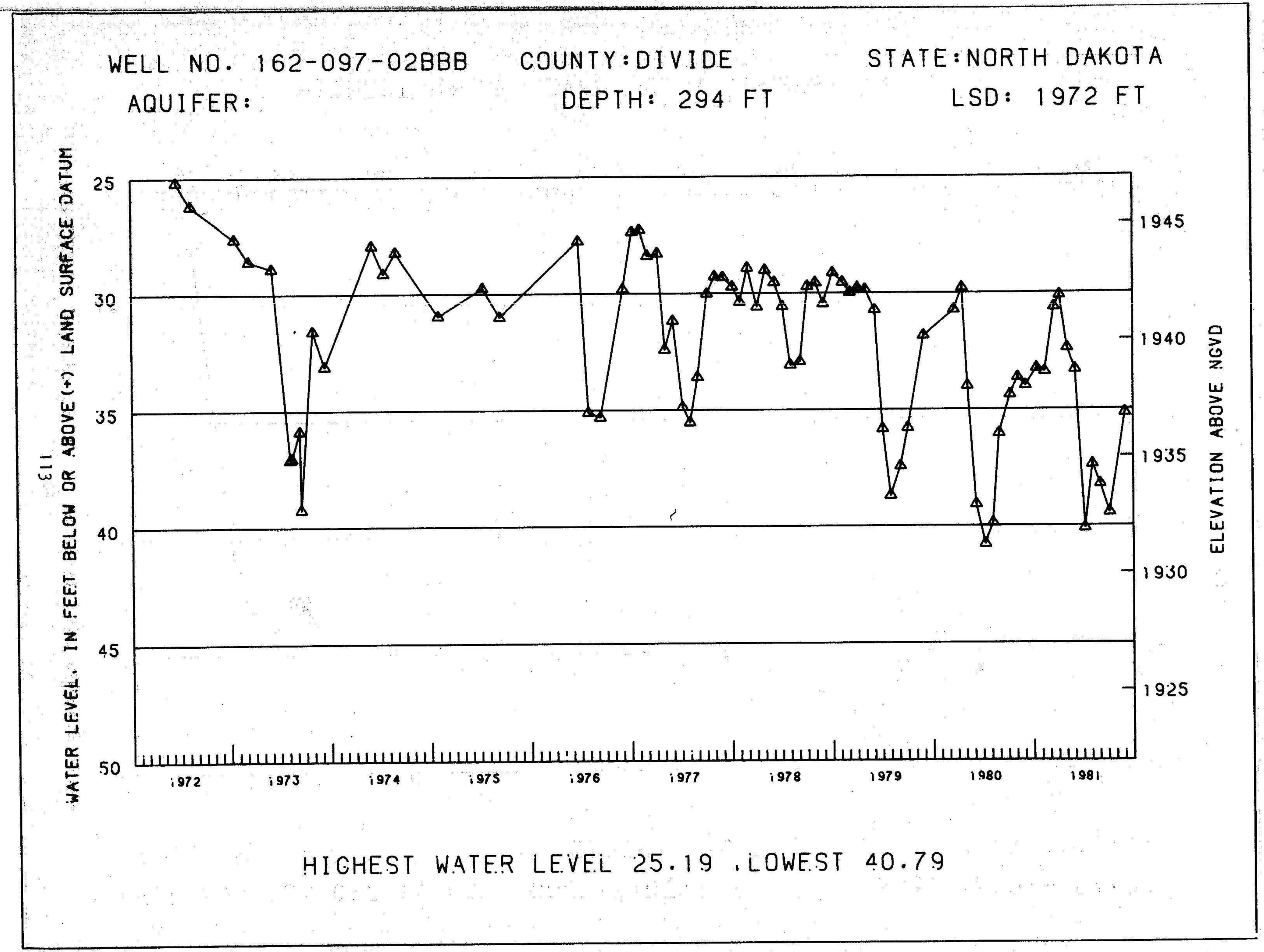
Well 163-97-35BCC is located 72 feet east of the Crosby municipal well. The water level in this well fluctuates in direct response to the pumping of the municipal well. The general water level in this observation well declined approximately ten feet from 1972 through 1980. In addition to the general decline, the well fluctuates 15-20 feet in response to the municipal well pumping schedule. The low water levels measured during summer months reflect more pumping of the municipal well during this time.

The influence of the municipal well on the water level in the upper zone of the Crosby aquifer can be seen in the hydrographs of well 162-97-02BBB.

This observation well is located 3000 feet south of the municipal well. The water level in the observation well fluctuates five to ten feet through the year with the lowest water levels occurring in the summer. The water level in this observation well has declined approximately two feet from 1973 to 1980.

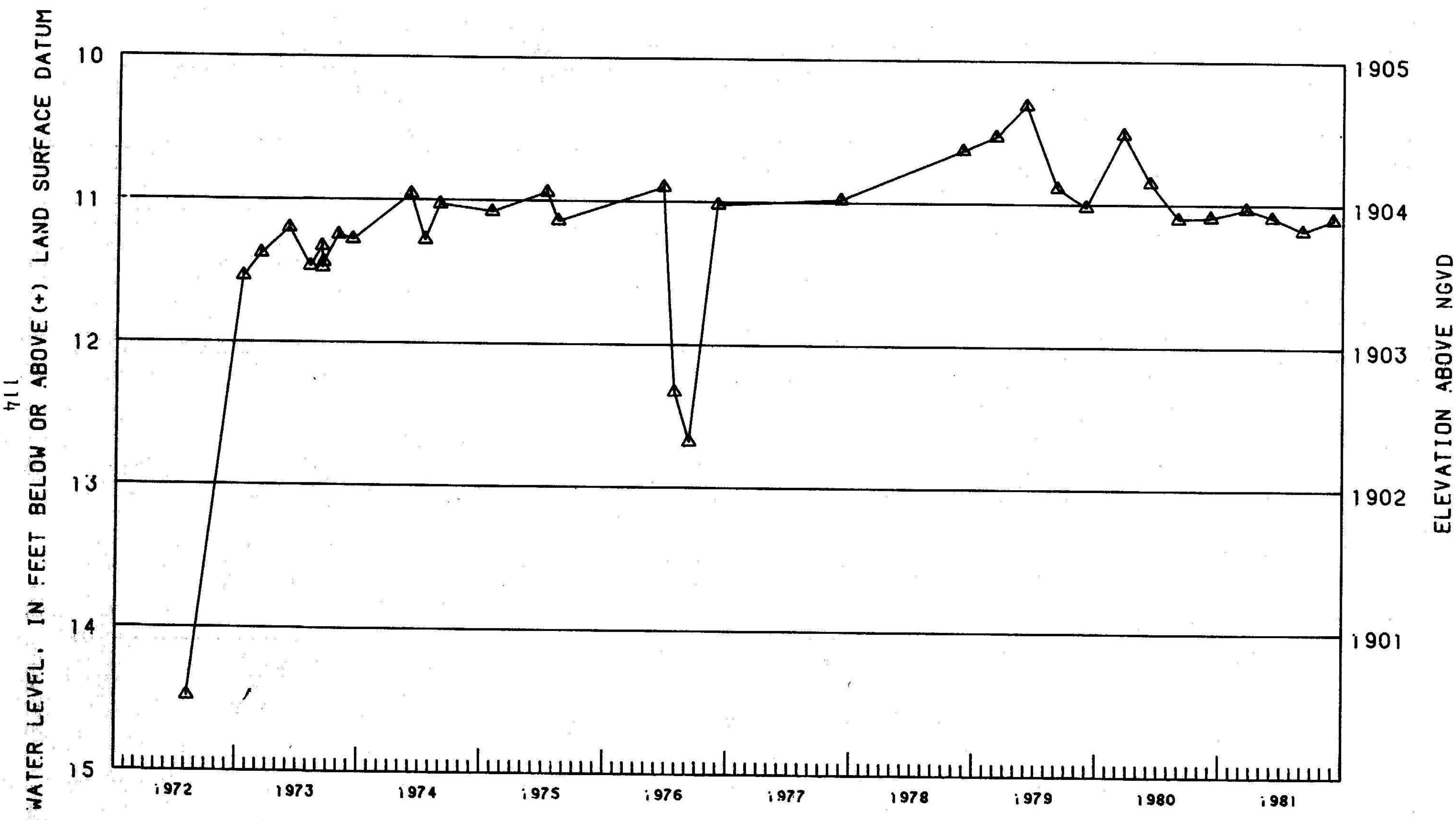
Another observation well of interest is well 163-97-34ABB, located 3000 feet northwest of the municipal well. This well is screened in the lower zone of the Crosby aquifer. Twenty-one feet of glacial till separate the upper and lower zones of the Crosby aquifer at this location. The water level in this observation well has declined approximately eight feet from 1972 to 1980. The water level in this well declines in summer then partially recovers in winter. These fluctuations suggest that a limited hydraulic connection exists in places between the upper and lower zones of the Crosby aquifer.

The normal ground-water fluctuations over time are apparent from the hydrographs for other observation wells. These wells are screened in the lower zone of the Crosby aquifer, the Columbus aquifer, the Yellowstone aquifer and isolated sand and gravel lenses. The water levels in these wells fluctuate as much as five feet, generally having the lowest water levels in the summer, but do not show the overall decline in water level which is experienced in wells within one mile of the Crosby municipal well.


WELL NO. 162-097-02BBB
COUNTY:DIVIDE
STATE:NORTH DAKOTA
AQUIFER:
DEPTH: 294 FT
LSD: 1972 FT
WATER LEVEL, IN FEET BELOW OR ABOVE(+) LAND SURFACE DATUM
ELEVATION ABOVE NGVD
25
30
35
40
45
50
1945
1940
1935
1930
1925
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
HIGHEST WATER LEVEL 25.19 ,LOWEST 40.79

WELL NO. 163-097-15BCC COUNTY:DIVIDE STATE:NORTH DAKOTA

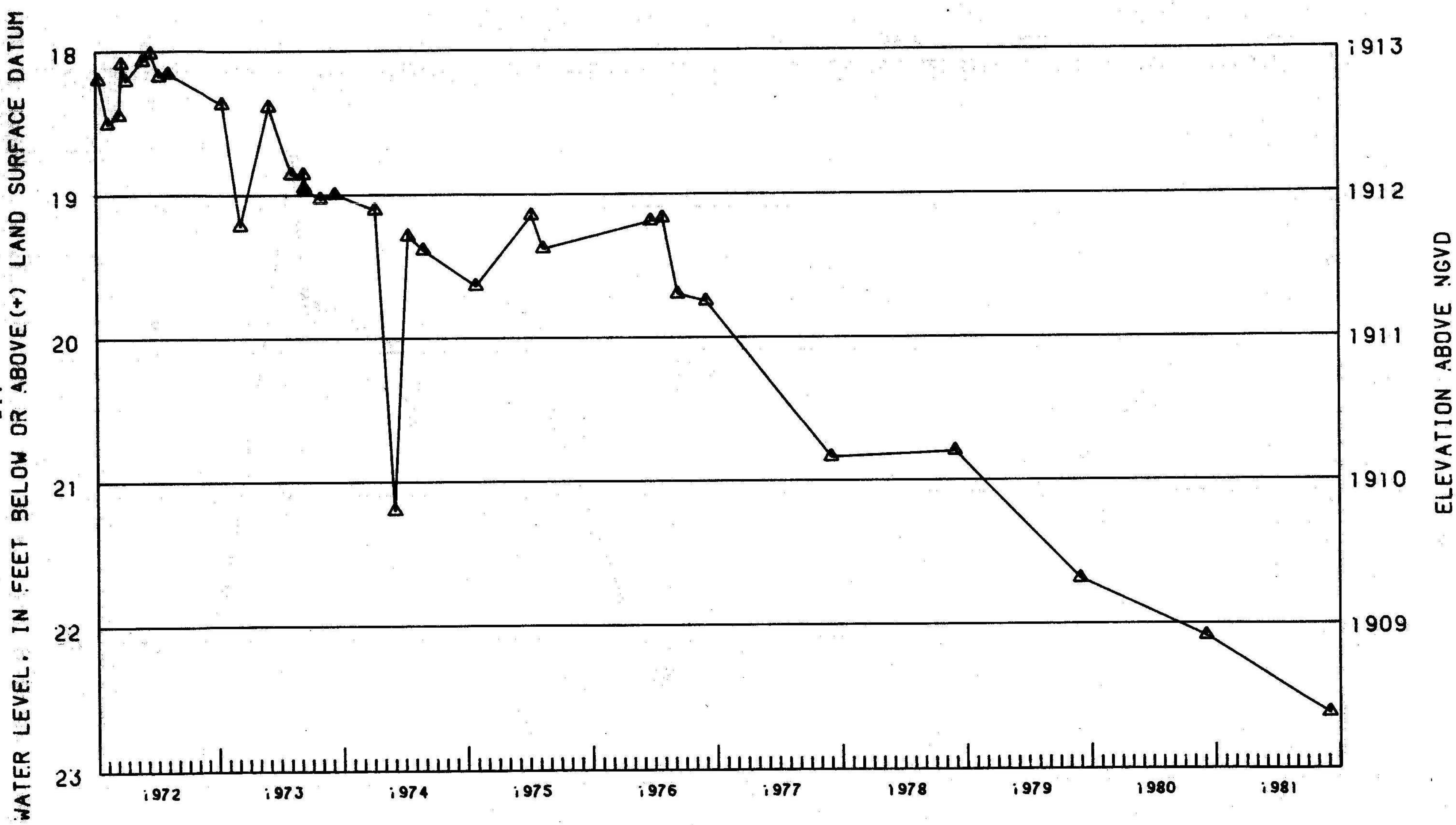
AQUIFER: DEPTH: 558 FT LSD: 1915 FT



HIGHEST WATER LEVEL 10.31 ,LOWEST 14.48

WELL NO. 163-097-23DDD COUNTY:DIVIDE STATE:NORTH DAKOTA

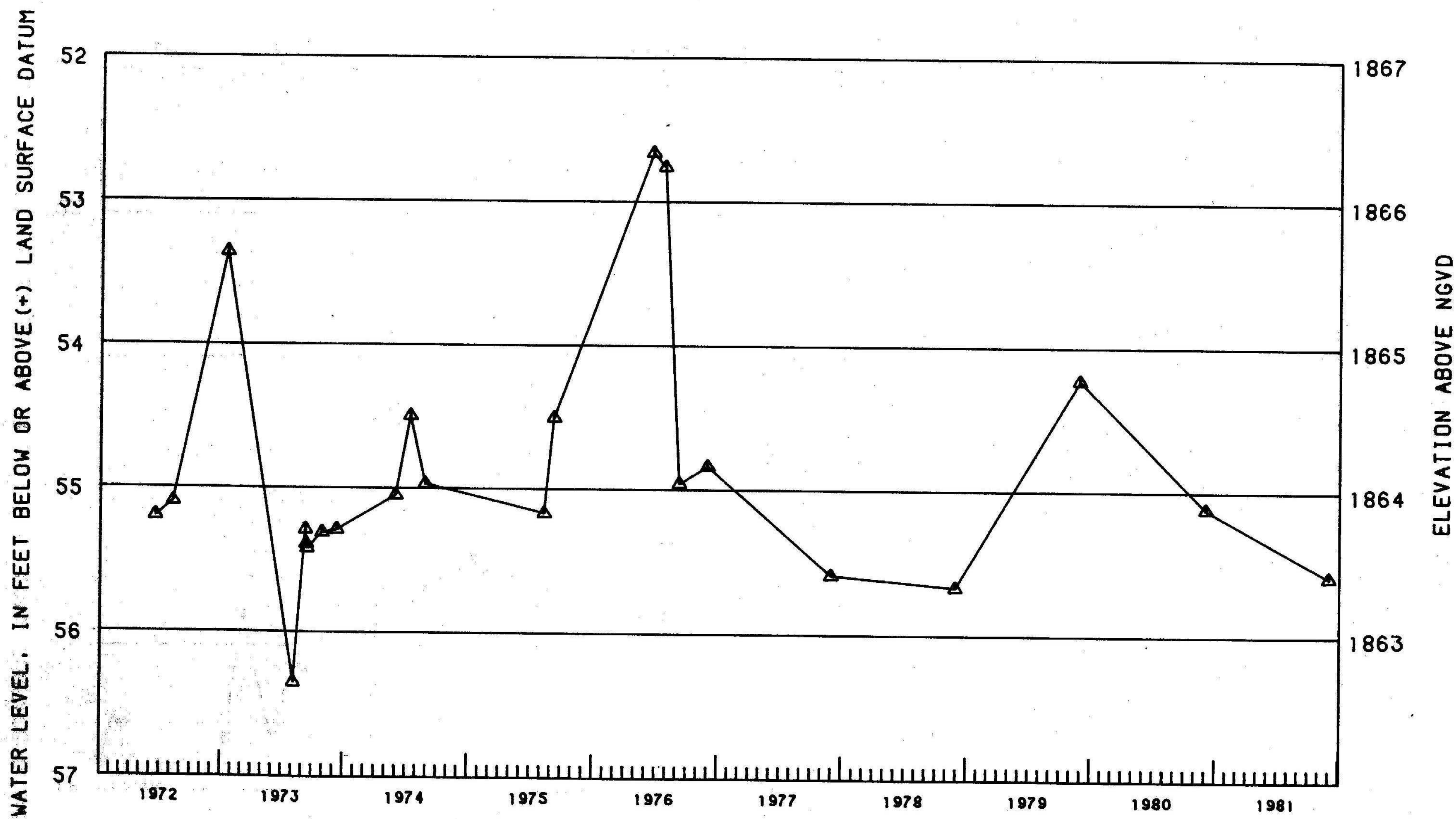
AQUIFER: DEPTH: 327 FT LSD: 1931 FT



HIGHEST WATER LEVEL 18.02 ,LOWEST 22.62

WELL NO. 163-097-24AAA COUNTY:DIVIDE STATE:NORTH DAKOTA

AQUIFER: DEPTH: 411 FT LSD: 1919 FT

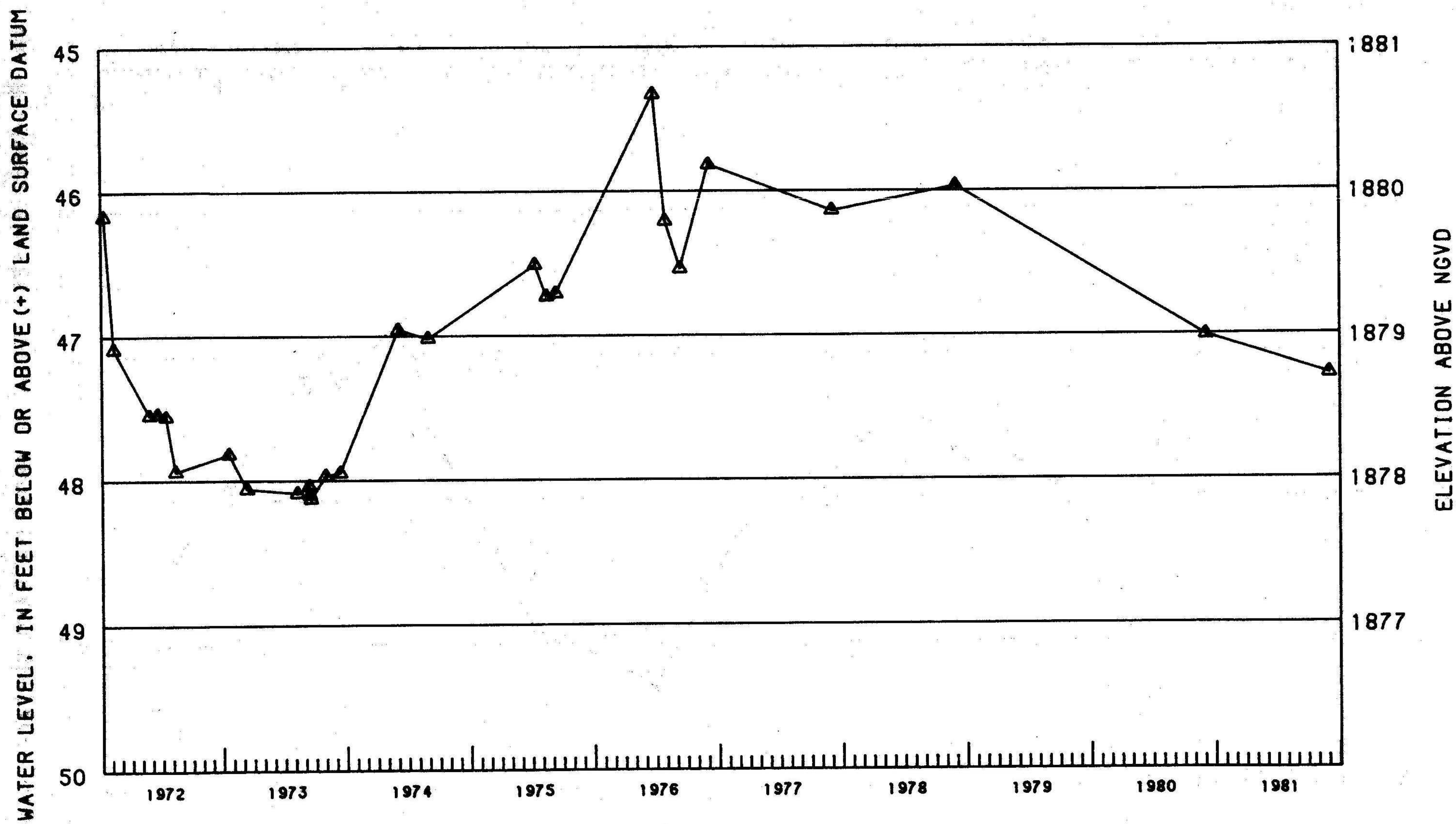


116

HIGHEST WATER LEVEL 52.66 ,LOWEST 56.35

WELL NO. 163-097-25AAA COUNTY:DIVIDE STATE:NORTH DAKOTA

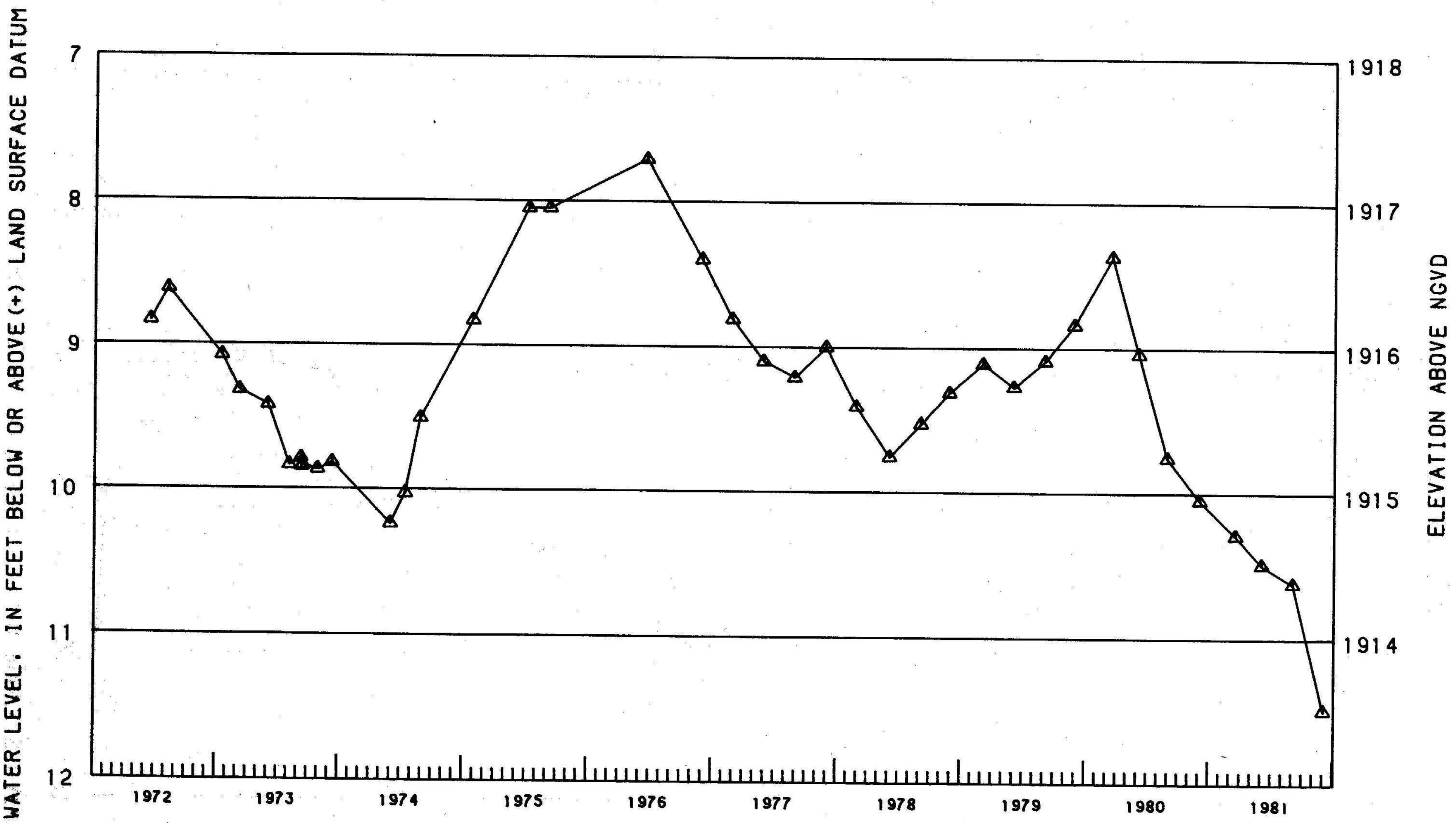
AQUIFER: DEPTH: 390 FT LSD: 1926 FT



HIGHEST WATER LEVEL 45.33 ,LOWEST 48.13

WELL NO. 163-097-25DDD COUNTY:DIVIDE STATE:NORTH DAKOTA

AQUIFER: DEPTH: 126 FT LSD: 1925 FT

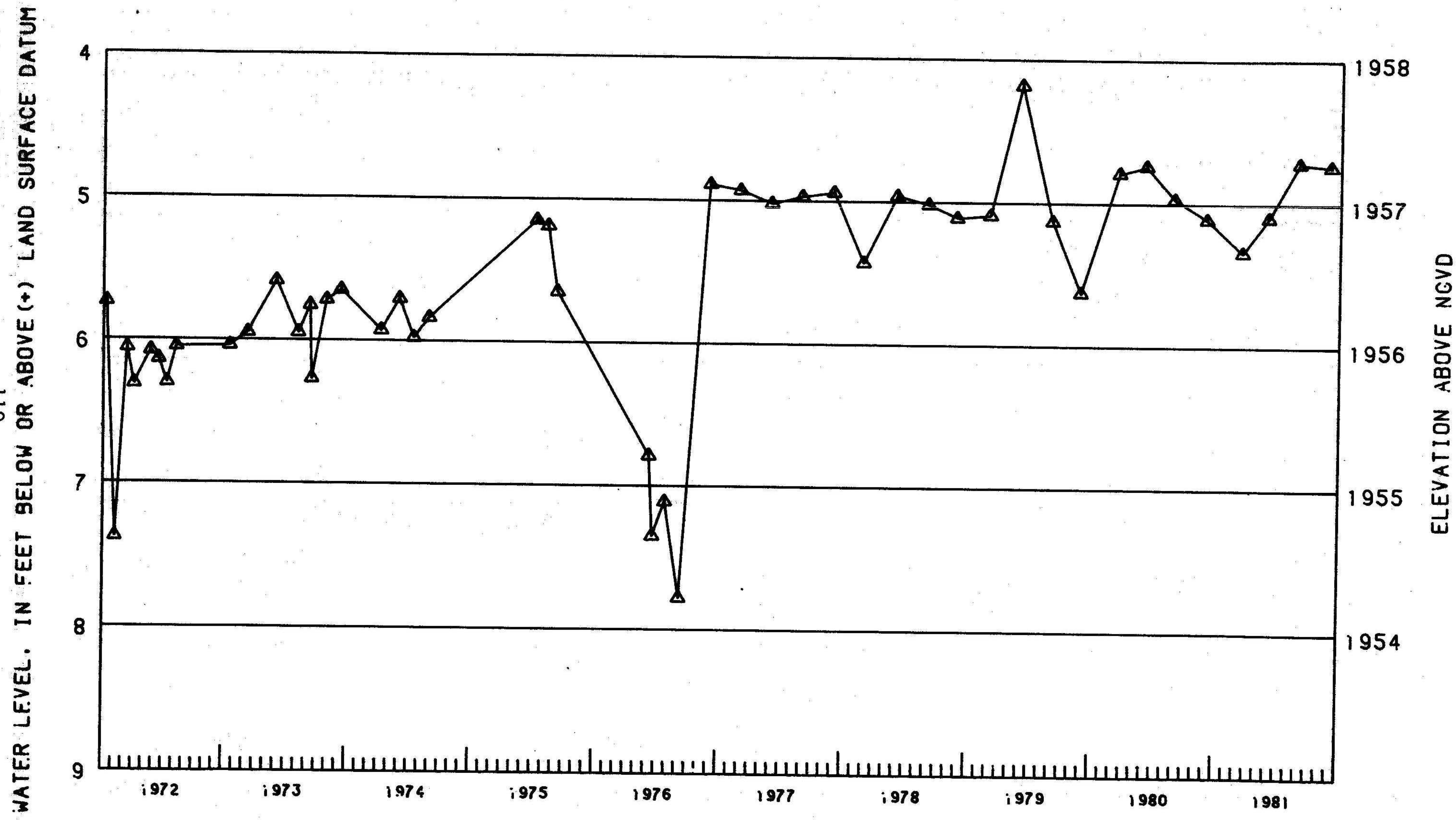


118

HIGHEST WATER LEVEL 7.71 ,LOWEST 11.49

WELL NO. 163-097-27CCC COUNTY:DIVIDE STATE:NORTH DAKOTA

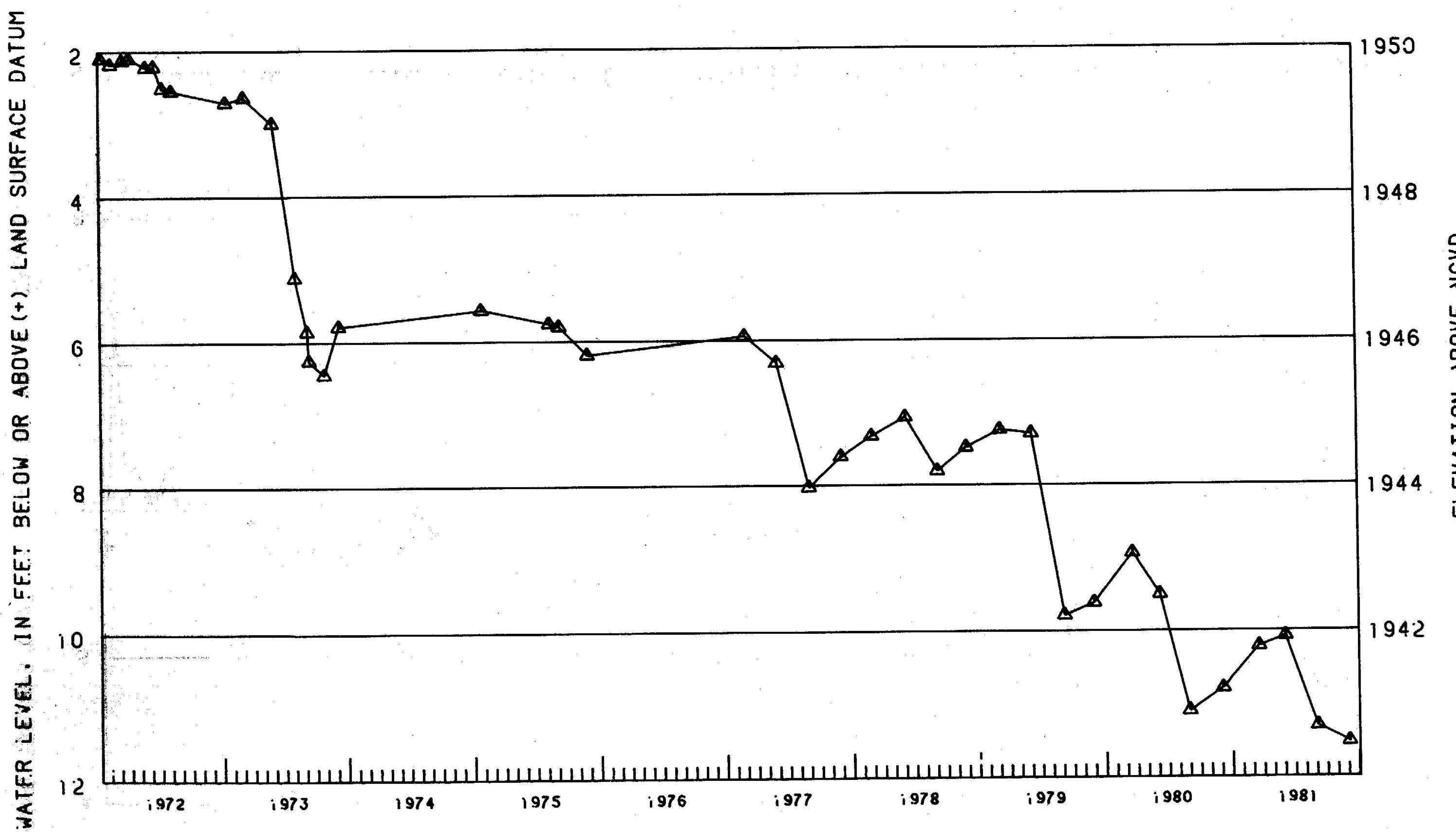
AQUIFER: DEPTH: 263 FT LSD: 1962 FT



HIGHEST WATER LEVEL 4.18 LOWEST 7.78

WELL NO. 163-097-34ABB COUNTY:DIVIDE STATE:NORTH DAKOTA

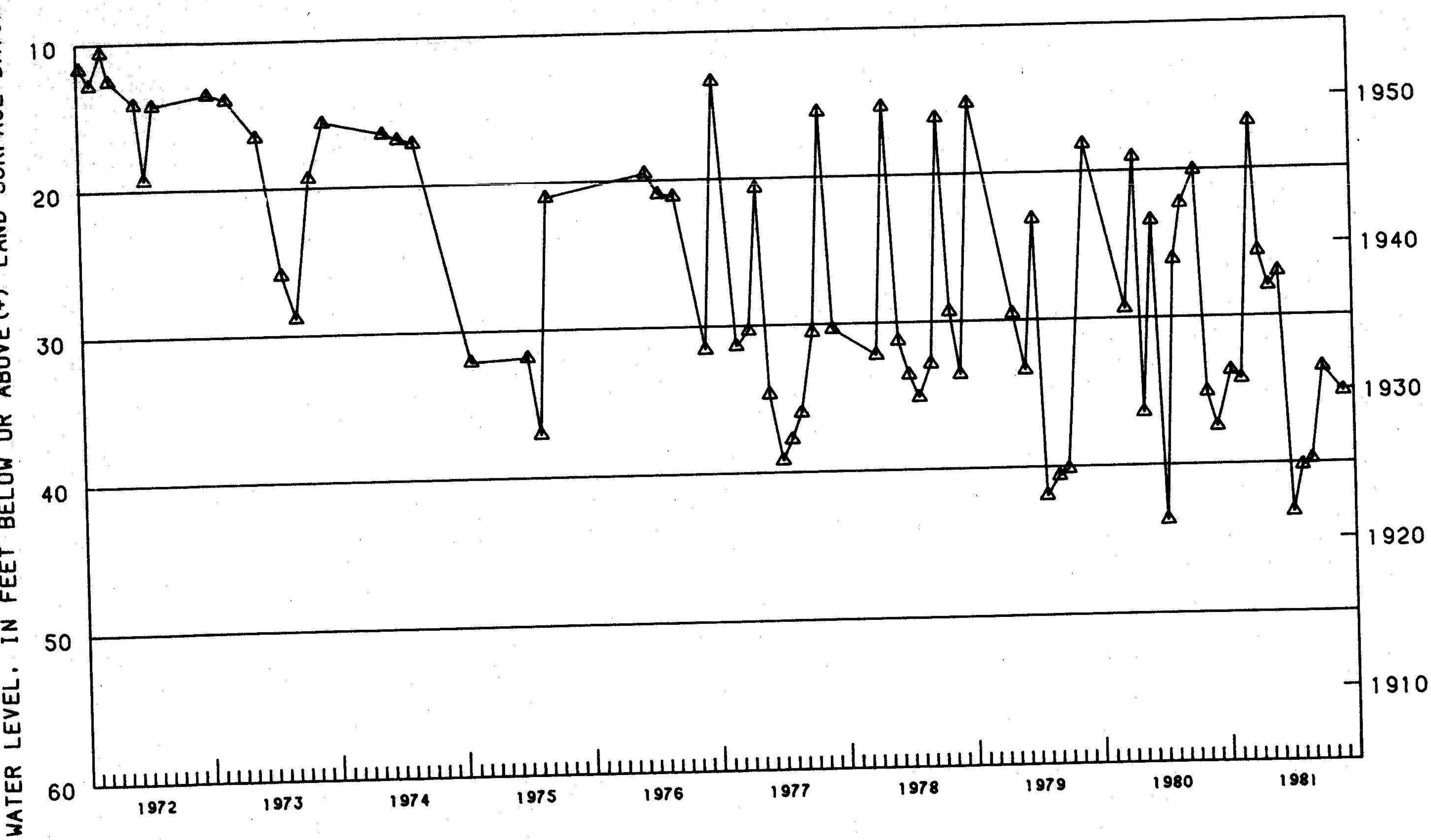
AQUIFER: DEPTH: 378 FT LSD: 1952 FT



HIGHEST WATER LEVEL 2.10 ,LOWEST 11.53

WELL NO. 163-097-35BCC   COUNTY:DIVIDE   STATE:NORTH DAKOTA

AQUIFER: DEPTH: 300 FT   LSD: 1965 FT



HIGHEST WATER LEVEL 10.60 ,LOWEST 43.74

121