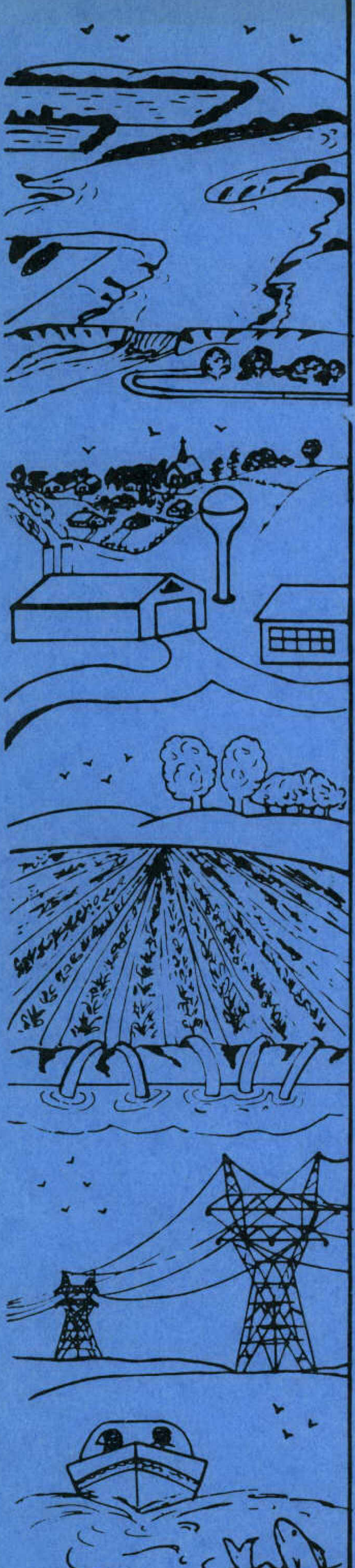

"BUY NORTH DAKOTA PRODUCTS"

GROUND-WATER RESOURCES OF THE ZAP AREA MERCER COUNTY, NORTH DAKOTA

NORTH DAKOTA GROUND-WATER STUDIES

OPEN FILE REPORT NUMBER 86

By
Philip A. Burke, Ground-Water Geologist
North Dakota State Water Commission

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State Office Building
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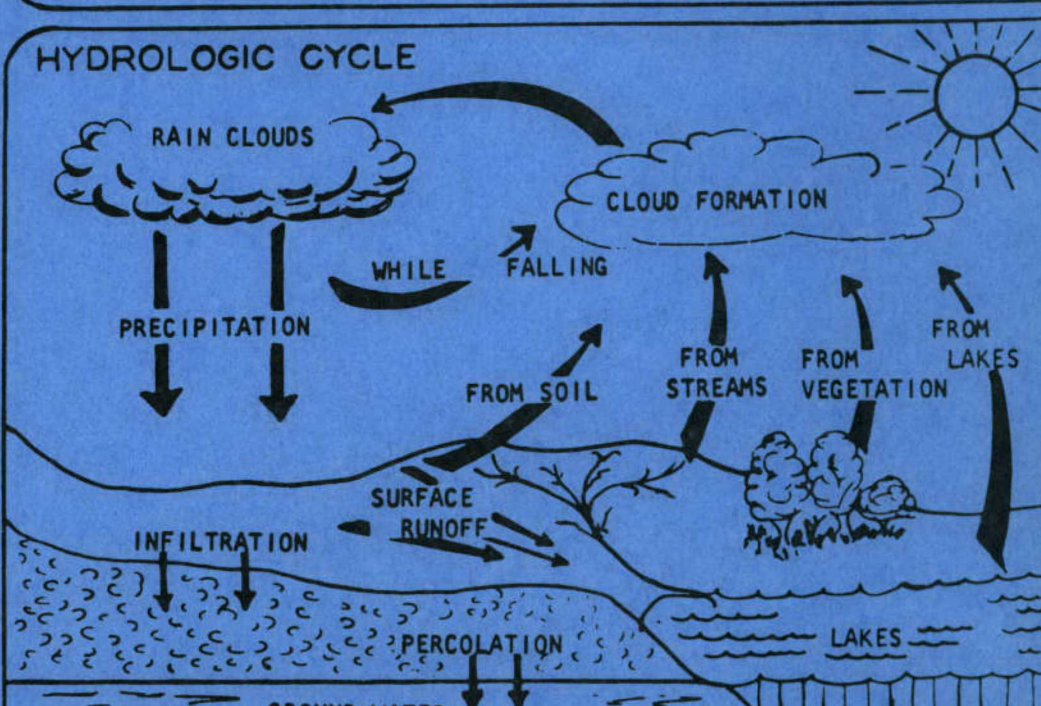

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GROUND-WATER RESOURCES OF THE ZAP AREA
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INTRODUCTION

PURPOSE AND SCOPE

On August 10, 1978, the Zap City Council passed a resolution requesting that the North Dakota State Water Commission conduct a ground-water survey for the city. Presently (1978) the Zap area is experiencing rapid development due to nearby strip mining of lignite and power plant construction at Beulah. The present city water supply is adequate for existing population, but will exceed capacity with expected development. Also this present supply from the Fox Hills Formation has a high fluoride concentration. The Commission approved the resolution on August 23, 1978, and field work began November 7, 1978.

The geohydrology of the area was determined by test drilling, installation of observation wells and collection of water samples for chemical analysis. Data compiled during the field work and from additional sources was evaluated February and March of 1979.

Acknowledgements

Test drilling was accomplished by Gary Calheim using the state-owned hydraulic rotary drilling machine. Field work was under direct supervision of the author. Chemical analyses were performed by Garvin Muri, State Water Commission chemist, at the North Dakota State Laboratories Department in Bismarck. Special acknowledgement is extended to city auditor, Chip Unruh, for information concerning city wells and water facilities.

LOCATION AND GENERAL FEATURES

The study area is located in the south-central portion of Mercer County and is within the Missouri Slope District of the glaciated Missouri plateau section (fig. 1). The geohydrologic data compiled for this study encompasses a 11 aquare mile area in portions of Township 144 North, Range 89 West (fig. 3). Climatological data based on a 29-year period of record of the National Weather Service Station located in Beulah, shows the mean annual temperature to be 42.5^{o}F (5.8C^{o}). The mean annual precipitation based on the same period is 17.2 inches (43.69cm) (National Oceanic and Atmospheric Administration 1977).

Physiography for the area is a glacially modified bedrock topography. Surface elevations range from 1840 feet (561m) in Zap to 2010 feet (613m) in the hills south of the city. Glacial deposits for the Zap area include unsorted drift in the form of ground moraine and hummocky moraine. Post-glacial events have added alluvium; dark brown, gray or black silt, clay and sand, to the diversion channels and present stream valleys.

Relief for the Zap area resembles a badland topography due to the resistant ridges and cap rock of scoria and sandstone. The Sentinel Butte Formation of Paleocene age outcrops over most of the study area. Extensive areas of baked sand, silt, and clay (scoria) occur along valley walls where outcropping lignite beds have burned. Most of these zones of natural brick occur where the Beulah-Zap lignite bed has burned along the dissected highlands south and southwest of Zap.

Zap (1978 population 347) is a mining and agricultural community and is served by State Highway 200 and branch lines of the Burlington Northern Railroad.

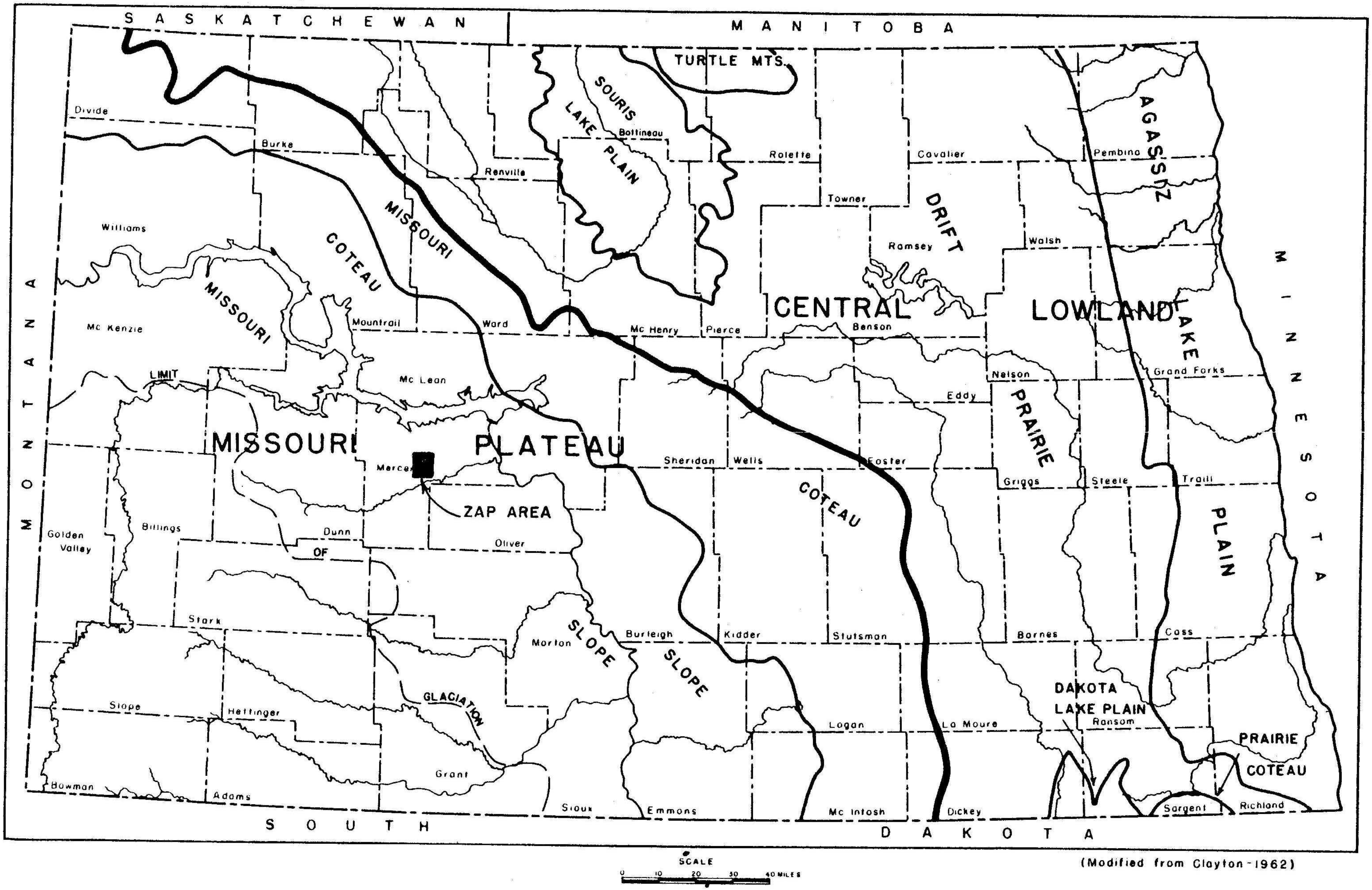


FIGURE 1 -- MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE ZAP AREA

PRESENT WATER SUPPLY

The city of Zap obtains its water supply from two wells. One of these wells taps into the Colgate member of the Fox Hills Formation at a depth of 1241-1281 feet (378-384m). The other city well is at a depth of 100-120 feet (30-35m) and is completed in the Sentinel Butte Formation. Pumping rates for the two wells vary and water is stored in an elevated storage tank.

Due to the poor quality of the water from the Fox Hills Formation a second shallow well is used as a blender in order to reduce exceedingly high flouride concentrations. This water is also treated with chlorine before storage or entry into municipal lines in order to prevent bacteria from living in the system.

During the past several years the city's daily water consumption averages about 22,000 gallons per day. Peak water use occurs during the summer months particularly in the month of August. During 1978, average monthly use was 691,633 gallons, August of this same year the city used 1,076,200 gallons, 35% above average.

PREVIOUS INVESTIGATIONS

A general reconnaissance of Mercer and Oliver Counties was conducted by Simpson (1929) to assess the ground-water resources of this area. His report includes a brief discussion of geology, ground-water resources, and quality of ground water in Mercer and Oliver Counties.

In 1966, an investigation of Mercer and Oliver Counties began to determine the quantity and quality of ground water available for municipal, domestic, livestock, industrial, and irrigation uses. The investigation completed in 1970, was made cooperatively by the U. S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and Mercer and Oliver Counties Water Management Districts. The results of the investigation were published in three separate parts of the bulletin series of the North Dakota State Water Commission. Data referenced in this report are from Parts II and III of the above series.

LOCATION - NUMBERING SYSTEM

The wells and test holes discussed in this report are numbered according to a system of land survey used by the U. S. Bureau of Land Management (BLM). 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 site 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 or 4-hectare tract). For example, well 145-91-15daa is the NE¼ NE¼ SE¼ Section 15, Township 145 North, Range 91 West. Consecutive terminal numerals are added if more than one well, test hole, or spring is recorded within a 10-acre tract.

BASIC HYDROLOGIC CONCEPTS

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

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. The movement of ground water is generally very slow and may be only a few feet per year. The rate of movement is

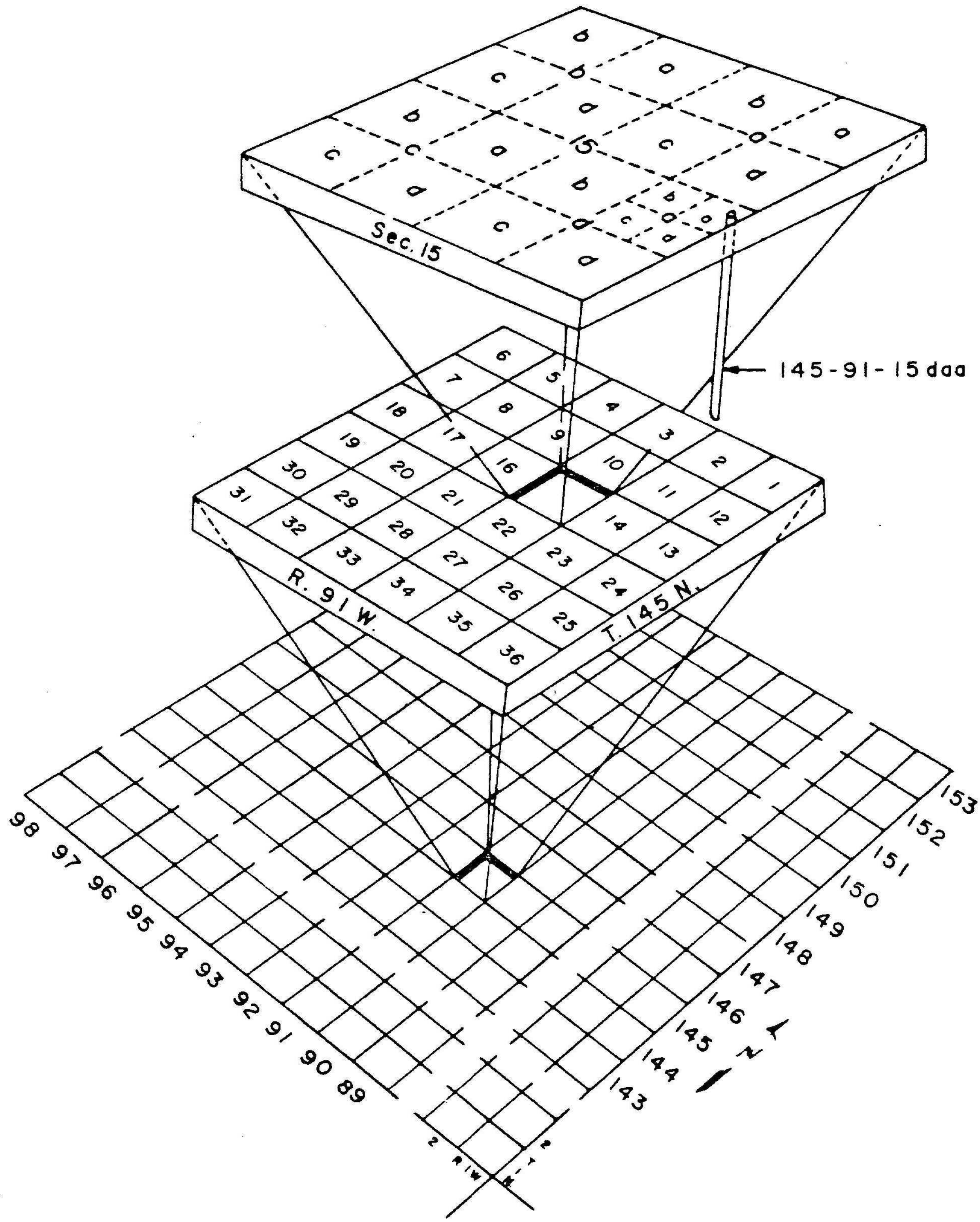


FIGURE 2--SYSTEM OF NUMBERING WELLS, TEST HOLES, AND SPRINGS

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

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

When the upper surface of an aquifer is the water surface and this surface is free to fluctuate with recharge and discharge, the aquifer is called a water-table aquifer. The shape of the upper surface of the zone of saturation is called the water table. (It is controlled by gravity and topographic relief).

Pumping a well causes its water level to be lowered and the water level surface surrounding the well will resemble a cone referred to as the cone of depression. Water-level drawdown is the difference between static and pumping levels. The amount of drawdown is controlled by the hydraulic properties of the aquifer, the physical characteristics of the well, and the rate and duration of pumping. During constant and uniform discharge from a well, the water level declines rapidly at first and continues to decline at a decreasing rate as the cone of depression expands.

WATER QUALITY

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

Dissolved mineral constituents are reported in milligrams per liter (mg/l). A milligram per liter is one thousandth (0.001) of a gram of dissolved material per liter of solution. Hardness is usually reported in milligrams per liter, but may be converted to grains per U. S. gallon (gr/gal) by dividing milligrams per liter by 17.12.

Table 1 gives the significance of the various chemical constituents of water for domestic or municipal water supply in North Dakota. Results of chemical analyses for wells in the study area are listed in Table 2.

Table 1 -- Dissolved chemical constituents in water -- their effects upon usability and recommended concentration limits for domestic and municipal water supplies in North Dakota.

Constituent or Parameter	Effects of dissolved constituents on water use	Suggested limits for drinking water in North Dakota[1]	U.S. Public Health Service recommended limits for drinking water[2]
Silica (SiO_2)	No physiological significance		
Iron (Fe)	Concentrations over 0.1 mg/l will cause staining of fixtures. Over 0.5 mg/l may impart taste and colors to food and drink.		0.3 mg/l
Manganese (Mn)	Produces black staining when present in amounts exceeding 0.05 mg/l		0.05 mg/l
Calcium(Ca) and Magnesium (Mg)	Calcium and magnesium are the primary causes of hardness. High concentrations may have a laxative effect on persons not accustomed to this type of water.		
Sodium (Na)	No physiological significance except for people on salt-free diets. Does have an effect on the irrigation usage of water.		
Potassium (K)	Small amounts of potassium are essential to plant and animal nutrition.		
Bicarbonate (HCO_3) and Carbonate (CO_3)	No definite significance, but high bicarbonate content will impart a flat taste to water.		
Sulfate (SO_4)	Combines with Calcium to form scale. More than 500 mg/l tastes bitter and may be a laxative	0-300 mg/l - low 300-700 mg/l - high over-700 mg/l - very high	250 mg/l
Percent Sodium and Sodium Adsorption Ratio (SAR)	Indicate the sodium hazard of irrigation water.		
Chloride (cl)	Over 250 mg/l may impart a salty taste, greatly excessive concentrations may be physiologically harmful. Humans and animals may adapt to higher concentrations.		250 mg/l
Flouride (F)	Flouride helps prevent tooth decay within specified limits. Higher concentrations cause mottled teeth.	Limits of 0.9 mg/l to 1.5 mg/l	Recommended limits depend on average of daily temperatures. Limits range from 0.6 mg/l at 32°C. to 1.7 mg/l at 10°C.
Nitrate (NO_3)	Over 45 mg/l can be toxic to infants. Larger Concentrations can be tolerated by adults. More than 200 mg/l may have a deleterious effect on livestock health		45 mg/l
Boron (B)	No physiological significance. Greater than 2.0 mg/l may be detrimental to many plants		
Total dissolved solids	Persons may become accustomed to water containing 2,000 mg/l or more dissolved solids.	0-500 mg/l - low 500-1400 mg/l average 1400-2500 mg/l high over 2500 mg/l very high	500 mg/l
Hardness (as $CaCO_3$)	Increases soap consumption, but can be removed by a water-softening system.	0-200 mg/l - low 200-300 mg/l average 300-450 mg/l high over 450 mg/l very high	
pH	Should be between 6.0 and 9.0 for domestic consumption		
Specific Conductance	An electrical indication of total dissolved solids measured in micromhos per Centimeter at 25°C. Used primarily for irrigation analyses.		

1. Schmid, R. W., 1965, Water Quality Explanation: North Dakota State Water Commission, unpublished report, File No. 989.
2. U.S. Public Health Service, 1962, Public Health Service Drinking Water Standards: U.S. Public Health Service, Pub. No. 956, 61 p.

TABLE 2 -- CHEMICAL ANALYSES

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

AQUIFERS Owner or Designation	Location	Depth of Well (feet)	Temp(°F)	Date of Collection	(SiO_2)	(Fe)	(Mn)	(Ca)	(Mg)	(Na)	(K)	(HCO_3)	(CO_3)	(SO_4)	(Cl)	(F)	(NO_3)	(B)	Total Dissolved Solids	Total Hardness as $CaCO_3$	Total Hardness Noncarbonate	Percent Sodium	SAR	Specific Conductance	pH
NORTH BRANCH GOODMAN CREEK AQUIFER																									
Test Hole 10370	144-89-23abb	47	-	11-8-78	24	0.18	0.14	51	25	220	5.2	596	0	190	2.7	0.4	0.7	.13	823	230	0	67	6.3	1280	8.0
Test Hole 10372	144-89-23acc	121	54	11-14-78	21	0.55	0.08	61	29	240	5.7	658	0	270	4.2	0.4	1.0	0.07	897	270	0	65	6.4	1460	7.9
Test Hole 10381	144-89-23aoc$_2$	81	54	11-29-78	21	0.75	0.72	86	45	240	5.0	635	0	350	4.0	0.3	1.0	0.23	1090	400	0	56	5.2	1600	7.9
Test Hole 10387	144-89-15ddd$_1$	84	50	12-12-78	19	1.9	0.06	59	32	200	5.6	595	0	230	2.1	0.4	1.0	0.06	846	280	0	60	5.2	1290	7.8
Test Hole 10388	144-89-15ddd$_2$	50	54	12-14-78	18	0.95	0.16	63	32	200	5.4	598	0	210	2.2	0.4	0.6	0.09	805	290	0	59	5.1	1270	8.0
Test Hole 10389	144-89-15dda	108	54	12-13-78	18	0.20	0.08	49	21	250	5.0	668	0	220	3.5	0.5	1.0	0.09	886	210	0	72	7.5	1390	8.1
Test Hole 10390	144-89-15ddb	46	-	12-18-78	18	0.20	0.25	65	31	210	5.8	611	0	250	3.8	0.4	1.0	0.22	889	290	0	61	5.4	1360	8.1
Test Hole 10391	144-89-15ddd$_3$	81	54	12-14-78	19	2.0	0.04	61	33	190	5.3	585	0	220	2.9	0.3	1.0	0.22	793	290	0	58	4.8	1260	8.0
Test Hole 10392	144-89-15dac	68	54	12-14-78	17	1.5	0.14	68	32	190	5.3	580	0	240	3.1	0.3	1.0	0.16	803	300	0	57	4.8	1280	7.9
SOUTH BRANCH GOODMAN CREEK AQUIFER																									
Test Hole 10375	144-89-30aaa	193	54	11-9-78	26	4.6	0.10	120	29	130	5.8	605	0	180	2.0	0.3	0.7	0	792	420	0	40	2.8	1210	7.8
Test Hole 10378	144-89-23bcda	164	56	11-29-78	19	0.8	0.10	98	30	99	5.9	546	0	130	2.2	0.1	1.0	0.03	606	370	0	36	2.2	1040	7.9
ANTELOPE CREEK AQUIFER																									
Test Hole 10393	144-88-17cbc	240	54	12-14-78	19	0.24	0.26	76	24	210	6.9	660	0	170	30	0.5	1.0	0.28	876	290	0	60	5.4	1360	7.8
FOX HILLS - HELL CREEK AQUIFER																									
City Well 1	144-89-14cda	1281	-	5-18-69	11	0.05	-	4.0	0.5	601	1.8	1160	0	4.9	237	4.9	0.2	1.8	1510	12	0	99	75.0	2370	8.2
City Well 1	144-89-14cda	1281	-	11-15-78	10	0.08	0.02	4.2	0.1	600	1.4	1160	0	4.9	240	4.9	1.0	1.3	1470	11	0	99	79.0	2400	8.1
TONGUE RIVER AQUIFER																									
T. H. 3651	142-88-1CDC	560	48	5-24-69	4.5	.05	—	6.1	2.7	828	4.1	1920	49	15	124	1.9	0.5	.33	2030	26	0	98	71	3190	8.6

GROUND-WATER IN PREGLACIAL FORMATIONS

The Zap area is located near the center of the Williston Basin. Structural effects due to the presence of the Nesson Anticline cause sediments to dip gently to the northeast. The complete sequence of sedimentary rocks overlying the Precambrian crystalline basement exceeds 11,000 feet (3350m) in the Zap area. This investigation is concerned only with formations of the upper Cretaceous and Tertiary Age that are of importance as potential aquifers for a municipal water supply.

Bedrock aquifers in the study area are divided into the following units: (1) Pierre, Fox Hills, and Hell Creek Formations of Cretaceous Age, and (2) Ludlow - Cannonball, Tongue River, and Sentinel Butte Formations of Tertiary age.

CRETACEOUS SYSTEM

Pierre Formation

The upper part of the Cretaceous System consists of clastic rocks that were deposited mostly in a marine environment; and, in fact, all the formations from the Belle Fourche through the Pierre are mostly thick beds of gray shale.

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

Fox Hills and Hell Creek Formations

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

The Fox Hills Formation is a marine deposition which probably formed near the shore of a sea and materials washing into the sea were somewhat coarser than were the silt and clay of the underlying formations which were deposited at greater distances from shore. The Hell Creek Formation, which was also deposited toward the end of Cretaceous time, consists of still coarser material, mainly sand, silt, and clay, that was deposited by running water flowing on deltas into the same seas in which the Fox Hills and Pierre Formations were deposited (Bluemle 1977).

The Fox Hills - Hell Creek contact was picked at a depth of 1260 feet (38.4 m) in a test hole at Golden Valley, Township 144 North, Range 90 West, Section 15 DB, 6 miles west of Zap. Sixty-five feet (19.8 m) of fine - to medium grained sandstone was penetrated from 1260 to 1325 feet below land surface. Stratigraphic correlation indicates this sandstone is the Colgate member of the Fox Hills Formation. The Colgate is the major producing aquifer of the Fox Hills Formation, many domestic and municipal wells obtain water from this interval, the Zap city well presently taps into this unit. In 1969 a shut in test was conducted on this same well and results showed a water level of 154 feet (46.9 m) above land surface. A current study on wells in the Fox Hills Formation have shown a decline in head of 1.1 to 2.0 ft/yr (Baldwin Et. Al. 1980). Using an average of 1.5 ft/yr decline, the city well should now have a head of approximately 139 feet (42.4 m). One other well in the Zap are has been completed in the Hell Creek Formation, that in Township 144 North, Range 89 West, Section 23 CB, which flows at approximately 5 gpm (gallons per minute) with a head of 68 feet (20.7 m). Using a correction similar to above the well should now have an expected head of 41 feet (12.5m).

The fine-grained lithology, small amounts of intergranular clay and silt, and low permeability of the sandstone do not permit the rapid movement of water into a well bore. Therefore, well yields from the Fox Hills are generally low. A study made by Croft (1973) in Mercer and Oliver Counties showed that specific capacities of wells tapping the Fox Hills Formation range from 0.1 to 0.6 gpm per foot of drawdown. More recent hydrologic data collected on the Fox Hills in western North Dakota suggests that an average specific capacity for the Colgate member would be about 0.3 gpm per foot. This same study has indicated that wells completed in the Fox Hills Formation can expect a yield of 25 to 150 gpm.

Complete chemical analysis from water samples taken in June 1969 and November 1978 from the Zap public supply well show a very soft, sodium bicarbonate water with 1470 mg/l dissolved solids (table 2). Flouride concentrations of 4.9 mg/l from these samples have exceeded the maximum recommended limits set by the U. S. Public Health Service. Sodium accounts for 99 percent of the total cations. Because of this high sodium percentage, this water is generally undesirable for watering lawns and gardens and should only be used occasionally on soils of good or high permeability where special leaching is provided to remove excess salt.

TERTIARY SYSTEM

Cannonball and Ludlow Formations

The sandstone and shale of the Ludlow and Cannonball Formations were deposited at the beginning of tertiary time, perhaps 70 million years ago, by the only invasion of tertiary seas into North Dakota. As the Paleocene sea water gradually flooded the area, alternating layers of marine sandstone and shale of the Cannonball Formation were deposited. At the same time, silt, sand, and shale of the Ludlow were deposited on land. Due to facies changes and complex interfingering in the subsurface, these units remain undifferentiated in this report.

Geophysical logs and drill cuttings show that the Cannonball-Ludlow interval consists of interbedded greenish-black, brownish-gray, and olive gray sandstone, siltstones, shales, lenticular limestones, and lignitic sands.

Except for a few thin beds of sandstone at the base, most of the rocks forming this unit are relatively impermeable and for practical purposes are considered non-water-bearing.

Tongue River Formation

The Tongue River Formation is a nonmarine deposition which occurred after the tertiary seas began to retreat. This formation consists of silt, sand, shale, and lignite-bearing sediments which were deposited in vast marshes, somewhat like those along the east coast of the United States today. Streams meandered through the low-lying swamps, but they flowed slowly and often became choked with silt, clay, leaves and wood of thick swamp vegetation. These materials were dropped in quiet areas and soon covered by sand and silt as the streams shifted course.

This formation generally consists of interbedded silt, clay, lignite, shale, sand, and limestone, predominantly silt and clay. Shales are generally brownish gray, carbonaceous, and usually are closely associated with lignite beds.

No wells are known to be completed in the Tongue River Formation within the Zap area. Consequently, hydrologic data concerning the formation is limited. A test hole at Golden Valley, T144N-90-15DB has shown a fine grained sandstone and siltstone from 545-600 feet (169-183m) below land surface Should this unit continue under the Zap area, it is expected that the aquifer would have low hydraulic conductivity and low yield. Therefore, this unit would not yield a good municipal supply.

Water quality for the Tongue River aquifer is generally a sodium bicarbonate type with 1,810 to 2,030 ppm total dissolved solids, based on samples from the southwestern corner of Mercer County (table 2).

Sentinel Butte Formation

The Sentinel Butte Formation was deposited in much the same way as the Tongue River Formation. While the Tongue River Formation was being deposited in central North Dakota, the swamps further west were gradually filling as rivers carried sand and silt (now the Sentinel Butte Formation sediments) eastward over river plains onto the Tongue River sediments.

Except for the basal sand and the upper sand, the Sentinel Butte Formation is mostly interbedded silt, clay, and lignite. None of these sand beds appear to form a major hydrologic unit.

Lignite beds found within this sequence of sediments are probably more important hydrologic units due to their greater abundance and larger lateral extent. The second Zap municipal supply well and domestic wells in the area have been completed in this upper portion of the Sentinel Butte Formation. Many livestock and domestic wells in the rural areas tap fractures and joints in undifferentiated beds of lignite for water supplies. The yield from most of these wells is probably only a few gallons per minute.

Water from the lignite aquifers is highly variable in chemical quality. The water is generally a sodium sulfate or sodium bicarbonate type. Conductivity of samples taken during Croft's study (1973), throughout Mercer and Oliver Counties ranged from 5,000 to 7,000 micromhos per centimeter. Hardness varied from soft to very hard and concentrations of iron exceeded 1.0 mg/l.

GROUND WATER IN THE GLACIAL DRIFT

During the Pleistocene Epoch, which began about one million years ago continental ice sheets advanced southward over the Zap area several times. About 12,000 years ago the last Wisconsinian ice sheet retreated from the area depositing glacial drift that consists mostly of ground moraine and outwash. Each time glaciers advanced over this area, they transported vast quantities of rock and soil that was redeposited as glacial sediment.

The Zap area is covered in most places by glacial drift that ranges in thickness from less than 1 foot (0.3m) to greater than 150 feet (45.7m). The average thickness is about 75 feet (22.8m). The glacial drift consists of silt, sand, gravel, and clay. Several thousand years ago glacial meltwaters sorted and deposited varying amounts of sand and gravel in the valleys surrounding the Zap area. Outwash deposits underlying the Spring Creek Valley constitute the north branch of the Goodman Creek aquifer. Similar glacial diversion channels have been filled with outwash, and now constitute aquifers. The southern branch of Goodman Creek and Antelope Creek aquifers (fig. 3) both show potential for development in the Zap area.

QUATERNARY SYSTEM

Antelope Creek Aquifer

The Antelope Creek aquifer (fig. 3) underlies a narrow valley that extends from Lake Sakakawea to the Knife River. The deposits forming the aquifer consist of glaciofluvial sand and gravel interbedded with silt and clay. The aquifer is less than 1 mile in width, and about 250 feet thick. Two test holes were drilled in the Antelope Creek aquifer in the Zap vicinity,

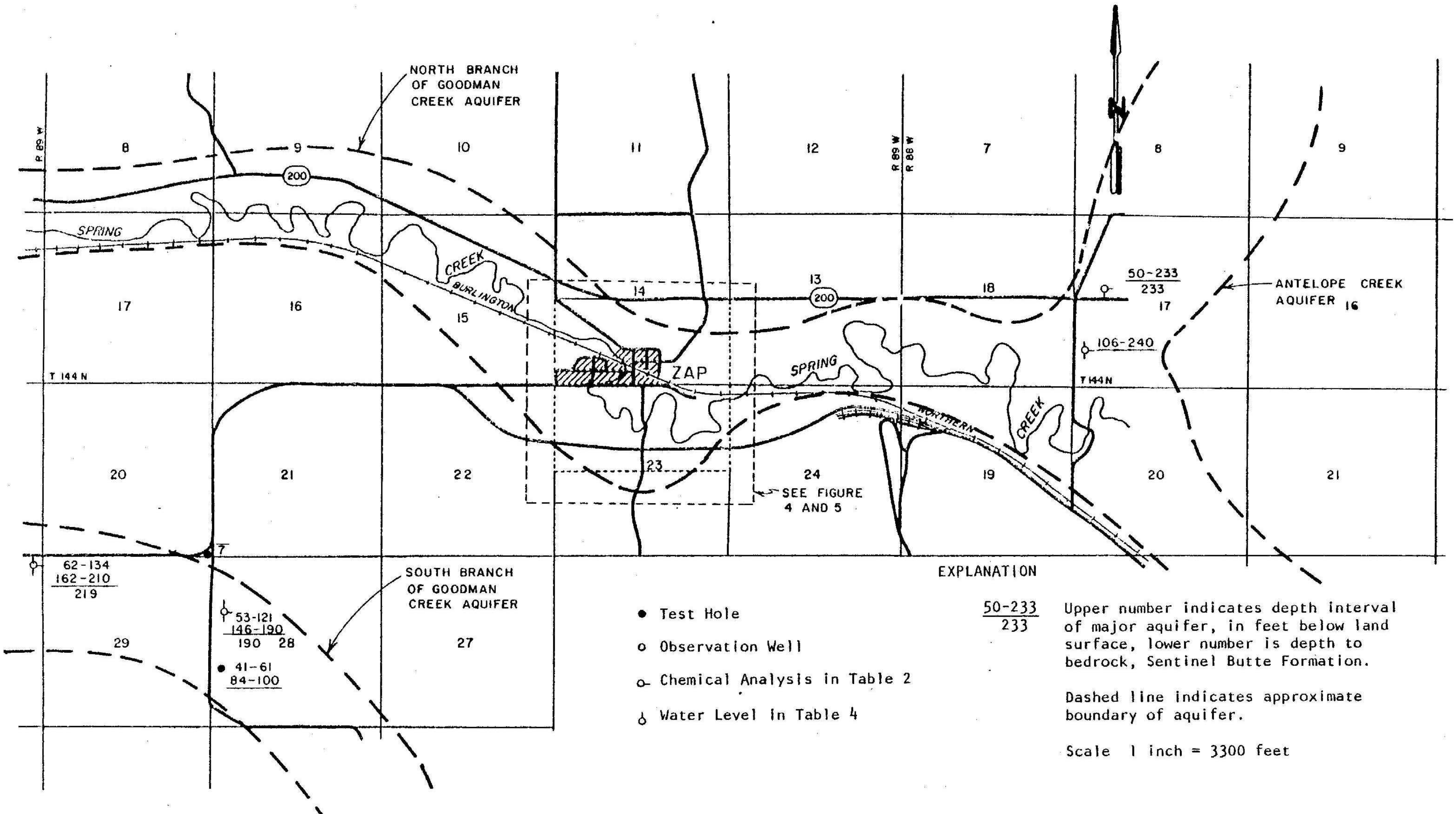


FIGURE 3 - Location of Wells, Test Holes and Related Features in the Zap area.

test hole numbers 10393 and 3656 at locations T144N-R88W-17CBC and T144N-R88W-17BCD respectively. Test drilling indicates that aquifer material had a thickness of 183 feet (55.8m) and consisted of fine- to medium-grained sand.

Wells in the central part of the aquifer from Spring Creek to Lake Sakakawea should yield 100 to 500 gpm, the aquifer contains about 260,000 acre-feet of ground water in Mercer County without recharge, about 130,000 acre-feet should be recoverable through wells (Croft 1973).

Chemical analysis of water from well 10393 (T144N-R88W-17CBC) shows the total dissolved solids to be 876 ppm and the hardness as $CaCO_3$ to be 290 mg/l, which is considered to be an average hardness as set by the North Dakota State Department of Health. Sodium accounts for 50% of the total cations making this water suitable for watering lawns and gardens with good to moderate permeability (table 2).

South Branch of the Goodman Creek Aquifer

The Goodman Creek aquifer is a long, narrow glaciofluvial deposit of sand and gravel that underlies Goodman Creek Valley in western Mercer County. The aquifer is 1 to 1½ miles (1.6-2.4km) wide and about 200 feet (61.0m) thick.

This report divides the Goodman Creek aquifer into a north and south branch. The divide begins just south of the city of Golden Valley in the middle of T144N-R90W. The north branch of the aquifer underlies Spring Creek Valley through Zap and eventually enters the Antelope Creek aquifer at Sections 17, 18 and 19, T144N-R88W. The southern part of the aquifer underlies an abandoned stream valley which runs east and then south where it joins the Knife River aquifer in the middle of T143N-R89W.

Three test holes were drilled in the south branch of Goodman Creek aquifer 3 miles southwest of Zap, T144N-R89W Sections 20, 28 and 30. The first location T144N-R89W-28BCB$_2$ showed 64 feet (19.5m) of a predominately fine well sorted sand, then 25 feet (7.6m) of sandy silt followed by 34 feet (10.4m) of sand and gravel. The two other test holes T144N-R89W-28BCB$_2$ and 28CBC also show similar sequences of sand and silt.

The south branch of the Goodman Creek aquifer in the study area is from a one half to three quarters of a mile (0.8-1.2Km) wide and extends over an area of about 2 square miles (5.2 square Km)in the vicinity of Zap. Assuming a porosity of 30 percent, an average thickness of 75 feet (22.9m) and an area of 1280 acres, the south branch of Goodman Creek aquifer contains about 28,800 acre-feet of ground water in storage. Potential well yields of up to 500 gpm may be possible at selected locations in the aquifer.

Water quality in the South Branch of the Goodman Creek aquifer is generally of the sodium bicarbonate or sodium sulfate type. Chemical analysis of samples taken from two wells, T144N-R89W Section 30AAA and 23BCB$_2$ have shown similar results to the north branch of the Goodman Creek and Antelope Creek aquifers. Total dissolved solids in this section of the aquifer is somewhat less 606 and 792 mg/l yet hardness as $CaCO_3$ is slightly higher 420 and 370 mg/l, which is classified as high by the North Dakota Health Department (table 2). Iron content from these two wells is highly variable ranging from .08 mg/l, which is considerably low, to 4.6 mg/l which is extremely high. More than 0.3 mg/l may cause staining of laundry and fixtures.

This water is also suitable for watering soil with a fairly good to moderate permeability.

North Branch of Goodman Creek Aquifer

Nineteen test holes were drilled in order to trace the North Branch of the Goodman Creek aquifer through the city of Zap (fig. 4). Test drilling has indicated that the aquifer is one half to three quarters of a mile (0.8-1.2km) in width and bounded on either side by bedrock topography. Average thickness of aquifer throughout the Zap area is 26 feet (7.9m). Within the above aquifer, test drilling has also shown a deeper narrow section of aquifer that enters Zap through the southeast corner of Section 15 (fig. 5). This narrow deep section is one eighth to one quarter of a mile (0.2-0.4km) in width and has an average thickness of 48 feet (14.6m)(figs. 6, 7, and 8).

Using the above dimensions with an area of about one half of a square mile and assuming a porosity of 30 percent, this section of the Goodman Creek aquifer throughout the Zap area should contain about 2500 acre-feet of ground water in storage of which 1200 acre-feet should be recoverable. Recharge to the North Branch of the Goodman Creek aquifer occurs by direct infiltration from precipitation, snowmelt, and surface runoff. Spring Creek, a perennial stream, intersects the North Branch of the Goodman Creek aquifer in the vicinity of the city of Zap. During peak flow periods, in the Spring, the creek probably contributes water to the aquifer. During periods of low flow in the summer and fall the aquifer probably contributes water to the creek.

A total of 9 water samples were collected from the North Branch of the Goodman Creek aquifer (table 3). The chemical analyses have shown the samples contained moderate amounts of mineral matter. Total dissolved solids ranged from 793 to 1090 ppm, iron content was highly varied from .18 to 2.0 mg/l, over .03 mg/l has a potential for staining laundry and plumbing fixtures, sulfate ranged from 190 to 240 ppm. Total hardness as $CaCO_3$ varied from 230 to 400 indicating a high hardness as classified by the North Dakota State Department of Health.

SAR values for this water average 5.6, which is classified by the USDA (1954) as a water that should be used on coarse textured soils with good permeability. High values for SAR imply a hazard of sodium replacing adsorbed calcium and magnesium and this replacement is damaging to soil structure. On the average sodium accounts for 62% of the total cations making this water suitable for watering lawns and gardens where the soils have a coarse texture and good permeability.

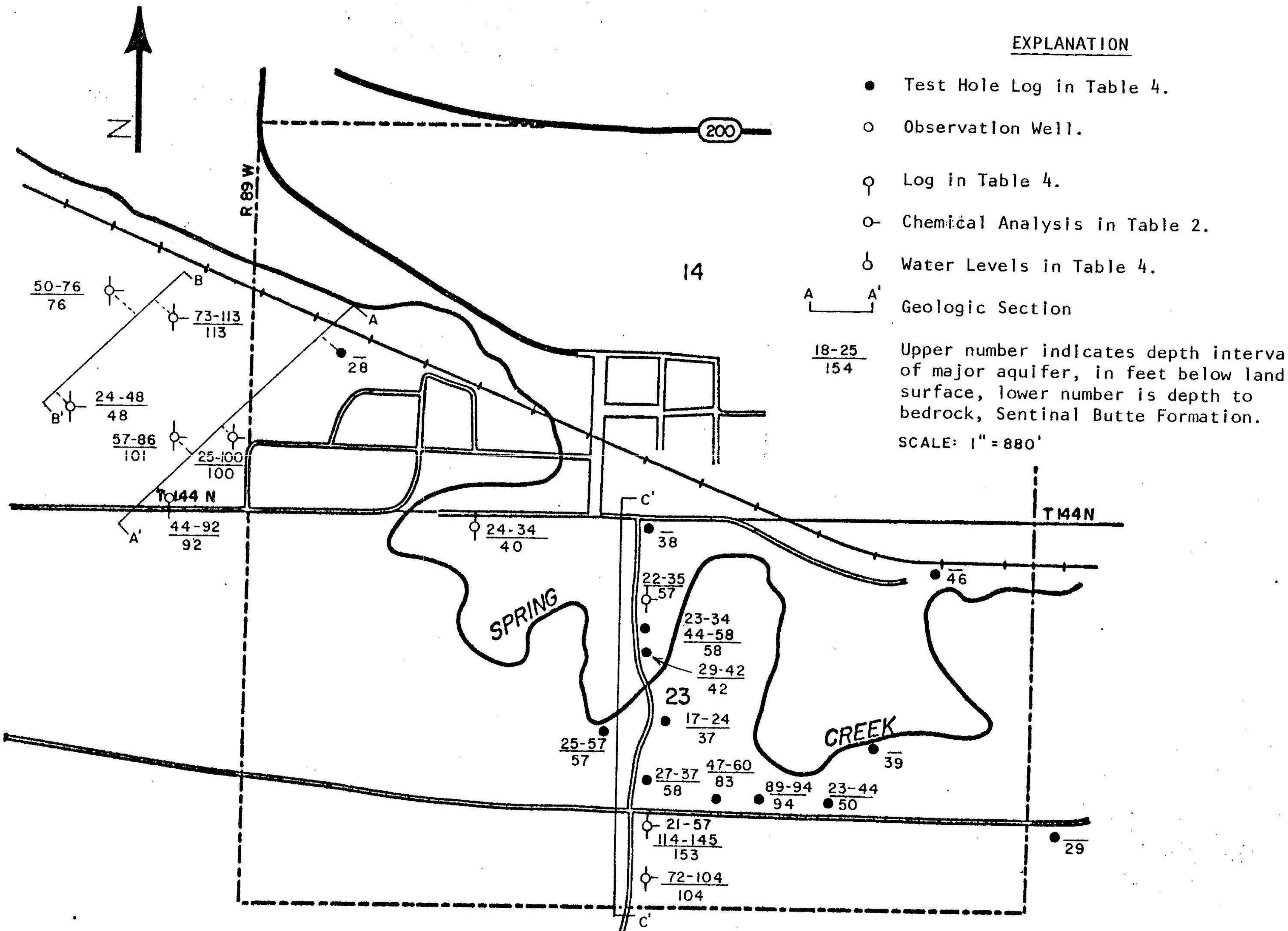


Figure 4 - Location of wells, test holes, geological sections, and related features for the city of Zap.

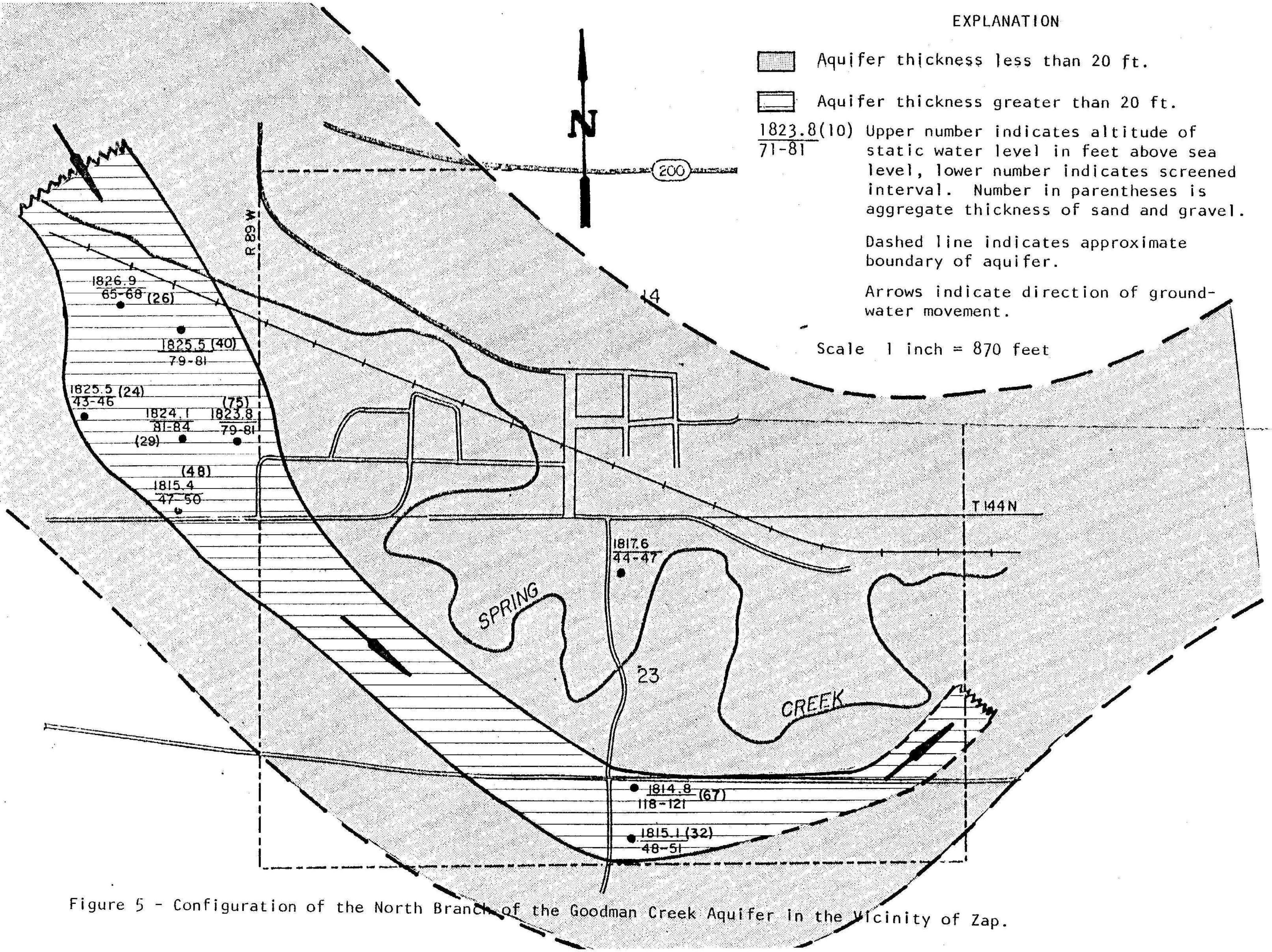


Figure 5 - Configuration of the North Branch of the Goodman Creek Aquifer in the Vicinity of Zap.

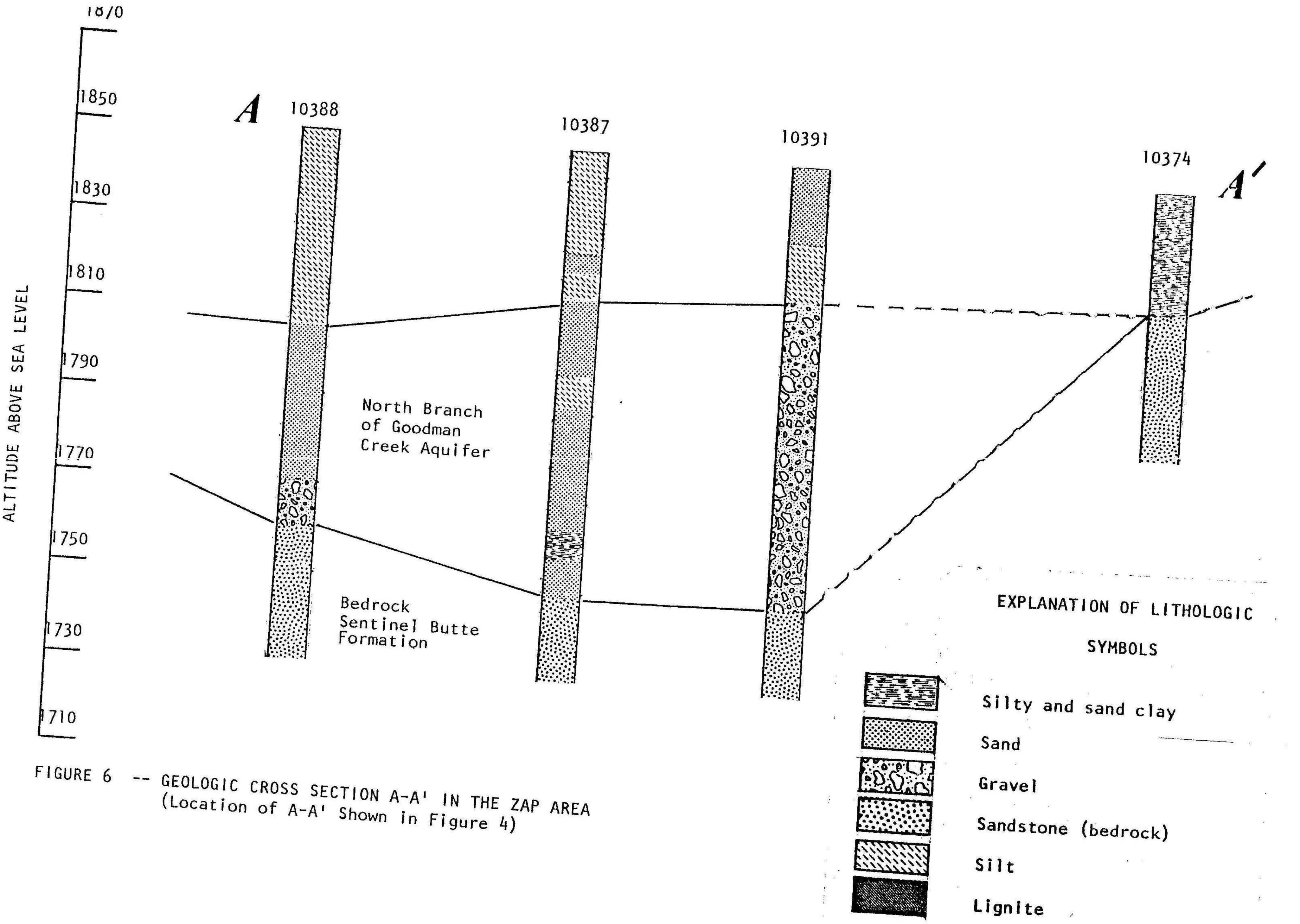
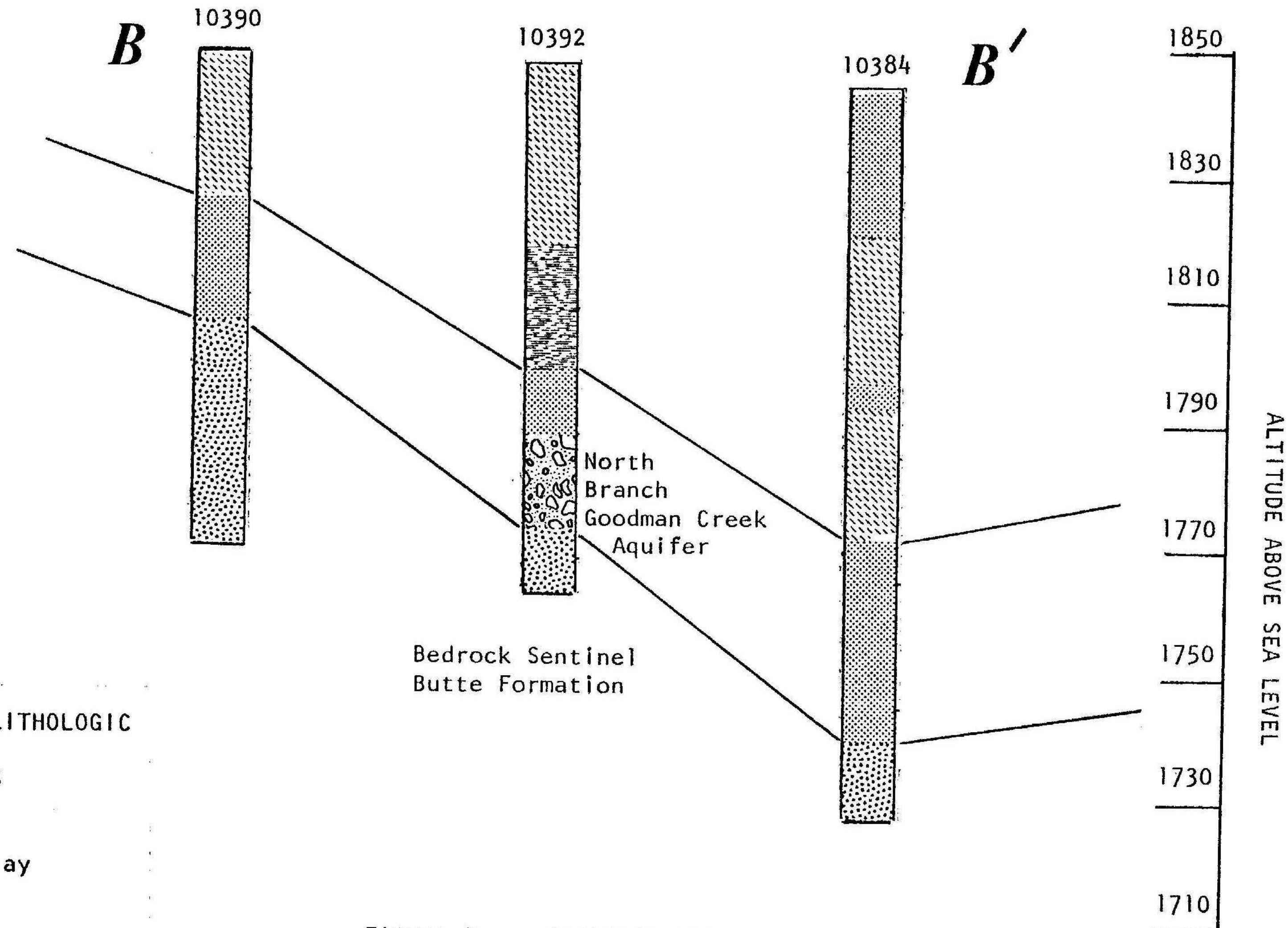


FIGURE 6 -- GEOLOGIC CROSS SECTION A-A' IN THE ZAP AREA (Location of A-A' Shown in Figure 4)



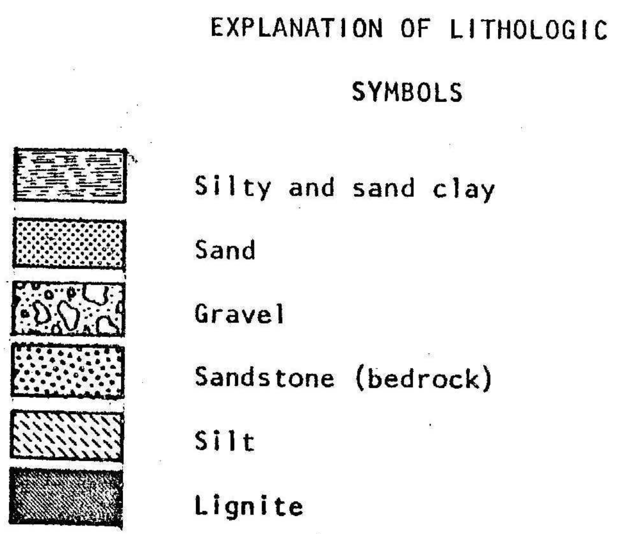


FIGURE 7 -- GEOLOGIC CROSS SECTION B-B' IN THE ZAP AREA (Location of B-B' Shown in Figure 4)

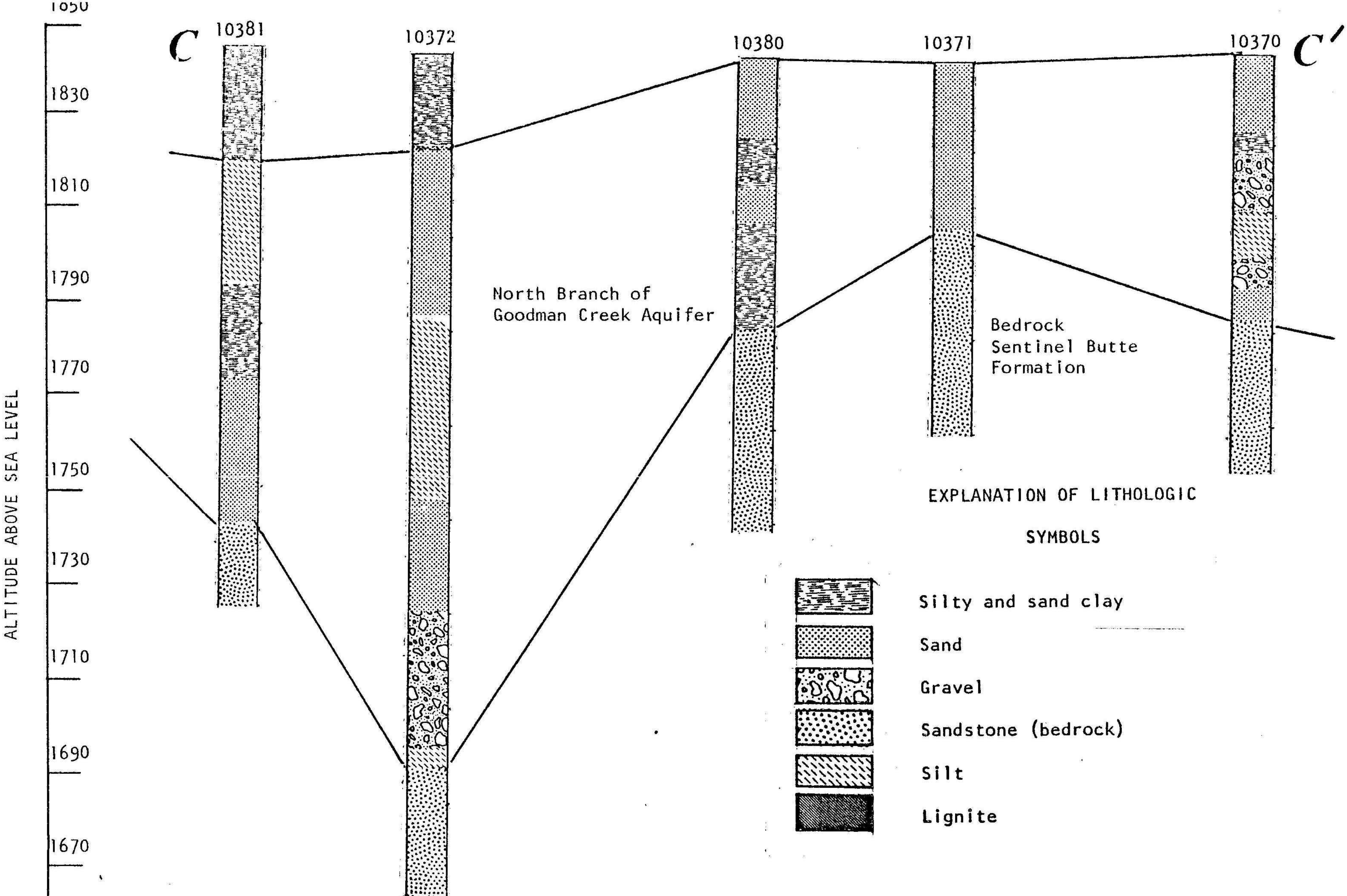


FIGURE 8 -- GEOLOGIC CROSS SECTION C-C' IN THE ZAP AREA
(Location of C-C' Shown in Figure 4)

SUMMARY

Geohydrologic data collected and evaluated during the investigation describe a 11 square mile area of Zap in southcentral Mercer County. The area is situated with the Missouri Slope District of the Missouri Plateau physiographic province of North Dakota. The average annual temperature is 42.5°F (5.8°C) and the average annual precipitation is 17.2 inches (43.7cm).

The Zap area is situated near the center of the Williston Basin and is underlain by more than 11,000 feet of consolidated sedimentary rocks. This investigation was concerned only with upper Cretaceous and Tertiary rocks that are potential aquifers at Zap.

The most important bedrock aquifer for the Zap area is the Fox Hills-Hell Creek Formation. The Colgate member is the major producing aquifer of the Fox Hills Formation. The Zap municipal supply well presently obtains water from this member. The city well is screened in an interval from 1241 to 1281 feet (378-384m) below land surface. Data on specific yields for the Fox Hills-Hell Creek aquifer, as interpolated from the Mercer and Oliver County ground-water investigation, suggest that yields of up to 150 gallons per minute are possible. Water common to the Fox Hills-Hell Creek aquifer is of the sodium bicarbonate type, is soft, and may contain more than 1,500 mg/l dissolved solids. Concentrations of iron and manganese are within accepted limits but the flouride concentration is excessive (table 2).

The Cannonball and Ludlow Formation have a few thin beds of sandstone at the base, most of the rocks forming this unit are relatively impermeable and for practical purposes are considered non-water-bearing.

The Tongue River Formation is predominately a silt and clay, no wells are known to be completed in this formation within the Zap area. It is expected that the Tongue River Formation would have low hydraulic conductivity and low yield, water quality is generally a sodium bicarbonate type with 1,800 to 2,000 ppm total dissolved solids.

Except for the basal sand and the upper sand, the Sentinel Butte Formation is mostly interbedded silt, clay, and lignite. Lignite beds found within this sequence of sediments are probably more important hydrologic units due to their greater abundance and larger lateral extent. The second Zap municipal supply well and domestic wells in the area have been completed in this upper portion of the Sentinel Butte Formation. Water from the lignite aquifers is highly variable in chemical quality and the yield from most of these wells is only a few gallons per minute.

The Zap area is covered in most places by glacial drift which consists of silt, sand, gravel, and clay. Outwash deposits underlying the Spring Creek Valley constitute the north branch of the Goodman Creek aquifer. Two other aquifers, the southern branch of Goodman Creek and Antelope Creek, also show potential for development in the Zap area.

The Antelope Creek aquifers underlies a narrow valley from Lake Sakakawea to Knife River and consists of glaciofluvial sand and gravel interbedded with silt and clay. Wells in the central part of the aquifer should yield 100 to 500 gpm. Water quality is good and would be suitable for a municiple supply.

The southern part of the Goodman Creek aquifer underlies an abandoned stream valley and test drilling indicates the aquifer is composed of fine well sorted sand and gravel. This section of aquifer closest to

Zap is from 1/2-3/4 mile (0.8-1.2km) wide and extends over an area of about 2 square miles (5.2 sq. km) in the study area. Overall it is much larger. Potential well yields of up to 500 gpm may be possible at selected locations in the aquifer. Water quality is generally of the sodium bicarbonate or sodium sulfate type, iron content is variable and this water is hard yet still suitable for a municipal supply.

The North Branch of Goodman Creek aquifer is located directly west and south of the City. Test drilling indicates the aquifer is 1/2-3/4 mile (0.8-1.2km) wide and has an average thickness of 26 feet (7.9m). Test drilling has also shown a deeper section of aquifer that shows excellent potential for a municipal supply. Water quality is similar to the other glacial aquifers mentioned. Iron content was highly varied and treatment might be necessary.

RECOMMENDATIONS

Based on the distance from Zap, the quality of water and the potential for a sufficient quantity, the North Dakota State Water Commission recommends the following:

1. That the city of Zap consider tapping that portion of the North Branch of the Goodman Creek aquifer lying on the west side of the city, Township 144 North, Range 89 West, Section 15 southeast quarter.
2. It is also recommended that a test well be constructed and an aquifer test be conducted in order to determine the hydraulic properties of the aquifer.

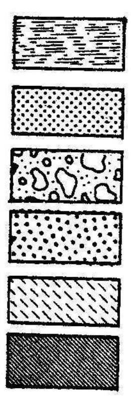
TABLE 2 -- LOGS OF TEST HOLES

The following test hole logs are compiled data of geologist's sample descriptions, drillers logs and geophysical logs which included resistivity and spontaneous potential. Grain-size classification throughout this report uses the C. K. Wentworth's scale from Compton (1967). Color descriptions are of wet samples and are based upon color standards of the national research council (Goddard Et. Al., 1948).

Test holes are called observations wells when they have been completed with 1¼ inch diameter plastic casing and screened at the bottom. Well depths, screened producing intervals (S.I.) and water levels with date measured, are so designated, water levels are in feet below land surface.

Elevations, based on mean sea level datum were interpreted from the Zap and Beulah quadrangles, published by the U.S. Geological Survey.

EXPLANATION OF LITHOLOGIC SYMBOLS



Silty and sand clay

Sand

Gravel

Sandstone (bedrock)

Silt

Lignite

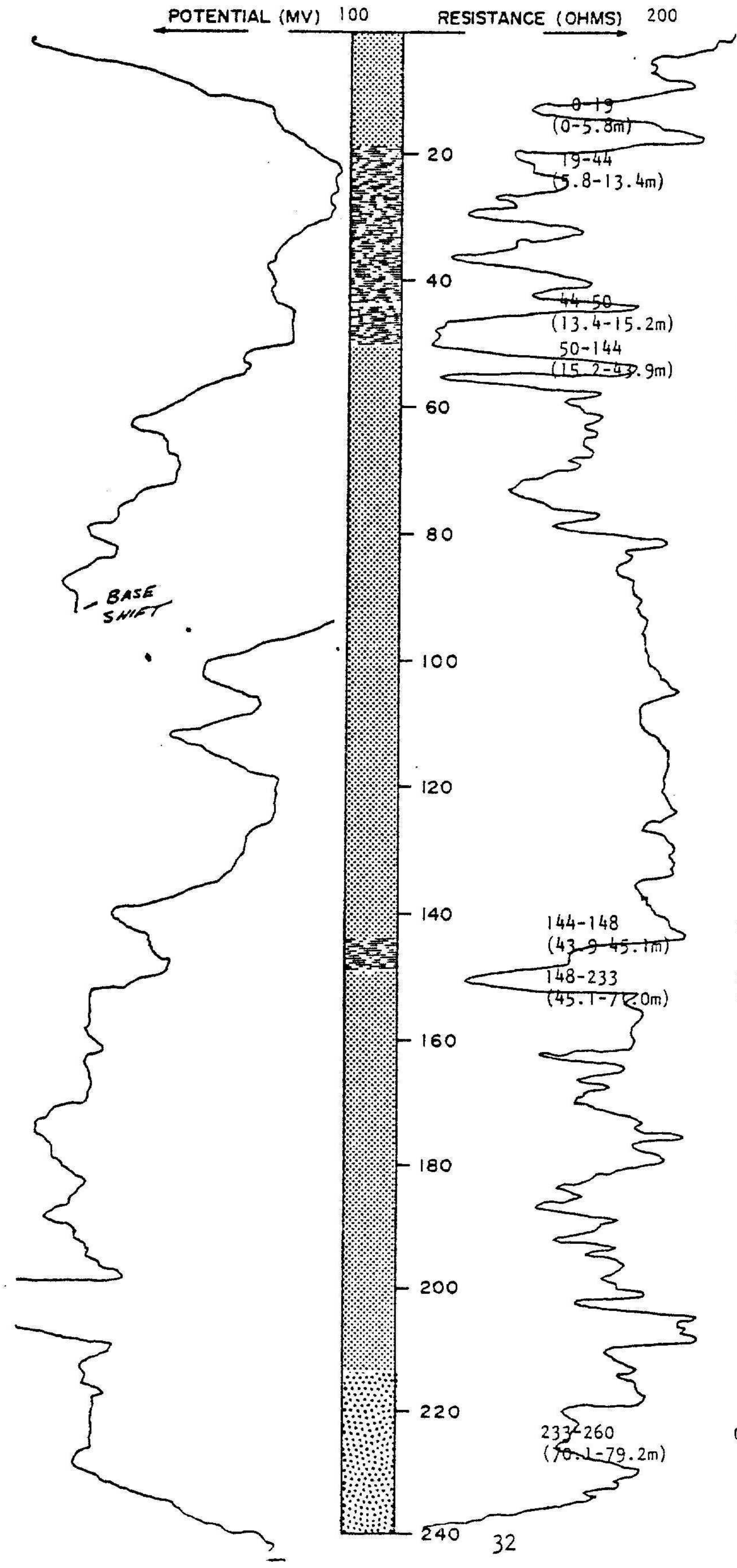
TEST HOLE 3656

LOCATION: T144N-R88W-17BCD

DATE DRILLED: 11-1-68

ELEVATION:
(FT, MSL)

DEPTH: 260 (79.2m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

Sand, fine- to medium-grained, silty, moderate-yellowish-brown.

Clay, fine- to medium-grained, silty, sandy, moderate-yellowish-brown to light olive gray

Clay and sand, plastic, olive gray

Sand, fine- to medium-grained, light-olive-gray; silty in upper part; gastropods at 55 to 60 ft.

Clay, silty, sandy.

Sand, pebbly, lignitic; a few silty beds

Tongue River Formation

Claystone, silty, light-olive-gray

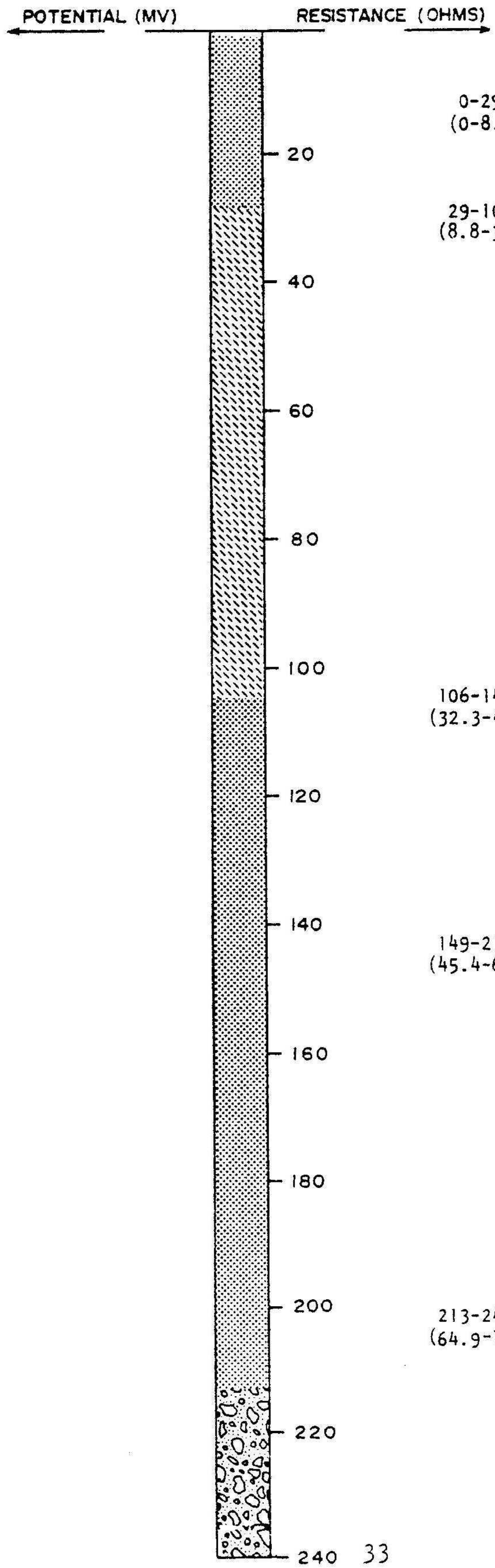
TEST HOLE 10393

LOCATION: T144N-R89W-17CBC

DATE DRILLED: 12-12-78

ELEVATION: 1820 feet (555m)
(FT, MSL)

DEPTH: 240' (73.2m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-29 (0-8.8m)	Sand, "dirty", clayey; very silty, predominantly a fine, well sorted, yellowish brown, oxidized.
29-106 (8.8-32.3)	Silt; slightly sandy; poorly compacted, sticky, drilling very easy, no cohesion, some lignite, some scoria, some carbonates, hole booting, poor recovery, olive gray.
106-149 (32.3-45.4m)	Sand, very fine to medium, predominantly fine, well sorted, abundant lignite fragments, some 10-20 mm, sand well rounded, possibly some small interbedded clay lenses, olive gray.
149-213 (45.4-64.9m)	Sand, similar to above, predominantly a medium, abundant lignite, poorly to moderately sorted, well rounded, olive gray.
213-240 (64.9-73.2m)	Gravel; sandy (40%), ranging from a fine sand to medium gravel, predominantly a fine gravel, poorly to moderately sorted, well rounded to angular, abundant lignite, some carbonates, some granitic fragments, olive gray, taking water.

Observation Well

Depth: 240 (73.2m)
S.I.: 234-240 (71.4-73.2m)
Water Level: 32.75 feet
Measured: 12-21-78

500-1/76

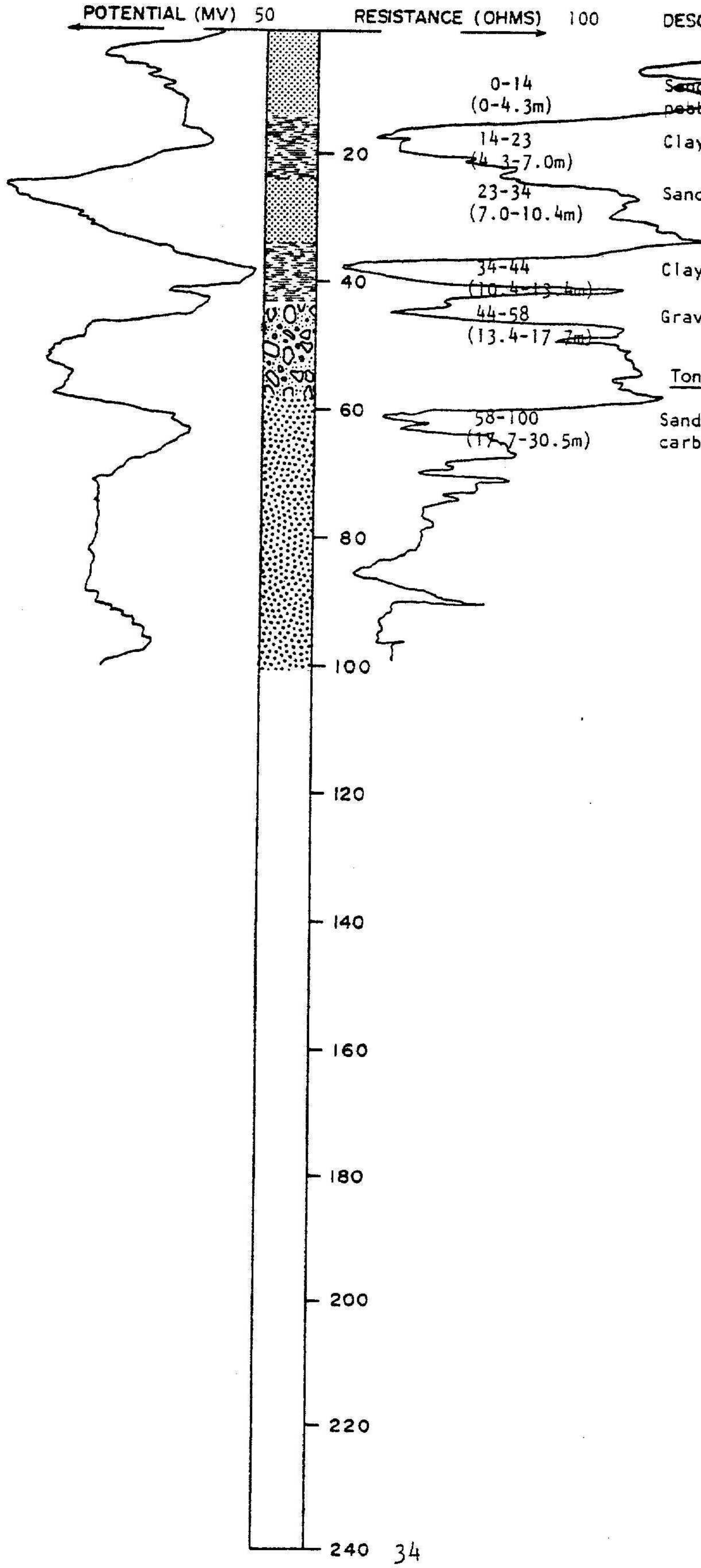
TEST HOLE 3756

LOCATION: T144N-R89W-23ABC(2)

ELEVATION (FT, MSL): 1832

DATE DRILLED: 7-26-69

DEPTH (FT): 100(30.5m)



DESCRIPTION OF DEPOSITS

Alluvium

Sand, medium- to coarse-grained, pebbly, yellowish-gray

Clay, silty, dusky-yellow.

Sand, medium- to coarse-grained.

Clay, silty, lignitic

Gravel, sandy, lignitic.

Tongue River Formation

Sandstone, fine-grained, clayey, carbonaceous, greenish gray.

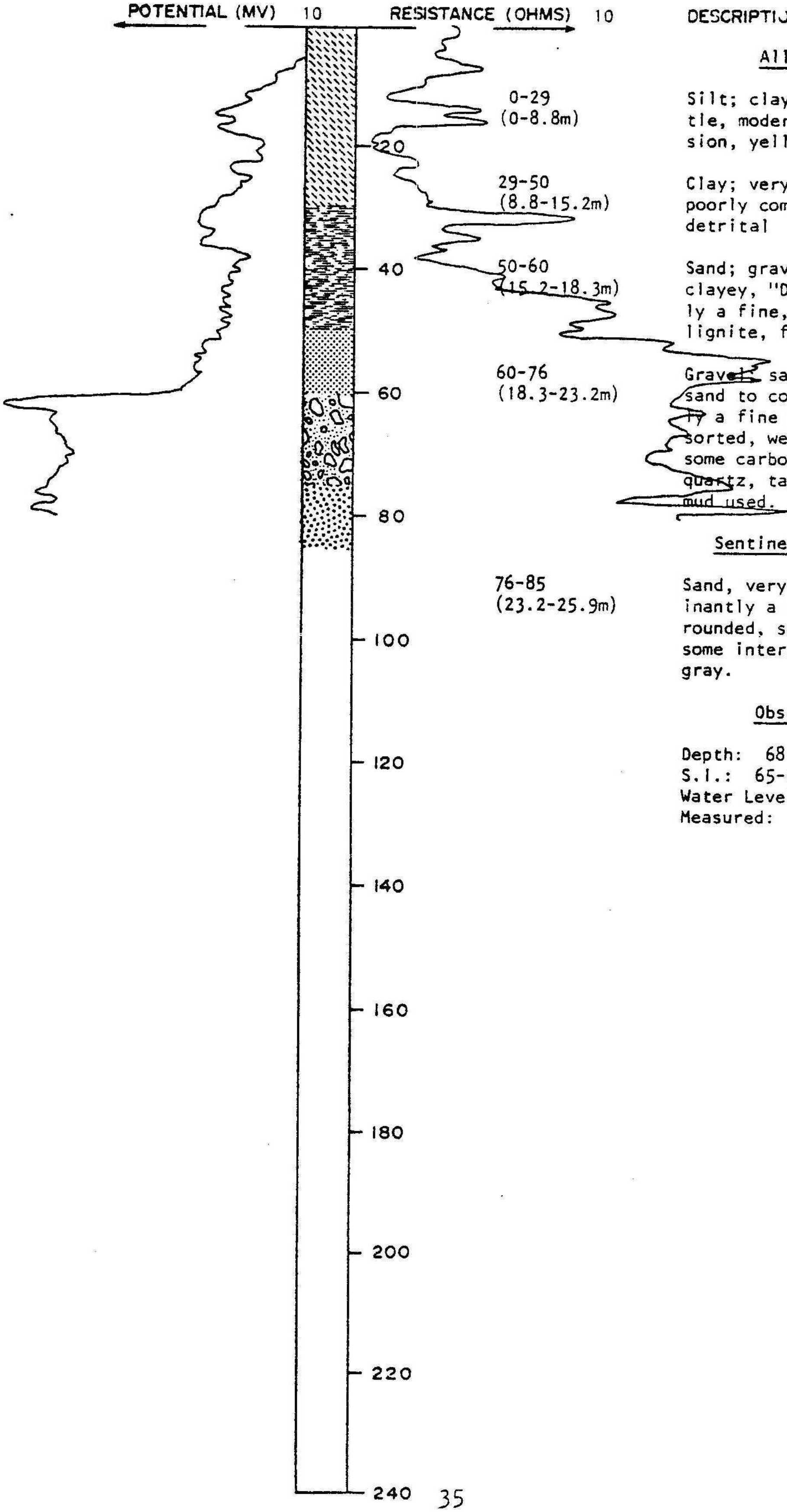
TEST HOLE 10392

LOCATION: T144N-R89W-15DAC

DATE DRILLED: 12-11-78

ELEVATION: (FT, MSL) 1840 (560m)

DEPTH: (FT) 85 (25.9m)



DESCRIPTION OF DEPOSITS

Alluvium

0-29 (0-8.8m) — Silt; clayey; slightly sandy, brittle, moderately compact, no cohesion, yellowish brown, oxidized.

29-50 (8.8-15.2m) — Clay; very silty; slightly sandy, poorly compact, smooth, some detrital lignite, olive gray.

50-60 (15.2-18.3m) — Sand; gravely (5-10%), silty; clayey, "Dirty", sand predominantly a fine, poorly sorted, abundant lignite, few carbonates.

60-76 (18.3-23.2m) — Gravel; sandy, ranging from a fine sand to coarse gravel, predominantly a fine to medium gravel, poorly sorted, well rounded to angular, some carbonates, shale, abundant quartz, taking water 1 bag drilling mud used.

Sentinel Butte Formation

76-85 (23.2-25.9m) — Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clay, greenish gray.

Observation Well

Depth: 68 (20.7m)
S.I.: 65-68 (19.8-20.7m)
Water Level: 23.75 feet
Measured: 12-21-78

TEST HOLE 10391

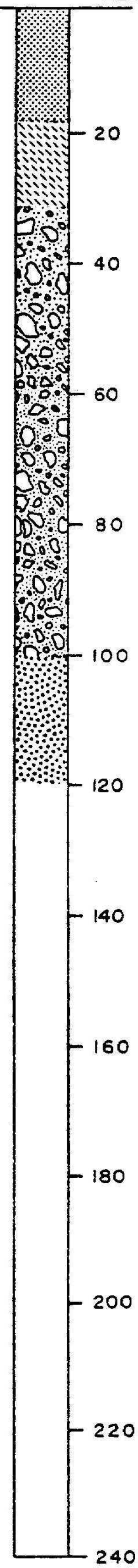
LOCATION: T144N-R89W-15DDD

DATE DRILLED: 12-4-78

ELEVATION (FT, MSL): 1850 (564m)

DEPTH (FT): 120 (35.6m)

POTENTIAL (MV) RESISTANCE (OHMS)



DESCRIPTION OF DEPOSITS

<u>Alluvium</u>

0-17 (0-5.2m)
Sand, very fine to coarse, predominantly a medium, well sorted, well rounded some detrital lignite, possibly some interbedded silts, yellowish brown oxidized.

17-25 (5.2-7.6m)
Silt; sandy, drilling easy, sand predominantly a fine, yellowish brown, oxidized.

25-100 (7.6-30.5m)
Gravel; sandy, ranging from fine sand to coarse gravel, poorly sorted, predominantly a medium gravel, angular to well rounded, abundant carbonates and shales, some lignite, olive gray, taking water 2 bags drilling mud used.

<u>Sentinel Butte Formation</u>

100-120 (30.5-35.6m)
Sand, very fine to medium predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clays, greenish gray.

<u>Observation Well</u>

Depth: 81 (24.7m)
S.I.: 78-81 (23.7-24.7m)
Water Level: 23.43 feet
Measured: 12-21-78

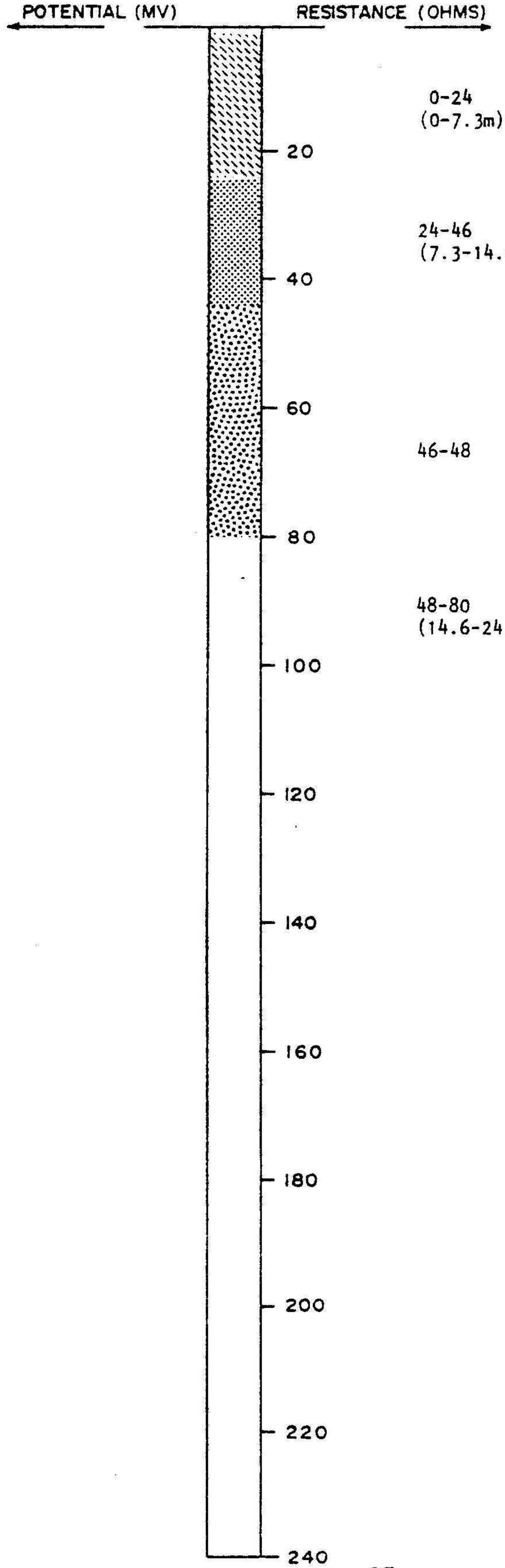
TEST HOLE 10390

LOCATION: T144N-R89W-15DDB

DATE DRILLED: 12-4-78

ELEVATION: 1850 (564m)
(FT, MSL)

DEPTH: 80 (24.4m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-24 (0-7.3m) — Silt; clayey; slightly sandy, smooth, well compact, poorly cohesive, brittle, dark yellowish brown, drilling hard, tight, oxidized.

24-46 (7.3-14.0m) — Sand; gravely, ranging from fine sand to fine gravel (20%), predominantly a fine sand, very poorly sorted, fragments of: Lignite, scoria, carbonates, igneous and metamorphic pebbles, abundant quartz, taking water, 1 bag drilling mud used, olive gray to dark brown.

46-48 — Sandstone, gravely, similar to above, hard drilling predominately a medium gravel, poorly sorted, abundant carbonates.

Sentinel Butte Formation

48-80 (14.6-24.4m) — Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clays, greenish gray.

Observation Well

Depth: 46 (14.0m)
S.I.: 43-46 (13.1-14.0)
Water Level: 25.91 feet
Measured: 12-17-78

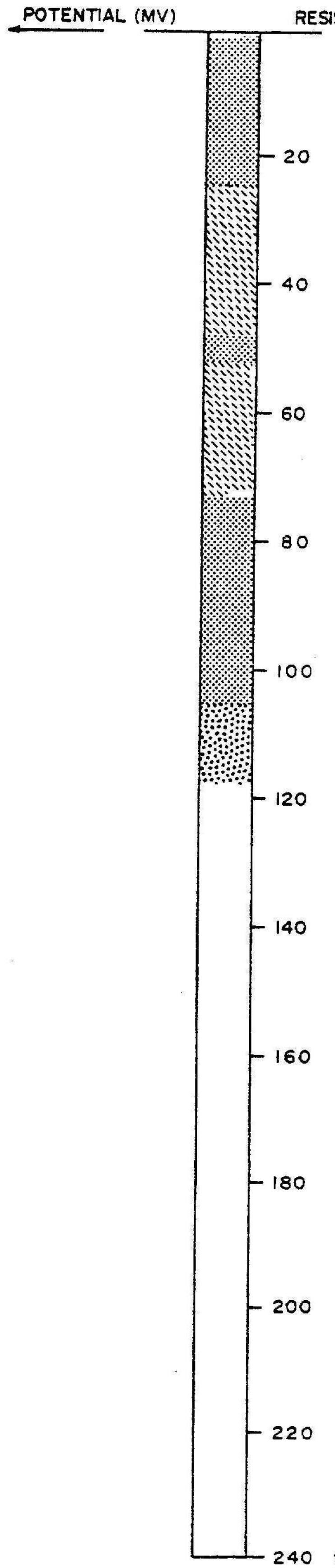
TEST HOLE 10389

LOCATION: T144N-R89W-15DDA

DATE DRILLED: 12-4-78

ELEVATION: 1841 (560m)
(FT, MSL)

DEPTH: 117 (35.7m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-20 (0-6.1m)	Poor recovery first 20', annulus leaking, some recovery of sand predominantly a medium to coarse, well sorted, drilling smooth and fast, yellowish brown, oxidized.
20-24 (6.1-7.3m)	Sand; gravely (20%), ranging from a fine sand to medium gravel, predominantly a coarse sand, abundant lignite, abundant scoria, abundant quartz, some carbonates, yellowish brown, oxidized.
24-48 (7.3-14.6m)	Silt; clayey; sandy moderately to poorly compacted, somewhat plastic, cohesive, drilling easy, olive gray.
48-53 (14.6-16.1m)	Sand, abundant lignite, ranging from fine to very coarse sand, predominantly a coarse sand, poorly sorted, well rounded to subangular, taking water, olive gray.
53-73 (16.1-22.2m)	Silt, similar to above, poorly cohesive, olive gray.
73-81 (22.2-24.7m)	Sand, similar to above, predominantly a coarse, poorly sorted, abundant lignite.
81-101 (24.7-30.8m)	Sand, with interbedded clays, silts, and some gravel drilling easy, smooth, taking water, sand predominantly a coarse, some detrital lignite, some carbonates.
101-113 (24.7-34.4m)	Sand; gravely (30%), fine sand to fine gravel, predominantly a medium sand, poorly sorted, abundant lignite 20% shale (well rounded), abundant quartz and silicates, 30% carbonates.

Sentinel Butte Formation

113-117 (34.4-35.7m)	Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clays, greenish gray.

Observation Well

Depth: 108 (32.9m)
S.I.: 105-108 (32.0-32.9m)
Water Level: 22.92 feet
Measured 12-21-78

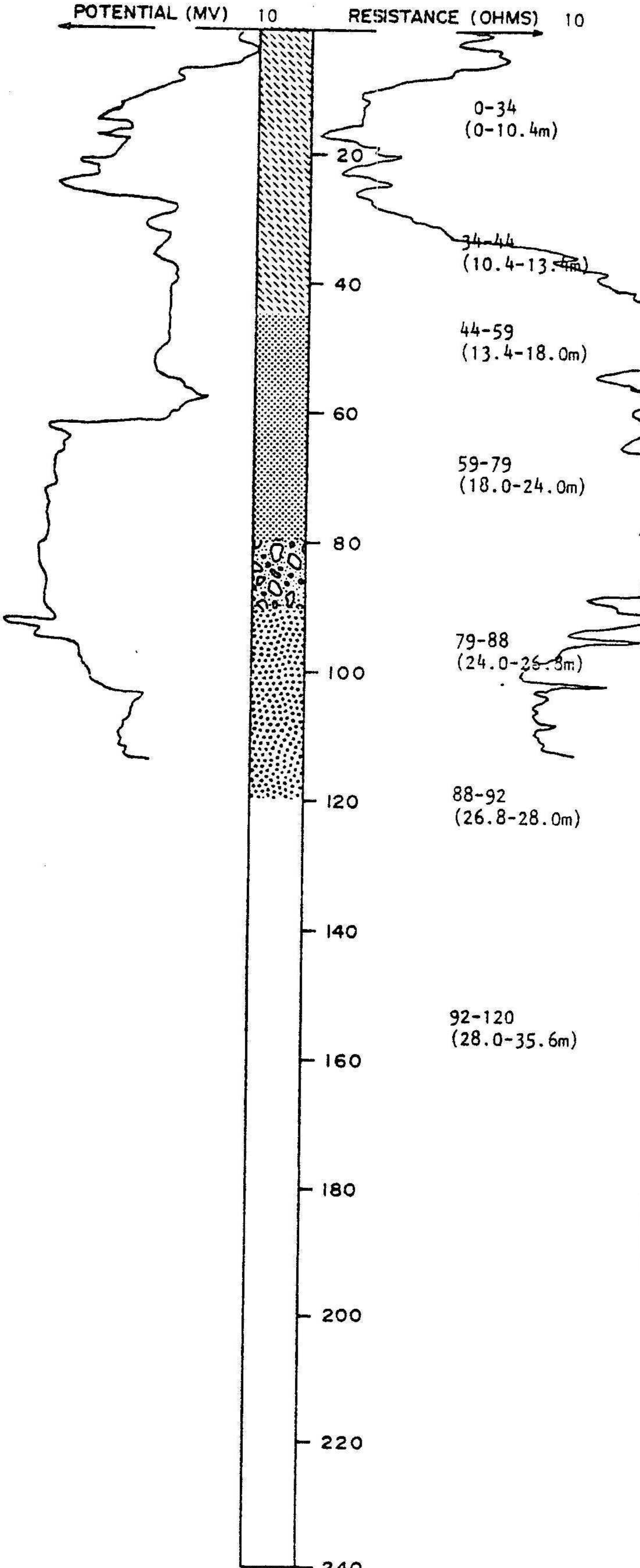
TEST HOLE 10388

LOCATION: 144N-R89W-15DDD$_2$

DATE DRILLED: 11-28-78

ELEVATION: (FT, MSL) 1840 (560m)

DEPTH: (FT) 120 (35.6m)



DESCRIPTION OF DEPOSITS

Alluvium

0-34 (0-10.4m) — Silt; clayey; slightly sandy, poorly compacted; poorly cohesive, sticky, dark yellowish brown, 15 ft (4.6m) some scoria and carbonate fragments, oxidized.

34-44 (10.4-13.4m) — silt; very sandy; abundant scoria, moderately compacted, moderately cohesive, olive gray.

44-59 (13.4-18.0m) — Sand; very fine to very coarse, predominantly a medium, well to moderately sorted, abundant lignite, some carbonates, abundant quartz.

59-79 (18.0-24.0m) — Sand; gravely (30%), ranging from sand to coarse gravel, predominantly a very coarse sand, poorly sorted, abundant lignite, sand well rounded to subangular, abundant carbonates, some shale, abundant quartz, olive gray, taking water.

79-88 (24.0-26.8m) — Gravel; sandy (40%), ranging from a medium sand to coarse gravel. predominantly a fine gravel, poorly sorted, abundant carbonates, some lignite, abundant quartz, easy drilling, "clean", olive gray.

88-92 (26.8-28.0m) — Gravel; sandy (30%), ranging from a medium sand to coarse gravel, predominantly a fine gravel, abundant carbonates, abundant quartz, some lignite, some scoria, well rounded to subangular, taking water, 1 bag drilling mud used.

Sentinel Butte Formation

92-120 (28.0-35.6m) — Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clays, greenish gray.

Observation Well

Depth: 50' (15.2m)
S.I.: 47-50 (14.3-15.2m)
Water Level: 31.84 feet
Measured: 12-21-78

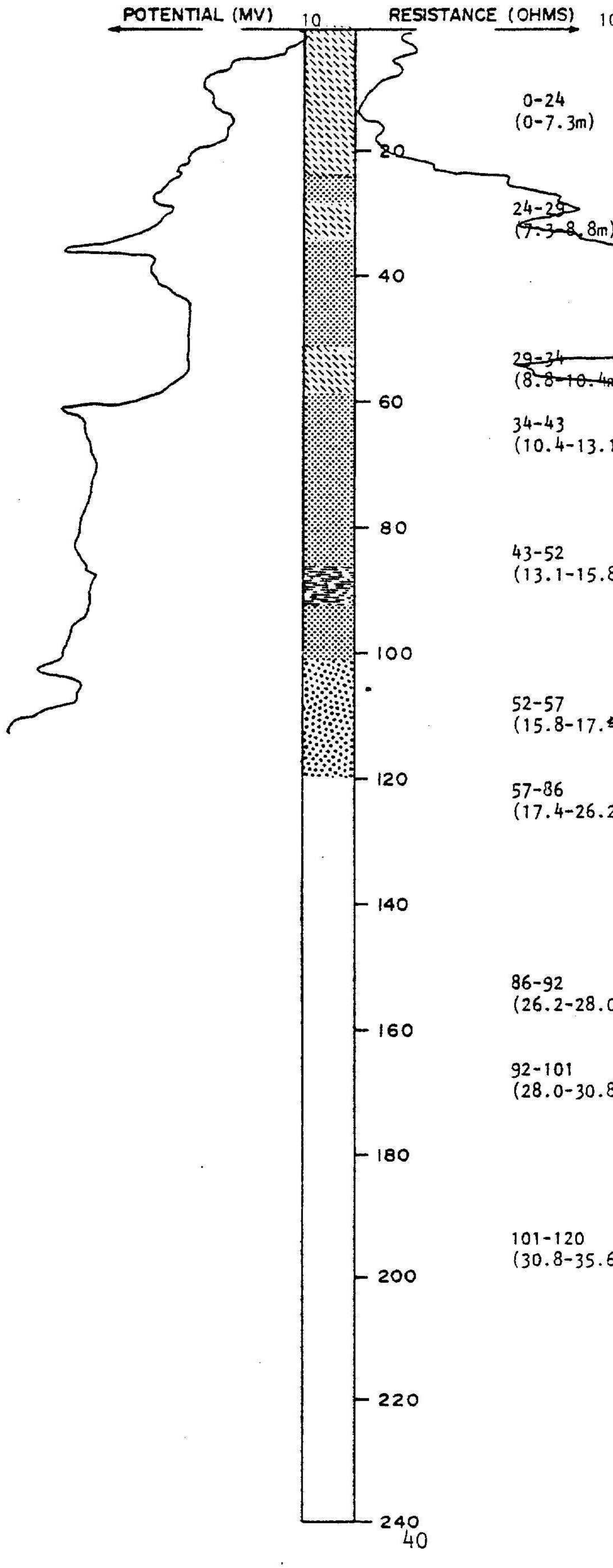
TEST HOLE 10387

LOCATION: 144N-R89W-15DDD$_1$

DATE DRILLED: 11-15-78

ELEVATION: 1840 (561m)
(FT, MSL)

DEPTH: 120 (35.6m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-24 (0-7.3m) — Silt; clayey, very smooth drilling, somewhat brittle, poor cohesion, well compact, yellowish brown, oxidized.

24-29 (7.3-8.8m) — Sand, "Dirty", some interbedded clays, some gravel about 10%, some detrital lignite, sand predominantly a coarse, poorly sorted, clay poorly compacted, moderately cohesive, olive gray.

29-34 (8.8-10.4m) — Silt; clayey, well compact, poorly cohesive, olive gray.

34-43 (10.4-13.1m) — Sand; gravely (10%), abundant lignite, range of sand: Fine sand to fine gravel, predominantly a coarse sand, poorly sorted, well rounded olive gray.

43-52 (13.1-15.8m) — Sand; gravely (30%), fine sand to medium gravel predominately a very coarse sand, poorly sorted, well rounded to subangular abundant lignite, abundant quartz, some carbonates, olive gray.

52-57 (15.8-17.4m) — Silt; clayey, very sandy, poorly compact, poorly cohesive, olive gray.

57-86 (17.4-26.2m) — Sand; gravely (45%), abundant detrital lignite, range from fine sand to coarse gravel, predominantly a coarse sand, poorly sorted, well rounded to angular, abundant quartz, abundant lignite, some metamorphic and igneous gravel fragments, taking water.

86-92 (26.2-28.0m) — Clay; silty; very sandy, poorly compacted, poorly cohesive, olive gray.

92-101 (28.0-30.8m) — Sand; gravely, same as above sequence of sand and gravel still abundant lignite, moderately to poorly sorted, well rounded to angular, olive gray, taking water.

Sentinel Butte Formation

101-120 (30.8-35.6m) — Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some detrital lignite, also some interbedded carbonaceous clays, greenish gray.

Observation Well

Depth: 84 (25.6m)
S.I.: 81-84 (24.7-25.6m)
Water Level: 22.86 feet
Measured: 12-21-78

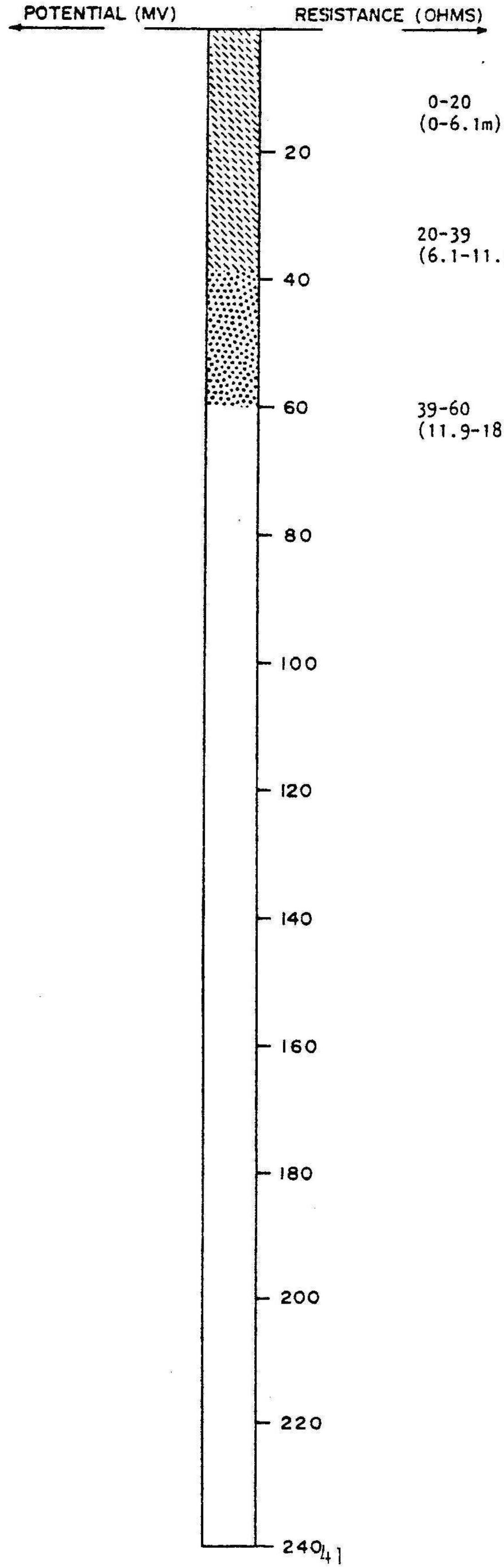
TEST HOLE 10386

LOCATION: T144N-R89W-23ADB

DATE DRILLED: 11-16-78

ELEVATION (FT, MSL): 1838 (560m)

DEPTH (FT): 60 (18.2m)



DESCRIPTION OF DEPOSITS

<u>Alluvium</u>

0-20 (0-6.1m)	Silt; clayey; slightly sandy, poorly compacted, poor cohesion, possibly some carbonaceous clays, interbedded, poor recovery, oxidized.
20-39 (6.1-11.9m)	Silt; clayey; sandy, some scoria, fragments, drilling very easy, silt poorly compacted, poorly cohesive, yellowish brown, oxidized zone ending about 22 ft. (6.7m).

<u>Sentinel Butte Formation</u>

39-60 (11.9-18.3m)	Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clay, greenish gray.

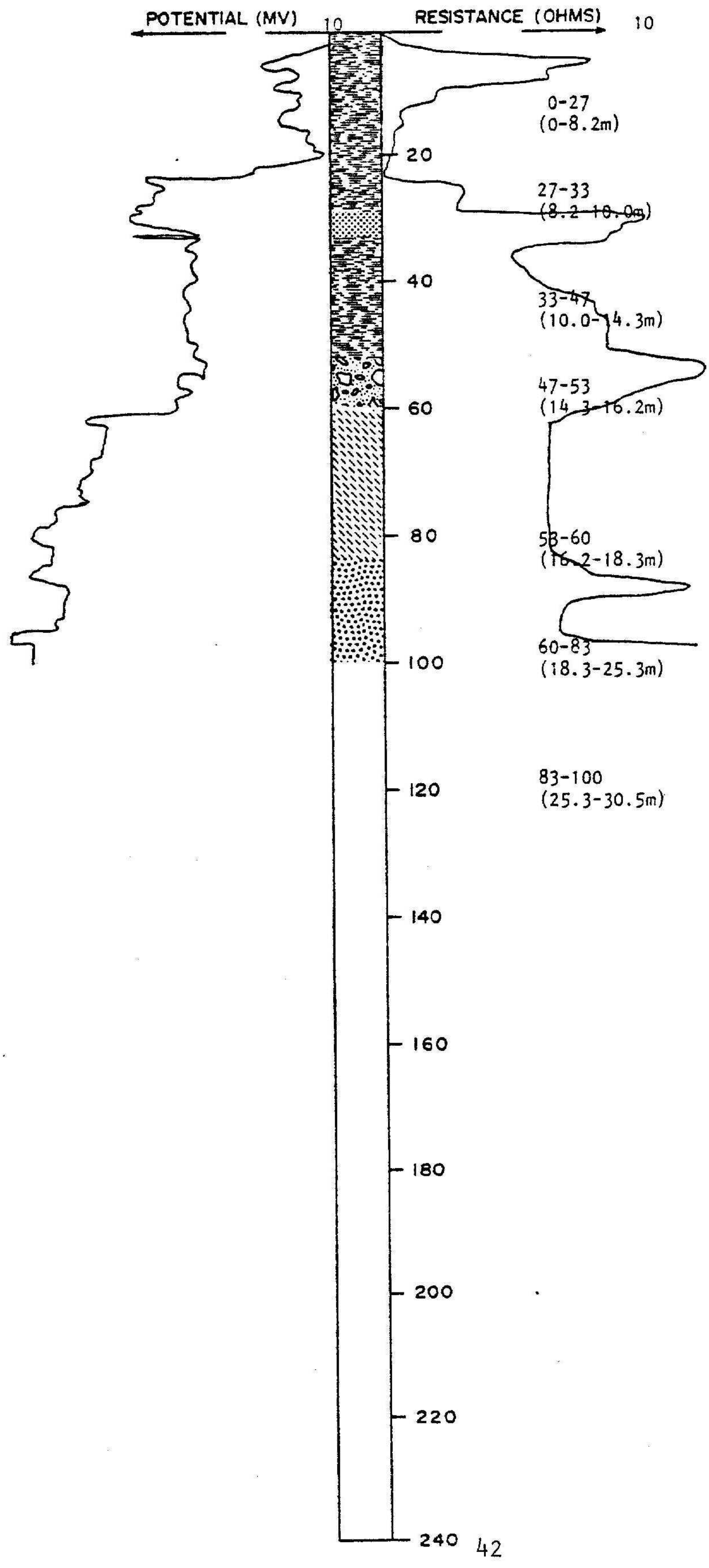
TEST HOLE 10385

LOCATION: T144N-R89W-23ACB

DATE DRILLED: 11-15-78

ELEVATION (FT, MSL): 1870 (570m)

DEPTH (FT): 100 (30.5m)



DESCRIPTION OF DEPOSITS

Alluvium

0-27 (0-8.2m) Clay; very silty; slightly sandy, poorly compacted, poorly cohesive, yellowish brown, oxidized.

27-33 (8.2-10.0m) Sand, very fine to coarse predominantly a medium, well sorted, well rounded, abundant quartz, some detrital lignite, olive gray.

33-47 (10.0-14.3m) Clay; sandy; silty, moderately compact, plastic, clay will ribbon, cohesive olive gray.

47-53 (14.3-16.2m) Sand; gravely (20%), ranging from a coarse sand to coarse gravel, predominantly a very coarse sand, poorly sorted, well rounded to angular, abundant quartz and carbonates.

53-60 (16.2-18.3m) Gravel; sandy (30%), well rounded to subangular, predominantly a medium gravel, poorly sorted, abundant carbonates and silicates.

60-83 (18.3-25.3m) Silt; clayey; sandy, drilling easy, poorly compacted, no cohesion, no plasticity, olive gray.

Sentinel Butte Formation

83-100 (25.3-30.5m) Sand, very fine to medium, predominantly a medium, well sorted, well rounded, some detrital lignite, some interstitial clays, greenish gray.

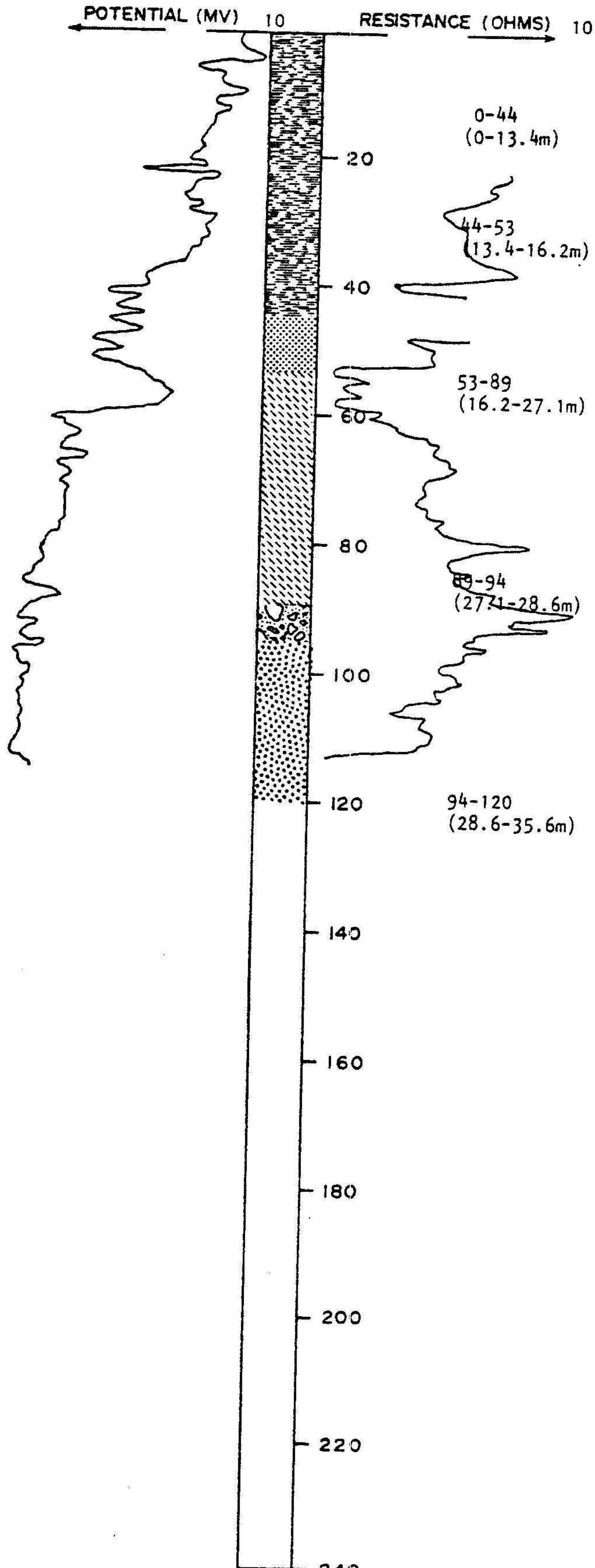
TEST HOLE 10384

LOCATION: T144N-R89W-23ACA$_2$

ELEVATION: (FT, MSL) 1870 (570m)

DATE DRILLED: 11-15-78

DEPTH: (FT) 120 (35.6m)



DESCRIPTION OF DEPOSITS

Alluvium

Clay, silty, sandy, moderately to poorly compacted, moderately cohesive, plastic, yellowish brown, oxidized.

Sands, gravely (50%), ranging from fine sand to coarse gravel, predominantly a coarse sand, poorly sorted, well rounded to subangular, abundant lignite, abundant carbonates, taking water.

Silty, clayey, slightly sandy, poorly compacted, no plasticity or cohesiveness, drilling fast, olive gray.

Gravel; sandy (30%), ranging from a medium sand to a coarse gravel, predominantly a fine to medium gravel, poorly sorted, well rounded to subangular, abundant lignite (detrital), some shale, some carbonated, abundant quartz.

Sentinel Butte Formation

Sand, very fine to medium, predominantly a fine, well sorted, well rounded, few lignite grains, some interstitial clays, greenish gray.

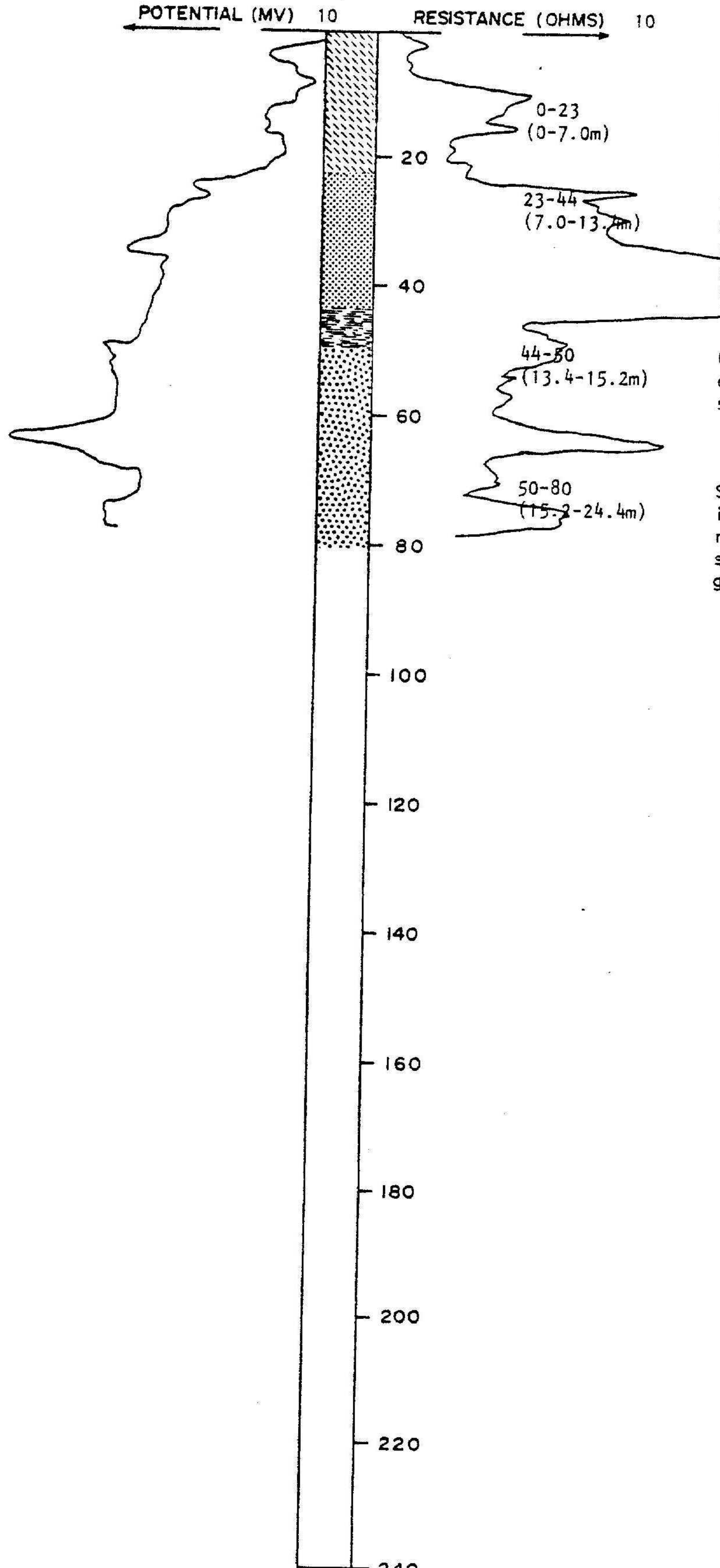
TEST HOLE 10383

LOCATION: T144N-R89W-23ACA$_1$

ELEVATION (FT, MSL): 1850 (564m)

DATE DRILLED: 11-15-78

DEPTH (FT): 80' (24.4m)



DESCRIPTION OF DEPOSITS

Alluvium

Silt, clayey, slightly sandy, moderately compacted, poorly cohesive yellowish brown, oxidized.

Sand; gravely (30%), ranging from medium sand to medium gravel, predominantly a very coarse sand, poorly sorted, some detrital lignite, abundant carbonates, subangular to well rounded.

Clay, silty, slightly sandy, moderately compact, moderately cohesive, yellowish brown, oxidized.

Sentinel Butte Formation

Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clays, greenish gray.

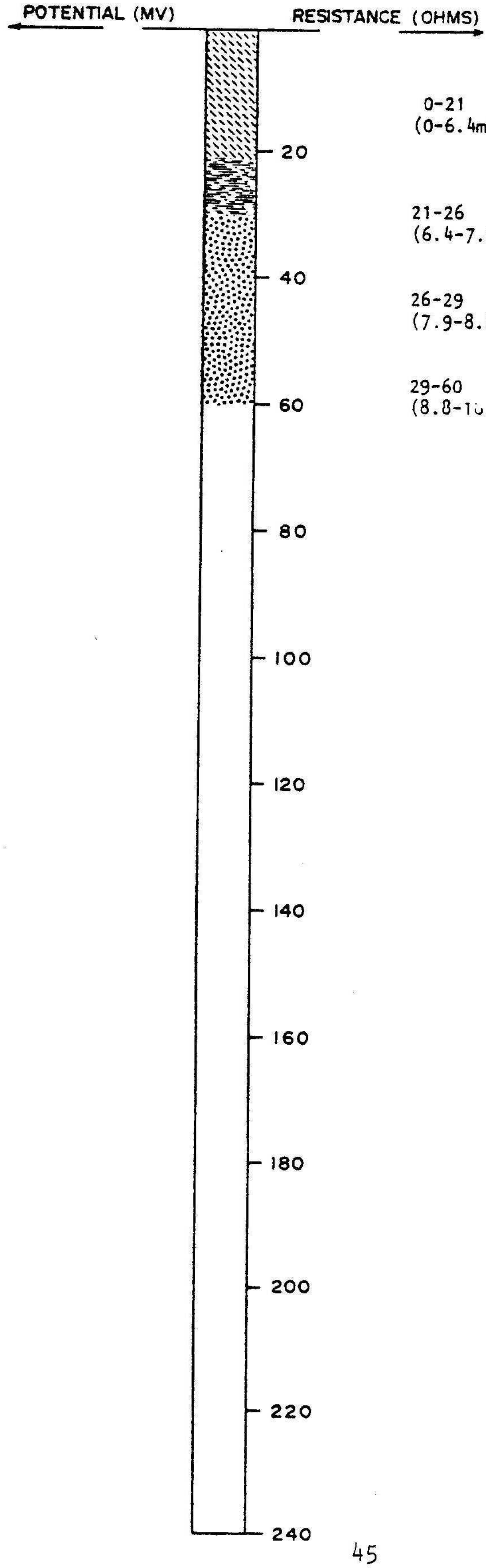
TEST HOLE 10382

LOCATION: T144N-R89W-24BCC

DATE DRILLED: 11-15-78

ELEVATION: (FT, MSL) 1870 (570m)

DEPTH: (FT) 60 (18.3m)



DESCRIPTION OF DEPOSITS

Alluvium

0-21 (0-6.4m)	Silt; clayey, slightly sandy, moderately compacted, somewhat plastic (slightly), yellowish brown, oxidized.
21-26 (6.4-7.9m)	Clay, somewhat silty, sandy, very cohesive, plastic, moderate to well compacted, yellowish brown.
26-29 (7.9-8.8m)	Clay, resembles carbonaceous clays, moderately compact, well cohesive dark brown.
29-60 (8.8-1[illegible].5m)	Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clay, greenish gray.

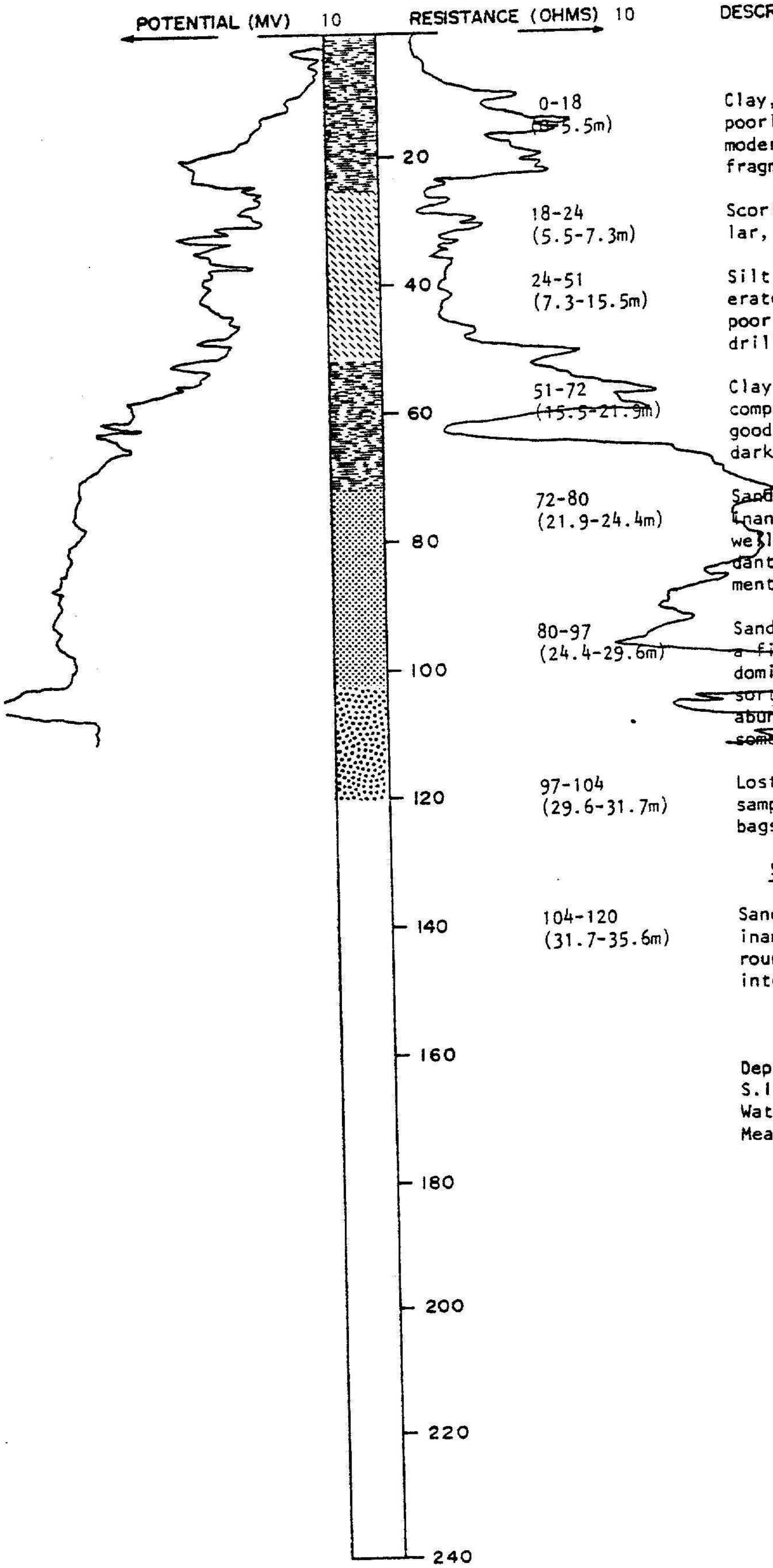
TEST HOLE 10381

LOCATION: T144N-R89W-23ACC2

ELEVATION: (FT, MSL) 1846 (563m)

DATE DRILLED: 11-15-78

DEPTH: (FT) 120 (35.6m)



DESCRIPTION OF DEPOSITS

Alluvium

0-18 (0-5.5m) Clay, very silty, slightly sandy, poorly compact, somewhat plastic, moderately cohesive, some scoria fragments, dark yellowish brown.

18-24 (5.5-7.3m) Scoria, easy drilling, very angular, taking water, orange.

24-51 (7.3-15.5m) Silt, clayey, slightly sandy, moderately compacted, not plastic, poor cohesion, yellowish brown, drilling easy.

51-72 (15.5-21.9m) Clay, slightly sandy, silty, well compacted, very good cohesion, good plasticity, olive gray to dark black.

72-80 (21.9-24.4m) Sand, very fine to coarse, predominantly a medium, poorly sorted, well rounded to subangular, abundant quartz, some lignite fragments, some carbonates.

80-97 (24.4-29.6m) Sand; gravely (10%), ranging from a fine sand to fine gravel, predominantly a coarse sand, poorly sorted subangular to rounded, abundant large lignite fragments, some carbonates, taking water.

97-104 (29.6-31.7m) Lost circulation, no recovery of samples, taking lots of water, 5 bags drilling mud used.

Sentinel Butte Formation

104-120 (31.7-35.6m) Sand, very fine to medium, predominantly a fine, well sorted, well rounded, few lignite grains, some interstitial clays, greenish gray.

Observation Well

Depth: 81 (24.7)
S.I.: 78-81 (23.8-24.7m)
Water Level: 36.76
Measured: 12-21-78

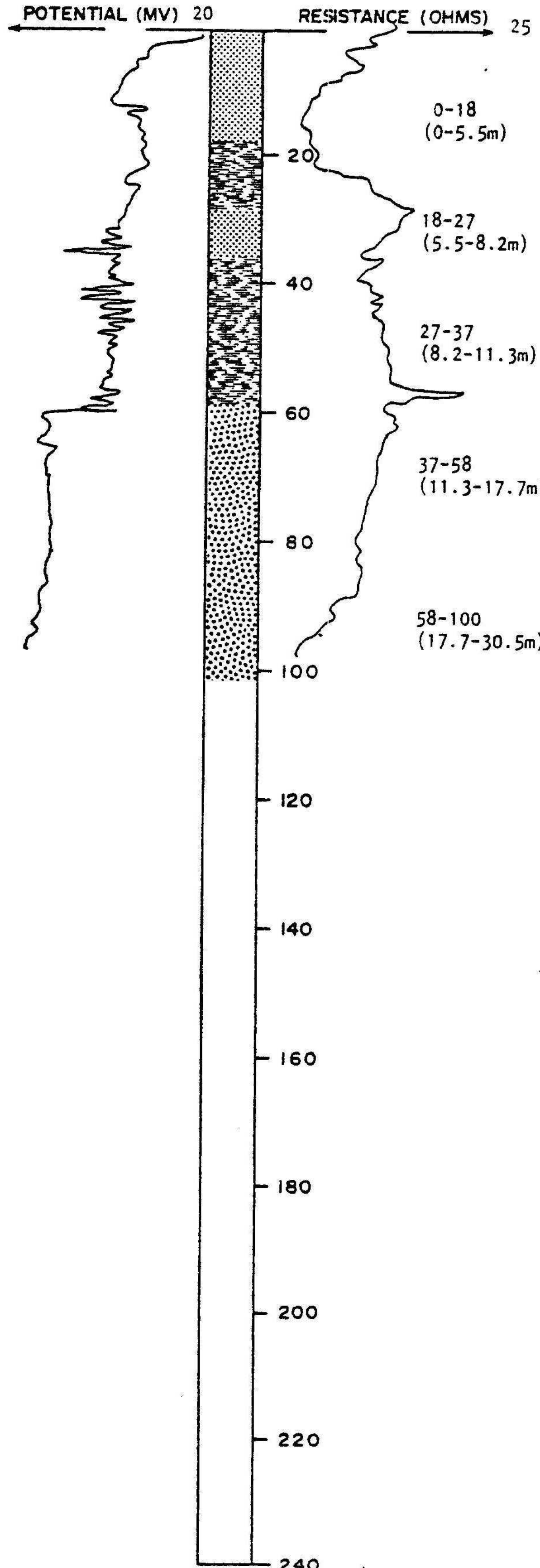
TEST HOLE 10380

LOCATION: T144N-R89W-23ACB

DATE DRILLED: 11-14-78

ELEVATION (FT, MSL): 1845 (562m)

DEPTH (FT): 100 (30.48m)



DESCRIPTION OF DEPOSITS

Alluvium

0-18 (0-5.5m)
Sand, very silty, very fine to medium, predominantly a fine, well sorted, well rounded, yellowish brown, oxidized.

18-27 (5.5-8.2m)
Clay, very silty, very sandy, moderately compact, moderately cohesive, dark yellowish brown, oxidized.

27-37 (8.2-11.3m)
Sand, very fine to medium, predominantly a fine, well sorted, well rounded, abundant quartz, some lignite, yellowish brown to olive gray.

37-58 (11.3-17.7m)
Clay, very sandy, some detrital lignite, sand predominantly a fine well sorted, clay moderately compact, poorly cohesive, olive gray.

Sentinel Butte Formation

58-100 (17.7-30.5m)
Sand, very fine to medium, predominantly a fine, well sorted, well rounded, few lignite grains, some interstitial clays, also some carbonaceous clays, greenish gray.

TEST HOLE 10379

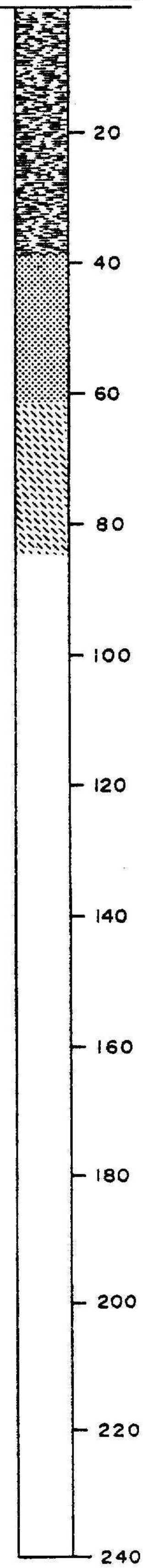
LOCATION: T144N-R89W-28CBC

DATE DRILLED: 11-8-78

ELEVATION: (FT, MSL) 1980 (603m)

DEPTH: (FT) 100 (30.5)

POTENTIAL (MV) RESISTANCE (OHMS)



DESCRIPTION OF DEPOSITS

Alluvium

0-41 (0-12.5m)	Clay; very silty, moderately to poorly compact, poorly cohesive, yellowish brown, possibly some fine interbedded sands, oxidized.
41-61 (12.5-18.6m)	Sand; very silty, "Dirty", very fine to medium sand, predominantly a fine, well sorted, well rounded to subangular, some lignite grains yellowish brown, oxidized.
61-84 (18.6-25.6m)	Silt, with very fine sands, some lignite, taking water olive gray.
84-100 (25.6-30.5m)	Sand, very fine to coarse predominantly a medium, well to moderately sorted few lignite grains, some carbonates subangular & subrounded.
100' (30.5m)	Lost circulation 9 bags of drilling mud used taking lots of water, hole abandoned.

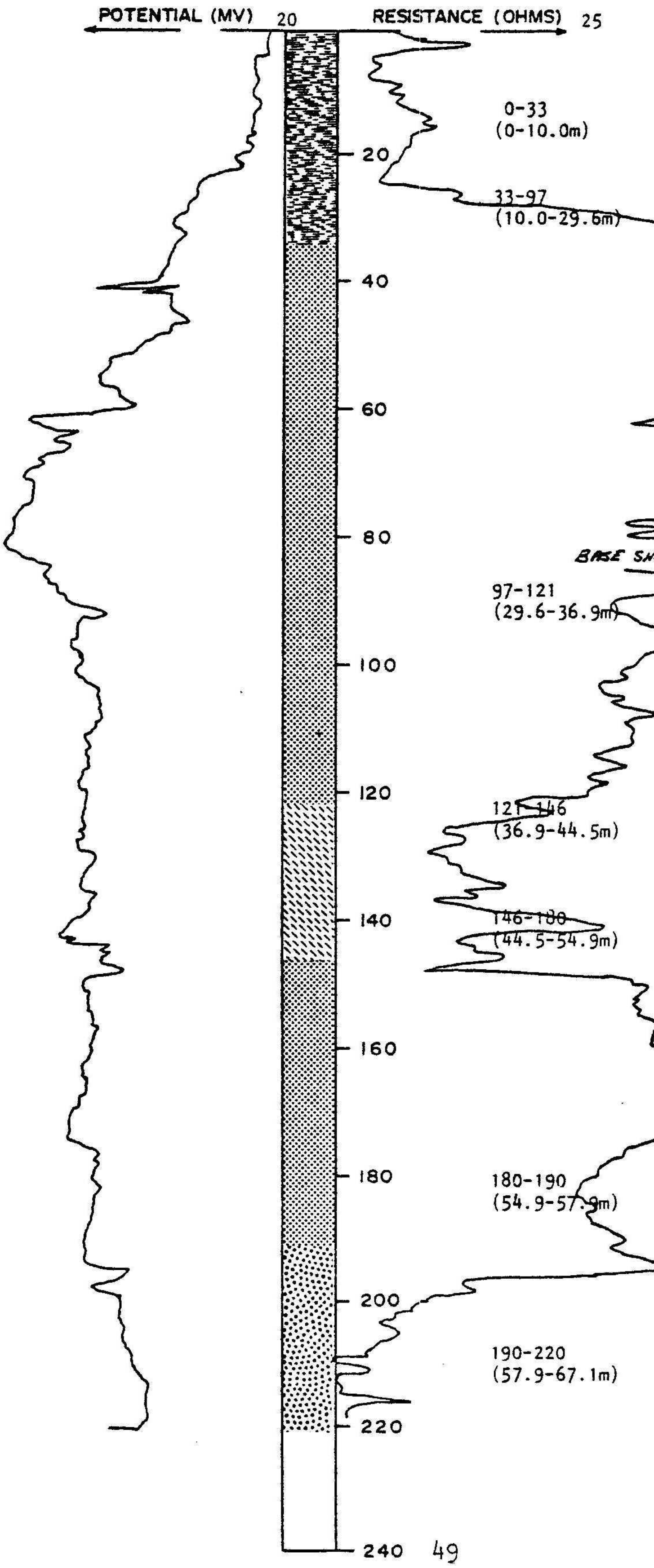
TEST HOLE 10378

LOCATION: T144N-R89W-23BCB$_2$

DATE DRILLED: 11-8-78

ELEVATION: (FT, MSL) 1965 (599m)

DEPTH: (FT) 220 (67.1m)



DESCRIPTION OF DEPOSITS

Alluvium

0-33 (0-10.0m) — Clay, very silty, well compacted, poorly cohesive, yellowish brown, oxidized.

33-97 (10.0-29.6m) — Sand; silty, very fine to medium predominantly a fine, well sorted, well rounded, yellowish brown, oxidized.

97-121 (29.6-36.9m) — Sand very fine to coarse predominantly a fine, well sorted, some lignite fragments, well rounded, olive gray.

121-146 (36.9-44.5m) — Silt; clayey; slightly sandy, poorly compacted, poorly cohesive olive gray, taking water.

146-180 (44.5-54.9m) — Sand; gravely poor recovery of gravel bit chattering heavily, sand predominantly a fine, well sorted, olive gray.

180-190 (54.9-57.9m) — Sand, with possible gravel, poor recovery on gravel, drilling tough, abundant lignite, recovery predominantly a very coarse sand, moderately sorted, rounded.

Sentinel Butte Formation

190-220 (57.9-67.1m) — Sand, very fine to medium predominantly a fine, well sorted, well rounded, few lignite grains, some interstitial clays, greenish gray.

Observation Well

Depth: 164 (50.0m)
S.I.: 158-164 (48.16-50.0m)
Water Level: 91.81 feet
Measured: 12-21-78

TEST HOLE 10376

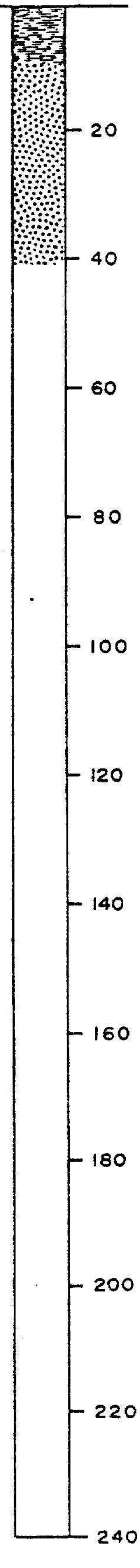
LOCATION: T144N-R89W-20DDD

DATE DRILLED: 11-8-78

ELEVATION: 1980 (603m)
(FT, MSL)

DEPTH: 40 (12.2m)
(FT)

POTENTIAL (MV) RESISTANCE (OHMS)



DESCRIPTION OF DEPOSITS

Alluvium

0-7
(0-2.1m)

Clay; very silty; slightly sandy, well compacted, poorly cohesive, yellowish brown oxidized. Taking water.

Sentinel Butte Formation

7-40
(21.-12.2m)

Silt; sandy; clayey, well compacted, poorly cohesive, some interbedded carbonaceous clay, olive gray to greenish gray.

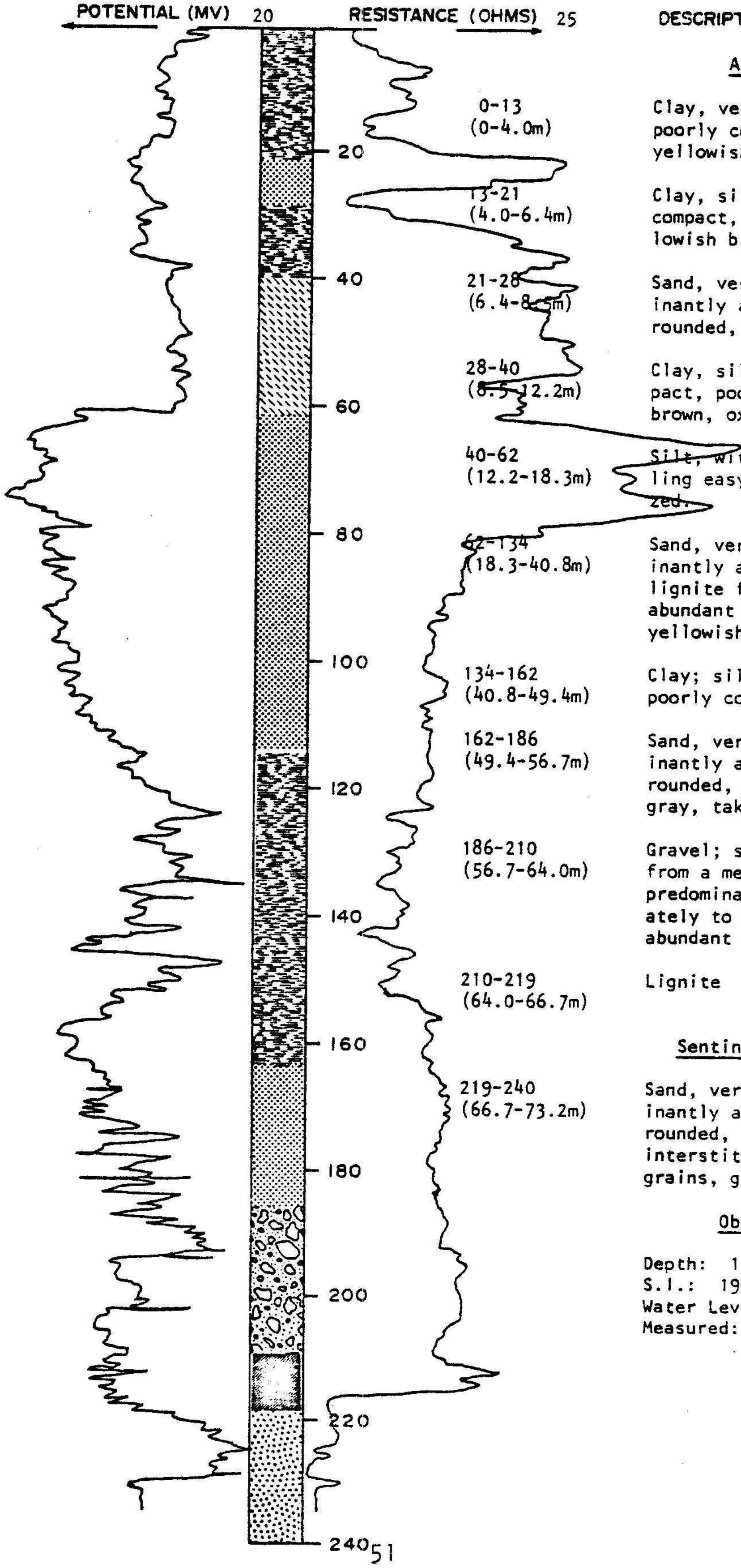
TEST HOLE 10375

LOCATION: T144N-R89W-30AAA

DATE DRILLED: 11-8-78

ELEVATION: 1970 (600m)
(FT, MSL)

DEPTH: 240 (73.1m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-13 (0-4.0m) — Clay, very silty, slightly sandy, poorly compacted, poorly cohesive, yellowish brown.

13-21 (4.0-6.4m) — Clay, silty, very sandy, moderately compact, moderately cohesive, yellowish brown, oxidized.

21-28 (6.4-8.5m) — Sand, very fine to medium predominantly a fine well sorted, well rounded, yellowish brown, oxidized.

28-40 (8.5-12.2m) — Clay, silty, sandy, very well compact, poorly cohesive, yellowish brown, oxidized.

40-62 (12.2-18.3m) — Silt, with very fine sands, drilling easy, yellowish brown, oxidized.

62-134 (18.3-40.8m) — Sand, very fine to medium predominantly a fine, well sorted, some lignite fragments, 100-120 feet abundant lignite, taking water, yellowish brown, oxidized.

134-162 (40.8-49.4m) — Clay; silty; sandy poorly compacted poorly cohesive, olive gray.

162-186 (49.4-56.7m) — Sand, very fine to medium, predominantly a medium, well sorted, well rounded, abundant lignite, olive gray, taking water.

186-210 (56.7-64.0m) — Gravel; sandy, 60% gravel, ranging from a medium sand to coarse gravel predominantly a fine gravel moderately to well sorted, rounded abundant quartz, taking water.

210-219 (64.0-66.7m) — Lignite

Sentinel Butte Formation

219-240 (66.7-73.2m) — Sand, very fine to medium, predominantly a fine, well sorted, well rounded, few lignite grains, some interstitial clays binding sand grains, greenish gray.

Observation Well

Depth: 193 (58.8m)
S.I.: 190-193 (58.0-58.8m)
Water Level: 83.09 feet
Measured: 12-21-78

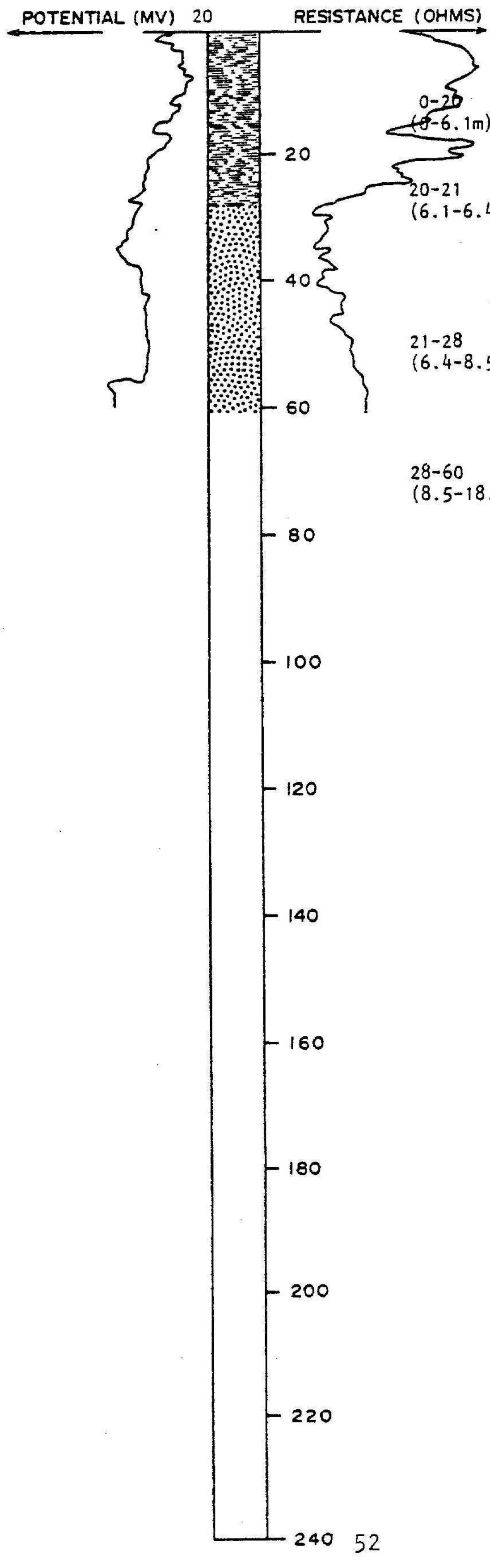
TEST HOLE 10374

LOCATION: T144N-R89W-14CCB

DATE DRILLED: 11-8-78

ELEVATION (FT, MSL): 1840 (560m)

DEPTH (FT): 60 (18.3m)



DESCRIPTION OF DEPOSITS

Alluvium

0-20 (0-6.1m) — Clay; very silty; very sandy, poorly compacted no cohesion, yellowish brown, oxidized.

20-21 (6.1-6.4m) — Gravel; sandy, 40% gravel, abundant lignite, scoria, poorly sorted ranging from fine sand to medium gravel, predominantly a very coarse sand well rounded to angular.

21-28 (6.4-8.5m) — Clay; very silty, slightly sandy, well compact poorly cohesive olive gray.

Sentinel Butte Formation

28-60 (8.5-18.3m) — Sand, very fine to medium, predominantly a fine, well sorted, well rounded few lignite grains, some interstitial clay binding sand, greenish gray.

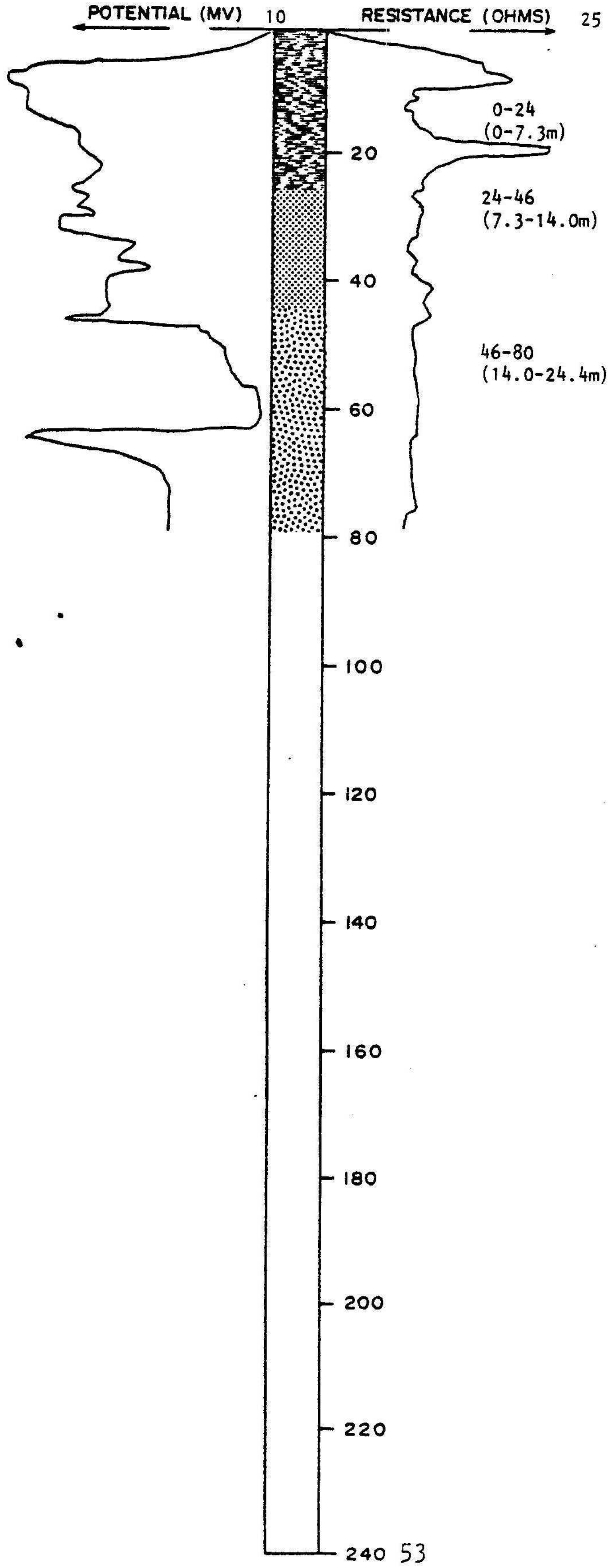
TEST HOLE 10373

LOCATION: T144N-R89W-23AAA

DATE DRILLED: 11-7-78

ELEVATION: 1845 (562m)
(FT, MSL)

DEPTH: 80 (24.4m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-24 (0-7.3m) — Clay, very silty, very sandy, poorly campacted no cohesion, yelowish brown, oxidized.

24-46 (7.3-14.0m) — Sand, with interbedded clays, also some small lenses of lignite, sand "dirty", clay similar to above, olive gray.

Sentinel Butte Formation

46-80 (14.0-24.4m) — Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some lignite, some interstitial clay binding sand, greenish gray.

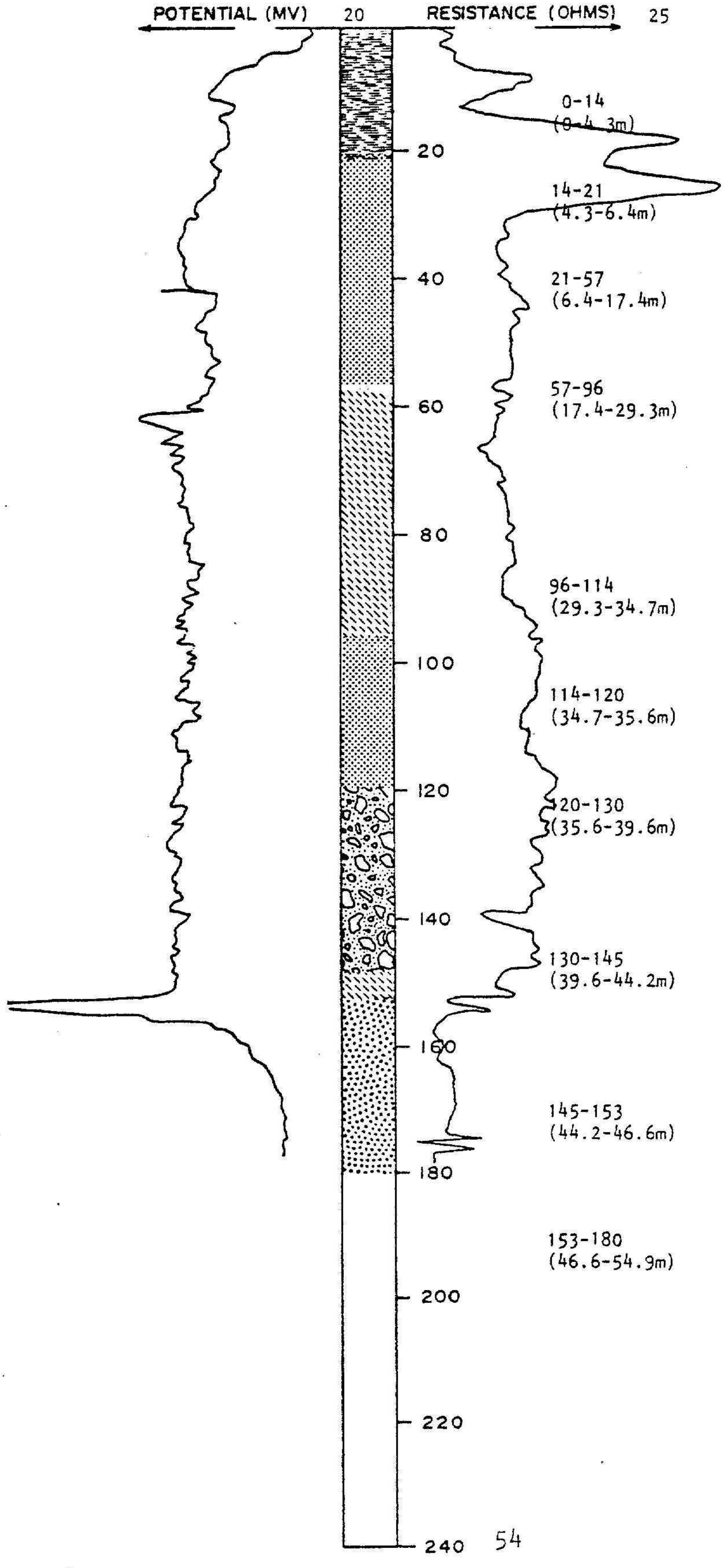
TEST HOLE 10372

LOCATION: T144N-R89W-23ACC

DATE DRILLED: 11-7-78

ELEVATION: 1843 feet (562m)
(FT, MSL)

DEPTH: 180 feet (54.9m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-14 (0-4.3m)	Clay, very silty, well compact, moderately to poorly cohesive, dark brown, oxidized.
14-21 (4.3-6.4m)	Clay, very silty, very sandy, well compact, poorly cohesive, yellowish brown, oxidized.
21-57 (6.4-17.4m)	Sand, very fine to medium, predominantly a fine, well sorted, well rounded, some lignite grains, yellowish brown, oxidized.
57-96 (17.4-29.3m)	Silt; clayey, poorly compacted no cohesion, drilling very easy and taking water, olive gray.
96-114 (29.3-34.7m)	Lignite, with interbedded clays, drilling like a gravel, clay similar to above.
114-120 (34.7-35.6m)	Sand, fine to very coarse, predominantly a very coarse, moderately to poorly sorted, subangular to rounded, abundant lignite
120-130 (35.6-39.6m)	Gravel; sandy, 80% gravel ranging from a coarse sand to medium gravel predominantly a fine gravel, well sorted, well rounded to angular, abundant silicates, some carbonates and shale.
130-145 (39.6-44.2m)	Gravel, medium to very coarse, predominantly a coarse, poorly sorted, well rounded, abundant shale, scoria, carbonates, hole caving, taking water, 1bag drilling mud used.
145-153 (44.2-46.6m)	Silt; clayey; slightly sandy, well compacted, poorly cohesive, light olive gray.

Sentinel Butte Formation

153-180 (46.6-54.9m)	Sand, very fine to medium, predominantly a fine, well sorted, well rounded, few lignite grains interstitial clays binding sand also some carbonaceous clays, greenish gray.

Observation Well

Depth: 121 feet (36.9m)
S.I.: 118-121 (36.0-36.9m)
Water Level: 31.35
Measured: 12-12-78

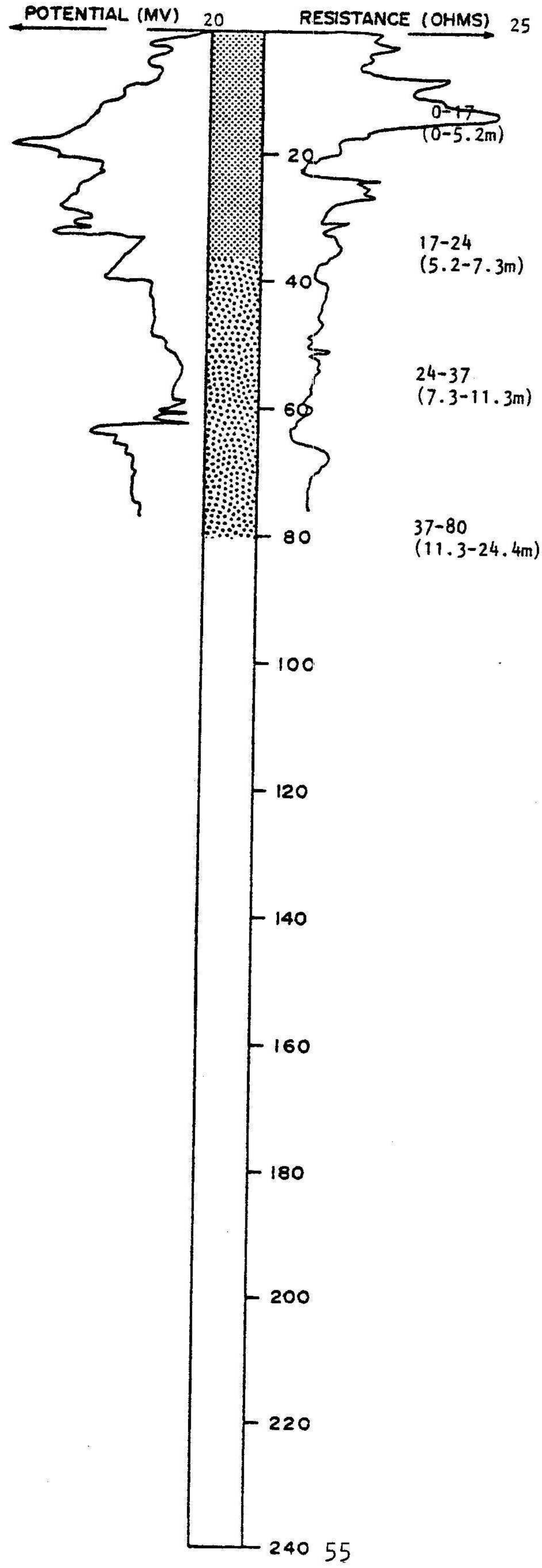
TEST HOLE 10371

LOCATION: T144N-R89W-23ABC

ELEVATION: 1835 feet (559m)
(FT, MSL)

DATE DRILLED: 11-7-78

DEPTH: 80'
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

Sand, very fine to very coarse, predominantly a coarse, poorly sorted, some small interbedded clay lenses, yellowish brown, oxidized.

Sand similar to above, yet "clean" no interbedded clays, sand predominantly a coarse well rounded to angular, some scoria fragments, yellowish brown, oxidized.

Sand with interbedded clays, some gravel, overall sand "dirty" predominantly a medium sand, well rounded, poorly sorted, olive gray.

Sentinel Butte Formation

Sand, very fine to medium predominantly a fine, well sorted, well rounded few lignite grains, some interstitial clay binding sand . grains, greenish gray.

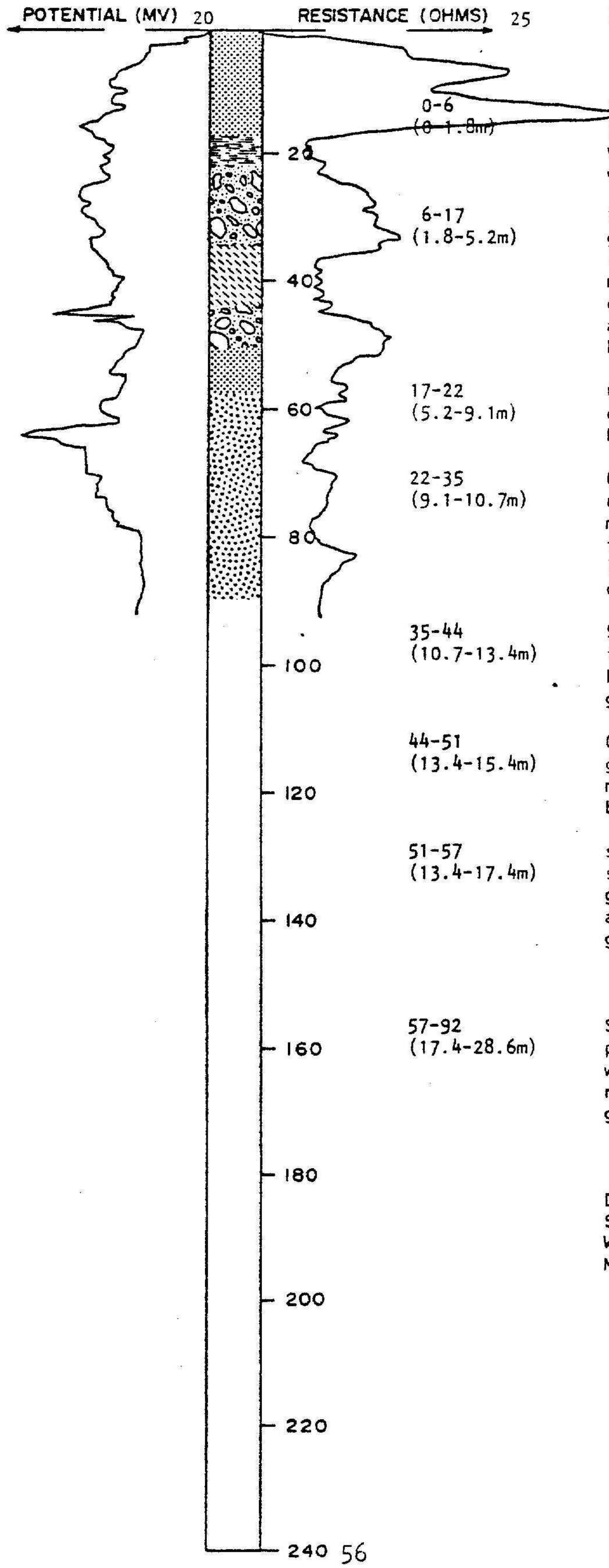
TEST HOLE 10370

LOCATION: T144N-R89W-23ABB

DATE DRILLED: 11-7-78

ELEVATION: 1835 feet (559m)
(FT, MSL)

DEPTH: 92 ft. (28.0m)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-6
(0-1.8m)
Sand, very fine-to medium-grained, predominantly a fine, well rounded, well sorted, yellowish brown, oxidized.

6-17
(1.8-5.2m)
Sand with abundant lignite, some gravel, about 25%, poorly sorted, ranging from a fine sand to medium gravel, predominantly a coarse sand, angular to rounded, abundant carbonates, yellowish brown, oxidized.

17-22
(5.2-9.1m)
Clay, carbonaceous, well to moderately compact, moderately cohesive, olive gray to brown.

22-35
(9.1-10.7m)
Gravel; sandy, some detrital lignite. Range from a medium sand to medium gravel, predominantly a fine gravel, poorly sorted, angular to well rounded, abundant carbonates.

35-44
(10.7-13.4m)
Silt; clayey; slightly sandy, well to moderately compact, poorly cohesive, olive gray to greenish gray.

44-51
(13.4-15.4m)
Gravel; sandy, abundant lignite, gravel predominantly a fine, moderately sorted, abundant carbonates, angular to well rounded.

51-57
(13.4-17.4m)
sand; somewhat gravely; slightly silty, range from fine-to medium grained sand, poorly sorted, angular to well rounded, olive gray.

Sentinel Butte

57-92
(17.4-28.6m)
Sand, very fine-to medium-grained, predominantly a fine, well sorted, well rounded, some detrital lignite, some interstitial clays, greenish gray.

Observation Well

Depth: 47 ft. (14.3m)
S.I.: 44-47 (13.4-14.3m)
Water Level: 16.63 feet
Measured: 12-21-78

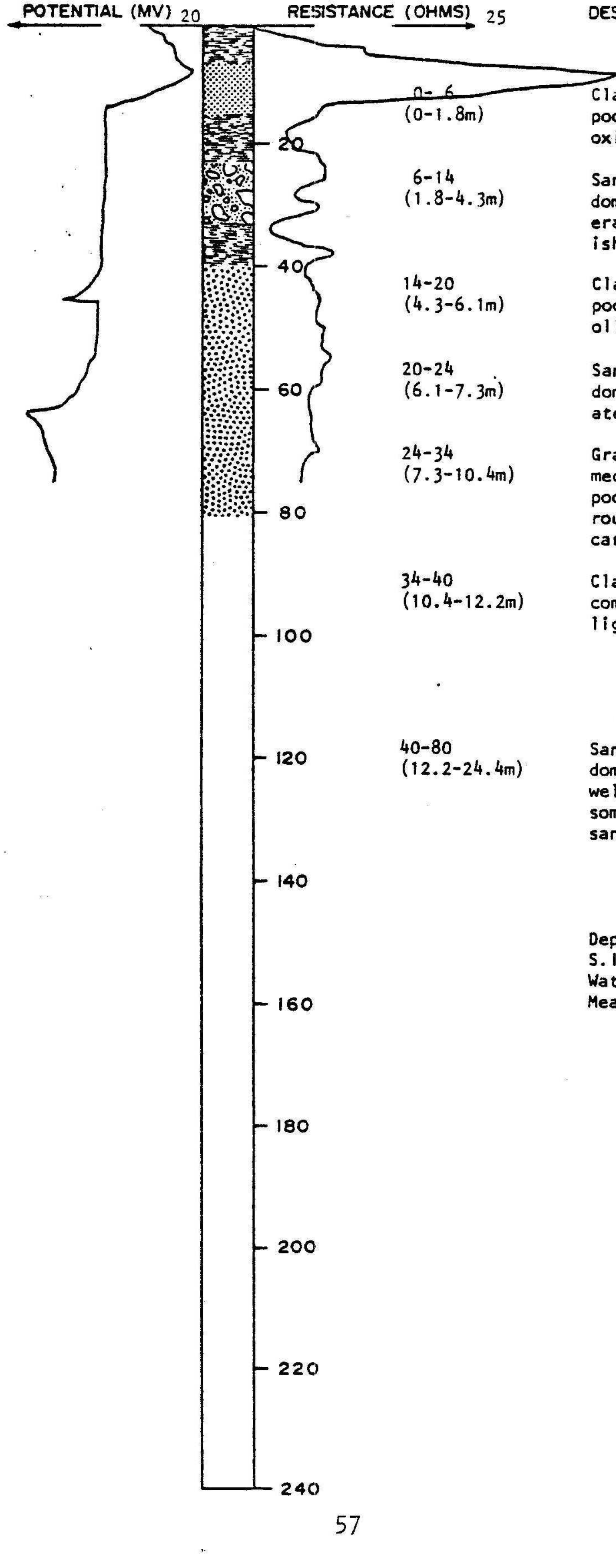
TEST HOLE 10369

LOCATION: T144N-R89W-23BAB

DATE DRILLED: 11-7-78

ELEVATION: 1838 (560m)
(FT, MSL)

DEPTH: 80 feet (24.4M)
(FT)



DESCRIPTION OF DEPOSITS

Alluvium

0-6 (0-1.8m) — Clay, very silty, poorly compact, poor cohesion, dark brown, oxidized.

6-14 (1.8-4.3m) — Sand, very fine to coarse, predominantly a coarse sand, moderately to poorly sorted, yellowish brown, oxidized.

14-20 (4.3-6.1m) — Clay, very silty, sandy, very poorly compacted, poorly cohesive, olive gray to black.

20-24 (6.1-7.3m) — Sand, very fine to coarse, predominantly a medium sand, moderately sorted, olive gray.

24-34 (7.3-10.4m) — Gravel; sandy, ranging from a medium sand to coarse gravel, poorly sorted, abundant lignite, rounded to subangular, some shale, carbonates and silicates.

34-40 (10.4-12.2m) — Clay, silty, very sandy, poorly compacted, poor cohesion, some lignite fragments, olive gray.

Sentinel Butte Formation

40-80 (12.2-24.4m) — Sand, very fine to medium, predominantly a fine, well sorted, well rounded, few lignite grains, some interstitial clay binding sand grains, greenish gray.

Observation Well

Depth: 23 (7.0m)
S.I.: 20-23 feet (6.1-7.0m)
Water Level: 0.73 feet (0.24m)
Measured: 12-21-78

T144N-R89W-23ABC1
Auger Hole M-68-2

Geologic Source	Material	Thickness (feet)	Depth (feet)
Alluvium:			
	Sand, fine- to medium-grained, dark-yellowish-brown-----------------------	13	13
	Sand, fine- to medium-grained, light-olive-gray----------------------------	29	42
Tongue River Formation:			
	Sandstone and siltstone, fine-grained, light-olive-gray----------------------	16	58

T144N-R89W-23BDA
Auger Hole M-68-1

Dated Drilled: 1968

Geologic Source	Material	Thickness (feet)	Depth (feet)
Alluvium:			
	Silt, clayey, sandy, dark-yellowish-brown---------------------------------	7	7
	Sand, fine grained, silty, dark-yellowish-brown-----------------------	13	20
Glacial Drift:			
	Till, pebbly, dark-yellowish-brown-----	2	22
	Sand, fine- to medium-grained, pebbly, dark-yellowish-brown------------------	3	25
	Sand, fine-grained, silty-------------	32	57
Tongue River Formation:			
	Siltstone, clayey, sandy---------------	2	59

T144N-R89W-14DC1
(Log from Northern Pacific Railway)

Geologic Source	Material	Thickness (feet)	Depth (feet)
	Clay, Sandy	22	22
	Sand	2	24
	Shale	18	42
	Shale, sandy, gray	34	76
	Sandstone, hard	3	79
	Rock, hard, dry	3	82
	Clay, sandy, gray	36	118
	Coal	3	121

T144N-R89W-23ABB
Auger Hole M-68-3

Geologic Source	Material	Thickness (feet)	Depth (feet)
Alluvium:			
	Sand, fine- to medium-grained, dark yellowish brown; pebbly at 20 ft.	25	25
	Sand, fine- to medium-grained, light olive gray	13	38
Tongue River Formation:			
	Siltstone, sandy, clayey, dark greenish-gray	6	44

T144N-R89W-23CB
(Log from Bandy Drilling Co.)

Material	Thickness (feet)	Depth (feet)
Surface soil	19	19
Shale, blue	63	82
Sand	42	124
Shale, blue	322	446
Sand	74	520
Shale, blue	170	690
Hard rock	5	695
Shale, blue	255	950
Sand	15	965
Shale, blue	55	1020
Water, sand	27	1047
Shale, blue	13	1060

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