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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D. C. 20242

AVAILABILITY AND QUALITY OF WATER FROM THE DAKOTA AQUIFER, NORTHWEST IOWA

GEOLOGICAL SURVEY OPEN FILE REPORT 82-264

PREPARED IN COOPERATION WITH THE
IOWA GEOLOGICAL SURVEY

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JAMES G. WATT, SECRETARY

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DALLAS L. PECK, DIRECTOR

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by M. R. Burkart

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SELECTED FACTORS FOR CONVERTING

INCH-POUND UNITS TO THE INTERNATIONAL

Mulitiply inch pound unit	By	To obtain SI unit
acre	4047.0	square meter
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
gallon	0.0038	cubic meter
gallon per day	0.0038	cubic meter per day
gallon per minute	0.0038	cubic meter per minute
gallon per minute per foot	0.0124	meter squared per minute
inch	25.4	millimeter
micromho	1.0	microsiemens

Availability and Quality of Water from the Dakota Aquifer, Northwest Iowa

M. R. Burkart

ABSTRACT

The Dakota aquifer in northwest Iowa consists of sandstones in the Dakota Formation. It underlies most of the study area and is the most extensive source of ground water in the area. Individual sandstone beds are from less than 10 to more than 150 feet thick. The cumulative thickness of sandstone is more than 200 feet throughout much of the area. The aquifer is confined by overlying Cretaceous limestone and shale, Quaternary glacial deposits and loess. The underlying confining material is shale of the Dakota Formation, undifferentiated Paleozoic age rocks, or Precambrian crystalline rock.

Water flows through the aquifer from the north-central part of the study area to the east, south and southwest. Recharge is dominantly by infiltration from the land surface through the confining materials. Discharge is to underlying Paleozoic aquifers and to the alluvium and glacial outwash deposits along the Missouri and Big Sioux Rivers in the southwest part of the area. Flow components toward bedrock valleys may reflect discharge to Quaternary sand and gravel deposits in these valleys.

Pumping tests conducted in the study area indicate a narrow range of hydraulic conductivities of the Dakota aquifer, from 37 to 50 feet per day. Consequently, an average hydraulic conductivity of 40 feet per day was used to estimate the potential yield to wells completed in the aquifer. Yields of more than 250 gallons per minute can be expected throughout much of the study area and more than 1000 gallons per minute could be produced in some areas.

The quality of water from the Dakota is a calcium, magnesium, sulfate type. It is generally suitable for irrigation purposes, based on comparisons of sodium adsorption ratios and electrical conductivities. In some areas the aquifer has water with high salinity hazard that may restrict its use to irrigation of only well drained types of soil. The concentration of radium-226 and other radionuclides exceed recommended limits at several sites.

The quality of water pumped from the aquifer may be altered by induced leakage from the underlying aquifers in Paleozoic age rocks if withdrawals reverse the pattern of natural flow from the Dakota into the Paleozoic aquifers. Evidence for such a reversal exists in the area around the city of LeMars.

INTRODUCTION

Scope and Purpose of Project

This project was a cooperative project between the Iowa Geological Survey and the United States Geological Survey and included 16 counties in northwestern Iowa: Buena Vista, Calhoun, Cherokee, Clay, Dickinson, Emmet, Ida, Lyon, O'Brien, Osceola, Palo Alto, Plymouth, Pocahontas, Sac, Sioux, and Woodbury Counties (figure 1). The project included; (1) a study of the water resources of the Floyd River Basin (Wahl, Meyer and Karsten, 1981); (2) an evaluation of the regional geologic setting (Ludvigson and Bunker, 1979): and (3) an appraisal of the availability and quality of water from the Dakota aquifer, (this report). A report of geologic and pumping test information from the Dakota aquifer is being prepard by the Iowa Geological Survey (Jim Munter, written communication August, 1981).

The purpose of the project was to evaluate the availability and quality of ground-water resources in northwest Iowa. The project was began in August 1976, during a drought, in response to an increase in demand for information on sources of irrigation water in northwestern Iowa. This demand posed questions about the availability and quality of ground water in the area which could not be answered by using available information.

Scope and Objectives of Report

This report is a regional appraisal of the availability and chemical quality of water from the Dakota Formation in the project area. Adjacent geologic units were empirically evaluated to determine their influence on the Dakota aquifer flow system. Hydrologic interpretations in this report are based on data from existing wells and test holes drilled for this project, and include lithologic logs, geophysical logs, drillers logs, water-level measurements in observation wells and chemical analyses of samples of ground water. The objectives of this report are to (1) define and describe the location, extent and characteristics of the Dakota aquifer, (2) evaluate the occurrence, movement, recharge and discharge of water in the aquifer, (3) estimate the potential yields to wells penetrating the aquifer, and (4) describe the chemical quality of the water obtained from the aquifer.

Acknowledgments

Collection of data for this report was made possible by the cooperation of residents of northwest Iowa, municipal water superintendents in the area, the staffs of the Iowa Department of Environmental Quality and the Iowa Natural Resource Council. Darwin Evans of the Iowa Geological Survey drilled and developed the observation wells and provided most of the sample descriptions of the test holes. Jim Munter of the Iowa Geological Survey contributed to the interprtation of the geohydrology of the area and provided a thorough and helpful

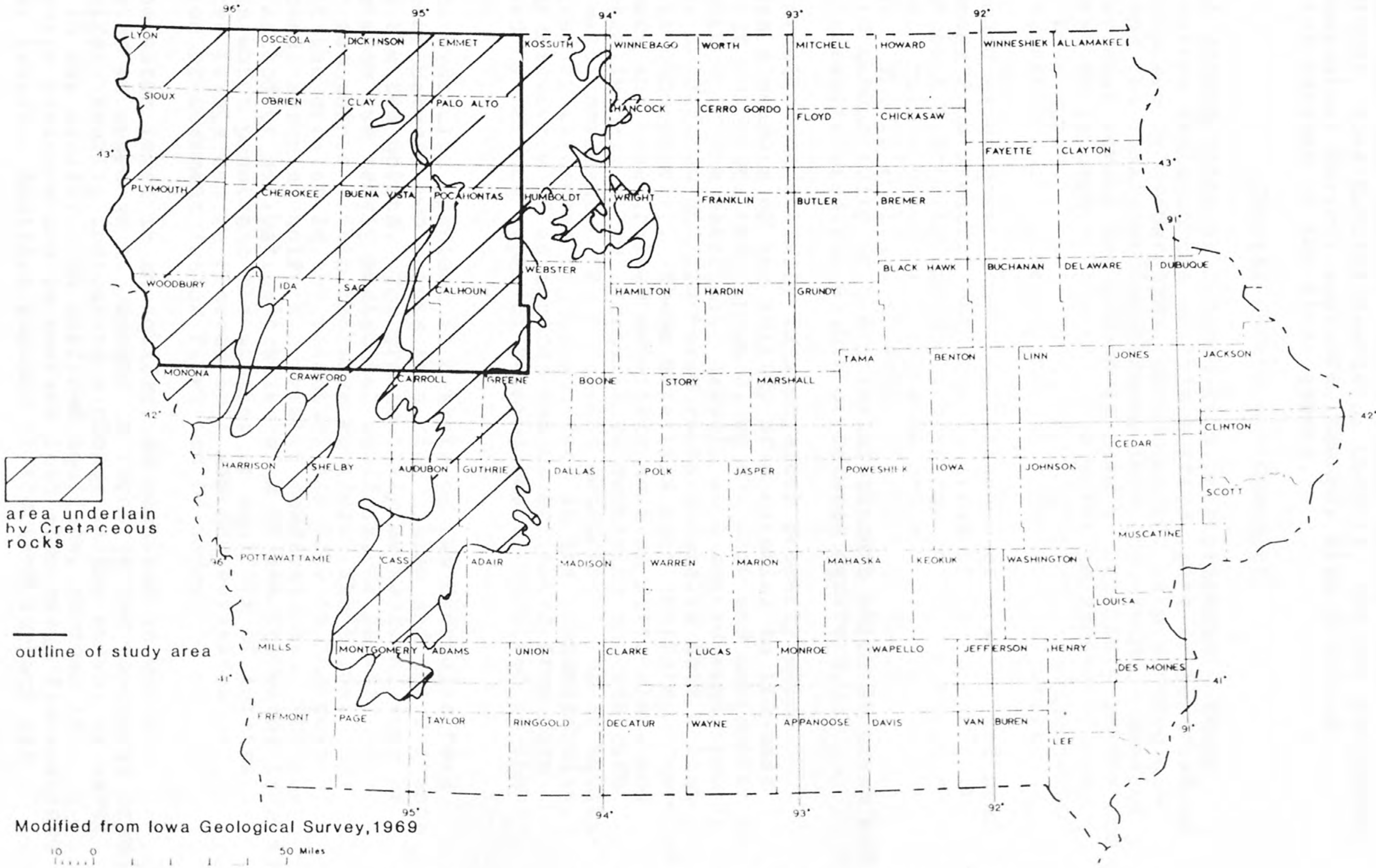

Figure 1. Location of Cretaceous rocks in Iowa and location of the study area.

review of the final report. Jim Wiegand, Deputy Water Commissioner, Iowa Natural Resources Council, and Don Jorgensen, U.S. Geological Survey, Lawrence, Kansas, also provided thoughtful reviews of the final report.

General Hydrologic Concepts

All ground water is derived from precipitation. After precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, part runs off into streams and lakes, and the remainder infiltrates into the ground. Some of the water that enters the ground is held by capillary action and evaporates or is used by plants. The water in excess of the near-surface demand of soil and plants infiltrates downward to the water table and ultimately becomes available to wells.

Ground water moves under the influence of gravity and head differences from areas of recharge to areas of discharge. It moves through fractures and small openings among grains of soil and rock. This movement is very slow and may be only a few feet per year. The rate of ground-water movement is governed by the hydraulic conductivity of the material through which it moves and by the hydraulic gradient within or between aquifers.

Hydraulic conductivity is a physical property which expresses a measure of the ability of a material to transmit water. It is determined, in part, by the size and connection of the openings in the material. Gravel, well-sorted sand, poorly cemented sandstones and fractured rocks generally have a high hydraulic conductivity. These materials form aquifers. Cemented sandstones and fine-grained materials such as silt, clay, and shale usually have a low hydraulic conductivity and restrict ground-water movement. The hydraulic conductivity of an aquifer multiplied by thickness of the aquifer is the transmissivity. The transmissivity of an aquifer can be estimated from data collected by various types of pumping tests conducted in the field.

The hydraulic gradient is a ratio of the hydraulic head difference between two points in a flow system and the distance between the two points. The gradient may be vertical such as that between two nearly horizontal aquifers, or lateral as between two points within the same aquifer. The higher the gradient the greater is the potential for flow to the point of lower head, assuming uniform hydraulic conductivity. The most common method of evaluating gradients is to measure water levels in wells which penetrate the aquifer or aquifers of interest. The water levels can be plotted on a map and estimates of direction of movement (water flow) can be made.

The water level in an aquifer, as measured in wells, fluctuates in response to changes in recharge and discharge from the aquifer, usually indicating a change in the amount of water stored in the aquifer. In confined aquifers, changes in atmospheric pressure and in surface load also cause fluctuations in water levels. Aquifers exposed at the land surface are recharged by direct infiltration of precipitation and snow melt. Aquifers that are confined by thick deposits of fine-grained materials are recharged at very slow rates by leakage from above or below through the fine-grained confining materials. The rate of recharge to an aquifer may increase as water levels in the aquifer are lowered by pumping. This induced recharge is a result of increasing the hydraulic gradient toward the pumped aquifer in the area around a well or wells. However, water levels in the aquifer may decline for several years before sufficient recharge is induced to balance the rate of withdrawal. In some places this balance may never be achieved without curtailment of withdrawals.

Throughout much of the project area potholes, lakes or rivers are important sources of recharge to the ground-water system. The retention of rainfall, snowmelt and runoff in potholes and lakes recharges aquifers in which the water level is below the surface water level. In addition, because many of these surface-water features receive water from the local water table during periods of low precipitation, attempts to drain the features will lower the water table in the area. The effects of altering these potholes and lakes may not be seen for many years, but, because seepage from lakes and potholes is a major source of recharge water, the ultimate effect of a reduction in surface-water storage will be a reduction in availability of ground water.

The suitability of water for various uses usually is determined by the kind and amount of dissolved material it contains. The chemical constituents, physical properties and indices most likely to be of concern are: iron, sulfate, nitrate, fluoride, chloride, total dissolved solids, hardness, temperature, odor, taste, specific conductance, sodium-adsorbtion ratio (SAR), and percent sodium. The major chemical constituents, their effects on usability, and the recommended limits are given in table 1. Additional information regarding drinking-water standards may be found in "Water-Quality Criteria, 1972", published by the U.S. Environmental Protection Agency (National Academy of Sciences-National Academy of Engineering, 1973).

In this report, references are made to ground-water types, such as calcium sulfate and calcium bicarbonate types. These types are derived from inspection of the water analyses and represent the predominant cation (sodium, calcium, or magnesium) and anion (sulfate, bicarbonate, or chloride), expressed as milligrams per liter (mg/L).

The quality of water used for irrigation is an important factor in productivity and in quality of the irrigated crops. Irrigation classifications were determined from selected water samples from the Dakota aquifer in the project area, using a classification system developed by the U.S. Salinity Laboratory Staff (1954). This classification compares the sodium hazard, as measured by the sodium adsorbtion ratio, and the salinity hazard, as measured by the conductivity. The conductivity is an electrical property of the water which is approximately proportional to the total dissolved solids content of water. The sodium adsorption ratio (SAR) is a ratio of the sodium concentration to the calcium and magnesium concentrations measured in equivalents per million.

The type of water suitable for irrigation will depend to some degree upon the type of soil and crop to which the water will be applied. However, water with a medium to very high salinity hazard or sodium hazard may be suitable for only a limited range of irrigation uses.

Location-Numbering System

The location-numbering system used in this report is based on the system of land survey used by the U.S. Bureau of Land Management and the Iowa District of the U.S. Geological Survey. The first number indicates the township north of a base line, the second number indicates the range west of the fifth principal meridan, and the third number indicates the section in which the well is located. The letters A, B, C, and D designate the northeast, northwest, southwest and southeast quarters of a section or quarters of any smaller square area of a section. The letters following the section number are in order of decreasing areal size from left to right. The first letter designates the 160 acre quarter, the second designates the 40 acre quarter, the third designates the 10 acre quarter and the fourth designates the 2 1/2 acre quarter. For example, well 87-44-15CBBD is in the the SE 1/4 of the NW 1/4 of the NW 1/4 of the SW 1/4 of section 15, in township 87 north and range 44 west. Consecutive sequence numbers are added if more than one well is located in the same tract.

GEOLOGIC DESCRIPTION OF THE DAKOTA AQUIFER

Stratigraphic Position

The Dakota aquifer is defined, for this report, as the saturated sandstone which constitutes part of the Dakota Formation. The Dakota Formation comprises the oldest rocks of Cretaceous-age recognized in northwest Iowa, and lies unconformably on Paleozoic and Precambrian rocks. The relative position of geologic units with the oldest at the bottom is shown in figure 2. In the western part of the study area, the Dakota Formation is conformably overlain (from oldest to youngest) by the Graneros Shale, Greenhorn Limestone, and Carlile Shale all of the Cretaceous age. However, throughout more than 80 percent of the project area the Dakota Formation is overlain by Quaternary deposits consisting of glacial till, loess, sand, and gravel.

The top of the Dakota Formation is generally difficult to determine from drill-hole cuttings. The shale in the upper part of the Dakota Formation is similar to the shale which constitutes the overlying Graneros Shale. It is only where the top of the Dakota Formation consists of sandstone that the top can be picked with reasonable certainty. The Dakota Formation is the only Cretaceous formation in Iowa which includes sandstone. Because the Graneros Shale and shale in the upper part of the Dakota Formation are similar, it is not essential to determine the top of the Dakota for hydrologic purposes where it is a shale.

For this report, the top of the Dakota aquifer is defined in most areas as the first sandstone below the Greenhorn Limestone or, where the Greenhorn is not present, the first sandstone below the bedrock top. Where a Quaternary sand or gravel is in contact with a sandstone in the Dakota aquifer, the top of this sand or gravel is the top of the aquifer and is included in the total thickness of the aquifer.

The base of the Dakota aquifer is the bottom of the lowest sandstone in the Dakota Formation. In many areas the base of the aquifer conforms to the pre-Cretaceous surface shown on plate 1.

Distribution of Materials

Three groups of rock types have been recognized in the Dakota Formation in the study area. These are; (1) sandstone, (2) shale and siltstone, and (3) a group consisting of approximately equal parts of thin-bedded shale, siltstone and sandstone (Whitley, 1980). The sandstone group is commonly found at or near the base of the Dakota Formation whereas the shale and siltstone group is found near the top (Whitley, 1980; Ludvigson and Bunker, 1979). Between the sandstone group and the shale and siltstone group are thin-bedded sandstone, siltstone and shale beds. This intermediate group is both laterally and vertically transitional with the sandstone and shale groups.

The distribution and composition of sandstone bodies in

ERATHEM	SYSTEM	FORMATION
CENOZOIC	QUATERNARY	
	CRETACEOUS	Carlile Shale
		Greenhorn Limestone
		Graneros Shale
		Dakota Formation
PALEOZOIC	PENNSYLVANIAN	Undifferentiated
	MISSISSIPPIAN	
	DEVONIAN	
	SILURIAN	
	ORDOVICIAN	
	CAMBRIAN	
PRECAMBRIAN		Sioux Quartzite

Figure 2. Geologic units used in this report

the Dakota Formation is of primary concern in this report. The cross sections on plate 2 and the total sandstone-thickness map on plate 3 are included to show the regional distribution and position of major sandstone units. However, significant local variations from the regional trends in total sandstone thickness may exist throughout the study area.

The sandstone comprising the Dakota aquifer occurs in beds which range from less than 10 feet to more than 150 feet thick. Beds less than 5 feet thick were not included in the total thickness of the aquifer. The base of the Dakota Formation is generally sandstone with a basal shale occuring more frequently in the eastern part of the study area than in the west (plate 2). Generally more shale occurs in the upper part of the Formation. Where a complete section of the Dakota Formation exists, particularly along the western part of the study area, the uppermost sequence includes a few sandstones, most of which are very thin or contain significant quantities of material finer than sand size. Because the sandstone units are frequently separated by shale or siltstone, the potential for water exchange among the sandstone bodies is restricted by the thickness, extent and hydraulic properties of the interbedded material. This factor is particularly important when considering local flow systems. However in evaluating the regional flow system, the sandstones are considered as a unit.

The individual sandstone beds are composed of from fine to coarse sand, some gravel, and variable amounts of silt and clay. Coarse sand is very common, particularly in the lower part of the formation. Sandstone beds are generally coarser grained near the top than near the base (Whitley, 1980) although some are finer grained upward. Sorting of grain sizes within the sandstone bodies likely results in greater hydraulic conductivity than that expected of poorly sorted sandstones. Sample descriptions indicate very little cementation of the sandstone. The sandstone is occasionally interbedded with siderite (iron carbonate) and contains abundant pyrite (iron sulfide) nodules in some locations. Siderite may be incorrectly described as dolomite in some of the logs in table 2.

The thickness of sandstone in the aquifer appears to be related to the pre-Cretaceous and bedrock topographic surfaces. The surface mapped on plate 1 was drawn to conform with the Precambrian surface in southern Minnesota (Anderson and others, 1976). The bedrock topographic surface on plate 4 was drawn to match the preglacial topography (Anderson, and others, 1976) and the bedrock topography immediately east of the study area (Hansen, 1978).

The thickest (more than 200 feet) sandstone sequences (plate 3) in the Dakota aquifer are associated with the elongate depressions in the pre-Cretaceous surface (plate 1). Major areas of thick sandstone include; north central Plymouth County, central and southern Sioux County, central Woodbury County, west-central Cherokee County and northeastern O'Brien County northeast into Dickinson County. In many of the areas where the bedrock surface (plate 4) intersects the Dakota aquifer, bedrock valleys coincide with a decrease in total sandstone thickness. For example, plate 4 shows a relatively deep bedrock valley in eastern Woodbury and southeastern Plymouth Counties and plate 3 shows a significant change in sandstone thickness in the same area. The bedrock valley is also shown on section C-C', plate 2, between test wells 88-44-06BAAB and 87-41-05CCCC. Other bedrock depressions and valleys shown in sections A-A' and B-B' illustrate the coincidence in sandstone thickness and bedrock valleys.

The areas on plate 3 outlined by the zero (0) contour line are where the Dakota aquifer does not exist because of non-deposition or lack of sandstone. These areas include the bedrock channel in eastern Woodbury County and the long narrow bedrock channel which extends through much of the eastern third of the study area (plate 4). Also included is the Manson area of anomalous crystalling rocks (Hoppin and Dryden, 1958 and Holtzman, 1970) in southeastern Pocahontas and northeastern Calhoun Counties and an area in the extreme northwestern part of Lyon County where Precambrian age rocks form the bedrock surface.

The extent and influence of Quaternary sand and gravel deposits on the hydrology of the Dakota aquifer are poorly defined. Data from test holes located at 87-44-15CBBB1 and 96-34-24BBB (table 2) show that these sand and gravel deposits are in direct contact with the Dakota aquifer. Because the bedrock valleys in the area are the result of Quaternary stream activity, there may be significant amounts of sand and gravel in hydrologic communication with the Dakota aquifer. Most test hole sites in the project area were chosen to evaluate only the Cretaceous sequence of rocks. Consequently, sites in areas outside the bedrock channels were given priority. If these channels contain significant amounts of sand and gravel they could provide an additional highly productive source of water.

Confining Materials

The Dakota aquifer is confined throughout most of the study area by overlying shale in the Dakota Formation, other Cretaceous-age shale and limestone and Quaternary clay and till. These materials are distinctly less permeable than the sandstone which comprises the aquifer. Till is poorly sorted glacial sediment composed of clay, silt, sand, gravel, and boulders. The shales overlying the aquifer include the mudrock (claystone, silty clay shale, and clayey siltstone) of the Dakota Formation described by Whitley (1980), and the calcareous clay shales of the Graneros Shale and the Carlile Shale. Some characteristics of the materials overlying the aquifer are described in table 2 and a general description of the Cretaceous materials are presented in Whitley (1980) and Whitley and Brenner (1981). On plate 3, adjacent to each data point is the depth to the first Cretaceous sandstone at the top of the Dakota aquifer. This value can be used to estimate the total thickness of the overlying confining materials in many areas. However, because the Quaternary material has not been fully investigated there are areas which may have significant deposits of gravel and sand which would act as aquifers above the Dakota aquifer, particularly where the Quaternary materials fill a bedrock valley.

The confining material beneath the Dakota aquifer cannot be adequately evaluated from existing data. However, the underlying material consists of shale or mudrocks in the Dakota Formation and limestone, dolomite, shale and sandstone of Paleozoic age and crystalline rocks of Precambrian age. Cross sections in Ludvigson and Bunker (1979) show a general southeast inclination of the Paleozoic strata. Therefore, the first rock units encountered beneath the Dakota Formation are successively younger toward the southeast. There are several sites where observation wells were initially completed to aquifers (sandstones and carbonates) in the uppermost Paleozoic unit. These wells were later plugged back and perforated in the Dakota aquifer. Also some test hole sites have two wells, one completed in the Dakota aquifer and one completed in an underlying Paleozoic aquifer. With the exception of a site near LeMars, at all these locations the water levels were the same or higher in the Dakota aquifer than in the Paleozoic aquifers. The difference does not exceed 4 or 5 feet at any location but the difference is widely distributed throughout the project area.

WATER AVAILABILITY AND MOVEMENT

Distribution of Potential Head and Ground-water Flow

The areal distribution of the level to which water would rise in a well completed in the Dakota aquifer is shown on the potentiometric map (plate 5). The data used to make this interpretation are water levels measured during the calendar years 1979 and 1980 in observation wells drilled for this project and private wells measured during November, 1979. Representative water levels reported by drillers and pump contractors were also considered, particularly in areas where no other information was available.

The water levels measured in wells drilled for this project are listed in table 3. The records included in this table are not sufficient for an evaluation of long-term changes in the aquifer but they provide the basis for the areal interpretations in this report.

The wells from which data were used to produce the map on plate 5 were completed in various sandstones in the Dakota aquifer. It is probable that all the sandstones are hydraulically related, however the hydraulic head may vary among sandstones at any site. For this reason the potentiometric map presented here may contain some local variations due to the completion of the individual wells. Therefore the map represents an interpretation of the regional flow and not necessarily details of local flow in the aquifer.

Lateral water movement in the aquifer is generally from the north-central part of the area to the southwest, south and east. The higher water levels are in the uplands of the north and lower water levels are mostly near the Big Sioux river along the southwestern border. Stream altitudes, were determined from 7-1/2 minute series topographic maps at several points along the Big and Little Sioux, Rock, Raccoon, Des Moines, and Floyd Rivers (plate 5). These data along the Big Sioux River agree with extrapolated regional ground-water levels in the Dakota aquifer along the western edges of Woodbury and Plymouth Counties. In these areas the ground-water flow is directly toward and possibly into the Big Sioux River. At Sioux City, the aquifer directly underlies river alluvium and is exposed in the bluffs along the Big Sioux River. The flow may be directly into the stream or the surrounding alluvium in this area. The aquifer is under water-table conditions.

In Sioux and southern Lyon Counties the Big Sioux river recharges the aquifer. Water levels presented in this report indicate that the flow in the Dakota aquifer is toward South Dakota along this segment of the Big Sioux River.

On plate 5, upstream deflections in the regional potentiometric surface occur near the mouth of the Floyd and part of the Little Sioux Rivers. These deflections indicate flow toward the streams and bedrock valleys (plate 4). The altitude of the Little Sioux River through Cherokee County is consistently lower than the potentiometric surface of the Dakota aquifer (plate 5). This is evidence of a potential for ground-water movement upward into overlying aquifers and ultimately into the Little Sioux River. Municipal withdrawal between the 1160 and 1180 foot contours (plate 5) from Marcus to Alta may have some effect on this relationship. However, the amount of withdrawal has apparently not significantly altered the direction of movement and the water-level history is not adequate to determine the magnitude of any effects of withdrawal.

The deflections in regional potentiometric contours along the eastern part of the study area are a result of flow through the aquifer toward the area where the Cretaceous rocks are absent. A ground-water divide exists from western Pocahontas County to western Dickinson County and regional flow is generally east and southwest away from this divide. Water-level data from the eastern tier of counties are not extensive and much of these data are from drillers' reports rather than from measurements collected as part of this project. The extent of the Dakota aquifer is not well known in this area nor are the relationships with Quaternary deposits understood. In this area, the relatively small total thickness of sandstone in the Dakota Formation (plate 3) may result in a more complex potentiometric surface than that shown in plate 5.

It is assumed that there is flow from the upper sandstone beds to the lower ones within the Dakota aquifer throughout much of the study area. One area where this can be documented is in 98-39-26C where a group of observation wells were completed to monitor a pump test. Here the water level in a well completed in a shallow and thin Dakota sandstone (98-39-26CDAD2) is consistantly about two feet higher than that in another nearby observation well (98-39-26CDCC) completed in the deeper part of the Dakota aquifer. In addition, there are several locations where water levels have been measured in both the Dakota aquifer and underlying Paleozoic aquifers. With the exception of a site near LeMars, all the water levels in the wells penetrating the Dakota aquifer are higher than the water levels in wells completed in the underlying units. This downward head gradient probably is reversed in discharge areas such as along the Big Sioux River.

Hydrographs of four Dakota aquifer observation wells maintained by the United States Geological Survey are shown in figure 3. With the exception of the well at 89-47-22BADC2, they show an overall decline in water levels during the periods of record. The decline appears to be occurring at a relatively uniform rate indicating that the aquifer has not reached equilibrium with recharge and discharge conditions. The well at 89-47-22BADC2, near Sioux City, shows no regular pattern of decline. This may be a result of the water-table conditions in the aquifer in that area and the changes in pumping patterns at Sioux City.

It is possible that the long-term decline in water levels

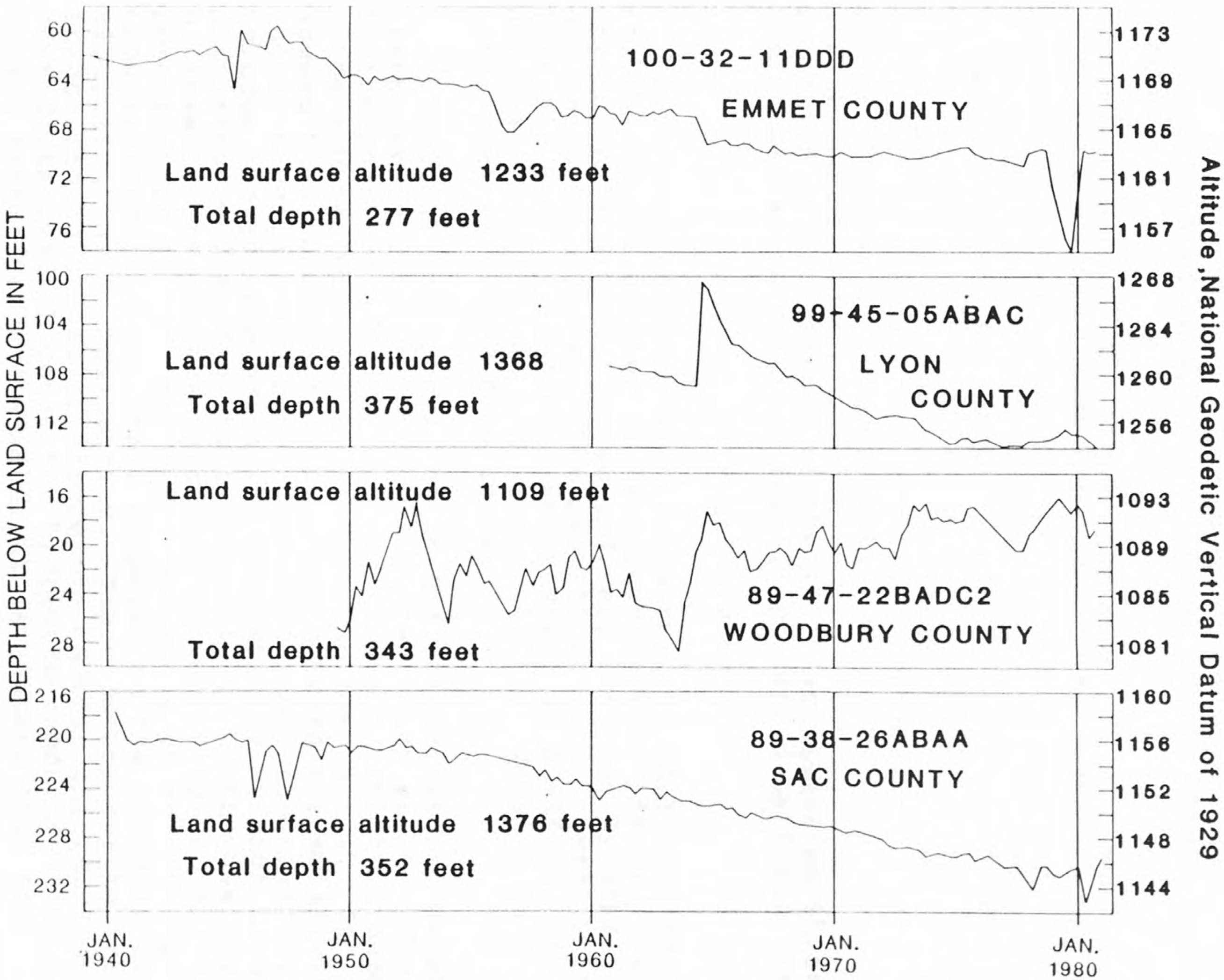

Figure 3. Hydrographs of selected observation wells in the Dakota aquifer

will continue at a reduced rate if the withdrawal from the aquifer remains at the existing level. Theoretically, a balance will be reached when water levels throughout the aquifer are reduced to the point where induced recharge due to pumping or decreased discharge compensates for withdrawal. However, if pumpage increases, water levels will continue to decline, perhaps at an accelerated rate, to even lower levels before a balance results.

Three of the hydrographs on figure 3 show anomalous water level changes during the 1964 record. Two hydrographs, 99-45-05ABAC and 89-47-22BADC2, show a sudden rise and hydrograph 100-32-11DDD shows a sudden decline shortly following the time of the March 1964 Alaskan earthquake. The sudden and long lasting change in water levels in these wells may have been caused by reorientation of aquifer materials and confining units, resulting in changes in porosity and hydraulic conductivity The change was not the same in all observation wells because of variations in textures of sandstone which comprise the aquifer. A discussion of the effects of the 1964 earthquake on these and other observation wells in Iowa is presented by Coble (1965).

Transmissivity

Data used to calculate transmissivity have been collected from the Dakota aquifer at five pumping test sites. These pumping tests were conducted and (or) analysed by staff of the Iowa Geological Survey. The results of three tests, Hanson at 97-46-28; Ritz at 92-47-31; and Hosteng at 87-35-30, are published in Ludvigson and Bunker (1979). Table 4 is a summary of the results of all five tests.

Regional interpretation of the transmissivity depends on interpolation between points where test data exist. The method of interpolation used in this report was to relate transmissivity to the aquifer material at the pumping test sites. It was assumed that observed relationships between transmissivity and aquifer materials are consistent throughout the aquifer. Table 4 includes the average hydraulic conductivity at each site, calculated by dividing the transmissivity by the average thickness. The average hydraulic conductivity for all sites is approximately 40 feet per day. The range of average hydraulic conductivities is very small compared to the possible errors in calculating the transmissivity. These errors may be very large because the thickness of the Dakota aquifer changes locally over short distances. Because the hydraulic conductivities at all the pumping test sites are similar it is assumed that the conductivity of the Dakota aquifer is regionally uniform. To obtain an estimate of the transmissivity of the aquifer in any area, multiply the sandstone thickness shown on plate 3 by the average hydraulic conductivity (40 feet per day). This is an intermediate calculation used to estimate the potential yield discussed later and shown on plate 6. Because this report is a regional appraisal of the Dakota aquifer, only approximate conditions are presented in untested areas. A more detailed analysis may be needed to precede any specific development plans.

Table 4. Summary of pumping test results in the study areas.

Location	Transmissivity (feet squared per day)	Average Thickness of Dakota Aquifer (feet)	Average Hydraulic Conductivity (feet per day)
Hosteng Irrigation Site 87-35-30	4600	124	37
Ritz Irrigation Site 92-47-31	7600	157	48
Southern Sioux County Rural Water System, Inc. 93-45-04	7400	148	50
Hansen Irrigation Site 97-46-28	3900	89	44
Hibbing Irrigation Site 98-39-26	6400	162	40

Discharge and Recharge

Natural recharge to the Dakota occurs where the potentiometric surface is below a surface-water source or an aquifer which has a higher potentiometric surface. This source may be adjacent confined aquifers and overlying water table aquifers or surface-water bodies such as lakes, potholes, and streams. These sources may be positioned above, below or adjacent to the Dakota aquifer. Conversely, natural discharge occurs where the potentiometric surface of the Dakota aquifer is higher than other such surfaces. Exchange of water can occur directly, or through very thick confining layers. Rates of recharge and discharge will vary depending on the permeability and thickness of the confining layers, and the magnitude of the head differences.

Recharge occurs to the Dakota aquifer directly from precipitation where the Dakota aquifer is exposed at the land surface and from leakage from lakes, streams, and overlying aquifers. The potential for direct recharge of the Dakota aquifer from streams in the study area is limited to the area near the Big Sioux River in Plymouth and northern Woodbury counties. The recharge here is limited to areas where sandstone in the Dakota aquifer outcrops and occurs only when stream levels are above the sandstone exposures. However, the regional flow pattern shown on plate 5 indicates potential for discharge to the stream exceeds any local or short-term recharge in that area.

Recharge to most of the Dakota aquifer is indirectly from the water table through confining material or from aquifers overlying the Dakota aquifer. Because the confining materials, mostly shale, till and loess, have a very small hydraulic conductivity, the rate of recharge is very small. The rate at which water enters the Dakota aquifer depends upon; (1) the hydraulic conductivity of the confining material, (2) the thickness of the confining material, and (3) the difference in altitude between the water table and the potentiometric surface of the Dakota aquifer.

In the absence of a detailed analysis of the confining material it is difficult to assess the volume of recharge. However, for a regional analysis a range of recharge volume can be approximated. The rate of flow through the confining layer can be expressed as (Bredehoeft and Pinder, 1970):

$$q=K'(h-h')/l$$

where:

- q= rate of flow into the aquifer per unit area, in feet per day
- K'= vertical hydraulic conductivity of the confining layer, in feet per day
- l = thickness of the confining layer, in feet
- h= head in the water table, in feet
- h'= head in the confined aquifer, in feet

Assumptions can be made to estimate (h-h') and l in the formula above. The water table throughout most of the study area is within 20 feet of the land surface. The average depth to water in observation wells of the Dakota aquifer shown in table 3 is approximately 150 feet. The difference of 130 feet can be used as an estimate of h-h'. The average depth to the Dakota aquifer in the wells shown in table 2 is approximately 275 feet. Because the water must move from the water table to the top of the aquifer the average thickness of the confining layer (l) is estimated to be 255 feet. The errors in estimating these two factors are not significant when compared to the possible error of estimating the vertical hydraulic conductivity of the confining material.

Information regarding the confining material above the Dakota aquifer in the study area is mostly qualitative. Vertical hydraulic conductivity for the confining unit overlying the Dakota aquifer was estimated by comparing the confining materials to published values of conductivity for similar materials. Freeze and Cherry (1979, table 2.2, p. 29) summarize a range of hydraulic conductivity values for materials similar to those which constitute the confining layer. These include: till, 1.3 to 0.0000013 feet per day; loess, 13 to 0.0013 feet per day; and unweathered marine clay (similar to the Cretaceous shales), 0.0013 to 0.00000013 feet per day. For this example it is assumed that the confining unit has an average hydraulic conductivity range of 0.0013 to 0.000013 feet per day. This range is toward the smaller values of the range of conductivities suggested by Freeze and Cherry. This choice of values should produce a relatively low estimate of the recharge potential. Kunkle (1968), determined the leakage rate through till in east-central Iowa to be 0.0005 feet per day. This value supports the approximation of a low estimate for this parameter.

Using the values of (h-h') = 130 feet, l=255 feet and K'=0.0013 and 0.000013 feet per day the range of recharge rate, q, is 0.00067 to 0.0000067 feet per day.

Natural discharge from the Dakota aquifer occurs where the potentiometric surface in the Dakota aquifer is higher than that in nearby aquifers. The aquifers receiving water in such a process may be Quaternary sand and gravel deposits above the Dakota, the bedrock valleys which are laterally adjacent to the Dakota and the Paleozoic rocks underlying the Dakota aquifer. The cross sections on plate 2 show the relative position of the bedrock valleys. However, little is known about the distribution of potential water-bearing material in these valleys. The potentiometric map of the Dakota aquifer, plate 5, shows potential for flow through the Dakota aquifer toward the southeastern part of the study area where a bedrock valley is interpreted and toward the bedrock valley in eastern Woodbury County. The flow toward these valleys is indirect evidence that significant aquifers with lower heads are likely in the materials which fill these valleys. It is not possible to estimate the leakage from the Dakota in these areas without more extensive data than are currently available.

Water levels gathered for this study indicate that, with local exceptions, discussed later, there is leakage from the Dakota aquifer to underlying aquifers in Paleozoic rocks. At several test sites, observation wells were established in aquifers in Paleozoic or Precambrian rocks. After a static water level was measured and a water sample was taken, the wells were plugged at the bottom with cement. After perforation with an explosive wire-line device, an observation well was developed in the Dakota aquifer at most of these sites. These sites, and sites where at least two separate wells in the Dakota and underlying aquifers were completed are as follows:

87-44-15CBBB	91-39-01ADAD	94-47-35AAAB	100-39-17DCCB
89-46-36BBDC	91-42-16DDDD	98-39-26CDAD	100-48-31CCCC
90-38-16DDDD	92-45-02CBCB	98-42-33AABB	

With the exception of three of the sites listed above, the measured values of head in the Dakota aquifer are higher than in the underlying Paleozoic or Precambrian unit, table 3. At two of these sites, 100-39-17DCCB and 100-48-31CCCC, the head in the underlying unit was less than one foot higher than in the Dakota aquifer. A third site, 92-45-02CBCB, is apparently within the area affected by pumpage from the Dakota aquifer in the LeMars area, and consequently water may be moving upward from aquifers in Paleozoic rocks. This represents a reversal of the regional direction of flow.

The wide distribution of heads higher in the Dakota aquifer than those in the aquifers in Paleozoic rocks indicates that these aquifers are recharged in part by the Dakota aquifer. Among the aquifers in Paleozoic rocks are the Ordovician St. Peter and Cambrian Jordan aquifers as well as Devonian carbonate aquifers (Ludvigson and Bunker, 1979). A quantitative estimate of the flow from the Dakota into these units is not possible from available data.

The direction of downward leakage can be reversed by withdrawals from the Dakota, such as the pumping in the LeMars area. At test site 92-45-02CBCB, approximately two miles northeast of the LeMars municipal wells, one observation well is completed to the Dakota aquifer (92-45-02CBCB2) and a second is cased through the Dakota and open to Paleozoic age rocks (92-45-02CBCB1). At this site the head in the Dakota aquifer is consistently lower than the head in the Paleozoic aquifers. Water levels in both wells declined during April through September, table 3, apparently in response to increased pumping during that period. The effects of leakage from the Paleozoic aquifers to the Dakota aquifer are seen in the quality of water pumped from wells in the Dakota aquifer in the area (Plates 7 and 8).

Withdrawal from the Dakota aquifer in the study area is dominantly for municipal water supplies. Several industrial and irrigation wells also use water from the Dakota, but these wells are not metered. The 32 municipalities which use water from the Dakota and the average daily withdrawal are shown on plate 5.

The withdrawal rates were obtained from the Iowa Department of Enviromental Quality, Spencer, Iowa. In 1979 the average withdrawal ranged from 9000 gallons per day at Oyens to more than 13,000,000 gallons per day at Sioux City. Excluding Sioux City, the total municipal withdrawal from the Dakota aquifer in the study area in 1979 was 6,500,000 gallons per day, about 52 percent of which was pumped by the cities of LeMars and Cherokee.

Because one of the principal demands for water in the study area is for irrigation, it is interesting to compare the amount of water needed for irrigation with the municipal demands. An irrigation system supplying 160 acres with 12 inches of water annually would withdraw approximately 52,000,000 gallons per year. Of the 32 municipalities shown on plate 5, 22 used less than this amount and 10 used more in 1979. It would take more than 95 such irrigation systems to equal the municipal withdrawal of Sioux City and approximately 140 systems to equal the total 1979 municipal withdrawal from the Dakota aquifer in the study area.

Estimated Potential Yield

One way to demonstrate the regional variations in productivity of an aquifer is to show how much water is potentially available to wells which penetrate the aquifer. The potential yield, as used in this report, is the amount of water which can be pumped from a 100 percent efficient well penetrating the entire aquifer under ideal conditions. The amount which can be pumped will vary with the amount of available drawdown in the pumping well.

The method used in this report to calculate the potential yield determines the specific capacity based on estimates of transmissivity. Specific capacity is a measure of the productivity of a well and is defined as the pumping rate per unit of water level drawdown in the well. Meyer (1963) published a graph relating specific capacity, storage coefficient, and transmissivity. The storage coefficient is a dimensionless property of an aquifer which reflects the amount of water which is released from or added to storage per unit surface area of aquifer, per unit hydraulic head change. The ratio of transmissivity to specific capacity is about 267:1 under the following conditions(Meyer, 1963):

a. the transmissivity of the aquifer is within the range 270 to 13,400 feet squared per day;
b. the storage coefficient is less than 0.005; and
c. the specific capacity is given in gallons per minute per foot of drawdown after 24 hours pumping.

From table 4 it can be seen that all of the transmissivities calculated from the five pumping tests fall in the range of 270 to 13,400 feet squared per day. Estimates of the storage coefficient (Jim Munter, written communication, 1981) are all less than 0.005.

Plate 6 shows regional estimates of potential yield. The transmissivity was determined by the product of sandstone thickness (plate 3) and average hydraulic conductivity, which is assumed to be 40 feet per day. The transmissivity was then divided by 267, resulting in a specific capacity in units of gallons per minute per foot of drawdown. For this report an arbitrary drawdown of 20 feet was multiplied by the specific capacity to determine the potential yield shown on plate 6.

As an example of this method, on plate 3, in Plymouth County T91N R44W the total thickness of sandstone is shown to be about 150 feet. The potential yield of this thickness of sandstone is determined by first multiplying the thickness by 40 feet per day (average hydraulic conductivity). This results in a transmissivity of 6000 feet squared per day . Dividing this transmissivity by 267 (ratio of transmissivity to specific capacity) results in a specific capacity of 22.5 gallons per minute per foot of drawdown. The final step is to multiply the specific capacity by the drawdown (20 feet for this report) giving a potential yield of 450 gallons per minute. On plate 6, the same location shows the area to have a potential yield of 100 to 500 gallons per minute. The area is near the 500 gallons per minute line.

If drawdown of more than 20 feet in the producing well is acceptable, then the potential yield will be greater than that shown on plate 6. Conversly, if 20 feet of drawdown is excessive then the potential yield will be less than that on plate 6. Of course, no well is 100 percent efficient so the actual yield will be reduced by the well efficiency factor. The values shown on figure 6 are to be used as a guide to understanding the regional availability of water from the complete Dakota aquifer.

WATER QUALITY

Major Dissolved Constituents

Water samples from the Dakota aquifer were collected from 28 of the wells drilled for this project. These samples were analysed by the University of Iowa, Hygienic Laboratory. In addition to these analyses, the most recent analyses available from the various municipal wells in the Dakota aquifer in the area are included in table 5.

Water from the Dakota aquifer can be generally characterized as a calcium-magnesium sulfate type. It is very hard (from 180 to 1600 mg/L as calcium carbonate) and has a relatively high dissolved solids content (from 279 to 2820 mg/L). Many samples contain quantities of radionuclides in excess of recommended limits (table 1). Nitrate and fluoride are below the recommended limits and only one sample exceeded the recommended limit for chloride.

The dissolved sulfate content in water from the Dakota aquifer exceeded 1000 mg/L (plate 7) throughout much of the study area. About 20 percent of the samples had more than 1000 milligrams per liter (mg/L) sulfate. Sulfate content is highest in areas of recharge, particularly the north-central part of the study area. Sulfate content is less than 250 mg/L in much of the southern and western parts of the area, down-gradient from the major recharge areas. Approximately 17 percent of the samples have less than 100 mg/L SO_4. The high sulfate content in the recharge areas may result from solution of sulfate minerals such as gypsum ($CaSO_4 \cdot 2H_2O$) or anhydrite ($CaSO_4$) by water as it moves through the Quarternary deposits and Cretaceous rocks which form the confining units and through the Dakota aquifer itself. However, data on rock chemistry is needed to verify the assumption.

Both the dissolved solids (plate 8) and the sulfate distribution (plate 7) show anomalies in the central part of Plymouth county, near LeMars. The concentrations of both TDS and sulfate in this area are much higher than in nearby wells. This anomaly is likely caused by a reversal of the natural flow direction between the Dakota and the underlying aquifer in Paleozoic rocks. At sites where it was possible to analyse water from both aquifers, the samples from aquifers in underlying Paleozoic rocks had higher concentrations of dissolved solids and sulfate than did the samples from the Dakota aquifer. The water levels in observation wells 92-45-02BCB1 and 92-45-02BCB2 indicate there is potential for flow from the aquifers in the Paleozoic rocks to the Dakota aquifer in this area. Therefore, the water sampled in the LeMars area wells probably represents a local change in quality of natural water in the Dakota aquifer by leakage and mixing of water from the underlying Paleozoic rocks.

Thorstenson, Fisher, and Croft (1979) present a process to explain changes in dissolved sulfate in an aquifer comprised of rocks of the Cretaceous Fox Hills Formation of North Dakota and

South Dakota. In this process anaerobic bacterial action reduces the sulfate in the aquifer to sulfide and uses the oxygen for metabolism of organic material such as lignite. Carbon dioxide and hydrocarbons such as methane are produced by decomposition of organic matter in the later phase of the reducing process.

The rocks and water chemistry studied by Thorstenson, Fisher and Croft (1979) are very similar to the Dakota aquifer in this study area. Both involve rocks which include sandstone, shale and lignite. Therefore, the decrease in concentrations of sulfate within the Dakota aquifer could be explained by anerobic reduction. The conversion of sulfate to sulfide is supported by the occurrence of an iron sulfide mineral, pyrite, in the Dakota Formation and observations of hydrogen sulfide gas in some of the test-wells, particulary in the southern and western parts of the area. Gases, possibly carbon dioxide and methane, have also been reported from wells which penetrate the Dakota Formation. Unfortunately, dissolved gas samples which could help support the reducing conditions hypothesis were not collected.

Iron and manganese are generally present in quantities exceeding the suggested limits shown in table 1. About 80 percent of the samples contained more than 300 ug/L (micrograms per liter) iron and 56 percent contained more than 50 ug/L manganese. An analysis of the distribution of these two cations is difficult because their source and sensitivity to chemical conditions in a well may be affected by well construction and the casing materials used. Because of the rapid precipitation of iron and manganese upon exposure to air, special sampling techniques are necessary to obtain consistently satisfactory samples in the field.

Radionuclides

The data on the radionuclides, radium, gross alpha, and gross beta activity, are significantly fewer than for other constituents because these parameters are analysed using a screening procedure. When gross alpha activity exceeds 5 pCi/L (picocuries per liter), an equivalent sample is analyzed for radium-226. If the concentration of radium-226 exceeds 3 pCi/L, an equivalent sample is analyzed for radium-228. Approximately 75 percent of all the samples were analysed for gross alpha, about 50 percent for radium-226 and about 12 percent for radium-228. The data in table 5 include 4 samples which exceed the recommended limits of 15 pCi/L gross alpha (municipal wells at Arthur, Holstein, Sioux City, Maurice and Primghar); 9 which exceed 5 pCi/L radium-226 (Municipal wells in Arthur, Holstein, Sioux City, Cherokee, LeMars, and West Bend) 4 which exceed 5 pCi/L radium-228, (test wells at 91-42-16DDDD, 92-48-06-DDDA, 95-43-07AAAA and 96-44-08ADAA). Fourteen samples exceed 5 pCi/L radium-226 and radium-228 combined (Municipal wells in Arthur, Holstein, Sioux City, West Bend and Hull, test wells at 94-47-35AAAB, 95-47-05AAAA and the test wells listed above). A statistical summary of radium-226 in water from the Dakota aquifer and other aquifers in Iowa is presented in Mackey, 1976.

Quality of Water for Irrigation

Three important factors with respect to dissolved solids are involved in appraising the useability of water for irrigation; (1) the mineral species in the soil and the drainage properties of the soil, (2) the tolerance of the irrigated crop to the major constituents in the water and (3) the concentration of major constituents in the water. It is not within the scope of this report to evaluate more than the constituents in the water, but it is important to understand that the greater the quantity of dissolved constituents in the water the narrower the range of soils and crops to which the water can successfully be applied.

The method used in this report to classify irrigation water involves the sodium and salinity hazards. This method, developed by the U.S. Salinity Laboratory Staff (1954), uses electrical conductivity (specific conductance) of the water to measure the salinity hazard and the sodium-adsorption-ratio (SAR) to evaluate the sodium hazard. Figure 4 is a graphic form of this classification system.

The electrical conductivity of water is a sufficiently accurate indirect measurement of the total concentration of dissolved salts to estimate the salinity hazard. Because the relationship between dissolved salts and conductivity is more logarithmic than linear, the left-to-right axis in figure 4 is on a logarithmic scale. The divisions of the salinity hazard are based on the following criteria developed by the U.S. Salinity Staff (1954): (1) most water supplies used successfully for irrigation over long periods of time have had conductivities of less than 2250 micromhos, (per centimeter at 25 degrees C) (2) water in the range of 750 to 2250 micromhos has been used but will produce saline soil conditions if adequate drainage and leaching are not provided and, (3) water with conductivity of less than 750 micromhos is considered satisfactory although conductivity values above 250 micromhos may contain dissolved salts in excess of the tolerance of sensitive crops.

The sodium adsorption ratio (SAR) is a measure of the relative concentration of the ions of calcium, magnesium and sodium. The formula for calculating the SAR is:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{++}+Mg^{++})/2}}$$

where Ca++, Mg++ and Na+ are the concentrations in milliequivalents per liter of the respective ions. To convert values from milligrams per liter, as shown in table 5, to milliequivalents, multiply those of Ca by 0.04990, Mg by 0.08224, and Na by 0.04350. These ions may become attached (adsorbed) to the clay minerals in the soil when chemical and moisture conditions in the soil are favorable. When the proportion of sodium ions is high, sodium will replace the calcium and

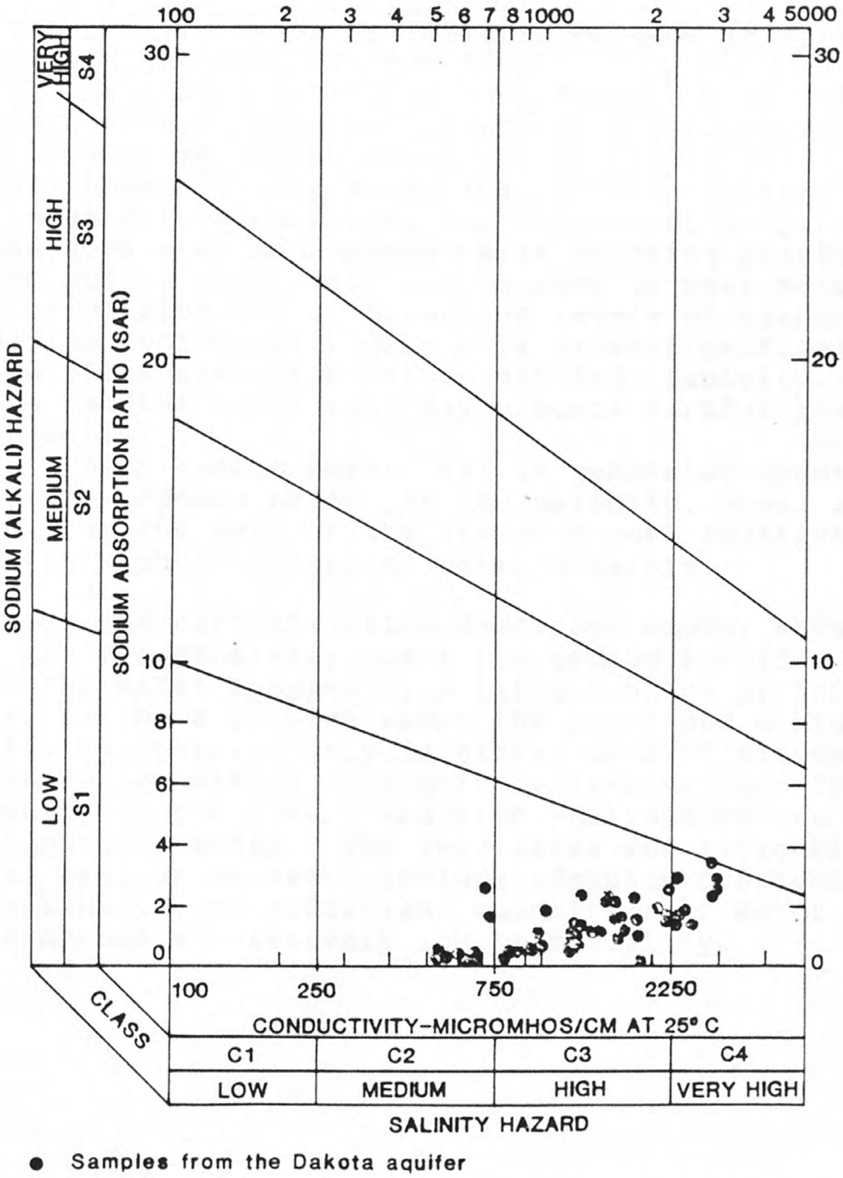

Figure 4. Irrigation classification of water from the Dakota aquifer.

magnesium ions in the clays and the sodium hazard of the soil will rise. When concentrations of calcium and magnesium ions are proportionately high the process will be reversed and the sodium hazard in the soil will be reduced. An alkali-, or sodium-rich soil can be formed by the continuous addition of water with a high SAR.

The following descriptions provide a guide to the use of the diagram on figure 3, summarized from U.S. Salinity Staff, 1954:

Low salinity water (C1) can be used on most crops and soils. Some leaching is necessary, so soils with extremely low permeability may be affected.

Medium salinity water (C2) can be used if soil permeability and drainage are sufficiently high.

High salinity water (C3) should not be used on soils with low permeability. Even with adequate drainage, crops with low salt tolerance may be adversely affected.

Very high salinity water (C4) is not suitable for irrigation water under most conditions. The soils must be permeable, drainage adequate, and considerable leaching provided.

Low sodium water (S1) can be used on most soils with little danger of development of hazardous levels of exchangable sodium.

Medium sodium water (S2) will present problems in fine-textured soils with high cation exchange capacity.

High sodium water (S3) may produce harmful levels of sodium in most soils.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low salinity, where solution of calcium from the soil or the use of a soil additive may make irrigation with this type of water possible.

Using the classification described above, water from the Dakota aquifer generally has a low sodium hazard. Figure 3 is a plot of the water samples from table 5. The salinity hazard, however, may be a problem where the water has a high conductivity, particularly in excess of 2250 micromhos/cm. In addition, water with a conductivity greater than 750 micromhos/cm may require specific soil and crop analysis before extensive irrigation is planned. The requisites for irrigation with these marginal classes of water include adequate drainage of the soil and availability of sufficient quantities of water to leach any soil which has a relatively low permeability.

SUMMARY AND CONCLUSIONS

The Dakota aquifer is the most extensive source of large quantities of ground-water in northwestern Iowa. The aquifer is composed of multiple layers of sandstone in the Cretaceous Dakota Formation. For this report Quaternary sand and gravel deposits which are directly in contact with these sandstones are included in the aquifer. Individual sandstone layers are separated by shale and the thickness of the individual sandstone beds varies from a few inches to more than 150 feet. The composite thickness of sandstone is more than 200 feet throughout much of the western and north-central parts of the study area.

The Dakota aquifer is confined by a sequence of overlying Cretaceous shales and limestones and Quaternary till and loess. Beneath the aquifer are shales of the Dakota Formaton and Paleozoic shales, carbonate rocks, sandstones and Precambrian crystalline rocks.

Lateral movement of water through the aquifer is from the north-central part of the area to the south, southwest and east. The aquifer is under water-table conditions in the extreme southwestern part of the study area near the Big Sioux and Missouri Rivers. Water recharges the aquifer throughout the study area through overlying confining units. Discharge through the overlying material occurs along the west-central part of the study area beneath the Big Sioux River valley where the potientiometric surface is above the river. Regional gradients indicate flow in the aquifer is toward South Dakota. Discharge from the aquifer occurs along the bluffs of the southern end of the Big Sioux River and along the Missouri River where the Dakota aquifer is exposed at the surface.

The results of pumping tests in the study area indicate the hydraulic conductivity of the Dakota aquifer ranges from 37 to 50 feet per day. For purposes of estimating potiential yield throughout the aquifer 40 feet per day was multiplied by the cumulative thickness of sandstone comprising the aquifer. The resulting transmissivity determination was used to estimate the potiental yield of the aquifer.

Estimated potential yields to wells completed in the Dakota aquifer exceed 250 gallons per minute throughout much of the study area. The estimates were made assuming only 20 feet of drawdown in pumping wells. Production of greater quantities of water is possible if more than 20 feet of drawdown is acceptable.

The quality of water from the Dakota aquifer is typically a calcium-magnesium sulfate type. Sulfate and dissolved solids are most abundant in the recharge areas. Sulfate concentrations commonly exceed 1000 mg/L and dissolved solids exceed 2000 mg/L in these areas. However, sulfate content is less than 250 mg/L in much of the area with lower hydraulic heads. Evidence, which includes observed hydrogen sulfide gas and pyrite nodules, indicates that the sulfate may be undergoing biochemical reduction within the aquifer.

The quality of water pumped from the Dakota aquifer may be altered by leakage from the underlying Paleozoic aquifers if large withdrawals reverse the natural flow from the Dakota into the Paleozoic aquifers. An example of this reversal may exist near the city of LeMars where water from the Dakota aquifer has a dissolved solids and sulfate content which is abnormally high for the area. This is also the only area where the head in the Dakota aquifer is known to be below that in the aquifers in Paleozoic rocks. In this area, water from aquifers in Paleozoic rocks contains higher concentrations of TDS and sulfate than water from the Dakota aquifer.

There are insufficient data on radionuclides to make a regional interpretation of distribution, but several of the samples indicate radionuclides occur in quantities which exceed the limit for gross alpha activity, radium-226, radium-228, or a combination of these constituents.

The quality of water from the Dakota is generally suitable for irrigation purposes. However, there are areas where the water has a relatively high salinity hazard, as measured by electrical conductivity. In these areas a careful evaluation of soil, drainage, crop tolerances and irrigation rates may be necessary before water from the Dakota aquifer is applied to soils containing a large percentage of clays.

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Table 1. Major chemical constituents in water, their effects upon usability and their concentration limits

Constituents	Maximum contaminant levels in community water supplies(1)		Effects on usability
	Primary regulations	Proposed secondary regulations	
Iron(Fe)		300 μg/L(2)	If more than 100 μg/L is present, it will precipitate when exposed to air; causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts tastes and colors to food and drinks. More than 200 g/L is objectional for most industrial uses.
Manganese(Mn)		50 μg/L	More than 200 μg/L precipitates upon oxidation. Causes undesirable taste and dark-brown or black stains on fabrics and porcelain fixtures. Most industrial uses require water containing less than 200 μg/L.
Calcium(Ca) and Magnesium(Mg)	Not Applicable		Combine with bicarbonate, carbonate, sulfate and silica to form scale in heating equipment. Retard the suds-forming action of soap and detergent (hardness). High concentration of magnesium has a laxative effect.
Sodium(Na) and Potassium(K)	Not Applicable		More than 50 mg/L sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.
Bicarbonate(HCO_3) and Carbonate(CO_3)	Not Applicable		Can combine with calcium and magnesium to form scale.
Sulfate(SO_4)		250 mg/L(3)	Combines with calcium to form scale. More than 500 mg/L tastes bitter and may be a laxative.
Chloride(Cl)		250 mg/L	In excess of 250 mg/L may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/L.
Fluoride(F)	Limits very from 1.8 to 2.2 mg/L based on average maximum daily air temperatures.		Optimum concentration has a beneficial effect on the structure and resistance to decay of children's teeth. Excess concentrations may cause mottling of children's teeth.
Nitrate(NO_3)	45 mg/L		Concentrations in excess of 45 mg/L are reported to cause methemoglobinemia in infants.
Dissolved solids		500 mg/L	Less than 300 mg/L is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.

Table 1.--Continued

Constituents	Primary regulations	Proposed secondary regulations	Effects of usability
Radionuclides			Radionuclides in drinking water are estimated to increase the risk of various forms of cancer. Radioactivity is monitored through a screening process. When gross activity exceeds 5 pCi/L, an equivalent sample is analyzed for radium-226; if the concentration of radium-226 exceeds 3 pCi/L, an equivalent sample is analyzed for radium-228. The combined radium-226 and radium-228 should not exceed 5 pCi/L. The gross alpha activity (including radium-226, but excluding radon and uranium) should not exceed 15 pCi/L.
Radium (radium-226 and radium-228 combined)	5 pCi/L(4)		
Gross alpha activity	15 pCi/L		

(1)-National Interim Primary Drinking Regulations (Federal Register, v. 40, no. 248 and v. 41, no. 133) and Proposed Secondary Drinking Water Regulations (Federal Register, v. 42, no. 62).

(2)-μg/L-micrograms per liter.

(3)-mg/L-milligrams per liter.

(4)-The State may require annual monitoring of supplies that exceed 3 pCi/L radium-226. (pCi/L-picocuries per liter).

Table 2. Logs of selected test holes

Included is a representative selection of test holes drilled for this project. All test holes which are specifically referred to in the text or used in cross sections have been included. Descriptions of materials are field observations provided by the Iowa Geological Survey.

At the top of each log is the identification used by the Iowa Geological Survey.

Altitude datum is the National Geodetic Vertical Datum of 1929 (NGVD, 1929)

Depths are shown in feet below land surface.

Natural gamma radiation logs are uncalibrated.

IGS - D10

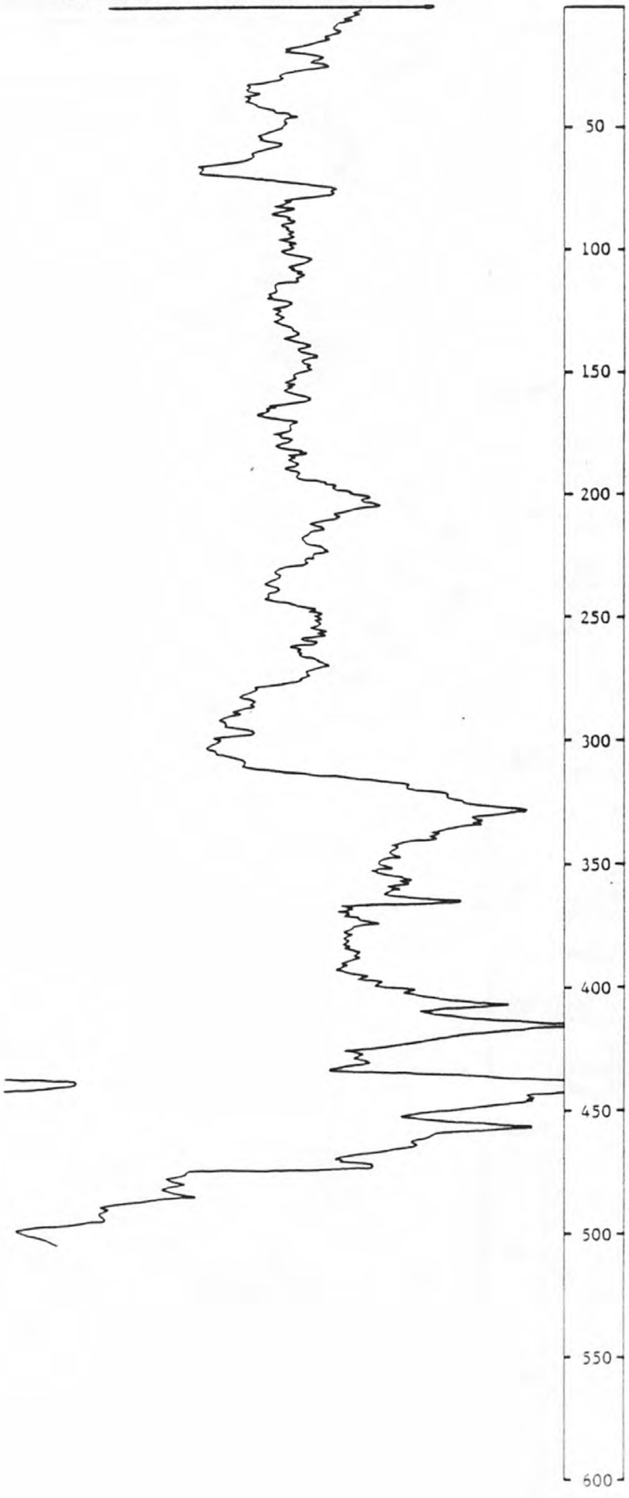
LOCATION: 87-41-05CCCC1

ALTITUDE: 1344
(FEET, NGVD 1929)

DATE COMPLETED: November 23, 1977

DEPTH: 510
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-13 Loess, yellow-brown
13-15 Gumbo, brown and gray
15-16 Till, dark yellow-brown
16-26 Clay, silty, yellow-brown
26-31 Clay, silty, yellow-gray
31-40 Till, light yellow-brown with some gray
40-68 Till, yellow-brown with boulders and gravel
68-73 Sand and gravel, fine grained, yellow-brown
73-76 Till, yellow-brown

76-137 Till, blue-gray

137-155 Clay, some sand, gray with some gray-green clay

155-195 Clay or till, yellow-gray

195-241 Clay or till, blue-gray

241-273 Clay or till, silty, blue-gray

CRETACEOUS
DAKOTA FORMATION

273-280 Sandstone, very fine, silty, tan to gray
280-312 Sandstone, fine to coarse grained, cemented, gray-green
312-341 Shale, interbedded sandstone, gray to gray-green
341-355 Shale, maroon

355-401 Shale, maroon and light-gray
401-427 Shale, maroon, lignite, and sandstone
427-435 Sandstone
435-442 Shale, maroon and gray

442-452 Sandstone, fine to coarse grained

452-470 Shale, maroon, some very thin sandstones
470-494 Sandstone, fine to medium grained

PALEOZOIC UNDIFFERENTIATED

494-510 Limestone, light tan and light gray

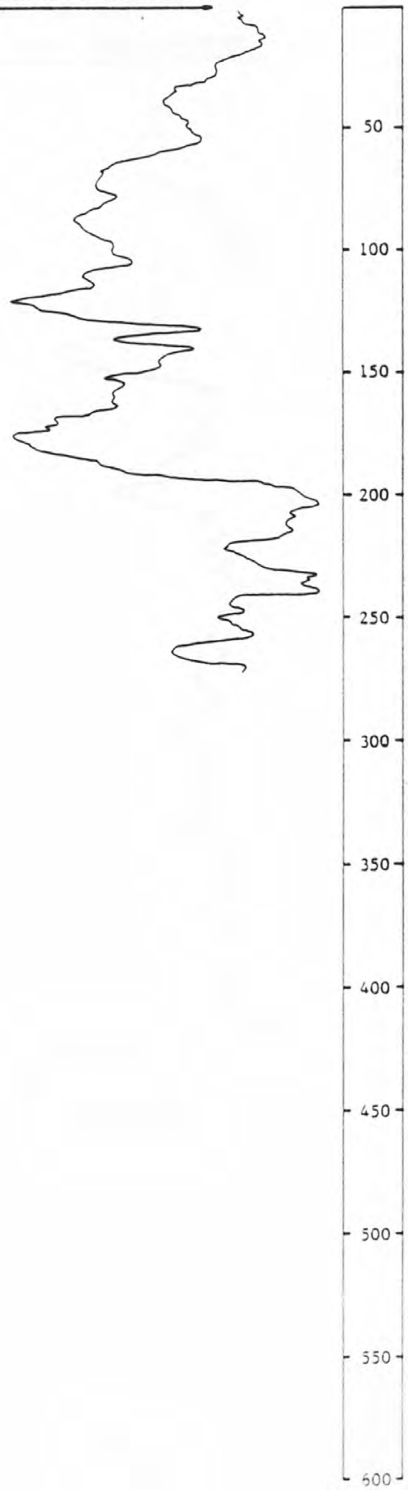
LOCATION: 087-44-15CBBB1

ALTITUDE: 1165
(FEET, NGVD 1929)

DATE COMPLETED: October 26, 1979

DEPTH: 281
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-30 Loess, brown and tan
30-35 Clay, sandy, brown and tan
35-38 Clay, sandy, gray
38-49 Sand and gravel, fine sand, fine to coarse gravel, slightly oxidized
49-50 Clay, sandy, hard, yellow and tan
50-60 Clay, sandy, silty, hard, tan
60-66 Clay, silty, gray to light-gray
66-82 Sand and gravel, fine-grained, yellow-brown
82-84 Clay, sandy, gray
84-120 Sand and gravel, fine-grained, some clay layers, yellow-brown

CRETACEOUS
DAKOTA FORMATION

120-142 Sandstone, fine to medium grained at top to medium to coarse at base, oxidized, brown
142-160 Shale, silty, thin layers of sandstone, gray
160-170 Sandstone, fine-grained, interbedded shale and lignite
170-195 Sandstone, medium to coarse grained, tan
195-196 Dolomite, brown
196-198 Shale, light gray
198-204 Shale, reddish-brown
204-221 Shale, gray to black at base, some lignite
221-226 Shale, light gray
226-228 Shale, yellow-gray to reddish- . brown
228-231 Shale, light gray
231-235 Shale, yellow-brown
235-245 Shale, silty, sandy, interbedded very fine sandstone, gray
245-259 Shale, silty, sandy, lignite, interbedded sandstone, gray and brown
259-262 Shale, reddish-brown
262-265 Shale, maroon
265-268 Shale, reddish-brown at top, grading to light gray
268-273 Shale, very sandy, limestone layers, very light-gray
273-275 Shale, red and yellow-brown
275-276 Shale, light gray

PALEOZOIC UNDIFFERENTIATED

276-278 Limestone, tan and brown
278-281 Limestone, light colored, losing fluid

LOCATION: 088-37-22CCCD

ALTITUDE: 1320
(FEET, NGVD 1929)

DATE COMPLETED: July 10, 1978

DEPTH: 435
(FEET)

INCREASING NATURAL GAMMA RADIATION

DESCRIPTION OF MATERIALS

QUATERNARY

0-5 Top soil and loess

5-48 Till, yellow-brown

48-66 Till, blue-gray and olive, with fine sand layers at base (Boulder at 55 feet)

66-95 Till, silty, sandy, blue-gray

95-120 Sand, fine to coarse, some blue-gray till and wood, trace of gravel at base

120-132 Sand and gravel, fine to medium, occasional boulder

132-135 Till, blue-gray

135-140 Till, yellow-brown, occasional boulder

140-163 Till, blue-gray, occasional boulder, layer of sand at 155 ft

163-166 Sand and gravel, fine, some till

166-174 Till, blue-gray, occasional boulder

174-183 Sand and gravel, fine to coarse

183-315 Till, blue-gray, in places silty, sandy and gravely

315-390 Till, yellow-gray and blue-gray

CRETACEOUS
DAKOTA FORMATION

390-399 Shale, gray, silty

399-428 Sandstone, tan, medium to coarse

PALEOZOIC UNDIFFERENTIATED

428-435 Limestone, brown and gray, some pyrite and chert

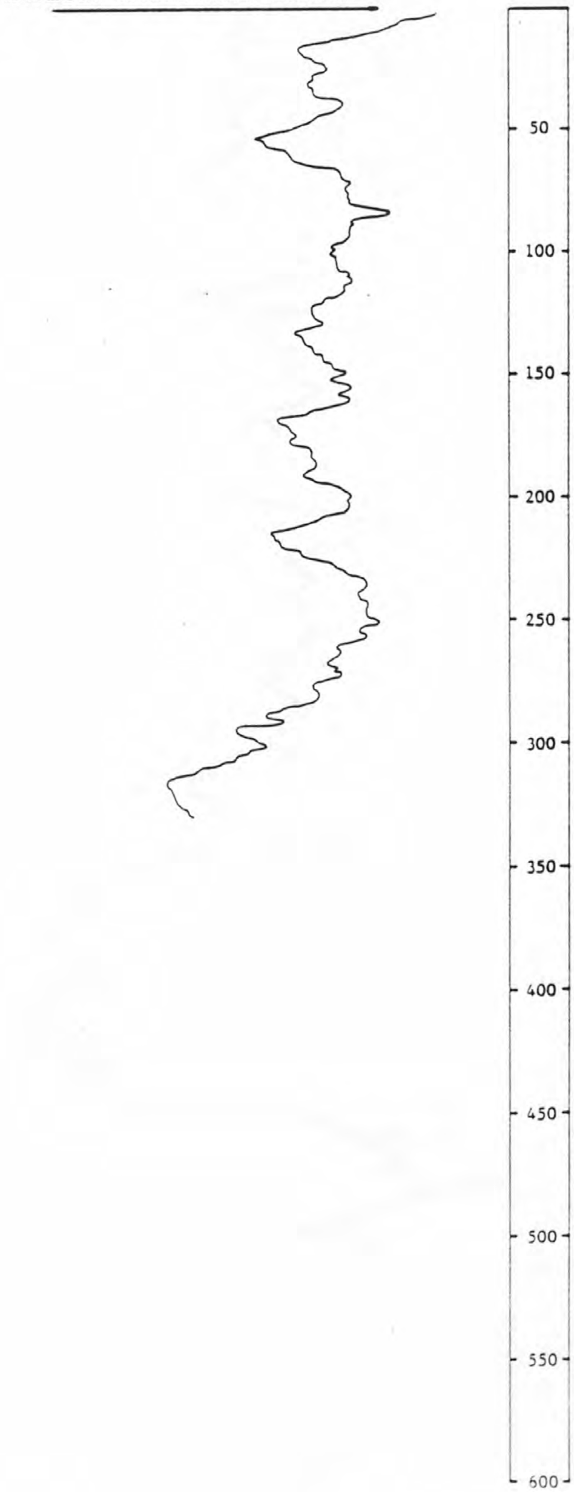
LOCATION: 088-44-06BAAB

ALTITUDE: 1340
(FEET, NGVD 1929)

DATE COMPLETED: October 8, 1979

DEPTH: 521
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-4 Loess, yellow-brown
4-15 Loess, dark brown to brown
15-40 Till, yellow-brown to yellow-gray with thin sand
40-47 Till, gray
47-53 Till, yellow-brown
53-61 Sand and gravel, fine to medium, yellow-brown
61-67 Sand, fine with till layers
67-131 Till, gray with yellow, blue and olive
131-135 Sand and gravel, fine to coarse, gray
135-140 Till, gray with sand and gravel layers
140-148 Sand and gravel, fine to coarse with till layers
148-168 Till, gravelly, blue-gray with sand and gravel layers
168-178 Sand and gravel, fine to coarse, gray
178-210 Till, blue-gray
210-221 Sand, fine to coarse, cemented, gray

CRETACEOUS
DAKOTA FORMATION

221-285 Sandstone, fine to medium, gray, some shale streaks
285-286 Dolomite or limestone
286-303 Sandstone, fine to medium, gray
303-320 Sandstone, fine to medium, tan
320-379 Sandstone, fine to coarse, tan
379-381 Shale, silty, gray
381-401 Sandstone, fine to medium, tan
401-409 Shale, silty, gray
409-415 Sandstone, coarse, brown, some shale
415-423 Sandstone, very coarse
423-425 Sandstone, coarse, hard, brown
425-430 Sandstone, coarse to medium, tan
430-432 Sandstone, medium, hard, brown
432-445 Sandstone, coarse, tan, gray shale at base
445-452 Sandstone, fine to medium with some shale, dolomite at base
452-455 Shale, very light gray with sandstone layers
455-470 Shale, silty, gray
470-471 Dolomite or limestone, brown
471-498 Sandstone, fine and shaly at top to fine to medium at base, tan
498-499 Shale, silty and sandy, light gray
499-506 Shale, sandy and silty, gray to reddish-brown
506-512 Shale, silty, sandy, very light gray

PALEOZOIC UNDIFFERENTIATED

512-516 Limestone, fractured with some shale and sandstone
516-521 Limestone, fractured, coarse grained

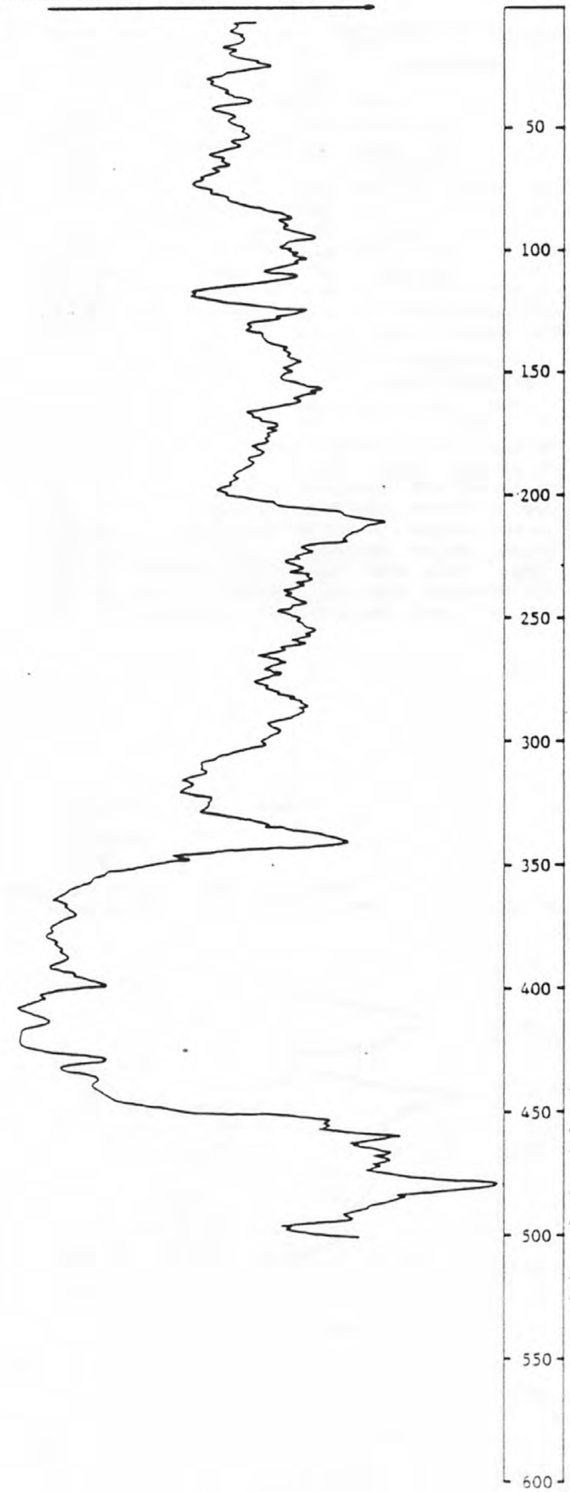
LOCATION: 089-38-36 CBCC

ALTITUDE: 1445
(FEET, NGVD 1929)

DATE COMPLETED: July 18, 1978

DEPTH: 521
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-4 Topsoil, dark
4-8 Loess, sandy, yellow-tan
8-24 Till, yellow-brown to yellow-gray
24-37 Till, blue-gray
37-88 Till, yellow-brown to olive, boulder at 74 feet
88-104 Till, blue-gray
104-108 Till, sandy, yellow-brown to olive
108-113 Till, blue-gray
113-120 Till, sandy, olive
120-153 Till, blue-gray
153-154 Clay, silty, dark brown
154-160 Clay, blue-gray, few sand grains
160-170 Till, light blue-gray to yellow-brown
170-195 Till, yellow-brown, boulder at 189 feet
195-200 Sand, fine to medium, some till
200-206 Till, yellow-brown
206-220 Till, blue-gray
220-305 Till, some gravel, blue-gray
305-335 Clay, silty, sandy, hard, light gray to yellow-brown at base

CRETACEOUS
DAKOTA FORMATION

335-341 Shale, silty, gray
341-390 Sandstone, fine to medium, yellow-brown
390-430 Sandstone, fine, tan grading to brown
430-452 Sandstone, fine grading to medium, tan
452-456 Shale, sandy, silty, gray
456-460 Shale, gray and maroon
460-490 Shale, gray to light gray
490-510 Shale, silty, sandy, gray

PALEOZOIC UNDIFFERENTIATED

510-518 Limestone, shaly, brown
518-521 Dolomite, coarse, dark brown

IGS - D14

LOCATION: 089-39-14DDD

DATE COMPLETED: June 22, 1978

ALTITUDE: 1330
(FEET, NGVD 1929)

DEPTH: 375
(FEET)

DEPTH (FEET)	DESCRIPTION OF MATERIALS
	QUATERNARY
0-3	Topsoil, black
3-5	Till, brown
5-8	Sand and gravel, tan
8-10	Clay, sandy, silty, brown
10-11	Till, yellow-tan
11-15	Sand, fine to coarse, tan to yellow-brown
15-22	Sand and gravel, fine to coarse, yellow-brown
22-50	Till, blue-gray and olive
50-107	Till, gray-brown to blue-gray
107-113	Till, light gray to light yellow-gray
113-167	Clay, silty, very little sand, tan
167-200	Sand, fine to medium, cemented, brown to gray-brown
200-207	Sand, fine to coarse, cemented, red-brown
	CRETACEOUS DAKOTA FORMATION
207-210	Sandstone, fine, brown
210-213	Shale, silty, gray
213-244	Sandstone, fine to medium, brown, some shale
244-267	Shale, silty, gray and red
267-280	Sandstone, fine to medium, tan
280-310	Sandstone, medium to coarse, tan
310-320	Sandstone, coarse, tan to yellow-brown
320-332	Sandstone, medium, yellow-brown
332-352	Shale, some silty, light gray and maroon
352-362	Shale, some sandstone and dolomite, light gray to gray
362-375	Sandstone, fine, tan, some shale

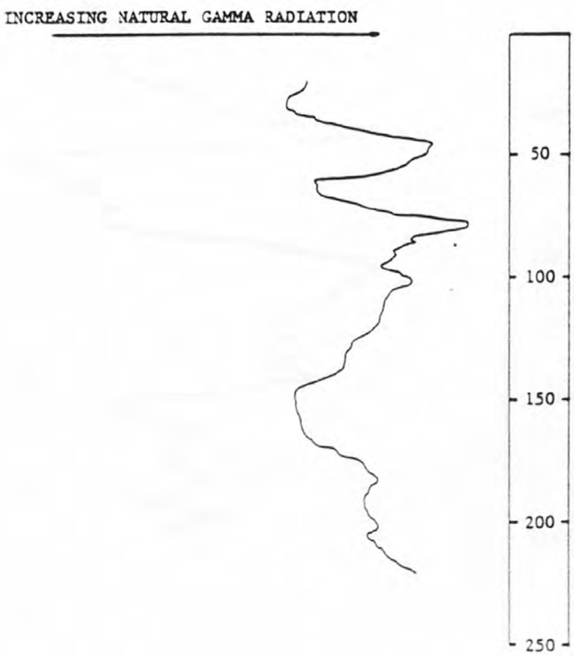
IGS - D32

LOCATION: 089-44-20DCDC

DATE COMPLETED: October 1, 1979

ALTITUDE: 1160
(FEET, NGVD 1929)

DEPTH: 221
(FEET)



DESCRIPTION OF MATERIALS

QUATERNARY

0-5 Clay, sandy, silty, tan
5-15 Sand, fine to coarse, tan
15-32 Sand, fine to gravel, coarse tan to yellow-brown
32-38 Till, yellow-brown grading to blue-gray at base
38-50 Sand and fine gravel, tan to yellow-brown
50-70 Sand and medium gravel
70-71 Clay, tan
71-79 Sand, fine to coarse
79-81 Clay, tan
81-110 Sand and gravel, fine to medium, yellow-brown and tan

CRETACEOUS
DAKOTA FORMATION

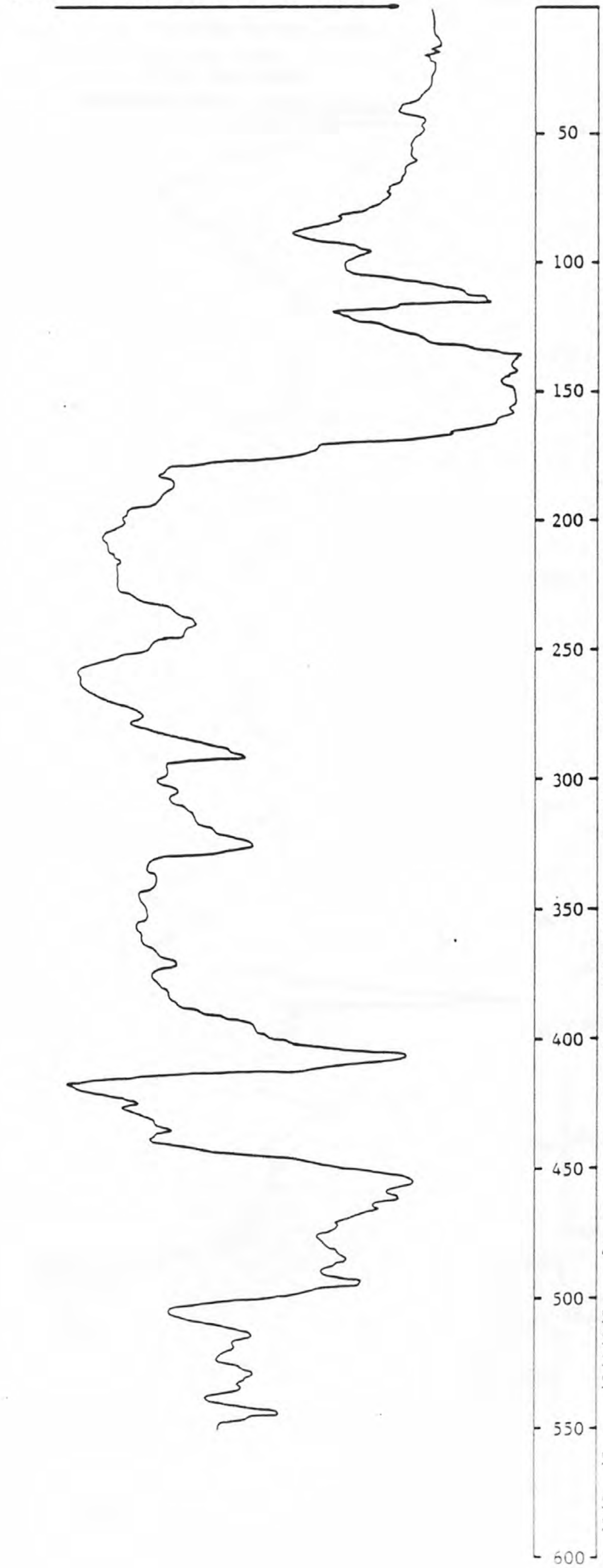
110-221 Sandstone, medium to coarse

LOCATION: 089-46-36BBDC1

ALTITUDE: 1268
(FEET, NGVD 1929)

DATE COMPLETED: June 20, 1979

DEPTH: 557
(FEET)



DESCRIPTION OF MATERIALS

QUATERNARY

0-20 Loess, iron concretions, yellow-brown

20-50 Loess, iron concretions, yellow-brown, some gray, lighter colors at base

50-60 Loess, yellow-brown and gray

60-76 Loess, silty, blue and gray

76-79 Gravel and till, yellow-brown and gray

CRETACEOUS

DAKOTA FORMATION

79-88 Sandstone, fine to medium, 79-80 and 85-88 iron cemented

88-96 Shale, silty, tan to gray

96-105 Sandstone, very fine, some shale, light yellow-brown

105-111 Shale, silty, gray

111-115 Sandstone, fine to very fine, pyrite nodules, tan

115-175 Shale, silty, some pyrite and lignite, gray to brown

175-245 Sandstone, fine to medium, tan

245-290 Sandstone, medium to coarse

290-320 Sandstone, fine to medium, tan

320-328 Sandstone, medium to coarse, tan

328-331 Shale, silty, light-gray

331-360 Sandstone, fine to medium, tan

360-373 Sandstone, medium to coarse, tan

373-374 Dolomite or limestone, brown

374-377 Sandstone, silty, shaly, gray

377-396 Sandstone, medium to coarse, tan

396-400 Limestone, fractured, some sand

400-405 Dolomite or limestone, coarse sandstone

405-501 Shale, silty, yellow ,gray, maroon, some lignite and thin sandstone layers

501-512 Sandstone, medium to coarse

512-513 Dolomite, light tan

513-517 Shale, silty, gray

517-525 Shale, chert, limestone and sand-stone all mixed

PALEOZOIC UNDIFFERENTIATED

525-535 Shale, sandy, some limestone and chert

535-539 Limestone, shaly

539-557 Limestone, some shale

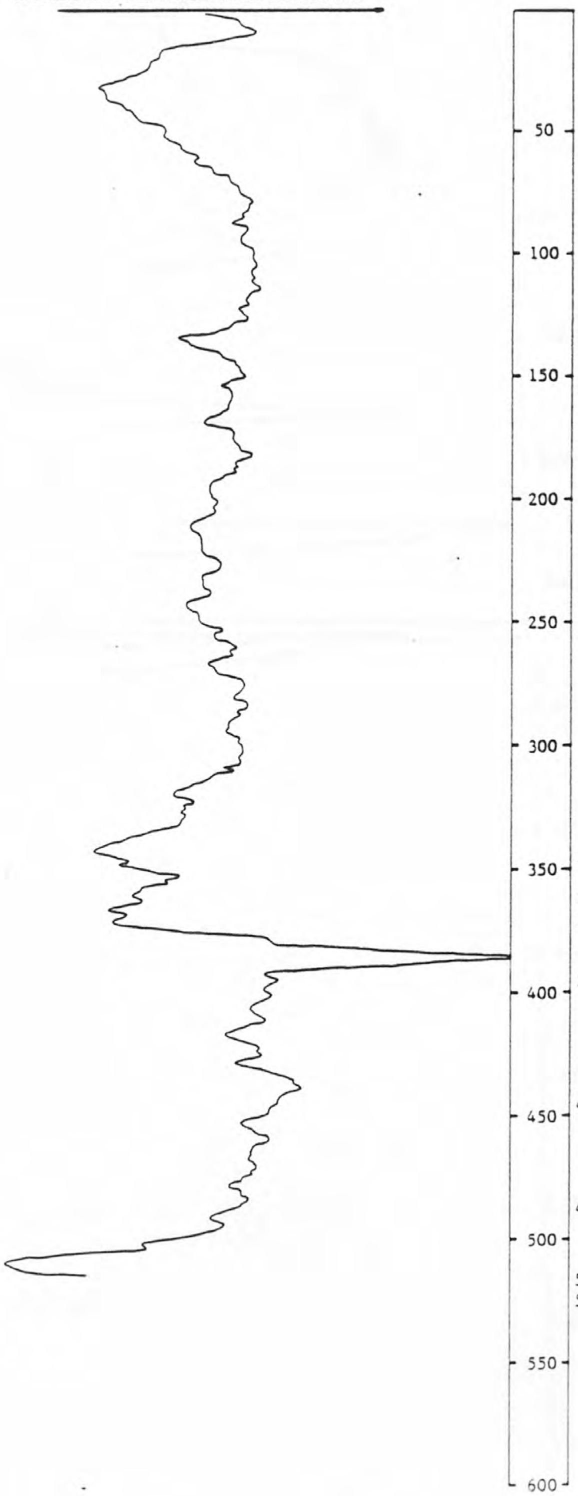
LOCATION: 090-38-16DDDD

ALTITUDE: 1365
(FEET, NGVD 1929)

DATE COMPLETED: April 24, 1979

DEPTH: 517
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-4 Topsoil, loess or clay
4-16 Till, yellow-brown to olive
16-35 Till, boulders, blue-gray
35-52 Sand and gravel, fine to coarse
52-58 Till, sandy, silty, blue-gray
58-61 Sand and gravel, cemented, brown
61-312 Till, boulders, some gravel, blue-gray with streaks of olive and yellow-brown
312-324 Sand and gravel, mostly fine, well cemented, brown

CRETACEOUS
DAKOTA FORMATION

324-340 Sandstone, fine, tan to brown, shale streaks
340-375 Sandstone, fine to medium, hard, some shale, gray
375-380 Shale, silty, yellow-brown
380-384 Sandstone, fine, tan to brown
384-405 Shale, light-gray with maroon streaks
405-490 Shale, reddish-brown to light-gray
490-500 Shale, silty, sandy, light-gray to reddish-brown

PALEOZOIC UNDIFFERENTIATED

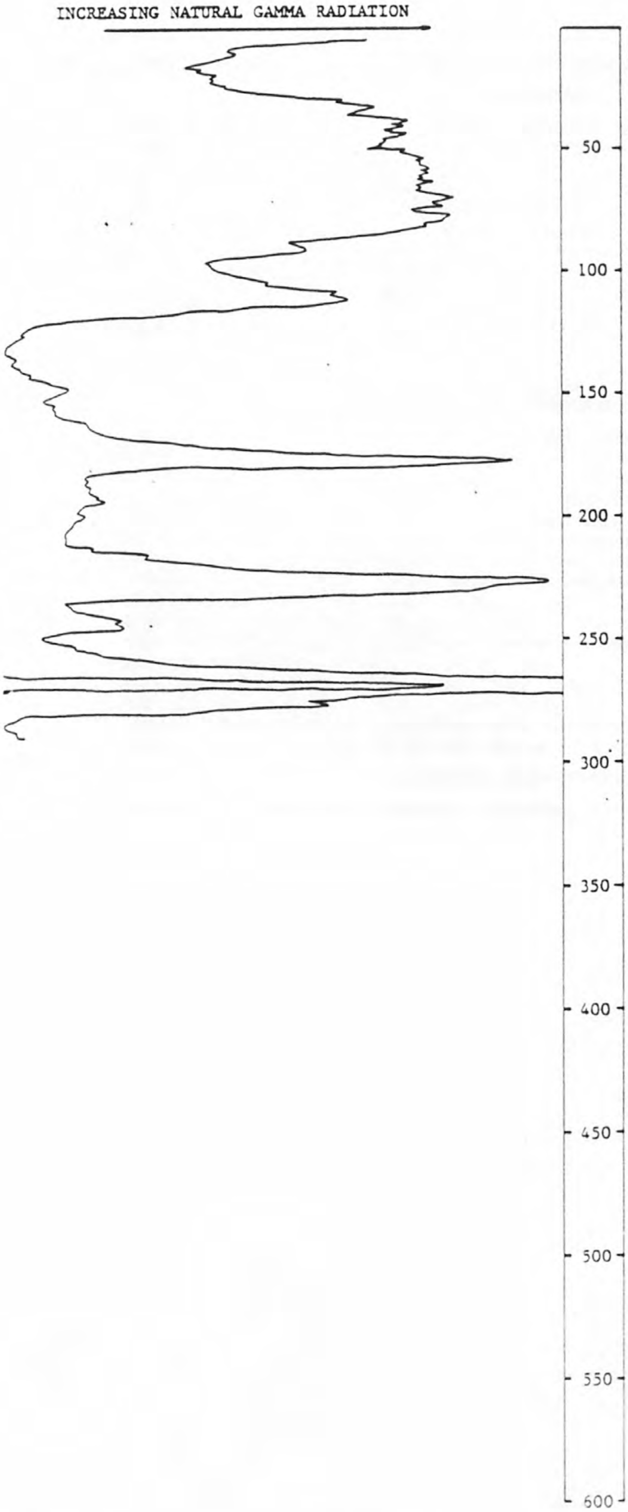
500-504 Limestone, tan, some pyrite
504-517 Limestone and dolomite, tan to brown

LOCATION: 090-40-06BDCD

ALTITUDE: 1182
(FEET, NGVD 1929)

DATE COMPLETED: August 30, 1977

DEPTH: 293
(FEET)



DESCRIPTION OF MATERIALS

QUATERNARY

0-5 Clay, silty, sandy, yellow-tan
5-15 Sand and gravel, some clay, yellow-brown
15-29 Sand and gravel, tan
29-37 Till, orange at top to blue-gray
37-85 Clay, some sand, blue-gray and gray-green mixed
85-92 Sand, fine, gray
92-109 Sand, fine to coarse, gray-green
109-112 Clay, soft, blue-gray
112-119 Sand, fine to coarse with gray-green clay layers

CRETACEOUS
DAKOTA FORMATION

119-140 Sandstone, fine to medium, yellow to tan
140-177 Sandstone, fine to coarse, tan to yellow
177-180 Shale, silty, gray
180-215 Sandstone, fine to medium, tan
215-224 Sandsotne, medium to coarse, yellow-tan
224-230 Shale, silty, gray-tan
230-244 Sandstone, fine to medium, tan
244-245 Shale, light gray
245-260 Sandstone, fine to medium
260-265 Sandstone, medium to very coarse
265-278 Shale, silty, gray to light gray

PALEOZOIC UNDIFFERENTIATED

278-293 Limestone, tan to brown

LOCATION: 090-45-28CCD

DATE COMPLETED: September 12, 1979

ALTITUDE: 1300
(FEET, NGVD 1929)

DEPTH: 487
(FEET)

DEPTH (FEET)	DESCRIPTION OF MATERIALS
	QUATERNARY
0-10	Topsoil and loess with iron concretions, yellow-tan
10-15	Loess, dark yellow-brown
15-18	Loess, yellow-brown, sandy at bottom
18-23	Till, dark brown to yellow-brown
23-30	Till, yellow-gray to olive
30-115	Till, silty, blue-gray
115-135	Sand and gravel, coarse, boulders, yellow-brown
135-137	Clay, silty, tan
137-159	Sand and gravel, fine to medium, yellow-brown
159-189	Till, gray
189-193	Sand, fine to medium, gravel, gray
193-199	Clay, gray
	CRETACEOUS DAKOTA FORMATION
199-203	Shale, silty, gray to gray-tan
203-211	Sandstone, fine to medium, tan
211-217	Shale, silty, light gray to gray
217-235	Shale, silty, pyrite, lignite, gray-brown
235-250	Shale, silty, light gray, red-brown and yellow-brown
250-265	Shale, silty, few sandstone layers, light gray and maroon
265-275	Sandstone, very fine, shale layers
275-295	Shale, sandy, some sandstone layers, pyrite, light gray
295-298	Shale, silty, gray to gray-brown
298-335	Sandstone, fine to medium, tan
335-374	Sandstone, medium to coarse, tan
374-378	Shale, silty, gray
378-380	Sandstone, fine, tan
380-383	Shale, silty, gray
383-390	Sandstone, fine to medium, hard, some shale
390-480	Sandstone, medium to coarse, tan
	PALEOZOIC UNDIFFERENTIATED
480-487	Limestone and chert, yellow-brown and tan

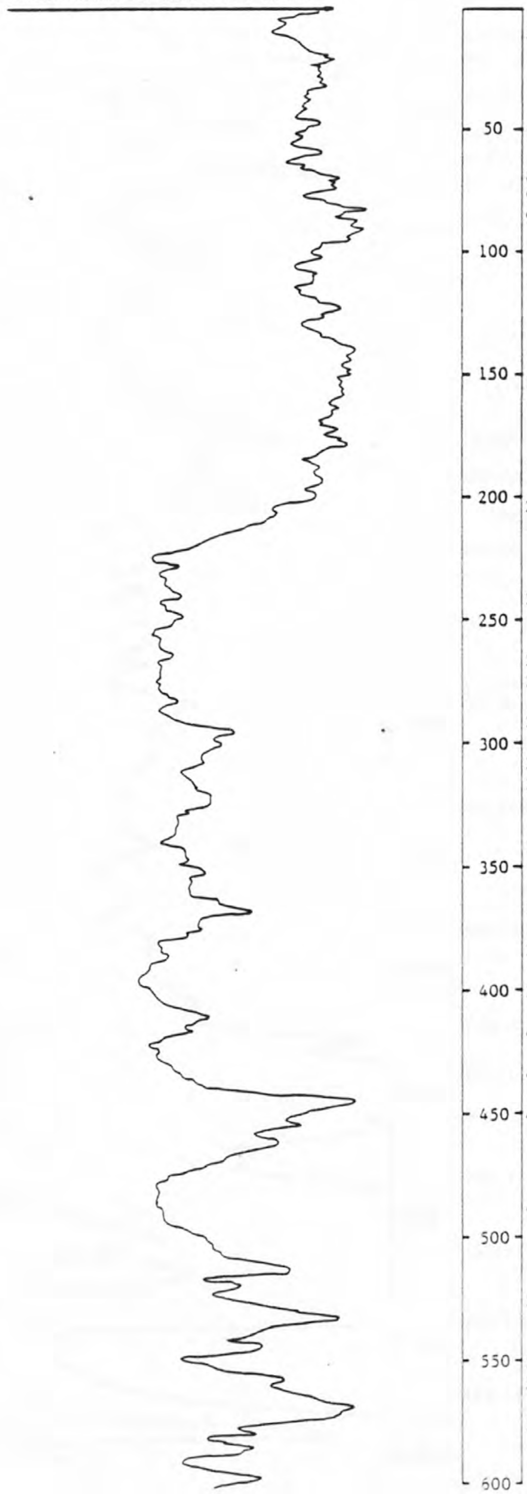
LOCATION: 091-39-01ADAD1

ALTITUDE: 1370
(FEET, NGVD 1929)

DATE COMPLETED: June 6, 1979

DEPTH: 1545
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

5-14 Till, sand and gravel, very light brown
14-80 Till, sand and gravel, very light yellow
80-90 Till, very light brown, gray
90-96 Till, sandy, pebbles, light gray
96-100 Till, very light yellow-orange
100-120 Till, very light yellow-orange to light olive-gray
120-170 Till, sand and gravel, light medium gray
170-215 Till, sand and gravel, very light orange-brown
215-225 Sand, fine to very coarse, calcareous

CRETACEOUS
DAKOTA FORMATION

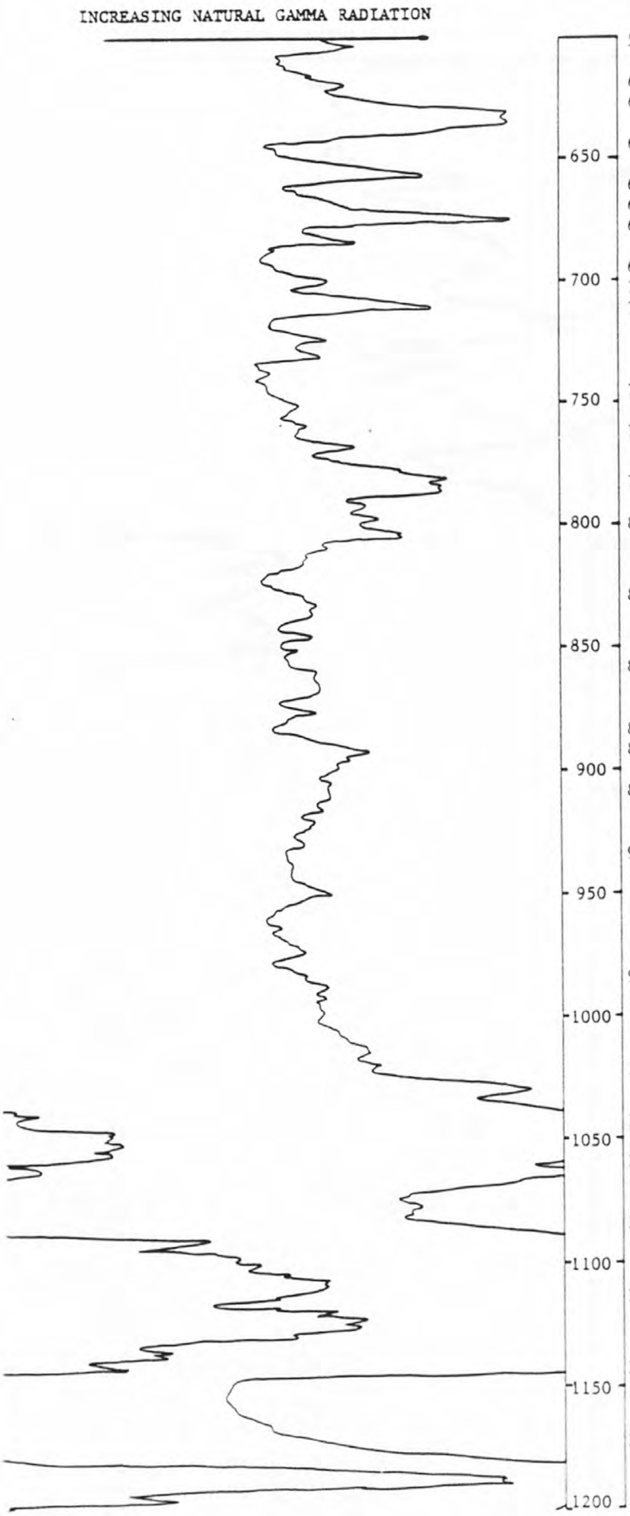
225-241 Sandstone, very fine to fine, some clay, dark gray to medium brown
241-253 No sample
253-273 Sandstone, very fine to fine, light gray to light orange
273-290 Sandstone, very fine to medium, red-brown
290-293 No sample
293-303 Sandstone, coarse, dark red-brown
303-343 Sandstone, very fine to fine, some medium, micaceous, yellow-orange
343-363 Sandstone, fine to medium, partly hematite cement, orange-yellow
363-393 Sandstone, fine to medium, clay bands
393-413 Clay, some sandstone, very light gray
413-443 Sandstone, very fine to medium, cemented, some clay, gray
443-457 Clay, white to pale gray, some sand
457-473 Clay, sandy, some chert, white to light olive-gray

PALEOZOIC
MISSISSIPPIAN

473-508 Dolomite, porous, fossiliferous, yellow-orange to light gray at bottom

DEVONIAN

508-529 Dolomite, argillaceous, sand filling fractures at top, gray to green
529-537 Shale, dolomitic, green
537-544 Dolomite, brecciated, shale in bottom 2 feet
544-593 Limestone, fractured and shale, gray-green



DESCRIPTION OF MATERIALS

593-625 Dolomite, limestone, shale interbedded
625-642 Shale, light to medium gray
642-654 Limestone, yellow-orange to light gray
654-672 Dolomite, fractured, porous, some shale, calcareous
672-675 Shale, dolomitic, medium gray
675-676 Limestone, argillaceous
676-699 Dolomite, fine grained, argillaceous, some limestone
699-711 Limestone, dolomitic, some shale
711-734 Dolomite, argillaceous, fractured
734-738 Limestone, argillaceous, grading to dolomite at base

738-777 Dolomite, very fine to medium, some shale, porous
777-784 Shale, dolomitic, very light green
784-800 Dolomite, dense, fractured, argillaceous, light gray
800-802 Shale, very light green-gray

ORDOVICIAN UNDIFFERENTIATED

802-843 Limestone, dolomitic, fine to coarse, fractured, very light gray

843-853 Limestone, dolomitic, very fine to coarse, some chert, very light gray
853-860 Dolomite, argillaceous, calcareous
860-864 Limestone, dolomitic, argillaceous fossiliferous
864-945 Dolomite, fine to medium, partly argillaceous, porous, gray to brown, fossiliferous
945-968 Dolomite, fine to medium, porous, argillaceous zones, yellow-orange to brown-gray, chert nodules 958-968

968-1034 Dolomite, very fine to fine, quite argillaceous, mostly light gray, some yellow-gray

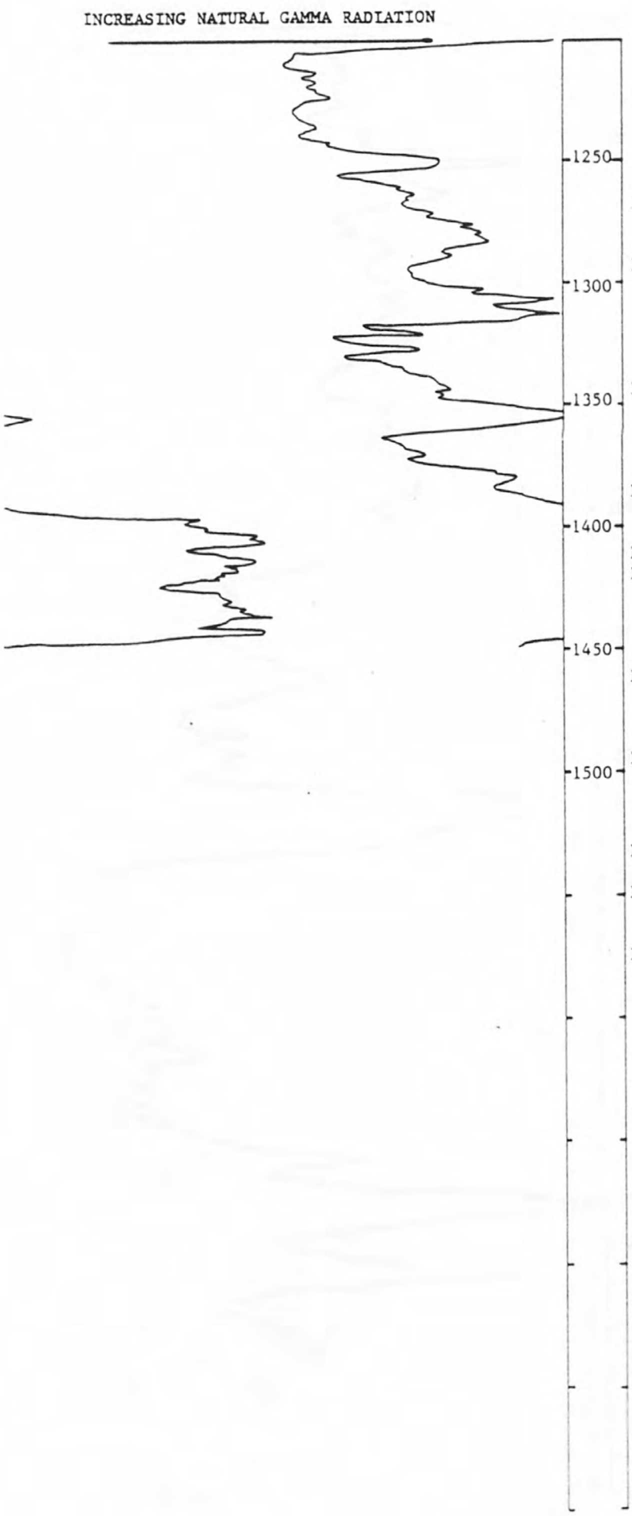
1034-1041 Limestone, interbedded shale, dense, light gray
1041-1064 Shale, calcareous, gray to green, limestone 1053-1055
1064-1085 Limestone and dense shale, fossiliferous, light green

1085-1125 Shale, calcareous, fossiliferous, light to medium green

1125-1136 Shale and dolomite interbedded, light brown

1136-1139 Sandstone, fine to medium, and shale, brown

1139-1200 Sandstone, fine to coarse, some shale, white to light green



DESCRIPTION OF MATERIALS

1200-1310 Dolomite, some chert, very fine to coarse, argillaceous zones, generally very light gray

1310-1322 Sandstone, very fine to medium, and dolomite, fine, argillaceous

1322-1370 Sandstone, very fine to medium, argillaceous

CAMBRIAN UNDIFFERENTIATED

1370-1415 Siltstone, argillaceous, some very fine sandstone

1415-1428 Limestone, dolomitic, dense, shaly, silty, pale gray

1428-1432 Shale, green-gray

1432-1439 Limestone, dolomitic, interbedded with shale

1439-1473 Limestone, argillaceous, flat pebbles, light to medium gray

1473-1500 Limestone, as above, interbedded with shale, light to medium gray

1500-1509 Siltstone, calcareous, dense, argillaceous, very light gray

1509-1543 Shale, silty, some fossils, slightly calcareous, mostly medium gray

1543-1545 Limestone, rounded clasts, light brown-gray to gray

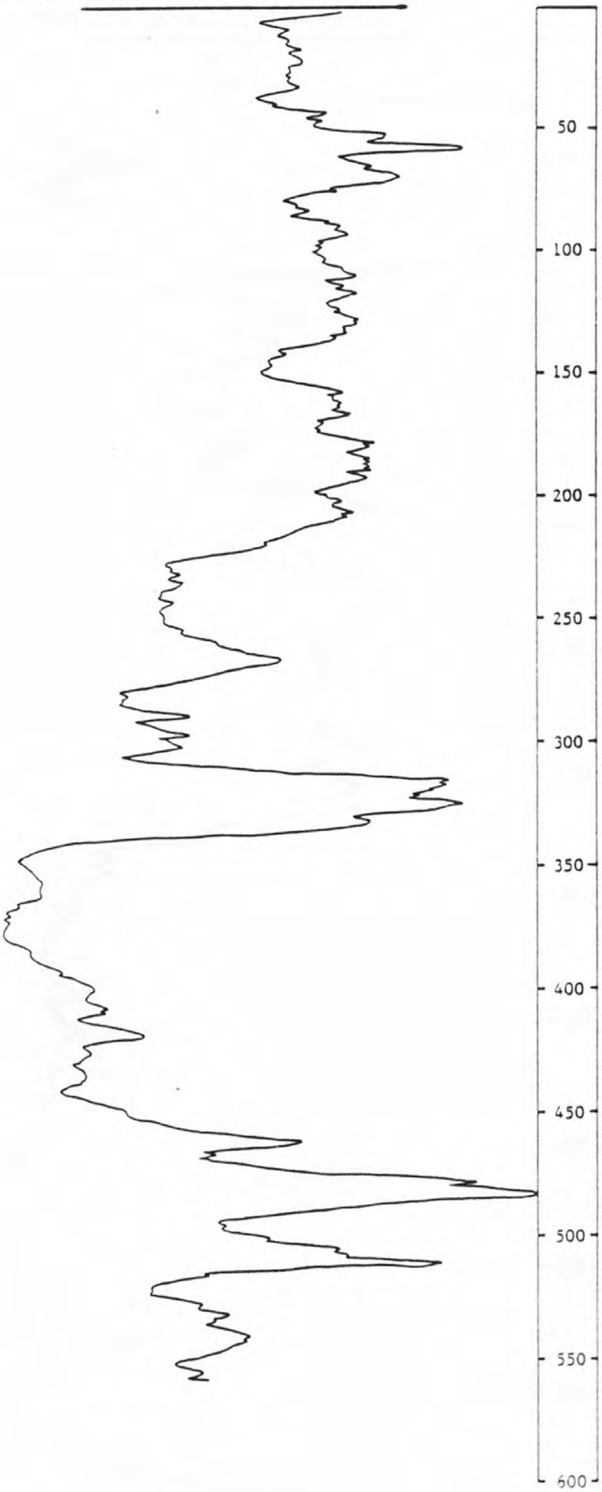
LOCATION: 091-42-16DDDD

ALTITUDE: 1320
(FEET, NGVD 1929)

DATE COMPLETED: April 13, 1979

DEPTH: 576
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-7 Clay, silty, tan to light yellow-brown
7-9 Clay, silty, sandy, blue-gray
9-30 Till, yellow-brown
30-36 Till, yellow-gray
36-40 Till, blue-gray to yellow-gray
40-49 Till, yellow-gray
49-60 Till, blue-gray to olive
60-142 Till, blue-gray
142-150 Sand and gravel, fine, tan
150-173 Till, blue-gray
173-176 Clay, gumbo, gray
176-195 Till, tougher than above, blue-gray
195-200 Clay, gray
200-220 Till, gray to blue-gray

CRETACEOUS
DAKOTA FORMATION

220-261 Sandstone, very fine to medium, gray and tan
261-312 Sandstone, very fine to fine, tan
312-335 Shale, silty, hard, interbedded sandstone, tan
335-406 Sandstone, medium, tan
406-407 Limestone, hard
407-410 Sandstone, very fine, hard
410-450 Sandstone, medium, tan
450-478 Sandstone, fine to medium, tan
478-490 Shale, reddish-brown
490-510 Shale, sandy, some sandstone layers, light-gray
510-540 Sandstone, fine to medium, pinkish-tan
540-550 Sandstone, fine to medium, with shale and limestone layers

PALEOZOIC UNDIFFERENTIATED

550-554 Sandstone, hard, yellow-brown
554-576 Dolomite and limestone, chert, tan to brown

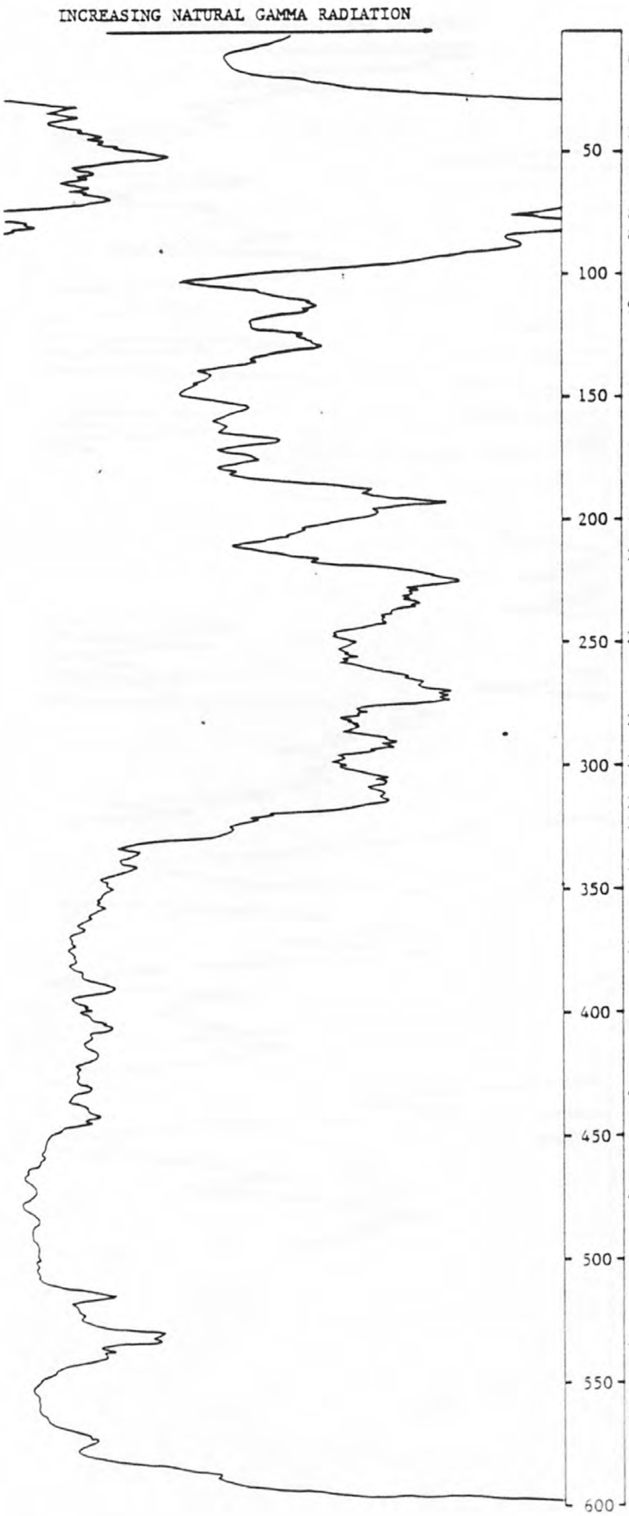
IGS - D21

LOCATION: 092-45-02CBCB1

ALTITUDE: 1245
(FEET, NGVD 1929)

DATE COMPLETED: October 11, 1978

DEPTH: 1089
(FEET)



DESCRIPTION OF MATERIALS

QUATERNARY

0-27 Till, boulders and gravel

CRETACEOUS
GRANEROS SHALE

27-77 Shale, silty, some pyrite, gray to gray-brown
77-80 Limestone, silty with clay layers, blue-gray
80-86 Shale, silty, dark gray
86-95 Limestone, silty, some shale and pyrite, light gray to brown

DAKOTA FORMATION

95-135 Shale, silty, some pyrite, thin sandstone and dolomite layers, gray to brown

135-162 Shale, silty, sandy, interbedded with sandstone, pyrite, tan to gray
162-165 Sandstone, dolomitic, hard, pyrite, tan

165-210 Shale, gray to gray-brown, some red, occasional dolomite streak
210-223 Shale, sandy, silty, sandstone layers, gray to brown

223-270 Shale, gray, brown, yellow

270-310 Shale, silty, red, gray, maroon

310-321 Shale, sandy, some gravel, gray to dark-gray
321-326 Sandstone, medium, well cemented
326-328 Shale, silty, gray

328-350 Sandstone, fine, tan to pink

350-400 Sandstone, fine to medium, tan to yellow-brown

400-460 Sandstone, fine to coarse, tan to yellow-orange

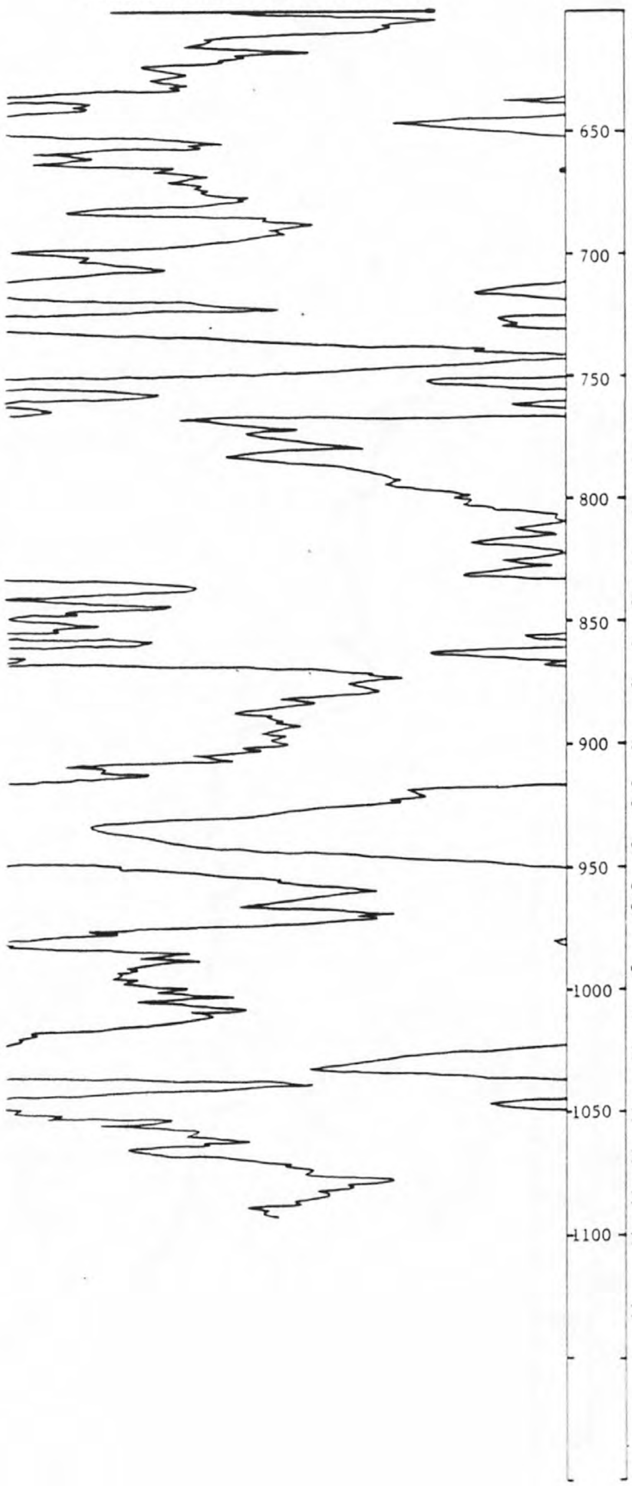
460-530 Sandstone, fine to coarse, tan to yellow-brown

530-568 Sandstone, fine to medium, tan

ORDOVICIAN UNDIFFERENTIATED

568-598 Dolomite, tan to gray-green, some shale

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

598-618 Dolomite and shale, dark gray-green

618-721 Dolomite, dark olive to gray-green, interbedded shale

721-734 Sandstone, shaly, well cemented, reddish-brown

734-743 Dolomite and shale, gray

743-747 Shale, gray, some dolomite and pyrite

747-759 Sandstone, tan, shale, gray-green at base

759-763 Shale, dark olive-brown, interbedded sandstone

763-782 Sandstone, fine, silty, shaly, tan

CAMBRIAN UNDIFFERENTIATED

782-793 Dolomite, fractured, sandstone filling

793-812 Sandstone, siltstone, shale, interbedded

812-833 Dolomite, silty, shaly, sandy, gray-green and gray-tan

833-851 Dolomite, shaly, brown to gray-green, some glauconite

851-871 Dolomite, some shale, gray-green

871-920 Shale, dolomite interbedded, gray-green, gray, and olive

920-925 Dolomite, shaly, tan, green

925-941 Sandstone, medium to coarse, shaly, gray-green to tan

941-950 Sandstone, very shaly, fine to medium, gray-green

950-960 Dolomite, shaly, gray-green

960-970 Shale, gray-green

970-1010 Dolomite, silty, sandy, glauconitic, tan

1010-1021 Dolomite, thin shale layers, tan and gray-green

1021-1031 Sandstone, fine to coarse, pinkish-tan, interbedded shale has pyrite and fossils

1031-1038 Shale, sandy, silty, pyrite, gray-green

1038-1050 Sandstone, fine to coarse, shaly, yellow and red to tan

1050-1058 Sandstone, fine to medium, very shaly, gray-green

1058-1062 Sandstone, medium to coarse, pinkish-tan, some shale

PRECAMBRIAN UNDIFFERENTIATED

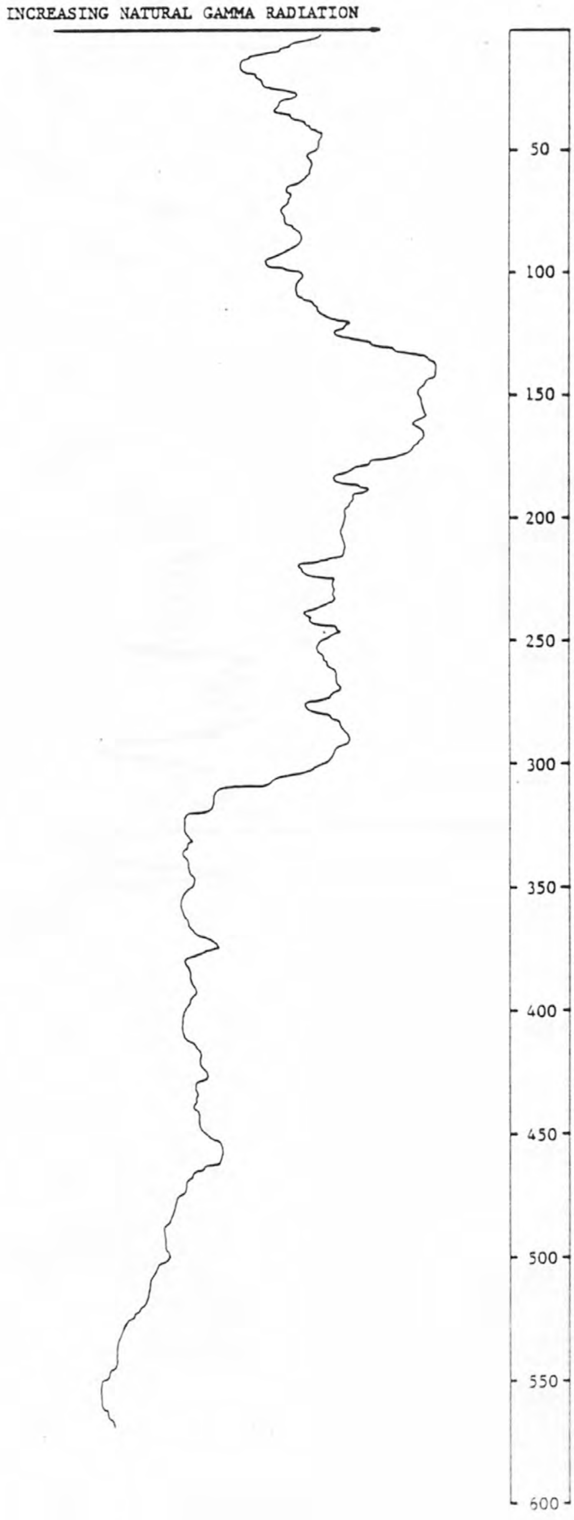
1062-1089 Granite, weathered, red and dark gray

LOCATION: 092-48-06DDDA1

ALTITUDE: 1282
(FEET, NGVD 1929)

DATE COMPLETED: November 1979

DEPTH: 581
(FEET)



DESCRIPTION OF MATERIALS

QUATERNARY

0-10 Loess, sandy, tan
10-35 Sand and gravel, fine to medium, tan to pink
35-36 Clay, tan-gray
36-42 Sand and gravel, tan to pink
42-72 Clay, some sandy or silty, tan to gray
72-78 Clay, silty, yellow-brown
78-95 Clay, silty, sand, gray
95-106 Sand, fine to medium, some cemented
106-110 Clay, sandy, blue-gray, possibly till

CRETACEOUS

GREENHORN LIMESTONE

110-130 Limestone, shaly, fossiliferous, dark colored

GRANEROS SHALE

130-175 Shale, silty, some siltstone, pyrite, dark gray

DAKOTA FORMATION

175-216 Shale, silty, sandy, siltstone, pyrite, dolomite at 203 feet
216-218 Coal, very dark shale
218-228 Sandstone, fine, pyrite, interbedded shale
228-285 Shale, sandy, silty, some thin dolomite and siltsone beds, pyrite, trace of lignite
285-302 Shale, silty, gray to blue-gray
302-303 Sandstone, fine to medium
303-314 Shale, silty, some dolomite
314-448 Sandstone, fine to medium, some coarse, tan
448-480 Shale, sandy, silty, some sandstone layers, gray
480-487 Sandstone, fine, some shale
487-500 Shale, very sandy, light gray
500-531 Sandstone, medium to coarse, pink to tan, thin shale
531-555 Shale, silty, sandy, maroon to gray, some limestone
555-575 Shale, silty, maroon and gray, some limestone

PALEOZOIC UNDIFFERENTIATED

575-581 Limestone, tan and shale, gray-green

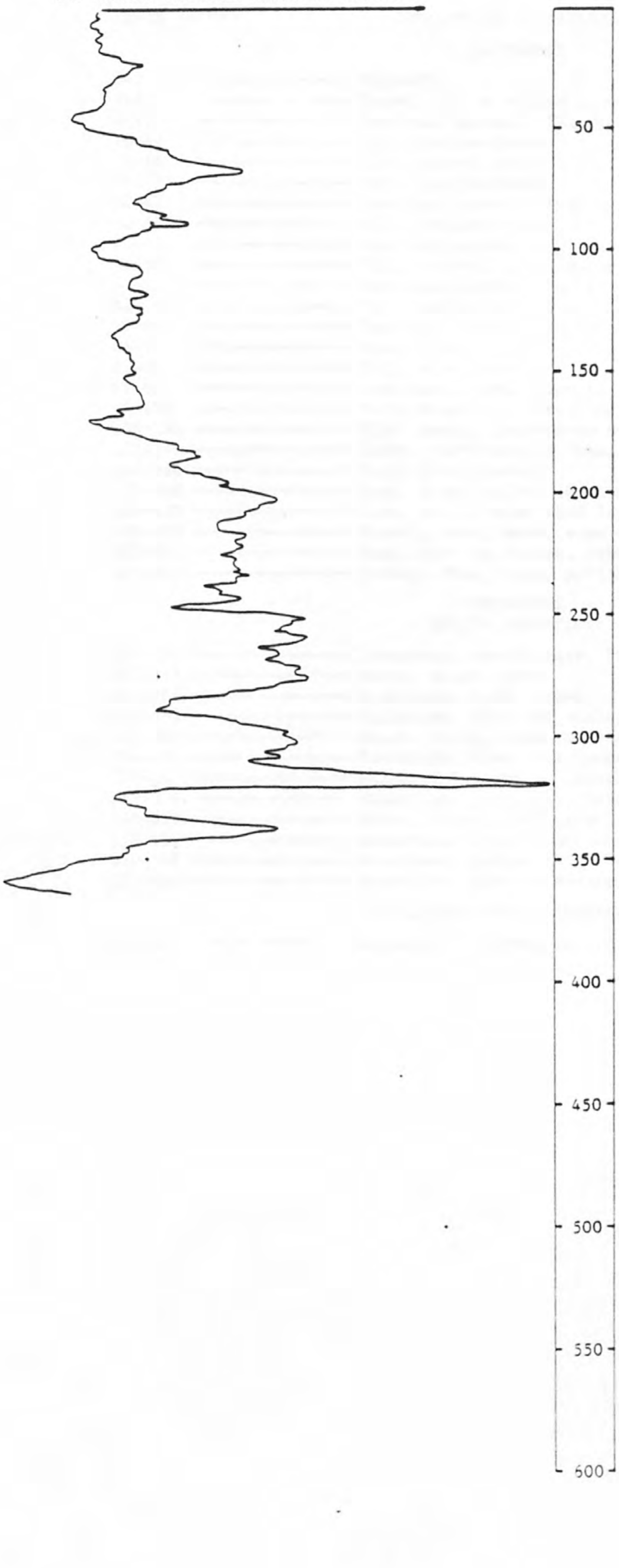
LOCATION: 093-35-19DCBB

ALTITUDE: 1322
(FEET, NGVD 1929)

DATE COMPLETED: May 30, 1979

DEPTH: 381
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-5 Clay, sandy, topsoil
5-30 Sand and gravel, fine to coarse, brown to yellow-brown
30-46 Till, gravelly, blue-gray
46-55 Sand and gravel, fine, yellow-brown
55-57 Till, blue-gray
57-67 Sand and gravel, fine, yellow-brown
67-75 Till, yellow-brown
75-86 Till, some gravel, blue-gray
86-89 Sand and gravel, fine, yellow-brown
89-161 Till, boulders, gravel, blue-gray
161-171 Till, yellow-brown
171-174 Sand and gravel, yellow-brown
174-220 Till, gravelly, yellow-brown to yellow-gray
220-243 Till, some gravel, blue-gray

CRETACEOUS
DAKOTA FORMATION

243-249 Sandstone, tan, some shale
249-256 Shale, silty, light gray
256-285 Shale, maroon to red-brown
285-290 Sandstone, fine grading to coarse
290-318 Shale, silty, some sand, light gray to red-brown
318-325 Sandstone, fine to medium, shale streaks, lignite
325-341 Shale, sandstone streaks, silty, very light gray

PALEOZOIC UNDIFFERENTIATED

341-381 Chert and dolomite, tan

LOCATION: 093-44-36CCC

DATE COMPLETED: April 26, 1978

ALTITUDE: 1350
(FEET, NGVD 1929)

DEPTH: 645
(FEET)

DEPTH (FEET)	DESCRIPTION OF MATERIALS
	QUATERNARY
0-2	Topsoil
2-8	Loess, tan to yellow-brown
8-10	Sand and gravel, till mixed, yellow-brown
10-12	Till, yellow-brown
12-16	Clay, gumbo, gray
16-40	Till, yellow-brown
40-42	Sand and gravel, fine to medium, yellow-brown
42-43	Till, yellow-brown
43-45	Sand and gravel, till mixed, iron oxide
45-50	Till, gravelly, yellow-brown and gray
50-52	Sand and gravel, fine to medium, yellow-brown
52-60	Till, gravelly, olive and blue-gray
60-64	Sand and gravel, till mixed
64-71	Sand, fine to coarse, cemented, yellow-tan
71-91	Till, blue-gray
91-94	Sand and gravel, fine to coarse, gray
94-108	Till, blue-gray, sand and gravel 101-102
108-121	Clay, sandy, gray-green to gray-brown
121-142	Sandy, very fine to fine, silty, gray
142-144	Clay, gray-green
144-148	Sand, fine, silty, tan and gray
148-180	Clay, silty, some sand layers, gray-green
180-220	Gravel, sand, wood, some cemented
220-245	Sand, fine to coarse, cemented, gray
245-249	Gravel, sand, clay, pyrite, boulders
	CRETACEOUS DAKOTA FORMATION
249-252	Limestone, sandy, hard, brown
252-261	Shale, silty, gray
261-262	Limestone, hard, brown
262-265	Sandstone, fine and shale, silty, gray
265-304	Shale, silty, some sandstone layers, brown to gray
304-316	Sandstone, fine, tan, some shale, gray
316-343	Shale, silty, gray, interbedded sandstone, fine, tan
343-370	Sandstone, fine, tan, layers of shale, silty, gray
370-430	Shale, silty, light gray, some sandstone streaks
430-450	Sandstone, fine to medium, tan
450-507	Sandstone, medium to coarse, some fine, tan
507-641	Sandstone, fine to medium, tan, some shale
	PALEOZOIC UNDIFFERENTIATED
641-645	Limestone, coarse, tan and white chert

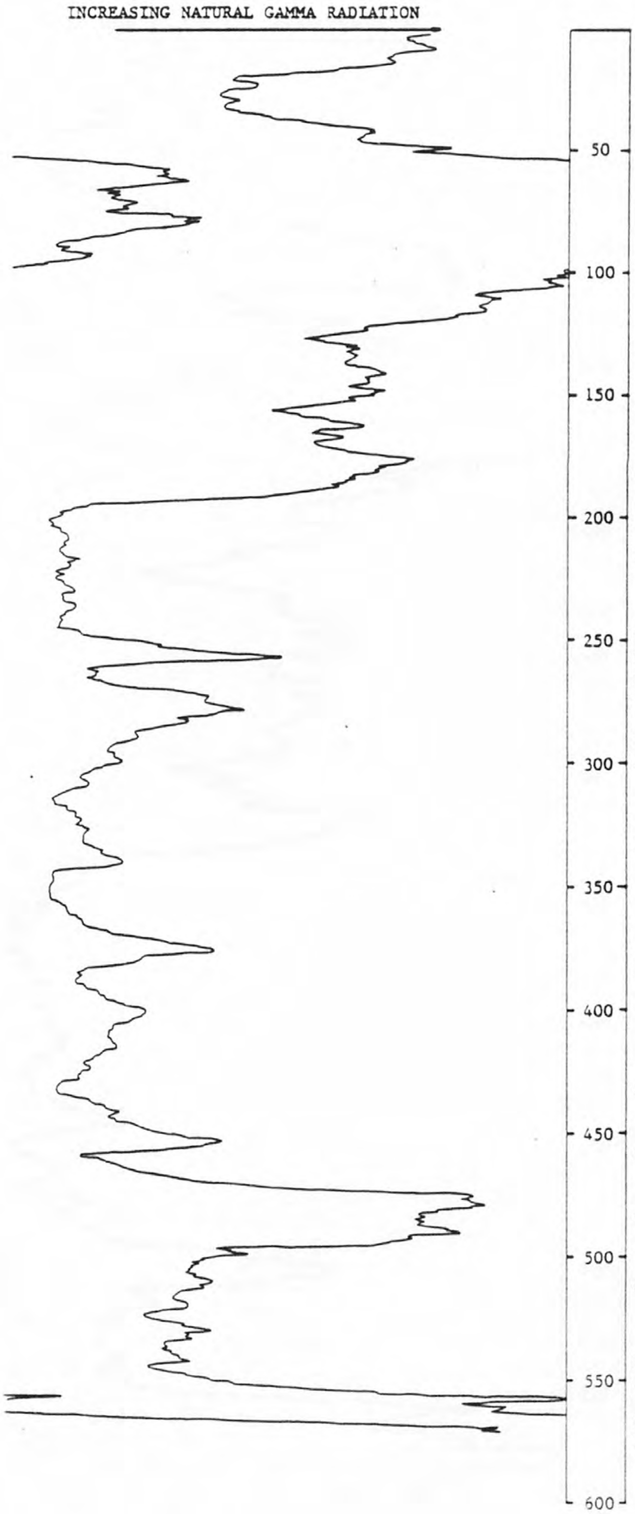
IGS - D2

LOCATION: 093-46-12DDDD

ALTITUDE: 1280
(FEET, NGVD 1929)

DATE COMPLETED: July 20, 1977

DEPTH: 570
(FEET)



DESCRIPTION OF MATERIALS

QUATERNARY

0-3 Topsoil
3-20 Clay, silty, wood
20-30 Till, sandy, tan

CRETACEOUS

GREENHORN LIMESTONE

30-36 Clay, limestone fragments, yellow-brown
36-61 Limestone, soft, shale, silty

GRANEROS SHALE

61-108 Shale, silty, some siltstone, pyrite, dark to light gray, thin limestone layers 104-108

DAKOTA FORMATION

108-156 Shale, silty, some limestone streaks, pyrite
156-162 Sandstone, very fine, silty, pyrite, gray
162-193 Shale, silty, some limestone, pyrite, gray to gray-brown
193-256 Sandstone, very fine to fine, pyrite, lignite, tan
256-259 Shale, silty, light gray
259-265 Sandstone, fine, tan
265-279 Sandstone, fine to coarse, some shale, tan
279-316 Sandstone, very fine, tan
341- 395 Sandstone, fine to coarse, dolomite at 375
395-420 Sandstone, fine, some dolomite streaks, tan
420-452 Sandstone, very fine to fine, some dolomite streaks, tan
252-271 Sandstone, fine grading to coarse, tan
471-494 Shale, sandy, red, maroon and light gray
494-555 Sandstone, fine, some shale, dolomite and limestone, tan

PALEOZOIC UNDIFFERENTIATED

555-560 Shale, gray-green
560-567 Dolomite, gray-green to gray-brown
567-568 Shale, gray
568-570 Dolomite, brown and shale, gray

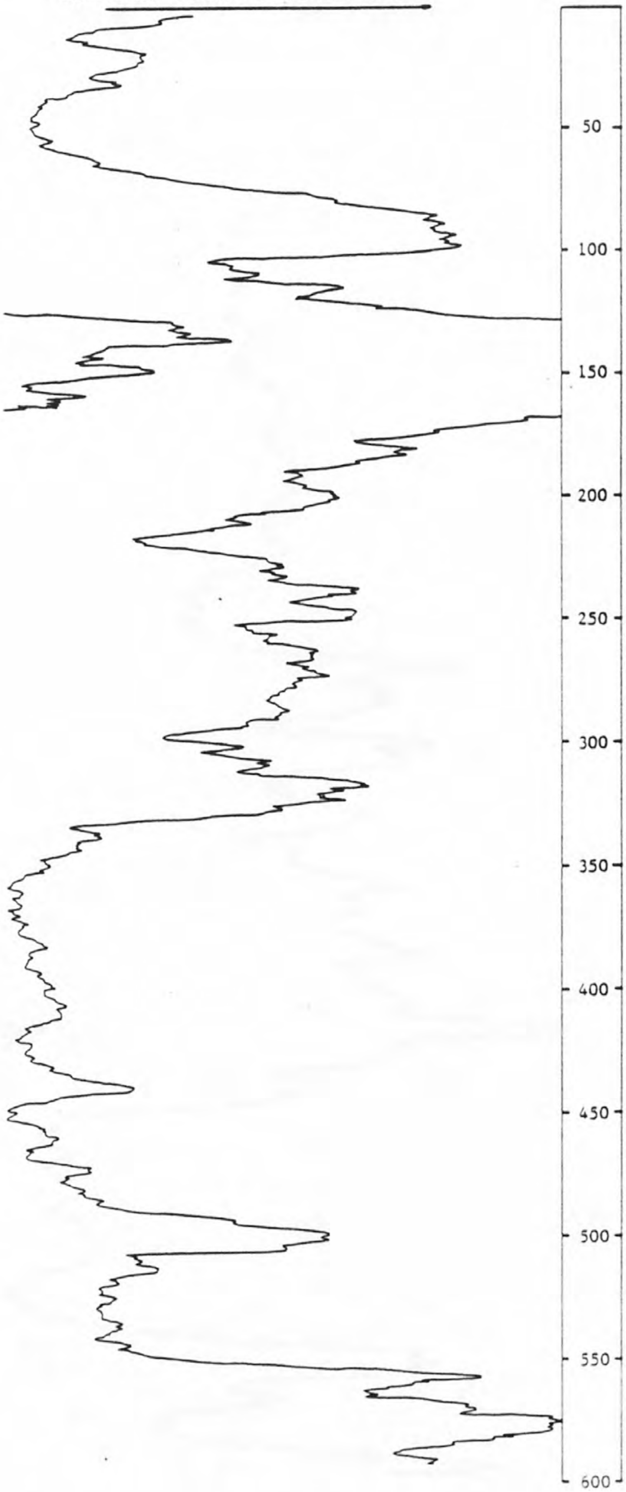
LOCATION: 094-47-35AAAB

ALTITUDE: 1305
(FEET, NGVD 1929)

DATE COMPLETED: July 30, 1978

DEPTH: 601
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-10 Clay, tan to brown
10-28 Sand, some silty clay, tan
28-34 Sand and gravel, fine to boulders
34-37 Till, sandy, silty, yellow to blue-gray
37-75 Sand and gravel, medium to coarse, yellow-brown

CRETACEOUS

CARLILE SHALE

75-102 Shale, silty, gray to blue-gray

GREENHORN LIMESTONE

102-113 Limestone, brown to dark brown
113-128 Shale, hard, calcareous, brown and dark gray

GRANEROS SHALE

128-170 Shale, silty, pyrite, gray-brown

DAKOTA FORMATION

170-190 Shale, siltstone and limestone, pyrite, gray
190-215 Shale, silty, sandy, pyrite, gray
215-221 Sandstone, very fine, pyrite, tan
221-330 Shale, sandy, silty, some pyrite and lignite, tan to gray
330-360 Sandstone, very fine to fine, tan
360-381 Sandstone, fine to medium, tan
381-400 Sandstone, medium, tan
400-420 Sandstone, fine, tan
420-460 Sandstone, fine to medium, tan
460-494 Sandstone, medium to coarse, tan, dolomite at 483 feet
494-505 Shale, silty, gray to light gray
505-550 Sandstone, very, fine to medium at base, gray to tan

PALEOZOIC UNDIFFERENTIATED

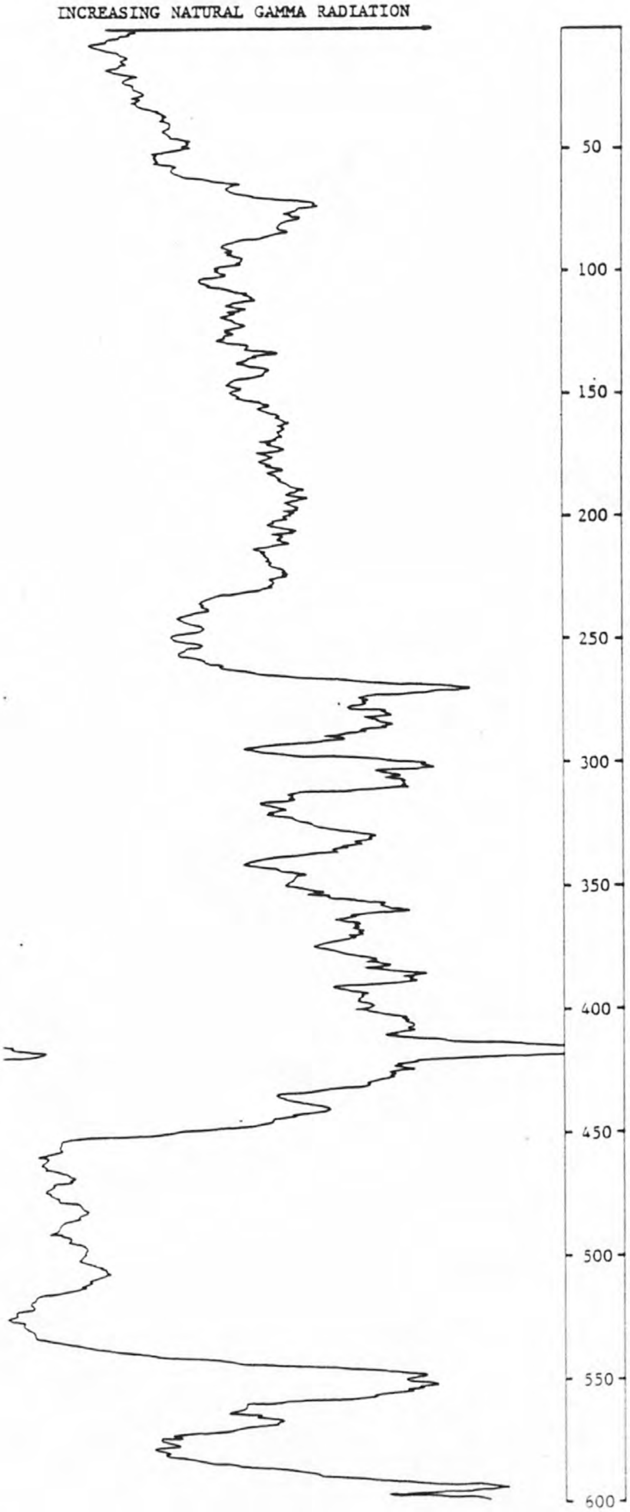
550-572 Shale, maroon, yellow, gray, and green
572-581 Shale, sandy, red-brown
581-601 Limestone and shale, tan, gray-green, red-brown

LOCATION: 095-39-04ABCB

ALTITUDE: 1390
(FEET, NGVD 1929)

DATE COMPLETED: August 11, 1977

DEPTH: 620
(FEET)



DESCRIPTION OF MATERIALS

QUATERNARY

0-12 Sand, fine to coarse, gravel, yellow-brown

12-90 Till, yellow-brown alternating yellow-gray

90-105 Till, yellow-brown, some gravel
105-107 Sand and gravel, fine to coarse

107-109 Till, yellow-brown
109-127 Clay, gumbo, gray

127-185 Till, mostly clay, gray-brown to blue-gray

185-230 Clay, silty, gray to light gray

CRETACEOUS
DAKOTA FORMATION

230-235 Clay, interbedded sandstone, silty, yellow-tan
235-267 Sandstone, very fine to coarse, cemented, brown
267-269 Lignite
269-278 Shale, silty, some sandstone, gray
278-281 Sandstone, fine
281-295 Shale, silty, gray, interbedded sandstone
295-297 Dolomite, brown
297-318 Shale, silty, gray
318-328 Sandstone, fine, interbedded shale
328-336 Shale, silty, gray
336-342 Sandstone, fine, tan

342-440 Shale, silty, light gray, and reddish-brown

440-445 Shale, silty, interbedded sandstone
445-510 Sandstone, fine to medium
510-520 Sandstone, fine, shaly, tan
520-533 Sandstone, fine to medium, tan

533-542 Sandstone, very coarse, tan
542-557 Shale, silty, sandy
557-565 Sandstone, fine to medium, tan
565-567 Shale, gray
567-587 Sandstone, fine, tan, soft shale layers
587-589 Shale, gray
589-591 Sandstone, fine
591-605 Shale, soft, brown, gray

PALEOZOIC UNDIFFERENTIATED

605-620 Dolomite, coarse, light colored

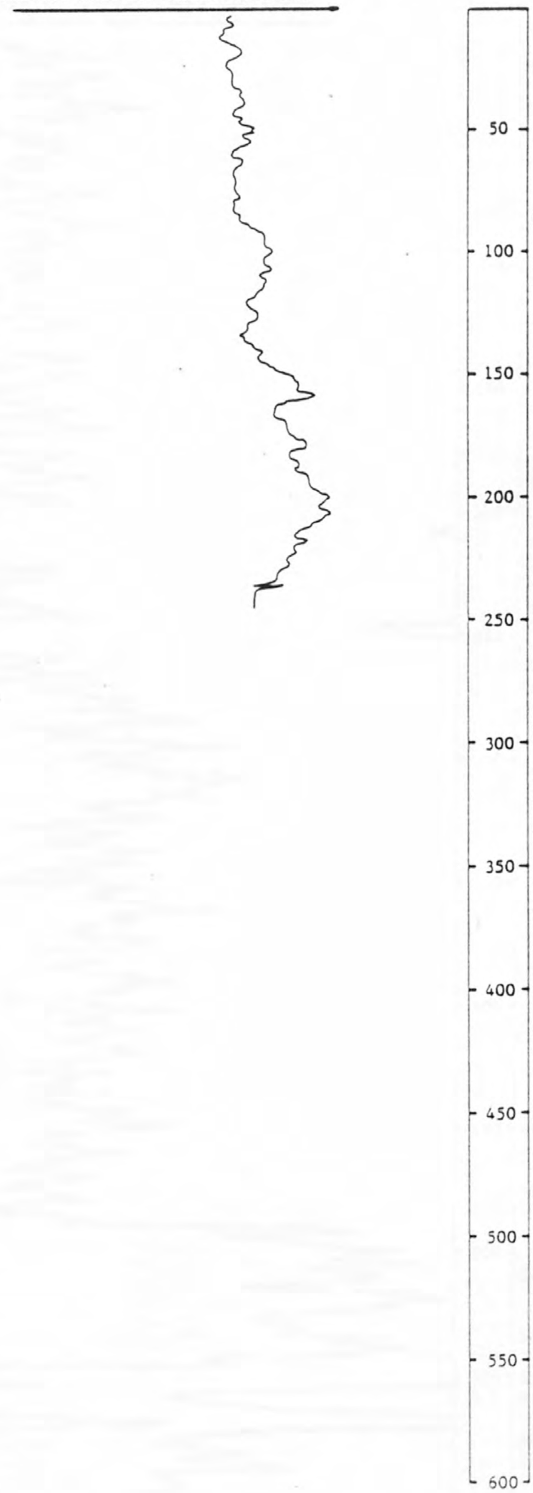
LOCATION: 096-34-24BBB

ALTITUDE: 1315
(FEET, NGVD 1929)

DATE COMPLETED: November 1979

DEPTH: 501
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-14 Till, gravelly, yellow-brown
14-86 Till, thin gravel layers, blue-gray
86-97 Till, sandy, olive
97-120 Till, blue-gray
120-124 Sand and gravel, fine to coarse, gray
124-140 Till, sandy, blue-gray
140-146 Till, light blue-gray
146-155 Till, yellow-gray to yellow-brown
155-161 Till, gumbo, dark gray
161-190 Till, yellow-brown
190-200 Till, olive to blue-gray
200-290 Till, boulders, blue-gray
290-310 Till, sandy, gravelly, boulders, blue-gray
310-321 Sand, fine to medium, gray
321-330 Sand and gravel, cemented
330-350 Sand and gravel, some clay streaks
350-360 Sand and gravel, cemented

CRETACEOUS
DAKOTA FORMATION

360-387 Sandstone, fine to very coarse, tan
387-430 Shale, silty, sandstone interbedded, gray
430-436 Shale, silty, light gray
436-466 Shale, silty, gray
466-498 Sandstone

PALEOZOIC UNDIFFERENTIATED

498-501 Limestone

IGS - D41

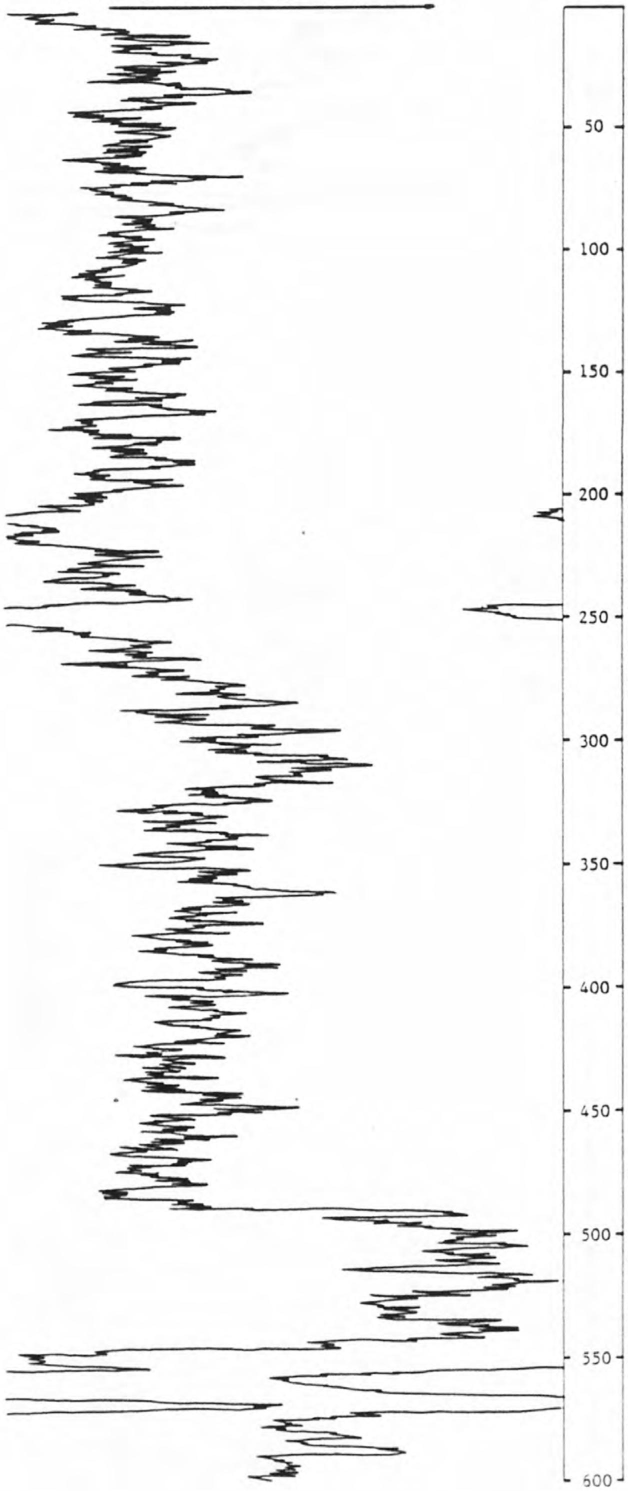
LOCATION: 096-40-05DDDA

ALTITUDE: 1560
(FEET, NGVD 1929)

DATE COMPLETED: June 1980

DEPTH: 704
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-35 Till, yellow-brown to yellow-gray

35-190 Till, some boulders, blue-gray

190-208 Till, gravelly, blue-gray

208-211 Sand and gravel, fine to medium, gray

211-214 Clay, silty, brown

214-218 Till, sandy, light blue-gray

218-221 Sand and gravel, fine to coarse, mostly fine, gray

221-226 Till, sandy, light blue-gray

226-234 Till, thin gravel layers, yellow-brown

234-236 Till, sandy, gray

236-244 Till, yellow-brown

244-252 Sand, fine to coarse, some gravel, medium

252-310 Till, sandy, some sand and gravel, yellow-brown to gray

310-487 Till, sandy, gravelly, few sand and gravel layers at base

CRETACEOUS

DAKOTA FORMATION

487-501 Shale, silty, blue-gray

501-541 Shale, silty, some dolomite, gray-brown

541-544 Shale, silty, some pyrite, gray-brown

544-550 Sandstone with shale, silty, sandy, light gray

550-561 Sandstone, fractured

561-565 Sandstone, fine with shale, silty, gray-brown

565-567 Shale, silty, gray

567-580 Sandstone, fine to medium, tan to brown

INCREASING NATURAL GAMMA RADIATION

DESCRIPTION OF MATERIALS

580-645 Sandstone, fine to medium, tan and brown

645-688 Sandstone, fine to medium, softer, less cemented at base, tan

PALEOZOIC UNDIFFERENTIATED

688-695 Shale, sandy, silty, some dark chert, gray-green

695-700 Shale, silty, sandy, light gray

700-701 Shale, maroon and gray-green

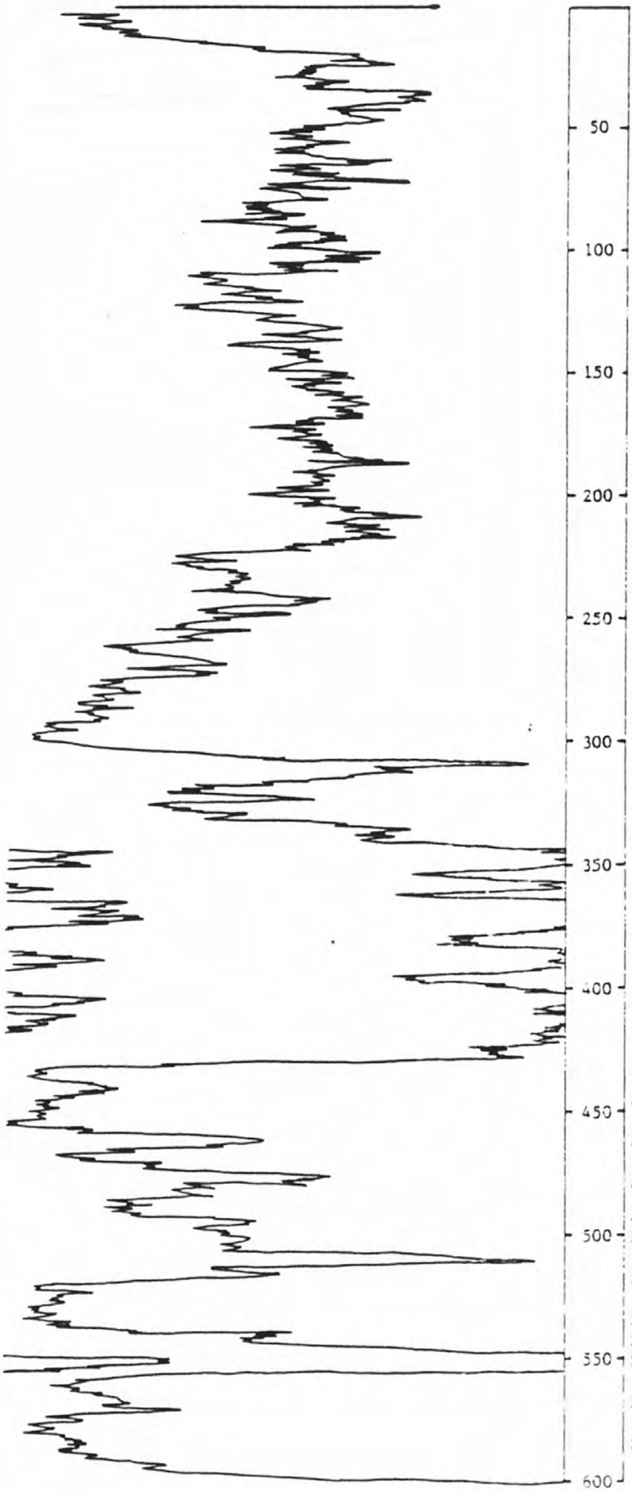
LOCATION: 098-39-26CDAD1

ALTITUDE: 1401.98
(FEET, NGVD 1929)

DATE COMPLETED: May 21, 1980

DEPTH: 662
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-20 Sand and gravel, fine to coarse

20-61 Till, blue-gray

61-114 Till, gravel, boulders, blue-gray

114-143 Till, gravel, boulders, yellow-brown

143-185 Till, very little sand, gray-tan

185-206 Clay, lime nodules, gray-yellow

206-220 Clay, silty, light gray-green to tan

220-240 Clay, very sandy, sand layers, gray-green

240-250 Clay, as above, yellow-brown

250-270 Clay, sand and gravel mixed, yellow-brown to brown

270-280 Clay, very sandy

280-300 Clay, sand and gravel mixed, gray-tan

CRETACEOUS
DAKOTA FORMATION

300-320 Shale, interbedded sanstone, gray

320-335 Sandstone, fine, tan

335-348 Shale, silty, gray with carbonate at top

348-352 Sandstone, fine, tan

352-385 Shale, silty, interbedded sandstone 370-385

385-425 Shale, very silty, several thin dolomite streaks

425-470 Sandstone, fine to medium, thin shale layers

470-480 Sandstone, fine to medium, grading to coarser

480-490 Sandstone, finer than above, hard

490-502 Sandstone, fine to coarse

502-507 Shale, silty, sandy, light gray

507-540 Sandstone, fine to medium, harder than above, tan

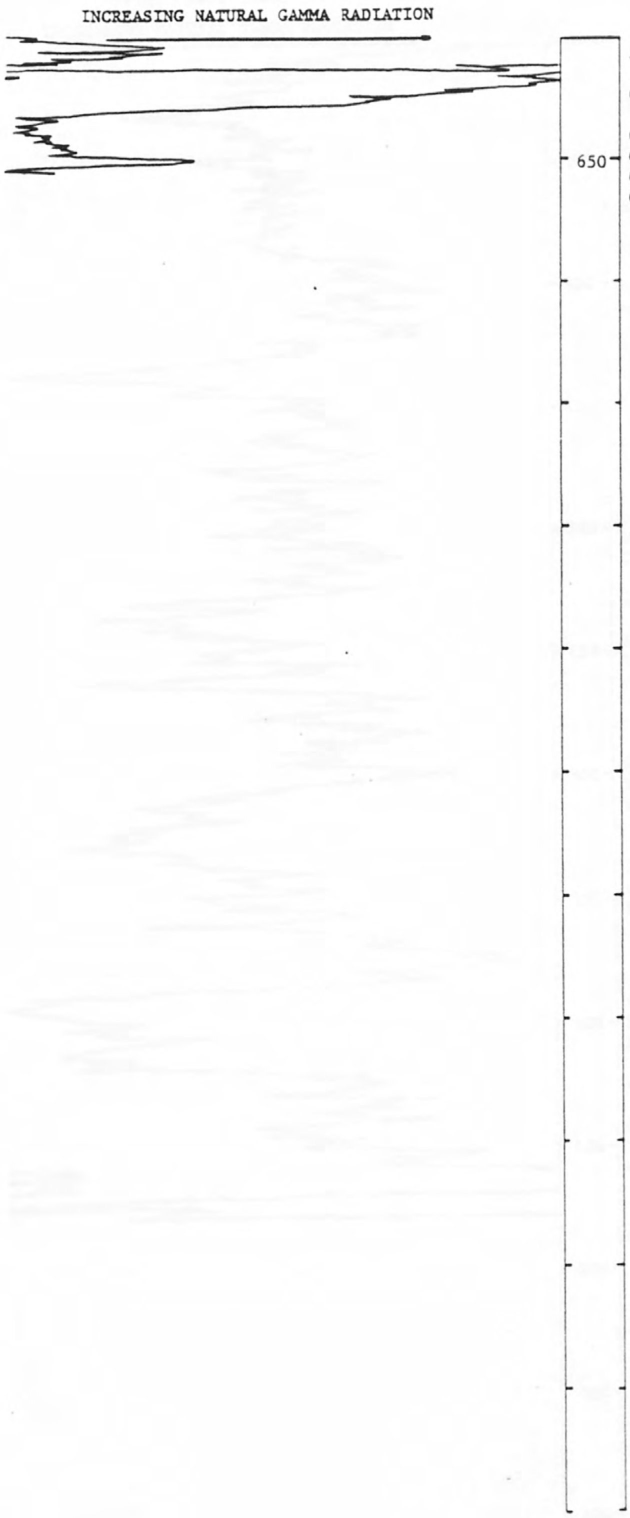
540-544 Sandstone, medium to coarse

544-549 Shale, silty, gray

549-564 Sandstone, fine to medium, some shale

564-580 Sandstone, fine grading to coarse, tan

580-592 Sandstone, medium to very coarse



DESCRIPTION OF MATERIALS

PALEOZOIC UNDIFFERENTIATED

592-620 Shale, sandy, silty, light green to light gray
620-624 Shale, sandy, silty, yellow-brown to gray-green
624-632 Sandstone, medium, light color
632-640 Shale, very sandy, some sandstone
640-650 Sandstone, light colored
650-662 Sandstone, shaly, calcareous

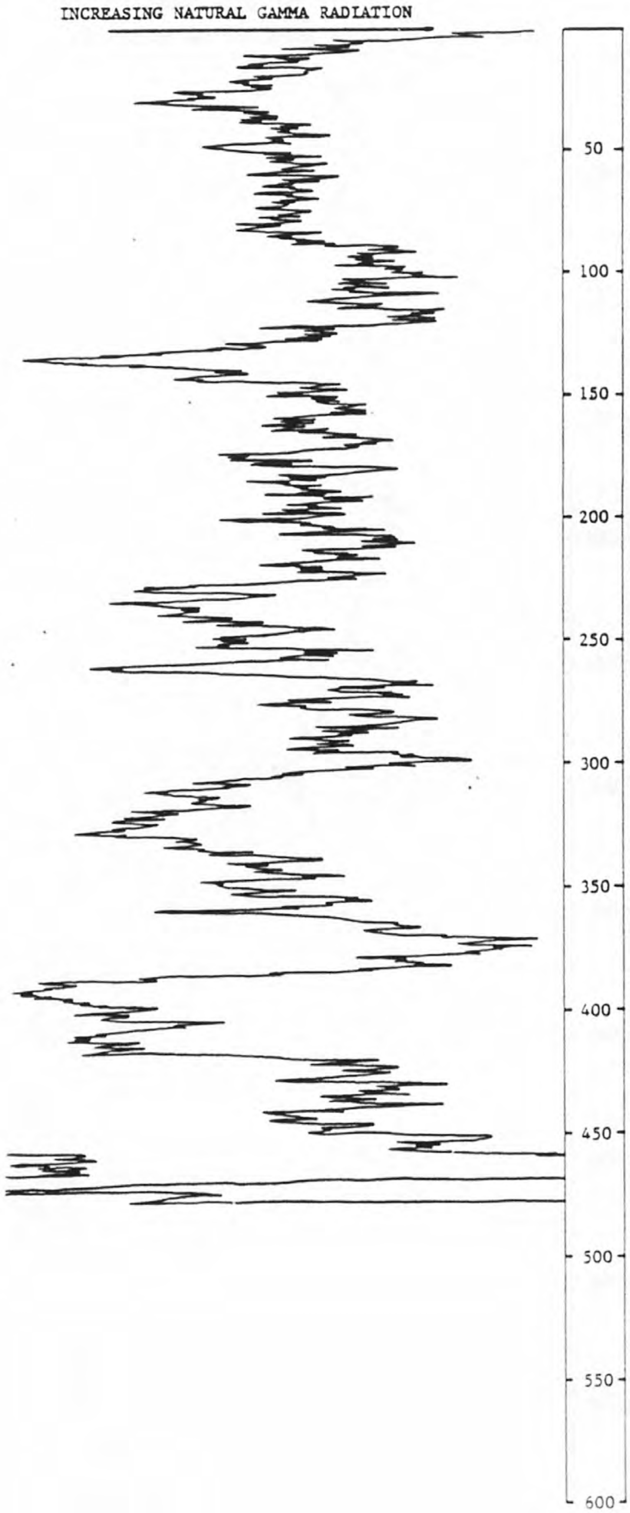
IGS - D40

LOCATION: 098-42-33AABB

ALTITUDE: 1440
(FEET, NGVD 1929)

DATE COMPLETED: June 6, 1980

DEPTH: 481
(FEET)



DESCRIPTION OF MATERIALS

QUATERNARY

0-17 Till, yellow-brown
17-22 Till, blue-gray
22-24 Sand, gravel, some clay, yellow-brown
24-26 Till, blue-gray
26-30 Sand and gravel, fine to coarse, gray
30-65 Till, sandy, peat at top, blue-gray to light blue-gray
65-70 Till, silty, gray-green

70-125 Till, some sand layers, yellow-brown
125-129 Clay, gray
129-132 Till, yellow-brown
132-138 Sand, gravel, some clay, yellow-brown
138-140 Clay, gray
140-160 Till, yellow-brown to yellow-gray

160-225 Till, some gravel, blue-gray
225-233 Till, as above, more sand and gravel
233-240 Sand, gravel, till layers

240-257 Till, blue-gray
257-261 Sand, fine to coarse, gray

261-300 Till, tough, blue-gray
300-305 Till, very sandy, blue-gray
305-310 Sand, fine to medium, cemented

310-345 Sand, fine to coarse, clay at 333
345-350 Till, very sandy, gray-green
350-359 Sand, gravel, clay mixed, green-gray

CRETACEOUS
DAKOTA FORMATION

359-360 Dolomite with siderite, brown
360-383 Shale, silty, pyritic, gray-brown
383-418 Sandstone, very fine, shale, silty, interbedded, gray-brown
418-419 Dolomite, brown

419-465 Shale, interbedded sandstone, some pyrite, gray-brown
465-473 Shale, sandy, silty, light gray

PRECAMBRIAN
SIOUX QUARTZITE

473-481 Quartzite, pink, weathered

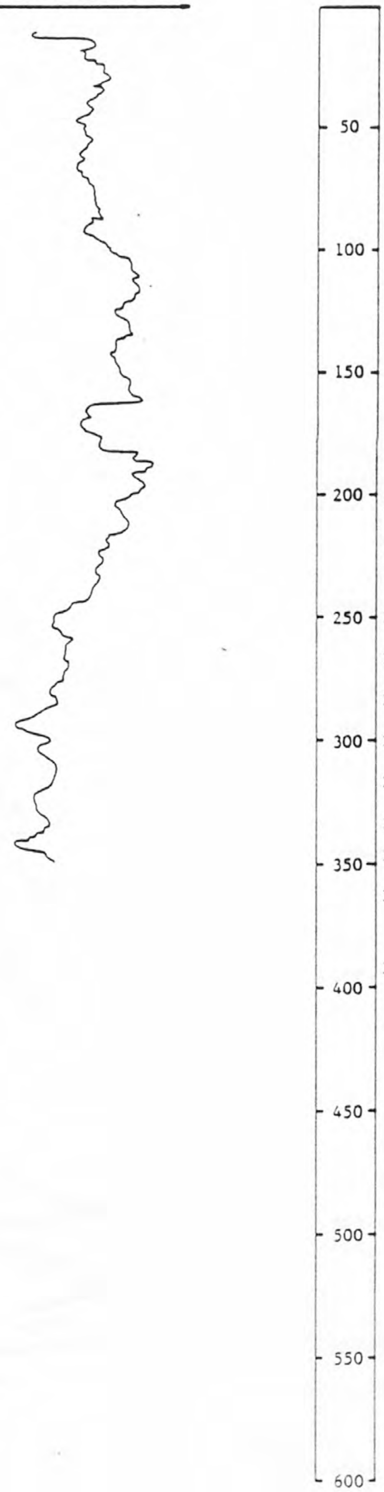
LOCATION: 098-48-16DDAD

ALTITUDE: 1268
(FEET, NGVD 1929)

DATE COMPLETED: August 29, 1978

DEPTH: 358
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-7 Clay, silty, gray and tan

7-18 Sand, gravel, boulders, oxidized

18-100 Till, blue-gray

100-115 Till, very sandy, blue-gray

CRETACEOUS
DAKOTA FORMATION

115-161 Shale, silty, hard, gray to gray-brown

161-205 Shale, silty, with brown limestone, pyrite, gray-brown

205-250 Shale, silty, gray, limestone layer at 215

250-270 Shale, silty, dolomite streaks, gray

270-290 Shale, silty, dolomite and sandstone streaks, gray

290-295 Shale and sandstone, fine, tan and gray

295-310 Shale, silty, sandy, dolomite and lignite streaks

310-330 Shale, silty, gray

330-350 Shale, silty, sandy, sandstone and lignite layers

350-353 Quartzite, weathered

PRECAMBRIAN
SIOUX QUARTZITE

353-358 Quartzite, pink

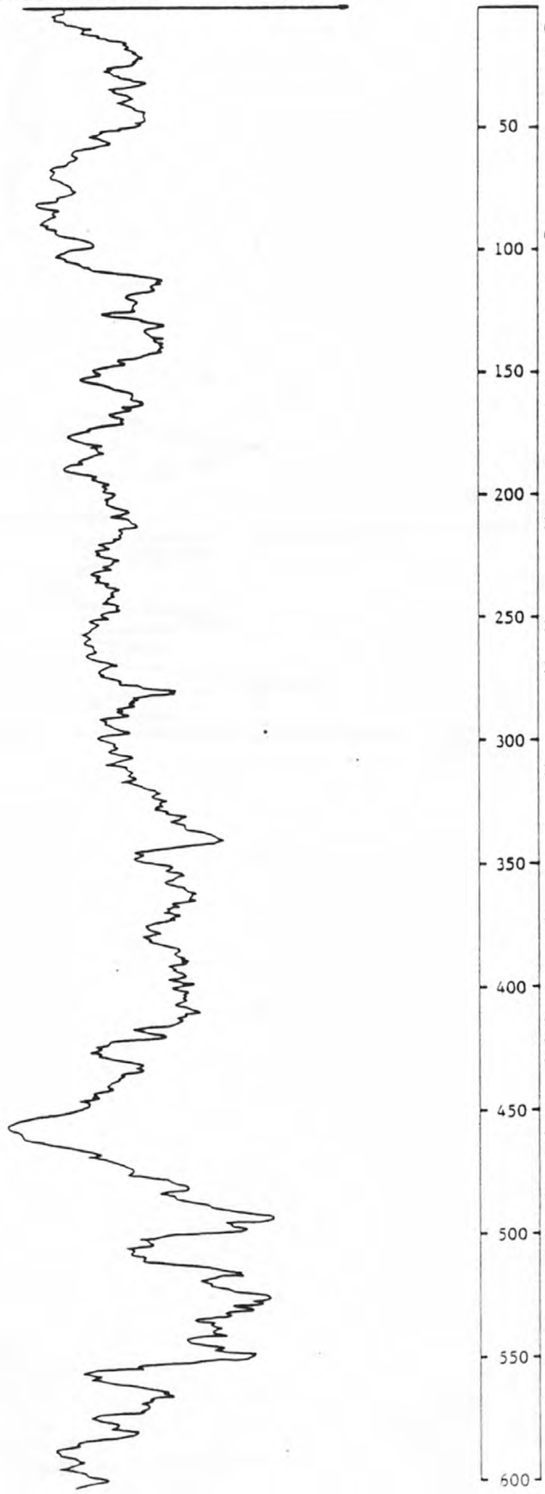
LOCATION: 100-39-17DCCB

ALTITUDE: 1560
(FEET, NGVD 1929)

DATE COMPLETED: June 14, 1978

DEPTH: 923
(FEET)

INCREASING NATURAL GAMMA RADIATION



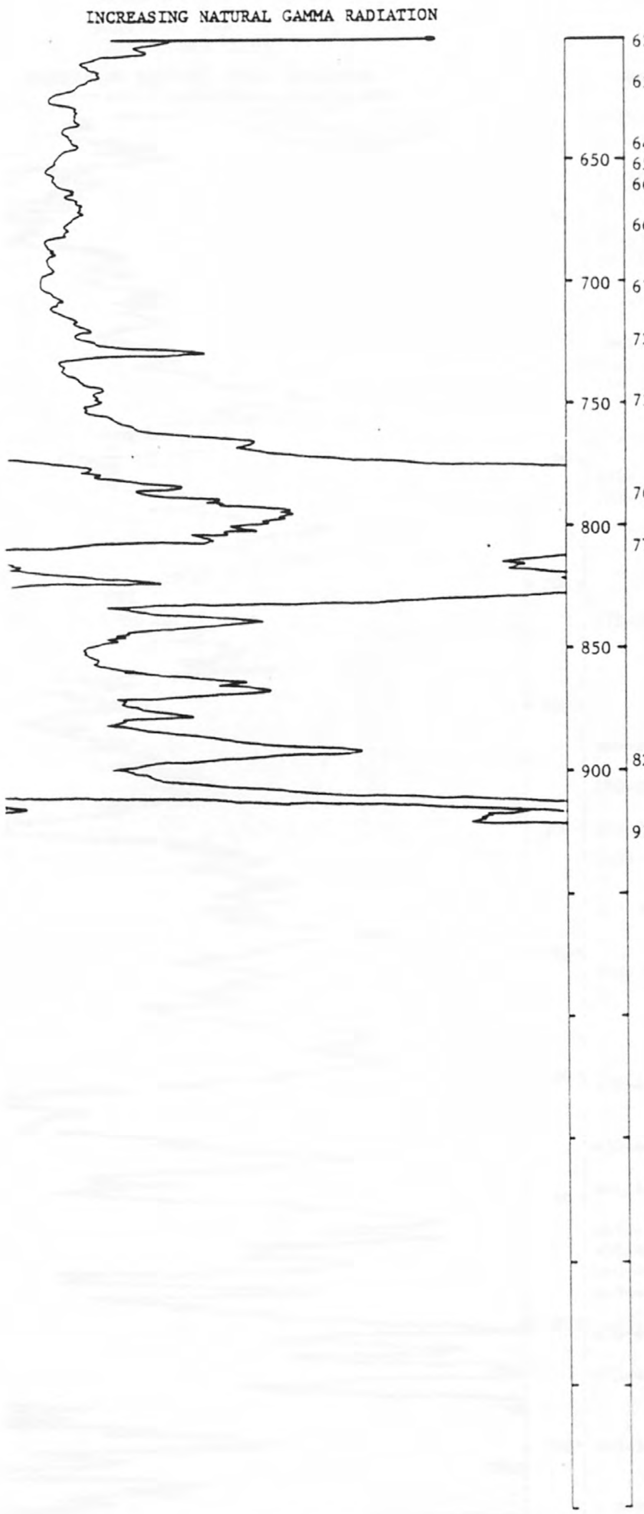
DESCRIPTION OF MATERIALS

QUATERNARY

0-12 Till, light yellow
12-14 Sand and gravel, yellow-brown
14-69 Till, blue-gray
69-109 Sand and gravel, some boulders
109-125 Till, sandy, yellow-brown
125-129 Till, very sandy, olive
129-152 Till, blue-gray
152-157 Clay, silty, gray to light gray
157-166 Till, some gravel, blue-gray
166-168 Sand, fine, gray
168-176 Till, blue-gray
176-190 Till, pebbles, light-gray to blue-gray
190-201 Till, yellow-gray to gray
201-212 Till, pebbly, light gray
212-278 Till, yellow-gray to blue-gray
278-284 Till, sandy, medium gray
284-345 Till, sand and pebbles, very light brown
345-430 Till, sandy, some gravel, very light gray to light brown-gray
430-435 Sand, very fine to medium
435-443 Till, brown-gray to green-gray
443-449 Till, silty, yellow-green

CRETACEOUS
DAKOTA FORMATION

449-450 Shale or siltstone, brown
450-461 Shale, silty, yellow
461-490 Siltstone and very fine sandstone, argillaceous
490-515 Shale, silty, some siltstone
515-570 Sandstone, fine to coarse, shale interbedded
570-620 Sandstone, very fine to fine, some medium, trace of shale



DESCRIPTION OF MATERIALS

620-630 Sandstone, medium to coarse, light gray

630-640 Sandstone, fine to very coarse

640-655 Sandstone, fine to medium

655-661 Sandstone, coarse to very coarse

661-665 Sandstone, fine to medium

665-675 Sandstone, medium to very coarse

675-720 Sandstone, fine to medium, trace of shale, light gray

720-730 Sandstone, medium to coarse, trace of pyrite

730-761 Sandstone, fine to coarse, trace of pyrite

CAMBRIAN UNDIFFERENTIATED

761-770 Siltstone, dolomitic, trace of pyrite

770-822 Dolomite, some shale, fossiliferous, light green to white

822-913 Sandstone, fine to coarse, green to white, some pale orange

913-923 Granite, unweathered 919-923

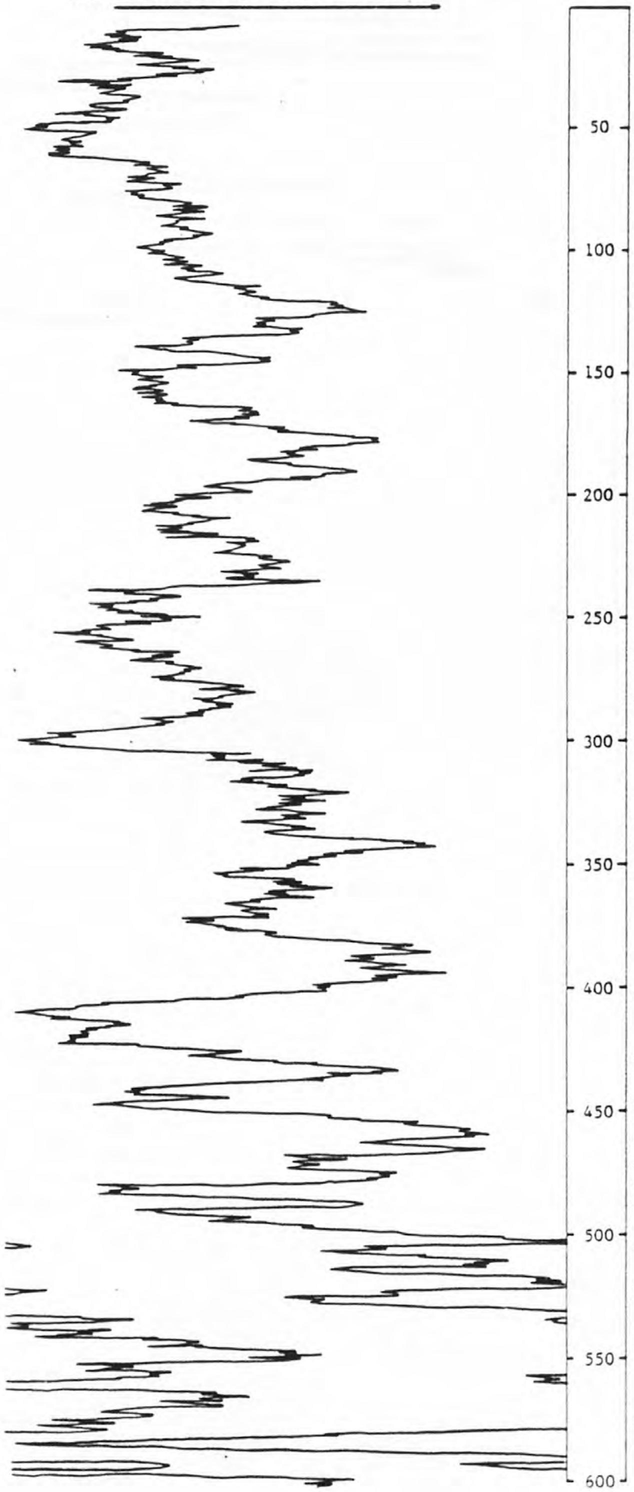
LOCATION: 100-43-33CCCD

ALTITUDE: 1465
(FEET, NGVD 1929)

DATE COMPLETED: August 1, 1980

DEPTH: 732
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

1-16 Till, yellow-brown
16-17 Sand and gravel, fine to medium, yellow-brown
17-25 Till, yellow-gray
25-32 Sand and gravel, fine to coarse, some till and boulders
32-50 Till, blue-gray
50-65 Sand and gravel, medium to very coarse, very gray
65-95 Till, sandy, gray to blue-gray
95-132 Till, yellow-gray
132-134 Sand, fine to coarse, brown
134-143 Till, gravelly, gray-brown
143-152 Sand and gravel, some till, yellow-brown
152-158 Till, yellow-brown
158-162 Sand and gravel, fine to coarse, yellow-brown
175-260 Till, sandy, some gravel, blue-gray
260-290 Till, blue-gray
290-298 Sand and gravel, fine to coarse, some till, gray
298-310 Till, gray to blue-gray
310-317 Clay, sandy, gray-brown
317-340 Clay, hard, dark gray
340-379 Till, sandy, light blue-gray

CRETACEOUS
DAKOTA FORMATION

379-430 Shale, some silty, pyrite, some dolomite beds less than 1 foot thick
430-441 Shale, silty, sandy, lignite, some sandstone
441-445 Sandstone, fine, interbedded shale and dolomite
445-455 Shale, silty, gray-brown
455-460 Dolomite, pyrite, tan to brown
460-463 Shale, silty, gray and lignite
463-470 Sandstone, fine to very fine, interbedded shale
470-473 Shale, silty, sandy, dolomite, brown
473-480 Sandstone, very fine, interbedded shale, silty, gray
480-570 Shale, silty, gray to brown, interbedded dolomite, lignite and black shale
570-600 Shale, silty, gray, interbedded sandstone

DESCRIPTION OF MATERIALS

600-615 Sandstone, fine to coarse, pink

615-617 Shale, silty, gray

617-640 Sandstone, fine to coarse, pink

640-695 Sandstone, medium to very coarse, pink

PRECAMBRIAN
SIOUX QUARTZITE

695-725 Quartzite, shaly, weathered, white to light gray

725-732 Quartzite, weathered, pink

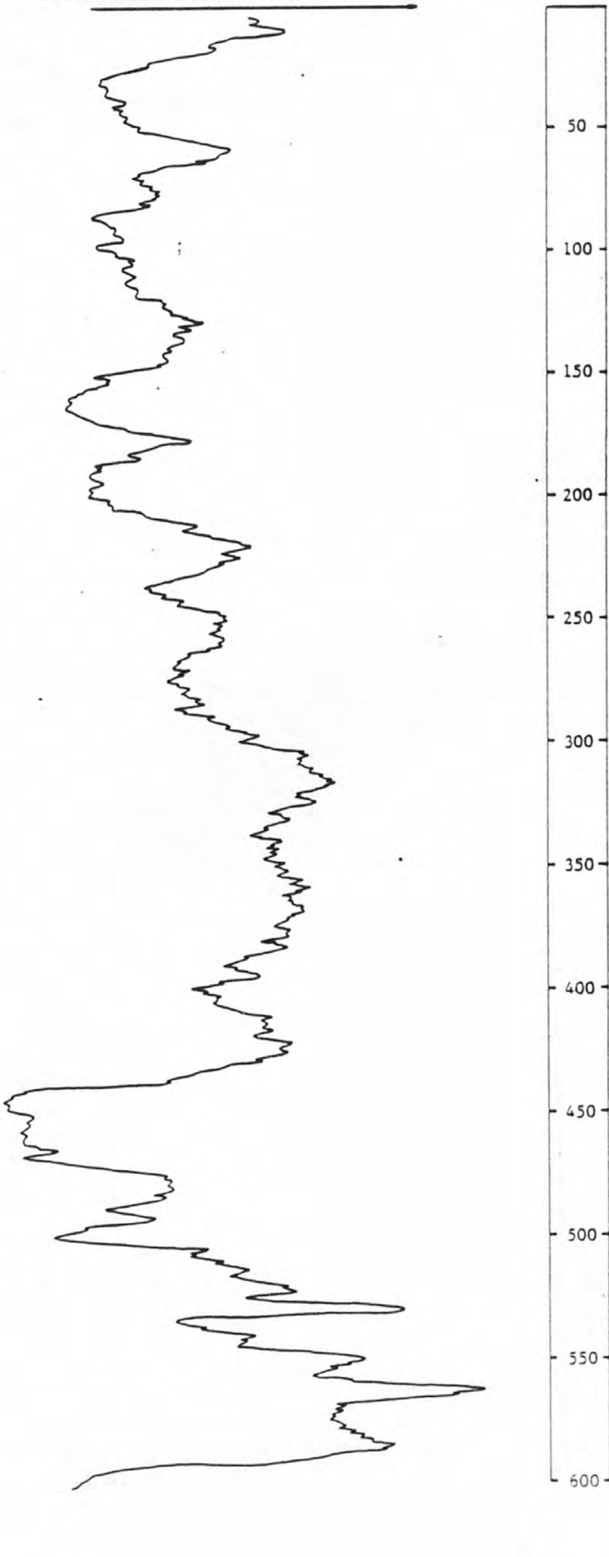
LOCATION: 100-48-31CCCC

ALTITUDE: 1417
(FEET, NGVD 1929)

DATE COMPLETED: August 21, 1980

DEPTH: 657
(FEET)

INCREASING NATURAL GAMMA RADIATION



DESCRIPTION OF MATERIALS

QUATERNARY

0-18 Loess

18-25 Till, light yellow-brown

25-58 Till, some gravel, yellow-brown

58-69 Till, dark gray

69-150 Till, some sand layers, blue-gray to light blue-gray

150-154 Sand and gravel, gray

154-155 Clay, gumbo, blue-gray

155-162 Sand and gravel, gray

162-176 Sand, fine to gravel, medium, gray

176-188 Till, clay, gray-green

188-210 Sand and gravel

210-215 Sand and clay, gray

215-235 Till, gray-green

235-300 Till, very silty, sandy, gray to gray-green

CRETACEOUS

CARLILE SHALE

300-310 Clay, silty, gray

310-325 Shale, silty, sandy, hard, gray

325-340 Shale, very hard, gray

340-383 Shale, hard, gray

GREENHORN LIMESTONE

383-390 Shale, silty, streaks of sandstone, gray

390-408 Shale, silty, gray-blue, some sandstone

GRANEROS SHALE

408-435 Shale, silty, sandy, gray

DAKOTA FORMATION

435-460 Sandstone, fine, pyrite

460-470 Sandstone, fine, some shale

470-524 Sandstone, fine, and shale interbedded

524-530 Shale, pyrite, gray

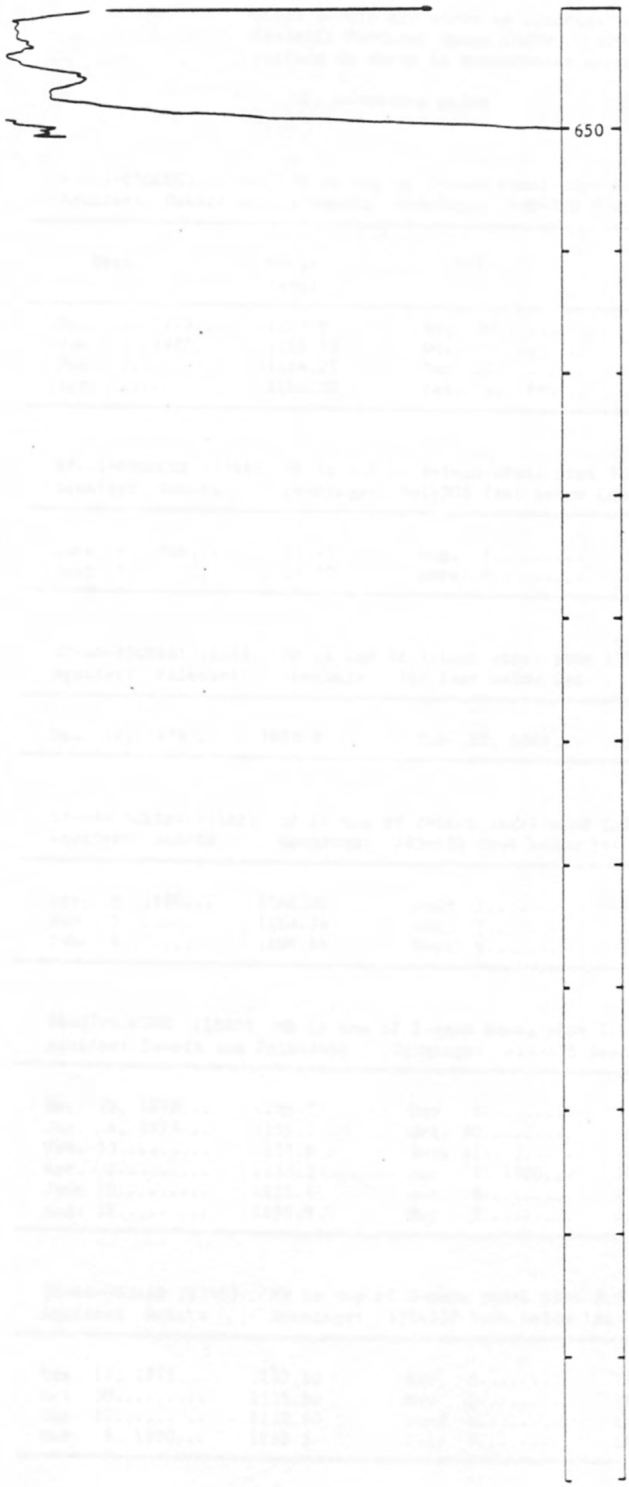
530-560 Sandstone and shale interbedded

560-590 Shale, silty, hard, gray

590-610 Sandstone, fine to medium

INCREASING NATURAL GAMMA RADIATION

DESCRIPTION OF MATERIALS



610-644 Sandstone, fine to coarse

644-653 Shale, silty, sandy, white

PRECAMBRIAN
SIOUX QUARTZITE

653-657 Quartzite, weathered, pink

Table 3.--Water levels in observation wells

Water levels are shown as altitude in feet above the National Geodetic Vertical Datum (NGVD), 1929. The altitude of land surface is shown in parentheses after the location of each well.

MP, measuring point lsd, land surface datum

87-41-05CCCC1 (1344) MP is top of 2-inch steel pipe 3.0 feet above lsd.
Aquifer: Dakota and Paleozoic Openings: 490-510 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Dec. 12, 1978...	1127.0	Aug. 30.........	1126.60	Mar. 6.........	1127.2
Jan. 5, 1979...	1126.15	Oct. 29.........	1127.35	Apr. 8.........	1127.40
Feb. 13.........	1126.25	Dec. 12.........	1127.00	Plugged and abandoned	
Apr. 2.........	1126.10	Feb. 6, 1980...	1127.20		

87-41-05CCCC2 (1344) MP is top of 2-inch steel pipe 3.0 feet above lsd.
Aquifer: Dakota Openings: 301-305 feet below lsd

June 4, 1980...	1141.45	Aug. 7.........	1138.31	Dec. 11.........	1137.90
July 9.........	1139.10	Sept. 9.........	1138.45		

87-44-15CBBB1 (1165) MP is top of 2-inch steel pipe 1.5 feet above lsd.
Aquifer: Paleozoic Openings: 281 feet below lsd

Dec. 12, 1979...	1098.9	Feb. 28, 1980...	1100.1	Plugged and abandoned	

87-44-15CBBB2 (1165) MP is top of 2-inch steel pipe 1.5 feet above lsd.
Aquifer: Dakota Openings: 185-189 feet below lsd

Apr. 8, 1980...	1104.80	July 9.........	1104.50	Dec. 11.........	1103.00
May 5.........	1104.74	Aug. 7.........	1104.27		
June 4.........	1104.64	Sept. 9.........	1103.82		

88-37-22CCCC (1320) MP is top of 2-inch steel pipe 2.5 feet above lsd.
Aquifer: Dakota and Paleozoic Openings: 417-435 feet below lsd

Dec. 12, 1978...	1155.75	Oct. 5.........	1155.35	June 2.........	1155.40
Jan. 4, 1979...	1155.1	Oct. 30.........	1155.85	July 8.........	1155.36
Feb. 13.........	1155.6	Dec. 11.........	1155.50	Aug. 4.........	1155.06
Apr. 2.........	1155.3	Mar. 5, 1980...	1155.8	Sept. 8.........	1155.03
June 10.........	1155.4	Apr. 8.........	1155.38	Dec. 16.........	1154.6
Aug. 16.........	1155.9	May 5.........	1155.36		

88-44-06BAAB (1340) MP is top of 2-inch steel pipe 3.5 feet above lsd.
Aquifer: Dakota Openings: 332-337 feet below lsd

Oct. 17, 1979...	1137.10	Apr. 8.........	1135.75	Aug. 7.........	1138.64
Oct. 30.........	1138.60	May 5.........	1138.83	Sept. 9.........	1138.28
Dec. 12.........	1138.90	June 4.........	1138.77	Dec. 11.........	1137.95
Mar. 5, 1980...	1138.5	July 9.........	1138.77		

89-38-36CBCC (1445) MP is top of 2-inch steel pipe 4.0 feet above lsd.
Aquifer: Dakota Openings: 410-430 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Dec. 12, 1978...	1154.7	Oct. 5.........	1156.6	June 2.........	1156.95
Jan. 4, 1979...	1154.0	Oct. 30.........	1155.0	July 8.........	1154.28
Feb. 13.........	1154.0	Dec. 11.........	1154.15	Aug. 4.........	1154.40
Apr. 2.........	1154.1	Feb. 6, 1980...	1153.92	Sept. 5.........	1153.92
June 10.........	1154.2	Mar. 5.........	1155.10	Dec. 16.........	1153.90
Aug. 16.........	1154.1	Apr. 8.........	1153.50		
Aug. 30.........	1154.2	May 5.........	1154.68		

89-41-13CCCC (1320) MP is top of 2-inch steel pipe 1.5 feet above lsd.
Aquifer: Paleozoic Openings: 465-468 feet below lsd

Dec. 12, 1978...	1129.2	Dec. 12.........	1130.40	May 5.........	959.99
Jan. 5, 1979...	1129.00	Feb. 5, 1980...	1131.70	July 9.........	1075.45
Feb. 13.........	1128.85	Mar. 6.........	1122.00	Aug. 6.........	1093.00
Apr. 2.........	1128.90	Mar. 12.........	pumped	Sept. 9.........	1105.90
Aug. 30.........	1130.15	Apr. 8.........	1112.86	Dec. 11.........	1127.90
Oct. 29.........	1130.45	Apr. 8.........	pumped		

89-44-20DCDC (1160) MP is top of 2-inch steel pipe 4.0 feet above lsd.
Aquifer: Dakota Openings: 206-221 feet below lsd

Oct. 16, 1979...	1134.0	Apr. 8.........	1134.50	Aug. 6.........	1133.82
Oct. 30.........	1134.15	May 5.........	1134.28	Sept. 9.........	1133.79
Dec. 12.........	1134.7	June 4.........	1134.52	Dec. 11.........	1133.35
Mar. 6, 1980...	1136.1	July 9.........	1134.14		

89-46-36BBDC1 (1268) MP is top of 2-inch steel pipe 3.0 feet above lsd.
Aquifer: Paleozoic Openings: 519-537 feet below lsd

Oct. 10, 1979...	1107.25	Dec. 12.........	1129.7	Feb. 28.........	1129.8
Oct. 30.........	1129.25	Feb. 1, 1980...	1129.4	Plugged and abandoned	

89-46-36BBDC2 (1268) MP is top of 2-inch steel pipe 3.0 feet above lsd.
Aquifer: Dakota Openings: 358-362 feet below lsd

Apr. 8, 1980...	1134.88	July 9.........	1134.45	Dec. 11.........	1133.50
May 5.........	1137.20	Aug. 7.........	1133.64		
June 4.........	1134.55	Sept. 9.........	1133.69		

90-36-13ADDA (1281) MP is top of 2-inch steel pipe 3.3 feet above lsd.
Aquifer: Paleozoic Openings: 223-235 feet below lsd

May 10, 1979...	1180.4	Feb. 7.........	1179.82	June 2.........	1179.94
June 10.........	1180.4	Mar. 5.........	1180.15	July 8.........	1179.60
Aug. 30.........	1179.9	Mar. 10.........	1181.10	Aug. 5.........	1179.18
Dec. 11.........	1179.80	Apr. 8.........	1180.67	Sept. 4.........	1179.56
Jan. 1, 1980...	1180.00	May 5.........	1180.16	Dec. 16.........	1179.8

90-38-16DDDD1 (1365) MP is top of 2-inch steel pipe 3.5 feet above lsd.
Aquifer: Paleozoic Openings: 499-517 feet below lsd

Date	Water level	Date	Water level	Date	Water level
May 7, 1979...	1174.10	Oct. 30.........	1174.90	Mar. 10.........	1173.62
June 10.........	1174.70	Dec. 11.........	1174.40	Plugged and abandoned	
Aug. 30.........	1174.45	Feb. 7, 1980...	1174.23		
Oct. 5.........	1174.65	Feb. 27.........	1174.5		

90-38-16DDDD2 (1365) MP is top of 2-inch steel pipe 3.5 feet above lsd.
Aquifer: Dakota Openings: 346.5-349.5 feet below lsd

Apr. 8, 1980...	1176.70	July 8.........	1176.69	Dec. 16.........	1176.15
May 5.........	1176.73	Aug. 4.........	1176.62		
June 2.........	1176.75	Sept. 4.........	1176.54		

90-40-06BDCD (1182) MP is top of 1.25-inch steel pipe 4.0 feet above lsd.
Aquifer: Dakota Openings: 252-254 feet below lsd

Dec. 12, 1978...	1145.4	Dec. 12.........	1149.30	July 9.........	1148.01
Jan. 5, 1979...	1145.2	Feb. 5, 1980...	1148.25	Aug. 6.........	1147.45
Feb. 13.........	1145.25	Mar. 6.........	1148.15	Sept. 4.........	1147.06
Apr. 2.........	1148.3	Mar. 31.........	1148.4	Dec. 11.........	1146.0
Aug. 30.........	1148.15	May 5.........	1148.74		
Sept.29.........	1148.10	June 4.........	1148.20		

91-35-26BCCC (1291) MP is top of 2-inch steel pipe 2.0 feet above lsd.
Aquifer: Dakota Openings: 338-347 feet below lsd

Dec. 12, 1978...	1195.70	Oct. 15.........	1238.1	May 5.........	1266.92
Jan. 1, 1979...	1195.40	Dec. 11.........	1271.50	June 2.........	1266.46
Feb. 13.........	1197.15	Jan. 7, 1980...	1272.60	July 8.........	1266.05
Apr. 2.........	1197.80	Mar. 5.........	1266.30	Aug. 5.........	1265.55
June 10.........	1198.70	Mar. 10.........	1266.60	Sept. 4.........	1265.58
Aug. 30.........	1200.20	Apr. 11.........	1267.33	Dec. 16.........	1265.05

91-39-01ADAD1 (1370) MP is top of 6-inch steel pipe 3.2 feet above lsd.
Aquifer: Paleozoic Openings: 1126-1545 feet below lsd

Sept.13, 1979...	1176.2	May 5.........	1176.36	Sept. 4.........	1175.81
Dec. 11.........	1176.05	June 4.........	1176.37	Dec. 16.........	1174.75
Feb. 7, 1980...	1175.90	July 10.........	1176.24		
Apr. 8.........	1176.70	Aug. 6.........	1176.21		

91-39-01ADAD2 (1370) MP is top of 4-inch steel pipe 3.3 feet above lsd.
Aquifer: Dakota Openings: 235-240 feet below lsd

Sept.13, 1979...	1178.3	May 5.........	1178.87	Sept. 4.........	1178.53
Dec. 11.........	1178.50	June 6.........	1178.80	Dec. 16.........	1178.40
Feb. 7, 1980...	1178.11	July 10.........	1178.80		
Apr. 8.........	1178.90	Aug. 6.........	1178.86		

91-42-16DDDD1 (1320) MP is top of 2-inch steel pipe 1.5 feet above lsd.
Aquifer: Paleozoic Openings: 561-576 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Dec. 12, 1978...	1180.90	Aug. 29.........	1164.50	Dec. 12.........	1164.8
Apr. 2, 1979...	1179.20	Sept.13.........	1164.20	Feb. 5, 1980...	1165.90
May 7.........	1180.15	Oct. 4.........	1164.20	Feb. 27.........	1164.9
June 10.........	1163.80	Oct. 29.........	1165.40	Plugged and abandoned	

91-42-16DDDD2 (1320) MP is top of 2-inch steel pipe 1.5 feet above lsd.
Aquifer: Dakota Openings: 386-390 feet below lsd

Mar. 31, 1980...	1165.5	June 8.........	1165.44	Sept. 4.........	1164.83
Apr. 8.........	1166.0	July 9.........	1165.44	Dec. 15.........	1164.50
May 5.........	1165.74	Aug. 6.........	1165.07		

92-40-10BDDD (1210) MP is top of 2.5-inch steel pipe at lsd.
Aquifer: Dakota Openings: 114-118 feet below lsd

Apr. 7, 1980...	1182.0	June 4.........	1181.52	Aug. 6.........	1180.90
May 7.........	1181.66	July 8.........	1181.28	Sept. 4.........	1180.94

92-45-02CBCB1 (1245) MP is top of 5-inch steel pipe 3.2 feet above lsd.
Aquifer: Paleozoic Openings: 598- 1089 feet below lsd

May 7, 1979...	1149.10	Mar. 12.........	1149.75	Aug. 6.........	1142.90
Aug. 31.........	1148.90	Apr. 8.........	1147.43	Sept. 4.........	1143.71
Oct. 4.........	1148.20	May 5.........	1145.87	Dec. 15.........	1145.65
Dec. 12.........	1149.30	June 8.........	1145.86		
Feb. 22, 1980...	1149.70	July 9.........	1144.29		

92-45-02CBCB2 (1245) MP is top of 4-inch steel pipe 3.5 feet above lsd.
Aquifer: Dakota Openings: 347-365 feet below lsd

Apr. 17, 1979...	1143.8	Feb. 22.........	1145.15	Aug. 6.........	1139.66
May 7.........	1143.8	Apr. 8.........	1144.40	Sept. 4.........	1138.44
Aug. 16.........	1143.8	May 6.........	1142.70	Dec. 15.........	1142.9
Dec. 12.........	1144.7	June 8.........	1142.99		
Jan. 21, 1980...	1145.1	July 9.........	1141.16		

92-45-02CBAB (1220) MP is top of 4-inch steel pipe 5.0 feet above lsd.
Aquifer: Quaternary Openings: 10-22 feet below lsd

Apr. 17, 1979...	1213.85	Mar. 4, 1980...	1213.50	Aug. 6.........	1212.19
May 7.........	1213.20	Apr. 8.........	1214.95	Sept. 3.........	1213.77
Aug. 16.........	1213.25	May 6.........	1213.12	Dec. 15.........	1212.30
Oct. 4.........	1212.7	June 5.........	1214.65		
Dec. 12.........	1216.5	July 9.........	1212.67		

92-48-06DDDA1 (1282) MP is top of 2-inch steel pipe 4.8 feet above lsd.
Aquifer: Dakota Openings: 510-515 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Dec. 14, 1979...	1131.5	Mar. 27.........	1132.05	Plugged and abandoned	
Mar. 4, 1980...	1131.8	Apr. 8.........	1132.22		

92-48-06DDDA2 (1282) MP is top of 2-inch steel pipe 4.8 feet above lsd.
Aquifer: Dakota Openings: 430-434 feet below lsd

Date	Water level	Date	Water level	Date	Water level
May 5, 1980...	1126.13	July 9.........	1125.02	Sept. 9.........	1122.82
June 4.........	1125.69	Aug. 6.........	1122.18	Dec. 11.........	1123.60

93-35-13ADAA (1330) MP is top of 1.5-inch steel pipe 3.0 feet above lsd.
Aquifer: Dakota Openings: 350-360 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Feb. 6, 1980...	1196.85	May 7.........	1196.84	Sept.10.........	1196.53
Mar. 5.........	1196.75	June 2.........	1196.94	Dec. 10.........	1196.45
Mar. 10.........	1197.05	July 8.........	1196.61		
Apr. 11.........	1196.99	Aug. 4.........	1196.42		

93-35-19DCBB (1322) MP is top of 2-inch steel pipe 3.8 feet above lsd.
Aquifer: Dakota Openings: 253-268 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Aug. 16, 1979...	1194.70	Jan. 7, 1980...	1195.50	June 2.........	1195.72
Aug. 30.........	1194.75	Mar. 5.........	1195.35	July 8.........	1195.55
Oct. 15.........	1196.45	Mar. 10.........	1195.68	Aug. 5.........	1195.32
Oct. 30.........	1195.30	Apr. 11.........	1195.80	Sept.10.........	1195.23
Dec. 11.........	1195.30	May 7.........	1195.46		

93-46-12DDDD (1280) MP is top of 2.5-inch steel pipe 4.8 feet above lsd.
Aquifer: Dakota Openings: 356-360 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Apr. 9, 1980...	1162.22	July 17.........	1160.63	Dec. 15.........	1160.25
May 5.........	1161.86	Aug. 6.........	1160.07		
June 5.........	1161.53	Sept. 4.........	1159.73		

94-39-26BADB (1212) MP is top of 2.5-inch steel pipe at lsd.
Aquifer: Dakota Openings: 291-295 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Apr. 17, 1980...	1173.20	July 10.........	1173.61	Dec. 15.........	1175.15
May 6.........	1173.71	Aug. 6.........	1173.45		
June 4.........	1173.72	Sept. 9.........	1173.30		

94-42-09DDDD (1440) MP is top of 2-inch steel pipe 4.0 feet above lsd.
Aquifer: Dakota Openings: 516-536 feet below lsd

Date	Water level	Date	Water level	Date	Water level
July 10, 1980...	1179.36	Sept.10.........	1191.16	Dec. 12.........	1199.15
Aug. 6.........	1185.3				

94-47-35AAAB1 (1305) MP is top of 2-inch steel pipe 1.4 feet above lsd.
Aquifer: Dakota and Paleozoic Openings: 520-540 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Dec. 11, 1978...	1159.65	June 10.........	1156.65	Feb. 1, 1980...	1159.85
Jan. 3, 1979...	1159.7	Aug. 29.........	1158.35	Feb. 28.........	1160.30
Apr. 3.........	1159.9	Oct. 29.........	1159.40	Plugged and abandoned	
May 7.........	1160.45	Dec. 13.........	1159.50		

94-47-35AAAB2 (1305) MP is top of 2-inch steel pipe 1.4 feet above lsd.
Aquifer: Dakota Openings: 450-454 feet below lsd

Mar. 28, 1980...	1161.30	June 5.........	1168.31	Sept. 3.........	pumped
Apr. 4.........	1161.4	July 9.........	1169.23	Sept.10.........	1157.62
May 5.........	1166.67	Aug. 6.........	1169.21	Dec. 15.........	1158.60

95-43-07AAAA (1390) MP is top of 2-inch steel pipe 3.7 feet above lsd.
Aquifer: Dakota Openings: 641-681 feet below lsd

July 16, 1980...	1174.2	Sept. 9.........	1174.43	Dec. 12.........	1174.25
Aug. 6.........	1174.59				

95-47-05AAAAD (1292) MP is top of 4-inch steel pipe 4.3 feet above lsd.
Aquifer: Dakota Openings: 570-571.5 feet below lsd

May 7, 1979...	1182.95	Apr. 8.........	1167.10	Sept. 3.........	1160.44
Dec. 13.........	1165.30	May 6.........	1162.49	Dec. 15.........	1160.9
Feb. 1, 1980...	1164.90	July 10.........	1161.		
Mar. 4.........	1166.7	Aug. 5.........	1160.3		

96-40-05DDDA (1560) MP is top of 2-inch steel pipe 4.0 feet above lsd.
Aquifer: Dakota and Paleozoic Openings: 661-701 feet below lsd

July 16, 1980...	1198.6	Sept.10.........	1200.63	Dec. 12.........	1200.20

96-44-08ADAA (1373) MP is top of 2-inch steel pipe 3.7 feet above lsd.
Aquifer: Dakota Openings: 647-667 feet below lsd

Aug. 6, 1980...	1179.97	Sept. 9.........	1179.95	Dec. 12.........	1179.95

98-39-26CDAD1 (1401.98) MP is top of 2-inch steel pipe 1.47 feet above lsd.
Aquifer: Paleozoic Openings: 622-662 feet below lsd

June 17, 1980...	1203.90	Aug. 5.........	1202.46	Nov. 26.........	1203.40
July 10.........	1203.60	Sept. 3.........	1203.61		

98-39-26CDAD2 (1401.98) MP is top of 2-inch steel pipe 2.6 feet above lsd.
Aquifer: Dakota Openings: 333-345 feet below lsd

Date	Water level	Date	Water level	Date	Water level
June 17, 1980...	1209.36	Aug. 5.........	1209.50	Nov. 26.........	1208.83
July 10.........	1209.63	Sept. 3.........	1209.55		

98-39-26CDCC (1397.69) MP is top of 2-inch steel pipe 2.7 feet above lsd.
Aquifer: Dakota Openings: 490-500 feet below lsd

June 17, 1980...	1207.70	Aug. 5.........	1204.83	Nov. 26.........	1206.09
July 10.........	1206.20	Sept. 3.........	1206.47		

98-42-33AABB1 (1440) MP is top of 2-inch steel pipe 2.8 feet above lsd.
Aquifer: Precambrian Openings: 476-481 feet below lsd

June 18, 1980...	1192.29	Aug. 5.........	1192.15	Plugged and abandoned	
July 10.........	1192.46				

98-42-33AABB2 (1440) MP is top of 2-inch steel pipe 2.0 feet above lsd.
Aquifer: Quaternary Openings: 310-359 feet below lsd

Dec. 12, 1980...	1199.45

98-48-16DDAD (1268) MP is top of 2-inch steel pipe 2.0 feet above lsd.
Aquifer: Dakota and Precambrian Openings: 335-355 feet below lsd

Dec. 28, 1978...	1172.8	Oct. 24.........	1173.90	June 6.........	1174.59
Jan. 3, 1979...	1172.75	Feb. 6, 1980...	1174.14	July 10.........	1173.94
Feb. 19.........	1173.55	Feb. 29.........	1174.20	Aug. 5.........	1173.74
Apr. 3.........	1173.10	Mar. 28.........	1174.60	Sept. 3.........	1173.47
Aug. 29.........	1171.55	May 6.........	1174.60	Dec. 12.........	1172.10

100-39-17DCCB1(1560) MP is top of 5-inch steel pipe 3.0 feet above lsd.
Aquifer: Cambrian Openings: 770-923 feet below lsd

Dec. 8, 1978...	1208.6	Aug. 29.........	1217.80	Feb. 6, 1980...	1217.22
Jan. 4, 1979...	1217.2	Oct. 30.........	1218.1	Apr. 10.........	1217.75
Apr. 3.........	1217.35	Dec. 13.........	1217.20	Plugged and abandoned	

100-39-17DCCB2 (1560) MP is top of 5-inch steel pipe 3.0 feet above lsd.
Aquifer: Dakota Openings: 680-700 feet below lsd

July 10, 1980...	1217.6	Sept. 9.........	1217.50	Dec. 10.........	1216.7
Aug. 5.........	1218.2				

100-43-33CCCD (1465)   MP is top of 2-inch steel pipe 3.8 feet above lsd.
Aquifer: Dakota   Openings: 728-732 feet below lsd

Date	Water level	Date	Water level	Date	Water level
Aug. 5, 1980...	1224.47	Sept. 3.........	1124.39	Dec. 12.........	1223.95

100-48-31CCCC1 (1417)   MP is top of 2-inch steel pipe at lsd.
Aquifer: Dakota   Openings: 630-650 feet below lsd

Dec. 8, 1978...	1260.45	Aug. 29.........	1262.15	Feb. 29.........	1261.8
Jan. 3, 1979...	1260.15	Oct. 24.........	1261.75	Plugged and abandoned	
Apr. 3.........	1260.90	Feb. 6.........	1261.70		

100-48-31CCCC2 (1417)   MP is top of 2-inch steel pipe at lsd.
Aquifer: Dakota   Openings: 450-455 feet below lsd

Mar. 28, 1980...	1260.6	June 6.........	1260.93	Sept. 3.........	1260.46
Apr. 4.........	1260.7	July 10.........	1260.79	Dec. 12.........	1259.55
May 6.........	1260.90	Aug. 5.........	1260.59		

Table 5. Selected chemical analyses of water from the Dakota aquifer

Station name includes location and local name of well

Temperature is in degrees Celsius (DEG C)

Most constituents are measured in milligrams per liter (MG/L)

Iron and manganese are measured in micrograms per liter (UG/L)

Gross alpha is measured in micrograms per liter (UG/L) equivalent of naturally occuring uranium (U-NAT)

Radium is measured in picocuries per liter (PCI/L)

Gross beta is measured in picocuries per liter (PCI/L) equivalent of cesium-137

STATION NAME			DATE OF SAMPLE	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	TEMPER-ATURE, WATER (DEG C)	HARD-NESS (MG/L AS CACO3)	SODIUM AD-SORP-TION RATIO	IRON, DIS-SOLVED (UG/L AS FE)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)	SULFATE DIS-SOLVED (MG/L AS SO4)	NITRO-GEN, NITRATE DIS-SOLVED (MG/L AS NO3)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	BICAR-BONATE (MG/L AS HCO3)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)	RADIUM 226, DIS-SOLVED (PCI/L)	RADIUM 228, TOTAL (PCI/L)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)
08631W12ACC	02975	1947FARNHAMVILLE WELL NO 3	77-04-12	848	1200	11.0	510	1.2	450	110	56	62	20	<10	300	<.10	1.9	12	365	6.7	2.2	--	15
08636W11DCDC		1980GRANITE CITY OBS D-48E	80-10-14	528	790	--	450	.2	20	120	36	13	2.7	170	110	1.3	.6	2.0	395	--	--	--	--
08635W24BBA	01584	1942TOWN OF AUBURN NO 2	76-12-15	1060	1300	10.0	720	1.1	5600	180	65	67	6.8	920	420	.40	.3	1.0	483	7.7	1.2	--	5.0
08635W24BBD	06210	1952TOWN OF AUBURN NO 3	76-12-15	1130	1400	10.0	780	1.1	4900	200	67	68	6.4	100	470	<.10	.3	1.5	490	2.0	--	--	.0
08735W30DDDD	24560	1977HOSTENG #2	78-07-28	516	820	11.0	420	.4	1900	110	35	23	4.0	40	28	.10	.2	1.0	533	--	--	--	--
08739W23ACBD	19840	1967ARTHUR TOWN NO 4	76-11-29	1580	2000	10.0	870	2.1	3700	230	71	140	11	470	880	<.10	.9	7.5	310	25	5.8	--	12
08740W14DDD	07264	1955IDA GROVE NO 3	77-05-16	537	830	--	410	.4	10	120	27	18	2.9	<10	76	22	.5	46	360	1.5	--	--	3.0
08744W15CBBB	25735	1979IGS CRET PROJ D-34	80-04-23	351	550	11.0	320	.3	1600	90	23	12	3.9	120	21	.20	.4	1.5	366	2.4	.4	1.9	5.0
08747W35BCDB		1949SALIX NO 1	75-08-11	560	880	--	450	.6	9200	110	43	28	9.4	240	45	.80	.4	6.0	553	2.1	--	--	20
08844W06BAAB	25594	1979 IGS D-33NW IA PROJECT	79-10-16	377	570	13.0	280	.3	2400	80	20	14	5.0	170	52	.50	.3	3.0	318	--	--	--	--
08938W26ABAA	01076	1939TOWN OF SCHALLER NO 1	75-11-10	2730	2900	14.0	1400	2.4	6600	320	150	210	11	2400	1500	2.0	.4	12	334	.0	--	--	33
08938W26ACDC	09380	1957TOWN OF SCHALLER NO 3	75-11-10	2420	2700	14.0	1200	2.5	240	300	120	200	9.5	2800	1300	1.9	.4	<.5	372	10	2.3	--	23
08940W35BBB	05120	1951HOLSTEIN TOWN NO 4	74-04-25	1250	1600	12.2	780	1.6	900	210	62	100	9.1	960	630	<.10	.9	5.0	398	26	7.3	--	25
08940W35BBBC	00567	1937HOLSTEIN TOWN NO 3	77-05-25	1510	1800	--	860	1.4	1800	240	64	96	14	190	750	<.10	.9	6.5	349	13	15	--	40
08942W34CDC	08854	1957CORRECTIONVILLE NO 2 DW	75-05-12	1464	1700	--	780	2.0	1500	210	61	130	12	130	730	<.10	1.2	9.0	357	8.5	--	--	29
08944W20DCDC	25593	1979IGS CRET PROJ D-32	79-10-16	447	570	11.0	290	.3	1300	87	18	14	4.4	190	54	.30	.3	2.0	324	--	--	--	--
08946W36BBDC	25591	1979IGS CRET PROJ D-30	80-04-09	378	620	12.0	320	.2	70	93	21	12	4.3	190	65	<.10	.4	2.0	338	4.3	1.9	2.9	12
08947W28BBCC		1949SIOUX CITY NO 20 PERRY C	74-10-22	881	1300	12.0	590	1.1	510	150	51	62	12	280	260	<.10	.2	90	405	5.1	5.0	--	25
08947W29AABD		1919SIOUX CITY NO 16 PERRY	74-10-22	759	1100	12.0	490	1.1	380	130	41	58	11	110	250	.40	.5	58	344	11	3.3	--	19
08947W29ABDC		1969SIOUX CITY NO 11-MAIN ST	77-08-02	796	1100	13.0	520	.9	620	140	41	48	11	260	290	.20	.4	14	359	8.9	5.8	--	15
08947W29ACAA		1911SIOUX CITY NO 14-PERRY C	74-10-22	628	930	11.5	390	1.2	450	100	34	53	9.8	150	230	.50	.3	13	332	3.5	2.3	--	23
08947W29ADAB		1926SIOUX CITY NO 17-PERRY C	77-08-02	788	1200	13.0	530	.9	360	140	44	48	12	220	160	.20	.3	73	432	--	--	--	--
08947W29ADBA		1941SIOUX CITY NO 18-PERRY C	74-10-22	715	1100	12.0	530	.8	10	130	50	43	11	90	200	3.6	.2	49	468	11	2.7	--	16
08947W29CADA		1971SIOUX CITY NO 5-MO RIVER	73-04-05	549	870	10.0	350	1.3	460	94	29	56	7.1	240	200	<.10	.4	29	307	--	--	--	--
08947W29CCCA		1971SIOUX CITY NO 4-MO RIVER	73-04-05	490	830	10.0	350	1.1	410	93	29	48	6.9	240	22	<.10	.3	11	261	--	--	--	--
08947W29CCDA		1971SIOUX CITYNO 3-MO RIVER	73-04-05	467	780	10.0	300	1.4	430	78	26	56	6.6	470	210	<.10	.4	17	246	--	--	--	--
08947W29CDCD		1971SIOUX CITY NO 2-MO RIVER	73-04-05	450	740	10.0	280	1.5	420	74	22	56	6.3	260	210	<.10	.5	19	210	--	--	--	--
08947W29DCCB		1971SIOUX CITY NO 1-MO RIVER	73-05-23	510	750	12.7	290	1.2	450	76	24	48	6.9	200	210	<.10	.4	9.0	227	--	--	--	--
08947W35DAAB		1964SIOUX CITY NO 2-SP PARK	77-08-02	455	730	13.0	390	.4	770	110	27	16	6.3	110	74	*.20	.5	3.5	390	17	10	--	16
08947W35DAAD		1965SIOUX CITY NO 3-SP PARK	74-10-22	355	630	12.0	340	.2	610	92	26	10	5.5	110	31	<.10	.3	<.5	386	8.2	4.0	--	12
08947W35DADB		1969SIOUX CITY NO 4-SP PARK	74-10-22	368	610	12.0	340	.3	930	92	26	11	6.0	110	28	.20	.4	<.5	392	8.4	5.1	--	17
08947W35DADD		1956SIOUX CITY NO 1-SP PARK	77-08-27	375	630	13.0	340	.2	670	94	26	8.9	7.0	170	18	.40	.4	2.0	398	4.4	3.4	--	12
09038W16DDDD	25526	1979IGS CRET PROJ D-25 (DAK)	80-04-08	901	1200	10.0	630	.5	80	180	44	30	3.6	200	400	<.10	.3	2.0	377	--	--	--	--
09040W06BDCD	25521	1979IGS CRET PROJ D-6	80-02-05	546	740	--	250	E1.6	80	29	42	60	7.2	40	280	.40	.3	2.0	88	.0	--	--	7.0
09041W11ADAD		1967QUIMBY CITY NO 1	77-10-11	849	1100	10.0	550	.7	2400	150	42	39	8.3	160	310	.10	.7	1.5	350	3.8	1.8	--	8.0
09046W17ACAC		1974HINTON NO 4	76-04-19	397	640	11.0	340	.3	540	91	28	11	3.3	120	84	.20	.5	.5	332	--	--	--	--
09135W26BCCC	25525	1979IGS CRET PROJ D-24	80-02-05	441	710	--	180	2.6	140	8.9	37	80	8.9	30	160	.20	.2	19	154	.6	--	--	7.0
09137W02CBA	08104	1955TRUESDALE CITY NO 1	77-05-11	1030	1300	--	700	.6	6600	180	61	39	7.5	170	370	.10	.2	.5	503	2.9	--	--	10
09138W26ACA	14165	1963ALTA CITY NO 4	77-06-08	1270	1500	--	780	.9	730	200	68	56	9.6	930	560	.10	.6	1.5	460	1.8	--	--	5.0
09138W26BACA		1950ALTA TOWN WELL NO 3	77-06-08	1290	1600	--	810	.9	2100	210	69	58	10	730	560	.20	.6	1.0	468	1.8	--	--	7.0
09139W01ADAD	25529	1979IGS CRET PROJ D-29	80-01-28	785	840	9.0	430	.5	8400	110	37	25	4.4	480	150	.20	.1	6.0	366	6.9	1.1	1.0	10
09139W10ADDA		1961AURELIA NO 3	74-06-07	385	570	--	310	.3	50	83	26	13	2.0	<10	41	.50	.2	.5	338	2.1	--	--	6.0
09139W10BDDB		1972AURELIA CITY NO 4	74-06-07	340	520	--	290	.3	20	76	23	9.9	2.1	70	23	<.10	.2	<.5	322	1.6	--	--	6.0
09139W10DBBB	00696	1937AURELIA CITY	77-06-08	403	620	--	304	.5	240	82	24	19	2.9	<10	63	1.1	.2	<.5	337	1.6	--	--	2.0
09140W03BACB		1965CHEROKEE NO 5	73-10-05	791	1100	--	510	.9	760	140	40	46	6.6	260	290	<.10	.7	3.0	378	--	--	--	--
09142W16DDDD	25114	1978IGS CRET PROJ D-11	80-04-11	1370	1700	10.0	760	2.2	330	200	63	140	14	120	730	<.10	1.2	9.0	370	7.5	1.3	5.5	30
09232W31CDAA	01549	1941POCAHONTAS #1	77-02-14	1200	1500	10.0	783	1.2	830	190	74	76	5.1	1300	470	<.10	.3	1.0	503	12	1.3	--	19
09240W10BDDD	24569	1977IGS CRET PROJ D-	80-04-07	1220	1500	10.0	680	1.5	110	180	56	92	8.2	1600	560	.20	.4	7.0	390	--	--	--	--
09240W26CBD	12538	1960MENTAL HEALTH NO 4	75-07-28	590	840	14.0	406	.9	780	100	34	42	5.4	150	190	.10	.6	2.0	360	2.5	--	--	11
09240W26CCDD		1952CHEROKEE NO 3	77-05-03	735	990	--	490	.8	1800	130	39	40	7.0	260	260	<.10	.6	2.5	361	15	2.7	--	14
09240W27DACC		1921MENTAL HEALTH	75-07-28	852	1100	1.4	530	1.1	1300	140	44	58	6.8	250	330	.30	.7	6.0	370	7.2	2.8	--	18
09240W27DACC		1942MENTAL HEALTH	75-07-28	835	1100	14.0	500	1.0	1000	130	43	53	6.8	210	290	.60	.7	4.0	362	6.5	2.7	--	14

STATION		NAME	DATE OF SAMPLE	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	TEMPER-ATURE, WATER (DEG C)	HARD-NESS (MG/L AS CACO3)	SODIUM AD-SORP-TION RATIO	IRON, DIS-SOLVED (UG/L AS FE)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)	SULFATE DIS-SOLVED (MG/L AS SO4)	NITRO-GEN, NITRATE DIS-SOLVED (MG/L AS NO3)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	BICAR-BONATE (MG/L AS HCO3)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)	RADIUM 226, DIS-SOLVED (PCI/L)	RADIUM 228, TOTAL (PCI/L)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)
09240W35BBBB		1951CHEROKEE CITY NO 4	77-05-03	576	820	--	400	.7	1100	110	31	33	6.8	280	160	<.10	.7	1.0	361	5.2	1.8	--	9.0
09241W05CACD		1935CLEGHORN CITY NO 1	76-07-30	1020	1400	--	560	2.0	820	140	51	110	10	170	460	.20	.9	3.5	397	.0	--	--	9.0
09241W05CBDA		1976CLEGHORN NO 2	76-07-30	1050	1400	--	600	2.1	1100	150	55	120	10	200	480	.70	1.0	4.0	403	.0	--	--	13
09241W12CCD	08106	1956MERIDEN CITY NO 1	74-08-16	1870	2100	--	1090	1.6	1400	290	96	120	14	500	970	<.10	.5	14	427	4.9	1.4	--	6.0
09244W05AA		1953OYENS NO 1	76-12-08	460	680	10.0	375	.3	1200	100	28	13	4.2	420	74	.10	.3	1.0	361	.0	--	--	3.0
09245W01DABB		HOSPERS RWD NO 1 F-1	77-03-16	840	1200	7.0	598	.6	3000	160	48	36	1.8	620	200	1.1	.3	110	368	14	.6	--	6.0
09245W02CBCB		1978IGS CRET PROJ D-22	80-03-12	279	540	11.0	250	.4	30	72	16	17	14	40	42	<.10	3.4	<.5	302	2.1	1.1	2.1	12
09245W09CAAD		1972LE MARS NO 8	77-05-05	1060	1300	--	670	1.1	850	180	53	64	14	110	500	.20	.9	8.0	351	7.2	4.3	--	11
09245W20BBAB		HOSPERS RWD NO 1 F-4	77-03-16	2600	2800	5.0	1390	2.2	2300	360	120	190	23	720	1400	<.10	.5	20	434	4.5	.6	--	5.0
09245W30BCBA		HOSPERS RWD NO 1 F-3	77-03-16	712	1100	7.0	497	.9	2400	140	37	47	2.1	490	150	.20	.3	100	340	4.6	.4	--	3.0
09248W06DDDA	25736	1979IGS CRET PROJ D-35	80-04-23	1880	2200	12.0	980	2.2	360	250	87	160	23	490	940	.20	1.8	64	383	6.1	1.4	5.6	21
09335W13ADAA	25737	1979IGS CRET PROJ D-36	80-01-30	1220	1500	10.0	530	2.2	3600	140	44	120	10	230	410	3.6	.7	560	365	.6	--	--	16
09335W19DCBB	25528	1979IGS CRET PROJ D-27	80-01-30	1940	1800	10.0	970	.2	8800	260	78	15	70	340	760	<.10	.8	6.0	344	3.9	2.6	1.8	20
09337W36CABC		1935REMBRANDT TOWN WELL	79-02-08	1530	1800	--	970	1.0	2900	250	84	75	5.6	560	750	.10	.8	2.0	427	4.6	4.2	--	11
09342W36DCCD		CHEROKEE RWD MC 1	77-06-20	1260	1600	12.0	680	1.8	1900	180	57	110	16	90	620	<.10	1.2	5.0	388	2.3	--	--	12
09346W12DDDD	24556	1977IGS CRET PROJ D-2	80-03-26	439	610	--	330	.2	50	97	22	10	7.1	100	96	<.10	.3	<.5	315	4.7	1.9	3.0	5.0
09431W13ACCC	03595	1949WEST BEND TOWN WELL	76-04-12	1000	1300	10.0	652	.9	4300	160	58	52	15	460	380	6.0	.7	11	439	3.2	13	--	11
09433W25ABA	02863	1947MALLARD CITY WELL #2	77-08-29	1140	1400	13.0	751	1.1	15000	180	69	69	4.5	100	390	.50	.2	3.0	567	3.0	--	--	8.0
09439W07CAB	00110	1930SUTHERLAND TOWN WELL	74-05-08	1940	2200	--	1110	1.6	2900	290	90	120	10	550	1000	.50	.5	8.0	371	2.8	--	--	19
09439W07CAB	06045	1953SUTHERLAND 3	77-07-26	2030	2200	--	1220	1.2	4000	320	100	92	9.7	550	1000	.20	.5	3.5	378	.9	--	--	5.0
09439W26BADB	24557	1977IGS CRET PROJ D-3	80-04-07	1550	1800	11.0	1000	1.1	110	280	80	81	10	120	900	.60	.6	2.0	396	--	--	--	--
09442W09DDDD	25964	1980IGS CRET PROJ D-42	80-06-30	2250	2300	13.0	1160	.5	110	300	99	150	14	300	1100	<.10	1.0	16	406	8.7	1.5	1.6	19
09444W05AACB		1968ORANGE CITY WELL NO 6	76-02-24	1230	1600	--	790	1.2	16000	200	70	76	7.7	1200	550	2.8	.4	53	371	2.9	--	--	8.0
09445W17AACB		1975TOWN OF MAURICE NO 4	76-12-08	2420	2700	10.0	1400	1.8	1700	350	120	160	26	900	1200	.10	1.7	26	388	19	3.6	--	26
09445W17AACD	14860	1962TOWN OF MAURICE NO 3	74-05-23	515	820	--	480	.4	260	110	38	18	7.0	180	150	<.10	.3	1.0	388	3.4	.4	--	15
09446W07DAD	02310	1946IRETON TOWN WELL	77-04-20	1140	1400	--	727	1.0	1300	170	71	64	15	210	510	<.10	.4	5.0	394	4.4	1.1	--	14
09446W07DDAB		1967IRETON CITY WELL NO 4	77-04-20	1280	1600	--	800	1.1	2800	190	78	73	16	240	590	.10	.5	6.0	416	2.3	--	--	17
09447W35AAAB	25321	1980IGS CRET PROJ D-18	80-03-27	2070	2400	11.0	1100	2.0	790	260	120	160	22	270	1100	<.10	.9	19	392	9.1	2.1	3.4	11
09543W07AAAA	25965	1980IGS CRET PROJ D-43	80-07-10	2330	2600	--	960	3.6	30	320	40	260	21	120	1200	2.4	2.6	25	415	5.6	3.4	5.7	31
09547W05AAAA		1978IGS CRET PROJ D-7	80-04-24	2000	2300	12.0	650	3.0	60	260	.1	180	18	--	1000	.40	.6	64	439	7.2	2.1	4.9	15
09634W18DCAC	08630	1957RUTHVEN #5	76-03-17	1250	1600	--	788	1.3	3500	200	69	83	6.2	280	540	11	.4	4.0	421	3.0	--	--	9.6
09634W18DDBB	01960	1944RUTHVEN CITY #4	76-03-17	1230	1500	--	771	1.4	6200	190	68	86	6.1	300	550	.80	.4	4.5	425	.4	--	--	3.4
09641W36DAD	07930	1956PRIMGHAR TOWN WELL	75-07-29	2070	2300	--	1190	1.8	1700	300	100	140	13	390	1100	1.0	.4	21	437	17	2.1	--	36
09644W08ADAA	25941	1980IGS CRET PROJ D-44	80-07-18	2580	2800	13.0	1200	2.8	3800	290	120	230	17	240	1400	<.10	.8	33	372	8.7	2.6	5.9	16
09739W32ACC	00817	1938HARTLEY TOWN WELL NO 1	73-10-12	2270	2600	10.0	1420	1.5	5300	370	130	130	13	450	1200	.20	.1	37	493	--	--	--	--
09739W32ACC	12222	1960HARTLEY TOWN WELL	76-08-16	2190	2400	--	1370	1.1	1400	350	120	97	14	580	1100	4.7	.4	32	456	.0	--	--	36
09742W30ACDB	15818	1963SHELDON TOWN WELL	76-04-09	2190	2400	12.0	1200	1.7	1700	300	120	140	21	130	1200	.10	.8	13	409	.8	--	--	47
09745W26CBAA	10434	1959HULL CITY WELL NO 4	76-07-01	2420	2700	12.0	1320	--	1400	300	--	190	23	160	1400	1.6	.5	27	381	12	1.2	3.5	24
09745W26CBAA	14647	1963HULL CITY WELL NO 5	76-07-01	2290	2200	12.0	1260	2.3	3100	280	140	190	23	180	1200	2.1	.5	28	376	9.9	1.6	4.7	36
09746W28DBAD	24520	1977LOREN HANSEN IRRIG STUDY	78-01-17	1460	1700	9.0	544	1.4	2000	210	79	91	18	310	720	13	.5	22	356	--	--	--	--
09837W15DDDD		1980IGS CRET PROJ D-46	80-08-27	1350	1600	11.0	810	1.3	30	220	64	88	6.7	230	650	.40	.3	2.5	368	.5	--	--	13
09839W26CDAD	25898	1980IGS CRET PROJ D-38	80-05-21	1680	2000	12.0	920	2.0	140	250	72	140	9.4	690	820	13	.4	30	361	9.5	1.2	<.6	.0
09839W26CDCC	25899	1980IGS CRET PROJ D-39	80-05-30	2090	2300	11.0	1200	1.9	400	300	100	150	9.6	610	1100	.30	.3	40	411	5.6	.7	<.6	4.0
09842W33AABB		1980IGS CRET PROJ D-40	80-10-02	2830	2900	11.0	1490	3.0	40	340	140	260	16	520	1600	17	.6	23	367	11	3.8	1.7	16
09847W18AAC	15926	1963INWOOD TOWN WELL 3	74-04-18	1040	1300	12.7	570	1.4	4800	140	60	76	15	90	480	<.10	.8	6.0	327	4.4	1.8	--	30
09847W18ACDC		1966INWOOD TOWN WELL NO 4	74-04-18	1030	1300	14.4	660	1.0	1600	160	63	60	15	50	500	<.10	.7	5.5	333	4.4	3.0	--	28
09847W18BDB	01344	1940INWOOD TOWN WELL 1	76-11-03	1050	1300	3.0	630	1.2	30	150	62	68	20	40	460	<.10	.8	9.0	332	11	1.8	--	15
09848W16DDAD	25523	1978IGS CRET PROJ D-20	79-05-22	756	1000	13.0	380	1.3	1100	93	33	86	17	80	230	<.10	1.2	14	318	--	--	--	--
09942W13ACC	02273	1946SIBLEY TOWN WELL	77-08-04	2020	2900	13.0	1510	2.0	440	330	140	100	20	280	1500	12	.3	30	374	2.4	--	--	20
09942W13ACCB		1946SIBLEY TOWN WELL NO 2	77-08-04	2310	2900	--	1600	2.2	860	390	140	200	21	200	1500	2.3	.3	34	388	--	--	--	--
09942W13DBBC	12223	1960SIBLEY CITY WELL NO 3	77-05-24	2810	2900	10.0	1520	2.2	2300	330	140	200	20	240	1600	<.10	.3	31	400	.3			2.0
10039W17DCCC	25106	1978IGS CRET PROJ D-13	80-05-01	2320	2300	11.0	1200	1.4	70	340	110	120	8.0	1200	1100	<.10	.2	44	432	2.7	--	--	.0
10043W33CCCD	25966	1980IGS CRET PROJ D-45	80-08-01	1140	1800	12.0	700	2.3	50	180	60	140	15	200	700	<.10	.4	7.0	305	7.6	1.3	.8	20
10048W31CCCC	25313	1978IGS CRET PROJ D-19	80-03-29	709	1000	11.0	480	.7	50	120	43	39	11	190	320	<.10	.4	9.0	321	--	--	--	--

POCKET CONTAINS
8 ITEMS