GEOLOGY AND GEOHYDROLOGY OF THE KNIFE RIVER BASIN AND ADJACENT AREAS OF WEST-CENTRAL NORTH DAKOTA

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REPORT OF INVESTIGATION NO. 64

NORTH DAKOTA GEOLOGICAL SURVEY

Lee C. Gerhard, State Geologist

1979

THIS PROJECT WAS SUPPORTED BY REGIONAL ENVIRONMENTAL ASSESSMENT PROGRAM CONTRACT NO. 5-01-1 AND IN PART BY ENVIRONMENTAL PROTECTION AGENCY GRANT NO. R-803727

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ACKNOWLEDGMENTS

This study would not have been possible without the assistance of a large number of people. Special thanks are due to Gordon Prichard, William Peterson, Janell Schafer, Constance Triplett, Dr. John Bluemle, and William Hofer. Special thanks are due to the North American Coal Corporation and Baukol-Noonan, Inc. for so generously allowing the use of coal exploration test-hole data. We would also like to thank the numerous people in Mercer, McLean, Oliver, and Dunn Counties who were so very helpful in supplying water-well data to this project. Others whose assistance is gratefully acknowledged include Drs. Robert Koob and Dennis Tallman, Department of Chemistry, North Dakota State University; Dr. William McKellar, Department of Chemistry, Concordia College; Larry Anna and Daniel Ackerman, U.S.G.S.; and Dave Ripley, North Dakota State Water Commission. We also wish to acknowledge the assistance of Drs. B. Michael Arndt, Kenneth L. Harris, and S. R. Moran. Portions of this research were supported by EPA Grant R-803727 and by U.S.B.M. Contract J0275010.

EXECUTIVE SUMMARY

This study discusses the surface and subsurface geology, regional groundwater-flow systems, chemistry, and chemical evolution of groundwater in the units overlying the Pierre Formation in west-central North Dakota. The study has concentrated on the area within the Knife River basin. Also discussed are two additional study sites outside the Knife River basin, the Center and Falkirk sites. A discussion of the groundwater-flow patterns, chemistry, and chemical evolution of water in the Fox Hills aquifer throughout southwestern North Dakota is also included. Detailed mapping of surface and near-surface materials in the Beulah-Hazen area has allowed for the generation of a series of land-use suitability maps for that area.

This study has determined the regional stratigraphic framework of the units overlying the Pierre Formation with emphasis on detailed correlation of the Tertiary lignite-bearing strata. A series of detailed cross sections based on several hundred test holes has been constructed which demonstrates the correlation of the various lignite beds in the Sentinel Butte and Bullion Creek Formations across the study area. Each major lignite bed has been named, with type and reference test holes. The relationship between the present lignite-bed terminology and the terminology of previous workers has been discussed in detail. This study has demonstrated that individual lignite beds are traceable for many tens of miles and serve as convenient stratigraphic markers for subdividing the Sentinel Butte and Bullion Creek Formations.

The detailed stratigraphic framework, thus defined, has allowed for a specific designation of the intake zone for most of the farm and domestic wells in the study area. This information, in conjunction with previously published groundwater chemical data and additional selective sampling of wells as part of this study, has allowed for a detailed definition of the chemical characteristics of water within the various stratigraphic units. This, in turn, has allowed for the formulation of groundwater geochemical models for the various groundwater systems. The key processes which influence the evolution of groundwater in the Knife River basin are: pyrite oxidation, carbonate dissolution, gypsum precipitation and dissolution, cation exchange, and sulfate reduction. The hydrostratigraphy and hydrochemistry of five proposed and active lignite-mining sites have been discussed in detail. These include the Indian Head, Beulah-Hazen, and Dunn Center sites within the Knife River basin and the Center and Falkirk sites which lie in close proximity to the Knife River basin.

The implications of the interpretive groundwater geochemical framework relative to post-mining groundwater quality have been addressed. Of major concern is the generation, in the post-mining landscapes, of waters characterized by adverse sulfate contents generated by pyrite oxidation. Major differences between premining and post-mining landscapes include the large volumes of oxygen trapped within voids in the spoils and the lack of organic matter in the spoils relative to the premining landscape. The consumption of most of the entrapped oxygen by pyrite oxidation rather than organic-matter oxidation is therefore an anticipated eventuality and potentially could result in the generation of very high levels of sulfate in post-mining groundwater. In one case the sulfate concentration in a groundwater sample from spoils at the Indian Head site exceeded 9 400 mg/L. Sulfate concentrations in spoil waters commonly exceeded 2 500 mg/L. A detailed knowledge of the overburden in conjunction with proper placement of overburden during mining and contouring operations is necessary to assure acceptable post-mining groundwater quality.

1 INTRODUCTION

1.1 Description of the Study Area

1.1.1 Location

The area of the present study includes the drainage basin of the Knife River as well as the Falkirk (Underwood) and Center areas of McLean and Oliver Counties, respectively (fig. 1.1.1-1). It is roughly bounded on the west by the Dunn-Billings County line and the Killdeer Mountains; on the north by the uplands south of the Little Missouri River and Lake Sakakawea; on the east by old U.S. Highway 83; on the southeast by the Missouri River and a line from Fort Clark due south to the Morton County line, then southwest to the badlands east of Glen Ullin; and on the south by the divide between the Heart River and Knife River drainages (fig. 1.1.1-1). The project area is about 100 miles (160 km) long and 30 miles (50 km) wide and is bisected by State Highway 200 through much of its length.

The towns mainly affected by development of rich lignite reserves in the study area include Underwood, east of the Missouri River; Center in the Square Butte Creek drainage basin; and Beulah, Hazen, Stanton, and Dunn Center in the Knife River basin proper.

1.1.2 Physiography and Topography

The Knife River basin is located in west-central North Dakota within the Missouri Plateau section of the Great Plains Physiographic Province (Lobeck, 1950). The Knife River is the master stream in the study area. It and its principal tributary, Spring Creek, flow roughly eastward through wide valleys with maturely dissected slopes. These valleys are about 200-300 feet (60-90 m) deep and are bordered by gently rolling, grassy uplands of interstream divides. Prominent buttes, with crests standing as much as 200 feet (60 m) above the surrounding uplands are scattered throughout the study area. Medicine Butte, located in Mercer County about 12 miles southwest of Beulah, is one of the most striking of these landmarks.

The Knife River and Spring Creek rise in the highlands that form the divide east of the Little Missouri River. Maximum elevation at the source of the Knife River is about 2 700 feet (810 m). The elevation of the uplands of the Killdeer Mountains, where Spring Creek begins, is about 3 000 feet (990 m). Spring Creek joins the Knife River about one mile west of Beulah. From here the stream flows northeast to its confluence with the Missouri River near the town of Stanton. The elevation at Stanton is about 1 700 feet (410 m), which means that the regional slope rises a maximum of 1 600 feet (480 m) to the west across the study area.

The Knife River basin is mostly within the glaciated portion of the Missouri Plateau (fig. 1.1.1-1), but erosion has removed much of the glacial sediment, so the drainage is, for the most part, well integrated. Where drift still remains, it veneers the preglacial topography, which seems to have been modified very little by glaciation. The exception occurs in the northeastern part of the project area in the vicinity of the towns of Beulah, Hazen, and Underwood where constructional topography exists, and where test-hole drilling indicates the presence of buried valleys containing as much as 300 feet (90 m) or more of glacial deposits.

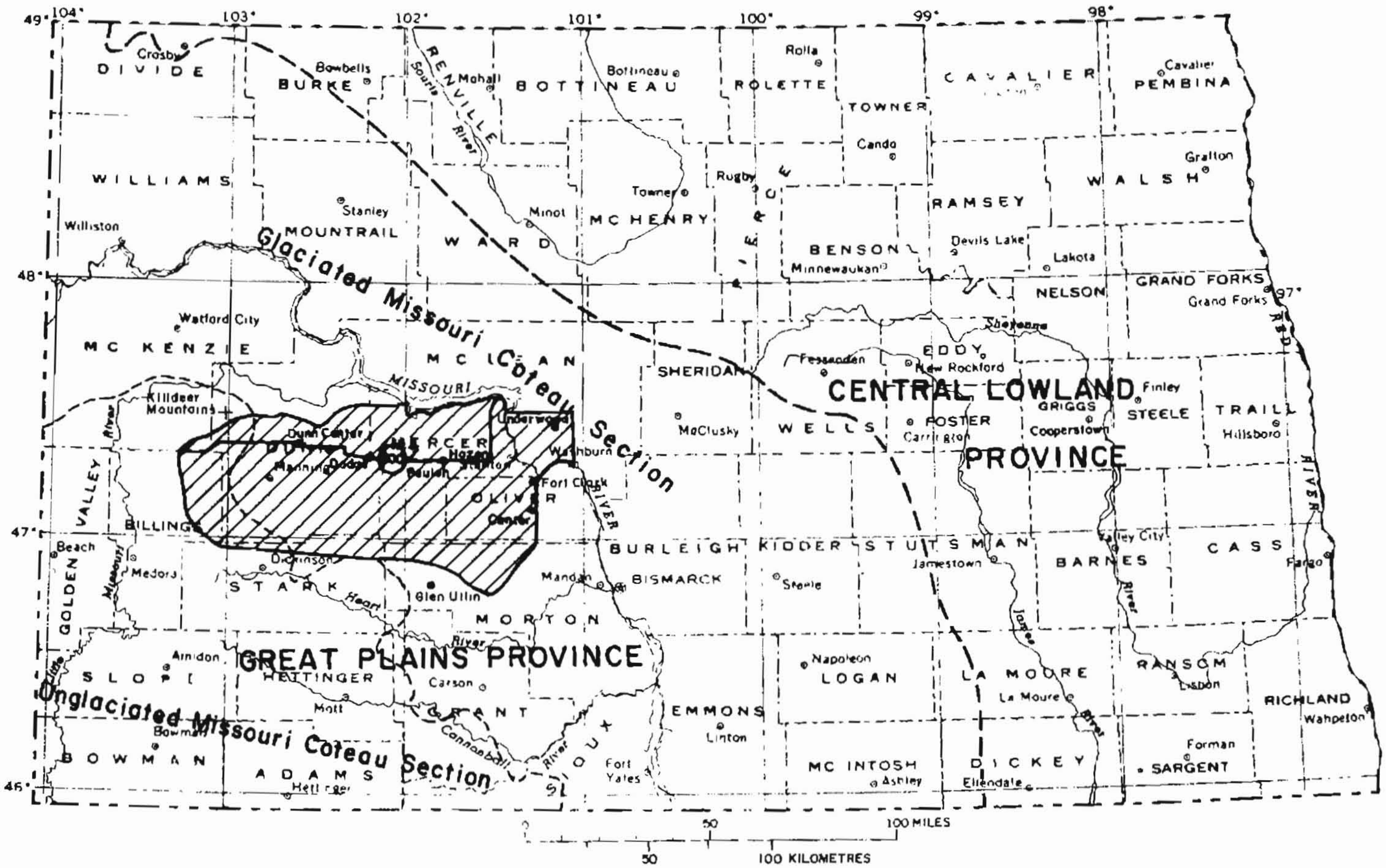


Figure 1.1.1-1. Location of the study area.

The most striking features of the Knife River basin are the deep, flat-floored valleys that cut across the drainage pattern in a northwest to southeast direction. These large trenches, which contain only small underfit streams or no streams at all, were cut by glacial meltwater flowing at the margin of an ice sheet. Waters of the ancient Missouri River, which flowed to the northeast across North Dakota, were diverted through these valley systems by advancing glaciers. Benson (1952) and Moran et al. (1976) discuss these diversion trenches in some detail. Benson (1952) names the South Fork and Elm Creek trenches in the Grancho and Medicine Butte quadrangles, the Goodman Creek and Golden Valley trenches (near the town of Golden Valley), and the Beulah trench (near the towns of Zap, Beulah, and Hazen).

1.1.3 Geologic Setting--General Stratigraphic Framework

The area of the present study is underlain by 11 000-14 000 feet (3 300-4 200 m) of sedimentary strata ranging in age from Recent to Cambrian (fig. 1.1.3-1). These layered rocks overlie Precambrian igneous and metamorphic basement rocks.

Only Paleocene age and younger bedrock formations outcrop in the study area. The oldest exposed unit is the Cannonball Formation which outcrops along the Missouri River trench south of Underwood in the vicinity of Washburn and Hensler. The Cannonball Formation is the only marine formation present at the surface in the project area. It consists of an alternating succession of silt and clay beds and very fine grained silty sand. The thickness of the Cannonball is about 300 feet (90 m) in the eastern part of the study area and about 200-250 feet (60-75 m) in the west.

Although the Slope Formation (Clayton et al., 1977) is present in the study area, it was not observed in outcrop. Lithologically, this unit is similar to the Ludlow Formation which underlies the Cannonball Formation in the Knife River basin. The Slope Formation is less than 20 feet (6 m) thick in the eastern part of the study area and as much as 100 feet (90 m) thick in the western part of the area.

The Bullion Creek Formation (Clayton et al., 1977) overlies the Cannonball Formation in the east and the Slope Formation in the west. To the south, along the Missouri River drainage, the contact between the Cannonball and Bullion Creek Formations can be observed in outcrops. According to Kume and Hansen (1965, p. 47) "Excellent exposures of this contact are at the SE corner NW¼sec 13, T140N, R81W...., and NE¼ SE¼sec 11, T140N, R80W."

In the area of the present study, only the upper part of the Bullion Creek Formation can be seen in outcrop. The exposures occur along the Missouri River trench below Garrison Dam, with the most extensive outcrops occurring in the Fort Mandan Badlands east of Stanton (Hemish, 1975).

The Bullion Creek Formation ranges in thickness from about 250 feet (75 m) in the eastern part of the study area to as much as 700 feet (210 m) in the west. Lithologically, the Bullion Creek Formation consists of interbedded silt, clay, sand, and lignite. Hemish (1975) tentatively assigned a thick unit of fine-grained, poorly sorted, bluish sand to the lower part of the Bullion Creek Formation in southwestern McLean County. Recent

ERA	SYSTEM	SEQUENCE	GROUP	FORMATION	DOMINANT LITHOLOGY
CENOZOIC	Quaternary	Tejas		Oahe	Silt, Clay, Sand, Gravel
				Colcharbor	Pebble-loam, Sand, Gravel, Silt, Clay
	Tertiary	Zuni	Fort Union	Golden Valley	Silt, Clay, Sand
				Sentinel Butte	Silt, Sand, Clay, Lignite
				Bullion Creek	Silt, Sand, Clay, Lignite
				Slope	Silt, Clay, Sand, Lignite
				Cannonball	Marine Clay, Silt, Sand
				Ludlow	Silt, Clay, Sand, Lignite
MESOZOIC	Cretaceous			Hell Creek	Sandstone, Shale, Lignite
			Montana	Fox Hills	Marine Sandstone
				Pierre	Shale
			Colorado	Niobrara	Shale, Calcareous
				Carlile	Shale
				Greenhorn	Shale, Calcareous
				Belle Fourche	Shale
			Dakota	Mowry	Shale
				Newcastle	Sandstone
				Skull Creek	Shale
				Fall River	Sandstone, Shale
				Lakota	Sandstone, Shale
	Jurassic			Morrison	Shale, Clay
				Sundance	Shale, green and brown, Sandstone
				Piper	Limestone, Anhydrite, Salt, red Shale
	Triassic	Absaroka		Spearfish	Siltstone, Salt, Sandstone
PALEOZOIC	Permian			Minnekahta	Limestone
				Opeche	Shale, Siltstone, Salt
	Pennsylvanian			Minnelusa	Sandstone
				Amsden	Interbedded Dolomite Limestone, Shale, Sandstone
				Tyler	Shale, Sandstone
	Mississippian	Kaskaskia	Big Snowy	Heath	Shale
				Otter	Sandstone, Limestone
				Kibbey	Interbedded Limestone, Evaporites
				Madison	Limestone
	Devonian			Bakken	Siltstone, Shale
				Three Forks	Shale, Siltstone, Dolomite
				Birdbear	Limestone
				Duperow	Interbedded Dolomite, Limestone
				Souris River	Interbedded Dolomite, Limestone
				Dawson Bay	Dolomite, Limestone
				Prairie	Salt
				Winnipegosis	Limestone, Dolomite
	Silurian	Tippecanoe		Interlake	Dolomite
	Ordovician			Stonewall	Dolomite, Limestone
				Stony Mountain	Limestone, Dolomite
				Red River	Limestone, Dolomite
			Winnipeg	Roughlock	Calcareous Shale, Siltstone
				Ice Box	Shale
				Black Island	Sandstone
	Cambrian	Sauk		Deadwood	Limestone, Shale, Sandstone
	Precambrian				

Figure 1.1.3-1. Stratigraphic column for the study area.

work (see pl. 2) indicates that this sand unit is also present in the subsurface in the western part of the area.

The Sentinel Butte Formation overlies the Bullion Creek Formation and outcrops throughout the Knife River basin. Lithologically, the two formations are very similar. In outcrop, the Bullion Creek and Sentinel Butte Formations are differentiated on the basis of color. The Bullion Creek is typically yellowish; the Sentinel Butte is typically somber gray-brown (Royse, 1967).

Where complete sections of the Sentinel Butte Formation are preserved in the Knife River basin, they reach thicknesses between 500 and 550 feet (150 and 165 m). A widespread, thick, yellowish-brown sand unit is present in the upper part of the formation. Where it is well cemented, it is often seen capping ridges and buttes.

The Golden Valley Formation is the youngest bedrock unit present in the study area. It overlies the Sentinel Butte Formation and is preserved as erosional remnants on divides between major drainages. It is well exposed in the vicinity of the town of Golden Valley, for which it is named. It consists of interbedded sand, silt, clay, and minor carbonaceous materials and lignite. The lower part of the Golden Valley Formation is highly kaolinitic.

A veneer of unconsolidated Quaternary sediment mantles the bedrock in the northern and eastern parts of the project area. Only scattered boulders and thin patches of clayey to silty pebble loam (till) are present over the remainder of the area. In this study all of the Quaternary deposits (till, sand, gravel, clay, and silt) are included within the Coleharbor Formation.

Sand, silt, and clay deposits that are stratigraphically above the Coleharbor Formation are placed in the Oahe Formation. These deposits include windblown silt and sand, modern pond and stream sediment, and slope-wash sediments.

1.1.4 General Groundwater Conditions

This discussion will provide a general overview of groundwater conditions in the study area. The five detailed study sites, discussed in chapter 4, can then be superimposed on, and incorporated into, this general framework. The units of concern include all the formations overlying the Pierre Formation (fig. 1.1.3-1). The Pierre Formation is the regional aquitard in the study area. Fletcher (1974) has estimated the rate of groundwater flow through this formation to be less than a few feet in a million years. The top of the Pierre Formation, in the study area, lies at a depth varying between 1 200 and 2 000 feet (360 and 600 m).

The only materials in the study area that can be considered as potential aquifers are Quaternary sand and gravel and Tertiary and Cretaceous lignite and sand units. These represent a small fraction of the total volume of materials overlying the Pierre Formation. The remaining units consist largely of silty and clayey materials and are aquitards.

The major regional aquifer in the study area is the Fox Hills-Hell Creek aquifer. The top of this aquifer lies at depths between about 700 and 1 400 feet (210 and 420 m). This aquifer actually consists of several sand units in the two formations. The total thickness of the units ranges from 100-300 feet (30-90 m). The major direction of flow in the aquifer is from west to east (Croft, 1973; Moran et al., 1976). This aquifer generally yields several tens of gallons per minute and is the water supply for various towns and domestic and stock users in the study area. The Fox Hills-Hell Creek aquifer is discussed in detail in chapter 4.

Sand and lignite units in the interval above the top of the Fox Hills-Hell Creek aquifer to within 500 feet (150 m) of the land surface produce very little water. The major constraint upon water yielding capability of a given unit appears to be the depth at which the unit lies below the surface. Regional structure, topography, and erosion has generally resulted in increasingly younger bedrock units being exposed at the surface as one moves from west to east across the study area (pl. 2). Thus, a given lignite may lie 100 feet (30 m) below the land surface in the eastern part of the study area and 500 feet (150 m) below the surface in the western part of the study area. Typically such a unit will constitute a water supply in the eastern (shallow) area but will have extremely low yield capacities in the western (deeper) area. The probable cause for this relationship is increased fracture permeability in the shallow units resulting from unloading accompanying erosion of the overlying materials. Unloading associated with the ablation of continental ice masses may also have played a role in this phenomenon.

Bedrock aquifers within 500 feet (150 m) of the land surface are commonly used for domestic and stock, and occasionally for municipal, water supplies. Yields are generally less than ten gallons per minute. These include all the major lignites in the Bullion Creek and Sentinel Butte Formations, as well as various sand units which lie within the lignite-bounded intervals. The stratigraphic relationships are discussed in detail in chapter 2.

Of particular interest from the standpoint of regional groundwater movement is a series of variable thickness sand units in the lower part of the Bullion Creek Formation. Plate 2 indicates the highly variable, although somewhat continuous, nature of these units. Moran et al. (1976) indicate that potentiometric head values below this interval generally increase with depth indicating upward groundwater movement. Head values above this interval generally decrease with depth indicating downward groundwater movement. Thus it appears that these units constitute a regional groundwater sink and thus have a considerable impact upon regional groundwater movement. Flow within the interval is apparently to the east toward the Missouri River valley trench.

Detailed discussions of various sites within the study area by Moran et al. (1978) and chapter 4, this report, indicate that groundwater flow is primarily horizontal in both the bedrock and Quaternary aquifers. Flow is primarily vertical and downward through the various aquitards. Topography, largely resulting from stream erosion, controls the location of recharge and discharge sites in the shallow aquifers. Thus, the size of the surface drainages in a given area determines the size of the associated flow system(s). Topography, in conjunction with regional structure, controls the recharge-discharge characteristics of regional aquifers such as the Fox Hills-Hell Creek aquifer. These topics are discussed in greater detail in chapter 4.

1.2 Objectives and Scope

The major objective of the geologic and hydrogeologic studies conducted in the study area was to define and describe, in as much detail as was possible, the surface and subsurface geological conditions and subsurface hydrogeological systems. This information will serve as a data base for a part of the state scheduled for early development of its lignite reserves. This data will be coordinated with data from similar studies in other disciplines to provide information to decision makers and the public. It is expected that these data will aid in forecasting the impact of lignite development on the communities where change is imminent, as well as to provide new knowledge about the extent of lignite resources throughout the Knife River basin. The investigation was designed to meet specific objectives of both geologic and hydrogeologic significance.

1.2.1 Geologic Information

1.2.1.1 Surficial deposits of the Knife River basin

A map of the surficial deposits of the Knife River basin and adjacent areas was constructed at a scale of 1:250 000 (pl. 1). This map was compiled from data in various published and unpublished sources. It is accompanied by a cross section (pl. 2) which was constructed from logs of oil test holes.

1.2.1.2 Surficial deposits of two 15-minute quadrangles in the Beulah-Hazen area

A detailed surficial deposits map and an accessory lignite map of two 15-minute quadrangles in the Beulah-Hazen area were constructed at a scale of 1:63 000 (pls. 3 and 4). These maps were based upon field reconnaissance mapping and test drilling. The maps are accompanied by a discussion of the geology and resources of the map area (chapter 3, this report).

1.2.1.3 Mapping for land-use application in the Beulah-Hazen area

Several maps designed for land-use application were constructed for an approximately 80-square-mile (205-sq.-km) area around the towns of Beulah and Hazen. These are accompanied by cross sections which delineate the materials in the upper 30 feet (9 m) and consist of a geologic materials map at a scale of 1:24 000 (pl. 5) and several smaller scale suitability maps. These maps were based upon detailed field reconnaissance mapping and detailed drilling with a truck-mounted auger. A detailed discussion accompanies the maps and cross sections (chapter 5, this report).

1.2.1.4 Subsurface mapping

The subsurface stratigraphy of the study area was defined in detail based largely upon lignite exploration test holes from various sources. A series of detailed cross sections were constructed (pls. 6-16) which define the distribution of the various bedrock units in the upper 500-700 feet (150-210 m). Emphasis was placed on the correlation of the various lignite beds.

1.2.2 Hydrogeologic Information

1.2.2.1 Physical framework

A major objective of this project was to define the physical hydrologic framework of the study area. The generalized hydrostratigraphic framework of the study area is based largely upon, and integral with, the stratigraphic framework. Five specific study sites, each having considerable hydrogeological data available, are discussed in detail. These included the Dunn Center area, the Beulah-Hazen area, the Center area, the Falkirk area, and the Indian Head Mine area near Zap, North Dakota (fig. 1.2.2.1-1). Existing pump testing information and single well response testing information was combined with single well response testing data obtained through this project. Several hundred existing piezometers were monitored on a regular basis thereby allowing for the definition of the various flow systems in the study area.

1.2.2.2 Geochemical framework

The second objective within the realm of hydrological information was to define the geochemical characteristics of groundwater in the study area. This involved bringing together all available chemical data from federal and state agencies, universities, and private industry. All available data on wells were compiled. It was possible to identify the aquifer in which many of the wells were screened. Selected wells were then sampled for chemical analysis, allowing for a representative sampling both geographically and stratigraphically throughout the study area, with emphasis placed on the five detailed study sites. Of particular interest, in addition to the shallow aquifers at the five detailed sites, were the characteristics of the Fox Hills-Hell Creek aquifer. This unit was treated separately and is discussed in detail in chapter 4.

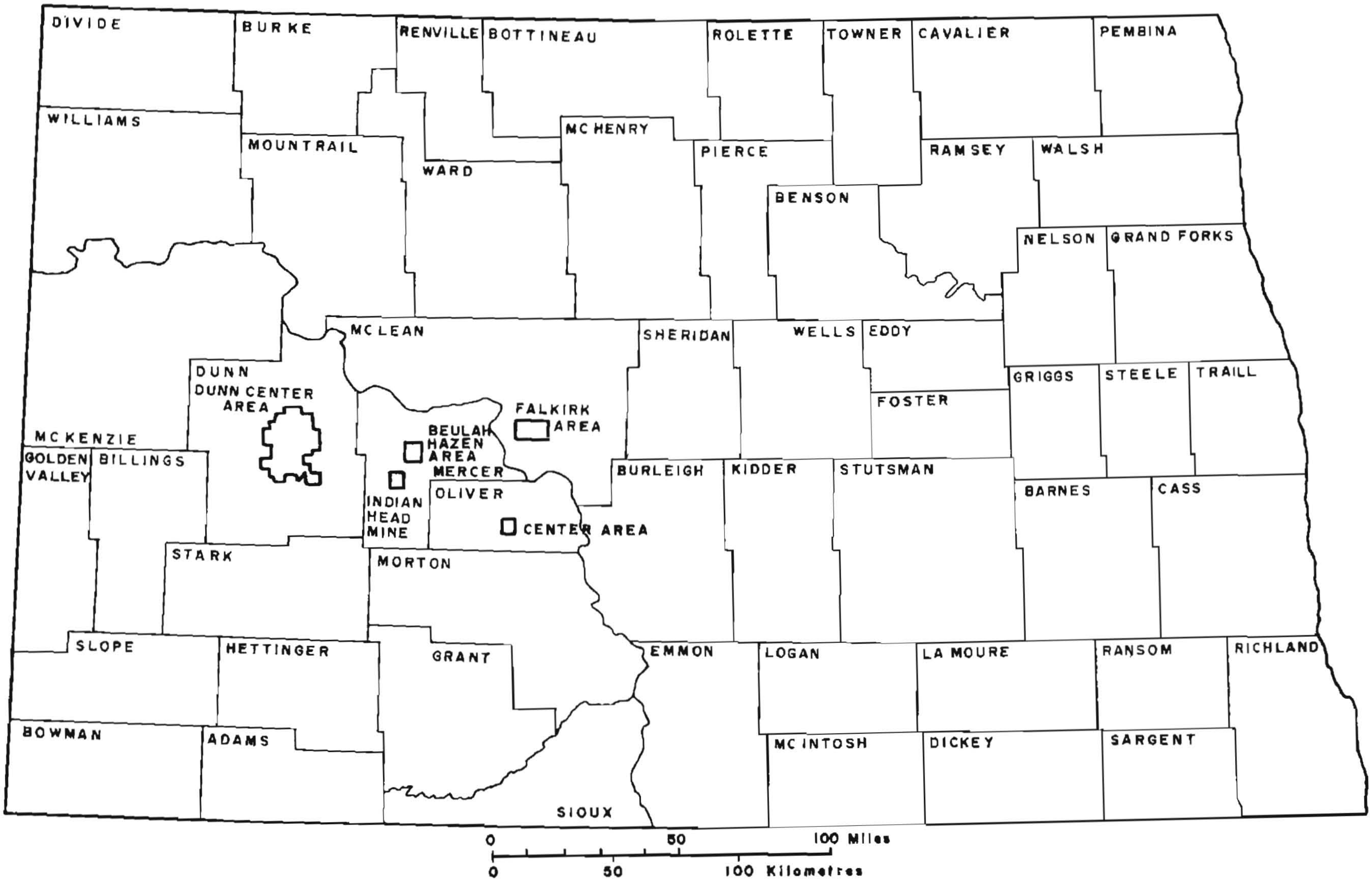


Figure 1.2.2.1-1. Location of the five detailed hydrogeologic study sites.

2 GENERAL GEOLOGY

2.1 Study Methodology

2.1.1 Introduction

Studies for this project were conducted on several levels, depending on the amount of detail required, and also on possible future uses for the results of the investigations. Only a review of relevant literature was carried out for the more general regional aspects of the discussion.

More detail studies, involving field reconnaissance for mapping purposes, and test drilling for stratigraphic purposes were conducted in areas of particular importance to the project. Geophysical and descriptive logs from recent test drilling by the United States Geological Survey were relied on heavily for regional stratigraphic information. Additional test holes were drilled at critical locations where available data were insufficient to define the various stratigraphic relationships.

Existing facilities or research installations were used to aid in the study wherever possible. For example, as part of the hydrogeologic study, piezometers installed by the University of North Dakota Engineering Experiment Station, the North Dakota State Water Commission, various coal companies, and other organizations were utilized to collect data.

2.1.2 Existing Data

Data for compiling the map of the surficial deposits of the Knife River basin (1:250 000) were obtained principally from previous reports and maps relating to the area. Data from these reports were supplemented by the study of logs from oil tests, water wells, and coal exploration test holes for the construction of the accompanying cross section. Most of this information was found in the University of North Dakota Geology Department Library, the files of the North Dakota Geological Survey, or the files of the North Dakota State Water Commission at Bismarck.

The structure contour map of the Bullion Creek-Sentinel Butte contact (pl. 22) was prepared principally through the use of geophysical logs from U.S. Geological Survey drilling. This drilling program was begun in 1974 and is ongoing. The purpose of the program is to gather data on the thickness, quality, extent, and recoverability of lignite beds and the lithologic characteristics of the coal-bearing units in western North Dakota. The logs from this program were also used extensively in the preparation of the cross sections showing the relationship and position of coal beds throughout the Knife River basin.

The structure contour map drawn on the top of the Beulah-Zap lignite bed in the Beulah-Hazen areas (fig. 3.3.2-1, see sec. 3.3.2) was prepared largely from logs of coal exploration test holes provided by the North American Coal Corporation. These data were supplemented by data from previous structure mapping by Benson (1952), U.S.G.S. test holes, and by test drilling done specifically for the REAP study by the North Dakota Geological Survey.

2.1.3 Test Drilling

More than 8 600 feet (2 622 m) of rotary rig test drilling at 19 sites was completed for the REAP project during August and September of 1976 and April of 1977. H and H Service of Bowman, North Dakota, and Mohl Drilling Company of Beulah, North Dakota, were contracted to do the work, which was accomplished using forward-circulation Failing rotary drilling rigs. All of the test holes were drilled by circulating a water-based drilling mud.

A geologist from the North Dakota Geological Survey supervised the drilling at each site. Assistance for collecting samples was provided by a field assistant. Procedures followed in collecting the samples involved the following steps:

1. As the cuttings emerged from the borehole, they were collected in a long-handled wire-mesh net.

2. Cuttings from each 5-foot (1.5-m) interval were placed in plastic trays.

3. The lithology of the samples was then described in detail by the geologist, using a ten-power hand lens, a sand card, and diluted hydrochloric acid.

4. Representative samples from each tray were then bagged, labelled, and placed in storage in the sample library of the North Dakota Geological Survey at Grand Forks, North Dakota.

In addition to the rotary rig drilling, 167 test holes were drilled using the North Dakota Geological Survey mobile auger rig. Eight-inch-diameter test holes were made ranging in depth from 10-75 feet (3-22 m). Test drilling of this nature was confined to the 80-square-mile (205-sq.-km) study area around the towns of Beulah and Hazen. Procedures for handling, describing, bagging, and storing the drill cuttings were similar to those used for the rotary rig cuttings. The geologist's logs for these 167 test holes are presented in appendix A. Auger rig test holes were not geophysically logged, but the deeper, rotary rig test holes were.

2.1.4 Geophysical Logging

All of the 19 test holes drilled by the rotary rig for the REAP project were geophysically logged immediately following completion of the hole. The North Dakota Geological Survey logger, operated by a Survey technician, was used to log each hole.

The logging procedure was to run the gamma-ray, self-potential (SP), and resistivity probes, followed by the density probe. A lithologic column was constructed on a copy of the geophysical log by the geologist who had originally done the on-site logging of the drill cuttings. Data for presentation of the composite log in its final form are thus seen to have come from several sources: (1) a geologist's sample log, (2) a driller's log, (3) a geophysical log. Reliability of geologic interpretation is maximized through use of the above-mentioned procedures.

All of the driller's logs, sample logs, original geophysical logs, and composite interpretive logs are on open file at the North Dakota Geological Survey office in Grand Forks. Reductions of the composite interpretive logs are presented at a scale of 1 inch=50 feet in appendix A.

2.1.5 Surficial Materials Mapping

As previously stated, data for compiling the map of the surficial deposits of the Knife River basin (1:250 000) were obtained principally from available published and unpublished reports and maps relating to the area. This map (pl. 1) is accompanied by an associated map which indicates the data sources used for the various portions of the study area. Methods used in constructing the 1:63 360- and 1:24 000-scale maps in the Beulah-Hazen area are discussed in considerable detail in following sections of this report (secs. 3.1.2 and 5.1.1).

2.2 Stratigraphy

2.2.1 Introduction

A cursory discussion of the general stratigraphic framework of the study area was given in section 1.1.3 of this report. Because new drilling in the project area has not been of sufficient depth to penetrate much more than the upper Paleocene formations, no detailed discussion of strata lower in the section will be entered into here. Additional information concerning stratigraphy is presented in section 2.4, below, which deals with the geologic history of the area. Part of that section includes a perfunctory discussion of the stratigraphy of units which are not of major importance to the present study.

In this section of the report our discussion will begin with the Pierre Formation, a predominantly shale unit which is significant because it is the base of the regional flow system. The Pierre underlies the Fox Hills Formation, the major aquifer in the project area (see sec. 4.7 below).

2.2.2 Regional Framework

2.2.2.1 Pierre Formation

The Pierre Formation is the lowermost unit of the Cretaceous Age Montana Group. It varies in thickness from 1 200-2 000 feet (360-600 m) across the Knife River basin, thickening toward the northwest, where an oil test in southeastern Williams County shows a thickness of 2 390 feet (715 m) (Laird, 1944). Lithologically, the Pierre Formation consists predominantly of micaceous and bentonitic gray shale containing abundant pyrite, selenite, and siderite. Examination of plate 2 shows that depth to the Pierre varies from about 1 200-2 000 feet (360-600 m) across the study area. The contact with the overlying Fox Hills Formation is more or less transitional, making it rather difficult to pick consistently on mechanical logs (Cvancara, 1976).

2.2.2.2 Fox Hills Formation

The Fox Hills Formation is the uppermost unit of the Montana Group. It occurs in about the western two-thirds of North Dakota, but outcrops are sparse and are confined mostly to the south-central part of the state. A smaller outcrop area also occurs in the southwesternmost part of North Dakota along the flanks of the Cedar Creek anticline.

The Fox Hills Formation is carried into the subsurface throughout the Knife River basin by regional dip toward the center of the Williston basin. An isopach map by Cvancara (1976, pl. 4) shows that the thickest sequence of strata in the study area occurs in eastern Dunn County, southwestern Mercer County, and western Oliver County. More than 300 feet (90 m) of Fox Hills rocks are present in this area, while about 250 feet (75 m) are reported elsewhere in the study area.

Waage (1968), Feldman (1972), Erickson (1971, 1974), and Cvancara (1976) have studied the Fox Hills Formation in North Dakota and neighboring states. For detailed stratigraphic discussions of the formation, the interested reader is referred to their reports.

Cvancara (1976) recognizes four members in the Fox Hills Formation in North Dakota. In ascending order they are: Trail City, principal lithology--poorly consolidated sandy shale and siltstone; Timber Lake, principal lithology--fine- to medium-grained, poorly consolidated and well-indurated sandstone; Iron Lightning (with Bullhead and Colgate lithofacies), principal lithology--interbedded, poorly consolidated sandstone and shale or siltstone (Bullhead lithofacies), and medium-grained, poorly consolidated muddy sandstone (Colgate lithofacies); and Linton, principal lithology--very fine to fine-grained, indurated, siliceous sandstone. This sequence of rocks is overlain unconformably by the Hell Creek Formation, the youngest Cretaceous age unit occurring in North Dakota.

2.2.2.3 Hell Creek Formation

In southwestern North Dakota, the Hell Creek Formation consists of hundreds of feet of somber carbonaceous clays and sandstones with occasional lignite zones (Moore, 1976). In the subsurface in the western part of the project area, it varies from 74-165 feet (22-50 m) in thickness (Moran et al., 1976). It is nonmarine except for a thin marine tongue in south-central North Dakota. The presence of dinosaur fossils establishes an Upper Cretaceous age for the formation.

The Hell Creek Formation and the overlying Ludlow Formation are lithologically similar, if not identical, according to Moore (1976). Separation of the two units is made on the basis of floral and faunal differences and the lack of persistent lignites in the Hell Creek. Neither of the two formations outcrops in the project area; however, test-hole logs show that they are both present in the subsurface.

2.2.2.4 Ludlow Formation

The Ludlow Formation is the oldest Paleocene formation present in the study area. Moore (1976) subdivided the Ludlow into several informal units bounded by lignites which could be traced laterally over large areas. He defined the lower contact of the Ludlow by the occurrence of the first persistent lignite or lignite zone.

Like the other Paleocene formations of North Dakota, sediment of the Ludlow Formation is unlithified or only moderately lithified. It consists predominantly of alternating beds of somber gray and brown clays, silt, sand, and lignite. Surface exposures occasionally weather to buff and yellows (Moore, 1976). In outcrop, the nearest occurrence of the Ludlow Formation to the study area is in southwestern Burleigh County where it is only about 13 feet (4 m) thick (Kume and Hansen, 1965). Its thickness across the study area varies from 120-220 feet (36-66 m) (pl. 2).

In the southwestern part of the state the Ludlow Formation is overlain conformably by nonmarine beds of the newly named Slope Formation (Clayton et al., 1977). In the central part of the state, and throughout the study area, the Ludlow is overlain by marine beds of the Cannonball Formation.

2.2.2.5 Cannonball Formation

The Paleocene Cannonball Formation is a marine, non-lignitic bearing sequence consisting primarily of poorly consolidated, very fine to fine-grained, light- to medium-brownish-yellow, weathering sandstone and light-gray, weathering sandy mudstone (Cvancara, 1976). The thickest sequence in the eastern part of the study area is more than 300 feet (90 m) in southwestern McLean County (Bluemle, 1971). Thinning occurs to the west away from this area except for another thickening in Dunn County where more than 350 feet (105 m) of Cannonball rocks occur in the subsurface (pl. 2).

2.2.2.6 Slope Formation

The newly defined Slope Formation is a nonmarine, Paleocene age sequence of sedimentary rocks that rest on the Cannonball Formation in central North Dakota (pl. 2) and on the Ludlow Formation in western North Dakota where the Cannonball is generally absent (Clayton et al., 1977). Poorly consolidated, unbedded or thinly laminated clay and silt; plane-bedded and cross-bedded sand; and lignite (less than one-tenth) are the principal types of lithology (Clayton et al., 1977).

Most of the knowledge of the Slope Formation comes from studies of outcrops along the western and southwestern margins of the Williston basin. It is about 290 feet (87 m) thick in its type area (Clayton et al., 1977) in Slope County, North Dakota. Its thickness in the subsurface across the project area varies from 30 feet (9 m) in the east to 250 feet (75 m) in the west (pl. 2).

The Slope Formation is apparently unconformably overlain by the Bullion Creek Formation (Moore, 1976). A widespread, white bleached zone, commonly associated with a siliceous bed, occurs at the top of the Slope Formation. This white marker zone is quite persistent and is easily recognized in outcrops. In areas of outcrop the drab, brownish-gray Slope Formation is distinguished from the overlying, yellow-weathering Bullion Creek Formation by the color difference (Clayton et al., 1977). Picking the contact in the subsurface is more difficult.

2.2.2.7 Bullion Creek Formation

Bullion Creek is another new lithostratigraphic name that has recently been introduced in North Dakota by Clayton et al. (1977). It replaces the Tongue River Formation in North Dakota and was introduced to resolve stratigraphic correlation problems in the state.

The Bullion Creek Formation underlies the entire project area, but it is exposed only in outcrops along the Missouri River trench and in the vicinity of Square Butte Creek and Glen Ullin. The Bullion Creek Formation is about 300 feet (90 m) thick in the Dunn Center area. The Bullion Creek Formation generally thins to the east and is less than 200 feet (60 m) thick in the vicinity of Stanton. Lithologically, the Bullion Creek Formation consists of alternating beds of silt, clay, sand, and lignite. The basal portion of the formation, as previously discussed, consists of a series of highly variable sand units which reach a maximum thickness of 150 feet (45 m).

The Bullion Creek Formation is overlain conformably by the Sentinel Butte Formation. Royse (1967) names the criteria for distinguishing between the two formations in outcrop areas. For the purposes of the present study, the following criteria are used as a basis for identifying the contact in the subsurface:

1. A recognizable sequence of named lignite beds (see sec. 2.2.3) must be present in the test hole for proper orientation in the stratigraphic section.

2. Two persistent lignite beds (or zones of lignite beds) must be identified: the Tavis Creek bed, which always occurs below the contact; and the Hagel bed, which always occurs above the contact. Previous workers have identified these beds in outcrop areas within the present study area (Barclay, 1974; Hemish, 1975) and have observed that the contact (as defined by Royse, 1967) always occurs somewhere in the interval between the two beds. Different names were formerly used for the two marker beds because previous work was done only on a local level--

extensive new data used in the present study have shown that lignite beds can be correlated over large areas, so many local names have been discarded. A detailed discussion of lignite bed nomenclature can be found in section 2.2.3. In the Dunn Center area, Moran et al. (1976) arbitrarily placed the upper contact of the Bullion Creek Formation at the base of their informally named J-lignite, which is shown to be equivalent to the Hagel bed (see pls. 6-16).

3. A distinctive deflection on mechanical logs indicates the presence of a high density, high resistivity rock (usually a limestone, but occasionally a well indurated, calcium carbonate-cemented siltstone or sandstone) in the stratigraphic interval between the Tavis Creek and Hagel beds. This deflection can be identified on approximately seventy percent of logs examined for the present study. Both Barclay (1974), who worked in the Glen Ullin area, and Hemish (1975), who worked in the Underwood area, noted the presence of zones of limestone pods or lenses associated with the contact in outcrop areas. Hemish suggested that the lenses were useful as a guide for picking the contact in the subsurface, but noted that they were discontinuous. He suggested that the contact should be placed at the base of the first lithologic unit, coarser than clay, encountered above his "TR bed" (Tavis Creek bed). In the present study this practice has been followed at most of the test-hole sites where no limestone or cemented zone was present in the interval between the Tavis Creek bed and the Hagel bed. In rare instances, it was necessary to arbitrarily pick the contact in the interval between the Tavis Creek bed and the Hagel bed in order to maintain logical continuity of correlation.

To summarize--in this study, the Bullion Creek-Sentinel Butte contact was picked in the subsurface in the interval between the Hagel bed and the Tavis Creek bed, at the top of the distinctive high-resistivity, high-density deflection on mechanical logs. In the absence of this marker, the contact was picked at the bottom of the first silt or sand bed encountered above the Tavis Creek bed, or in rare instances, arbitrarily selected in the interval between the Tavis Creek bed and the Hagel bed if use of the alternate criterion was not practical. Selection of the above criteria for identifying the Bullion Creek-Sentinel Butte contact in the subsurface was based on tracing the known contact from an outcrop area in the Dengate quadrangle (Barclay, 1974) into the subsurface, and eventually to another known contact in an outcrop area in southwestern McLean County (Hemish, 1975). This was accomplished by constructing a network of cross sections throughout the study area (see pls. 6-16), which demonstrate through stratigraphic correlations the feasibility of the method.

Of additional interest is the fact that Munsell color identification of drilling samples from several test holes in the Underwood area showed a consistent color change across the Sentinel Butte-Bullion Creek contact. Colors above the contact were predominantly 2.5Y to 5Y hues, whereas those below the contact were predominantly 10YR hues with occasional 5Y and 7.5YR hues. This color contrast corresponds well with the "drab" over "bright" contact color change commonly observed in outcrops. It was not possible, in other parts of the project area, to obtain Bullion Creek samples of sufficient thickness to test these observations. The observed subsurface color change, if consistent, may be a significant tool in the subsurface identification of the Bullion Creek-Sentinel Butte contact. Additional deep test drilling and sample analysis are required to test these observations.

2.2.2.8 Sentinel Butte Formation

The Sentinel Butte Formation is a lignite-bearing, nonmarine, Paleocene unit which is generally somber gray and brown in outcrop (Jacob, 1976). Yellow colors, resembling those of the underlying Bullion Creek Formation characterize some of the beds, particularly in the lower part of the Sentinel Butte Formation. As a result, problems have arisen in distinguishing between the two formations where outcrops are poor, particularly in the eastern part of the study area.

Lithologically, the formation consists of alternating beds of silt, clay, sand, and lignite, with individual beds varying from less than 1 foot (0.3 m) in thickness to several tens of feet (Moran et al., 1976). The upper surface of the formation is eroded, except in scattered areas where it is protected by remnants of the overlying Golden Valley Formation. Where the total thickness of the Sentinel Butte Formation is preserved in the Knife River basin, it varies in thickness from 525-575 feet (160-172 m).

Nine major lignite beds or zones of lignite beds are recognized in the Sentinel Butte Formation in the project area (see pls. 6-16 and sec. 2.2.3, this report). Of these nine lignite beds, only two are presently being mined on a commercial scale; the Beulah-Zap bed, in the vicinity of Beulah, and the Hagel bed, in the vicinities of Center and Stanton. The Hagel bed will also be mined in the vicinity of Underwood in the near future.

2.2.2.9 Golden Valley Formation

The uppermost bedrock unit preserved in the Knife River basin is the Paleocene-Eocene age Golden Valley Formation. Thin lignite beds and carbonaceous zones are present in this formation, but they are not considered commercially valuable. Hickey (1977) has formally divided the formation into two members, a lower (Bear Den) member, and an upper (Camels Butte) member. The lower member is up to 60 feet (18 m) thick and consists of a lower unit of gray silt and clay, a middle unit of white or orange kaolinitic clay or silt, and an upper unit of lavender-gray silt and clay. The upper member is up to 170 feet (51 m) thick and consists of conspicuously cross-bedded, micaceous sand, sandstone, or silty, fine-grained sand, bentonitic clay, and chert. Carbonaceous beds are present in both members, and a thin lignite bed, termed the Alamo Bluff bed, separates the two members over much of the area (Carlson, 1973).

2.2.2.10 Coleharbor Formation

The Coleharbor Formation, for the purposes of this study, includes all of the unconsolidated Pleistocene age sediments resulting from deposition during glacial or interglacial periods. Lithologic types include gravel, sand, silt, clay, and pebble loam (till).

The Coleharbor Formation unconformably overlies either the Golden Valley, Sentinel Butte, or Bullion Creek Formations in the study area. No attempt has been made to differentiate the various units within the formation because it was not considered important for purposes of this study.

Although most of the Knife River basin was glaciated, sediment of the

Coleharbor Formation occurs only as discontinuous patches over all but its northern and eastern parts. Thicknesses of till range up to 200 feet (60 m) or more in the vicinity of Underwood. Valley fill, consisting of outwash gravels, sand, silt, clay, and pebble loam occurs in diversion trenches and preglacial and glacial stream channels and valleys. Thickness of these valley fills ranges up to 300 feet (90 m) or more. Their primary importance is in their usefulness as shallow aquifers. The configuration of some of these valley-fill units is shown on the cross sections accompanying this report (see pls. 6-16).

2.2.2.11 Oahe Formation

The Oahe Formation, as used in this study, includes all of the Holocene age stream, pond, and windblown sediment. A discussion of the Oahe Formation is included in appendix B. Lithologic units range from gravel, to sand, to silt, to clay, to highly organic clays that have accumulated in slough and pond bottoms. Where present, the Oahe Formation is the surface unit, and although generally not very thick, local accumulations of more than 50 feet (15 m) are known. Thickest deposits occur on flood plains of streams and in windblown sand dunes such as those south of the Knife River between Hazen and Stanton. Mappable loess deposits occur downwind from the Missouri River trench (see pl. 1).

2.2.3 Lignite Deposits

2.2.3.1 History of nomenclature

Previous studies of the lignites in the Knife River basin and McLean County area have generally been restricted to specific localities. Most previous studies relied heavily upon outcrop data which was often widely scattered and poorly exposed. Very little subsurface data was available; thus, the determination of the stratigraphic position of the various lignite beds and their relationship to lignites in other areas was extremely difficult. In most cases, local names were applied to the lignites in a given area, with only highly generalized suggestions of correlation to other parts of the area. As a result there is presently a very large number of names, many of which are duplicative, and a great deal of confusion as to the stratigraphic and geographic distribution of the various lignites.

Studies by Leonard et al. (1925) included a brief discussion of the lignites in the Dunn Center, Beulah, and Wilton areas. Benson (1952) mapped the lignites in the Mercer County area and suggested correlations to lignites previously mapped in adjacent areas. Johnson and Kunkel (1959) mapped the lignites in several areas of Oliver County and suggested correlations between those areas and with lignites mapped by Benson in Mercer County. Barclay (1973 and 1974) mapped the lignite deposits in the Glen Ullin and Dengate quadrangles, Morton County. He was also able to delineate the contact between the Bullion Creek and Sentinel Butte Formations in those areas. Moran et al. (1976), with the aid of considerable test-hole data, discussed the detailed stratigraphic relationships of the various lignites and associated materials in the Dunn Center area, Dunn County, North Dakota.

The present study has relied heavily upon subsurface data. A series of cross sections of the study area (pls. 6-16) were constructed which demonstrate the lateral continuity and traceability of the various lignites in the upper 500-700 feet

(150-210 m) of materials. This interval generally represents the entire Sentinel Butte Formation as well as the upper portion of the Bullion Creek Formation, particularly in the eastern part of the study area where erosion has removed the upper part of the Sentinel Butte Formation. The cross sections were based upon existing state and federal agency test-hole data, lignite exploration data supplied by the North American Coal Corporation, and test-hole data obtained by rotary rig and auger rig drilling for this project.

Nine lignites, each consisting of one or more beds, are present in the Sentinel Butte Formation and are mappable throughout the study area. Three lignites in the upper part of the Bullion Creek Formation are also traceable across the study area (pls. 6-16). In addition, two lower lignites in the Bullion Creek Formation have been tentatively correlated with the Harmon and Hansen beds which outcrop in southwestern North Dakota.

In the following sections, the nine traceable lignites in the Sentinel Butte Formation and three lignites in the upper Bullion Creek Formation are discussed in detail. Each lignite is named; in as many cases as possible existing names are used. New names are proposed where the existing nomenclature is imprecise or confused. An attempt has been made to relate as many as possible of the numerous names used in previous studies to the new nomenclature (fig. 2.2.3.1-1). In some cases this is not possible due to the lack of specific reference sections. Additional confusion has resulted from the fact that in some areas either one name has been mistakenly applied to several lignite beds or several names have been applied to a single bed. These problems have been largely due to a lack of understanding of local and regional structure by previous workers.

2.2.3.2 Bullion Creek Formation

2.2.3.2.1 Hansen and Harmon beds (tentatively named on cross sections).--The Hansen and Harmon beds outcrop in various areas of southwestern North Dakota and have been mapped and discussed by various workers (Leonard et al., 1925; Hares, 1928; Brant, 1953; Rehbein, 1977). These beds appear to be persistent over larger geographic areas, and are generally considered to be stratigraphically the lowest major lignites in the Bullion Creek Formation. Insufficient data is available to permit definite correlation of two major lignites encountered in deep test holes (pls. 10 and 11) in this study with the Hansen and Harmon beds. However, the stratigraphic position of these two lignite beds in the lower part of the Bullion Creek Formation, their thickness, and their apparent persistence across the study area strongly suggest that such correlation may be possible. These lignites are correlated with the M- and N-lignites of Moran et al. (1976, p. 95) in the Dunn Center area. Additional deep test-hole data may eventually permit the formal naming of the two lignite beds throughout the Knife River basin.

2.2.3.2.2 Weller Slough bed (New).--Source of name: The Weller Slough bed was named for Weller Slough in southwestern McLean County, North Dakota. The lignite bed is well developed in the subsurface in this vicinity.

Type area: Southwestern McLean County, North Dakota.

Type test hole: NDSWC 3914, SW¼SE¼-SW¼sec 32, T146N, R82W (see appendix A).

Reference test hole: REAP 18, NW¼-NW¼NW¼sec 5, T146N, R83W (see appendix

Names of Lignite Beds as Applied by Various Workers

Formation	This Report	Leonard, et al. (1925)	Andrews (1939)	Benson (1952)	Johnson and Kunkel (1959)	Barclay (1974)	Hemish (1975)	Moran, et al. (1976)
Sentinel Butte Formation	Harnisch			Harnisch				C
	Twin Buttes			Twin Buttes	Byer(?)			B
	Schoolhouse			Schoolhouse	Otter Creek			A
	Beulah-Zap	Beulah-Zap Dunn Center		Beulah-Zap	Herman			Dunn Center
	Spaer			Spaer				E
	Jim Creek							F, G
	Antelope Creek				Yeager– (eastern Oliver County Buckmann– (western Oliver County)			H
	Kinneman Creek			Star Hazen B– (Beulah area)	Berg } – Kuether } (eastern Oliver County) "Beulah-Zap"– (western Oliver County)			I
	Hagel		Garrison Creek(?)	Stanton Hazen B } upper and lower splits Hazen A } in Hazen area	Hagel	Richter	Underwood A	J
Upper Bullion Creek Formation	Tavis Creek			Knoop		Tavis Creek	TR	K
	Coal Lake Coulee			Hancock(?)				L(?)
	Weller Slough							

Figure 2.2.3.1-1. Formally named traceable lignite beds in the Sentinel Butte and upper Bullion Creek Formations and their relationship to names applied by previous workers.

A).

Description of unit: The Weller Slough bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. It is locally impure and may include stringers of brown carbonaceous clay as well as lenses of gray sand, silt, or clay.

Regional extent and thickness: The Weller Slough bed has been traced from its type area into southwestern Mercer County (see pls. 10, 11, and 12). In boring no. USGS G 169-46, NE¼NE¼NW¼sec 12, T143N, R90W, it is a single lignite bed 12 feet (3.6 m) thick with only a minor clay parting near its top. Test drilling in the Dunn Center area indicates that a lignite bed is present at a depth of 600 feet (180 m) in the approximate stratigraphic position of the Weller Slough bed, but a definite correlation cannot be made at this time. In the type well the Weller Slough bed is 3 feet (0.9 m) thick; however, it thickens laterally, and in the reference test hole it consists of a 5-foot (1.5-m) thick lignite associated with thin carbonaceous clay stringers separated by silty clay partings.

Differentiation from other units: The Weller Slough bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the type test hole it occurs 14 feet (4.2 m) below the base of the Coal Lake Coulee bed and 35 feet (10.5 m) above the top of the next major coal bed, which has been tentatively correlated with the M-lignite of Moran et al. (1976, p. 95). Similar intervals prevail between the Weller Slough bed and the lignite beds lying above and below in the reference test hole.

Correlation: The Weller Slough bed appears to be equivalent to the Hancock bed of Benson (1952). However, the proximity of the Weller Slough bed to the overlying Coal Lake Coulee bed and a lack of good exposures in the area where the Hancock bed was named allow for the possibility that the Hancock bed is equivalent to the Coal Lake Coulee bed. No other previously named lignites are known that may be correlative with the Weller Slough bed.

Age: The Weller Slough bed is Paleocene in age and is included in the Bullion Creek Formation.

2.2.3.2.3 Coal Lake Coulee bed (New).--Source of name: The Coal Lake Coulee bed was named for Coal Lake Coulee in southwestern McLean County, North Dakota. The lignite bed is well developed in the subsurface in this vicinity.

Type area: Southwestern McLean County, North Dakota.

Type test hole: NDSWC 3914, SW¼SE¼-SW¼sec 32, T146N, R82W (see appendix A).

Reference test hole: REAP 18, NW¼-NW¼NW¼sec 5, T146N, R83W (see appendix A).

Description of unit: The Coal Lake Coulee bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. It may include dark-brown to black carbonaceous clay and gray clay or silt locally.

Regional extent and thickness: The Coal Lake Coulee bed has been traced in the subsurface as far south as the Morton County line (see pls. 10, 11, and 12), and into eastern Dunn County in the vicinity of Halliday (see pls. 13, 15, and 16). Insufficient control prevented any further correlations. In the type well the Coal Lake Coulee bed is 8 feet (2.4 m) thick, but it is generally only 2-4 feet

(0.6-1.2 m) thick. It frequently occurs as a split bed, one of which may be carbonaceous clay. It also appears to merge locally with the Tavis Creek bed.

Differentiation from other units: The Coal Lake Coulee bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the type test hole it occurs 14 feet (4.2 m) below the base of the Tavis Creek bed, and 14 feet (4.2 m) above the top of the Weller Slough bed. In the reference test hole it occurs 22 feet (6.6 m) below the base of the Tavis Creek bed and 9 feet (2.7 m) above the top of the Weller Slough bed.

Correlation: As previously discussed, the Coal Lake Coulee bed may be correlatable with the Hancock bed discussed by Benson (1952, p. 258), but because of lack of adequate data no positive statement can be made.

Age: The Coal Lake Coulee bed is Paleocene in age and is included in the Bullion Creek Formation.

2.2.3.2.4 Tavis Creek bed (Old).--Source of name: The Tavis Creek bed was informally named by Barclay (1974), p. 8-9 in a report on the lignite deposits of the Dengate quadrangle, Morton County, North Dakota.

Type area: The Dengate and Glen Ullin quadrangles, Morton County, North Dakota.

Type test hole: USGS C-67 D4143, SE¼SW¼SW¼sec 18, T139N, R87W (see Barclay, 1974).

Reference test hole: REAP 7, SW¼SW¼-SW¼sec 14, T144N, R85W (see appendix A).

Description of unit: The Tavis Creek bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. It frequently splits into two or more beds 1-20 feet (0.3-6 m) apart separated by gray sand, silt, or clay. Brown carbonaceous clay and silt are commonly included.

Regional extent and thickness: The Tavis Creek bed is present throughout the project area. It occurs at considerable depths everywhere except for small areas near Glen Ullin and on the east side of the Missouri River trench in the Fort Mandan badlands (Hemish, 1975). In the type area the Tavis Creek bed is commonly 20-40 feet (6-12 m) below the upper contact of the Bullion Creek Formation (Barclay, 1974, p. 9). It is only about 3 feet (0.9 m) thick in the type well, but at that site a local upper split is present about 12 feet (3.6 m) above the main bed. Barclay (1974, p. 9) has mapped the upper bed as a local upper bench of the Tavis Creek bed. He observed that this local upper bench, which is a carbonaceous shale or thin lignite bed in some places, appears to merge with the main Tavis Creek bed in some areas. Examination of the cross sections (pls. 6-16) shows that the upper split is quite persistent north of the type area and that it appears to merge with the main bed in eastern Oliver and Mercer Counties. Here the Tavis Creek bed is generally just below the contact between the Bullion Creek and Sentinel Butte Formations.

The Tavis Creek bed is generally thicker than it is in the type test hole. It reaches thicknesses of 5-6 feet (1.5-1.8 m) in a single bed in the type area (Barclay, 1974, p. 9). In the reference test hole where the bed is split apart by clay partings the total thickness of the interval is 17 feet (5.1 m) with the main seam being 6 feet (1.8 m) thick.

According to Moran et al. (1976), the Tavis Creek bed (K bed) is not well developed in the subsurface in the Dunn

Center area. However, recent new drilling in southern Dunn County, northern Stark County, and southeastern Billings County shows that the Tavis Creek bed is present there, and that it has characteristics similar to those considered typical for the bed.

Differentiation from other units: The Tavis Creek bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the project area it is the uppermost named bed in the Bullion Creek Formation. In the type test hole the upper split of the Tavis Creek bed is 54 feet (16.2 m) below the base of the Hagel (Richter) bed, and 32 feet (9.6 m) below the contact between the Sentinel Butte and Bullion Creek Formations.

In the reference test hole the Tavis Creek bed is 71 feet (21.3 m) below the base of the lower split of the Hagel bed and 3 feet (0.9 m) below the contact between the Sentinel Butte and Bullion Creek Formations. It is 29 feet (8.7 m) above the top of the Coal Lake Coulee bed.

Correlation: The Tavis Creek bed is equivalent to the TR bed of Hemish (1975, p. 22), named informally in the southwestern McLean County area. The Tavis Creek bed is also equivalent to the Knoop bed of Benson (1952) and the K bed of Moran et al. (1976). Barclay (1974, p. 9) lists several local informally named beds in the Glen Ullin area that he considers to be approximately equivalent to the Tavis Creek bed. The relationship between the Tavis Creek bed and the HT Butte lignite, a thick lignite bed that occurs at the top of the Bullion Creek Formation in parts of western North Dakota, is unclear at this time.

Age: The Tavis Creek bed is Paleocene in age and is included in the Bullion Creek Formation.

2.2.3.3 Sentinel Butte Formation

2.2.3.3.1 Hagel bed (Old).--Source of name: The Hagel bed was named for the Hagel mine in sec 2, T141N, R84W, Oliver County, North Dakota (Johnson and Kunkel, 1959).

Type area: The Square Buttes area of eastern Oliver County, North Dakota.

Type test hole: REAP 1, SE¼SE¼SE¼-sec 35, T142N, R85W (see appendix A).

Reference test hole: REAP 7, SW¼-SW¼SW¼sec 14, T144N, R85W (see appendix A).

Description of unit: The Hagel bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. It may include dark-brown to black carbonaceous clay locally and is usually characterized by one or more brown or gray clay partings. Silt or sand lenses may be included locally.

Regional extent and thickness: The Hagel bed is present throughout the project area. It is the lowermost formally named lignite in the Sentinel Butte Formation. The Hagel bed is sufficiently close to the surface in the eastern and southeastern areas (Underwood area, Center area, Glen Ullin area) to make it amenable to strip mining. According to Moran et al. (1976, p. 89-90), the J-lignite (equivalent to the Hagel bed) has a mean thickness of 8 feet (2.4 m) throughout the central part of Dunn County. This figure seems appropriate for the entire Knife River basin project area and is representative of the thickness of the Hagel bed in the type test hole. Examination of plates 6-16 indicates that the Hagel bed often splits into two or more minor seams that are separated by several feet of intervening sediment. In the Underwood area an associated 4-foot (1.2-m) thick lignite seam informally named the B bed by Hemish (1975, p. 28-29) occurs about 15-20 feet (4.5-6 m) below the Hagel bed. This bed is included in the Hagel lignite interval. Another lignite bed, informally named the C bed by Hemish (1975, p. 28-29), and not traceable west of the Missouri River, occurs between the B bed and the base of the Sentinel Butte Formation.

Differentiation from other units: The Hagel bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the type test hole it occurs 64 feet (19.2 m) below the base of the Kinneman Creek bed and 82 feet (24.6 m) above the top of the Tavis Creek bed.

Correlation: The Hagel bed is equivalent to the Richter bed informally named by Barclay (1974, p. 8-9); the Stanton bed of Benson (1952, p. 256); the Underwood A bed of Hemish (1975, p. 28-29); and the J-lignite of Moran et al. (1976, p. 88-90). The lower split of the Hagel bed in the Hazen area is equivalent to the Hazen A bed of Benson (1952, p. 255). The Hagel bed is also apparently equivalent to the Garrison Creek bed of Andrews (1939, p. 72).

Age: The Hagel bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.2.3.3.2 Kinneman Creek bed (New).--Source of name: The Kinneman Creek bed was named for an exposure in a small abandoned mine adjacent to Kinneman Creek in the NW¼NW¼NW¼sec 19, T144N, R85W, Mercer County, North Dakota.

Type area: The Knife River basin area of west-central North Dakota.

Type test hole: USGS 306-L8, SW¼-SW¼SE¼sec 18, T144N, R85W (see USGS Open-File Report 77-857; also pl. 7, this report).

Reference test hole: REAP 12, SE¼-SW¼SW¼sec 8, T144N, R87W (see appendix A).

Description of unit: The Kinneman Creek bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. Its main seam is one of the most persistent and consistent lignites observed in the Knife River basin. It is readily identified by distinctive deflections on geophysical logs. The main seam of the Kinneman Creek bed is associated with overlying and underlying seams of lignite and carbonaceous clay which are not as persistent. Sedimentary bodies of sand, silt, and clay commonly separate these seams from the main seam, making the total interval quite variable across the study area.

Regional extent and thickness: The Kinneman Creek bed is present throughout the Knife River basin, except where it has been removed by erosion. It has also been identified in scattered areas at higher elevations to the east of the Missouri River in southwestern McLean County. In the type test hole, the main seam of the Kinneman Creek bed consists of 8 feet (2.4 m) of lignite overlain by 4 feet (1.2 m) of black carbonaceous clay and underlain by 2 feet (0.6 m) of black carbonaceous clay. A 4-foot (1.2-m) thick associated lignite seam occurs about 38 feet (11.4 m) lower in the section. Examination of plate 7 indicates that the interval between these two seams closes to only 8 feet (2.4 m) in the reference test hole located approximately eleven miles west of the type test hole. This pair of seams is typical of the Kinneman Creek bed over much of the study area (see pls. 6-16).

Differentiation from other units: The Kinneman Creek bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the reference test hole it occurs 66 feet (19.8 m) below the base of the Antelope Creek bed and 41 feet (12.3 m) above the top of the Hagel bed.

Correlation: The Kinneman Creek bed is equivalent to the I-lignite of Moran et al. (1976). It is equivalent to the Hazen B bed as mapped by Benson (1952) in the Beulah area. However, the "Hazen B bed" as mapped in the Hazen area is the upper split of the Hagel bed. The Kinneman Creek bed is equivalent to the Star bed of Benson (1952, p. 255). The Kinneman Creek bed is equivalent to both the Berg and Kuether beds of Johnson and Kunkel (1959, p. 39 and 41) in eastern Oliver County. It is also equivalent to the bed mistakenly identified as the "Beulah-Zap bed" in the Otter Creek area by Johnson and Kunkel (1959, p. 44-45).

Age: The Kinneman Creek bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.2.3.3.3 Antelope Creek bed (New).--Source of name: The Antelope Creek bed was named for Antelope Creek, which flows southeastward through north-central Mercer County, North Dakota, and joins the Knife River at Hazen. The Antelope Creek bed outcrops in steep valley walls adjacent to Antelope Creek west of Hazen.

Type area: The Knife River basin area of west-central North Dakota.

Type test hole: REAP 12, SE¼SW¼SW¼-sec 8, T144N, R87W (see appendix A).

Reference test hole: REAP 6, SE¼SE¼-SE¼sec 36, T146N, R89W (see appendix A).

Description of unit: The Antelope Creek bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. It includes dark-brown carbonaceous clay locally. The bed generally occurs as a pair of lignite seams separated by brown or gray clay, but may also occur as several seams split apart by deposits of sand, silt, or clay.

Regional extent and thickness: Except where it has been removed by erosion, the Antelope Creek bed is traceable throughout the Knife River basin. It is eroded east of the Missouri River. The Antelope Creek bed is the most variable bed found in the study area. It ranges from a 4-foot (1.2-m) thick single lignite seam (REAP 6) to a 50-foot (15-m) thick zone of lignite and carbonaceous clay seams interbedded with sands, silts, and clays. In central Dunn County (Moran et al., 1976, p. 85) the H-lignite (Antelope Creek equivalent) reaches a thickness of 9 feet (2.7 m).

Differentiation from other units: The Antelope Creek bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the type test hole it occurs 53 feet (15.9 m) below the base of the Spaer bed (Jim Creek bed is not present) and 46 feet (13.8 m) above the top of the Kinneman Creek bed. In the reference test hole the Antelope Creek bed occurs 12 feet (3.6 m) below the base of the Jim Creek bed and 62 feet (18.6 m) above the top of the Kinneman Creek bed.

Correlation: The Antelope Creek bed is equivalent to the H-lignite of Moran et al. (1976). It is also equivalent to the Yeager bed of Johnson and Kunkel (1959, p. 39) as mapped in eastern Oliver County and the Buckmann bed as mapped by Johnson and Kunkel (1959, p. 44) in the Otter Creek area.

Age: The Antelope Creek bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.2.3.3.4 Jim Creek bed (New).--Source of name:. The Jim Creek bed was named for Jim Creek, which drains an area in northern Dunn County, North Dakota where the coal seam is well developed.

Type area: The northwestern part of the Knife River basin area of west-central North Dakota.

Type test hole: USGS G 169-43, SE¼NE¼SW¼sec 10, T149N, R93W (see USGS Open-File Report 76-869; also pl. 15, this report).

Reference test hole: USGS G 169-37, NE¼SW¼NE¼sec 20, T146N, R92W (see USGS Open-File Report 76-869; also pl. 15, this report).

Description of unit: The Jim Creek bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. It occasionally grades laterally into dark-brown carbonaceous clay.

Regional extent and thickness: The Jim Creek bed is generally a single lignite seam that rarely exceeds 4 feet (1.2 m) in thickness. Locally it splits into two seams. It is equivalent to the F bed of Moran et al. (1976) and merges with the G-lignite (of their report) northeast of Dunn Center to form a single bed 10 feet (3 m) or more in thickness. From the type well the Jim Creek bed can be traced east and southeast in the subsurface to approximately the area of Beaver Creek bay (see pl. 15), and the Mercer-Oliver County line (see pl. 16). The Jim Creek bed is not present in much of the eastern part of the project area.

Differentiation from other units: The Jim Creek bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the type test hole it occurs 40 feet (12 m) below the base of the Spaer bed and 31 feet (9.3 m) above the top of the Antelope Creek bed.

Correlation: The Jim Creek bed is equivalent to the F- and G-lignites of Moran et al. (1976).

Age: The Jim Creek bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.2.3.3.5 Spaer bed (Old).--Source of name: The Spaer bed was named from exposures of the Spaer ranch in the NE¼sec 12, T143N, R89W, Mercer County, North Dakota (Benson, 1952, p. 253).

Type area: The Knife River basin area of west-central North Dakota.

Type test hole: REAP 6, SE¼SE¼SE¼sec 36, T146N, R89W (see appendix A).

Reference test hole: USGS B 74-89, NE¼NW¼NE¼sec 11, T144N, R89W (see appendix A; also pl. 6, this report).

Description of unit: The Spaer bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. Locally it may include gray or green clay and brown carbonaceous clay. In places it is capped by a thin, silicified carbonaceous shale that weathers white in part.

Regional extent and thickness: In the Beulah-Zap area the Spaer bed generally ranges from 2-6 feet (0.6-1.8 m) or more in thickness. Where it has been traced in the remainder of the Knife River basin area, it is generally thinner and occasionally pinches out. It also splits into as many as four thin lignite stringers separated by clay, silt, or silty sand. In places the lignite grades laterally into carbonaceous clay. Except for local areas where the bed pinches out, and east of a line running generally south from Garrison Dam, where it has been truncated by erosion, the Spaer bed is present throughout the project area. In an area occupying several square miles north of Beulah, the Spaer bed merges with the Beulah-Zap bed to form a single lignite seam in excess of 22 feet (6.6 m) in thickness (see pls. 6 and 9).

Differentiation from other units: The Spaer bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the type test hole it occurs 36 feet (10.8 m) below the base of the Beulah-Zap bed and 39 feet (11.7 m) above the Jim Creek bed. The distance between the beds is extremely variable, and correlations are best accomplished through the use of distinctive deflections on geophysical logs.

Correlation: The Spaer bed is equivalent to the E-lignite of Moran et al. (1976).

Age: The Spaer bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.2.3.3.6 Beulah-Zap bed (Old).--

Source of name: The Beulah-Zap bed was named and mapped near the towns of Beulah and Zap in Mercer County, North Dakota, by Leonard et al. (1925, p. 125-130).

Type area: The Knife River basin area of west-central North Dakota.

Type test hole: REAP 12, SE¼SW¼SW¼-sec 8, T144N, R87W (see appendix A).

Reference test hole: REAP 6, SE¼SE¼-SE¼sec 36, T146N, R89W (see appendix A).

Description of unit: The Beulah-Zap bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. According to numerous sections measured by Benson (1952, figs. 17, 18, and 19) the upper 3 feet (0.9 m) or more of the bed often includes minor impurities, dark-brown carbonaceous clay, bony lignite, soft impure lignite, and black lignitic clay.

Regional extent and thickness: The Beulah-Zap bed is present throughout the project area except where it has been removed by erosion (mostly in the areas along drainages such as the Knife River and Spring Creek, and in the eastern part of the study area, generally east of a north-south line paralleling state highways 200 and 31). Its thickness is variable, but in general averages about 12 feet (3.6 m). The Beulah-Zap bed commonly splits, and occurs locally as two to five lignite and carbonaceous clay seams separated by clay, silt, or sand. Thus, the entire interval may expand to 30 feet (9 m) or more in thickness (see pls. 6-16). The Beulah-Zap bed and Spaer bed, as previously discussed, merge north of Beulah in T144N, R88W, to form a seam over 20 feet (6 m) in thickness (see pls. 6 and 9).

Differentiation from other units: The Beulah-Zap bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the reference test hole it occurs 58 feet (17.4 m) below the base of the Schoolhouse bed and 60 feet (18 m) above the top of the Spaer bed. In the type test hole, the top of the Beulah-Zap bed occurs 74 feet (22.2 m) below the surface. The Schoolhouse bed is eroded at this site. The top of the Spaer bed is only 15 feet (4.5 m) below the base of the Beulah-Zap bed in the type test hole.

Correlation: The Beulah-Zap bed is equivalent to the Dunn Center bed of Leonard et al. (1925, p. 83) and Moran et al. (1976). It is also equivalent to the Herman bed of Johnson and Kunkel (1959, p. 44) as mapped in the Otter Creek area of Oliver County.

Age: The Beulah-Zap bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.2.3.3.7 Schoolhouse bed (Old).--Source of name: The Schoolhouse bed was named for an exposure in a small mine near a rural school in the southern part of sec 27, T142N, R89W, Mercer County, North Dakota.

Type area: The south-central part of the Knife River basin, west-central North Dakota.

Type test hole: USGS 306-L14, NW¼-SW¼NW¼sec 24, T142N, R89W (see USGS Open-File Report 77-857; also pl. 12, this report).

Reference test hole: USGS G 169-52, SE¼SE¼SE¼sec 10, T142N, R88W (see USGS Open-File Report, 76-869; also pl. 16, this report).

Description of unit: The Schoolhouse bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. In the vicinity of its type and reference test holes it splits into two seams that are separated by 8-12 feet (2.4-3.6 m) of clay, sand, and silty sand. Elsewhere in the study area it may include gray silty clay and brown carbonaceous clay.

Regional extent and thickness: The Schoolhouse bed is widely distributed throughout the study area. It is locally truncated by erosion in areas of low elevation to the west and throughout the eastern part of the study area where the upper part of the Sentinel Butte Formation has been eroded. The Schoolhouse bed apparently merges with the Beulah-Zap bed in western Dunn County (see pl. 16) where it splits into several thin lignite seams which grade laterally into carbonaceous clay and eventually pinch out to the west. In the type test hole the Schoolhouse bed consists of an upper lignite seam 5 feet (1.5 m) thick and a lower lignite seam 4 feet (1.2 m) thick separated by about 8 feet (2.4 m) of gray clay and very fine sand. Examination of plates 6-16 demonstrates that the Schoolhouse bed may occur as a single bed, as several beds of variable thickness, or as beds composed of a high proportion of carbonaceous clay.

Differentiation from other units: The Schoolhouse bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the type test hole it occurs 56 feet (16.8 m) below the bottom of the Twin Buttes bed and 38 feet (11.4 m) above the top of the Beulah-Zap bed. Discontinuous lignite beds occur locally between the Schoolhouse and Beulah-Zap beds, specifically in the central part of the project area. The intervals between the named beds above and below the Schoolhouse bed are extremely variable. For example, Benson (1952, p. 251) observed that the Schoolhouse bed ranges from 45-100 feet (13.5-30 m) above the Beulah-Zap bed in the Medicine Butte and Broncho quadrangles.

Correlation: The Schoolhouse bed is equivalent to the A-lignite of Moran et al. (1976). It is also equivalent to the Otter Creek bed of Johnson and Kunkel (1959, p. 45).

Age: The Schoolhouse bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.2.3.3.8 Twin Buttes bed (Old).--Source of name: The Twin Buttes bed was named for exposures near a pair of small conical buttes in sec 28, T143N, R90W, Mercer County, North Dakota (Benson, 1952, p. 252).

Type area: The southwestern part of

the Knife River basin, west-central North Dakota.

Type test hole: USGS G 169-52, SE¼-SE¼SE¼sec 10, T142N, R88W (see USGS Open-File Report 76-869; also pl. 16, this report).

Reference test hole: USGS G 169-38, SE¼NE¼NE¼sec 2, T146N, R94W (see USGS Open-File Report 76-869; also pl. 15, this report).

Description of unit: The Twin Buttes bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. In the area where it was named it is thin and impure, with a persistent clay parting near the middle. The Twin Buttes bed is one of the most variable of all the named coals in the Knife River basin. Locally the Twin Buttes bed may thicken into a bed of good quality lignite or grade laterally, in a very short distance, into brown carbonaceous shale.

Regional extent and thickness: In the type test hole the Twin Buttes bed is 5 feet (1.5 m) thick; however, in the reference test hole in northern Dunn County, it consists of two 5-foot (1.5-m) thick beds separated by 4 feet (1.2 m) of gray clay. In general, the Twin Buttes bed is thickest in the western part of the Knife River basin where it is of some economic importance (see pls. 13, 14, 15, and 16). As previously stated, the Twin Buttes bed is extremely variable, and often occurs as a thin lignite or carbonaceous clay seam. Because several seams of lignite reaching a thickness of only about 1 foot (0.3 m) occur locally in the interval between the Harnisch bed and the next named lignite below the Twin Buttes, correlation is often uncertain. The variability in the extent and thickness of the Twin Buttes bed is due in part to the presence of a thick widespread sand body present in the upper 100 feet (30 m) or more of the Sentinel Butte Formation.

Differentiation from other units: The Twin Buttes bed is differentiated from other coal beds on the basis of its stratigraphic position in a known sequence of beds. In the type test hole it occurs 58 feet (17.4 m) below the base of the Harnisch bed and 91 feet (27.3 m) above the top of the Schoolhouse bed. These intervals are extremely variable; the interval between the Twin Buttes bed and the Schoolhouse bed is only 35 feet (10.5 m) in the reference test hole in northern Dunn County.

Correlation: The Twin Buttes bed is equivalent to the B-lignite of Moran *et al.* (1976). It may also be equivalent to the Byer bed of Johnson and Kunkel (1959, p. 46).

Age: The Twin Buttes bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.2.3.3.9 Harnisch bed (Old).--Source of name: The Harnisch bed was named by Benson (1952, p. 71, 83, and 84) from exposures in the SE¼SE¼sec 23, T140N, R91W, northeastern Stark County, North Dakota.

Type area: The southwestern part of the Knife River basin, west-central, North Dakota.

Type test hole: USGS 306-M58, NW¼-NE¼NE¼sec 8, T140N, R88W (see USGS Open-File Report 77-857; also pl. 12, this report).

Reference test hole: USGS G 169-46, NE¼NE¼NW¼sec 12, T143N, R90W (see USGS Open-File Report 76-869; also pl. 16, this report).

Description of unit: The Harnisch bed is black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. It includes stringers of brown carbonaceous shale locally, and may grade into brown carbonaceous clay.

Regional extent and thickness: The Harnisch bed is the uppermost named coal bed in the Sentinel Butte Formation. Where present it occurs just below the contact with the Golden Valley Formation. In northeastern Stark County, Benson (1952, p. 71) observed that a sandy phase of the lower member of the Golden Valley Formation channeled into the Harnisch bed. The bed is well developed in southwestern Mercer County and parts of adjoining counties. It is typically about 4 feet (1.2 m) thick, but may vary locally. In central Dunn County the bed splits into two or more lignites separated by clay partings and having a total thickness of as much as 18 feet (5.4 m) (see pls. 13 and 14). The Harnisch bed has been largely removed by erosion in the western parts of the Knife River basin and is totally absent in the eastern and northeastern parts of the project area.

Differentiation from other units: The Harnisch bed is differentiated from other coal beds on the basis of its stratigraphic position; i.e., its relationship to the Golden Valley Formation, and its presence at the top of the Sentinel Butte Formation. In the type test hole it occurs about 36 feet (10.8 m) above the top of the next lower named lignite bed, the Twin Buttes bed. This interval is extremely variable.

Correlation: The Harnisch bed is apparently equivalent to the C-lignite of Moran et al. (1976).

Age: The Harnisch bed is late Paleocene in age and is included in the Sentinel Butte Formation.

2.3 Structure

2.3.1 Regional Structure

The study area is located wholly within the Williston basin (fig. 2.3.1-1), a shallow structural and sedimentary basin which includes 51 600 square miles (133 000 sq. km) in North Dakota (Carlson and Anderson, 1970). The center of the basin lies just to the northwest of the project area in northwestern Dunn County. According to Moran et al. (1976), rocks older than the Cannonball Formation dip toward the west in the vicinity of Dunn Center, but the regional dip in the Bullion Creek and Sentinel Butte Formations is toward the east. It is not clear whether this indicates a migration of the center of the Williston basin to the east or whether the subsidence of the basin had ceased and the basin was filled.

Cross sections prepared for the present study (pls. 15 and 16) show that the beds in the Bullion Creek and Sentinel Butte Formations dip from the west and the east toward a center located approximately along the Dunn County-Mercer County boundary in the vicinity of Dodge. Displacement of the center of the Williston basin at the onset of the Cenozoic Period is thus shown to have been about 40 miles (64 km) to the east.

A structure map of the Knife River basin drawn on the top of the Bullion Creek Formation (pl. 22) supports the evidence provided by the cross sections. The contact between the Bullion Creek and Sentinel Butte Formations occurs in the subsurface at an elevation of 1 488 feet (450 m) above MSL about four miles northeast of Dodge and just east of the Dunn County line. This elevation repre-

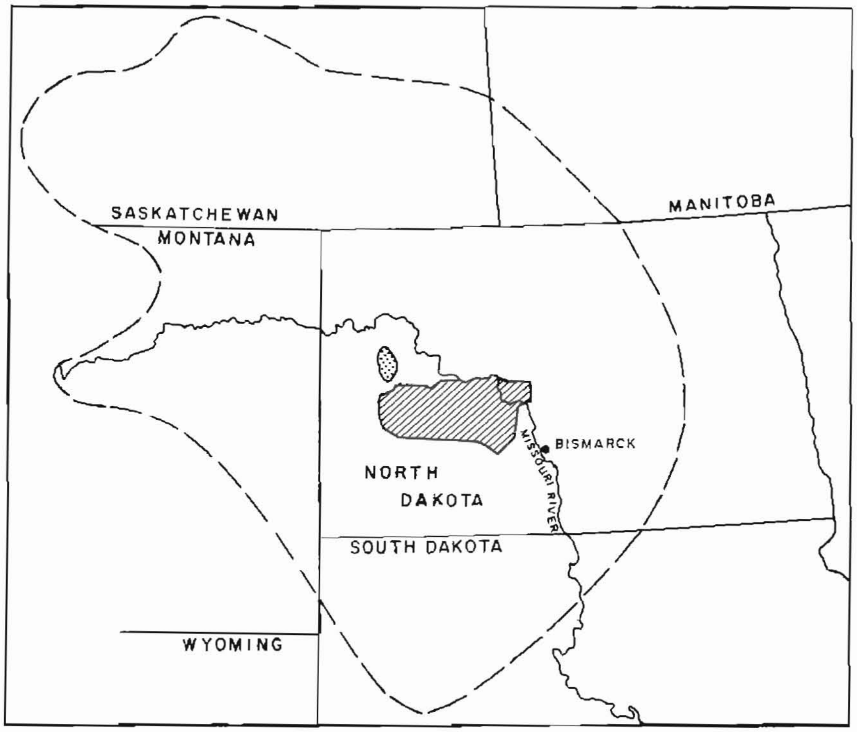


Figure 2.3.1-1. Map showing the Williston basin and the study area (cross-hatched). The stippled area is the deepest part of the basin. (Modified from Carlson and Anderson, 1970.)

sents the lowest point in North Dakota where strata of the Sentinel Butte Formation have been recognized to date.

Although the bedrock strata in the study area generally appear to be flat-lying in outcrops, they do dip gradually (10-25 feet per mile (2-4.7 m per km)) according to Benson, 1952; Hemish, 1975; and Hickey, 1966. Locally, beds with greater dip angles or even flat-lying beds may be present due to small-scale structures.

2.3.2 Small-Scale Structure

Examination of the structure map (pl. 22) of the Bullion Creek-Sentinel Butte contact shows that numerous small synclines and anticlines are superimposed on the regional structure. Some of these structures locally reverse the regional dip. A north-south trending, elongated structural depression in western Dunn County brings the contact down to an elevation near 1 750 feet (525 m) even though it is well above 2 000 feet (600 m) a few miles to the west and at 1 900 feet (570 m) a few miles to the east. Other smaller structural depressions and ridges interrupt the regional dip, which brings the Tertiary strata up toward the margins of the Williston basin where they either feather out or are truncated by erosion.

A more detailed discussion of small-scale structures and the processes that may have produced these features is presented in section 3.3 of this report.

2.4 Geologic History

2.4.1 Pre-Tertiary

The geologic history of the Knife River basin is recorded by the sequence of sediments preserved in the Williston basin (fig. 1.1.3-1). Because strata occupying a basin are exposed only along its edges (far from the study area, in this case), subsurface information is required to make proper interpretations about the buried pre-Tertiary formations. Our present knowledge of these rock strata in the project area comes mostly from deep drilling for water and petroleum.

Drill hole data show that sediment of the Cambrian Deadwood Formation, which rests unconformably on Precambrian basement rocks, consists of limestone, shale, and sandstone. Carlson and Anderson (1970) described the Deadwood as a stable shelf deposit extending eastward from the Cordilleran geosyncline. Sediment was probably derived from the transcontinental arch, a large ridge-like cratonic feature extending from Lake Superior southwest toward Arizona. To the east of the study area the Cambrian sandstones lap unconformably against the pre-Paleozoic basement rocks of the Canadian Shield.

Other preserved pre-Tertiary rocks in the Williston basin also show by their thickness and distribution a primary convergence toward the transcontinental arch. In some cases, this thinning reflects truncation by erosion, marking major unconformities.

Following deposition of the Deadwood Formation, and during the remainder of the Paleozoic Era, the Williston basin continued to receive sediment. A Middle Ordovician clastic sequence (Winnipeg Group) was deposited. Predominantly carbonate deposition followed and continued through Middle Silurian time (Carlson and Anderson, 1970).

Subsequent to a period of erosion marked by a major unconformity, predominantly carbonate deposition in marine waters once again occurred. Thin clastic beds and evaporites (mostly halite and anhydrite) were also deposited during this interval of Devonian and Mississippian time. Another unconformity is at the top of clastic sediments of the Upper Mississippian Big Snowy Group.

Slight subsidence characterized the Williston structural basin during the Pennsylvanian, Permian, and Triassic Periods. Clastics, minor carbonates, and evaporites were deposited under marine conditions. These are overlain by nonmarine redbeds and another major unconformity (Carlson and Anderson, 1970).

Beginning in Middle Jurassic time, epeiric seas advanced over western North Dakota from the north and west. Middle and Upper Jurassic strata that lap across the above mentioned unconformity, record transgression of the sea over the western craton. Restricted environment evaporites and red shales were deposited first, followed by normal marine carbonates, and then fine-grained clastics of the Sundance Group. Late Jurassic time marks the last significant carbonate and evaporite deposition in the Williston basin. Subsequent to retreat of the Sundance seas, nonmarine silts and shales of the Morrison Formation were deposited, followed by sandstone, siltstone, and shale of the Lakota Formation at the onset of the Cretaceous Period.

Transgression again occurred during Cretaceous time. About one-third of the present land area of the earth was submerged during the middle of the period, roughly 100 million years ago. The western craton was flooded from both the Arctic and Gulf regions. Thick deposits of marine sediment were laid down in North Dakota as waters merged over the area. Sand and sandstone which comprise the Dakota aquifer were deposited as transgression progressed. Marine shales, comprising a section approximately 3 000 feet (900 m) thick in the Knife River basin were deposited in the epeiric seas.

Regression commenced during Late Cretaceous time about 75 million years ago, and the transitional Fox Hills Formation was deposited. Sandstones of this formation are an important aquifer in the study area where they reach a thickness of 300 feet (90 m) (Cvancara, 1976). By the end of the period, the sea had retreated and continental deposits of the Hell Creek Formation were being laid down. The close of the Cretaceous is marked by extinction of the great dinosaurs, whose presence in western North Dakota is recorded by abundant fossil remains in the Hell Creek Formation.

2.4.2 Tertiary

During the early Cenozoic the western part of North Dakota was an area undergoing aggradation. Sediment eroded from newly uplifted ranges in the Rocky Mountains to the west was being dumped by streams flowing eastward. Deposition occurred in rivers, lakes, and swamps, and to some extent in deltas and along the coastal plains bordering the Cannonball seas. Sediment deposited in the Cannonball Sea during the Paleocene Epoch records the last vestige of marine conditions in the Williston basin. About the end of Paleocene time, the continent's last epeiric sea apparently retreated to the Gulf of Mexico.

At many places in the study area the strata contain well-preserved plant and animal fossils which indicate that the early Cenozoic climate was subtropical to temperate. Petrified stumps, plant fragments, whole leaves, pollen grains, and other vegetative debris in various stages of coalification are abundant. Most of the faunal remains are fresh water gastropods and mollusks (except for the fossils found in the Cannonball Formation, which are marine). Volcanic ash is an abundant constituent of many of the sediments attesting to great eruptions in the area to the west.

Conditions were right for preservation of the lush growth of vegetation that fell into the Paleocene swamps. A delicate balance between the water table and the sediment surface had to be maintained if the vast coal swamps were to persist. According to Moore (1976) a coal swamp may be terminated by an influx of water, by an influx of sediment, or it may be partially or totally destroyed by erosion. The lateral continuity and thickness of some of the coal beds in the Bullion Creek and Sentinel Butte Formations seems to indicate that long periods of widespread, uniform conditions prevailed in the Williston basin during the latter part of the Paleocene. The environment was probably similar to that of the modern Mississippi delta of the southern United States.

The youngest Tertiary age formation preserved in the project area is the continental Golden Valley Formation. According to Hickey (1977, p. 2) "the predominance of channel-facies sandstone lenses interbedded with typical overbank and backswamp deposits throughout both members indicates a fluvial origin." This contradicts the interpretations of previous workers who believed that the lower member of the formation had a lacustrine origin. Hickey (1977) also concluded from fossil plant evidence that western North Dakota had a subtropical climate during early Eocene time. Sediment was being transported into the Williston basin from weathered highlands lying to the west.

No other Tertiary age rocks are preserved in the study area; however, remnants of sediments preserved on high buttes in marginal areas provide clues to the geologic events that transpired during the time preceding the Quaternary Period. About 425 feet (128 m) of Oligocene and Miocene deposits cap isolated buttes in the unglaciated southwestern part of North Dakota (Stone, 1972). All of the rocks of these erosional remnants are of continental origin. It seems likely that they were continuous over the project area prior to the onset of downwasting, which commenced in the late Tertiary and completely erased all traces of their presence. Erosion was the dominant geologic force acting on the region up to the time of continental glaciation.

2.4.3 Quaternary

Pleistocene glaciation was one of the most dramatic events in the geologic history of North Dakota. Although the effect of this climatic event is not as profound in the project area as elsewhere in the state, it left its mark in many ways. Ice sheets advanced across the area from the north and northeast an unknown number of times. The maximum advance of the earliest glacier to invade the Knife River basin is now marked only by scattered erratics. Erosion has removed almost all other material brought in by the ice sheet. Although the age of the onset of glaciation in the project area is uncertain, it was probably in excess of one million years ago.

The preglacial drainage system in the region was characterized by eastward flowing streams which ultimately discharged into Hudson Bay. The valleys of the modern Spring Creek and Knife River had been established prior to glaciation. The principal effects of glaciation were modification of the landscape by temporary drainage diversions (Moran et al., 1976). Eastward and northeastward flowing streams were blocked by glacial ice, creating lakes which eventually rose until they topped low places in the interstream divides. The water then spilled over the divides, cutting outlets which permitted water of the original streams as well as glacial meltwater to drain to the southeast. Benson (1952), and Moran et al. (1976) present a much more detailed discussion of these diversion trenches; the interested reader is referred to those reports for further information.

Extensive alteration of the landscape by glaciation is manifested most obviously in the northeast one-third of the project area. Deep valleys were filled with drift; till was deposited to form hummocky topography with numerous closed depressions; a veneer of till was draped over much of the area, smoothing the preexisting landscape; and the segment of the Missouri River valley below Garrison Dam was cut by diversion waters.

Alteration of the landscape by glaciation over the remainder of the study area is largely manifested by the diversion trenches mentioned above. Erosion has removed most of the glacial sediment so that the form of the present day topography is much like it was prior to glaciation.

2.4.4 Post-Quaternary

The post-glacial era has been a time when wind and running water have been largely responsible for shaping the landscape. Surface rocks have undergone chemical and physical changes. Weathering has loosened particles which have washed down hill slopes and accumulated in ponds, sloughs, trenches, and on the flood plains of streams.

Wind has played a role in reshaping the landscape, particularly in areas where a supply of unprotected sand or silt is available. Sand dunes (now largely stabilized) deposited by post-glacial winds, cover many square miles adjacent to the Knife River along its lower reaches. Loess deposits thinly veneer almost all of the area and locally attain thicknesses of six feet (2 m) or more downwind from the Missouri River trench. Lesser accumulations of windblown sediment resulted from severe erosion of agricultural land during the drought years of the 30s when "black blizzards" were common in the Great Plains.

Not to be discounted are the changes to the landscape being brought about by the presence of man. Not only does tillage of the land create opportunities for erosive processes to go to work, but also overgrazing by domestic stock, drainage of wetlands, damming of rivers (bluffs along Lake Sakakawea), construction of highways and railroads, and perhaps the most obvious--stripping of the land to develop the region's vast lignite reserves.

3 BEULAH-HAZEN AREA

3.1 Introduction

3.1.1 Scope and Purpose of Study

This part of the report describes the geology of the Beulah-Hazen area located in west-central North Dakota wholly within Mercer County (fig. 3.1.1-1). The primary purpose is to provide a map, at a scale of 1:63 000, of the lithologic, lithogenetic, morphogenetic, and lithostratigraphic units in the Beulah-Hazen area and to provide information on the existence, thickness, and depth of lignite beds in the eight adjoining 7½-minute quadrangles included within the area of study.

3.1.2 Study Methodology

The field work for the Beulah-Hazen study began in June, 1976. Surficial geologic mapping was done directly on U.S. Geological Survey 7½-minute series topographic maps, scale 1:24 000. Maps used included the Beulah, Beulah NW, Beulah NE, Hazen East, Hazen West, Hazen NE, Hazen NW, and Zap quadrangles. In addition, aerial photo stereopairs, scale 1:20 000, were used as an aid for placing geologic contacts. Soil maps prepared by the U.S. Department of Agriculture Soil Conservation Service were obtained from the Mercer County A.S.C.S. Office in Hazen. The information provided by these maps proved to be extremely valuable, not only in permitting more accurate placement of geologic contacts, but also in allowing better use of time.

It should be noted here that there are certain limitations to maps of the scale prepared for this study. Because it is difficult to show small areas, dissimilar units may be included within the boundaries of units indicated on the map. Boundaries between units are generally not distinct in the field, but change gradually over a distance of a few feet to several hundred feet. The geologist must arbitrarily draw a line of contact between map units; thus, occasional discrepancies may be found.

The surficial mapping was done by traversing all section line roads and trails accessible by vehicle. Generally, the roads were good, permitting access to all but the most rugged areas. It was necessary to walk into these areas on several occasions to examine exposures and to verify interpretations made from some of the above mentioned sources. Lithologic information was obtained by studying exposures in road ditches, roadcuts, railroad cuts, freshly dug excavations, lignite mine highwalls, and areas of badlands topography. Additional information was obtained by use of a shovel and hand pick. Surficial lithologic units less than 2.5 feet (0.75 m) thick were ignored. Color names used in the lithologic descriptions were those given in the Munsell Soil Color Charts, 1973 Edition.

Subsurface information was obtained from test-hole drilling by the North Dakota Geological Survey, the United States Geological Survey, and the North Dakota State Water Commission. Additional information was obtained from commercial well drillers' logs, and logs provided by The North American Coal Corporation.

3.1.3 Previous Studies

The geology and lignite resources of the Beulah-Hazen area have been mapped and discussed by various workers in varying levels of detail. Leonard et al.

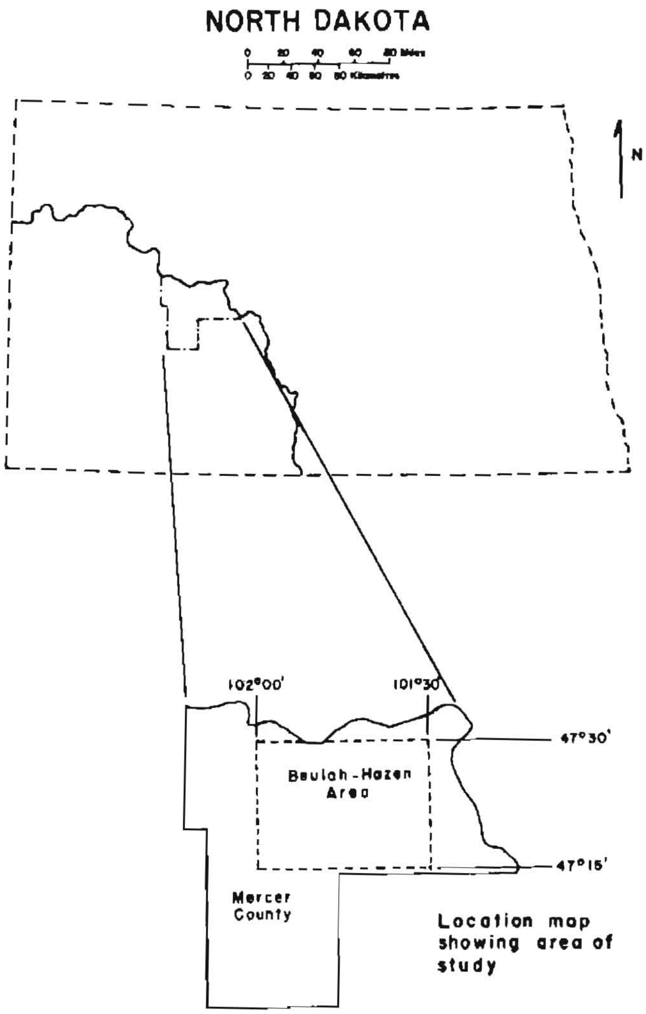


Figure 3.1.1-1. Map showing the Beulah-Hazen area, Mercer County, North Dakota.

(1925) named the Beulah-Zap bed and included a brief discussion of the lignite resources in the area. Benson (1952) mapped the lignite resources of the area and proposed names for many of the individual beds. Carlson (1973) mapped the surficial materials in the area at a scale of 1:250 000 and included a comprehensive discussion of previous studies.

3.1.4 Geographic Setting

The Beulah-Hazen area is located in west-central North Dakota between 101°30' to 102° west longitude and 47°15' to 47°31' north latitude (fig. 3.1.1-1). These coordinates bound an area of approximately 404 square miles (1 047 sq. km). Topographically, this region belongs to the Missouri Plateau section of the Great Plains Province (Lobeck, 1950).

The topography is characterized, for the most part, by integrated drainage. The exception is an elongate hummocky glacial feature, known as the Krem moraine, which caps the divide between the Knife River and Missouri River drainages. This area is characterized by numerous closed depressions.

The most striking features of the

Figure 3.1.4-1. Badlands topography developed on the Sentinel Butte Formation in the NE¼SE¼sec 22, T144N, R87W. (Note fragments of petrified wood in foreground of photograph.)

landscape are the flat-floored, Missouri River diversion trenches, which are incised as much as 400 feet (120 m) below the surrounding highlands, giving the western part of the area almost a mountainous aspect. These trenches represent partially-filled glacial meltwater valley systems. They trend generally northwest-southeast across the southwest corner (Golden Valley Trench) and west-central (Beulah Trench) part of the project area (pl. 3).

The highest point in the map area occurs on a small hummock on the Krem moraine. A U.S. Coast and Geodetic Survey triangulation station at the northeast corner of sec 7, T145N, R85W, marks an elevation of 2 340 feet (702 m) above MSL. The lowest point occurs in the SW¼SW¼sec 34, T145N, R85W, just east of Highway 200 where the Knife River flows out of the mapped area. The elevation at this point is approximately 1 690 feet (507 m) above MSL.

The principal stream in the Beulah-Hazen area is the Knife River, which flows northeastward and joins the Missouri River about six miles (9.6 km) east of the mapped quadrangles. It is joined from the south by Otter Creek, Brady Creek, and Kinneman Creek; from the north by Raymond Creek, Coal Creek, and Antelope Creek; and from the west by Spring Creek. Lake Sakakawea, Beaver Creek Bay, Rener Bay, and Beulah Bay adjoin the area along most of the northwestern boundary (pl. 3).

Although much of the area consists of sloping bedrock topography draped with glacial sediment, local dissection of the Golden Valley and Sentinel Butte Formations has produced badlands topography (fig. 3.1.4-1). Extensive areas of scoria from resistant brick-colored rims or caprock where lignite beds have burned and the overlying sediment has been baked.

The climate of the area is semiarid, characterized by long, severe winters and short, hot summers. Average annual precipitation is about 18 inches (45.7 cm), more than half of which falls during the summer months.

Mixed prairie vegetation dominates the region, with native grasses covering most of the uncultivated uplands and slopes. Woodlands occur along valley bottoms and on steep gully sides. Trees in windbreaks and shade belts are common around farm sites.

Beulah and Hazen are the two towns of the area, both having populations of approximately 1 300 according to the 1970 census. Renewed interest in development of the lignite industry has led to recent, rapid expansion of these towns and current population figures are considerably higher. The Burlington Northern, Inc. (formerly Northern Pacific Railroad) links the region to Bismarck as well as points west. State Highways 49 and 200 and a number of county and township roads traverse the area making accessibility to most points quite easy. The extreme northwestern corner of the region is occupied by the Fort Berthold Indian Reservation. The Beaver Creek State Game Management Area and the Hille State Game Management Area adjoin Lake Sakakawea along many miles of shoreline in the northern part of the area.

3.2 Stratigraphy

3.2.1 General Statement

The strata underlying the Beulah-Hazen area are included in two general categories: (1) the subsurface rocks not exposed in the study area (only briefly mentioned); and (2) the Paleocene and younger rocks which outcrop or were penetrated during test-hole drilling.

The Sentinel Butte Formation of Paleocene age and the Golden Valley Formation of Paleocene-Eocene age are the only bedrock formations that outcrop in the study area. These rocks are extensively covered by Pleistocene age glacial drift and Holocene deposits. Stratigraphic sections measured in the Beulah-Hazen area are included in appendix A. A geologic map is presented on plate 3. An accessory lignite map and a generalized stratigraphic section of the part of the Sentinel Butte Formation exposed in the Beulah-Hazen area are presented on plate 4. Four cross sections (pls. 6, 7, 8, and 9) show the stratigraphic position of the lignites in the Beulah-Hazen area.

3.2.2 Subsurface Rocks

According to Carlson (1973), an oil test hole drilled in eastern Oliver County penetrated Precambrian rock at a depth of 8 850 feet (2 655 m). Because depths to the Precambrian increase to the north and west toward the axis of the Williston basin, it can be inferred that depth to the basement rock in the study area is about 10 500-11 000 feet (3 150-3 300 m).

Carlson (1973) also discussed the Paleozoic rocks in Mercer and Oliver Counties. Thicknesses ranged from 4 500 feet (1 350 m) in the southeast to 7 500 feet (2 250 m) in the northwest. He recognized four sequences in the Paleozoic; the Sauk, Tippecanoe, Kaskasia, and Absaroka, with the Absaroka including some Triassic rocks. The thickness of the Paleozoic section in the Beulah-Hazen area is approximately 6 000 feet (1 800 m).

The Mesozoic section should be approximately 4 200 feet (1 260 m) thick according to data provided by Carlson (1973). The Cretaceous age Hell Creek Formation is the uppermost Mesozoic lithostratigraphic unit occurring in the subsurface in the study area. It is overlain by Cenozoic rocks of the Zuni

Sequence which vary greatly in thickness, ranging from 250 feet to 1 350 feet (75-405 m), due to regional dip, regional slope, and processes of erosion (Carlson, 1973). Bedrock formations of Cenozoic age present in the study area include the Ludlow, Cannonball, Slope, Bullion Creek, Sentinel Butte, and Golden Valley Formations.

A test hole was drilled about six miles (9.6 km) northeast of Hazen (REAP 17, SW¼NW¼NW¼NW¼sec 34, T145N, R85W). The Bullion Creek-Cannonball contact was reached at a depth of 340 feet (102 m) at an elevation of 1 394 feet (418 m) above MSL (pl. 11). Although the hole was drilled an additional 260 feet (78 m), the total sequence of beds in the Cannonball Formation was not penetrated. Thus, the total thickness of the Cannonball Formation was not established. Because no other test holes were drilled to depths sufficient to penetrate the top of the Cannonball Formation, these rocks will not be discussed in further detail.

The contact between the Sentinel Butte and Bullion Creek Formations was reached at a depth of 123 feet (37 m) in test hole REAP 17 at an elevation of 1 611 feet (483 m) above MSL (pl. 11). Thus, the thickness of the Bullion Creek Formation in the southeastern part of the study area is about 217 feet (65 m) which agrees very well with the thickness as shown on plate 2. The Bullion Creek-Sentinel Butte contact was picked at the top of a tan limestone lying just above the Tavis Creek bed (pls. 7, 8, 9, and 11) in accordance with criteria outlined in section 2.2.2.7. The Bullion Creek Formation, in test hole REAP 17, is composed predominantly of silty clay and clayey silt, with some very fine grained sand and silty sand. About 20 percent of the total thickness of the formation consists of lignite and carbonaceous clay. An 8-foot (2.4-m) thick lignite bed with a carbonaceous clay parting lies just above the contact with the Cannonball Formation. The upper part of the Cannonball in this test hole is composed of dark-gray, very fine sand and silty sand occasionally interbedded with silt, silty clay, and brown carbonaceous silty sand.

3.2.3 Surface Rocks

3.2.3.1 Sentinel Butte Formation

The Sentinel Butte Formation of Paleocene age outcrops over most of the study area. In some areas the Sentinel Butte is overlain by a veneer of glacial drift and locally may be overlain by the Golden Valley Formation. It is well exposed in the highwalls of active and abandoned lignite pits, road and railroad cuts, and in steep areas adjacent to the Knife River, Spring Creek, and Lake Sakakawea. Sections were measured at Beulah and at the Indian Head Mine (see app. A) which give detailed descriptions of the rocks of part of the Sentinel Butte Formation. A generalized stratigraphic section of the portion of the formation exposed in the Beulah-Hazen area is included on plate 4.

In general, the Sentinel Butte Formation is composed of weakly indurated, interbedded sand, silt, clay, carbonaceous clay and shale, lignite and a small amount of limestone. The color of the rocks is usually a drab gray-brown with occasional lighter gray or yellow-brown bands. White-weathering, silicified, carbonaceous shale, and petrified tree stumps (fig. 3.2.3.1-1) occur locally. A good outcrop of a silicified carbonaceous shale zone can be seen in the NW¼ of sec 24, T144N, R89W, just west of the railhead at the Indian Head Mine, where the road crosses a small tributary stream of Spring Creek.

The outcrop appearance of the Sentinel Butte rocks in the Beulah-Hazen area is strikingly similar to those described in other parts of western North Dakota (Barclay, 1972; Benson, 1952; Carlson, 1973; Hemish, 1975; Moran et al., 1976). No attempt was made to divide the formation into units as was done by Barclay (1974) and Stancel (1974); however, it should be noted that a widespread very fine to fine-grained sandstone, yellowish-brown with black grains, is present in the upper 120 feet (36 m) of the Sentinel Butte in the western part of the study area. This sandstone is resistant to erosion and caps many ridges and buttes in the highlands adjacent to the Golden Valley trench and west of the Beulah trench at elevations ranging from 2 000-2 150 feet (600-645 m) above MSL (fig. 3.2.3.1-2).

A 740-foot (222-m) deep test hole (REAP 6) was drilled in the SE corner of sec 36, T146N, R89W, that penetrated the entire thickness of the Sentinel Butte Formation (see pl. 6). The contact between the overlying Golden Valley Formation and the Sentinel Butte Formation was penetrated at a depth of 130 feet (39 m). The Bullion Creek Formation was reached at a depth of 662 feet (199 m). Thus, the thickness of the Sentinel Butte Formation is known to be at least 532 feet (160 m) in northwestern Mercer County. This figure agrees fairly well with Carlson (1973, p. 26) who considered the formation to be slightly over 500 feet (150 m) in thickness in the same area.

3.2.3.2 Golden Valley Formation

The Golden Valley Formation is the uppermost bedrock unit present in the Beulah-Hazen area. It occurs as erosional remnants in highlands in the extreme southwest corner of the mapped area, and also in the northwestern part of the area where it outcrops west of Beulah trench at elevations generally above 2 150 feet (655 m).

Hickey (1977) has formally named two members in the Golden Valley Formation. Both the lower (Bear Den) member, consisting predominantly of kaolinitic, fine-grained sediment with some sand, carbonaceous clay, and lignite, and the upper (Camels Butte) member, consisting (in the study area) mostly of yellowish-brown, calcareous, micaceous, cross-bedded sandstone were recognized. Two sections were measured (see app. A) in the northwest part of the mapped quadrangles. A contact was picked between the Sentinel Butte Formation and the Golden Valley Formation at an outcrop in the SW¼SE¼NE¼ sec 9, T145N, R88W. As can be noted from the description of the sediments (see Northeast Zap Section, app. A), the contact is gradational. This interpretation is in agreement with Hickey (1972, p. 111), who states, "Although sharp changes in lithology are sometimes found at the boundary, in most cases, Fort Union sediments simply grade upward into those of Golden Valley aspect through a zone of transition, making its exact placement impossible."

Good exposures of the upper member of the Golden Valley Formation were rarely seen. However, a micaceous sandstone outcropping in the road ditch in the NE¼SE¼sec 7, T145N, R88W, was identified as the Camels Butte member. Another exposure of this member was seen in the NE¼NW¼NE¼sec 10, T145N, R89W, at an elevation of about 2 260 feet (678 m). At this site the sandstone has weathered to rounded, billowing forms protruding

Figure 3.2.3.1-1. Petrified tree stump exposed in the SW¼SW¼sec 20, T145N, R85W. Dimensions–8 feet (2.4 m) in diameter.

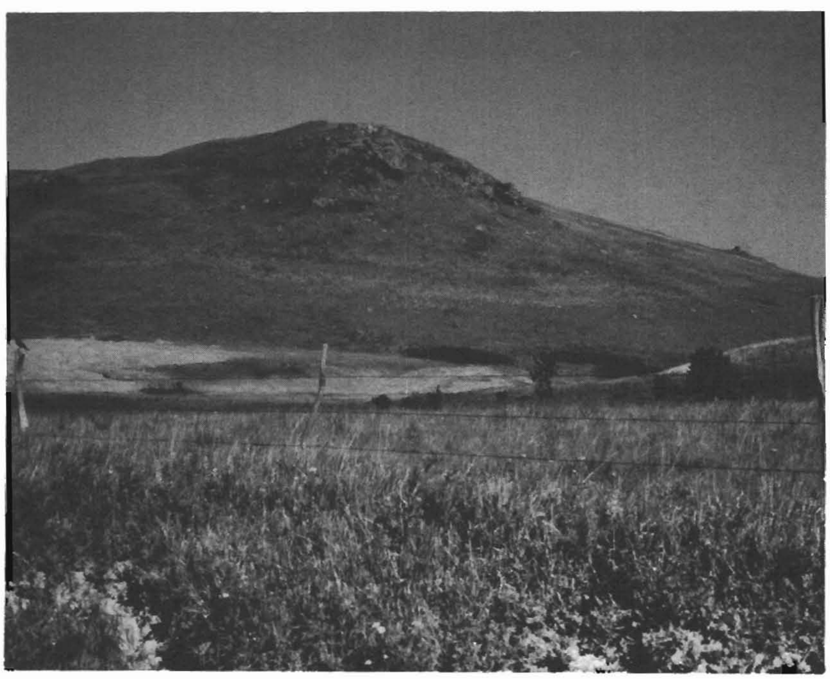


Figure 3.2.3.1-2. Sandstone at the top of the Sentinel Butte Formation capping a butte in the SE¼NW¼sec 10, T145N, R88W.

through grass covered soil that has developed on glacial drift (fig. 3.2.3.2-1).

The thickness of the Golden Valley Formation was not determined in the Beulah-Hazen area because the entire section is nowhere present. Where eroded remnants are present in upland areas they are generally overlain unconformably by Pleistocene age glacial deposits (fig. 3.2.3.2-2).

3.2.3.3 Coleharbor Formation

The principal occurrences of sediment of the Coleharbor Formation include: (1) thick deposits of sand, gravel, silt, and pebble loam (till) in glacial meltwater trenches (Golden Valley and Beulah trenches) and (2) generally thin patches of pebble loam (till) on upland surfaces, predominantly in the area north of Beulah and Hazen. No serious attempt was made to differentiate the various Pleistocene age units, largely because it was not considered significant to the objectives of the study. However, three, or possibly four, different tills were recognized in various exposures and test holes.

Bluemle (1976) examined two tills exposed in cut banks along Lake Sakakawea and concluded that the lower unit was equivalent to the pre-Wisconsinan Dead Man till of Bluemle (1971) and the Medicine Hill Formation of Ulmer and Sackreiter (1973). It is a compact, mottled, reddish-brown to gray bench-forming unit, containing abundant shale pebbles and lignite fragments up to four inches or more in diameter. Bluemle (1976) believed that the till overlying this unit was equivalent to the early Wisconsinan Napoleon till of Bluemle (1971) and Carlson (1973), and the Snow School Formation of Ulmer and Sackreiter (1973). This till is present at the surface over a large part of the mapped area (see pl. 3). It is silty, sandy, and clayey, mottled yellow-brown and gray with orange iron oxide spots. Carbonate pebbles predominate, but igneous and metamorphic types as well as locally derived sedimentary rock fragments are also included. Small weathered lignite fragments are common.

Lithologically, the surface till on the Krem moraine is indistinguishable from the surface till observed over most of the remainder of the glaciated area (pl. 3). However, because of the comparative lack of integrated drainage, the presence of outwash deposits associated with it, and the sharpness of the hummocks on it, it is believed that the glacial deposits of the Krem moraine represent a stratigraphically younger unit than the deposits underlying the more subdued areas. One radiocarbon date, W-402, from a site on the Krem moraine in Mercer County (11 220±300 yrs) indicates that the Krem deposits are probably correlative with the late Wisconsinan Lostwood drift of western McLean County (see Bluemle, 1971, p. 55).

Deposits of the Coleharbor Formation were described at an outcrop in Beulah and at an exposure in a cutbank along Kinneman Creek (see app. A). It is apparent that the materials observed at Beulah represent at least three glaciations, while the units at Kinneman Creek represent two glaciations. The lower unit at Kinneman Creek appears to be correlative with the Dead Man till, but the upper unit's stratigraphic designation is problematical.

3.2.3.4 Oahe Formation

Windblown silt and sand of Holocene age is present as the surface material over much of the area studied; however, it is generally too thin to map at the

Figure 3.2.3.2-1. Exposures of sandstone of the Camels Butte member of the Golden Valley Formation, NE¼NW¼NE¼sec 10, T145N, R89W at an elevation of about 2 260 feet.

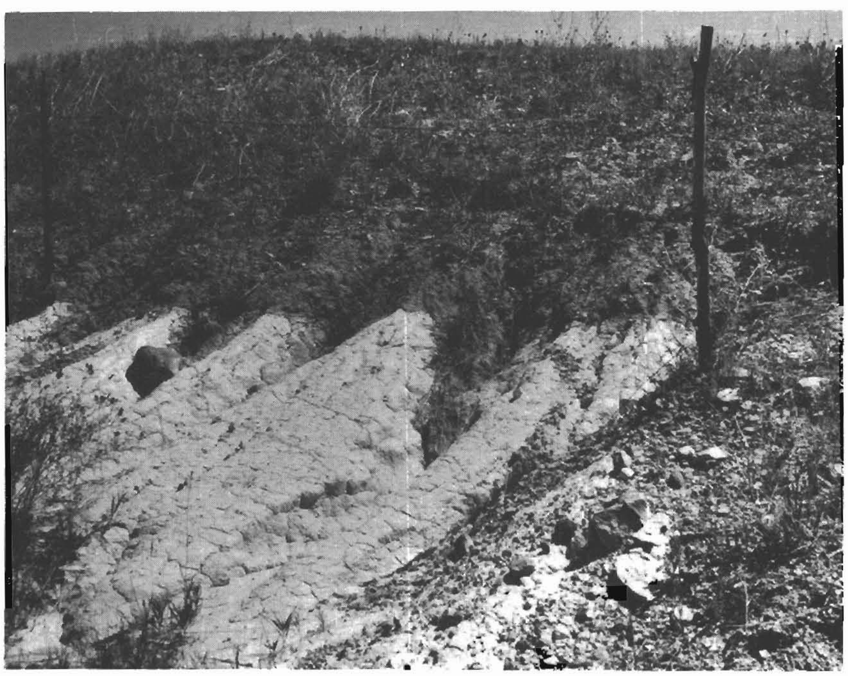


Figure 3.2.3.2-2. Till unconformably overlying kaolinitic clay beds of the Bear Den member of the Golden Valley Formation, NE¼NE¼NE¼sec 24, T145N, R89W. Contact occurs at base of fence posts at an elevation of about 2 180 feet.

scale used for this project. An exception to this occurs in the north-central part of the study area (see pl. 3) where loess deposits 2-6 feet (0.6-1.8 m) or more thick blanket the highlands southeast of the Missouri River trench (now occupied by Lake Sakakawea). Mappable windblown sand deposits also occur on the uplands south of the Knife River and Spring Creek (see pl. 3).

Other Holocene age surficial units found locally in the study area include highly organic clays in marshes and sloughs; dirty gray, black, and brown silts and clays containing pebbly sand on flood plains of streams and on the lower parts of hillslopes; laminated gray and black organic silts and clays in ponds and lake basins; and fine- to medium-brown and gray sand, including some gravel, on terraces, flood plains, and alluvial fans. All of the above have been included in the Oahe Formation. A detailed discussion of the Oahe Formation is included in appendix B.

3.3 Structure

3.3.1 Regional

The Beulah-Hazen area is located on the east side of the Williston basin, an intracratonic, broad structural downwarp extending under most of western North Dakota (see fig. 2.3.1-1). The deepest point of the basin is located approximately in the area of the Killdeer Mountains in Dunn County, about 50 miles west of the Beulah-Hazen study area.

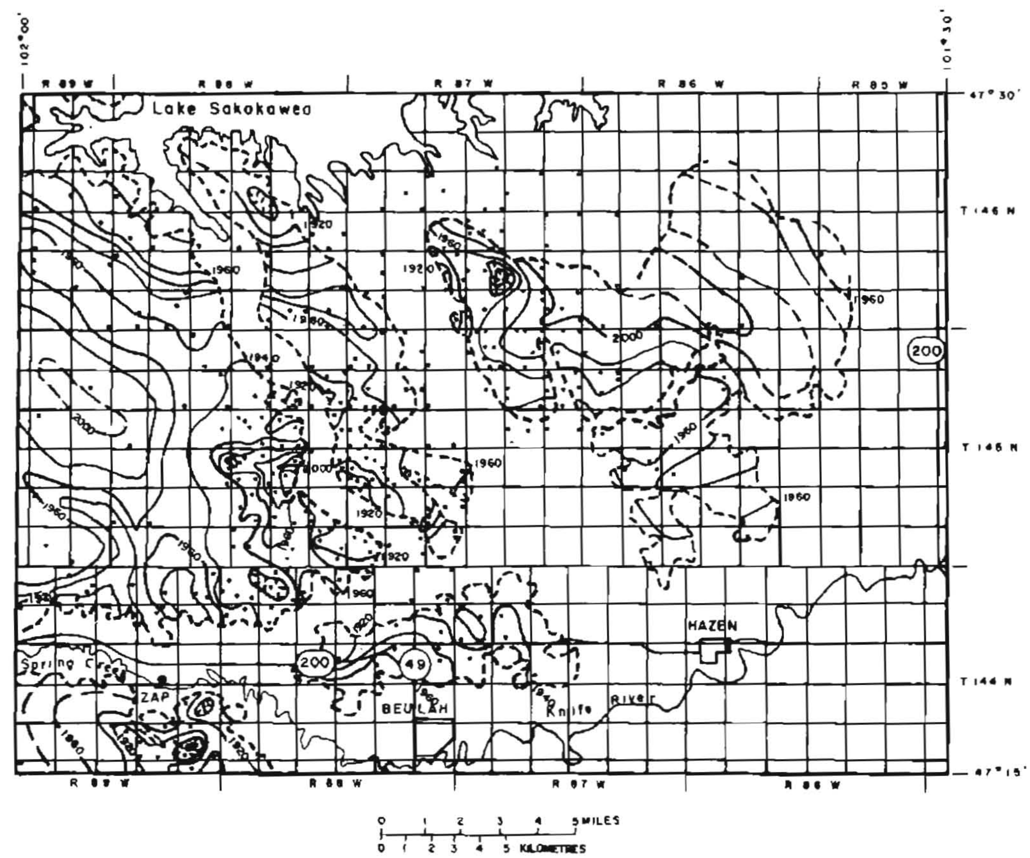
An east-west cross section (pl. 2), extending from central Dunn County through northern Mercer County to eastern McLean County, shows that the regional dip on the Sentinel Butte strata is about six feet per mile to the west through the Beulah-Hazen area.

3.3.2 Local

A structure map of the top of the Beulah-Zap bed indicates that numerous small-scale local structures are present in the Beulah-Hazen study area (fig. 3.3.2-1). The strata have been folded into round or elongated domes, synclines, and anticlines. Two noteworthy anticlinal features are evident. One is about 8 miles (12.8 km) long and strikes N45°W from sec 31, T146N, R87W to sec 15, T146N, R89W. Data are somewhat limited in the area of the other, but it appears to strike N40°W from sec 2, T145N, R86W to sec 22, T146N, R87W.

A structurally low area in secs 9, 10, 11, 12, 13, 14, 15, and 16, T145N, R88W, is manifested in several ways. Its existence was first suspected when it was noted that white, kaolinitic silty sand beds of the Golden Valley Formation outcrop at anomalously low elevations in this area. An alternate explanation for this occurrence could be that a large stream channel in the Golden Valley Formation has been incised into the top of the Sentinel Butte Formation (see Hickey, 1972, p. 112). However, it was also noted that outcrops of scoria resulting from the burning of the Beulah-Zap lignite bed are conspicuously absent in this area, even though they are almost continuously present where structure brings the Beulah-Zap bed above the surface along the walls of the Beulah trench elsewhere (see pl. 3). Finally, preparation of the structure map, using test-hole data, confirmed the existence of the suspected synclinal structure.

Larger, intermediate scale structures in the form of elongate synclines affect the geomorphology of the area. Benson



EXPLANATION

C.I. = 20'

Contour Lines

Inferred Contour Lines

Crop Line

Data Points

Figure 3.3.2-1. Structure contour on the top of the Beulah-Zap bed.

(1952) suggests that the valleys of the Knife River and Spring Creek follow such synclines. It has been noticed that lignite beds commonly tend to dip toward the stream valleys, and it has been suggested that this might be the result of land slides, slumping, or camber of the lignite beds into the valleys (Barclay, 1974). Although this probably does occur locally, deep test-hole drilling reveals that beds below the valley walls also dip toward the axis of the stream valleys (see pls. 6-16) suggesting that the locations of the stream valley are, at least in part, structurally controlled.

Faults resulting from local slumping are common in the area, but a fault observed in the highwall of the Indian Head Mine at Zap seems to indicate tectonism as a causative factor. The fault is a normal fault, striking N5°W and dipping NE at an angle of 48°. Displacement is 15 feet (4.5 m) (fig. 3.3.2-2). The time of the faulting was not determined; however,

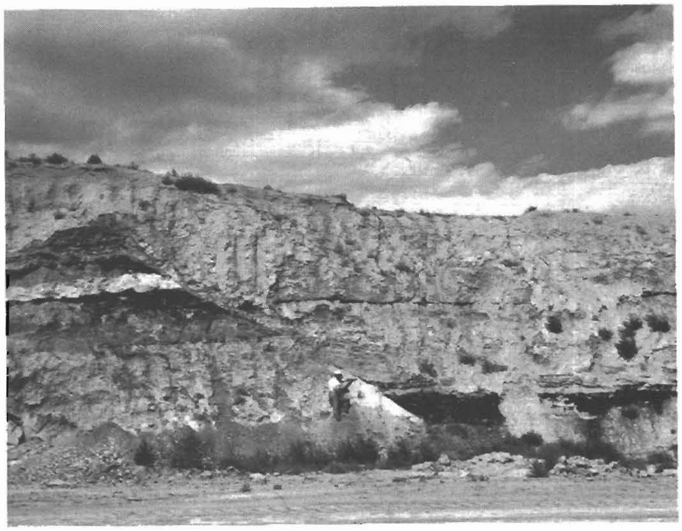


Figure 3.3.2-2. Normal fault exposed in the NE¼NE¼sec 36, T144N, R89W in the highwall of the Indian Head Mine.

it seems unlikely that it occurred recently as the result of slumping because of the presence of slickensides on rock along the fault plane (see Indian Head Mine Section, app. A).

3.3.3 Processes

Several processes have been suggested that may have produced the structural features superimposed on the regional structure in the Knife River basin. Moran et al. (1976) cite differential solution of underlying Paleozoic or Mesozoic salt beds; landsliding along major stream valleys and glacial meltwater trenches; original irregularities of the land surface at time of deposition; and differential compaction of sediment types as possible causes for the irregularities.

Benson (1952) gives evidence for three episodes of deformation in western North Dakota during early Tertiary time. The first occurred during the Paleocene epoch and consisted of local warping and basin settling accompanied by minor folding and faulting. It is recorded by deformed strata overlain by flat-lying beds totally within the Sentinel Butte Formation and were observed by Benson in exposures resulting from the construction of the Garrison Dam.

The second episode occurred in Eocene time and is recorded by the unconformity at the base of the White River Formation. Differential uplift and tilting away from the Black Hills dome was cited by Benson (1952) as the cause.

The third episode of deformation occurred after the Oligocene epoch, but prior to the latter part of the Tertiary period. Evidence seen in the Little Badlands in Stark County and in the Chalky Buttes in Slope County indicates that the deformation consisted of the folding of all Tertiary formations into small domes and synclinal basins (Benson, 1952).

3.4 Geomorphology

3.4.1 General Statement

In a general way, the Beulah-Hazen area can be subdivided into six discrete geomorphic areas (see fig. 3.4.1-1).

1. Areas of rolling hills with slopes usually ranging from 1-15 percent; characterized by till mantling and modifying pre-existing topography; boulders locally numerous; closed depressions rare; drainage integrated; includes loess-mantled topography along the north-central and northeastern part of the mapped area. Bedrock may be exposed locally. Well suited for tillage.

2. Areas of hummocky topography; characterized by sharp, small hills composed of till with slopes usually ranging from 6-15 percent; relief of 20-30 feet (6-9 m); numerous closed depressions and boulders; suitable for tillage, but erodibility a factor; well suited for pastures in places too steep or rocky for tillage.

3. Areas of eolian sand dunes or sand-blanketed topography; characterized by stabilized, grassed-over dunes with local relief of 40-50 feet (12-15 m); blowouts active locally; suitable only for pasture; may be suitable for tillage where sand thinly veneers till; poor water-holding capability.

4. Diversion trenches; characterized by steep walls and flat floors manifesting post-glacial alluvial fill; segments may contain small, underfit streams and local poorly drained areas; gravelly terrace remnants common; underlain by 300 feet (90 m) or more of glacial and interglacial fluvial and lacustrine sediment; well suited to tillage where drainage is adequate. Includes the Golden Valley trench and the Beulah trench with its Zap and Hazen branches (see fig. 3.4.1-1).

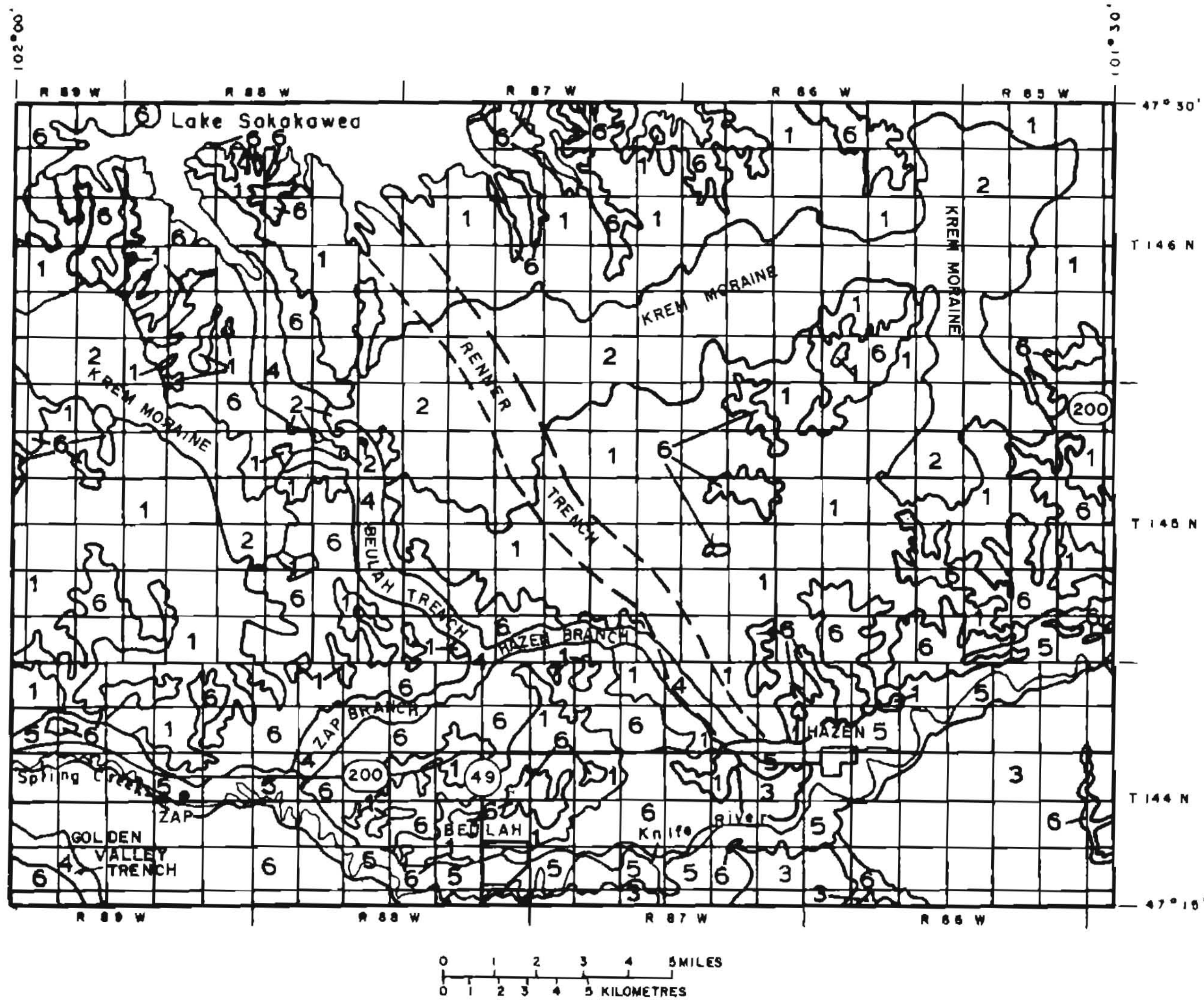
5. Bottomlands of the Knife River and Spring Creek, characterized by flood plains having a relief of about 10-15 feet (3-4.5 m), a width of 1-2 miles (1.6-3.2 km), and gradients of 4 feet per mile (0.75 m per km) for the Knife River flood plain--10 feet per mile (1.9 m per km) for the Spring Creek flood plain. Oxbow lakes, meander scars, cutbanks, point-bar deposits, natural levees, and terrace remnants are common features; well suited to tillage in most areas.

6. Areas of steep slopes underlain by bedrock, mostly in highlands adjacent to stream bottomlands and trenches; may include patches of glacial drift; usually deeply dissected, with slopes from 15-50 percent; includes local areas of barren badland topography; resistant ridges and caprock of scoria and sandstone widely distributed; mass wasting phenomena common; generally best suited for pasture except where slope wash deposits have accumulated locally.

3.4.2 Landforms

Because the map prepared for this study is largely self-explanatory and includes the morphogenetic units in the Beulah-Hazen area (pl. 3), no lengthy discussion of the landforms is deemed necessary. Carlson (1973) aptly discusses this topic, as does Benson (1952), who presents a detailed discussion of the geology of the entire Knife River basin, including the Beulah-Hazen area.

During the course of the current study the existence of a previously unrecognized deep trench, thought to be a diversion trench of the Missouri River, has been revealed. This trench trends southeast from Renner Bay in a direct line toward the town of Hazen (fig. 3.4.1-1). The Hazen branch of the Beulah trench joins it approximately in the SE corner of sec 36, T145N, R87W (about 3 miles (4.8 km) northwest of Hazen). Antelope Creek flows through the southeast part of the trench. Except for the fact that this diversion valley is largely



EXPLANATION

1. Rolling, well-drained topography with till and loess veneering pre-existing landforms.
2. Hummocky topography with sharp, small hills of till and numerous closed depressions.
3. Eolian sand dunes and sand-blanketed topography.
4. Diversion trenches with flat floors.
5. Bottomlands of the Knife River and Spring Creek.
6. Steep slopes underlain by bedrock except for local patches of till; mostly dissected highlands.

Figure 3.4.1-1. Major geomorphic subdivisions--Beulah-Hazen area.

filled with glacial deposits, and is obviously older, it is almost identical to the Beulah trench as to its dimensions, depth, and directional trend. Two test holes drilled by The North American Coal Corporation in sec 30, T146N, R87W penetrated 300 feet (90 m) into the trench without encountering its bottom. Other holes drilled along its course show similar results. The buried trench is outlined on the map by dashed lines (fig. 3.4.1-1) and is herein named the Renner trench. Although not as striking as the other diversion trenches in the area, its existence is manifested by a definite sag in the topography along its entire course.

3.4.3 Geologic History

Only a brief summary of the geologic history of the Beulah-Hazen area will be included here. The pre-Paleocene history can be subdivided into five major episodes of marine transgression and regression. During this time several thousand feet of sediment accumulated in the Williston basin, of which about 6 000 feet (1 800 m) is preserved in the study area.

All of the Paleocene age sediment was deposited in a continental environment except for the rocks of the Cannonball Formation, which originated under marine conditions. Lignite beds, which are now of so much interest throughout the Knife River basin, had their beginning as vegetation growing in swamps during this epoch, probably not too far removed from the retreating Cannonball Sea.

During the middle Tertiary period it is probable that additional sediment accumulated in the Beulah-Hazen area, but subsequent erosion has removed all traces of it. Only scattered remnants of the Golden Valley Formation remain, overlying the top of the Sentinel Butte Formation, which was also undergoing downwasting at the close of the Tertiary.

Continental glaciers moved across the Beulah-Hazen area during the Pleistocene epoch, modifying the landscape and leaving behind material which partially buried the Tertiary formations. In the 11 000 or more years since glacier ice left the area, erosion and deposition have again modified the landscape. Deposition of eroded material has occurred in lakes and other depressions, in stream valleys, and at the foot of steep slopes. Soil erosion has been greatly accelerated during the modern epoch in those areas used for agricultural purposes. Wind erosion was severe during the 1930s and is continuing at the present time on a smaller scale (fig. 3.4.3-1).

Since the construction of Garrison Dam, the shoreline of Lake Sakakawea has been greatly changed. Wind-blown waves have eroded projecting headlands producing cliffs. Longshore currents have been sufficiently vigorous to build spits and bars across re-entrant bays and otherwise to smooth the shoreline.

3.5 Economic Geology

3.5.1 Lignite

The Beulah-Hazen area is located in the heart of the lignite producing region of North Dakota. A map of active and proposed lignite mines and related consuming facilities in western North Dakota, compiled by Groenewold (1977), shows that the Indian Head Mine, operated by The North American Coal Corporation, is the only active mine within the boundaries of the study area at the present time. Production from this open-pit mine was listed as 1 065 021 short tons for the fiscal year ending June 30, 1976.

Figure 3.4.3-1. Sand drifts resulting from present-day wind erosion of cultivated land. Photograph was taken in the SE¼SE¼sec 35, T144N, R87W on August 27, 1976, when wind velocities reached 40 miles per hour with gusts up to 55 miles per hour. Sand drifts varied in depth from one inch to two feet (2.5 to 60 centimetres) on southeast-facing slopes.

Development of another large open-pit lignite mine is being proposed by The Coteau Properties Company (a subsidiary of The North American Coal Corporation) about 7 miles (11 km) north of Beulah. Projected annual production from this mine is 14.0 million tons by 1984. Construction of two power plants and a coal gasification plant are also proposed near the mine site.

Orphaned land, where lignite has been mined in the past, can be seen about 5 miles (8 km) northwest of Hazen and along Highway 200 between the towns of Beulah and Hazen (fig. 3.5.1-1). A rather extensive area peppered with subsidence craters can also be seen northeast of Beulah and in other locations where collapse is occurring in abandoned underground lignite mines (fig. 3.5.1-2). Numerous, small abandoned open-pit lignite mines are scattered throughout the study area wherever lignite beds outcrop along valley walls (pl. 4). Seven major lignite beds, all in the Sentinel Butte Formation outcrop in the Beulah-Hazen area (pl. 4).

Several cross sections were constructed in the Beulah-Hazen area (see pls. 6, 7, 8, 9, and 16). These sections graphically show the depth to coal, thickness of the beds, attitude of the beds, lateral variations, lithology of overburden materials, and much other information which should be useful to anyone interested in the lignite deposits of the area.

All of the current production of lignite in the Beulah-Hazen area is from the Beulah-Zap bed. It is conceivable that in the future, with application of modern technological concepts, more of the lignite resources can be exploited. Current figures on the reserves in the study area are not available at this time. New data from extensive test-hole drilling are available, but it is not within the scope

Figure 3.5.1-1. Spoil piles on orphaned land, NW¼NE¼sec 8, T144N, R87W.

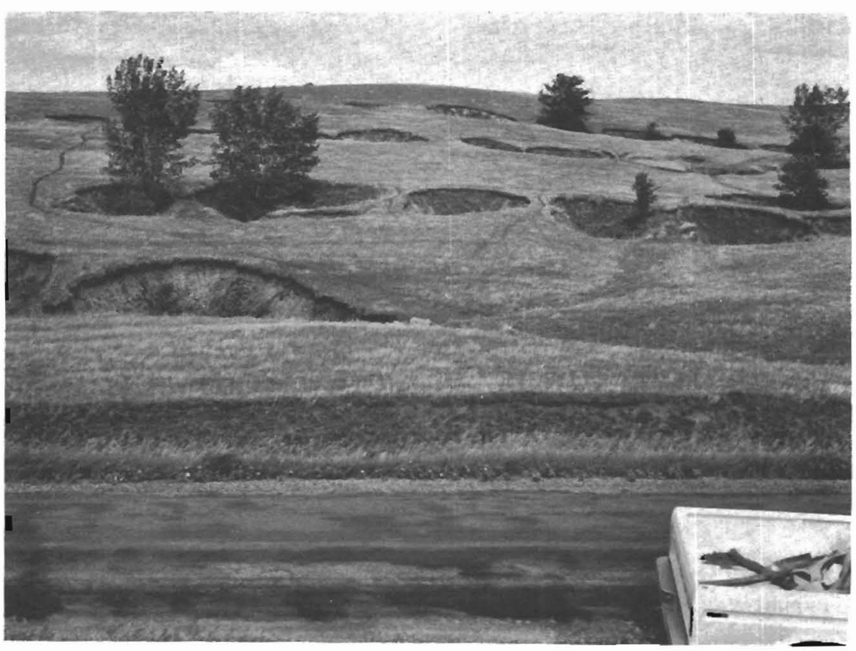


Figure 3.5.1-2. Subsidence craters overlying collapsed underground lignite mine north of Beulah in the SW¼sec 12, T144N, R88W.

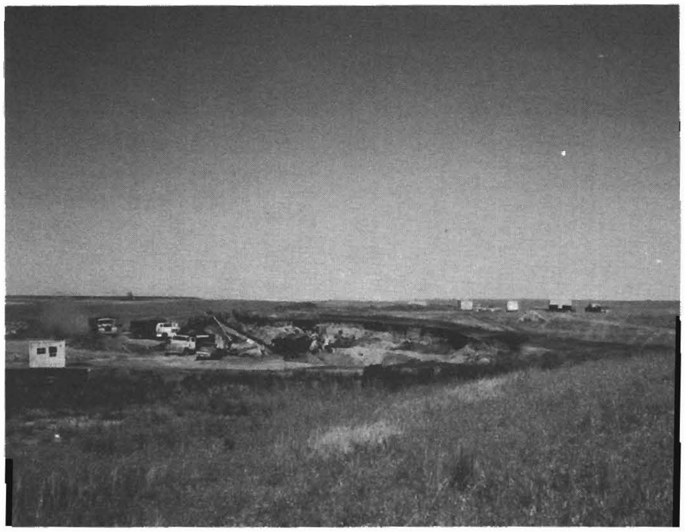


Figure 3.5.2.2-1. Quarrying gravel in glacial outwash deposits, NE¼sec 23, T145N, R89W.

of this study to make such calculations.

3.5.2 Other Resources

3.5.2.1 Scoria

Extensive areas of baked sand, silt, and clay (scoria) occur along valley walls where outcropping lignite beds have burned (see pls. 3 and 4). Most of these zones of natural brick occur where the Beulah-Zap bed has burned, such as along the Beulah trench and in the dissected highlands south and southwest of Zap. Several scoria pits are located in these burned areas (pl. 4). The scoria is crushed and used principally as road surfacing material, although it has also found some use as decorative stone.

3.5.2.2 Sand and gravel

Surficial gravel deposits are scattered throughout the mapped area (see pl. 3). Most of these materials were deposited by glacial meltwater. They occur in terraces, kames, eskers, outwash plains, and point bars. Large commercial gravel operations in the study area are located in the Zap branch of the Beulah trench in the SW¼sec 2, T144N, R88W, and also in the NE¼sec 23, T145N, R89W (fig. 3.5.2.2-1).

Sand occurs extensively in the study area, particularly along Spring Creek and the Knife River. Large deposits cover about 20 square miles (51 sq. km) southeast of Hazen (pl. 3) where wind has reworked flood plain and terrace sediments.

3.5.2.3 Riprap and building stone

Resistant beds of sandstone in the Sentinel Butte and Golden Valley Formations are a possible source of building stone and riprap. Glacial boulders are particularly abundant throughout the Beulah-Hazen area and can also be used for riprap.

3.5.2.4 Petroleum

Eight petroleum exploration tests have been drilled in the study area. None of these wells found commercial oil production.

4 HYDROGEOLOGY AND HYDROGEOCHEMISTRY

4.1 Study Methodology

4.1.1 Introduction

The purpose of this section is to describe the methods used to obtain hydrogeological and hydrogeochemical information. The procedures, materials, and equipment used are discussed in detail, thus enabling the reader to better appraise the data. Compilations of all previously existing chemical data in the project area, as well as chemical and inventory data generated by this project are included in appendix C. With the exception of those wells for which one ion was determined by difference, standard errors were calculated for all wells having complete major ion analyses.

From the standpoint of the hydrogeology and hydrogeochemistry of units overlying the Hell Creek Formation, the project was generally divided into three areas. These include the Knife River drainage basin, which includes the Dunn Center, Indian Head, and Beulah-Hazen detailed study sites, the Center area in Oliver County, and the Falkirk (Underwood) area in McLean County (fig. 1.2.2.1-1). The latter two areas are outside the Knife River basin but add significantly to a regional understanding of the hydrogeochemical systems operating in that part of the state. The Center and Falkirk areas also represent the two major areas of west-central North Dakota, outside the Knife River basin, which are experiencing accelerated lignite-related development. Due to its regional significance, the discussion of the Fox Hills-Hell Creek aquifer incorporates data from the entire southwestern portion of the state of North Dakota.

4.1.2 Previous Work and Existing Data

Existing hydrogeological and hydrochemical data were obtained from various sources. These included published county groundwater reports (Ackerman, 1977; Armstrong, 1975; Croft, 1970, 1974; Klausing, 1971, 1976; Randich, 1965, 1975; Trapp, 1971) as well as unpublished USGS inventory data made available in computer tabulations. Several detailed studies of various portions of the project area were also utilized (Moran et al., 1976, 1978; Woodward-Clyde, 1975). In addition, well logs made by the K. J. Thompson and Son well drilling company in the western part of the project area and well inventory data compiled by the Works Progress Administration were utilized.

4.1.3 Well Inventory

An inventory of farm wells in the Beulah-Hazen area was initiated in the summer of 1976. Specific information was obtained on nearly all wells in the area. This included, wherever possible, well location, depth, use, drilling date, drilling method, casing, diameter, length of intake interval, pump type, and pumping rate. The inventory was initiated in late June of 1976 and continued through August of 1976. The inventory data was incorporated with previous inventory data for the Beulah-Hazen area (Croft, 1970) and is included in appendix C-I.

4.1.4 Detailed Study Sites

Five study sites are discussed in detail in later sections of this chapter. These sites include the Dunn Center, Indian Head, and Beulah-Hazen areas in the Knife River basin and the Center and Falkirk (Underwood) areas outside the Knife River basin in Oliver and McLean Counties, respectively (fig. 1.2.2.1-1). All five detailed sites had been previously instrumented, to a greater or lesser extent, with groundwater observation wells. With the exception of the Beulah-Hazen area, considerable detailed physical hydrological data were available from these sites. Figures 4.5.1-1 and 4.6.1-1, and plate 29 show the locations of observation wells at the Center, Indian Head, and Falkirk sites. The intake zone for each installation is indicated. The Beulah-Hazen area was less well instrumented than the other sites. Thus, the discussion of that area (sec. 4.4) relies heavily upon data obtained through the well inventory and sampling and analysis of water from farm wells.

Water levels in observation wells at the detailed sites were monitored on a biweekly basis. Water levels were also monitored in selected North Dakota State Water Commission wells outside the detailed study areas. The water levels were monitored using electrical contact tapes. The precision of the water levels is generally ±0.25 feet (±0.075 m).

4.1.5 Identification of Intake Zones

In order to achieve the level of detail desired for the hydrogeological and geochemical portion of this project, it was necessary to determine the specific intake zone of as many wells as possible. An attempt was made to identify the intake zone of all wells in existing county inventories as well as those from the Beulah-Hazen inventory and from the published report by Woodward-Clyde (1975). Emphasis was placed on those wells already having a complete chemical analysis. Each well was evaluated relative to the stratigraphic framework as based upon the various cross sections (pls. 3 and 6-16) and additional associated stratigraphic data.

The intake zones, as defined in this project, include major aquifer systems such as the Fox Hills-Hell Creek, Ludlow-Cannonball-Slope, Golden Valley, and Coleharbor, as well as highly detailed subdivisions within the Bullion Creek and Sentinel Butte Formations.

It was not considered appropriate to subdivide the Fox Hills-Hell Creek and Coleharbor wells due to the lack of detailed stratigraphic information. The very small number of wells in the Ludlow-Cannonball-Slope and Golden Valley as well as a lack of detailed stratigraphic data precluded the subdivision of these units.

The Bullion Creek and Sentinel Butte Formations were subdivided on the basis of the various lignite beds (sec. 2.3) and associated intervals between the lignites. In cases where a given lignite was split by a nonlignite parting, a well screened in the parting was considered to be in the lignite bed. The name of the interval between two lignites corresponds to the name of the overlying lignite. Thus, for example, the interval between the Beulah-Zap bed and the underlying Spaer bed was designated the Beulah-Zap interval. This seems a logical approach as the materials underlying a given lignite generally grade upward into the lignite, whereas the upper contact of a given lignite is typically very sharp and occasionally unconformable with the overlying materials.

This system resulted in two intervals, one at the top of the Bullion Creek Formation and another at the top of the

Sentinel Butte Formation, not having an associated lignite. The interval at the top of the Bullion Creek Formation (between the Tavis Creek bed and the Sentinel Butte contact) is generally very thin and was not found to be an intake zone for any wells. The interval at the top of the Sentinel Butte Formation (between the Harnisch bed and the lower contact of the Golden Valley Formation) is not present in the eastern half of the project area. Wells are occasionally screened in this interval in the western part of the study area. For the purpose of this study, this interval has been combined with the underlying Harnisch bed which is typically very thin in the western portion of the project area.

Selected wells, for which the intake zone could be identified, and not already having chemical analyses, were sampled and analyzed. These analyses, combined with identifiable pre-existing chemical data are included in appendix C.

A series of maps were generated which display the distribution of wells in each aquifer and the availability of chemical analyses. Plate 23 shows the location of all the wells in southwestern North Dakota which are screened in the Fox Hills-Hell Creek aquifer. The map indicates which of these wells have complete chemical analyses. These data, together with several carbon-14 dates made available by the USGS, were the basis for the detailed discussion of the Fox Hills-Hell Creek aquifer included later in this chapter. All chemical data from the Fox Hills-Hell Creek are included in appendix C-II.

Plate 24 shows the location of all wells in the Knife River basin, which are screened in the Coleharbor Formation. These include observation wells and farm wells. The map indicates those wells which have complete chemical analyses. All chemical analyses from wells in the Coleharbor Formation are included in appendix C-III.

Plate 25 shows the location of all wells in the Knife River basin, exclusive of detailed study sites and excluding Fox Hills-Hell Creek and Coleharbor, for which the intake zone could be identified. The majority of wells sampled for this project were selected from those shown on plate 25. Figure 4.6.1-1 shows the location of observation wells at the Indian Head detailed site.

Plate 26 shows the location of all wells in the Knife River basin including the Dunn Center and Indian Head sites, and excluding Fox Hills-Hell Creek and Coleharbor, for which complete chemical analyses are available. All chemical data from these wells are included in appendix C-IV. Maps of sampled farm and observation wells utilized in the Center and Falkirk discussions are included in sections 4.5 and 4.3. All chemical analyses from these sites are also included in appendix C-IV.

4.1.6 Water Sampling

4.1.6.1 Piezometers

This section describes the procedures and materials used during this project for obtaining water samples from piezometers and water wells. As many as six different samples were collected from each well by blowing, bailing, or pumping water from the well. The blowing method was used only in the Falkirk Underwood area and was used in that area only during 1976, at which time it was abandoned as being unsatisfactory.

The dissolved oxygen, temperature, pH and electrial conductivity of the water were measured at the collection site. Two samples were collected for analysis of major ions (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, hardness, total alkalinity, SO_4^{-2}, Cl^{-}, NO_3^{-}, F^{-}, and total dissolved solids) one of which was placed in storage. Samples were also collected for trace metals (Fe, Mn, Cu, Cd, Se, As, and Pb), two isotopes (^{18}O, ^{3}H), and, from a few selected wells, dissolved organic carbon.

Before taking the sample from a piezometer, the piezometer was pumped until at least three times the volume of water standing in the piezometer was removed. Three methods of pumping were used: blowing the water out of the well with an air compressor (1976 Falkirk only), bailing, and pumping with a cylinder pump.

Pumping with an air compressor did not flush the very fine sediment from the piezometer, but rather caused the sediment to become suspended in the water. This suspended material made filtering very difficult and often resulted in as much as a day's delay in sample collection to allow time for the suspended sediment to settle. A bailer was then used to collect the sample. Blowing also caused a rise in pH by driving off CO_2. Because of these problems, this method is no longer being used.

The cylinder pump allowed for a much larger volume of water to be pumped (approximately 0.25-4 gal/min) and removed any sediment which may have entered through the well screen. However, a good deal of equipment was required for this operation as was a fair amount of set-up time (0.5-1 hr depending on the depth to which the pump was set).

A bailer was used to sample those piezometers which did not recharge fast enough to permit pumping with either the air compressor or the cylinder pump.

4.1.6.2 Farm wells

Water wells were sampled by simply having the owner of the well turn on the pump or open the tap. It was usually not practical to pump out three times the volume of water in the well before taking a sample because many of the wells had large storage reservoirs. About 1 gallon (3.785 L) of water was collected in a plastic bottle and taken to the truck where the field chemistry was recorded and the individual samples prepared.

4.1.6.3 Field chemistry

<u>4.1.6.3.1 Dissolved Oxygen</u>.--A Yellow Springs Instrument Company, Model 54 dissolved oxygen meter and YSI 5739 dissolved oxygen probe were used to measure the dissolved oxygen content of the water both before and after pumping. The dissolved oxygen meter was placed in the desired position before calibration since any change in the position of the meter would have necessitated readjustment of the meter. With the switch in the off position, the meter needle was set to zero with the adjustment screw. The control dial was switched to red line and the red line knob adjusted until the meter needle aligned with the red mark at the 31°C position. The control dial was then switched to zero and the zero knob was turned until the meter read zero. The probe was attached to the meter and allowed to stabilize about 15 minutes.

The dissolved oxygen probe was calibrated against air by inserting the probe into the calibration bottle along with a few drops of water. About ten minutes were needed for temperature stabilization. This was done simultaneously while the probe was stabilizing. The control switch was set to temperature and the temperature was read on the meter face. The altitude correction factor was determined from tables in the instruction manual. The correction factor was multiplied by the solubility of oxygen in water at the temperature indicated by the meter to get the corrected calibration value. The control dial was switched to the appropriate ppm range and the calibration knob was adjusted until the meter read the corrected calibration value. At least two minutes were given to verify the calibration stability.

Once the meter had been calibrated and stabilized, the probe was lowered into the piezometer until the probe was well into the water column. The probe was slowly raised and lowered 1-2 feet (30-60 cm) to provide a stirring action. With the selector set to the appropriate range, the dissolved oxygen in ppm was read from the meter after allowing sufficient time for the probe to stabilize to the water's temperature and dissolved oxygen content.

4.1.6.3.2 Temperature.--A plastic container was filled with a sample of water to measure temperature, pH, and electrical conductivity. The temperature of the water was taken and the pH and electrical conductivity meters were adjusted to the temperature of the sample. This temperature was recorded as the field temperature. The pH and electrical conductivity were read as soon as possible because they are temperature dependent and because as CO_2 escapes from solution, the pH rises.

4.1.6.3.3 pH.--The pH meter (Coleman Model 37A) was prepared by standardizing the meter to a 4.00 pH buffer solution. This solution was prepared by dissolving 10 Coleman 4.00 pH buffer tablets in 500 ml of distilled water. The function control was set to zero and the zero adjust knob was turned until the meter indicated zero. The readout dial was set to 4.00, the electrodes were placed in the buffer solution, and the temperature control was set to the temperature of the buffer solution. The function control was set to pH and the standardized control was adjusted until the meter read zero. The function control was then returned to zero. The electrodes were rinsed with distilled water and placed in a beaker of distilled water. This completed the standardizing procedure.

The pH electrodes were placed in the sample, the temperature control set to the temperature of the sample, and the function control set to pH. The readout control was rotated until the meter read zero. The function control was then switched to zero and the meter was readjusted to zero using the zero adjust control. The function was returned to pH and the meter was adjusted to zero using the readout control. The sample's pH was then read on the readout dial. The function control was then returned to zero and the electrodes were rinsed with distilled water.

4.1.6.3.4 Electrical Conductivity.--The electrical conductivity was measured by a Beckman Instruments RB3 Solubridge with a Beckman conductivity cell CEL-VS2. The meter's temperature control knob was set to the temperature of the sample. The conductivity cell was immersed in the sample to a depth at least 0.5 inch (1.27 cm) above the air vents and moved rapidly up and down in the water to remove any air bubbles trapped under the electrode shield. While the ON button was pressed, the upper dial was rotated until the needle pointed to zero on the meter. The electrical conductivity in micromhos/cm was then read directly from the scale which surrounds the upper dial.

4.1.6.4 Sample preparation

4.1.6.4.1 Major Ions/Trace Metals.--The samples for major ions and trace metals were filtered before being placed in plastic bottles. A pressurized filtration unit with nitrogen gas drive was used to filter the samples through MF-Millipore filters composed of mixed esters of cellulose (Ghering, 1976). The filtration unit was first rinsed with water then filled with the water to be filtered. Filters with pore size 8.0 microns were used to remove the major portion of the sediment. The sample was then filtered through 0.45 micron filters and placed in plastic containers--two 1-quart (950-ml) and one 1-pint (475-ml)--which had been rinsed with filtered water. In cases where the sample had considerable sediment, 3.0 micron filters were used in an intermediate filtering step.

The trace metals sample (1-pt. (475-ml) bottle) was filtered before adding a preservative (5 ml of concentrated HNO_3) to prevent the release of trace metals which would have resulted from reaction of the acid with the suspended sediment. No preservative was needed for the major ion samples.

4.1.6.4.2 Isotopes.--Water for the ^{18}O sample was collected directly from the well in a 3.38-ounce (100-ml) glass serum vial capped with a rubber stopper. The vial was filled to the top to exclude air. The ^{3}H sample was also taken directly from the well and placed in either 8-ounce (236-ml) glass bottles or 4-ounce (118-ml) plastic bottles. The tritium sample was also filled to the top to exclude air.

4.1.6.4.3 Dissolved Organic Carbon.--Samples collected for analysis of dissolved organic carbon were first filtered through 0.45 micron silver filters then placed in 4-ounce (118-ml) fired glass (4 hrs at 175°C) bottles and capped with rubber stoppers. The rubber stoppers were wrapped in aluminum foil to avoid contact between the stoppers and the sample.

The samples were labeled (sample identifier, well depth, date, pH, temperature, electrical conductivity, type of preservative if used, and whether or not the sample was filtered), placed in styrofoam coolers packed with ice, and shipped via bus to the laboratory.

4.1.7 Hydraulic Conductivity Testing

Hydraulic conductivity tests were run in the Falkirk area. Existing hydraulic conductivity data was available for the Dunn Center and Beulah-Hazen areas (Moran et al., 1976; Woodward-Clyde, 1975). The hydraulic conductivity of a saturated porous medium in the immediate vicinity of a piezometer screen can be determined from single-well response tests. A single-well response test is carried out by changing the equilibrium hydraulic head in a piezometer and then monitoring the rate at which the head returns to its original equilibrium position. The hydraulic head can be changed by pouring water into the piezometer, monitoring the subsequent decline in head (falling head test) or removing water from the piezometer with a pump or bailer, in which case the head rises back to its original equilibrium level (rising head test). The change in head can also be effected using slugs of known volume that, when dropped into the water in a piezometer, will raise the water level a known amount (falling head test). Once the head has reattained its equilibrium level the slug can be quickly removed resulting in a decrease in hydraulic head (rising head test).

When the hydraulic conductivity of the porous medium is high the rate of recovery is high. The slugs yield better data in this case since the initial change in head is more nearly instantaneous, the magnitude of the change is known, and the measurement of the response of a rising head test can begin sooner since there is no need to remove the bailer from the piezometer. In materials with low hydraulic conductivities the very long time periods required to reestablish equilibrium water levels allow one to bail the piezometer (rising head test) without any loss of accuracy in the determination of recovery rates.

The data presented in this report (sec. 4.6) were collected using slugs designed to raise the water level in a 2-inch (5-cm) PVC pipe 3.3 feet (1.0 m) and 1.7 feet (0.5 m). For those piezometers that were installed in low hydraulic conductivity materials, the head was changed by bailing water from the piezometer. If there was less than 30 inches (0.75 m) of water in the piezometer a single-well response test was not conducted. Several piezometers could not be tested because the slugs could not be lowered down the pipe due to constrictions or bends in the pipes. The procedure for the single-well response tests included the following steps:

1. The equilibrium hydraulic head and the total depth of water in the piezometer were measured with an Ott Type Series IL 100 electric water level tape.

2. The bottom of the slug was then lowered to within several centimetres of the water and the electric tape lowered to the top of the slug.

3. The slug was then lowered quickly into the water and the time the slug contacted the water was noted.

4. As the head fell the depth to water was measured as frequently as possible and the depth and time of measurement were recorded until the water level had recovered to at least 70% of its equilibrium level.

5. After equilibrium had been reestablished and the electric tape removed the slug was pulled out of the piezometer, by hand, as fast as possible and the electric tape was lowered to measure the rate at which the water level rose.

When the single-well response test was conducted with a bailer the following procedure was used:

1. Approximately five bailers' full of water were removed from the piezometer, lowering the water level 9-13 feet (3-4 m) below the equilibrium water level.

2. The recovery was then monitored for periods of several hours to several days.

The data collected were analyzed using techniques developed by Hvorslev (1951).

4.2 Hydrogeology and Hydrochemistry of the Dunn Center Area

The Dunn Center area, as shown in figure 4.2-1 was studied by Moran et al. (1976) who conducted field studies of the geology, hydrogeology, and hydrochemistry during 1975 and 1976. These studies were conducted to provide a basis for environmental impact assessment for a proposed strip mine and coal gasification plant to be operated by the Natural Gas Pipeline Company of America. In 1972, 1973, and 1974, the North Dakota State Water Commission, in cooperation with the Water Resources Division of the U.S. Geological Survey, conducted a routine regional groundwater resources study of

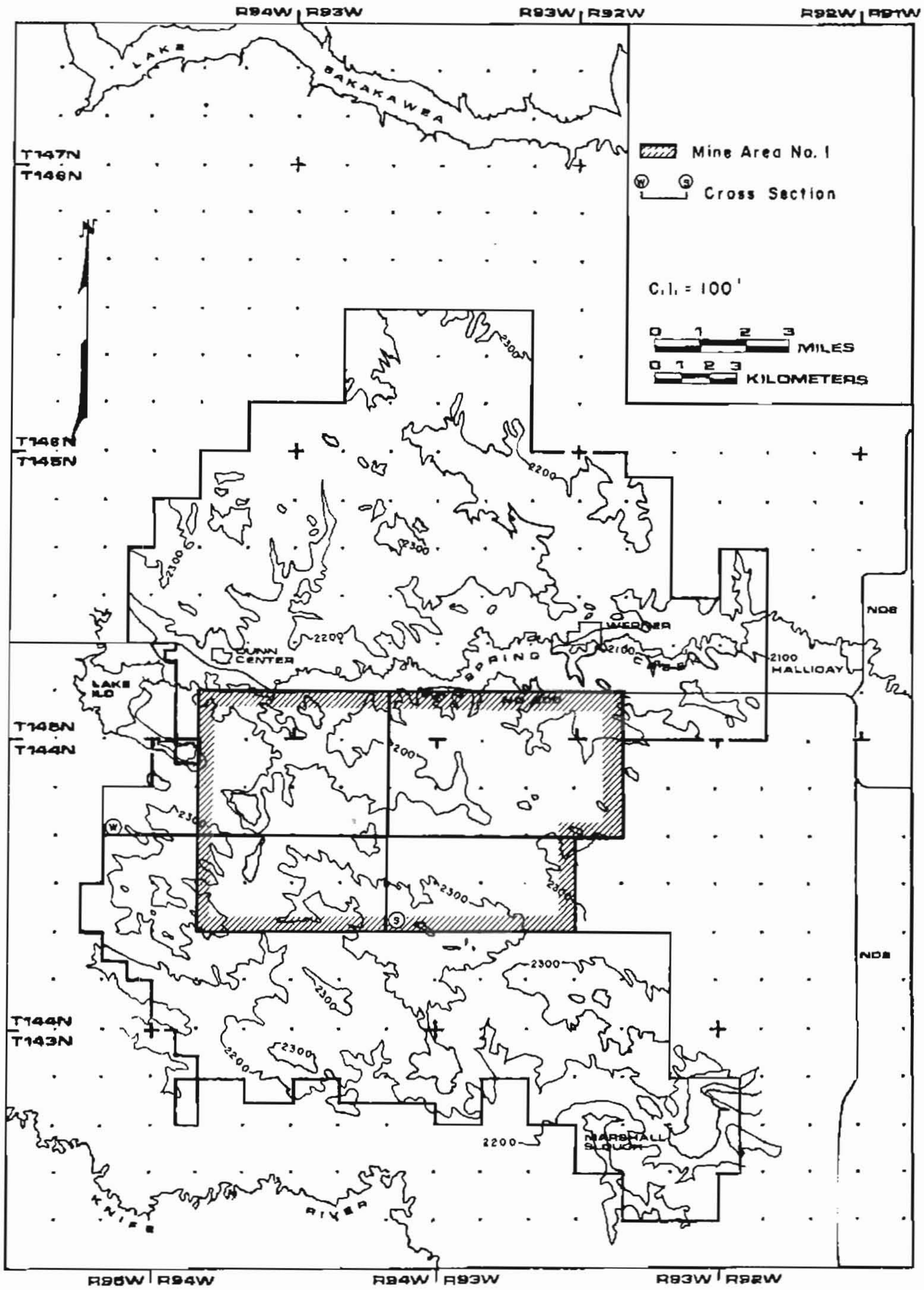


Figure 4.2-1. Location of the Dunn Center study area (from Moran et al., 1976).

Dunn County. The data from this study were published in a data compilation report by Klausing (1976). These data were made available to Moran et al. prior to publication for use in the study of the Dunn Center area. No significant hydrogeological or hydrochemical studies were conducted in Dunn County prior to the work by Moran et al. (1976) and Klausing (1976).

In late 1975 a study of a small portion of the Dunn Center area, in which federal coal reserves occur, was initiated by the Bureau of Land Management in cooperation with the Bureau of Reclamation and the U.S. Geological Survey. This study encompassed an area of approximately four square miles (10 sq km) located southeast of the town of Dunn Center. This study continued into 1976 and was reported on in 1977 as EMRIA REPORT NO. 9, "Resource and Potential Reclamation Evaluation, Horse Nose Butte Study Area--Dunn Center Lignite Field."

As part of the REAP study approximately 30 wells were sampled in the Dunn Center area, including farm wells and existing observation wells installed by Moran et al. (1976). Routine water-level data were obtained from the observation well network. No new investigations were otherwise conducted in the Dunn Center area.

The following discussion of the hydrogeology and the hydrochemistry of the Dunn Center area is based almost exclusively on the results reported by Moran et al. (1976). The Horse Nose Butte study contributed little new hydrogeologic information and although we have taken the report into consideration, the conclusions arrived at by Moran et al. are found to require little or no revision at this time.

4.2.1 Hydrostratigraphy and Hydraulic Properties

The Dunn Center area, like most other areas in southwestern North Dakota, has geologic materials that are typically aquifers and geologic materials that are aquitards. The aquifers consist of the lignite beds, which generally decrease in permeability with depth, channel sand deposits in the Sentinel Butte Formation and deeper formations, and sand and gravel zones in the Coleharbor Formation in locations where river valleys existed during Quaternary time. The aquitards in the bedrock are formed of silt, clay, and very silty or clayey sand strata. In the Coleharbor Formation the aquitards are formed primarily of silty clayey till.

The distribution of lignite and bedrock sand are shown in figure 4.2.1-1 from Moran et al. (1976). Since the water table in the Dunn Center area is generally in the range of 30-60 feet (10-20 m) below ground surface, sand and lignite at shallow depth is commonly not an aquifer because of occurrence above the water table. At shallow depth below the water table lignite is generally moderately permeable and offers a good probability of yielding sufficient water for farm water supply. At depth of more than 100-200 feet (30-60 m) below ground surface the probability of obtaining yields suitable for farm supplies is lower. The Dunn Center (Beulah-Zap) bed is the main aquifer in the area because it is a relatively thick lignite and in much of the area occurs under less than 200 feet (60 m) of overburden.

The zones of bedrock sand (fig. 4.2.1-1) are much less stratigraphically continuous than the lignite aquifers. Permeability of the bedrock sand is de-

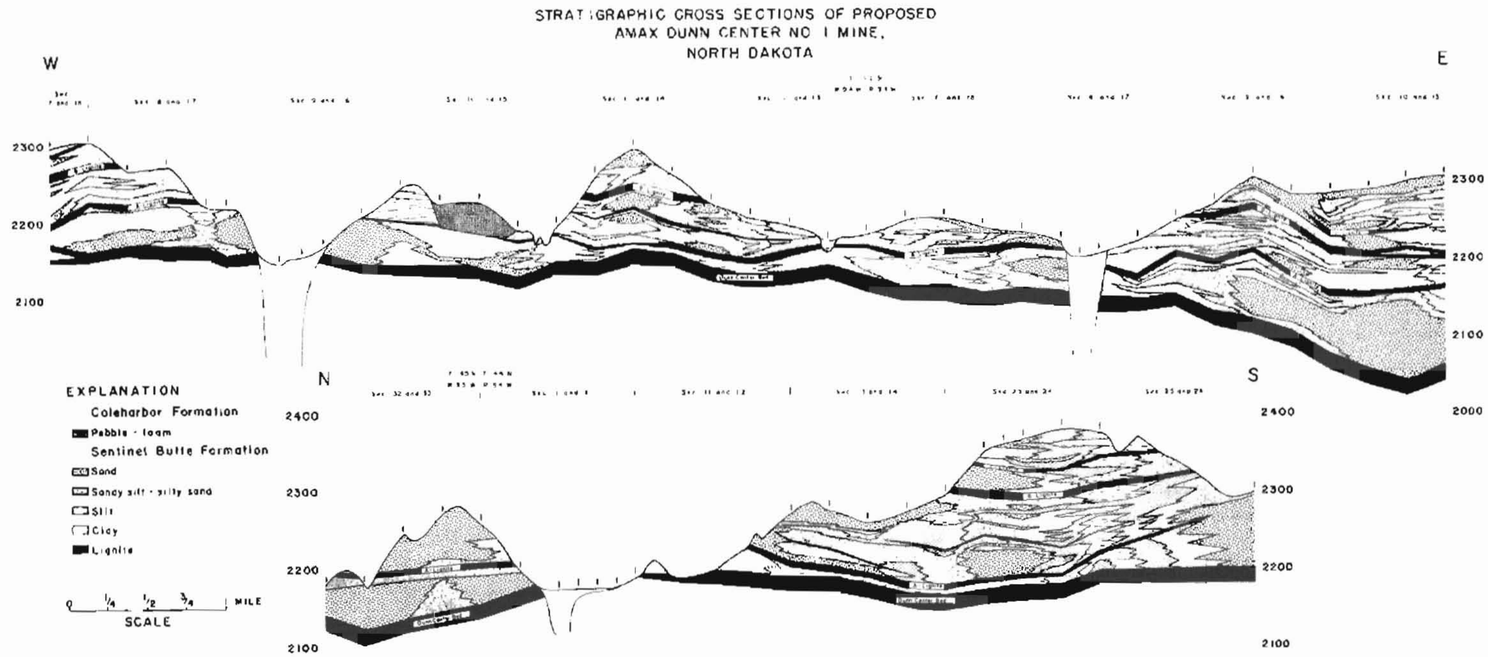


Figure 4.2.1-1. North-south and east-west cross sections of the Dunn Center area (from Moran et al., 1976).

TABLE 4.2.1-1. Comparison of values of hydraulic conductivity of lignite (from Moran et al., 1976)

Well	Single-Well Response Test	Pump Test	K (Pump Test)[a] / K̄ (Single-Well Response)	Packer Test
NDSWC 4794-e	2.16×10^{-3}	2.65×10^{-2}	12.27	
NDSWC 4794-f	9.90×10^{-4}	2.64×10^{-2}	26.67	
NDSWC 4794-g	7.21×10^{-4}	2.54×10^{-2}	35.23	
NDSWC 4794 (e,f,g)	1.32×10^{-3} [b]	2.61×10^{-2}	19.77	
NDSWC 4794 (a,b,d)	1.45×10^{-2} [b]	6.08×10^{-1}	41.19	
UND 75-2-4	7.2×10^{-4} [b]	2.52×10^{-4}	0.35	
UND 75-17-2-3	1.29×10^{-3}			3.14×10^{-3}

[a]Ratio of hydraulic conductivity determined by pump test to the hydraulic conductivity determined by pumping test.

[b]Value estimated from regression analysis of relationship between hydraulic conductivity and depth.

pendent on the content of clay and silt, which is quite variable.

The hydraulic conductivity of lignite aquifers was evaluated using pumping tests, single-well response tests, and packer tests. The hydraulic conductivity of sand aquifers was evaluated using pump tests, single-well response tests, permeameter tests, and packer tests. The hydraulic conductivity of confining beds was evaluated using single-well response tests, permeameter tests, and packer tests. This section is a discussion of the hydraulic conductivity of each of these major groups of materials as determined by each of the above methods. It focuses both on differences in the values determined by each technique and on variations in the hydraulic conductivity of the materials.

The hydraulic conductivity of lignite aquifers was determined by 78 single-well response tests and 3 pump tests. The single-well response-test values ranged from 1.8×10^{-2} to 1.4×10^{-6} cm/s; the pump-test values ranged from 6.2×10^{-1} to 2.5×10^{-4} cm/s; and a single packer-test value was 3.14×10^{-3} cm/s.

Table 4.2.1-1 shows the comparison of values of hydraulic conductivity for lignite determined by single-well response test and pump testing. Some of the values were determined on the same well by both methods. Others are estimated using the relationship between hydraulic conductivity and depth that is discussed below. From these data, it is evident that in five or six cases the pump-test value is from 1-1.5 orders of magnitude greater than the single-well response-test value. Since long-term pumping tests are generally considered to give accurate values of hydraulic conductivity, and because the values of hydraulic conductivity determined by single-well response tests are probably minimal for reasons discussed by

Moran, et al., 1976, the values of hydraulic conductivity used in calculations have been corrected to corresponding pump-test values by multiplying by 1.2×10^1.

On the basis of data both from the pump testing and single-well response testing, there appears to be an inverse relationship between depth and hydraulic conductivity. Although only three pump-test values are available, they strongly suggest that the log of the hydraulic conductivity of lignite decreases by 2.47 per 100 feet (30 m) of depth. This is a decrease in hydraulic conductivity of nearly 2.5 orders of magnitude every 100 feet (30 m). The coefficient of determination, r^2, which expresses the degree to which a set of observations fits the calculated regression line, has a value of 0.996. This coefficient varies from 0 for no fit to 1.0 for a perfect fit. Although the slope of the regression line that describes the relation is steeper and the fit of the 78 data points not nearly so tight (r^2=0.263), the data for the single-well recovery tests also strongly suggest a depth control on hydraulic conductivity. The log of the hydraulic conductivity decreases by 0.37 per 100 feet (30 m). This is a decrease of one order of magnitude every 300 feet (90 m) of depth.

These conclusions are consistent with the fact that permeability in lignite is entirely fracture permeability. These relationships result from an increase in the number and size of joints and bedding partings in the lignite as the thickness of cover over the lignite decreases. Further analyses are needed to determine whether the permeability is controlled by depth of burial, thickness of cover removed by erosion, thickness of glacial cover, or some other factor that has affected the loading history of the region during the geologic past.

The hydraulic conductivity of sand beds in the Sentinel Butte and Bullion Creek Formations was estimated with 24 single-well response tests, 1 pump test, and 3 permeameter tests. The hydraulic conductivity of sand beds ranges from about 2×10^{-2} to 5×10^{-6} cm/s with most values falling in the range from about 2×10^{-3} to 2×10^{-5} cm/s. There seems to be a decrease in hydraulic conductivity with depth, although this trend is weaker than for the lignite aquifers. The one pump-test value from the E-interval is above the mean of the single-well response-test values for sand in the same interval. The permeameter-test values are all low.

The hydraulic conductivity of silt and clay beds in the Sentinel Butte and Bullion Creek Formations was assessed by four single-well response tests and ten permeameter tests. The values ranged from 10^{-6} to 10^{-8} cm/s, with most values lying between 5×10^{-7} and 10^{-8} cm/s. Two of the single-well response-tests values are in the range 5×10^{-7} to 10^{-6} cm/s. At least one of these wells, UND 75-55-1, has not yet reached static level, so the drawdown figures used to calculate the hydraulic conductivity are too small. As a result, the actual hydraulic conductivity is smaller than the presently calculated value.

Porosity is defined as the ratio of the volume of the voids to the total sample volume. There are in general two types of effective porosities that can occur in geologic materials: (1) intergranular porosity, and (2) fracture porosity. Intergranular porosity is a measure of the volume of the voids that occur between the grains that comprise sediments such as gravel, sand, silt, or clay. Fracture porosity is a measure of the voids that occur because of fractures, joints, bedding planes, or solution channels. The term "effective" porosity refers to the porosity that involves voids that are effective in transmitting fluids. In other words, it includes only the voids that are interconnected as part of the permeability network. Effective intergranular porosities for gravel, sand, silt, or clay sediments that are nonindurated are normally in the range of 0.2-0.4. Effective fracture porosities of fractured or jointed rock are normally in the range of 10^{-2}-10^{-5}.

Data on the effective porosities of deposits in the Dunn Center area were obtained from laboratory tests on relatively undisturbed core samples and from pumping tests in the field. The laboratory data for samples of sand, silt, and clay are reported by Moran et al. (1976, app. C-X). Except for one sample with a porosity of 0.24, the values are within the narrow range of 0.30-0.43 and are probably representative of the non-lignite beds in the Sentinel Butte Formation.

In terms of hydraulic properties, the porosity of interest for the lignite beds is the fracture porosity, since it is this porosity that relates to the effective storage of drainable groundwater from these beds. The porosity of the lignite beds in the Dunn Center area is assumed to be about the same as the storage coefficient, from 10^{-2}-5 X 10^{-5}.

The sediments of the Coleharbor Formation constitute important aquifers and aquitards in the project area. The areas of thin deposits of pebble loam that cap uplands are generally aquitards. The low hydraulic conductivity of the sediment prevents rapid movement of water. In addition, these areas are generally high enough in the landscape that they are in the unsaturated zone and contain no water even where hydraulic conductivity is higher.

The sediments filling the valleys constitute both aquitards and aquifers. Sand and gravel, which generally constitute less than half the thickness of the valley fill, are aquifers. Silt, clay, and pebble loam are aquitards.

In most of the area, the distribution of thick deposits of Coleharbor Formation is clearly limited by conspicuous surface valleys. However, in an area immediately southeast of Dunn Center, in secs 3 and 4, T144N, R94W, sec 31, T145N, R93W, and sec 36, T145N, R94W, the location of the deep valley poses a problem. We traced a narrow, deep valley from the southeast, through secs 12, 1, and 2, T144N, R94W but lost it in section 3. The deep valley continues north or west by three possible routes. One meanders north out of section 3 into section 31; the second trends more or less straight northwest from section 3 into section 36 and then on toward Dunn Center; the third trends southwestward from section 3 into section 4. The first route is a narrow meandering valley with dissected margins that is currently occupied by the ephemeral stream that drains the large flat area in secs 1, 2, 11, and 12, T144N, R94W. The second and third possible routes are low sags in the topography that are floored by sand. No drainage presently occupies these sags. The test drilling that would have indicated the location of the extension of the valley was precluded by problems of access to the appropriate locations. For several reasons we believe that the valley extends northward from section 3 into section 31 through the narrow dissected valley. The meander geometry of the valley is consistent with the pattern of this outlet and its extension across the valley of Spring Creek. On the other hand, the northwestern route is very straight; the southwestward route through section 4 is not ruled out on this basis. The steep gradient of the potentiometric surface in the Coleharbor Formation through the possible southwestern route suggests that only fine-grained material is present in the sag, which is inconsistent with the nature of the valley fill. The northern route is also favored by the buried valley that enters the Spring Creek valley immediately east of Dunn Center, which can best be continued as the northward extension of the same valley.

The fill within the buried valleys is complex. The basal unit in the valley fill is sand and gravel. A layer of clayey pebble loam overlies this, and in some places, is overlain by lacustrine clay. One or more layers or lenses of sand and gravel occur within the pebble loam. In many places, the pebble loam extends to the land surface; in others, the pebble loam is overlain by another unit of sand or sand and gravel. This upper unit of permeable material is generally discontinuous. In some places, it is overlain by silt and clay that probably consists of lake sediment and sediment of alluvial fans washed into the valley from adjacent slopes.

The hydraulic conductivity of the sand and gravel unit at the base of the valley fill was determined at nine wells using the single-well response-test method. The values ranged from 2.30×10^{-4} cm/s to 2.95×10^{-2} cm/s with a mean value of 6.59×10^{-3} cm/s. These values are considered representative only of the finer grained portions of the permeable valley fill and are believed to be too low for much of the material for three reasons:

(1) In several wells, water level recovery was so rapid that either no drawdown was possible during pumping, or recovery was complete before measurement was possible (approximately 15-30 seconds following cessation of pumping). In either case, the hydraulic conductivity at these wells is much greater than any values measured.

(2) The upper limit of hydraulic conductivity that can be measured using the well installation procedure that was employed for this project is about 5.5×10^{-2} cm/s because of the size of the sand pack used. The procedure was designed for the lignite and fine-sand aquifers of the Sentinel Butte Formation rather than for the more permeable valley-fill sediments.

(3) Long-term pumping tests in valley-fill deposits in Mercer County, east of the project area, indicate hydraulic conductivity values of 3.0×10^{-1} cm/s (Croft, 1973, p. 57 and 61). There is no reason to believe that these values are not representative of the more permeable portions of the valley-fill deposits in the project area.

Hydraulic conductivity of the upper permeable unit of the valley fill was determined at eight sites using the single-well response-test method. The values ranged from 2.37×10^{-3} cm/s to 2.67×10^{-2} cm/ s with a mean value of 6.54×10^{-3} cm/s. For the reasons outlined in the previous paragraph, these values are believed to represent minimum values for the unit.

Hydraulic conductivity of confining beds in the valley fill was determined at six sites, two sites in pebble loam and four sites in silt, using the single-well response-test method. The values ranged from 7.49×10^{-5} cm/s to 7.60×10^{-5} cm/s for the pebble loam and from 2.28×10^{-4} cm/s to 5.03×10^{-4} cm/s for the silt.

4.2.2 Hydrologic Information from Isotope Data

Moran et al. (1976) reported analyses of farm well and observation well samples for the environmental isotopes, tritium (^{3}H), oxygen-18 (^{18}O), carbon-14 (^{14}C) and carbon-13 (^{13}C). The following is a synopsis of the hydrologic information that Moran et al. derived from these data.

Forty-nine farm wells and nine observation wells were analyzed for ^{3}H. Emphasis was placed on the farm wells to avoid the possible influence by contamination of drill water. The tritium analyses were conducted in the Environmental Isotope Laboratory of the Department of Earth Sciences, University of Waterloo. Direct scintillation counting of unenriched samples was used. The lower limit of detection by method is approximately 10 TU (a TU represents tritium unit which is one ^{3}H atom in 10^{18} ^{1}H atoms).

Of the 49 sample analyses, 9 had concentrations greater than 30 and less than 250 TU, 5 had concentrations between 10 and 30 TU and the rest had no detectable tritium. It can be concluded that samples with detectable tritium are modern water or are a mixture of modern or older water. In this context the term "modern" refers to water that entered the groundwater zone since 1953 because it was in 1953 that rain and snow in the Northern Hemisphere acquired a significant tritium concentration as a result of testing thermonuclear weapons in the atmosphere. Pre-1953 water contains ^{3}H, but at levels that are below the detection limit mentioned above. During the past 5-7 years, ^{3}H concentrations in precipitation in the Plains Region have been in the range of approximately 50-200 TU with a slight general decrease during this period. In the 1960s, values of many hundreds to several thousand TU were common. In the 1950s (after 1953) values on the order of hundreds of TU were typical. This water would now be much lower in tritium content as a result of more than two half-lives of radioactive decay.

The results of the ^{18}O analyses of samples from observation wells and selected inventory wells are given by Moran et al. (1976, app. C-XI). The ^{18}O values are in the range of -18.9 to -9.2 per mille. Of the total of 210 groundwater samples analyzed, 184 are lighter than -14 per mille (i.e., more negative), with the remaining 26 heavier samples having values between -9.2 and -13.9. On the basis of where they occur in the groundwater-flow system, it is highly likely that the samples in the -9.2 to -13.9 range, which will be referred to as the heavy group, represent groundwater that was recharged from surface-water sources that underwent significant evaporation or mixtures of groundwater and evaporitic surface water.

When water evaporates from surface water bodies isotopic fractionation occurs, causing the water to become enriched in ^{18}O (i.e., heavier, less negative). In the hydrologic setting of the Dunn Center area, ^{18}O values heavier than about -12 per mille have undoubtedly undergone relatively strong evaporation, whereas values between about -13 and -14 represent weaker evaporitic effects or mixing of evaporitic and non-evaporitic water. The evaporitic water obtained from UND wells may be water from lakes, sloughs, ditches, or streams that has entered the groundwater regime through natural seepage, or it may have entered the system as circulation or wash water during drilling or well installation activities. One of the purposes of the isotopic studies is to identify wells that require additional cleaning before they can be used to provide samples for base-line water quality monitoring points. The evaporitic water from the farm wells indicates surface water seepage, except in the rare case where faulty well construction could cause seepage of surface water down along the well casing into the well intake zone.

Appraisal of the ^{18}O data and consideration of the well depths and the hydrogeologic setting of the wells leads to the conclusion that several wells were contaminated with surface water used during the drilling and well installation operations. These wells had ^{18}O values between -11.6 and -9.3. A few wells were moderately or weakly contaminated. These wells have ^{18}O values between -13.9 and -13.4 per mille. The conclusion that these wells are contaminated with drilling or wash water is based on the fact that almost all drill and wash water was obtained from sloughs, streams, or lakes that had been exposed to evaporation processes during several weeks or months prior to drilling use. An example of the effect of continued well cleaning on a well contaminated with drill or wash water was provided by one well which was sampled after an initial cleaning stage and yielded an ^{18}O value of -10.1 per mille and then was sampled after additional cleaning and yielded a value of -16.3, which is in the range of normal groundwater in the area. It was concluded that there are very few wells in the study area that have not been cleaned sufficiently to adequately remove all, or nearly all, of the drill and wash water.

Four samples that had ^{18}O values heavier than -12.6 were not attributed to contamination. These samples were from very shallow wells that were cleaned thoroughly before sampling. Because the wells were shallow and because they are located very near permanent or ephemeral surface water in bodies in areas with downward components of hydraulic gradient, it is reasonable to conclude that the natural seepage from the evaporitic surface water regimes into the groundwater-flow system is the cause of the heavy ^{18}O concentrations. The following samples, which are significantly, but not strongly, heavier than the normal groundwater, are also near surface-water sources and therefore probably result from natural surface-water seepage: well 32-4, -13.5, beside Spring Creek; 49-3, -13.3, near a surface stream; and 46-1, -13.4, near Lake Ilo. The conclusion that seepage from Lake Ilo is a significant contributor to the groundwater zone near the lake is supported by ^{18}O data from farm wells.

Moran et al. (1976) conducted ^{14}C and ^{13}C analyses of 14 groundwater samples from the Dunn Center area; two of the samples were obtained from the Fox Hills Formation and are discussed in section 4.8.1, three were from the Coleharbor Formation, and the remainder were from the Sentinel Butte Formation. The ^{14}C content of the Coleharbor samples ranged from 13-24 percent modern. One of the samples from the Sentinel Butte Formation was from a well 20 feet (6 m) deep that contained very young water as indicated by a tritium content of 192 TU. This sample had a ^{14}C content of 119 percent modern, which is a normal ^{14}C value for young water. The modern ^{14}C standard is carbon that has a ^{14}C content representative of conditions prior to atmospheric thermonuclear weapons testing. The other eight samples from the Sentinel Butte Formation were from wells at depths between 38 and 300 feet (11 and 90 m) deep. The ^{14}C content of two of these samples obtained from depths of 90 and 100 feet (27 and 30 m), were 45 percent modern; the rest of the samples were in the range of 6-13 percent modern.

The half-life of ^{14}C is 5 730 years. If the ^{14}C content of carbon in groundwater declines only as a result of radioactive decay, it is evident that four half-lives (22 800 yrs) would be required to achieve a ^{14}C content of 6.25 percent modern and three half-lives (17 100 yrs) would cause decline of the ^{14}C content to 12.5 percent modern.

As described in section 4.8.1, however, geochemical effects can cause the apparent age (decay age) of a sample based on ^{14}C content to be older than the actual age. A preliminary interpretation of the ^{14}C data from the Dunn Center area is described by Moran et al. (1976), who indicated that interpretation of ^{14}C data from lignite-rich deposits is at present quite problematic. Even with the various uncertainties in mind, however, the ^{14}C content of seven of the eight samples from the Sentinel Butte Formation (depths from 38 to 300 feet (11 to 90 m)) provides a basis for concluding that much of the water in the Sentinel Butte Formation, even at depths that are not large, is many thousands of years old. To our knowledge the ^{14}C data for groundwater in the Sentinel Butte Formation in the Dunn Center area are still the only ^{14}C data available for this information. Before more specific information on groundwater age in the Sentinel Butte Formation can be derived from ^{14}C studies, more detailed investigations will be necessary.

4.2.3 Major Ion Chemistry of the Groundwater

The chemical analyses of water samples in the Dunn Center area are grouped by water type and stratigraphic unit in table 4.2.3-1. The stratigraphic designations are those used by Moran et al. (1976) within the Dunn Center area. Present terminology is indicated in parentheses. When the mean values of the ratios, EPM $(Na^{+}K)$/EPM total cation vs. EPM (HCO_3)/EPM total anion are plotted for each water type in table 4.2.3-1, 11 groups of analyses are evident (fig. 4.2.3-1). The values of these ratios are referred to as the relative Na and relative HCO_3 content of the water in the following discussions.

Five groups, I-V, consisting of 76 analyses from the Coleharbor Formation, A-interval and lignite, Dunn Center bed and Dunn Center interval, E-interval and lignite, F-interval, G-interval, H-lignite, I-interval, and J-lignite form a set with a mean relative Na-HCO_3 composition of 0.39-0.44. This set ranges from $(NaCa)HCO_3$ type water of group I, through $Na(SO_4HCO_3)$ type water of group IV, to $CaSO_4$ type water of group V. The unifying characteristics of this set are low salinity and low pH. The mean conductivity is 1 294 mhos/cm and the mean pH is 7.4. In general, the pH increases with increasing bicarbonate content and to a lesser extent with increasing sodium content. The conductivity tends to increase with increasing sodium content.

Group I consists of three analyses of $(CaNa)HCO_3$ type water with a mean relative Na-HCO_3 content of 0.50-0.82. One sample from the B-lignite has a specific conductance of 4 531 μmhos/cm and a pH of 6.8. The other two samples, from the Dunn Center interval and Dunn Center bed, have a mean conductivity of 456 μmhos/cm and pH of 7.6.

The analyses in group I are scattered

TABLE 4.2.3-1.--Summary of chemical analyses of groundwater in the Dunn Center area

Stratigraphic Unit	Water Type	Analysis Group	Number of Samples	Statistic	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Specific Conductance µmhos/cm	TDS mg/L	pH
Coleharbor	$NaHCO_3SO_4$	IX	39	$\bar{x}$	62	25	469	7.9	748	0.8	4.7	577	2116	1292	8.0
				s	36	15	228	4.1	187	0.0	3.8	389	830	546	0.2
	$NaCaHCO_3SO_4$	III	7	$\bar{x}$	141	41	239	7.4	420	0.0	2.5	454	1436	681	7.8
				s	58	16	68	2.7	150	0.0	2.4	179	307	--	0.3
	$CaNaSO_4$	VI	5	$\bar{x}$	296	111	320	15	544	0.2	5.0	1464	2529	1280	7.7
				s	143	43	166	6.4	126	0.0	5.6	649	785	--	0.4
	$CaMgHCO_3SO_4$	II	5	$\bar{x}$	115	49	47	6.3	430	0.0	4.3	260	985	790	7.9
				s	54	30	27	2.7	179	0.0	3.9	43	502	396	0.2
	$CaHCO_3$	V	2	$\bar{x}$	72	18	11	2.8	282	0.0	6.2	192	519	--	7.8
	$NaSO_4$	VII	2	$\bar{x}$	267	276	1530	40	974	0.0	19	4691	8407	--	7.7
B-lignite (Twin Buttes bed)	$NaSO_4$	VII	2	$\bar{x}$	149	141	952	34	771	0.0	0.0	2895	5288	--	7.6
	$NaSO_4HCO_3$	VIII	1		42	28	842	14	987	0.0	10	1000	3474	--	8.0
	$NaCaHCO_3$	I	1		43	16	63	1.5	415	0.0	22	38	4531	--	6.8
A-interval (Twin Buttes interval)	$MgCaNaHCO_3SO_4$	II	7	$\bar{x}$	42	22	31	14	179	0.0	4.1	96	676	--	7.3
				s	20	16	23	20	123	0.0	3.4	84	503	--	0.4
	$NaMgSO_4$	VII	2	$\bar{x}$	318	373	846	18	313	0.0	59	3445	5577	--	7.0
	$NaSO_4HCO_3$	VIII	1		43	3.9	852	16	1054	0.0	2.0	992	3563	--	8.2
A-lignite (Schoolhouse bed)	$CaNaSO_4HCO_3$	V	6	$\bar{x}$	127	40	104	6.8	221	0.0	10	494	1008	--	7.5
				s	56	23	18	1.2	38	0.0	11	162	198	--	0.3
	$NaSO_4$	VII	5	$\bar{x}$	126	52	1144	20	682	0.2	14	2350	4876	--	7.8
				s	66	37	464	7.8	369	0.0	16	998	2112	--	0.4

TABLE 4.2.3-1.--Summary of chemical analyses of groundwater in the Dunn Center area--Continued

Stratigraphic Unit	Water Type	Analysis Group	Number of Samples	Statistic	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Specific Conductance µmhos/cm	TDS mg/L	pH
A-lignite--cont.	$CaMgHCO_3$	II	2	$\bar{x}$	86	38	23	3.1	329	0.0	1.0	149	739	559	7.0
	$NaHCO_3SO_4$	IX	2	$\bar{x}$	38	12	325	11	456	0.0	11	315	1416	--	7.5
	$NaHCO_3$	XI	2	$\bar{x}$	8.4	0.8	581	6.0	1478	2.6	8.6	105	2002	--	8.4
Dunn Center interval (Schoolhouse interval)	$NaHCO_3SO_4$	IX	3	$\bar{x}$	29	11	610	14	708	1.6	7.1	825	2415	--	8.2
				s	17	14	103	3.4	9.5	0.0	9.5	182	351	--	0.3
	$NaCaMgHCO_3SO_4$	II	2	$\bar{x}$	67	40	89	9.4	318	0.0	19	174	1029	--	7.9
	$NaCaMgHCO_3$	I	1		24	16	52	2.4	249	0.0	0.0	44	470	256	7.2
Dunn Center bed (Beulah-Zap bed)	$NaCaHCO_3SO_4$	III	19	$\bar{x}$	91	36	155	8.1	357	0.7	4.6	408	1533	1243	7.4
				s	45	15	127	3.8	88	0.0	4.1	303	1623	748	0.5
	$NaHCO_3SO_4$	IX	8	$\bar{x}$	46	21	454	15	781	2.0	6.3	458	2011	1545	8.1
				s	22	13	131	9.4	184	2.8	6.3	117	452	--	0.4
	$CaMgSO_4$	V	7	$\bar{x}$	233	72	80	6.2	293	0.0	29	732	1613	1742	6.7
				s	112	34	35	1.3	132	0.0	18	350	462	191	0.3
	$NaHCO_3$	XI	5	$\bar{x}$	6.2	4.7	504	17	934	34	5.4	255	1884	575	8.6
				s	5.1	4.1	185	16	343	49	2.1	223	655	--	0.6
	$NaSO_4$	VIII	1		31	8.7	900	12	1018	3.6	18	1640	3641	--	8.4
	$NaCaHCO_3$	I	1		26	16	53	2.3	249	0.0	1.6	46	442	274	7.9
	$NaMgSO_4$	VII	1		283	484	1820	14	728	0.0	239	5210	10000	1990	7.3
E-interval (Beulah-Zap interval)	$NaSO_4HCO_3$	IX	6	$\bar{x}$	26	5.1	650	12	930	5.2	7.0	722	2540	1555	8.4
				s	18	3.0	84	3.5	164	5.1	2.6	254	386	671	0.2

TABLE 4.2.3-1.--Summary of chemical analyses of groundwater in the Dunn Center area--Continued

Stratigraphic Unit	Water Type	Analysis Group	Number of Samples	Statistic	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Specific Conductance μmhos/cm	TDS mg/L	pH
E-interval--cont.	$NaSO_4$	VII	2	$\bar{x}$	57	121	2008	25	916	0.0	5.5	3665	7185	--	8.0
	$NaHCO_3SO_4$	II	1		97	41	246	8.5	444	1.2	0.0	248	1122	--	8.3
E-lignite (Spaer bed)	$NaHCO_3SO_4$	IX	20	$\bar{x}$	25	11	630	11	865	5.1	7.8	718	2455	--	8.2
				s	15	14	206	6.0	244	8.0	9.6	567	817	--	0.4
	$NaCaHCO_3SO_4$	III	5	$\bar{x}$	173	38	240	7.4	626	0.0	34	444	1540	1653	7.4
				s	68	12	93	1.6	162	0.0	24	143	491	--	0.4
F-interval (Spaer interval)	$NaHCO_3SO_4$	X	7	$\bar{x}$	15	3.8	692	16	1011	23	8.8	547	2531	--	8.6
				s	5.9	3.4	171	15	149	49	5.0	278	560	--	0.4
	$NaSO_4HCO_3$	IV	2	$\bar{x}$	77	38	479	9.8	662	0.0	18	855	2040	--	7.5
	$NaMgSO_4$	VII	1		415	228	591	12	760	0.0	47	2640	5220	4880	7.9
F-lignite (Jim Creek bed)	$NaHCO_3SO_4$	X	20	$\bar{x}$	16	5.0	582	5.4	971	8.8	5.2	479	2257	1315	8.3
				s	16	4.4	139	4.1	262	9.7	6.2	282	320	120	0.3
	$NaSO_4$	VII	2	$\bar{x}$	175	141	945	26	462	0.0	125	2449	4154	--	7.4
	$NaMgSO_4$	VII	1		319	326	789	21	749	0.0	309	2250	5820	--	7.4
G-lignite & interval (Jim Creek interval)	$NaHCO_3$	XI	5	$\bar{x}$	13	2.7	709	5.9	1025	6.6	5.6	262	2065	2385	8.4
				s	8.2	3.4	239	1.0	260	9.1	2.2	59	196	--	0.2
	$NaSO_4HCO_3$	IV	2	$\bar{x}$	60	38	312	12	480	0.0	17	555	1616	--	7.3
	$NaCaMgSO_4$	VI	2	$\bar{x}$	176	48	234	12	278	0.0	7.0	974	2039	--	6.6
	$NaSO_4HCO_3$	IX	1		8.0	2.9	662	5.0	582	0.0	3.5	874	1722	--	8.1

TABLE 4.2.3-1.--Summary of chemical analyses of groundwater in the Dunn Center area--Continued

Stratigraphic Unit	Water Type	Analysis Group	Number of Samples	Statistic	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Specific Conductance µmhos/cm	TDS mg/L	pH
H-interval (Jim Creek interval)	$NaHCO_3SO_4$	VIII	3	$\bar{x}$	43	21	749	8.2	1109	2.0	4.3	868	3128	--	8.1
				s	37	17	145	5.0	280	0.0	1.5	238	540	--	0.2
H-lignite (Antelope Creek bed)	$NaHCO_3$	XI	15	$\bar{x}$	15	3.6	641	8.7	1367	2.8	18	189	2272	--	8.5
				s	9.6	4.2	111	5.0	258	7.9	14	90	289	--	0.3
	$NaHCO_3SO_4$	IX	9	$\bar{x}$	19	6.1	716	10	1034	13	9.3	792	2955	--	8.3
				s	12	3.0	93	4.8	188	5.1	7.4	395	499	--	0.2
	$CaMgSO_4$	V	1		244	102	137	7.9	271	0.0	15	1040	2000	1670	6.6
I-interval (Antelope Creek interval)	$NaHCO_3SO_4$	X	5	$\bar{x}$	24	8.6	719	9.5	1217	5.5	10	562	2868	--	8.2
				s	14	7.1	76	5.8	323	0.0	6.8	316	282	--	0.4
	$NaCaSO_4HCO_3$	VI	1		207	58	388	24	586	0.0	3.0	1098	2384	--	--
J-lignite (Hagel bed)	$NaHCO_3$	XI	2	$\bar{x}$	21	1.2	800	13	2072	18	36	221	2923	--	8.3
	$NaMgSO_4$	VI	1		115	161	478	53	488	0.0	9.5	1575	2974	--	8.3
	$NaHCO_3SO_4$	IX	1		87	15	550	13	1027	0.0	13	704	2435	--	8.3
	$NaSO_4HCO_3$	III	1		143	56	410	20	759	0.0	20	720	2220	--	8.3
N-interval & lignite (Harmon interval & Hanson bed)	$NaHCO_3$	XI	5	$\bar{x}$	12	3.7	743	13	1632	25	33	55	2720	1990	8.8
				s	8.1	2.9	111	5.4	523	25	25	66	393	--	0.2

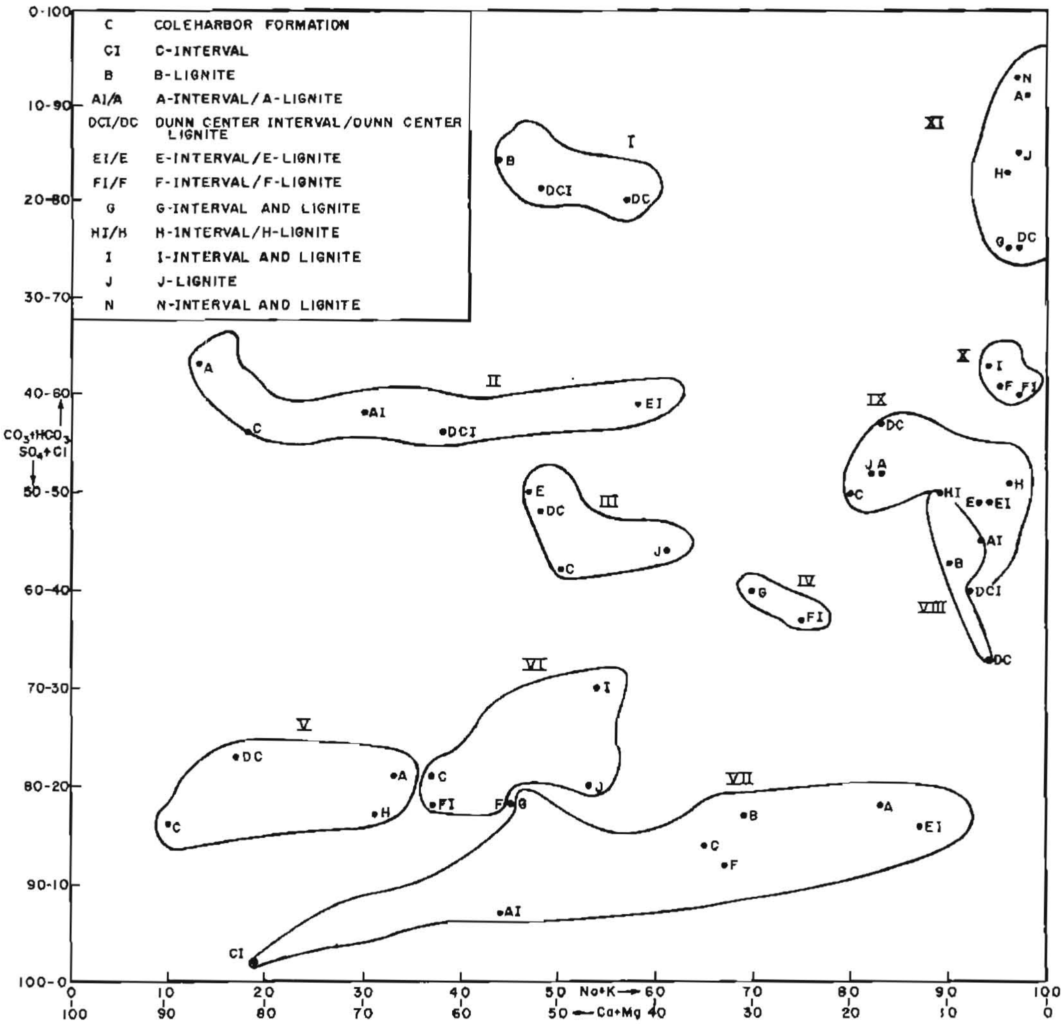


Figure 4.2.3-1. Plot of mean values of the ratios $Na^{+}K/Ca+Mg$ to CO_3+HCO_3/SO_4+Cl of groundwater in the Dunn Center area grouped by water type and by stratigraphic unit. The analysis group is shown by Roman numerals. (From Moran et al., 1976.)

in the northern and central part of the project area. These samples reflect water that has been recharged almost entirely through sand, so very little dissolved mineral matter has entered the water. A further requirement may be recharge directly into the aquifer without passing through a soil zone. There are too few samples in the group to permit any meaningful generalizations about the origin or significance of this type of water.

Group II consists of 17 samples of $Ca(HCO_3SO_4)$ type water, with a mean relative $NaHCO_3$ composition of 0.27-0.58, from five units, the Coleharbor Formation, A-interval, A-lignite, Dunn Center interval, and E-interval (fig. 4.2.3-1). The relative sodium content of the group ranged from a mean of 23 for two samples from the A-lignite to 246 for a single sample from the E-interval. The relative bicarbonate content varied from a mean of 329 for two samples from the A-lignite and five samples from the Coleharbor Formation to a mean of 0.63 for two samples from the A-lignite. The electrical conductivity of samples in group II was 842 μmhos/cm and pH was 7.6. There is a slight tendency toward an increase in conductivity and pH with increasing sodium content. This increase in sodium, conductivity, and pH is roughly related to stratigraphic position. The sample with the highest conductivity, pH, and sodium content is in the lowest unit, the E-interval. The samples with the lowest conductivity, pH, and sodium content are in the A-interval and A-lignite, respectively.

Except for two samples from sandy valley fills south of Dunn Center and along Spring Creek, all samples of this relatively fresh Ca-HCO_3, SO_4 type water were collected in the northern part of the area high in the stratigraphic section. They reflect recharge through calcareous glacial sediment of the Coleharbor Formation and sandy sediment in the upper part of the Sentinel Butte Formation.

Group III consists of 34 samples, with a mean relative Na-HCO_3 composition of 0.49-9.47, from four units, the Coleharbor Formation, Dunn Center bed, E-lignite, and J-lignite. The relative sodium content varies from a mean of 0.47 for seven samples from the E-lignite to 0.61 for a single sample from the J-lignite. The relative bicarbonate content varies from a mean of 0.42 for seven samples from the Coleharbor Formation to a mean of 0.50 for seven samples from the E-lignite. The mean electrical conductivity and pH of this Ca, Na-SO_4, HCO_3 type water are 1 535 μ mhos/cm and 7.5, respectively. As in group II, there is a slight tendency toward an increase in pH and conductivity with an increase in sodium.

Analyses in this group are concentrated in two areas, in the north-central part of the area and in the central part of the area along the partly buried meltwater channel beneath the proposed plant site. The analyses in the northern part of the project area are generally from wells situated along the small stream valley that flows southeastward to join Spring Creek. They are thus lower in the landscape than the wells in group II which are generally located on the higher divide areas east and west of this drainage. Like the analyses in group II, these analyses are from wells high in the stratigraphic section. The higher sodium and sulfate content of analyses in group III is believed to reflect recharge through the floor of valleys eroded below the upland level. In these valleys the thin veneer of calcareous glacial sediment has been removed, so a continued supply of Ca^{2+} ions is not present. As is discussed below, gypsum is concentrated by surface water in depressional areas producing a source for sulfate ions.

Group IV consists of two analyses each from the F- and G-intervals. The mean relative Na-HCO_3 composition is 0.72-0.38 making the water a Na-SO_4, HCO_3 type. The conductivity ranges from 1 616-2 039 with a mean of 1 828 μ mhos/cm. The pH is 7.4.

There are too few analyses in this group to permit any meaningful generalizations about their distribution or origin.

Group V consists of 18 analyses of Ca-SO_4 type water from four stratigraphic units, Coleharbor Formation, A-lignite, Dunn Center bed, and H-lignite. The mean relative Na-HCO_3 composition of the group is 0.22-0.21, but individual values range from a mean of 0.10-0.16 for two samples from the Coleharbor Formation to a mean of 0.33-0.21 for six samples from the A-lignite. The mean electrical conductivity and pH are 1 211 and 7.1, respectively. Nine samples from the Dunn Center bed and one from the H-lignite had pH values of 6.7 and 6.6, respectively.

The distribution of analyses in group V is very similar to that in group III. Most of the analyses are from the center of the northern part of the area along the small stream valley that flows southeastward into Spring Creek. A small group of samples occurs in the central part of the area along the buried valley west of the proposed plant site. In general, samples from group V are from a higher stratigraphic position than those in group III in the same area. On the basis of these observations, the analyses from group V appear to represent water with the same origin and history as those in group III. Those in group V are shallower and have been recharged more recently than those in group III. They reflect a build-up of gypsum in the valley floors over time.

Set II contains nine samples in group VI. They consist of Ca, Na-SO_4 type water from the Coleharbor Formation, G-interval, I-interval, and J-lignite. They are characterized by a mean relative Na-HCO_3 composition of 0.42-0.31, mean electrical conductivity of 2 453 μ mhos/cm, and a mean pH of 7.5. They form a group of medium conductivity, low to medium pH waters. These samples have been separated from those in group V because of their mean conductivity, which is greater than 2 000 μ mhos/cm.

The higher sodium content of the samples in group VI relative to group V may reflect the absence of excess calcium ions because of the absence of calcareous glacial sediment in the southern part of the area, where these samples are concentrated. It is more likely, however, that it reflects greater cation exchange during recharge through the silty and clayey sediment that is more abundant in the Sentinel Butte Formation in the southern part of the area.

Set III is composed of 15 analyses from a single group, group VII. These analyses are from the Coleharbor Formation, C-lignite, B-lignite, A-interval and lignite, E-interval, and F-interval and lignite. These analyses are characterized by high salinity, mean electrical conductivity of 6 100 μ mhos/cm, and a medium pH of 7.7. The group ranges from a composition of $CaSO_4$, a relative Na-HCO_3 content of 0.19-0.02, for one sample from the C-lignite to $NaSO_4$, a mean relative Na-HCO_3 content of 0.87-0.16, for two samples from the E-interval. The mean relative Na-HCO_3 content of the group is 0.62-0.14, a Na, Ca-SO_4 type water.

Most of the analyses in this group are from the central part of the project area. A few are located near Lake Ilo, along Spring Creek and its tributaries, and near Marshall Slough. Nearly all these samples are from shallow wells situated in areas where leakage of evaporitic surface water into the aquifer is possible. The analyses near Lake Ilo, the projected plant site, and Marshall Slough are in areas where ^{18}O and T data indicate that evaporitic surface water is penetrating into aquifers (Moran et al., 1976, secs. 8.3.9, 8.3.10, and 8.6). A number of analyses are from the A-lignite near its outcrop south and southeast of the proposed plant site. It is not known whether these analyses reflect an increase in salinity near a groundwater discharge area or recharge of saline surface water for areas of temporary ponding in side-slope positions.

Set IV consists of a small group of six analyses in group VIII from the B-lignite, A-interval, Dunn Center bed, and H-interval. These samples are characterized by high salinity, mean electrical conductivity of 3 344 μ mhos/cm, and high pH of 8.2. The mean relative

$Na-HCO_3$ composition of this group of $Na-SO_4$, HCO_3 type water samples is 0.91-0.45. This group differs from group VII by having a lower salinity, higher pH, and sodium and bicarbonate content.

These samples have a distribution similar to that of group VII and probably also represent recharge of slightly evaporated surface water.

The largest set of analyses make up set V, which consists of 154 analyses in three groups (fig. 4.2.3-1). The set is characterized by medium salinity, mean electrical conductivity of 2 315 μ mhos/cm, and a high pH of 8.2. The mean relative $Na-HCO_3$ composition of the set is 0.90-0.60. Composition of waters in the set ranges from $Na-HCO_3$, SO_4, a mean relative $Na-HCO_3$ composition of 0.86-0.50 from group IX, to $Na-HCO_3$, a mean relative $Na-HCO_3$ composition of 0.96-0.83 for group XI. The pH generally tends to increase as the bicarbonate content increases.

Group IX consists of 88 analyses from the Coleharbor Formation, A-interval and lignite, Dunn Center bed and interval, E-interval and lignite, H-lignite and J-lignite. The mean relative $Na-HCO_3$ content of the $Na-HCO_3$, SO_4 type water making up this set is 0.86-0.50. The electrical conductivity has a mean value of 2 296 μ mhos/cm and the mean pH is 8.1.

Samples in this group are spread throughout the project area. Many samples are concentrated along the Spring Creek valley, the buried meltwater channels southeast of Lake Ilo, southeast of the proposed plant site, and around Marshall Slough, and along the tributary to Spring Creek that flows southeastward from the north-central part of the project area. The distribution of these samples in group IX is very similar to that of samples in group III. Group IX differs from group III in having a higher sodium content and greater salinity and pH. The waters in group IX are believed to have the same origin as those in group III differing only in that they were recharged through silty and clayey sediment permitting greater ion exchange of Na^+ for Ca^{2+}. Other samples occur in settings in the southern part of the area analogous to those in group II in the northern part of the area. These samples in group IX reflect recharge through upland sites underlain by silt and clay in the upper part of the Sentinel Butte Formation.

Group X consists of 32 analyses of $Na-HCO_3$, SO_4 type water from the F-interval and lignite and the I-interval. The mean relative $Na-HCO_3$ content of these analyses is 0.95-0.61. The mean electrical conductivity is 2 412 μ mhos/cm and the mean pH is 8.4.

The analyses in group X are concentrated along buried meltwater channels beneath and southeast of the proposed plant site and southeast of Lake Ilo and along Spring Creek between Dunn Center and Werner in the area where wells in the F-lignite flow at the surface. These analyses are believed to reflect water that has encountered sufficient silt and clay for nearly all the Ca^{2+} ions to have been replaced by ion exchange with Na^+ ions. The concentration of analyses of group X along meltwater trenches reflects recharge through the low lying areas where sulfate is concentrated by surface water. The significance of the sulfate in the flowing wells is not known.

Group XI consists of 34 analyses of $Na-HCO_3$ type water, which had a mean relative $Na-HCO_3$ composition of 0.96-0.83, from the A-lignite, Dunn Center bed, G-interval, H-lignite, J-lignite, and H-interval and lignite. The mean conductivity was 2 274 μ mhos/cm and the mean pH was 8.5.

These analyses are distributed, more or less uniformly throughout the project area. The absence of analyses in this group in the northern part of the area reflects the absence of wells in the deeper part of the flow system. These analyses generally reflect water that was recharged beneath upland areas where sulfate concentrations were not especially great. The water has passed through sufficient silt and clay for nearly all the Ca^{2+} ions to be replaced by ion exchange by Na^{+} ions.

4.2.4 Groundwater-Flow Systems

In the investigation of the Dunn Center area described by Moran et al. (1976), a network of observation wells (piezometers) was installed in the Sentinel Butte Formation and to a much lesser extent in the Tongue River Formation and in the valley deposits of the Coleharbor Formation. Observation wells were installed at 68 sites in the area. Each of these sites has stratigraphic information and one or more observation wells. Seven of the sites are at locations where the single standpipe-type wells were installed previously by the North Dakota Water Commission as part of the county groundwater resources investigation in 1972-74. Of the 68 sites at which observation wells were installed by Moran et al. (1976), 26 are referred to as major hydrologic monitoring sites. These sites have between three and seven observation wells at different depths below ground surface. Of the remaining sites 29 have two or three wells and 13 have only a single well.

A description of the groundwater-flow systems in the Dunn Center area is provided by Moran et al. (1976) based on an integrated interpretation of the stratigraphy, isotope data, chemical data, and water-level data obtained from the observation well network during the summer and fall of 1975 and early part of 1976. Since this interpretation was made, additional water-level data have been acquired on a regular basis. The more recent data have provided no reason to make any significant modifications to the flow-system descriptions presented by Moran et al. in 1976. The following overview of the flow-system conditions has therefore been adapted directly from Moran et al. (1976).

The Dunn Center area occupies a broad upland between two regional valleys, the valley of the Missouri River in which exists the man-made impoundment known as Lake Sakakawea and the valley of the Knife River (fig. 4.2-1). Most of the Dunn Center area is at an elevation between 2 100 and 2 350 feet (636 and 712 m) above MSL. Lake Sakakawea located north of the study area has a mean water surface elevation of approximately 1 850 feet (565 m). The Knife River in the area south of the Dunn Center area has elevations in the range of 2 100-2 200 feet (636-670 m). The occurrence of these regional topographic lowlands cutting through the stratified sediment of the Sentinel Butte Formation, in which the layered aquifers (sand and lignite) and aquitards (clay, silt, and very clayey or silty sand) have hydraulic conductivity contrasts of 2-6 orders of magnitude, has produced a regional condition of downward flow in the aquitards and lateral flow in the aquifers.

At nearly all multi-well monitoring sites in the Dunn Center area the hydraulic head decreases with depth. This condition, in general, extends through the Sentinel Butte Formation and also in the Cannonball Formation. Calculations of groundwater-flow rates indicate that it takes decades to hundreds of years for groundwater to flow from local recharge areas to local discharge areas such as Spring Creek, which traverses the area from west to east in a minor valley, and thousands of years for groundwater to move from recharge areas downward through several aquifers and aquitards and laterally to the regional discharge areas along valley walls near Lake Sakakawea and the Knife River. These conclusions are supported by the tritium, oxygen-18, and carbon-14 data referred to above.

Three significant surface water bodies occur in the Dunn Center area: Lake Ilo, Marshall Slough, and Spring Creek (fig. 4.2-1). Lake Ilo appears to be located in a groundwater recharge area. The presence of tritiated water and enriched ^{18}O values, indicative of evaporative source conditions, in wells near Lake Ilo as much as 100 feet (30 m) deep suggests the intrusion of lake-derived water deep into the groundwater-flow system. The lake overlies a gravel valley fill, which is believed to be the path by which the water moves downward (Moran et al., 1976).

Very limited chemical data is available on Marshall Slough, in the southeastern part of the area. The hydraulic head data suggest that here too water flows from the slough and recharges the groundwater reservoir.

During non-snowmelt periods, the flow of Spring Creek appears to be largely supplied by groundwater discharge from the Dunn Center bed and the E-lignite. Tributaries of Spring Creek are fed by springs and seeps that occur at the outcrop of lignite beds ranging from the C-lignite to the E-lignite. On the basis of sample calculations, as much as 0.25 of the total discharge in Spring Creek at Halliday from mid-July to October 1975, can be accounted for by direct seepage into the creek and one of its tributaries from the Dunn Center bed and E-lignite and A-lignite, respectively. Since several rainfall events occurred during this period, it is evident that this estimate is quite good. A groundwater recharge of 0.5 in/yr over the entire area of the Dunn Center bed that feeds Spring Creek is adequate to produce this flow. Given the climate of the Dunn Center area, this value is also believed to be a reasonable estimate of the actual recharge.

Other minor surface water regimes are generally groundwater discharge areas where lignite beds outcrop in side-hill positions or groundwater recharge areas in upland or valley sites.

4.3 Hydrogeology and Hydrogeochemistry of the Falkirk Area

4.3.1 Hydrostratigraphy

The shallow hydrostratigraphic units in the bedrock within the Falkirk area consist of thin sand and lignite aquifers separated by silt and clay aquitards. In the Quaternary deposits, sand and gravel aquifers of glaciofluvial origin are surrounded by pebble loam (till). The major hydrostratigraphic units in the Falkirk site are: the pebble loam which covers most of the study area; the glaciofluvial sands and gravel; the Underwood sand; the main Hagel bed; the B bed (lower split of the Hagel bed); the sheet sand; and the Hensler bed (pls. 27 and 28). Figure 4.3.1-1 shows the locations of the cross sections. Other, less significant, hydrostratigraphic units are present but lack sufficient instrumentation to be discussed on an individual basis. Plate 29 shows the locations of all observation well nests and identified farm wells in the Falkirk area. Table 4.3.1-1 lists all piezometers and identified farm wells in the Falkirk area and indicates the intake zone for each.

The bulk of the hydrostratigraphic units can be described in terms of five hydrologic units. The Coleharbor and Oahe Formations are made up of two units: low permeability pebble loam (till) and silt and clay alluvium, and highly permeable sand and gravel glaciofluvial deposits. The Sentinel Butte and Bullion Creek Formations can be divided into three hydrologic units: lignite beds, silt and clay and carbonaceous clay beds, and the sand beds. The distribution of the hydrologic units is shown in plates 27 and 28.

4.3.1.1 Oahe and Coleharbor Formations

4.3.1.1.1 Aquitards.--Most of the study area is covered by pebble loam to thicknesses of up to 150 feet (46 m). As of November 1977, single-well response tests could be carried out in 4 of 14 piezometers finished in the pebble loam. The average hydraulic conductivity determined from these tests was 1.8×10^{-4} cm/s. The individual values are given in table 4.3.1.1.1-1. Six other piezometers had not yet reached an equilibrium water level from the time they were installed in August 1977, indicating that the hydraulic conductivity of the material around the piezometer tip is probably on the order of 10^{-7}-10^{-9} cm/s.

Alluvial deposits, consisting of silt and clay, are also present and make up a limited portion of the surficial materials in the Falkirk area. No hydraulic conductivity determinations were made in this material. The conductivity of silt and clay is generally between 10^{-5}-10^{-9} cm/s.

4.3.1.1.2 Aquifers.--Aquifers in the Coleharbor Formation consist of glaciofluvial sands and gravels confined to buried channels south and east of the city of Underwood (fig. 4.3.1.1.2-1). The fill within these valleys is very complex, consisting of interbedded sands, gravels, and some silt, clay, and pebble loam. The sand and gravel beds can be well sorted to poorly sorted. Occasionally the aquifers will contain significant quantities of silt and clay.

Data collected by Klausing (1974) from six pump tests conducted in the central portion of McLean County indicate that the hydraulic conductivity of the Coleharbor aquifers ranges from 5.5×10^{-1} cm/s to 3.5×10^{-2} cm/s with an average conductivity of 1.1×10^{-1} cm/s. Single-well response tests, listed in table 4.3.1.1.1-1, were conducted on four piezometers finished in sands and gravels in the study area. The average hydraulic conductivity from these tests is 3.1×10^{-3} cm/s.

4.3.1.2 Bedrock hydrostratigraphic units

4.3.1.2.1 Aquitards.--The aquitards within the Sentinel Butte and Bullion Creek Formations consist of clayey silt, silty clay, and carbonaceous clay. These beds divide the bedrock into numerous, thin sand and lignite aquifers (pls. 27 and 28). Successful single-well response tests were accomplished only in the aquitards of the Kinneman Creek interval above the Hagel bed. The mean hydraulic conductivity, determined from four tests, is 5.9×10^{-6} cm/s with a range of 3.6×10^{-4} cm/s to 2.6×10^{-7} cm/s.

4.3.1.2.2 Sand aquifers.--A great deal of study area is underlain by large thicknesses of sandy material which is divided into thin aquifers. Three of the

TABLE 4.3.1-1. Intake zone of piezometers and farm wells and availability of chemical analyses--Falkirk area

PIEZOMETER	CHEMICAL ANALYSIS	LOCATION	DEPTH ft/m	STRATIGRAPHIC UNIT
1-1		146-82-32 DDD	86.9/ 26.5	Coleharbor Formation
1-2		146-82-32 DDD	66.3/ 20.2	Coleharbor Formation
2-1	*	146-82-34 CBC	52.2/ 15.9	Coleharbor Formation
2-2	*	146-82-34 CBC	43.0/ 13.1	Coleharbor Formation
3-1	*	145-82-04 CDC	41.3/ 12.6	Tavis Creek bed
3-2	*	145-82-04 CDC	13.8/ 4.2	Coleharbor Formation
4-1	*	145-82-03 DCC	86.6/ 26.4	Hagel interval (below C bed)
4-2		145-82-03 DCC	12.1/ 3.7	Coleharbor Formation
5-1	*	146-82-22 DDD	71.5/ 21.8	Hagel bed
6-1		146-83-24 DDD	127.0/ 38.7	Hagel bed
6-2	*	146-83-24 DDD	130.9/ 39.9	Hagel bed
6-3		146-83-24 DDD	51.8/ 15.8	Coleharbor Formation
6-4		146-83-24 DDD	34.1/ 10.4	Coleharbor Formation
6-5		146-83-24 DDD	24.3/ 7.4	Coleharbor Formation
7-1		146-82-30 CBB	71.5/ 21.8	Kinneman Creek interval (Underwood sand)
7-2		146-82-30 CBB	55.8/ 17.0	Coleharbor Formation
7-3		146-82-30 CBB	24.0/ 7.3	Coleharbor Formation
8-1	*	146-82-21 CCC	59.1/ 18.0	Underwood sand
8-2	*	146-82-21 CCC	37.7/ 11.5	Underwood sand
8-3	*	146-82-21 CCC	19.4/ 5.9	Underwood sand
9-1	*	146-82-16 CCB	61.0/ 18.6	Kinneman Creek interval
9-2		146-82-16 CCB	39.4/ 12.0	Kinneman Creek interval
9-3		146-82-16 CCB	20.0/ 6.1	Coleharbor Formation
10-1		146-82-07 CCC	156.2/ 47.6	Hagel bed (B bed)
10-2		146-82-07 CCC	51.8/ 15.8	Coleharbor Formation
10-3		146-82-07 CCC	34.4/ 10.5	Coleharbor Formation
36-1		145-82-04 DDD	41.3/ 12.6	Hagel bed (B bed)
36-2		145-82-04 DDD	25.9/ 7.9	Hagel interval
37-1	*	145-82-04 DAA	34.4/ 10.5	Hagel bed (B bed)
38-1		145-82-04 AAA	28.9/ 8.8	Hagel bed
38-2		145-82-04 AAA	15.4/ 4.7	Underwood sand
39-1	*	146-82-34 BCC	51.2/ 15.6	Hagel bed
40-1	*	146-82-27 CCC	79.1/ 24.1	Hagel bed
40-2		146-82-27 CCC	38.1/ 11.6	Underwood sand
40-3		146-82-27 CCC	19.4/ 5.9	Kinneman Creek interval
41-1	*	146-82-27 BBC	56.4/ 17.2	Hagel bed

TABLE 4.3.1-1. Intake zone of piezometers and farm wells and availability of chemical analyses--Falkirk area--Continued

PIEZOMETER	CHEMICAL ANALYSIS	LOCATION	DEPTH ft/m	STRATIGRAPHIC UNIT
42-1	*	146-82-22 CCD	95.1/ 29.0	Hagel bed
43-1	*	146-82-21 ADD	112.9/ 34.4	Hagel bed
45-1	*	146-82-15 CCC	104.3/ 31.8	Hagel bed (B bed)
73-1	*	146-82-34 CDD	69.2/ 21.1	Sheet sand
74-1	*	146-82-34 CDD	24.3/ 7.4	Hagel bed (B bed)
75-1	*	146-82-26 BCC	88.3/ 26.9	Hagel bed (B bed)
76-1	*	146-82-22 DDD	69.9/ 21.3	Hagel bed
76-2		146-82-22 DDD	39.0/ 11.9	Underwood sand
76-3		146-82-22 DDD	19.7/ 6.0	Coleharbor Formation
77-1	*	146-82-22 ADD	71.5/ 21.8	Hagel bed
78-1	*	146-82-27 DCC	67.6/ 20.6	Hagel bed
79-1	*	146-82-28 CDD	68.2/ 20.8	Hagel bed
80-1	*	146-82-20 CDD	157.2/ 47.9	Hagel bed (B bed)
80-2		146-82-20 CDD	41.7/ 12.7	Underwood sand
80-3		146-82-20 CDD	20.3/ 6.2	Coleharbor Formation
81-1	*	146-82-20 CBB	109.9/ 33.5	Hagel bed
82-1	*	146-82-20 CCC	118.8/ 36.2	Hagel bed
82-2		146-82-20 CCC	62.7/ 19.1	Underwood sand
82-3		146-82-20 CCC	39.0/ 11.9	Coleharbor Formation
83-1	*	146-83-24 BBB	138.1/ 42.1	Hagel bed
84-1	*	146-83-24 CCC	135.2/ 41.2	Hagel bed
85-1	*	146-83-36 BCC	62.0/ 18.9	Hagel bed
86-1	*	146-82-30 CCC	101.0/ 30.8	Hagel bed (B bed)
87-1	*	146-82-31 CCC	57.1/ 17.4	Hagel bed (B bed)
88-1	*	146-82-30 DAA	69.6/ 21.2	Hagel bed
88-2		146-82-30 DAA	48.6/ 14.8	Underwood sand
88-3		146-82-30 DAA	30.8/ 9.4	Coleharbor Formation
88-4		146-82-30 DAA	21.7/ 6.6	Coleharbor Formation
89-1	*	146-82-31 AAA	57.1/ 17.4	Hagel bed
90-1	*	146-82-31 DAA	56.4/ 17.2	Hagel bed (B bed)
90-2		146-82-31 DAA	24.3/ 7.4	Coleharbor Formation
91-1		146-82-32 CCC	97.4/ 29.7	Hagel bed
91-2		146-82-32 CCC	18.0/ 5.5	Coleharbor Formation
91-3		146-82-32 CCC	43.3/ 13.2	Coleharbor Formation

TABLE 4.3.1-1. Intake zone of piezometers and farm wells and availability of chemical analyses--Falkirk area--Continued

PIEZOMETER	CHEMICAL ANALYSIS	LOCATION	DEPTH ft/m	STRATIGRAPHIC UNIT
92-1	*	145-82-06 DAA	60.0/ 18.3	Hagel bed (B bed)
92-2		145-82-06 DAA	20.3/ 6.2	Kinneman Creek interval
93-1		146-82-32 DCC	97.2/ 29.6	Hagel bed
94-1		145-82-05 ADD	52.2/ 15.9	Hagel bed (B bed)
101-1	*	145-82-08 ADD	357.0/108.8	Cannonball Formation
101-2	*	145-82-08 ADD	249.7/ 76.1	Coleharbor Formation
101-3	*	145-82-08 ADD	48.9/ 14.9	Coleharbor Formation
102-1	*	145-82-05 DAA	273.9/ 83.5	Hensler sand
102-2	*	145-82-05 DAA	177.8/ 54.2	Tavis Creek interval
102-3	*	145-82-05 DAA	88.6/ 27.0	B bed interval
102-4		145-82-05 DAA	29.5/ 9.0	Hagel bed
103-1		146-82-32 CDC	203.4/ 62.0	Coal Lake Coulee bed
103-2		146-82-32 CDC	118.8/ 36.2	Sheet sand
103-3		146-82-32 CDC	83.3/ 25.4	Underwood sand
103-4		146-82-32 CDC	44.0/ 13.4	Kinneman Creek interval
103-5		146-82-32 CDC	21.0/ 6.4	Kinneman Creek interval
104-1	*	146-82-32 DDD	109.6/ 33.4	Sheet sand
104-2		146-82-32 DDD	64.6/ 19.7	Hagel bed
104-3		146-82-32 DDD	39.0/ 11.9	Underwood sand
104-4		146-82-32 DDD	19.4/ 5.9	Underwood sand
105-1	*	146-82-28 CCC	269.0/ 82.0	Hensler sand
105-2	*	146-82-28 CCC	120.1/ 36.6	Sheet sand
105-3		146-82-28 CCC	39.0/ 11.9	Underwood sand
105-4		146-82-28 CCC	9.2/ 2.8	Underwood sand
105-5		146-82-28 CCC	25.3/ 7.7	Underwood sand
105-6	*	146-82-28 CCC	67.6/ 20.6	Hagel bed
106-1		146-82-20 DDD	389.1/118.6	Hensler sand
106-2		146-82-20 DDD	179.5/ 54.7	C bed interval
106-3	*	146-82-20 DDD	132.2/ 40.3	B bed interval
106-4	*	146-82-20 DDD	73.2/ 22.3	Underwood sand
106-6	*	146-82-21 CCC	83.7/ 25.5	Hagel bed
107-1	*	145-82-04 AAA	238.2/ 72.6	Hensler sand
107-2	*	145-82-04 AAA	147.6/ 45.0	Tavis Creek bed
107-3	*	145-82-04 AAA	69.2/ 21.1	Sheet sand
108-1	*	146-82-32 ADD	99.7/ 30.4	Sheet sand
108-2	*	146-82-32 ADD	59.7/ 18.2	Hagel bed
109-1	*	146-82-29 DAA	121.4/ 37.0	Hagel bed (B bed)

TABLE 4.3.1-1. Intake zone of piezometers and farm wells and availability of chemical analyses--Falkirk area--Continued

PIEZOMETER	CHEMICAL ANALYSIS	LOCATION	DEPTH ft/m	STRATIGRAPHIC UNIT
109-2	*	146-82-29 DAA	60.0/ 18.3	Underwood sand
109-3	*	146-82-29 DAA	87.6/ 26.7	Hagel bed
110-1	*	146-82-20 DAD	58.7/ 17.9	Hagel bed
110-2	*	146-82-20 DAD	99.1/ 30.2	Hagel bed (B bed)
111-1	*	146-82-33 DCC	117.8/ 35.9	Hagel bed (B bed)
111-2	*	146-82-33 DCC	71.2/ 21.7	Hagel bed
111-3		146-82-33 DCC	28.5/ 8.7	Kinneman Creek interval
111-4		146-82-33 DCC	39.7/ 12.1	Kinneman Creek interval
111-5		146-82-33 DCC	19.7/ 6.0	Kinneman Creek interval
112-1		145-82-05 DBB	44.9/ 13.7	Hagel bed
112-2	*	145-82-05 DBB	63.0/ 19.2	Hagel interval
113-1		145-82-05 DBA	41.0/ 12.5	Hagel bed
113-2	*	145-82-05 DBA	61.0/ 18.6	Hagel interval
114-1	*	145-82-05 DAB	66.9/ 20.4	Hagel bed
514		146-82-33 DCC	69.6/ 21.2	Hagel bed
526		146-83-25 CCC	130.1/ 39.7	Hagel bed
527		146-82-30 CCC	83.8/ 25.6	Hagel bed
531		146-82-28 CCC	66.6/ 20.3	Hagel bed
537		146-82-26 DDD	40.0/ 12.2	Hagel bed
538		146-82-36 BAA	41.0/ 12.5	Hagel bed
540A		146-81-30 CDC	45.0/ 13.7	Hagel bed
540B		146-81-30 CDD	59.7/ 18.2	Hagel bed (B bed)
542		146-82-30 BCC	96.8/ 29.5	Hagel bed
546		146-82-26 BCC	75.2/ 22.9	Hagel bed
548		146-83-23 CCC	93.1/ 28.4	Hagel bed
551		146-83-24 DDD	129.5/ 39.5	Hagel bed
553		146-82-20 CDD	135.3/ 41.2	Hagel bed
554		146-82-20 DDD	96.8/ 29.5	Hagel bed
556		146-82-22 DDD	63.6/ 19.4	Hagel bed
567		146-83-24 AAA	129.6/ 39.5	Hagel bed
569		146-82-16 DDD	95.3/ 29.1	Hagel bed
570		146-82-14 CCC	99.9/ 30.4	Hagel bed
575		146-83-12 CCC	139.0/ 42.4	Hagel bed
578		146-82-16 BBB	98.1/ 29.9	Hagel bed
585		146-82-08 BBB	76.0/ 23.2	Hagel bed
589A		146-82-12 BBB	118.4/ 36.1	Hagel bed (B bed)
589B		146-82-12 BBB	71.3/ 21.7	Hagel bed

TABLE 4.3.1-1. Intake zone of piezometers and farm wells and availability of chemical analyses--Falkirk area--Continued

PIEZOMETER	CHEMICAL ANALYSIS	LOCATION	DEPTH ft/m	STRATIGRAPHIC UNIT
590		146-82-12 AAA	47.0/ 14.3	Hagel bed
595A		146-83-25 CDD	109.5/ 33.4	Sheet sand
595B		146-83-25 CDD	100.1/ 30.5	Hagel bed
599		146-83-24 DAA	126.9/ 38.7	Hagel bed
601		146-82-20 DAD	85.1/ 25.9	Hagel bed
608		146-81-31 BBC	96.5/ 29.4	Sheet sand
NDSWC 3911		146-82-34 ADD	80.1/ 24.4	Coleharbor Formation
NDSWC 3914		146-82-32 CDC	309.4/ 94.3	Hensler bed
NDSWC 3922		146-82-05 CCC	315.0/ 96.0	Hensler bed

FARM WELLS	CHEMICAL ANALYSIS	LOCATION	DEPTH ft/m	STRATIGRAPHIC UNIT
Elvrum	*	145-81-05 CCB	175.0/ 53.3	Hensler bed
Elvrum		145-81-05 CCB	50.0/ 15.2	Hagel bed (B bed)
Sheldon	*	145-81-08 CCB	230.0/ 70.1	Hensler bed
North American Coal		145-82-04 CCC	110.0/ 33.5	Tavis Creek bed
Stevens		145-82-11 CDC	85.0/ 25.9	C bed
Stevens		145-82-12 BCD	125.0/ 38.1	Weller Slough bed
Heger		145-82-18 BBC	126.0/ 38.4	Coal Lake Coulee bed
Heger	*	145-82-18 BBC	150.0/ 45.7	Hensler bed
Landenberger		145-83-03 DAA	100.0/ 30.5	Tavis Creek bed
Schauer	*	146-81-06 DDD	260.0/ 79.2	Hensler bed
Seidler	*	146-81-08 BCB	150.0/ 45.7	Hensler bed
Weisz	*	146-81-18 CCA	248.0/ 75.6	Hensler bed
Weisz		146-81-18 CCA	148.0/ 45.1	Tavis Creek bed
Sayler	*	146-81-18 DDD	186.0/ 56.7	Hensler bed
Johnson		146-81-30 DCC	100.0/ 30.5	Sheet sand
Johnson		146-81-30 DCC	245.0/ 74.7	Hensler bed
Sayler		146-81-31 CCC	80.0/ 24.4	Sheet sand
Sayler	*	146-81-31 CCC	280.0/ 85.3	Hensler bed
Ecklund		146-81-32 DBC	16.0/ 4.9	Coleharbor Formation
Ecklund		146-81-32 DBC	22.0/ 6.7	Coleharbor Formation
Gunther		146-82-02 CBB	90.0/ 27.4	Underwood sand
Johnson		146-82-05 ADA	70.0/ 21.3	Hagel bed
Johnson		146-82-05 ADA	30.0/ 9.1	Coleharbor Formation
Berg		146-82-09 DDD	83.0/ 25.3	Kinneman Creek interval
Schuler		146-82-10 DCC	22.0/ 6.7	Kinneman Creek interval
Schuler		146-82-10 DCC	25.0/ 7.6	Kinneman Creek interval

TABLE 4.3.1-1. Intake zone of piezometers and farm wells and availability of chemical analyses--Falkirk area--Continued

FARM WELLS	CHEMICAL ANALYSIS	LOCATION	DEPTH ft/m	STRATIGRAPHIC UNIT
Mautz	*	146-82-13 DDB	252.0/ 76.8	Hensler bed
Berg		146-82-15 BBB	90.0/ 27.4	Kinneman Creek interval
Underwood		146-82-20 ADC	98.0/ 29.9	Hagel bed
Sigurdson	*	146-82-20 CAD	304.0/ 92.7	Hensler bed
Sigurdson		146-82-20 DAA	80.0/ 24.4	Hagel bed
Sigurdson		146-82-20 DAA	100.0/ 30.5	Hagel bed
Sigurdson		146-82-20 DAA	43.0/ 13.1	Underwood sand
Sigurdson		146-82-20 DAA	90.0/ 27.4	Hagel bed
Seidler		146-82-21 AAA	90.0/ 27.4	Hagel bed
Underwood		146-82-21 BBD	95.0/ 29.0	Hagel bed
Underwood	*	146-82-21 BDC	395.0/120.4	Hensler bed
Underwood #3	*	146-82-21 CBB	82.0/ 25.0	Hagel bed
Underwood #4		146-82-21 CBB	87.0/ 26.5	Hagel bed
Schell	*	146-82-22 CBC	240.0/ 73.2	Hensler bed
Miller	*	146-82-23 BAC	550.0/167.6	Cannonball Formation
Miller		146-82-23 BAC	550.0/167.6	Cannonball Formation
Stadick		146-82-28 ADA	75.0/ 22.9	Hagel bed
Mautz		146-82-28 CBB	110.0/ 33.5	Sheet sand
Hoff		146-82-29 BAA	50.0/ 15.2	Underwood sand
Mautz		146-82-29 DBD	100.0/ 30.5	Underwood sand
Swanson		146-82-30 BCA	84.0/ 25.6	Underwood sand
Swanson		146-82-31 CCC	70.0/ 21.3	Hagel bed
Berg		146-82-35 BAB	90.0/ 27.4	Tavis Creek bed
Buchert		146-83-10 BAA	310.0/ 94.5	Coleharbor Formation
Buchert		146-83-10 BAA	200.0/ 61.0	Hensler bed
Ash		146-83-10 DDD	200.0/ 61.0	Tavis Creek bed
Snyder		146-83-14 BCC	160.0/ 48.8	Hagel bed (B bed)
Freborg		146-83-22 DCD	22.0/ 6.7	Coleharbor Formation
Freborg		146-83-22 DCD	16.0/ 4.9	Coleharbor Formation
Swanson		146-83-24 DDD	120.0/ 36.6	Hagel bed
Schafer		146-83-35 CAD	145.0/ 44.2	Tavis Creek bed

TABLE 4.3.1.1.1-1. Hydraulic conductivity values--Falkirk area

STRATIGRAPHIC POSITION	PIEZOMETER NUMBER	DEPTH (m)	K cm/s	LOG K	MATERIAL
Coleharbor	1-1	26.5	~5.4×10^{-3}	-2.27	Sand & Gravel
	3-2	4.2	3.2×10^{-3}	-2.50	
	4-2	3.7	3.7×10^{-3}	-2.43	
	2-2	13.1	1.5×10^{-3}	-2.82	
	6-3	15.8	3.7×10^{-6}	-5.43	Till (pebble loam)
	6-5	7.4	2.4×10^{-4}	-3.62	
	7-3	7.3	4.1×10^{-6}	-5.39	
	10-2	15.8	3.1×10^{-5}	-4.51	
Kinneman Creek interval	9-1	18.6	2.8×10^{-4}	-3.56	Silt/Clay
	9-2	12.0	3.2×10^{-6}	-5.50	
	40-3	5.9	5.5×10^{-6}	-5.26	
	111-4	12.1	2.6×10^{-7}	-6.59	
Kinneman Creek interval (Underwood sand)	8-1	18.0	5.5×10^{-4}	-3.26	Sand
	8-2	11.5	1.2×10^{-3}	-2.92	
	8-3	5.9	5.5×10^{-4}	-3.26	
	40-2	11.6	9.3×10^{-5}	-4.03	
	106-4	22.3	8.0×10^{-4}	-3.10	
	109-2	18.3	4.8×10^{-4}	-3.32	
Hagel bed (main)	6-2	39.9	1.3×10^{-5}	-4.89	Lignite
	39-1	15.6	~9.7×10^{-3}	-2.01	
	40-1	24.1	~3.4×10^{-3}	-2.47	
	41-1	17.2	1.7×10^{-3}	-2.77	
	42-1	29.0	1.6×10^{-4}	-3.80	
	76-1	21.3	2.4×10^{-3}	-2.62	
	77-1	21.8	5.3×10^{-3}	-2.28	
	78-1	20.6	~5.1×10^{-3}	-2.29	
	79-1	20.8	~3.1×10^{-3}	-2.57	
	81-1	33.5	2.8×10^{-4}	-3.55	
	82-1	36.2	3.1×10^{-3}	-2.51	
	83-1	42.1	3.3×10^{-5}	-4.48	
	85-1	18.9	3.9×10^{-5}	-4.41	
	88-1	21.2	~1.5×10^{-3}	-2.82	
	105-6	20.6	7.0×10^{-5}	-4.16	
	106-6	25.5	2.5×10^{-4}	-3.60	
	108-2	18.2	5.4×10^{-6}	-5.27	
Hagel bed (B bed)	10-1	47.6	4.8×10^{-5}	-4.32	Lignite
	45-1	31.8	1.4×10^{-5}	-4.85	

TABLE 4.3.1.1.1-1. Hydraulic conductivity values--Falkirk area--Continued

STRATIGRAPHIC POSITION	PIEZOMETER NUMBER	DEPTH (m)	K cm/s	LOG K	MATERIAL
Hagel bed (B bed) continued	75-1	26.9	2.4×10^{-4}	-3.62	
	80-1	47.9	1.4×10^{-4}	-3.85	
	86-1	30.8	1.3×10^{-3}	-2.89	
	92-1	18.3	$\sim 7.9 \times 10^{-3}$	-2.10	
	94-1	15.9	$\sim 7.0 \times 10^{-3}$	-2.14	
Hagel interval (sheet sand)	73-1	21.1	$\sim 2.0 \times 10^{-6}$	-5.70	Sand
	104-1	33.4	2.9×10^{-4}	-3.54	
	105-2	36.6	$\sim 4.0 \times 10^{-4}$	-3.40	
	107-3	21.1	1.5×10^{-4}	-3.82	
Hagel interval (B bed interval)	106-3	40.3	2.5×10^{-4}	-3.60	Sand & Silt
Hagel interval (C bed interval)	4-1	26.4	4.1×10^{-5}	-4.39	Sand
Tavis Creek bed	3-1	12.6	7.3×10^{-4}	-3.14	Lignite
	107-2	45.0	4.6×10^{-7}	-6.34	
Tavis Creek interval	102-2	54.2	$\sim 2.5 \times 10^{-4}$	-3.60	Sand
Hanson interval (Hensler bed)	102-1	83.5	$\sim 1.2 \times 10^{-3}$	-2.92	Sand
	105-1	82.0	3.8×10^{-4}	-3.42	
	107-1	72.6	2.8×10^{-4}	-3.55	
Cannonball Formation	101-1	108.8	9.9×10^{-8}	-7.00	Sand
Miscellaneous	111-2	21.7	1.2×10^{-3}	-2.92	Lignite/Silt
	113-2	18.6	7.5×10^{-5}	-4.13	

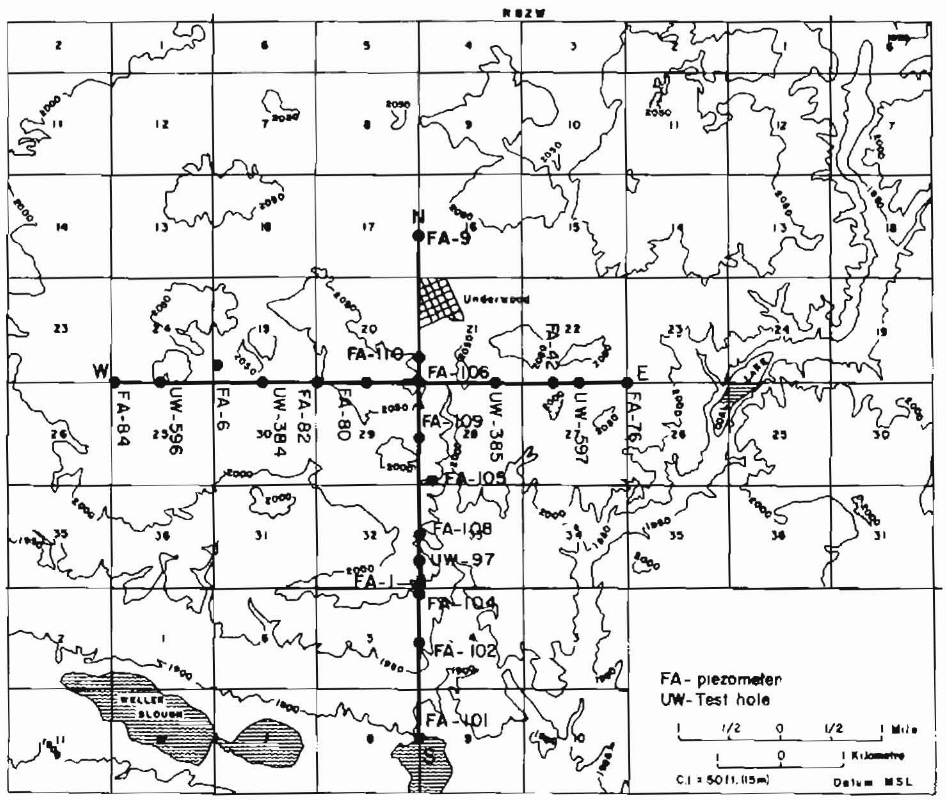


Figure 4.3.1-1. Location of cross sections, Falkirk site.

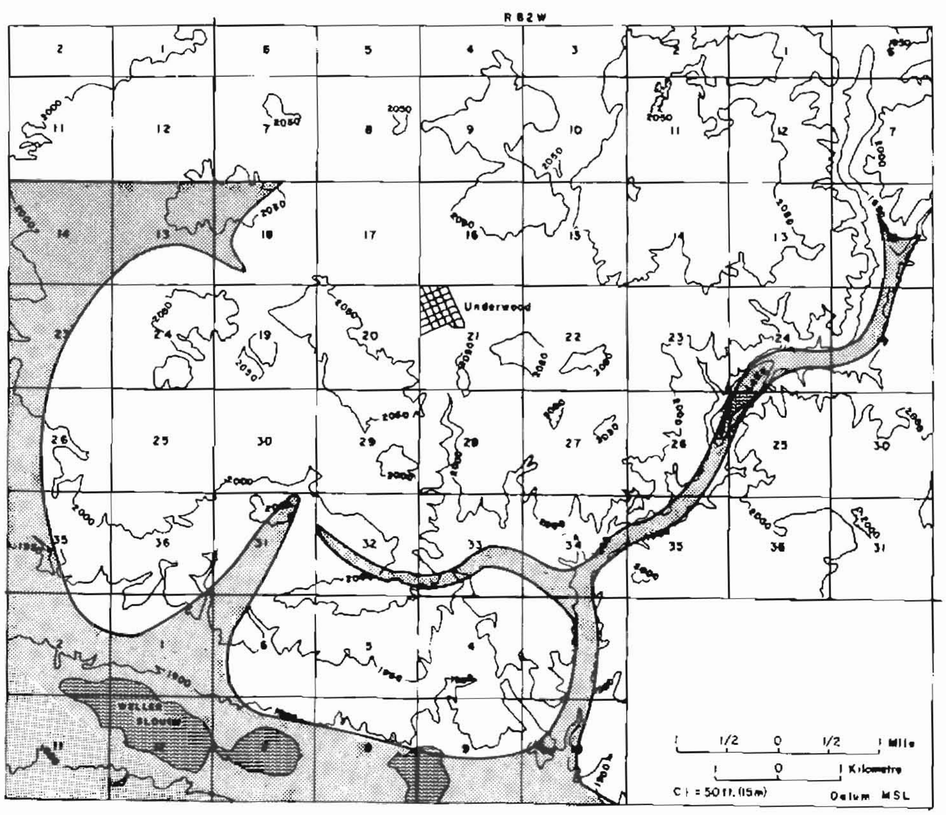


Figure 4.3.1.1.2-1. Approximate extent of sand and gravel channel deposits.

sandy units are extensive enough to be named at the Falkirk site. They are the Underwood sand, which is part of the Kinneman Creek interval; the sheet sand, which is below the B bed in the Hagel interval; and the Hensler bed, which is part of the Hansen interval.

Textural analysis of cores from the shallowest sandy aquifer, the Underwood sand, were undertaken by personnel at the Agricultural Experiment Station, Mandan. The material generally consists of 10 to 20 percent clay, 5 to 15 percent silt and 75 to 85 percent sand. Permeameter tests of 21 samples resulted in hydraulic conductivity values that ranged between 1×10^{-3} cm/s and 6×10^{-7} cm/s with a mean value of 1×10^{-4} cm/s.

A total of 17 single-well response tests were conducted in piezometers in these three units and in several less extensive bedrock sand units. The hydraulic conductivity values ranged from 1.2×10^{-3} cm/s to 4.6×10^{-6} cm/s with a mean value of 2.4×10^{-4} cm/s. An additional 28 tests were executed in similar material of the Sentinel Butte Formation at Dunn Center (Moran et al., 1976). The mean hydraulic conductivity was 4×10^{-4} cm/s with a range of 2×10^{-2} cm/s to 5×10^{-6} cm/s. The specific storages of two sand aquifers determined from pump tests were 5×10^{-6} 1/m and 1×10^{-5} 1/m.

4.3.1.2.3 Lignite aquifers.--The two shallowest lignite beds, the main Hagel and the B bed split, are extensively instrumented. A total of 24 single-well response tests were carried out in these two units and the Tavis Creek bed (table 4.3.1.1.1-1). The average hydraulic conductivity of the lignite beds is 2.5×10^{-4} cm/s with a range of 9.7×10^{-3} cm/s to 4.6×10^{-7} cm/s. In the Dunn Center area, the 81 values of hydraulic conductivity for the lignite have a mean value 6×10^{-4} cm/s with a range of 6×10^{-1} cm/s to 1×10^{-6} cm/s (Moran et al., 1976). Nine of the values were obtained from pump tests. Storativity values are listed for seven observation wells divided between two pump tests. The deeper of the two tests yielded a mean specific storage value of $5 \times 10^{-5} m^{-1}$. The shallower test, which yielded a very high specific storage value, was conducted on a lignite bed that may have been under water table conditions. A very high specific storage value is indicative of unconfined conditions, in which case, the storativity value approaches the specific yield of the aquifer which approximates the aquifer's porosity. The specific storage values determined from the shallow pump test are on the order of $5 \times 10^{-3} m^{-1}$. The storativity of the Hagel bed in the vicinity of piezometer 5-1 was estimated from the barometric efficiency of the aquifer following the procedures described by Jacob (1940). The porosity of the lignite is due to fracturing and parting along bedding planes. A general porosity for fractured porous media is on the order of 0.1 to 0.01 (Walton, 1970) which agrees with the data from the shallow pump test. Assuming an effective porosity value of 10^{-2} for the lignite at site 5 results in a very small specific storage value of $4 \times 10^{-8} m^{-1}$. The reasons for this extremely low value are not known.

The areal distribution of hydraulic conductivity in the main Hagel and the B beds is shown in figure 4.3.1.2.3-1. The conductivity of the B bed increases from

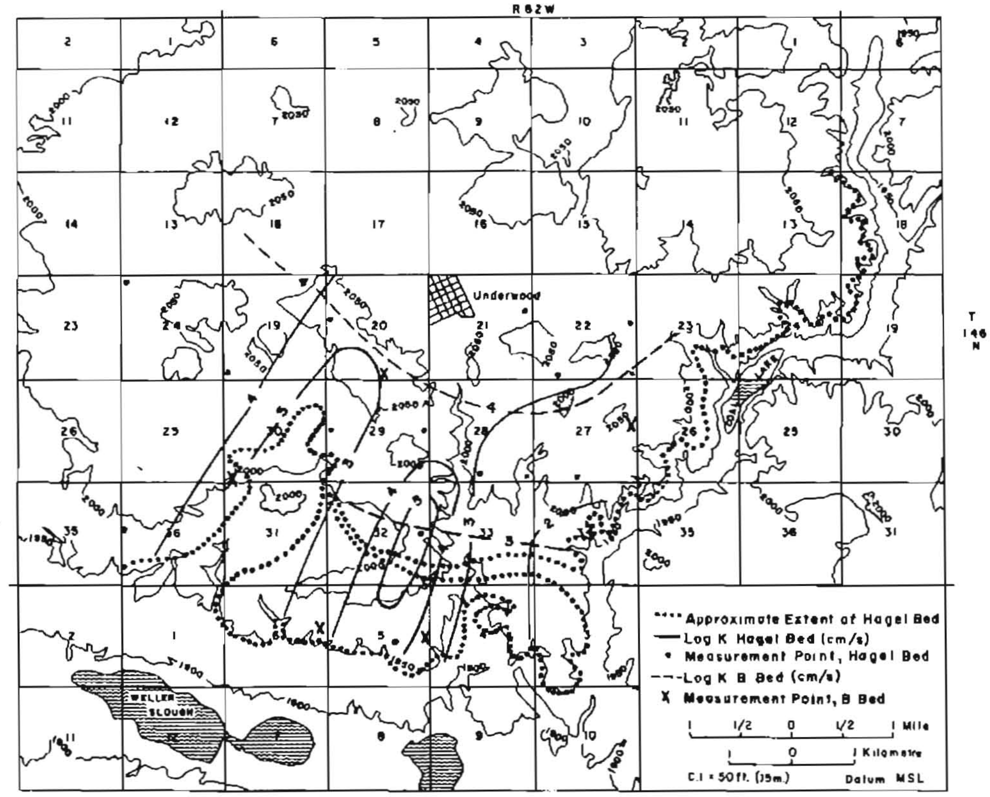


Figure 4.3.1.2.3-1. Areal distribution of hydraulic conductivity in the main Hagel and B beds.

north to south in a very regular manner. The distribution of hydraulic conductivity within the main Hagel bed is more complex. There are two zones of low conductivity running approximately north-northeast to south-southwest through the center and along the western third of the bed. The eastern margin of the main Hagel bed and a narrow zone just southwest of the town of Underwood are zones of higher hydraulic conductivity. At present, the reasons for this distribution of conductivity are not known.

There also appears to be a very approximate relationship between the hydraulic conductivity of the lignite and the depth below ground surface of the conductivity measurement (fig. 4.3.1.2.3-2). The equation of the line of the least squares linear regression is:

$$\log K = -4.4759 - (0.0636d)$$

$$r = 0.487$$

where d is the depth of the measurement in metres and K is the hydraulic conductivity in cm/s. The correlation coefficient of the line is 0.487. If the fractures in the lignite through which flow occurs are horizontal or subhorizontal, then it would be likely to expect the fracture opening, and therefore the hydraulic conductivity, to be a function of vertical confining pressures or overburden thickness. The exact relationship is probably obscured by several episodes of loading and unloading due to erosion and deposition of sediments associated with glacial advances and the loading and unloading caused by the advance and retreat of the ice itself.

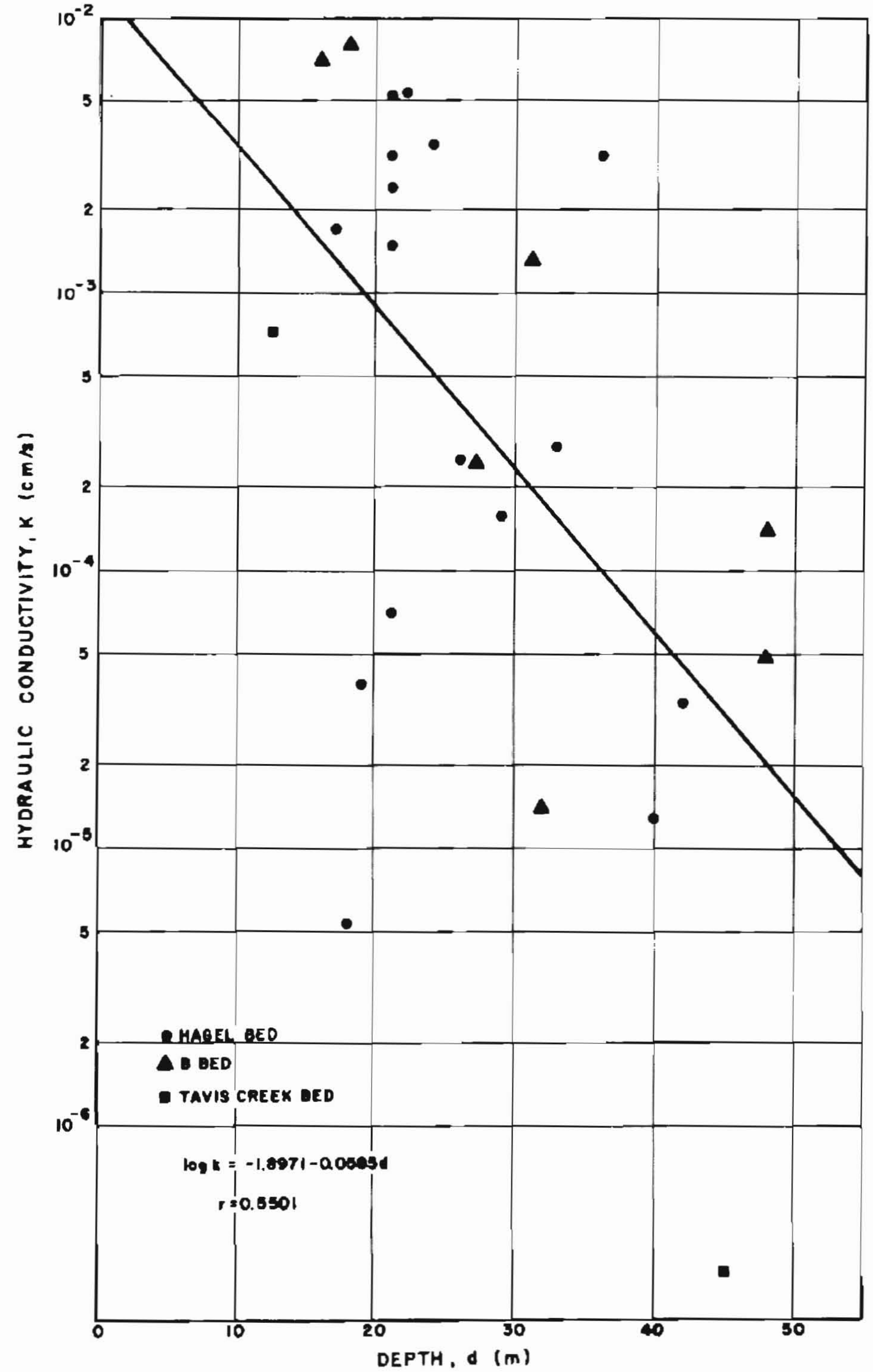


Figure 4.3.1.2.3-2. Relationship between the hydraulic conductivity of the lignite and the depth below the ground surface of the measurement.

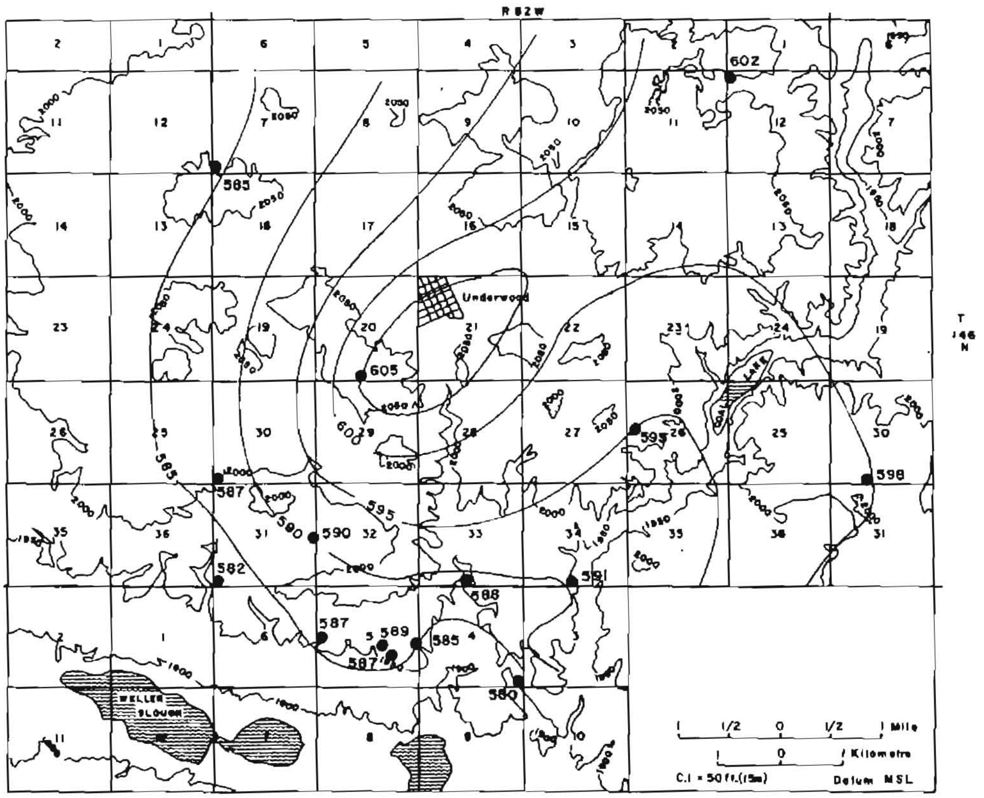


Figure 4.3.2.1.4-1. Elevation of the potentiometric surface of the B bed in metres above MSL. April, 1977.

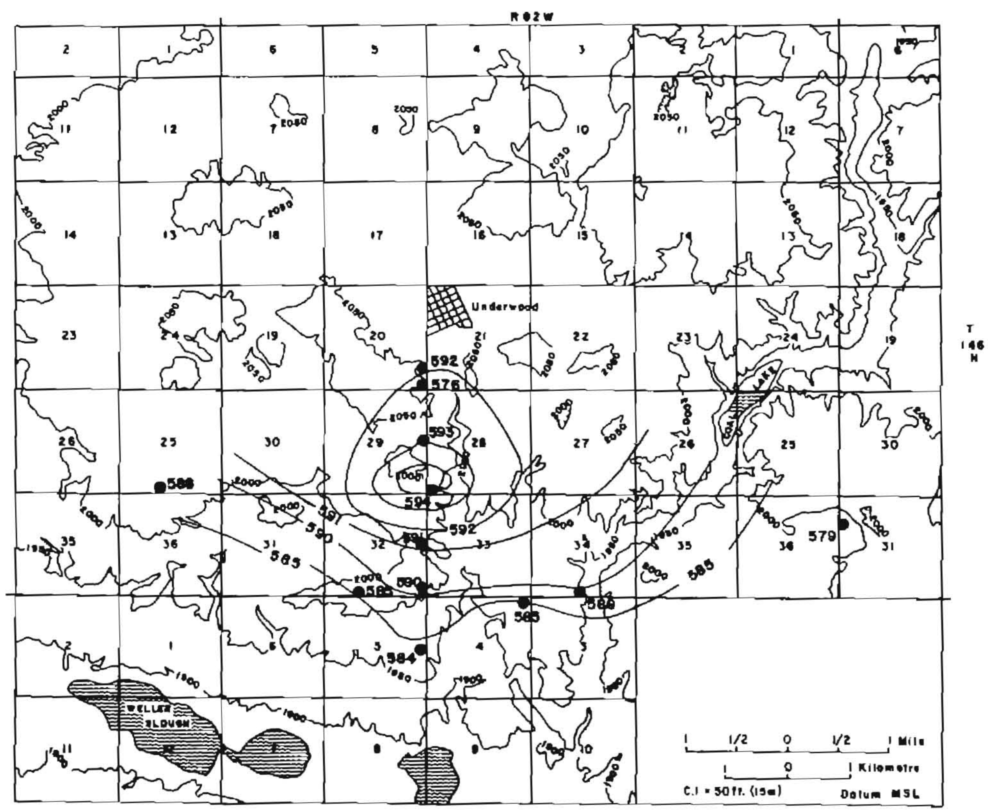


Figure 4.3.2.1.5-1. Elevation of the potentiometric surface of the sheet sand in metres above MSL. May 26, 1977.

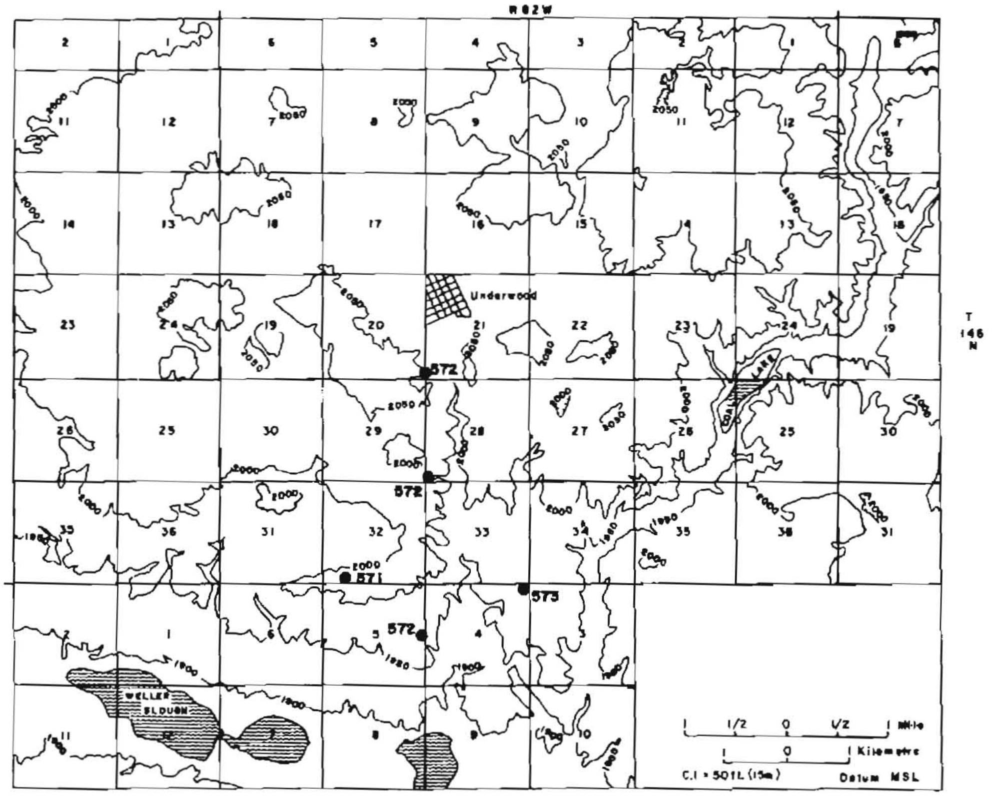


Figure 4.3.2.1.6-1. Elevation of the potentiometric surface of the Hensler bed in metres above MSL. April 26, 1977.

piezometer nests containing closely spaced piezometers finished within the aquitards or within the aquifers on either side of an aquitard are required. There are very few sites instrumented to this extent within the Falkirk study area, therefore there is little data available on vertical hydraulic gradients.

Some estimates of vertical hydraulic gradients are presented in table 4.3.2.2-1. The gradients in the Underwood sand are negative (downward flow) and average -0.23. The situation in the Hagel interval is more complex. The vertical gradients in the area extending due west from piezometer nest 8 is a zone of very low gradients that are generally negative. Two areas of strongly upward hydraulic gradients have also been identified. The first is located in SW¼SW¼SW¼sec 15, T146N, R82W, and the second, larger zone extends from NE¼sec 4 to NW¼sec 5, T145N, R82W. The significance of this distribution is not known. Three hydraulic gradient values for the Hagel interval are presented in table 4.3.2.2-1. Vertical flow components through the study area are shown in figures 4.3.2.2-1 and 4.3.2.2-2.

4.3.3 Groundwater-Flow Systems

The large water table and potentiometric mounds that dominate the groundwater-flow system at the Falkirk site probably result from a combination of two processes: (1) site specific recharge just south of the town of Underwood and (2) regional drainage of the Sentinel Butte and Bullion Creek aquifers

TABLE 4.3.2.2-1. Approximated vertical hydraulic gradients

	Piezometer Nest	Gradient
Underwood sand	8	0.00
	106	-0.09
	78	-0.59
	43	-0.32
	105	-0.17
	Average	-0.23
Hagel interval	75	-0.83
	80	-0.14
	111	+0.14

by the deep, permeable channel-fill complexes in the Weller Slough, Coal Lake Coulee and preglacial Knife River channels.

Water enters the groundwater-flow system as precipitation and snowmelt that infiltrates through the unsaturated zone to the water table. At the Falkirk site the thickness of the unsaturated zone varies in thickness from less than 6 feet (2 m) at piezometer nest 8 to over 98 feet (30 m) approximately 1 mile (1.6 km) west of nest 8. Over most of the study area a combination of the following four factors control the actual recharge to the groundwater: (1) an extensive, low permeability till cover, (2) high evapotranspiration rates, (3) the months of maximum precipitation coincide with periods of high evapotranspiration rates, and (4) low frequency of high intensity precipitation that would result in flow occurring through the unsaturated zone to the water table.

The high evaporation rates result in the removal of large amounts of precipitation before the water enters the soil. The low permeability of the soil prevents the rapid downward movement of the infiltrating water allowing for further evaporation and transpiration. In areas of very low slopes and in closed depressions or sloughs, where precipitation and runoff can collect, the quantity of water infiltrating may be greater than the amount of water that is evapotranspired leading to infiltration well into the unsaturated zone below the reach of plant roots. If the water table is close enough to the ground surface, direct recharge of the groundwater will occur. The presence of permeable sand and gravels above the water table will also facilitate groundwater recharge by allowing rapid infiltration of water below the reach of evapotranspiration processes.

Over much of the Falkirk study area the water table is over 45 feet (15 m) below the ground surface. In these areas of deep water tables, water from a single precipitation event, that is of sufficient magnitude to result in infiltration below the zone of evapotranspiration, cannot reach the water table. This water is stored in the pores of the unsaturated zone and further downward movement of water will not occur until there is another significant infiltration event.

In the area in which the water table mound and potentiometric high are greatest the till cover is thin (less than 15 feet (5 m)) to nonexistent, the material underlying the till is relatively permeable silty sands and the water table is as little as 3-6 feet (1-2 m) below the ground surface. These conditions increase the probability of actual groundwater recharge in this area, relative to much of the remainder of the uplands in the study area, which leads to the establishment of the groundwater mound. Recharge in the area surrounding Underwood may also be favored by extensive glaciofluvial outwash deposits. These deposits may be in contact with the bedrock sand thereby allowing a greater amount of direct ground-

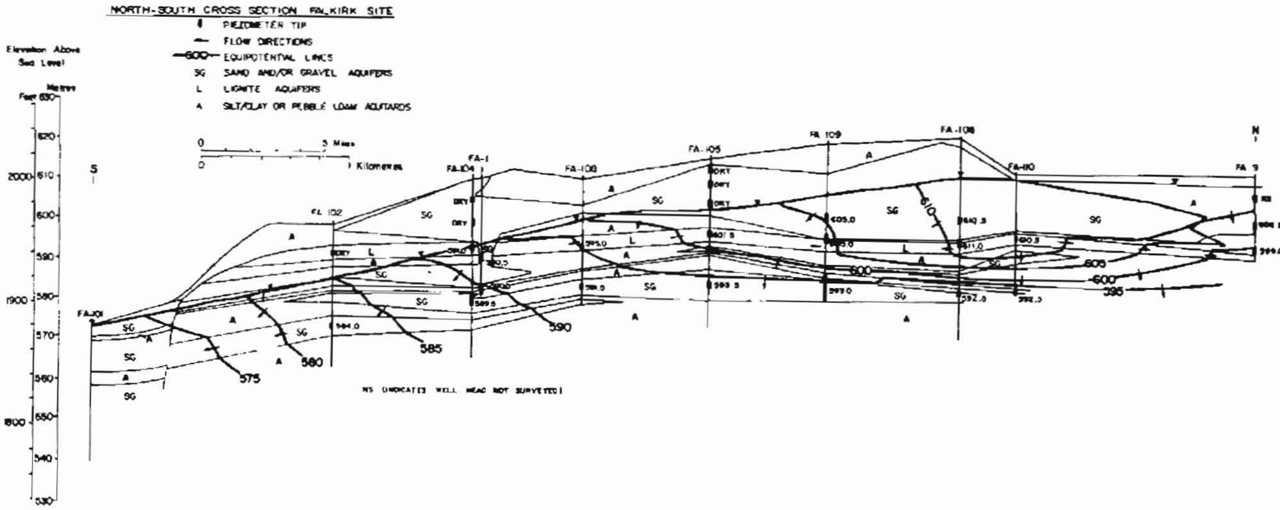


Figure 4.3.2.2-1. North-south cross section of the Falkirk site showing vertical hydraulic gradients.

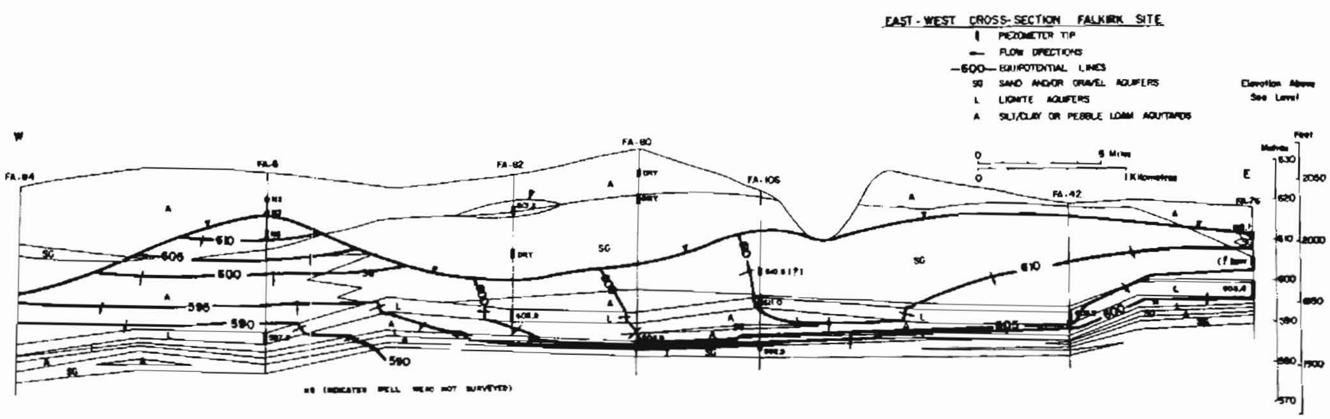


Figure 4.3.2.2-2. East-west cross section of the Falkirk site showing vertical hydraulic gradients.

water recharge. The channels are also slight topographic lows which cause them to be collection points for precipitation and runoff.

Once the water reaches the water table it flows downward and outward toward the channel complexes to the east, south, and west. The dominant downward flow is first interrupted by the main Hagel bed (fig. 4.3.2.2-1 and 4.3.2.2-2) in which the flow is predominantly horizontal. The flow direction in the Hagel interval is again downward due to the high permeability contrast between the lignite aquifers and the silt/clay aquitards.

The creation of a potentiometric high in the B bed and sheet sand solely by site specific recharge (or leakage) would require that the leakage through the 15-26 feet (5-8 m) of silt and clay between the main Hagel and B beds in the area of the high be greater than leakage elsewhere in the study area. There is no evidence to support or refute the interpretation, but the existence of the very permeable channel deposits on three sides of the study area could control the formation of the high without the need of site specific recharge or leakage. Recharge would take place throughout the study area whenever the soil moisture conditions permit the infiltrating water to reach the water table. Leakage through the Hagel interval would be dependent only on the potential drop between the Hagel and B beds. The hydraulic head within the Underwood sand, main Hagel bed, B bed and sheet sand would drop along the eastern, southern, and western edges of the study area due to the drainage of the groundwater by the permeable sand and gravel channel deposits. The situations are analogous to the establishment of drainage ditches, with an essentially infinite hydraulic conductivity, in agricultural areas to lower water table elevations.

In the case of the Underwood sand and main Hagel bed both site specific recharge and regional groundwater drains probably control the formation of the groundwater high since the possibility for groundwater recharge is greater in the area around Underwood. For the B bed and sheet sand the regional drainage established by the channel deposits is probably the major control since higher recharge rates are not likely to occur through the Hagel interval in the area of the potentiometric high.

The directions of groundwater flow within the channel deposits have not been defined. According to the bedrock map compiled by Bluemle (1971), the water would probably flow west from the Weller Slough area (101-1 water level 1890 feet (576 m)). The Coal Lake Coulee channel would direct water southwards into Weller Slough channel. Along the western and northwestern side of the study area the preglacial Knife River channel would direct water southwestward to the Missouri River. Another interpretation of the same data, by Klausing (1974), indicates that the Weller Slough complex trends northward to the west of Underwood and the Coal Lake Coulee channel trends northward into the Nettie Lake Aquifer System in the preglacial Missouri River channel. This bedrock configuration would seem to indicate that water in the Coal Lake Coulee channel would flow northward. Water in the east-west portion of the Weller Slough complex would probably still flow westward, but it would not follow the channel northward since this would be perpendicular to the regional groundwater gradients.

4.3.4 Distribution of Environmental Isotopes

4.3.4.1 Introduction

Samples from selected wells were analyzed for oxygen-18 and tritium. The purpose of these analyses was (1) to gain further information about the sources, flow patterns, and ages of groundwater in the Falkirk area, (2) to establish some base line isotopic data that can be used in the future for comparison with new values when mining activities are in progress, (3) to test for the presence of drill water in observation wells that may not have been adequately cleaned. Before proceeding with discussion of the results of the isotope analyses, some of the terminology and principles necessary for interpretation of the data are presented.

Water (H_2O) is composed of two atoms of hydrogen and one atom of oxygen that are bound by a combination of covalent and ionic bonding processes. The normal hydrogen in water has an atomic number of 1 and an atomic weight of approximately 1, and normal oxygen has an atomic number of 8 and an atomic weight of approximately 16. In the hydrological cycle, nearly all water molecules are composed of these normal hydrogen and oxygen components. Some water molecules, however, are formed partly or entirely of other isotopes of hydrogen and oxygen. Hydrogen has two other isotopes referred to as deuterium and tritium. Normal hydrogen (^1H) has 1 proton in its nucleus, deuterium (^2H, but commonly designated as D) has 1 proton and 1 neutron with an atomic mass of 2, and tritium (^3H, but commonly designated as T) has 1 proton and 2 neutrons for a mass of 3. Tritium is radioactive with a half life of 12.3 years; the other two isotopes are stable. The isotope of oxygen that is of interest here is oxygen-18. In the hydrologic cycle, the abundant type of water molecule is, of course, $^1H_2{}^{16}O$. The molecules $HD^{16}O$, $HT^{16}O$, and $H_2{}^{18}O$ and other combinations occur in only very small concentrations. For example, in sea water $HD^{16}O$ and $H_2{}^{18}O$ occur in average concentrations of 320 and 2 000 ppm, respectively (Payne, 1972). The isotope ratios, measured in a mass spectrometer, are normally expressed in delta units (per mille) with notation $\delta\,^{18}O$ and D based on the definition:

$$\delta = [(R-R_{standard})/(R_{standard})] \times 1\ 000$$

where R and $R_{standard}$ are the isotopic ratios of the sample and standard, respectively. In this study, as is generally the case in hydrology, the standard used is Standard Mean Ocean Water represented by the abbreviation SMOW. The standard is a close approximation of the isotopic composition of the oceans.

Based on the SMOW standard, the ^{18}O content of waters in the hydrological cycle normally range between about O and -25 per mille. In inland continental regions the lightest values (i.e., the most negative) are found in snow and the heaviest values in surface water that has undergone considerable evaporation. The ^{18}O values differ for individual rain events depending on the meteorological history of the vapour mass from which the rain is derived and on the temperature of the air mass as the rainfall is produced. Colder climatic conditions tend to produce lighter ^{18}O rainfall values. The ^{18}O content of infiltration water that recharges the water table zone of groundwater-flow systems depends on the ^{18}O content of the rain or snow that lands on the ground surface and on the extent of evaporation that occurs before the water infiltrates a significant distance into the soil. If the groundwater is being recharged by seepage from a surface-water body such as a lake or river, the ^{18}O content of the groundwater will be the same as the surface water and will mainly reflect the extent of evaporation that occurred in the surface-water environment. The ^{18}O content of the water, as it resides in the groundwater-flow system, remains unchanged by chemical or biochemical processes except in exceptional circumstances, such as in geothermal areas. Oxygen-18 can therefore be viewed as a conservative (non-reactive) natural tracer that is controlled by meteorological factors, surface evaporation, and recharge frequency and occurrence. In favorable circumstances, ^{18}O contents of groundwater can yield usedful information on the source areas of recharge, aquifer mixing, and surface water-groundwater interactions.

Tritium has always occurred in water in the hydrologic cycle, but it has only been since 1953 that the concentrations in rain, snow, surface water and young groundwater have become relatively high. The large increase in tritium concentrations occurred in 1953 because of atmospheric tests of thermonuclear devices by the USA and USSR. The atmospheric tests began in 1952, with further series of tests in 1954 and 1958, with a final series of tests in 1961 and 1962 before the moratorium on atmospheric testing. In this study, as in most hydrological studies, the tritium concentrations are expressed in tritium units, abbreviated as TU. One tritium unit corresponds to a concentration of 1 tritium atom per 1×10^{18} atoms of hydrogen.

Before atmospheric testing of thermonuclear devices, rain and snow had very low tritium concentrations (believed to have been in the range of 5 to 10 TU; Payne, 1972) that were produced by cosmic ray bombardment of nitrogen in the atmosphere. As a result of the atmospheric testing, the tritium values for rain and snow in the interior of North America rose to peaks above 1 000 TU following the major tests. By 1967 the annual peaks had fallen below about 600 TU and during the past few years in the interior of North America have gone down to the range of about 50 to 200 TU. The tritium content of groundwater is dependent on the concentration of the rain or snow that fell on the ground surface and on the time elapsed since the water infiltrated below ground surface. Because the half life of tritium is 12.3 years and because the pre-1953 tritium concentrations were only 5 to 10 TU, concentrations of tritium in pre-1953 water in the groundwater zone are now less than about 3 TU.

In this study the tritium analyses were done at the University of Waterloo by direct liquid scintillation counting. To avoid interference by luminescence, the samples were distilled prior to placement in the counting apparatus. The samples were not, however, enriched. The lower limit of detection by this method of analysis is approximately 10 to 15 TU (expressed as a mean value). Samples with small mean values, have, in proportion large counting errors (expressed as one standard deviation about the mean) because the tritium levels are close to or at the level of background activity to which the counting apparatus is exposed. Because the tritium content of rain and snow in the Northern Hemisphere has been far above 10 to 15 TU since 1953, the detection limit and precision of the tritium analyses used in this study are quite adequate for differentiation of pre-1953 water from post-1953 water. In situations where a small portion of modern water has mixed with a large portion of old water, the detection limit is not low enough to permit identification of the presence of the modern water.

4.3.4.2 Tritium in groundwater and surface water

The results of tritium analyses of samples from observation wells (piezometers), farm wells, and surface water bodies in the Falkirk area are listed in table 4.3.4.2-1. Quite a few samples did not yield a positive number of disintegrations relative to the background. There is a very high degree of probability that these samples contain no significant bomb tritium. The samples with mean values less than about 10 TU also have a very high probability of containing no significant bomb tritium. With the exception of five samples, the groundwater samples therefore are devoid of tritium that originated during atmospheric weapons testing since 1953.

The three surface water samples from the Falkirk area that were analysed have tritium values in the range of 57 to 102 TU. A sample of rain collected in the Dunn Center area on September 27, 1975 had a tritium content of 102±9 TU. Precipitation sampling stations operated during the past two years in Gimli, Manitoba, and Wynyard, Saskatchewan have yielded mean values on accumulated monthly precipitation samples of 50 to 140 TU. It can be concluded that the three tritium values for surface water in the Falkirk area are in the range expected for rain and snow that has fallen during the past few years.

During the period of 1964 to 1969, monthly samples of precipitation from Bismarck, North Dakota, were analysed by the International Atomic Energy Agency, Vienna, and are reported in a data summary published by this organization in 1975. In 1964 the weighted mean annual tritium content of precipitation at Bismarck was 2 900 TU. By 1969 the annual value decreased to 377 TU. By analogy with long-term sampling results elsewhere in North America, it is reasonable to conclude that the mean annual values have decreased gradually to a present-day value of about 100 TU.

The absence of significant tritium levels in nearly all of the groundwater samples indicates that nearly all of the groundwater in the Falkirk flow system was recharged prior to 1953. Using tritium data, a similar conclusion was arrived at by Moran et al. (1976) for the Dunn Center area. This conclusion is in corroboration with the results of a groundwater velocity analysis based on the Darcy equation, as described in later sections of this report.

Of the four groundwater samples that contain tritium at levels that are significantly above the detection limit, only one (78-1) has a value that indicates a large percentage of modern water. The other three (83-1, 94-1, 106-6, and the farm well at SWNWSWsec 23, T146N, R82W) are closer to the detection limit than to the range typical of modern-day precipitation.

The tritium at site 83 is probably the result of contamination with drilling fluid, and a second site, 78, may be a result of contamination by drilling fluid from the drilling of a nearby test hole. The well at site 83 is in the main Hagel bed beneath approximately 30 to 40 metres of mostly fine-grained sediment of the Coleharbor and Sentinel Butte Formations. Considerations of hydraulic conductivity and flow velocity suggest that it is very unlikely that tritiated water would occur here.

TABLE 4.3.4.2-1. Tritium content of groundwaters at the Falkirk site

Sampling Point	Stratigraphic Unit	Depth (m)	Tritium Content (TU)
Underwood Slough #3	---	---	57±10
Underwood Sewage Lagoon	---	---	68±10
Weller Slough East	---	---	102±10
			120±10
5	Main Hagel bed	21.8	-13± 9
42	Main Hagel bed	29.0	0± 9
43-1	Main Hagel bed	34.4	-23± 9
			-20±10
			-3±10
75-1	B bed	26.9	-30± 9
76-1	Main Hagel bed	21.3	7± 9
77-1	Main Hagel bed	21.8	4± 9
			15± 9
78-1	Main Hagel bed	20.6	47±10
83-1	Main Hagel bed	42.1	29±10
			-2± 9
94-1	B bed	15.9	27±10
101-1	Cannonball Formation	108.8	-3± 9
101-2	Coleharbor Formation	76.1	-6± 9
			-9±10
104-1	Sheet sand	33.4	-1± 9
106-3	B bed interval	40.3	-15± 9
			-4± 9
106-4	Underwood sand	22.3	-20± 9
106-6	Main Hagel bed	25.5	21± 9
109-1	B bed & Sheet sand	37.0	4± 9
109-3	Main Hagel bed	26.7	-10± 9
Water Supply Wells			
Underwood City Well	Hensler bed	120.5	-17± 9
NWSWSWsec 08, T145N, R81W	Hensler bed	70.1	-1± 9
			6± 9
SESESEsec 06, T146N, R81W	Hensler bed	79.2	10± 9
NWSWNWsec 08, T146N, R81W	Hensler bed	45.7	-16± 9
			-17± 8
NESWSWsec 18, T146N, R81W	Tavis Creek bed	45.1	-12± 9
SESESEsec 18, T146N, R81W	Hensler bed	56.7	-12± 9
SWSWSWsec 31, T146N, R81W	Hensler bed	85.3	-1± 9
			-40± 9
NWSESEsec 13, T146N, R82W	Hensler bed	76.8	-19± 8
SENESWsec 20, T146N, R82W	Hensler bed	92.7	4± 9
			-25± 8
SWNWSWsec 22, T146N, R82W	Hensler bed	73.2	22± 9
SWNENWsec 23, T146N, R82W	Cannonball Formation	167.6	-17± 9

TABLE 4.3.4.3-1. Oxygen-18 ratios for groundwater at the Falkirk site

Sampling Point	Stratigraphic Unit	Depth (m)	^{18}O Content* (°/oo)
5-1	Main Hagel bed	21.8	-12.94
81-1	Main Hagel bed	33.5	-15.41
82-1	Main Hagel bed	36.2	-14.95
88-1	Main Hagel bed	21.2	-13.59
89-1	Main Hagel bed	17.4	-15.56
94-1	B bed	16.2	-15.86
101-1	Cannonball Formation	108.8	-16.80
101-2	Coleharbor Formation	76.1	-14.23
102-1	Hensler bed	83.5	-13.45
104-1	Sheet sand	33.4	-15.91
104-3	Underwood sand	11.9	-14.72
106-4	Underwood sand	22.3	-15.68
106-6	Main Hagel bed	25.5	-15.74
107-1	Hensler bed	72.6	-12.38
Weisz	Hensler bed	75.6	-15.80
		Average	-14.87±1.28

*All ^{18}O values relative to SMOW.

Site 78 underlies about 20 m of Underwood sand. The tritiated water may therefore be natural recharge. However, when test hole UW 534 was drilled at this site in 1974 an extremely large amount of water was pumped down this hole as a result of lost circulation. The tritium in well 78 could conceivably be due to the presence of this drilling water in the formation. Repeated pumping and sampling for tritium would be necessary to determine conclusively the origin of tritium at this site.

4.3.4.3 Oxygen-18 in groundwater

The 15 oxygen-18 values that were determined on groundwater samples from the Falkirk site range from -12.4 to -16.8 0/00 (table 4.3.4.3-1). As was explained above, the oxygen-18 content of water is related to the climatic conditions under which the precipitation and recharge occurred. Dansgaard (1964) related oxygen-18 content of precipitation to the mean annual air temperature, t_a, by the expression:

$$\delta^{18}O=0.695t_a-13.6$$

From this relation the calculated average annual $\delta^{18}O$ value for precipitation in the Falkirk areas is -10.1 °/oo. This $\delta^{18}O$ value represents the weighted mean of monthly accumulated precipitation throughout the year. Values for cold rain or snow will be much lighter, more negative, and values for warm summer rainfall will be heavier, less negative. The $\delta^{18}O$ for groundwater recharging from standing surface water is almost invariably heavier than for the precipitation because any evaporation that occurs from standing water results in selective loss of the lighter ^{16}O molecules. In their study of the Dunn Center area, about 100 km west of the Falkirk site, Moran and others (1976) found that groundwater that was directly recharged from snowmelt had values of $\delta^{18}O$ from -18 to -19 °/oo. Groundwater that had undergone considerable evaporation had values of $\delta^{18}O$ from -9.5 to -11.0 °/oo. Whereas water that was only slightly evaporitic ranged from -11.0 to -14.0 °/oo. On this basis four or five of the Falkirk samples (table 4.3.4.3-1) are in the weakly evaporated range.

Most of the oxygen-18 analyses are from wells in the upper part of the Sentinel Butte Formation, in the Underwood bed, the Hagel bed, and the sheet sand. Eight samples from these units form a group with a mean $\delta^{18}O$ of -15.5±0.4 ‰. The remaining two values, -12.9 and -13.6 ‰ are weakly evaporitic. Both wells with evaporitic $\delta^{18}O$ values are situated in the middle part of the slope down from the upland around Underwood and adjacent to surface water bodies. Well 5-1 with a $\delta^{18}O$ value of -12.9 ‰ is located just south of a large slough depression about 500 m X 250 m in size. Recharge from this slough appears to be a significant component of the groundwater at site 5. Similarly site 88 at which the $\delta^{18}O$ value was -13.6 ‰ lies between two small drainageways. Ponded water in the floor of these depressions may be responsible for a significant component of the recharge at this site. The mean value of $\delta^{18}O$=-15.5±0.4 for the shallow aquifers in the Sentinel Butte Formation suggests that most recharge occurs in spring and fall. This conclusion is based on the assumption that the Dansgaard equation above can be used, at least semiquantitatively, to give an approximation of the dominant temperature during recharge even though this is not the mean annual temperature. Inserting this value of $\delta^{18}O$ in the Dansgaard equation gives a temperature range of -3.31°C to -2.2°C. These temperatures occur in the Falkirk area in late March to early April and again in October.

Four oxygen-18 values are available from wells completed in the lower part of the Bullion Creek Formation (Hensler bed) and in the Cannonball Formation. The single sample from the Cannonball Formation is the lightest sample in the Falkirk area, $\delta^{18}O$=16.8 ‰. This value was typical of most of the deeper wells in the Sentinel Butte Formation in the Dunn Center area (Moran et al., 1976). One of the oxygen-18 values from the Hensler bed is very similar to those from the shallow aquifers discussed above. The other two values from the Hensler bed are anomalously heavy with $\delta^{18}O$ of -12.4 ‰ (well 107-1) and -13.4 ‰ (well 102-1). Because both of these wells were drilled with water from the Underwood town well that is completed in the Hensler bed, the heavy $\delta^{18}O$ values cannot be attributed to contamination with evaporitic surface water. Rather they appear to reflect the actual values of groundwater in the Hensler bed. There appear to be two possibilities to account for the source of this water:

1. Recharge under much warmer climatic conditions than at present.
2. Recharge from strongly evaporitic surface water bodies under existing climatic conditions. The Hensler bed is known to subcrop beneath the permeable valley fill sediment that underlies Coal Lake Coulee. It is therefore possible that strongly evaporitic water from Coal Lake has moved downward through this fill to recharge the Hensler bed.

A single determination on water from a well completed in the Coleharbor Formation deep in the valley fill beneath Weller Slough had a $\delta^{18}O$=-14.2 ‰. This value, which is heavier than those typical of the shallow aquifers in the Sentinel Butte Formation, probably represents a mixture of light water from the Sentinel Butte Formation with heavier water from the Hensler bed or the Weller Slough complex of lakes.

Groundwater that was recharged during glacial episodes of the Pleistocene

Epoch (13 000 years ago) would be expected to have very light ^{18}O contents. Observations in southern Manitoba and southern Saskatchewan indicate that groundwater that is Pleistocene in age has ^{18}O values in the range of -20 to -23 ‰. Precipitation with average annual values in this range occur at present in the Arctic region of North America. The absence of very light ^{18}O values anywhere in the flow system of the Falkirk area implies that the groundwater has not been recharged to the system under conditions appreciably colder than at present.

4.3.5 Distribution of Major Ions

The vast majority of analysed groundwater samples from the Falkirk area were sampled during this project. The collection of groundwater samples is described in section 4.1.6. Once the analyses were completed their reliability was evaluated using the cation-anion balance in the form of a standard error. The standard error was defined as the difference of cations and anions, in milliequivalents per liter, divided by the sum of cations and anions, the total being multiplied by 100 to yield a percent. If the standard error was greater than 30 percent the analysis was regarded as totally inaccurate and not considered further. An analysis with a standard error less than or equal to 5 percent was considered a good analysis and an analysis with an error greater than 5 percent but less than or equal to 10 percent was considered acceptable. For analyses with errors between 10 percent and 30 percent, an attempt was made to balance the cation and anion concentrations by difference using either sodium or sulfate. These anions, along with chloride, were difficult to analyze by the methods used during 1976 and early 1977. Chloride concentrations are generally so small as to not significantly effect the standard error. The choice of whether to increase or decrease sodium or sulfate to achieve a charge balance was somewhat subjective. Generally, if the total hardness matched the concentration of calcium plus magnesium, the total concentration of calcium plus magnesium was "low," the sulfate concentration was not "exceptionally high," and the standard error was negative, the sodium concentration was determined by difference. When the total hardness matched the concentration of calcium plus magnesium, the total concentration of calcium plus magnesium was "high," the sodium concentration was "low," and the standard error was negative or positive, the sulfate concentration was determined by difference. Occasionally there was an analysis with a positive error and an "exceptionally high" sodium concentration. In this case the sodium was redetermined by difference to achieve a charge balance. The analyses used in the following discussion of groundwater chemistry are listed in tables 4.3.5-1 through 4.3.5-7. These analyses, as well as all other groundwater analyses from the Falkirk area, are also included in appendix C.

The figures that follow use solid circles to indicate an analysis with a standard error of less than 5 percent, a solid square represents an analysis with a standard error between 5 percent and 10 percent, and an open square is used to represent an analysis that has been corrected by difference.

4.3.5.1 Coleharbor Formation sand and gravel

The chemistry of waters from the Coleharbor sands and gravels is given in

TABLE 4.3.5-1. Selected chemical analyses of groundwater--Coleharbor Formation

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alka- linity	Total Hard- ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Stand- ard Error
FA-3-2 8-25-76	Sand & Gravel	4.0	NA	NA	NA		8.22	1128	972	380	583	184.4	29.7	62.0	5.5	463	14.52	251.40	+4.50
FA-2-1 8-25-76	Sand & Gravel	14.9	NA	NA	NA		7.42	2970	240	153	159	62.7	1.0	1.2	6.6	187	1.49	18.13	-0.72
FA-101-2 8-10-77	Sand & Gravel	76.8	8	7.39	1675	0.2	7.58	1242	919	653	177	31.7	24.2	309.0	14.6	797	11.60	170.30	+0.13

TABLE 4.3.5-2. Selected chemical analyses of groundwater--Underwood sand

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alka- linity	Total Hard- ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Stand- ard Error
FA-106-4 8-2-77	Sand	22.86	10	7.33	1675	0.15	7.75	1257	1473	234	764	198.0	67.0	8.5	1.4	286.0	57.5	570.0	-7.0
FA-8-2 7-7-77	Sand	11.50	8	7.04	1500	0.50	7.32	1271	992	608	620	152.0	53.0	90.0	6.7	742.0	88.6	71.4	-0.4
FA-8-1 7-7-77	Sand	18.00	9	6.98	900	0.40	7.02	743	551	311	342	66.0	38.0	39.0	5.9	379.0	12.5	82.1	0.0
FA-8-1 8-25-76	Sand	18.00					7.84	1230	806	574	582	233.6	0.0	81.0	7.0	701.0	137.1	38.7	-2.5
FA-8-3 8-25-76	Sand	5.90					8.20	847	546	318	357	66.9	44.7	35.6	7.3	388.0	125.9	12.9	-7.4
FA-109-2 8-16-77	Sand	18.30	7	8.27	750	0.40	8.39	739	436	343	365	69.6	39.9	9.5	4.7	418.5	1.2	45.1	-5.6

TABLE 4.3.5-3. Selected chemical analyses of groundwater--main Hagel bed

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alka-linity	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Stand-ard Error
FA-81-1 7-7-77	Lignite	34.30	7	7.75	1100	0.70	7.59	964	724	468.0	445.0	110.0	45.0	68.0	4.9	571.0	46.90	162.2	-6.70
FA-5-1 7-20-77	Lignite	22.30	8	6.97	600	0.20	7.17	633	438	354.0	329.0	74.0	35.0	13.0	6.8	432.0	30.60	46.5	-9.90
FA-88-1 7-20-77	Lignite	21.80	7		1500	1.00	6.87	1192	1034	498.0	656.0	143.0	75.3	45.2	7.5	608.0	43.70	326.0	-7.40
FA-89-1 7-18-77	Lignite	17.40	8		1250	0.85	6.32	1155	1107	420.0	602.0	96.8	96.2	46.7	6.8	512.0	32.90	373.0	-7.70
FA-76-1 7-28-77	Lignite	21.64	11	6.81	790	0.20	7.65	675	712	383.0	360.0	81.2	37.8	10.9	4.0	467.0	5.60	66.0	-8.60
FA-76-1 7-22-77	Lignite	21.64	8		860	0.20	8.13	632	463	310.0	295.0	81.5	37.4	9.5	5.0	378.0	9.60	61.0	-0.26
FA-5-1 7-26-77	Lignite	21.80	8		725		7.60	603		352.0	314.0	67.5	33.1	10.9	2.5	429.0	7.24	23.0	-7.60
FA-83-1 7-15-76	Lignite	43.80	12	7.00	2850		7.78	2371	2006	741.0	368.0	56.2	55.2	337.5	13.5	904.5	19.05	142.2	+9.90
FA-84-1 7-15-76	Lignite	40.90	11	7.40	1875		7.32	1650	2110	796.0	694.0	154.2	75.0	115.6	15.2	971.0	80.12	53.3	0.00
FA-85-1 7-15-76	Lignite	18.90	11	7.80	1490		7.33	1310	1798	245.0	285.0	7.9	64.5	100.5	11.4	299.0	20.42	200.6	+3.50
FA-105-6 6-16-76	Lignite	20.60	10	7.40	825		7.67	723	465	395.3	345.0	6.0	80.1	25.0	7.9	482.0	2.82	52.4	-5.20
FA-39-1 7-1-76	Lignite	15.60	10	7.20	960		7.32	866	558	375.0	352.0	32.1	66.1	45.4	9.8	457.0	10.50	155.0	-8.70
FA-106-6 6-4-76	Lignite	25.50	10	7.50	490		7.81	457	274	333.7	245.0	15.3	50.3	17.5	4.6	407.0	3.16	19.2	-10.70
FA-78-1 8-12-77	Lignite	20.60	7	8.93	675	0.40	7.28	648	440	353.0	335.0	62.3	41.3	75.4	5.9	431.0	5.25	130.9	0.00
FA-77-1 8-16-77	Lignite	20.80	7	6.88	900	0.30	7.11	973	739	361.0	461.0	127.0	67.0	14.5	9.4	440.0	8.50	274.6	0.00

TABLE 4.3.5-3. Selected chemical analyses of groundwater--main Hagel bed--Continued

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alka-linity	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Stand-ard Error
Underwood City Well #3 8-26-76	Lignite	27.40	14	8.10						.270.0	300.0	73.0	29.0	18.0	3.1	329.0	15.00	28.0	+1.00
FA-79-1 7-15-76	Lignite	21.80	11	7.60	980		7.45	875	1468	555.5	547.9	46.2	74.7	70.6	10.7	678.0	20.89	118.9	+0.40
FA-83-1 8-16-77	Lignite	42.10	7	7.54	2450		7.67	2327	1787	764.0	301.0	83.2	41.3	569.0	12.3	932.0	13.50	694.2	+4.00

TABLE 4.3.5-4. Selected chemical analyses of groundwater--B bed

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alka-linity	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Stand-ard Error
FA-37-1 7-1-76	Lignite	10.50	9.0		1575		7.41	1351	1280	442.0	743.0	98.9	120.5	11.5	7.0	539	20.40	334.00	-2.6
FA-86-1 7-15-76	Lignite	30.80	11.0	7.5	890		7.51	1015	1572	335.5	347.6	58.1	49.2	41.3	8.8	409	2.19	132.40	-3.0
FA-90-1 7-15-76	Lignite	17.20	11.0	7.2	2010		7.12	1683	2306	485.1	484.4	233.0		99.0	12.3	592	8.71	322.70	-2.8
FA-92-1 7-15-76	Lignite	18.30	11.0	8.0	1750		7.40	1521	2128	447.3	492.3	66.9	79.0	134.5	9.8	546.	12.02	340.70	-1.3
FA-113-2 7-1-76	Lignite	18.60	9.0	7.2	1450		6.31	1249	1308	212.2	658.0	195.6	41.1	30.6	10.6	259	15.85	508.00	-1.8
FA-112-2 7-1-76	Lignite	19.20	10.0	7.0	1650		6.35	1529	1506	303.0	841.0	243.9	56.2	37.9	10.2	369	21.88	680.00	-5.4
FA-94-1 7-15-77	Lignite	15.90	8.0		990	0.25	6.97	925	674	372.0	340.0	78.9	33.4	70.4	4.1	454	39.30	61.92	0.0

TABLE 4.3.5-5. Selected chemical analyses of groundwater--sheet sand

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alka-linity	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Stand-ard Error
FA-107-3 6-16-77	Sand	21.1	14.0	7.30	1395		7.55	1289	940	687.0	309.0	9.8	69.2	247.9	10.9	838	7.76	91.5	-4.1
FA-104-1 8-9-77	Sand	33.4	9.0	6.44	1600	0.2	7.17	1308	1020	611.0	539.0	119.0	50.8	151.0	10.1	745	7.24	284.4	-3.9
FA-104-1 8-9-77	Sand	33.4	9.0	6.44	1600	0.2	7.36	1301	1018	610.0	548.0	131.0	52.9	144.0	10.4	744	8.22	281.2	-2.0
FA-105-2 6-16-76	Sand	36.6	10.0	8.10	700		7.75	678	430	349.8	55.9	5.1	10.5	142.8	5.0	427	0.94	20.6	0.0

TABLE 4.3.5-6. Selected chemical analyses of groundwater--Hensler bed

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alka-linity	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Stand-ard Error
Saylor J. 8-11-77	Sand	57.0	17.0	7.74	1150		7.89	1020.0	710	541	79.6	21.4	7.1	278.0	8.5	660.0	17.40	127.2	0.0
Sheldon O. 8-12-77	Sand	70.0	15.0	8.15	2850		8.28	18.5	1369	889	25.8	7.6	2.2	533.0	3.7	1085.0	39.80	114.2	+5.7
Weisz R. 8-11-77	Sand	76.0	14.0	7.34	1075		7.68	1010.0	622	531	225.0	51.7	22.1	175.0	8.7	648.0	7.24	107.1	-3.2
Saylor R. 8-12-77	Sand	85.0	20.0	8.01	1500		8.19	1285.0	935	700	37.7	5.8	1.8	383.0	3.6	854.0	19.30	136.3	-0.6
Heger L. 8-16-77	Sand	46.0	20.0	7.37	1750		7.82	1589.0	1198	755	356.0	78.0	60.0	379.0	93.0	921.0	15.90	323.3	+6.9
FA-102-1 7-13-77	Sand	54.2	8.0	8.24	1500	0.3	8.18	1374.0	962	677	35.3	0.9	0.7	460.7	1.8	826.0	77.00	215.0	0.0
Underwood City Well 8-19-77	Sand	120.4	10.0	8.69	1290		8.50	1402.0	802	594	14.9	2.5	1.0	351.0	2.4	724.7	1.30	173.4	0.0

TABLE 4.3.5-6. Selected chemical analyses of groundwater--Hensler bed--Continued

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alkalinity	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error
Underwood City Well 8-19-77	Sand	120.4	10.0	8.69	1290		8.73	1402.0	817	597	8.5	2.5	1.1	354.0	1.7	728.3	1.60	175.8	0.0
Schauer E.	Sand	79.3	11.0	7.35	1300		7.78	1696.0	1021	598	390.0	107.0	52.0	262.0	14.2	729.6	1.00	377.0	+3.8
Mautz H.	Sand	76.9	15.0	7.29	950		7.91	954.0	632	538	133.0	46.2	24.4	197.7	8.1	656.4	10.00	100.6	0.0
Schell E.	Sand	72.0	15.0	7.24	535		8.26	511.0	228	336	181.0	48.0	30.9	70.1	6.1	409.9	1.00	67.6	0.0
Sigurdson R. 8-18-77	Sand	91.5	8.0	8.61	1650		8.79	1675.0	1026	712	27.7	3.2	1.1	394.0	2.4	879.6	2.20	109.8	+4.0
Sigurdson R. 8-18-77	Sand	91.5	8.0	8.61	1650		8.69	1668.0	1041	719	14.9	2.5	1.2	386.0	3.3	877.2	2.30	100.0	+1.7
Elurum	Sand	53.4	16.0	7.98	1350		8.83	2700.0	1629	1061	3.4	7.2	3.0	625.0	5.0	1294.4	1.90	308.0	-0.4
FA-105-1 6-16-76	Sand	82.0	11.0	8.20	1310		8.31	1193.0	882	631	45.4	2.3	9.6	314.0	3.8	770.0	4.33	84.0	0.0

TABLE 4.3.5-7. Chemical analyses of miscellaneous groundwater samples

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alkalinity	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error
Surface Water																			
Underwood Slough #3 6-22-77		0.0	16	8.65	1525		8.55	1286	1159.0	584.0	405.0	42.0	74.0	198.0	23.0	912.0	35.50	292.0	-3.70
Kinneman Creek Interval																			
FA-9-1 8-25-76	Silt	18.6	NA	NA	NA		8.29	1110	810.0	365.8	399.3	153.7	3.6	178.0	10.3	446.0	138.40	230.7	0.00

TABLE 4.3.5-7. Chemical analyses of miscellaneous groundwater samples--Continued

Well No. Sampling Date	Material	Depth (M)	Field Temp. (°C)	Field pH	Field Cond.	DO	Lab pH	Lab Cond.	TDS	Alka- linity	Total Hard- ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	Stand- ard Error
B Bed Interval																			
FA-106-3 8-1-77	Sand & Silt	41.2	9	8.33	1300	0.2	8.56	996	750.0	589.0	49.5	7.3	0.5	317.0	2.5	719.0	25.70	71.4	0.00
FA-102-3 6-18-76	Sand	27.0	10	7.80	1590		7.50	1287	896.0	648.4	210.7	1.4	50.3	269.9	10.0	791.0	9.55	143.0	0.00
C Bed Interval																			
FA-4-1 8-25-76	Sand	26.4	NA	NA	NA		7.68	1445	1206.0	490.9	726.4	261.5	17.6	90.0	9.6	598.9	13.60	388.9	0.00
Tavis Creek Bed																			
FA-3-1 8-25-76	Lignite	12.6	NA	NA	NA		7.95	1523	1114.0	709.6	211.7	64.6	12.2	310.0	7.6	866.0	9.40	162.8	+1.00
Tavis Creek Interval																			
FA-102-2 6-18-76	Sand	54.2	10	8.50	2200		8.43	1975	1332.8	962.8	58.1	5.6	3.4	527.0	6.5	1175.0	22.90	181.0	0.00
FA-102-2 7-13-77	Sand	54.2	8	7.83	1850	0.3	8.16	2013	1458.0	945.0	23.7	3.4	1.5	642.0	3.3	1153.0	105.80	308.0	0.00
Cannonball Formation																			
FA-101-1 8-11-77	Sand	118.9	8	8.18	2075	0.1	8.22	1873	1385.0	1063.0	75.7	7.6	3.6	539.0	5.3	1224.0	21.30	196.8	-0.01
Miller (M.) 8-16-77	Sand & Gravel	152.0	11	6.98	1550		7.44	1438	1108.0	515.0	368.0	99.0	57.0	210.8	13.7	628.0	10.00	41.2	0.00

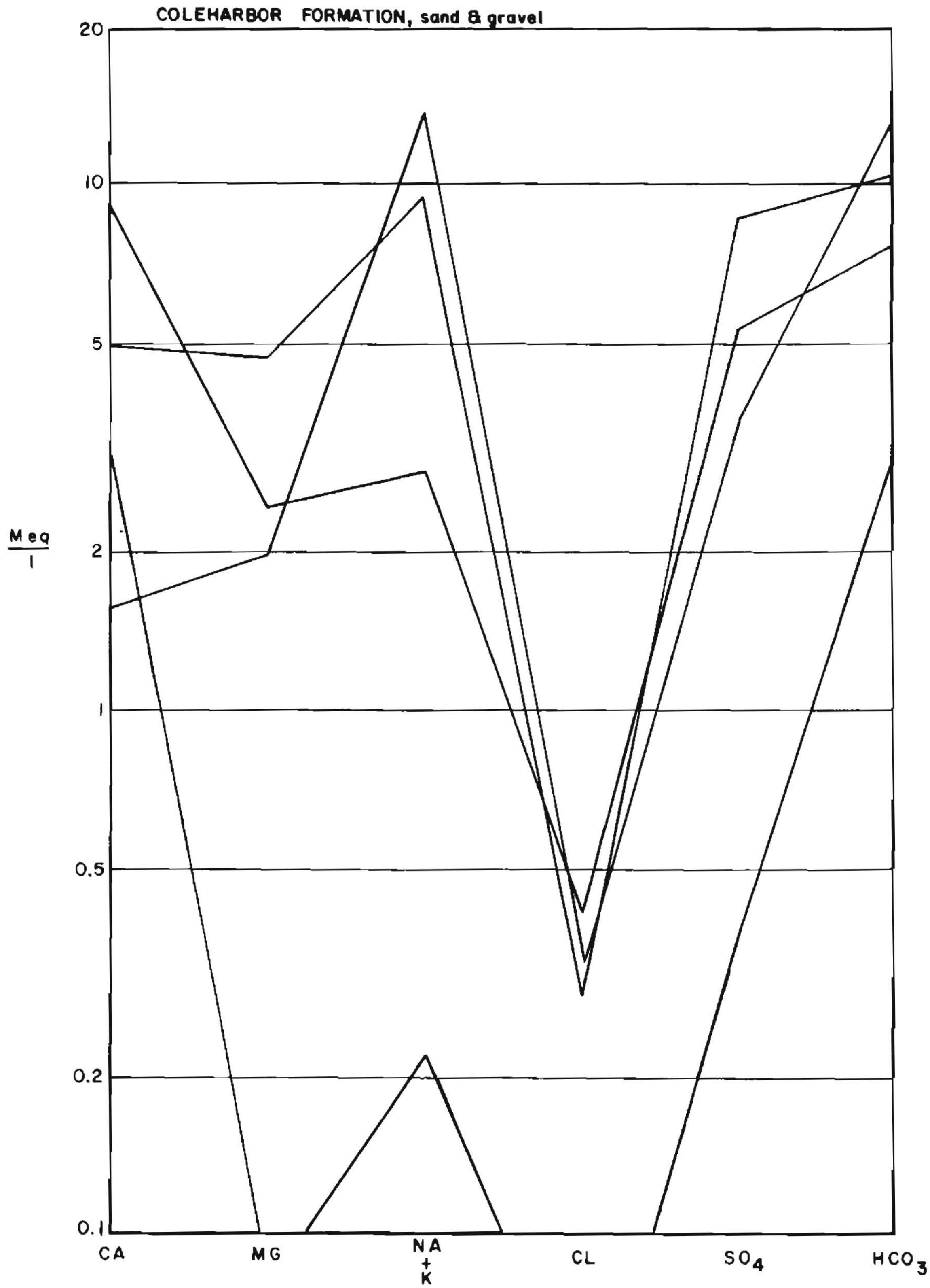


Figure 4.3.5.1-1. Schoeller diagram of groundwaters from the Coleharbor sand and gravel.

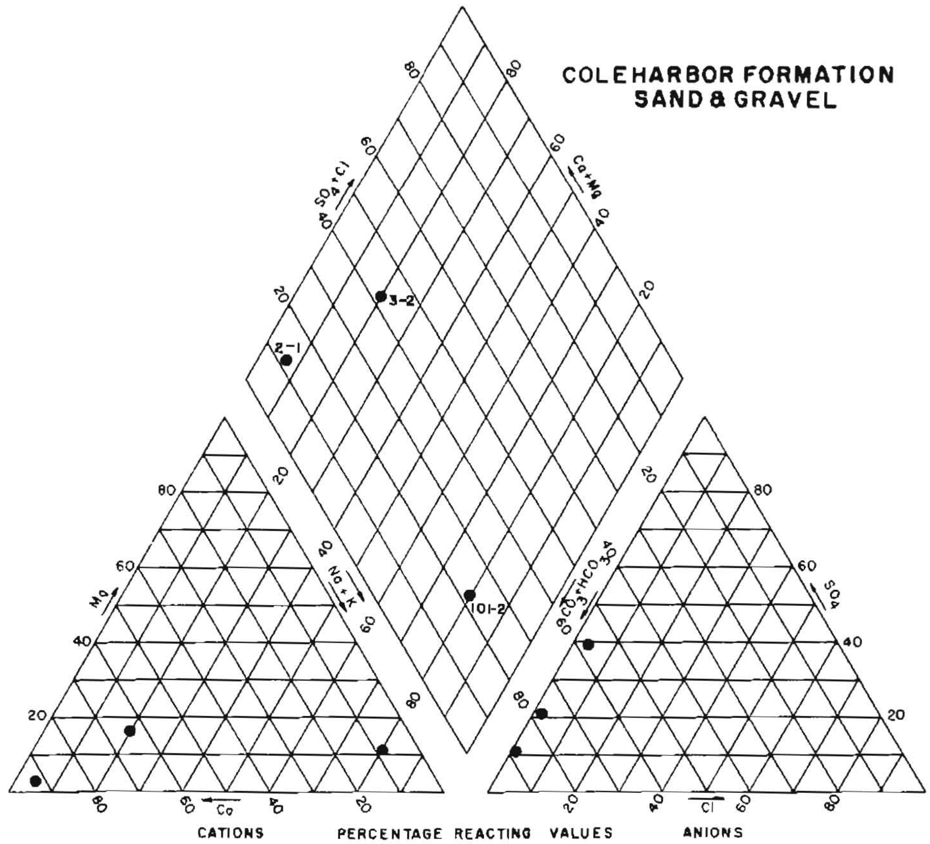


Figure 4.3.5.1-2. Trilinear plot of groundwater chemistry from the Coleharbor sand and gravel.

figures 4.3.5.1-1 and 4.3.5.1-2. The Schoeller diagram in figure 4.3.5.1-1 illustrates each analysis as a single line connecting points representing the concentrations of given ions. It is a useful means of summarizing the raw data presented in tables 4.3.5-1 through 4.3.5-7. Trends or groupings of groundwater analysis are easier to visualize on trilinear plots such as figure 4.3.5.1-2; therefore, the following discussions will center around the trilinear plots.

The shallow groundwater from sand and gravel aquifers is represented by samples from piezometers 2-1 and 3-2 which are located in the east-west channel through the center of the study area. The water is Ca^{2+}, Mg^{2+}-HCO_3^-, SO_4^- with a TDS between 240 and 1 108 mg/L. The sample from piezometer 101-2, located deep within the Weller Slough complex, is a Na^+-HCO_3^- water with a TDS of 919 mg/L. This water is entering the channel complex from the deeper bedrock hydrologic units which contain $Na^+HCO_3^-$ waters (secs. 4.3.5.5 and 4.3.5.6).

Klausing (1974) lists 14 analyses from the Turtle Lake aquifer, a glaciofluvial sand and gravel complex northwest of Underwood. These water samples were Ca^{2+}-HCO_3^- or Na^+-HCO_3^- with TDS values between 277 and 1 360 mg/L. The sodic waters were found along the edges of the valley fills where the influence of inflowing bedrock waters is greatest. Three analyses of waters from the Weller

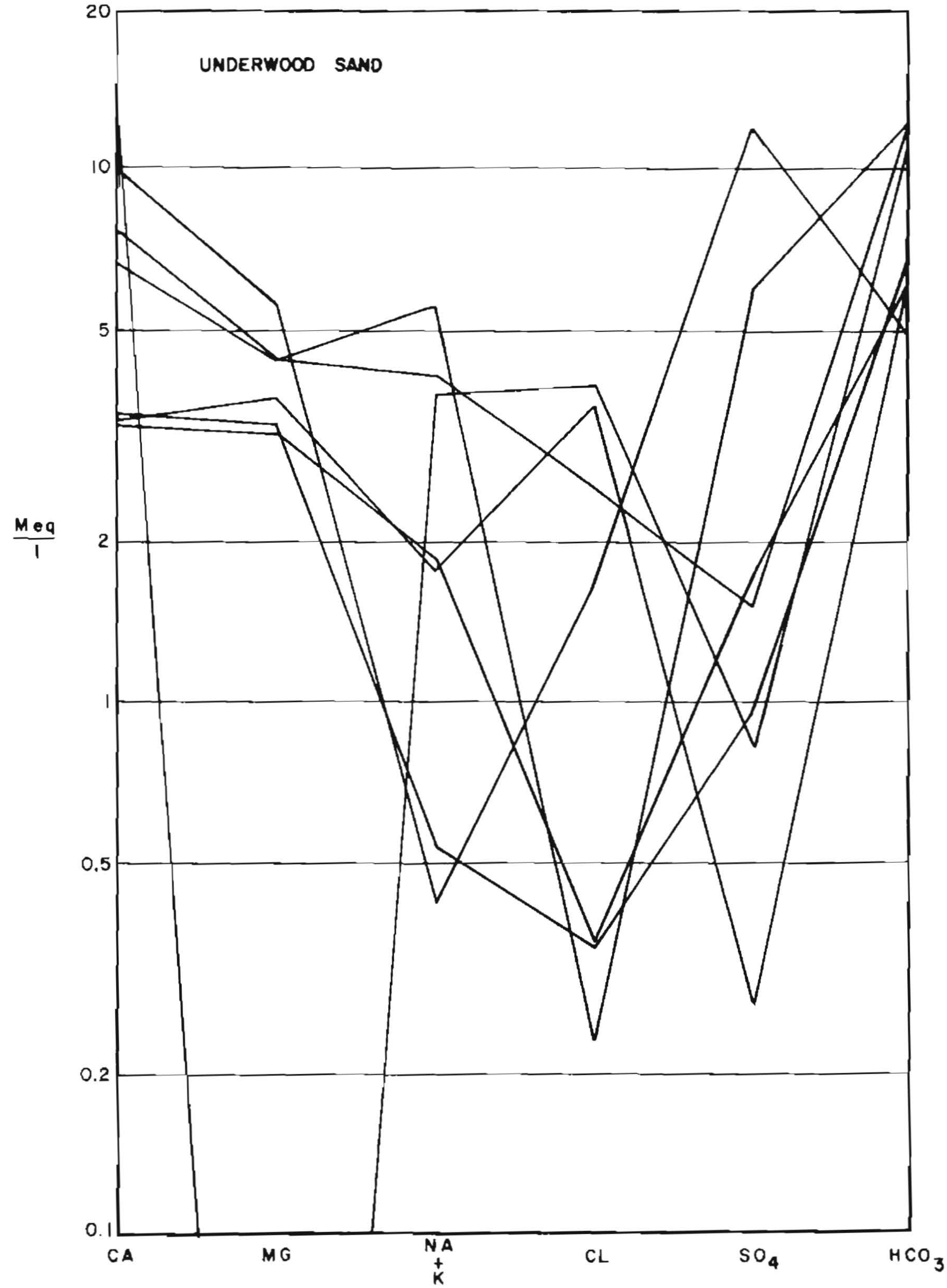


Figure 4.3.5.2-1. Schoeller diagram of groundwaters from the Underwood sand.

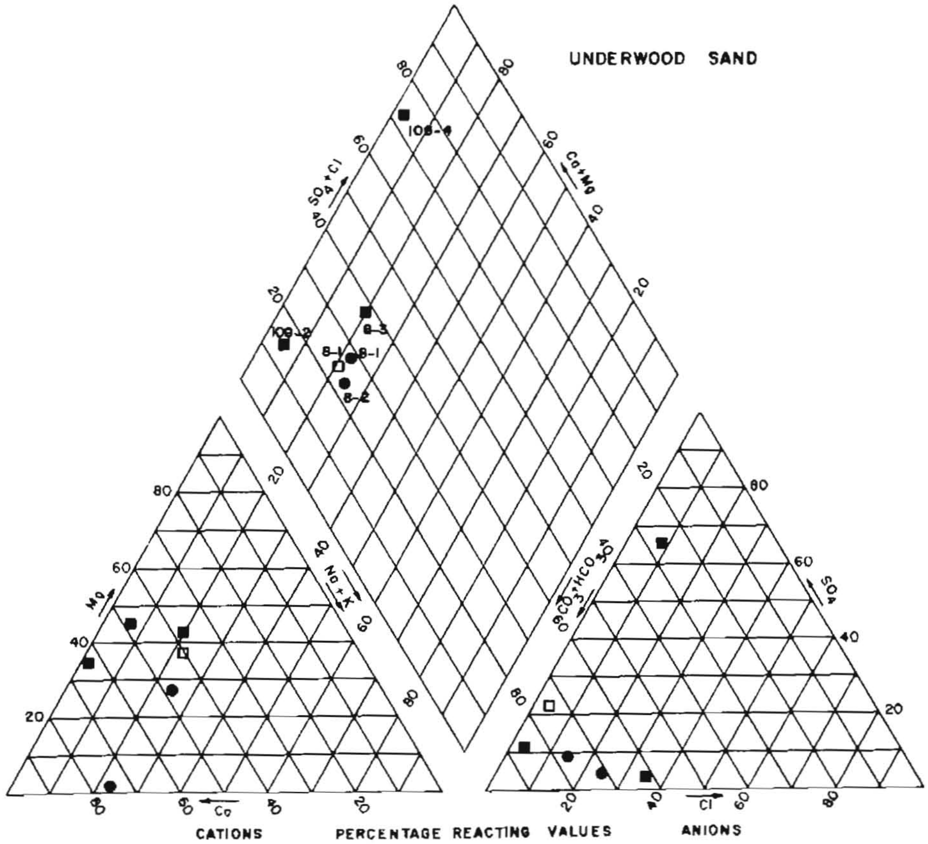


Figure 4.3.5.2-2. Trilinear plot of groundwater chemistry from the Underwood sand.

Slough channel complex are also listed. These waters were all of the Na^+-HCO_3^- type with TDS values between 867 and 1 730 mg/L.

4.3.5.2 Underwood sand

The Schoeller diagram (fig. 4.3.5.2-1) seems to indicate that the groundwater chemistry within the Underwood sand is highly variable and the samples unrelated, but the trilinear plot (fig. 4.3.5.2-2) clusters the samples in the Ca^{2+}, Mg^{2+} to Ca^{2+}, Na^+-HCO_3^-, SO_4^{2-} field. Several analyses show relatively high chloride concentrations. The piezometers from which these samples were collected are located next to the Underwood city sewage lagoon and the elevated chloride concentrations probably result from infiltration of water from the sewage lagoon. The very high sulfate concentration in the sample from piezometer 106-4 may result from the close proximity of the piezometer tip to the lignite of the main Hagel bed.

4.3.5.3 Hagel bed

The analyses of water collected from the main Hagel bed can be split into two groups; those with calcium concentration greater than magnesium concentrations and those with magnesium concentrations greater than calcium concentrations (figs. 4.3.5.3-1 and 4.3.5.3-2). The calcium-richer waters are found north of an east-west trending line that lies about 1.5

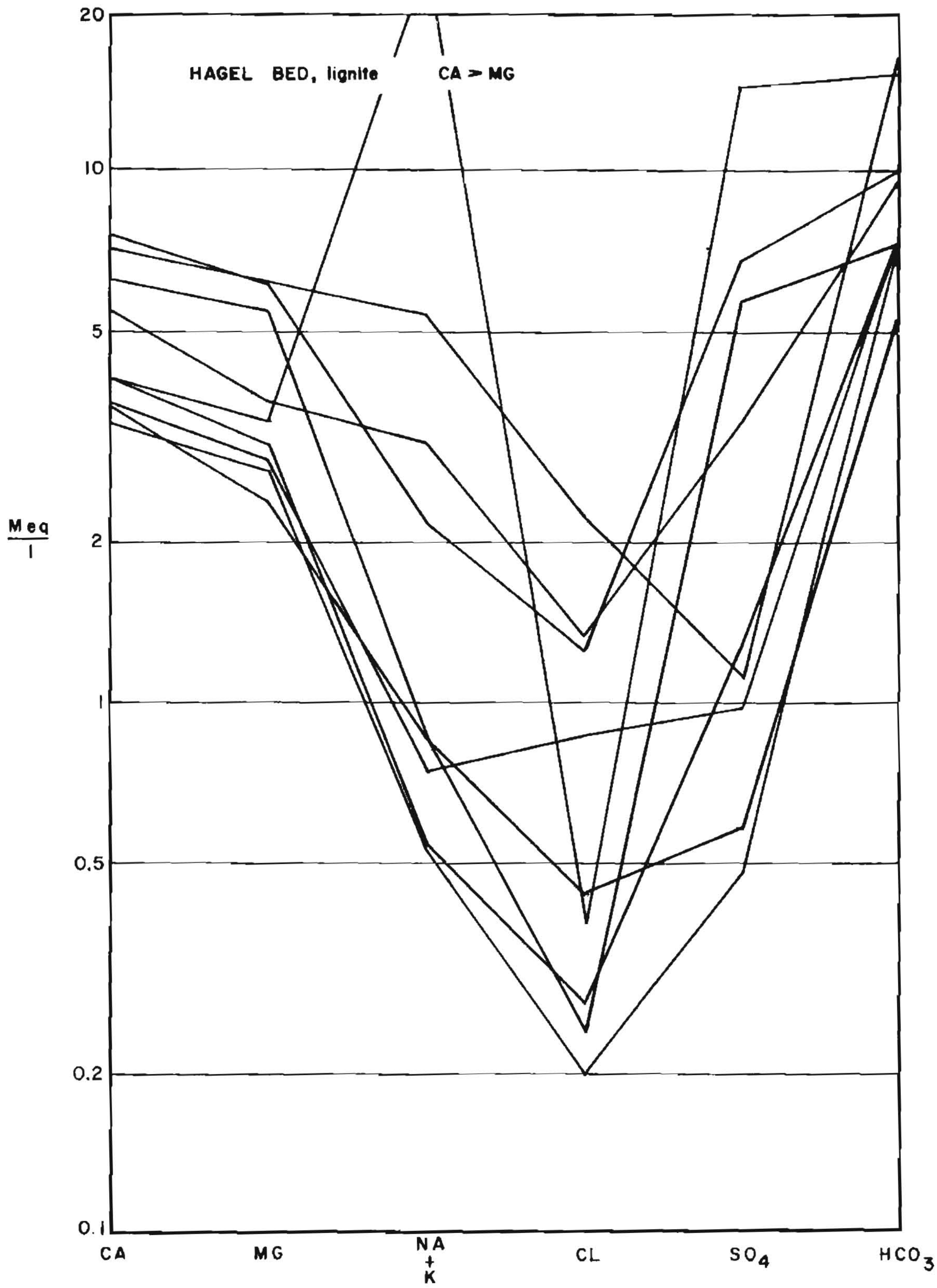


Figure 4.3.5.3-1. Schoeller diagram of groundwaters from the main Hagel bed with Ca/Mg ratios greater than one.

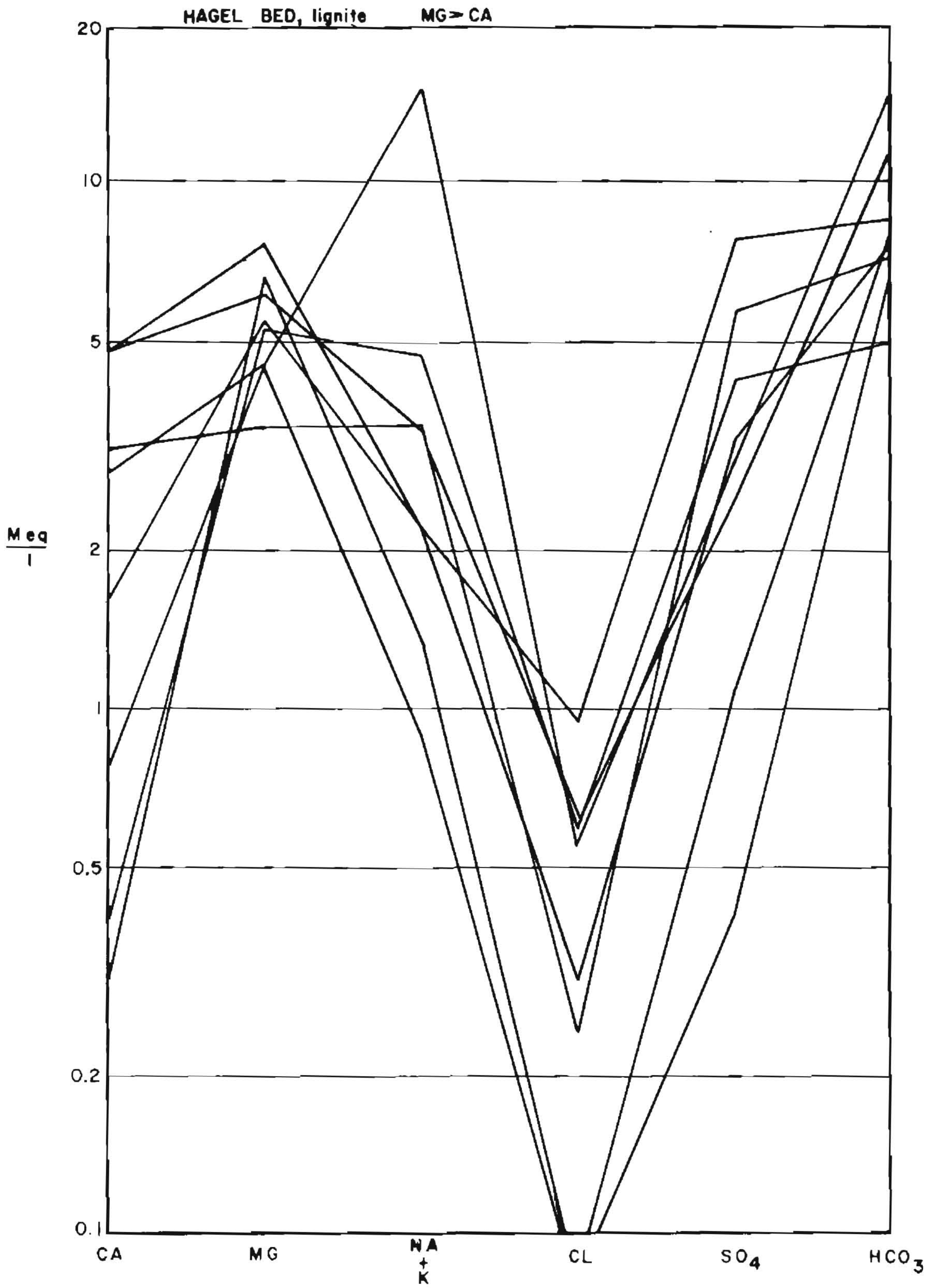


Figure 4.3.5.3-2. Schoeller diagram of groundwaters from the main Hagel bed with Ca/Mg ratios less than one.

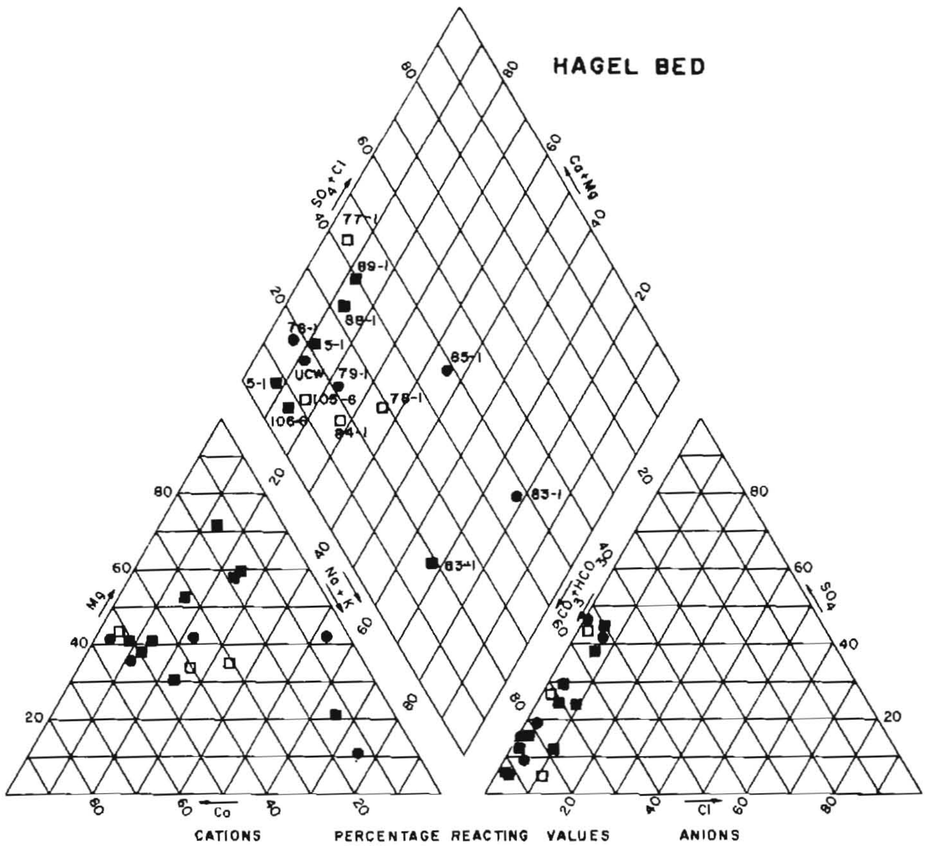


Figure 4.3.5.3-3. Trilinear plot of groundwater chemistry from the main Hagel bed.

miles (2.6 km) south of Underwood. There is an even stronger relationship between the date of the analysis and the value of the Ca^{2+}/Mg^{2+} ratios. Of the 12 analyses reporting Ca^{2+}/Mg^{2+} ratios of less than one (from both the main Hagel and B beds), 92 percent were analyzed in 1976 and 8 percent, or one sample, was analyzed in 1977. Unfortunately, only one piezometer, 83-1, was sampled and analyzed successfully in both years. In 1976, the Ca^{2+}/Mg^{2+} ratio was less than one and in 1977, the ratio was greater than one. It is therefore unclear, as yet, as to whether the variation in Ca^{2+}/Mg^{2+} ratio is a real phenomenon or due solely to analytical techniques.

The same data is plotted as a trilinear diagram in figure 4.3.5.3-3. The water chemistries cluster in the Ca^{2+}, Mg^{2+}-HCO_3^-, SO_4^{2-} and Ca^{2+}, Na^{2-}-HCO_3^-, SO_4^{2-} fields of the diagram. The exceptions to this are the samples collected from piezometer 83-1 in both 1976 and 1977. It is not known why the water chemistry is different at this point.

4.3.5.4 B bed

The Schoeller diagrams for the B bed are also split according to Ca^{2+}/Mg^{2+} ratios (figs. 4.3.5.4-1 and 4.3.5.4-2). The trilinear plot (fig. 4.3.5.4-3) of the chemical analyses is very similar to that of the main Hagel bed. Two of the samples, from piezometers 112-2 and 113-2, are much higher in sulfate. This may be

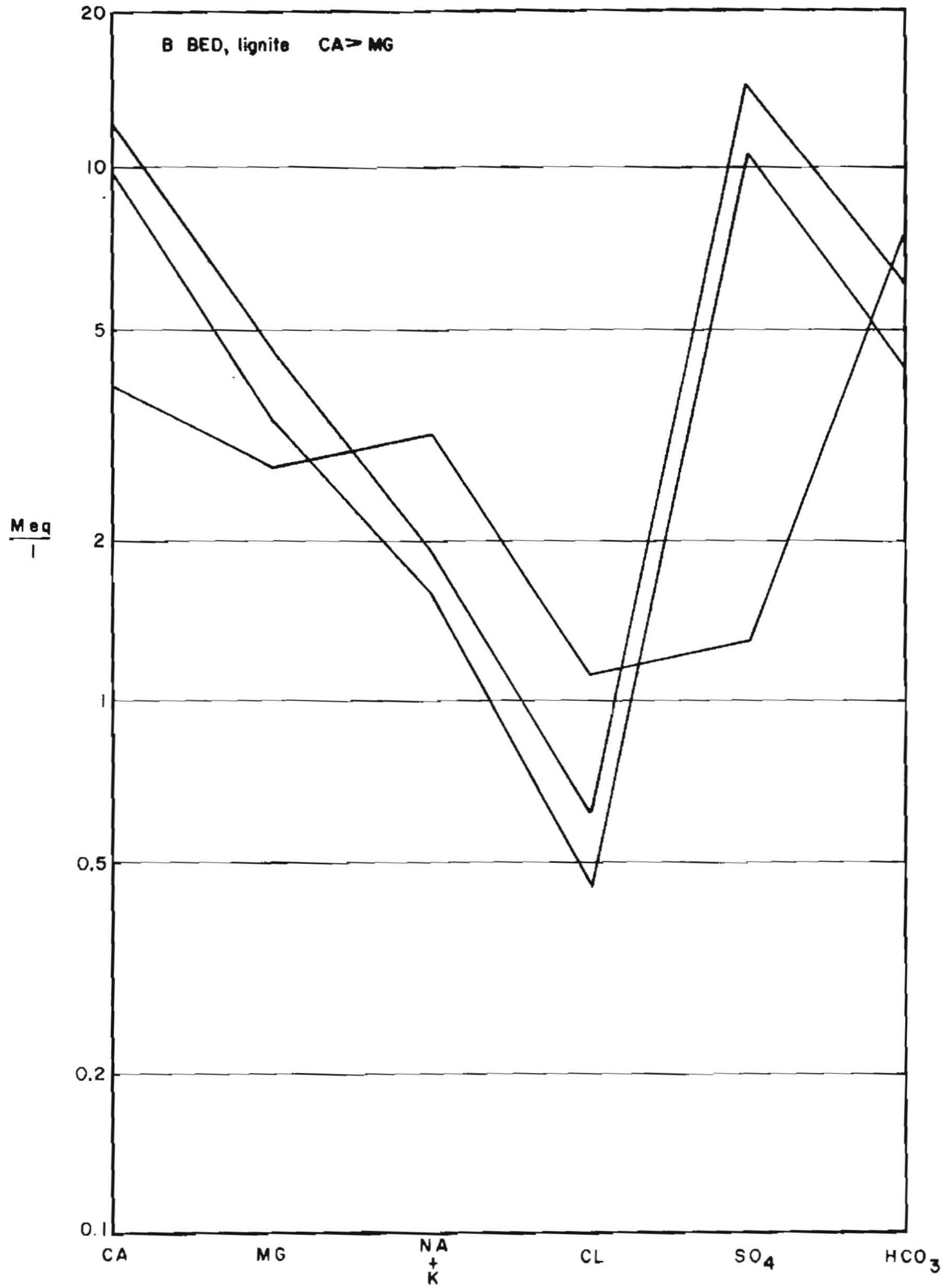


Figure 4.3.5.4-1. Schoeller diagram of groundwaters from the B bed with Ca/Mg ratios greater than one.

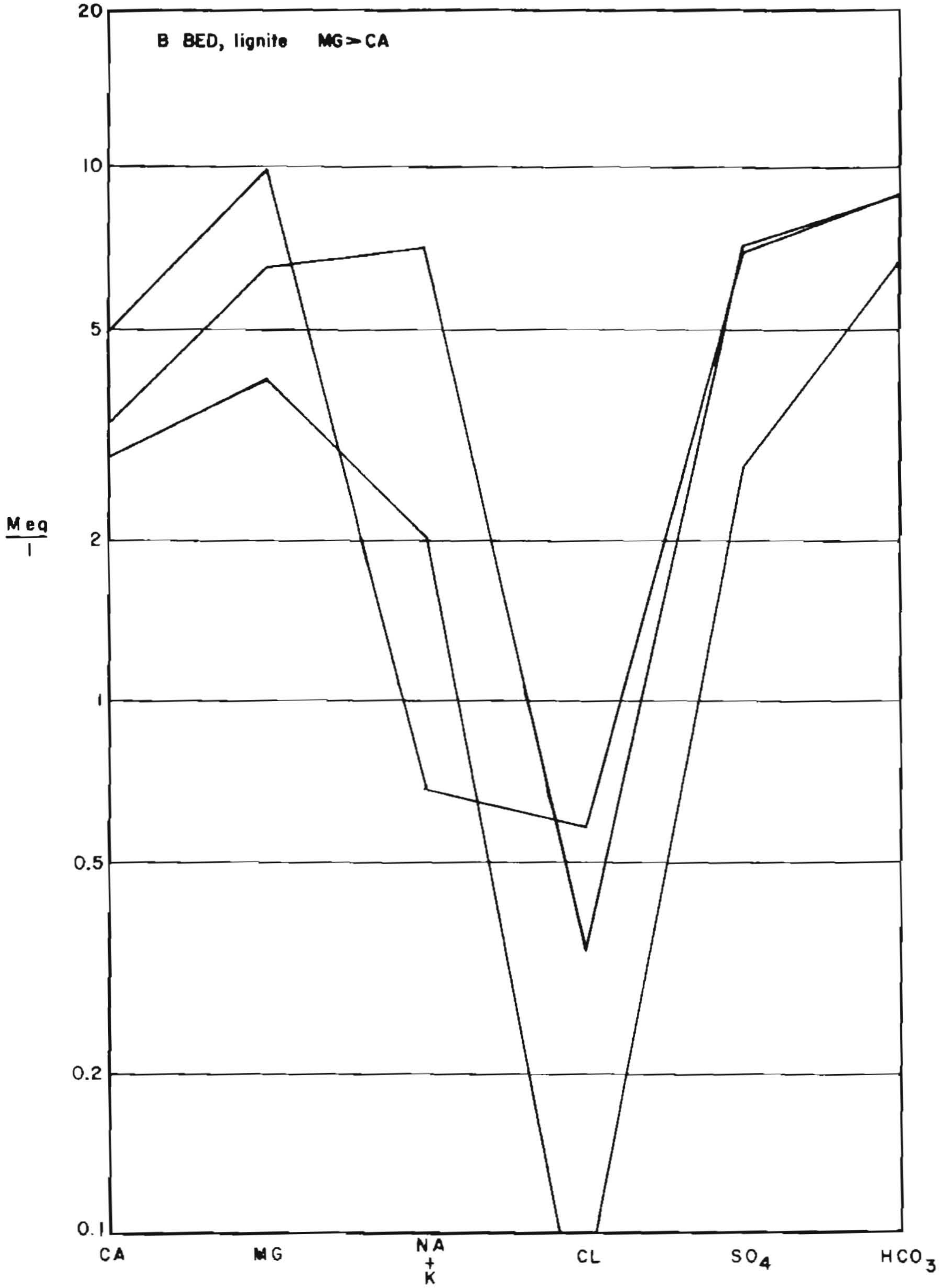


Figure 4.3.5.4-2. Schoeller diagram of groundwaters from the B bed with Ca/Mg ratios less than one.

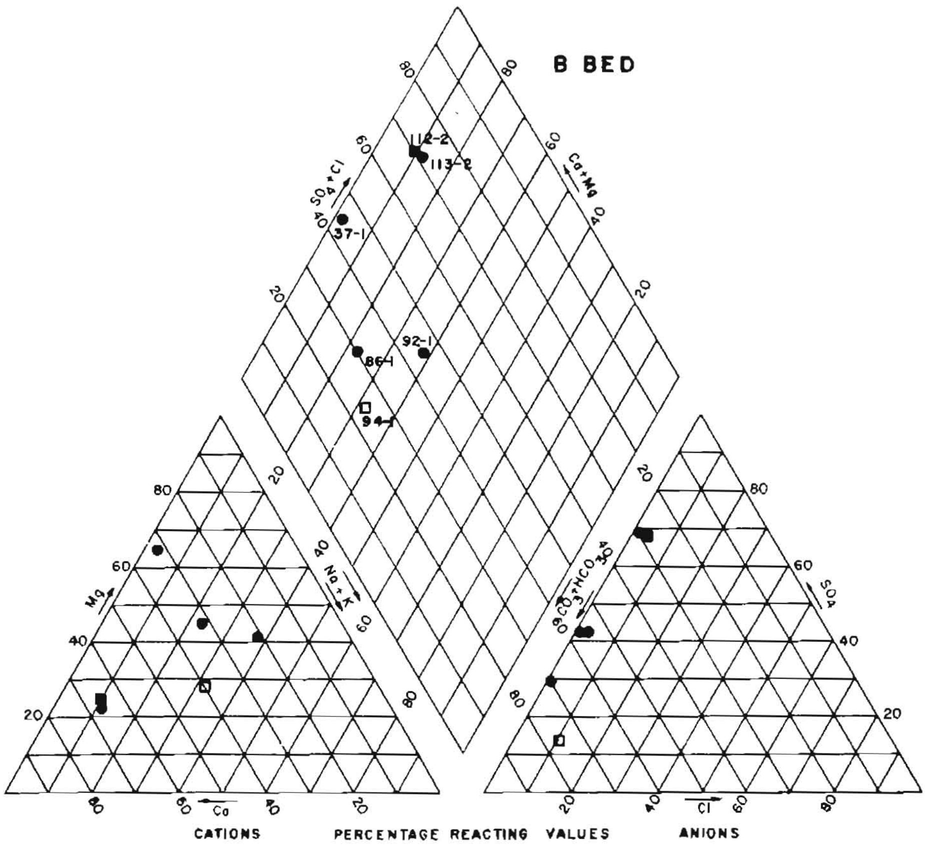


Figure 4.3.5.4-3. Trilinear plot of groundwater chemistry from the B bed.

due to the oxidation of iron sulfides associated with the lignites. The lignites in these areas are near the water table which may allow for sufficiently oxygenated water to come in contact with the sulfides to cause oxidation and SO_4^{2-} generation.

4.3.5.5 Sheet sand

The chemistry of groundwaters from the sheet sand is plotted in figure 4.3.5.5-1 as a Schoeller diagram and as a trilinear plot in figure 4.3.5.5-2. The few samples analyzed tend to fall within the Na^+, Ca^{2+}-HCO_3^-, SO_4^{2-} field of the trilinear plot, in between the Ca^{2+}-HCO_3^- waters of the shallower hydrologic units described above and the deeper Bullion Creek units yet to be discussed.

4.3.5.6 Hensler bed

The Schoeller diagram for the Hensler bed groundwaters (fig. 4.3.5.6-1) indicates a very high, narrow range of sodium contents and a highly variable, lower calcium and magnesium concentration. The same trend is also apparent on the trilinear plot (fig. 4.3.5.6-2) where the analyses fall within the Na^+, Ca^{2+}-HCO_3^-, SO_4^{2-} and Na^+-HCO_3^-, SO_4^{2-} fields.

4.3.5.7 Miscellaneous water samples

These samples were collected from several stratigraphic units within the Sentinel Butte and Bullion Creek Forma-

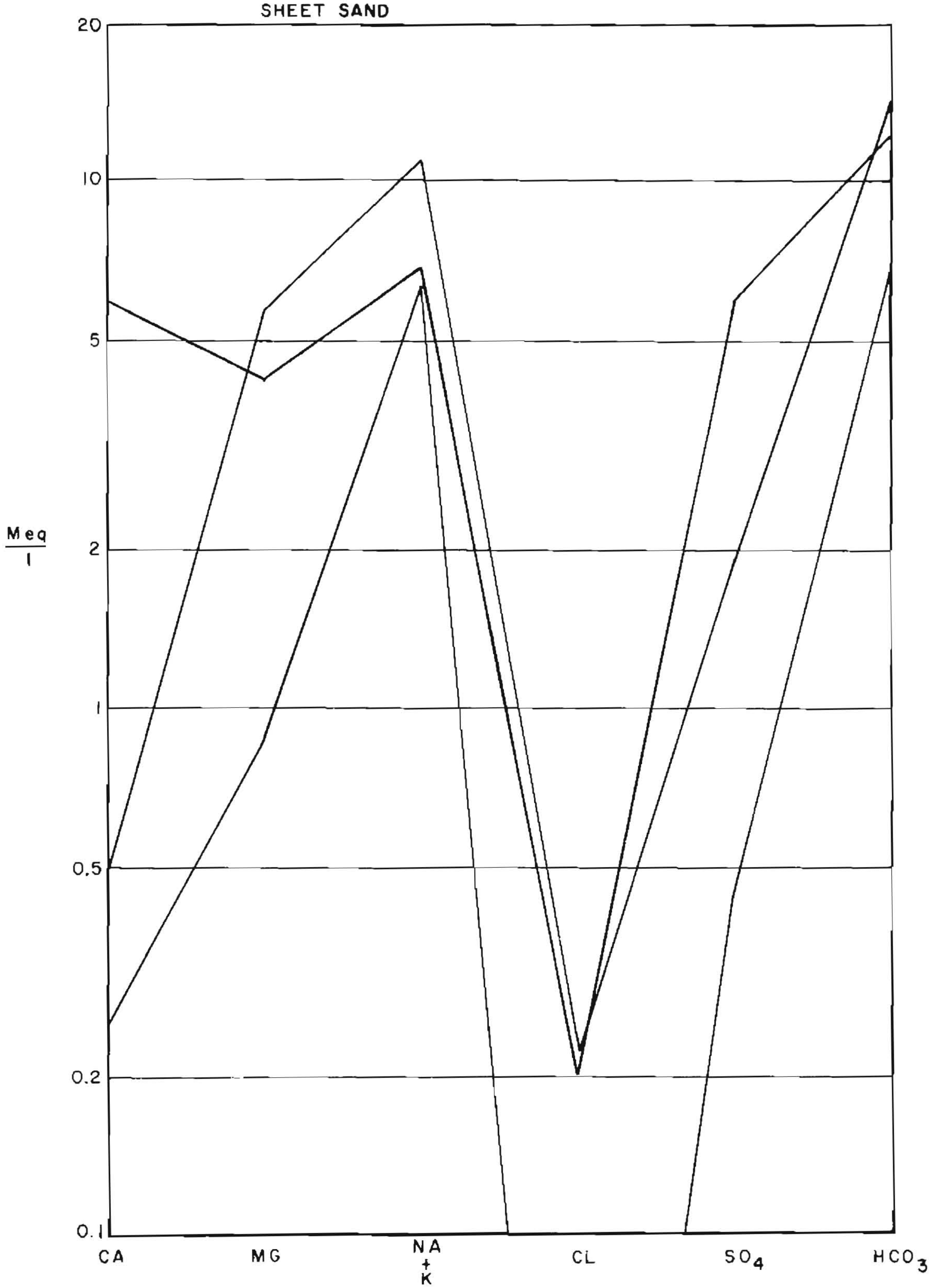


Figure 4.3.5.5-1. Schoeller diagram of groundwaters from the sheet sand.

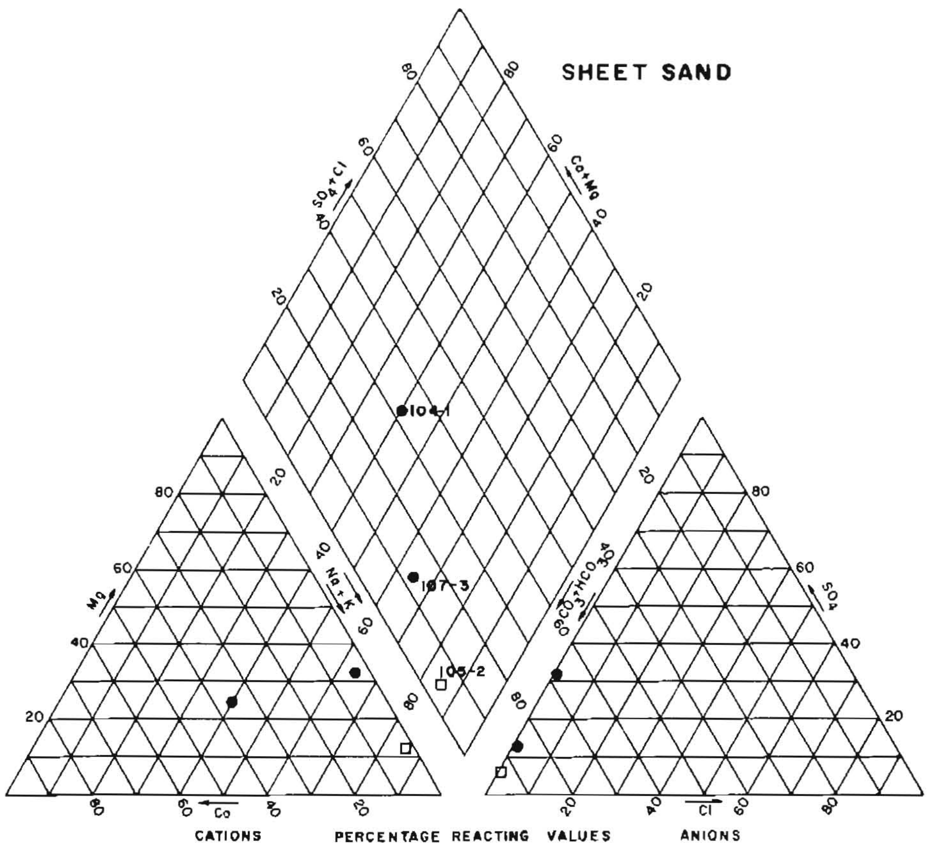


Figure 4.3.5.5-2. Trilinear plot of groundwater chemistry from the sheet sand.

tions that are not well enough instrumented to warrant individual attention. One surface water sample is also included in this group. It can be noted from table 4.3.5-7 that, beginning with the interval below the B bed, the groundwater becomes more and more sodic as one moves down through the stratigraphic column. The surface water sample is also relatively sodic because it is situated in an area where it receives groundwater inflow from the sheet sand.

Additional chemical analyses of McLean County groundwaters from the Fort Union Group, which includes all the units discussed above with the exception of the Coleharbor Formation, are reported by Klausing (1974). The 65 samples analyzed from the Fort Union aquifers are predominantly Na^+-HCO_3^- with a TDS content between 206 and 3 350 mg/L.

4.3.5.8 Geochemical evaluation of groundwater

The trilinear plots presented above have been summarized in figure 4.3.5.8-1. The relative anion concentrations are quite similar for all the hydrologic units sampled with the groundwater being predominantly of the HCO_3^-, SO_4^{2-} type. The major water chemistry variations occur among the cations. As one moves down through the stratigraphic units, from the Coleharbor Formation to the Hensler bed, the relative cation percentages move from 100 percent cal-

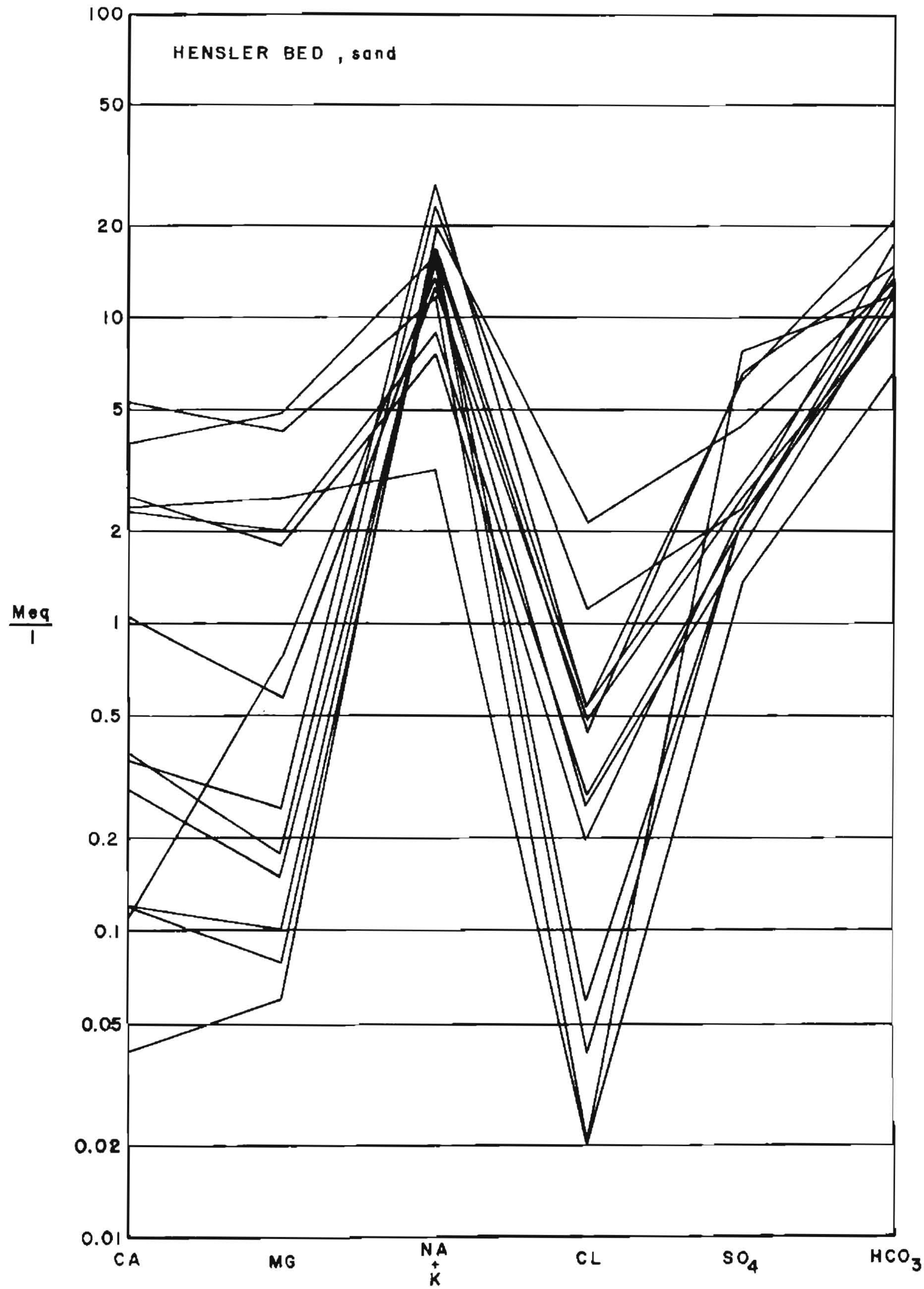


Figure 4.3.5.6-1. Schoeller diagram of groundwaters from the Hensler bed.

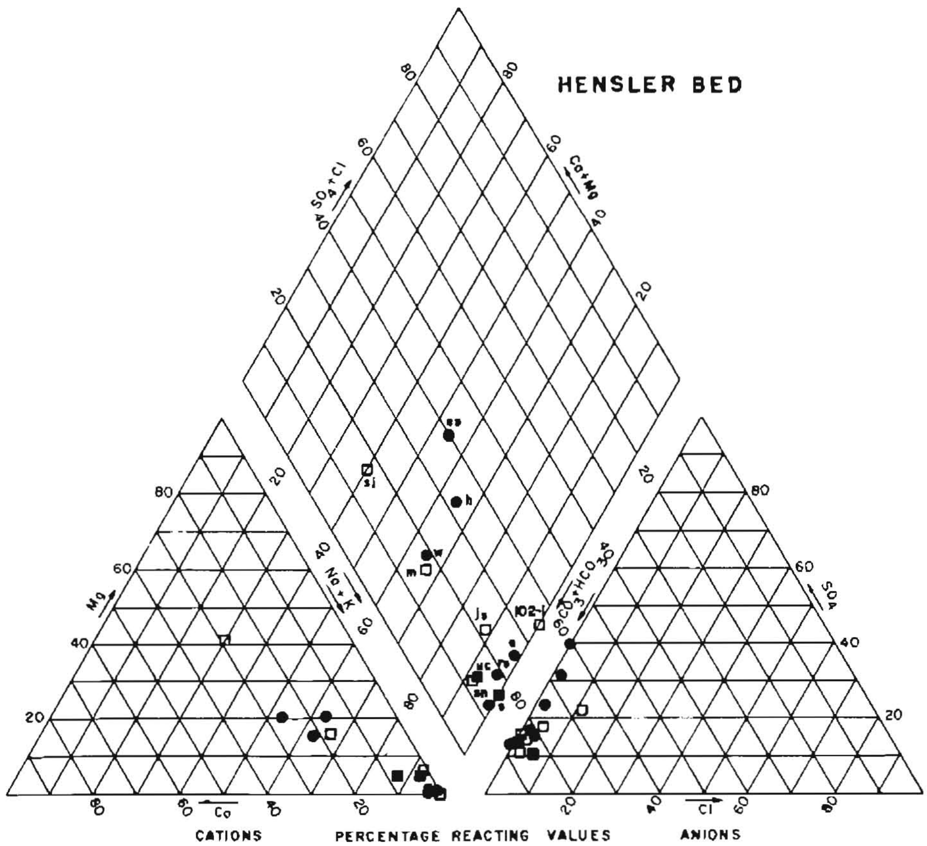


Figure 4.3.5.6-2. Trilinear plot of groundwater chemistry from the Hensler bed.

cium corner toward the center of the triangle, where all three cation species are represented in equal quantities, to the 100 percent sodium corner. When plotted on the diamond field of the diagram, the samples split into two groups; a Ca^{2+}, Mg^{2+} to Ca^{2+}, Na^{2+}-HCO_3^-, SO_4^{2-} group that includes groundwater from the B bed, main Hagel bed, Underwood sand, and Coleharbor Formation and a Na^+, Ca^{2+} to Na^+-HCO_3^-, SO_4^{2-} group that includes all the units below the B bed.

The chemical evolution of the groundwater becomes more distinct when the ratio of calcium plus magnesium to sodium are plotted as a function of depth below ground surface (fig. 4.3.5.8-2). The graph indicates a gradual change to more sodic waters with increasing depth. The same relationship is shown when the data is plotted as a function of elevation.

The pattern of groundwater evolution presented here may be due to the exchange of calcium for sodium by sodium-rich clay minerals present in the aquitards at the Falkirk site. As the water moves vertically through the aquitards, the calcium in solution is exchanged for sodium sorbed on the clay minerals. The longer the flow path, or residence time, within the aquitards the more calcium will be sorbed and sodium will gradually become the dominant cation in solution. The relationship appears to be a function of depth because the flow through the

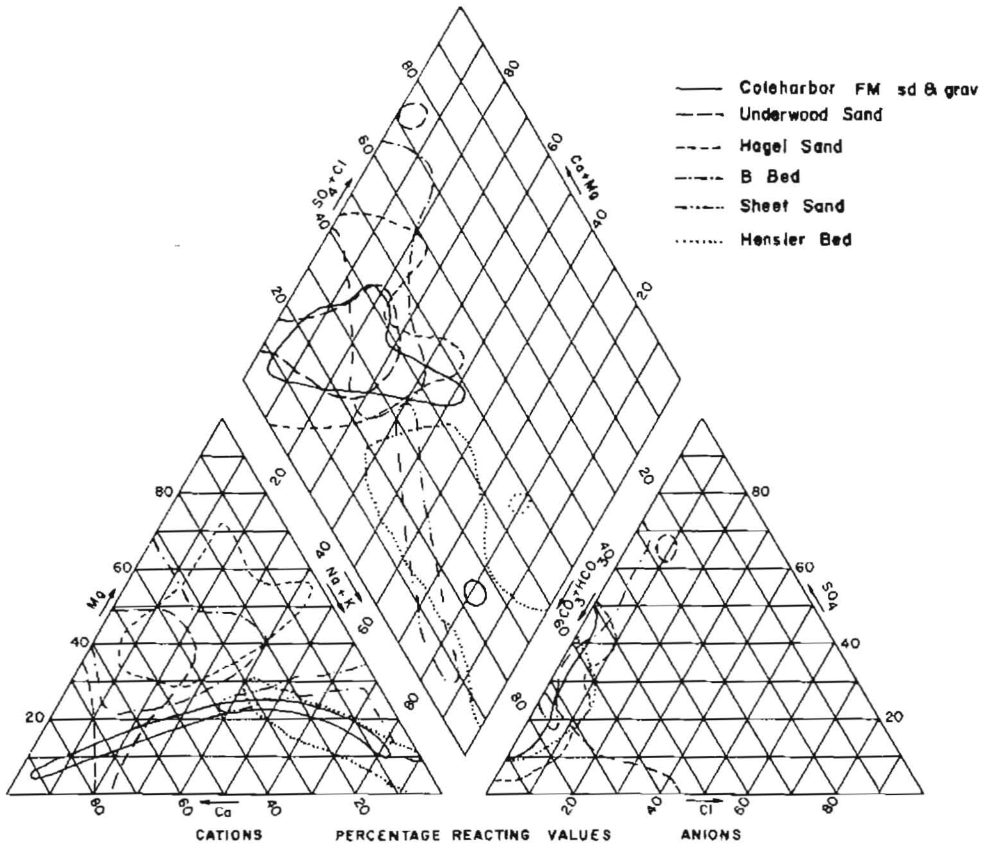


Figure 4.3.5.8-1. Summary trilinear plot of groundwater chemistry.

clay-rich aquitards is predominantly vertical. Once the groundwater enters the clay-deficient lignite and sand aquifers, it flows horizontally without further significant cation exchange reactions. This interpretation is further supported by the lack of correlation between the areal distribution of the calcium plus magnesium to sodium ratio values and the distribution of hydraulic head values, which indicate the flow directions within the aquifers.

4.3.6 Distribution of Trace Constituents

Water samples collected during the 1976 and 1977 field seasons were analyzed for iron (Fe), manganese (Mn), copper (Cu), cadmium (Cd), lead (Pb), nitrate (NO_3^{-2}), fluoride (F^-), phosphate (PO_4^{-3}), total arsenic (As), and total selenium (Se). During the 1977 field season, the trace metal samples were filtered through 0.45 micron cellulose filter paper before being acidified by adding 5 ml of nitric acid to each 475 ml of sample. The filtering step was not carried out in the 1976 field season. This omission resulted in the release of metals from suspended material when the sample was acidified. For example, the average lead concentration of the unfiltered 1976 samples was 141 μg/L while the filtered samples collected in 1977 averaged 15.7 μg/L. Therefore, all trace metal analyses from the unfiltered samples have been

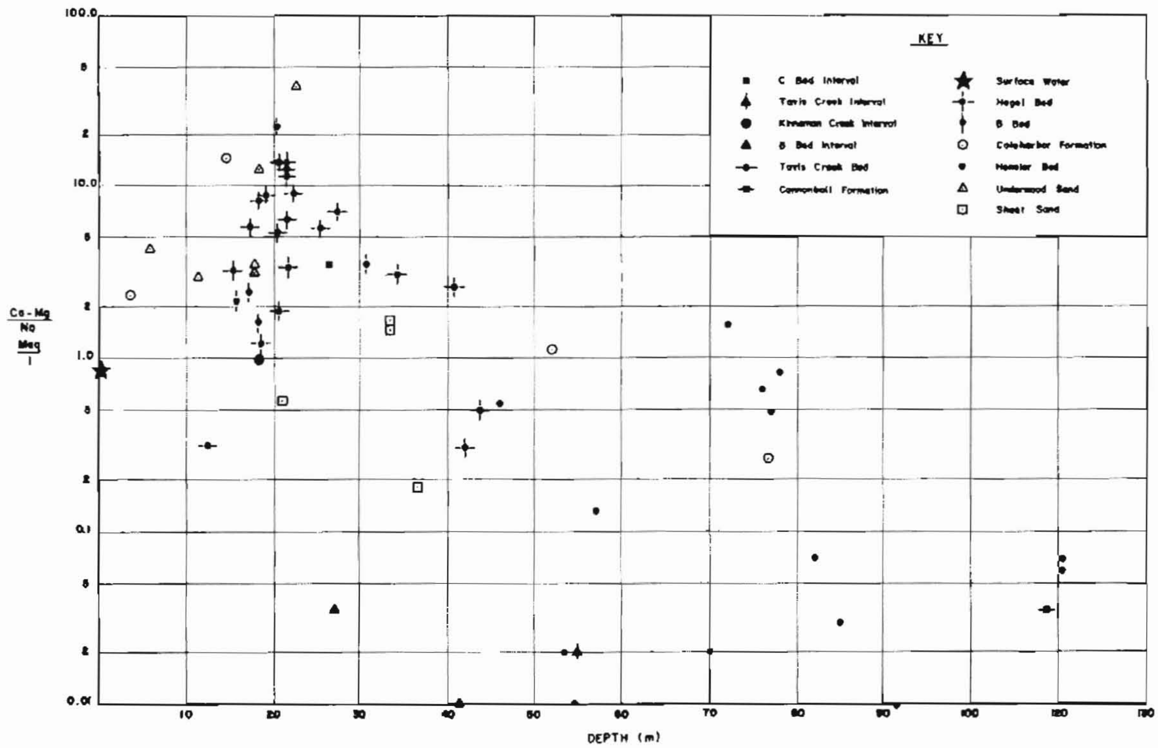


Figure 4.3.5.8-2. The ratio of Ca and Mg to Na plotted as a function of a depth below ground surface.

omitted from the following discussion.

4.3.6.1 Trace metals

The recommended concentration limit for manganese (table 4.3.6.1-1) is equaled or exceeded in 77 percent of the properly collected samples that have been analyzed to date (table 4.3.6.1-2). Of the remaining low manganese samples 90 percent were collected from the Hensler bed and the Cannonball Formation. Generally, manganese concentrations are less than iron concentrations in groundwater environments (Hem, 1970), but 25 percent of the samples analyzed from the Falkirk site have manganese concentrations greater than iron concentrations. The majority of these samples was collected from the main Hagel bed and the Underwood sand.

Iron concentrations at the Falkirk site exceed the U.S. Environmental Protection Agency's (1975) recommended concentration limits in 67 percent of the samples. Some of the highest values listed in table 4.3.6.1-2 were collected from farmers' wells finished in the Hensler bed. The one sample from a PVC piezometer in the Hensler bed contains 10-20 times less iron than the farm well samples; therefore, it is quite probable that the high iron concentrations are the result of corrosion of the well casing and/or the plumbing of the farmers' water supply systems.

Copper concentrations are well below the recommended concentration limits of 1 000 μg/L, ranging from 4-52 μg/L and average 12 μg/L. These values are within the range of concentrations that would be expected for the redox and pH conditions found in the groundwater and surface water within the study area (Hem, 1970).

TABLE 4.3.6.1-1. Recommended and permissible concentration limits established by the EPA (1975)

CONSTITUENT	RECOMMENDED CONCENTRATED LIMIT*
Inorganic	mg/L
Total Dissolved Solids	500.
Chloride (Cl)	250.
Sulfate (SO_4)	250.
Nitrate (NO_3)	45.
Iron (Fe)	0.3
Manganese (Mn)	0.05
Copper (Cu)	1.0
Zinc (Zn)	5.0
Boron (B)	1.0
Hydrogen Sulfide (H_2S)	0.05
	MAXIMUM PERMISSIBLE CONCENTRATION**
Arsenic (As)	0.05
Barium (Ba)	1.00
Cadmium (Cd)	0.01
Chromium (CrVI)	0.05
Selenium	0.01
Antimony (Sb)	0.01
Lead (Pb)	0.05
Mercury (Hg)	0.002
Silver (Ag)	0.05
Fluoride (F)	1.4-2.40***
	MAXIMUM PERMISSIBLE CONCENTRATION
Organic	
Cyanide	0.05
Endrine	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP silvex	0.01
Phenols	0.001
Carbon Chloroform Extract	0.2
Synthetic detergents	0.5

TABLE 4.3.6.1-1. Recommended and permissible concentration limits established by the EPA (1975)--Continued

	MAXIMUM PERMISSIBLE ACTIVITY
Radionuclides and Radioactivity	pecocuries/litre
Radium-226	3.
Strontium-90	10.
Plutonium	50 000.
Gross beta activity	30.
Gross alpha activity	3.
Bacteriological	
Total coliform bacteria	1 per 100 ml

*Recommended concentration limits for these constituents are mainly to provide acceptable esthetic and taste characteristics.

**Maximum permissible limits are set according to health criteria.

***Limit depends on average air temperature of the region, fluoride is toxic at about 5 to 10 mg/L if water consumed over a long period of time.

The maximum permissible concentration limit of 10 μ g/L for cadmium is exceeded in one of the 35 samples analyzed. The significance of this value cannot be evaluated because very little is known about the occurrence of cadmium in natural groundwater systems.

Two samples collected from the main Hagel bed exceed the maximum permissible concentration limit of 50 μg/L for lead, while 51 percent of all samples analyzed contain less than 10 μg/L of lead.

4.3.6.2 Trace non-metals

Water samples collected from the Falkirk site during the 1976 and 1977 field seasons were analyzed for nitrate, fluoride, phosphate, total arsenic, and total selenium. The samples were analyzed by the Chemistry Department at NDSU.

TABLE 4.3.6.1-2. Concentration of trace metals in selected groundwater sampled--Falkirk area

WELL NO.	DATE	Fe	Mn	Cu	Cd	Pb
		Concentration in μ g/L				
Hagel Bed						
5-1	7-77	857.0*	306.0*	4.7	1.76	4.6
5-1	7-77	1160.0*	259.0*	3.8	0.19	69.0*
41-1	7-77	2990.0*	1400.0*	6.4	0.80	43.0
42-1	7-77	39.0	181.0*	4.8	0.32	2.3
43-1	7-77	21.8	110.0*	30.0	6.00	13.3
76-1	7-77	263.0	272.0*	10.8	1.10	6.3
76-1	7-77	596.0*	267.0*	7.2	0.90	51.0*
77-1	8-77	600.0*	300.0*	8.0	0.44	4.2
81-1	7-77	338.0*	477.0*	11.3	0.40	4.0
82-1	7-77	126.0	214.0*	8.6	0.21	4.3
88-1	7-77	576.0*	265.0*	6.0	0.60	35.8
89-1	7-77	125.0	68.0*	6.4	0.60	6.5
106-6	8-77	16.0	303.0*	9.8	0.65	4.6
Hensler Sand						
102-1	7-77	119.0	36.0	10.2	1.10	12.0
Saylor J.	8-77	1150.0*	33.0	22.2	0.88	10.8
Sheldon O.	8-77	1750.0*	19.0	18.7	1.40	6.9
Weisz	8-77	7000.0*	200.0*	7.0	0.85	3.1
Saylor R.	8-77	2300.0*	19.6	10.5	0.64	7.6
Heger L.	8-77	1800.0*	35.5	7.2	0.43	2.6
Seidler	8-77	207.0	14.2	17.0	14.60*x	6.6
Underwood Sand						
8-1	7-77	67.0	659.0*	4.0	0.32	2.1
8-2	7-77	312.0*	1744.0*	8.3	0.53	3.7
106-4	8-77	29.5	810.0*	22.6	6.50	9.6
Cannonball Formation						
101-1	8-77	1150.0*	46.6	24.7	3.10	14.5
B Bed						
75-1	8-77	550.0*	220.0*	12.2	1.10	12.0
94-1	7-77	1214.0*	231.0*	4.0	1.70	12.6
Tavis Creek Interval						
102-2	7-77	62.4	66.7*	17.0	0.80	28.7
Sheet Sand						
104-1	8-77	8300.0*	650.0*	5.7	0.52	24.5
104-1	8-77	9000.0*	600.0*	2.9	0.16	7.1
B Bed & Sheet Sand						
109-1	8-77	600.0*	66.0*	7.6	1.10	5.5
B Bed Interval						
106-3	8-77	167.0	50.0	52.0	6.00	32.0
Surface Water						
Lagoon	6-77	77.0	55.0*	12.6	0.38	25.7
Wellers Slough	6-77	51.0	72.0*	18.2	0.51	18.8
Slough #3	6-77	44.0	32.0*	16.8	6.60	40.0

*Exceeds recommended or maximum permissible concentration limits for public water supplies.
xExceeds recommended limits for agricultural usage.

Nitrate concentrations in the groundwater and surface water are well below the recommended concentration limit of 45 mg/L (U.S. Environmental Protection Agency, 1975). Forty-eight percent of the samples contain less than 0.1 mg/L and 48 percent have nitrate concentrations between 1.0 mg/L and 0.1 mg/L. Only one sample has a nitrate concentration greater than 1.0 mg/L. Piezometer number 8-2, located next to the Underwood sewage lagoon, measured 8.3 mg/L of nitrate.

One of the 52 water samples analyzed for fluoride exceeds the maximum permissible concentration of 1.4-2.4 mg/L (U.S. Environmental Protection Agency, 1975). This sample was collected from piezometer 102-1 in the Hensler bed. Two other samples contained relatively high fluoride concentrations. Piezometer 102-2, in the Tavis Creek interval, contained 1.1 mg/L and 106-3, in the B bed interval, measured 1.2 mg/L. Of the remaining samples, 66 percent contain less than 0.2 mg/L and 26 percent are between concentrations of 0.75 and 0.21 mg/L.

Only 11 water samples were analyzed for phosphate. All 11 samples contained less than 0.06 mg/L of phosphate.

Three surface water and two groundwater samples were analyzed for arsenic (III), arsenic (IV), and total arsenic. None of the samples exceed the maximum permissible concentration of 50 μg/L. One of the surface water samples was collected from the Underwood sewage lagoon and the other two come from the permanent sloughs to the south of the mine area. The surface water samples contain 0.89, 1.91, and 3.81 μg/L, while the groundwater samples contain 0.42 and 0.52 μg/L.

Total selenium was determined for the same surface water samples analyzed for arsenic. All three surface water samples exceed the maximum permissible concentration of 10 μg/L for domestic use and the 20 μg/L limit for irrigation. The Underwood sewage lagoon measured 53.2 μg/L and the sloughs south of the Falkirk mining site contain 45.7 and 37.1 μg/L of selenium.

4.4 Hydrogeology and Hydrochemistry of the Beulah-Hazen Area

4.4.1 Hydrostratigraphy

4.4.1.1 Coleharbor Formation

4.4.1.1.1 Aquitards.--Much of the Beulah-Hazen area is covered by glacial till in the uplands and fine-grained alluvium, but very little data is available on the hydrologic characteristics or water levels within these materials. Generally these materials have hydraulic conductivities in the range of 10^{-4}-10^{-8} cm/s. One sample of silt collected from the Beulah trench yielded a hydraulic conductivity of 1 X 10^{-4} cm/s (Woodward-Clyde, 1975). Several conductivity values for similar materials from the Dunn Center area have an average value of 1 X 10^{-4} cm/s.

There are no data available on water levels within the till, but from observations at the Falkirk and Dunn Center study areas it is very likely that water flows downward through the till to the sand and lignite aquifers.

4.4.1.1.2 Aquifers.--Aquifers of the Coleharbor Formation generally consist of glaciofluvial deposits of sand and gravel within trenches and river valleys that dissect the Sentinel Butte Formation. The sand and gravel aquifers are generally a series of lenticular bodies interbedded with fine-grained alluvium and till.

There are two large trenches (and associated aquifer complexes) within the proposed mine areas. The locations of the major trenches are shown in figure

3.4.1-1 and in cross section on plate 9. Both the Beulah and Renner trenches are about 0.5-1.5 miles (800-2 400 m) wide and 200-300 feet (60-90 m) deep.

Enough is known about the Beulah trench to define a hydrostratigraphic unit designated the Antelope Creek aquifer. A very limited amount of data is available on the composition of the material within the Renner trench, but it appears to be very similar to the Beulah trench. Geophysical logs indicate the presence of a 30-60-foot (9-18-m) thick zone of sand and gravel generally within the interval between 200 and 300 feet (60 and 90 m) below the surface.

Data for three pump tests conducted in the Knife River aquifer and one pump test conducted in the Missouri River aquifer in Mercer and Oliver Counties are presented by Croft (1973). The average hydraulic conductivity estimated from the Knife River aquifer tests is 567 ft/day (0.2 cm/s) with a storativity of 0.0003. The Missouri River aquifer test yielded an estimated hydraulic conductivity of 850 ft/day (0.3 cm/s) with a storativity of 0.0008.

Vertical gradients near the proposed coal gasification site can be determined from data presented by Butler (1978). The average vertical gradient determined from four pairs of piezometers is 0.25 and gradients ranged between 0.09 and 0.44. The range of gradients can probably be explained by the physical configuration of the aquifers within the trench. The sand and gravel units form long lenticular bodies, separated from each other by lower permeability till and alluvium. The difference in hydraulic head between two separate sand and gravel units will depend on the thickness and permeability of the aquitard separating the units. This also makes it very difficult to determine flow directions and horizontal gradients within the trenches without a relatively detailed knowledge of the stratigraphy within the trench.

If it is assumed that all the piezometers near mine area 4 (Butler, 1978) that are screened at an elevation of approximately 1 820 feet (555 m) (MSL) are within a single sand and gravel aquifer, the average horizontal gradient within the aquifer is 0.0035 with water moving north and south from a divide in NW¼sec 13, T145N, R88W. If the same assumptions are used for piezometers set at an approximate elevation of 1 690 feet (515 m) the same pattern of flow results but horizontal gradients average 0.0005.

4.4.1.2 Sentinel Butte Formation

4.4.1.2.1 Aquitards.--Much of the material between the lignite aquifers within the Sentinel Butte Formation consists of low permeability silts and clays which form aquitards. Above the Beulah-Zap bed 49 percent to 100 percent (average of 88 percent) of the thickness of the material consists of silt and clay (Woodward-Clyde, 1975). A vertical gradient of 0.94 was measured in the aquitards above the Beulah-Zap bed in sec 19, T145N, R88W (Gilman, 1975). The gradient between the Beulah-Zap and Antelope Creek beds is also downward but there is insufficient data to quantify the gradient.

4.4.1.2.2 Aquifers.--The aquifers within the Sentinel Butte Formation consist of interbedded sand and lignite beds with the major aquifers being the Beulah-Zap and Antelope Creek lignite beds. The areal extent of the Beulah-Zap bed is shown in figure 3.3.2-1. Sand aquifers appear to be of minor significance in this area. The average aggregate thickness of sands above the Beulah-Zap bed has been determined by Woodward-Clyde (1975) to be 14 feet (4.3 m).

Two single-well response tests were conducted by Gilman (1975) in the Beulah-Zap bed in sec 19, T145N, R88W and sec 27, T146N, R27W. Analyzing the data presented by Gilman with the methods developed by Hvorslev (1951) yielded hydraulic conductivity values of 1×10^{-3} and 2×10^{-4} cm/s. These values are in good agreement with lignite hydraulic conductivities determined in the Dunn Center and Falkirk study areas. There is no data available on the hydrologic characteristics of the Antelope Creek bed.

Generally the Beulah-Zap bed is not totally saturated. The saturated thickness of the lignite bed ranges from 0-18 feet (0-5.5 m) with an average of 4 feet (1.2 m) while the average total thickness of the bed is 12 feet (3.7 m). There is generally a perched water table above the Beulah-Zap bed at a depth of 30-50 feet (9.1-15.2 m) in the upland areas and 15 feet (4.6 m) along the valley walls (Butler, 1978).

Very little hydraulic head data is available for much of the area. Water levels are generally in the range of 1 920-1 960 feet (585-597 m) above MSL. In the area east of the proposed coal gasification plant site a relatively detailed potentiometric map of the Beulah-Zap bed has been compiled by Butler (1978) for mine area 4. This data indicates that the groundwater in the lignite bed flows south and east toward the Beulah trench from the center of the bedrock mound between the Beulah and Renner trenches (fig. 3.4.1-1). Horizontal gradients within this area are on the order of 0.005. Pre-mining discharge of water from the lignite can be estimated from Darcy's Law. Using a hydraulic conductivity of 2.0 ft/day (7×10^{-4} cm/s) and a gradient of 0.005 the lignite would discharge 3.02 L/day/m^2.

The potentiometric surface of the Antelope Creek bed is between the elevations of 1 860-1 960 feet (567-597 m) above MSL. Enough data is available for the area north of Hazen to contour the potentiometric surface. The data indicate that the groundwater flows outward to the south and west from an area 8 miles square (13 km sq). The horizontal gradients in this area are on the order of 0.005 to 0.002. The lignite bed apparently discharges into the Renner trench and the Knife River valley.

4.4.2 Groundwater-Flow Systems

Recharge to the lignite aquifers results from infiltration of ponded precipitation and spring snowmelt in the upland areas between the trenches. The low permeability of the surficial materials and the high potential evapotranspiration in the region probably result in relatively low recharge rates but sufficient to maintain steady-state conditions in the sluggish flow systems in the lignite beds.

Data from mine area 4 indicate that groundwater within the Beulah-Zap bed flows west and south to discharge in the Beulah trench. Water also leaks from the Beulah-Zap bed downward to recharge the Antelope Creek bed which also discharges into the trench complexes that dissect the area. The general pattern of recharge in the uplands with slow groundwater flow radially outward and downward from the bedrock mounds into the aquifers within the trenches and river valleys is better documented in the Falkirk study area (sec. 4.3.2.1).

The trenches and river valley fills act as large regional drains. Water in the aquifers within the trenches is a combina-

TABLE 4.4.3-1. Average concentration of major dissolved species from water samples collected in the Beulah-Hazen area (all units in mg/L)

Stratigraphic Unit	Number of Samples	TDS	Total Hardness	Ca	Mg	Na	HCO_3	SO_4
Coleharbor Formation	26	1080	489	103	47	176	598	300
Harnisch interval	4	800	500	42	63	67	490	290
Twin Buttes bed	2	1240	440	99	42	240	700	410
Schoolhouse bed	1	808	363	73	35	158	434	329
Beulah-Zap bed	11	2250	305	58	40	440	830	615
Spaer-bed	4	1500	265	40	16	425	1090	307
Antelope Creek bed	5	1660	375	37	36	490	925	540

tion of infiltration of precipitation and snowmelt in the valley bottoms and water discharging from subcrops of aquifers within the Sentinel Butte Formation. Outflow from the Antelope Creek aquifer in the Beulah trench has been estimated at 518 acre-ft per year (6.4 X $10^5 m^3$ per year).

4.4.3 Distribution of Major Ions

Water samples collected from the Coleharbor Formation are basically of the Na-Ca-HCO_3 type. The average composition of 26 samples, with standard errors of less than ten percent, is shown in table 4.4.3-1. The individual analyses can be found in appendix IV. The cation concentrations are relatively constant within the group but the bicarbonate and sulfate concentrations vary widely, ranging from 240-1 090 mg/L and 26-3 010 mg/L, respectively. The variation in anion concentrations does not appear to be related to the depth at which the sample was collected.

The stratigraphic units between the Coleharbor Formation and the Beulah-Zap bed are poorly represented. Generally the seven analyses are similar to those of the Coleharbor waters with the exception of sulfate concentrations which increase with depth.

The average composition of dissolved ion species from the Beulah-Zap bed falls in the Na-HCO_3-SO_4 range. The water chemistry is quite variable for all dissolved species and there is no apparent relationship between species concentration and depth. The water in this unit contains approximately twice as much sodium, bicarbonate, and sulfate than waters collected from stratigraphic units above them. The increase in concentrations is also reflected in total dissolved solids concentrations which range from 1 000-2 250 mg/L.

The increased concentrations may reflect greater rates of sulfide mineral oxidation or greater quantities of sulfide minerals available for oxidation within or just above the Beulah-Zap bed. As discussed earlier this process could lead to increased sulfate concentrations and pH as the sulfides oxidize. The hydrogen ions are consumed in calcium carbonate dissolution which releases calcium and bicarbonate into solution. The calcium is then exchanged for sodium on clay minerals, the net result being a Na-HCO_3-SO_4 type water.

Several water samples were collected

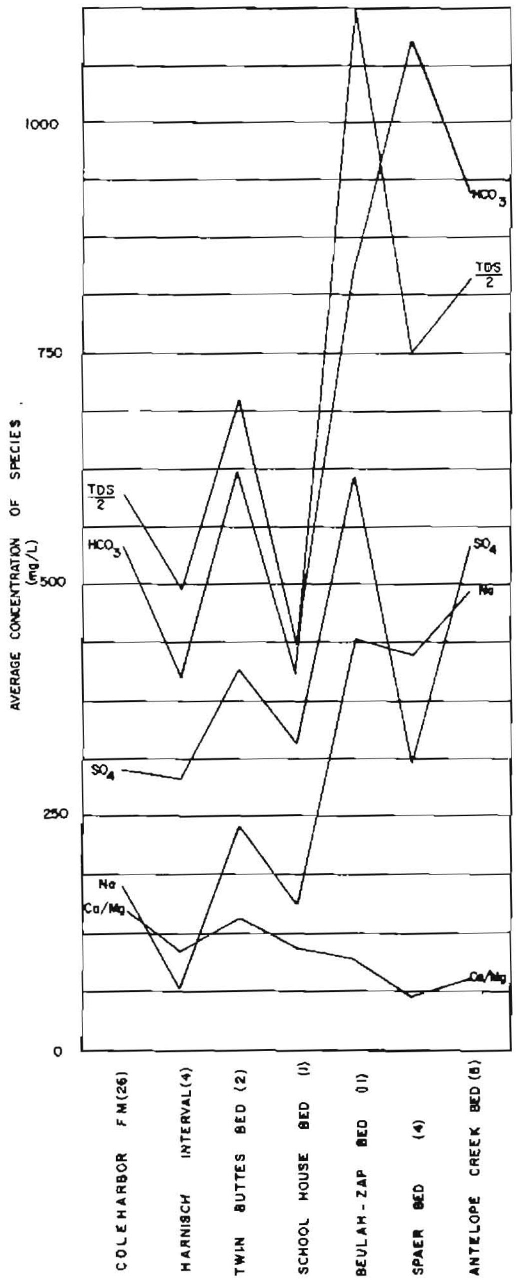


Figure 4.4.3-1. Stratigraphic distribution of major ions–Beulah-Hazen area.

from the two lignite beds below the Beulah-Zap bed. The Spaer bed, which is immediately below the Beulah-Zap bed in much of the area, has a very similar water chemistry to that of the Beulah-Zap bed with the exception of sulfate concentration which decreases by 50 percent. The reasons for this are not known at present. It may be merely a function of the small number of analyses available. The Antelope Creek bed water chemistries are also similar to the Beulah-Zap bed water analyses.

The distribution of major ions is summarized in figure 4.4.3-1. The figure clearly shows the increasing concentrations of sodium, bicarbonate, and sulfate (and decreasing calcium and magnesium concentrations) with lower stratigraphic position.

The variability of water chemistry within the stratigraphic units is readily apparent from plate 30 which shows representative water chemistries from wells in the area superimposed on a stratigraphic cross section of the area. For example, in the vicinity of test holes L-13 and M74-184 two analyses from the Beulah-Zap bed, east of M74-184, show concentrations varying from 40-300 mg/L for calcium and magnesium and from 180 to 680 mg/L for sulfate. Analyses of water from both sides of L-13 in the lignite bed below the Beulah-Zap and Spaer beds indicate calcium concentrations of 8, 202, and 32 mg/L and bicarbonate concentrations of 1 630, 1 350, and 220 mg/L.

Within all the stratigraphic units the variability of the water chemistries was large. Possible reasons for this might include: (1) localized changes in subsurface geochemical environments, (2) varying distances from recharge areas, (3) variation in flow velocities (due to permeability and/or gradient variability) with lower velocities allowing for greater dissolution minerals and higher dissolved ion concentrations.

4.4.4 Water Quality of Sentinel Butte and Coleharbor Aquifers

The following discussion of water quality will be limited to the two major aquifer systems in the Beulah-Hazen area; the glaciofluvial deposits within the Coleharbor Formation and the Beulah-Zap and Spaer lignite beds in the Sentinel Butte Formation.

Only those trace metal analyses for which the sampling method is known to be correct are included in this discussion (see sec. 4.3.6 for a more detailed discussion of this problem).

Water quality in the Coleharbor aquifers is generally good. The water is very hard with an average total dissolved solids content of 1 080 mg/L. Chloride, iron, and copper are all well below recommended concentration limits set by the U.S. Environmental Protection Agency (1975). Average sulfate concentrations are 20 percent above the recommended limits but this is not critical to human health. Manganese concentrations are twice the recommended limits so minor stain problems may result. Fluoride, nitrate, cadmium, and lead are all below the maximum permissible concentration limits.

Within the Sentinel Butte Formation the only aquifer of any significance is in the Beulah-Zap and Spaer lignite beds. The water in this aquifer is very hard with an average total dissolved solids content on the order of 2 000 mg/L. Sulfate, iron, and manganese are all above the recommended concentration limits while copper and chloride are again well below their concentration limits. Neither fluoride or nitrate are at concentrations that could result in health problems.

The major problem with the water from the lignite aquifers in the Beulah-Hazen area is their high content of the trace metals cadmium and lead. In 6 of 11 analyses cadmium exceeded permissible concentration limits and lead exceeded its limits in 4 of 11 analyses. The average cadmium concentration in the lignite aquifers is 21 μg/L while leads average concentration is 75 μg/L. Maximum permissible concentrations for these elements are 10 μg/L and 50 μg/L, respectively.

Several samples were analyzed for selenium and arsenic. None of these analyses indicated selenium or arsenic

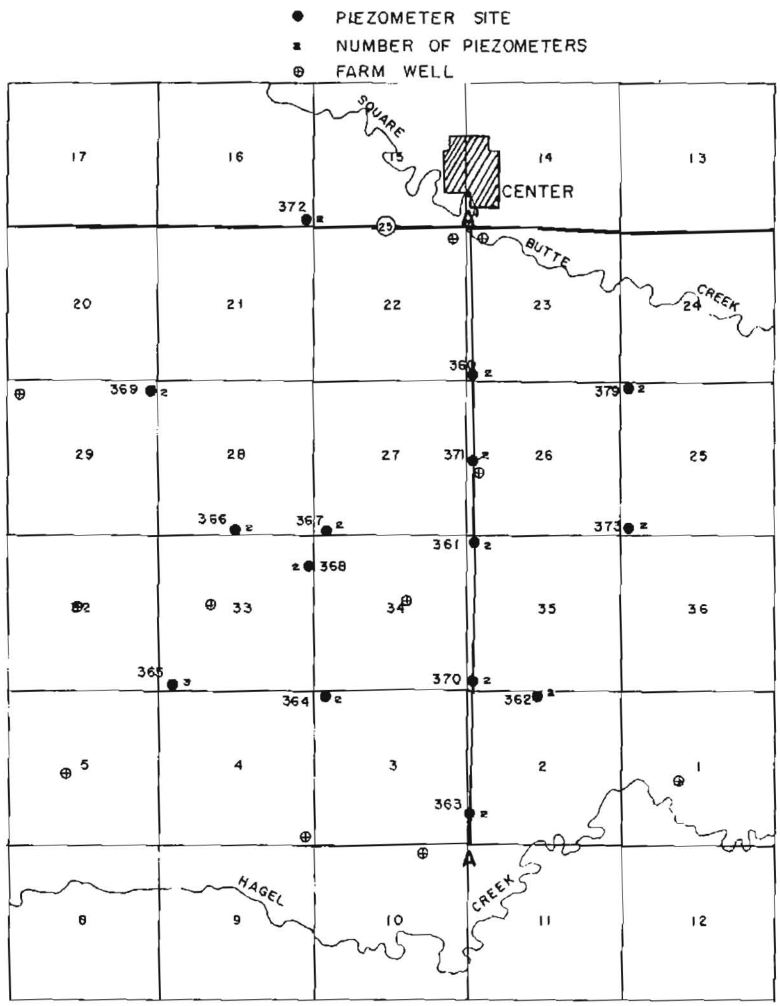


Figure 4.5.1-1. Locations of piezometer nests, identified farm wells, and cross section (figure 4.5.1-3) in the Center area.

concentrations to be above the maximum permissible concentration limits of 10 μg/L and 50 μg/L, respectively.

4.5 Hydrogeology and Hydrochemistry of the Center Area

4.5.1 Hydrostratigraphy

The Center area is located on an upland divide bounded on the north and northeast by the Square Butte Creek valley and on the south by the Hagel Creek valley. Figure 4.5.1-1 shows the topography and physiography of the area and indicates the locations of piezometer nests and farm wells for which the intake zone could be identified. Table 4.5.1-1 lists the intake zone for each piezometer and farm well.

The shallow bedrock hydrostratigraphic units within the Center area consist of sand, silty sand, and lignite aquifers separated by silty and clayey materials. Much of the area is overlain by a veneer of glacial till (fig. 4.5.1-2). Glaciofluvial sand and gravel aquifers are present in the Square Butte Creek valley. The shallow stratigraphic units of major concern hydrologically include two lignites; the Kinneman Creek bed and the Hagel bed, and a silty sand unit which lies approximately 50 feet (15 m) below the Hagel bed (fig. 4.5.1-3). Much of the

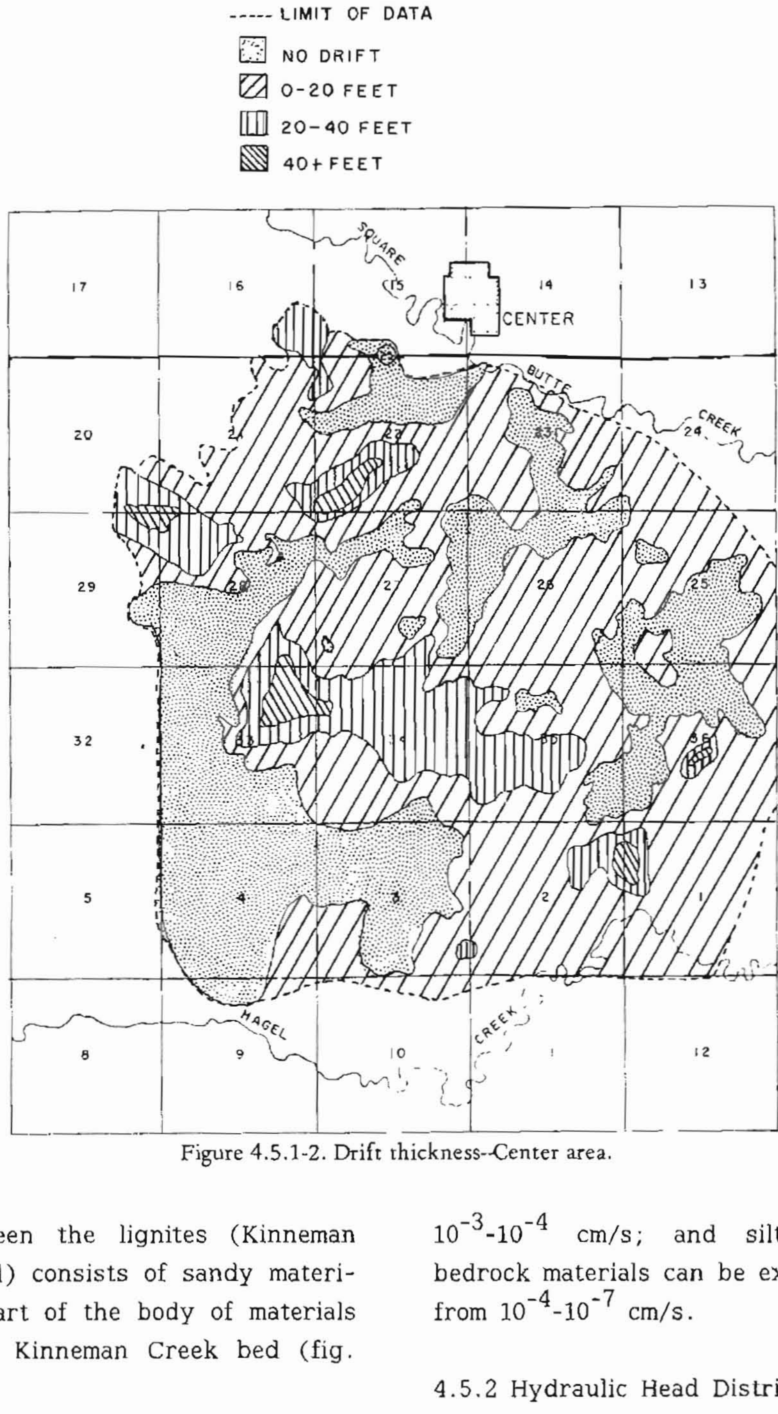


Figure 4.5.1-2. Drift thickness--Center area.

interval between the lignites (Kinneman Creek interval) consists of sandy materials as does part of the body of materials overlying the Kinneman Creek bed (fig. 4.5.1-3).

Hydraulic conductivity data are not available for the Center area. Estimates can be made based upon data from the Falkirk area. The glacial till can be expected to have hydraulic conductivities ranging from 10^{-4}-10^{-9} cm/s; the lignites from 10^{-3}-10^{-5} cm/s; sandy bedrock from 10^{-3}-10^{-4} cm/s; and silty and clayey bedrock materials can be expected to vary from 10^{-4}-10^{-7} cm/s.

4.5.2 Hydraulic Head Distribution

Figures 4.5.2-1, -2, and -3 are potentiometric surface maps of the Kinneman Creek bed, Hagel bed, and sheet sand, respectively. The distribution of hydraulic head values in these units indicates that there is a general trend

TABLE 4.5.1-1. Intake zone for farm wells and piezometers, Center area

Location	Sampled	Depth	Stratigraphic Position	Farm Owner or Piezometer Number
141-84-1 CAA	*	47'	Coleharbor	J. Berger
141-84-2 BAA	*	80'	Sheet sand	362
141-84-2 BAA		33'	Hagel bed	362 A
141-84-3 BBB		77'	Hagel bed	364
141-84-3 BBB		33'	Kinneman Creek bed	364 A
141-84-3 DDA	*	80'	Sheet sand	363
141-84-3 DDA		38'	Hagel bed	363 A
141-84-4 DDD	*	250'	Hanson interval	S. Henderscheid
141-84-5 CAA	*	35'	Kinneman Creek bed	W. Mosbrucker
141-84-10 ABA	*	69'	Sheet sand	K. Reinke
141-84-26 CBB	*	65'	Kinneman Creek bed	E. Reinke
142-83-19 CCB	*	16'	Coleharbor	J. Schmidt
142-84-16 DDD		47'	Hagel bed	372
142-84-16 DDD		42'	Kinneman Creek bed	372 A
142-84-22 AAA	*	65'	Sheet sand	O. Light
142-84-23 BBB	*	54'	Coleharbor	A. Meyhoff
142-84-23 CCC	*	108'	Sheet sand	360 A
142-84-23 CCC		45'	Hagel bed	360 B
142-84-25 BBB		89'	Hagel bed	379
142-84-25 BBB		27'	Kinneman Creek bed	379A
142-84-25 CCC		87'	Hagel bed	373 A
142-84-25 CCC		42'	Kinneman Creek bed	373 B
142-84-26 CBB		112'	Hagel bed	371
142-84-26 CBB	*	67'	Kinneman Creek bed	371 A
142-84-27 CCC		180'	Hagel bed	367
142-84-27 CCC	*	132'	Kinneman Creek bed	367 A
142-84-28 CDD		115'	Hagel bed	366
142-84-28 CDD		65'	Kinneman Creek bed	366 A
142-84-29 AAA		129'	Hagel bed	369
142-84-29 AAA		109'	Kinneman Creek bed	369 A
142-84-29 BBB	*	70'	Kinneman Creek bed	V. Ganske
142-84-32 BDD	*	32'	Kinneman Creek bed	T. Lipp
142-84-33 ADA		110'	Hagel bed	368
142-84-33 ADA	*	70'	Kinneman Creek bed	368 A
142-84-33 BDD	*	55'	Kinneman Creek bed	J. Bobb
142-84-33 CCC		140'	Sheet sand	365
142-84-33 CCC	*	90'	Hagel bed	365 A
142-84-33 CCC		43'	Kinneman Creek bed	365 B
142-84-34 ACC	*	46'	Kinneman Creek bed	B. Dresser
142-84-35 CCC		100'	Hagel bed	370
142-84-35 CCC		37'	Kinneman Creek bed	370 A

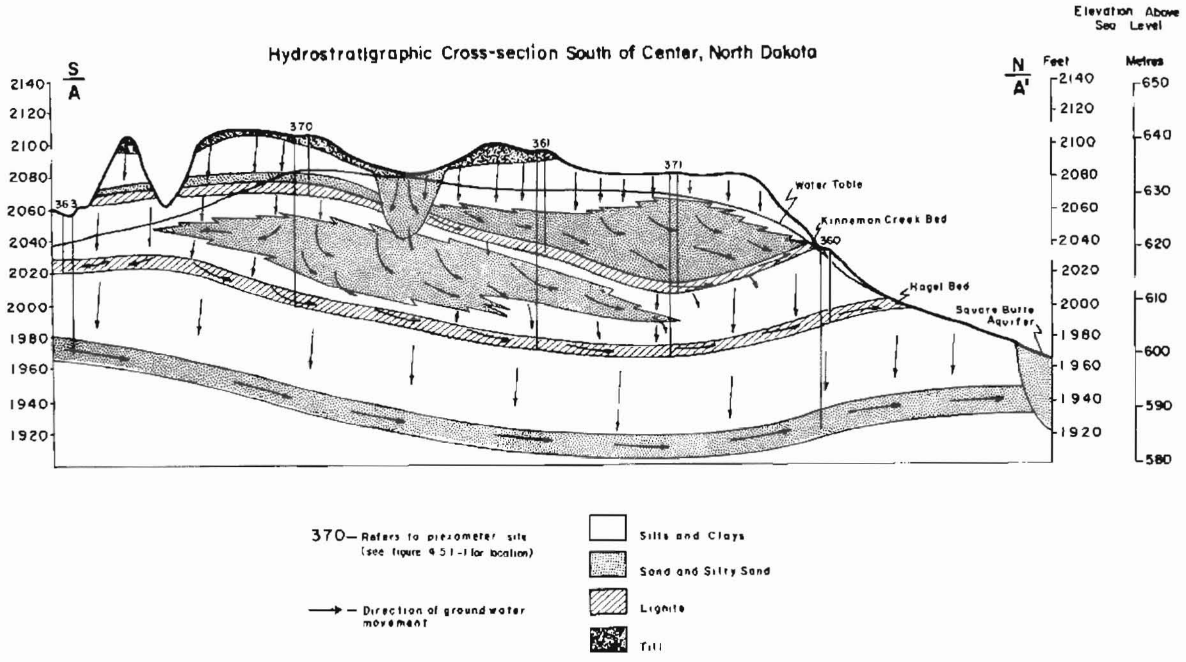


Figure 4.5.1-3. Hydrostratigraphic cross section of the Center area. See figure 4.5.1-1 for location of cross section.

toward decreasing head values with increasing depth below the surface. The lowest hydraulic head values in the two lignites occur around the margins of the study area. The highest head values in these units occur, in general, in the vicinity of the areas of highest surface topography.

The head values in the Kinneman Creek bed indicate that the bed is either dry or slightly saturated throughout much of the southwestern portion of the study area. The Kinneman Creek bed is also dry to the northeast, at site 379. The Kinneman Creek bed is saturated in the vicinity of sites 367, 368, and 371 and constitutes a major water supply for wells to the west of the study area. The Hagel bed, on the other hand, appears to be a major aquifer throughout most of the study area (fig. 4.5.2-2).

The limited number of hydraulic head values in the sheet sand show a much different trend than those in the lignites (fig. 4.5.2-3). The head values in this unit indicate an apparent decrease across the study area from the south to the north. There is no apparent relationship to surface topography as is the case with the lignites. However, the limited number of head values for the sheet sand allow for varying interpretations of the data.

4.5.3 Groundwater-Flow Systems

Groundwater movement within the Kinneman Creek bed, Hagel bed, and sheet sand is indicated by the arrows on figures 4.5.2-1, -2, and -3. Figure 4.5.1-3 is a generalized north-south cross section of the study area showing the hydraulic interaction between the various stratigraphic units.

In general, the movement of groundwater in the fine-textured materials (aquitards) is vertical. The decrease in hydraulic head with depth, as mentioned previously, indicates that flow within the aquitards is downward. Movement of groundwater in the sand and lignite aquifers is essentially horizontal or lateral.

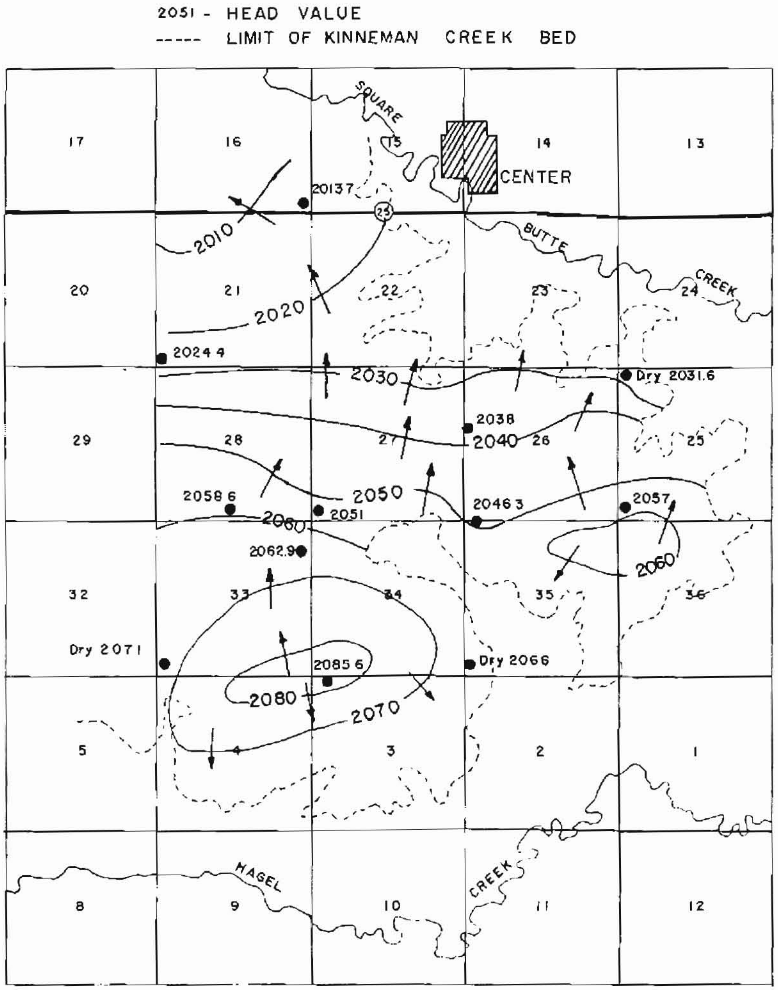


Figure 4.5.2-1. Potentiometric surface–Kinneman Creek bed–Center area.

Very slow downward movement of groundwater through the various aquitards supplies water to the aquifers. The aquifers, in turn, lose water by downward seepage to underlying aquitards and transmit water laterally to discharge areas along slopes or, as in the case of the sheet sand, to glaciofluvial valley-fill materials (fig. 4.5.1-2).

The locations of recharge and discharge areas vary according to the type of flow system. Figures 4.5.2-1 and -2 indicate that the major recharge areas for both lignites correspond closely with upland areas. These are also areas of generally thin till (fig. 4.5.1-2). Discharge from the two lignites is along valley slopes, particularly along Hagel Creek and Square Butte Creek. Thus, essentially all groundwater flow within both the Kinneman Creek bed and the Hagel bed is local, originating and terminating within the study area.

Groundwater flow within the sand, as indicated by figure 4.5.2-3, is apparently related to a larger flow system than that which controls overlying aquifers. The general decreasing trend in hydraulic head values across the study area from south to north indicates that flow within this unit is probably controlled by the Square Butte Creek valley. Thus, the

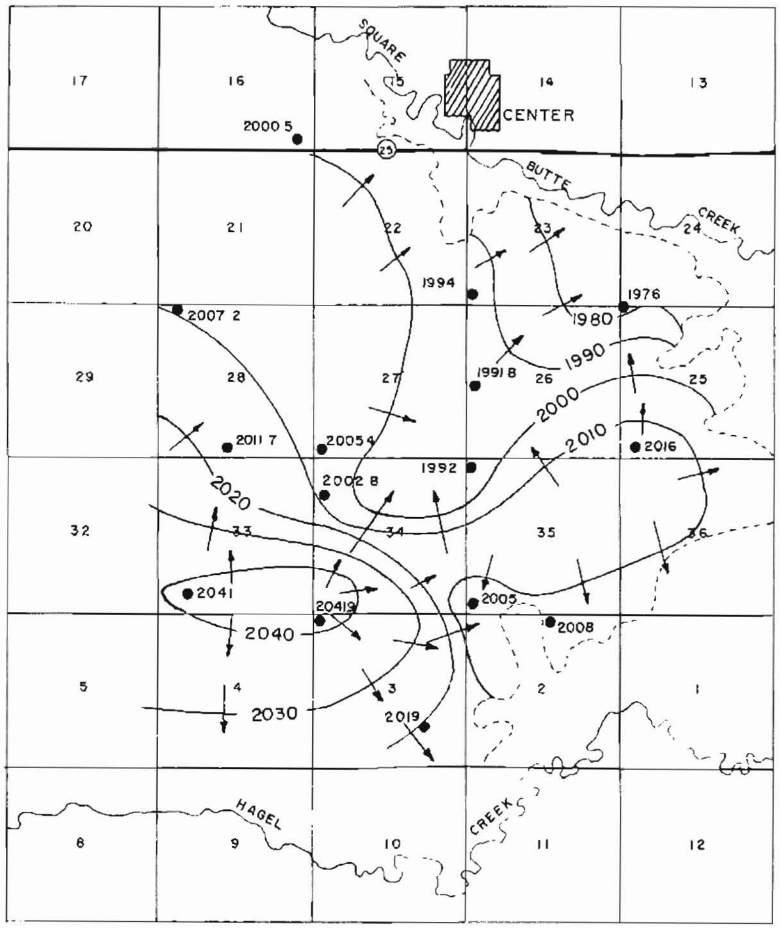


Figure 4.5.2-2. Potentiometric surface--Hagel bed--Center area.

major discharge area for the sand is apparently in the buried sand and gravel below Square Butte Creek. The major area of recharge to this unit is apparently to the south or southwest of the study area.

4.5.4 Distribution of Major Ions

Plate 31 is a cross section of the Center area which shows groundwater chemical variability in shallow stratigraphic units. The variability in water chemistry is large in all the units. However, certain trends are apparent. The Kinneman Creek and Hagel beds typically contain NA, Ca-HCO_3, SO_4 to SO_4, HCO_3 type water. Total dissolved solids concentrations in the Kinneman Creek and Hagel beds vary from 863-3 310 mg/L. The sheet sand is characterized by Na to Na, Ca-HCO_3 to HCO_3, SO_4 type water. Total dissolved solids in the sheet sand vary from 556-2 960 mg/L (pl. 31). The increase in Na with depth is apparently due to calcite dissociation in the near surface together with exchange of Ca for Na on clays as the water slowly migrates downward through clay-rich materials. High HCO_3 concentrations in the sheet sand,

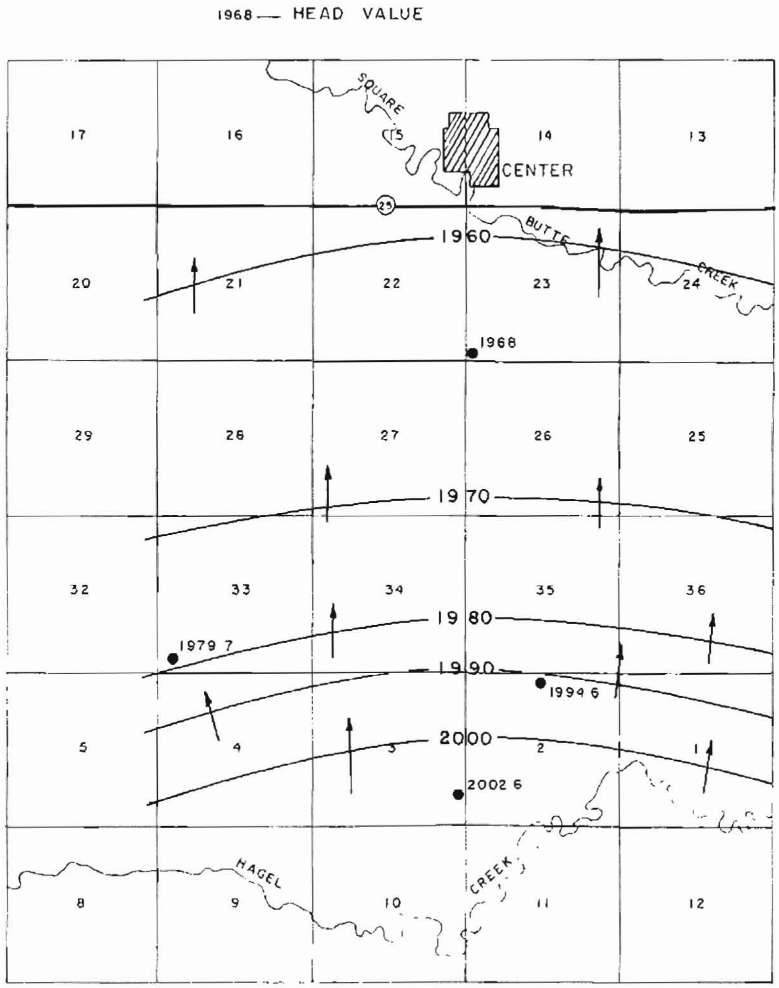


Figure 4.5.2-3. Potentiometric surface–sheet sand--Center area.

particularly in the south part of the area, may be due to recharge of this unit from glaciofluvial sand and gravel valley fill in the Hagel Creek valley or elsewhere to the south of the study area. Croft (1973) indicates that water in the Square Butte aquifer, as well as other Coleharbor aquifers, is generally of the $Na\text{-}HCO_3$ type.

4.5.5 Distribution of Trace Constituents

The concentrations of iron in the Kinneman Creek bed, Hagel bed, and sheet sand range from 96-2 850 µg/L (pl. 31). The majority of the samples exceed the recommended limit of 300 µg/L (U.S. Environmental Protection Agency, 1975). Manganese concentrations range from 59-329 µg/L, all in excess of the recommended limit of 50 µg/L. Copper concentrations in the aquifers range from 5-67.5 µg/L. These concentrations are all well below the recommended limit of 1 000 µg/L copper.

Cadmium values are also well below the maximum permissible concentration of 10 µg/L, ranging from 0.22-3 µg/L. Lead concentrations range from 4-39 µg/L, all of which are below the maximum permissible level of 50 µg/L (U.S. Environmental Protection Agency, 1975).

4.6 Premining and Post-mining Hydrogeology and Hydrochemistry of the Indian Head Mine

4.6.1 Introduction

Throughout many areas of western North Dakota, groundwater from shallow wells constitutes the sole water supply for domestic and stock purposes. In many of these areas, fractured lignite beds are the major source of shallow groundwater. Strip mining for lignite and associated post-mining reconstruction of the landscape results in the creation of new physical and geochemical environments. These changes can potentially have a marked effect on local groundwater conditions. Of major concern is the potential for chemical degradation of the groundwater.

Of the five detailed hydrogeologic study sites included in this study, the Indian Head site is the only one at which detailed hydrologic instrumentation of spoils has been possible. Data obtained from the Indian Head site allow for an excellent comparison of groundwater quality in premining and post-mining landscapes. The following discussion will focus largely on the implications of spoil water chemistry at the Indian Head site relative to the hydrochemical model discussed previously in section 4.2.

The Indian Head Mine is located about two miles (3.2 km) southeast of the town of Zap, in Mercer County, North Dakota (fig. 1.2.2.1-1). The mine is situated on an upland area between Spring Creek and the Knife River. The topography of the site is rolling to very steep. Maximum relief is about 225 feet (70 m).

Hydrologic instrumentation of the site began in 1974. Nineteen piezometers have been installed in undisturbed areas (table 4.6.1-1). Instrumentation of spoils has been concentrated in two, approximately 40-acre (16-ha) study sites identified as the MSU and USBM sites (fig. 4.6.1-1). Approximately 70 piezometers have been installed in the two spoils study areas.

4.6.2 Premining Hydrostratigraphy

The Sentinel Butte Formation in the vicinity of the Indian Head Mine is characterized by a series of thin cyclic intervals. Each cycle is bounded both above and below by a lignite or carbonaceous zone. The sediments between the various lignites and carbonaceous zones are of variable thickness and consist of predominantly silty and clayey flood basin sediments. The silt and clay materials are commonly pyritic. The dominant clay mineral is sodium montmorillonite.

Plate 32 is a cross section through a portion of the Indian Head site. At the base of the section is a thick lignite, the Beulah-Zap bed. This is the bed that is presently being mined. As can be seen from the cross section, as many as four or five cyclic intervals are present in certain test holes above the Beulah-Zap bed.

The Coleharbor Formation is represented by a few patches of thin pebble loam (till) on upland areas, by scattered occurrences of wind-blown silt (loess), and by interbedded till and valley-fill sediment in partly buried valleys.

In general, the movement of groundwater in the fine-textured materials in the premining setting is vertical and downward. Recharge typically results from infiltration of ponded precipitation and spring snowmelt in upland areas. Hydraulic conductivities of the silty and clayey sediments range from 10^{-4}-10^{-7} cm/s. The very slow downward movement of ground-

TABLE 4.6.1-1. Intake zone of piezometers at the Indian Head Site

Well Number	Location	Depth (ft)	Stratigraphic Position
Ind 5	144-88-31 BBB	90.2	Beulah-Zap bed
Ind 6	144-88-31 BBC	72.75	Beulah-Zap bed
Ind 25	144-88-30 CCC	94.5	Beulah-Zap bed
Ind X-1	144-89-36 AAB	139.6	Beulah-Zap bed
Ind X-2	144-89-36 ABB	85.45	Schoolhouse interval
Ind 12	144-89-36 BAA	80.25	Beulah-Zap bed
Ind 14	144-89-36 BBB	67.7	Beulah-Zap bed
Ind 149	144-89-25 BDD	162.25	Beulah-Zap interval
Ind 117	144-89-36 BBB	73.3	Beulah-Zap bed
Ind 115	144-89-36 BCD	44.4	Beulah-Zap bed
Ind 111	144-89-36 BCC	80.2	Beulah-Zap bed
Ind 112	144-89-36 CBB	125.7	Beulah-Zap bed
Ind 99	144-89-36 CCB	123.25	Beulah-Zap bed
Ind 98	144-89-36 CCC	93.1	Buelah-Zap bed
Ind 97	143-89-01 BBD	137.7	Beulah-Zap interval
Ind 100	144-89-36 CCD	47.1	Beulah-Zap bed
Ind 108	144-89-36 CBA	52.1	Beulah-Zap bed
Ind 165	144-89-26 DCB	70.1	Beulah-Zap bed
Ind 127	144-89-26 DCC	94.8	Beulah-Zap bed

water through the fine-textured materials supplies water to the sand and lignite aquifers. The aquifers, in turn, lose water through downward seepage to underlying materials and transmit water laterally to discharge areas. Hydraulic conductivities range from 10^{-3}-10^{-5} cm/s in the lignites and 10^{-3}-10^{-4} cm/s in the sandy bedrock materials.

4.6.3 Spoils Hydrology

Eleven hydraulic conductivity values for piezometers in the base of the spoils were determined by slug testing (table 4.6.3-1). Six values from wells located in precontouring spoils ridge areas range from 3.0 X 10^{-5} cm/s to 7.3 X 10^{-7} cm/s. Five values from wells located in precontouring spoils valley areas range from 4.6 X 10^{-3} cm/s to 5.9 X 10^{-7} cm/s indicating considerably greater variability in precontouring valley areas than in ridge areas (table 4.6.3-1). In conjunction with these data, there is some indication of a decrease in saturation in locations of precontouring spoils ridges as opposed to precontouring spoils valleys indicating preferential movement of water in the base of the spoils through the generally linear precontouring valley areas.

Given the very sluggish nature of the flow systems, it is difficult to determine the long-term characteristics of water movement in the spoils. It is possible that many years may be required to reestablish a steady-state condition in these materials. Preliminary hydraulic head data

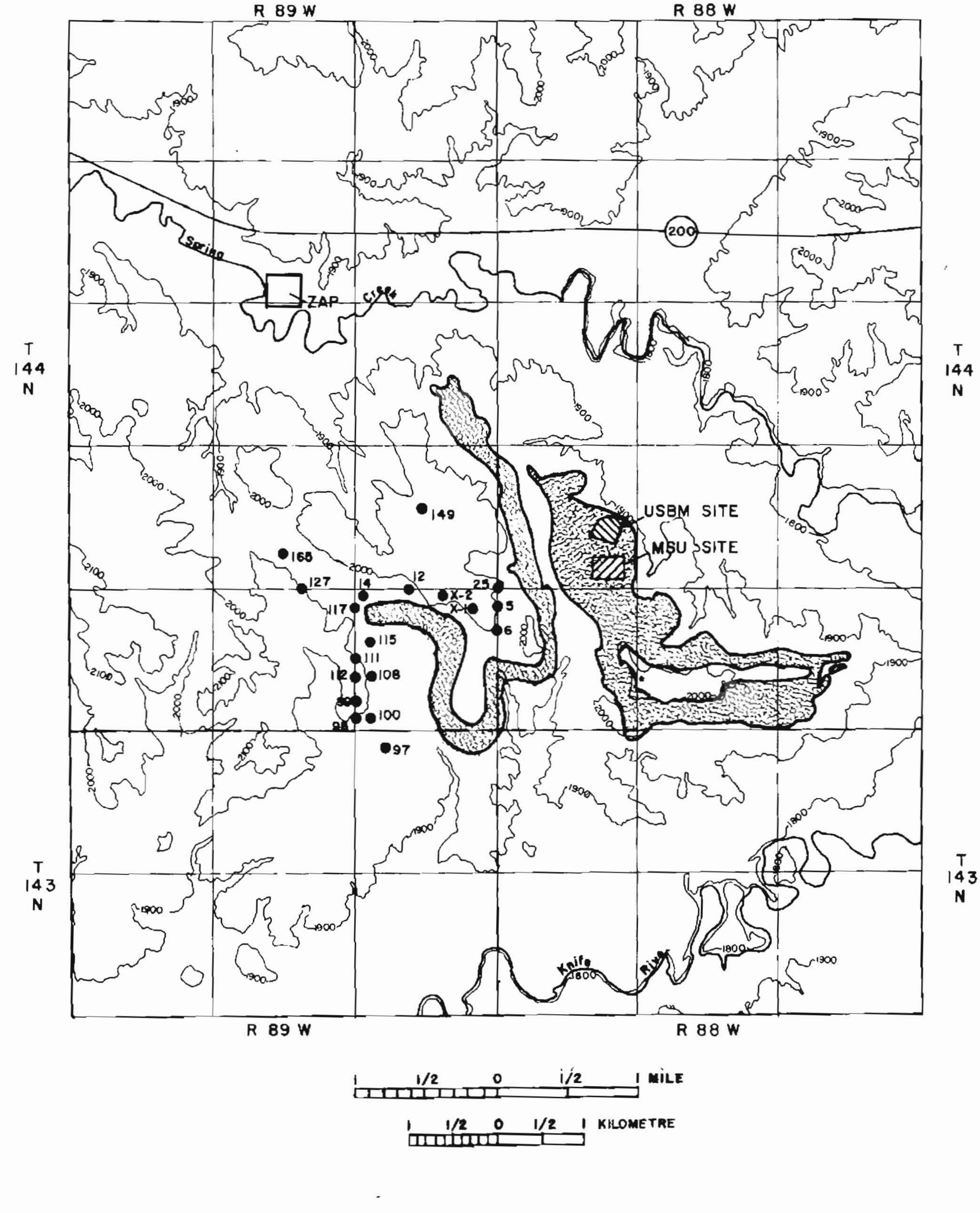


Figure 4.6.1-1. Location of piezometers and spoil test site at the Indian Head Mine. See table 4.6.1-1 for intake zone of piezometers.

TABLE 4.6.3-1. Hydraulic conductivity values from wells in base of spoils

Well No.	Precontouring Morphology	Hydraulic Conductivity (cm/s)
2	valley	5.4×10^{-4}
8	valley	4.6×10^{-6}
11	ridge	1.2×10^{-6}
22	ridge	7.3×10^{-7}
27	ridge	4.8×10^{-7}
30	ridge	3.0×10^{-5}
32	valley	4.6×10^{-3}
35	ridge	5.8×10^{-6}
36	valley	5.9×10^{-7}
40	coalescing ridges	8.2×10^{-6}
43	valley	2.9×10^{-7}

and field observations indicate that the majority of the water in the base of the spoils is the result of lateral recharge. The source of the water is either seepage from old highwalls and pits or from adjacent areas of older spoils.

Vertical infiltration in the spoils is minimal except locally where fractures and piping features allow for the rapid downward movement of large volumes of surface water. Fine-textured overburden, such as are found at Indian Head, are highly susceptible to differential subsidence, fracturing, and piping. Concentrations of blocky materials in the subsurface of the body of spoils are a major factor controlling these spoil instability phenomena. These problems are compounded by winter contouring, which results in concentrations of large frozen blocks of spoil, and by dozer rather than scraper contouring. Scraper-contoured spoils tend to be better compacted and therefore less susceptible to instability than dozer-contoured spoils (Groenewold and Winczewski, 1977).

4.6.4 Comparison of Water Chemistry from Wells in Undisturbed Areas and in Spoils

Quality of water from wells in unmined materials is variable. Groundwater analyses from selected wells in the Beulah-Zap bed are included in table 4.6.4-1. The Beulah-Zap bed in the vicinity of the Indian Head Mine typically contains Na, Ca-HCO_3, SO_4 to SO_4, HCO_3 type water. Sodium concentrations in the Beulah-Zap bed range from 278-1 107 mg/L; sulfate from 409-1 608 mg/L and bicarbonate from 415-1 663 mg/L. Total dissolved-solids concentrations in the Beulah-Zap bed range from 938-4 390 mg/L (table 4.6.4-1).

The observed chemical characteristics of shallow groundwater in western North Dakota are the result of several interrelated near-surface geochemical processes. The dissolution of carbonate minerals (largely calcite) results in increased HCO_3^{2-} and Ca^{2+} concentrations. Ca^{2+}-Na^+ exchange on sodium-montmorillonitic clays results in elevated Na^+ concentrations and allows for continued calcite dissolution. Elevated SO_4^{2-} concentrations result from the oxidation of pyrite by infiltrating water as well as from the dissolution of gypsum in the near-surface environment. Generally high concentrations of Na^+ and SO_4^{2-} in water in the Beulah-Zap bed are apparently a function of the highly clayey, pyritic overburden at the Indian Head Mine. The geochemical evolution of groundwater in western North Dakota has been discussed in detail in sections 4.2 and 4.10.

Analyses of water from spoils at the Indian Head Mine are included in table 4.6.4-2. The analyses show extreme variability. Sodium concentrations in spoil waters from the Indian Head site vary

TABLE 4.6.4-1. Chemical analyses of groundwater samples from the Beulah-Zap bed--Indian Head Mine

Depth (m)	Field pH	Cond. (μmhos/cm)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)
25.0	--	3038	3390	28.4	44.0	985	31.4	1520	18.9	1025
19.5	7.66	4437	3380	19.4	12.8	1039	31.4	1455	25.0	1211
26.6	7.83	1508	938	72.0	29.9	305	21.2	445	8.2	409
36.3	7.52	1497	990	75.0	37.8	278	18.5	415	10.0	434
20.7	7.28	5587	4390	63.5	30.0	1107	35.5	1663	37.7	1608

TABLE 4.6.4-2. Chemical analyses of water from spoils--Indian Head Mine

Depth (m)	Field pH	Cond. (μmhos/cm)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)
15.6	7.22	2322	1590	52.9	20.3	548	30.0	859	6.6	559
19.6	7.94	16560	15880	524.0	978.0	3445	238.0	2206	1.8	9408
13.5	6.26	5120	8600	736.0	499.0	977	37.8	1404	27.1	2117
15.0	7.38	2980	1936	79.0	63.0	411	63.0	1428	6.6	450
15.0	7.12	2100	1560	74.2	48.0	589	24.4	1119	10.0	591
13.0	6.76	6390	4438	328.0	231.0	515	88.0	1510	5.9	1793
18.3	--	10000	--	192.0	179.0	2488	--	2346	13.2	5146
7.5	--	--	2070	36.6	19.9	813	27.0	885	9.8	434

from 411-3 445 mg/l; sulfate ranges from 434-9 408 mg/L; bicarbonate varies from 859-2 346 mg/L. Total dissolved-solids concentrations in spoils at Indian Head vary from 1 560-15 880 mg/L.

The chemical characteristics of spoil waters at the Indian Head Mine are apparently dependent upon several factors. The most significant of these are the physical and geochemical characteristics of the original overburden and variables in the methods and time of emplacement of those materials. An understanding of the original depositional environment of the sediments is critical. Localized high sodium and sulfate concentrations in spoil waters at Indian Head are largely a function of the emplacement of unoxidized pyritic and sodium-montmorillonitic clayey flood basin materials in the near-surface oxidizing environment. Fractures and piping phenomena, as are common in fine-textured materials, increase O_2 availability and allow for localized accelerated SO_4^{2-} generation. This is discussed in greater detail in section 4.10. Dozer contouring of fine-textured materials, especially if the spoils are frozen, increases the potential for fracturing and piping.

Sodium and sulfate generation can be expected to be much less severe in mines having sandy overburden. Sandy (natural levee and channel) deposits contain less clay, and therefore are less sodic. Sandy materials are also much less likely to be pyritic and are much less susceptible to differential subsidence and fracturing.

Thus, a premining inventory of the overburden oriented toward the identification of these critical geochemical factors is essential to post-mining groundwater design. An understanding of the original environment of deposition of the overburden materials in conjunction with a well-integrated mining and reclamation plan will allow for the design of a post-mining landscape in which the water chemistry is predictable. Selective handling and placement of spoils will be required in some settings. Sodium or sulfide-rich unoxidized materials should be placed in the base of the spoils. This position will generally be below the post-mining water table. Such positioning will greatly decrease the potential for sulfate and sodium generation in the post-mining groundwater system and should, over the long term, result in the generation of water of similar quality to that which existed prior to mining.

4.7 Regional Distribution of Aquifers

4.7.1 The Fox Hills Aquifer

The Fox Hills aquifer is the only continuous regionally-extensive sandstone aquifer with potable water that underlies the Knife River basin and the rest of the southwestern part of North Dakota. The aquifer is composed primarily of sandstone beds in the upper part of the Fox Hills Formation. The sandstone is fine- to medium-grained, formed of sediment deposited in a shoreline coastal or lagoonal environment. In the Knife River basin the sandstone of the Fox Hills Formation varies in thickness from about 100-300 feet (30-90 m). Although the major part of the Fox Hills aquifer consists of sandstone of the Fox Hills Formation, in some parts of western North Dakota the aquifer comprises sandstone beds of the lowermost part of the Hell Creek Formation. Sediment of the Hell Creek Formation is believed to be continental in origin.

Permeable zones in the lower part of the Hell Creek Formation probably owe their origin to deposition in the higher velocity zones in stream channels. These zones are expected to be irregular and discontinuous in comparison to the extensive sheet-like sand of the Fox Hills Formation. It is rarely possible on the basis of borehole descriptions and geophysical logs to separate the aquifer zone into Fox Hills and Hell Creek segments. For convenience we have chosen to refer to the aquifer as the Fox Hills aquifer even though in places the permeable zone extends into the basal part of the Hell Creek Formation.

No regional studies of the Fox Hills aquifer have been reported on the literature. Descriptions of the yield capability of the aquifer and its water quality are included on a county by county basis in county groundwater resource studies conducted by the North Dakota State Water Commission in cooperation with the U.S. Geological Survey. The following comments on the hydraulic conductivity and yield capabilities of the aquifer are based on information in these reports.

The Fox Hills aquifer is of special importance in areas where surface mining occurs or is planned because in the event that the groundwater in the reclaimed land is unsuitable for domestic or livestock use, deeper wells will have to be used. In many areas the Fox Hills aquifer is the only aquifer with major yield capabilities existing below the main coal that will be removed or otherwise affected by mining. Since the Fox Hills aquifer is a regional water-supply zone and since withdrawals in one part of the aquifer have potential to affect other parts of the aquifer, the discussion that follows considers the aquifer in the Knife River basin and in areas much beyond the basin.

Figure 4.7.1-1 shows the distribution of outcrop and subcrop areas of the Fox Hills Formation and the regional stratigraphy in North Dakota and in neighboring segments of Montana and South Dakota. Figure 4.7.1-2 indicates the southern limit of ice coverage during major episodes of Pleistocene glaciation. In the area between the limit of the earliest glaciation and the limit of the early Wisconsinan glaciation, the glacial deposits are thin, generally less than 10 or 20 feet (3 or 6 m) thick. In the extreme southwestern part of North Dakota and neighboring areas of Montana and South Dakota a significant area of outcrop occurs in the unglaciated region. In the south-central part of North Dakota extensive areas of outcrop occur where the glacial deposits are generally very thin. This outcrop belt extends into the northern part of South Dakota. A large area of subcrop occurs in central and northern North Dakota.

The regional stratigraphic setting shown in figure 4.7.1-1 indicates that the Fox Hills aquifer is basin shaped, with its structurally lowest zone occurring beneath the Knife River area. In the Knife River basin the top of the aquifer ranges in depth from 700-1 400 feet (210-420 m) below ground surface. The aquifer attains a maximum depth in Dunn County where it is about 1 400 feet (420 m) below ground surface. Figure 4.7.1-1 indicates that the Fox Hills aquifer is underlain by the Pierre Formation of Cretaceous age. This formation is composed almost exclusively of marine shale rich in montmorillonitic clay minerals. It is an aquitard of extremely low permeability. The Fox Hills aquifer is confined above by siltstone and shale strata in the Hell Creek Formation. Although these beds are not nearly as thick and regionally extensive as the shale of the Pierre Formation, and although the Hell Creek Formation also has numerous sandstone strata, they nevertheless are believed to act as a regional aquitard. Trapp and Croft (1975) provide results of a particle size analysis on a core of shale from the middle of the Hell Creek Formation in Mercer County. Clay and silt-sized particles constituted 49 percent of the sample. Core samples from sandy strata in the upper part of the Hell Creek Formation had silt and clay contents ranging between 6 and 23 percent.

4.7.2 Aquifers in the Upper Hell Creek, Cannonball, and Ludlow Formations

Permeable zones occur in the upper Hell Creek Formation and in various positions in the Lower Cannonball and Ludlow Formations. These zones consist of discontinuous units of fine- to medium-grained sand, interbedded with silty and clayey sediment. These aquifers are within an approximate 250-foot (75-m) interval, the depth of which varies from 300-1 200 feet (90-365 m) across the study area (pl. 2). Very few wells in the study area are screened in these units.

Very little data is available regarding the hydraulic properties of the upper Hell Creek and Cannonball-Ludlow aquifers. Hydraulic conductivity values from cores obtained in Stark County (Trapp and Croft, 1975) ranged from 3.4×10^{-4} to 7×10^{-3} cm/s. Because of the discontinuous nature of the permeable zones and more readily available water supplies in the overlying Lower Bullion Creek aquifer

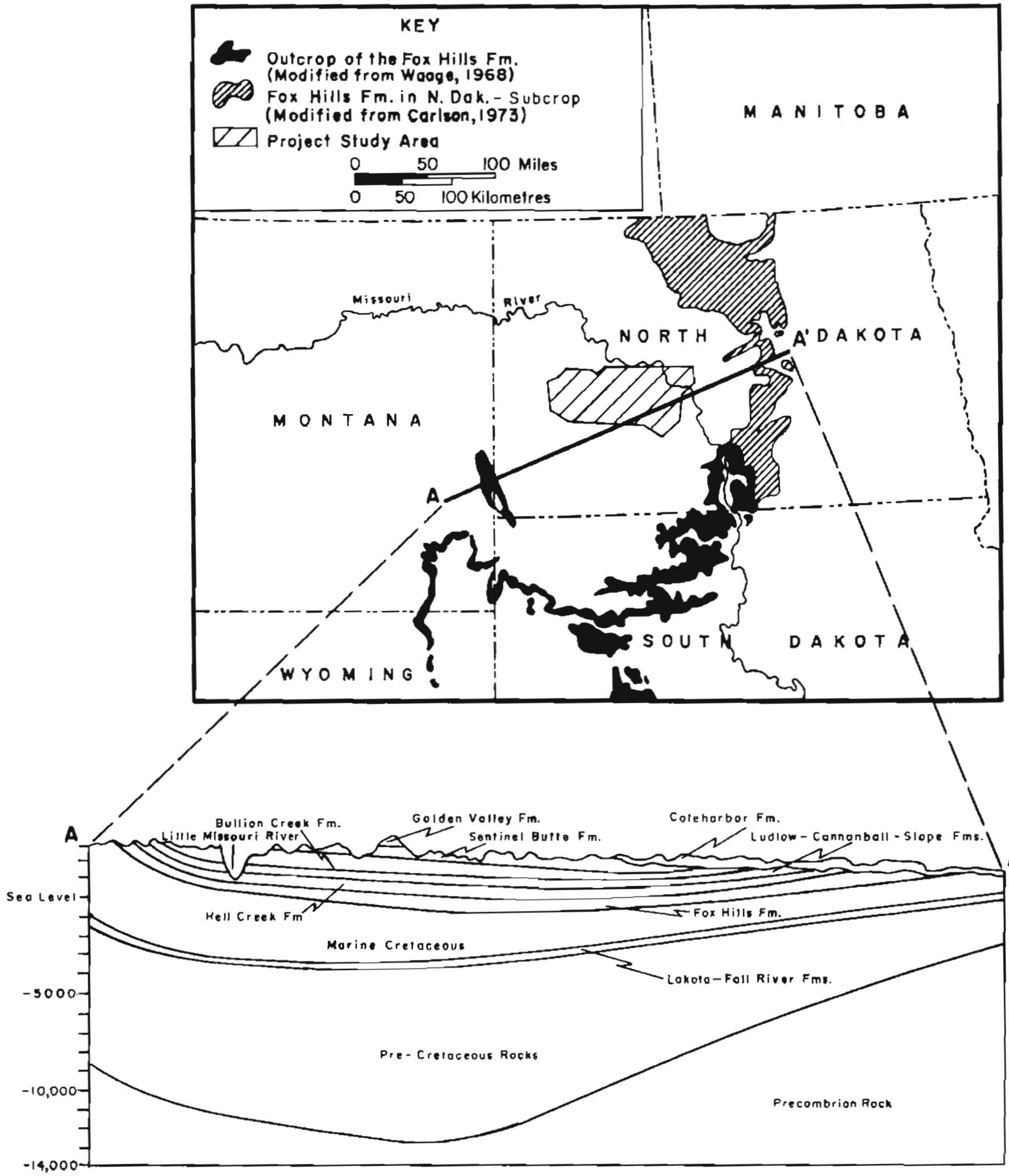


Figure 4.7.1-1. Areas of outcrop and subcrop and stratigraphic setting of the Fox Hills aquifer in North Dakota and neighboring segments of Montana and South Dakota.

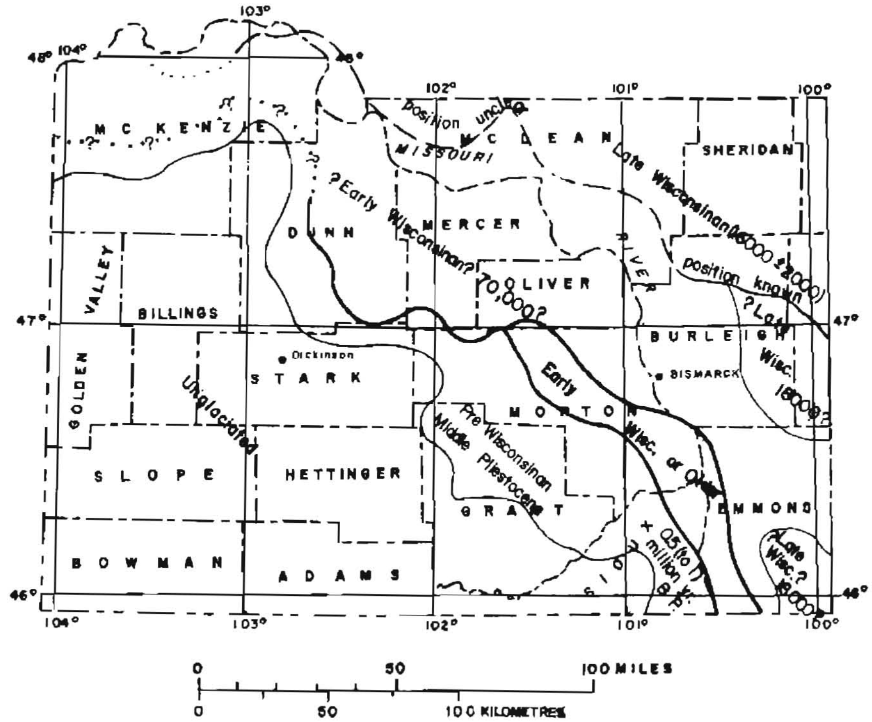


Figure 4.7.1-2. Southern limit of glaciation and thickness of non-valley fill Pleistocene deposits in southwestern North Dakota.

zone, it is unlikely that this aquifer system will ever be extensively developed.

4.7.3 Lower Bullion Creek Aquifer Zone

The areal extent of the Lower Bullion Creek aquifer zone is much more limited than that of the Fox Hills aquifer, being largely restricted to the Knife River basin and adjacent areas to the north and south. The Bullion Creek Formation outcrops or is covered by thin glacial drift in northern Burleigh, eastern Oliver, and eastern Morton Counties. The unit is also exposed in western North Dakota in McKenzie, Golden Valley, Billings, and Slope Counties.

The Lower Bullion Creek aquifer zone was briefly discussed in section 1.1.4. References to this aquifer are to be found in various published reports. In a report on the groundwater resources of Mercer and Oliver Counties, Croft (1973) described a regional aquifer in the lower part of the Bullion Creek (Tongue River) Formation. He referred to the aquifer as the "Lower Tongue River aquifer." Croft (1973) indicated that the aquifer, which is composed mainly of sandstone beds, underlies most of Oliver County and the southwestern corner of Mercer County.

In a report on the geology and groundwater resources of Hettinger and Stark Counties, Trapp and Croft (1975) describe an aquifer system that they consider to include beds in the upper part of the Ludlow Formation and all of the Bullion Creek (Tongue River) Formation. In this "system" they include the "basal sandstone member" of the Bullion Creek Formation. They include a map of the transmissivity and yield of this aquifer. In a compilation of basic hydrogeologic data for Dunn County, Klausing (1976) identified deep wells screened in the Bullion Creek Formation (referred to by Klausing as the "Tongue River Aquifer") without indicating if the wells occur in the basal part of this formation.

As is indicated by plate 2, the lower part of the Bullion Creek Formation consists of numerous discontinuous sand units rather than a single widespread unit. The total composite thickness varies from 0-200 feet (0-60 m) and includes sand units within the Hansen, Harmon, and Weller Slough intervals. We therefore refer to this composite of sand unit as an "aquifer zone" rather than as a distinct aquifer. The Hensler bed, as described in the discussion of the Falkirk area (sec. 4.3) is within this aquifer zone.

There is a very limited amount of data on the hydraulic properties of the Lower Bullion Creek aquifer zone within the study area. Several cores were analyzed from Dunn County (Klausing, 1976). These cores yield an average hydraulic conductivity of 4×10^{-5} cm/s.

The occurrence of water supply zones in the Bullion Creek Formation has importance with respect to coal mining in the Knife River basin. If groundwater in the cast overburden in the reclaimed land develops water quality that renders it unsuitable for domestic or livestock use, there will be a need for alternative water supplies at greater depth. The aquifer zone in the Lower Bullion Creek Formation would, in this circumstance, constitute a logical alternative water supply. This aquifer zone, unlike the Fox Hills aquifer, generally does not have fluoride concentrations at levels above the maximum permissible limits for drinking water and may therefore have enhanced value relative to the Fox Hills Formation. This topic is discussed further in section 4.9.3.

In this report our consideration of the hydrogeology and hydrochemistry of the aquifer zone in the Lower Bullion Creek Formation is restricted to the Knife River basin and adjacent areas.

4.8 Regional Aspects of Groundwater Flow

4.8.1 Flow in the Fox Hills Aquifer

The following discussion will consider flow in the Fox Hills aquifer on a regional scale extending from the outcrop areas in eastern Montana and southwestern North Dakota to the outcrop and subcrop areas in south-central North Dakota. The northern limit of the region of flow system analysis generally follows the valley of the Missouri River. Figure 4.8.1-1 shows the potentiometric surface of Fox Hills aquifer in the region of interest. The depth of wells in the aquifer is included in appendix C-II. The locations of wells with water-level data used in preparation of figure 4.8.1-1 are shown in figure 4.8.1-2.

The water level and chemical data used in this study were largely obtained from published county groundwater studies from the respective portions of the area as well as from unpublished U.S. Geological Survey data made available in computer tabulations. Plate 23 shows the locations of all Fox Hills wells having complete chemical analyses. All analyses are included in appendix C-II. As part of the present investigation several samples from Fox Hills wells were analyzed. These additional wells and corresponding analyses are also included on plate 23 and in

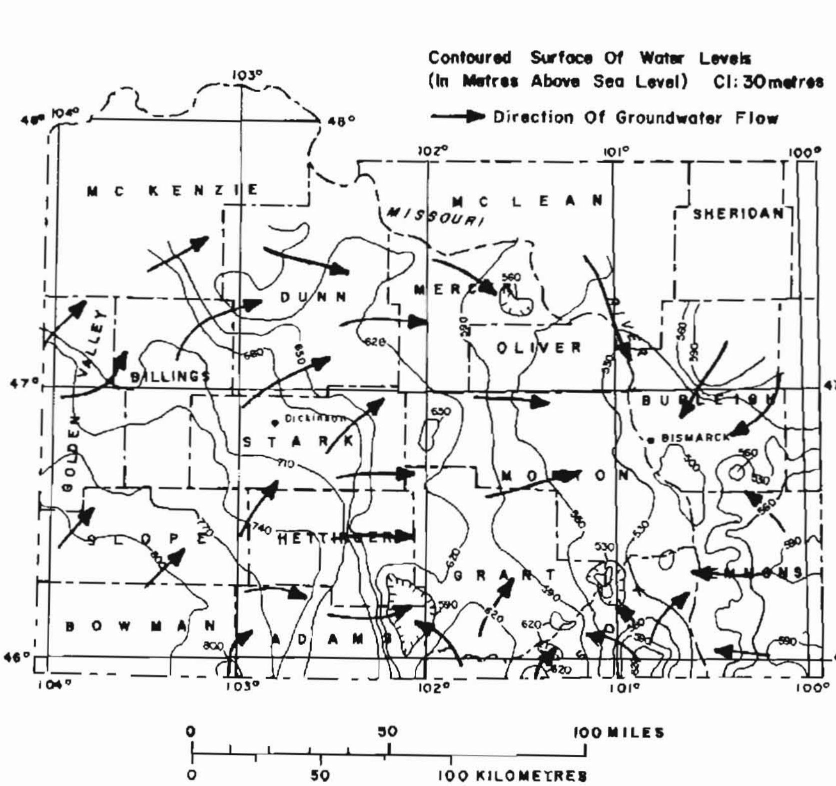


Figure 4.8.1-1. Potentiometric surface and approximate directions of regional groundwater flow in the Fox Hills aquifer in southwestern North Dakota.

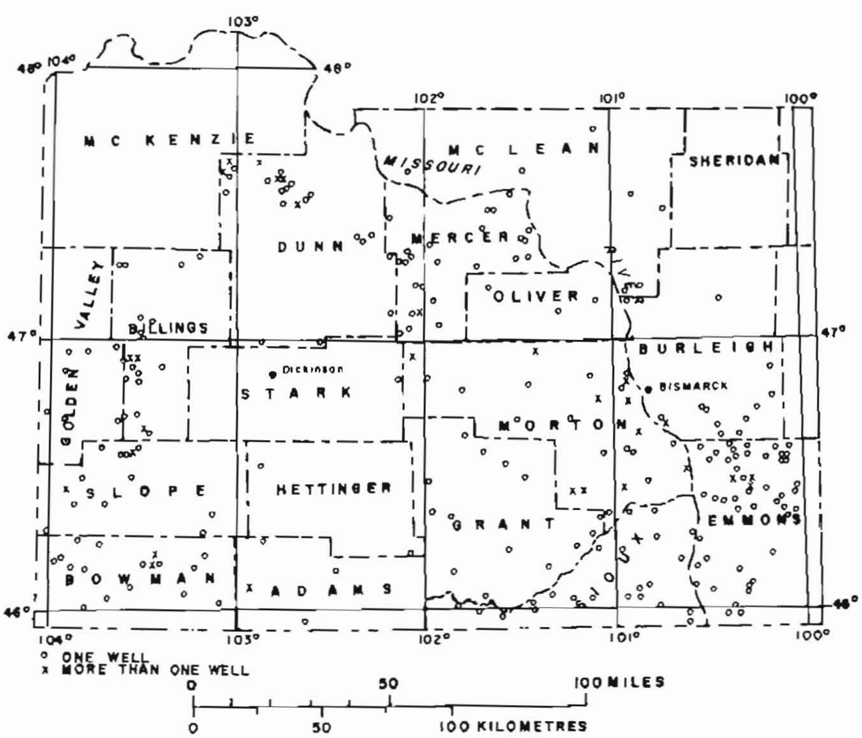


Figure 4.8.1-2. Locations of wells with water-level data used in preparation of figure 4.8.1-1.

appendix C-II. With the exception of a regional potentiometric map, the maps of other parameters in the Fox Hills aquifer presented in this report were produced by trend surface analyses. Contoured surfaces obtained by trend surface analysis reflect the regional trends of the data instead of the actual values and are very useful for the presentation of highly complex data. The lack of complexity of potentiometric values allowed for standard contouring techniques to be used in the construction of the potentiometric surface map.

A trend surface map is produced by fitting a polynomial surface to data using the least-squares criterion. The surface is computed by minimizing the sum of the squared deviations between given values at the data points and the value of the surface at the data points. The complexity of the surface to be fitted is defined by the order of the polynomial. That order is the order of the trend surface analysis. For further discussion of the procedures used in trend surface analysis, see Dougenik and Sheehan (1975) or Harbough and Merriam (1967).

The complexity of the map representation is controlled by the order of the analysis. Larger orders of analysis allow more inflections on the map surface and the result will more closely resemble the standard contour map. Trend surface analysis is in effect a filter that reduces the complexity represented on the map and allows trends to become apparent. The lower the order of analysis, the greater the reduction in complexity.

However, the trend surface map can misrepresent the data, especially if the order selected does not approximate the complexity of the standard contoured surface. In this study, several orders of analysis were examined prior to the selection of an order for the final representation of a given set data. The highest order available in SYMAP, sixth order, was usually the most appropriate. In any case, any order trend surface map is likely to differ from the standard contour map. Therefore, a trend surface map should not be used to determine a given value at a given map location. Only the regional trends of the data are represented.

Approximate flow directions are shown in figure 4.8.1-1. These flow directions were obtained by interpretation of the potentiometric surface using the assumption that in the horizontal plane the aquifer is isotropic. Figure 4.8.1-3 shows the regional topography of southwestern North Dakota and adjacent areas. As would be expected from the location of the outcrop areas in relation to the regional topography, the southwestern portion of the region is dominated by flow from the west and southwest which gradually trends eastward toward the Missouri River lowland in the south-central part of the state. Water in the Fox Hills aquifer in the Knife River basin is part of this flow domain. A portion of the aquifer south of the Knife River basin is fed by water recharged in upland areas near the North Dakota-South Dakota border. Figure 4.8.1-1 indicates that water flows toward the Missouri River lowland in south-central North Dakota from the west and from the east. Uplands that are generally associated with outcrops or subcrops of the Fox Hills Formation east of the Missouri River are recharge areas for the eastern flow domain of the aquifer.

To obtain estimates of the velocity of groundwater flow in the Fox Hills aquifer the following relation, which is an adapta-

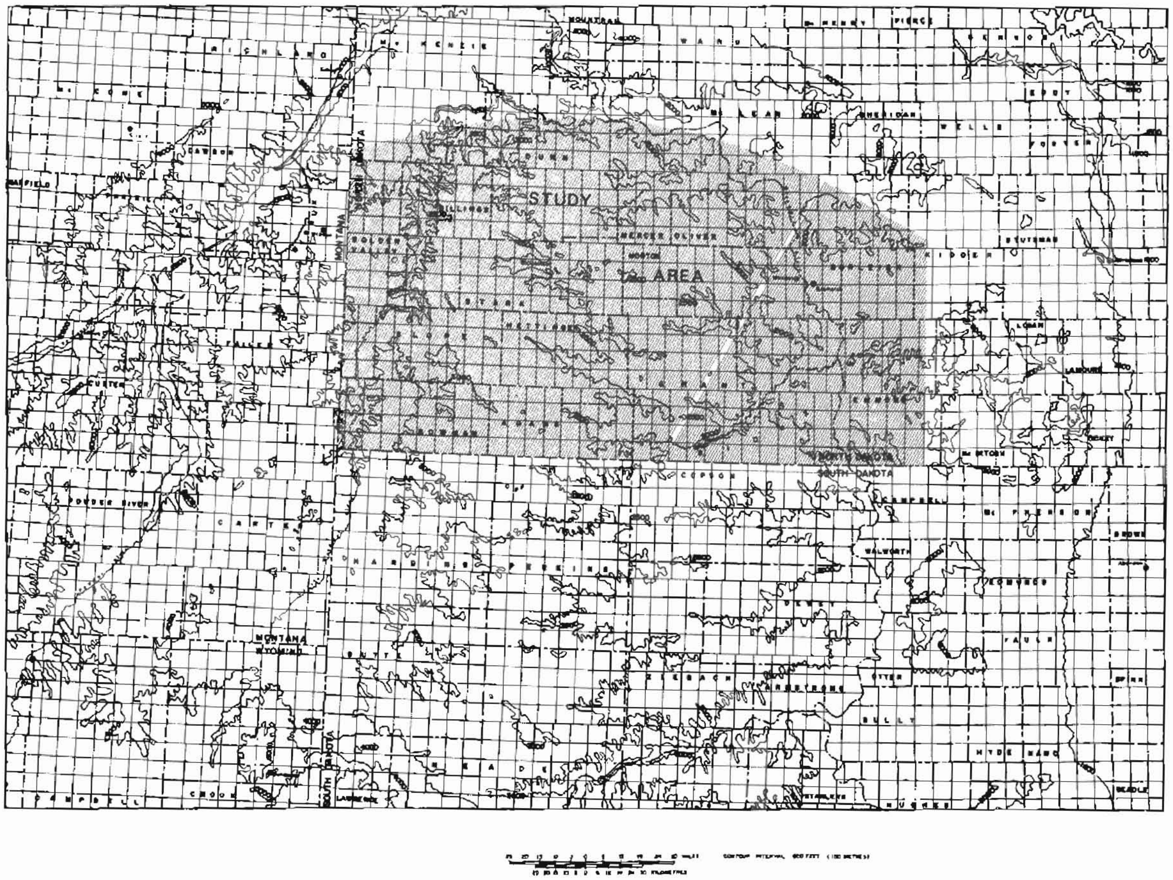


Figure 4.8.1-3. Regional topography of southwestern North Dakota and adjacent areas.

tion of the Darcy equation, will be used:

$$v = -\frac{K}{n}\frac{\Delta h}{\Delta l} \qquad (4.8.1\text{-}1)$$

where v is the average linear groundwater velocity, K is the hydraulic conductivity, n is the porosity, and $\Delta h/\Delta l$ is the hydraulic gradient. For purposes of illustrative calculation, a groundwater flow path extending from the southwest corner of North Dakota will be considered. The flow path extends northeastward and then eastward toward the valley of the Missouri River. From figure 4.8.1-1 an average value of about 1.5/1 000 for the horizontal hydraulic gradient along this regional flow path is obtained.

Croft and Wesolowski (1970) made 11 flow tests and 38 recovery tests on wells in the Fox Hills aquifer in Mercer and Oliver Counties. These tests yielded values of hydraulic conductivity in the range of < 0.134-16 feet (<.04-4.8 m) per day and averaged 2 feet (0.6 m) per day. Based on interpretation of resistivity curves of electric logs of oil, gas, and groundwater test holes, Trapp and Croft (1975) estimated that the range of transmissivity for the Fox Hills aquifer in Hettinger and Stark Counties is between 110 ft^2 and 390 ft^2 (33 m^2 and 117 m^2) per day. Based on a thickness of 400-500 feet (120-150 m) in this area, this is equivalent to a hydraulic conductivity range of about 0.25-1 foot (.08-.3 m) per day. The porosity of sand units in the Fox Hills aquifer is estimated to be within the range of 0.15-0.35. A reasonable average for the porosity of the sand is 0.25. Using equation 4.8.1-1 and the average values indicated above for n, K, and $\Delta h/\Delta l$, an average groundwater velocity of 4 feet (1.2 m) per year is obtained. In this discussion this value will be used as an order-of-magnitude estimate of regional velocity of groundwater in the Fox Hills aquifer. About 1 300 years would be required for groundwater to travel a distance of one mile at this velocity. In the Knife River basin segment of the Fox Hills aquifer, groundwater that has been recharged in the extreme southwestern part of the state or in western Montana has travelled a distance of about 75-125 miles (120-200 km). If the water travels at the average velocity indicated above, the age of Fox Hills water in the Knife River basin would be in the range of about 100 000 to 160 000 years. Considering the fact that the most permeable beds in the aquifer have hydraulic conductivities that are a factor of four or more larger than the "average" value used in the velocity calculation and considering that the most permeable zones could provide for a large portion of the total northeastward and eastward flux through the aquifer, the age of much of the water in the Fox Hills aquifer in the Knife River basin could be much less than the ages indicated above. A few tens of thousands of years would be a reasonable estimate as a minimum age for water from this western source area that has travelled as far as Dunn, Mercer, or Oliver Counties.

The Fox Hills aquifer also receives water as a result of vertical leakage through the aquitards that confine it above and below. The Pierre Formation, which is composed of montmorillonitic shale with thin interlayers of bentonite, occurs beneath the Fox Hills Formation. Little is known about the hydrogeological characteristics of this formation. Since it is thick and has an overburden load of 1 500 feet (450 m) or more, it is reasonable to expect that the hydraulic conductivity of the Pierre Formation is extremely small. Shurr and Bredehoeft (1977), based on regional modeling study of deep groundwater flow in South Dakota, concluded that the hydraulic conductivity of this formation is on the order of 3×10^{-12} ft/s (10^{-4} mD). To obtain an estimate of the flux of water that may be moving vertically through the Pierre Shale, a vertical hydraulic gradient of 10^{-1} will be assumed. For the purpose of illustrative calculations, the flux area used will be a strip 1 foot (0.3 m) wide and 1 mile (1.6 km) long. From the Darcy equation the flow across this area is:

0.05 feet^3 (0.0015 m^3) per year.

To place this flow estimate in perspective, the eastward horizontal flux of water in the Fox Hills aquifer will be estimated using the Darcy equation. For input, the same parameter values used above in the average groundwater velocity calculation are used. This yields a flow rate of 438 feet^3 (12.4 m^3) per year across a vertical strip of aquifer of 1 foot (0.3 m) in width and 400 feet (120 m) thick. If a hydraulic conductivity value at the upper end of the range reported by Croft and Wesolowski (1970) is used (i.e., 16 feet (4.8 m) per day), the calculated flow is 3 600 feet^3 (102 m^3) per year. With a vertical flux of 0.05 feet^3 (0.0015 m^3) per year per horizontal mile, 100 miles (160 km) of flow distance along the aquifer would be required to yield 5 feet^3 (0.15 m^3) per year of water to the aquifer. With a vertical input of this magnitude, only very little of the flow in the Fox Hills aquifer even at considerable distance from the recharge areas can be accounted for by vertical leakage from below. Even if the hydraulic gradient or the hydraulic conductivity of the Pierre Formation is much larger than the values used in the calculations (i.e., an order of magnitude larger), the vertical flux into the aquifer would still be very small relative to the vertical flow.

The above illustrative calculation in no way establishes whether or not upward leakage of water from the Pierre Formation into the Fox Hills aquifer actually occurs. Unfortunately, we know of no data indicating the potentiometric levels in the Pierre Formation or in permeable zones immediately below the Pierre Formation in or near the study region. Consideration of the topography and stratigraphy of the Plains region relative to the potentiometric levels in the Fox Hills aquifer in the study region, suggests that flow is likely downward from the Fox Hills aquifer through the Pierre Formation. This possibility will be pursued further in consideration of the chemical evolution of groundwater in the Fox Hills aquifer as discussed in section 4.10.1.

Trapp and Croft (1975), based on an appraisal of the geology and groundwater resources of Hettinger and Stark Counties, concluded that, although much of the water in the Fox Hills aquifer in these counties is contributed by lateral flow from the southwest, there is probably some contribution of downward leakage from an aquifer zone in upper part of the Hell Creek Formation and lower part of the Cannonball and Ludlow Formations. In these counties, the head in the Cannonball-Ludlow zone is generally higher than the potentiometric surface of the Fox Hills aquifer. For example, at Regent the head difference is about 100 feet (30 m). Trapp and Croft indicate, however, that in western Stark County the head in the Fox Hills aquifer is higher, indicating upward leakage from the Fox Hills aquifer through the silt and clay confining beds that overlie it. No comparative head data is available for areas to the west of Stark and Hettinger Counties.

Croft (1973) presents maps of 1968 potentiometric levels in the Fox Hills aquifer and for the upper Hell Creek and lower Cannonball-Ludlow aquifers in Mercer and Oliver Counties. Comparison of these maps indicates that potentiometric levels in the Fox Hills aquifer are higher than the overlying aquifer by as much as 50-100 feet (15-30 m). In a study of a major portion of Dunn County, Moran et al. (1976) also observed much higher potentiometric levels in the Fox Hills aquifer. From topographic and stratigraphic considerations it is expected that upward leakage of water from the Fox Hills aquifer through the Hell Creek Formation is the prevalent condition in most of the study region, with the exception of areas to the southwest where downward vertical leakage into the aquifer may contribute appreciable quantities of water.

We will now return to the question of the age of water that moves from the southwest and west toward the Missouri River lowland in the south-central part of the state. Our analysis will focus on age estimates based on analyses of the carbon-14 concentrations in samples from wells in the Fox Hills aquifer. Samples from wells at the towns of Medora, Bowman, Beach, Halliday, Dodge, and north of Dunn Center (referred to as the Dunn Co. well) have been analyzed for the content of ^{14}C in the dissolved inorganic carbon in the water (i.e., the ^{14}C in carbon extracted from H_2CO_3, CO_2, HCO_3, and CO_3). The data are listed in table 4.8.1-1. The ^{14}C results, which range from 1.8-0.8 percent, are ex-

TABLE 4.8.1-1. Carbon-14 contents and major ion analyses of six samples from the Fox Hills aquifer in southwestern North Dakota

Location & Sampling Date	Well Owner	Well Depth	Elec. Cond. μmhos	HCO_3^- content mg/L	Tritium (TU)	^{18}O per mille	^{13}C per mille	^{14}C % modern	Uncorrected Age (Years)
146-93-3 CDD 5-24-75	A. Voight (Dunn Co.)	1525	2100	1150	NIL	-17.4	-10.5	1.8	31 468 ±7 000
145-92-25 ABA 5-24-75	Town of Halliday	1555	2300	1100	NIL	-17.0	-9.7	1.5	34 000 ±7 000
144-91-10 -76	Town of Dodge	--	--	970	NIL	--	-10.7	0.8	38 800 ±1 900
131-102-14 AAB* 76?	City of Bowman	--	--	--	--	--	--	6.6	22 470±?
140-102-22 DCD* 4-12-75	Town of Medora	--	1750	738	--	--	--	5.2	24 560±?
140-106-25 CBBB* 8-07-74	Town of Beach	1259	2170	790	--	--	--	18.0	14 140±?

*Data obtained from U.S. Geological Survey, District Office, Bismarck, North Dakota.

pressed as "percent modern" relative to a modern standard and as unadjusted ages calculated directly from the percent modern values. Table 4.8.1-1 also indicates the major ion concentrations of the well water and in the case of the Dunn Co., Halliday, and Dodge wells indicates the carbon-13 contents (relative to the PDB standard), which are all close to -10 °/₀₀ . Samples from these wells were also analyzed for tritium and were found to have no detectable concentrations of this isotope.

The samples from the wells at Bowman, Medora, and Beach, which are closest to the recharge areas, have the largest concentrations of ^{14}C. The samples from Dunn Co., Halliday, and Dodge locations, which are much farther along the regional flow paths from the recharge areas, have much lower ^{14}C concentrations. If the ^{14}C content of the inorganic carbon in the aquifer water declines from its initial value (100% modern) solely as a result of radioactive decay, only 2.5 half-lives (half-life of ^{14}C is 5 700 years) would be required to attain the ^{14}C content in the sample from Beach which has the highest ^{14}C content of the six samples available. In contrast, seven half-lives of decay would be required to produce the value of 0.8 percent modern for the sample from Dodge.

Groundwater ages obtained in this manner based on direct application of the law of radioactive decay are known as uncorrected or unadjusted ages. The critical step in the interpretation of ^{14}C concentrations in groundwater is the adjustment of the age to take into account the effects of geochemical processes. The discussion presented below represents a preliminary geochemical interpretation of the ^{14}C data from the Fox Hills aquifer.

A more detailed quantitative interpretation will be described in a later report.

It is well known that in nearly all groundwaters a portion of the dissolved inorganic carbon is derived from carbonate minerals (calcite and dolomite) or organic matter that occurs below the water table. If the carbonate minerals and organic matter are geologically old, they will be devoid of ^{14}C. This is the case for these materials in the Fox Hills-Hell Creek Formations. Carbon that has no significant ^{14}C is referred to as dead carbon because it is radioactively dead with respect to ^{14}C. The portion of dead carbon that is added to the dissolved inorganic carbon as a result of geochemical processes acting below the water table causes the ^{14}C content of the total dissolved organic carbon to decrease in proportion to the amount added relative to the total inorganic carbon present in the water. If, for example, the dead carbon added from mineral dissolution below the water table constitutes one half of the total inorganic carbon, this in effect ages the sample by one half-life. If the dead carbon composes three quarters of the total inorganic carbon, it causes the equivalent to two half-lives of aging of the sample, and so on.

For systems in which the only source of dead carbon is through dissolution of calcite or dolomite, the amount of dead carbon added and therefore the extent of geochemical aging of the sample can be estimated by consideration of concentration relations of the dissolved inorganic carbon and the stable carbon isotopes, ^{13}C and ^{12}C. The regional distribution of HCO_3^- concentrations in the aquifer are described in detail in section 4.9.1. In this section it will be sufficient to comment on the general trends. Values of HCO_3^- in the range 800-1 400 mg/L are typical for the deep part of the aquifer away from the recharge areas. Since the pH of the water is generally in the range of about 7.5-8.5, the concentrations of H_2CO_3 and CO_3^{2-} are negligible relative to HCO_3^-. This can be deduced from figure 19 in Hem (1970) which shows the percentage distribution of species of dissolved inorganic carbons as a function of pH. The carbon in the HCO_3^- can therefore be taken as an accurate measure of the total dissolved inorganic carbon. A reasonable estimate for the total dissolved inorganic carbon in water that recharges the water table zone in the recharge areas of the Fox Hills aquifer is 400±100 mg/L, expressed as HCO_3^-. This estimate is based on the concentration values typical of very shallow groundwater that has been sampled in observation wells in various parts of southwestern North Dakota.

For purposes of illustrative calculations, it will be assumed that the HCO_3^- in the recharge area has carbon that has a 100 percent modern ^{14}C content. In other words, it is assumed that the water is young and has derived its carbon from CO_2 in the soil zone and by dissolution of calcite or dolomite above the water table as recharge occurs. It is well established that the ^{14}C in CO_2 in soil zone air is not significantly different than the ^{14}C content of CO_2 in the above-ground atmosphere. It is assumed that the ^{14}C content of the earth's atmosphere has not varied significantly during the past 50 000 years. This assumption is generally adopted in the interpretation of ^{14}C data from regional aquifer systems. As the water moves from the recharge area northeastward and eastward along the regional flow paths the HCO_3^- content increase from approximately 400 mg/L to a zone of maximum values located in Dunn, Mercer, and Oliver Counties where the HCO_3^- concentrations are as high as 1 400 mg/L (table 4.8.1-1). If all of the additional carbon is derived from dissolution of calcite or dolomite, the ratio of the original carbon (recharge area carbon) to the total carbon in the high HCO_3^- zone in Dunn, Oliver, and Mercer Counties is about 0.28. Thus, the equivalent of slightly less than two half-lives of radioactive decay would be necessary to produce this ratio in the absence of dilution by dead carbon. The sample has therefore been geochemically aged by approximately 10 500 years. This value is obtained from the expression adapted from Wigley (1975),

$$t=8290 \ln Q \quad (1)$$

where t is the age and Q is the ratio of original live carbon to the total carbon. If 300 mg/L is taken as the concentration of HCO_3^- acquired by the water in the recharge area during infiltration through the unsaturated zone, Q would be 0.21 and the amount of geochemical aging would be 12 900 years. As a general estimate we will consider the samples from Dunn Co., Halliday, and Dodge to have been aged by 11 000 years as a result of the acquisition of inorganic carbon by calcite and dolomite dissolution during movement along the groundwater flow paths. Thus, the adjusted ages of the samples from these locations are represented by the unadjusted ages minus 11 000 years, which for the Dunn Co., Halliday, and Dodge samples yields values of 20 500, 23 000, and 27 000 years, respectively. The ^{14}C data suggest, therefore, that the water in the interior region of the Fox Hills aquifer is Pleistocene in age. This age designation is within a range that is reasonable in light of calculations using the Darcy equation with hydraulic conductivity values that are in the upper part of the range of measured values indicated by Croft (1973) based on studies in Mercer and Oliver Counties.

In this analysis it is assumed that the water that is being "dated" is water that originates in the outcrop areas or as vertical leakage near the outcrop areas and moves northeastward and eastward within the aquifer. It was concluded in section 4.7.1 that vertical leakage into the Fox Hills aquifer from the Pierre Formation is insignificant. Old water from the Pierre Formation is, therefore, not a source that would "age" the Fox Hills water by mixing. It was also indicated in section 4.7.1 that in much of the interior region of the Fox Hills aquifer, hydraulic gradients are directed upward through the aquitards overlying the aquifer. Therefore water from these aquitards also should not be a significant influence on the age of the Fox Hills water in this region.

The ^{14}C age adjustment procedure described above will now be used in the interpretation of ages of the samples from Beach, Bowman, and Medora. The Beach and Bowman samples are from a segment of the aquifer in which the HCO_3^- content is on the order of 700 mg/L. The Medora sample is from a zone in which the water has about 800 mg/L. Using a recharge area HCO_3^- content of 400 mg/L, the Q value for the Beach and Bowman samples is 0.57, which is the equivalent of 4 600 years of geochemical aging. If 300 mg/L is used as the initial HCO_3^- content, the Q value is 0.43 and the amount of geochemical aging is 7 000 years. For the Medora sample this approach yields values of geochemical aging of 5 700 years and 8 100 years.

The interpretation described above indicates that adjusted age of the Beach sample is less than 10 000 years. The Bowman and Medora samples have adjusted ages on the order of 15 000 to 20 000 years. Considering the proximity of these sample locations to the recharge areas in eastern Montana and in the extreme southwestern segment of North Dakota, these ages are perhaps anomalously old. It should be kept in mind, however, that in the southwestern segment of the Fox Hills system, downward leakage of water through overlying silty and clayey aquitards may be an important contributor of water to the aquifer. Slow leakage over a large area could result in an appreciable amount of the aquifer water originating from overlying zones. This water, however, could be very old. For example, under a hydraulic gradient of 0.1 a shale bed with a hydraulic conductivity of 10^{-9} cm/s and a porosity of 0.2 would have pore water moving at an average velocity of 1 foot (0.3 m) per thousand years. A zone of shale a few tens of metres thick could therefore yield water that is devoid of measurable amounts of ^{14}C.

In the interpretation of the ^{14}C data described above, no attempt was made to account for the effect of molecular diffusion. The system was considered only on the basis of plug flow in the aquifer with possible contributions from vertical leakage. Molecular diffusion is a mechanism which may cause a significant decline in the ^{14}C content of water in the Fox Hills aquifer. As lateral movement along the regional flow paths occurs, ^{14}C will tend to diffuse upward and downward from the aquifer into the clayey strata in which the water is older and therefore lower in ^{14}C content. As the ^{14}C migrates by diffusion through the clayey aquitards, the ^{14}C content decreases as a result of radioactive decay; thereby maintaining a concentration gradient from the aquifer into the aquitards as the movement of younger water laterally through the aquifer from the recharge areas continues. The loss by diffusion of ^{14}C from the aquifer increases the unadjusted ^{14}C age of the carbon in the water. By neglecting the effect of diffusion, the tendency is for the water to be younger than is indicated by the adjusted age obtained using the geochemical adjustment procedure described above. We know of no cases in the literature where the effects of molecular diffusion have been taken into account in the interpretation of ^{14}C concentrations in groundwater. The possible effects of diffusion are discussed further in section 4.10.1.

It is reasonable to expect that in the geologic past the regional pattern of groundwater flow in the Fox Hills aquifer has been influenced by the effect of glacial advances across the outcrop areas of the aquifer. Major glacial advances produced ice cover a considerable distance south and west of the Missouri River valley (fig. 4.7.1-2). At distances of several metres from the ice margin position, the ice was probably a thousand or more feet (300 m) thick.

The most extensive ice coverage occurred in early Pleistocene time, probably between 0.5 and 1.0 million years ago (fig. 4.7.1-2). Another major period of ice cover occurred in early Wisconsinan time, which is believed to have been about 70 000 years ago but may have occurred as early as 200 000 years ago. During these two early glacial episodes, the ice extended across the Missouri River lowland. During more recent advances (15 000 to 20 000 years ago), the ice margin remained east and north of the Missouri River.

Although the effect of the recurring episodes of ice cover on the Fox Hills aquifer system is problematic, some speculations can be made. One of the major effects of the ice advances into the area south and east of the Missouri River valley would likely have been the invasion of the aquifer by pore waters squeezed out of the underlying Pierre Formation and the shale strata in the overlying Hell Creek Formation. These pore waters may have been quite saline. Since clayey strata are more compressible than sandstones, and since excess pore water pressure in the sandstone would be dissipated more rapidly, the pore waters that invaded the sandstone would probably have become mixed with the pre-existing water in the aquifer. Because of the ice load and the cover of ice across the outcrop and subcrop areas and across the Missouri River lowland, the direction of the regional flow of water in the aquifer was probably reversed. There were probably long periods of time during which the water flowed southwestward toward the outcrop areas or during which relatively stagnant conditions existed. The duration of the reversed flow period and the regional hydraulic gradients would have been controlled by the relative positions of the regional water table in the southwestern recharge areas and the elevated head in the aquifer zone below the glacier.

During the retreat of the early Wisconsinan glacier, glacial meltwater must have entered the groundwater zone in much of the area beneath the stagnant ice. During these periods of glacial stagnation significant amounts of meltwater may have recharged shallow groundwater zones, but because of the high elevation of the landscape (and therefore of the water table) in the Fox Hills outcrop areas in southwestern North Dakota and Montana, it is unlikely that much meltwater entered the Fox Hills aquifer west and south of the Missouri River lowland. Late Wisconsinan ice advances (fig. 4.7.1-2) terminated a considerable distance east and northeast of the Missouri River valley and therefore did not cover all of the Fox Hills outcrop and subcrop areas. Thus, the flow regime of the Fox Hills aquifer west of the Missouri River was probably not significantly influenced by these advances. It is reasonable to expect that the regional flow pattern that we now observe in the west-of-the-Missouri segment of the aquifer has existed since early Wisconsinan time. Since the age of the water in the Fox Hills aquifer is generally younger than 30 000 years, the effects of glaciation on the chemical evolution of the water that presently exists in the aquifer were probably minimal.

4.8.2 Aquifers in the Bullion Creek Formation

The following discussion is restricted to the area west of the Missouri River. See section 4.3 for a detailed discussion of the Bullion Creek aquifers (Hensler bed) to the east of the Missouri River.

We have made no attempt to conduct studies of the potentiometric pattern in aquifer zones in the Bullion Creek Formation in the region west of the Missouri River. The brief comments that follow in flow conditions in this region are based on the interpretations by Croft (1973), Moran et al. (1976), and Trapp and Croft (1975).

A map by Croft (1973) of the potentiometric surface of the Lower Bullion Creek aquifer zone (referred to by him as the Lower Tongue River aquifer) in Oliver County and the southwestern part of Mercer County (based on water-level data from eight wells) indicates that in this region the flow is toward the north and northeast with a slope on the potentiometric surface of approximately 10 feet per mile (2 m/km). Potentiometric levels in the northern part of Stark County are very high with a general northeastward slope. Moran et al. (1976) presented a map of the potentiometric surface in a portion of Dunn County based on water levels from five piezometers in the middle and lower part of the Bullion Creek Formation. The potentiometric surface slopes to the northeast at about 20 feet per mile (4 m/km) to about 5 feet per mile (1 m/km). In conclusion, it can be stated that the potentiometric data available from Dunn, Stark, Mercer, and Oliver Counties, which have been published in the form of potentiometric maps, indicates that in the Knife River basin the direction of groundwater flow in the Lower Bullion Creek aquifer zone is generally to the northeast. An average groundwater velocity can be estimated using Darcy's Law. Assuming a gradient of 2×10^{-3}, a porosity of 0.25, and a hydraulic conductivity of 5×10^{-4} cm/s the average flow velocity would be 0.004 m/d.

The potentiometric levels in aquifers in the Sentinel Butte Formation are generally higher than those in the Lower Bullion Creek aquifer zone. The potentiometric levels in the Upper Hell Creek and Lower Cannonball-Ludlow aquifer zone are also generally higher than those in the Lower Bullion Creek aquifer zone. It is evident, therefore, that water flows downward into the Lower Bullion Creek from overlying aquifers and upward into the Lower Bullion Creek from underlying aquifers. It is apparent, therefore, that the Lower Bullion Creek aquifer zone functions as a regional groundwater sink with flow generally toward the northeast (Missouri River valley).

4.9 Regional Groundwater Chemistry

4.9.1 The Fox Hills Aquifer

4.9.1.1 Distribution of dissolved constituents

The regional distributions of chemical constituents in the Fox Hills aquifer were determined by compilation of chemical analyses for the aquifer listed in published county groundwater reports by Ackerman (1977; Morton County), Armstrong (1975, Emmons County), Croft (1970, Mercer and Oliver Counties; 1974, Adams and Bowman Counties), Klausing (1971, McLean County; 1976, Dunn County), Randich (1965, Burleigh County; 1975, Sioux and Grant Counties), and Trapp (1971, Hettinger and Stark Counties). Data were also obtained for Dunn County from a report by Moran et al. (1976). Additonal data were made available by the U.S. Geological Survey and the N.D. State Water Commission for counties for which groundwater resource reports have not been published. These agencies also provided results of analyses obtained after publication of the county reports. All of the chemical analyses of samples from the Fox Hills aquifer that were used in this investigation are listed in appendix C-II. To our knowledge the chemical data for the Fox Hills aquifer in the entire southwestern North Dakota region have not previously been compiled and interpreted in light of the regional hydrogeologic conditions and processes of geochemical evolution. The location of the wells with analyses of major ions (K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, and SO_4^{2-}) and in most cases other constituents such as F, B, NO_3^-, Fe, and Mn are shown in plate 23. This plate indicates that with the exception of Stark, Hettinger, and Adams Counties there is good coverage of chemical data.

Figure 4.9.1.1-1 shows a scatter diagram of total dissolved solids versus electrical conductance for samples from wells in the Fox Hills aquifer. The trend of the data points is quite linear and can be described by the relation

$$TDS=AC$$

where TDS denotes total dissolved solids expressed as mg/L, C is electrical conductance in μS, and A is an emperical constant. This value is within the normal range for groundwater, reported by Hem (1970) as 0.55-0.75. Because of the good linear correlation between TDS and electrical conductance in the Fox Hills aquifer, trends in salinity of water in the aquifer can be represented by maps of electrical conductance, as is normally the case for groundwater systems.

Appendix C-II includes pH values, which are generally in the range of 7.7-8.7, for the Fox Hills aquifer. Nearly all of the pH measurements were made in the laboratory and therefore cannot be taken as representative of pH conditions within the aquifer. Theoretical considerations suggest that because of off-gassing (exsolution) of CO_2, the pH values obtained by measurement in the laboratory are higher than the actual aquifer values. A limited number of field-measured pH values were obtained in our investigation. These values are in the same range as the laboratory values. The field measurements were made at well heads immediately after samples were obtained. These samples may also, however, have undergone considerable off-gassing of CO_2 as the water travelled from the well screen upwards in the well bore to the well head. For most Fox Hills wells this travel distance is relatively large (fig. 4.8.1-1). As samples are collected, the occurrence of small bubbles gives the visual impression that off-gassing is an active process. The nature of the bubbles is not known. There is the possibility that methane is an important component. The field and laboratory pH values provide a good indication of the pH of water in the condition it is used in a water supply context, but the problem of off-gassing introduces sufficient uncertainty with regard to "in situ" aquifer pH conditions to render these values of little use in geochemical interpretations of the groundwater system.

The regional distribution of electrical conductance, Cl^-, HCO_3^-, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}, total hardness, F^-, K^+, NO_3^-, total Fe, and total Mn in the Fox Hills aquifer are shown in figures 4.9.1.1-2 to 4.9.1.1-15, inclusive. The temperature of water samples measured at well heads is shown in figure 4.9.1.1-15. The isoconcentration lines and isotemperature lines represent the results of a sixth order trend surface fit as described in section 4.8.1. In the following discussion of the hydrochemical data from the Fox Hills aquifer, the emphasis is first placed on consideration of the quality of the water with respect to drinking water standards and agricultural use criteria. Secondly, in section 4.9, relationships between the regional concentration patterns and the regional flow pattern are described. Thirdly, in section 4.10.1, the hydrogeochemical processes that have controlled the chemical evolution of the water are described. The Fox Hills aquifer is a vast reservoir of water that in some areas has good quality. In other areas the water quality is marginal or even unacceptable in light of current drinking water standards. The purpose of

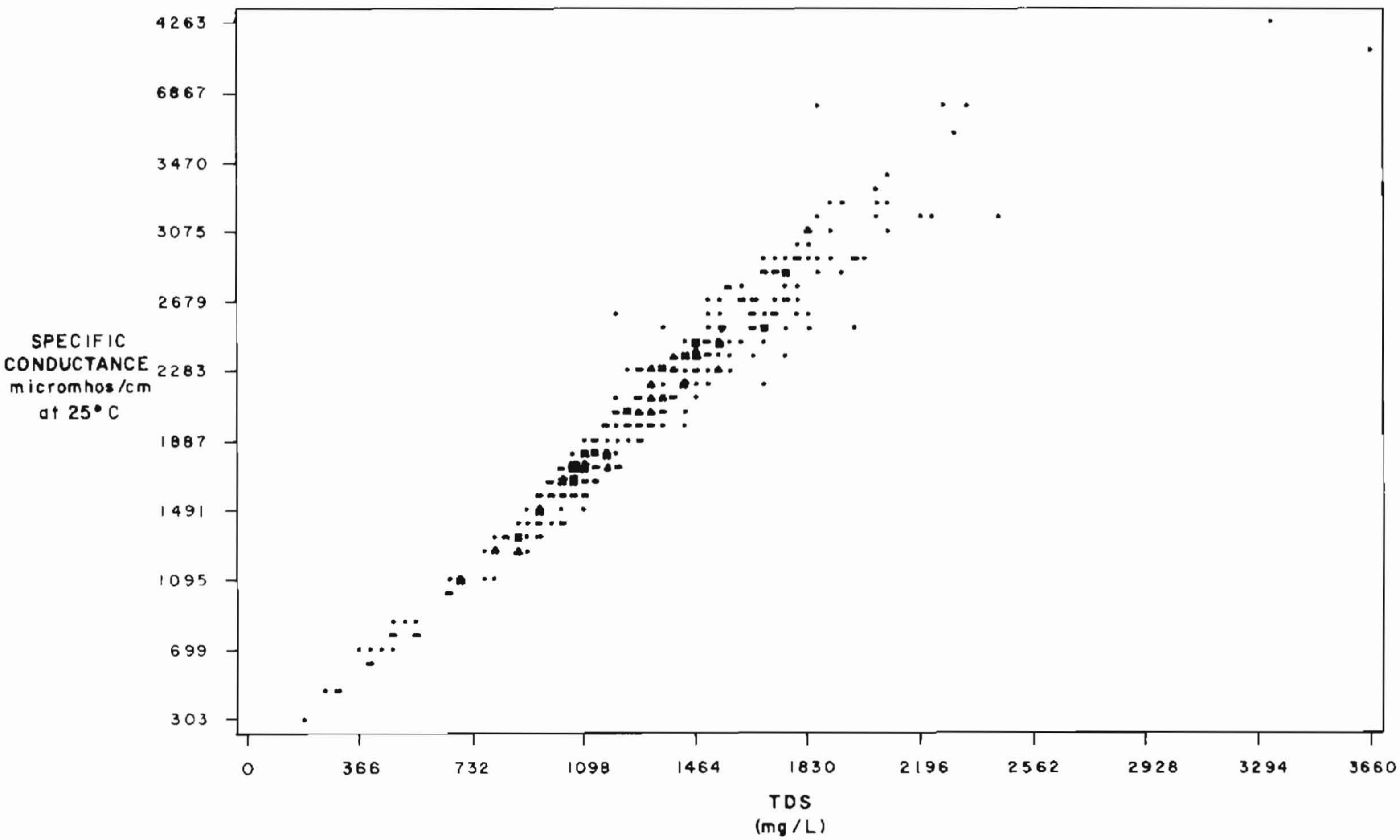


Figure 4.9.1.1-1. Total dissolved solids (mg/L) versus electrical conductivity (micromhos/cm) for water in the Fox Hills aquifer.

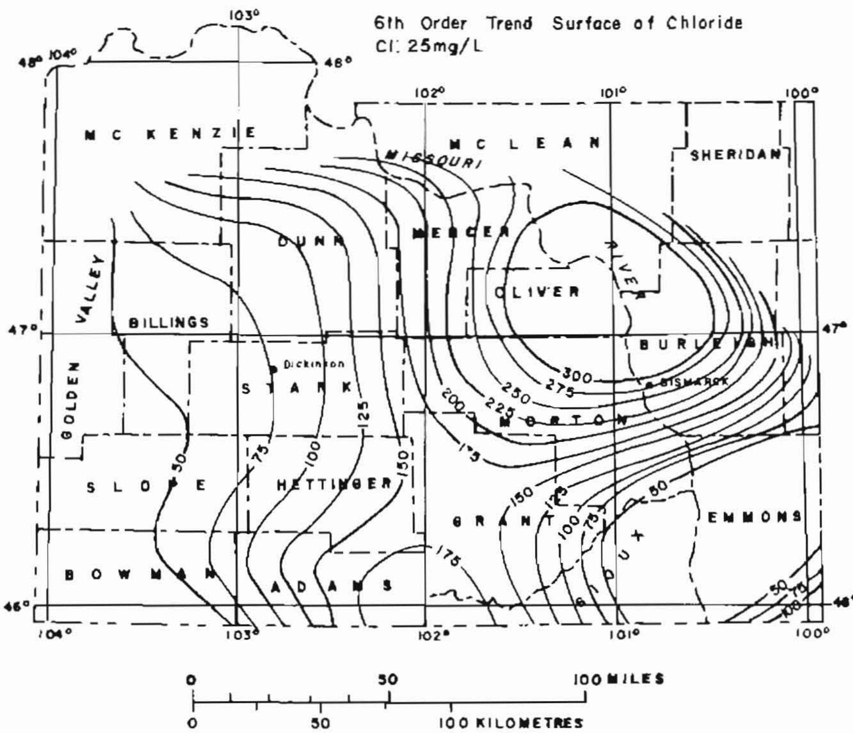


Figure 4.9.1.1-2. Distribution of electrical conductance in the Fox Hills aquifer (micromhos/cm at 25°C, laboratory measurements).

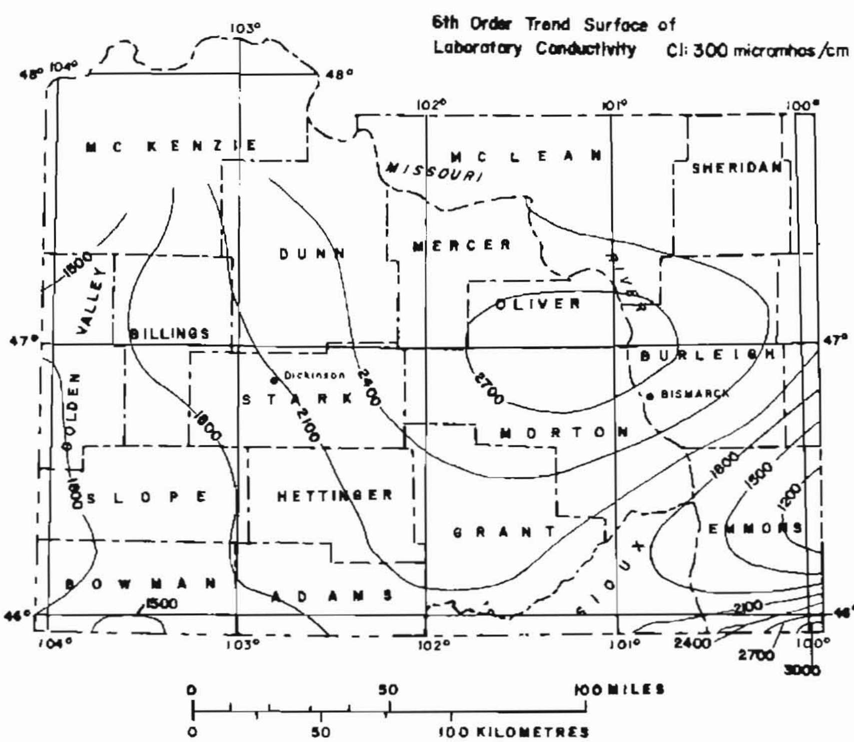


Figure 4.9.1.1-3. Distribution of Cl⁻ (mg/L) in the Fox Hills aquifer.

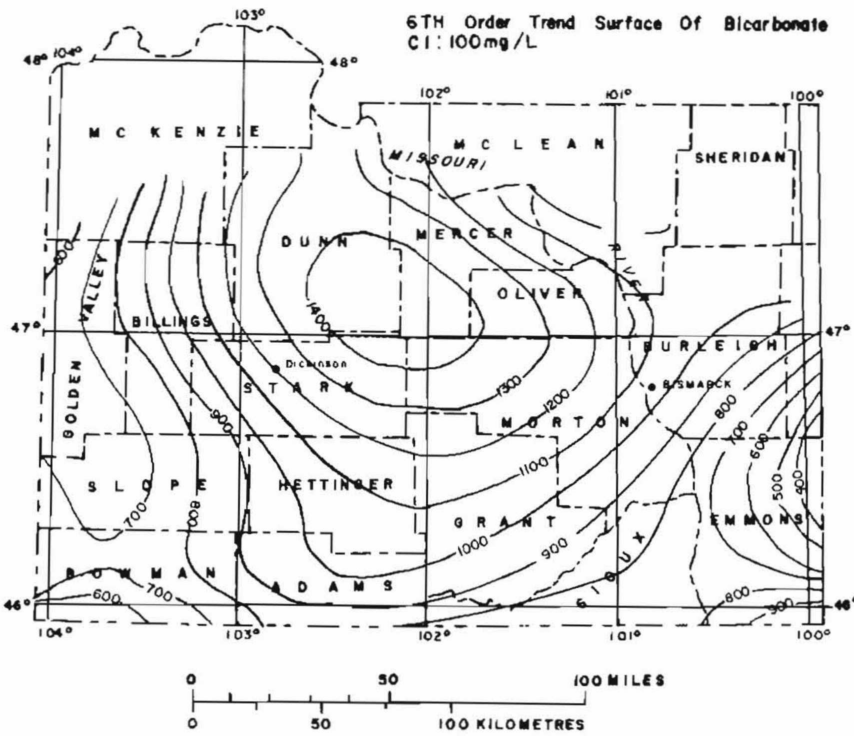


Figure 4.9.1.1-4. Distribution of HCO_3^- (mg/L) in the Fox Hills aquifer.

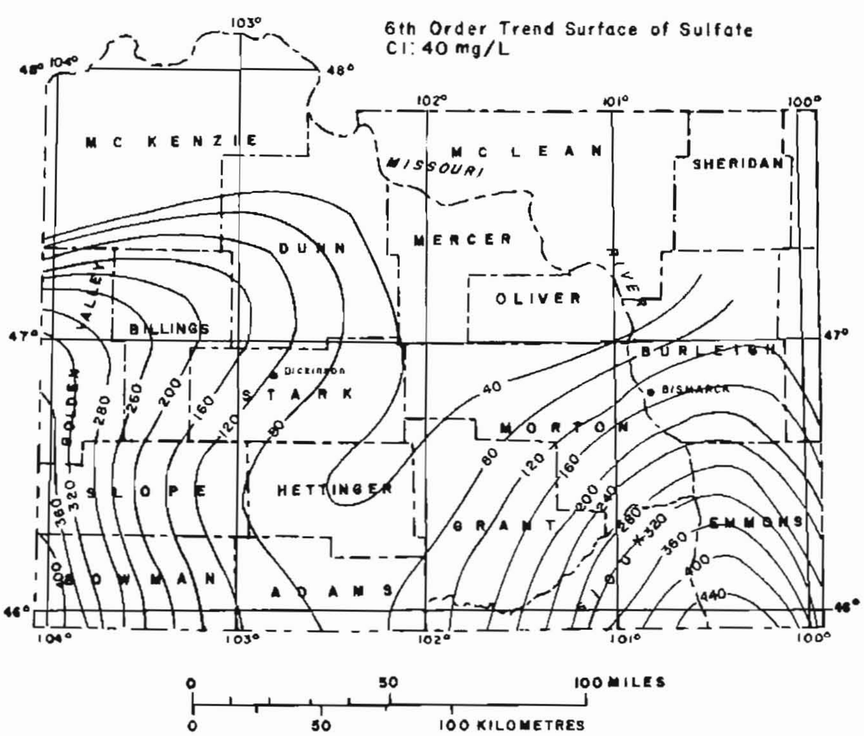


Figure 4.9.1.1-5. Distribution of SO_4^{2-} (mg/L) in the Fox Hills aquifer.

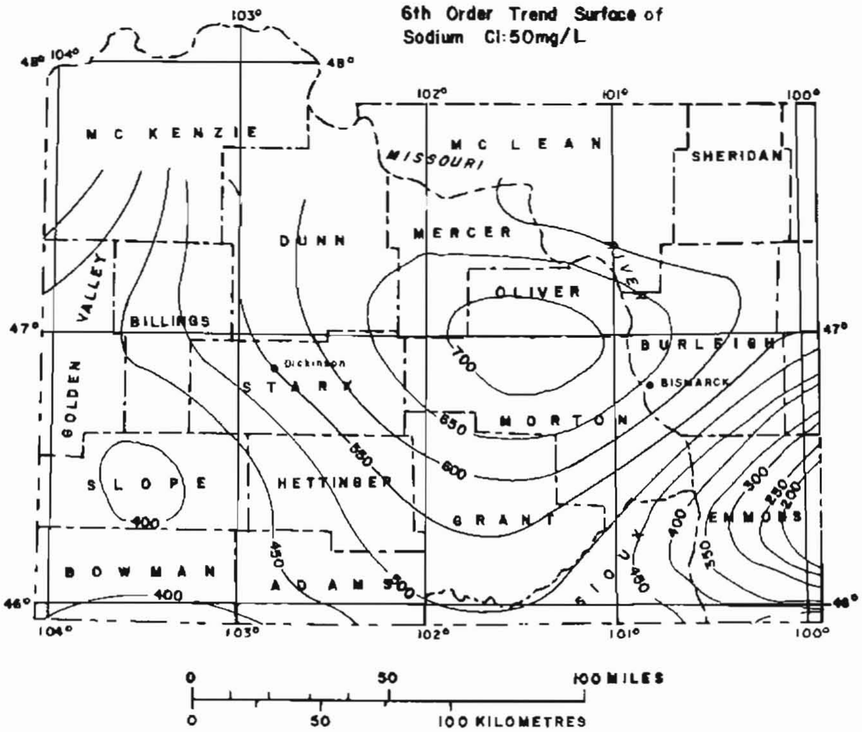


Figure 4.9.1.1-6. Distribution of Na^{+}(mg/L) in the Fox Hills aquifer.

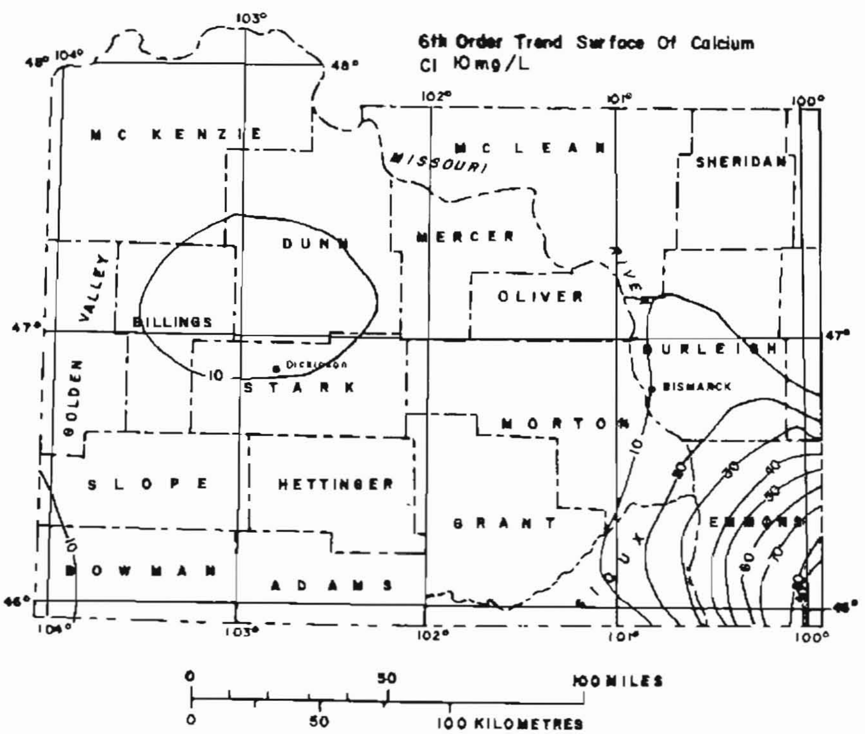


Figure 4.9.1.1-7. Distribution of Ca^{2+}(mg/L) in the Fox Hills aquifer.

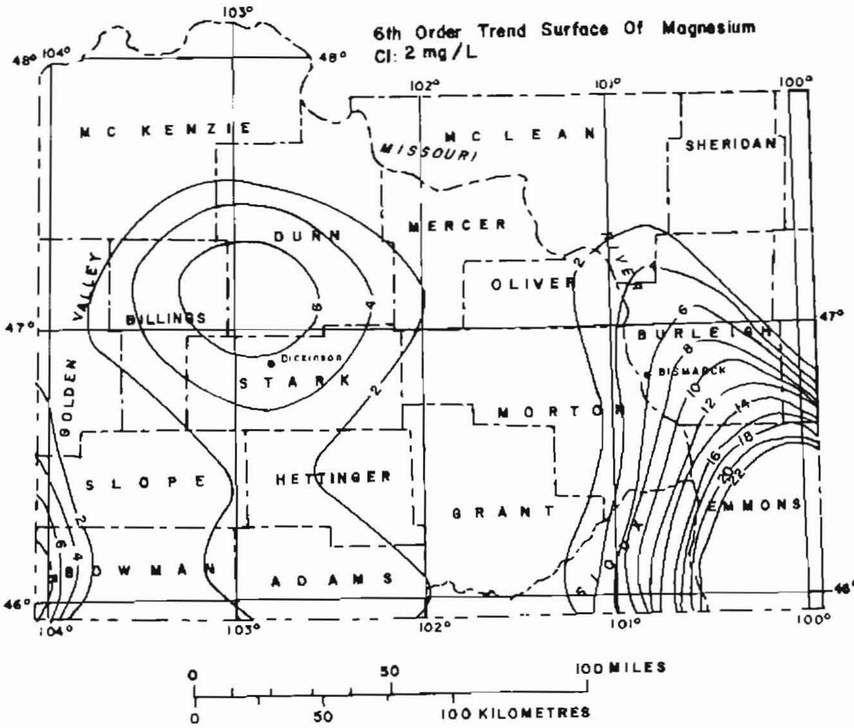


Figure 4.9.1.1-8. Distribution of Mg^{2+} (mg/L) in the Fox Hills aquifer.

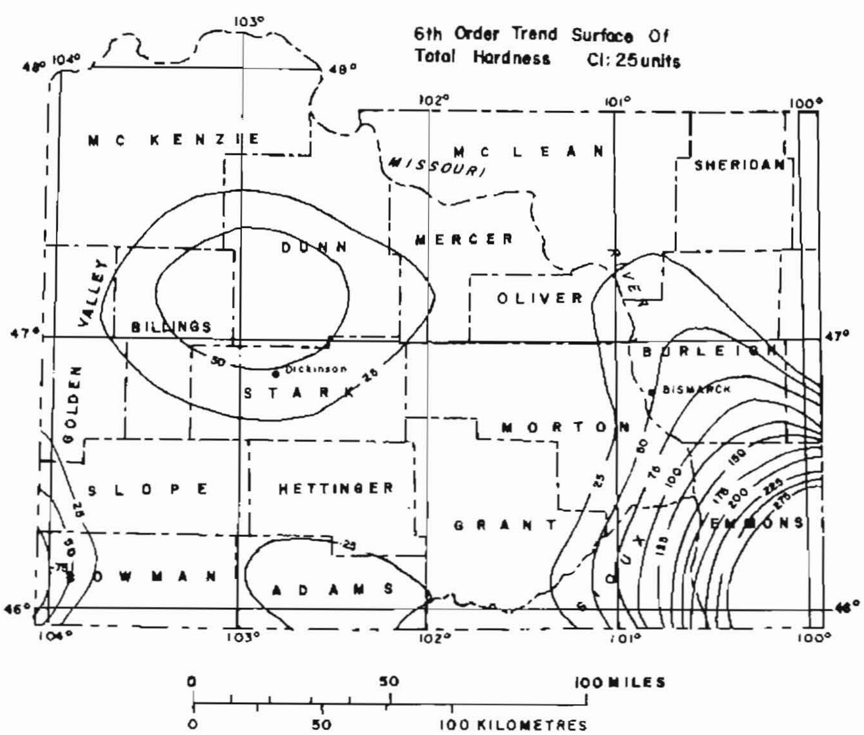


Figure 4.9.1.1-9. Distribution of total hardness (expressed as $CaCO_3$) in the Fox Hills aquifer.

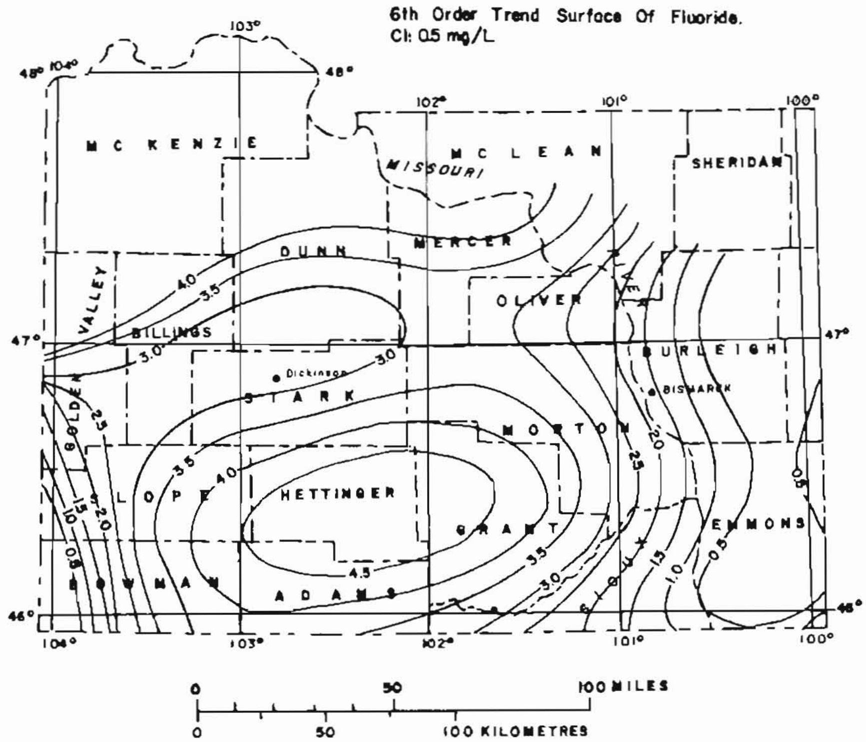


Figure 4.9.1.1-10. Distribution of F^- (mg/L) in the Fox Hills aquifer.

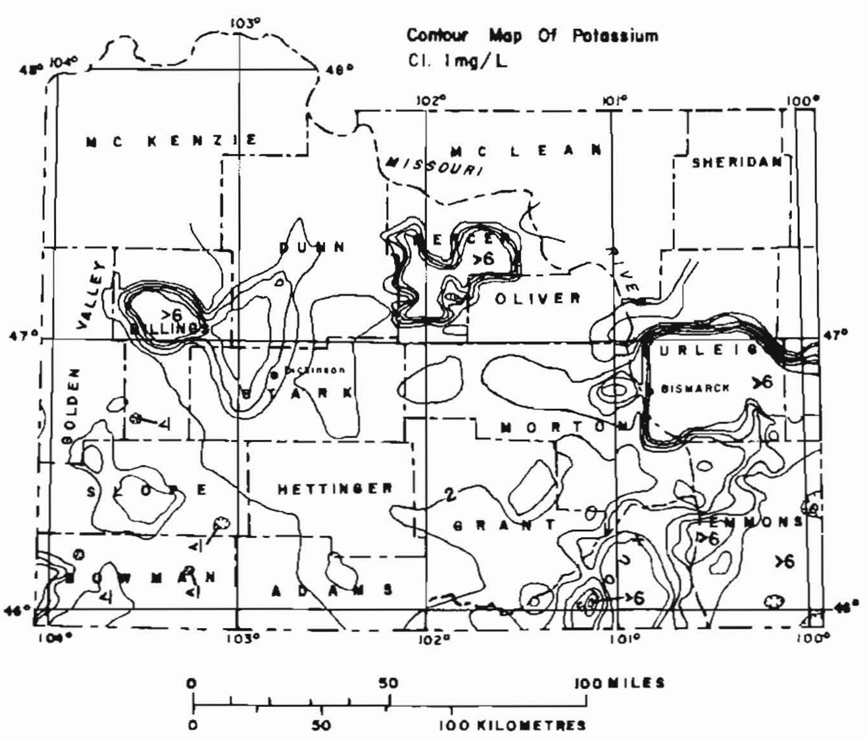


Figure 4.9.1.1-11. Distribution of K^+ (mg/L) in the Fox Hills aquifer.

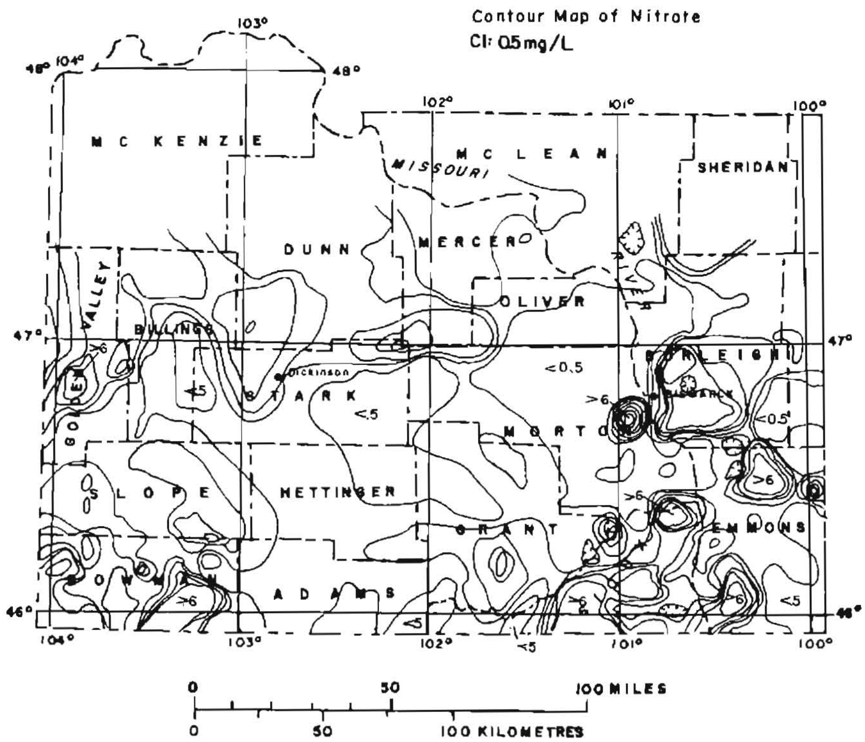


Figure 4.9.1.1-12. Distribution of NO_3^- (mg/L) in the Fox Hills aquifer.

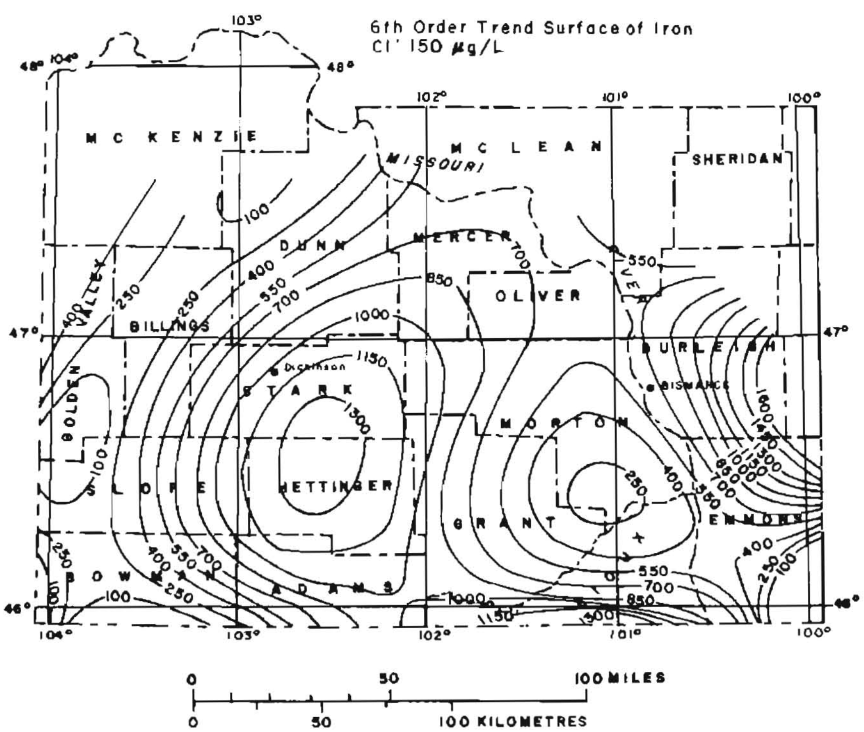


Figure 4.9.1.1-13. Distribution of total Fe (µg/L) in the Fox Hills aquifer.

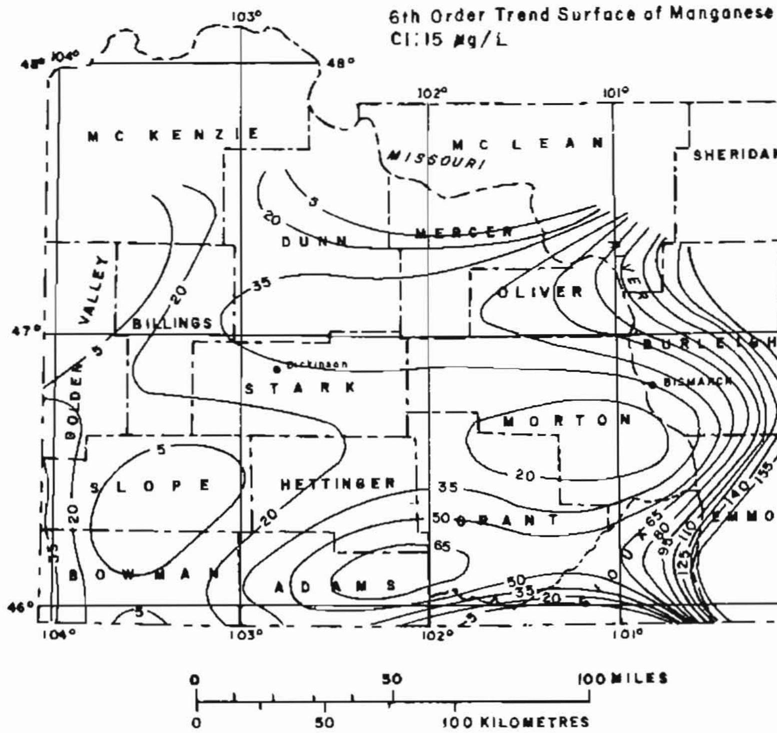


Figure 4.9.1.1-14. Distribution of total Mn (µg/L) in the Fox Hills aquifer.

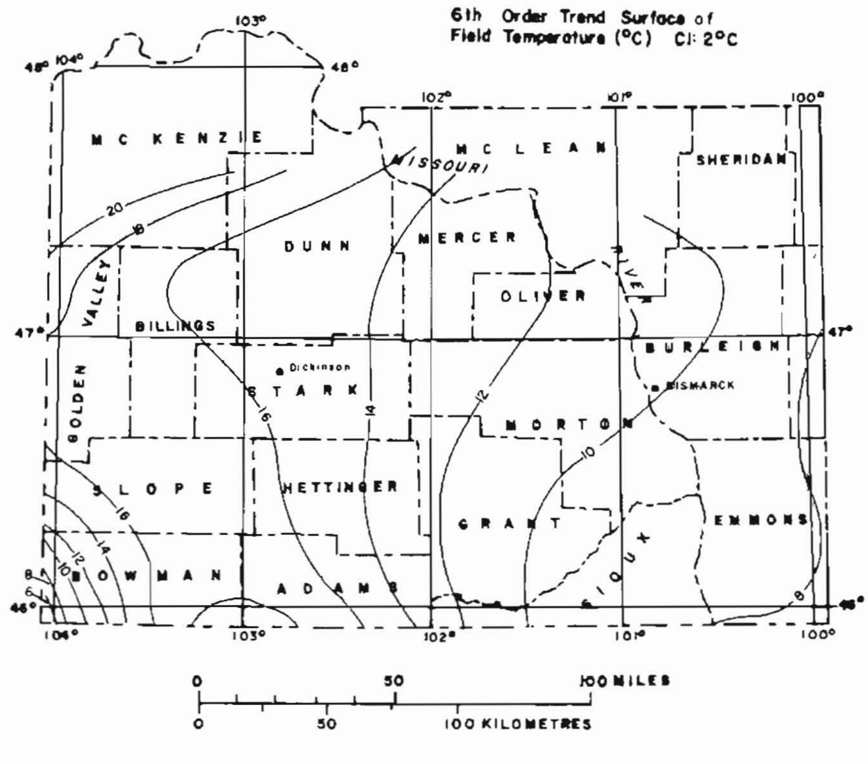


Figure 4.9.1.1-15. Distribution of water temperature in the Fox Hills aquifer based on well-head measurements.

describing the hydrogeochemical processes that control the water quality is to provide a preliminary geochemical framework that could be eventually used in development of predictions of long-term water quality changes that could result from regional increases in aquifer withdrawals or from aquifer recharge by injection well networks. These and other factors may become important if the Fox Hills aquifer is subjected to large-scale increases in usage as coal developments proceed in southwestern North Dakota.

4.9.1.2 Suitability of Fox Hills water for domestic and agricultural uses

As mining of the shallow lignite aquifers proceeds, replacement water supplies for domestic and agricultural uses may be required if water quantity and/or quality deteriorate. One possible source of new water supplies is the Fox Hills aquifer. The recommended and permissible concentration limits established by the U.S. Environmental Protection Agency (1975) are listed in table 4.3.6.1-1. The water chemistry of the Fox Hills aquifer is tabulated in appendix C-II.

Fox Hills water is generally soft (calcium and magnesium hardness < 61 mg/L expressed as $CaCO_3$) but it has a total dissolved solids content twice that of the recommended limits. The recommended limits are set on the basis of esthetic and taste characteristics and concentrations in excess of these limits do not pose health problems. Most groundwater that is used for domestic and livestock purposes in the Interior Plains region exceeds the recommended limit of 500 mg/L total dissolved solids.

The recommended limit for SO_4^{2-} in drinking water is 250 mg/L. The concentration of SO_4^{2-} is generally below this limit in the Fox Hills aquifer in North Dakota, except in the extreme southwest and southeast parts of the study area (fig. 4.9.1.1-5), where it attains values of 400 mg/L or higher. The origin of the large variation of SO_4^{2-} in the aquifer is discussed in section 4.10.1.

Chloride concentrations are generally below the recommended limit for drinking water (250 mg/L) in all areas except in the northwest part of Oliver County and adjacent areas in McLean and Burleigh County. The area of highest Cl^- concentrations coincides with most of the areas in North Dakota where strip mining is underway or is planned; and therefore may be an important factor in consideration of future water supplies in areas of reclaimed land. Although the recommended limit for Cl^- is 250 mg/L, Cl^- normally does not impart of detectable salty taste to water unless the concentration rises to 400 to 500 mg/L.

In addition to the recommended limits for the major dissolved constituents in the water (TDS, SO_4^{2-}, Cl^-) and hardness, the quality of Fox Hills water can be appraised with regard to several minor or trace constituents. The recommended limit for NO_3^- in drinking water is 45 mg/L expressed as NO_3^- (and 10 mg/L expressed as N). Figure 4.9.1.1-12 indicates that NO_3^- does not exceed this limit. The usual cause of NO_3^- in groundwater is agricultural practice and it is therefore not surprising that NO_3^- is very low because the aquifer outcrops in only a small part of the study area.

Two other constituents that have recommended limits in the drinking water standards are total dissolved iron and total dissolved manganese, with recommended limits of 0.3 mg/L and 0.05 mg/L, respectively. Figures 4.9.1.1-13 and -14 indicate that iron concentrations in the

Fox Hills aquifer range from less than 0.1 mg/L to more than 1.6 mg/L and that manganese concentrations range from less than 0.005 mg/L to more than 0.155 mg/L. Although both iron and manganese occasionally exceed recommended limits, neither constitutes a health hazard, but may cause staining of fabrics and porcelain.

In the Fox Hills aquifer fluoride is an important constituent because in much of the aquifer it occurs at concentration levels (see appendix C-II) that may be hazardous to health if the water is used for human consumption. According to the U.S. Environmental Protection Agency (1975), the maximum concentration of F^- to be permitted for public water supply systems is 2.4 mg/L. This maximum concentration is specified for regions in which the average of the maximum daily air temperatures is 53.7°F or lower. From figure 4.9.1.1-10 it is apparent that the only segments of the Fox Hills aquifer that have F^- concentrations below the maximum permissible concentration are located in the recharge area in the extreme southwestern part of North Dakota and eastern part of the aquifer along the valley of the Missouri River and to the east where the Fox Hills outcrop and subcrop zones occur.

From the information on F^- presented above it is evident that most of the towns and farms that have wells in the Fox Hills aquifer are using water for drinking that does not meet national drinking water standards. Whether or not harmful effects are arising as a result of this water use is not known. Camp (1963) indicates that F^- is a poison that can cause bone changes when water containing 8-20 mg/L is consumed over a long period of time. At levels above 20 mg/L, crippling fluorosis may be expected to occur. Wells in the Fox Hills aquifer that yield water with a F^- content above 8 mg/L are very rare. The question of whether or not the long-term consumption of water with F^- content in the range of 2.5-5 mg/L (i.e., typical Fox Hills concentrations) poses a significant health hazard has been a subject of considerable debate in the field of environmental medicine. For a review of some aspects of this topic the reader is referred to Gotzsche (1975).

In the areas of North Dakota that are being mined and that are expected to be mined, the most common sources of well water are the main coal and zones above the coal. At the present time it is not possible to predict the quality of groundwater that will develop after land reclamation in the cast overburden. If the quality is poor, there will be a necessity to obtain water from aquifers at greater depth. In this regard the Fox Hills aquifer may take on importance much beyond that with which it is viewed at present. Based on the delineation of F^- levels in the Fox Hills aquifer described above, it is reasonable to conclude the excessive F^- may be a factor that could prevent large scale use of this aquifer as an alternative water supply on a regional basis.

The following list of chemical species are well below the recommended and permissible concentration limits: copper, zinc, arsenic, barium, cadmium, chromium, selenium, lead, mercury, and silver.

4.9.2 Lower Bullion Creek Aquifer Zone

The following discussion is based on results of chemical analyses of water samples from the Lower Bullion Creek aquifer zone west of the Missouri River presented by Croft (1970), Klausing (1976), and Moran et al. (1977) and on chemical analyses for the Hensler bed in the Falkirk area obtained as part of the present investigation. The Hensler bed is discussed in greater detail in section 4.3. The chemical analyses of Lower Bullion Creek wells west of the Missouri River are listed in table 4.9.2-1. Those for which the specific intake zone could be identified are also included in appendix C-IV and include wells in the Weller Slough, Harmon, and Hansen intervals. The analyses for the Hensler bed are presented in table 4.9.2-2. These analyses represent a relatively small number of sampling points in large regions. The consistency of the results within each region, however, suggests that the data are probably sufficient for purposes of appraisal of the general water quality of these groundwaters. The data are insufficient to warrant interpretations regarding relations of chemical parameters to regional flow paths. Our comments are restricted to the suitability of the water for domestic and agricultural use and to consideration of the geochemical processes that have caused the water to acquire its major characteristics.

4.9.3 Suitability of Lower Bullion Creek Aquifer Water for Domestic and Agricultural Uses

In the Falkirk area the water quality of the aquifer is generally quite good for both domestic and agricultural uses. The water is moderately hard with total dissolved solids approximately twice the recommended levels of 500 mg/L. Concentrations of chloride, nitrate, sulfate, fluoride, and copper are all below the recommended concentration limits. Iron and manganese are commonly above the recommended limits. Only cadmium and lead in the trace metals group were analyzed. Lead is within the maximum permissible limits and all but one sample showed acceptable cadmium concentrations. Cadmium in the anomalous sample (0.015 mg/L) was only slightly above the maximum permissible concentration of 0.010 mg/L.

The Dunn, Mercer, and Oliver County samples indicate that water in the discharge area of the western portion of the aquifer is of acceptable quality. The water is soft with a total dissolved solids content on the order of 1 400 mg/L. Again, concentrations of chloride, sulfate, nitrate, and fluoride are within the recommended and maximum permissible limits as is manganese. Iron slightly exceeded its recommended limit in only one sample.

4.10 Interpretive Geochemical Framework

4.10.1 Fox Hills Aquifer

The purpose of this section is to present a brief description of the dominant hydrogeochemical processes that control the chemical evolution of water in the Fox Hills aquifer. As indicated in section 4.9.1 water in the Fox Hills aquifer is characterized by high concentrations of Na^+ and HCO_3^-, very low concentrations of Ca^{2+}, Mg^{2+}, and K^+, concentrations of Cl^- that increase from low to intermediate levels along the regional flow paths, and concentrations of SO_4^{2-} that decrease from intermediate to very low values as the water moves from the recharge areas toward the interior of the aquifer in the central portion of the study area.

The Cl^- content of Fox Hills water is not controlled by factors such as mineral solubility, ion exchange or redox processes as in the case for the other major ions. Chloride minerals of sedimentary origin are highly soluble. Water in the

TABLE 4.9.2-1. Groundwater chemical analyses--lower Bullion Creek Formation west of Missouri River

Location & Date	Depth (ft)	Field Temp.	Field pH	Field Cond.	TDS mg/L	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	Cu µg/L	Cd µg/L	Pb µg/L	Well No.	Owner
141-84-4 DDD 05-13-76	250				1180	27			421		693	67	6	160.0	4.66		10.0						S. Henderscheid
142-88-1 CDC 05-24-69	560	9.0			2030	26	6.1	2.7	828	4.1	1920	49	124	15.0	50.00		0.5	1.9				3651	NDSWC
143-90-34 DCB 06-17-68	680	11.0		2830	1810	17	4.4	1.5	756	2.8	1850	14		4.3				.6					R. Backfish
143-91-19 AAA 01 04-19-74	670	10.5			1830	130	33.0	12.0	660	7.2	1320	50	12	420.0	40.00	40	1.0	.9				4602	NDSWC
144-93-20 ADA 01 11-04-75	882					60	21.0	1.9	800	12.0	1835	50	59	170.0			0.0					DC 29-1	UND-EES
144-94-21 CDC 01 10-28-75	740					60	21.0	1.9	571	15.0	1386	54	10	54			.1					DC 20-1	UND-EES
145-92-28 DAA 01 11-10-75	354					38	13.0	1.4	790	11.0	1976	0	34	26.0			.1					DC 31-1	UND-EES
145-93-36 BCC 01 11-04-75	760					56	8.0	8.7	722	18.0	2033	12	61	17.0			1.2					DC 15-1	UND-EES
145-94-34 DDA 01 10-27-75	768					28	6.4	2.9	750	16.0												DC 33-1	UND-EES
147-91-29 BCA 05-23-72	917	13.5		3650	2380	35	7.8	3.8	973	4.1	2400	0	159	8.5	90.00	40	1.0	1.8					J. Fredericks
147-97-6 ABB 04-05-73	475	13.0		2830	1820	14	3.4	1.3	772	3.3	2050	0	17	1.2	400.00	40	1.0	4.0					C. Danielson
147-97-18 DBC 10-11-72	700	13.0		2940	1850	17	3.6	2.0	824	3.3	2120	0	44	0.0	310.00	0	1.0	1.7					D. Harris
148-96-18 ABC 05-18-72	600	14.0		3230	2140	23	5.0	2.6	881	3.7	2360	0	16	0.0	180.00	40	1.0	4.4					G. Fenton
148-97-4 DBA 05-16-73	700	5.0		2750	1730	15	3.9	1.3	736	4.2	1970	0	19	0.8	0.00	0	1.0	2.5					G. Olson
148-97-28 ACB 04-05-73	675	15.5		2900	1940	14	3.0	1.6	798	3.1	2110	0	41	0.8	20.00	40	1.0	1.6					C. Danielson

TABLE 4.9.2-2. Groundwater chemical analyses--Hensler bed, Falkirk area

Location & Date	Depth (ft)	Field Temp.	Field pH	Field Cond.	TDS mg/L	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	FE µg/L	Mn µg/L	NO_3 mg/L	F mg/L	Cu µg/L	Cd µg/L	Pb µg/L	Well No.	Owner
145-81-8 CCB 08-12-77	230	15	8.15	2850	1369	25.8	7.6	2.2	533	3.7	1085		39.8	114.2	1750	19	0.1	0.71	18.7	1.40	6.9		O. Sheldon
145-82-4 AAA 06-16-76	237	10	8.30	1510	465	83.7	13.0	7.9	308	9.1	1089		660.7	63.5	8403	375			82.0	13.80	76.0	FA 107-1	UND-EES
145-82-5 DAA 06-18-76	279	11	8.40	1500	888	34.3	4.2	2.6	16	5.3	819		9.3	98.1	1483	127			35.0	1.32	210.0	FA 102-1	UND-EES
145-82-5 DAA 10-09-76	279				948	31.9							7.2	295.3	436	66	1.4	0.27	23.0	0.40	14.5	FA 102-1	UND-EES
145-82-5 DAA 07-13-77	279	8	8.24	1500	962	35.3	0.9	0.7	315	1.8	826		77.0	215.2	119	36	0.1	2.10	10.2	1.10	12.0	FA 102-1	UND-EES
145-82-18 BBC 08-16-77	150	20	7.37	1750	1198	356.0	78.0	60.0	379	9.3	921		15.9	323.2	1800	37		0.32	7.2	0.43	2.6		L. Heger
146-81-6 DDD 08-19-77	260	11	7.35	1300	1021	390.0	107.0	52.0	262	14.2	730		1.0	377.0	17244	276	0.1	0.10	3.6	0.80	7.1		E. Schauer
146-81-8 BCB 08-15-77	150	9	8.18	1650	1000	21.3	32.2	17.4	502	4.7	839		20.4	61.7	207	14	0.1	0.21	17.0	14.60	6.6		H. Seidler
146-81-18 CCA 08-11-77	248	14	7.34	1075	622	225.0	51.7	22.1	175	8.7	648		7.2	107.1	7000	200	0.1	0.10	7.0	0.85	3.1		R. Weisz
146-81-18 DDD 08-11-77	186	17	7.74	1150	710	79.6	21.4	7.1	278	8.5	660		17.4	512.5	1150	33	0.3	0.10	22.2	0.88	10.8		J. Sayler
146-81-31 CCC 08-12-77	280	20	8.01	1500	935	37.7	5.8	1.8	383	3.6	854		19.3	136.3	2300	20	0.1	0.32	10.5	0.64	7.6		R. Sayler
146-82-13 DDB 08-15-77	252	15	7.29	950	632	133.0	46.2	24.4	308	8.1	656		10.0	100.6	1100	56	0.1	0.10	10.0	0.65	3.6		H. Mautz
146-82-20 CAD 08-18-77	300	8	8.60	1650	1041	14.9	2.5	1.2	386	3.3	877		2.3	100.0	733	13	0.3	1.50	5.2	0.62	10.2		R. Sigurdson
146-82-21 BDC 08-19-77	395	10	8.69	1290	817	8.5	2.5	1.1	354	1.7	728		1.6	93.1	131	11			4.0	3.70	43.0		City of Underwood
146-82-21 CCC 08-19-76	320-360		8.85	1320	896	12.0	3.1	1.1	350	1.7	762	35	0.4	74.0	900	0	1.0	0.20				FA 137	UND-EES
146-82-22 CBC 08-19-77	120	15	7.23	535	228	181.0	48.0	30.9	32	6.1	410		1.0	67.6	2008	204	0.1	0.10	3.0	0.40	1.6		E. Schell
146-82-28 CCC 06-16-76	259	11	8.20	1310	882	45.4	2.3	9.6	225	3.8	770		9.3	83.9	2211	106			30.0	1.44	45.0	FA 105-1	UND-EES

Fox Hills aquifer is grossly undersaturated with respect to all chloride minerals of sedimentary origin that could occur in the aquifer. Chloride minerals of sedimentary origin would not be expected to occur in the sandstone strata of the Fox Hills Formation in appreciable amounts. If minor amounts of these minerals actually existed in the aquifer during the period of deposition of the sediments that comprise the aquifer, the chloride salts would probably have been removed during the many millions of years of water circulation through the aquifer since its formation.

Chloride minerals dissolve rapidly when in contact with water in which they are grossly undersaturated. The fact that Cl^- concentrations in the Fox Hills aquifer are at most only a few hundred milligrams per litre is evidence that if a chloride mineral such as halite (NaCl), for example, is present in the aquifer, its bulk content would be extremely small. To produce a concentration of 300 mg/L, an initial content of chloride salt of only about 0.02 percent (by weight) of the porous medium would be required. Soluble components of the aquifer at such a low fraction of the aquifer would be expected to disappear rapidly as undersaturated water passes through the system. Based on this line of reasoning, it appears unlikely that the Cl^- content of water in the Fox Hills aquifer is derived by dissolution of chloride-bearing minerals in the aquifer.

A more reasonable explanation for the Cl^- content of water in the Fox Hills aquifer and the trend of increasing Cl^- concentrations in the directions of regional groundwater flow involves the process of molecular diffusion.

In a study of the water-soluble chloride content of borehole samples of shale from formations ranging from Tertiary to Cambrian in age in the Plains Region of Canada, Williams (1967) observed appreciable chloride contents, with an average value of 1 386 parts per million. If pore water in shale with this content of chloride salt were to acquire the chloride by dissolution of all of the chloride salt, the solution concentration would be about 2 400 mg/L of Cl^-. This is a very high Cl^- content relative to Cl^- in the Fox Hills aquifer. Although we have no data on the chloride salt contents of the shale strata below and above the Fox Hills aquifer, it is reasonable to expect that they would be a source of considerable Cl^-. If, as suggested in section 4.8.1, upward groundwater flow occurs in the Pierre Formation, the very low permeability of this formation would limit the upward velocities to extremely small values. As indicated in section 4.8.1, it is likely that in much of the aquifer, flow is upward from the aquifer through the overlying confining beds and downward into the Pierre Shale below the aquifer. It was also indicated, however, that the velocities of groundwater that are expected to occur in the shale above and below the Fox Hills aquifer are extremely small. In situations where concentration gradients exist, and where groundwater velocities are extremely small, the main mechanism causing migration of ions is molecular diffusion. As a hypothesis to explain the presence of Cl^- in the Fox Hills aquifer and to explain the trends of concentration increase, we suggest diffusion of Cl^- into the aquifer from shale strata below and possibly above the aquifer is a reasonable hypothesis. A diffusion-generated vertical flux of Cl^- into the aquifer from the Pierre Formation would cause a gradual increase in the Cl^- content of the water as it moves laterally along the regional flow paths. Although molecular diffusion is a slow process, the area over which the diffusion would occur is very large relative to the thickness of the aquifer. Studies that are in progress are designed to evaluate this hypothesis within a quantitative framework based on a diffusion-based computational model. The following is a semi-quantitative analysis of the diffusion process with a view to establishing whether or not it may be feasible for diffusion to exert a major influence on the water quality of the Fox Hills aquifer.

Fick's First Law of Diffusion can be expressed as,

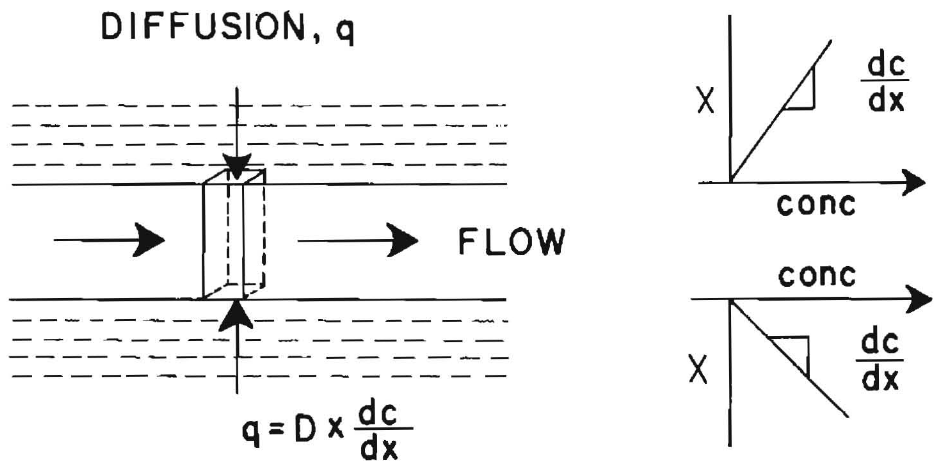
$$q=D_x \frac{dc}{dx} \qquad (4.10.1\text{-}1)$$

where D is the diffusion coefficient $(\frac{L^2}{T})$, dc/dx is the concentration gradient $(\frac{M}{L^3 \cdot L})$, and q is the mass flux per unit area normal to the flux vector. Diffusion is a mechanism of migration of dissolved solids in all porous geological materials. For diffusion in water, values of D for major ions of interest in groundwater studies are in the range of 1×10^{-5} to 3×10^{-5} cm^2/s at temperatures of 0 to 25°C. In porous media, diffusion coefficients are small because of the tortuosity of the diffusion paths. In dense clayey deposits the values of the diffusion coefficients for non-adsorbed ions are smaller by a factor of about 5-10.

Sandstone aquifers such as the Fox Hills are commonly devoid of minerals that can provide appreciable quantities of dissolved solids as a result of mineral dissolution. Quartz and feldspar, which make up nearly all of the bulk mass of sandstone aquifers are relatively non-reactive. Calcite, which is a common minor or trace constituent of sandstone aquifers, dissolves rapidly in water, but because of solubility constraints only yields a few hundred milligrams per litre in most situations. Sandstone aquifers, however, commonly contain dissolved solids at concentrations of many hundreds or thousands of milligrams per litre. The question to be addressed in this discussion is whether or not diffusion from clayey aquitards can play an important role in the generation of dissolved solids in aquifers. This mechanism is worthy of scrutiny because the geochemical nature of clayey aquitards is such that their pore waters commonly contain high concentrations of dissolved solids. This is the case because they: (1) normally contain minerals that are more reactive than those in aquifers, (2) the mineral surface area to pore water volume ratios are much larger, thereby enhancing rates of mineral dissolution, and (3) aquitards can for long periods of time contain entrapped saline solutions that originate during depositional or fluid invasion episodes associated with marine environments.

Silty and clayey aquitards of the type that overlie and underlie the Fox Hills aquifer have hydraulic conductivities on the order of 10^{-9} cm/s or smaller. Under the influence of normal hyraulic gradients, the flux of water in materials with conductivities of this magnitude is extremely small and is insignificant in many situations. Groundwater transport (advection) of dissolved solids from these clayey strata into the Fox Hills aquifer are therefore probably inconsequential relative to contributions resulting from molecular diffusion.

In this analysis the hypothetical aquifer-aquitard system shown in figure 4.10.1-1 will be considered. It is assumed that the aquitards have pore water with dissolved solids much higher than in the aquifer. For the illustrative calculations that follow, the origin of the dissolved



Assumptions:

1. Steady - state lateral flow in aquifer with complete mixing.
2. Vertical steady - state concentration gradients in the aquitards.
3. Over the time interval for calculated diffusive flux, concentration increase in the aquifer is insignificant relative to concentration of pore water in the aquitards.

Figure 4.10.1-1. Schematic diagram of an aquifer-aquitard system with vertical diffusion from aquitards.

solids need not be specified. A diffusion coefficient value of 3×10^{-6} cm^2/s will be assumed and the vertical concentration gradient in the aquitard will be taken as 100 mg/L (0.1 mg/cm^3) per metre. Therefore, from Fick's First Law the diffusive flux for this case is,

$$q = 0.1 \text{ mg/yr.cm}^2 \quad (4.10.1\text{-}1)$$

For this hypothetical situation, 0.1 mg/yr will diffuse upward from the shale into the aquifer per square centimetre of surface area of aquifer-aquitard interface. Considering a 3.3-foot (1-m) thick aquifer with a porosity of 20 percent, the pore volume represented by a column segment of aquifer with a 1 cm^2 area (top and bottom), is 0.02 litres. Assuming a condition of lateral plug flow in the aquifer with complete mixing of constituents entering by diffusion, the diffusive flux calculated above would produce a concentration increase of 5 mg/L per year (diffusion from above and below). If the aquifer is 33 feet (10 m) thick, the concentration increase would be .5 mg/L per year. If the aquifer is 330 feet (100 m) thick, it would be 0.05 mg/L per year and so on.

Taking an average thickness of the Fox Hills aquifer as 330 feet (100 m), this calculation indicates that for the assumed conditions with uniform diffusion flux across the contact between the Pierre Formation and the aquifer, an increase of 1 000 mg/L would occur during an interval of 10 000 years. Since the water in the Fox Hills aquifer takes tens of thousands of years to travel from the western and southwestern recharge areas to the deep interior regions of the aquifer, it is evident that if the parameters used in the illustrative case described above are reasonable, diffusion of dissolved constituents from clayey confining strata must be an important process. It is unlikely that the diffusion coefficients for unadsorbed ion species such as Cl^-, SO_4^{2-}, and HCO_3^- are much less than the value used in the calculation. The main uncertainty is the concentration gradient in the clayey strata above and below the Fox Hills aquifer. The gradient used in the calculation (100 mg/L per m) is not a very large gradient. If geochemical processes in the clayey strata generate reaction products such as HCO_3^-, SO_4^{2-}, Na^+, and F^- it would be expected that significant concentration gradients would develop between the interior of the clayey strata and the aquifer.

The marine origin of the Pierre Formation suggests that Na^+ and Cl^- are more likely derived from it than from clayey strata of the Hell Creek Formation, which has a non-marine origin. Since balance of electrical charge is maintained in aqueous systems, a diffusive flux of Cl^- from the shale into the Fox Hills aquifer would be accompanied by a cation flux of equivalent but opposite charge, which in this case would be predominantly Na^+. Only about half of the Na^+ increase in the Fox Hills water as it moves along the regional flow paths can be accounted for by this process. For example the Na^+ content of the water increases from values on the order of 400 mg/L in the extreme western and southwestern parts of North Dakota to values on the order of 700-800 mg/L in Oliver and Morton Counties located more than 100 miles to the east. Over this flow distance, the Cl^- increase is about 250 mg/L (7 mmol/L) which, assuming a NaCl origin, would produce a corresponding increase of 160 mg/L (7 mmol/L) of Na^+. About half of the Na^+ increase (6.1 mmol/L) is therefore not accounted for by the mechanism of NaCl diffusion from the shale.

The fact that there is a large gradual increase in HCO_3^- as the water moves along the regional flow paths and a decrease in SO_4^{2-} concentrations suggests that SO_4^{2-} reduction is an active process in the aquifer or in its associated aquitards. This process can be represented schematically by the expression,

$$SO_4^{2-} + 2CH_2O \longrightarrow H_2S + 2HCO_3^- \qquad (4.10.1\text{-}2)$$

where CH_2O (carbohydrate) is used as a representation of organic matter that acts as the reducing agent. This reaction is catalyzed by bacteria known as sulfate reducers (Desulfovibro). Sulfate-reducing bacteria have been found to produce H_2S in the laboratory and in nature using a wide variety of organic substances as reducing agents (Berner, 1971). Wells that yield waters that smell of H_2S are common in the Fox Hills aquifer. This provides further evidence that sulfate-reduction is an active process in the aquifer or in its associated aquitards. Croft (1973) and Trapp and Croft (1975) have also suggested that the very low concentrations of SO_4^{2-} in Mercer and Oliver Counties and in Stark and Hettinger Counties are due to SO_4^{2-} reduction.

Figure 4.9.1.1-5 indicates that the difference in SO_4^{2-} concentrations between the recharge areas in the west and southeastern parts of the study area and the low SO_4^{2-} region in the north-central part of the area is about 360 mg/L (3.75 mmol/L). Over the same flow paths, the increase in HCO_3^- content is about 800 mg/L (13.1 mmol/L). Equation 4.10.1-2 indicates that for every mole of SO_4^{2-} that is reduced, 2 moles of HCO_3^- are released. The reduction of 360 mg/L of SO_4^{2-} would therefore result in a corresponding increase of 450 mg/L of HCO_3^-. However, of the observed 800 mg/L increase in HCO_3^-, about 350 mg/L (5.75 mmol/L) is unaccounted for by this mechanism. On a molar basis this is close to the amount of Na^+ (6.1 mmol/L) that was left unaccounted for by the mechanism of NaCl diffusion from shale.

At pH levels above 7, the predominant dissolved species that would form as a result of SO_4^{2-} reduction would be HS^-. This occurs as a result of disassociation of H_2S, as described by the equilibrium expression,

$$H_2S = HS^- + H^+ \qquad (4.10.1\text{-}3)$$

Of particular importance in this reaction is the production of H^+. In geologic materials that contain calcite, this causes production of Ca^{2+} and HCO_3^-

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^- \qquad (4.10.1\text{-}4)$$

and, if dolomite is present,

$$CaMg(CO_3)_2 + 2H^+ \rightarrow Ca^{2+} + Mg^{2+} + 2HCO_3^- \qquad (4.10.1\text{-}5)$$

Figures 4.9.1-8 and -9 indicate that there are no significant increases in Ca^{2+} or Mg^{2+} along the trend of SO_4^{2-} decrease. These ions exist at very low concentrations in the interior region of the Fox Hills flow system. From the geologic nature of the Fox Hills aquifer and its associated aquitards it is reasonable to expect that Ca^{2+} and to a lesser extent Mg^{2+} are released by calcite and dolomite dissolution, but that cation exchange maintains these ions at low concentrations. The exchange processes can be expressed as

$$Ca^{2+} + 2Na(clay) \rightarrow 2Na^+ + Ca(clay) \qquad (4.10.1\text{-}6)$$

$$Mg^{2+} + 2Na(clay) \rightarrow 2Na^+ + Mg(clay) \qquad (4.10.1\text{-}7)$$

where Na(clay), Ca(clay), Mg(clay) denotes cations in an adsorbed state on clay minerals or other particles. If the exchange sites on the clay minerals or other colloids that participate in the process have an appreciable percentage of Na^+, these reactions proceed far to the right to achieve equilibrium. The end result of calcite and dolomite dissolution is therefore water with an increased concentration of Na^+ and HCO_3^-. For each mole of HCO_3^- formed, a mole of Na^+ enters the solution by ion exchange. In the presence of calcite and dolomite, the water would be maintained at or very near equilibrium with respect to these minerals. Cation exchange reactions are known to be very rapid such that exchange equilibrium would be expected to persist. The key mechanism that drives these reactions in the directions indicated above is the release of H^+ that occurs because of sulfate reduction.

In the above discussion the dominant characteristics of the major-ion chemistry of water in the Fox Hills aquifer were accounted for using a combination of geochemical processes, namely NaCl dissolution, sulfate reduction, calcite (and possibly dolomite dissolution), and cation exchange. It was concluded that although NaCl is the likely primary source, the actual initial location of the NaCl is probably the Pierre shale beneath the aquifer, with the molecular diffusion being the mechanism by which the dissolution products, Na^+ and Cl^-, enter the aquifer. With this line of reasoning in mind, the question can be asked as to whether or not the processes of sulfate reduction, calcite dissolution, and cation exchange influence the chemistry of water in the aquifer as a result of occurrence in the aquifer or in associated siltstone or shale strata. Since there is no information on the pore-water chemistry in the silt and shale zones, we can only speculate on the answer to this question.

The reduction of SO_4^{2-}, which is the key process causing the progressive increases in HCO_3^- and Na^+, is a process that generates H^+ and HCO_3^- as indicated by equations 4.10.1-2 and 4.10.1-5. The H^+ in turn causes the release of Ca^{2+} and more HCO_3^- by calcite dissolution as indicated by equations 4.10.1-6 and 4.10.1-7. This causes a progressive Na^+ increase by cation exchange. Without SO_4^{2-} reduction, progressive calcite dissolution that causes progressive release of Na^+ by cation exchange would not occur. The hydrochemical system would be maintained in a relatively stable equilibrium without major increases in Na^+ and HCO_3^-. For the process of SO_4^{2-} reduction to proceed, the presence of organic matter that is assimulatable by sulfate-reducing bacteria is necessary. Of the three stratigraphic zones, the Fox Hills aquifer, the Pierre Shale, and the shale of the Hell Creek Formation, the Hell Creek Formation is the most likely source of organic matter. The Hell Creek sediments were deposited in non-marine flood plain environments. The sediments should therefore be rich in organic matter relative to the sediments of the Fox Hills and Pierre Formations. The least likely sources of assimulatable organic matter are the sediments of the Fox Hills Formation, which are predominantly marine shoreline sands.

The fact that the SO_4^{2-} content of the Fox Hills aquifer declines as the water moves eastward and northeastward from the southwestern part of North Dakota indicates that the process of SO_4^{2-} reduction is severely limited by some rate-controlling mechanism, which in some way is probably related to constraints on the availability of organic matter suitable for use by sulfate-reducing bacteria. Molecular diffusion is probably the rate controlling process for SO_4^{2-} reduction. SO_4^{2-} reduction may be occurring in the aquifer at a rate controlled by diffusion into the aquifer of dissolved organic matter from fine-grained beds such as silty or clayey strata in the Hell Creek Formation. There is also the possibility that the main location of SO_4^{2-} reduction is in the organic-rich silty or clayey zones in the Hell Creek Formation and that SO_4^{2-} in the aquifer migrates by molecular diffusion upward from the aquifer into these sulfate-deficient zones. The products from SO_4^{2-} reduction and associated reactions such as calcite dissolution and cation exchange would move by diffusion under the influence of their own concentration gradients into the aquifer. It is conceivable, therefore, that the main characteristics of the water chemistry in the Fox Hills aquifer are to a major extent a result of geochemical processes in the aquitards associated with the aquifer rather than processes occurring in the aquifer. The initial chemical characteristics of the water are, of course, controlled by geochemical processes that occur in the recharge areas, and primarily in the above water table part of the recharge areas. Diffusion-controlled processes in the aquitards then become dominant as the water moves through the aquifer along the regional flow paths.

4.10.2 The Bullion Creek Formation

Table 4.9.2-1 indicates that water in the Bullion Creek Formation west of the Missouri has Na^+ and HCO_3^- as dominant ions with only minor concentrations of K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-}. In this respect the water is similar to water in part of the Fox Hills aquifer. With the exception of two wells at depths less than 150 feet (50 m), all of the analyses have HCO_3^- values in the range of 1 400-2 500 mg/L and nearly all of the analyses have SO_4^{2-} values less than 15 mg/L. Ca^{2+} and Mg^{2+} values are very low relative to Mg^{2+} and the water is generally very soft. With the exception of the shallow wells, Na^+ values range from 610-930 mg/L. Comparison of the Na^+ and HCO_3^- values for the Bullion Creek Formation with the concentrations of these ions in the Fox Hills aquifer (figs. 4.9.1.1-4 and 4.9.1.1-6) indicates that the highest values occur in the Bullion Creek Formation. The Na^+ and HCO_3^- values are exceptionally high in comparison to the values for aquifers in the Sentinel Butte Formation. The only zone in southwestern North Dakota in which similarly high values are obtained is the Upper Hell Creek-Lower Cannonball-Ludlow aquifer zone.

Table 4.9.2-2 indicates that water in the Bullion Creek Formation east of the Missouri River also has Na^+ and HCO_3^- as the two dominant ions. This water, however, has major concentrations of SO_4^{2-}, Ca^{2+}, and Mg^{2+}. The Na^+ and HCO_3^- values are not as high as in the Bullion Creek aquifer zone described above nor as high as in most of the Fox Hills aquifer.

The water in the Bullion Creek Formation west of the Missouri River represents water that has evolved further hydrochemically than other groundwater in southwestern North Dakota. These processes that control the hydrochemical evolution toward high Na^+ and HCO_3^- concentrations are described in some detail in section 4.10.1. Our purpose here is to comment briefly on the role that these processes play in generating the exceptionally high Na^+ and HCO_3^- concentrations in the Bullion Creek Formation in the area west of the Missouri River. The data base differs from that of the Fox Hills aquifer in that the regional flow pattern and hydrochemical trends along the flow pattern are not defined in sufficient detail to indicate progressive stages in the hydrochemical evolution process. Conceptually the water in the Bullion Creek Formation west of the Missouri can be viewed as a very late stage end-member of an evolution sequence. The water in the Hensler aquifer east of the Missouri River can be viewed as an intermediate stage in the sequence.

Much or most of the water in the Bullion Creek Formation in the areas considered in this study appears to be derived by downward seepage from the Sentinel Butte Formation. Based on information presented in sections 4.3, 4.4, 4.5, and 4.6, it is apparent that water in the Sentinel Butte Formation generally has less HCO_3^- and Na^+ more SO_4^{2-}, Ca^{2+}, and Mg^{2+} than the intermediate-stage water represented by the analyses for the Hensler aquifer (table 4.9.2-2). The hydrogeochemical processes that control the evolution of waters in the Sentinel Butte Formation are described by Moran and Cherry (1977), Moran et al. (1976), and Moran et al. (1978) and are summarized in section 4.10.4. The focus in this discussion will be on processes that change the water as it evolves to the intermediate and late stages as represented by water in the Bullion Creek Formation.

The late-stage water in the Bullion Creek Formation (high Na-HCO_3 water) achieves its condition as a result of the processes of sulfate reduction and cation exchange. The concentration of HCO_3^- rises to such exceptionally high levels because sulfate reduction produces HCO_3^- as a reaction product,

$$2CH_2O+SO_4^{2-} \rightarrow H^++HS^-+2HCO_3^- \quad (4.10.3\text{-}1)$$

and because the H^+ causes dissolution of calcite and possibly dolomite,

$$CaCO_3+H^+ \rightarrow Ca^{2+}+HCO_3^- \quad (4.10.3\text{-}2)$$

$$CaMg(CO_3)_2+2H^+ \rightarrow Ca^{2+}+Mg^{2+}+4HCO_3^- \quad (4.10.3\text{-}3)$$

The release of Ca^{2+} and Mg^{2+} to the aqueous system by dissolution causes Na^+ to increase as a result of ion exchange. Without sulfate reduction there is insufficient H^+ available in the water to cause a significant amount of calcite and dolomite dissolution even though Ca^{2+} and Mg^{2+} are maintained at very low levels. The ion exchange reaction controls the ratio of Na^+ to Ca^{2+} and Mg^{2+}. Sulfate reduction is the process that drives the concentrations of Na^+ and HCO_3^- upward. Because of the strongly reducing conditions and the low solubility of FeS_2, much of the HS^- produced in the reduction process is probably removed by precipitation of FeS_2. Iron that enters the water from other mineralogical constituents probably provides a source for FeS_2 formation.

In southwestern North Dakota deep groundwater that acquires high Na^+ and HCO_3^- concentrations and has very low Ca^{2+}, Mg^{2+}, and SO_4^{2-} concentrations has probably achieved a relatively stable condition because of the lack of geochemical mechanisms to drive the water toward a new chemical condition. Without additional sources of H^+, calcite or dolomite dissolution will not proceed further. Without additional Ca^{2+} or Mg^{2+} a rise in Na^+ content by exchange cannot occur.

Tables 4.9.2-1 and -2 indicate that Cl^- concentrations in the Bullion Creek Formation are low and particularly so in comparison to Cl^- levels in the Fox Hills aquifer, which are in the range of 100-400 mg/L in the interior region of the aquifer. In section 4.10.1 it was suggested that much of the Cl^- and some of the Na^+ in the Fox Hills aquifer is acquired by diffusion from the Pierre Formation which is shale of marine origin. Except for the Hensler bed which may be marginal marine, the Bullion Creek Formation is non-marine and is overlain and underlain by non-marine strata. The low content of Cl^- in water in this formation is therefore not surprising. What is surprising, however, is that the water is so exceptionally high in Na^+ without at least a moderate increase in Cl^-. The origin of the exchangeable Na^+ is problematic. If the exchange sites were loaded with Na^+ as a result of saline water invasion during a marine transgression in late Tertiary time, we would expect to find more Cl^- in the groundwater. There is, however, no other apparent source for the Na^+.

The water in the Hensler bed of the Bullion Creek Formation east of the Missouri River has not evolved past the $Na\text{-}HCO_3\text{-}So_4$ stage. This water is shallower and closer to recharge areas and is therefore probably younger than the $Na\text{-}HCO_3$ water in the Bullion Creek Formation represented in table 4.9.2-1. Since the process of SO_4^{2-} reduction proceeds so slowly, it is likely that time is the main factor in the difference in water chemistry in the two regions.

4.10.3 The Sentinel Butte Formation

Since Quaternary deposits are absent, discontinuous, or very thin in most of the areas of strippable lignite in southwestern North Dakota, most of the shallow groundwater in the lignite region has hydrochemical characteristics that are acquired during flow in Sentinel Butte deposits. The chemical evolution of groundwater in aquifers in the Sentinel

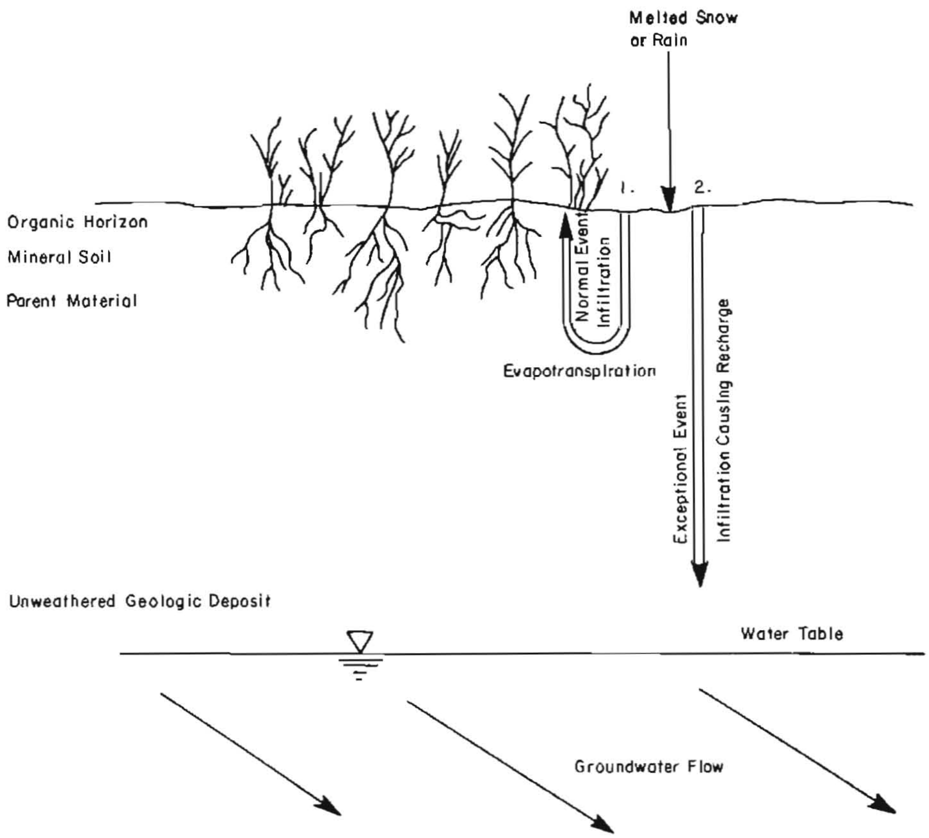


Figure 4.10.3-1. Schematic diagram of chemical processes and salt movement in much of the plains region (from Moran et al., 1978).

Butte Formation is described by Moran and Cherry (1977), Moran et al. (1976), and Moran et al. (1978).

Our purpose here is to present a brief overview, based on Moran and Cherry (1977) of the chemical processes that are important in this formation. In this regard the main hydrologic zone in which there occurs the most intense geochemical influence on the water is the zone above the water table (the unsaturated zone).

Figure 4.10.3-1 indicates the major geochemical processes that occur in the soil and subsoil as infiltration takes place. The sequence of processes illustrated in this diagram have been grouped according to the nature of the infiltration event. These processes and this effect are described below.

Rain and snowmelt has less than 10-20 mg/L of total dissolved solids and has a pH of 5-6. As it flows on and below the ground surface it acquires much higher contents of dissolved salts and much higher pH. The portion of the rain and snowmelt that infiltrates directly into the soil quickly changes in composition. Biochemical decay of organic matter in the soil generates abundant CO_2 to the soil air and H^+ in the soil water. Oxygen in the soil air and dissolved oxygen in the infiltrating water causes oxidation of pyrite in the mineral soil. This generates H^+ (acidity) and SO_4^{2-}. In the mineral soil, the water dissolves carbonate miner-

TABLE 4.10.3-1. Chemical representation of major processes in the chemical evolution of soil water and groundwater in shallow Tertiary deposits

1/ CO_2 production in organic horizons of the soil

$$CH_2O+O_2 \rightarrow CO_2+H_2O$$

2/ Oxidation of pyrite

$$4FeS_2+15O_2+14H_2O \rightarrow 4Fe(OH)_3+16H^++8SO_4^{2-}$$

3/ Dissolution of calcite and dolomite

$$CaCO_3+H^+ \rightarrow Ca^{2+}+HCO_3^-$$

$$CaMg(CO_3)_2+2H^+ \rightarrow Ca^{2+}+Mg^{2+}+2HCO_3^-$$

4/ Precipitation and dissolution of gypsum

$$Ca^{2+}+SO_4^{2-}+2H_2O \rightarrow CaSO_4\cdot 2H_2O$$

5/ Cation exchange

$$Ca^{2+}+2Na\ (adsorbed) \rightarrow 2Na^++Ca\ (adsorbed)$$

als. As this occurs, the H^+ content in the water decreases (the pH increases) and the HCO_3^-, Ca^{2+}, and possibly Mg^{2+} contents increase. Mg^{2+} would be important if dolomite were present. The chemical reactions that represent the processes described above are indicated in table 4.10.3-1. The processes of CO_2 generation, pyrite oxidation, and carbonate mineral dissolution occur in the soil and in the shallow subsoil, that is, within one or two metres of ground surface. Therefore, pore water that occurs in this zone after rainfall or snowmelt periods is characterized by Ca^{2+}, HCO_3^-, SO_4^{2-} and in dolomitic areas by Mg^{2+}. Because of the infrequency of infiltration events that cause passage of water to the water table (i.e., infrequency of recharge), pore waters that acquire these constituents often undergo concentration as a result of evapotranspiration. This causes precipitation of calcite and gypsum in this shallow zone in which penetration by infiltration is common and in which throughflow is rare. These geochemical processes and the pore water chemistry that results from their activity are summarized in figure 4.10.3-2.

Gypsum is a key ingredient in the hydrochemical framework. During the very infrequent, but nevertheless geochemically significant, infiltration events that cause throughflow to the water table, gypsum formed during non-throughflow events dissolves. Since gypsum is a moderately soluble salt, dissolution of even small amounts of this mineral causes the water to acquire major concentrations of SO_4^{2-}. Groundwater in the regions under consideration contains Na^+ as the dominant cation rather than Ca^{2+}. This is attributed to the process of cation exchange caused by Na-rich clay minerals. The clays provide Na^+ to the pore water if Ca^{2+} is present in the water to serve as an exchange ion. The reservoir of exchangeable Na^+ is gradually depleted as the process occurs through repeated infiltration events; as a result, the zone in which the exchange process occurs will migrate deeper with time. The chemistry of shallow groundwater suggests that the exchange process produces Na^+-rich groundwater prior to arrival of the water in the water table zone. Depletion of exchangeable Na^+ in the clayey materials in the zone above the water table may require many tens of thousands of years or longer. The geochemical processes that occur during recharge events and their effects are summarized in figure 4.10.3-3. For convenience of diagrammatic display the processes have been arranged in sequence. In nature, they can occur simultaneously or in sequence depending on the mineralogy of the materials encountered along the paths of infiltration.

In nature, the above framework of geochemical processes accounts for the occurrence of Na^+-SO_4^{2-}-HCO_3^--rich water as the dominant type of groundwater in the Tertiary deposits of continental origin. It provides an explanation for the occurrence of mobile salts in the subsurface environment. In situations where the salts can accumulate within the root zone, the agricultural productivity of the soil is threatened. This may occur in areas of groundwater discharge and exfiltration as well as in recharge areas as outlined above.

The rate at which gypsum is produced in the soil or subsoil depends on the frequency and magnitude of infiltration events, the amount of pyrite in the soil and subsoil, the extent to which oxygen in the upper part of the soil is consumed by oxidation of organic matter, and the rate of gas diffusion in the soil and subsoil. At present very little is known about the specific nature and interrelations of these factors as they exist under natural conditions. Extension of this interpretive framework to post-mining terrain will remain problematic until appropriate field and laboratory experiments are conducted.

Some of the water that temporarily accumulates in minor depressions may be lost by evaporation, thereby causing concentration of salts in the remaining water that infiltrates. The accumulated water in the depressions would be expected to contain minor amounts of Ca^{2+} and HCO_3^- as a result of dissolution of particulate calcite during runoff, which in some areas involves some degree of surface erosion. If pyrite is encountered by the runoff water, oxidation will produce SO_4^{2-}. If water in the depressions evaporates to dryness, it is reasonable to expect that small amounts of precipitated gypsum and calcite will occur. The calcite is of little consequence because it also occurs in most of the bedrock materials. The gypsum is important because it serves as a Ca^{2+} and SO_4^{2-} source for water that infiltrates during major rainfall and snowmelt events. In areas of grassland, it is unlikely that particulate mineral matter occurs in the runoff water to an extent that significantly increases the salt content prior to infiltration in the depressions. In areas of cultivation, and areas of exposed bedrock particulate pyrite as a

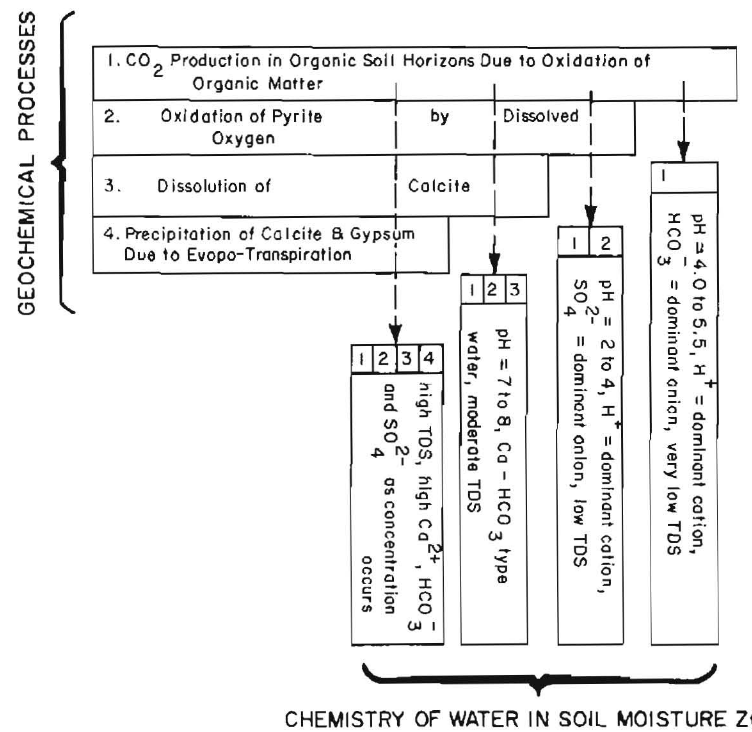


Figure 4.10.3-2. Diagram illustrating relations between major geochemical processes and water chemistry resulting from infiltration that does not pass below the root zone (from Moran et al., 1978).

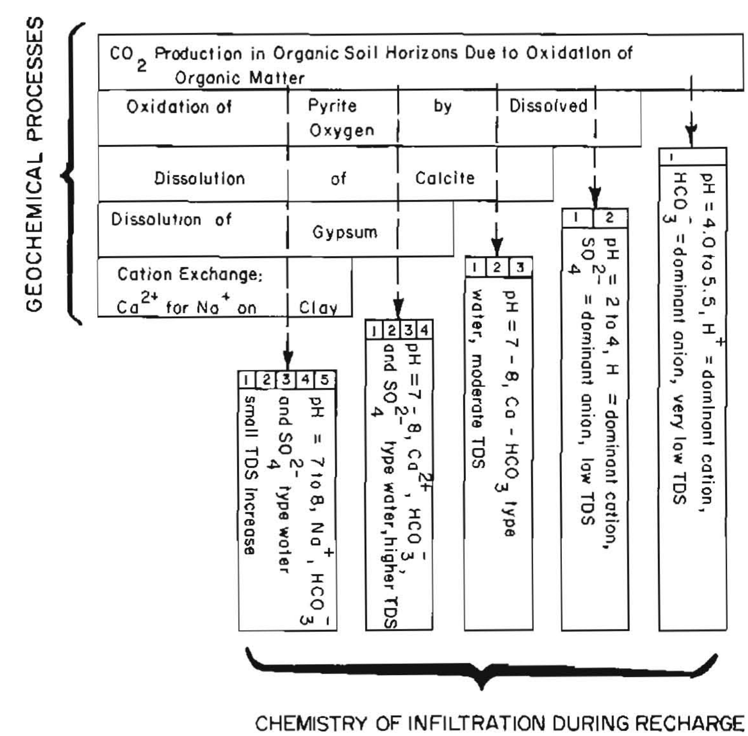


Figure 4.10.3-3. Diagram illustrating relations between major geochemical processes and water chemistry resulting from infiltration that penetrates below the root zone (from Moran et al., 1978).

SO_4^{2-} source in surface runoff is a much more likely possibility.

In situations where Na-rich clays are absent, Ca^{2+}, SO_4^{2-}, and HCO_3^- will be dominant (fig. 4.10.3-3). In situations where pyrite is absent, water that is much lower in dissolved salts and has dominant concentrations of Na^+ and HCO_3^- will develop. If the soil and subsoil are devoid of calcite and dolomite, the water will become very acidic as a result of SO_4^{2-} production from pyrite and from CO_2 generation. The chemistry of soil water and groundwater in reclaimed land will be governed by the processes indicated in figures 4.10.3-2 and -3. What is not known, however, is the manner in which the processes will combine and the net result. In section 4.10.5, we draw attention to some potential manifestations of these processes in areas of reclaimed land.

4.10.4 The Coleharbor Formation

The chemical analyses listed in appendix C-III and the discussions in sections 4.2-4.6 indicate that the chemistry of water in the Coleharbor Formation is highly variable. Nearly all of the chemical analyses are for samples from wells in valley-fill deposits. In many cases the chemical character of the water can be attributed to geochemical processes that influence the water as it flowed through strata of the Sentinel Butte Formation before entering the valley fill. In some areas, however, the water has not flowed through other formations and therefore has acquired its dissolved constituents entirely within the Coleharbor sediments. Chemical analyses of samples from wells in this category are listed in table 4.10.4-1. These analyses are listed for illustrative purposes; they do not represent all of the wells in this category for which data are available.

In this discussion Coleharbor groundwater refers to groundwater of the type represented in table 4.10.4-1. In relation to much of the shallow water of the Sentinel Butte Formation, this water is distinguished by a higher percentage of Ca^{2+} and Mg^{2+}, a lower percentage of Na^+ and usually by a lower total dissolved solids. The concentrations of HCO_3^- and SO_4^{2-} are generally lower but, as is the case for Sentinel Butte water, they are the dominant anions.

The major geochemical processes in the development of the Coleharbor water are calcite and dolomite dissolution, pyrite oxidation, gypsum precipitation and dissolution and cation exchange. These are the same processes that control the chemical evolution of water in the Sentinel Butte Formation. The main difference, however, is that the Ca^{2+} released by dissolution of calcite, dolomite, and gypsum, and the Mg^{2+} released by dissolution of dolomite is not as extensively exchanged for Na^+ as is the case in many zones in the Sentinel Butte Formation. Less Ca^{2+} for Na^+ exchange in the Coleharbor Formation would be expected because these deposits are generally not thick and in many places have been flushed by active groundwater flow since Pleistocene time. Na^+, as a significant component of the cations on the exchange site, is a relic condition from the environment in which the clay minerals existed prior to glacial erosion and deposition. As water with Ca^{2+} and Mg^{2+} from calcite and dolomite moves through the Coleharbor deposits, the percent Na^+ on the exchange sites decreases and the ability of the deposits to contribute Na^+

TABLE 4.10.4-1. Chemical analyses from selected Coleharbor wells

Location	Depth (ft)	Lab pH	Lab Cond.	TDS mg/L	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error
143-92-7 DDD	25	7.70	480	272	260.0	71.0	19.0	4.9	1.8	289	0	1.30	33.00	-0.90
143-92-8 CCC 2	50	7.80	557	322	260.0	72.0	17.0	17.0	3.7	275	0	11.00	53.00	-0.80
143-92-16 BBA	48	8.30	1000	681	280.0	72.0	24.0	130.0	3.4	380	4	4.00	220.00	1.70
143-93-14 AAD 1	133	7.90	1250	789	310.0	64.0	36.0	190.0	12.0	606	0	1.80	213.00	1.10
144-92-31 DCD	216	8.20	1220	779	130.0	27.0	15.0	250.0	6.0	612	0	2.90	170.00	-0.20
144-92-31 DDC	89	8.20	1460	985	270.0	60.0	26.0	250.0	9.3	707	0	2.80	240.00	-1.30
144-93-8 CBB 6	50	7.70	1051	--	252.0	83.0	11.0	192.0	6.8	508	0	0.00	230.00	1.70
144-94-4 ABB	36	8.10	1330	932	660.0	160.0	63.0	66.0	5.0	610	0	6.10	310.00	-1.40
144-94-6 DAA	74	8.10	1130	764	260.0	52.0	32.0	175.0	6.0	536	0	3.80	200.00	-0.20
145-82-4 CDC	15	8.20	1128	972	583.0	184.0	30.0	62.0	5.5	463	--	14.50	251.40	4.50
145-82-7 DAA	241	8.10	1320	867	350.0	77.0	38.0	192.0	8.3	712	0	2.70	188.00	-0.42
145-82-8 ADD	241	7.77	1396	910	235.2	49.7	27.0	156.3	7.7	828	--	13.18	295.00	-26.00
145-82-8 ADD	47	7.55	752	450	230.8	13.5	47.9	30.6	6.6	467	--	0.63	129.20	-26.00
146-82-34 CBC	49	7.42	2970	240	159.0	62.7	1.0	1.2	6.6	187	--	1.49	18.13	-0.70
146-93-34 CCC	37	8.10	433	259	200.0	49.0	19.0	16.0	3.6	180	0	10.00	71.00	0.90
146-94-25 BAA	66	8.00	1070	768	540.0	140.0	46.0	42.0	5.0	450	0	2.20	260.00	-0.50

to the water decreases.

4.10.5 Implications with Respect to Impact of Mining

In the interpretive geochemical framework described above, five geochemical processes were shown to be the dominant influence on the chemical evolution of groundwater in the Knife River basin. These are: pyrite oxidation, carbonate-mineral dissolution (mainly calcite), gypsum precipitation and dissolution, cation exchange, and sulfate reduction. In the natural groundwater systems in the Knife River basin these processes combine to produce waters in some areas that are suitable for drinking and livestock use and waters in other areas that have excessive concentrations of sulfate, H_2S, iron, or fluoride. Since fluoride only occurs in excessive concentrations in deep zones where groundwater is very old (such as the interior of the Fox Hills aquifer), it is very unlikely that changes in the shallow groundwater zone caused by mining will cause fluoride to increase to unacceptable levels.

Groundwater under natural conditions in the overburden of the Sentinel Butte Formation commonly has marginal quality for purposes of drinking or livestock use. In general, the most undesirable feature of the water is excessive SO_4^{2-}. A limit of 250 mg/L is recommended for drinking water. Water in aquifers in the Sentinel Butte Formation is commonly much higher than this limit. Concerns with respect to the quality of water in the cast overburden and in the natural overburden or lignite aquifer near the cast overburden should probably focus on SO_4^{2-} as one of the main constituents that may cause degradation of the groundwater quality during the post-mining period.

The cast overburden in the areas of reclaimed land will at least initially contain considerable gaseous oxygen because large amounts of air will be trapped in the void space that inevitably is present in cast overburden. The initial porosity of the cast overburden is normally about 30 percent. In the zone above the water table, much of this void space will have air; the rest will be water. The water will contain dissolved oxygen which at least initially will be at or near saturation levels ($\approx$ 10 mg/L of dissolved O_2). It is appropriate that concern with regard to post-mining groundwater quality focus on the potential for the oxygen in the entrapped air and in the water to cause degradation of water quality. From the interpretive framework that we have developed to account for the chemistry of natural groundwater, it is reasonable to expect that there is considerable probability that much of the entrapped and dissolved oxygen in the cast overburden will be consumed by the process of pyrite oxidation. The important question in this regard is whether or not this process could cause a significant degradation in groundwater quality.

At this time the answer to this question is not known because the necessary laboratory experiments have not yet been done and because of the lack of adequate field measurements from areas of reclaimed land. Research on these topics are in progress (see sec. 4.6). To indicate the potential groundwater quality degradation, however, some illustrative calculations are useful. For this purpose we will consider cast overburden with a porosity of 33 percent and a water saturation of 33 percent. For this condition each 1 000 cm^3 (1 L) volume of air in the cast overburden would be contained with a bulk mass of cast overburden of 3 000 cm^3. This bulk volume of cast overburden would contain 2 000 cm^3 of solid material and 330 cm^3 of water. The water, initially saturated with dissolved O_2, would contain 0.3 mmol/L of O_2. The air would contain 60 mmol/L of O_2 in the void space contained within the bulk volume of cast overburden in which 330 cm^3 of water occurs. This is the equivalent of 180 mmol per litre of pore water. It is evident that the initial amount of dissolved oxygen in the pore water is negligible relative to the oxygen in the air in the pore space.

The occurrence of pyrite, even in extremely small amounts, in the cast overburden could result in consumption of dissolved oxygen by pyrite dissolution. As the dissolved oxygen in the pore water is consumed, oxygen from the air in the pore space will enter the water, thereby enabling the oxidation process to proceed. In the extreme case all of the oxygen in the pore space would be consumed. From the reaction, $4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 16H^+ + 8SO_4^{2-}$ it is apparent that consumption of 180 m moles per litre of pore water would produce 96 mmol/L (9 200 mg/L) of SO_4^{2-} as a reaction product in the water. In the absence of minerals (calcite or dolomite) to cause neutralization, the pH would drop to about 1. In the presence of calcite or dolomite, Ca, Mg, and HCO_3^- concentrations would rise to relatively high levels. The pore water in the cast overburden would have very poor quality. If infiltration causes the pore water to move downward to the water table, the quality of the groundwater could be seriously degraded.

The amount of pyrite necessary to produce by oxidation adverse water quality is very small. In the example described above, consumption of the 180 m moles per litre of pore water would only require that the solid material in the cast overburden contain about 0.1 percent by weight pyrite. Likewise, neutralization of the acid produced in the oxidation process would only require that the solid materials contain a small fraction of a percent by weight calcite or dolomite. The development of strongly acidic groundwater in mining areas of western North Dakota is an unlikely eventuality because calcite and dolomite are common mineral components of overburden. The development of waters with adverse SO_4^{2-} contents, however, is a possibility that should not be disregarded. The oxidation process may proceed slowly. The adverse effects may take many years or many decades to influence the quality of groundwater over appreciable areas.

We have indicated that pyrite oxidation is the major mechanism of SO_4^{2-} generation under natural (pre mining) conditions in the overburden. Extreme levels of SO_4^{2-} in the shallow groundwater are rarely observed, however. This is probably due to the fact that oxygen which enters the surface soil from the atmosphere is to a large extent consumed by oxidation of organic matter and to a lesser extent by oxidation of pyrite. The surface soil (i.e., the topsoil and the organic-rich subsoil with the main root zone) is a zone of production of large amounts of readily oxidizable organic matter. In comparison, the cast overburden formed of the geologic materials below the surface soil generally has only small amounts of organic matter. Consumption of most of the entrapped oxygen by pyrite oxidation rather than organic matter oxidation is therefore an anticipated eventuality.

5 APPLIED GEOLOGY IN THE BEULAH-HAZEN AREA

5.1 Purpose and Scope

Due to increased lignite development and the concomitant construction of new coal gasification and electric generation plants in the area, the towns of Beulah and Hazen are expected to expand at a rapid rate. New subdivisions are already appearing, and at the time of this report both towns have or are seeking to increase and improve their school systems, water supplies, and sewage disposal facilities. Future projections for expansion vary from two- to tenfold (Soil Conservation Service, 1977). The purpose of this study is to provide geologic data that can be useful in aiding both state and municipal authorities, as well as individual landowners in further planning for the expansion and development that will be concurrent with the influx of workers and their families into the area.

Rapid expansion of population and industry will increase the competition for available land. This will require more stringent controls and regulations to prevent uncontrolled building in areas with unstable conditions or subject to periodic flooding, to insure proper disposal of increasing amounts and varieties of waste products, and to avoid destruction and impairment of some of the aesthetic features of the landscape (Hackett and McComas, 1969). Long term and careful planning can largely avert potential conflicts. Decisions arrived at in land-use planning can only reflect the amount and scope of information available. Geologic information in this report, combined with other pertinent information, will give a more complete picture to the decision-maker.

The detailed geologic study of the Beulah-Hazen area involved mapping the near surface as well as the surficial materials of a 90-square-mile (230-sq-km), rectangular area circumscribing the two towns (fig. 5.1-1). A detailed map (pl. 5), four cross sections of the area, two east-west and two north-south (pls. 18, 19, 20, and 21) and four land-use suitability maps were constructed (pls. 34, 35, 36, and 37). The surficial and near surface materials map was constructed at a scale of 1:24,000, the largest scale thought practical for showing the available geologic information. The suitability maps were compiled at a scale of 1:63,000 (approx. 1 in=1 mi). The maps should not be enlarged to a scale greater than that in which they were compiled or a false sense of accuracy will result.

5.2 Study Methodology

Field work was done during the summers of 1976 and 1977, being completed in early June of 1977. Initially, the surficial geology was mapped using both soil maps and aerial photographs. Preliminary copies of soil maps and accompanying explanations as compiled by the Soil Conservation Service were available. Aerial photo coverage for the entire area was available at a scale of 1:20,000. Soil units were combined into geologically meaningful units and mapped on 7.5-minute quadrangles which had contour intervals of 10-20 feet. Contacts were then checked in the field by travelling all roads and trails and examining all good exposures, stream cuts, railroad cuts, roadcuts, and many mine sink holes. Geologic maps by Benson (1952), at a scale of 1:63,000, and Carlson (1973), at a scale of 1:126,000, were also helpful.

Mapping of the near surface materials

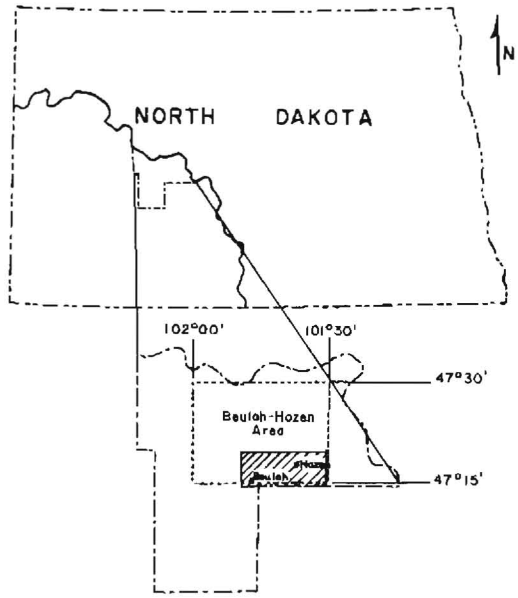


Figure 5.1-1. Location of the Beulah-Hazen detailed study area.

was accomplished by extensive drilling utilizing the North Dakota Geological Survey's truck-mounted 8-inch (20 cm) diameter, continuous flight power auger. Logged descriptions of 167 boreholes are included in the appendix A. Locations of the boreholes and cross sections are shown on plate 33. Additional subsurface data was also obtained from Croft (1970); from lignite evaluation rotary drilling under the supervision of the U.S. Geological Survey (1975-76); rotary drilling by REAP (1976), and from other sources. Auger drilling in this study was done at half-mile intervals where necessary and feasible. In those areas where topography was rugged, adequate exposures were available and extensive drilling was generally unnecessary. Subsurface information is less extensive in a few locations where permission to drill was not granted by the landowner.

An attempt was made in preparing the surface and near surface materials map to represent lithology to a depth of 9 metres (30 ft). This seemed to be an appropriate depth for most engineering concerns in the area. Many holes greater than 15 metres (50 ft) were drilled in the uplands to give better understanding of the lateral variations in lithologies of the bedrock and a more complete picture of the geological history of the region.

Upon completion of the surface and near surface materials map and cross sections, the materials units were evaluated in terms of their engineering properties. The results were used in preparation of various land-use maps including a hazard map and three suitability maps for sanitary landfill, septic tank system, and general construction.

5.3 Surface and Near Surface Materials Map

The surface and near surface materials map is designed to show a maximum of three material units and their relative depths and thicknesses to a depth of 9 metres (30 ft). Each unit was assigned a letter designation. The thickness of the surficial unit in metres is indicated by the number 2, 3, or 9, which follows the first letter designation, that is, the surficial unit, and represents a maximum thickness of 2, 3, and 9 metres (7, 10, and 30 ft), respectively. Units less than 0.5 metres (1.6 ft) in thickness were not mapped. The following serves to illustrate this system:

Symbol	Explanation
A	Minimum of 9 metres of unit A
A_{3B}	Maximum of 3 metres of unit A overlying unit B
A_{9B}	Maximum of 9 metres of unit A overlying unit B
A_{3BC}	Maximum of 3 metres of unit A overlying unit B, unit C at a maximum depth of 9 metres
A_{9BC}	Maximum of 9 metres of unit A overlying unit B, unit C at a maximum depth of 9 metres

In cases where four or more materials occurred within 9 metres (30 ft) of the surface, those considered more important, typically, the thicker units, were chosen for representation. Some generalization was necessary. For these reasons, data from nearby boreholes should be consulted in conjunction with the materials map. Contacts shown by a solid line should be given an error factor of ±30 metres (100 ft), and those shown by a dashed line should be given an error factor of ±60 metres (200 ft). The lithologic and inferred engineering properties of each map unit are discussed below. Engineering information was derived from Arndt and Moran, 1974; Flawn, 1970; Gross, 1970; the Soil Conservation Service, 1977; and Terzaghi and Peck, 1967. For lithostratigraphic, morphogenetic, and lithogenetic descriptions of these materials, see comparable units in plate 5.

5.3.1 Unit A

Unit A consists of silty clay and clay, organic to highly organic. This unit was only mapped at the surface, generally within flood plains, and in a few areas in gully bottoms on residual uplands. In the subsurface, silty clay and clay was included in unit B.

Unit A is generally characterized by low bearing capacity, high compressibility, high to very high shrink-swell properties, high water content, liquid limit and plasticity index and low permeability. In most cases it is poorly drained and subject to periodic flooding.

5.3.2 Unit B

Unit B consists of sandy silt and clay, often organic near the surface, with lenses of fine silty sand and clay, the latter occasionally being very organic. This unit contains occasional pebbles and pebble-rich lenses, generally of lignite, scoria, and iron concretion fragments. At the surface it is found over much of the flood plains, and in swales on uplands. In the subsurface it includes some material in buried valleys beneath or within pebble loam. Unit B is generally characterized by moderate to low bearing capacity, moderate to high compressibility, moderate shrink-swell properties, and some potential for frost heave. The water table is usually below 3 metres (10 ft), but in many areas it is subject to periodic flooding. Unit B is characterized by low to moderate permeability and gentle to moderate slopes. Quick conditions may develop when sand lenses under pressure are exposed in deeper excavations, while foundation problems may result from differential compaction of clay lenses at depth.

5.3.3 Unit C

Unit C consists of slightly sandy and clayey, unbedded silt. It was mapped only at the surface, with an estimated maximum thickness of 2 metres (7 ft). Unit C occurs as a thin veneer over much of the uplands over a variety of materials, often being reworked and mixed with the sediment below.

This unit is characterized by low to moderate bearing capacity, low to moderate compressibility, and high shrink-swell properties. Silt is particularly susceptible to frost heave as it is capable of lifting the greatest amount of water in the shortest time by capillary action to the freezing zone (Peck, Hansen, and Thornburn, 1974, p. 50). Unit C is characterized by a low water table and gentle to moderate slopes.

5.3.4 Unit D

Unit D consists of sand, very fine to medium-grained, very well-sorted, loose, some coarse grains in places; generally silty and fine-grained where shallow over more consolidated material. This unit was mapped only at the surface, but reaches thicknesses over 9 metres (30 ft) in dune areas. It also occurs locally on the Knife River flood plain where scroll bars have been reworked by the wind and commonly grades into unit E both vertically and laterally.

The bearing capacity of unit D is relatively low without compaction. The water table is generally low, but may be high in places where the sand is thin or clayey. The unit has generally good internal drainage, high permeability and is characterized by gentle to steep, unstable slopes.

5.3.5 Unit E

Unit E consists of sand and silty sand, fine- to coarse-grained, well-sorted, with lenses of clay and gravel. This unit is quite extensive, but is often covered on the flood plains and lower terraces by unit B, and covered on the higher terraces by unit D, the latter being derived from unit E. It is the predominant unit in the top 9 metres (30 ft) of the Knife River flood plain and the terraces to the south of the river. It is found on the uplands at the surface generally as reworked bedrock sand, and in the subsurface beneath or within pebble loam or as fill in glacial meltwater trenches.

Unit E is characterized by a relatively high bearing capacity, low compressibility and a low water table except where the unit is clayey. It is further characterized by good internal drainage above the water table, high permeability, and gentle to moderately steep slopes at the edges of terraces. Clay lenses at depth may cause foundation problems due to differential compaction.

5.3.6 Unit F

Unit F consists of silty, sandy, pebbly, bouldery clay (pebble loam), with gravel, sand, silt, and clay lenses. It is draped over bedrock on much of the uplands. Unit F is generally from 2-6 metres (7-20 ft) thick except in buried valleys and glacial meltwater trenches where it is typically over 9 metres (30 ft) in thickness and often overlies units B and E. It is often underlain by a metre or more of reworked bedrock, both sand and clay. Unit F is characterized by high bearing capacity, low to moderate compressibility, low water table, and poor internal drainage. It typically has low permeability except in areas where the unit is consistently drained and dry, causing cracks to form which increase the permeability. The unit is susceptible to shrink-swell and frost heave. In some places the upper metre resembles unit B, but becomes hard and dense below. Boulders at the surface and within the unit may cause workability problems. Slopes range from gentle on the broad uplands to the south of Hazen to moderate to very steep on the uplands in the rest of the study area.

5.3.7 Unit G

Unit G consists of sand and gravel, silty, moderately poor to poorly sorted. The unit is cobbly in many places, especially where it overlies units E and F. Sand and gravel in the subsurface occurs as lenses in pebble loam (unit F) and as fill in the glacial meltwater channels and in the Knife River valley. Gravel on upper terraces is patchy and less than 2 metres (7 ft) thick. On the lower terraces bordering the meltwater channels and the river valley, sand and gravel deposits reach thicknesses of 5 metres (16 ft) and more. The gravel is, mostly, rather poor quality, as gravel from deposits near the Missouri River must be brought in for use as concrete aggregate. An asphalt mixing operation has been set up about three miles north of Beulah, using gravel deposits in the Beulah trench.

This unit is characterized by high bearing capacity, low compressibility, generally low water table, good internal drainage, and high permeability. It is found on gentle to steep slopes.

5.3.8 Unit H

Unit H consists of silt, coarse-grained, to very fine grained sand, very well-sorted and uniform in appearance, interbedded with silty clay and fine silty sand, with carbonaceous layers and occasional lenses of detrital lignite and scoria fragments. This unit occurs only on the flanks or within the fill of meltwater channels and the Knife River valley. The unit is well exposed in the Zap branch of the Beulah trench, north of Beulah. It is also present in the Hazen branch and is in the subsurface near Beulah and in the northern part of the broad terrace to the east of Hazen, as well as in the deeper valley fills.

Unit H is characterized by low to moderate bearing capacity, moderate compressibility, low water table, and moderate to high permeability. It is susceptible to frost heave and shrink-swell. It is characterized by gentle to moderate slopes, often covered with pebble loam and sand or gravel.

5.3.9 Unit I

Unit I is scoria which consists of baked clay, silt, and sand of unit J, and baked pebble loam of unit F. It is a common unit in the uplands north and northeast of Beulah and west of Hazen. It typically occurs on steep to very steep slopes of gullies. Scoria is also found on gentle to moderate slopes where it is overlain by about a metre of loamy material. In such settings it is differentiated by the symbol I_1. All significant scoria deposits in the study area resulted from the burning of the thick Beulah-Zap lignite bed, and thus always overlie unit J.

The bearing capacity of unit I can be expected to be high and compressibility low. The water table is low and permeability is quite high due to extensive fracturing of the baked material. Workability may be a problem. Scoria is a source for road subbase and surfacing of roads with low traffic load.

5.3.10 Unit J

Unit J consists of partially consolidated and consolidated sand, silt, and clay. This unit was differentiated in surface exposures into a fine-grained subunit (J_f) and a coarse-grained subunit (J_c). It was considered as a single combined unit in the subsurface (J). The subunits tend to interbed and grade into each other. For this reason it was not possible to differentiate them in the subsurface. All other units overlie unit I to a greater or lesser extent throughout the area. Widespread exposures of unit J occur in the western half of the study area. It is also exposed to the north of Hazen, predominantly in the more rugged areas along gully sides and steep divides.

At the surface J_f consists of partially consolidated silt, silty clay, and clay with lignite and carbonaceous beds and minor limestone and iron concretions. Bearing capacity should be fairly high, compressibility and shrink-swell characteristics moderately low to low, water table low, and permeability low. In many areas, clayey residual soils overlying the more consolidated materials are characterized by low bearing capacity, high compressibility, moderate to high shrink-swell tendencies, and susceptibility to frost heave. Workability may be a problem.

J_c consists of sandstone and locally consolidated sand, silty sand, and sandy silt. The sand is very fine to medium-grained. This subunit also contains some lignite and carbonaceous beds, and iron concretions. It is characterized by high bearing capacity, low compressibility, low water table, high permeability at the surface, and moderately low permeability below about one metre. Workability may prove difficult at depth.

5.4 Applications to Land-Use Planning

5.4.1 Geologic Hazards

Geologic hazards in the study area are shown in plate 34. These include areas of mine sink hole subsidence, unstable slopes, and drifting sand, as well as those areas which are susceptible to flooding.

The rather unique mine sink hole subsidence area lies about 1.5 miles (2 km) north and northeast of Beulah. The sink holes have resulted from the collapse of overlying materials into underground lignite mines. Collapse apparently began almost immediately after termination of mining, and has continued to the present, thus, creating a considerable hazard to any kind of construction. Steep to vertical slopes around the holes represent a hazard to stock grazing, although much of the sink hole area is being used for pasture.

Flooding presents the most widespread and serious hazard in the Beulah-Hazen area. The area designated as an area of potential flooding on plate 34 reflects the 100-year flood frequency level as derived from aerial photos (Soil Conservation

Service, 1977). The 100-year flood level encloses all the area designated as "2" on plate 34 and implies that this entire area will be inundated once every 100 years. Most flooding in the region occurs in the spring of the year as a result of a combination of rapid snowmelt and frozen soil conditions, as well as ice jams in the river.

Flooding also occurs following torrential thunderstorms in the summer. In Beulah, water from heavy downpours is funneled down small tributaries of the Knife River, which are located on the east and west sides of the town, occasionally causing extensive flooding. In Hazen, a major flooding problem occurs when water flows toward the town, from the northwest, down Antelope Creek and a smaller tributary. At present, a levee, built in conjunction with a bypass of State Highway 200 north of Hazen, is being considered as a means of controlling this particular situation.

Pressure to build within the 100-year flood frequency level will probably become greater as development continues. This development should be closely regulated to avoid such problems as have developed at Minot, North Dakota, and other expanding communities. For further discussion of flooding hazards see Harrison (1968) and Soil Conservation Service (1977).

A third type of hazard delineated on the map was slumping and sliding, or mass movement. Mass movement is caused by gravity, and the nature of the movement is controlled by the earth materials involved, friction, and the slope over which the mass is moving. This hazard is present in areas of steep slopes, which includes strip-mine spoil piles and highwalls, as well as cut banks along streams. Principal triggering events in Mercer County include heavy rains or large amounts of meltwater that reduce internal friction of the materials, unloading or undercutting of stable slopes by natural erosion such as by streams or springs, and by alteration of natural slopes through the actions of man (Flawn, 1970).

Except for a few residences and sections of road that are lying near advancing cut banks of the Knife River and Spring Creek, no direct hazards due to slumping and sliding exist in the study area. Some of these areas were not mapped as areas of slumping and sliding as they also were within the 100-year flood level. In several places along the Knife River and Spring Creek, attempts are being made to impede erosion by lining the bank with riprap and junk cars. Otter, Brady, and Kinneman Creeks all show the scars of slumping and sliding along their steep banks where the slope has been undercut. Smaller scale soil creep is also evident along these streams. Mass movement also occurs along steep slopes having springs at their bases, which serve to unload the toe of the slope.

The fourth and probably least significant hazard considered was that of blowing and drifting sand. The major area where this is of concern is to the east and southeast of Hazen. In this area, sand, originally reworked during an arid period approximately 3 000-4 000 years ago, has been deposited in longitudinal dunes. Local relief in the dune areas reaches 15 metres (50 ft). Most of the area has been more or less stabilized by vegetation, although some areas experience blowouts and drifting sand, particularly in the eastern part of sec 24, T144N, R86W, where overgrazing has removed the vegetation. Brush, rotten hay, manure, and similar materials are used to impede the progress of drifting sand and help establish vegetation.

Most of the area of dunes is used for pasture and, given proper grazing practices, should remain stable. Attempts have been made to further develop land to the east of Hazen along State Highway 200. Should this development continue to expand south of the highway, in the form of new trailer courts or subdivisions, care must be taken to insure that the natural cover is not disturbed to such an extent that blowing sand becomes a problem. This danger could become severe given a change in the climate such as occurred in the 1930s.

5.4.2 Suitability Maps

Three interpretive maps describing suitability for sanitary landfills, septic systems, and general construction were compiled (pls. 35, 36, and 37). These were constructed using a color coding system first developed by Quay (1966) for presenting information about soils, and applied to environmental geology by Gross (1970). The system borrows from the traffic stoplight, where green indicates favorable conditions; yellow, caution; and red, unfavorable conditions. In this study the colors are represented by the letters G, Y, and R, respectively; whereas, the numbers 1 and 2 affixed to the letters refer to different shades of the basic colors, or different kinds of limitations within the main color group. For example, a G^1 (green-one) rating indicates an area with the fewest limitations, while R^2 (red-two) indicates an area with the most limitations. Each interpretive map (pls. 35, 36, and 37) has a corresponding explanation which briefly discusses each rating and shows how the color scheme can be applied.

5.4.2.1 Sanitary landfills

The sanitary landfill is defined by the American Society of Civil Engineers (1959) as:

> "A method of disposing of refuse on land without creating nuisance or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary."

The landfill is considered sanitary if it serves to contain and isolate fill material and prevent the contamination of surface and subsurface water. Water that comes into contact with decomposing wastes in a landfill becomes highly mineralized due to the leaching of soluble constituents in the refuse. Surface seepage of this polluted water, or leachate, may also contaminate surface water and produce undesirable odors. The production of leachate may be prevented or at least curtailed by keeping the waste as dry as possible. Locating the base of the landfill well above the water table and covering the fill with a well compacted, low-permeability material helps to prevent precipitation infiltration and saturation by subsurface water (Arndt and Moran, 1974). The cover material also acts to prevent gas and fluids produced by chemical and biological action from escaping into the atmosphere and surface water or subsurface water. In addition, it prevents insects, rodents, and other animals from continued access to the wastes (Flawn, 1970).

Locating the disposal site in materials having low permeability restricts the movement of leachate. Fine-grained materials such as clay, silt, and pebble loam, or till, retard the movement of contaminants, thereby allowing for bacterial or chemical adsorption and filtration.

Topography is also an important factor in selecting disposal sites. Steep slopes should be avoided because of the increased groundwater flow gradient and possible slope instability. Moderate slopes, however, would be acceptable as infiltration rates are less than those in more flat lying areas. Groundwater recharge areas, generally in the uplands, should be well above the water table and occur in relatively impermeable materials to insure proper retardation and filtration of leachate which naturally moves downward with the groundwater gradient toward underlying aquifers. Discharge areas, although by their nature retain the leachate and prevent it from reaching underlying aquifers, present a problem of surface pollution as they usually occur near a body of surface water such as a pond or stream (Groenewold, 1974). Areas of potential flooding should be avoided, including the bottoms and heads of gullies which may be well above the water table, to prevent the flushing of contaminants away from the site and into nearby surface water.

The Beulah-Hazen area is characterized by a semi-arid climate with long, cold winters. Due to the limited amounts of precipitation, leaching of fills is slight. A proper cover material prevents rain from entering and reacting with the waste material. The use of cover materials having extreme shrink-swell characteristics should be avoided. Cool temperatures tend to inhibit chemical reactions within the landfill. Although this tends to increase the amount of time needed for stabilization, it also prevents large amounts of leachate from being generated at any particular time. The landfill site should be easy to excavate and compact in both wet and very cold weather, as the landfill will probably be in use year around.

Lignite strip mines and underground mine sink holes should be avoided as disposal sites unless contamination of surface water or access to a potential lignite aquifer can be prevented. The site of the present landfill north of Beulah as well as the active lignite strip mines immediately to the south of Beulah are generally above the local water table and appear to be acceptable sites. The area of sand dunes east of Hazen is not suitable for landfills due to the highly permeable nature of the materials and locally high water table. All flood plains should be avoided. Old gravel pits are generally poor sites due to the highly permeable nature of the surrounding materials. Areas rated either Y1 or Y2 are suitable for disposal sites, provided proper investigation and development of the site is accomplished. For further information concerning the siting and design of sanitary landfills, see Hughes (1972).

5.4.2.2 Septic tank systems

Septic tank disposal systems consist of an enclosed holding tank and a drain tile field. The tank receives the liquid wastes and allows solids to settle to the bottom, or to be liquefied by anaerobic micro-organisms. The micro-organisms help to neutralize harmful contaminants, within the tank, and condition the effluent for easy percolation into the soil by causing colloidal and dissolved organics to degrade into simpler organic compounds. The drainage tile field filters solids and allows fluids to escape by seepage through open joints or perforation (Clark and Lutzen, 1971).

The principal factors in assessing the suitability of an area for septic disposal systems is the permeability of the materials and depth to the water table. Low permeabilities, as in clayey materials, prevent proper filtration and lead to the clogging of the drain tiles. If the permeability is too high, filtration will be rapid and effluent will not be properly neutralized in the septic tank. Septic systems in areas of high water table pose a potential threat to groundwater quality. A high water table will also prevent proper movement of the effluent through the system.

Topography is also an important consideration in the placement of septic systems. When slopes exceed 20 percent, it is probable that effluent will surface downhill from the system, regardless of depth of burial (Franks, 1972). Filter fields should be placed such that surface runoff flows away from rather than into them. Areas which are susceptible to flooding should be avoided as the filter fields will clog, sometimes permanently. Systems should not be located close to roadcuts or other construction cuts, nor to any surface water or wells. The presence of boulders or hard bedrock gives rise to workability problems in the installation of the system.

The septic tank and drainage filter field were developed primarily for rural areas. If this type of disposal system is to be employed in more concentrated conditions, careful consideration of the earth materials and water position must be carried out to insure proper design and location of the septic tank system. Otherwise, ultimate failure may result if filtration capacity is exceeded by too many disposal systems. A sewage collector system ending either in a lagoon or mechanical treatment plant could replace a faulty septic tank system, but it would be much more economical to design and install adequate sewage systems before rather than after development (Clark and Lutzen, 1971).

Many suitable sites for septic tank systems are available in the Beulah-Hazen area (pl. 36), provided that areas prone to flooding and areas of steep slopes are avoided. Proper spacing and design of the systems are essential, especially in areas of permeable sands and gravels.

5.4.2.3 Sewage lagoons

Sewage lagoons are shallow, flat-bottomed ponds built to hold sewage within a depth of 0.6-1.5 metres (2-5 ft). The purpose of the lagoon is to allow bacterial action to decompose the solids while the water is evaporated. Thus, it is important that the lagoon either be located in low permeability materials or have an impermeable liner to prevent leakage of the sewage into the groundwater system or surface waters. High water tables are undesirable due to the increased probability of groundwater contamination. Areas susceptible to flooding should be avoided as sewage could be flushed into surface water systems during periods of flooding. Presence of considerable organic matter in materials upon which a lagoon is built could modify the desired biological action within it. Sewage lagoons should be located in areas of low relief, for ease of construction and to avoid high groundwater drainage gradients which could cause leakage (Arndt and Moran, 1974). Prevailing winds should be taken into account in the siting of the sewage lagoon to prevent unpleasant odors from entering the community it serves.

A suitability map was not compiled for sewage lagoons. Generally, those areas rated as favorable for sanitary landfills are also favorable for sewage lagoons, given a proper slope.

The disposal ponds for the town of Beulah are located to the southeast of town on the Knife River flood plain. The ponds have clay liners designed to prevent movement of effluent away from the site. They are also built above the 100-year flood level. Problems of leakage and an expanding population, however, are necessitating consideration of alternative sites to either augment or replace the present location. Potential sites to the north and west are not feasible due to rugged terrain, flood hazard, or prevailing wind conditions. Areas to the east in secs 29 and 30, T144N, R87W, seem to be the most suitable. However, borehole data indicates that permeable material is close to the surface in that area which, along with the flooding hazard, would require special engineering precautions to prevent surface and subsurface water pollution. A suitable site might also be developed south of the rodeo grounds in sec 36, T144N, R88W, but sand at the surface could prove to be problematic.

Disposal ponds for the town of Hazen are located to the northeast of town. Except for occasional unpleasant downwind odors this is an adequate site for sewage retention, and is presently being expanded to meet increasing demands. Soil and borehole data (HB-109) indicate that the lagoon is located on thick deposits of relatively impermeable materials. The disposal ponds had to be built up to lie above the 100 year flood level. No other location near Hazen would be as suitable for a sewage lagoon due to either flooding hazards or prevailing wind problems.

5.4.2.4 General construction

General construction refers to residential and small commercial structures, road building, and other projects of similar size. Construction conditions within the study area were coded as shown in plate 37. All engineering interpretations were based on the known characteristics of earth materials similar to those found in the study area. Laboratory tests were not run on any of the samples collected during this study. For this reason, plate 37 should be used only as a general indicator of site suitability. A competent foundation engineer should be engaged to evaluate specific construction sites and insure proper design.

The engineering properties of the materials, water conditions, and the character of the slope were considered in evaluating the construction conditions within the study area. Engineering properties considered included bearing capacity, compressibility, compaction, shrink-swell characteristics, potential for frost heave, workability, and sidewall stability. Water conditions considered included position water table, internal drainage, and flooding potential. Slopes, except where adjacent to areas undergoing active erosion, are generally stable. Steep slopes often need to be altered, especially for high-density construction, which not only increases the cost of development, but may reduce the stability of the slope. Much basic material pertaining to engineering properties of the earth materials was derived from Soil Conservation Service, 1977; as well as Arndt and Moran, 1974; Flawn, 1970; Gross, 1970; and Terzaghi and Peck, 1967.

Development in Beulah is presently predominantly to the north and northeast, where there are good foundation conditions and no danger of flooding. Further construction on the flood plain would be ill-advised as many areas are susceptible to flooding. Gravel deposits to the west of Beulah should be utilized prior to construction in order to make the most efficient use of the land.

The areas to the north and northwest of Hazen are best suited for construction due mainly to the flooding hazard in other directions. The danger of flash flooding from gullies to the north of town should be considered in planning the area's development. Settlement problems have developed with some of the larger buildings in southeast Hazen as evidenced by cracks in the walls and foundations. City water well logs show 5-9 metres (16-30 ft) of organic clay within 1-2 metres (3-7 ft) of the surface. This material is probably responsible for the differential settlement of the buildings. This problem serves to illustrate the need for proper site investigation and foundation design, especially in areas of such variability as a flood plain.

6 RECOMMENDATIONS FOR ADDITIONAL STUDY

This project has demonstrated the need for additional research in several areas of geologic, geohydrologic, and geochemical interest. An improved definition of the physical and chemical hydrological characteristics of several potentially significant aquifers in both bedrock and Quaternary materials is needed. Of stratigraphic significance is a need for a determination of the subsurface characteristics of the Bullion Creek-Sentinel Butte contact. Correlation of the various lignite beds in the Knife River basin, as defined in this project, with lignite beds in the southwestern part of the state is also needed. Another important area requiring additional study is within the realm of rock-water relationships and is essential to proper surface-mine reclamation design. Additional study is also needed to determine the long-term effects of groundwater withdrawals from deeper aquifers, particularly the Fox Hills-Hell Creek aquifer.

6.1 Determination of the Characteristics of Potentially Significant Aquifers

Three potentially significant aquifers require additional definition and study. These include two regionally significant zones--the Upper Hell Creek-Cannonball zone and the Lower Bullion Creek zone and a potentially significant local aquifer--the Renner Trench in northern Mercer County. The need for alternative water supplies due to the potential effects of surface mining on certain shallow aquifers and the increased demand for water due to population growth requires that all aquifers be evaluated in detail. A very limited amount of data is available for the Upper Hell Creek-Cannonball and Lower Bullion Creek zones (see secs. 4.7.2 and 4.7.3). Neither is as laterally continuous nor as thick as the underlying Fox Hills aquifer. However, elevated fluoride concentrations in the Fox Hills and the shallower depths may increase the desirability of obtaining water from these units.

The Renner Trench, as first defined by this study, is potentially a significant aquifer. At present, virtually no information is available on the geohydrologic and stratigraphic characteristics of the materials in the Renner Trench. Its location, in the center of the most active area of lignite-related development, emphasizes the necessity for a detailed study of the characteristics of this aquifer.

6.2 Regional Subsurface Correlation of the Sentinel Butte and Bullion Creek Formations

Regional correlation of the lignite beds and associated intervals in the Bullion Creek and Sentinel Butte Formations as defined by this study in the Knife River basin, with similar units in southwestern North Dakota, is presently not possible on more than a tentative basis. This is largely the result of insufficient detailed subsurface stratigraphic data in southern Dunn and northern Stark Counties. Additional test drilling in those areas will be necessary for such correlation to be accomplished. Regional correlation of the various lignites is a prerequisite to a realistic evaluation of the state's lignite resources.

In conjunction, a critical evaluation of the regional significance of the criteria used in this study to identify the Sentinel Butte-Bullion Creek contact is needed (sec. 2.2.2.7). A great deal of confusion and disagreement exists as to the position of this contact in the subsurface. Widely scattered test drilling and associated geophysical logging and detailed sample description in areas adjacent to exposures of the contact are required for such an evaluation to be meaningful. Particularly significant is an evaluation of the usefulness of subtle color differences, as determined with a Munsell chart, for distinguishing the contact in the subsurface.

6.3 Rock-Water Interactions and Reclamation Design

At the present time it is possible to make fairly detailed determinations of the stratigraphy, general hydrology, and hydrochemistry of premining landscapes in western North Dakota. The geochemical model for the evolution of groundwater in shallow Tertiary sediments was discussed in some detail in section 4.10. Of major concern, however, is the evolution of groundwater in post-mining landscapes. This was discussed in sections 4.6 and 4.10.5.

A key element in the prediction of post-mining groundwater characteristics, and one which has not been addressed, is an understanding of the long-term reactions that occur between subsurface water and the various geologic materials. A detailed evaluation of the mineralogy of the materials together with an understanding of the reactions and the various geochemical environments in which they operate is needed.

Tests must be developed which will allow for the identification of very small quantities of pyrite and carbonate minerals. Existing laboratory methodology is inadequate for evaluating either of these. Detailed studies of the clay mineralogy and cation exchange capacity of the materials are also needed. In addition, a determination of the role played by oxygen trapped within spoil materials must be made. Only then will we have a truly predictive, and therefore design, capability with regard to post-mining groundwater chemistry.

6.4 Effects of Groundwater Withdrawals upon Deeper Aquifers

Mining of lignite in western North Dakota over the next several decades can be expected to cause disruption and degradation of near-surface groundwater supplies in and adjacent to the mining areas. As previously discussed, near-surface groundwater sources, particularly fractured lignites, are presently extensively utilized for domestic, stock, and municipal purposes. In some areas alternate water supplies will be required.

Increased population associated with accelerated lignite development will also continue to place increasing stress upon existing municipal water systems. Often, additional or alternate sources of water will be needed. In most areas of active or proposed lignite development the only alternate high quality, high yield water sources are the Fox Hills-Hell Creek and Cannonball-Ludlow aquifers. At the present time numerous wells exist in these aquifers. Yearly head declines are occurring in many of these wells. An evaluation of the effects of increased development of these aquifers is needed. Head measurements from wells in the deep aquifers should be compared with past data from these wells. Effects of increased utilization of the deep aquifers could then be evaluated in terms of expected future demands and decisions made as to the proper utilization of these aquifers.

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APPENDIX A

STRATIGRAPHIC DATA

APPENDIX A-I

DESCRIPTIVE LOGS OF AUGER TEST HOLES--

BEULAH-HAZEN DETAILED STUDY AREA

All depths in feet--divide by 3.28 to convert to metres.

APPENDIX A-I
DESCRIPTIVE LOGS OF AUGER TEST HOLES--
BEULAH-HAZEN DETAILED STUDY AREA

Depth (ft.)	Lithologic Description
HB-1	
NENESE Sec 33, T144N, R86W	
Elev. 1 978	
0 - 2	Loam.
2 - 6	Pebble loam, sandy, clayey, lignitic, light-olive-brown.
6 -12	Sand, fine-grained, silty, clayey carbonaceous, light-olive-brown; poorly sorted.
12 -15	Sand, fine-grained, clayey, clay laminae, light-brown; iron concretions.
15 -20	Sand, fine-grained, silty, light-brown to brown; iron concretions.
20 -25	Sand, fine-grained, clayey, brown.
25 -30	Sand, fine-grained, silty, clayey, to silt, sandy, brown to olive-brown; clay pebbles, iron concretions.
HB-2	
SESESE Sec 33, T144N, R86W	
Elev. 2 016	
0 - 2	Loam, sandy, dark-brown.
2 - 6	Pebble loam, very lignitic, olive-brown to olive-gray.
6 - 8.5	Clay, silty, gray to light-gray.
8.5- 9	Clay, silty, gray; organic-rich with thin black laminae.
9 -10	Sand, fine-grained, silty, brownish-gray; clay laminae.
10 -16	Sand, fine-grained, silty, olive-gray to brown; clay and lignitic laminae, small iron concretions, selenite crystals.
16 -30	Silt, clayey, sandy, olive-brown; some very fine silty sand.
HB-3	
SWSWSE Sec 33, T144N, R86W	
Elev. 1 948	
0 - 1	Loam, sandy, brown to dark-brown.
1 - 3	Pebble loam, clayey, sandy, dark-olive-brown.
3 - 7	Pebble loam, clayey, sandy, lignitic, olive-brown.
7 -35	Sand, very fine- to fine-grained, carbonaceous, light-brown to brownish-gray; compact, iron concretions, silty sand at about 25 feet.
HB-4	
SESWSW Sec 33, T144N, R86W	
Elev. 1 892	
0 - 1	Loam, fine-grained, sandy, dark-brown.
1 - 5	Sand, fine-grained, gravelly, brown; pebble and granule gravel, poorly sorted.
5 -13	Sand, fine- to coarse-grained, gravelly, brown; pebbles, granules, and cobbles, poorly sorted.
13 -15	Pebble loam, sandy, brown to dark-brown; very coarse textured.
15 -17	Pebble loam, sandy, clayey, lignitic, gray.
17 -22	Pebble loam, silty, clayey, gray.
22 -25	Clay, gray.
25 -30+	Lignite.
HB-5	
NENESE Sec 32, T144N, R86W	
Elev. 1 893	
0 - 5	Loam, fine-grained, sandy, dark-brown to brown.

Depth (ft.)	Lithologic Description
5 -12	Pebble loam, clayey, lignitic, iron-stained, olive-brown and gray; selenite crystals.
12 -17	Silt, sandy, iron-stained, olive-brown with gray streaks.
17 -21	Silt, sandy, olive-brown; numerous gray clay balls.
21 -25	Clay, gray and dark-gray.
25 -30	Silt and sand, very fine-grained, gray and dark-gray; very thinly-laminated.

HB-6
SWSWSE Sec 32, T144N, R86W
Elev. 1 922

0 -20	Pebble loam, silty, clayey, lignitic, olive-brown; slightly coarse in upper 5 feet.
20 -23	Pebble loam, clayey, dark-brown.
23 -25	Loam, silty, clayey, olive-gray; gray clay balls, dark-brown silt laminae; poor samples.
25 -30	Loam, silty, clayey, olive-gray to olive-brown, lignitic and scoriaceous, with clay balls and iron concretions.

HB-7
NWNWSW Sec 16, T144N, R86W
Elev. 1 780

0 - 4	Sand, silty, dark-brown.
4 -13	Sand, fine-grained, silty, brown, moderately sorted; silt to medium-grained sand; some coarse sand; rare pebbles.
13 -18	Sand, medium- to coarse-grained, reddish-brown, moderately sorted, lignitic and scoriaceous; a few large pebbles included.
18 -28	Sand, medium-grained, silty, dark-brown; moderately sorted; some coarse sand, scoria and lignite pebbles; pebbles increasing downward; sand becomes coarser downward.
28 -30	Pebble loam, clayey, lignitic, olive-brown.

HB-8
NENESW Sec 16, T144N, R86W
Elev. 1 784

0 - 2	Sand, silty, dark-brown.
2 - 8	Sand, fine- to medium-grained, brown to light-brown.
8 -11	Sand, coarse-grained, light-reddish-brown; moderately sorted; fine to coarse sand, lignitic and scoriaceous.
11 -15	Sand, coarse-grained, pebbly, reddish-brown; more poorly sorted than above; a few cobbles included; scoriaceous.
15 -17	Sand, medium- to coarse-grained, pebbly, dark-brown; scoriaceous.
17 -28	Sand, fine- to medium-grained, pebbly, orangish-brown; moderately well-sorted, lignitic and scoriaceous; brown from 19-24 feet.
28 -35	Sand, fine- to medium-grained, silty, brown; moderately sorted, a few pebbles and granules included.

HB-9
SESESW Sec 16, T144N, R86W
Elev. 1 805

0 - 2	Loam, fine-grained, sandy, dark-brown.
2 -12	Sand, very fine- to fine-grained, silty, brown and light-brown; some medium-grained sand.
12 -14	Clay, silty, iron-stained, brown and olive-brown; a little fine-grained sand.

Depth (ft.)	Lithologic Description
14 -30	Sand, fine-grained, silty, dark-brown to brown; a little medium-grained sand, lignitic and scoriaceous.

HB-10
SWSWSW Sec 16, T144N, R86W
Elev. 1 788

0 - 2	Loam, sandy, gray-brown.
2 -12	Sand, fine- to medium-grained, brown; some coarse-grained sand, lignitic and scoriaceous.
12 -15	Sand, medium-grained, dark-brown; moderately sorted, a few pebbles, lignitic and scoriaceous.
15 -17	Sand, fine- to medium-grained, silty, very dark-brown; some small pebbles.
17 -20	Sand, medium- to coarse-grained, dark-brown; moderately sorted, lignitic and scoriaceous.
20 -21	Sand, medium- to coarse-grained, pebbly, dark-brown and brown.
21 -22	Silt, sandy, olive-gray.
22 -24	Sand, medium-grained, dark-yellow-brown; some coarse sand, lignitic and scoriaceous.
24 -28	Sand, medium-grained, dark-brown; some coarse sand and small pebbles included; moderately sorted, lignitic and scoriaceous.
28 -30	Pebble loam, clayey, lignitic, gray.

HB-11
SESESE Sec 5, T144N, R86W
Elev. 1 750

0 - 1	Loam, silty, gray-brown.
1 -11	Pebble loam, silty, clayey, light-brown.
11 -14	Silt, clayey, olive-brown.
14 -16	Silt, blue-gray; lignitic streaks.
16 -17	Clay, silty, iron-stained, blue-gray.
17 -18	Silt, sandy, iron-stained, olive-brown; laminated.
18 -18.5	Siltstone, lignitic, gray; well indurated.
18.5-22	Silt, lignitic, gray-brown.
22 -26	Silt, sandy, olive-brown; lignitic towards top.
26 -27.5	Silt, coarse-grained, yellow-olive-brown; iron concretions.
27.5-28.5	Clay, gray.
28.5-29	Lignite.
29 -30	Silt, lignitic, dark-gray.

HB-12
NWNWSW Sec 4, T144N, R86W
Elev. 1 759

0 - 1	Loam, silty, brown.
1 - 4	Silt, sandy, gray; loosely compacted.
4 - 6	Sand, fine- to medium-grained, brown and gray; some coarse-grained sand, moderately sorted.
6 - 9	Sand, medium-grained, pebbly, dark-brown; moderately to poorly sorted, fine-grained sand to large pebbles.
9 -22	Pebble loam, lignitic, olive-brown and gray; clay to cobbles.
22 -28	Pebble loam, gray; lignitic; less coarse than above, no cobbles.
28 -30	Sand and silt, fine-grained, gray to olive-brown; laminated.

Depth (ft.)	Lithologic Description
HB-13 NWNWSE Sec 5, T144N, R86W Elev. 1 812	
0 - 3	Pebble loam, light-olive-brown.
3 -18	Sand, very fine-grained, silty, light-gray-brown; light-brown in last 3 feet.
18 -19.5	Silt, sandy, olive-brown.
19.5-23	Lignite, silty, black; highly weathered.
23 -30	Clay, lignitic, dark-brownish-gray to blue-gray; silty toward bottom.
HB-14 SWSWSE Sec 5, T144N, R86W Elev. 1 792	
0 - 4	Pebble loam, silty, light-brownish-gray to light-gray; clay to boulders.
4 - 9	Silt, sandy to clayey, light-grayish-brown.
9 -13	Clay, silty, brown and gray; laminated.
13 -15	Clay, silty, lignitic, brownish-gray.
15 -19	Lignite, silty, black.
19 -22	Clay, silty, lignitic, brownish-gray; poor samples.
22 -23	Silt, iron-stained, olive-brown; laminated.
23 -30	Silt, gray; iron-banded near top, massive.
HB-15 NENESE Sec 31, T144N, R86W Elev. 1 913	
0 - 1.5	Loam, fine-grained, sandy, light-brown.
1.5- 3	Sand, fine-grained, silty, brown; some coarser grains.
3 - 4	Pebble loam, sandy; cobbles.
4 - 9	Pebble loam, clayey, lignitic, iron-stained, olive-brown.
9 -16	Clay, silty, iron-stained, yellowish-brown; gray-brown toward bottom, numerous small concretions.
16 -17	Sand, very fine-grained, cemented, blue-gray.
17 -30	Sand and silt, very fine-grained, lignitic, blue-gray; iron-stained near bottom.
HB-16 SESESE Sec 31, T144N, R86W Elev. 1 940	
0 - 2	Loam, fine-grained, sandy, brown; some medium-grained sand.
2 - 4	Pebble loam, clayey, sandy, olive-brown.
4 - 8	Pebble loam, clayey, lignitic, olive-brown.
8 -13	Loam, fine-grained, clayey, dark-brown to gray-brown.
13 -16	Silt, very dark-gray-brown; hard.
16 -23.5	Lignite.
23.5-25	Sand, very fine-grained, silty, lignitic; clay balls.
25 -26	Silt, light-blue-gray.
26 -30	Silt to sand, very fine-grained, blue-gray.
HB-17 SWSWSE Sec 31, T144N, R86W Elev. 1 959	
0 - 3	Loam, sandy, brown.
3 -14.5	Pebble loam, clayey, olive-brown; scoria, lignite fragments, carbonate cobbles.
14.5-16	Silt, sandy, light-brown.

Depth (ft.)	Lithologic Description
16 -30	Sand, very fine-grained, silty, light-brown and light-gray; loose, dry; some fine-grained sand.

HB-18
NENENW Sec 36, T144N, R87W
Elev. 1 890

0 - 1	Loam, sandy, dark-brown.
1 - 3	Pebble loam, clayey, sandy, dark-brown to brown.
3 -10	Pebble loam, clayey, olive-brown; lignite, scoria, granite fragments.
10 -16	Sand, very fine-grained, silty, iron-stained, light-brown.
16 -19	Loam, clayey, highly lignitic black; some gray clay balls.
19 -22.5	Loam, clayey, dark-gray-brown; mostly reworked lignitic silt and clay; clay balls present.
22.5-24	Clay, lignitic, dark-gray.
24 -30	Clay, blue-gray; slightly silty.
30+	Siltstone, lignitic, light-gray; hard.

HB-19
SESENW Sec 36, T144N, R87W
Elev. 1 927

0 - 1	Loam, sandy, gray-brown.
1 - 4	Sand, fine-grained, silty, brown.
4 -12.5	Pebble loam, clayey, lignitic, olive-brown; darkening downwards.
12.5-14	Sand, very fine-grained, silty, light-brown; some fine- and medium-grained sand, intercalated with silt.
14 -30	Sand, very fine-grained, silty, yellow-brown; some fine-grained sand, small iron concretions; dark-yellow-brown from 20 to 22 feet, light-yellow-brown from 22 to 24 feet, light-brown from 24 to 30 feet.

HB-20
SWSWNW Sec 36, T144N, R87W
Elev. 1 891

0 - 1	Sand, fine-grained, loamy, dark-yellow-brown.
1 -10	Pebble loam, clayey, lignitic, scoriaceous, mottled gray and brown; clay to cobbles; metamorphic, granitic and carbonate rock fragments included.
10 -18	Pebble loam, clayey, olive-brown.
18 -20	Pebble loam, clayey, olive-gray-brown.
20 -22	Pebble loam, clayey, dark-brownish-gray.
22 -30	Pebble loam, clayey, dark-gray.

HB-21
NWNWNW Sec 36, T144N, R86W
Elev. 1 835

0 -30	Sand, very fine- and fine-grained, brown; occasionally lignitic and silty.

HB-22
SESENE Sec 15, T144N, R87W
Elev. 1 892
In ditch, 3 feet of pebble loam exposed above hole.

0 - 6	Pebble loam, clayey, lignitic, olive-brown.
6 - 8	Sand, very fine- to fine-grained, silty, brown.
8 - 9.5	Pebble loam, clayey, lignitic, olive-brown.

Depth (ft.)	Lithologic Description
9.5-11	Silt, sandy, iron-stained, brownish-gray.
11 -17	Silt, sandy, iron-stained, lignitic (?), gray to dark-gray.
17 -20	Clay, light-greenish-gray.
20+	Hard rock; lithology unknown, poor return of samples.

HB-23
SWSWSW Sec 14, T144N; R86W
Elev. 1 826 6 to 8 feet of pebble loam exposed above hole.

0 - 1	Pebble loam, olive-brown.
1 - 4	Sand, very fine-grained, silty, gray to light-brownish-gray; laminated.
4 - 9	Clay, highly iron-stained, olive-gray; some silt.
9 -13	Silt, very sandy, brown.
13 -19	Sand, very fine-grained, blue-gray; thinly laminated, silty and lignitic in spots; sand coarser in spots.
19 -21	Silt, very sandy, dark-gray; many clay balls.
21 -24	Silt and sand, very fine-grained, dark-gray and blue-gray; laminated.
24 -28	Clay, dark-brownish-gray.
28 -30+	Lignite.

HB-24
SESENE Sec 22, T144N, R87W
Elev. 1 845

0 - 1	Silt, brownish-gray.
1 - 3	Clay, lignitic, dark-gray.
3 - 5	Clay, dark-gray.
5 -14.5	Clay, silty, dark-gray to brownish-gray; laminated and iron-stained in spots, lignitic and gray toward bottom.
14.5-18	Lignite.
18 -23	Silt, sandy, lignitic, gray-brown; grading downward to very fine-grained sand.
23 -26	Lignite.
26 -30	Silt to sand, very fine-grained, lignitic, blue-gray; laminated.

HB-25
SWSWSW Sec 20, T144N, R86W
Elev. 1 814

0 - 2	Sand, fine-grained, loamy, gray-brown.
2 - 5	Sand, fine- to medium-grained, brown; some coarse sand and a few pebbles.
5 - 8	Sand, fine- to medium-grained, gray-brown; some coarse sand.
8 -10	Sand, fine- to medium-grained, iron-stained, yellowish-brown; some coarse sand.
10 -12.5	Sand, medium-grained, reddish-brown; fine-grained sand to pebbles.
12.5-14	Sand, medium-grained, brown; fine-grained sand to cobbles; mostly sand but many pebbles and cobbles; lignitic laminae.
14 -14.5	Pebble loam, clayey, dark-gray-brown.
14.5-25	Pebble loam, clayey, lignitic, dark-gray.
25 -27	Pebble loam, gray; very wet.
27 -30	Pebble loam, sandy, lignitic, dark-gray.

HB-26
SESENE Sec 30, T144N, R86W
Elev. 1 828

0 - 5	Pebble loam, silty, lignitic, light-olive-brown; clay to large pebbles.

Depth (ft.)	Lithologic Description
5 -14	Pebble loam, silty, lignitic, iron-stained, olive-brown and gray; many pebbles; small cobbles.
14 -15	Clay, sandy, lignitic, iron-stained, olive-gray to dark-olive-gray.
15 -19	Pebble loam, silty, clayey, olive-brown; olive-gray clay partings.
19 -19.5	Clay, lignitic (?), olive-gray.
19.5-26	Pebble loam, clayey, iron-stained, olive-brown; olive-gray clay partings, some of which are probably several inches thick.
26 -28	Sand, fine- to medium-grained, light-olive-brown; possible clay and silt partings.
28 -30	Sand and gravel, very silty, olive-gray-brown; cobbles abundant; very poorly sorted.

HB-27
NENENE Sec 31, T144N, R86W
Elev. 1 854

0 - 1	Loam, fine-grained, sandy, dark-brown.
1 - 9	Pebble loam, sandy, clayey, lignitic, olive-brown.
9 -20	Sand, fine-grained, lignitic, brown; some medium-grained sand, well-sorted, wet at 13 feet; pebbles at 19.5 feet; possible 6-inch pebble loam layer around 20 feet.
20 -26	Sand, medium-grained, lignitic, gray-brown; fine-grained sand to a few cobbles, moderately to poorly sorted.
26 -29.5	Pebble loam, clayey, gray.
29.5-30	Sand, medium-grained, pebbly, gray-brown; very wet.

HB-28
SWSWSW Sec 19, T144N, R86W
Elev. 1 752
Drilled in 3-foot ditch.

0 - 1	Loam, sandy, dark-brown.
1 - 4	Silt and clay, brown; laminated (?).
4 - 6	Silt, sandy, light-brownish-gray; a few small pebbles.
6 - 9.5	Sand, very fine- to fine-grained, silty, light-brown; some coarser sand grains and small pebbles.
9.5-11	Sand, fine- to medium-grained, lignitic, light-brown; some coarse sand and small pebbles.
11 -14	Sand, fine- to medium-grained, lignitic, brown to dark-brown; silty toward the bottom.
14 -15	Silt, sandy, gray-brown; some medium-grained sand, laminated (?).
15 -22	Sand, fine- to medium-grained, lignitic, brown; iron-stained in spots, light-gray-brown from 20 to 22 feet.
22 -30	Sand, medium-grained, lignitic, gray-brown; fine-grained sand and cobbles; much coarse-grained sand; some pebbles and scoria fragments.

HB-29
SWSWSE Sec 24, T144N, R86W
Elev. 1 749
Drilled in 2-foot ditch.

0 - 3.5	Loam, silty, clayey, dark-gray-brown.
3.5- 8	Sand, very fine-grained, silty, light-brown; some coarser sand grains, carbonaceous around 5 feet.
8 -14.5	Sand, very fine- to fine-grained, lignitic, light-brown; some medium-grained sand, but moderately well-sorted.
14.5-16	Sand, fine- to medium-grained, lignitic, dark-gray-brown; wet.
16 -26	Sand, fine-to medium-grained, lignitic, slightly silty, brown, very wet.

Depth (ft.)	Lithologic Description
26 -30	Clay and silt, sandy, lignitic, blue-greenish-gray; mostly clay and silty clay toward the bottom.

HB-30
SWSWSW Sec 24, T144N, R87W
Elev. 1 780
Drilled in 2-foot ditch.

0 - 3	Silt, sandy, brown; silt to medium-grained sand.
3 - 5	Loam, pebbly, reddish-brown; mostly silt to medium-grained sand; some cobbles.
5 -10	Sand, medium-grained, reddish-brown; fine-grained sand to small pebbles, moderately well-sorted.
10 -13	Sand, fine- to medium-grained, reddish-dark-brown; a few large cobbles, some coarse-grained sand.
13 -19.5	Sand, fine-grained, carbonaceous, dark-brown; some medium- to coarse-grained sand.
19.5-21	Sand, very fine- and fine-grained, silty, carbonaceous, very dark-brown; some coarser sand grains.
21 -28	Sand, fine-grained, silty, carbonaceous, reddish, very dark-brown; moderately to poorly sorted; silt, pebbles, and coarse-grained sand included.
28 -30	Sand, medium-grained, silty, carbonaceous, reddish, very dark-brown; coarse-grained sand and pebbles included.

HB-31
NENESE Sec 26, T144N, R87W
Elev. 1 797
Drilled in 3-foot ditch.

0 - 1	Loam, sandy, gray-brown.
1 - 7	Sand, very fine-grained, silty, light-olive-brown.
7 -10	Sand, fine-grained, silty, light-olive-brown; some medium-grained sand; laminated.
10 -14	Sand, fine- to medium-grained, lignitic, dark-brown; some coarse-grained sand.
14 -22	Sand, medium-grained, pebbly, lignitic, dark-reddish-gray-brown; carbonaceous laminations, scoria fragments, pebbles and cobbles, moderately to poorly sorted.
22 -24	Sand, medium- to coarse-grained, reddish-brown lignitic and scoriaceous.
24 -25	Sand, medium-grained, silty, very dark-reddish-brown, lignitic and scoriaceous.
25 -30	Sand, medium-grained, silty, dark-reddish-brown; much coarse-grained sand, small pebbles, scoria and lignite fragments; sand looks "oily."

HB-32
SWSWSE Sec 36, T144N, R86W
Elev. 1 769
Drilled in 1-foot ditch.

0 - 2	Loam, sandy, brownish-gray; some coarse-grained sand and pebbles.
2 - 4.5	Sand, fine-grained, silty, light-gray-brown; medium- to coarse-grained sand and small pebbles.
4.5-14	Sand, fine-grained, lignitic, olive-brown; coarse-grained sand to small pebbles present; silty in spots; laminated, sandy silt layer at about 13.5 feet.
14 -19	Sand, fine- to medium-grained, silty, reddish-brown; some coarse-grained sand, rare large pebbles, lignitic and scoriaceous.
19 -21	Clay, silty, olive; rare sand-size scoria chips.
21 -25	Loam, clayey, olive-brown; laminated in spots; some dark-brown carbonaceous layers, scoria and lignite fragments; rare coarse sand and pebbles.
25 -30	Sand, fine-grained, silty, olive-brown, lignitic and scoriaceous, wet.

Depth (ft.)	Lithologic Description

HB-33
SESESE Sec 27, T144N, R87W
Elev. 1 758
Drilled in 2-foot ditch.

0 - 4	Sand, very fine-grained, silty, light-brown.
4 - 9	Sand, fine-grained, silty, lignitic, light-gray-brown; some medium-grained sand, silt layer at about 8.5 feet.
9 -19.5	Sand, fine- to medium-grained, lignitic, brown; some coarse-grained sand, a few small pebbles, moderately well-sorted.
19.5-20	Clay, silty, olive-gray.
20 -22.5	Sand and gravel, reddish-brown; fine-grained sand to large pebbles.
22.5-27	Sand, fine- to medium-grained, gravelly, lignitic, brownish-gray; coarse-grained sand and pebbles present.
27 -30	Sand, medium-grained, gravelly, lignitic, brownish-gray; coarse-grained sand, pebbles, and scoria chips present.

HB-34
SWSWSE Sec 27, T144N, R86W
Elev. 1 750
Drilled in 3-foot ditch.

0 - 1	Loam, silty, gray-brown.
1 - 7	Sand, very fine-grained, silty, light-gray-brown.
7 -10	Sand, fine-grained, silty, light-brown; silty layers in last foot.
10 -13	Sand, fine- to medium-grained, lignitic, reddish-brown, well-sorted.
13 -19	Sand, medium-grained, lignitic, dark-reddish-brown; well-sorted, some coarse-grained sand. Last foot a pebble-cobble layer with cobble-sized lignite fragments.
19 -30	No samples; drill flights indicated wet, dark-brownish-gray, medium-grained, gravelly sand.

HB-35
SWNWNW Sec 34, T144N, R87W
Elev. 1 752

0 - 8.5	Sand, very fine-grained, silty, light-brown.
8.5-12	Loam, very fine-grained, sandy, olive-brown.
12 -19	Sand, medium-grained, lignitic, pebbly, reddish-brown; fine-grained sand to large pebbles; lignite cobbles, silty in spots, moderately to poorly sorted; thin olive-brown clay at the bottom.
19 -28.5	Poor samples; mostly sand and gravel, silt to cobbles, poorly sorted, very blue-gray silt at the bottom.
28.5+	Hard rock; possibly siltstone, probably large cobble in the gravel.

HB-36
SWSWSE Sec 11, T144N, R87W
Elev. 1 767
Drilled in 2-foot ditch.

0 -14	Loam, silty, clayey, olive-gray-brown; rare small pebbles.
14 -16	Loam, clayey, olive-gray-brown; not as well sorted as above material; water at about 15 feet.
16 -20	Loam, gravelly, silty, dark-olive-gray-brown; very wet; silt to large pebbles.
20 -26	Sand, silty, olive-brown; very wet; silt to pebbles; coarsens downwards.
26 -30	Sand, very fine-grained, silty, iron-stained, olive to olive-brown; well-sorted, wet; possibly gravelly toward the bottom.

Depth (ft.)	Lithologic Description

HB-37
NWNWNW Sec 14, T144N, R87W
Elev. 1 822
Drilled in 6-foot ditch.

0 -10	Pebble loam, olive-brown; coarse-textured, clay to cobbles.
10 -23	Pebble loam, clayey, olive-brown; coarse-textured, lignite, scoria, metamorphic and igneous rock fragments present.
23 -30	Clay, iron-stained, olive-brown to olive-gray; silty in spots.

HB-38
SESESW Sec 14, T144N, R87W
Elev. 1 787

0 - 2	Loam, silty, gray-brown.
2 - 4	Silt, sandy, light-brown.
4 - 9	Loam, gravelly, silty, light-grayish-brown.
9 -12	Loam, sandy, dark-brown.
12 -15	Loam, gravelly, silty, gray-brown; very coarse material (large cobbles) in fine, sandy silt matrix.
15 -20	Sand, fine-grained, gray-brown; well-sorted, some small pebbles.
20 -30	Sand, fine-grained, reddish-brown; well-sorted, some pebbles, lignitic and scoriaceous; somewhat coarser in last 4 feet.

HB-39
SWSWSW Sec 13, T144N, R87W
Elev. 1 824

0 - 2	Pebble loam, light-olive-gray-brown.
2 - 7	Silt, iron-stained, light-yellow-brown; iron concretions.
7 - 8	Clay, silty, lignitic, olive-gray.
8 -11	Sand, very fine-grained, silty, iron-stained, light-olive-brown; somewhat compacted.
11 -12	Silt, sandy, light-brown.
12 -16	Sand, very fine-grained, silty, light-olive-brown; somewhat compacted.
16 -18	Silt and sand, very fine-grained, iron-stained, light-olive-brown; laminated; hard iron concretion at 18 feet with selenite crystals.
18 -21.5	Silt to silty clay, iron-stained, dark-olive-brown; laminated.
21.5-24	Clay, iron-stained, dark-olive-brown and dark-olive-gray; laminated; silty in spots.
24 -31	Lignite.
31 -35	Clay, iron-stained, blue-gray; lignitic at the top.

HB-40
NENESE Sec 14, T144N, R87W
Elev. 1 758

0 - 1	Sand, fine-grained, silty, dark-brown.
1 - 3	Loam, sandy, clayey, dark-reddish-gray-brown.
3 - 5	Sand, fine-grained, silty, dark-reddish-brown; some coarser sand, moderately well-sorted.
5 -10	Sand, fine- and medium-grained, reddish-brown; some coarse-grained sand and pebbles, especially in last foot.
10 -12	Sand, fine-grained, silty, reddish-brown; some coarse-grained sand and small pebbles; wet.
12 -16	Sand, fine- and medium-grained, reddish-brown; some coarse-grained sand and pebbles; wet.

Depth (ft.)	Lithologic Description
16 -19	Clay, silty, iron-stained, olive-brown and olive-gray; mottled.
19 -30	Sand, very fine- and fine-grained, silty, olive-brown; some coarser grains; very wet.

HB-41
NENENE Sec 14, T144N, R87W
Elev. 1 761

0 - 6	Loam, silty, light-gray-brown.
6 -10	Loam, silty, clayey, dark-olive-gray-brown.
10 -15	Loam, silty, clayey, olive-brown; some sand, scoria chips; wet.
15 -18	Silt, sandy, olive-brown and gray; laminated; very wet.
18 -21	Sand, very fine-grained, silty, olive-brown; very wet.
21 -23	Silt, sandy, olive-gray-brown; very wet.
23 -30	Sand, very fine- to fine-grained, silty, olive-brown; some medium-grained sand; very wet. Wet, fine-grained, lignitic sand toward bottom, well-sorted with a few pebbles.

HB-42
NENESE Sec 11, T144N, R87W
Elev. 1 828

0 -10	Pebble loam, lignitic, olive-brown; clay to cobbles.
10 -17	Sand, very fine-grained, silty, light-olive-brown; well-sorted; some slightly coarser sand grains.
17 -30	Pebble loam, lignitic, dark-olive-brown; last 5 feet uncertain, but probably the same.

HB-43
SESENW Sec 6, T144N, R86W
Elev. 1 891
Drilled in 4-foot ditch.

0 - 7	Pebble loam, clayey, lignitic, olive-brown.
7 -13.5	Sand, very fine-grained, silty, iron-stained, olive-gray.
13.5-16.5	Lignite.
16.5-18	Silt and silty clay, lignitic.
18 -21	Silt, sandy, lignitic, iron-stained, olive-gray-brown; laminated.
21 -25	Clay, silty, blue-gray; lignitic in spots.
25 -30	Sand, very fine-grained, silty, olive-gray-brown; iron concretions.

HB-44
SWSWNW Sec 6, T144N, R86W
Elev. 1 840

0 - 2	Loam, dark-brown; organic-rich.
2 - 5	Loam, silty, dark-gray-brown.
5 - 7	Loam, silty, brown.
7 - 9	Loam, clayey, dark-brown; clay to pebbles.
9 -11.5	Loam, clayey, olive-brown; clay to pebbles.
11.5-16	Clay, silty, iron-stained, olive-brown and dark-gray; moderately compacted.
16 -20	Silt to silty clay, dark-bluish-gray; clay partings.
20 -24	Sand, very fine-grained, silty, blue-gray; laminated in spots.
24 -30	Silt, bluish-gray; some very fine-grained sand.

Depth (ft.)	Lithologic Description

HB-45
NWNENW Sec 6, T144N, R86W
Elev. 1 919
Drilled in 1-foot ditch.

0 - 2	Pebble loam, clayey, dark-brown.
2 - 7	Pebble loam, clayey, olive-brown; grading downward to sand.
7 -12	Sand, very fine-grained, silty, olive-brown; wet.
12 -13	Clay, olive-brown and gray; poor samples.
13 -15	Silt, purplish-gray.
15 -17	Clay, greenish-gray.
17 -22	Silt, iron-stained, olive to olive-brown; compact.
22 -24.5	Lignite (possibly thicker).
24.5-27.5	Clay, lignitic, dark-gray.
27.5-28	Lignite; brownish, hard (possibly thicker).
28 -30	Clay, silty, dark-gray; lignitic laminae.

HB-46
NWNWNW Sec 6, T144N, R86W
Elev. 1 962
Drilled in 1-foot ditch.

0 - 8.5	Silt and sandy silt, iron-stained, brown to olive-brown; iron concretions.
8.5-13	Silt to silty clay, olive-brown; compact, iron-stone concretion at 11 feet.
13 -15.5	Silt, lignitic, purplish-gray.
15.5-16	Lignite.
16 -20	Clay, lignitic, dark-gray.
20 -22	Sand, very fine-grained, olive-gray-brown; lignitic in spots.
22 -29	Silt, iron-stained, olive-brown; mottled, lignitic in spots, sandy toward the bottom.
29 -30	Sand, very fine-grained, silty, olive-brown; wet.

HB-47
SESESW Sec 15, T144N, R87W
Elev. 1 920

0 - 1	Loam, fine-grained, sandy, dark-brown.
1 - 4	Sand, very fine-grained, loamy, gray-brown.
4 -18.5	Sand, very fine- and fine-grained, silty, lignitic, light-brown; moderately well-sorted, some coarser grains; reddish-brown, iron-stained beds.
18.5-20	Clay, lignitic, gray; fossil plant fragments.
20 -22	Clay, silty, lignitic, dark-brown.
22 -26	Lignite, impure, clay layers present.
26 -27	Sand, very fine-grained, silty, lignitic, dark-gray.
27 -37	Sand and silt, very fine-grained, blue-gray; commonly lignitic and laminated.
37 -39	Silt, gray.
39 -40	Clay, gray.
40 -40.5	Sand, very fine-grained, blue-gray.
40.5-44.5	Lignite; hard; possible clay parting between 42 and 43 feet.
44.5-50	Clay and silty clay, lignitic, dark-blue-gray; hard drilling at 49 feet, possibly lignite.

HB-48
NWNWSW Sec 15, T144N, R87W
Elev. 1 970

0 - 1	Silt, brown.
1 - 8	Silt, coarse-grained, very light-yellow.

Depth (ft.)	Lithologic Description
8 -19	Sand and silt, very fine-grained, iron-stained, light-brownish-gray to light-grayish-brown; iron concretions.
19 -27	Sand, very fine-grained, silty, light-brownish-gray; iron concretions.
27 -39	Clay, silty, lignitic, dark-gray; increasingly lignitic downward, seams up to several inches thick at about 36 feet; laminated; some lignite toward the bottom.
39 -41.5	Silt, coarse-grained, green; some very fine-grained sand. Hard rock at 41.5 feet, probably sandstone.

HB-49
SESESE Sec 16, T144N, R87W
Elev. 1 990

0 - 7	Pebble loam, clayey, lignitic, very light- to light-brown.
7 - 8	Silt, reddish-dark-brown; appears scoriaceous, possibly burnt or weathered lignite.
8 -10	Silt and silty clay, lignitic, gray and dark-gray.
10 -17	Sand, very fine-grained, silty, light-gray-brown to light-brownish-gray; lignitic partings near the top.
17 -30	Sand, very fine-grained, light-brownish-gray; well-sorted, lignitic partings in spots; iron-stained in spots; salt and pepper appearance.

HB-50
SESENW Sec 22, T144N, R87W
Elev. 1 932

0 - 3	Pebble loam, light-olive-brown; sandy toward the bottom.
3 -34	Sand, very fine-grained, light-grayish-brown; well-sorted, becomes yellow-brown at about 22 feet as iron staining increases downward; also more silty downward, except in last 3 feet.
34 -35	Lignite, hard.
35 -39	Silt and silty clay, dark-blue-gray; lignitic toward the top.
39 -43	Sand, very fine-grained, silty, blue-gray; increasingly lignitic and laminated downward.
43 -45	Lignite.
45 -46.5	Silt, coarse-grained, sandy, lignitic, green.
46.5-50	Clay and silt, lignitic, blue-green; fining downward.

HB-51
SWSWSE Sec 16, T144N, R87W
Elev. 1 929

0 - 9	Loam, dark-brown; organic-rich; abundant scoria fragments up to cobble-size; laminated.
9 -15	Loam, fine-grained, sandy, reddish-brown; abundant scoria fragments up to pebble-size.
15 -45	Sand, very fine-grained, silty, brown, wet; becomes blue-gray at about 30 feet; scoria chips present. Hard drilling at 45 feet, probably sandstone.

HB-52
NWNWSW Sec 11, T144N, R87W
Elev. 1 777
Drilled in 3-foot ditch.

0 -10	Loam, silty, clayey, light-olive-brown.
10 -22	Pebble loam, clayey, olive-brown; top 5 feet relatively fine-grained, tends to coarsen downward; dolomite, greenstone, chert, and lignite fragments present; more lignitic towards bottom. Boulder at 22 feet.

Depth (ft.)	Lithologic Description

HB-53
NWNWNE Sec 4, T144N, R87W
Elev. 1 815
Drilled in 1-foot ditch.

0 - 2	Silt, sandy, light-gray-brown.
2 - 5	Sand and gravel, silty, light-brown; silt to cobbles.
5 -17	Sand and gravel, reddish-brown, poorly sorted; fine sand to cobbles; silty toward the bottom; scoria and lignite fragments.
17 -20	Pebble loam, clayey, olive-gray-brown; very lignitic.
20 -30	Pebble loam, clayey, lignitic, dark-gray.

HB-54
NENENE Sec 4, T144N, R87W
Elev. 1 808

0 - 1	Silt, gray-brown.
1 -11	Silt, coarse-grained, very light-brown; some very fine-grained sand.
11 -35	Silt, coarse-grained, sandy, light-brown, clayey in spots, olive-brown below 19 feet; water near the bottom.

HB-55
NENESW Sec 3, T144N, R87W
Elev. 1 820
Drilled in 2-foot ditch.

0 - 1	Loam, sandy, dark-brown.
1 -45	Pebble loam, clayey, lignitic, olive-brown; carbonate, sandstone, igneous, metamorphic, scoria and chert fragments; finer-grained and brown in color from about 25 to 35 feet, coarsest material being small pebbles; coarsens below 35 feet.

HB-56
SESESW Sec 3, T144N, R87W
Elev. 1 788
Drilled in 1-foot ditch.

0 -10	Loam, clayey, olive-gray-brown; laminated; lignite and scoria grains present.
10 -14	Sand and gravel, silty, gray-brown; very poorly sorted, silt and very fine-grained sand matrix with abundant pebbles; wet.
14 -30	Pebble loam, clayey, olive-brown; lignite and scoria fragments; last 10 feet mottled gray, selenite crystals included; water at about 20 feet.

HB-57
NENENE Sec 10, T144N, R87W
Elev. 1 780

0 -19	Loam, olive-gray-brown; organic-rich near the surface, laminated; generally fine-grained material, sand-size or less.
19 -24.5	Silt, sandy, olive-brown; very wet.
24.5-29	Loam, clayey, olive-brown; some pebbles, very wet; possibly laminated.
29 -30	Sand and gravel, dark-brown.

Depth (ft.)	Lithologic Description
HB-58 NWNWNE Sec 33, T144N, R87W Elev. 1 807 Drilled in 1.5-foot ditch.	
0 -13.5	Sand, fine-grained, brown; much very fine-grained sand, some medium- and coarse-grained sand, abundant lignite grains.
13.5-15	Sand, very fine-grained, silty, carbonaceous, dark-brown; some coarser grains.
15 -25.5	Sand, fine- and very fine-grained, brown; lignitic, dark-brown, carbonaceous bed from 24 to 25 feet.
25.5-27	Sand, very fine-grained, silty, carbonaceous, dark-brown; some coarser grains.
27 -40	Sand, medium-grained, silty, lignitic, dark-reddish-brown; abundant scoria grains; carbonaceous, silty, and pebbly layers; much coarse-grained sand.
40 -55	Sand, fine- to medium-grained, silty, very dark-red-brown; moderately well-sorted, carbonaceous, lignitic, scoriaceous; pebble and cobble layers, much coarse-grained sand and small pebbles; general coarsening downward; almost black in color, although somewhat lighter in the last 6 feet.
HB-59 SENESE Sec 31, T144N, R87W Elev. 1 893	
0 - 9.5	Pebble loam, clayey, gray-brown.
9.5-11	Clay, silty, iron-stained, olive-gray.
11 -19	Silt, iron-stained, olive-gray; laminated, clayey in spots; iron concretion at about 16 feet.
19 -22	Silt, sandy, olive-gray.
22 -26	Silt and silty clay, olive-gray; laminated.
26 -34	Clay, silty, iron-stained, olive-brown; some silt, iron concretions and selenite crystals.
34 -39	Clay, dark-olive-gray; silty in spots; thin, silty, very fine-grained sand between 36 and 37 feet.
39 -50	Clay, lignitic, dark-gray; lignite laminae; silty in spots, olive-brown silt with iron concretions from about 42 to 44 feet; light-gray siltstone near the bottom.
HB-60 SESENE Sec 1, T144N, R88W Elev. 1 961	
0 - 8.5	Pebble loam, clayey, olive-brown.
8.5-10	Sand, fine-grained, lignitic, iron-stained, red-brown and gray-brown.
10 -10.5	Lignite, powdery.
10.5-11.5	Clay, silty, lignitic, gray; selenite crystals.
11.5-20	Silt, sandy, iron-stained, gray; selenite crystals.
20 -22	Silt, dark-gray.
22 -25	Silt, olive-gray to blue-gray.
25 -32	Silt, sandy, iron-stained, olive-gray; coarsening downward.
32 -34	Sand, very fine-grained, silty, light-gray.
34+	Sandstone; too hard to drill.
HB-61 NENENE Sec 1, T144N, R88W Elev. 1 895	
0 - 3	Loam, light-brown.

Depth (ft.)	Lithologic Description
3 -11	Clay and silty clay, lignitic, gray to dark-gray; iron concretions at 7 feet; some silt layers.
11 -11.5	Lignite; soft.
11.5-14.5	Silt and silty clay, lignitic, olive-gray.
14.5-16	Clay, silty, lignitic, iron-stained, light-gray.
16 -20	Clay, lignitic, dark-blue-gray to dark-gray; slightly silty, with lignite laminae.
20 -27.5	Silt and sandy silt, lignitic, dark-gray to dark-blue-gray, laminated.
27.5-33	Lignite, hard near the top.
33 -38	Silt, sandy, very lignitic, blue-gray and gray; some very fine-grained silty sand, lignite laminae.
38 -38.5	Lignite, brownish-black.
38.5-40	Clay, lignitic, dark-blue-gray.

HB-62
NWNWNE Sec 1, T144N, R88W
Elev. 1 852

0 - 6	Loam, silty, light-gray-brown.
6 -15	Loam, olive-brown to brown; scoria chips present.
15 -16	Sand, fine-grained, silty, olive-brown.
16 -22	Loam, sandy, olive-brown; last 2 feet very wet.
22 -30	Loam, silty, clayey, olive-brown; very wet; occasional scoria chips; laminated sandy layers.

HB-63
NWNWNW Sec 12, T144N, R88W
Elev. 1 904

0 -14	Loam, gray-brown to dark-olive-gray-brown; some pebbles, scoria chips; carbonaceous and laminated; last 5 feet somewhat coarser texture.
14 -30	Sand, very fine-grained, silty, lignitic, brown; some medium- and coarse-grained scoriaceous sand, well-sorted. Darker brown (more carbonaceous) at about 18 feet; pebble-cobble layer at 22 feet; brown sand from 24 to 26 feet, less silty and less carbonaceous than above; dark-brown, silty, carbonaceous sand from 26 to 28 feet; less silty and less carbonaceous from 28 to 30 feet.

HB-64
NWNWSW Sec 1, T144N, R88W
Elev. 1 863
Drilled in 1.5-foot ditch.

0 -20	Loam, clayey, carbonaceous, gray-brown to dark-olive-gray-brown; scoria and lignite chips up to pebble-size; silty sand from about 4.5 to 6 feet.
20 -25	Loam, olive-gray-brown; wet.
25 -30	Silt and clay, iron-stained, olive-gray-brown; possibly some sandy layers; wet.

HB-65
NWNWNW Sec 1, T144N, R88W
Elev. 1 872

0 - 2	Sand, fine-grained, silty, gray-brown.
2 - 4	Sand, fine-grained, silty, pebbly, gray-brown; very fine- to medium-grained sand; some coarse-grained sand with abundant pebbles, moderately sorted.
4 - 7.5	Sand, medium- to coarse-grained, brown; moderately to poorly sorted, very fine sand to cobbles.
7.5-20	Pebble loam, clayey, lignitic, iron-stained, olive-brown.
20 -24	Silt, clayey, olive-brown; dark-gray clay balls.
24 -26	Clay, silty, iron-stained, olive-gray.

Depth (ft.)	Lithologic Description
26 -29	Silt, iron-stained, olive-gray.
29 -30	Sand, very fine- to fine-grained, lignitic, dark-olive-gray, well-sorted.

HB-66
SESESW Sec 3, T144N, R88W
Elev. 1 895
Drilled in 2-foot ditch.

0 - 5	Loam, fine-grained, silty, olive-brown; a few small pebbles.
5 -30	Silt, coarse-grained, olive-gray-brown, slightly sandy, a few small pebbles.
30 -35	Silt, coarse-grained, sandy, olive-gray-brown.
35 -45	Sand, very fine-grained, silty, olive-brown; well-sorted.
45 -50	Silt, sandy, gray-brown; scoria chips up to large pebble- and small cobble-size, possibly a scoria gravel layer; thin beds of very fine-grained, wet sand toward the bottom.
50 -55	Silt, iron-stained, olive-gray, wet, slightly sandy.

HB-67
SWSWSW Sec 3, T144N, R88W
Elev. 1 905

0 - 1	Silt, sandy, gray-brown.
1 -19	Silt, coarse-grained, light-brown; micaceous, more olive-brown and wet at 10 feet.
19 -23	Silt, sandy, lignitic, iron-stained, olive-gray-brown; laminated; olive-gray-brown clay about 6 inches thick near the top.
23 -30	Silt, coarse-grained, micaceous, olive-brown; well-sorted.

HB-68A
NWSWNW Sec 3, T144N, R88W
Elev. 2 080

0 - 8	Pebble loam, light-gray-brown.
8 -17	Pebble loam, clayey, lignitic, iron-stained, light-olive-brown. Encountered boulders at 17, 11, and 9 feet in four separate drilling attempts; probably buried boulder lag surface; no samples taken.

HB-68B
SWNWNW Sec 3, T144N, R88W
Elev. 2 085

0 -11.5	Pebble loam, clayey, lignitic, iron-stained, light-gray-brown to light-olive-brown.
11.5-55	Sand, very fine- and fine-grained, silty, iron-stained; salt and pepper appearance; well-sorted, laminated; some iron concretions toward the bottom. Orangish-brown from 11.5 to 22.5 feet, olive-brown from 22.5 to 39 feet, olive-gray-brown from 39 to 47 feet, dark-olive-gray-brown from 47 to 50.5 feet, and brown in the last 4 to 5 feet. Very little silt below 39 feet with the exception of a thin, dark-gray, lignitic, silty clay layer at about 47 feet.

HB-69
NENESE Sec 16, T144N, R88W
Elev. 2 085

0 - 5	Pebble loam, light-gray-brown.
5 -25	Pebble loam, clayey, lignitic, iron-stained, olive-brown to gray-olive-brown.

Depth (ft.)	Lithologic Description
25 -35	Sand, very fine- and fine-grained, silty, olive-brown; salt and pepper appearance, well-sorted; dark-gray, iron-stained, lignitic clay toward the bottom.
35+	Sandstone or iron concretion; too hard to drill.

HB-70A
SESESE Sec 16, T144N, R88W
Elev. 2 030

0 -14	Pebble loam. (Boulders at 7 feet and 14 feet interrupted three separate drilling attempts. No samples taken.)

HB-70B
SWSWSW Sec 15, T144N, R88W
Elev. 2 040

0 - 5	Pebble loam, light-gray-brown.
5 - 7.5	Pebble loam, clayey, lignitic, iron-stained, olive-brown.
7.5-18.5	Clay and silty clay, dark-olive-gray, laminated; iron-stained near the top; iron-banded, manganese-stained.
18.5-22	Silt and silty clay, iron-stained, dark-olive-gray; some sandy silt.
22 -24	Clay, silty, lignitic, dark-brownish-gray.
24 -37	Silt and silty clay, lignitic, iron-stained, dark-gray and olive-gray; iron concretions and selenite crystals common.
37 -41	Lignite, black.
41 -50	Silt and sandy silt, coarse-grained, lignitic, iron-stained, olive-gray and gray; laminated and iron-banded, iron concretions and selenite crystals; thin, hard, gray, calcareous siltstone near the bottom.

HB-71
SENESE Sec 15, T144N, R88W
Elev. 2 035

0 - 4	Pebble loam, light-gray-brown.
4 -11	Pebble loam, clayey, lignitic, iron-stained, olive-brown.
11 -11.5	Sandstone, fine- to medium-grained, yellow-brown.
11.5-13.5	Sand, very fine- and fine-grained, silty, yellow-brown.
13.5-14	Clay, silty, olive-gray; manganese- and iron-stained.
14 -16	Sand, very fine- and fine-grained, silty, iron-stained, yellow-brown.
16 -24	Silt and silty clay, iron-stained, olive-gray and gray; iron concretions and selenite crystals, lignitic in spots.
24 -27	Lignite, black, powdery.
27 -31.5	Silt, sandy, coarse-grained, very lignitic, gray-brown; abundant thin lignite seams; iron concretions and selenite crystals.
31.5-35	Silt, sandy silt, and silty clay, lignitic, iron-stained, olive-gray; iron concretions and selenite crystals.
35 -48	Silt, fine- to coarse-grained, sandy, dark-gray to blue-gray, laminated; becoming more bluish downward.
48+	Sandstone or siltstone; too hard to drill.

HB-72
NWSWNW Sec 14, T144N, R88W
Elev. 2 075

0 - 6.5	Pebble loam, clayey, gray-brown changing to olive-brown; sandy toward the bottom.
6.5-12.5	Sand, very fine- and fine-grained, silty, light-yellow-brown changing to dark-yellow-brown; salt and pepper appearance, well-sorted.

Depth (ft.)	Lithologic Description
12.5-13	Iron concretion, orange; mostly silty material.
13 -20	Silt, iron-stained, olive-gray changing to olive-gray-brown; iron concretions, laminated; occasionally sandy, compacted, and lignitic.
20 -24	Clay, silty, iron-stained, olive-gray; occasionally lignitic.
24 -25	Lignite, soft and lignitic, gray-brown, silty clay.
25 -26	Silt and silty clay, lignitic, olive-gray, slightly sandy; selenite crystals.
26 -30	Silt and sand, very fine-grained, olive-gray; iron concretions and selenite crystals.

HB-73
NWNWNE Sec 14, T144N, R88W
Elev. 2 038

0 - 1	Loam, fine-grained, sandy, dark-gray-brown.
1 -45	Pebble loam, clayey, lignitic, iron-stained, olive-gray-brown changing to dark-olive-brown; iron concretion fragments common.
45 -50	Sand, very silty, olive-brown; wet.
50 -57	Pebble loam, clayey, dark-olive-brown.
57 -60	Sand, very silty, olive-brown.

HB-74
NENESE Sec 14, T144N, R88W
Elev. 1 970

0 - 4	Pebble loam, clayey, light-olive-brown.
4 -30	Pebble loam, clayey, lignitic, iron-stained, olive-brown to dark-olive-brown; pebbles and cobbles present, but not abundant.
30 -40	Loam, fine-grained, clayey, yellow-olive-brown; silt-clay pebbles; coarse sand grains and small pebbles; sandy layer from 30-32 feet.
40 -50	Pebble loam, clayey, olive-brown; relatively fine-grained although some cobbles are present.

HB-75
NENENE Sec 13, T144N, R88W
Elev. 2 052
Drilled in 3-foot ditch.

0 - 7.5	Pebble loam, clayey, lignitic, olive-gray-brown to olive-brown-gray; clay to cobbles.
7.5-19	Sand, very fine- and fine-grained, olive-brown; salt and pepper appearance, well-sorted, somewhat silty; iron concretions and iron-stained in places, especially the last 2 feet.
19 -19.5	Clay, lignitic, dark-gray-brown.
19.5-22	Silt and silty clay, lignitic, iron-stained, dark-gray; iron concretions and laminated, silty sand in places.
22 -25.5	Silt and sand, very fine-grained, iron-stained, olive-gray, olive-brown, and brown; laminated.
25.5-26	Siltstone, calcareous, light-blue-gray; well-indurated.
26 -32.5	Clay, silty, dark-gray; slightly bluish, lignitic toward bottom.
32.5-33+	Lignite, pyritic; too hard to drill.

HB-76
NWNWNE Sec 24, T144N, R88W
Elev. 1 980
Boulders and cobbles at the surface.

0 - 4.5	Silt, brown to olive-brown; some very fine-grained sand.

Depth (ft.)	Lithologic Description
4.5-13.5	Sand, very fine-grained, silty, light-olive-brown; coarsening downward to a fine-grained sand; coarser sand grains and small pebbles become more abundant downward, larger pebbles and cobbles toward the bottom.
13.5-43	Pebble loam, sandy, clayey, lignitic, iron-stained, olive-gray-brown, to olive-gray; clay to cobbles; small pebbles of local derivation abundant.
43 -44.5	Clay, silty, olive-gray; mottled gray.
44.5-46.5	Loam, clayey, dark-olive-brown; a few coarse sand grains.
46.5-50	Clay, silty, iron-stained, olive-gray, mottled gray; laminated, lignitic, clay loam at the bottom.

HB-77
NENESE Sec 19, T144N, R86W
Elev. 1 815
Drilled in 3.5-foot ditch.

0 - 2	Sand, very fine-grained, silty, light-olive-brown; some fine- and medium-grained sand.
2 -25	Sand, very fine-grained, olive-brown; some fine- and medium-grained sand, a few coarse sand grains; layers of dark-brown, carbonaceous silt, especially from 14 to 17 feet; olive-brown; sandy silt layers also common.
25 -30	Sand, very fine- to fine-grained, silty, carbonaceous, dark-brown; some medium- and coarse-grained sand.
30 -35.5	Sand, very fine- to fine-grained, silty, carbonaceous, lignitic, scoriaceous, reddish-dark-brown; some medium- and coarse-grained sand.
35.5-37.5	Sand, fine-grained, silty, carbonaceous, lignitic, scoriaceous, reddish, very dark-brown; moderately sorted; silt to pebbles and small cobbles.
37.5-42	Sand, very fine- to fine-grained, silty, carbonaceous, lignitic, scoriaceous; dark-reddish-brown changing to very dark-reddish-brown; pebble-sized lignite fragments toward the bottom; some medium- and coarse-grained sand.
42 -43.5	Sand, fine- to medium-grained, dark-reddish-brown; a few large pebbles.
43.5-44.5	Sand, very fine- to fine-grained, silty, dark-reddish-brown; some olive-brown; sandy silt; a cobble layer at the bottom.
44.5-60	Sand, fine- to medium-grained, pebbly; carbonaceous, lignitic, scoriaceous; dark-reddish-brown; moderately poorly sorted, silt to large cobbles; cobble-sized lignite fragments. Blue-gray, sandy silt at the bottom.

HB-78
NWNWNE Sec 29, T144N, R86W
Elev. 1 860
Drilled in 3-foot ditch.

0 - 8.5	Pebble loam, clayey, lignitic, iron-stained, olive-brown.
8.5-11.5	Loam, clayey, iron-stained, olive-yellow-brown; reworked local material; no lignite; all coarse material consists of iron concretions.
11.5-12	Clay, lignitic.
12 -15	Silt, sandy, iron-stained, olive-gray; laminated, lignitic toward the top.
15 -19	Sand, very fine-grained, very silty, olive-brown.
19 -23	Sand, very fine-grained, cemented, blue-gray; hard drilling.
23 -27	Sand, very fine-grained, silty, iron-stained, olive-bluish-gray to olive-brown.
27 -38	Clay, silty, and silt, dark-gray; lignitic toward the bottom.
38 -43	Lignite, black to brownish-black.
43 -50	Clay, silty, to silt, sandy; dark-gray; laminated, lignitic toward the top.

Depth (ft.)	Lithologic Description

HB-79
NENESE Sec 29, T144N, R86W
Elev. 1 900
Drilled in 2-foot ditch.
Scattered cobbles at the surface.

0 - 1	Sand, silty, light-olive-gray.
1 - 6.5	Sand, very fine-grained, silty, olive-gray-brown.
6.5- 7	Sand, very fine-grained, silty, carbonaceous.
7 -17	Sand, very fine-grained, silty, iron-stained, olive-gray to olive-gray-brown.
17 -20	Sand, cemented, blue-gray; hard drilling.
20 -35	Sand, very fine-grained, silty, iron-stained, blue-gray; laminated; iron concretions.
35 -38	Lignite, black.
38 -38.5	Sand, very fine-grained and silty, to silty clay, lignitic, laminated.
38.5-43	Lignite.
43 -50	Clay, silty clay, and silt, lignitic, blue-greenish-gray; poor samples.

HB-80
NWNWNE Sec 33, T144N, R86W
Elev. 1 950
Drilled in 2-foot ditch.

0 - 1	Loam, silty, gray-brown.
1 - 6.5	Pebble loam, clayey, lignitic, iron-stained, olive-brown.
6.5-36	Sand, very fine-grained, silty, iron-stained, olive-brown and yellow-olive-brown; slightly cemented in places; olive-gray silt layers around 18 feet, and from 34 to 36 feet; slightly darker downward.
36 -47	Sand, very fine-grained, very silty, iron-stained, dark-olive-brown; laminated; iron concretions.

HB-81
SWSWSW Sec 10, T144N, R86W
Elev. 1 780

0 - 7	Sand, very fine-grained, silty, brown; some coarser grains, especially toward the bottom; very dark-brown to black and carbonaceous in the last foot.
7 - 9	Sand, fine-grained, silty, pebbly, dark-reddish-brown; moderately sorted, silt to large pebbles.
9 -10	Clay, greenish-gray, wet.
10 -12.5	Lignite.
12.5-19	Silt, silty clay, and sandy silt, iron-stained; lignitic near the top; mostly poor samples.
19 -21	Lignite.
21 -49.5	Clay and silty clay, dark-gray to blue-gray,- wet. Possible thin lignite 33.5 to 34 feet; probable lignite from 44 to 45 feet bounded by olive-gray silty clay. Possible silt layers in the clay, and possibly sand toward the bottom. Too hard to drill at 49.5 feet, probably sandstone.

HB-82

SESESW Sec 10, T144N, R87W
Elev. 1 890
Drilled in 3-foot ditch.

0 - 5	Pebble loam, clayey, lignitic, iron-stained, olive-brown.
5 - 6.5	Lignite, soft.
6.5- 7	Clay, silty, lignitic, dark-gray.

Depth (ft.)	Lithologic Description
7 -16.5	Silt and sandy silt, iron-stained, olive-brown to yellow-olive-brown; laminated; iron concretions.
16.5-19.5	Lignite, soft.
19.5-22	Clay, silty, dark-gray; lignitic near the top.
22 -24	Silt and sandy silt, iron-stained, olive-gray; laminated.
24 -26	Silt and sandy silt, dark-olive-gray; lignitic in places.
26 -30.5	Silt and silty clay, dark-gray, gray, and olive-gray; lignitic in places.
30.5-34	Clay, dark-gray; lignite laminae.
34 -50	Clay, silty clay, and silt, gray; hard, compact; thin, very light-gray siltstone layer around 44 feet; lignitic clay in the last 5 feet.

HB-83
SESESE Sec 9, T144N, R87W
Elev. 1 850

0 -17	Loam to clay loam, iron-stained, olive-brown to olive-gray-brown; pebble-sized lignite, scoria, and iron concretions.
17 -22	Clay, dark-olive-gray to dark-gray; thin layers of lignite near the top.
22 -27	Lignite, very hard.
27 -29.5	Clay, lignitic, dark-gray.
29.5-34.5	Silt to sandy silt, bluish-gray.
34.5-38	Clay, silty, bluish-gray; at least one light-gray siltstone layer.
38 -41	Lignite, hard, wood fragments present.
41 -44	Silt, sandy, blue-greenish-gray; lignitic toward the top.
44 -46	Clay, silty, dark-gray; lignitic in spots.
46 -50	Sand, very fine-grained, silty, blue-gray, laminated, lignitic in spots; some silt and sandy silt present.

HB-84
NENWSE Sec 9, T144N, R87W
Elev. 1 947

0 - 1.5	Loam, silty, gray-brown.
1.5-11.5	Pebble loam, clayey, iron-stained, lignitic, olive-brown.
11.5-17.5	Clay, silty, to sandy silt, iron-stained, dark-gray to olive-gray.
17.5+	Hard rock, siltstone or sandstone; too hard to drill.

HB-85B
SESESE Sec 7, T144N, R87W
Elev. 2 028

0 - 1.5	Loam, silty, gray-brown and brown.
1.5-34.5	Pebble loam, clayey, iron-stained, lignitic, olive-brown; large pebbles noticeably present, dark-olive-brown from 15 to 22 feet; more sandy in the last 4 to 5 feet.
34.5-40	Sand, very fine and fine, silty, olive-brown.

HB-86
SWNWNW Sec 24, T144N, R88W
Elev. 1 903

0 - 4	Loam, sandy, lignitic, olive-brown to olive-gray-brown.
4 -36	Sand, very fine- and fine-grained, silty, lignitic, iron-stained, olive-brown; some medium- and coarse-grained sand, moderately well-sorted except for occasional cobble-sized iron concretions and thin, lignitic, iron-stained, sandy, dark-gray clay layers; sand size detrital iron concretions common; dark-gray-brown and carbonaceous from 26 to 29 feet, dark-olive-brown from 29 to 36 feet.

Depth (ft.)	Lithologic Description
36 -40	Sand, very fine- to fine-grained, silty, pebbly, reddish-brown.
40 -50	Sand, very fine- to fine-grained, silty, pebbly, dark-olive-gray-brown; dark-gray lignitic clay layers; sandstone and iron concretion cobbles included.

HB-87
NENESW Sec 5, T144N, R87W
Elev. 1 962

0 - 2	Loam, silty, gray-brown.
2 - 3.5	Loam, reddish-gray-brown.
3.5-13.5	Sand, fine-grained, very silty, reddish-orange, scoriaceous; moderately to poorly sorted; chips of lignite in the last 6 inches.
13.5-15	Silt to sandy silt, dark-olive-gray.
15 -20	Clay, silty, lignitic, olive-gray and dark-olive-gray.
20 -24	Silt, sandy, blue-green; laminated.
24 -28.5	Silt, sandy, to sand, very fine-grained and silty, lignitic, blue-gray; wet, laminated.
28.5-31	Silt, lignitic and sandy.
31 -34	Clay, silty, blue-green; possibly some silt.
34 -50	Silt to sandy silt, blue-gray, compact; hard and lignitic in places.

HB-88
NENESW Sec 4, T144N, R87W
Elev. 1 880

0 - 3.5	Loam, silty, gray-brown to brown.
3.5-19	Pebble loam, clayey, lignitic, iron-stained, olive-gray changing to dark-olive-gray-brown; mottled gray.
19 -22	Clay, silty, olive-gray-brown; thin, woody lignite layers included.
22 -24	Lignite.
24 -25.5	Clay, dark-gray to olive-gray; lignitic toward the top.
25.5-33	Silt and silty clay, iron-stained, olive-gray-brown to olive-gray; a little sandy silt, lignitic in spots, selenite crystals and iron concretions.
33 -35	Clay, dark-gray.
35 -40	Silt, lignitic, dark-gray to dark-olive-gray; lignite laminae and iron concretions.
40 -44	Sand, very fine-grained, silty, brown; iron concretions.
44 -45	Silt, coarse-grained, olive-gray.
45 -50	Lignite, with dark-olive-gray, lignitic, silty clay parting, some dark-gray-brown silt included.
50 -55	Silt to sand, very fine-grained, blue-gray; lignitic near the top, laminated, pyritic.

HB-89
SENENW Sec 2, T144N, R88W
Elev. 1 965

0 - 1	Loam, silty, gray-brown.
1 -23	Pebble loam, clayey, light-olive-brown to dark-olive-brown; somewhat lignitic; coarse materials range from coarse sand to small pebbles; only rare cobbles.
23 -25.5	Clay, silty, dark-olive-gray and olive-gray-brown.
25.5-37.5	Sand, fine- and very fine-grained, silty, gray, salt and pepper appearance, laminated; thin cemented sand around 27 feet; olive-gray below 31 feet.
37.5-50	Silt, olive-gray and gray; laminated, iron-stained; sandy in the last 5 feet.

Depth (ft.)	Lithologic Description
HB-90 SESESW Sec 2, T144N, R88W Elev. 1 910	
0 - 3	Loam, fine-grained, sandy, gray-brown.
3 - 6.5	Sand and gravel, light-reddish-brown; sand, mostly fine-grained, silt to small cobbles present.
6.5-30	Silt, coarse-grained, iron-stained, light-olive-brown; some very fine-grained sand in places, laminated, iron banded, very well-sorted. Slightly carbonaceous and clayey around 12 feet; more clayey, finer grained, and slightly darker in the last 4 feet; includes some iron-stained silty clay.
30 -40.5	Sand, very fine-grained, olive-brown to dark-brown; well-sorted, somewhat silty, carbonaceous; olive-gray, iron-stained clay in the last 5 feet.
40.5-45	Silt, coarse-grained, olive-brown; some very fine-grained lignitic sand included; gray, iron-stained silty clay near the bottom.
HB-91 SESESE Sec 3, T144N, R88W Elev. 1 870	
0 -12.5	Loam, silty, dark-gray-brown; generally silt-size material with occasional sand and pebble-sized scoria fragments.
12.5-18	Loam, sandy, dark-gray-brown; scoria chips.
18 -30	Loam, clayey, dark-gray-brown; a few scoria chips; some fine-grained sand, especially in the last 3 feet.
HB-92 SESENW Sec 22, T144N, R88W Elev. 1 960	
0 - 4.5	Loam, gray-brown.
4.5- 7	Silt, light-gray to olive-gray; laminated.
7 - 8.5	Silt, iron-stained, yellow-brown; iron concretions.
8.5-15.5	Silt to silty clay, iron-stained, lignitic, laminated; clay from 10 to 11 feet.
15.5-22	Clay, silty, lignitic, dark-gray to dark-brownish-gray; thin lignite(s) at about 20 feet.
22 -31.5	Silt and coarse-grained silt, gray to dark-gray.
31.5-34.5	Clay, silty, gray; hard, increasingly calcareous downward.
34.5+	Limestone; too hard to drill.
HB-93 SWSWSW Sec 22, T144N, R88W Elev. 1 937	
0 - 1	Loam, silty, gray-brown.
1 -16	Pebble loam, clayey; light-olive-brown from 1 to 8 feet, olive-yellow-brown from 8 to 16 feet; sandy from 6 to 7 feet.
16 -20	Sand, fine- to medium-grained, brown; moderately sorted, coarse-grained sand and pebbles.
20 -34	Sand, fine- to medium-grained, brown; better sorted than above, some coarse-grained sand and small pebbles, lignitic and scoriaceous; pebble and small cobble layers from 26 to 27.5 feet. Pebbles and small sandstone cobbles in the last 4 to 5 feet.
34 -34.5	Silt, dark-gray.
34.5+	Siltstone or sandstone; too hard to drill.

Depth (ft.)	Lithologic Description

HB-94
SWSWNW Sec 27, T144N, R88W
Elev. 1 795

0 - 2	Loam, sandy, grayish-brown.
2 - 6.5	Loam, silty, gray-brown.
6.5-15	Sand, very fine- to fine-grained, silty, brown; some medium-grained sand, well-sorted.
15 -22	Sand, very fine- to fine-grained, silty, brown; less well-sorted than the above; medium- and coarse-grained sand, pebbles, and a few cobbles; carbonaceous layers.
22 -35	Pebble loam, clayey, dark-gray; scoria chips and other pebble-sized material.

HB-95
NENENW Sec 27, T144N, R88W
Elev. 1 917

0 - 2	Loam, brownish-gray.
2 - 3	Loam, light-yellow-brown.
3 - 9	Silt, sandy, light-olive-brown to mottled olive-gray; some silty, very fine-grained sand.
9 -12.5	Silt, iron-stained, olive-yellow-brown.
12.5-13.5	Clay, lignitic, dark-gray; mottled olive-gray.
13.5-16.5	Lignite; soft.
16.5-22	Silt, coarse-grained, lignitic, iron-stained, light-olive-gray-brown.
22 -29	Silt, sandy, light-olive-brown; laminated, lignitic in places; thin lignite at about 29 feet.
29 -35	Clay and silty clay, dark-gray to dark-greenish-gray; lignitic in places; thin lignite at about 33 feet.
35 -50	Clay, silty, to coarse-grained silt, dark-gray to blue-gray; laminated; sandy toward the bottom.

HB-96
NENENE Sec 27, T144N, R88W
Elev. 1 850

0 - 5	Loam, fine-grained, gray-brown.
5 -13.5	Loam, dark-olive-brown; pebble-sized scoria chips.
13.5-18	Sand, very fine-grained, silty, brown; some scoria chips. Pebbly from 16-17.5 feet consisting of scoria, sandstone, and iron concretions.
18 -25	Sand, very fine- to fine-grained, silty, iron-stained, orange to yellow-brown; salt and pepper.
25 -27.5	Lignite.
27.5-37	Silt and silty clay, dark-blue-gray to gray; laminated; lignitic in spots; some sandy silt.
37 -40	Lignite, hard, water.
40 -50	Clay and silty clay, lignitic, dark-gray to blue-gray; silt laminae toward the bottom.

HB-97
NENWSE Sec 19, T144N, R87W
Elev. 1 900

0 - 4.5	Pebble loam, clayey, light-gray-brown.
4.5-16.5	Sand, fine-grained, pebbly, gray-brown; medium- and coarse-grained sand and small pebbles common.
16.5-34	Sand, very fine- to fine-grained, olive-brown; salt and pepper appearance; somewhat silty; iron concretions and staining around 26 feet.

Depth (ft.)	Lithologic Description
34 -36	Lignite.
36 -40	Clay and silty clay, gray to dark-gray.
40 -46	Silt and sandy silt, coarse-grained, blue-gray to gray; laminated; possibly a little silty clay at the bottom.
46 -51	Lignite.
51 -55	Clay and silty clay, olive-gray to gray.

HB-98
SESENW Sec 18, T144N, R87W
Elev. 2 025

0 - 3	Loam, silty, gray-brown.
3 -10	Pebble loam, clayey, light-olive-gray-brown to olive-brown.
10 -22	Silt to sand, very fine-grained, iron-stained, olive-yellow-brown; salt and pepper appearance.
22 -37	Silt to sand, very fine-grained, iron-stained, olive-gray; salt and pepper appearance; calcareous, cemented sand from 28.5-29.5 feet.
37+	Sandstone; too hard to drill.

HB-99
NENESE Sec 18, T144N, R87W
Elev. 1 963

0 -13	Pebble loam, clayey, olive-gray-brown, mottled gray, very clayey toward the bottom; not much coarse-grained material other than lignite and scoria chips.
13 -28	Sand, very fine- to fine-grained, olive-brown to olive-gray-brown; somewhat silty, salt and pepper appearance.
28 -30	Sand, very silty, olive-brown.
30 -38	Sand, very fine- to fine-grained, silty, olive-brown to brown; some coarse sand-sized scoria, lignite, and iron concretions.
38 -40	Sand, very fine-grained, very silty, gray-brown.
40 -50	Sand, very fine- and fine-grained, silty, olive-brown to olive-gray-brown; salt and pepper appearance.

HB-100
NENESE Sec 19, T144N, R87W
Elev. 1 918

0 - 2	Pebble loam, clayey, light-olive-brown.
2 - 6	Pebble loam, clayey, sandy, light-olive-brown.
6 -19	Pebble loam, clayey, dark-olive-brown and olive-gray-brown; very little coarse material, mostly clay balls and iron concretions, some small cobbles; very little lignite apparent; dark, carbonaceous layer at 18 feet.
19 -30	Pebble loam, clayey, olive-gray-brown; more pebbly than the above, some cobbles and lignite fragments.
30 -50	Pebble loam, clayey, brown to gray-brown; not as much coarse material as above.

HB-101
SESENW Sec 30, T144N, R87W
Elev. 1 770

0 -15	Loam, clayey, gray-brown changing to olive-gray-brown; a few coarse sand grains and small pebbles; fining downward; mottled gray toward the bottom.
15 -25	Clay and silty clay, blue-gray to gray; sandy near the top; mottled olive-gray and brown; wet.
25 -27	Loam, silty, clayey, gray to blue-gray; some fine-grained sand, very wet.
27 -30	Sand, fine-grained, very silty, dark-gray; a few coarse sand grains; very wet.

Depth (ft.)	Lithologic Description

HB-102
SENENE Sec 30, T144N, R87W
Elev. 1 770

0 - 1.5	Loam, fine-grained, sandy, light-brown.
1.5- 5	Sand, fine- to medium-grained, silty, lignitic, brown; well-sorted, some coarse-grained sand and small pebbles.
5 -11.5	Sand, fine- to medium-grained, silty, dark-brown; some large pebbles and rare cobbles.
11.5-15	Sand, fine-grained, brown; very well-sorted, some very fine- and medium-grained sand.
15 -18.5	Sand, fine- to medium-grained, brown.
18.5-19.5	Clay, silty, greenish-gray and dark-gray.
19.5-25	Sand, fine-grained, silty, dark-gray; well-sorted, some coarse-grained sand and small pebbles, wet.
25 -30	Clay, silty, sandy, olive-gray to gray; some very fine-grained sand and coarse-grained, sand-sized lignite.

HB-103
NESESE Sec 19, T144N, R87W
Elev. 1 890

0 -20	Pebble loam, clayey, very light-brown changing to olive-brown at 6 feet; mostly fine-grained material, very little lignite.
20 -24	Loam, silty, clayey, olive-gray-brown; very few sand grains.
24 -32	Pebble loam, clayey, dark-olive-brown; small pebbles common; some lignite fragments.
32 -35	Loam, silty, clayey, olive-gray-brown; minor sand.
35 -40.5	Loam, silty, clayey, olive-gray-brown; very fine-grained sand with minor coarse-grained sand; some cobbles.
40.5-50	Silt, iron-stained, olive-brown, olive-yellow-brown, and olive-gray; laminated; iron concretions.

HB-104
SESESE Sec 30, T144N, R87W
Elev. 1 768
Drilled in 2-foot ditch.

0 - 4.5	Loam, sandy, gray-brown to brown.
4.5- 7	Loam, olive-gray.
7 -15	Sand, fine-grained, lignitic, brown; very well-sorted, some very fine-grained sand; carbonaceous layer at 11 feet.
15 -21	Sand, fine-grained, brown; some medium- to coarse-grained sand and pebbles.
21 -27.5	Sand, fine- to medium-grained, dark-brown; pebbles common, some small cobbles.
27.5-30	Sand and gravel; dark-brown.

HB-105
SESENE Sec 7, T144N, R86W
Elev. 1 744

0 - 5	Loam, silty, gray-brown.
5 - 8.5	Loam, sandy, brown; some coarse-grained sand and small pebbles.
8.5-15	Pebble loam, sandy, clayey, olive-brown; last 2 feet mostly fine-grained material with an absence of any large pebbles.
15 -20	Clay and silty clay, light-gray to gray; a little lignite toward the top.
20 -43	Silt to sandy silt, olive-gray; compact, gray silty clay layer(s) in the interval from 35 to 40 feet.

Depth (ft.)	Lithologic Description
43 -43.5	Lignite.
43.5-52	Clay and silty clay, lignitic, gray.
52 -54	Lignite; hard.
54 -55+	Clay; difficult to drill.

HB-106
SWSESE Sec 7, T144N, R86W
Elev. 1 741

0 - 5	Loam, pebbly, gray-brown.
5 -24.5	Clay and silty clay, gray to olive-gray; iron concretions, iron-stained in places; thin weathered lignite or lignitic clay at the top; thin, wet lignite at about 15.5 feet.
24.5-25	Sandstone, very hard, 6 to 8 inches thick.
25 -30	Sand, very fine-grained, silty, olive-brown.
30 -33.5	Silt and sandy silt, lignitic, blue-gray; laminated.
33.5-35.5	Lignite.
35.5-40	Clay, silty, blue-gray; lignitic toward the top.
40 -45	Silt to sandy silt, blue-gray.

HB-107
SWNWNW Sec 5, T144N, R86W
Elev. 1 852

0 - 7.5	Pebble loam, light-olive-brown to gray-brown; a few cobbles.
7.5-28.5	Pebble loam, clayey, olive-brown, changing to dark-olive-brown at 16 feet; mottled gray.
28.5-35	Silt, iron-stained, olive-yellow-brown; laminated; iron concretions; light-yellow-brown, laminated, sandy silt toward the bottom.

HB-108
NWNWNE Sec 5, T144N, R86W
Elev. 1 902

0 - 9.5	Pebble loam, clayey, light-gray, changing to olive-brown at 5 feet.
9.5-17.5	Silt and silty clay, iron-stained, olive-gray-brown.
17.5-22.5	Clay and silty clay, iron-stained, gray to olive-gray.
22.5-23	Clay, lignitic, gray.
23 -32	Silt, sandy, to very fine-grained, silty sand; iron-stained, lignitic, olive-gray changing to dark-olive-brown at about 28 feet; laminated.
32 -33	Siltstone, gray to light-blue-gray; calcareous.
33 -36	Silt, sandy, to very fine-grained, silty sand, olive-gray to blue-gray.
36 -41	Lignite; wet.
41 -47	Clay and silty clay, light-bluish-gray to gray; wet.
47 -50	Silt, light-bluish-gray; wet.

HB-109
SESENW Sec 8, T144N, R86W
Elev. 1 740

0 - 5	Loam, fine-grained, light-brown.
5 -13	Loam, silty, clayey, gray-brown; some fine-grained sand.
13 -25	Loam, clayey, olive-brown; very fine-grained.
25 -30	Sand, fine-grained, silty, brown; well-sorted; coarse-grained sand to small pebbles present.

Depth (ft.)	Lithologic Description

HB-110
NWNWNE Sec 9, T144N, R86W
Elev. 1 730
Drilled in 1.5-foot ditch.

0 - 6	Loam, silty, clayey, light-olive-brown; only very fine-grained sand present.
6 -20	Loam, silty, clayey, olive-gray-brown; mottled gray; sand present but rare.
20 -30	Sand, very fine- to fine-grained, silty, lignitic, olive-gray; very well-sorted, wet; dark-brown carbonaceous layer at the top; blue-gray toward the bottom.

HB-111
NENESW Sec 13, T144N, R87W
Elev. 1 782

0 - 5	Loam, sandy, gray-brown; some medium- and coarse-grained sand.
5 - 8.5	Sand, fine- to medium-grained, pebbly, reddish-gray-brown; moderately sorted, silt to large pebbles.
8.5-19	Pebble loam, sandy, clayey, dark-olive-brown; lignite rare, no cobbles.
19 -35	Pebble loam, clayey, lignitic, iron-stained, olive-brown; mottled gray, clay to cobbles.
35 -46	Pebble loam, clayey, dark-gray to olive-gray; lignite and scoria pebbles common.
46 -55	Clay, silty, dark-gray; cohesive and tough; bluish-gray downward.

HB-112
SWNWNW Sec 24, T144N, R87W
Elev. 1 792

0 - 1	Loam, silty, gray-brown.
1 - 4	Loam, light-olive-brown.
4 -13	Silt, sandy, iron-stained, light-gray to light-olive-gray; iron concretions; silt and clay layers.
13 -13.5	Sand, very fine-grained, silty, iron-stained, light-gray; salt and pepper appearance.
13.5-14+	Sandstone, very fine-grained, calcareous; too hard to drill.

HB-113
SESESW Sec 6, T144N, R86W
Elev. 1 828
Drilled in 2-foot ditch.

0 - 9	Pebble loam, clayey, lignitic, iron-stained, olive-brown; many cobbles.
9 -11	Pebble loam, clayey, olive-brown; finer grained than above; mostly only small pebbles; no noticeable lignite.
11 -18.5	Loam, fine-grained, sandy, clayey, olive-gray-brown; only rare coarse-grained sand and small pebbles, no lignite.
18.5-24	Clay, silty, gray to dark-gray; laminated, iron-stained near the top.
24 -28	Clay, silty, dark-brownish-gray; lignitic.
28 -33.5	Lignite; hard, black; brownish-black in spots.
33.5-36.5	Clay and silty clay, lignitic, dark-gray.
36.5-41.5	Lignite; mostly brownish-black.
41.5-50	Silt, sandy, to silty clay, blue-gray; laminated; lignitic in places.

Depth (ft.)	Lithologic Description

HB-114
SESENW Sec 7, T144N, R86W
Elev. 1 763
Drilled in 3-foot ditch.

0 - 5	Loam, fine-grained, sandy, gray-brown to olive-gray-brown.
5 -14	Pebble loam, sandy, clayey, dark-olive-brown; pebble-cobble layer from 6 to 8 feet.
14 -18.5	Pebble loam, sandy, clayey, brown; more pebbly than above.
18.5-30	Clay to silt, blue-gray to gray; 2-inch-thick siltstone at about 25 feet; thin lignite from about 28.5 to 29 feet, underlain by lignitic clay.

HB-115
SESWNE Sec 4, T144N, R86W
Elev. 1 740

0 - 6	Loam, gray-brown.
6 -10	Pebble loam, clayey, dark-olive-brown.
10 -23	Silt, coarse-grained, olive-brown; very well-sorted.
23 -28	Clay, silty, iron-stained, olive-gray-brown to olive-gray; compact.
28 -28.5	Lignite, wet.
28.5-36.5	Clay and silty clay, greenish-gray to blue-gray.
36.5-37.5	Lignite, wet.
37.5-48	Silt, sandy, blue-gray.
48 -49.5	Lignite, wet.
49.5-50	Clay, gray.

HB-116
NWSWNW Sec 18, T144N, R86W
Elev. 1 748
Drilled in 1.5-foot ditch.

0 -21	Loam, clayey, sandy, very fine-grained, dark-gray-brown to dark-olive-gray-brown; olive-brown and wet from 6 feet; mottled dark-gray; increasingly sandy downward. Quite wet from about 12 feet.
21 -30	Sand, very fine-grained, silty, olive-gray-brown; some fine-, medium-, and coarse-grained sand, very wet, lignitic, and scoriaceous; blue-gray sandy clay from about 26 to 27 feet, mottled olive-green.
30 -53	Silt and clay, sandy, blue-gray, mottled olive-green, very wet.
53 -60	Clay, sandy, blue-gray; hard drilling.

HB-117
NWNENE Sec 24, T144N, R87W
Elev. 1 745

0 -10	Silt, sandy, light-brown to brown; some fine sand.
10 -15	Sand, fine- to medium-grained, brown; somewhat silty; some coarse sand.
15 -18	Sand, medium-grained, silty, dark-brown; some coarse sand; much fine sand.
18 -30	Sand, medium-grained, pebbly, silty, dark-brown; fine gravel, scoriaceous and lignitic; thin olive-brown sandy clay with gray mottling between 25 and 30 feet. Wet from about 28 feet.
30 -42	Sand, fine-grained, silty, brownish-gray to olive-gray; medium and coarse sand grains, no pebbles; very wet.
42 -50	Sand, fine-grained, pebbly, silty, brownish-gray to olive-gray; wet cobbles and gravel in last two feet.

Depth (ft.)	Lithologic Description

HB-118
SESESW Sec 7, T144N, R86W
Elev. 1 747

0 -20	Loam; light-gray-brown to dark-gray-brown; only very fine sand present; cohesive at about 6 feet; more clayey from about 10 feet; the last 5 feet olive-brown in color and very cohesive; water at about 20 feet.
20 -37.5	Sand, fine-grained, silty, olive-brown; rare coarse-grained sand; very wet.
37.5-40	Clay, silty, dark-gray, brown mottling.

HB-119
NWNENW Sec 25, T144N, R88W
Elev. 1 841

0 -20	Pebble loam, iron-stained, lignitic, olive-brown to dark-olive-brown; some cobbles.
20 -25	Pebble loam, sandy, dark-brown, contains much fine to coarse sand.
25 -35	Loam, clayey, silty, iron-stained, olive-brown; only very fine sand present, no pebbles; thin clay layers.
35 -41	Sand, very fine, very silty and clayey, olive-brown, some fine sand.
41 -50	Sand, very fine, silty, brown to dark-brown; loose, dry, very dirty appearance; coarse sand to small pebble-size lignite chips; mica flakes common; possibly clayey in spots.

HB-120
SESENW Sec 26, T144N, R88W
Elev. 1 815

0 - 6	Loam, fine-grained, gray-brown and light-brown; few pebbles.
6 -19	Pebble loam, sandy, brown; many small pebbles; not noticeably lignitic; nearly the same as the above material.
19 -30	Silt, sandy to clayey, blue-gray, olive mottling.
30 -44	Silt, sandy, blue-gray.
44 -46	Clay and sandy silt, blue-gray; some lignite grains.
46 -52	Silt, sandy, clayey, blue-gray; lignitic and pebbly.
52 -60	Sand, very fine, silty, lignitic, blue-gray, wet; rare, coarse lignite grains.

HB-121
SWSWNE Sec 26, T144N, R88W
Elev. 1 805

0 - 6	Loam, dark-gray-brown; a few small pebbles.
6 -21	Loam, olive-brown; some small pebbles but no cobbles; lignite rare; cohesive.
21 -24	Sand, fine, very silty, olive-brown, wet.
24 -30	Clay to sandy silt, blue-gray; lignite fragments; green near the top.

HB-122
NWNWNE Sec 26, T144N, R88W
Elev. 1 894

0 - 1.5	Loam, organic, dark-brown.
1.5-50	Pebble loam, iron-stained, lignitic, sandy, olive-brown; dark-olive-brown at about 25 feet; carbonate cobbles, scoria, iron concretion, greenstone, and carbonate pebbles.
50 -70	Pebble loam, dark-gray; as above, but wet, possibly a thin sandy layer at 50 feet; drills somewhat easier.
70 -75	Clay, silty, to sandy silt, dark-bluish-gray.

Depth (ft.)	Lithologic Description

HB-123
SWNESE Sec 36, T144N, R88W
Elev. 1 790

0 -22	Sand, fine, silty, dark-brown and brown; medium and coarse sand and a few pebbles, rare small cobbles.
22 -25	Sand, fine, silty, lignitic, very dark-brown.
25 -33.5	Sand, fine to medium, silty, dark-brown; some coarse sand and small pebbles, very wet.
33.5-40	Gravel, cobbly; no samples; hard drilling.

HB-124
NWNWNW Sec 35, T144N, R88W
Elev. 1 778

0 - 5	Sand, fine to medium, silty, lignitic, brown and dark-brown.
5 - 7	Sand, very fine to fine, silty, light-brown; some coarser grains.
7 -10	Sand, very silty, gray-brown; rather poorly sorted, very fine to very coarse sand and very fine gravel; scoriaceous and lignitic.
10 -10.5	Clay, sandy, olive-gray.
10.5-15	Sand, medium-grained, brown; very fine to coarse sand, much fine sand, a few small pebbles; little silt.
15 -23.5	Sand, medium-grained, brown; lignitic, some silt, much coarse sand and a few scoria chips and small flat pebbles, moderately well-sorted, wet.
23.5-24	Clay, sandy, very organic, black.
24 -37.5	Gravel, coarse; large pebbles and small cobbles.
37.5-50	Silt, sandy, to very fine silty sand, blue-gray; lignitic in spots, micaceous, cohesive.

HB-125
SWSWSESW Sec 34, T144N, R88W
Elev. 1 794

0 - 6.5	Sand, very fine to fine, very silty, brown; moderately well-sorted, some medium and coarse grains.
6.5-15	Silt, sandy, olive-brown and gray-brown; laminated, consistent, coarsening downward; last 3 to 4 feet laminated with fine brown sand.
15 -21	Sand, fine-grained, brown; very well-sorted, some very fine and medium sand.
21 -23	Sand, medium-grained, pebbly, silty, dark-brown; lignite and other pebbles; much coarse sand; wet.
23 -29.5	Sand, coarse-grained, very pebbly, dark-brown; scoria, lignite, and other pebbles; some small cobbles; much medium sand; brownish-gray to dark-gray in the last 3 feet or more; wet.
29.5-30	Silt, sandy, blue-gray.
30 -35	Gravel, no samples; drilled like cobbly gravel.

HB-126
SWNWSWSW Sec 24, T144N, R88W
Elev. 1 845 (approx.)

0 - 1.5	Silt, sandy, dark-brown.
1.5- 6	Silt, sandy, cobbly, light-gray.
6 - 9	Pebble loam, sandy, iron-stained, lignitic, olive-brown.
9 -12.5	Sand, fine to medium, silty, brown, lignitic; a few pebbles and coarse sand grains.
12.5-14	Sand, medium to coarse, silty, pebbly, reddish-brown; moderately sorted.
14 -24	Pebble loam, lignitic, iron-stained, olive-brown, sandy; many pebbles and cobbles.

Depth (ft.)	Lithologic Description
24 -35	Pebble loam, brownish-gray; lignite, scoria, and some carbonate pebbles; first 2 to 3 feet appear to be more a sandy silt--lacks pebbles but some consistency as pebble loam; dark-gray from about 30 feet with many pebbles.
35 -40	Silt, clayey, to silty clay, blue-gray; olive clay inclusions.
40 -50	Silt, sandy, to very fine silty sand, blue-gray; some coarse sand-size lignite and fine mica flakes; appears laminated; drills somewhat easier than pebble loam; olive clay inclusions; wet in the last foot or more.

HB-127
NWNENWSW Sec 24, T144N, R88W
Elev. 1 894
Drilled in 4-foot ditch.

0 -10	Pebble loam, lignitic, iron-stained, olive-brown.
10 -12.5	Sand, fine-grained, silty, olive-brown; medium to coarse sand and some pebbles present; moderately well-sorted.
12.5-15.5	Sand, medium-grained, silty, pebbly; cobble layer at top, cobbles also in the sand; all sand sizes, much coarse sand.
15.5-30	Pebble loam, iron-stained, dark-olive-brown to dark-brown; many lignite pebbles.
30 -37	Loam, clayey, olive-gray-brown; some small pebbles; tough.
37 -40	Clay, silty, olive-brown.
40 -50	Sand, fine-grained, silty, lignitic, very dark-brown, dry; coarser sand and pebbles present, olive-brown and gray, lignitic, sandy clay to clayey sand stringers common; sand gray-brown in last few feet.

HB-128
NESENENE Sec 14, T144N, R88W
Elev. 2 020 (approx.)
Drilled in 3-foot ditch.

0 - 6	Loam, dark-gray-brown; grading down to pebble loam.
6 -42	Pebble loam, lignitic, iron-stained, olive-brown; carbonate and other cobbles not of local origin; pebbles common but fewer with depth; dark-olive-brown from about 20 feet.
42 -43	Clay, silty, slightly purplish-gray; hard, slightly lignitic.
43 -57	Lignite, black.
57 -60	Silt, sandy, olive-gray to blue-gray.

HB-129
NESWSWSW Sec 3, T144N, R86W
Elev. 1 726

0 -10	Silt, sandy, very fine-grained, light-brown; sand grains getting somewhat coarser downward.
10 -11	Sand, very fine to fine, silty, light-brown.
11 -22.5	Sand, medium-grained, brown; well-sorted; generally getting coarser with depth; small lignite and scoria chips; wet in the last 2 feet.
22.5-23	Clay, silty, olive-brown.
23 -25	Sand, medium-grained, brown; well-sorted; wet.
25 -29	Sand, medium-grained, silty, pebbly, dark-gray; lignite and scoria pebbles; wet.
29 -30	Gravel, wet.

Depth (ft.)	Lithologic Description

HB-130
NENWNWNE Sec 3, T144N, R86W
Elev. 1 754 (approx.)

0 -12	Loam, clayey, light-gray-brown to olive-brown; some small lignite grains and coarse sand.
12 -16	Loam, clayey, brown, moist, small pebbles, many scoria chips and some lignite grains.
16 -25	Loam, clayey, olive-brown; wet, tough, some lignite but no pebbles, few scoria chips, most sand very fine; getting wetter downward.
25 -26.5	Loam, sandy, pebbly, olive-brown; pebbles angular; much water.
26.5-30	Loam, clayey, olive-brown; very wet; no pebbles. Last 2 feet or more quite lignitic with some small pebbles.

HB-131
NENENE Sec 3, T144N, R86W
Elev. 1 745

0 - 9	Loam, clayey, lignitic, olive-brown.
9 -20	Loam, dark-gray-brown to dark-brown; moist, some very coarse sand, scoria pebbles, and a few lignite grains; wet in the last 4 feet.
20 -28	Pebble loam, dark-brown; many more pebbles than above, lignite fragments common, occasional small cobbles in the last 2 feet; wet and more pebbly with depth.
28 -30.5	Sand, gravelly.
30.5-50	Sand, fine-grained, silty, iron-stained, blue-gray to blue, olive mottling, lignite laminae; somewhat cemented in places; moist and cohesive.

HB-132
NWNWNWNW Sec 1, T144N, R86W
Elev. 1 720
Drilled in 2-foot ditch.

0 - 5.5	Loam, clayey, olive-gray-brown.
5.5-12	Sand, very fine to fine, silty, clayey, brown.
12 -17.5	Sand, fine to medium, brown; some dark-brown organic layers and gray clayey layers; not as cohesive as above sand; general coarsening downward.
17.5-25	Sand, medium to coarse, silty, dark-brown and dark-gray-brown, wet; some very coarse sand, lignitic and scoriaceous; 6-inch-thick olive-gray sandy clay layer at about 21 feet.
25 -35	Sand, medium to coarse, pebbly, dark-gray; fine sand to fine gravel; much very coarse sand, somewhat silty, very wet.

HB-133
NWSWSWSE Sec 8, T144N, R86W
Elev. 1 730
Drilled in 6-foot ditch.

0 -14	Loam, sandy, clayey, olive-gray-brown, cohesive, laminated, some fine sand; a little iron-stained gray clay toward bottom.
14 -21	Sand, fine-grained, brown; very well-sorted, much very fine sand; coarsens downward.
21 -25.5	Sand, medium-grained, gray-brown; lignitic; much coarse and very coarse sand and fine sand; wet.
25.5-26	Clay, gray, small wood fragments.
26 -35	Sand, medium-grained, gray; very wet; small lignite pebbles and much coarse and very coarse sand; clayey beds in sand, a few wood fragments.

Depth (ft.)	Lithologic Description

HB-134
SWSWNW Sec 12, T144N, R88W
Elev. 1 981
Drilled in 6-foot ditch.

0 - 6	Silt, sandy, olive-brown to gray.
6 - 8	Sand, very fine-grained, very silty, gray.
8 -10	Silt, clayey, dark-gray; soft.
10 -11	Clay, silty, dark-gray; hard.
11 -12	Silt, clayey, dark-gray; soft.
12 -17.5	Clay, silty, and clay, dark-gray, hard; thin, buff-colored hard rock at 17.5 feet.
17.5-23	Clay, silty, and clay, lignitic, dark-brownish-gray, hard; some very thin lignite beds.
23 -30	Sand, very fine-grained, silty, blue-gray; some fine sand and lignitic laminae present.
30 -32	Clay, silty, lignitic to very lignitic, dark-brownish-gray, hard to very hard.
32 -49	Lignite, black; hard drilling; samples mostly dry powder.
49 -55	Silt, sandy, lignitic, light-gray-brown; grading down to blue-gray, very fine, silty sand.

HB-135
SESENE Sec 24, T144N, R88W
Elev. 1 920 (approx.)

0 - 1.5	Silt, sandy, brown.
1.5-42.5	Pebble loam, lignitic, light-gray-brown to olive-brown to olive-gray-brown; occasional cobbles, especially toward the top--granite-gneiss, greenstone, carbonate, iron concretion, and chert; becoming generally darker and finer-grained downward with occasional cobbles.
42.5-52	Sand, fine- to medium-grained, iron-stained, olive-gray-brown; slightly silty; salt and pepper appearance with small cemented balls of sand; hard, lignitic, and very fine toward the bottom.
52 -57.5	Clay and silty clay, lignitic, dark-bluish-gray; thin lignite seams present.
57.5-59.5	Lignite.
59.5-63	Clay, silty, lignitic, dark-blue-gray.
63 -65	Lignite.
65 -70	Silt, sandy, and silty, bluish-gray, hard.

HB-136
SENESE Sec 24, T144N, R88W
Elev. 1 856 (approx.)

0 - 2	Silt, sandy, dark-brown.
2 - 4	Gravel, cobbly; very poorly sorted, silt to cobbles.
4 -28.5	Pebble loam, lignitic, iron-stained, olive-brown to olive-gray-brown, many pebbles.
28.5-30	Silt, sandy, very fine-grained, light-grayish-brown; cohesive.
30 -32	Sand, fine-grained, silty, pebbly, dark-brown; water.
32 -40	Pebble loam, sandy, lignitic, iron-stained, olive-brown.
40 -44	Silt, sandy, to very fine silty sand, gray to bluish-gray; olive-green clay inclusions; detrital lignite grains up to small pebble-size and rare coarse iron concretion grains.
44 -50	Sand, fine-grained, gray-brown, wet; some coarse and very coarse sand; some occasional small pebbles toward the bottom.

Depth (ft.)	Lithologic Description

HB-137
NENWNWSE Sec 24, T144N, R88W
Elev. 1 902 (approx.)
Boulders at surface.

0 - 5.5	Sand and gravel, light-gray-brown to red-brown; silty, very fine to very coarse sand; gravel up to cobble size.
5.5- 8.5	Pebble loam, lignitic, olive-brown.
8.5-10	Sand, fine to medium, pebbly, brown; pebbles consist of fragments of iron concretions, sandstone, and limestone.
10 -13	Sand, fine to medium, olive-brown; well-sorted, pebble-free, loose.
13 -17.5	Sand, fine to medium, pebbly, brown; iron concretions, sandstone, limestone, and scoria pebbles; sandstone cobbles with selenite crystals towards bottom.
17.5-22.5	Clay, silty, lignitic, dark-gray; laminated toward the middle with very fine sandy silt; iron concretions present.
22.5-24.5	Lignite, poor quality.
24.5-30.5	Silt, sandy, and very fine silty sand, iron-stained, olive-gray-brown; laminated; iron concretions with large selenite crystals present.
30.5-33.5	Clay, silty, dark-gray; lignitic in places, especially toward the bottom; hard.
33.5-37	Lignite, black, hard.
37 -40	Sand, very fine-grained, silty, gray-brown.
40 -42	Silt, sandy, blue-gray.
42 -50	Clay to silt, dark-gray; hard.

HB-138
SESWSWSE Sec 24, T144N, R88W
Elev. 1 830 (approx.)

0 - 6.5	Sand and gravel, cobbly, light-gray-brown; interbedded with fine to medium pebbly sand.
6.5-27	Pebble loam, lignitic, olive-brown; small pebbles present.
27 -34	Clay, silty, iron-stained, light-brown; very fine sandy silt to clay present.
34 -45	Silt, sandy, very fine-grained, light-brown; cohesive, moist, pliable; fine mica flakes; dark-gray around 40 feet.
45 -50	Sand, very fine-grained, very silty, dark-gray; moist and pliable; some fine sand; occasional coarse and very coarse lignite grains; wet toward the bottom.

HB-139
NWSWSWSW Sec 36, T144N, R88W
Elev. 1 880

0 -74	Sand, very fine and fine, silty, light-gray; moist and slightly cohesive from near the top; iron-stained brown in several places; occasional concretions consisting of iron-cemented sand; light-olive-gray from about 20 feet, olive-gray-brown from about 25 feet, thin iron-cemented zones at 33 and 37 feet; more a silty fine sand from about 40 feet; iron-cemented zones between 50 and 55 feet and at 59 feet; getting darker brown and less silty with depth; more silty and slightly finer around 60 feet; blue-gray in the last 10 feet or more, with cemented sand; salt and pepper appearance.
74 -75+	Lignite; wet.

HB-140
NWNESENW Sec 36, T144N, R88W
Elev. 1 840

0 - 6	Sand, fine to medium, silty, dark-gray-brown to gray-brown; coarse sand present.

Depth (ft.)	Lithologic Description
6 -20.5	Pebble loam, very sandy, dark-olive-brown; iron concretion, scoria and clay pebbles; occasional iron concretion and sandstone cobbles.
20.5-33	Sand, fine-grained, silty, olive-yellow-brown to olive-brown; much very fine sand, iron-stained brown in places; salt and pepper appearance.
33 -36.5	Lignite; moist.
36.5-38	Clay, silty, dark-gray.
38 -41.5	Lignite.
41.5-42	Clay, silty, lignitic, dark-brownish-gray.
42 -50	Silt and very fine sandy silt, blue-gray; laminated and lignitic in places; very fine silty sand toward the bottom.

HB-141
SWSWNW Sec 30, T144N, R87W
Elev. 1 769

0 - 7	Loam to clayey loam, gray-brown; last foot appeared to be more a pebble loam; lignitic, with a greenstone cobble.
7 -11	Sand, very fine-grained, silty, brown; some fine sand.
11 -17.5	Sand, coarse-grained, silty, pebbly, reddish-brown; pebble-cobble near the top; very fine to very coarse sand; many scoria chips.
17.5-18	Clay, silty, olive-gray.
18 -22	Sand, medium to coarse, silty, pebbly, dark-brown; much fine sand and silt; very wet.
22 -30	Sand, fine to medium, silty, olive-gray; some coarse sand and occasional small pebbles; very wet.
30 -35	Sand, very fine and fine, silty, blue-gray; cohesive, drills with difficulty; occasional very coarse sand grains and lignite up to small pebble size.

HB-142
SESWNWNE Sec 20, T144N, R87W
Elev. 1 986

0 - 6	Pebble loam, light-gray-brown; very loose; some cobbles.
6 -11	Lignite, powdery, slightly damp.
11 -19.5	Silt, sandy, very fine-grained, iron-stained, light-gray to light-olive-gray.
19.5-20	Sand, very fine-grained, cemented.
20 -36	Silt, sandy, very fine-grained, gray; iron-stained, and iron-cemented in places; olive-yellow-brown and hard around 33 feet; occasional small selenite crystals.
36 -38	Silt, sandy, very fine-grained, blue-gray, hard.
38 -39	Silt, sandy, very fine-grained, olive-gray-brown; lignitic laminae.
39 -42	Sand, very fine-grained, silty, olive-gray-brown; lignitic laminae.
42 -46	Silt, sandy, very fine-grained, olive-brown; thinly laminated in places.
46 -50	Silt, sandy, very fine-grained, dark-gray to bluish-gray; laminated.

HB-143
SWSWSWSW Sec 33, T144N, R87W
Elev. 1 927 Drilled in 1-foot ditch.

0 - 1	Silt, sandy, dark-brown.
1 - 9	Pebble loam, very lignitic, iron-stained, olive-brown; granite, carbonate and flint pebbles.
9 -10	Siltstone, sandy, very hard.
10 -14	Silt, sandy, very fine-grained, brown; iron-stained in spots.
14 -15	Silt and iron concretions, orangish-brown.
15 -17.5	Lignite, soft.
17.5-19	Silt and clayey silt, lignitic, light-brownish-gray to light-greenish-gray.

Depth (ft.)	Lithologic Description
19 -31	Silt to clayey silt, light-green; light-blue-green in places; relatively indurated; thin lignitic zone around 30 feet.
31 -40	Silt and clayey silt, dark-bluish-gray to dark-gray, indurated; some very fine sandy silt around 36 feet.
40 -50	Silt and very fine sandy silt, dark-gray; some thin limestone; last 5 feet or more mostly very fine sandy silt, hard laminated in places, approaching very fine silty sand.

HB-144
SWSWSW Sec 36, T144N, R87W
Elev. 1 908
Drilled in 1-foot ditch.

0 - 0.5	Loam, sandy, fine-grained, dark-brown.
0.5-16	Pebble loam, lignitic, iron-stained, olive-brown; many pebbles and small cobbles; carbonate, greenstone, granite, scoria, iron concretion and others.
16 -32	Silt, sandy, very fine, iron-stained, light-olive-brown; pliable, soft and loose; harder with depth; iron concretions at 20 and 24 feet.
32 -34	Clay, silty, lignitic, dark-gray-brown.
34 -37.5	Lignite.
37.5-39	Clay, lignitic, dark-gray.
39 -43.5	Clay, silty, to silt, blue-gray to dark-bluish-gray; laminated in places.
43.5-46	Lignite, poor quality.
46 -50	Silt, sandy, very fine, light-blue-greenish-gray; lignitic toward top.

HB-145
SENWNWSW Sec 19, T144N, R86W
Elev. 1 751 (approx.)

0 - 4.5	Sand, fine-grained, silty, dark-gray-brown to gray-brown; some medium sand.
4.5- 5.5	Sand, very fine-grained, silty, light-brown.
5.5- 9.5	Sand, fine-grained, light-brown, loose, very well-sorted; some medium sand.
9.5-13	Sand, medium-grained, light-brown, well-sorted; some coarse and very coarse sand and occasional small pebbles; thin clayey layer at about 13 feet.
13 -24.5	Sand, medium-grained, lignitic, brown to reddish-brown, moderately well-sorted; coarse and very coarse sand; small pebbles, rare scoira chips; much fine sand; sandy clay layers at 15 and 21 feet; wet from about 21 feet.
24.5-25	Clay, gray.
25 -31	Sand, medium-grained, gray-brown; as sand above, wet.
31 -45	Sand, medium to coarse, pebbly, dark-gray; small pebbles, rare lignite cobbles; wet.

HB-146
NENENENE Sec 28, T144N, R86W
Elev. 1 879

0 - 5	Sand, very fine to fine, silty, dark-gray-brown to brown; medium and some coarse sand; occasional very coarse quartz grains.
5 -11.5	Pebble loam, lignitic, iron-stained, olive-gray-brown; lower foot or more reworked, bedrock.
11.5-17.5	Clay, silty, to silt, iron-stained, olive-gray-brown to gray; iron concretions present; lignitic at about 14.5 feet; dark-olive-gray from 15 feet.
17.5-22	Silt, sandy, and silt, olive-gray and gray; laminated.
22 -29	Clay, silty, and clayey silt, gray to dark-olive-gray; hard, limy zones; lignitic toward bottom.
29 -35.5	Lignite; very hard drilling from 31 feet; water in last two feet.
35.5-40	Silt, sandy, slightly greenish-gray; lignitic in spots, approaching very fine silty sand from 37 to 39 feet.

Depth (ft.)	Lithologic Description
40 -48	Silt and silty clay, gray; silt 40 to 42 feet, silty clay 42 to 45 feet, silt 45 to 48 feet.
48 -48.5	Lignite.
48.5-50	Silt, sandy, greenish-gray.

HB-147
NWSWSWNW Sec 26, T144N, R86W
Elev. 1 904 (approx.)

0 - 6	Sand, fine-grained, brown; very fine to medium sand common; some coarse and occasional very coarse sand, somewhat silty; gray from about 3 feet, wet from 4.5 feet; black, and very lignitic and organic near the bottom.
6 - 9	Sand, clayey, iron-stained, gray-brown; sandy clay toward bottom.
9 -12	Sand, fine to medium, gray; a few pebbles; wet.
12 -13.5	Pebble loam, lignitic, dark-gray.
13.5-15.5	Sand, fine to medium, pebbly, gray; very wet.
15.5-20	Pebble loam, lignitic, dark-gray.
20 -28	Sand, medium-grained, pebbly, dark-gray; much coarse sand, wet.
28 -35	Silt, sandy, to very fine silty sand, bluish-gray; hard at 28 feet.

HB-148
NENENE Sec 34, T144N, R86W
Elev. 1 952

0 - 1.5	Silt, sandy, gray-brown.
1.5-16	Silt, sandy, and silt, brown and olive-gray-brown; very thinly laminated, iron concretion layers at 2.5 and 12.5 feet.
16 -19.5	Sand, very fine and fine, silty, brown.
19.5-31	Sand, fine-grained, silty, blue-gray; relatively cohesive, moist; carbonate-cemented sand 25 to 27.5 feet, hard drilling; sand finer from 25 feet.
31 -34	Lignite, hard, wet near the bottom.
34 -40	Silt and clayey silt, blue-greenish-gray.
40 -42	Lignite, interbedded with clay.
42 -50	Clay, silty, light-blue-gray; possibly some clayey silt.

HB-149
SWSWNW Sec 36, T144N, R86W
Elev. 1 974

0 - 3.5	Sand, fine-grained, silty, gray-brown to brown; loose, well-sorted, very fine to medium sand present.
3.5-11	Sand, medium-grained, brown; much fine sand, some coarse grains; clayey layer around 9 feet; sand coarser below with a few very coarse grains.
11 -16	Pebble loam, sandy, very iron-stained, olive-gray-brown.
16 -22	Pebble loam, dark-gray; carbonate and metamorphic cobbles.
22 -25.5	Sand, fine-grained, silty, olive-gray-brown; wet, some coarse sand present.
25.5-35	Clay, silty, to sandy silt, dark-olive-gray; cohesive and tough, but easy drilling; detrital lignite up to small pebble size present; appears lignitic or organic in places.

HB-150
SESWNWNE Sec 35, T144N, R86W
Elev. 1 979

0 - 1.5	Loam, very organic, black.
1.5- 6	Sand, fine to medium, brown, well-sorted; wet from about 4.5 feet; pebbles at bottom.

Depth (ft.)	Lithologic Description
6 - 9	Sand, clayey, to sandy silt, brown; lignitic around 8.5 feet, iron concretions.
9 -24	Clay, silty, blue-greenish-gray to bluish-gray; indurated; siltstone at 22 feet; thin lignite seams from 23.5 to 24 feet.
24 -29	Silt, clayey, and silty clay, blue-gray to gray.
29 -36	Silt to very fine sandy silt, blue-gray to gray; some clayey silt.
36 -40	Silt and clayey silt, blue-gray to gray; thin siltstone at about 38 feet.
40 -47	Silt and very fine sandy silt, blue-gray to gray.
47 -50	Lignite, hard.
50 -55	Silt and clayey silt, lignitic; silty clay directly below lignite.
55 -60	Silt, hard, cemented.
60 -75	Silt and very fine sandy silt; mostly sandy silt in last 10 feet, cemented in places.

HB-151
NWNWNWNW Sec 25, T144N, R86W
Elev. 1 936

0 - 8	Sand, fine-grained, brown; much very fine and medium sand; a few coarse grains and rare very coarse grains.
8 -19.5	Pebble loam, lignitic, iron-stained, brownish-gray; many pebbles and carbonate cobbles.
19.5-25	Silt to clayey silt, light-olive-gray; indurated.
25 -31	Clay and silty clay, dark-gray and olive-gray; tough; lignite in spots.
31 -32	Lignite; water.
32 -40	Silt, coarse-grained, blue-gray; thinly laminated; lignitic in spots; approaching sandy silt.
40 -46	Silt, sandy, blue-gray; lignitic in spots; generally coarsening downward from 32 feet.
46 -50	Clay, silty, and clayey silt, dark-gray; some thin, light-gray siltstone.
50 -55	Silt, sandy, blue-gray; possible thin lignite.

HB-152
SESENW Sec 36, T144N, R86W
Elev. 2 045

0 - 2	Sand, fine-grained, silty, dark-brown to brown; medium and coarse sand present.
2 -11	Pebble loam, lignitic, iron-stained, light-gray-brown to olive-brown.
11 -15.5	Pebble loam, very iron-stained, brown; thin black clay directly below.
15.5-20.5	Silt, olive; slightly lignitic.
20.5-23.5	Clay, silty, olive-gray; lignitic towards bottom with very thin lignite seams.
23.5-25	Sand, very fine, silty, and very fine sandy silt, olive-gray.
25 -38	Silt, coarse-grained, and very fine sandy silt, blue-gray; laminated and lignitic in places; some clayey silt.
38 -42	Clay, silty, gray; indurated.
42 -46	Silt and clayey silt, gray.
46 -49	Silt, coarse-grained, and very fine sandy silt, gray to greenish-gray; laminated.
49 -50	Lignite; mostly poor quality, appears to have clay partings; water.
50 -55	Silt, coarse-grained, blue-green; approaching very fine sandy silt; lignitic at the top.

HB-153
NWNENW Sec 36, T144N, R86W
Elev. 1 992 (approx.)
Drilled in 1.5-foot ditch.

0 - 2	Sand, fine-grained, silty, brown; medium and coarse sand present, pebbles at bottom.

Depth (ft.)	Lithologic Description
2 - 5.5	Pebble loam, lignitic, iron-stained, olive-brown; mottled gray; some pebbles and cobbles.
5.5- 7.5	Silt, sandy, brown.
7.5- 9	Sand, very fine, silty, olive-brown.
9 -11	Silt, clayey; olive-brown and bluish-gray.
11 -20	Silt and coarse silt, gray to bluish-gray.
20 -24.5	Clay and silty clay, bluish-gray, indurated; brownish-gray, lignitic, and hard toward bottom.
24.5-25	Lignite, hard, poor quality.
25 -30	Clay, silty, dark-olive-gray; thin lignite at 27 feet, possibly other very thin lignite seams.

HB-154
SWSWSESW Sec 12, T144N, R86W
Elev. 1 840 (approx.)

0 - 2.5	Sand, fine-grained, silty, brown; medium to very coarse sand present, with rare small pebbles.
2.5-16	Pebble loam, lignitic, iron-stained, mottled gray.
16 -17.5	Sand, very fine-grained, silty, brown; wet.
17.5-19.5	Silt, sandy, to clayey silt, olive-gray.
19.5-30	Pebble loam, olive-gray-brown; pebbles small and mostly lignite, but some pebbles not of local origin; changing to dark-gray at about 23 feet; large limestone cobble at 23 feet.
30 -37	Clay, silty, to clayey silt, dark-olive-gray; tough; lignite pebbles; more a pebble-clay-loam in lower part.
37 -48	Sand, very fine to fine, silty, olive-brown; very wet; some coarse grains; pebbly in last 5 feet.
48 -50	Pebble loam, very lignitic, gray; some scoria pebbles.

HB-155
SESESESW Sec 11, T144N, R86W
Elev. 1 796

0 -10	Sand, fine-grained, brown; somewhat silty, much very fine sand; medium sand present, occasional coarse grains.
10 -18.5	Sand, fine-grained, brown; as above, but appears less silty.
18.5-22	Sand, fine-grained, silty, very dark-brown; moderately well-sorted; much medium and coarse sand, some very coarse grains (mostly scoria).
22 -25	Sand, medium to coarse, grayish-brown; much very coarse sand (quartz and scoria), moderately well-sorted; wet.
25 -32	Sand, coarse-grained, grayish-brown; some very small pebbles; layer of large pebbles at 27 feet; wet.
32 -34.5	Pebble loam, dark-gray; lignite pebbles and pebbles not of local origin; olive-blue-gray clay layers included.
34.5-42	Sand, medium-grained, silty, olive-gray-brown; wet; much coarse sand.
42 -50	Silt, coarse-grained, dark-olive-gray; very uniform, tough.

HB-156
SWNWNWSE Sec 11, T144N, R86W
Elev. 1 774

0 - 3	Sand, very fine-grained, silty, gray-brown to brown; some coarse sand.
3 - 5.5	Sand, very fine to fine, silty, gray-brown; some coarser grains.
5.5-11	Sand, fine to medium, silty, brown to orangish-brown; moderately well-sorted, much coarse sand, some very coarse sand; wet.
11 -15	Sand, fine to medium, silty, chocolate-brown; quite wet; cobble at 12 feet.

Depth (ft.)	Lithologic Description
15 -41	Pebble loam, lignitic, dark-gray; mostly small pebbles; water at 26 feet; thin, very fine silty sand parting included.
41 -47	Sand, medium-grained; wet; silt to very coarse sand and large pebbles included.
47 -50	Silt, sandy, bluish-gray, cohesive.

HB-157
NWNWNWNE Sec 11, T144N, R86W
Elev. 1 753 (approx.)

0 - 1.5	Sand, very fine, silty, dark-brown; some coarser grains.
1.5- 3	Sand, fine to medium, brown; some coarser sand and small pebbles.
3 - 5.5	Sand, fine to medium, pebbly, brown; large pebbles and small cobbles present.
5.5- 7	Sand, fine to medium, dark-gray-brown; somewhat silty; some coarse sand.
7 - 9.5	Sand, fine-grained, light-gray-brown; somewhat cleaner than above.
9.5-11	Sand, fine-grained, silty, organic, dark-gray-brown to black; some coarser grains.
11 -12.5	Sand, medium-grained, light-gray-brown; very well-sorted.
12.5-15.5	Sand, fine to medium, silty, lignitic and organic, dark-gray-brown to black.
15.5-20	Sand, fine-grained, light-gray-brown; much medium sand, some coarse and very coarse sand.
20 -23.5	Sand, fine-grained, yellow-brown; loose, very well-sorted; some very fine and medium sand.
23.5-25	Sand, medium-grained, yellow-brown; well-sorted; some coarse sand.
25 -29	Sand, medium-grained, silty, organic, black; lignite clasts, from large pebble to cobble size; wetter toward bottom.
29 -38	Pebble loam, lignitic, clayey, dark-bluish-gray; carbonate and greenstone pebbles present, but lignite predominates.
38 -49	Sand, fine-grained, gray; very well-sorted, much very fine sand, lignite grains present but mostly quartz; some small lignite chips; small lignite cobble near bottom.
49 -50	Silt, clayey, and silt, dark-olive-gray; lignite and chert pebbles in clayey silt at top.
50 -54.5	Sand, fine to medium, gray; well-sorted; occasional very coarse quartz grains; small lignite chips and rare lignite cobbles.
54.5-58	Sand, medium-grained, gray; not quite as well-sorted as above; small flat pebbles common; sand more coarse and wet toward bottom with some larger pebbles.
58 -60	Silt, clayey, to coarse silt, dark-olive-gray, tough.

HB-158
SESESWSE Sec 10, T144N, R86W
Elev. 1 785

0 - 1.5	Sand, fine-grained, brown; coarse sand common.
1.5-11	Sand, coarse-grained, brown; dark-gray-brown and organic at the top; much fine and medium sand, loose; very coarse sand common; sand more yellow-brown from 5 feet; small pebbles toward bottom.
11 -16	Clay, silty, iron-stained, olive-gray-brown.
16 -20	Silt to clayey silt, iron-stained, olive-gray-brown.
20 -25	Pebbly clay-loam, gray-brown; mottled blue-gray; occasional small pebbles; lignite, scoria, and iron concretions.
25 -30	Pebbly clay-loam, dark-gray; large pebbles are scoria; silty clay-loam in places.
30 -34	Sand, very fine to fine, silty, yellow-brown; coarse and very coarse sand grains.
34 -40.5	Sand, very fine, silty, yellow-brown; loose, well-sorted; occasional coarse and very coarse sand grains; thin light-brownish-gray clay at bottom.

Depth (ft.)	Lithologic Description
40.5-65	Sand, fine to medium, brown; somewhat silty, lignitic, occasional coarse sand; dark-yellowish-brown from 46 feet, dark-grayish-brown and wet in last 5 feet or more; occasional lignite cobbles.

HB-159
SESESENE Sec 16, T144N, R86W
Elev. 1 785

0 - 4	Sand, fine to medium, grayish-brown, somewhat silty, some coarse sand.
4 - 7.5	Sand, medium-grained, grayish-brown; coarse sand common, some very coarse sand and small pebbles.
7.5-13	Sand, coarse-grained, brown and dark-brown (varicolored); all sand sizes present, very coarse sand and small pebbles common.
13 -20	Sand, very coarse, silty, organic, black and very dark-brown; all sand and pebble sizes present; lignite, iron concretion, and flint cobbles.
20 -30	Sand, medium to coarse, brown; very well-sorted, no silt; thin iron-stained, light-brownish-gray silt at about 27.5 feet.
30 -36	Sand, fine to medium, light-brown and gray-brown; some coarse sand.
36 -42	Sand, fine-grained, light-olive-brown.
42 -50	Sand, fine-grained, dark-gray-brown and brown, somewhat silty; medium sand common; some coarse sand, rare pebbles and lignite cobbles.

HB-160
SENENW Sec 19, T144N, R86W
Elev. 1 742 (approx.)
Drilled in 3-foot ditch.

0 -14.5	Silt, coarse-grained, to very fine sandy silt, light-gray-brown to gray-brown; moist and cohesive from 7 feet; some fine sand present.
14.5-20.5	Sand, fine to medium, brown; well-sorted.
20.5-22.5	Sand, medium-grained, dark-brown; coarse sand common; wet.
22.5-28.5	Clay, blue-gray; mottled olive-brown; sandy and silty in first 2 to 3 feet; small wood fragments present.
28.5-38	Sand, coarse-grained, dark-gray-brown; all sand grades present; many small lignite chips and small pebbles; very wet.
38 -40	Gravel, cobbly.

HB-161
SESWSWSW Sec 8, T144N, R86W
Elev. 1 738

0 - 5	Silt, gray-brown; some very fine and fine sand.
5 - 9.5	Sand, very fine, silty, brown; well-sorted, loose.
9.5-15	Loam, silty, gray-brown, cohesive; mostly very fine sand.
15 -18.5	Pebbly clay-loam or gravelly clay; angular pebbles.
18.5-25	Silt, olive-yellow-gray, clayey; some iron concretions.
25 -32	Silt, sandy, olive-gray-brown, cohesive.
32 -35	Silt, sandy, blue-gray; lignitic laminae, coarse sand present.
35 -40	Clay and lignite; large, angular, pebble-size fragments of lignite.
40 -45	Silt, coarse-grained to very fine sandy silt, gray; lignitic laminae; detrital lignite grains; water from about 30 feet.

HB-162
SWSESWSW Sec 9, T144N, R86W
Elev. 1 728
Drilled in 5-foot ditch.

0 - 4	Sand, fine-grained, silty, dark-brown; some medium sand.

Depth (ft.)	Lithologic Description
4 - 9	Sand, fine to medium, brown; very well-sorted, loose, thin, olive-gray silty clay at bottom.
9 -13	Sand, medium-grained, brown, well-sorted; some coarse sand.
13 -15	Sand, coarse-grained, pebbly, dark-brown; some large pebbles; thin, iron-stained gray silt layer at bottom.
15 -18	Sand, medium to coarse, orangish-brown; some pebbles, very coarse sand common.
18 -18.5	Clay, bluish-gray.
18.5-25	Sand, medium to coarse, brownish-gray; very coarse sand, small pebbles, and small lignite chips common; wet; dark-gray and very wet from about 20 feet.
25 -29.5	Gravel, cobbly from 28 to 29.5 feet; little or no samples.
29.5-35	Sand, medium to coarse, pebbly, brownish-gray; most pebbles and lignite chips are small, but some large pebbles present; very wet.

HB-163
NENENENE Sec 28, T145N, R86W
Elev. 2 012
Drilled in 3-foot ditch.

0 - 1	Loam, dark-gray-brown.
1 - 4	Pebble loam, light-gray-brown.
4 -14.5	Pebble loam, lignitic, iron-stained, olive-brown; numerous small pebbles.
14.5-25	Silt, sandy, olive-brown to brown; loose at first, becoming more wet and cohesive with depth; laminated in places; rare coarser grains.
25 -33.5	Pebble loam, brown.
33.5-34	Lignite, wet.
34 -34.5	Clay, lignitic, dark-bluish-gray.
34.5-43.5	Silt, sandy, bluish-gray to gray; difficult drilling at around 40 feet.
43.5+	Siltstone; too hard to drill.

HB-164
NENENE Sec 33, T145N, R86W
Elev. 1 952 (approx.)
Boulders at surface.

0 -11.5	Pebble loam, lignitic, iron-stained, olive-brown; weathered to about 4.5 feet.
11.5-14	Clay, lignitic, dark-gray; hard.
14 -20	Clay to clayey silt, lignitic, brownish-gray; thin lignite seams.
20 -25	Silt and very fine sandy silt, iron-stained, olive-gray-brown, laminated; some clayey silt; pyritic iron concretions at the top.
25 -30	Silt to very fine silt, iron-stained, blue-gray and olive-yellow-brown; thinly laminated and lignitic; thin sandstone at about 29.5 feet.
30 -32	Sand, very fine, silty, bluish-gray; laminated.
32 -35	Silt, clayey, to silt, bluish-gray, hard; some silty clay.
35 -42	Silt, sandy, blue-gray; thinly laminated and lignitic.
42 -43	Silt, blue-gray.
43 -48	Silt, clayey, to silty clay; hard, with limy zones.
48 -49.5	Clay, silty, lignitic, brown; thin lignite seams and large pyrite nodules.
49.5-54	Clay, silty, light-blue-gray; hard; lignitic in spots.
54 -59	Lignite with parting(s).
59 -65	Silt and clayey silt, gray; hard.

HB-165
NESENW Sec 13, T144N, R87W
Elev. 1 751

0 - 4	Sand, very fine, very silty, grayish-brown; some coarser sand.
4 - 5.5	Sand, medium-grained, very silty, reddish-gray-brown; some coarser sand.

Depth (ft.)	Lithologic Description
5.5- 7	Sand, clayey, iron-stained, dark-gray.
7 - 9	Sand, medium-grained, silty, pebbly, reddish-brown, moderately sorted, wet.
9 -18.5	Sand, and gravel, cobbly, orangish-brown; much coarse material, but generally poor quality gravel; moderately poorly sorted; wet.
18.5-30	Silt, clayey, to silty clay, iron-stained, mottled gray, olive-gray to gray; tough and cohesive.

HB-166
SWSESWSE Sec 2, T144N, R87W
Elev. 1 845

0 - 1	Silt, sandy, brown.
1 - 5.5	Pebble loam, light-gray; occasional cobbles.
5.5-11.5	Pebble loam, lignitic, iron-stained, olive-brown.
11.5-18	Pebble loam, dark-olive-gray-brown; mostly small pebbles with occasional large pebbles present, some of which are not of local origin.
18 -45	Pebble loam, olive-brown; as above; cobbles rare, little lignite present.
45 -50	Pebble loam, dark-olive-gray-brown; as above with a few lignite cobbles.
50 -55	Pebble loam, dark-brownish-gray; as above.
55 -70	Pebble loam, dark-gray; a little more lignitic; occasional lignite cobbles and large pebbles not of local origin.

HB-167
SWSWSWSE Sec 9, T144N, R86W
Elev. 1 764
Drilled in 9-foot ditch.

0 - 8.5	Sand, medium to coarse, silty, varicolored, dark- to light-brown; much very coarse sand, some small pebbles; lignitic with lignite pebbles in last 2 feet.
8.5-12.5	Sand, very coarse, orange; well-sorted, with many small pebbles.
12.5-19	Sand, very coarse, pebbly, dark-orangish-brown; not as well-sorted as above with some large pebbles and small cobbles; wet, silty, and very dark, slightly orangish-brown from 15 feet.
19 -24	Pebble loam, lignitic, dark-gray; some pebbles not of local origin; very wet.
24 -29	Silt, clayey, olive-blue-gray, tough; iron concretions at 28.5 feet.
29 -33.5	Silt, clayey, to silt, blue-gray; limy zones, hard at 31 feet.
33.5+	Too hard to drill; limy material.

APPENDIX A-II

DESCRIPTIVE AND GEOPHYSICAL LOGS--
REGIONAL STRATIGRAPHIC TEST HOLES

APPENDIX A-II
DESCRIPTIVE AND GEOPHYSICAL LOGS--
REGIONAL STRATIGRAPHIC TEST HOLES

Depth (ft.)	Lithologic Description
REAP #1	
SESESESE Sec 35, T142N, R85W	
Elev. 2 158	
0 - 2	Silt, sandy, clayey, brown, organic (topsoil).
2 - 4	Silt, clayey, limy, ash-gray.
4 - 12	Sand, very fine, yellow-gray with orange spots, oxidized.
12 - 15	Lignite, soft, weathered, black, some purple-brown carbonaceous clay included.
15 - 17	Silt, slightly sandy, light-yellow-gray to olive with orange streaks, oxidized.
17 - 25	Clay, silty, olive-gray with some brown streaks, iron oxide streaks included and some gypsum crystals; oxidized.
25 - 28	Silt, medium-gray.
28 - 35	Clay, silty, medium-gray.
35 - 35.5	Lignite, soft.
35.5- 43	Clay, silty, gray.
43 - 43.5	Clay, carbonaceous, lignitic, very dark-brown to black.
43.5- 45	Clay, silty, light-gray.
45 - 46	Clay, smooth, dark-gray.
46 - 46.5	Lignite, hard, black.
46.5- 53	Clay, slightly silty, medium-gray.
53 - 57	Sand, very fine, silty, light-gray.
57 - 65	Sand, very fine, light-gray.
65 - 70	Lignite, hard, black; some red-brown silt in interval.
70 - 71	Sand, fine, light-gray.
71 - 78	Clay, blue-gray.
78 - 80	Siltstone, light-tan-gray, calcium carbonate.
80 - 81	Clay, gray, some black carbonaceous clay included.
81 - 82	Lignite, hard, black.
82 - 87	Clay, silty, medium-gray; some carbonaceous brown streaks at bottom of interval.
87 - 87.5	Lignite, hard, black.
87.5- 91	Clay, smooth, green-gray.
91 - 95	Clay, silty to silt, clayey, green-gray.
95 - 97	Silt, sandy to silt, clayey, green-gray.
97 - 99	Clay, gray with dark-brown streaks; some carbonaceous clay included.
99 -103	Clay, silty gray to green-gray.
103 -107	Silt, coarse, gray to silt clayey.
107 -108	Clay, silty, gray.
108 -119	Sand, very fine, light-gray.
119 -125	Silt to silt, clayey, medium-gray.
125 -130	Silt, coarse; becoming clayey downward.
130 -138	Clay, silty, gray.
138 -139	Clay, carbonaceous; very dark-gray.
139 -144	Lignite, black, hard.
144 -145	Clay, gray.
145 -150	Silt, clayey; very fine sand bed included; gray.
150 -160	Sand, very fine, light-gray.
160 -161	Clay, light-gray.
161 -164	Lignite, black, hard.
164 -165	Clay, light-gray.
165 -171	Sand, very fine, gray.
171 -173	Clay, silty, medium-gray.
173 -179	Limestone, dense, hard, dark-gray.
179 -195	Clay, smooth, medium-gray; light-tan marl included at about 193 feet.
195 -200	Clay, silty, changing to silt downward, medium-gray.
200 -202	Silt, slightly sandy, medium-gray, laminated.
202 -202.5	Lignite (very thin, few small chips in sample).
202.5-210	Sand, very fine, silty.

Depth (ft.)	Lithologic Description
210 -215	Silt, clayey to clay, silty, medium-gray.
215 -220	Sand, very fine, silty; minor silty-clay beds included; gray.
220 -221	Siltstone, tan, calcium carbonate cement.
221 -225	Clay, silty, very dark-gray, weakly carbonaceous; some silt in interval.
225 -240	Sand, very fine, light-gray; minor clay bed at 230 feet.
240 -242	Lignite, medium hard with some soft black carbonaceous clay.
242 -248	Clay, silty, gray.
248 -252	Sand, very fine, silty, gray.
252 -254	Clay, silty, medium-gray (possible thin lignite included).
254 -260	Silt, slightly sandy, light-tan (very fine sand with depth).
260 -275	Silt, coarse, sandy in part, light-gray.
275 -278	Limestone, dense, hard, dark-gray.
278 -280	Clay, silty, gray; carbonaceous in part.
280 -282	Silt, coarse, tan-gray with some silty clay, gray.
282 -284	Lignite (poor sample).
284 -293	Clay, dark-gray, some brown carbonaceous streaks.
293 -297	Sand, very fine, silty, some brown carbonaceous chips included.
297 -302	Clay, silty, medium-gray.
302 -304	Lignite, medium soft, brown-black.
304 -319	Clay, silty, light-gray (poor sample return).
319 -329	Silt, laminated, clayey in part; siltstone chips in sample; gray.
329 -338	Clay, silty, gray.
338 -340	Sand, very fine, silty, gray.
340 -341	Clay, gray.
341 -344	Lignite, black, hard.
344 -348	Clay, silty, gray.
348 -352	Silt, clayey, light-gray.
352 -354	Limestone, dense, hard, dark-gray.
354 -365	Clay, silty, dark-gray.
365 -370	Clay, silty, interbedded with fine sand; fossil shells abundant in interval, gray.
370 -385	Silt, light-tan, laminated, sandy, gray.
385 -395	Clay, silty, gray (lignite chips at 387-395 feet ?); poor samples.
395 -410	Silt, green to gray (possible lignite from 408-410 feet).
410 -422	Very poor samples; mostly silty clay; may be some very fine sand.

REAP #2
SESESESE Sec 16, T142N, R85W
Elev. 2 175

0 - 3	Silt, brown and scoria, reddish-orange (appears to be fill on old road).
3 - 7	Clay, light-gray, smooth.
7 - 9	Clay, smooth, brown.
9 - 15	Lignite, soft, weathered, black.
15 - 23	Clay, silty, medium-gray.
23 - 25	Lignite, medium hard, black.
25 - 28	Clay, silty, medium-gray.
28 - 32	Sand, very fine, silty, medium-gray.
32 - 39	Sand, very fine, light-gray (sandstone--calcium carbonate cement--at approximately 36-39 feet).
39 - 44	Clay, silty, medium-gray.
44 - 45	Sand, very fine, "salt and pepper," light-gray.
45 - 53	Clay, silty, medium-gray.
53 - 54	Clay, carbonaceous, dark-gray-brown to dark-brown.
54 - 60	Clay, smooth, medium-gray.
60 - 74	Clay, silty, medium-gray (lignite in sample at 60-62 feet; possible contamination resulting from connection of rods).
74 - 78	Sand, very fine, silty; some carbonaceous laminae; occasional thin clay beds included.

Depth (ft.)	Lithologic Description
78 - 80	Limestone, dark-gray, hard.
80 - 84	Clay, silty, medium-gray.
84 - 84.5	Lignite, black, hard.
84.5- 94	Clay, smooth, green-gray (possible carbonaceous clay bed at approximately 87 feet).
94 - 96	Sand, very fine, silty, light-gray.
96 -114	Sand, very fine, light-gray.
114 -118	Lignite, black and carbonaceous silty clay, dark-gray-brown to red-brown.
118 -120	Clay, silty, medium-gray.
120 -137	Sand, very fine, interbedded with silt and clayey silt, light-gray.
137 -139	Clay, silty, medium-gray.
139 -139.5	Lignite, black, hard.
139.5-148	Clay, silty, gray (lignite chips from 145-148 feet, possible contamination).
148 -151	Clay, smooth, gray.
151 -173	Sand, very fine, silty; gray (tan siltstone chips in 151-155-foot interval, these chips continue to appear in the samples through 172 feet; may indicate thin siltstones).
173 -174	Clay, carbonaceous, black to red-brown, soft.
174 -180	Lignite, black, hard (Hagel bed).
180 -184	Clay, silty, blue-gray interbedded with gray silty sand beds.
184 -192	Lignite; includes much clay in 185-190 feet interval; clay parting at 194-194.5 feet.
192 -200	Clay, silty, gray.
200 -204	Silt, coarse and silt, clayey, gray.
204 -204.5	Lignite.
204.5-215	Sand, very fine, silty, light-gray.
215 -220	Silt, sandy, light-gray (possible thin carbonaceous shale at 218 feet).
220 -228	Clay, silty, silt and silty sand, interbedded, gray.
228 -231	Lignite, black, medium hard to medium soft.
231 -236	Clay, silty, gray.
236 -242	Sand, very fine, silty; includes some red-brown fossil plant fragments.
242 -249	Silt, clayey to clay, silty, gray; minor siltstone included.
249 -251	Lignite, medium hard, black.
251 -252	Sand, very fine, gray, laminated.
252 -269	Silt, coarse, gray, somewhat clayey in part; laminated; includes carbonized fossil plant material.
269 -275	Lignite, hard, black.
275 -282	Sand, very fine, silty; green-gray, minor clay.
282 -285	Limestone, gray, hard.
285 -300	Clay, silty, medium-gray; some very fine sand beds included at approximately 292 feet and 296 feet (much lignite in sample, appears to be wash from above). Samples poor and badly contaminated.
300 -304	Clay, smooth, green-gray.
304 -306	Sand, very fine, silty, much washed lignite.
306 -380	Samples very poor, appear to be mostly gray interbedded silty clays and very fine sand (lignite contaminating all samples, impossible to log with any certainty).
380 -385	Silt, coarse, green-gray.
385 -400	Clay, silty, some siltstone chips at approximately 396 feet, much lignite contamination in cuttings.
400 -410	Clay, smooth, green to gray.
410 -420	Sand, silty, light-gray; fossil shell fragments after 415 feet.
420 -425	Clay, smooth; light-tan-gray; fossil shell fragments to 425 feet.
425 -426	Clay; silty, gray.
426 -480	Sand, very fine, gray.
480 -502	Clay, silty; gray; possible siltstone at 490 feet; also clay, smooth, green to gray.

Note: Lignite contaminated all samples below approximately 300 feet, interpretations uncertain in log.

REAP #3
SESESESE Sec 6, T142N, R85W
Elev. 2 310

Depth (ft.)	Lithologic Description
0 - 5	Sandy topsoil, brown with iron oxide concretionary fragments (large granite erratics abundant at the surface).
5 - 46	Sand, medium, gray-brown; composed of predominantly quartz, with igneous and carbonate clasts abundant (appears to be fluvial).
46 - 53	Sandstone, fine gradient, "salt and pepper", partially oxidized; tan to light-gray, calcium carbonate cement; bedrock.
53 - 60	Silt, clayey, mostly reddish-orange, highly oxidized; some dark-red-brown iron oxide concretionary fragments.
60 - 88	Sand, fine, yellow-brown, oxidized to approximately 85 feet; turning light-gray below 85 feet.
88 - 90	Lignite, black, medium soft.
90 -102	Clay, silty, medium-gray.
102 -115	Sand, very fine, highly silty, medium-gray.
115 -126	Clay, silty, medium-gray.
126 -128	Clay, carbonaceous, black.
128 -134	Lignite, black, medium soft to medium hard.
134 -139	Clay, silty, dark-gray.
139 -146	Sand, very fine, silty, gray.
146 -148	Clay, silty, medium-gray.
148 -152	Clay, carbonaceous, chocolate-brown to black.
152 -157	Lignite, black, medium hard.
157 -158	Clay, smooth, medium-gray.
158 -163	Silt, clayey, medium-gray.
163 -166	Lignite, medium hard, black.
166 -190	Clay, silty, medium-gray; includes silt and silty sand layers (possible lignite stringer at approximately 178 feet, much lignite contamination in samples).
190 -192	Lignite, black, medium hard.
192 -212	Clay, silty and silt, clayey, interbedded, medium-gray; minor carbonaceous clay at approximately 210 feet; minor very fine silty sand included.
212 -228	Silt, sandy to silt, clayey, green-gray.
228 -236	Clay, smooth, light-gray with some brown streaks.
236 -245	Silt, sandy, green-gray.
245 -252	Siltstone, light-gray, calcium carbonate cement; gray, silty clay also mixed in samples.
252 -256	Silt, clayey, gray.
256 -261	Lignite, black, medium hard, with clay partings.
261 -272	Sand, very fine, silty, green-gray with some brown-gray carbonaceous streaks, and sand, very fine, light-gray; some brown plant fragments included.
272 -274	Clay, silty, medium-gray.
274 -278	Lignite, black, hard.
278 -280	Clay, silty, blue-gray.
280 -286	Sand, very fine, silty, light-gray.
286 -292	Clay, silty, medium-gray to green-gray; includes some brown carbonaceous fossil plant fragments.
292 -313	Silt, clayey, light-green-gray.
313 -318	Clay, silty, medium-gray.
318 -328	Silt, brown, laminated; slightly carbonaceous.
328 -332	Clay, silty, green-gray.
332 -346	Silt, brown, laminated; slightly carbonaceous.

Depth (ft.)	Lithologic Description
346 -400	Samples very poor and badly contaminated, impossible to log with any certainty; may be sand (cuttings are about half silty clay and half lignite chips); at 384 feet mostly lignite to about 388 feet then quite clayey.
400 -403	Clay, smooth, medium-gray.
403 -405	Siltstone, light-gray, calcium carbonate cement, samples mixed with gray silty clay.
405 -416	Silt, clayey, gray.
416 -440	Sand, very fine, silty, light-gray, minor silty clay included.
440 -442	Siltstone, light-gray to very fine sandstone, light-gray.
442 -450	Sand, very fine, light-gray.
450 -454	Lignite, black, medium hard, some hard carbonaceous shale included.
454 -459	Clay, silty, gray; some clayey silt and minor clay, carbonaceous, dark-brown, included.
459 -460	Clay, smooth, medium-gray.
460 -462	Silt, clayey, gray.
462 -466	Sand, very fine, silty, gray.
466 -472	Lignite, medium hard, black.
472 -474	Clay, brown-gray.
474 -502	Sand, very fine, silty, light-gray; some thin silty clay and clayey silt beds included with depth.

REAP #4
SESESESE Sec 10, T143N, R86W
Elev. 1 890

0 - 2	Sand, fine, brown; contains scattered gravel clasts.
2 - 8	Pebble loam (till), somewhat sandy, yellow-brown; contains iron oxide spots and ironstone concretionary fragments; oxidized.
8 - 46	Pebble loam (till) olive-gray with red-brown mottling; includes numerous lignite chips; quite plastic and tough.
46 - 64	Clay, smooth, dark-gray.
64 - 85	Pebble loam (till), gravelly, partly oxidized, gray to gray-brown.
85 -110	Sand, medium and gravel, medium, mostly angular, but including some rounded clasts of dark-brown quartz; overall appearance is brown; contains abundant lignite, brown concretionary chips, some gray-white limestone; some scoria and some brown quartz pebbles of western derivation (not a typical glacial gravel).
110 -117	Clay, silty, medium-gray; bedrock.
117 -145	Silt, clayey, light-gray; some minor silty sand beds included; gradually becoming finer grained with depth, silty clay, gray in bottom few feet.
145 -154	Lignite, black, medium hard.
154 -158	Clay, light-gray, smooth.
158 -170	Clay, silty, medium-gray; includes some red-brown fossil plant fragments.
170 -172	Sand, very fine, silty, gray.
172 -174	Clay, silty, medium-gray.
174 -175	Clay, carbonaceous, black, with thin lignite.
175 -182	Silt, clayey and clay, silty, interbedded, medium-gray.
182 -200	Clay, silty, medium-gray; includes some red-brown fossil plant fragments.
200 -220	Silt, sandy, light-gray; some silty clay included; minor tan-gray siltstone at approximately 206 feet and 216 feet.
220 -240	Sand, very fine, gray, and silt, clayey, gray; samples include abundant siltstone chips (note--samples poor, may not represent true lithology).
240 -260	Samples are poor, mostly silty clay and small lignite chips, concentration of lignite from 240-244 feet (may be wash); some sand in samples from 250-255 feet.
260 -268	Sand, very fine, light-gray.
268 -274	Clay, silty, medium-gray.
274 -278	Lignite (may be wash).
278 -295	Silt, clayey, light-gray; includes some tan sandstone chips.

Depth (ft.)	Lithologic Description
295 -296	Siltstone, light-gray, calcium carbonate cement.
296 -310	Silt, clayey to silt, slightly sandy, light-gray; siltstone chips at approximately 305 feet.
310 -338	Clay, silty and silt, clayey, gray (samples poor--much lignite contamination).
338 -344	Lignite, medium hard, black.
344 -346	Silt, slightly carbonaceous, gray with red-brown streaks.
346 -355	Clay, silty, gray.
355 -356	Lignite, black, soft.
356 -362	Clay, carbonate, dark-brown to black.

REAP #5
(E of NW corner) Sec 18, T142N, R87W
Elev. 2 170

0 - 10	Sand, fine to very fine, buff with orange banding, oxidized; somewhat clayey (sandstone outcrops 10 feet east of hole).
10 - 13	Lignite, soft, black, weathered.
13 - 15	Clay, smooth; olive, with some chocolate-brown carbonaceous clay at approximately 13-13.5 feet.
15 - 21	Clay, silty, dark-gray with red-brown oxidized streaks.
21 - 33	Sand, very fine, olive-gray; some minor silty clay beds included.
33 - 34	Sand, silty, highly carbonaceous, dark-red-brown to black.
34 - 59.5	Sand, very fine, olive-gray with orange bands, some gray clay at approximately 41-41.5 feet.
59.5- 60	Sandstone, "salt and pepper," light-gray, calcium carbonate cement.
60 - 96	Sand, fine to very fine, olive-gray with some red-brown streaks, oxidized.
96 - 99.5	Sand, fine to very fine, gray, unoxidized.
99.5-102	Lignite, black, hard.
102 -105	Clay, gray.
105 -110	Lignite, black, hard.
110 -119	Clay, silty, medium-gray.
119 -121	Lignite, black, medium hard and black carbonaceous clay.
121 -122	Clay, gray.
122 -131	Silt, carbonaceous, black.
131 -139	Clay, gray, smooth.
139 -140.5	Clay, carbonaceous, dark-brown to black.
140.5-148	Clay, light-gray, smooth.
148 -150	Clay, silty, light-gray.
150 -177	Silt, coarse, light-gray; interbedded in part with clayey silt; some red-brown carbonaceous fossil plant fragments included.
177 -180	Clay, silty, dark-gray.
180 -200	Lignite, black, medium hard.
200 -217	Clay, smooth, dark-gray; slightly carbonaceous; contains fragments of fossil plant remains.
217 -234	Silt, clayey, medium-gray.
234 -235	Lignite, black, medium hard.
235 -240	Silt, slightly sandy, to silt, clayey, medium-gray.
240 -247	Clay, silty, medium-gray.
247 -249	Lignite, black, hard.
249 -259	Clay, silty, medium-gray, interbedded with some gray, slightly sandy silt.
259 -265	Clay, smooth, light-gray; possible thin lignite at approximately 264 feet.
265 -274	Silt, clayey, medium-gray, to silt.
274 -277	Lignite, hard, black.
277 -280	Sand, very fine, silty, contains dark-brown carbonaceous fossil plant fragments.
280 -298	Clay, smooth, green-gray.
298 -305	Clay, silty, green-gray to medium-gray.
305 -312	Silt, clayey, gray; minor silty sand included.
312 -312.5	Limestone, tan, hard.

Depth (ft.)	Lithologic Description
312.5-335	Clay, silty, green-gray with some dark-gray to black carbonaceous clay beds at 323 feet and 334 feet.
335 -345	Sand, very fine to fine, olive-gray to green-gray.
345 -346	Sandstone, light-gray, "salt and pepper," calcium carbonate cement.
346 -349	Sand, very fine, silty, green-gray.
349 -400	Sand, very fine to fine, light-green-gray, "salt and pepper," somewhat silty in part.
400 -412	Sand, very fine, silty alternating with silty clay beds.
412 -440	Clay, silty gray to green-gray; some clayey silt at 437-440 feet.
440 -453	Sand, very fine, silty, gray with brown carbonaceous streaks; some green-gray silty clay layers included.
453 -456	Lignite, black, medium hard.
456 -459	Clay, silty, gray and silt, clayey, gray, interbedded.
459 -460	Sand, very fine to fine, gray, with red-brown carbonaceous streaks.
460 -480	Very poor sample return, drills like sand.
480 -602	Lost circulation and ran out of water; no sample return.

REAP #6
SESESESE Sec 36, T146N, R89W
Elev. 2 270

0 - 2	Silt, dark-gray-brown, organic.
2 - 5	Pebble loam (till), whitish-tan, highly limy, oxidized, highly calcareous.
5 - 34	Pebble loam (till), yellow-brown with white limy spots, red-brown iron oxide streaks and spots, and weathered chips of lignite; includes pebbles of carbonate, igneous and metamorphic rock types as well as iron oxide concretionary fragments; oxidized.
34 - 39	Clay, smooth, bright-yellowish-gray, oxidized; bedrock (Golden Valley Formation).
39 - 48	Clay, silty, light-gray; minor siltstone at approximately 41 feet; few lignite chips at approximately 39 feet.
48 - 54	Sand, very fine, silty, light-gray.
54 - 56	Lignite, black, medium hard.
56 - 57	Clay, silty, green-gray.
57 - 60	Silt, coarse, slightly. sandy, light-gray; some whitish-gray clay beds included.
60 - 62	Clay, silty, light-gray.
62 - 66	Lignite, black, medium hard.
66 - 68	Clay, smooth, light-gray.
68 - 72	Sand, very fine, highly micaeous, light-gray; sparkles in sunlight.
72 - 76	Silt, clayey, medium-gray, micaceous.
76 - 80	Clay, silty, medium-gray.
80 - 82	Silt, clayey, light-gray, micaceous.
82 - 92	Clay, smooth, green-gray, some clay.
92 -105	Clay, silty, micaceous, sparkles in sunlight, medium-gray to dark-gray.
105 -118	Poor sample return; drilled like sand; lost circulation; few cuttings of fine sand, medium-gray.
118 -126	Clay, smooth, medium-gray to dark-gray, carbonaceous in part.
126 -130	Clay, smooth, whitish-gray, very slippery.
130 -140	Sand, very fine, light-whitish-gray, drilling mud is very light-gray in color.
140 -160	Sand, as above, but poor sample return; losing circulation, adding bentonite to drilling mud.
160 180	Poor samples; very few cuttings of fine-grained greenish-gray sand with black flecks beginning at approximately 160 feet.
180 -253	Sand, very fine to fine, light-gray with black flecks; some dark-brown-black carbonaceous streaks included; quite well-sorted, grains subred to red, much quartz; calcium carbonate cement sandstone at approximately 235 feet. (Good samples below 185 feet.) Note: some lignite contamination occuring in all

Depth (ft.)	Lithologic Description
	samples, slight increase in lignite chip concentration at approximately 235-240 feet; may be a thin lignite in this interval.
253 -275	Samples are mostly lignite, with some dark-brown carbonaceous clay cuttings at approximately 258 feet. Some gray, silty clay cuttings from 265-276 feet mixed with lignite chips.
275 -280	Clay, gray, silty.
280 -290	Poor samples, badly contaminated with lignite chips. Some gray silty clay cuttings from 280-285 feet; some very fine silty sand cuttings from 285-290 feet.
290 -300	Silt, sandy, dark-gray, interbedded with clayey silt and silty clay, dark-gray.
300 -315	Clay, silty, dark-gray; some marly streaks at approximately 310 feet.
315 -320	Clay, silty, green, hard.
320 -327	Clay, silty, weakly carbonaceous, dark-gray, and silt, clayey.
327 -330	Lignite; black, hard.
330 -335	Silt, clayey to clay, silty, gray.
335 -348	Lignite, black, medium hard to hard.
348 -350	Sand, very fine, silty, carbonaceous, red-brown.
350 -360	Sand, very fine, silty, dark-gray.
360 -365	Silt, clayey with some clay, silty, dark-gray.
365 -380	Clay, smooth, blue-gray to dark-gray.
380 -385	Poor sample (some carbonaceous clay and green-gray clay mixed with lignite).
385 -389	Clay, smooth, gray.
389 -392	Lignite, medium hard, black.
392 -403	Clay, silty, medium-gray.
403 -414	Sand, very fine, silty, medium-gray; minor clay included.
414 -430	Clay, silty, dark-gray with brown carbonaceous streaks; thin sand beds included. Sandstone at approximately 422 feet.
430 -450	Silt, coarse, interbedded with silty clay; lignite at approximately 442 feet.
450 -460	Silt, clayey, light-green-gray, some rusty-brown carbonaceous streaks included; minor limestone chips.
460 -470	Clay, smooth, green-gray.
470 -475	Clay, silty, light-gray.
475 -480	Sand, very fine, silty, gray to brown-gray.
480 -513	Clay, smooth, light-gray, some red-brown oxidized spots and clayey silt included; minor very fine sand.
513 -514	Sand, very fine, blue-gray.
514 -520	Clay, smooth, light-gray; sample includes some siltstone chips, much lignite (poor samples).
520 -535	Samples poor and contaminated with gravel and lignite from above; mostly gray, silty clay.
535 -539	Sand, silty, clayey, gray. Poor samples.
539 -540	Extremely hard drilling; no samples.
540 -550	Clay, gray, sample includes chips of hard black coal, silicified(?); probably from interval just above.
550 -560	Clay, silty, gray, some brown oxidized clayey silt included.
560 -573	Clay, smooth, gray; poor samples.
	Drilling with great difficulty; all samples below are poor, descriptions questionable.
573 -586	Sandstone, "salt and pepper," very fine, light-gray, calcium carbonate cement.
586 -592	Clay, silty, gray; includes fossil carbonaceous plant fragments.
592 -600	Sand, very fine, silty, gray to brown-gray with disseminated carbonaceous flecks, possible thin lignite included.
600 -602	Lignite, soft, to carbonaceous shale, black.
602 -628	Clay, silty, gray to silt, green-gray; lignite contamination.
628 -632	Lignite, soft (poor sample).
632 -640	Poor samples; appears to be light-gray clay interbedded with very fine gray sand; much lignite contamination.

Depth (ft.)	Lithologic Description
640 -660	Poor samples; mudded-up mixture of lignite chips, gray clay and fine sand.
660 -700	Very poor samples, impossible to interpret with any confidence; much lignite contamination. (Driller got stuck at approximately 665 feet, taking water at a high rate; continued drilling with many problems.) Interval includes gray clay interbedded with very fine-grained light-gray "salt and pepper" sand according to the predominant lithology in the cuttings.
700 -710	Samples somewhat better, appears to be sand, very fine, silty, dark-brown, weakly carbonaceous.
710 -715	Clay, smooth, gray.
715 -720	Lignite, medium hard, black.
720 -735	Samples poor; appears to be predominantly gray silty clay and silty sand.
735 -740	Lignite, black, medium hard to soft in part.
740 -742	Clay, gray.

REAP #7
SWSWSWSW Sec 14, T144N, R85W
Elev. 1 890

0 - 1	Sand, very fine to fine, some medium grains, brown, subred to red, not too well-sorted.
1 - 2	Gravel, medium, brown, includes glacial pebbles and iron oxide concretionary fragments.
2 - 5	Clay, silty, mottled yellow-gray and red-brown, oxidized.
5 - 8	Sand, very fine, silty, gray-brown with black flecks; includes minor clay stringers.
8 - 12	Silt, olive-gray with some orange banding.
12 - 18	Sand, very fine, highly silty, dark-gray, unoxidized; some clay.
18 - 22	Silt, clayey and clay, silty, medium-gray, unoxidized.
22 - 26	Sandstone, very fine, "salt and pepper," light-gray, calcareous.
26 - 57	Sand, very fine, light-gray, well-sorted.
57 - 68	Lignite, medium hard, black.
68 - 69	Clay, brown-gray.
69 - 70	Lignite, medium hard, black.
70 - 75	Clay, brown-gray, and lignite, medium hard, black.
75 - 78	Clay, silty, to silt, clayey, gray with brown oxidized fossil plant fragments.
78 - 88	Sand, very fine, silty, minor sandstone bed at 84 feet, gray.
88 - 92	Lignite, black, medium hard.
92 - 94	Clay, carbonaceous, dark-brown to black.
94 - 96	Silt, clayey and clay, silty, gray with red-brown fossil plant fragments.
96 - 98	Silt, clayey, gray with red-brown fossil plant fragments.
98 - 99	Sandstone, light-gray, "salt and pepper," calcium carbonate content.
99 -109	Silt, coarse, gray, some very fine silty sand included.
109 -111	Lignite.
111 -119	Silt, coarse, gray.
119 -123	Clay, smooth, gray, minor brown carbonaceous plant fragments; thin, light-gray-white marl stringer at about 123 feet.
123 -130	Silt, clayey, gray, and clay, silty gray, carbonaceous in part.
130 -134	Siltstone, gray, calcium carbonate cement.
134 -137	Silt, clayey, gray.
137 -139	Clay, silty, medium-gray.
139 -150	Silt to silt, clayey, medium-gray.
150 -152	Shale, black, highly carbonaceous; and thin lignite.
152 -153	Silt, clayey, gray.
153 -154	Clay, green-gray; some dark-brown carbonaceous clay included.
154 -160	Sand, very fine, silty, light-gray.
160 -162	Silt, medium-gray.
162 -165	Clay, smooth, carbonaceous in part, very dark-gray to gray-brown.
165 -168	Lignite, medium soft, black.
168 -170	Clay, gray, smooth.

Depth (ft.)	Lithologic Description
170 -172	Lignite, medium hard, black.
172 -173	Clay, carbonaceous, brown.
173 -175	Silt, clayey, medium-gray.
175 -176	Clay, gray.
176 -182	Lignite, medium soft, black.
182 -183	Clay, silty, gray.
183 -186	Silt, clayey, gray.
186 -192	Sand, very fine, silty, gray.
192 -199	Clay, silty, gray with brown carbonaceous fossil plant fragments; minor silt and silty sand from approximately 195-197 feet.
199 -200	Clay, gray, smooth.
200 -201	Claystone, light-gray.
201 -207	Limestone, dark-gray, hard.
207 -211	Clay, silty, gray.
211 -214	Clay, carbonaceous, black, and thin lignite.
214 -220	Clay, silty, gray and silt, clayey gray.
220 -223	Lignite, black, medium hard to medium soft.
223 -226	Clay, silty, gray; some clayey silt interbedded.
226 -234	Sand, very fine, silty, gray.
234 -251	Clay, silty, gray; fossil shell zones at approximately 238 feet and 242 feet; silty and sandy with depth (possible thin lignite and carbonaceous clay at about 244 feet).
251 -256	Lignite, medium soft, black; mostly black carbonaceous clay.
256 -262	Clay, smooth, gray; some clayey silt included.
262 -266	Sand, brown and green, fine-grained, interbedded with smooth green clay.
266 -270	Limestone, hard, dark-gray.
270 -276	Sand, silty, green-gray, very fine.
276 -279	Clay, smooth, light-gray with some yellow-gray streaks.
279 -281	Clay, carbonaceous, smooth, very dark-gray to brown-gray.
281 -305	Clay, green-gray and light-gray, interbedded with very fine silty sand with dark-brown carbonaceous flecks, carbonaceous clay included at approximately 286 feet and 294 feet.
305 -306	Marlstone, tan, "limy."
306 -308	Lignite, medium hard, black.
308 -309	Clay, silty, medium-gray.
309 -311	Siliceous silty sandstone, pinkish-brown with some pinkish-brown clay.
311 -314	Clay, silty, gray.
314 -320	Lignite, medium hard, black.
320 -334	Clay, silty, gray; some minor interbedded silty sand and carbonaceous clay at approximately 228 feet.
334 -340	Sand, very fine, silty, interbedded with silty clay, gray-brown to gray.
340 -344	Clay, green, silty.
344 -347	Lignite, black, medium hard.
347 -356	Clay, silty, medium-gray; some interbedded gray-brown silt.
356 -357	Lignite stringer.
357 -363	Clay, silty, medium-gray; interbedded with silt, brown-gray.
363 -376	Sand, very fine, green-gray, well-rounded and well-sorted.
376 -378	Lignite, medium hard, black.
378 -400	Clay, silty, medium-gray to green-gray with some yellow-gray and light-orange beds; interbedded occasionally with some very fine green-gray sand beds (thin carbonaceous clay at about 395 feet?).

REAP #8
SESESESE Sec 16, T145N, R86W
Elev. 2 025

0 - 20	Sand, very fine, silty, gray-brown, oxidized; sandstone at about 6 feet.
20 - 25	Silt, clayey, olive-gray with orange bands.
25 - 34	Clay, silty, gray, unoxidized.

APPENDIX A-II--Continued
DESCRIPTIVE AND GEOPHYSICAL LOGS--
REGIONAL STRATIGRAPHIC TEST HOLES

Depth (ft.)	Lithologic Description
34 - 46	Lignite, black, medium hard.
46 - 54	Clay, silty, medium-gray; includes brown fossil plant fragments.
54 - 55	Lignite.
55 - 60	Silt, clayey to clay, silty, medium-gray.
60 - 76	Clay, smooth, medium-gray; carbonaceous clay bed at about 73 feet.
76 - 78	Sand, very fine, silty, light-gray.
78 -120	Sand, fine, well-sorted, well-rounded; light-gray.
120 -125	Sandstone, very fine-grained, "salt and pepper," light-gray, calcium carbonate cement.
125 -140	Poor samples, some tan limestone chips from 130-135 feet, mostly very fine silty sand with much contamination; gray, silty clay at 138-140 feet.
140 -150	Silt, clayey with some clay and very fine sand, gray, poor samples.
150 -169	Clay, silty, gray, some clayey silt included.
169 -169.5	Thin lignite?
169.5-170	Sand, very fine, silty, light-gray.
170 -184	Clay, silty, medium-gray.
184 -192	Sand, very fine, silty, light-gray.
192 -194	Lignite, black, medium hard.
194 -196	Silt, clayey, gray.
196 -200	Clay, silty, medium-gray.
200 -221	Silt, clayey, light-gray; tan limestone concretions at approximately 212 feet.
221 -223	Lignite.
223 -225	Clay, silty, dark-gray.
225 -227	Silt, clayey, gray.
227 -250	Clay, silty, gray; thin tan smooth clay beds at approximately 238 feet and 242 feet.
250 -252	Clay, gray-brown.
252 -258	Lignite, black, medium hard.
258 -265	Clay, silty to silt, clayey to silt to very fine sand, gray (coarsening downward).
265 -270	Silt to clayey silt, gray.
270 -278	Clay, silty, gray.
278 -281	Lignite, medium soft, black.
281 -300	Clay, silty, medium-gray with dark-brown carbonaceous plant fragments; thin clay and carbonaceous clay beds in interval.
300 -305	Silt, clayey, gray.
305 -308	Clay, silty, gray.
308 -310	Limestone, hard, dark-gray.
310 -320	Silt, clayey, medium-gray with brown fossil plant fragments.
320 -322	Clay, silty, gray.
322 -324	Lignite, black, medium hard.
324 -330	Clay, smooth to silt, clayey, gray.
330 -336	Silt, green to sand, very fine, silty, gray with brown carbonaceous flecks.
336 -350	Clay, silty, medium-gray with brown carbonaceous plant fossil fragments.
350 -355	Lignite, hard, black.
355 -359	Silt, red-brown, oxidized.
359 -370	Silt, clayey to silt, coarse, medium-gray.
370 -380	Sand, very fine, highly silty; includes some clayey silt, medium-gray.
380 -380.5	Lignite? Probably contaminated.
380.5-400	Sand, very fine, gray.
400 -401	Lignite?
401 -436	Sand, very fine, gray, much lignite contamination; interval includes some silty clay stringers.
436 -438	Limestone concretion, tan, hard.
438 -440	Clay, silty, gray.

Depth (ft.)	Lithologic Description
REAP #9 NWNWNWNW Sec 30, T146N, R86W Elev. 2 102	
0 - 24	Pebble loam, yellow-brown to olive with white limy spots and orange iron oxide streaks; includes weathered lignite chips and ironstone concretion fragments, oxidized.
24 - 27	Pebble loam, buff to orange, gravel at top, very highly oxidized (different till than above).
27 - 30	Caliche zone, yellowish-white, very limy included as fossil "B" soil horizon in old till.
30 - 50	Pebble loam, orangish-yellow-brown, highly-oxidized, quite sandy, lignite fragments abundant; includes gravel size clasts of igneous, metamorphic, and sedimentary rock types (2nd till).
50 - 62	Pebble loam, as above, but gray and unoxidized.
62 - 64	Clay, silty, gray, abundant lignite chips and brown carbonaceous clay in this interval also.
64 - 67	Clay, silty, gray.
67 - 72	Silt, clayey, green.
72 - 74	Sand, very fine, silty, green to medium-gray, abundant carbonaceous fossil plant fragments.
74 - 93	Silt, clayey, green and clay silty, gray interbedded.
93 - 95	Lignite, hard, black.
95 -105	Clay, silty, green to gray; some smooth light-gray clay included.
105 -115	Silt, clayey, gray; gray-brown limestone concretions at about 112 feet.
115 -127	Silt, coarse with some very fine sand, gray.
127 -128	Limestone concretion, gray-brown, hard.
128 -135	Silt, coarse, gray; some silty clay included.
135 -150	Sand, very fine, highly silty, gray.
150 -154	Sand, very fine, gray with black flecks.
154 -157	Lignite, hard, black.
157 -177	Clay, silty, medium-gray with occasional light-tan clay; limestone concretionary fragments at about 176 feet.
177 -183	Lignite, black, hard.
183 -193	Clay, silty, medium-gray; includes abundant carbonaceous and lignitic fossil plant fragments.
193 -195	Lignite, hard, black.
195 -206	Clay, silty, medium-gray, interbedded with silt and minor very fine sand; may be thin lignite stringers at 202 feet and 204.
206 -207	Lignite.
207 -220	Silt, clayey, gray and clay, silty, gray; minor very fine silty sand.
220 -222	Limestone concretions, abundant lignite chips (may be contamination).
222 -234	Clay, silty, gray; includes minor silty sand beds.
234 -235	Lignite, medium hard, black.
235 -244	Clay, silty, gray; minor carbonaceous clay at approximately 238 feet.
244 -247	Lignite, hard, black.
247 -250	Sand, very fine, highly silty; includes brown carbonaceous streaks.
250 -252	Silt, coarse to silt, clayey, medium-gray.
252 -265	Clay, silty, medium-gray; limestone concretions at approximately 258 feet.
265 -285	Sand, very fine, silty, medium-gray; occasional thin silty clay beds.
285 -300	Clay, silty, medium-gray.
300 -302	Lignite, medium hard, black.
302 -318	Clay, silty, medium-gray; tan limestone concretion at approximately 306 feet.
318 -321	Lignite, medium hard, black.
321 -325	Clay, silty, medium-gray.
325 -330	Lignite, hard, black.
330 -340	Silt, brown, slightly carbonaceous; some gray, silty clay included.
340 -345	Clay, gray to clay, carbonaceous, brown (thin lignite at 343 feet?).

Depth (ft.)	Lithologic Description
345 -376	Clay, silty and silt, clayey, gray with brown carbonaceous streaks; some minor very fine silty sand included.
376 -381	Sand, very fine, silty to coarse silt, gray with brown streaks; cemented at about 380 feet.
381 -385	Clay, silty, gray and clay, smooth light-gray.
385 -386	Clay, smooth, gray.
386 -390	Clay, carbonaceous, black; interval includes thin lignite.
390 -395	Clay, smooth, light-gray to brown.
395 -415	Clay, silty, medium-gray; includes some coarse silt and minor very fine sand.
415 -417	Clay, smooth, gray.
417 -424	Lignite, hard, black.
424 -438	Sand, very fine, silty, interbedded with gray silty clay.
438 -445	Clay, gray, silty; possibly a thin lignite.
445 -470	Silt to clayey silt, gray with brown flecks; some silty clay included, samples "dirty"; lignite at 460 feet?
470 -476	Clay, silty, gray.
476 -479	Clay, carbonaceous, dark-brown, with thin lignite.
479 -485	Clay, silty gray, interbedded with coarse silt, gray.
485 -500	Clay, silty green; some green silty sand beds included.

REAP #10
SWSWSWSE Sec 18, T145N, R83W
Elev. 1 922

0 - 3	Sand, fine, well-rounded, well-sorted, brown, predominantly quartz (eolian).
3 - 12	Pebble loam (till), yellow-brown with orange mottling, calcareous, highly oxidized; contains iron oxide spots, limy streaks, and weathered lignite fragments.
12 - 27	Silt, clayey, light-brown-gray, oxidized; includes occasional orange iron oxide concretionary bands, minor clay included.
27 - 33	Lignite, medium soft to medium hard, black.
33 - 34	Silt, clayey, medium-gray, unoxidized.
34 - 40	Clay, silty, medium-gray.
40 - 42	Sand, very fine, medium-gray, silty.
42 - 44	Clay, silty, medium-gray.
44 - 47	Lignite, hard, black.
47 - 48	Clay, medium-gray.
48 - 52	Silt, coarse, sandy, medium-gray.
52 - 57	Clay, smooth, light-gray.
57 - 57.5	Lignite with some dark-brown carbonaceous clay.
57.5- 60	Clay, silty, to silt, clayey, medium-gray.
60 - 63	Clay, silty, medium-gray with brown carbonaceous fossil plant fragments.
63 - 64	Lignite.
64 - 74	Sand, very fine, light-gray, well-sorted and well-rounded.
74 - 76	Lignite, black, soft, shaly.
76 - 80	Sand, very fine, silty, medium-gray; minor gray clay at about 79 feet.
80 - 90	Silt, clayey, green, interbedded with gray silty clay; minor very fine silty sand beds included.
90 - 98	Sand, very fine, silty, gray, some interbedded clay, gray.
98 -100	Lignite, medium hard, black.
100 -110	Clay, silty, gray; minor very fine sand and silt included; some dark-brown carbonaceous clay at approximately 102 feet and 107 feet.
110 -112	Silt, brown-gray; interval includes abundant fossil shell fragments.
112 -114	Silt, clayey, gray with brown carbonaceous fossil plant fragments.
114 -114.5	Lignite.
114.5-116	Silt, gray.
116 -118	Clay, silty, gray to dark-brown.
118 -126	Sand, very fine, silty, light-gray.
126 -130	Clay, silty, gray.

Depth (ft.)	Lithologic Description
130 -135	Sand, very fine, silty, light-gray.
135 -140	Clay, silty, gray; much carbonaceous plant material included.
140 -148	Silt, coarse, slightly sandy, gray with brown streaks.
148 -164	Clay, silty to silt, clayey, medium-gray; brown fossil plant fragments included; limestone concretionary fragments at approximately 150-154 feet.
164 -168	Sand, very fine, highly silty, gray.
168 -170	Lignite, medium hard, black.
170 -173	Clay, silty, brown to dark-brown-gray, carbonaceous.
173 -182	Lignite, medium hard, black.
182 -184	Clay, carbonaceous, dark-brown to black.
184 -190	Clay, silty to silt, clayey, medium-gray.
190 -200	Sand, very fine, silty, light-gray.
200 -204	Silt, green and clayey silt, green-gray; minor gray silty clay.
204 -208	Silt, coarse to very fine sand, gray.
208 -208.5	Lignite, black, thin; carbonaceous clay included.
208.5-220	Clay, silty, brown-gray with some black lignitic plant fragments, coarsens downward to silt.
220 -224	Lignite, medium soft, black to red-brown.
224 -228	Clay, silty gray; possible thin carbonaceous clay at about 226 feet; minor very fine brown sand included at bottom.
228 -240	Sand, very fine, silty; light-gray, well-rounded and well-sorted; minor silty clay beds included.
240 -396	Sand, fine, light-gray, well-rounded and well-sorted, clay at 258-260 feet.
396 -400	Lignite, black, medium hard, little clay.
400 -420	Sand, fine, blue-gray; abundant tan limestone concretion chips in interval from 410 feet to 420 feet.
420 -440	Sand, very fine, silty, green-gray with interbedded red-brown carbonaceous sandy streaks; yellow-orange and green clay beds included.

REAP #11
NWNWNWSW Sec 32, T141N, R83W
Elev. 1 865

0 - 2	Silt, dark-gray-brown.
2 - 16	Pebble loam (till), yellow-brown, oxidized, calcareous, includes iron oxide spots, limy streaks and weathered lignite fragments.
16 - 20	Sand, very fine, silty, yellow-gray; interbedded with clayey silt; some red-brown iron oxide concretionary bands included.
20 - 22	Clay, silty, light-gray-brown.
22 - 24	Siltstone concretion, dense, hard, dark-gray, calcium carbonate cement.
24 - 36	Sand, very fine, gray-brown to gray, silty at top and again at bottom of interval.
36 - 40	Lignite, hard, black; some black carbonate clay included.
40 - 50	Clay, silty, medium-gray; brown carbonaceous fossil plant fragments included.
50 - 52	Lignite, black, soft, some dark-brown carbonaceous clay included.
52 - 61	Clay, silty, medium-gray; brown carbonaceous fossil plant fragments included.
61 - 70	Silt, clayey, medium-gray.
70 - 84	Silt, fine, to silt, coarse, light-gray; some brown fossil plant fragments included; coarsens downward.
84 - 86	Clay, silty, medium-gray.
86 - 98	Lignite, hard, black.
98 -105	Clay, silty to silt, clayey, medium-gray; minor very fine silty sand at about 101-102 feet.
105 -108	Sand, very fine, silty, gray.
108 -112	Clay, silty to silt, sandy, medium-gray; tan limestone concretion at about 109 feet; few fossil shell fragments at 110 feet.
112 -122	Sand, very fine, gray with brown streaks.

Depth (ft.)	Lithologic Description
122 -131	Clay, silty, gray, interval includes some very fine sand, gray.
131 -136	Lignite, soft, red-brown to black.
136 -142	Clay, carbonaceous, dark-brown to red-brown.
142 -146	Clay, silty, medium-gray with brown fossil plant fragments.
146 -154	Sand, fine, tannish-gray.
154 -165	Sand, very fine, silty, light-gray; abundant red-brown fossil plant fragments included; some minor gray clay beds included at about 154 feet and 158 feet.
165 -167	Sandstone, light-gray, calcium carbonate cement, very fine-grained.
167 -187	Sand, very fine to fine, light-gray with black specks.
187 -192	Clay, silty, medium-green-gray.
192 -220	Sand, fine, medium- to light-gray with black specks; minor gray silty clay beds from 212 to 218 feet.

REAP #12
SESWSW Sec 8, T144N, R87W
Elev. 2 050

0 - 12	Pebble loam, buff, oxidized; contains scoria chips and lignite fragments.
12 - 56	Sand, very fine, yellow-brown, oxidized, becoming light-gray-green at approximately 18 feet with some red-brown oxidized spots, gray with black flecks below 20 feet; whitish "limy" zone at about 25 feet; thin carbonate sand zone at about 43 feet; some red-brown oxidized streaks in last 5 feet of interval.
56 - 67	Sand, very fine, silty, light-green-gray; some black carbonaceous material near top of interval.
67 - 70	As above, but, medium-gray with black flecks.
70 - 75	Clay, smooth, dark-gray; limestone at approximately 73 feet.
75 - 91	Lignite, hard, black.
91 -100	Clay, dark-gray, smooth.
100 -105	Clay, silty, gray.
105 -106	Limestone, tan.
106 -108	Clay, smooth, dark-gray, minor lignite.
108 -111	Sand, very fine, silty, gray.
111 -113	Sandstone, very fine-grained.
113 -115	Clay, silty, gray.
115 -116	Silt, sandy, gray.
116 -117	Clay, smooth.
117 -123	Limestone, dark-gray, very hard drilling.
123 -125	Clay, silty, gray.
125 -130	Silt, gray.
130 -135	Sand, very fine, gray with black flecks.
135 -155	Sand, very fine, silty, some clayey layers included; some carbonaceous spots.
155 -160	Clay, silty; minor purple-gray, hard, silt layer included.
160 -165	Lignite and gray clay.
165 -166	Silt, highly carbonaceous, rusty-brown colored.
166 -170	Clay, purplish to greenish-gray.
170 -180	Silt; light-greenish-gray.
180 -191	Poor sample, mostly silt as above with clayey silt and some lignite (may be contamination).
191 -200	Sand, very fine, silty, light-gray.
200 -205	Poor samples, probably same as above.
205 -210	Sand, very fine, silty with hard cement zone at approximately 207-210 feet.
210 -220	Clay, silty and silt, clayey, some very fine silty sand at 219 feet.
220 -223	Sand, very fine, silty, gray.
223 -225	Silt to clayey silt, gray.
225 -234	Clay, medium-gray, carbonaceous zone at approximately 227-228 feet. Light-tan limestone at approximately 225 feet.
234 -250	Lignite, medium hard, black, some gray silty clay included.
250 -257	Silt, clayey, gray.

Depth (ft.)	Lithologic Description
257 -260	Clay, silty, gray.
260 -270	Sand, very fine, silty, gray.
270 -273	Silt, coarse, gray, minor silty clay.
273 -280	Sand, very fine, silty; cemented from 276-279 feet.
280 -285	Poor samples, clay?
285 -295	Silt, laminated, gray and red-brown.
295 -297	Clay, silty, gray.
297 -299	Clay, carbonaceous, black.
299 -302	Lignite, medium soft to medium hard, black.
302 -313	Clay, silty, gray (possible thin lignite at about 313 feet).
313 -314	Limestone, light-green-gray.
314 -316	Clay, silty, gray.
316 -320	Silt, green.
320 -344	Clay to silty clay, gray; limestone at approximately 331 feet, tan.
344 -347	Limestone, dark-gray, hard.
347 -352	Clay, silty, gray.
352 -353	Lignite, hard, black.
353 -360	Clay, silty, light-gray to medium-gray.
360 -370	Sand, very fine, silty, minor silty clay layers.
370 -373	Clay, light-gray.
373 -375	Limestone, dark-gray, hard.
375 -387	Sand, very fine, silty, interbedded with silty clay, gray.
387 -395	Lignite, hard, black.
395 -400	Clay, silty, light-gray (minor brown carbonaceous clay included at approximately 395-396 feet).
400 -405	Poor samples, appears to be same as above.
405 -410	Poor samples, some very fine, silty sand cuttings, gray.
410 -413	Sand, very fine, silty, light-gray.
413 -430	Silt, gray, interbedded with silty clay, gray; some sand present (very poor samples).
430 -437	Sand, very fine, very silty, light-gray; some hard, tan limestone chips present at 430 feet.
437 -443	Clay, medium-green-gray.
443 -446	Poor samples, probably lignite in the interval.
446 -450	Clay, silty, green-gray; minor tan limestone at about 446 feet.
450 -460	Sand, very fine, to sand, very fine, silty, with some minor clayey silt layers, gray.
460 -467	Poor samples, probably same as above.
467 -471	Clay, silty, gray.
471 -473	Lignite, black, hard.
473 -475	Clay, smooth, light-gray.
475 -480	Silt, clayey to clay, silty, gray.
480 -500	Clay, silty, gray, interbedded with silt and clayey silt, gray; minor light-tan poorly cemented limestone at approximately 442 feet; sand, very fine, at bottom of interval.

REAP #13
SWSWSWSW Sec 14, T144N, R87W
Elev. 1 885

0 - 10	Pebble loam, buff, oxidized, quite pebbly; abundant small lignite fragments.
10 - 14	Gravel, with iron oxide concretionary fragments abundant.
14 - 27	Sand, very fine, tan; hard iron oxide concretionary layer at top of interval along with silty clay.
27 - 32	Sand, very fine, silty, tannish-gray; minor olive-gray clay bed included.
32 - 35	Silt to silty clay, orange, highly oxidized; some iron oxide concretionary fragments included.
35 - 42	Sand, very fine, tan with orange bands, oxidized.

Depth (ft.)	Lithologic Description
42 - 48	Clay, silty, medium-gray, with thin lignite at approximately 44 feet.
48 - 55	Lignite, hard, black.
55 - 58	Clay, silty, gray.
58 - 60	Sand, very fine, silty, gray.
60 - 62	Clay, gray.
62 - 64	Lignite, hard, black.
64 - 66	Sand, very fine, silty, gray (lignite in samples).
66 - 67	Clay, gray, minor carbonaceous material.
67 - 72	Silt to very fine silty sand, gray.
72 - 80	Clay, silty, medium- to dark-gray.
80 - 83	Silt, clayey, medium-gray.
83 - 90	Clay, dark-gray, silty.
90 - 91	Clay, carbonaceous, black.
91 - 95	Lignite, black, hard.
95 -100	Silt, sandy and sand, very fine, silty, minor silty clay included, green-gray.
100 -114	Sand, very fine, "salt and pepper," green-gray.
114 -116	Lignite, hard, black.
116 -118	Clay, gray.
118 -136	Silt, medium-gray, coarse, sandy in part.
136 -155	Sand, very fine, gray; some very fine, silty sand included.
155 -159	Sandstone, very fine-grained, light-gray.
159 -205	Sand, very fine to fine, "salt and pepper," gray. Minor tan limestone at approximately 204 feet.
205 -207	Lignite, black, hard.
207 -220	Clay, silty, gray; thin very fine sand bed at approximately 213-214 feet.
220 -222	Sand, very fine, highly silty, gray.
222 -234	Clay, gray; some limestone chips at about 223 feet.
234 -235	Clay, carbonaceous, black.
235 -239	Lignite, black, medium soft, with some soft carbonaceous seams and minor clays.
239 -243	Clay, gray.
243 -251	Lignite, hard, black.
251 -265	Silt, sandy, interbedded clay, gray.
265 -268	Clay, gray.
268 -271	Lignite, black, medium hard.
271 -275	Clay, silty, gray.
275 -277	Sand, very fine, silty, gray.
277 -279	Sandstone, light-gray, calcium carbonate cement.
279 -282	Sand, very fine, silty, gray.
282 -285	Clay, silty, gray.
285 -287	Sand, very fine, gray.
287 -289	Limestone, hard, dark-gray.
289 -295	Sand, very fine, silty, gray (poor samples).
295 -300	Clay, smooth, light-gray.
300 -315	Clay, silty to silt, clayey, gray; tan limestone at about 306 feet.
315 -319	Clay, black, carbonaceous and lignite.
319 -320	Clay, gray.
320 -330	Sand, very fine to fine, gray.
330 -334	Clay, silty, gray.
334 -338	Limestone, dark-gray, hard.
338 -340	Poor samples, gray clay?

REAP #14
NENENENW Sec 32, T145N, R86W
Elev. 1 968

0 - 4	Pebble loam, buff, oxidized.
4 - 15	Lignite, black, soft, oxidized.
15 - 16	Clay, yellow-brown.

Depth (ft.)	Lithologic Description
16 - 20	Clay, silty to silt, clayey, gray-brown, partly oxidized; some minor silty sand included.
20 - 25	Clay, silty, gray.
25 - 30	Lost circulation, no samples.
30 - 42	Clay, silty, gray (poor samples).
42 - 47	Sand, very fine, "salt and pepper," blue-gray.
42 - 50	Clay, medium-gray; limestone at approximately 47 feet, tan.
50 - 53	Silt, clayey, blue-green.
53 - 56	Lignite, medium hard, black.
56 - 60	Silt, sandy to silt, clayey, gray.
60 - 65	Clay, gray, minor tan limestone at about 64 feet.
65 - 66	Lignite.
66 - 70	Clay, medium-gray, smooth.
70 - 72	Silt, coarse, brown-gray, sandy.
72 - 73	Clay, silty, brown-gray.
73 - 83	Silt, sandy, medium-gray.
83 - 87	Lignite, hard, black; interval includes some chocolate-brown sandy silt, carbonaceous.
87 - 90	Clay, silty, gray.
90 -100	Silt, sandy to sand, silty, medium-gray.
100 -120	Sand, very fine, blue-gray.
120 -126	Lignite, black, medium hard.
126 -140	Silt to clayey silt, light-gray, minor silty clay at about 136 feet.
140 -160	Clay, silty, light-gray; some clayey silt in the interval from 145 feet to 150 feet (poor samples).
160 -163	Silt, gray.
163 -165	Silt, clayey, carbonaceous, brown-black, lignitic at bottom of interval.
165 -171	Silt, light-gray.
171 -175	Limestone, dark-gray, hard, silty.
175 -180	Poor samples, some sand, very fine, gray.
180 -185	Sand, very fine, "salt and pepper," gray.
185 -195	Clay, silty, gray; some tan limestone chips at about 186 feet.
195 -200	Lignite, black, hard.
200 -203	Clay, gray to brown-gray.
203 -205	Lignite, hard, black.
205 -210	Clay, smooth, gray.
210 -215	Silt, clayey, to silt, gray.
215 -225	Silt, coarse to very fine silty sand, light-gray.
225 -227	Lignite, hard, black.
227 -228	Clay, gray.
228 -230	Lignite, black, hard.
230 -236	Clay, silty, gray.
236 -239	Sand, very fine, silty, blue-gray.
239 -247	Clay, green, smooth.
247 -248	Clay, carbonaceous, dark-gray to brown-black.
248 -258	Clay, silty to silt, clayey, to silt, gray and green-gray (fining upward sequence).
258 -268	Sand, very fine, blue-gray.
268 -272	Clay, silty, gray.
272 -274	Clay and silt, carbonaceous, dark-gray-brown, lignitic in part.
274 -278	Silt, sandy, gray-brown.
278 -290	Clay, silty to silt, clayey, gray; minor carbonaceous clay and coarse silt interbedded.
290 -295	Poor samples, chips of hard, calcium carbonate cemented, very fine-grained silty sandstone.
295 -300	Poor samples, as above, with some gray, very fine, silty sand cuttings.
300 -335	Sand, very fine, silty; some silt, clayey silt and silty clay included in interval; medium-gray.

Depth (ft.)	Lithologic Description
335 -388	Sand, very fine to fine; gray with black flecks; tan cemented zone at about 378 feet (limestone, sandy).
388 -392	Sandstone, calcium carbonate cement; some tan limestone chips included at base of interval.
392 -420	Clay, silty, gray, minor silt zones included; carbonaceous clay bed at about 403 feet; another at about 417 418 feet, some very fine sand at bottom of interval.

REAP #15
NWSWNW Sec 26, T146N, R86W
Elev. 2 168

0 - 8	Pebble loam, oxidized, buff with iron oxide spots; boulders abundant at the surface, sandy.
8 - 16	Sand, very fine, silty, yellow-brown, oxidized, red-brown streaks common.
16 - 17	Lignite, very soft, weathered, red-brown to black.
17 - 21	Silt, olive-brown, oxidized.
21 - 22	Clay, olive-brown, oxidized, silty.
22 - 26	Silt, coarse, sandy, gray-brown.
26 - 28	Sand, very fine, brown-gray.
28 - 29	Lignite, soft, black.
29 - 37	Silt, gray-brown with red-brown streaks, oxidized; contains fossil plant fragments; some clayey silt included.
37 - 42	Clay, silty, unoxidized, medium-gray.
42 - 44	Lignite, medium hard, black.
44 - 45	Clay, smooth, gray.
45 - 46	Silt, gray.
46 - 47	Lignite, hard, black.
47 - 58	Silt, medium-gray.
58 - 70	Sand, very fine, blue-gray with black specks.
70 - 75	Sand, very fine, silty to silt, sandy, blue-gray.
75 - 77	Clay, silty, gray; interval includes thin lignite stringer.
77 - 80	Silt, sandy, gray.
80 - 85	Silt, gray, clayey at bottom of interval.
85 - 86	Clay, carbonaceous, purple-brown to dark-brown.
86 - 90	Clay, medium-gray, smooth.
90 - 95	Silt, clayey, medium-gray.
95 -100	Sand, very fine, blue-gray.
100 -105	Silt, medium-gray.
105 -113	Clay, silty, gray, tan limestone chips at about 107 feet.
113 -115	Sand, very fine, silty, blue-gray.
115 -117	Clay, purple-brown, thin lignite included.
117 -120	Silt, green.
120 -125	Clay, silty, gray.
125 -135	Silt, green-gray, sandy from 133-135 feet.
135 -137	Sandstone, "salt and pepper," green-gray.
137 -143	Clay to silty clay, gray.
143 -150	Silt, laminated, gray, fine-grained.
150 -162	Clay, silty to silt, clayey, medium-gray.
162 -170	Clay, silty, gray with red-brown fossil plant fragments.
170 -175	Lignite, hard, black.
175 -178	Clay, gray.
178 -181	Lignite, hard, black.
181 -190	Clay, silty, gray; some clayey silt in interval.
190 -192	Clay, smooth, light-gray, few tan limestone chips included.
192 -198	Lignite, hard, black.
198 -203	Clay, silty, gray.
203 -205	Lignite, hard, black.
205 -208	Clay, silty, gray; some clayey silt included.

Depth (ft.)	Lithologic Description
208 -209	Siltstone, light-gray, calcium carbonate cement.
209 -218	Silt, gray.
218 -219	Clay, gray.
219 -225	Lignite, medium hard, black; some black carbonaceous clay and gray clay included.
225 -228	Siltstone, calcium carbonate cement, gray.
228 -236	Silt to clayey silt, gray; minor carbonaceous clay included.
236 -237	Clay, silty, gray.
237 -238	Lignite, black, medium hard.
238 -252	Clay, smooth; some hard, tan limestone chips at approximately 246 feet.
252 -260	Clay, silty, light-green.
260 -265	Lignite, hard, black; some clay in interval.
265 -267	Clay, smooth, gray.
267 -270	Lignite, hard, black (contamination?).
270 -275	Clay, silty, gray.
275 -280	Sand, very fine, silty, gray with black flecks.
280 -284	Lignite, hard, black (contamination?).
284 -300	Sand, very fine, silty, some silty clay beds included in interval; (possibly some thin lignite beds, probably contamination).
300 -307	Sand, very fine, gray; some silty sand at bottom of interval.
307 -310	Silt, dark-gray.
310 -311	Clay, gray.
311 -314	Lignite, hard, black.
314 -319	Clay and silty clay, gray.
319 -323	Lignite, black, hard (may be contamination).
323 -330	Clay, silty, gray to green-gray, limestone at approximately 328 feet.
330 -336	Lignite, black, medium hard.
336 -380	Samples are very badly contaminated with lignite; cuttings are mostly silty clay. Would be impossible to pick any lignites in this interval. Might be about 5 feet of lignite at 360 feet.
380 -385	Clay, gray.
385 -387	Clay, carbonaceous, dark-brown.
387 -391	Clay, silty, dark-gray.
391 -392	Clay, carbonaceous, dark-brown.
392 -394	Clay, silty, gray.
394 -412	Silt, clayey, gray; few tan limestone chips at about 396 feet.
412 -418	Silt, clayey, medium-gray.
418 -425	Sand, very fine, silty; gray; also some clay and silt in sample.
425 -435	Lignite, hard, black.
435 -436	Silt, clayey.
436 -441	Sand, very fine, silty, laminated, gray with brown carbonaceous laminae.
441 -450	Clay, silty, green-gray with a semi-indurated tan limestone layer at approximately 444 feet.
450 -455	Lignite, hard, black.
455 -463	Silt, gray; clayey in part.
463 -464	Clay, silty, gray.
464 -466	Lignite, hard, black.
466 -470	Clay, gray.
470 -472	Lignite, hard, black.
472 -479	Clay, silty, green.
479 -481	Sand, very fine, silty, gray.
481 -497	Clay, silty, gray and green.
497 -498	Lignite with some black carbonaceous clay.
498 -515	Clay, silty, gray and green; some clayey silt included.
515 -517	Silt, sandy, to sand, silty, gray.
517 -520	Sandstone, light-gray, calcium carbonate cement.
520 -530	Poor samples, appears to be very fine gray sand to clayey silt to silty clay, gray.
530 -540	Sand, very fine, silty, some interbedded silty clay, gray.

Depth (ft.)	Lithologic Description
540 -548	Clay; silty, green-gray; some minor black carbonaceous clays included.
548 -560	Sand, very fine, gray with black flecks and carbonaceous interbedded streaks; some silty clay in interval.
560 -580	Sand, very fine, green-gray with black flecks; minor sandstone at approximately 562 feet.
580 -600	Sand, very fine, silty, gray, interbedded with silty gray clay; some green shale cuttings at about 582-585 feet; a weakly cement off-white silty sand occurs from about 594-597 feet; some hard, green shale cuttings included in sample from 595-600 feet.

REAP #16
SESESESE Sec 14, T146N, R86W
Elev. 2 105

0 - 15	Pebble loam, yellow-brown, oxidized, numerous igneous, metamorphic, and carbonate pebbles; large boulder at approximately 8 feet (granite).
15 - 25	Pebble loam, highly gravelly, mostly fine, lithology same as pebbles listed above, oxidized, buff.
25 - 40	Pebble loam, gravelly, gray-brown, oxidized, large angular to subrounded granules and pebbles common.
40 - 45	Sand, very fine, silty, gray-brown (poor sample).
45 - 50	As above, more clayey.
50 - 55	Silt, sandy, clayey, gray.
55 - 60	Silt, clayey, yellow-brown; fine, rounded gravel zone at top of interval.
60 - 67	Silt, clayey, yellow-brown.
67 - 72	Pebble loam, olive-brown, oxidized, tough, clayey, pebbles scarce; more lignite fragments than till above, carbonate pebbles predominate.
72 -168	Pebble loam, as above, but dark-gray and unoxidized, lignite fragments common.
168 -205	Gravel, fine to medium, composed of about 75% angular black lignite fragments, 20% rounded dark-gray shale pebbles and about 5% igneous, metamorphic, and carbonate types.
205 -252	Pebble loam, dark-gray, unoxidized, tough, very similar to till from 72-168 feet (much contamination from lignite gravel in overlying unit). Driller thought he was drilling in sand (probably because of water saturation from overlying aquifer) from about 200-240 feet. Samples were poor in this interval. Till samples below 240 feet were good and as described above.
252 -292	Clay, silty, gray; some clayey silt included, Note: All samples contaminated by lignite from overlying lignite gravels, very difficult to pick any lignite beds in this interval.
292 -297	Clay, silty, green.
297 -300	Clay, carbonaceous, dark-brown.
300 -305	Clay, silty, gray.
305 -307	Limestone, tan, soft to medium hard.
307 -308	Clay, silty, medium-gray.
308 -315	Silt, sandy, interbedded with silty clay; some very fine silty sand at bottom of interval, gray.
315 -322	Clay, silty, gray, some brown carbonaceous clay at approximately 321 feet.
322 -325	Silt, clayey, gray.
325 -327	Clay, carbonaceous, dark-brown.
327 -330	Silt, laminated, dark-gray to brown-gray, slightly carbonaceous.
330 -340	Clay, silty gray to green.
340 -350	Poor samples, few cuttings of clayey silt, light-gray.
350 -355	Silt, clayey to clay, silty, medium-gray.
355 -361	Silt, coarse, gray.
361 -374	Clay, silty, gray.
374 -378	Lignite, hard, black, with some carbonate clay.
378 -392	Clay, silty, gray; minor silty sand at about 379 feet.
392 -396	Silt, sandy, gray with red-brown carbonaceous flecks.

Depth (ft.)	Lithologic Description
396 -400	Clay, silty, gray.
400 -405	Clay, light-gray.
405 -410	Lignite, medium hard, black.
410 -420	Clay, silty, gray-green, interbedded with very fine silty sand, gray with red-brown carbonaceous streaks; some carbonaceous clay, dark-brown, at about 416 feet.
420 -435	Clay, silty, gray; minor carbonaceous clay at about 226 feet.
435 -440	Silt, clayey, gray to green, some silty clay also.

REAP #17
NWNWSWNW Sec 34, T145N, R86W
Elev. 1 734

Depth (ft.)	Lithologic Description
0 - 2	Silt, chocolate-brown, with pavement of cobbles and boulders at the surface; rocks are mixed igneous, metamorphic, and carbonate types.
2 - 4	Lignite, soft, weathered, with carbonaceous clay.
4 - 7	Clay, silty, yellow-brown, oxidized; red-brown staining on joint surfaces.
7 - 41	Sand, very fine, yellow-gray, some orange iron oxide spots, oxidized; thin clay at about 11 feet; round iron-oxide cemented concretionary zone from 30-34 feet.
41 - 43	Sand, highly carbonaceous, black, with some weathered lignite.
43 - 45	Sand, very fine to fine, tan-brown with black flecks.
45 - 80	Sand, fine, blue-gray with black flecks.
80 - 84	Sand, very fine, silty, blue-gray with black flecks.
84 - 85	Lignite, hard, black.
85 - 87	Clay, silty, gray.
87 - 89	Sand, very fine, silty, blue-gray.
89 - 90	Clay, carbonaceous, brown.
90 - 93	Sand, very fine, silty, blue-gray.
93 -102	Clay; gray to very light-brown.
102 -110	Silt, coarse, gray with black flecks.
110 -120	Sand, very fine, silty, to coarse silt, blue-gray with black flecks.
120 -128	Clay, gray, silty, tan limestone chips at about 123 feet.
128 -138	Lignite, black, hard, mixed with gray clay; samples poor.
138 -158	Samples very poor, mostly small lignite chips and silty clay; some good coarse silt cuttings from 138-140 feet.
158 -160	Clay, light-brown-gray with fossil leaf fragments.
160 -165	Lignite?
165 -183	Clay, smooth, light-brown-gray, limestone chips at approximately 177 feet.
183 -187	Lignite, black, hard.
187 -197	Clay, silty, light-gray, brown carbonaceous silty clay at approximately 192 feet.
197 -200	Sand, very fine, silty, gray.
200 -207	Clay, silty, gray.
207 -210	Clay, silty, carbonaceous, black.
210 -215	Clay, light-gray, smooth; poor samples.
215 -220	Clay, dark-brown, carbonaceous; poor samples.
220 -230	Clay, silty, gray; some gray silt included.
230 -258	Clay, silty, gray, interbedded with clayey silt.
258 -260	Sand, very fine, silty, gray.
260 -265	Poor samples, some gray clay.
265 -268	Clay, carbonaceous, dark-brown to black, some lignite.
268 -273	Clay, gray-brown.
273 -280	Clay, black, carbonaceous, and lignite.
280 -290	Clay, silty, brown-gray, weakly carbonaceous.
290 -300	Silt, gray, somewhat sandy in part.
300 -307	Poor samples, appears to be silt, gray, to sand.
307 -320	Clay, silty, gray to silt, clayey, gray; brown carbonaceous clay at approximately 316 feet.

Depth (ft.)	Lithologic Description
320 -340	Very poor samples, probably gray silty clay to about 330 feet then black carbonaceous clay, lignite, and some gray silty clay in the next 10 feet.
340 -350	Poor samples.
350 -380	Sand, very fine, silty, interbedded with occasional silt beds and silty clay beds, predominantly dark- to medium-gray (sandstone at 364 feet).
380 -384	Silt, sandy, medium-gray.
384 -386	Sand, very fine, silty, whitish-gray, weakly cemented.
386 -400	Sand, very fine, highly silty, mostly blue-gray with some carbonaceous brown laminae; some silt beds.
400 -424	Sand, very fine, silty, medium-gray with occasional brown carbonaceous spots.
424 -430	Clay, silty to silt, clayey, medium-gray with occasional red-brown carbonaceous spots, minor gray silty sand.
430 -448	Clay, silty, medium- to dark-gray; minor clayey silt included.
448 -450	Silt, sandy, with gray siltstone, calcium carbonate cement; some off-white clay present also.
450 -465	Silt, sandy; has a dark-gray color.
465 -470	Silt, clayey, siltstone, dark-gray, calcium carbonate cement at about 466 feet.
470 -510	Clay, silty, medium-dark-gray to silt, clayey, medium-dark-gray.
510 -543	Sand, very fine, highly silty, medium-dark-gray; silty clay bed at about 535 feet; fossil shell fragments at approximately 520 feet.
543 -546	Sandstone, gray, calcium carbonate cement.
546 -553	Clay, silty, medium-dark-gray; some clayey silt at about 548 feet.
553 -557	Silt, clayey, medium-dark-gray.
557 -600	Clay, silty, medium-dark-gray to silt, clayey, medium-dark-gray, minor occasional silt layers; dark-gray siltstone concretion at about 595 feet.

REAP #18
NWNWNWNW Sec 5, T146N, R83W
Elev. 1 974

0 - 44	Pebble loam, yellow-brown with red-brown iron spots and streaks; iron oxide concretionary fragments very common; some small lignite fragments; oxidized; generally rather sand; gravelly at about 3-5 feet; igneous, metamorphic, and sedimentary pebbles present in all samples; becomes olive-brown-gray at about 10 feet; graywacke boulder at approximately 22 feet. (Note: till seems somewhat tougher below 10 feet and is mottled with iron oxide streaks; more clayey; pebbles not as abundant; 2nd till).
44 - 71	Pebble loam, yellow-brown (3rd till), highly oxidized; red-brown flecks disseminated throughout; lignite fragments are larger than in above till (up to ½" in diameter), pebbles rather scarce; lithology of pebbles tends more toward carbonates; unoxidized and dark-gray below 60 feet.
71 - 76	Gravel, coarse, poorly sorted; composed of igneous, metamorphic, and sedimentary rocks; carbonates predominate.
76 - 81	Pebble loam, buff, oxidized (4th till), sandy, very soft, saturated.
81 - 89	Limestone concretion, olive-gray (portions of red-brown oxidized rind evident in some cuttings).
89 -100	Sand, very fine, highly silty, yellow-brown with red-brown oxidized streaks, highly oxidized.
100 -105	Poor samples, appears to be olive-gray clayey silt.
105 -120	Silt, clayey, tan-yellow with bright-orange iron oxide bands; clay-ironstone concretionary zone at about 118 feet, highly oxidized.
120 -130	Silt, yellow, highly oxidized.
130 -160	Sand, very fine, silty, tan-gray with black flecks, partly oxidized; seems to coarsen slightly downward.
160 -195	Sand, very fine, silty, "salt and pepper," gray, becoming blue-gray at about 170 feet, unoxidized, fossil shell fragments at 185 feet; silty clay, gray at about 191 feet.

Depth (ft.)	Lithologic Description
195 -200	Clay, silty, gray; thin lignite and very dark-gray carbonaceous clay included in interval.
200 -207	Clay, silty, light-gray.
207 -209	Silt, off-white, sandy, weakly cemented with lime.
209 -225	Clay, silty to silt, clayey, gray, carbonaceous, lignitic at 218 feet.
225 -244	Silt, gray.
244 -247	Sand, very fine, highly silty, blue-gray.
247 -254	Clay, silty, gray; some smooth clay included.
254 -260	Lignite, medium hard, black.
260 -263	Clay, dark-gray, somewhat carbonaceous in part.
263 -269	Lignite, medium hard, black, some associated black carbonaceous clay.
269 -270	Silt, light-gray.
270 -272	Silt, clayey, light-gray.
272 -279	Silt to clayey silt, light-gray.
279 -281	Lignite, hard, black?
281 -290	Silt mixed with lignite (difficult to interpret).
290 -295	Lignite, hard, black.
295 -298	Clay, silty, gray.
298 -307	Lignite, hard, black; some brown carbonaceous clay at about 302 feet.
307 -320	Clay, silty, dark-gray to silt, clayey, gray (lignite contamination).
320 -326	Lignite, hard, black.
326 -338	Clay, silty, gray, some clayey silt included.
338 -342	Sand, very fine, silty, blue-gray.
342 -353	Clay, silty, gray, laminated; tan limestone chips at 343 feet.
353 -355	Silt, sandy, coarse, dark-gray.
355 -360	Clay, gray, silty; minor dark-brown carbonaceous clay included, some lignite.
360 -361	Sand, very fine, highly silty, dark-gray.
361 -380	Clay, gray, silty, some lignite.
380 -385	Samples poor.
385 -390	Silt, clayey, gray.
390 -394	Clay, silty, gray.
394 -395	Lignite, hard, black.
395 -397	Clay, gray-brown to gray.
397 -400	Lignite, hard, black.
400 -412	Clay, silty, medium-gray; minor brown streaks.
412 -414	Lignite, hard, black and carbonaceous clay, black.
414 -415	Clay, silty and very fine silty sand, gray.
415 -430	Silt, clayey, gray, to clay, silty, gray; some carbonaceous material included.
430 -452	Clay, silty, to silt, clayey, interbedded with laminated, very fine, silty sand; brown carbonaceous laminae included in the sand; some carbonaceous plant fragments in the finer grained material; overall color is medium-dark-gray.
452 -515	Sand, very fine, silty, blue-gray with occasional brown, weakly carbonaceous silt beds; calcium carbonate cement sandstone at approximately 486 feet, becoming finer grained with carbonaceous clayey silt laminae in last 10 feet of interval.
515 -530	Clay, silty, gray with some clayey silt included; smooth gray clay in bottom 4 feet.

REAP #19
SWSWSWNW Sec 26, T142N, R85W
Elev. 2 296

0 - 2	Clay, silty, yellow-brown, oxidized.
2 - 15	Sand, fine to very fine, "salt and pepper," gray-brown, some lime cemented sandstone near top of unit.
15 - 17	Clay-ironstone, bright-orange, hard.
17 - 20	Sand, fine to very fine, "salt and pepper," gray-brown.
20 - 22	Clay-ironstone concretion zone, rusty-orange, hard.

Depth (ft.)	Lithologic Description
22 - 50	Sand, fine to very fine, "salt and pepper," gray-brown iron oxide concretions at approximately 38 feet; possibly other iron oxide concretionary zones in the interval, as chips of clay; ironstone occurs throughout the interval.
50 - 58	Sand, very fine, silty, "salt and pepper," unoxidized.
58 - 61	Lignite, black, soft to medium soft.
61 - 62	Clay, gray, smooth; brown-gray at top of interval.
62 - 64	Clay, carbonaceous, dark-brown to black.
64 - 66	Silt, gray.
66 - 77	Clay, silty, medium-gray; limestone, tan, at approximately 69 feet; lignite at 72 feet?
77 - 78	Clay, carbonaceous, red-brown.
78 - 80	Clay, silty, gray.
80 - 85	Silt, gray.
85 - 92	Sand, very fine, silty, light-gray.
92 -104	Sand, very fine, "salt and pepper," blue-gray.
104 -105	Sandstone, light-gray.
105 -108	Sand, very fine, silty, blue-gray; tan limestone chips at approximately 107 feet.
108 -111	Lignite, black, medium hard and dark-brown carbonaceous clay.
111 -120	Clay, silty, medium-dark-gray.
120 -125	Silt, clayey, gray.
125 -135	Silt, sandy to very fine sand, silty, medium-gray; gray limestone chips at approximately 127 feet.
135 -140	Clay, dark-gray, weakly carbonaceous in part.
140 -142	Clay, carbonaceous, very dark-brown to black, lignitic.
142 -145	Clay, green-gray, silty.
145 -147	Silt, green.
147 -160	Clay, silty, gray and green; minor carbonaceous streaks at about 157 feet.
160 -170	Silt, clayey to clay, silty, green.
170 -173	Silt, light-gray.
173 -175	Sand, very fine, silty.
175 -180	Clay, gray.
180 -200	Clay, blue-green, some interbedded clayey silt, blue-green.
200 -210	Silt to sandy silt, gray; some gray, silty clay included.
210 -220	Silt, gray.
220 -225	Clay, silty, gray.
225 -228	Sand, very fine, "salt and pepper," medium-gray.
228 -237	Clay, silty, gray with red-brown fossil plant fragments.
237 -239	Sand, very fine, "salt and pepper," medium-gray.
239 -244	Clay, silty, gray; some dark-brown-gray carbonaceous clay included.
244 -250	Lignite, hard, black (difficult to interpret; bran in samples).
250 -255	Silt and clayey silt, dark-gray (samples poor).
255 -270	Clay, silty, gray; red-brown fossil plant fragments included.
270 -280	Lignite, hard, black.
280 -283	Clay, silty, green-gray with red-brown fossil plant fragments.
283 -300	Silt, laminated; gray with red-brown carbonaceous laminae in upper part of interval; some silty clay interbeds from 285-290 feet.
300 -317	Clay, silty, gray; minor silt layers included; some lignite.
317 -328	Silt, gray; coarsens downward.
328 -331	Mixture of calcium carbonate cemented siltstone, gray, and tan limestone chips; siltstone chips predominate.
331 -333	Silt, sandy, gray.
333 -338	Clay, silty, gray.
338 -340	Lignite, medium hard, black.
340 -355	Clay, silty, medium-gray with red-brown carbonaceous plant fragments.
355 -360	Lignite, medium hard, black.
360 -365	Clay, silty, light-gray; some very fine silty sand at top of interval.
365 -370	Silt, gray with red-brown carbonaceous laminae.
370 -374	Clay, blue-gray; minor brown carbonaceous clay included at about 373 feet.

Depth (ft.)	Lithologic Description
374 -400	Sand, very fine, light-green-gray; calcium carbonate cemented sandstone at about 392-393 feet.

USGS B-7489
NENW Sec 11, T144N, R89W
Elev. 2 087

0 - 16	Pebble loam, medium-brown, silty, pebbly.
16 - 18	Sand, yellow-brown, fine-grained.
18 - 30	Silt, light-brown.
30 - 48	Clay, medium-brown and silt, light-gray.
48 - 62	Silt, light-gray.
62 - 63	Lignite.
63 - 68	Silt, medium-light-gray; concretion at 66 feet.
68 - 70	No samples.
70 - 75	Clay, medium-light-gray.
75 - 78	Lignite.
78 - 95	Clay, medium-light-gray.
95 -100	Clay, medium-light-gray, concretion at 97 feet.
100 -110	Clay, medium-light-gray.
110 -125	Silt and clay.
125 -135	Lignite.
135 -137	Clay.
137 -138	Lignite.
138 -148	Clay.
148 -155	Lignite.
155 -180	Silt and clay.
180 -181	Lignite.
181 -200	Silt and clay.

NDSWC 3914
SWSESW Sec 32, T146N, R82W
Elev. 2 020

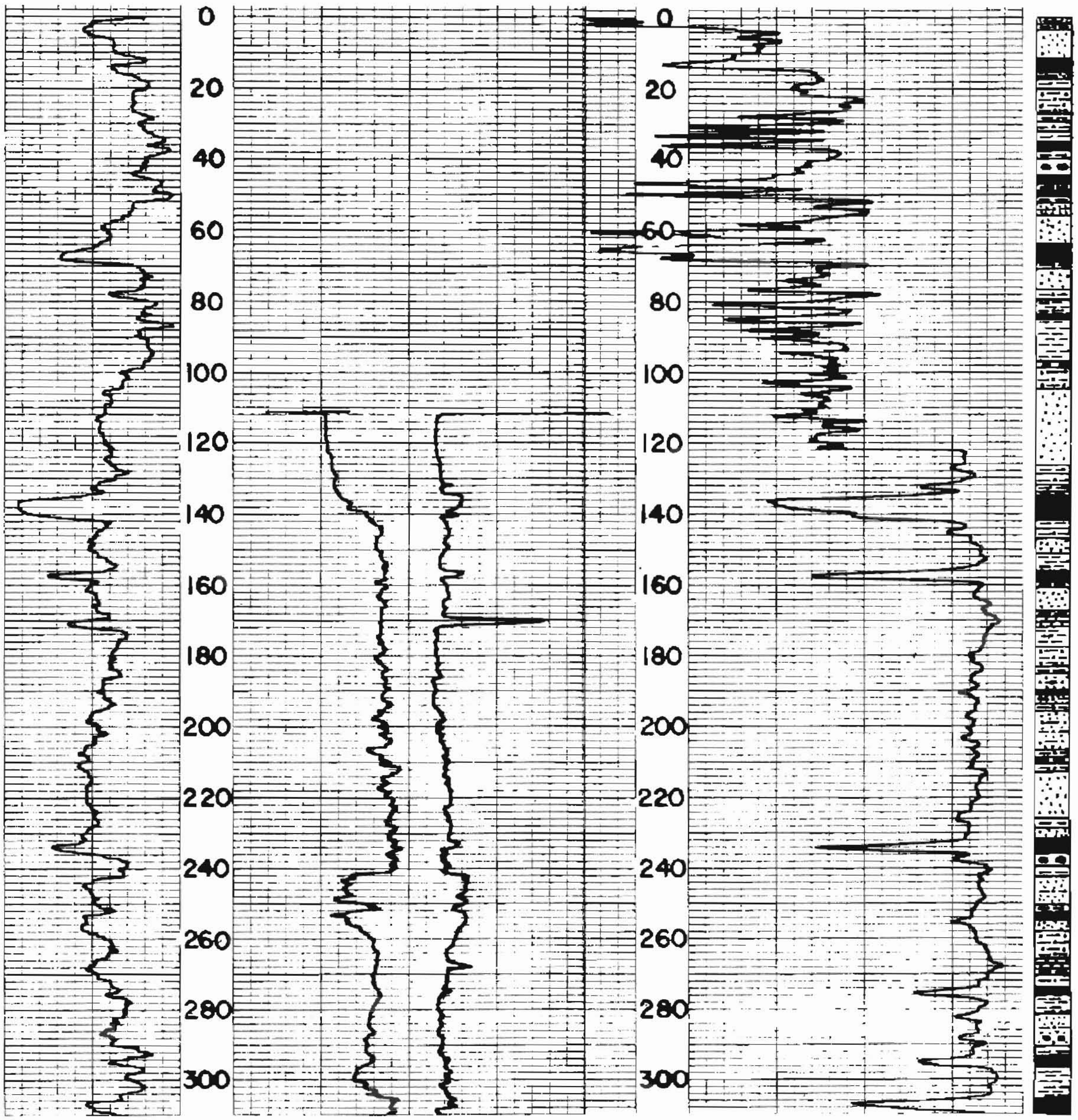
0 - 20	Clay, silty with sand grains and pebbles, medium-olive-brown, soft, very slightly cohesive, nonplastic dry; oxidized till to clay, silty with sand grains and pebbles, medium-olive-brown with yellowish limonitic stains, soft, moderately cohesive, slightly plastic, sticky, oxidized till, pebbles mostly carbonates.
20 - 40	Shale, silty, varigated oxidized browns, yellows, and grays with iron concretions, moderately soft, cohesive to slightly plastic, smooth to shale, black, oily, carbonaceous and lignitic to shale, silty to slightly sandy, turquoise-green,moderately soft and crumbly to slightly hard and brittle, smooth, tight.
40 - 60	Shale, black, carbonaceous and lignitic to shale, silty, dark-greenish-gray, moderately soft, cohesive, moderately plastic to shale, silty to sandy, medium-gray to medium-bluish-gray with interbedded light-gray bentonitic clay and indurated bentonite, generally moderately soft, moderately cohesive, slightly plastic.
60 - 80	Sand, very fine to fine, clayey, greenish-gray, soft, very slightly cohesive and slightly friable, micaceous.
80 -100	Lignite, black, slightly to moderately hard, fractured with interbedded brownish-green to gray carbonaceous silty and sandy shale.
100 -120	Shale, silty, predominantly medium-gray, moderately soft, cohesive and moderately plastic, interbedded with bentonitic clay and lignite, also dark-brownish-black carbonaceous shale.
120 -140	Shale, as above, silty, medium-gray to bluish-gray with interbedded bentonitic clay, lignite and greenish-gray clayey fine sand and silt.
140 -160	Silt and very fine clayey sand, light-medium-gray to light-greenish-gray, soft, slightly cohesive to moderately friable, micaceous, interbedded with

Depth (ft.)	Lithologic Description
	medium-gray silty shale and dark-gray, indurated, very fine-grained sandstone.
160 -180	Shale, silty, medium-bluish-gray to dark-greenish-gray, generally slightly hard and brittle, smooth, bentonitic and wrinkled cuttings; lignitic with dark-green, massive, waxy clay in lower part.
180 -200	Lignite, black, hard, brittle to shale, very silty, light-gray to light-olive-gray, slightly hard, brittle, laminated, calcareous, sandy streaks.
200 -220	Shale, silty to sandy, as above, lignitic and carbonaceous in upper part, moderately soft to slightly hard, generally light-medium- to medium-gray.
220 -240	Silt and silty shale, greenish-gray and medium-gray with interbedded tan, brown and black carbonaceous silt and silty shale, lignitic in upper part, generally moderately soft to slightly hard, moderately cohesive to slightly brittle, bentonitic.
240 -260	Silt and silty shale, as above, medium-gray and greenish-gray, carbonaceous streaks, lignitic and bentonitic.
260 -280	Silt, and silty shale, as above, with clayey very fine sand, predominantly light-greenish-gray to greenish-gray, mostly moderately soft, chunky and crumbly, interbedded lenses of loose, fine- to medium-dark-greenish-gray (white, green, and black) sand, possibly lignitic but lignite may be carrying over from above.
280 -300	Sand, very fine to medium, green, dark-green, and dark-greenish-gray with occasional streaks of light-olive-gray silty, carbonaceous and slightly fossiliferous, clayey very fine sand, sand generally loose to slightly cohesive and friable, soft.
300 -320	Sand, predominantly fine- to medium-grained, loose, dark-green, well-sorted and uniform, subangular and subrounded, clean, mainly quartz, and lignite or biotite specks.

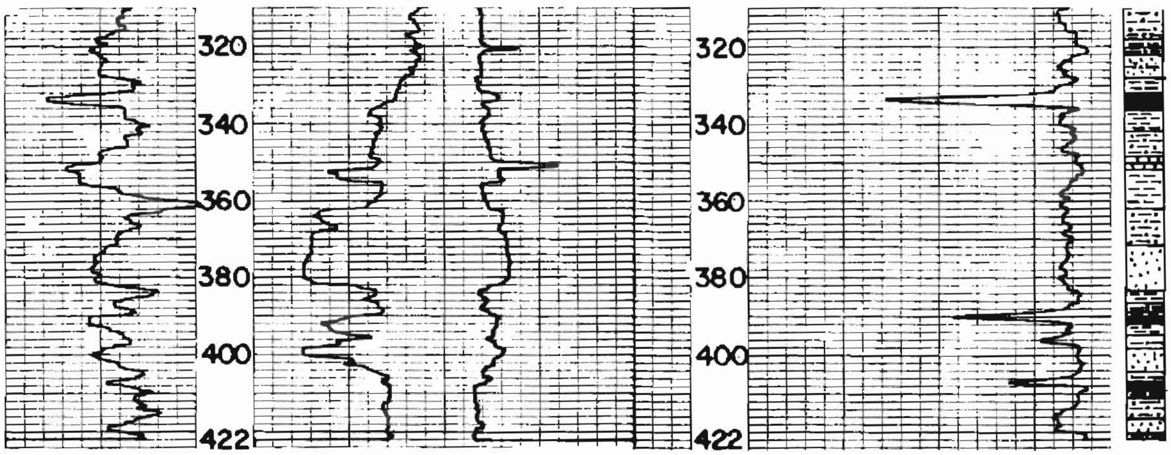
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 1 Date August 26, 1976
Location T 142N R 85W sec 35 ddd (F EW L) (F NS L)
Elevation 2 158' Topo Sheet Hannover TD 422' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



REAP # 1--Continued



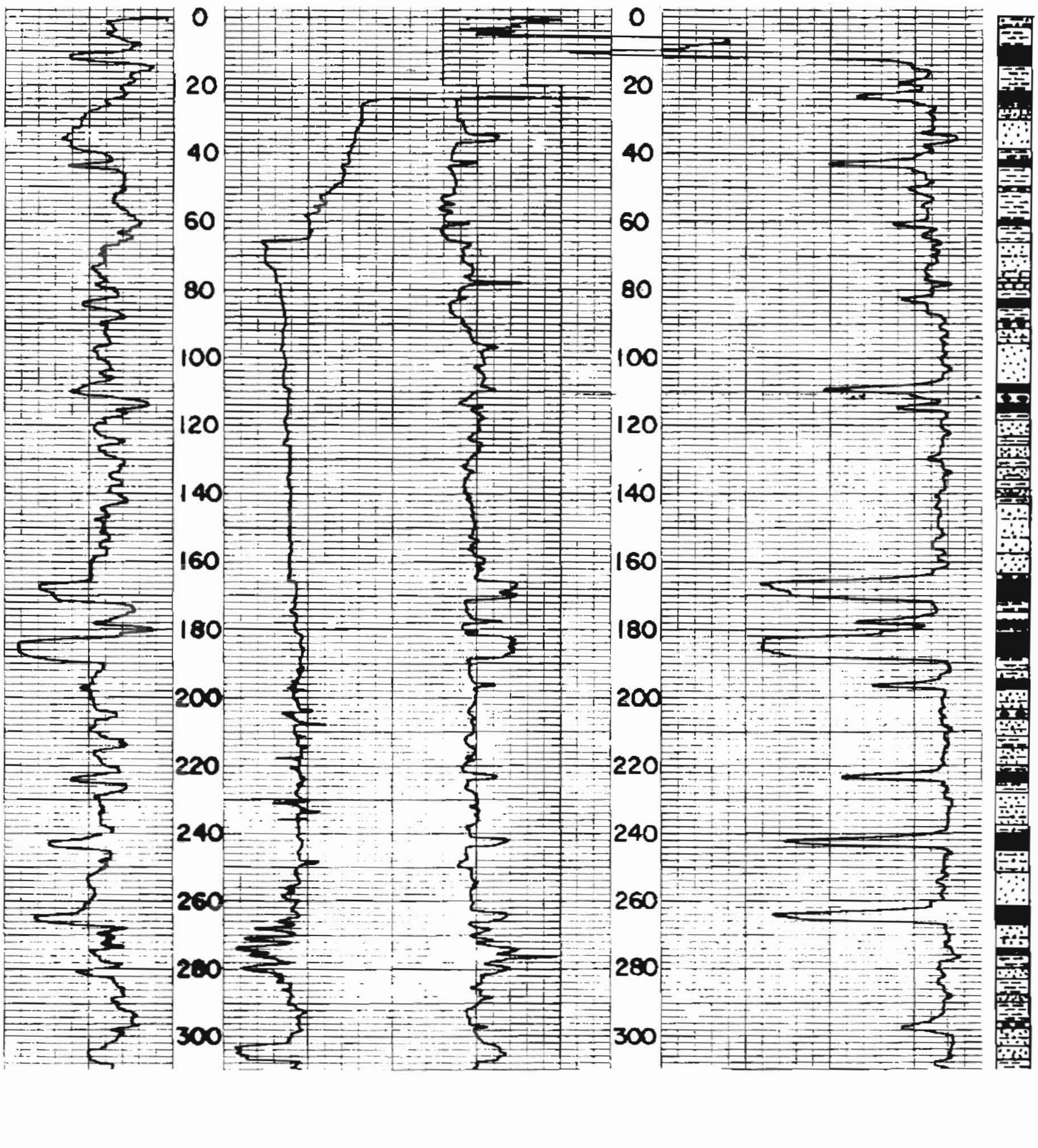
NORTH DAKOTA GEOLOGICAL SURVEY

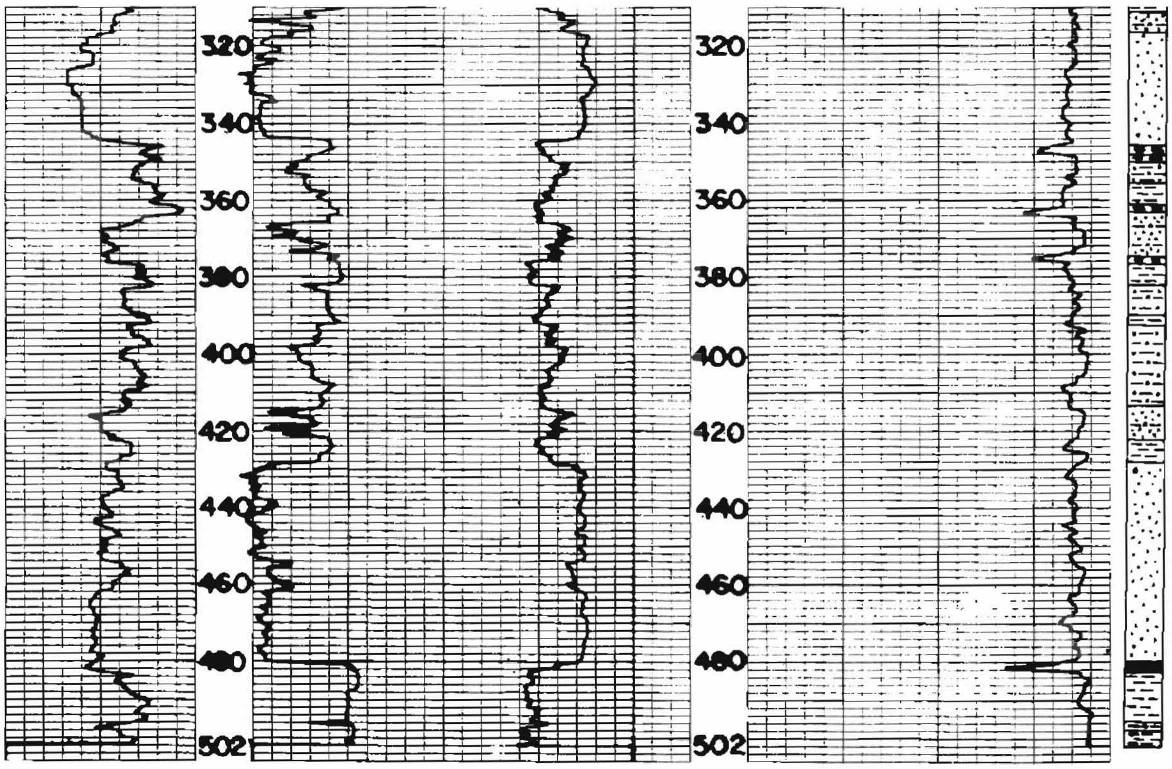
Hole No. REAP 2 Date August 26, 1976

Location T 142N R 85W sec 16 ddd (F EW L)____ (F NS L)____

Elevation 2 175' Topo Sheet Hannover TD 502' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.




320
340
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502

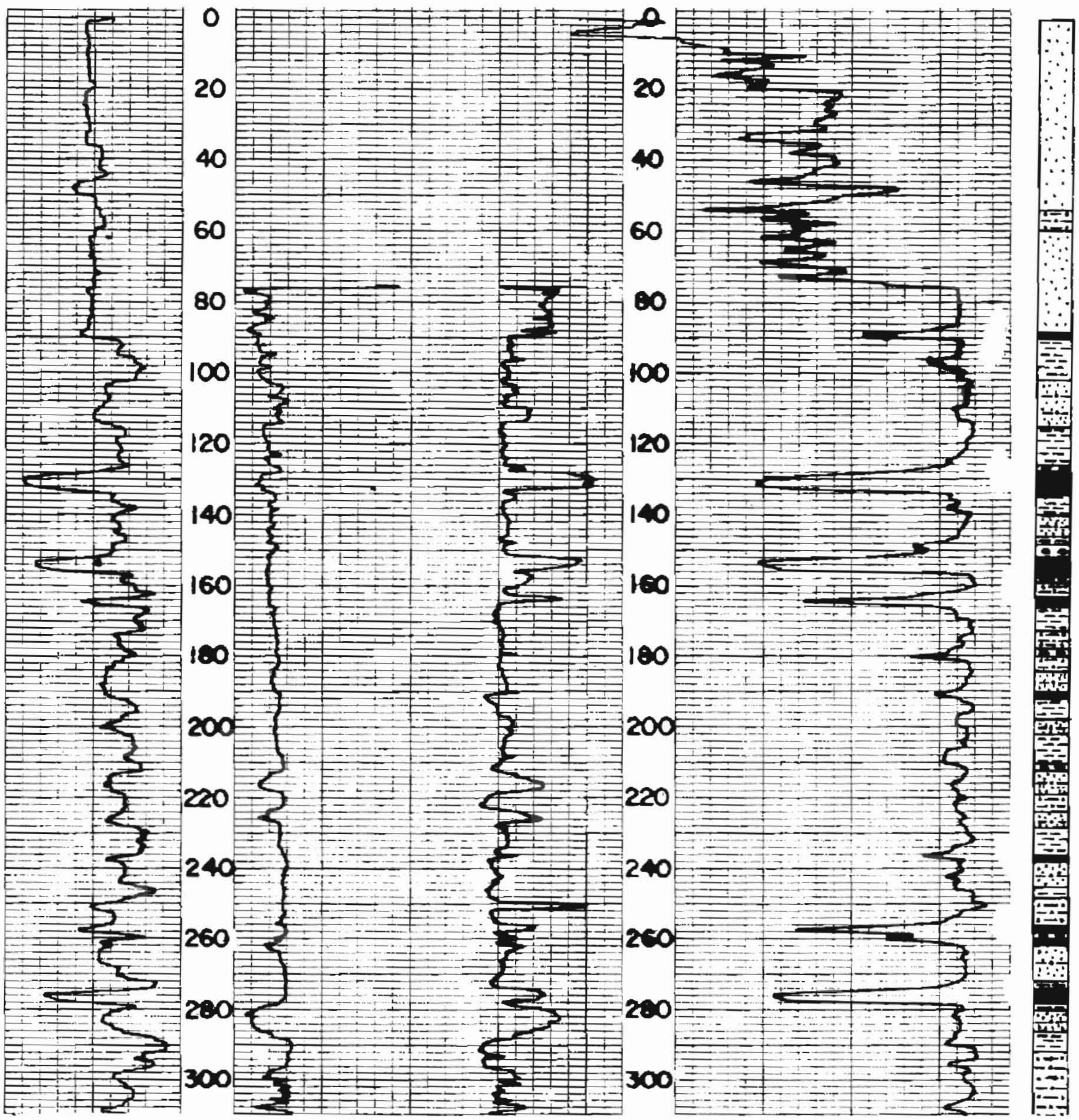
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 3 Date August 29, 1976

Location T 142N R 85W sec 6 ddd (FEL) 150' (FSL) 10'

Elevation 2 310' Topo Sheet Hannover NW TD 502' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



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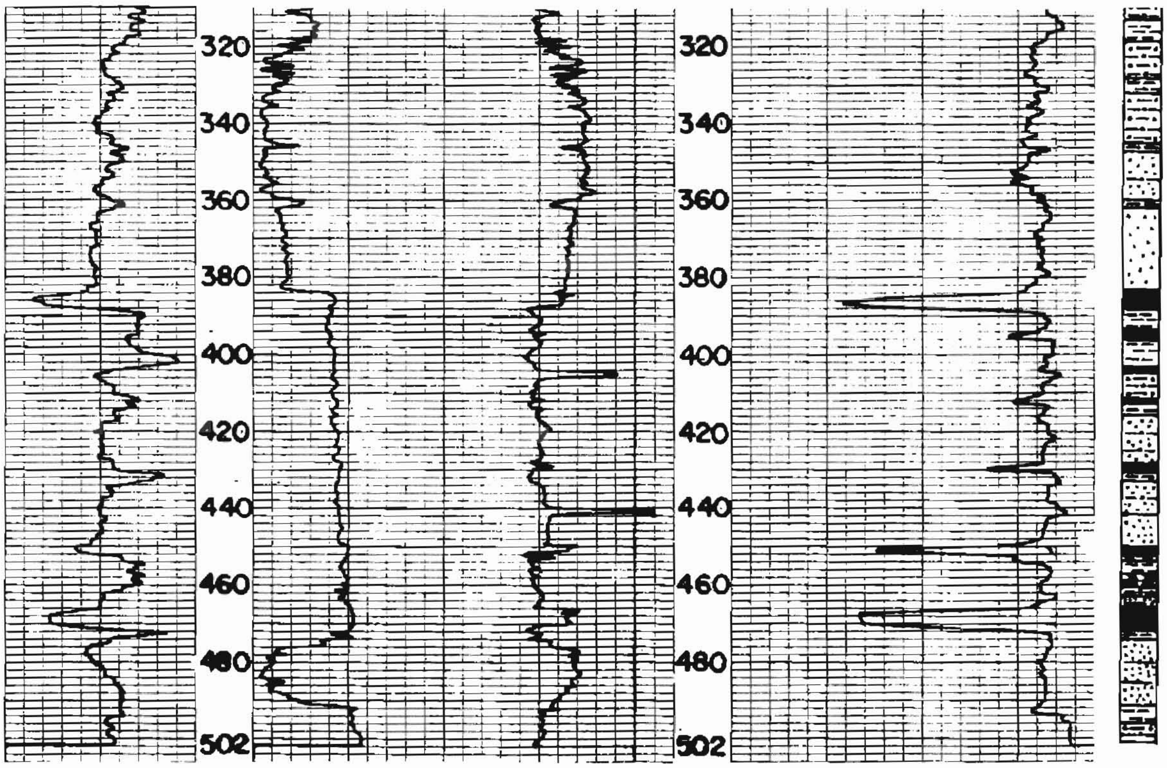


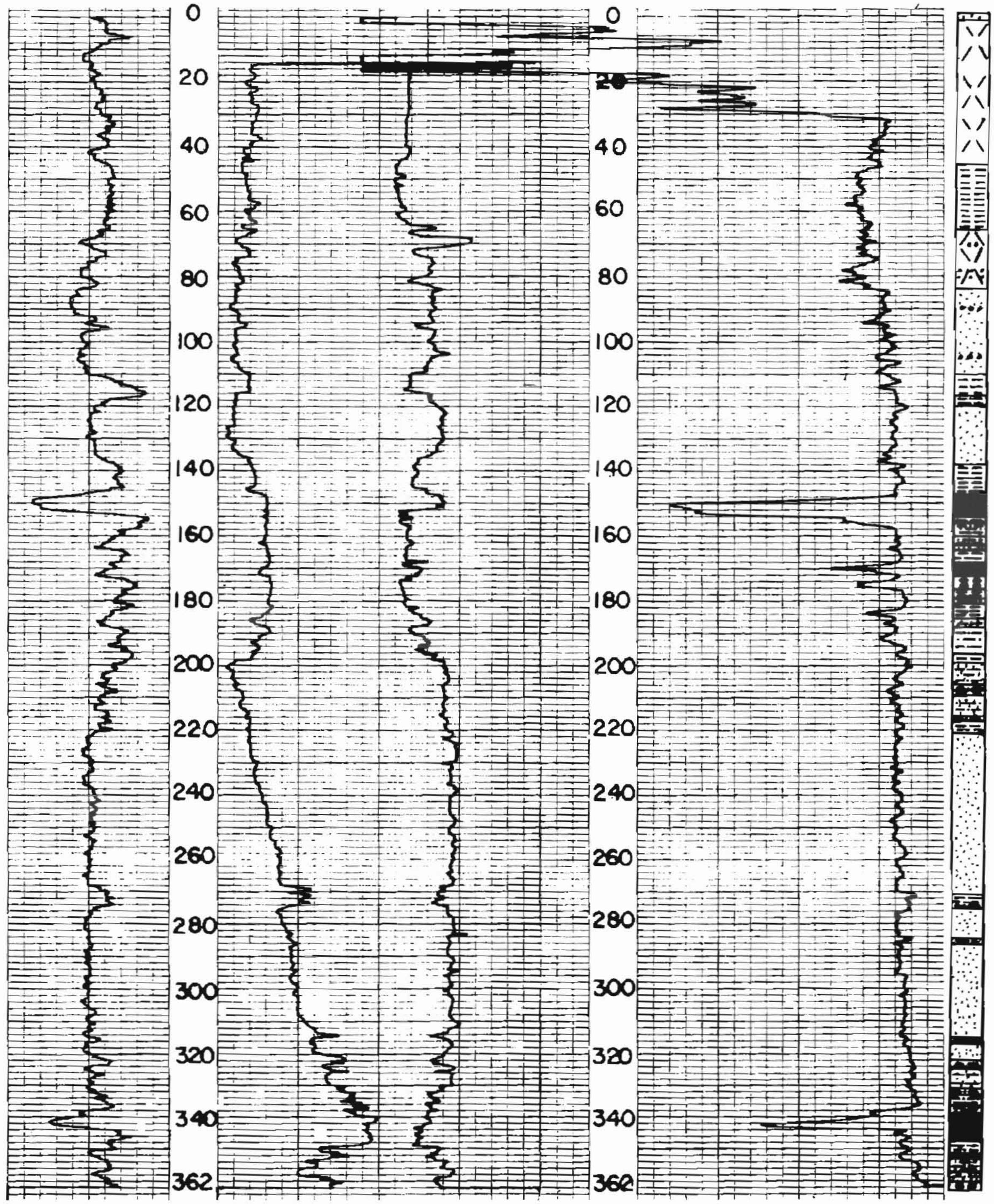
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 4 Date August 31, 1976

Location T 143N R 87W sec 10ddd (FEL) 5' (FSL) 100'

Elevation 1 890' Topo Sheet Red Butte NW TD 362' Fluid Type Water

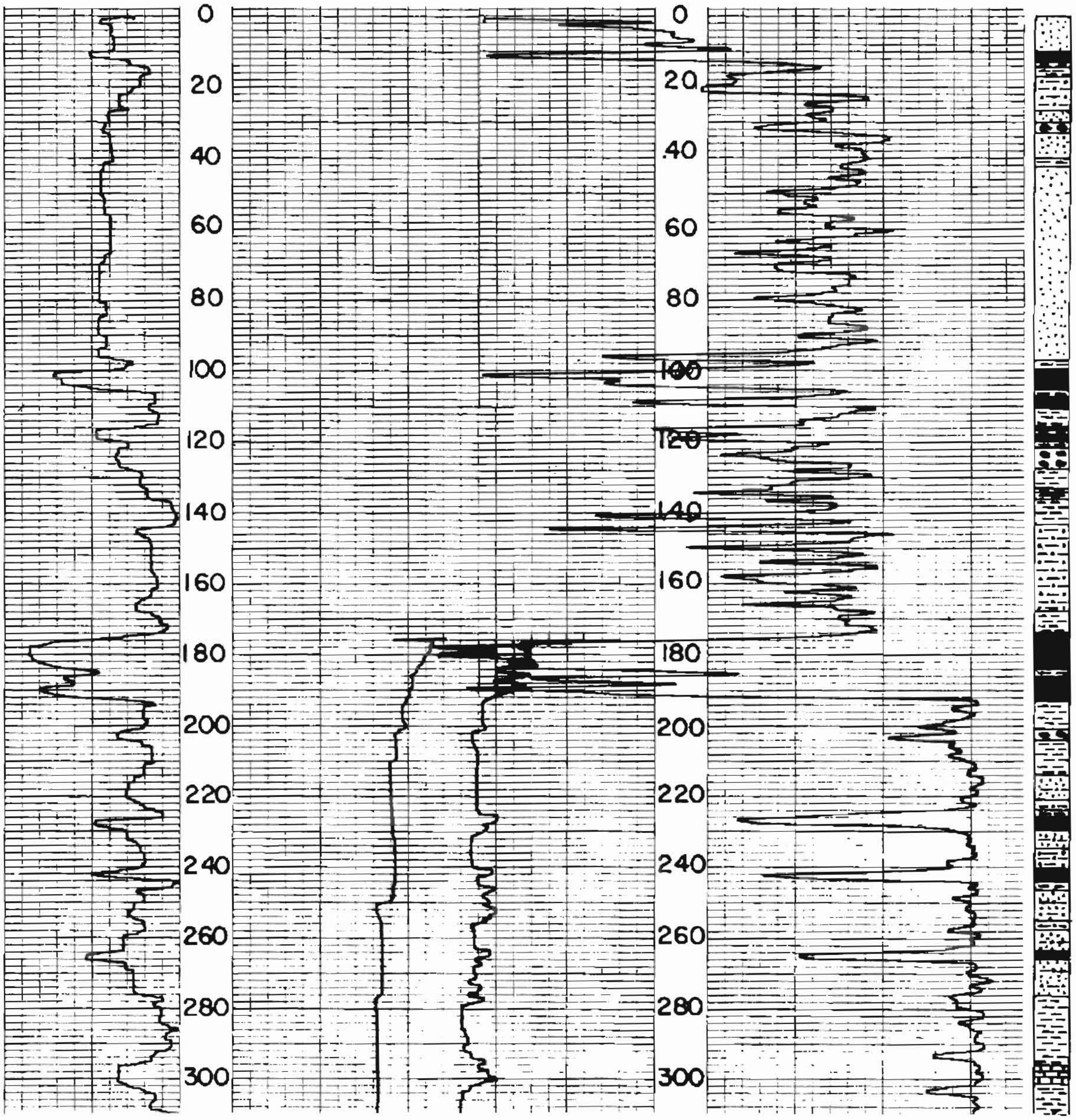
SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.

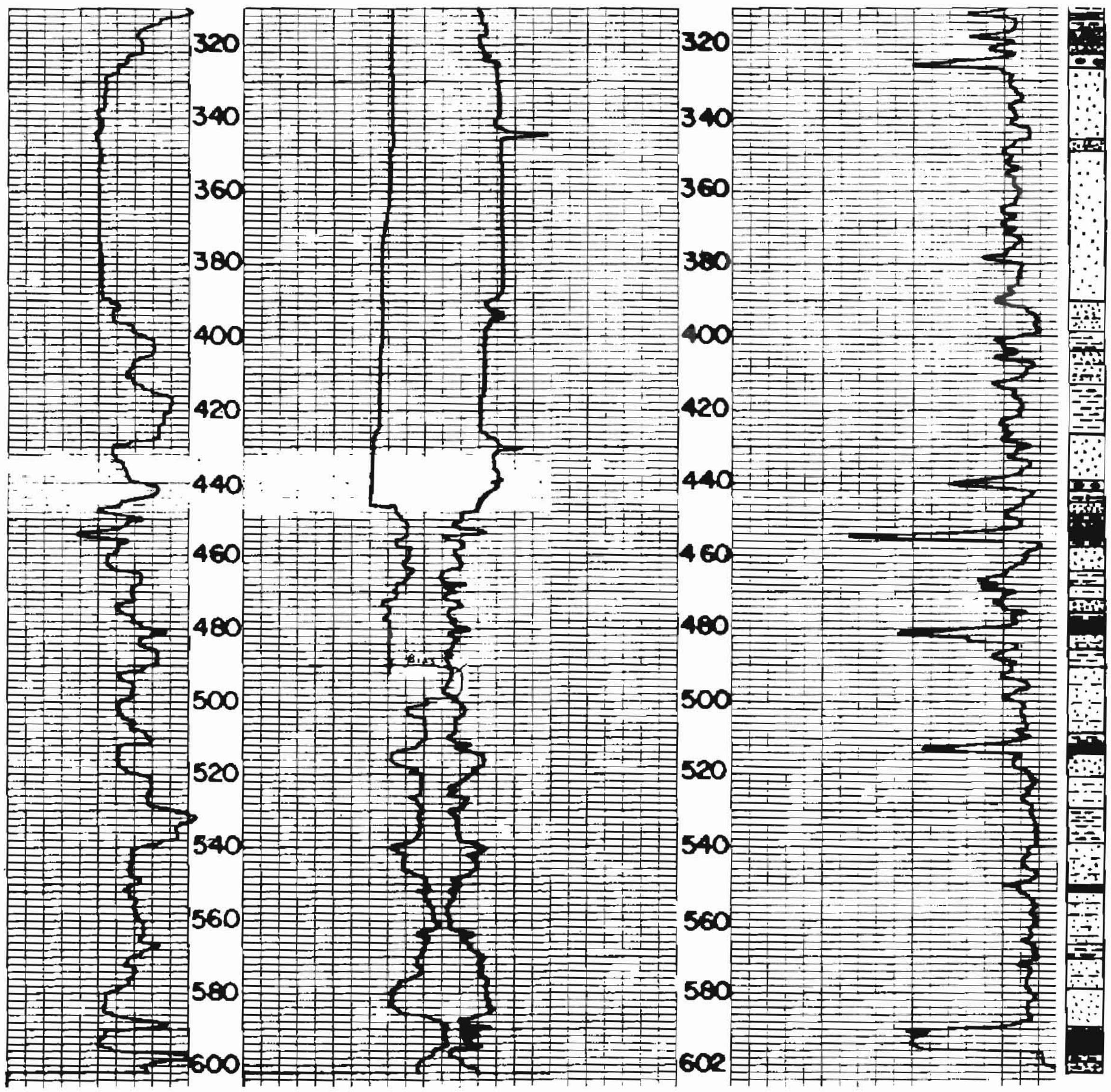


NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 5 Date August 30, 1976
Location T 142N R 87W sec 18 bbb (FWL) 120' (FNL) 12'
Elevation 2 170' Topo Sheet Medicine Butte NE TD 602' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.

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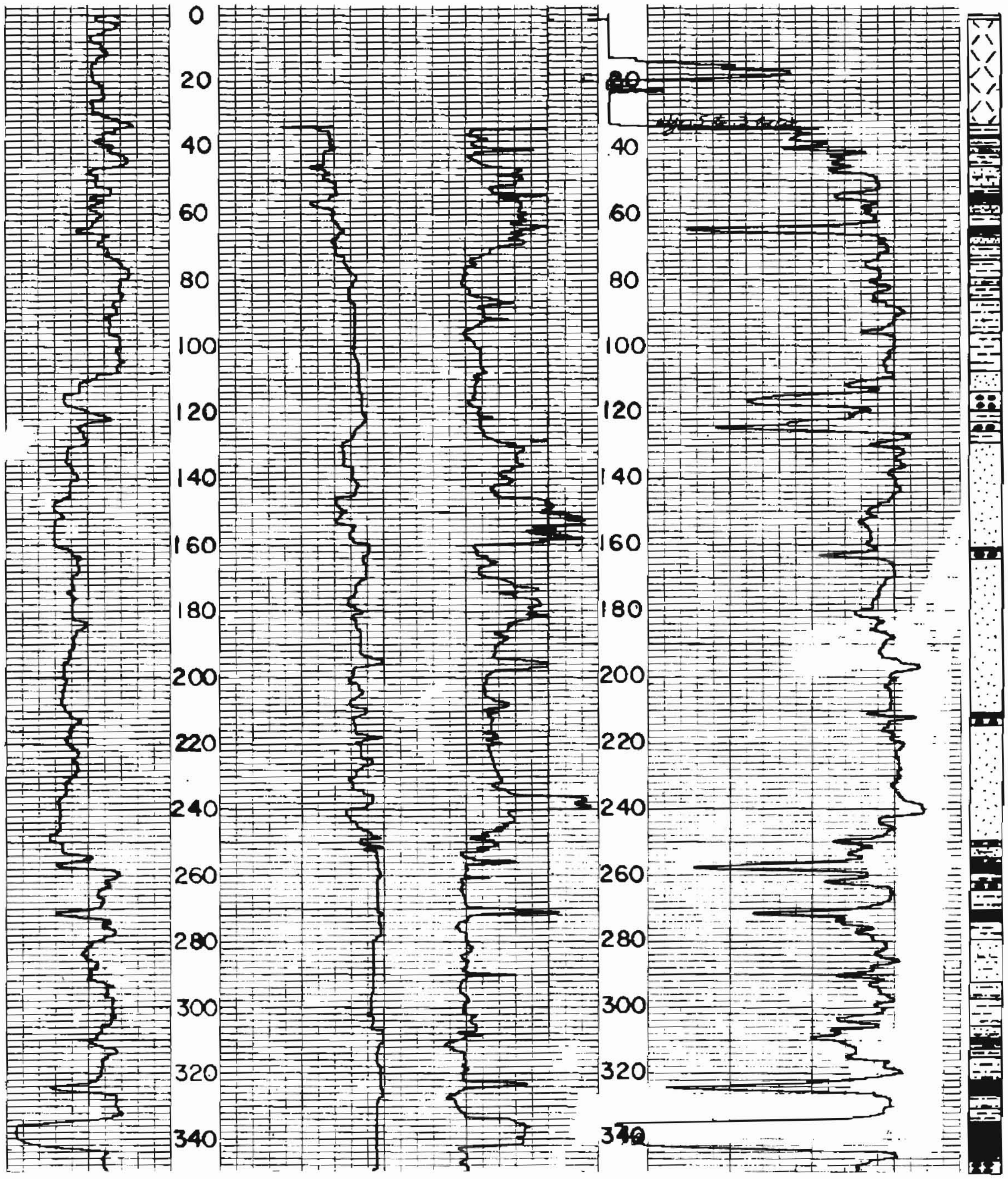
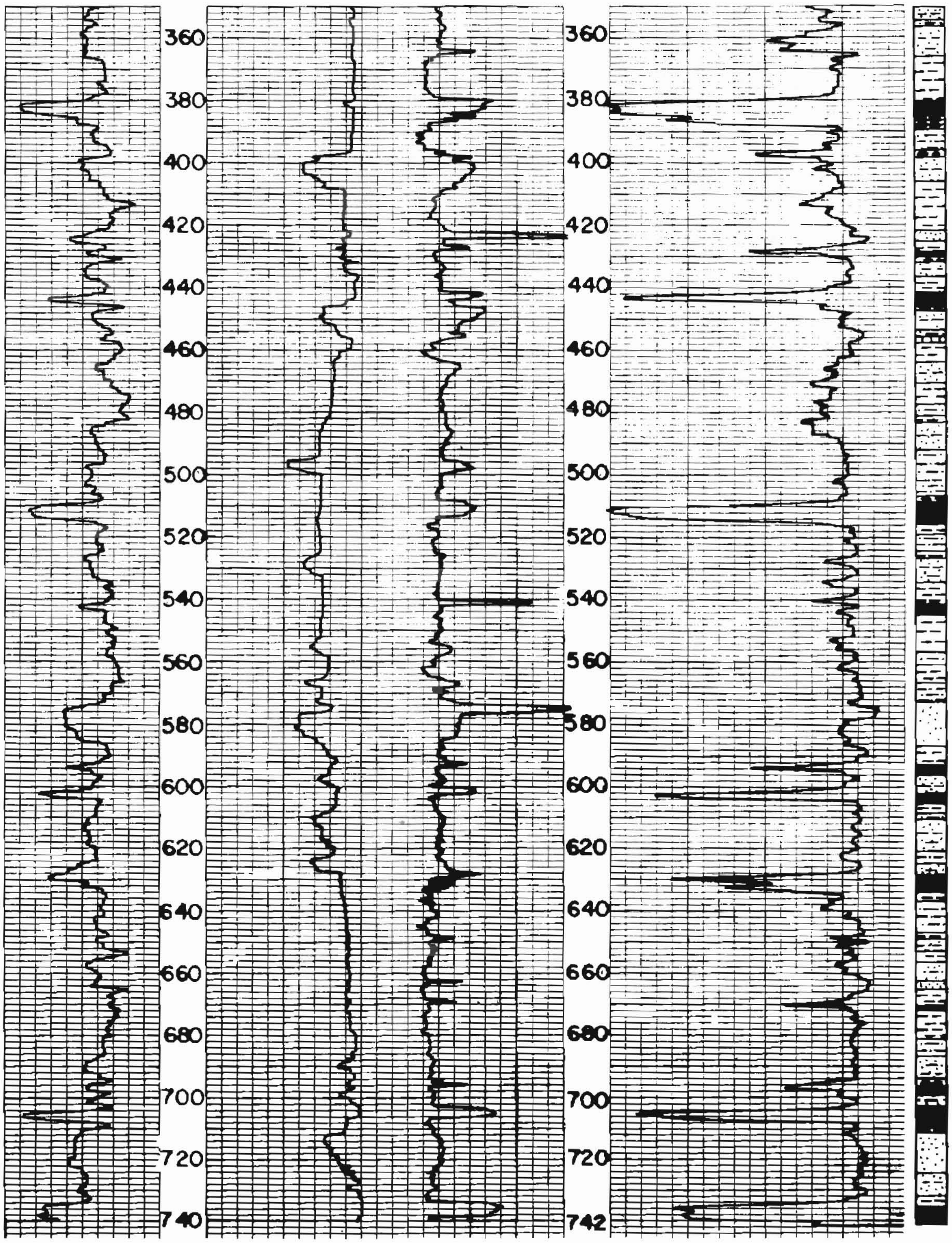
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 6 Date September 9 & September 10, 1976
Location T 146N R 89W sec 36 ddd (FEL) 25' (FSL) 150'
Elevation 2 270' Topo Sheet Beulah NW TD 740' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.

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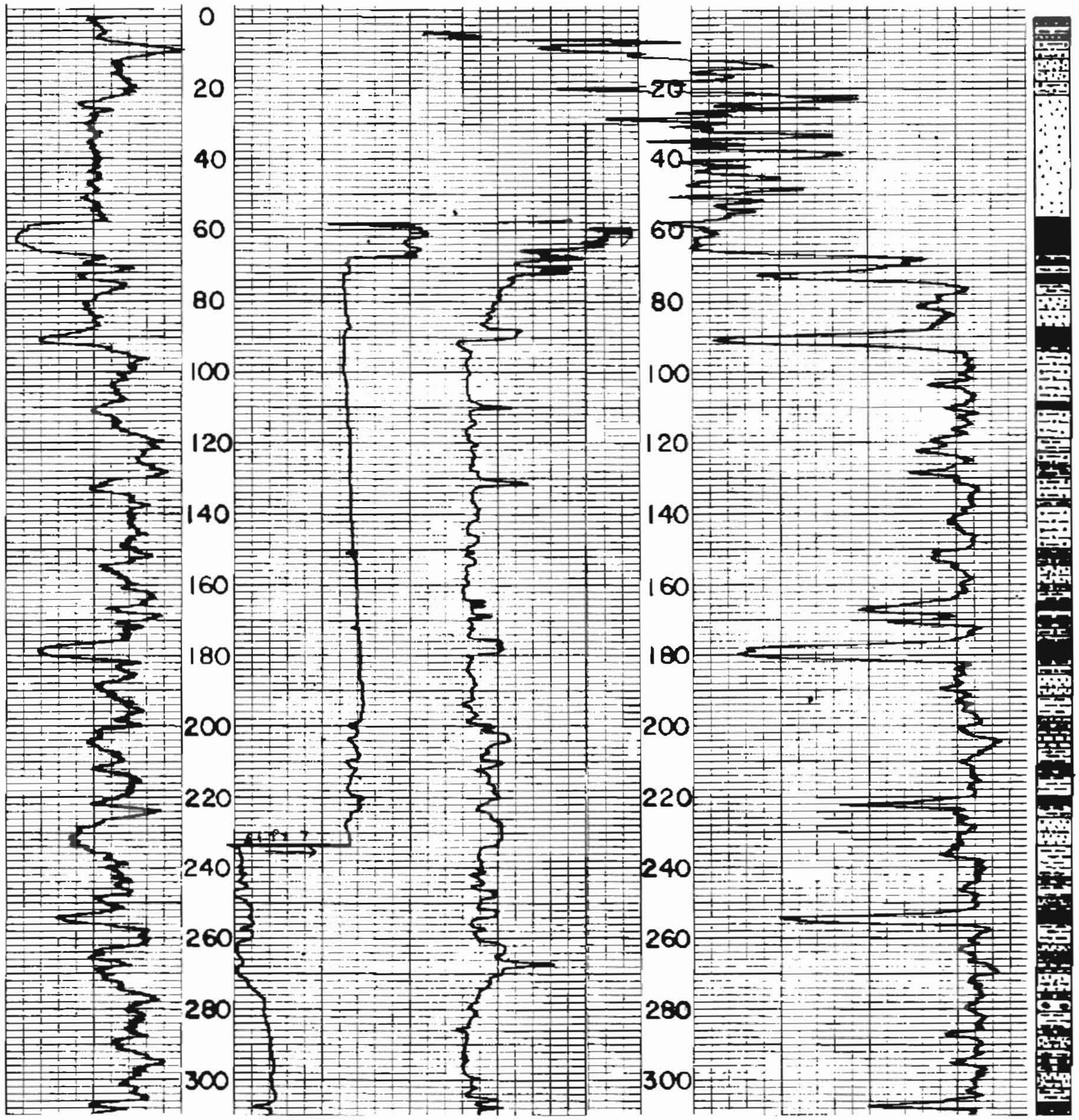
NORTH DAKOTA GEOLOGICAL SURVEY

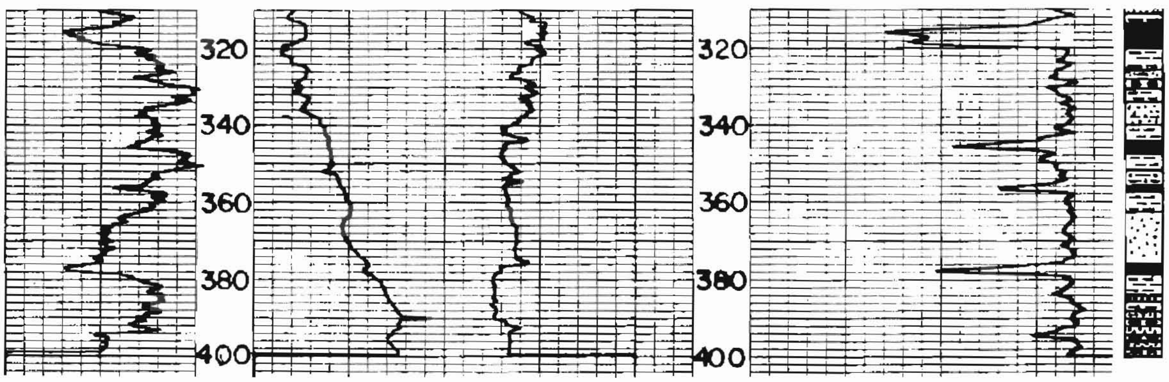
Hole No. REAP 7 Date September 26, 1976

Location T 144N R 85W sec 14 ccc (FWL) 15' (FSL) 180'

Elevation 1 890' Topo Sheet Stanton TD 400' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.

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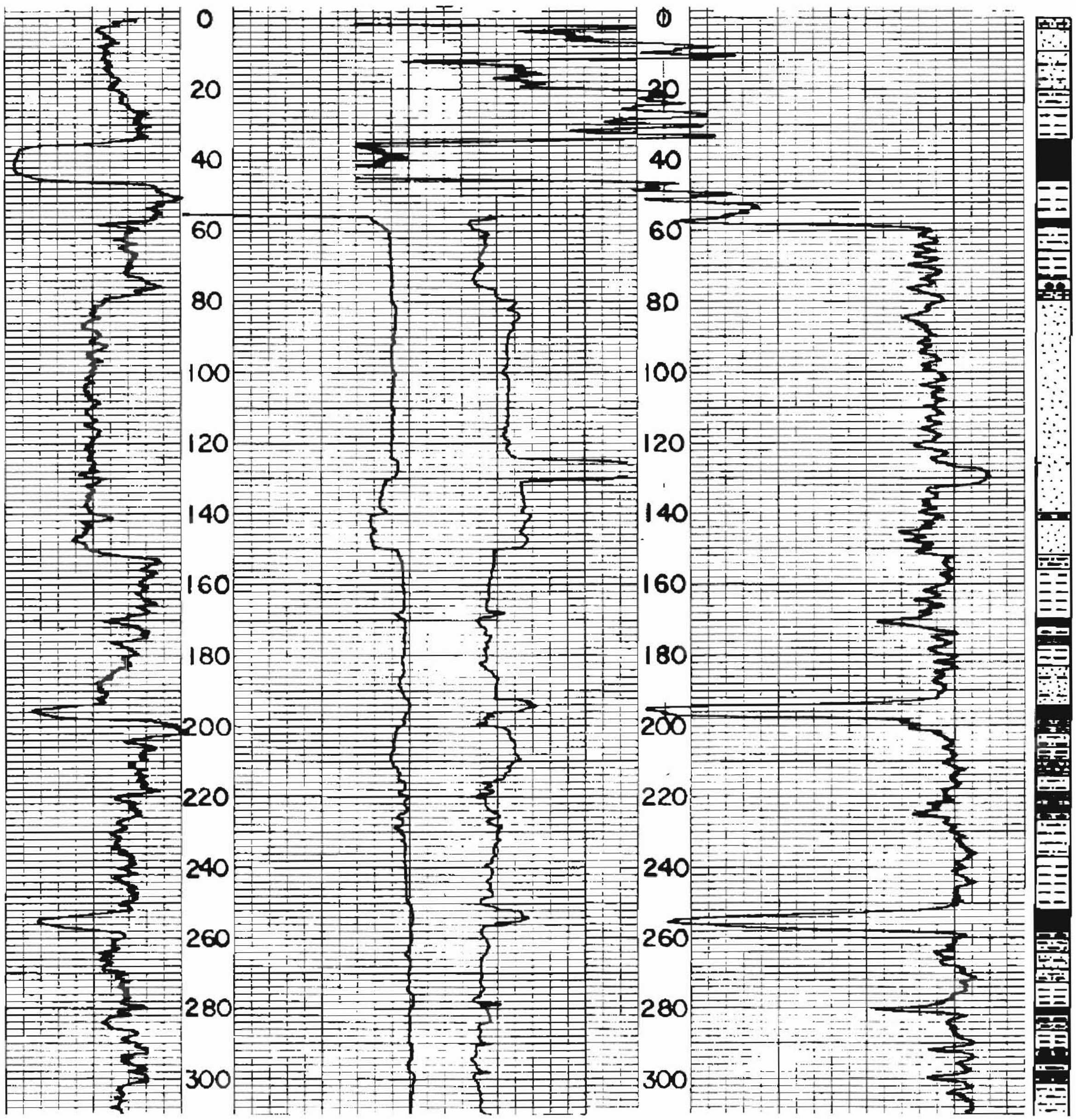
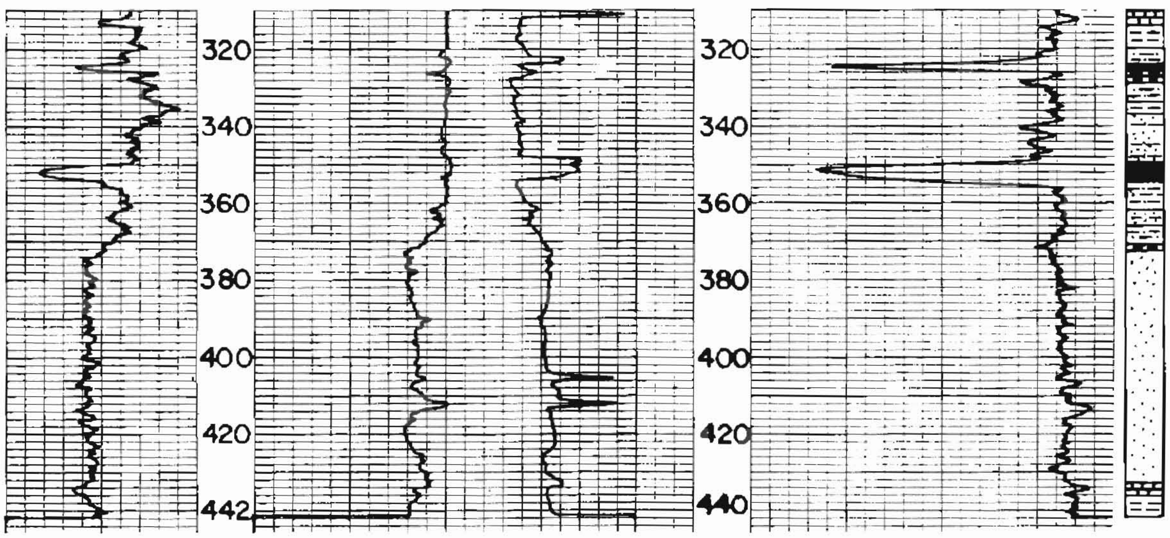
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 8 Date September 26, 1976
Location T 145N R 86W sec 16 ddd (FEL) 35' (FSL) 150'
Elevation 2 025' Topo Sheet Hazen W TD 442' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.

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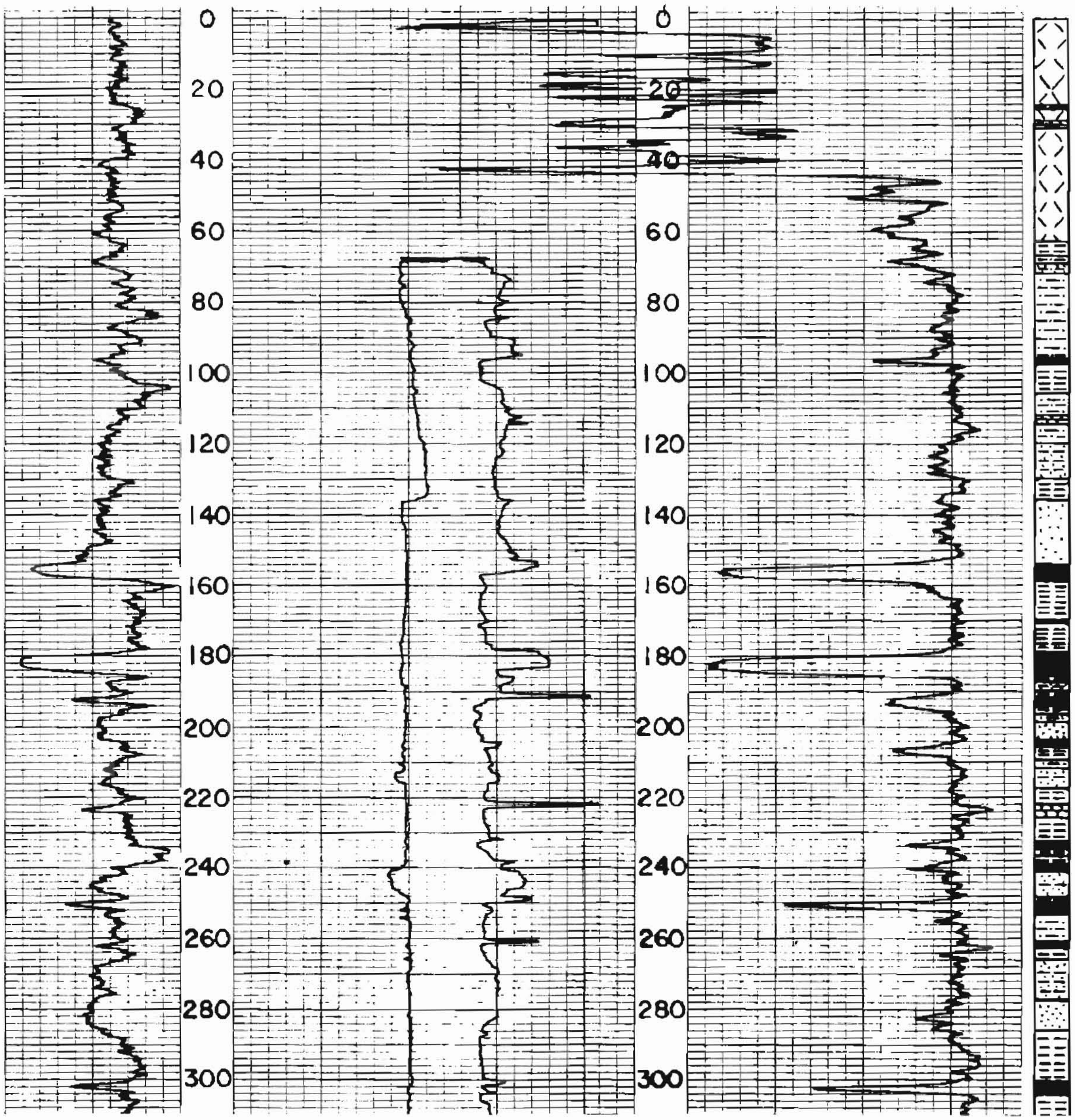
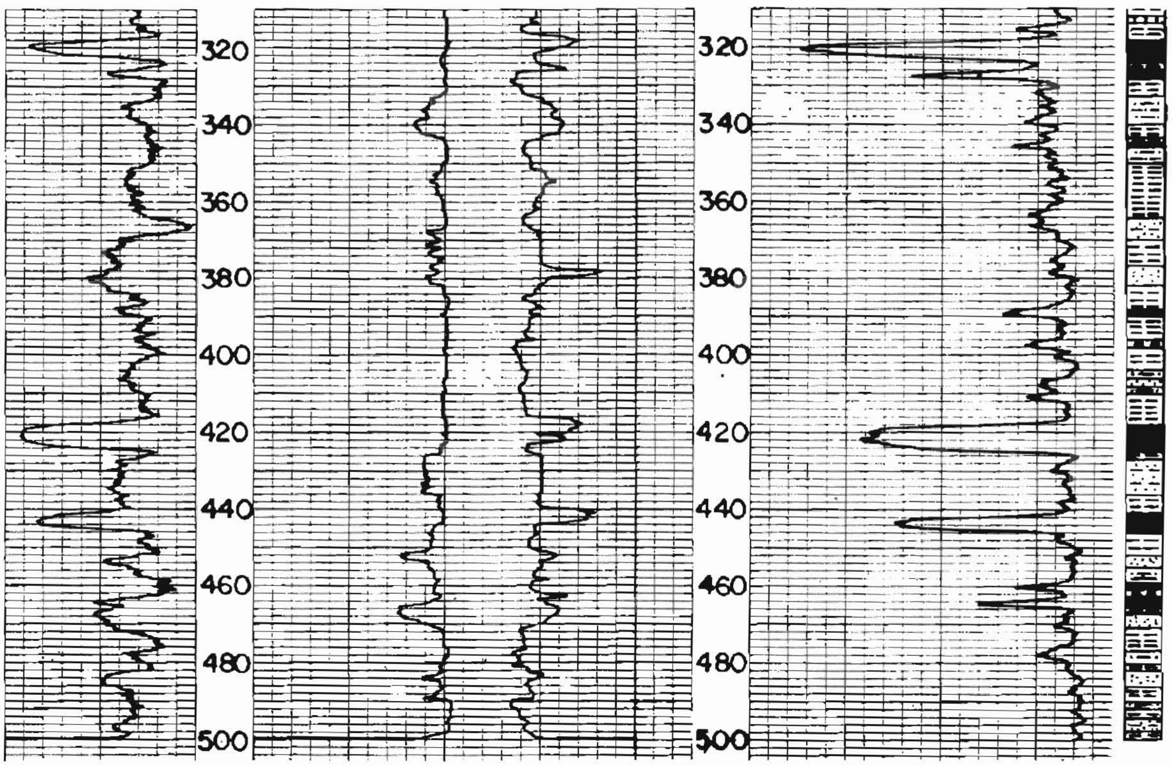
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 9 Date September 26, 1976
Location T 146N R 85W sec 30 bbb (FWL) 5' (FNL) 270'
Elevation 2 102' Topo Sheet Hazen NE TD 500' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



REAP # 9--Continued



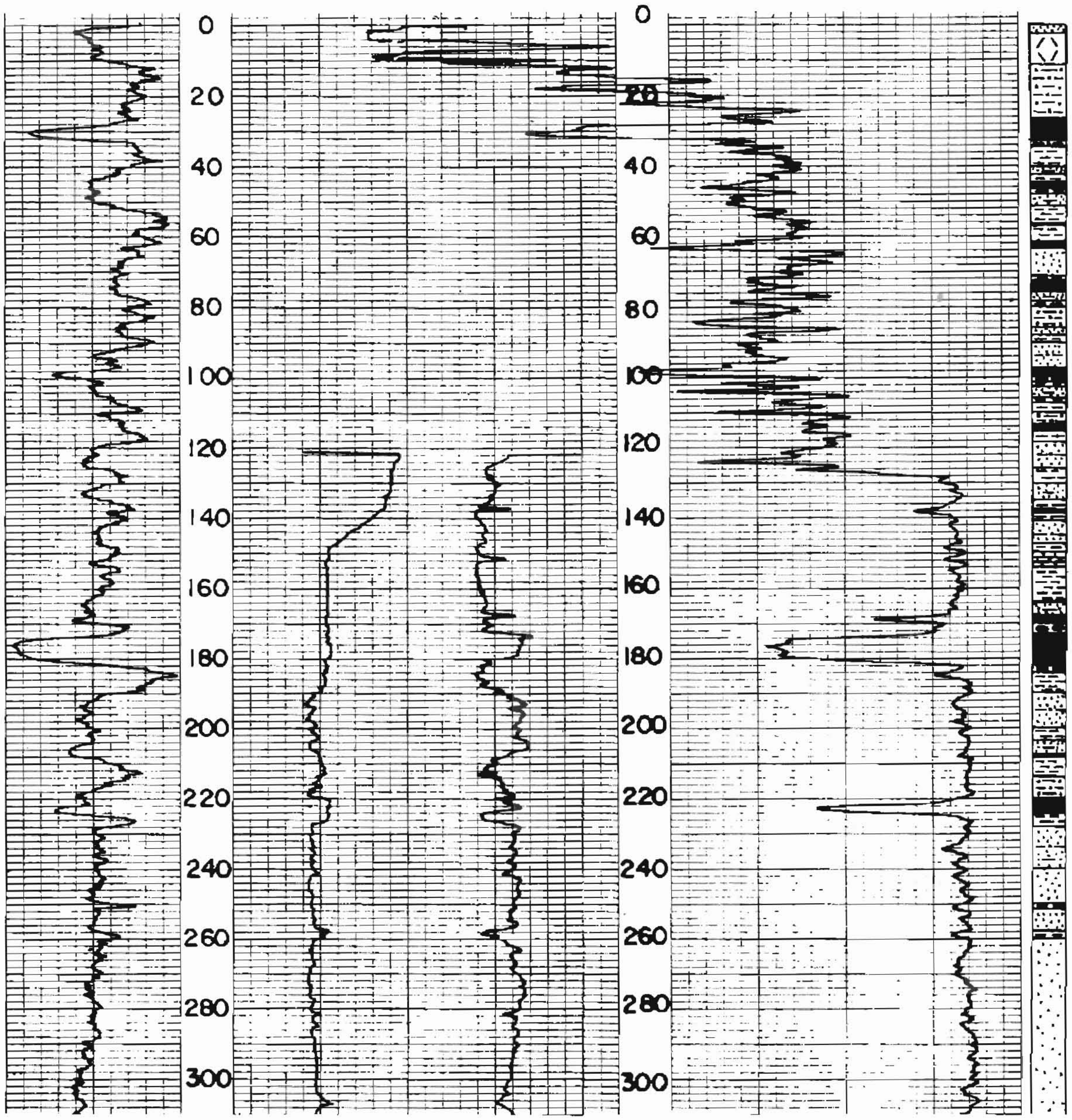
NORTH DAKOTA GEOLOGICAL SURVEY

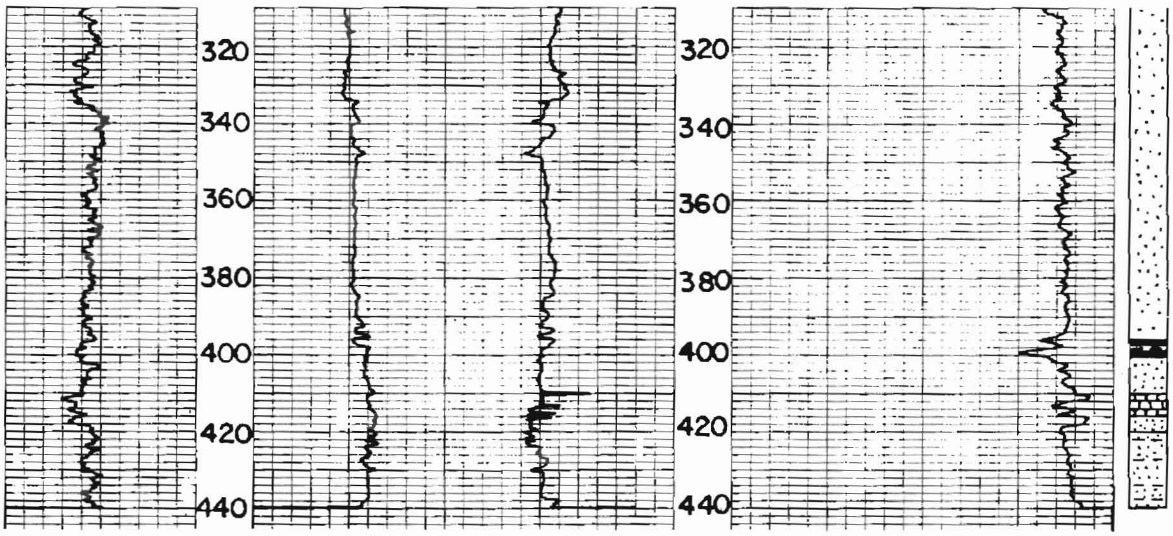
Hole No. REAP 10 Date September 27, 1976

Location T 145N R 83W sec 18 ddd (FEL) 2 420' (FSL) 30'

Elevation 1 922' Topo Sheet Stanton SE TD 440' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.

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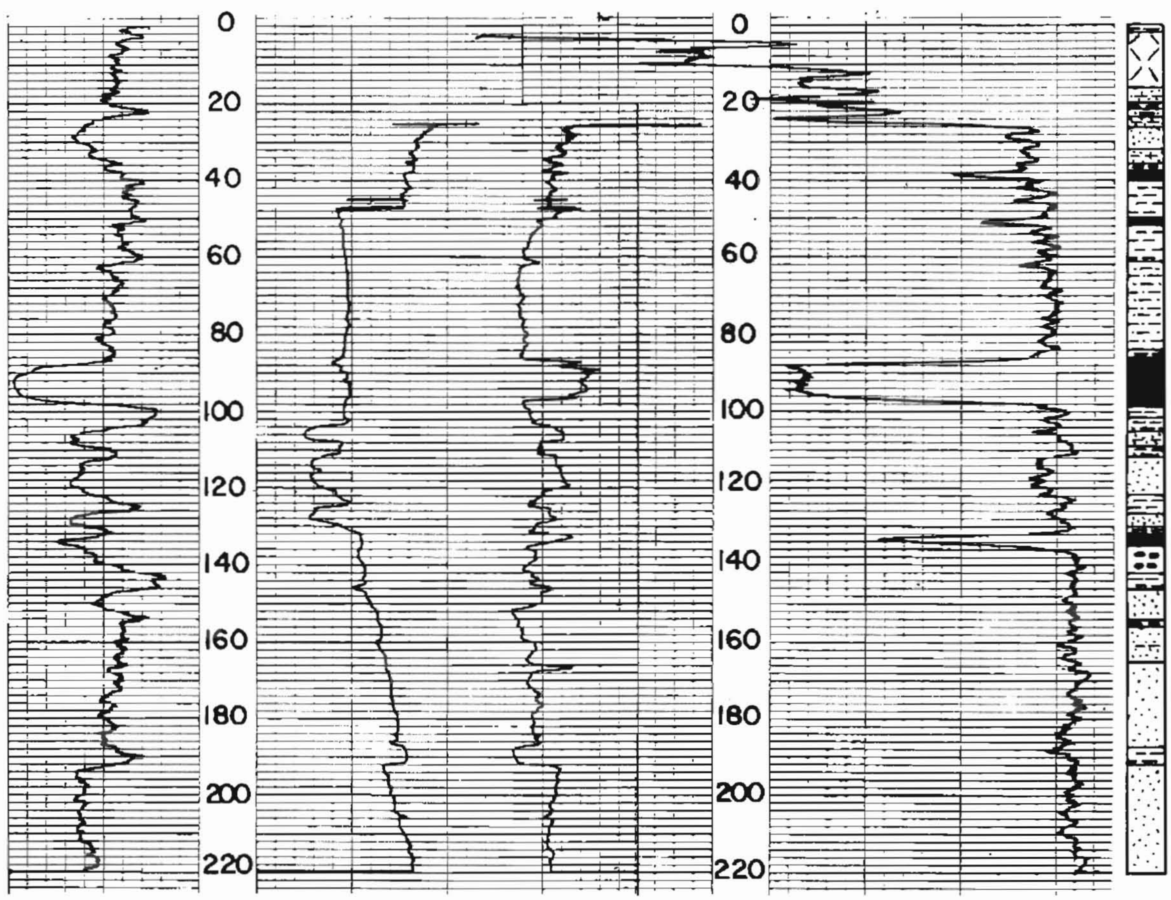
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 11 Date September 27, 1976

Location T 146N R 83W sec 32 ccc (FWL) 2' (FSL) 1 240'

Elevation 1 865' Topo Sheet Riverdale South TD 220' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



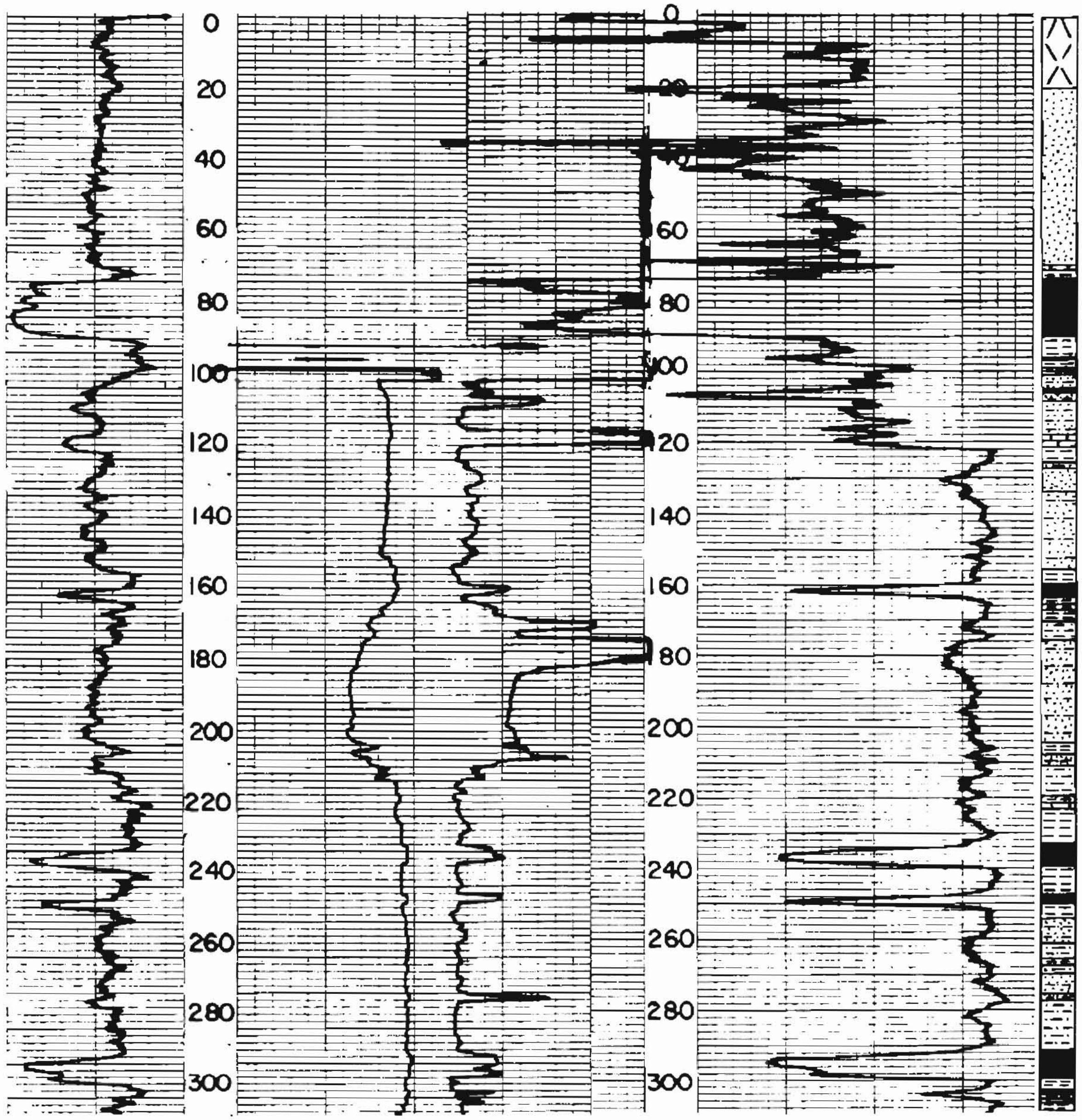
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 12 Date April 11, 1977

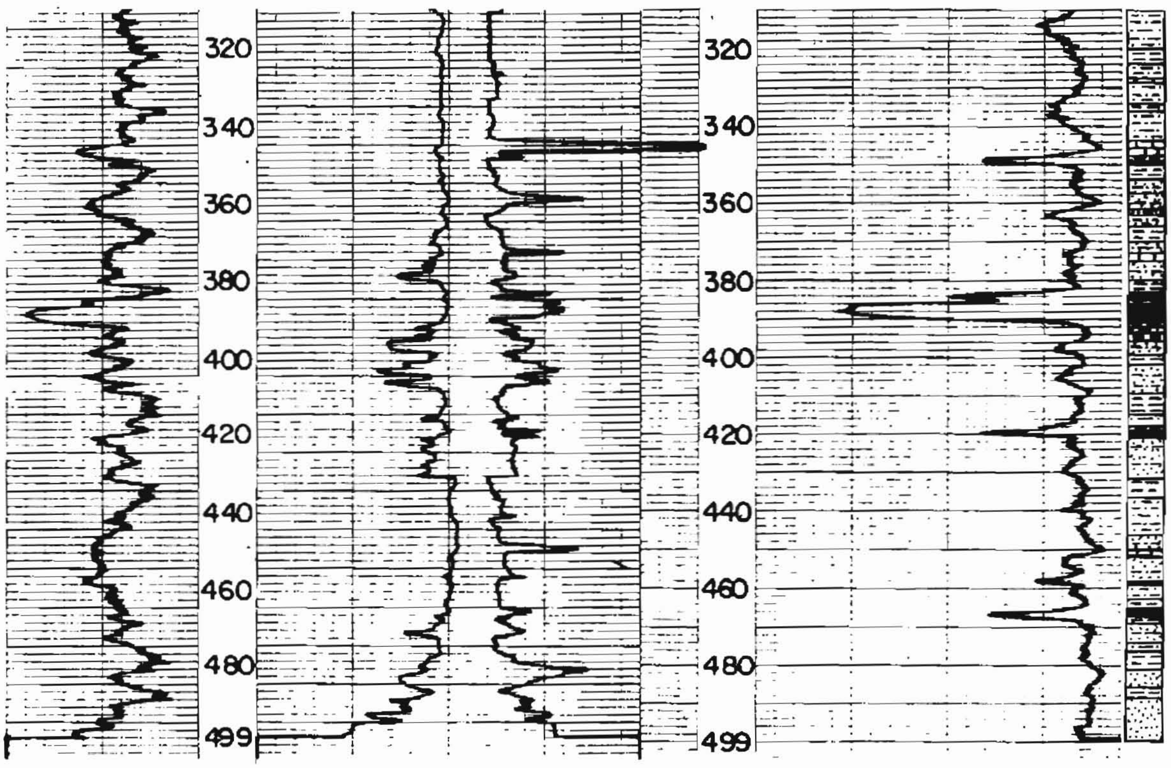
Location T 144N R 87W sec 8 ccd (FWL) 1 310' (FSL) 50'

Elevation 2 050' Topo Sheet Hazen W TD 499' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



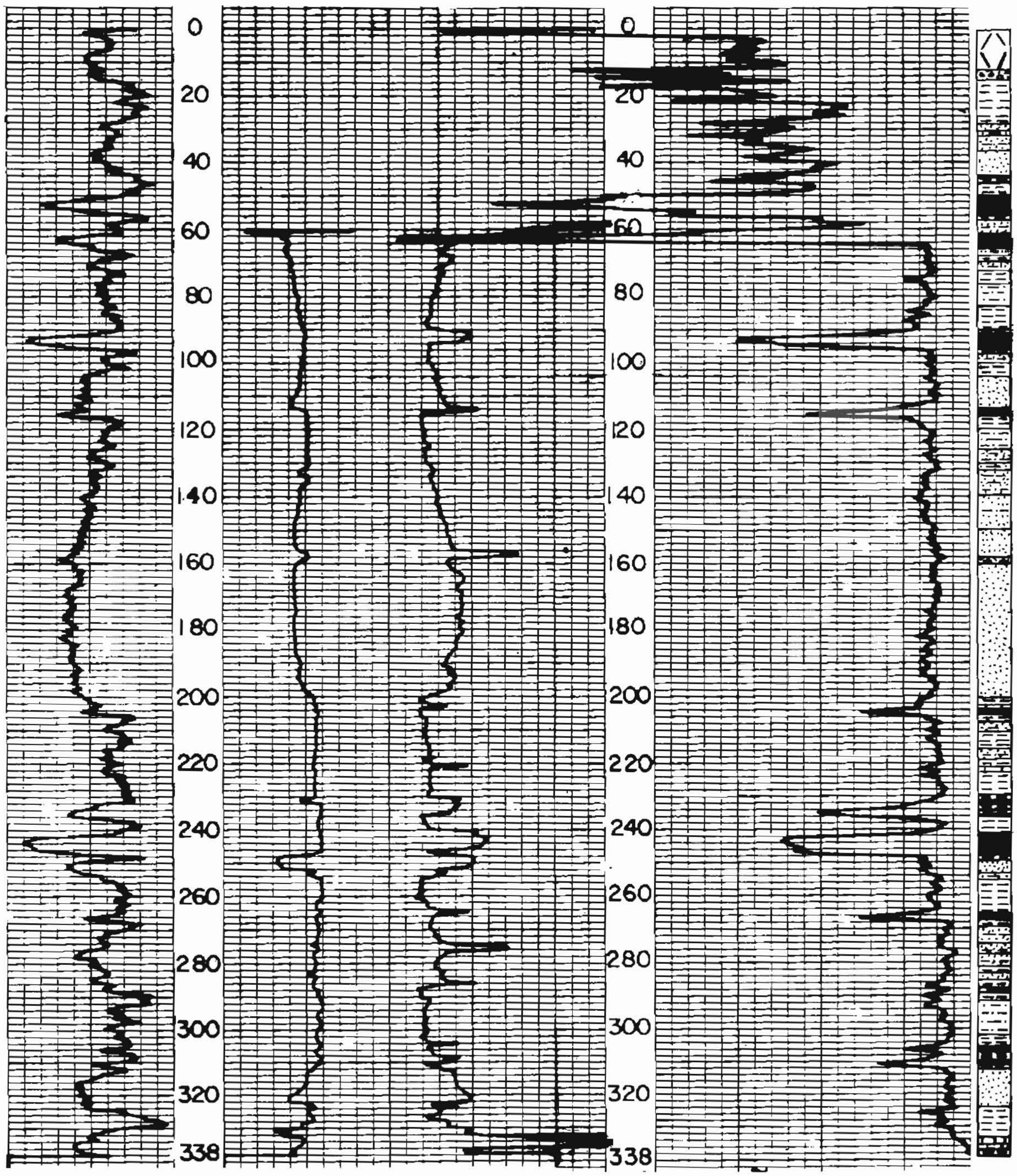
REAP # 12--Continued



NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 13 Date April 11, 1977
Location T 144N R 87W sec 14 bcc (FWL) 160' (FSL) 200'
Elevation 1 885' Topo Sheet Hazen W TD 338' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



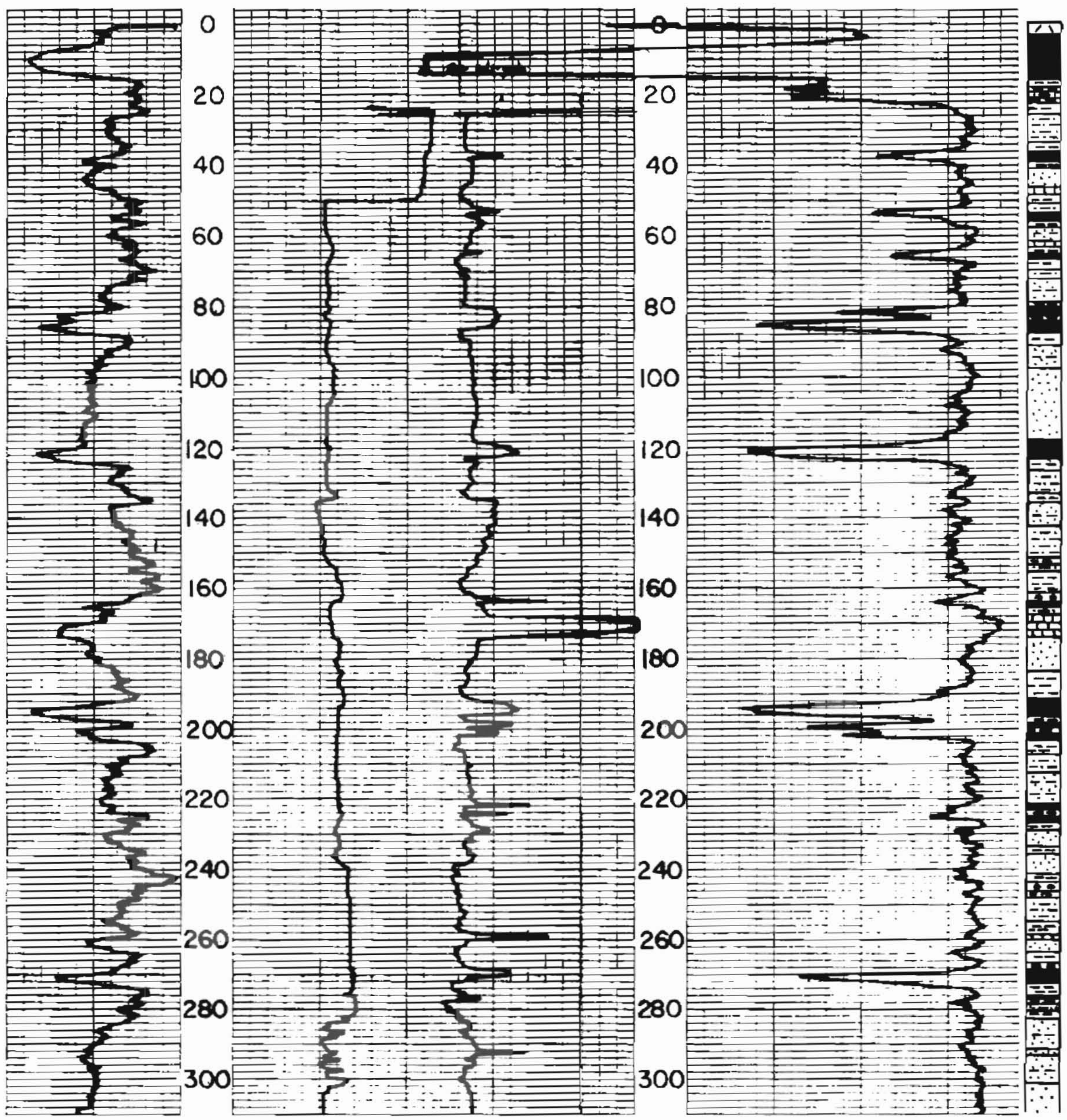
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 14 Date April 12, 1977

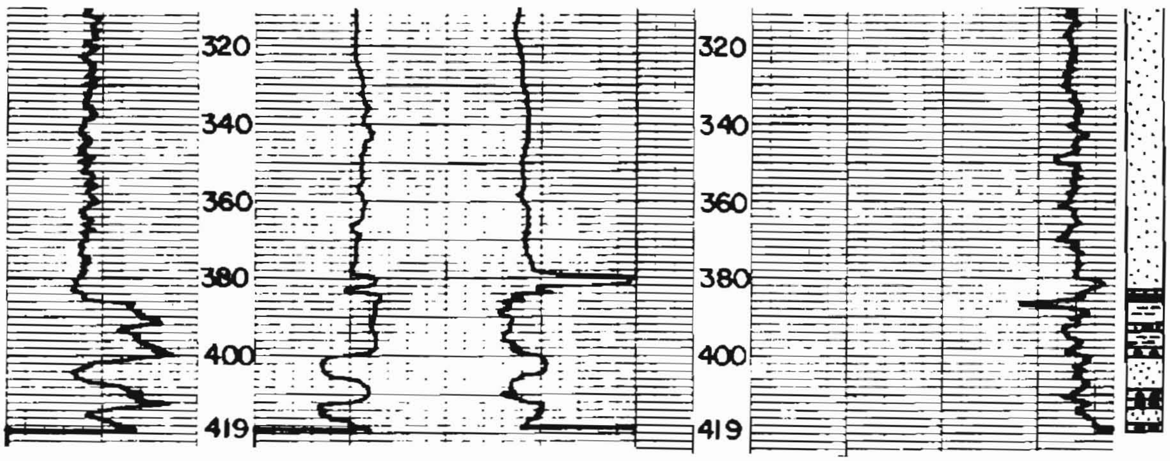
Location T 145N R 86W sec 32 baa (FWL) 2 620' (FNL) 6'

Elevation 1 968' Topo Sheet Hazen W TD 419' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



REAP # 14--Continued



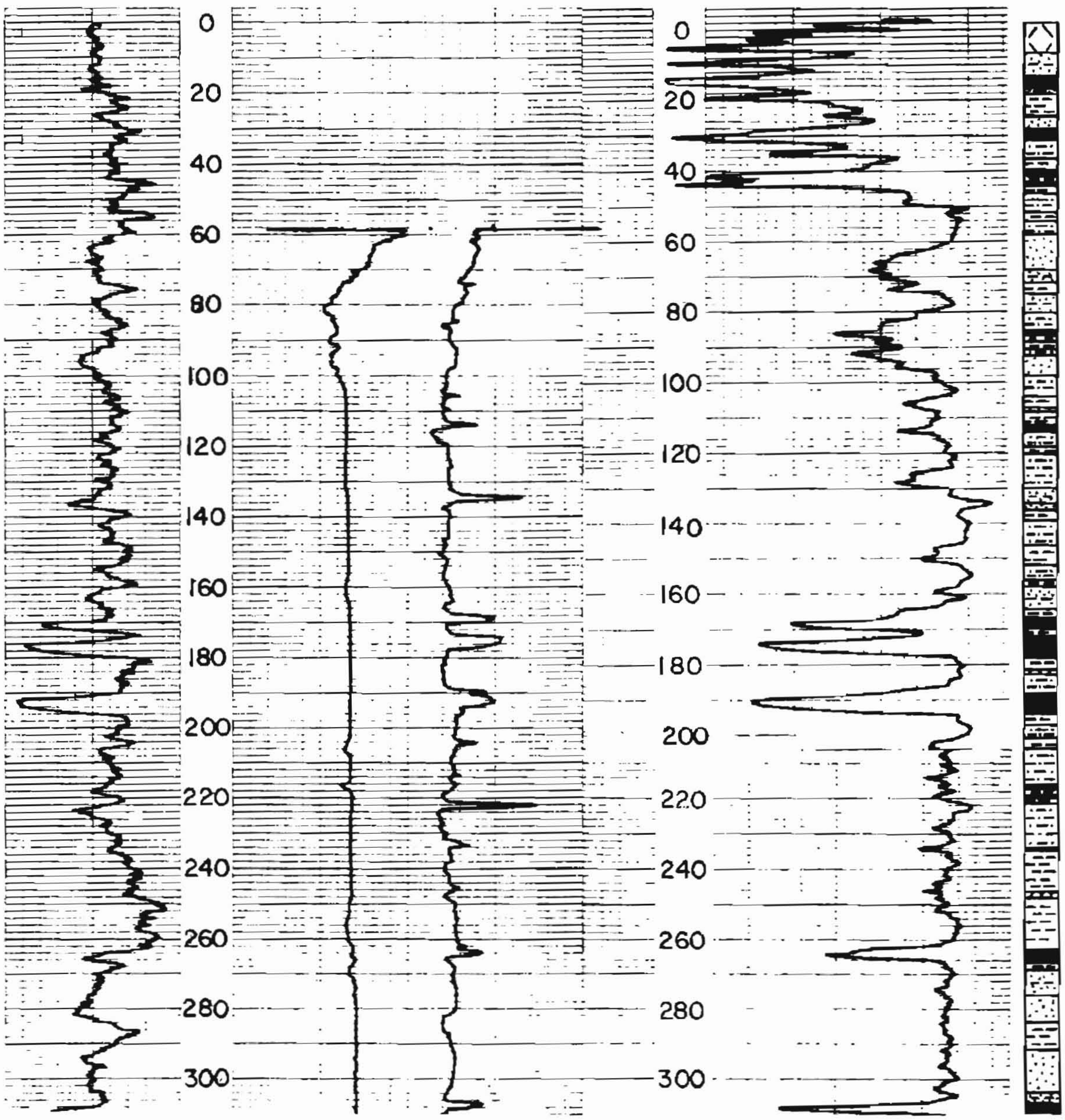
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 15 Date April 12, 1977

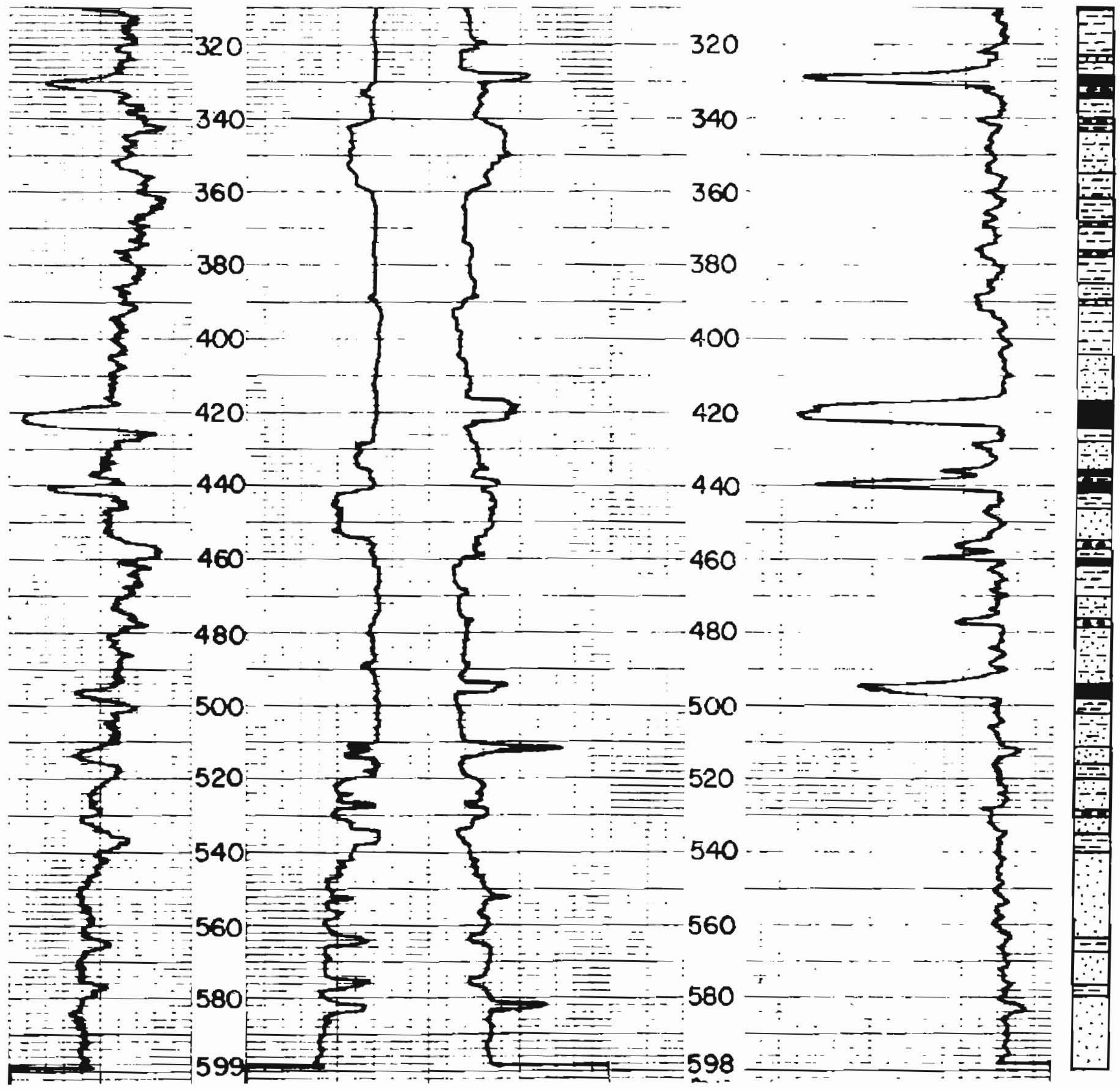
Location T 146N R 86W sec 26 bcb (FWL) 10' (FNL) 1 440'

Elevation 2 168' Topo Sheet Hazen NE TD 499' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



REAP # 15--Continued



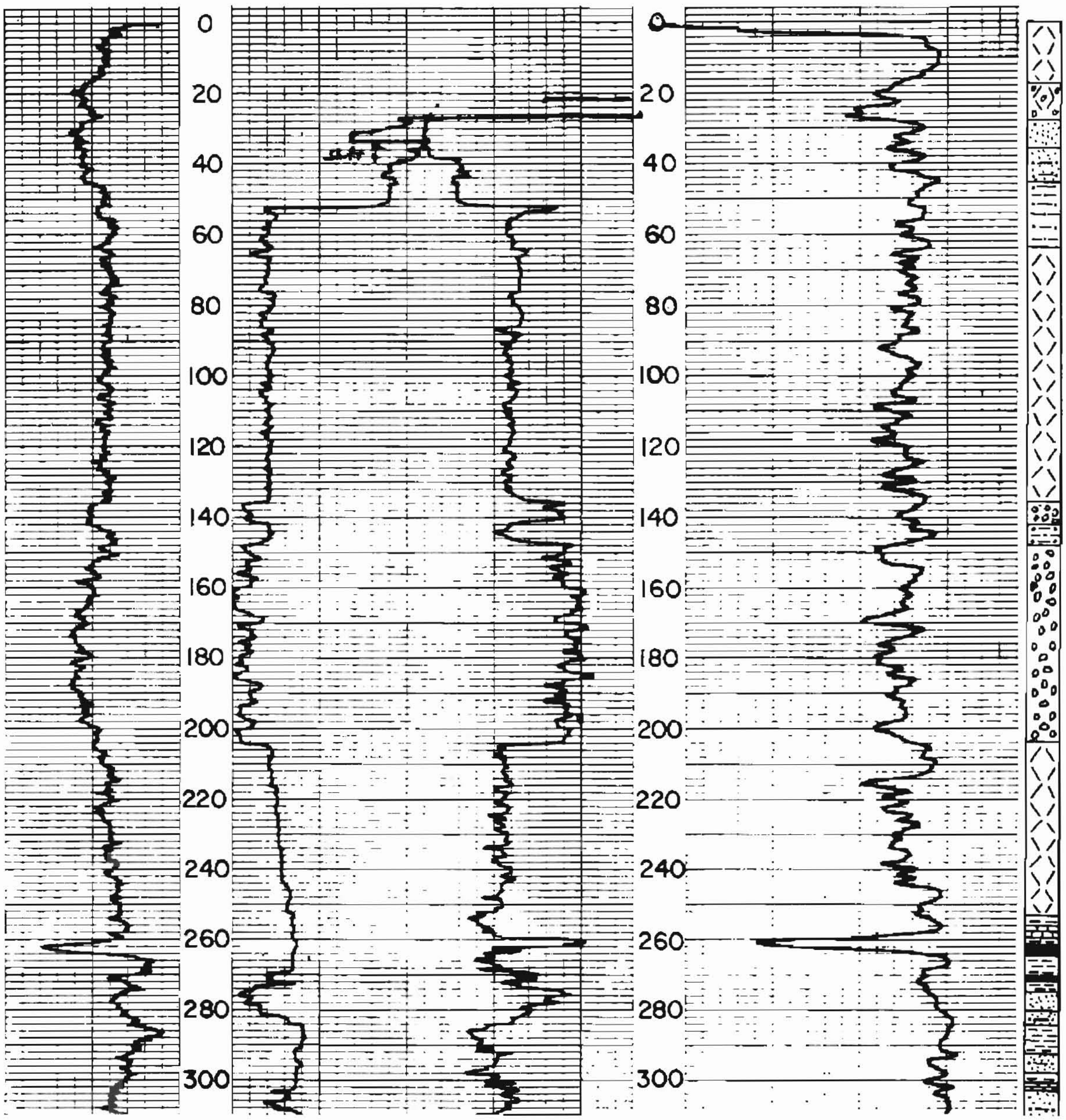
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 16 Date April 13, 1977

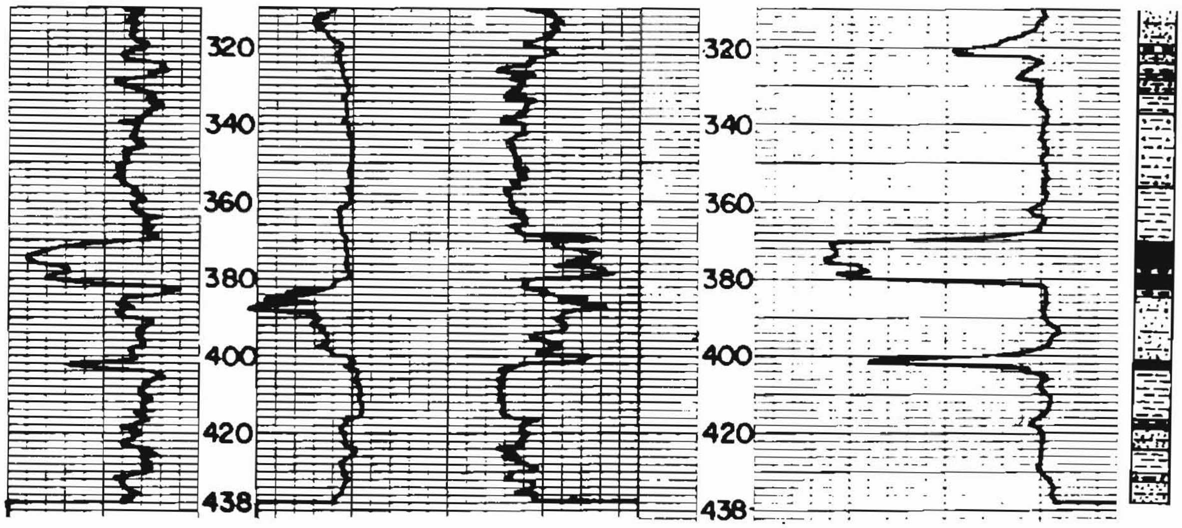
Location T 146N R 86W sec 14 ddd (FEL) 40' (FSL) 5'

Elevation 2 105' Topo Sheet Hazen NE TD 438' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



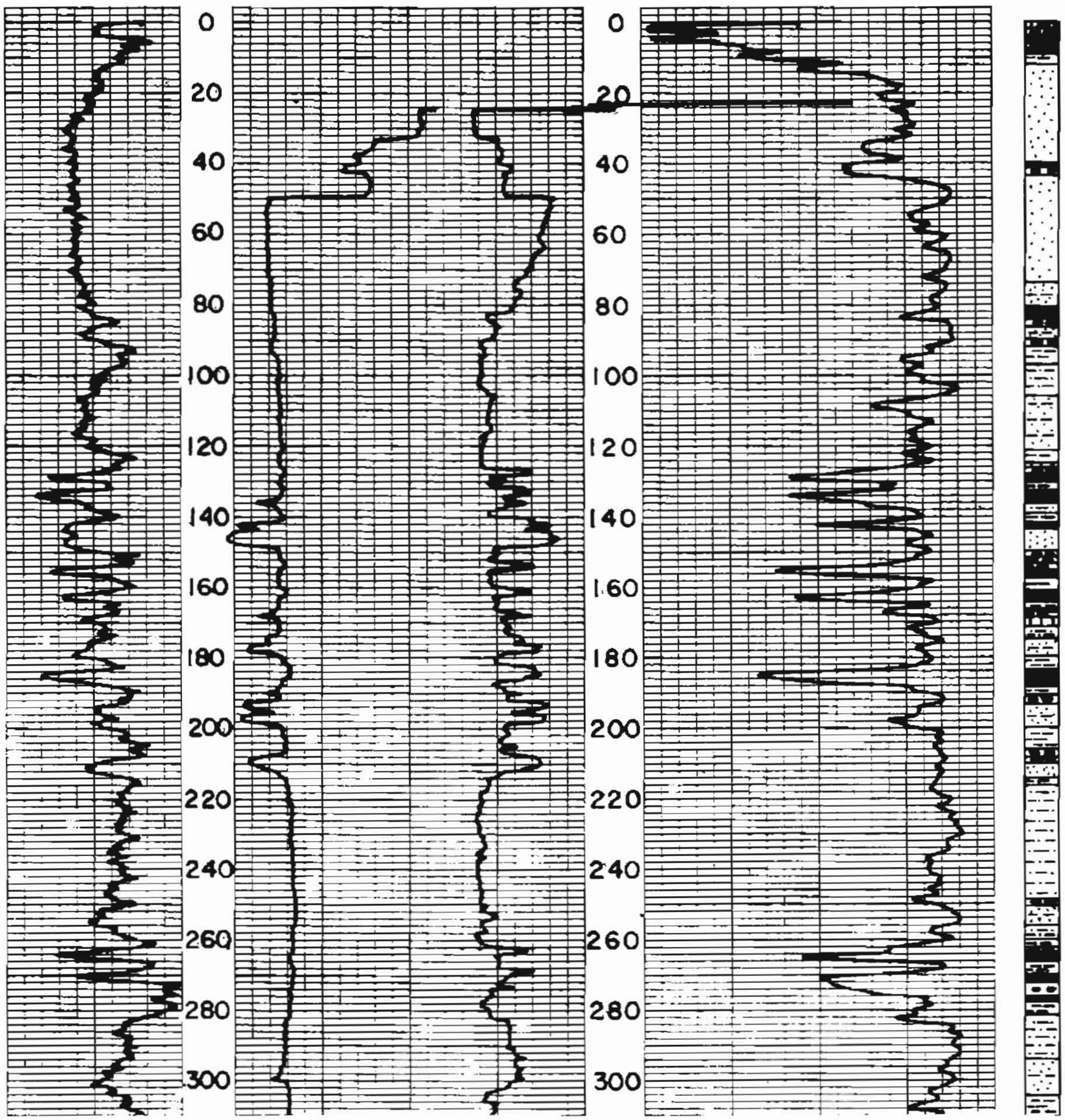
REAP # 16--Continued

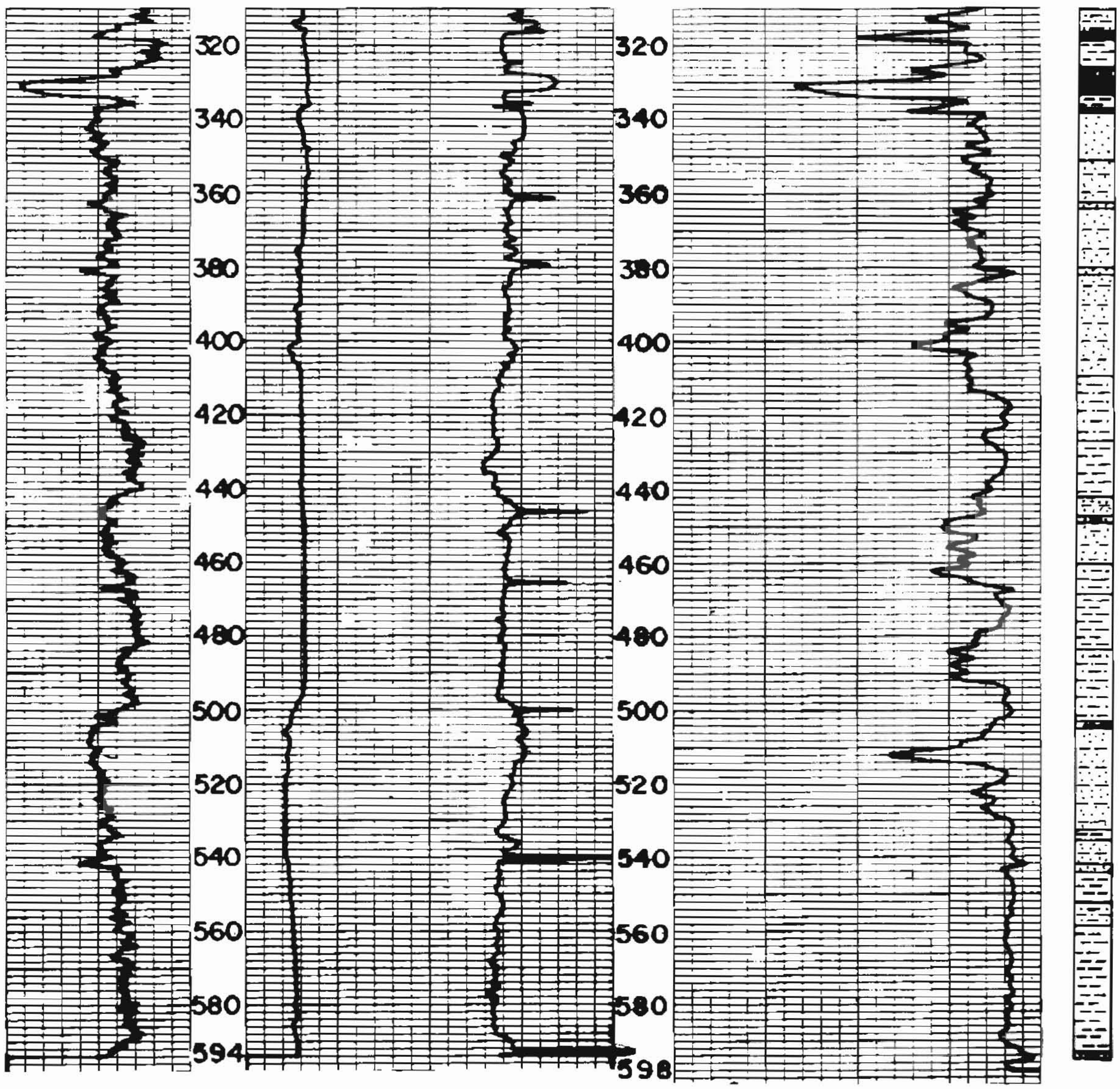


NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 17 Date April 14, 1977
Location T 145N R 85W sec 34 bcb (FWL) 140' (FNL) 1 200'
Elevation 1 734' Topo Sheet Hazen E TD 598' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.

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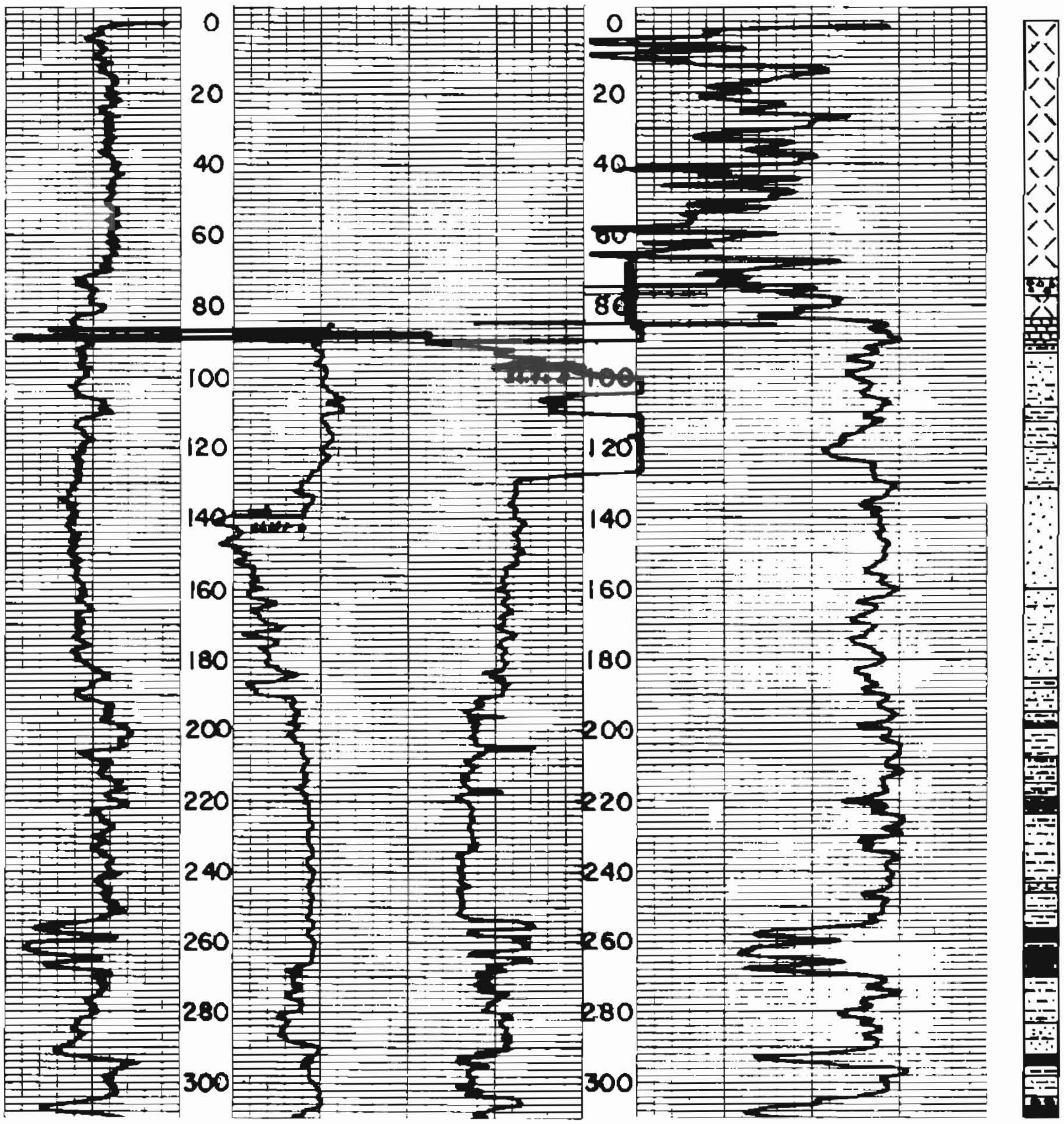
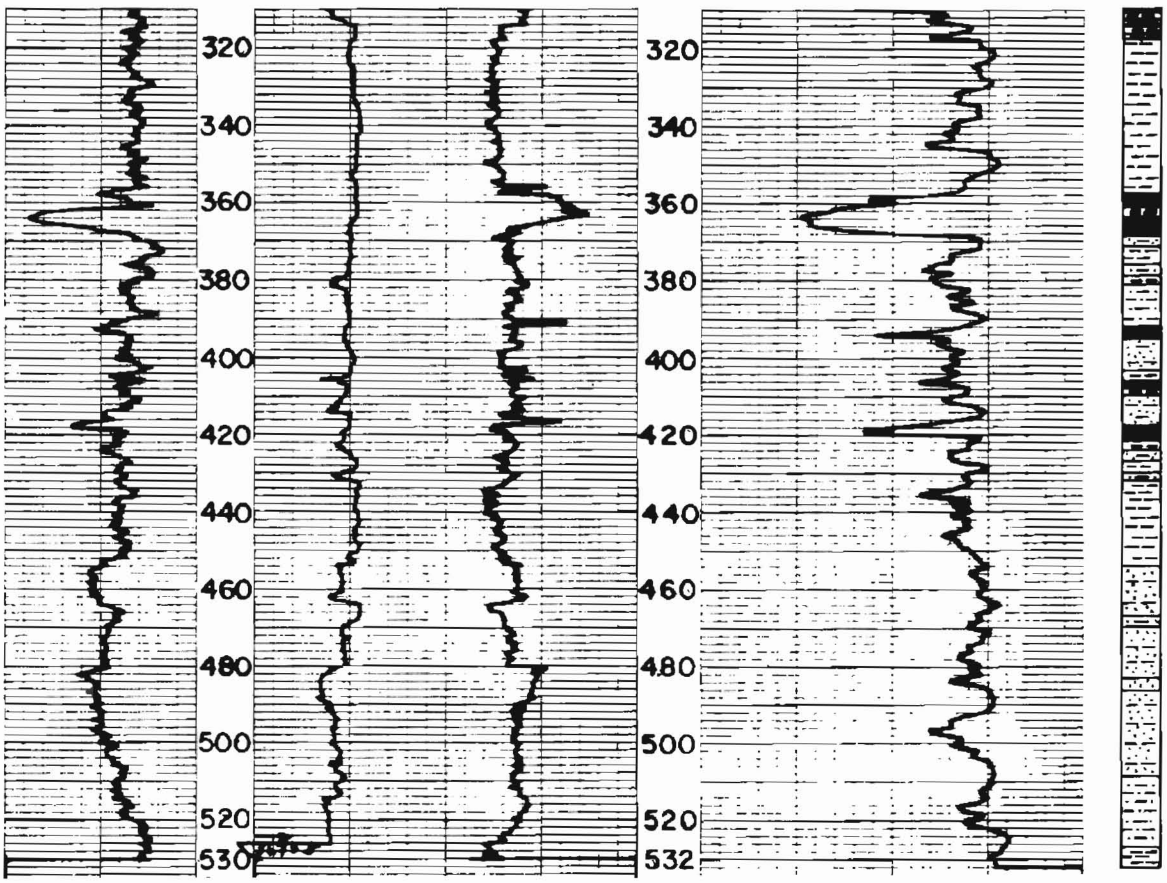
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 18 Date April 14, 1977
Location T 146N R 83W sec 5 bbb (FWL) 100' (FNL) 50'
Elevation 1 974' Topo Sheet Riverdale North TD 532' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



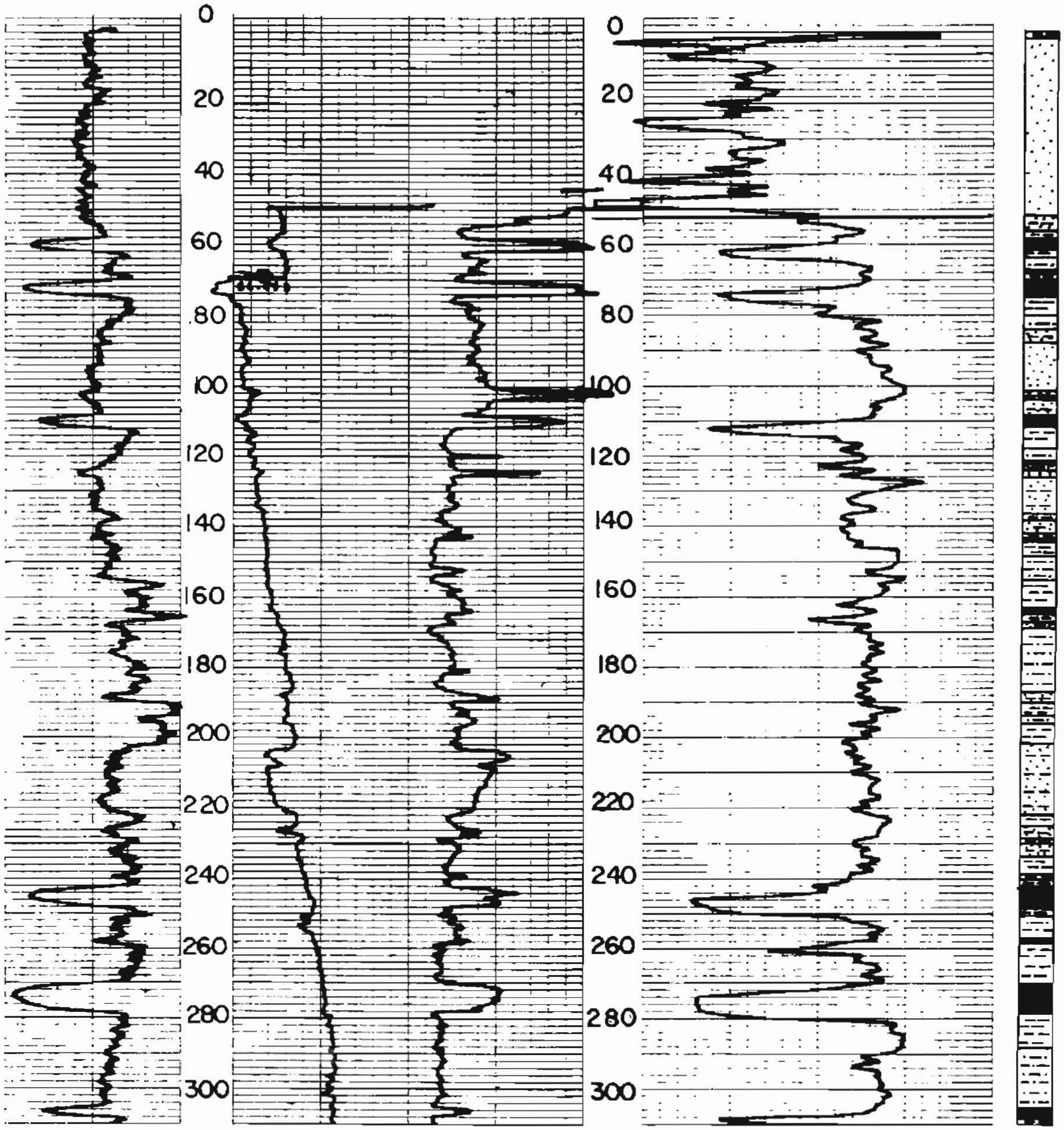
REAP # 18--Continued

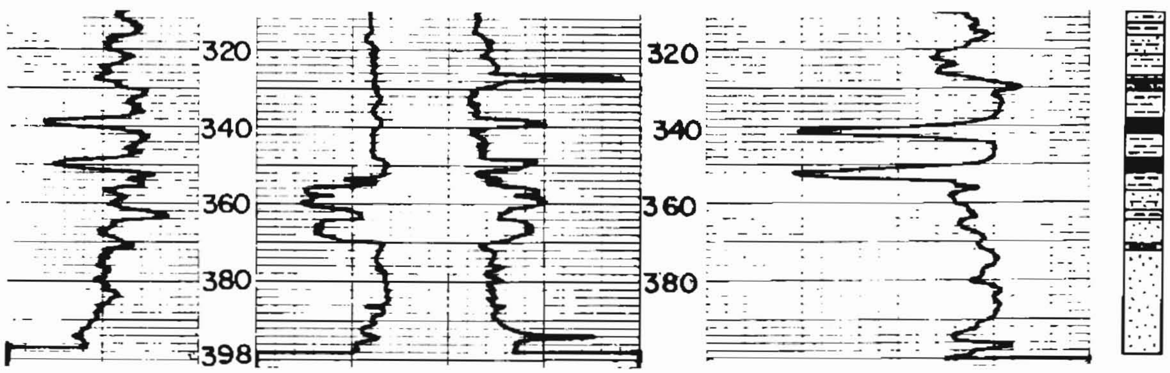


NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. REAP 19 Date April 15, 1977
Location T 142N R 85W sec 26 bcc (FWL) 96' (FNL) 2 470'
Elevation 2 296' Topo Sheet Hannover TD 400' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.

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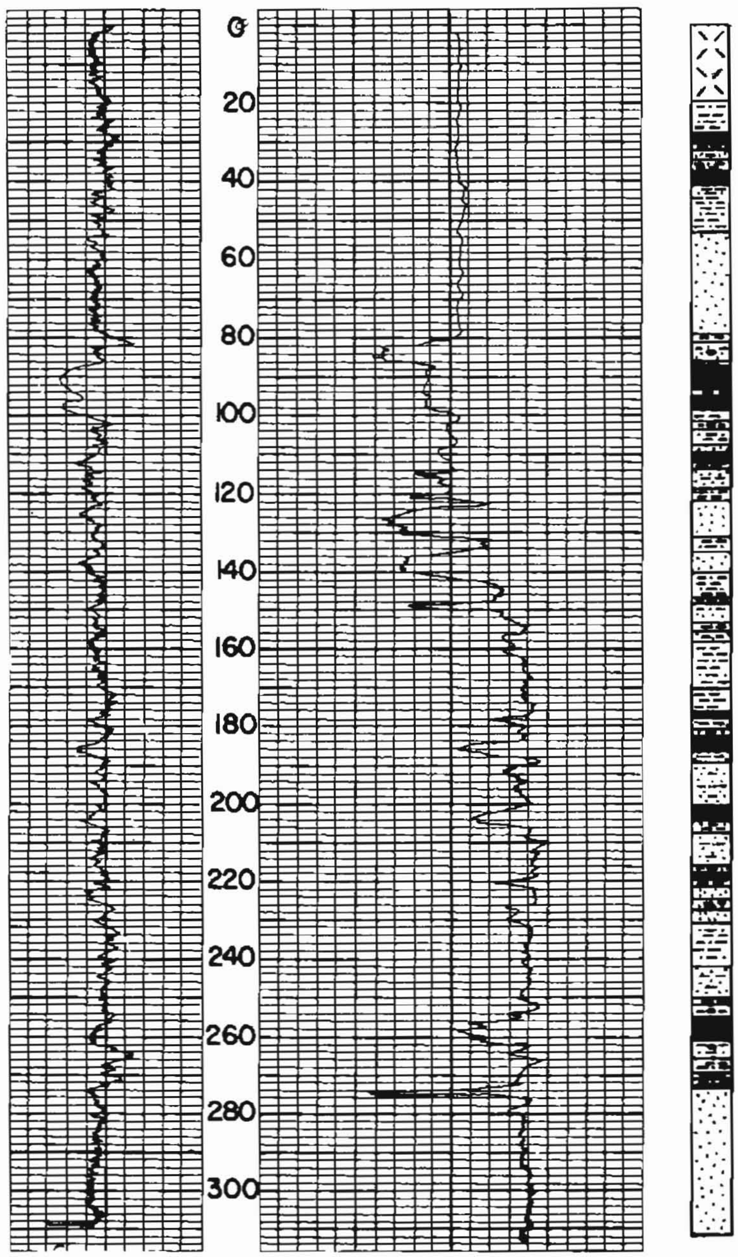
NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. NDSWC 3914 Date November 31, 1975
Location T 146N R 82W sec 32 cdc (FWL) 1 350' (FSL) 10'
Elevation 2 020' Topo Sheet Underwood TD 520' Fluid Type Water

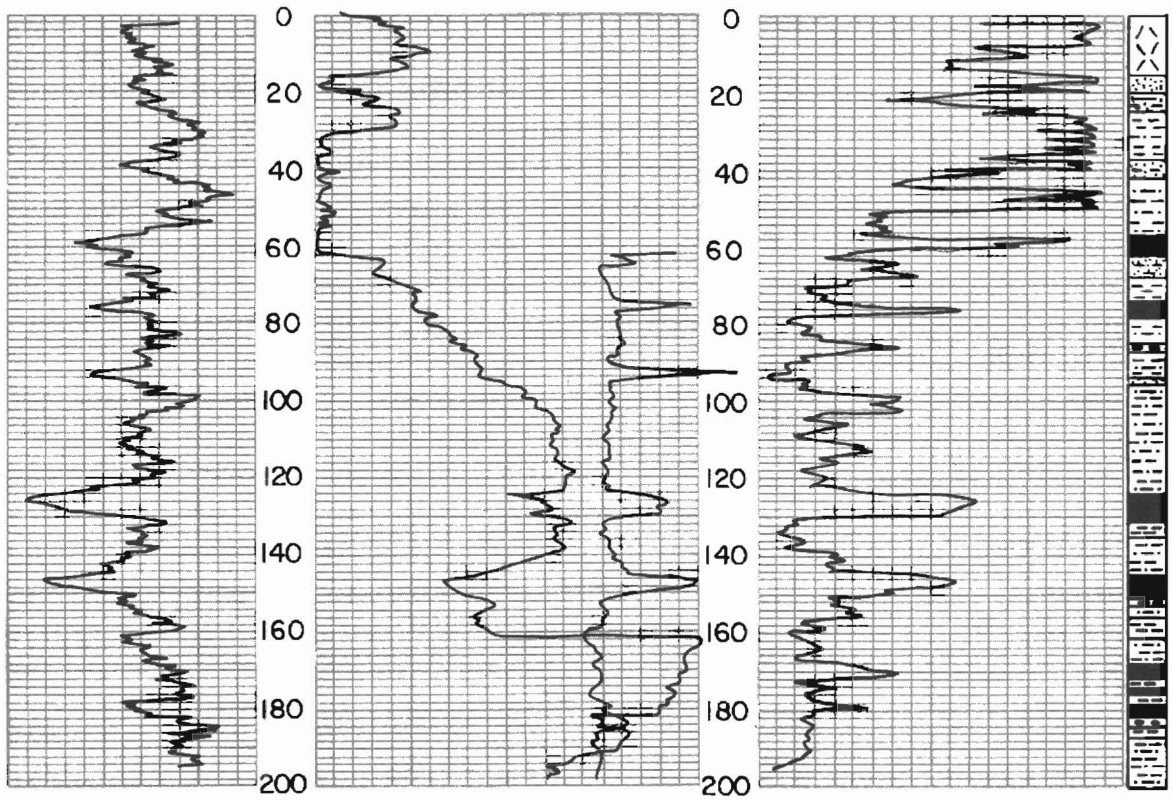
Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



NORTH DAKOTA GEOLOGICAL SURVEY

Hole No. USGS B 74-89 Date September 14, 1974
Location T 144N R 89W sec 11 aba (FEL) 1 440' (FNL) 5'
Elevation 2 087' Topo Sheet Zap TD 200' Fluid Type Water

SP, Res., Gamma - Rec. speed 20'/min. Density - Rec. speed 20'/min.



APPENDIX A-III

DESCRIPTION OF STRATIGRAPHIC SECTIONS

APPENDIX A-III
DESCRIPTION OF STRATIGRAPHIC SECTIONS

KINNEMAN CREEK SECTION

SE¼SE¼SE¼SE¼ Sec 12, T144N, R86W

Right bank of Kinneman Creek

Section described by L. A. Hemish

Elevation above sea level at top of section: 1 763 feet (537.36 m)

Depth	Thickness	Description
Oahe Formation		
0-1.0 ft (0-0.30 m)	1.0 ft (0.30 m)	Sand, fine-grained, gravelly, poorly sorted, very dark-gray-brown (2.5Y 3/2).
Coleharbor Formation		
1.0-5.0 ft (0.30-1.52 m)	4.0 ft (1.22 m)	Pebble loam (till), light-brown-gray (2.5Y 6/2), stained with iron oxides, yellowish-brown (10YR 5/8), along mostly vertical fractures about 2 inches to 4 inches apart in upper 2 feet; calcareous; lower 2 feet of exposure contains abundant cobbles and boulders of igneous, metamorphic, and sedimentary rock types of both foreign and local derivation; iron oxide staining is present, but occurs only about half as frequently as in the interval above. A stone line separates this till from unit below. The underlying till unit is mostly unjointed to weakly jointed, and from a distance of about 20 feet appears more yellowish than the overlying unit. An indistinct line marks what appears to be an erosional surface on the lower till. The concentration of stones occurs above this horizon at the base of the upper till unit.
5.0-11.0 ft (1.52-3.35 m)	6.0 ft (1.83 m)	Pebble loam (till), light-olive-gray (5Y 6/2), with white limy deposits occurring along joint planes. (Note: these lime deposits are truncated at the contact with the overlying till unit, and may represent remnants of an eroded fossil B soil zone). Cobbles and boulders occur with markedly less frequency in this till. Carbonate type pebbles occur with greatest frequency (estimated about 40 percent). Lignite chips are common in both till units; fragments up to 2 x 3 x 4 inches were observed in the lower till. Both tills are hard and compact; however, the lower till is slightly more resistant to weathering, and in places a narrow shelf has formed at the contact with the overlying unit.

BEULAH SECTION

NE¼NW¼SW¼NE¼ Sec 25, T144N, R88W

North face of cut north of power plant

Section described by L. A. Hemish

Elevation above sea level at top of section: 1 830 feet (557.79 m)

Depth	Thickness	Description
Coleharbor Formation		
0-2.0 ft (0-0.61 m)	2.0 ft (0.61 m)	Sand, fine to very fine, silty, dark-brown (10YR 3/3), poorly sorted; includes some scattered pebbles of brown quartz, chert, porcelanite, limonite concretion fragments and assorted glacially derived pebbles; noncalcareous.
2.0-3.0 ft (0.61-0.91 m)	1.0 ft (0.30 m)	Sand, fine, dark-gray (10YR 4/1), highly calcareous, poorly sorted; includes only a few small pebbles of types described above.
3.0-3.5 ft (0.91-1.06 m)	0.5 ft (0.15 m)	Gravel, medium, light-gray (5YR 7/1), highly calcareous; composed predominantly of glacially derived clasts, subangular to subrounded.
3.5-4.5 ft (1.06-1.36 m)	1.0 ft (0.30 m)	Silt to very fine sand, light-brown-gray (10YR 6/2), highly calcareous, well-sorted; includes extensive mottling with lime deposits, white (10YR 8/1).
4.5-6.0 ft (1.36-1.84 m)	1.5 ft (0.48 m)	Gravel, dark-gray-brown (10YR 4/2), poorly sorted; includes cobbles up to 4 inches in diameter; lithologic types include cherts, agates, carbonates, igneous and metamorphics; clasts range from rounded to angular; deposit is calcareous.
6.0-7.0 ft (1.84-2.14 m)	1.0 ft (0.30 m)	Sand, medium-grained, olive-gray (5Y 5/2); includes minor gravel-size clasts; some cobbles up to 2 inches in diameter (same lithology as above); deposit is poorly sorted and calcareous.
7.0-9.0 ft (2.14-2.75 m)	2.0 ft (0.61 m)	Gravel, yellowish-brown (10YR 5/6), poorly sorted, calcareous; some iron oxide cementing forming local chunks of conglomerate, reddish-brown (5YR 4/3); lithology as above.
9.0-11.5 ft (2.75-3.51 m)	2.5 ft (0.76 m)	Pebble loam (till), clayey, calcareous, oxidized, light-yellowish-brown (2.5Y 6/4); contains reddish-brown (5YR 4/3) iron oxide spots, minor small lignite fragments, and numerous carbonate, igneous and metamorphic cobbles and pebbles; unjointed.
11.5-17.0 ft (3.51-5.19 m)	5.5 ft (1.68 m)	Pebble loam (till), clayey, calcareous, oxidized, light-olive-gray (5Y 6/2) with strong brown (7.5YR 5/6) iron oxide staining and mottling; includes weathered lignite fragments up to 4 inches in diameter; lithologic composition as above; highly jointed, with extensive iron oxide staining along joint faces; hard and tough.

BEULAH SECTION--Continued

Depth	Thickness	Description
Coleharbor Formation--Cont.		
17.0-20.0 ft (5.19-6.10 m)	3.0 ft (0.91 m)	Silt, fine, pale-yellow (5Y 7/3), oxidized, highly calcareous; includes secondary gypsum crystals visible with a hand lens; deposit is well-sorted and laminated (appears to be a lacustrine deposit); upper and lower contacts are sharp.
20.0-21.5 ft (6.10-6.56 m)	1.5 ft (0.46 m)	Gravel and sand, medium, pale-olive (5Y 6/3), poorly sorted; lithology similar to gravel units above; subangular to subrounded, no visible bedding.
21.5-22.5 ft (6.56-6.86 m)	1.0 ft (0.30 m)	Gravel and conglomerate, brown (10YR 5/3) to strong brown (7.5YR 5/8), calcareous; iron oxide cemented in part; manganese oxide staining and dendrites common on pebbles and cobbles; lithology similar to overlying unit; poorly sorted; includes granitic cobbles up to 6 inches in diameter.
Sentinel Butte Formation		
22.5-23.0 ft (6.86-7.01 m)	0.5 ft (0.15 m)	Clay, silty, light-yellowish-brown (2.5Y 6/4), noncalcareous, laminated; includes carbonized fossil plant fragments.
23.0-23.3 ft (7.01-7.10 m)	0.3 ft (0.09 m)	Shale, carbonaceous, reddish-brown (5YR 5/3), thinly laminated.
23.3-25.0 ft (7.10-7.62 m)	1.7 ft (0.52 m)	Lignite, black (2.5YR 2/0), soft, weathered; includes minor carbonaceous shale parting about 4 inches above base of unit.
25.0-25.5 ft (7.62-7.77 m)	0.5 ft (0.15 m)	Clay, silty, gray-brown (10YR 5/2); includes iron oxide staining on joints; slightly carbonaceous, laminated.
25.5-27.0 ft (7.77-8.23 m)	1.5 ft (0.46 m)	Silt, gray (5Y 6/1), noncalcareous; includes iron oxide staining on joints; some lignitic fossil plant fragments and oxidized root casts present.
27.0-32.0 ft (8.23-9.75 m)	5.0 ft (1.52 m)	Sand, very fine, silty, gray (5Y 6/1), calcareous, laminated; well-jointed, with gypsum concentrated along joint planes locally; includes iron oxide staining in patches and scattered iron oxide-cemented concretions up to 1 inch in diameter; some calcium carbonate-cemented concretions up to 6 inches in diameter present at contact with underlying unit.
32.0-40.0 ft (9.75-12.19 m)	8.0 ft (2.44 m)	Clay, silty, and silt, interbedded, calcareous, light-gray (5Y 7/2) with yellowish-brown (10YR 5/6) banding; laminated; includes some iron oxide-cemented concretions up to 6 inches in diameter.

INDIAN HEAD MINE SECTION

SW¼NE¼NE¼NE¼ Sec 36, T144N, R89W
Highwall in open pit lignite mine
Section described by L. A. Hemish
Elevation above sea level at top of section: 2 000 feet (609.60 m)

Depth	Thickness	Description
Oahe Formation		
0-1.0 ft (0-0.30 m)	1.0 ft (0.30 m)	Silt (loess), light-brown-gray (10YR 6/2), well-sorted, noncalcareous, unbedded.
Sentinel Butte Formation		
1.0-3.0 ft (0.30-0.91 m)	2.0 ft (0.61 m)	Silt, clayey, light-gray (2.5Y 7/2); contains iron oxide and calcium carbonate concretions up to 4 inches in diameter; highly calcareous; some orange banding.
3.0-4.0 ft (0.91-1.21 m)	1.0 ft (0.30 m)	Sand, very fine, silty, light-gray (2.5Y 7/2), rounded, laminated; contains iron oxide specks; limonite concretions up to 1 inch in diameter and oxidized root traces present; slightly calcareous.
4.0-8.0 ft (1.21-2.43 m)	4.0 ft (1.22 m)	Clay, silty, light-olive-brown (2.5Y 5/3), noncalcareous; interbedded with coarse silt, light-brown-gray (2.5Y 6/2), slightly calcareous; unit includes a zone of ovate siltstone concretions about 3 inches in diameter, white (2.5Y 8/2), laminated, calcium carbonate cemented.
8.0-16.5 ft (2.43-5.02 m)	8.5 ft (2.59 m)	Sand, very fine, silty, olive-gray (5Y 5/2), laminated, noncalcareous; includes carbonaceous material on stratification planes.
16.5-20.0 ft (5.02-6.09 m)	3.5 ft (1.07 m)	Clay, olive-gray (5Y 5/2), with clayey siltstone, reddish-yellow (7.5YR 6/8) banding, laminated; oxidized plant fragments abundant on stratification planes.
20.0-23.8 ft (6.09-7.25 m)	3.8 ft (1.16 m)	Lignite, medium soft, black (2.5YR 2/0).
23.8-25.0 ft (7.25-7.62 m)	1.2 ft (0.37 m)	Clay, silty, lignitic, dark-olive-gray (5Y 3/2).
25.0-29.0 ft (7.62-8.84 m)	4.0 ft (1.22 m)	Sand, very fine, silty, gray (7.5YR 5/0), noncalcareous, laminated.
29.0-32.3 ft (8.84-9.84 m)	3.3 ft (1.00 m)	Clay, smooth, dark-gray (7.5YR 4/0).
32.3-33.0 ft (9.84-10.05 m)	0.7 ft (0.21 m)	Shale, highly carbonaceous, papery, gray (7.5YR 5/0); consists primarily of compressed fossil leaves.
33.0-33.3 ft (10.05-10.14 m)	0.3 ft (0.09 m)	Clay, smooth, gray (5YR 5/1); includes abundant fossil plant fragments on lamination planes.
33.3-35.0 ft (10.14-10.66 m)	1.7 ft (0.52 m)	Lignite, medium soft, black (2.5YR 2/0).

INDIAN HEAD MINE SECTION--Continued

Depth	Thickness	Description
Sentinel Butte Formation--Cont.		
35.0-37.0 ft (10.66-11.27 m)	2.0 ft (0.61 m)	Sand, very fine, silty, very pale-brown (10YR 7/3), laminated, carbonaceous and lignitic, minor structural deformation observed.
37.0-38.3 ft (11.27-11.67 m)	1.3 ft (0.40 m)	Lignite, medium soft, black (2.5YR 2/0).
38.3-39.3 ft (11.67-11.97 m)	1.0 ft (0.30 m)	Clay, very highly carbonaceous, black (10YR 2/1), slickensides associated with adjacent fault plane present; petrified log about 1 foot in diameter in growth position included in this unit and unit directly below.
39.3-42.3 ft (11.97-12.88 m)	3.0 ft (0.91 m)	Clay, silty, gray (10YR 5/1).
42.3-42.6 ft (12.88-12.97 m)	0.3 ft (0.09 m)	Clay, lignitic, black (10YR 2/1).
42.6-47.0 ft (12.97-14.31 m)	4.4 ft (1.34 m)	Silt, slightly sandy, laminated, light-gray (10YR 6/1).
47.0-51.0 ft (14.31-15.53 m)	4.0 ft (1.22 m)	Sand, very fine, salt and pepper, light-gray (2.5Y 7/1), laminated.

NORTH ZAP SECTION

NE¼SW¼NE¼ Sec 5, T145N, R88W

East face of high butte in pasture

Section described by L. A. Hemish and G. Prichard

Elevation above sea level at top of section: 2 270 feet (691.90 m)

Depth	Thickness	Description
Coleharbor Formation		
0-2.5 ft (0-0.76 m)	2.5 ft (0.76 m)	Pebble loam (till), clayey, silty, sandy, olive-brown (2.5Y 4/4), calcareous; abundant pebbles and cobbles included; mottled with iron oxide spots.
Golden Valley Formation		
2.5-4.0 ft (0.76-1.22 m)	1.5 ft (0.46 m)	Clay and silt, interbedded, olive-gray (5YR 4/3).
4.0-8.0 ft (1.22-2.44 m)	4.0 ft (1.22 m)	Clay, silty, with some interbedded silt, light-yellowish-brown (2.5Y 6/4); interval includes a 1-foot-thick, white (2.5Y 8/2), very fine-grained to cryptocrystalline limestone pod.
8.0-8.25 ft (2.44-2.52 m)	0.25 ft (0.08 m)	Silt, clayey, highly carbonaceous, dark-reddish-brown (5YR 3/3).

NORTH ZAP SECTION--Continued

Depth	Thickness	Description
Golden Valley Formation--Cont.		
8.25-8.5 ft (2.52-2.60 m)	0.25 ft (0.08 m)	Clay, silty, micaceous, yellow (10YR 8/6); orange iron oxide staining imparts a mottled appearance; minor silt interbedded.
8.5-12.0 ft (2.60-3.67 m)	3.5 ft (1.07 m)	Clay, kaolinitic, light-olive-brown (2.5Y 5/4); some silt and carbonaceous material included; on undisturbed outcrop surface weathers white (10YR 8/0).
12.0-14.5 ft (3.67-4.43 m)	2.5 ft (0.76 m)	Lignite, medium soft, black (2.5Y 2/0); unit includes a 10-inch-thick bed of brown (10YR 5/3), sulfurous silt with yellow mottling.
14.5-16.0 ft (4.43-4.89 m)	1.5 ft (0.46 m)	Silt and clay, carbonaceous, micaceous, brown-dark-brown (10YR 4/3); laminated, with carbonaceous material concentrated along stratification planes.
16.0-17.0 ft (4.89-5.19 m)	1.0 ft (0.30 m)	Silt, with some very fine sand, pale-yellow (2.5Y 8/4), mottled with streaks of orange; micaceous.
17.0-21.0 ft (5.19-6.41 m)	4.0 ft (1.22 m)	Sand, very fine, silty, pale-yellow (2.5Y 8/4); laminated, with orange streaks of iron oxides on stratification planes; micaceous.
21.0-30.0 ft (6.41-9.15 m)	9.0 ft (2.74 m)	Silt and silty clay, interbedded, light-olive-brown (2Y 5/4), calcareous; silt beds are micaceous; iron oxides stain stratification planes orange; sulfurous, very fine sand concretions stained with iron oxides included; unit contains layer of very fine laminated sand about 6 inches thick at 24 feet.
30.0-32.0 ft (9.15-9.76 m)	2.0 ft (0.61 m)	Silt, clayey, micaceous, mottled white to pale-yellow (2.5Y 8/2 to 8/4), calcareous; a 1-inch-thick bed of indurated siltstone, brownish-yellow (10YR 6/8), included at base of unit.
32.0-34.0 ft (9.76-10.37 m)	2.0 ft (0.61 m)	Clay, silty, micaceous, laminated, dark-gray (5Y 4/1); gypsum crystals concentrated at very top of unit.
34.0-38.0 ft (10.37-11.59 m)	4.0 ft (1.22 m)	Clay, very smooth, kaolinitic, dark-gray (2.5YR 4/0), slightly carbonaceous and lignitic; has purplish hue on fresh surface, with some iron oxide staining and mottling; laminated; on undisturbed outcrop surface weathers white (10YR 8/0).
38.0-40.0 ft (11.59-12.20 m)	2.0 ft (0.61 m)	Silt, clayey, micaceous, with some carbonaceous material, olive-brown (2.5Y 4/4).
40.0-42.5 ft (12.20-12.96 m)	2.5 ft (0.76 m)	Sand, very fine, silty, micaceous, laminated, slightly calcareous, pale-yellow (2.5Y 7/4).
42.5-45.0 ft (12.96-13.72 m)	2.5 ft (0.76 m)	Clay, silty, micaceous, laminated, iron oxide staining on stratification planes, light-olive-brown (2.5Y 5/4).
45.0-45.3 ft (13.72-13.82 m)	0.3 ft (0.10 m)	Siltstone, light-brown-gray (2.5Y 6/2), calcium carbonate cement.

NORTH ZAP SECTION--Continued

Depth	Thickness	Description
Golden Valley Formation--Cont.		
45.3-46.3 ft (13.82-14.12 m)	1.0 ft (0.30 m)	Clay, silty, micaceous, laminated, light-olive-brown (2.5Y 5/4); iron oxide stained banding present; weathers yellowish-white.
46.3-49.3 ft (14.12-15.03 m)	3.0 ft (0.91 m)	Clay, kaolinitic, smooth, feels soapy, laminated, dark-gray (5Y 4/1).
49.3-55.3 ft (15.03-16.86 m)	6.0 ft (1.83 m)	Sand, fine to very fine, well-sorted, rounded, laminated, bright-yellow to white colors (10YR 6/8 to 10/1); orange iron oxide staining present; a 1-foot-thick bed of calcium carbonate-cemented sandstone included at 53 feet.
55.3-67.3 ft (16.86-20.52 m)	12.0 ft (3.66 m)	Sand, fine, laminated, same colors as unit above, including dark carbonaceous flecks; mostly friable, but occasional indurated lenses included; weathered surface is polygonally cracked; gypsum filled joints common.
67.3-72.3 ft (20.52-22.04 m)	5.0 ft (1.52 m)	Silt, micaceous, with minor clay laminae; mottled gray and orange, but color is predominantly yellow (10YR 8/6).
72.3-74.3 ft (22.04-22.65 m)	2.0 ft (0.61 m)	Silt, clayey, kaolinitic, laminated, gray (10YR 6/1).
74.3-75.0 ft (22.65-22.85 m)	0.7 ft (0.20 m)	Clay, slightly silty, carbonaceous, black (10YR 2/1); a 1-inch-thick lignite bed included at top of unit.
75.0-90.0 ft (22.85-27.42 m)	15.0 ft (4.57 m)	Clay, silty, highly carbonaceous, laminated, gray (10YR 5/1), with bright-colored reddish-yellow (7.5YR 6/8) oxidized banding; weathers to a popcorn surface with a distinct purple hue; a 1-foot-thick bed of impure, laminated, clayey lignite included at 88 feet.
90.0-107.0 ft (27.42-32.60 m)	17.0 ft (5.18 m)	Shale, silty, grading downward into very fine sand, laminated; highly carbonaceous, with fossil plant fragments abundant along stratification planes; brown (7.5YR 5/2) with purplish hue; small trough-shaped sand lenses containing inclusions of lignitic material and jarosite commonly observed in this unit; appears to be a channel-fill deposit.

NORTHEAST ZAP SECTION

SW¼SE¼NE¼ Sec 9, T145N, R88W

South face of hill in pasture

Section described by L. A. Hemish and G. Prichard

Elevation above sea level at top of section: 2 215 feet (675.13 m)

Depth	Thickness	Description
Coleharbor Formation		
0-7.0 ft (0-2.13 m)	7.0 ft (2.13 m)	Pebble loam (till), sandy, gray-brown (10YR 5/2), oxidized, highly calcareous; contains abundant pebbles and cobbles of carbonate (about 55 percent), igneous and metamorphic (about 35 percent), and other rock types.
Golden Valley Formation		
7.0-8.0 ft (2.13-2.43 m)	1.0 ft (0.30 m)	Clay, kaolinitic, calcareous, smooth, light-gray (2.5Y 7/2).
8.0-9.0 ft (2.43-2.73 m)	1.0 ft (0.30 m)	Silt, kaolinitic, calcareous, light-gray (2.5Y 7/2); includes streaks and spots of partly oxidized pale-yellow silt (2.5Y 7/4).
9.0-9.17 ft (2.73-2.78 m)	0.17 ft (0.05 m)	Siltstone, olive-brown (2.5Y 4/4), calcareous, well indurated; stains underlying bed, olive-brown (2.5Y 4/4).
9.17-11.0 ft (2.78-3.34 m)	0.83 ft (0.56 m)	Silt, kaolinitic, calcareous, light-gray (2.5Y 7/2) with pale-yellow (2.5Y 7/4) iron oxide spots and streaks; grades downward into silty clay.
11.0-20.0 ft (3.34-6.08 m)	9.0 ft (2.74 m)	Clay, silty to smooth, highly kaolinitic, white (2.5Y 8/0), feels soapy, weakly calcareous to noncalcareous; includes minor number of reddish-yellow (5YR 6/8) concretions and banding of the same color near base of unit.
20.0-25.0 ft (6.08-7.60 m)	5.0 ft (1.52 m)	Silt, clayey, to silt, coarse, kaolinitic, noncalcareous, light-gray (2.5Y 7/2); includes some lenses of very fine sand, rounded, with occasional disseminated black grains of chert (?); bleaches white on the outcrop--has definite Golden Valley Formation aspects; grades downward into silty sand.
25.0-28.0 ft (7.60-8.51 m)	3.0 ft (0.91 m)	Sand, very fine, light-gray (2.5Y 7/2), noncalcareous, slightly micaceous, rounded, no apparent bedding, surface weathers white; has Golden Valley Formation aspects.
28.0-40.0 ft (8.51-12.17 m)	12.0 ft (3.66 m)	Sand, very fine, light-brown-gray (2.5Y 6/2), noncalcareous; includes some iron oxide mottling; no apparent bedding; weathers light-gray (2.5Y 7/2); has some Golden Valley Formation aspects and some Sentinel Butte Formation aspects; contact between the two formations appears to be gradational within this unit.

NORTH ZAP SECTION--Continued

Depth	Thickness	Description
Sentinel Butte Formation		
40.0-53.0 ft (12.17-16.13 m)	13.0 ft (3.96 m)	Sand, fine to medium, light-yellow-brown (2.5Y 6/4), noncalcareous; includes abundant black grains; clasts are subangular to subrounded, no apparent bedding; has Sentinel Butte Formation aspects, no Golden Valley Formation aspects.

APPENDIX B

OAHE FORMATION

by

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APPENDIX B

OAHE FORMATION (Revised)

The Oahe Formation was named by Clayton (1972) and described and defined by Bickley (1972) and Clayton, Moran, and Bickley (1976). It was defined to include only sediment that contains a large proportion of silt and little or no sand or gravel. This material is interpreted to be largely windblown sediment deposited during Holocene and latest Wisconsinan time.

The Oahe Formation was considered to be one of four formations overlying the Coleharbor Formation. The other units (not yet formally defined) were to include clay, sand, or gravel interpreted to be of offshore, eolian, stream, or slopewash origin. The four units span roughly the same time period, they grade laterally into each other, and in map view they form a complex mosaic. That is, these units were to have been distinguished from each other solely on the basis of characteristic lithology. However, lithostratigraphic units should be distinguished on the basis of both lithology and stratigraphic position.

As defined by Clayton, Moran, and Bickley (1976), the Oahe Formation has four members that are recognized largely on the basis of color differences. Since they were first recognized, these color zones have been traced laterally into material that was to have been included in the other three formations.

For these reasons, we here group all of the material above the Coleharbor Formation (or Group) into one formation. Where the color zones are recognizable, the formation can be subdivided into four members. This formation and its members are defined on the basis of both lithology and stratigraphic position.

Three different ways of treating this formation were considered:

(1) An entirely new formation could be named. We have rejected this course, because two existing names, the Walsh and the Oahe, have already been applied to much the same material.

(2) The name "Walsh" could be maintained. This would involve redefinition of the Walsh Formation with respect to reference and type sections. The Walsh Formation was informally named by Arndt (1972, p. 3) and described and defined by Bluemle (1973, p. 33-36); however, it has never been defined with respect to a type section. Bluemle intended that it include all of the material above the Coleharbor Formation; that is, it contains Holocene sediment distinguished from sorted sediment at the top of the Coleharbor by its darker color resulting from dispersed organic material. We have not used the name "Walsh" for this sequence because of the complexity of the required revision. Four new members would have to be named, or the four members of the Oahe would have to be transferred to the Walsh; the base of the Walsh would have to be lowered to the base of the lowest member of the Oahe (a more conspicuous lithologic contact than the one between the lower two members, which is the base of the Walsh Formation, as defined by Bluemle 1973); and a type section would have to be designated.

(3) The name Oahe could be maintained. The only change required for the Oahe Formation is a revision of the lithologic part of its definition.

Therefore, we here redefine the Oahe Formation (Clayton, Moran, and Bickley, 1976) by broadening the lithologic part of its definition to cover the complete range in grain sizes found in the material overlying the Coleharbor Formation (or Group). That is, the Oahe Formation is no longer restricted to silt such as that found in its type section; it includes clay, silt, sand, and gravel. To illustrate this broadened range in grain size, two reference sections are here designated.

The first reference section is in Seibold Slough (Bickley, 1970; Cvancara and others, 1971; Bickley, 1972, p. 60-63). It is in the SW¼NW¼sec 31, T141N, R67W, 16 kilometres south of Woodward, Stutsman County, North Dakota. From bottom to top it consists of the following: (1) blue-gray, laminated, slightly fossiliferous (ostracods, fish, and mollusks), silty clay; (2) 30 centimetres of green to brown, finely laminated, highly organic, extremely fossiliferous (more than 160 species of plants and animals) clay; (3) 20 centimetres of brown, highly calcareous, very fossiliferous (mollusks, ostracods, and fish), silty clay (marl); (4) 75 centimetres of black, calcareous, fossiliferous (mollusks, ostracods, and fish), organic, silty clay; (5) 90 centimetres of black to brown, slightly calcareous, slightly fossiliferous (a few ostracods and mollusks), sandy silt and silty clay; and (6) 70 centimetres of black, slightly calcareous, fossiliferous (mollusks and ostracods), highly organic, silty clay.

The second reference section is in the Denbigh Sand Hills (Bickley, 1972, p. 66). It is 0.3 kilometres south of the northwest corner of section 33, T156N, R77W, 2.3 kilometres south of Denbigh, McHenry County, North Dakota. The reference section consists of 6 metres of well-sorted, unconsolidated sand containing some large-scale cross-bedding. Pebbles, cobbles, or boulders are extremely uncommon, but may be present.

When they do occur, they are artifacts. The unit is composed of quartz, feldspar, limestone, dolomite, shale, and small amounts of a wide variety of other minerals.

APPENDIX C

WELL INVENTORY AND

GROUNDWATER CHEMICAL DATA

APPENDIX C-I

WELL INVENTORY BEULAH-HAZEN AREA

In Water Use column:

C--commercial
D--domestic
I--irrigation
S--stock
U--unused

In Elevation column:

C--determined from 10-foot contour interval topographic map
D--determined from 20-foot contour interval topographic map

APPENDIX C-I

WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
144-85-13 CCA	Walz	1 850 C	120	1955	-	DS	Tavis Creek bed	Lignite
144-85-30 BBA 01	Weil, R.	1 865 C	45	1960	Pressure	D	Coleharbor	Gravel
144-85-30 BBA 02	Weil, R.	1 865 C	50	1962	Pumpjack	S	Coleharbor	Gravel
144-85-30 BBA 03	Weil, R.	1 865 C	11	1962	None	S	Coleharbor	
144-85-30 BBA 04	Weil, R.	1 865 C	11	1967	None	S	Coleharbor	
144-86-3 ABC 01	Loewen, L.	1 720 C	80	1941	Submersible	S	Coleharbor	
144-86-3 ABC 02	Loewen, L.	1 720 C	25	1931	Pressure	D	Coleharbor	
144-86-3 DBB 02	Loewen, L.	1 720	85	1971	Submersible	-	Coleharbor	
144-86-5 DAA 01	Reichenberg, H.	1 780 C	42	1972	Pressure	DS	Hagel bed	Lignite
144-86-5 DAA 02	Reichenberg, H.	1 770 C	42	1952	Pressure	I	Hagel bed	Lignite
144-86-5 DAA 03	Reichenberg, H.	1 770 C	40	1930	Pumpjack	U	Hagel bed	Lignite
144-86-5 DAA 04	Reichenberg, H.	1 780 C	40	-	Pressure	SI	Hagel bed	Lignite
144-86-5 DAA 05	Reichenberg, H.	1 770 C	250	1960	Pumpjack	U	Tavis Creek interval	
144-86-6 BCD 01	Knoell, A.	1 885 C	72	1942	Pumpjack	S	Antelope Creek bed	Lignite
144-86-5 BCD 02	Knoell, A.	1 885 C	150	1944	Pumpjack	U	Hagel bed	Lignite
144-86-6 BDD 01	Sommer, D.	1 890 C	180	1973	-	D	Hagel interval	
144-86-6 BDD 02	Wegerle, A.	1 890 C	780	1974	Pressure	D	Fox Hills	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
144-86-6 BDD 03	Wegerle, A.	1 890 C	40	-	Pumpjack	D	Spaer interval	
144-86-8 DDD 01	Sailer, L.	1 730 C	33	-	-	S	Coleharbor	Gravel
144-86-8 DDD 02	Sailer, L.	1 730 C	18	1965	-	D	Coleharbor	Gravel
144-86-9 CDD	Berger, J.	1 770 C	90	1967	Pressure	D	Hagel interval	
144-86-10 DCC	Hoffmann, M.	1 780 C	940	1968	None	DS	Fox Hills	
144-86-13 BBA	Mehrer, D.	1 845 C	150	1975	-	D	Hagel interval	
144-86-13 BBB	Wiedrich, D.	1 830 C	150	1975	Submersible	DS	Hagel interval	
144-86-14 DDA 02	Bentz, E.	1 860 C	18	1930	-	S	Coleharbor	Sand
144-86-15 BBB 03	Suess, M.	1 785 C	93	1971	Pressure	D	Hagel interval	
144-86-15 BBB 04	Huber, C.	1 785 C	104	1974	Submersible	DS	Hagel interval	
144-86-15 CDB	Morgenstern, D.	1 830 C	20	1960	Pumpjack	S	Coleharbor	Sand
144-86-15 CDC 01	Morgenstern, D.	1 830 C	52	1969	Pressure	S	Coleharbor	Sand
144-86-15 CDC 02	Morgenstern, D.	1 835 C	36	1969	Pumpjack	S	Coleharbor	Sand
144-86-17 AAA 01	Ritter, J.	1 730 C	65	1968	Pressure	D	Coleharbor	
144-86-17 AAA 02	Heid, R.	1 730 C	21	1969	Pressure	D	Coleharbor	Sand
144-86-17 AAA 03	Heid, R.	1 730	21	1969	Pressure	C	Coleharbor	Sand
144-86-17 AAB 01	Reierson, W.	1 730 C	18	1967	Jet pump	D	Coleharbor	
144-86-17 AAB 02	Reierson, W.	1 730 C	18	1970	Jet pump	DI	Coleharbor	
144-86-17 DAA	Hoffman, M.	1 770 C	800	1966	None	S	Fox Hills	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
144-86-18 DBD 01	McGrath	1 740 C	200	1960	Pressure	D	Weller Slough bed	Lignite
144-86-18 DBD 02	Oster, E.	1 740 C	650	-	None	DS	Fox Hills	Sand
144-86-18 DBD 03	Oster, S.	1 740 C	1 050	1967	None	S	Fox Hills	
144-86-18 DDC 01	Haas, W.	1 739 C	28	1973	Submersible	DS	Coleharbor	
144-86-19 AAD 01	Reich, D.	1 770 C	30	1965	Pressure	DS	Coleharbor	Sand
144-86-19 AAD 02	Reich, D.	1 770 C	800	1960	None	S	Fox Hills	
144-86-20 CBC	Tensen, R.	1 815 C	70	1967	Jet pump	D	Hagel bed	Lignite
144-86-21 ABD	Morgenstern, D.	1 820 C	24	1958	Jet	DS	Coleharbor	Sand
144-86-24 BCB	Boeckel, L.	1 890 C	50	1964	Pumpjack	S	Coleharbor	Sand
144-86-24 DAD	Sheid, B.	1 750 C	37	1974	Jet	D	Coleharbor	Sand, gravel
144-86-24 DDA	Sheid, B.	1 750 C	30	1974	Jet	D	Coleharbor	Sand
144-86-25 DBC	Albers, R.	1 945 C	54	1973	Submersible	DS	Spaer bed	Lignite
144-86-28 BBB 01	Klein, J.	1 875 C	65	1960	Jet	D	Antelope Creek bed	Lignite
144-86-28 BBB 02	Klein, J.	1 875 C	18	1935	Jet pump	S	Coleharbor	
144-86-28 DDC 02	Wolf, T.	1 950 C	70	1975	Piston pump	S	Spaer bed	Lignite
144-86-28 DDC 03	Wolf, T.	1 950 C	70	1970	Jet pump	D	Spaer bed	Lignite
144-86-34 ACB	Goetz, R.	1 960 C	48	1972	-	D	Beulah-Zap interval	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
144-87-3 ABD 01	Knoell, R.	1 810 C	24	1936	Cylinder lift	D	Coleharbor	
144-87-3 ABD 02	Knoell, R.	1 810 C	24	-	Pressure pump	D	Coleharbor	
144-87-4 ABA	Mattheis, D.	1 830 C	40	1975	Pressure	D	Kinneman Creek bed	Lignite
144-87-4 ADB	Mattheis, H.	1 840 C	140	1974	Pressure	DS	Hagel bed	Lignite
144-87-10 ADD 01	Auwinger, M.	1 785 C	65	1966	Hand pump	U	Coleharbor	
144-87-10 ADD 02	Auwinger, M.	1 785 C	65	1966	Pressure	DS	Coleharbor	
144-87-10 DDD	Bauch, A.	1 825 C	60	1974	Submersible	D	Kinneman Creek bed	Lignite
144-87-11 CBB	Geist, S.	1 775 C	185	1975	Submersible	D	Coleharbor	
144-87-12 DCC 01	Knoell, J.	1 760 C	26	1975	Pumpjack	S	Coleharbor	
144-87-12 DCC 02	Knoell, J.	1 750 C	25	1935	Pressure	D	Coleharbor	
144-87-12 DCC 03	Knoell, J.	1 750 C	55	1968	Pressure	D	Hagel bed	Lignite
144-87-12 DCC 04	Christmann, A.	1 750	95	1965	Pumpjack	S	Tavis Creek bed	Lignite
144-87-13 BBA 01	Christmann, A.	1 770 C	80	1961	Pumpjack	S	Hagel bed	Lignite
144-87-13 BBA 02	Christmann, A.	1 770 C	80	1971	Submersible	D	Hagel bed	Lignite
144-87-13 BCC	Christmann, A.	1 770 C	693	1967	None	S	Fox Hills	
144-87-14 ACA	Oster, E.	1 770 C	190	1975	Submersible	I	Tavis Creek interval	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
144-87-14 BBB 01	McLaughlin	1 828 C	1 200	1967	None	DS	Fox Hills	
144-87-14 BBB 02	McLaughlin	1 828 C	75	1972	Submersible	D	Kinneman Creek interval	
144-87-14 CCD 01	McLaughlin, J.	1 820 C	250	1940	Pumpjack	S	Tavis Creek interval	
144-87-14 CCD 02	McLaughlin, J.	1 820 C	40	1969	Pressure	D	Kinneman Creek interval	
144-87-18 DAD 01	Rueb, J.	1 960 C	125	1949	Jet pump	DS	Spaer bed	Lignite
144-87-18 DAD 02	Rueb, J.	1 950 C	22	1920	Pumpjack	S	Coleharbor	
144-87-19 BCB	Schmidt, G.	1 900 D	125	1971	Electric pressure	DS	Kinneman Creek bed	Lignite
144-87-19 CBC	Winkler, A.	1 860 D	90	1968	Jet	DS	Kinneman Creek interval	Sand
144-87-20 BBD	Sasse, G.	1 925 C	250	-	Pressure	DS	Hagel interval	
144-87-26-ADA	Opp, A.	1 780 C	55	1975	Pressure	DS	Coleharbor	
144-87-29 BCB	Renner, W.	1 755 C	120	1971	Submersible	D	Coleharbor	
144-87-35 BCB 02	Schwarz, A.	1 765 C	80	-	Pressure	DS	Hagel bed	Lignite
144-88-1 BAB 01	Sailer, C.	1 860 D	60	1952	Pressure	DS	Coleharbor	
144-88-1 BAB 02	Sailer, C.	1 860 D	60	1935	Pumpjack	S	Coleharbor	
144-88-1 DDD	Kessler, F.	1 940 D	104	1953	Pumpjack	D	Coleharbor	Gravel
144-88-2 ABD	Pischel, A.	1 900 D	62	1949	Pressure	DS	Coleharbor	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
144-88-6 BDA 01	Wittmaier	2 020 D	13	1961	Jet	D	Coleharbor	
144-88-6 BDA 02	Wittmaier	2 020 D	28	1912	-	S	Coleharbor	
144-88-6 BDA 03	Wittmaier	2 020 D	28	1963	Electric pump	S	Coleharbor	
144-88-11 DDC	Schafer, W.	2 040 D	375	1974	Submersible	D	Hagel interval	Sand
144-88-11 DDD 01	Tri-County Imp.	2 040 D	115	1974	Submersible	CD	Spaer bed	Lignite
144-88-12 AAA 01	Kessler, F.	1 980 D	27	1920	Pumpjack	DI	Coleharbor	
144-88-12 AAA 02	Hartwig, D.	1 960 D	110	1951	Pumpjack	D	Coleharbor	
144-88-15 BDA 01	Raeszler, R.	2 080 D	100	1960	Submersible	D		
144-88-15 BDA 02	Raeszler, R.	2 080 D	390	1961	Submersible	S	Beulah-Zap bed	Lignite
144-88-17 DCA	Raeszler, R.	1 940 D	160	1962	Pumpjack	S	Hagel bed	Lignite
144-88-24 CCB	Schumaier, J.	1 850 D	170	1974	Submersible	DS	Hagel interval	Sand
144-88-24 CCC 01	Schumaier, J.	1 840 D	190	1935	Pumpjack	S	Hagel interval	Sand
144-88-29 DAA 01	Bieber, G.	1 810 D	94	1950	Pumpjack	DS	Hagel bed	Lignite
144-88-29 DAA 02	Bieber, G.	1 810 D	95	1974	Submersible	DS	Hagel bed	Lignite
144-88-34 DAD 02	Fandrich, C.	1 780 D	43	1971	Submersible	DS	Coleharbor	
144-88-35 ABB 01	Helm, N.	1 780 D	26	1971	Pumpjack	S	Coleharbor	Sand
144-88-35 ABB 02	Helm, N.	1 780 D	70	1964	Pumpjack	DI	Coleharbor	Sand
144-88-35 BAA 01	Helm, N.	1 780 D	26	1973	Pumpjack	S	Coleharbor	Sand

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
144-88-36 BAA	Helm, N.	1 760 D	26	1967	Pumpjack	S	Coleharbor	Sand
144-89-2 BAD	Wiedrich	2 120 D	90	1910	-	DS	Schoolhouse bed	Lignite
144-89-4 BAD	Horning, E.	1 990 D	40	1961	-	DS	Beulah-Zap bed	Lignite
144-89-5 DCC 01	Kusmenko, O.	1 950 D	13	1974	Submersible	S	Coleharbor	
144-89-5 DCC 02	Kusmenko, O.	1 950 D	18	1973	Pumpjack	S	Coleharbor	
144-89-5 DCC 03	Kusmenko, O.	1 940 D	10	1950	Pressure	D	Coleharbor	
144-89-5 DCC 04	Kusmenko, O.	1 940 D	20	1950	Pumpjack	-	Coleharbor	
144-89-5 DCC 05	Kusmenko, O.	1 940 D	24	1950	None	U		
144-89-8 ABC	Kusmenko, O.	1 920 D	8	1970	None	S	Coleharbor	
144-89-9 CCD	Dallman	1 860 D	900	1966	Pumpjack	U	Fox Hills	
144-89-11 BBB	Buchfink, T.	1 960 D	70	-	Pressure	DS	Spaer bed	Lignite
144-89-11 DAA	Buchfink, T.	1 980 D	60	1944	Pumpjack	S	Beulah-Zap interval	
144-89-20 CCB 04	Engbrecht, R.	1 970 D	50	1950	Pressure	D	Coleharbor	
144-89-30 AC	Engbrecht, R.	-	48	1958	Hand pump	U	Coleharbor	
144-89-32 BCA	Simenson, A.	2 140 D	260	1967	Pumpjack	U	Spaer bed	Lignite
144-89-35 AAA	Fuchs, A.	1 960 D	42	1957	Pressure	D	Coleharbor	
144-89-35 AAD	Fuchs, A.	1 975 D	70	1974	Pressure	S	Beulah-Zap bed	Lignite

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-85-4 ADC	Oster, E.	1 970 C	124	1952	Submersible	DS	Antelope Creek bed	Lignite
145-85-4 CAC 01	Grosz, R.	1 935 C	17	1961	Submersible	DS	Coleharbor	Sand, gravel
145-85-4 CAC 02	Grosz, R.	1 930 C	360	1 955	None	U	Tavis Creek interval	Sand
145-85-4 CAC 03	Grosz, R.	1 930 C	20	-	Pumpjack	U	Coleharbor	
145-85-5 AAD	Pischel, E.	1 960 C	15	1940	Pumpjack	S	Coleharbor	
145-85-5 ADA 01	Pischel, E.	1 980 C	68	1930	Pressure	DS	Spaer bed	Lignite
145-85-6 ABD 01	Weisz, H.	2 030 C	60	1960	Pressure	S	Beulah-Zap bed	Lignite
145-85-6 ABD 02	Weisz, H.	2 020 C	60	1974	Submersible	D	Beulah-Zap bed	Lignite
145-85-6 ABD 03	Weisz, H.	2 020 C	60	1930	Pumpjack	S	Beulah-Zap bed	Lignite
145-85-7 BBB	Reichenberg, H.	2 010 C	27	1969	Pumpjack	S	Beulah-Zap bed	Lignite
145-85-7 CBB 01	Maas, H.	2 015 C	83	1953	Submersible	D	Spaer bed	Lignite
145-85-7 CBB 02	Maas, H.	2 010 C	83	1936	Pumpjack	D	Spaer bed	Lignite
145-85-7 CBB 03	Maas, H.	2 010 C	83	1958	Pumpjack	D	Spaer bed	Lignite
145-85-8 CAB	Weiz, E.	1 950 C	72	1971	-	DS	Antelope Creek bed	Lignite
145-85-18 DCC 01	Mittelsteadt, W.	1 930 C	90	1966	Pumpjack	S	Kinneman Creek bed	Lignite

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-85-18 DCC 02	Mittelsteadt, W.	1 930 C	20	-	Pumpjack	D	Coleharbor	
145-85-18 DCC 03	Mittelsteadt, W.	1 940 C	60	1966	Pumpjack	S	Antelope Creek bed	Lignite
145-85-29 CCA	Sommer, E.	1 790 C	70	1945	Pumpjack	DS	Tavis Creek bed	Lignite
145-85-31 CBD	Mittelsteadt, F.	1 790 C	170	1955	Submersible	S	Weller Slough bed	Lignite
145-85-32 AAA 02	Mittelsteadt, R.	1 770 C	960	1967	None	DS	Fox Hills	
145-85-32 CDC 02	Mittelsteadt, L.	1 725 C	880	1973	None	DS	Fox Hills	
145-86-1 DDD 03	Reichenberg, H.	2 010 C	35	1970	Submersible	SI	Beulah-Zap bed	Lignite
145-86-2 ADB 01	Richter, E.	2 050 C	40	1945	Pumpjack	S	Coleharbor	
145-86-2 DDD	Richter, M.	2 005 C	45	-	Pumpjack	S	Beulah-Zap bed	Lignite
145-86-5 DBC 01	Miller, W.	2 100 D	160	1941	Submersible	D	Beulah-Zap bed	Lignite
145-86-5 DBC 02	Miller, W.	2 100 D	160	1956	Submersible	S	Beulah-Zap bed	Lignite
145-86-6 CDA	Wiedrich, E.	2 090 D	60	-	Pumpjack	S	Coleharbor	
145-86-6 CDD 03	Wiedrich, E.	2 090 D	180	-	Pumpjack	DS	Spaer bed	Lignite
145-86-10 AAC 01	Weisz, L.	1 990 C	80	1900	Pressure	S	Spaer bed	Lignite
145-86-10 AAC 02	Weisz, L.	1 990 C	120	1960	Pressure	DS	Antelope Creek bed	Lignite

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-86-10 DBA 02	Weisz, D.	1 980 D	60	1950	Jet	DS	Spaer bed	Lignite
145-86-10 DBA 03	Weisz, D.	1 980 D	30	1950	Pumpjack	U	Beulah-Zap bed	Lignite
145-86-11 CDD 02	Richter, E.	2 000 C	30	1915	Pumpjack	U	Beulah-Zap bed	Lignite
145-86-11 DDA	Mueller, A.	2 000 C	50	1960	Pumpjack	S	Beulah-Zap bed	Lignite
145-86-12 BBB 01	Richter, E.	2 010 C	40	1967	Pressure	D	Beulah-Zap bed	Lignite
145-86-12 BBC	Richter, M.	2 015 C	40	-	Pumpjack	DS	Beulah-Zap bed	Lignite
145-86-12 DAA 01	Maas, H.	2 000 C	83	1967	Pumpjack	S	Spaer bed	Lignite
145-86-14 AAB	Mueller, A.	2 000 C	94	1946	Pressure	DS	Spaer bed	Lignite
145-86-20 CDC 01	Sommer, A.	2 015 C	75	1976	Pressure	DS	Beulah-Zap bed	Lignite
145-86-22 AAA 02	Benz, H.	1 990 C	1 280	1972	Submersible	DS	Fox Hills	
145-86-26 AAD	Miller, E.	1 970 C	1 500	-	-	-	Fox Hills	
145-86-26 CBC 01	Goetz, O.	2 000 C	48	1973	Pressure	DS	Beulah-Zap bed	Lignite
145-86-26 CBC 02	Goetz, O.	1 990 C	48	1920	None	U	Beulah-Zap bed	Lignite
145-86-26 CBC 03	Goetz, O.	1 990 C	48	1940	Pumpjack	S	Beulah-Zap bed	Lignite

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-86-27 BBC 01	Wiedrich	2 015 C	140	1945	Submersible	DS	Antelope Creek bed	Lignite
145-86-28 ADB 01	Schramm, R.	2 000 C	40	1966	Pressure	D	Beulah-Zap bed	Lignite
145-86-28 ADB 02	Schramm, R.	2 000 C	40	1906	Pumpjack	U	Beulah-Zap bed	Lignite
145-86-30 ADA	Zuern, H.	1 940 C	25	1925	Pressure	DS	Spaer bed	Lignite
145-86-31 CBB 01	Geist, S.	1 825 C	35	1974	Submersible	D	Coleharbor	
145-86-31 CBB 02	Geist, S.	1 825 C	20	1925	Submersible	DS	Coleharbor	
145-86-35 CDB 03	Rahn, W.	1 930 C	1 150	1975	Submersible	DS	Fox Hills	
145-87-1 CBC	Sheid, R.	2 040 D	28	1973	Submersible	DS	Coleharbor	
145-87-1 CCB 01	Sheid, H.	2 040 D	160	1957	Pumpjack	S	Antelope Creek bed	Lignite
145-87-3 AAA 01	Gunsch, V.	2 100 D	25	1972	Pressure	DS	Coleharbor	Clay
145-87-3 AAA 02	Gunsch, V.	2 100 D	45	1955	Pumpjack	S	Coleharbor	Clay
145-87-3 BAA 01	Wiedrich, V.	2 080 D	150	-	Pumpjack	DS	Coleharbor	Sand, gravel
145-87-4 DDD 01	Oberlander, A.	1 980 D	1 300	1972	Submersible	DS	Fox Hills	Sand
145-87-5 AAB 01	Reiner, F.	1 995 D	40	1970	Pumpjack	DS	Coleharbor	Clay
145-87-5 AAB 02	Reiner, F.	1 995 D	40	1950	Pumpjack	S	Coleharbor	Clay
145-87-9 CDC 01	Hipfner, J.	1 970 D	184	1960	Pumpjack	S	Hagel bed	Lignite
145-87-9 CDC 02	Hipfner, J.	1 970 D	42	1968	Pressure	D	Coleharbor	Sand

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-87-12 DBC 01	Link, A.	2 020 D	139	1960	Pumpjack	DS	Antelope Creek bed	Lignite
145-87-12 DBC 02	Link, A.	2 020 D	148	1915	None	U	Antelope Creek bed	Lignite
145-87-13 CDC 02	Wolf, E.	1 920 C	40	1971	Pumpjack	S	Coleharbor	Sand
145-87-14 CDD 01	Galster, W.	1 880 C	12	1942	Pumpjack	S	Coleharbor	
145-87-14 CDD 02	Galster, W.	1 880 C	14	1944	Submersible	DS	Coleharbor	
145-87 14 DDC 01	Wolf, E.	1 910 C	12	1910	Submersible	D	Coleharbor	
145-87-14 DDC 02	Wolf, E.	1 900 C	30	1961	Pumpjack	S	Coleharbor	
145-87-15 CCD	Galster, D.	1 900 D	25	1970	Submersible	DS	Coleharbor	
145-87-16 ACD 01	Hoepfner, S.	1 920 D	20	-	Pressure	D	Coleharbor	Sand
145-87-16 ACD 04	Hoepfner, S.	1 920 D	20	1972	Pumpjack	S	Coleharbor	Sand
145-87-16 CCB	Heihn, G.	1 960 D	165	1970	Submersible	DS	Coleharbor	Gravel
145-87-18 AAB 01	Boeckel, A.	2 060 D	65	-	Pumpjack	S	Schoolhouse interval	
145-87-18 AAB 02	Boeckel, A.	2 060 D	80	1963	Submersible	D	Schoolhouse interval	
145-87-22 DAD 01	Oster, E.	1 880 C	20	1960	Pressure	D	Coleharbor	
145-87-22 DAD 02	Oster, E.	1 880 C	20	1945	Submersible	S	Coleharbor	
145-87-22 DAD 03	Oster, E.	1 880 C	250	1961	None	U	Coleharbor	
145-87-23 DCC	Galster, J.	1 870 C	960	1972	None	DS	Fox Hills	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-87-26 ADA 01	Oster, L.	1 865 C	25	1946	Pumpjack	S	Coleharbor	Sand, gravel
145-87-26 ADA 02	Oster, L.	1 860 C	20	1925	None	U	Coleharbor	
145-87-26 ADA 03	Oster, L.	1 865 C	200	1959	Pumpjack	U	Coleharbor	
145-87-26 ADB	Oster, L.	1 870 C	25	1960	Pressure	D	Coleharbor	Sand, gravel
145-87-26 ADD	Oster, L.	1 850 C	10	1973	Pressure	S	Coleharbor	Sand, gravel
145-87-28 CDC	Teske, T.	1 940 D	35	1969	Pressure	DS	Beulah-Zap bed	Lignite
145-87-30 ABC 01	Boeckel, L.	1 940 D	20	1954	Pressure	D	Beulah-Zap bed	Lignite
145-87-30 ABC 02	Boeckel, L.	1 940 D	30	1920	Pumpjack	S	Beulah-Zap bed	Lignite
145-87-30 ABC 03	Boeckel, L.	1 940 D	20	1960	Pressure	S	Beulah-Zap bed	Lignite
145-87-32-ACC 02	Buchmann, J.	1 880 D	46	1975	Pressure	D	Coleharbor	Sand
145-87-33 DCA 03	Sailer, J.	1 840 D	8	1973	None	S	Coleharbor	Clay
145-87-36 AAB	Zuern, E.	1 840 C	25	-	-	-	Coleharbor	
145-88-4 AAC 01	Walz, L.	1 950 D	22	1972	Submersible	S	Coleharbor	
145-88-6 ADA 02	Morast, W.	2 260 D	200	1967	Pumpjack	DS	Beaver Creek sand	Sand
145-88-6 DDD 02	Morast, W.	2 300 D	90	1960	Pumpjack	S	Coleharbor	Gravel
145-88-8 BCC 02	Renner, R.	2 290 D	56	1970	Submersible	DS	Golden Valley	Clay

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-88-10 DCD 01	Keller, W.	2 020 D	72	1949	-	DS	Coleharbor	Gravel
145-88-10 DCD 02	Keller, W.	2 010 D	65	1962	Pumpjack	S	Coleharbor	Gravel
145-88-11 BCC	Ricker, W.	2 000 D	86	1976	None	S	Beulah-Zap bed	Lignite
145-88-12 DCA	Keller, E.	1 980 D	1 250	1974	Submersible	DS	Fox Hills	Sand
145-88-14 BAA 01	Ost, G.	2 010 D	120	1960	Pressure	S	Spaer bed	Lignite
145-88-16 CCD	Reinhardt, A.	2 195 D	80	-	Pumpjack	-	Beaver Creek sand	
145-88-18 DAB	Herrmann, I.	2 180 D	130	1971	Submersible	D	Beaver Creek sand	Sand
145-88-18 DAC	Herrmann, I.	2 180 D	120	1925	Pumpjack	S	Beaver Creek sand	Sand, gravel
145-88-20 BAB 01	Reinhardt, A.	2 170 D	90	-	-	D	Beaver Creek sand	Sand
145-88-20 CCC 01	Becker, J.	2 190 D	135	-	-	D	Beaver Creek sand	Sand
145-88-21 ABD	Boeckel, H.	2 195 D	160	1963	Pumpjack	S	Twin Buttes bed	Lignite
145-88-22 BBA	Weiss, E.	2 125 D	52	1939	Pumpjack	S	Beaver Creek sand	
145-88-22 CDC	Weiss, E.	2 170 D	110	1933	Pumpjack	DS	Beaver Creek sand	Sand
145-88-23 AAA 01	Brecht, B.	1 960 D	38	-	Pressure	S	Spaer bed	Lignite

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-88-23 DDA 01	Boeckel, C.	1 950 D	54	1970	Pressure	D	Coleharbor	
145-88-23-DDA 02	Boeckel, C.	1 950 D	80	-	Pumpjack	S	Coleharbor	
145-88-23 DDB	Boeckel, C.	1 950 D	45	1970	Submersible	D	Coleharbor	
145-88-23 DDD	Boeckel, C.	1 980 D	60	1973	Pressure	S	Beulah-Zap bed	Lignite
145-88-26 BAB	Bauer	1 980 D	8	1958	Pumpjack	DS	Coleharbor	Clay
145-88-28 ABB 01	Mittelsteadt	2 135 D	32	1941	Pumpjack	S	Coleharbor	
145-88-28 ABB 02	Mittelsteadt	2 135 D	28	1941	Pumpjack	U	Coleharbor	
145-88-28 ABB 03	Mittelsteadt	2 135 D	38	1971	-	D	Coleharbor	
145-88-29 CAA	Walz, G.	2 160 D	90	1918	Pumpjack	DS	Beaver Creek sand	
145-88-29 DAB	Walz, G.	2 160 D	120	1966	Submersible	S	Twin Buttes bed	Lignite
145-88-30 ABB	Weiss, E.	2 150 D	95	1942	-	U	Twin Buttes bed	Lignite
145-88-32 BBC	Hafner, H.	2 100 D	288	1975	-	S	Kinneman Creek bed	Lignite
145-88-32 CCC 02	Hafner, H.	2 070 D	120	1925	Pressure	DS	Beulah-Zap bed	Lignite
145-88-33 DCD 01	Sasse, R.	2 100 D	110	-	Pumpjack	D	Schoolhouse bed	Lignite
145-88-33 DCD 02	Sasse, R.	2 100 D	70	1920	Pressure	S	Twin Buttes bed	Lignite

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
145-88-34 ABD	Wittmaier	2 120 D	120	1960	Pumpjack	S	Schoolhouse bed	Lignite
145-88-34 CCB	Sasse, R. J.	2 060 D	70	1945	Pumpjack	S	Schoolhouse bed	Lignite
145-88-34 DDB	Wittmaier	2 100 D	115	-	Pumpjack	S	Schoolhouse bed	Lignite
145-89-14 CCA 01	Lang, O.	2 095 D	49	1954	Pressure	D	Coleharbor	
145-89-14 CCA 02	Lang, O.	2 095 D	57	1958	Pressure	S	Coleharbor	
145-89-14 CCA 03	Lang, O.	2 095 D	115	1971	Pressure	S	Beulah-Zap bed	Lignite
145-89-14 DCB	Richau, A.	2 130 D	100	1960	Pumpjack	U	Coleharbor	
145-89-23 BAA 02	Richau, A.	2 140 D	80	1970	Submersible	D	Beaver Creek sand	
145-89-23 BAA 03	Richau, A.	2 140 D	86	1970	Pumpjack	S	Beaver Creek sand	
145-89-26 DDA 01	Renner, O.	2 150 D	130	1972	Submersible	D	Schoolhouse bed	Lignite
145-89-26 DDA 02	Renner, O.	2 150 D	110	1966	Pumpjack	S	Beaver Creek sand	
146-85-4 AAD 01	Buchman	1 980 C	78	1946	Pressure	S	Spaer bed	Lignite
146-85-4 AAD 02	Buchman	1 980 C	80	1920	None	S	Spaer bed	Lignite
146-85-4 AAD 03	Buchman	1 990 C	85	-	-	U	Spaer bed	Lignite
146-85-15 BBD 01	Ellwein, H.	2 035 C	22	1971	Submersible	DS	Coleharbor	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
146-85-15 BBD 02	Ellwein, H.	2 035 C	8	1964	None	U	Coleharbor	
146-85-17 ACD 01	Tschaekofske	2 055 C	45	1968	Submersible	S	Coleharbor	
146-85-17 ACD 02	Tschaekofske	2 055 C	25	1925	Pumpjack	S	Coleharbor	
146-85-17 ACD 03	Tschaekofske	2 060 C	45	1971	Pressure	D	Coleharbor	
146-85-21 CDC 01	Oster, L.	2 050 C	106	1960	Pumpjack	S	Beulah-Zap interval	
146-85-21 CDC 02	Oster, L.	2 050 C	118	1952	Pressure	DS	Beulah-Zap interval	
146-85-21 CDC 03	Oster, L.	2 050 C	40	-	Pumpjack	U	Coleharbor	
146-85-28 AAD 01	Lampert, H.	2 035 C	10	-	Pressure	S	Coleharbor	
146-85-28 AAD 02	Lampert, H.	2 035 C	60	-	Pressure	D	Coleharbor	
146-85-29 CDD 01	Richter, O.	2 060 C	152	1976	Submersible	DS	Spaer bed	Lignite
146-85-29 CDD 02	Richter, O.	2 060 C	83	1930	Pumpjack	S	Beulah-Zap bed	Lignite
146-85-29 CDD 03	Richter, O.	2 060 C	83	1962	None	U	Beulah-Zap bed	Lignite
146-85-29 CDD 04	Richter, O.	2 060 C	188	1969	None	U	Antelope Creek bed	Lignite
146-85-33 AAA 01	Kilber, E.	2 010 C	32	1965	Pressure	DS	Coleharbor	Sand
146-85-33 AAA 02	Kilber, E.	2 010 C	32	1954	Pumpjack	U	Coleharbor	Sand
146-85-33 AAA 03	Kilber, E.	2 010 C	32	1970	Pumpjack	S	Coleharbor	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
146-86-2 CBA 01	Victor, J.	1 975 C	187	1968	Pumpjack	S	Hagel bed	Lignite
146-86-2 CBB 01	Victor, J.	1 950 C	50	1955	Pressure	D	Antelope Creek bed	Lignite
146-86-4 CDA	Reinhardt, L.	1 980 D	120	-	Pumpjack	-	Kinneman Creek bed	Lignite
146-86-4 DCB 01	Reinhardt, L.	1 980 D	95	1972	Submersible	D	Antelope Creek bed	Lignite
146-86-4 DCB 02	Reinhardt, L.	1 980 D	95	-	Pumpjack	S	Antelope Creek bed	Lignite
146-86-7 ADC	Benz, E.	1 990 D	200	1960	Pumpjack	DS	Hagel bed	Lignite
146-86-9 DAA 02	Maas, R.	2 000 D	83	1968	Pressure	D	Coleharbor	
146-86-10 CCA	Adolf, C.	2 020 D	35	1885	Pressure	DS	Coleharbor	Gravel
146-86-11 DDC	Miller, H.	2 030 C	60	1960	Pumpjack	S	Coleharbor	
146-86-12 CCC 02	Miller, D.	2 055 C	120	1968	Pumpjack	DS	Spaer bed	Lignite
146-86-13 BDC 01	Knell, T.	2 080 C	56	1968	Submersible	DS	Schoolhouse interval	
146-86-13 BDC 02	Knell, T.	2 075 C	50	1956	Submersible	DS	Schoolhouse interval	
146-86-14 BBA	Miller, H.	2 055 C	1 320	1964	Submersible	DS	Fox Hills	
146-86-14 BBB	Miller, H.	2 040 C	46	1975	Pumpjack	S	Beulah-Zap bed	Lignite
146-86-15 BBD 01	Adolph, E.	2 040 D	70	1949	Pressure	D	Coleharbor	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
146-86-15 BBD 02	Adolph, E.	2 040 D	125	1952	Submersible	S	Antelope Creek bed	
146-86-16 CBB	Reinhardt, L.	2 040 D	80	1972	Pumpjack	S	Coleharbor	
146-86-22 DAD	Rasch, R.	2 130 C	32	1945	Pumpjack	S	Twin Buttes bed	Lignite
146-86-22 DBD 01	Rahn, H.	2 140 C	64	-	Pumpjack	DS	Schoolhouse bed	Lignite
146-86-22 DBD 02	Rahn, H.	2 140 C	45	1969	Pumpjack	S	Twin Buttes bed	Lignite
146-86-23 CDD 01	Maas, R.	2 120 C	102	1945	Pumpjack	DS	Beulah-Zap bed	Lignite
146-86-23 CDD 02	Maas, R.	2 115 C	190	1945	Pumpjack	S	Antelope Creek bed	Lignite
146-86-24 DAC	Neuberger, E.	2 100 C	19	1974	Pressure	DS	Coleharbor	Clay
146-86-25 DCC 01	Brunmeier, C.	2 075 C	94	1965	Pumpjack	DS	Beulah-Zap bed	Lignite
146-86-25 DCC 02	Brunmeier, C.	2 075 C	84	1968	Submersible	DS	Beulah-Zap bed	Lignite
146-86-26 AAD 01	Maas, W.	2 100 C	35	1960	Pressure	D	Coleharbor	
146-86-26 AAD 02	Maas, W.	2 110 C	70	1972	Pumpjack	S	Schoolhouse interval	
146-86-27 BBC 01	Rasch, E.	2 180 D	68	1972	Pressure	DS	Coleharbor	Clay
146-86-27 BCB 01	Rasch, E.	2 180 D	68	1960	Pumpjack	S	Coleharbor	Clay

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
146-86-28 DAD 01	Rasch, R.	2 140 D	85	1972	Submersible	DS	Schoolhouse bed	Lignite
146-86-28 DAD 02	Rasch, R.	2 140 D	65	1972	Submersible	DS	Twin Buttes bed	Lignite
146-86-29 ADD	Gutsche, R.	2 160 D	47	1918	Pressure	DS	Coleharbor	Clay
146-86-29 BBB	Madche, P.	2 160 D	150	1965	Pumpjack	U	Beulah-Zap bed	Lignite
146-86-31 ADD	Pfeifer, M.	2 140 D	50	1967	Pressure	DS	Coleharbor	
146-86-31 DDA 01	Knecht, R.	2 160 D	68	1972	Pressure	DS	Coleharbor	
146-86-33 CBD 01	Sheid, G.	2 120 D	160	1956	Pumpjack	DS	Beulah-Zap bed	Lignite
146-86-33 CBD 02	Sheid, G.	2 120 D	16	1975	None	U	Coleharbor	
146-86-34 CDC 01	Knell, A.	2 040 C	29	1970	-	S	Beulah-Zap bed	Lignite
146-86-36 AAA 03	Wolf, R.	2 075 C	35	-	Pumpjack	S	Coleharbor	Sand, gravel
146-87-1 CDD 01	Zeller	1 970 D	212	1935	None	U	Hagel bed	Lignite
146-87-1 CDD 02	Zeller	1 970 D	205	1925	Pressure	DS	Hagel bed	Lignite
146-87-4 DBA	Hafner, W.	1 870 D	170	1965	Submersible	D	Tavis Creek bed	Lignite
146-87-14 BAB	Benz, F.	1 940 D	60	1954	Pumpjack	DS	Kinneman Creek bed	Lignite
146-87-16 CCA	Boeshans, W.	2 000 D	220	1954	Pumpjack	S	Hagel bed	Lignite

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
146-87-21 BAB	Boeshans, W.	2 040 D	1 400	1965	Submersible	DS	Fox Hills	Sand
146-87-23 CAC	Boeshans, W.	2 040 D	240	1935	Pumpjack	S	Hagel bed	Lignite
146-87-25 BDD	Mattheis, R.	2 100 D	28	1972	Pumpjack	S	Coleharbor	
146-88-9 CCD 02	Pfenning, T.	1 980 D	9	-	None	DS	Schoolhouse interval	
146-88-9 CCD 03	Pfenning, T.	1 960 D	32	1953	Pumpjack	S	Beulah-Zap bed	Lignite
146-88-10 CBA	Jones, A.	1 900 D	295	1951	Submersible	D	Tavis Creek bed	Lignite
146-88-10 DDC	Renner, J.	1 900 D	310	1969	Pumpjack	D	Tavis Creek bed	Lignite
146-88-11 CCC 01	Renner, J.	1 860 D	125	1963	Pumpjack	S	Hagel bed	Lignite
146-88-13 DCD 01	Renner, E.	1 860 D	194	1973	Submersible	S	Coleharbor	Sand
146-88-15 ABA	Renner, J.	1 910 D	25	1962	Pumpjack	U	Spaer bed	Lignite
146-88-22 CBB 02	Christmann, L.	1 900 D	36	1955	Pressure	D	Spaer bed	Lignite
146-88-23 ABA 03	Pfenning, H.	1 890 D	86	1956	Pressure	DS	Antelope Creek bed	Lignite
146-88-23 ABA 04	Pfenning, H.	1 890 D	86	1936	Pumpjack	S	Antelope Creek bed	Lignite
146-88-25 BDD 02	Hafner, M.	1 930 D	50	1960	Pumpjack	U	Spaer bed	Lignite
146-88-26 BBA 01	Huber, L.	1 960 D	12	1930	Centrifugal	S	Beulah-Zap bed	Lignite

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
146-88-26 BBA 02	Huber, L.	1 960 D	40	1964	Pressure	D	Beulah-Zap bed	Lignite
146-88-27 CCC	Sailer, R.	1 880 D	50	1966	-	-	Coleharbor	Sand, gravel
146-88-27 DCB 01	Eisenbeis, R.	1 920 D	50	1935	Pumpjack	S	Spaer bed	Lignite
146-88-27 DCB 02	Eisenbeis, R.	1 920 D	100	1940	Pumpjack	DS	Spaer interval	Clay
146-88-28 BBB	Weigum, C.	1 900 D	42	1973	Pressure	DS	Coleharbor	
146-88-28 DAA	Sailer, R.	1 880 D	40	1965	Pumpjack	S	Spaer interval	
146-88-28 DDA 01	Sailer, R.	1 880 D	4	-	None	DS	Spaer bed	Lignite
146-88-28 DDA 02	Sailer, R.	1 880 D	6	-	Pressure	DS	Spaer bed	Lignite
146-88-29 BDB	Reinhardt, E.	1 980 D	18	1955	Pumpjack	S	Beulah-Zap bed	Lignite
146-88-33 DBC 01	Walz, D.	1 940 D	26	1948	Submersible	DS	Coleharbor	
146-88-33 DBC 02	Walz, D.	1 940 D	18	1962	Pumpjack	S	Coleharbor	
146-88-33 DBC 03	Walz, D.	1 940 D	60	1950	Pressure	D	Spaer bed	Lignite
146-88-34 ADC	Renner, R.	1 950 D	110	1961	Pumpjack	S	Spaer interval	Sand
146-89-13 ACB	Walker, V.	1 890 D	1 250	1973	None	S	Fox Hills	
146-89-13 ADD	Walker, V.	2 000 D	410	1961	Submersible	DS	Tavis Creek interval	
146-89-14 ABC	Bauer, E.	1 960 D	450	1941	Pumpjack	DS	Weller Slough bed	Lignite
146-89-23 DAD	Sailer, C.	2 120 D	1 280	1973	Submersible	DS	Fox Hills	

APPENDIX C-I--Continued
WELL INVENTORY BEULAH-HAZEN AREA

Location	Owner	Elev. (ft.)	Depth (ft.)	Year Drilled	Type of Pump	Water Use	Stratigraphic Position	Aquifer Lithology
146-89-26 BCA	Pfenning, R.	2 040 D	4	1960	None	D	Twin Buttes bed	Lignite
146-89-35 DBB	Fischer, R.	2 120 D	110	-	Submersible	DS	Schoolhouse bed	Lignite

APPENDIX C-II

GROUNDWATER CHEMICAL DATA--

FOX HILLS AQUIFER (DATA ARE

ARRANGED BY COUNTY)

** Na^+ and K^+ given as sum

ADAMS AND BOWMAN COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
129-96-4 DCB	880					8.7	1580	1010	46	14	5.3	.2	397	1.2	735	32	55	120	1.18	700	70	.4	3.6									06-15-71		A. Rose
129-96-12 DBB	1314	21.0				8.0	1840	1110	51	15	4.2	1.1	455	2.7	852	0	165	45	-20.61	320	40	1.0	2.7									07-23-70		Hettinger
129-96-13 ACA	1140	19.5				7.9	1890	1130	61	11	2.5	1.2	464	1.2	877	0	194	6.6	-2.51	200	0	1.0	3.8									07-23-70		Hettinger
129-96-13 ADD	1050	17.0				8.2	1550	983	57	9	2.5	.6	393	1.1	789	13	47	101	1.47	200	0	2.0	3.8									07-23-70		Hettinger
129-96-13 BBB 01	1180	17.5				8.3	1590	941	50	12	2.3	1.6	400	1.2	794	20	71	66	1.79	280	0	.0	4.4									07-23-70		Hettinger
129-96-13 BDD 01	1182	18.5				8.2	1530	950	54	10	2.3	1.1	390	1.1	853	1	44	70	1.42	480	0	1.0	4.9									07-23-70		Hettinger
129-99-4 ABA 02	940					8.6	1620	1010	61	8	1.9	.9	400	1.0	685	27	29	214	1.09	860	30	2.0	3.0									05-03-71		V. Czywczynski
129-99-4 CBB	926	13.5				8.3	1630	1040	57	9	2.2	.9	393	1.0	724	7	30	213	-.23	100	20	1.0	3.6									08-18-70		W. Kralicek
129-105-2 CAA	322	12.5				8.5	1290	866	67	4	1.8	.0	308	.8	581	15	1.0	180	-1.06	370	20	2.5	.3									07-25-72	4465	NDSWC
130-98-4 DBB	1274	22.0				8.2	1730	1040	47	15	3.4	1.6	418	1.9	897	0	129	11	-.11	0	10	1.0	4.8									10-11-71		Reeder
130-98-4 DCC	1200	19.5				8.2	1760	1050	57	11	2.0	1.5	438	1.1	892	4	138	4.1	1.50	140	10	1.0	4.6									07-23-70		Reeder
130-101-25 AAA	893					8.6	1610	971	20	63	11	8.6	373	1.3	680	23	36	208	.72	40	20	18	2.7									06-04-71		D. Lambourn
130-103-11 CCC	651	14.0				8.4	1650	1050	66	7	1.8	.7	402	1.0	733	16	11	241	-.56	120	10	1.0	6.5									08-26-70		H. Davis
130-104-21 BBA	406	13.0				8.9	1930	1240	56	13	2.5	1.7	461	.8	658	56	4.1	387	-.01	140	30	1.0	.6									05-24-72		M. Susag
130-104-26 DCD	600	13.0				9.0	1480	918	64	6	1.9	.4	360	1.0	621	50	3.2	194	-.53	220	10	1.0	1.3									05-04-71		S. Nias
131-94-20 CBC 01	1045	19.0				7.8	1930	1330	44	25	6.2	2.3	504	3.0	880	0	237	44	.01	260	50	1.0	3.6									07-22-71	4312	NDSWC
131-100-9 CCD	1068	14.0				8.2	1730	1090	52	12	2.1	1.7	416	1.0	783	0	44	212	.91	240	10	1.0	8.2									08-14-70		A. Freitag
131-100-23 DBA	1180	19.5				8.2	1660	997	68	7	2.2	.2	415	1.0	789	3	35	179	1.28	300	10	1.0	3.8									07-20-70		Scranton
131-100-26 ABA	1193	6.1				8.8	1870	1080	43	19	3.6	2.4	435	1.7	782	45	120	93	-.77	420	20	1.0	3.0									02-24-72		Scranton
131-101-18 BCC 01	900	12.0				8.8	2080	1280	66	11	3.4	.6	503	1.3	774	38	7.8	400	-.83	640	20	2.5	5.3									05-05-71		P. Lewton
131-102-2 DDA	1067	19.0				8.4	1710	1080	100	3	1.2	.0	409	1.1	743	11	26	240	-1.11	80	10	.0	2.3									07-28-70		Bowman
131-102-7 DDD 01	963	14.0				8.5	1890	1190	61	11	3.4	.6	465	2.8	779	23	133	165	-.51	230	20	2.5	2.9									07-20-72	4462	NDSWC
131-102-11 CAB	1042	19.0				8.7	1660	1050	100	3	1.2	.0	403	1.1	688	36	22	231	-.82	140	20	.3	2.5									07-28-70		Bowman
131-102-11 DAD	1059	21.0				8.3	1670	1050			.0	.0	415	1.0	751	4	33	219	.42	120	0	2.7	1.0									07-29-70		Bowman
131-102-14 AAB	1096	19.0				8.2	1660	1050	56	10	1.9	1.3	405	1.0	761	0	36	213	-.20	0	0	1.0	2.7									07-28-70		Bowman
131-103-8 CAC 01	927	16.5				8.7	1740	1200	66	8	2.2	.6	428	.7	722	43	10	248	.27	0	10	.6	3.6									05-27-71		J. Lutz
131-104-28 AAA 02	700	16.0				8.6	1490	940	46	12	3.3	1.0	366	1.0	663	25	3.6	209	.12	760	20	1.0	.8									08-27-70		M. Miller
131-105-18 DCC	80					8.8	1820	1150	64	9	3.1	.2	444	1.0	701	36	7.2	322	-.20	180	10	.7	.7									05-26-71		G. Larkin
131-105-21 ACC	287	9.0				8.9	1740	1060	65	8	2.6	.5	426	1.0	687	55	3.8	270	-.24	300	20	0	.7									05-26-71		G. Larkin
131-105-23 CDD	495	13.5				8.8	1760	1150	85	5	1.9	.2	435	1.1	767	45	7.5	242	-.68	160	0	2.5	.5									07-26-72	4466	NDSWC
131-106-3 DAA	96	9.0				7.8	2500	1680	16	206	46	22	541	5.4	825	0	5.7	681	-.14	100	80	4.4	.4									05-20-71		L. Miller
131-106-4 DCC	66					7.6	869	504	5.4	143	32	15	149	4.5	390	0	11	138	-.53	0	20	2.5	.7									05-20-71		L. Miller
132-97-7 CAB 01	1080	20.0				8.0	1790	1110	45	19	5.2	1.5	451	1.7	877	0	54	175	1.3	2800	30	1.0	5.3									07-29-71	4313	NDSWC
132-100-35 DDD	1200					8.2	1810	1130	50	15	4.1	1.2	447	1.3	908	0	37	179	2.5	0	10	0	4.0									08-18-70		K. Freitag
132-104-17 CCC	630					8.9	1740	1070	46	60	2.6	2.3	423	1.0	676	54	5.2	289	-.79	0	40	.4	1.0									05-14-71		R. Idler
132-104-2: AAA	750					8.7	1790	1170	56	12	2.5	1.5	444	1.1	792	35	7.7	250	.0	100	30	2.5	4.2									05-14-71		D. Meggers
132-105-16 BDB	459	13.0				8.7	1720	1100	41	20	3.4	2.8	425	1.0	736	35	3.2	259	.56	240	20	.0	.4									06-25-71	4308	NDSWC
132-106-26 BDC	229					8.5	2530	1640	51	29	5.8	3.5	627	1.6	769	18	2.3	661	1.58	·200	30	2.2	.1									05-19-71		J. Peterson

GRANT AND SIOUX COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
129-79-7 CBD	210					8.1	1600	1090	10	180	51	12	310	5.3	580	0	.4	390	-1.41	700	10	2.5	.6									12-14-71		A. Silbernagel
129-81-1 BAB	104	9.0				8.4	2520	1690	43	38	11	2.6	610	5.1	900	17	13	600	-1.37	2100	40	1.0	1.1									07-13-73	4520	NDSWC
129-86-4 CDD 01	56					8.5	1320	816	39	13	4.7	.4	330	1.2	680	13	1.7	140	.38	0	10	1.0	2.9									08-18-71		H. Fuchs
129-87-10 BBC	361	6.5				8.1	2030	1200	63	11	3.2	.7	480	1.4	910	0	220	21	-.98	2000	40	.00	2.9									11-15-72	4490	NDSWC
129-88-5 DDD 01	466	12.0				8.5	2120	1290	51	18	3.4	2.3	500	2.9	840	24	270	23	-1.09	260	20	1.0	3.2									07-04-73	4525	NDSWC
129-88-5 DDD 02	348	11.0				8.3	1670	1100	54	13	3.3	1.1	440	.8	870	0	60	110	3.11	420	30	.04	4.3									07-04-73	4525A	NDSWC
130-81-31 BBB 02	225					8.4	1440	928	35	18	6.7	.4	340	1.3	580	13	.0	250	.10	0	10	1.0	.4									12-10-71		S. Mosset
130-82-12 DDB	250					7.9	2000	1340	14	180	50	13	420	1.9	770	0	19	410	.44	0	130	33	.1									12-13-71		P. Kraft
130-82-34 ABD 01	145					7.7	1040	663	20	24	7.2	1.5	220	.8	410	0	4.3	170	-1.52	580	10	1.0	.4									12-13-71		Selfridge
130-83-25 CBC	220					7.9	2590	1780	36	56	16	3.9	620	1.3	820	0	5.2	740	-1.54	0	20	1.0	.7									12-09-71		B. Braun
130-84-13 AAD	160					8.2	2030	1340	46	24			510		770	0	.0	480		300		3.0	.3									01-26-66		M. Meisel
130-84-31 AAA 01	466	13.5				8.0	4260	3320	17	500	120	49	900	6.4	500	0	83	1900	-.76	150	70	28	0.3									07-10-73	4523	NDSWC
130-84-36 ABA	417	10.0				8.4	2470	1470	50	22	7.4	.9	540	2.0	680	11	130	410	.76	1200	80	.20	2.0									10-10-73	4489	NDSWC
130-85-17 DAA	245	6.0				8.1	2020	1280	64	11	3.8	.4	490	1.7	870	0	250	11	.07	4000	0	1.0	2.9									11-16-72	4488	NDSWC
130-86-28 CCC 01	424	11.0				8.5	2130	1310	55	16	3.8	1.6	510	3.2	870	20	250	30	-.04	0	10	.20	3.2									07-05-73	4524	NDSWC
130-86-28 CCC 02	210	11.0				8.1	1800	1200	43	20	5.6	1.4	440	1.4	820	0	45	240	-.33	50	0	1.5	3.2									06-10-73	4524A	NDSWC
130-88-22 CDD	350	8.5				8.5	1680	1040	43	17	4.0	1.7	410	1.2	890	19	97	7.9	.22	0	10	1.8	4.4									11-03-71		I. Olson
130-89-32 DDA	543	7.0				8.0	2000	1170	58	13	3.3	1.2	480	1.4	890	0	220	9.4	.43	5100	80	1.0	3.5									11-14-72	4492	NDSWC
130-90-9 ADA	233					7.8	2280	1520	52	24			590		1060	0	14	400		1900		.00										06-16-67		E. Barth
131-80-2 AD	50	8.0				7.2	2950	2020	17	300	76	28	680	7.5	1590	0	2.4	420	1.40	2300	250	.10	.3									04-11-59		A. Schaf
131-80-21 AAC	240					8.1	1100	699	6.2	170	40	18	190	5.0	550	0	7.5	120	.64	1600	130	1.0	.5									12-14-71		J. Running Bear
131-81-31 DBC	200					8.0	1730	1090	50	14	4.9	.5	430	1.4	970	0	30	100	.50	120	10	2.0	3.4									12-15-71		P. Henderson
131-81-33 ACA	200					8.1	2420	1530	41	40	12	2.4	590	2.6	980	0	18	480	-.06	260	10	1.0	1.0									12-15-71		T. Schmidt
131-85-8 DDD 01	394					8.4	1740	1040	43	18	4.7	1.6	420	1.2	830	13	150	19	.00	280	0	1.0	3.2									11-17-71		A. Leintz
131-87-6 BCB 01	560					8.5	1770	1100	40	21	4.4	2.4	420	1.3	740	14	13	290	-.77	100	40	2.5	2.3									11-05-71		D. Brinkman
131-89-30 AAA	809	13.0				8.5	2330	1380	72	12	3.9	.6	550	2.6	880	21	330	10	-.84	980	40	1.0	3.4									07-02-73	4526	NDSWC
132-82-30 ADB	400					8.0	1090	694	11	84	24	5.8	230	1.7	580	0	5.6	110	-.01	340	10	1.0	.4									12-09-71		J. Kraft
132-83-29 BBB	400					8.2	1760	1140	44	19	5.0	1.6	440	1.3	860	0	17	220	.01	430	10	1.0	3.2									12-03-71		Weinhandl Bros.
132-84-16 DAA	396	10.0				8.2	1770	1120	52	13	3.6	1.0	430	3.8	870	0	170	17	-.91	1200	10	.20	4.2									07-11-73	4518	NDSWC
132-87-27 ADA	180	9.5				8.0	1760	1070	57	11	3.1	.9	430	1.3	930	0	80	99	-1.58	100	80	1.0	3.3									11-15-72	4491	NDSWC
133-79-27 BD		8.0				7.3	2380	1650	12	280	59	34	480	8.1	920	0	6.2	560	-.15	1900	0	.50	.7									04-11-59		Allot
133-80-31 CCD 01	180	8.5				8.0	687	400	1.7	260	63	25	65	5.0	440	0	3.5	27	1.81	160	180	2.5	.2									05-15-73	8644	NDSWC
133-81-35 DCB	210					8.2	2270	1500	42	31	5.6	4.1	540	2.7	980	0	53	350	-1.35	100	20	1.0	1.7									12-15-71		J. Kary
133-83-6 CDD	307					8.0	1330	855	38	14	3.6	1.2	330	1.0	640	0	0	190	.72	0	0	1.0	1.4									12-03-71		E. Bornhoeft
133-83-12 ADA 01	230	10.0				8.4	2170	1410	56	18	4.7	1.6	540	2.5	950	19	24	330	.34	100	20	1.0	2.1									05-17-73	8655	NDSWC
133-83-34 CBC 02	310					8.0	1560	1030	6.7	290	77	24	260	3.7	780	0	29	200	-.02	2400	160	2.5	1.2									12-01-71		E. LaDuke
133-85-12 AAD	522	7.0				8.2	2270	1390	70	12	3.3	1.0	560	1.8	1130	0	220	6.2	-.42	920	0	1.0	3.4									11-16-72	4487	NDSWC
133-89-4 DAD	612	12.0				8.6	2020	1260	74	8	2.4	.5	480	1.5	1070	61	110	6.3	-3.92	450	10	1.3	7.8									05-03-73	4484	NDSWC

GRANT AND SIOUX COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
134-79-26 CC 02	96	12.0				8.3	476	296	13	14	3.0	1.6	110	1.6	280	4	2.4	15	.0	110	30	1.5	.5									04-11-59		Oak Grove School
134-80-31 BBA 01	67					8.4		1730		1	1.0	1.0	500		1040	36	150	10	-1.80	100	0	5.0	3.2									04-23-71		Solen, ND
134-82-36 DCD	157	8.0				8.2	2620	1840	60	22	6.2	1.6	650	2.9	1140	0	50	480	-2.21	300	160	.09	2.3									04-24-73	8086	NDSWC
134-89-22 BDD	876					8.4	2150	1370	68	12	2.5	1.5	540	1.5	1260	13	92	2.9	.08	50	120	.00	.9									03-17-70		Elgin City Test
134-90-36 CBC	880					8.0	2000	1250	66	12	2.6	1.3	520	1.5	1200	0	100	12	.28	1200	20	1.0	4.2									09-26-72		New Leipzig
135-86-15 DDD 01	592	11.5				8.6	2360	1430	69	14	2.4	1.9	590	3.7	1170	45	180	5.8	.29	790	10	1.0	3.6									06-22-73	4515	NDSWC
135-90-23 BBB 01	1047	10.0				8.8	2250	1280	71	12	3.3	1.0	570	2.9	1080	56	170	20	.58	300	80	.3	4.6									05-30-73	4509	NDSWC
136-87-36 ABD	428	7.5				8.1	2450	1520	88	9	2.9	.5	600	1.9	1240	0	240	1.2	-1.5	880	0	1.0	5.1									11-15-72	4486	NDSWC
136-88-13 AAA	732	12.0				8.5	2270	1320	66	14	2.6	1.8	570	2.6	1170	28	170	2.9	.32	610	40	1.0	5.9									05-25-73	4513	NDSWC
137-88-21 DDC	923	9.0				8.3	2800	1730	87	12	2.9	1.2	690	2.1	1250	9	340	1.6	1.2	520	0	1.0	5.1										4485	NDSWC
137-89-9 ABA 01	1026	12.0				8.6	2480	1460	91	9	3.9	.8	670	2.1	1180	33	230	3.3	4.3	220	40	.60	6.1									05-24-73	4511	NDSWC

EMMONS COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
129-77-5 DAD	120					7.8	2280	1550	32	56	16	3.8	550	5.5	1060	0	12	375	-.77	0	0	1.4	.6									08-10-72		S. VanderLaan
129-77-9 DBC	160					7.4	3180	2250	18	284	72	25	722	8.6	1500		8.9	603	-.17	2200	80	.22	.2									07-19-72		E. Ryckman
129-78-1 DAA	100					7.4	2590	1200	1.4	892	187	103	98	9.2	738	0	3.0	446	2.0	160	1000	1.2	.6									08-10-72		A. Becker
129-78-11 DCC 01	70					7.5	1870	1280	6.4	407	74	54	299	9.2	763	0	20	422	-1.2	0	250	.76	.2									08-10-72		E. Ryckman
130-77-1 CCC	43	8.0				7.7	1500	1020	3.9	462	80	64	196	11	545	0	9.8	395	2.0	250	500	.22	.2									12-15-72	8597	NDSWC
130-77-14 AAA	84	8.5				8.2	1980	1430	5.7	510	141	37	294	11	589	0	6.1	624	.46	1500	410	.23	.1									05-29-73	8674	NDSWC
130-77-23 ABC	130					8.0	1760	1170	34	26	7.9	1.6	405	3.9	691	0	0	357	1.1	0	50	.11	.1									07-06-72		M. Wagner
130-78-20 AAD	100	8.5				7.7	1280	795	3.4	370	58	55	150	6.7	455	0	9.6	280	1.8	140	100	9.0	.2									07-30-73		A. Kreffer
130-79-9 DDA	110	9.5				7.7	685	354	2.4	200	42	23	78	5.8	417	0	2.5	38	-.72	120	240	.34	.2									07-30-73		L. Paul
131-77-21 CAD	122	8.5				8.1	1720	1200	1720	370	87	37	270	9.5	661	0	11	430	-2.2	120	670	.54	.2									07-30-73		H. Heidrich
131-79-12 BBC	105					8.0	2320	1560	42	34	8.8	2.9	573	3.2	1020	0	0	409	.90	80	0	1.6	.7									08-18-72		H. Nagel
131-79-15 ADD	120					7.8	1370	863	6.9	245	39	36	250	5.7	817	0	.4	116	.44	0	0	1.8	.3									08-18-72		A. Nagel et al
132-74-18 DCC	56					7.6	1250	895	1.6	500	130	43	83	10	289	0	9.1	440	-1.1	120	730	.32	.7									07-31-73		C. Rohrich
132-76-35 ADD	57					7.4	2230	1500	5.3	650	160	61	310	16	999	0	12	500	-.43	500	580	.99	.1									07-31-73		
132-79-3 CDD 02	105					7.6	1030	643	2.1	370	98	30	93	6.5	544	0	2.4	130	-.43	430	550	.23	.2									07-31-73		A. Ohlhauser
133-75-10 DCD	80					7.7	667	463	.1	355	86	34	4.5	6.2	198	0	3.1	199	.47	720	1210	.22	.2									07-30-71		S. Loebs
134-74-6 DDA	70	8.0				7.6	611	395	1.1	242	55	26	40	9.8	266	0	13	68	4.5	0	10	6.5	.5									07-27-71		A. Olson, Sr.
134-74-32 CCD	280	10.0				8.0	1410	939	28	24	3.2	3.9	323	2.3	398	0	2.7	388	-.48	500	50	.22	.5									07-28-71		H. Kundert
134-75-15 BBB	103	7.5				7.7	1060	698	4.8	205	45	23	162	9.8	474	0	6.7	185	-2.3	300	240	.56	.3									10-25-72	8551	NDSWC
134-75-20 CCC 01	240	9.0				8.1	1280	868	20	40	10	3.6	300	4.8	655	0	5.6	153	-.50	0	10	.45	.4									07-23-71		B. Buck
134-75-34 BAA	130	7.0				7.3	458	311	.3	214	47	23	11	9.2	237	0	1.7	57	-2.3	1200	20	.45	.2									07-23-71		L. Witikko
134-76-2 DDD 01	200					7.8	2460	1670	8.7	478	86	64	440	7.2	816	0	69	648	.14	0	20	.63	.8									07-20-71		R. Schatz
134-76-5 CBC 01	165					7.6	1620	1090	9.3	207	44	24	309	6.7	644	0	0	336	-.48	90	30	2.2	.1									08-21-72		L. Buck
134-76-8 BBD	350	9.5				8.3	1500	954	36	19	4.6	1.8	360	3.9	674	6	2.8	250	-.92	40	10	.56	.4									07-27-73		E. Brindle

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Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 mg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
134-76-28 CDC	100	9.0				7.9	1440	1010	2.8	508	123	49	150	10	457	0	5.5	415	1.8	3100	90	.56	.2									07-23-71		N. Wilhelm
134-77-14 CDD 01	65					7.4	303	188	.4	142	33	14	12	3.5	192	0	4.5	.8	2.4	100	10	.22	.4									08-03-71		E. Flegel
134-77-18 CCB 01	230	8.5				7.9	1260	793	8.9	142	30	16	243	3.9	494	0	3.7	237	1.5	280	10	.81	.1									07-16-71		H. Will, Jr.
134-77-18 CCB 02	220	10.0				7.9	1310	811	8.6	160	35	18	250	5.2	541	0	41	230	-2.3	230	110	1.7	.3									08-01-73		H. Will
134-77-22 BBB	183	7.0				7.6	470	270	.5	207	46	22	19	4.5	266	0	2.4	35	-1.5	1200	220	.22	.2									10-31-72	8559	NDSWC
134-77-34 CAB	96	10.0				8.0	1090	685	6.4	174	41	17	196	5.5	535	0	3.9	158	-.70	1300	20	1.1	.3									08-04-71		E. Gimbel
134-78-8 ADD	360	8.5				8.1	1310	881	28	24	5.8	2.3	324	2.1	660	0	7.5	153	1.5	0	10	.56	.3									07-15-71		C. Watkinson
134-78-15 DDD	123					8.5		1110	39	22	4.9	2.4	420	4.7	758	22	8.9	270	-.32	340	80		.9									05-31-73	8558	NDSWC
135-74-32 BAA	68	7.0				7.8	639	416	1.9	180	49	15	59	9.3	284	0	3.2	100	-3.4	260	600	.05	.2									05-30-73	8669	NDSWC
135-76-19 CCC 01	137	8.0				8.1	1130	767	1.7	472	95	57	85	6.4	453	0	0	266	1.4	1700	240	1.8	1.0									04-20-72	8127	NDSWC
135-76-19 CCC 02	132	8.0				8.2	1110	717	7.2	164	34	19	212	6.3	535	0	2.8	165	1.5			.11	.1									06-07-73	8687A	NDSWC
135-76-19 CCC 03	132					8.2	1150	739	12	77	11	12	249	5.6	567	0	2.6	151	.08			.11	.1									06-07-73	1887B	NDSWC
135-76-19 CCC 04	132					8.3	1170	764	13	73	18	6.8	254	5.2	561	6	.6	166	-1.1			.09	.1									06-08-72	8687C	NDSWC
135-76-19 CCC 05	145	8.5				7.6	1210	784	8.5	140	31	15	230	5.3	563	0	3.3	190	-1.7	720	160	.81	.2									08-10-73	TM 1	NDSWC
135-76-29 BCB	140	7.5				7.8	1450	1010	22	42	11	3.5	337	3.6	554	0	2.1	309	.22	0	20	2.1	.3									07-02-71		Hazelton 3
135-76-30 DAA 02	133	7.5				8.0	2210	1680	4.1	770	160	91	260	8.6	600	0	26	780	.54	640	720	26	.1									11-20-72	8554	NDSWC
135-76-32 DCD	150					7.9	1310	913		160					440	0	7.7	314		480		7.7										08-04-69		J. Grenz
135-77-10 ADA	120	8.0				8.0	812	555	19	18	3.1	2.6	193	1.1	389	0	1.4	104	.86	30	10	1.4	.2									07-12-71		H. Schmidt
135-77-21 CDD	128	7.0				8.1	4120	3660	6.2	1440	300	168	544	10	502	0	22	2140	-.62	3700	320	22	.1									12-13-72	8555	NDSWC
135-77-28 BCA 01	220	9.0				8.3	1290	909	6.9	215	53	20	234	5.5	521	9	2.7	255	-7.4	450	90	2.7	.1									07-13-71		E. Schmitke
136-75-14 AAA	113	9.0				7.4	764	476	4.8	130	33	12	129	5.2	380	0	1.5	103	14.2	1600	130	.56	.3									09-27-71	8148	NDSWC
136-75-18 AAD	100	8.0				7.9	1380	980	15	80	21	6.7	313	3.9	558	0	3.3	280	27.4	540	20	.74	.3									06-29-71		Saville Bros.
136-75-27 DAC 02	80					7.3	1740	1170	43	16	3.4	1.8	397	4.9	428	0	1.7	499	43.1	80	0	.22	.1									08-07-72		J. Hammer
136-75-27 DBD 01	73					7.4	2010	1420	21	81	22	6.3	442	5.4	501	0	3.5	617	43.3	0	30	1.2	.1									08-07-72		T. Mock
136-75-27 DBD 02	80					7.4	1870	1300	15	126	33	11	401	5.2	529	0	1.7	549	39.2	0	50	.11	.1									08-07-72		J. Wolbaum
136-75-34 CBD	50	8.0				8.2	804	550	5.7	110	23	13	138	6.7	342	0	9.9	137	17.4	120	150	.14	.5									05-22-73	8660	NDSWC
136-75-35 CBD	85	10.0				7.3	1120	795	2.5	358	83	37	113	6.5	303	0	6.5	353	40.2	5600	270	.67	.6									06-30-71		F. Vetter
136-76-1 ACA	330	8.5				7.6	862	493	2.9	230	61	19	100	6.1	394	0	10	130	14.4	5700	500	.56	.2									08-01-73		L & R Ranch
136-76-2 ADB	180	8.5				7.5	1350	940	3.2	438	104	43	157	6.3	581	0	1.9	284	24.2	7500	200	.56	.3									07-08-71		L & R Ranch
136-76-7 BCC	83	8.0				7.7	614	355	4.3	113	25	12	106	3.7	388	0	2.7	24	0.0	1100	160	.09	.4									10-18-72	8539	NDSWC
136-76-18 CCA	150	8.5				7.7	1330	943	4.1	363	79	40	182	4.6	528	0	7.8	263	2.7	180	20	10	.4									07-06-71		R. Schlittenhart
136-76-26 CAA	280					8.0	2590	1730	25	109	28	9.5	609	5.1	958	0	4.4	602	.86	0	30	.81	.2									06-30-71		J. Vetter
136-77-4 BAB	185					8.2	1580	1060	45	13	4.0	.7	379	2.1	773	0	0	206	-.47	80	0	.42	.8									08-08-72		
136-77-16 ADD	83	7.0				7.9	1110	677	6.6	174	33	22	201	4.3	637	0	2.0	102	-1.4	4300	490	.22	.4									10-19-72	8543	NDSWC
136-77-21 DCD	190					7.7	1590	1000	30	28	7.2	2.4	370	2.4	639	0	2.1	287	.48	0	20	.79	.4									08-18-72		P. Moch
136-77-32 CDB	180	8.5				8.1	2440	1590	41	37	8.6	3.8	586	2.6	969	0	114	349	-.17	100	60	.22	1.7									09-12-71		R. Dahl
136-78-7 BDB	239					8.3	2100	1310	40	26	7.0	2.8	500	3.3	922	10	76	248	-.82	2800	40	.58	1.2									09-03-71	8106	NDSWC
136-78-14 CDC	310					7.9	1340	844	59	6	2.4	0	333	1.4	728	0	6.4	134	-.20	90	20	.45	.9									08-18-72		M. Marquart
136-78-34 ABC 01	240					7.8	2650	1800	43	38	11	2.6	612	2.7	722	0	15	767	-1.4	80	30	.83	.1									08-18-72		J. Wahl

BURLEIGH COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
137-76-5 DAA	190	9				8.4	2496	1500	60	20	5.6	1.2	610	1.8	1153	42	256	2.7	-1.14	780		0	.9									09-17-63		Schauer
137-76-32 BBB	305	9				7.0	888	534	2.1	276	40	43	76	3.6	356	0	2.0	149	-.28	1530		0	.4									05-21-63		P. H. McCoy
137-77-17 AAA	90	9				7.6	1132	690	7.7	140	31	16	212	9.1	641	0	6.0	72	.57	2240		4.0	1.3									09-17-63		D. Beard
137-77-28 ABC	266	9				8.0	743	478	10	44	8.8	6.1	155	6.0	354	0	8.0	98	-1.51	3550		0	1.1									09-17-63		W. Mills
137-79-6 A	200					8.3		0	9.3	178	7.1	39	28	5**	790	0	0	111.2		210		43.4	.29									01-19-51		J. Claridge
137-80-1 CBB 02	165					8.3			13	22	7.6	Trace	13	7**	502	0	6.8	Trace		220		Trace	.5									01-18-51		J. Swenson
137-80-11 DDA	125					8.1			27	13	3.1	1.4	32	2**	601	0	6.4	187.0		200		26.0	.4									01-19-51		A. Ashbridge
137-80-13 BDA	197					8.3			25	20	6.47	Trace	39	6**	887	0	12.2	131.1		120		Trace	1.4									01-19-51		J. Bobidou
138-75-4 CBA	302	4.4				8.1	2307	1470	24	80	14	11	500	14	720	0	124	420	-.69	960		0	.6									09-17-63		K. Fried
138-76-24 CBB 01	140	10.0				8.3	3806	2331	60	50	9.6	6.1	905	25	1055	15	825	3.7	-.18	1800		0	1.9									09-17-63		G. D. Adams
138-78-15 BCC	190					8.5	2357		60	22			580	22	989	33	18	413		1080												09-17-63		
138-78-27 DAD	280						1969			12					726	42	66	176		1700												-61		I. Funston
138-79-18 CCA 02	180					8.3			15	104	31.6	6.0	34	2**	765	0	54	134		100		2.1	.2									01-19-51		H. Tatley
138-80-4 ACC	390					8.2			72	16	6.4	0	78	2**	1140	0	312.0	389.0		540		Trace	.9									06-11-51		Armours Creamery
138-80-4 ACD	470					8.1			64	40	11	3.2	92	6**	1105	0	815.0	Trace		250		Trace	.25									01-18-51		Yegen Diary
139-77-28 CC 03	300	8.4				8.4	3443		60	40			760	22	1062	18	575	14		1080		2.0	.7									09-17-63		J. Maier
139-80-29 BCB	240					8.8			67	26	7.1	2.2	79	0**	1010	33.6	29.0	770		500		13.0	.4									05-08-51		B. Robertson
139-80-33 BDB	240								27	16	6.4	0.0	79	5**	992	43.2	232.5	510.0		660		0.0	5.5									09-16-49		C. Leonhard
140-75-27 DCC	130	8.4				8.3	2270		25	70			496	0	696	6.0	46	500	-3.90	1520		1.5	.7									09-17-63		J. Kocorrek
140-81-9 BAC	376	12.2				8.4	3004		67	20			690	0	1074	30	416	5.6		1520		0	1.2									09-17-63		C.L. Sanders
142-77-4 DDD	405	10.6				8.6	1250		26	20			274	0	595	29	6.0	72		620		1.0	.8									09-18-63		C. Little
142-81-4 ADC	435					8.1	3180	1870	72	21	4.9	2.2	761	2.1	1140	0	517	1.8	-.40	150		.3	2.3									08- -62	1984	USGS

DUNN COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-94-34 CAD	1380	15.0				8.2	2250	1460	75	12	4.5	.2	599	1.9	1560	0	.3	20	.69	90	40	1.5	2.7									06-01-72		M. Dillinger
141-96-29 CCC	1740					7.7	2470	1610	29	70	22	3.7	550	5.6	897	0	220	260	-1.7	1200	0	2.5	3.2									08-15-73	4529	NDSWC
142-91-25 DBB	1290	16.0				8.4	2310	1360	35	54	7.6	8.5	584	1.7	1350	13	131	17	-.11	0	20	1.0	5.7									08-03-71		A. Schnaidt
144-91-10						8.38	2051	1522		38.7	4.9	9.8	591.9	3.7			315	53.7		186.7	14.3	.61	3.8		800	1.45	13.6					02-02-77		Dodge
144-91-23 DBB	1300	13.0				8.2	2360	1560	85	10	2.7	.8	620	2.4	1580	0	74	8.1	-1.6	9	0		1.8									06-20-73		E. Stuhmiller
145-91-20 AAA 01	1450	10.0				8.1	2380	1480	62	19	4.1	2.2	630	1.9	1570	0	68	18	-.25	480	80	1.0	3.0									02-02-72		O. Flaget
145-92-25 ABB	1555	17.0				8.2	2410	1480	73	12	3.5	.9	590	1.7	1190	0	240	.4		2000	60	1.0	6.8									06-24-74		Halliday
145-92-25 ABB	1555	19.0				8.6	2380	1400	66	14	3.3	1.5	580	1.9	1100	31	240	6.6	-.85	550	0	1.0	6.7									06-26-74		Halliday
145-92-22 DAD 01	1636	13.0				8.0	1870	1170	58	13	2.8	1.5	480	3.1	1060	0	106	12	1.46	1100	50	1.3	4.8									08-23-72		
146-93-3 CDD	1525	15.0				8.2	2130	1450	90	7	2.0	.4	530	1.9	1150	0	180	8.4	-1.7	50	0		3.7									05-24-73		A. Voight
146-94-5 CBD	1410	19.0				8.2	2890	1800	64	24	4.5	3.2	732	2.8	1660	0	206	10	-1.3	0	40	1.0	1.6									05-25-72		R. Hammel
146-94-8 DAD	1404	14.0				8.3	3590	2300	76	27	6.6	2.6	913	3.4	1980	21	274	10	-.84	40	40	1.0	.6									05-25-72		R. Hammel
146-95-3 DCB	1602	15.5				8.2	2100	1360	82	8	2.0	.7	527	1.8	1160	0	154	0	-.41	30	0	1.0	5.9									07-12-72		J. Kupper

DUNN COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
147-94-26 BCB	1502	15.5				8.1	2350	1460	87	9	2.6	.6	596	1.9	1230	0	214	1.7	-.21	0	0	1.0	5.7									11-16-72		K. Knutson
147-94-34 BAD	1510	23.0				8.1	2230	1410	82	9	2.4	.7	560	1.8	1190	0	181	3.7	-.10	100	0	1.0	6.5									11-16-72		K. Knutson
147-95-4 BBA	1348	12.5				8.1	3210	2080	86	18	4.6	1.6	837	3.0	1730	0	323	15	-1.3	580	20	1.0	1.0									07-20-72		M. Kleeman
147-95-12 CAD	1410	18.5				8.1	2900	1790	90	13	3.4	1.0	736	2.6	1560	0	129	100	1.6	530	10	1.0	2.3									07-13-72		T. Sandvick
147-95-13 CCC 02	1935	12.0				8.5	2120	1200	92	6	1.8	.4	522	1.9	1100	26	150	9.5	-.87	250	20	1.0	6.1									07-07-72		NDSPS
147-95-14 AAA	1430	17.0				8.1	2880	1830	80	16	3.2	2.0	745	2.5	1570	0	136	94	2.0	0	10	1.0	2.3									07-13-72		NDSPS
147-95-24 AAC	1580	24.0				8.4	2070	1250	94	6	2.0	.2	519	1.6	1110	14	82	100	-.68	0	20	1.0	5.9									07-13-72		T. Sandvick
147-95-26 BBB 01	1850					8.2	2270	1350	63	15	3.4	1.6	564	1.7	1170	0	189	19	-.12	200	20	.6	4.9									12-08-71		A. Schwalbe
147-97-20 BAB	1425	23.5				8.2	1970	1180	88	6	2.2	.1	494	1.6	1140	0	109	0	-.32	40	0	1.0	5.2									10-11-72		D. Harris
148-95-22 CCA	1430	17.0				8.1	3080	1920	76	20	5.1	1.8	783	2.8	1560	0	292	30	.22	80	60	1.0	2.7									04-20-72		E. Chase
148-95-31 CCA	1350	20.0				8.4	2020	1280	62	12	2.1	1.7	500	1.5	1130	6	124	14	-1.1	220	10	1.0	5.3									07-20-72		G. Tabor
148-95-32 DBD	1365	19.0				8.2	2660	1760	81	14	2.7	1.8	703	2.5	1690	0	139	0	-1.1	100	10	1.0	2.5									07-20-72		G. Tabor
148-96-9 ABD	1460	22.0				8.3	2140	1290	88	7	2.8	0	535	1.9	1200	2	138	11	-.87	0	10	1.0	6.0									10-12-72		E. Jorgenson
148-96-11 BB	1455	16.5				8.0	3060	1840	59	32	4.3	5.2	771	2.2	1690	0	249	6.8	-.93	0	30	1.0	2.2									10-12-72		E. Jorgenson
148-96-15 AAA	1675	21.0				8.0	2310	1340	76	11	3.8	.4	580	1.9	1240	0	192	0	-.45	90	30	1.0	5.7									10-12-72		E. Jorgenson
148-97-9 DBD	1450	22.0				8.4	2180	1310	66	13	2.6	1.6	552	2.3	1150	16	154	3.3	1.3	0	20	1.0	6.3									05-16-73		G. Olson
148-97-17 DAA	1998	17.0				8.3	2380	1420	85	9	2.6	.6	587	2.6	1150	9	231	4.5	.12	0	200	1.0	5.7									05-17-73		O. Thorp
148-97-20 CAD	1693	22.5				8.2	2140	1360	92	7	1.6	.7	556	1.7	1170	0	150	4.1	1.9	60	20	1.0	6.1									04-05-73		C. Danielson
148-97-22 CDC	1401	23.0				8.5	2060	1250	88	6	1.9	.4	512	1.5	1140	21	122	0	-.75	290	10	3.9	5.9									09-10-72		R. Monroe
148-97-30 ADA	1565	25.0				8.3	2030	1230	73	9	2.9	.5	514	2.4	1140	10	119	4.9	.24	0	0	1.0	6.3									05-16-73		G. Olson
148-97-33 ABB	1325	23.0				8.3	1980	1310	95	5	1.6	.3	500	2.2	1150	0	120	5.9	-1.0	90	20	.3	6.0									05-18-73	4478	NDSWC
148-97-33 BCC	1130	19.5				8.0	2890	1860	96	11	3.3	.7	737	2.7	1760	0	148	2.5	-1.0	0	20	1.0	2.5									04-05-73		C. Danielson

HETTINGER AND STARK COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
132-91-28 DDD	1050					8.4	2260	1310	58	17	4.3	1.6	554	2.6	1010	18	242	5.7	.80	300		1.0	3.7									08-30-68	3627	NDSWC
135-97-4 DCA	1360	14.0				8.5	2290	1380	62	16	3.8	1.6	556	2.4	1080	21	191	46	.44	4000		.9	4.4									09-19-68	3628	NDSWC
139-91-11 DCD 02	1800					8.6		1540		19			827		844	56	647	4.7	1.6	4800		0										06- -69		ND Hwy Dept
139-95-1 DDA	1776	22.0				8.2	2420	1440	92	8	2.4	.5	600	1.9	1160	0	246	2.4	.58	150		.4	4.0									12-22-66		ND Hwy Dept

McLEAN COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lap pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
143-80-16 CCB 01	530	12.5				8.1	2370	1420	61	18	4.6	1.6	598	2.3	1170	0	249	4.2	.28	380		0	.6									07-01-68		P. Patrick
143-81-24 CDA	350	10.5				8.2	2480	1540	62	20	4.8	1.9	635	2.4	1220	0	277	3.5	.39	80		1.0	.7									07-03-68		L. Frankland
145-79-20 CCB	605	8.5				8.1	2440	1480	52	23	5.2	2.4	572	2.4	975		348	4.7	-2.6	820		0	3.7									04-18-68		J. Laib
145-79-23 ADA	510	7.5				8.4	1980	1200	51	17	5.6	.7	479	2.1	910	13	195	22	-.24	100		9.6	.6									06-20-68		E. Gessele
145-79-25 BDD	431	7.5				8.2	2060	1330	44	26	7.7	1.7	519	2.2	1040	0	169	66	-.43	660		3.0	.5									04-18-68		A. Wall
146-79-2 CCA 02	585	10.5				7.9	2490	1370	66	15	4.8	.7	587	2.4	954	0	355	9.1	.33			0	4.0									07-25-69		Mercer

McLEAN COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
146-79-6 ACC 01	530	10.0				8.2	2590	1500	60	20	4.4	2.2	613	2.6	1080	0	335	3.2	0	120		.4	.5									06-20-68		R. O'Shea
147-80-28 CBC	445	10.0				8.2	2400	1460	59	19	6.0	1.0	591	2.6	1130	0	268	3.6	-.38	200		1.0	1.2									04-26-68		Turtle Lake
148-85-23 CDC	1240	11.0				8.4	2640	1540	63	20	7.0	.6	648	2.1	1160	9	312	21	.19			1.0	.1									11-04-69		R. E. Weber
148-90-25 BC	1281	15.5				8.5	2500		77	13	3.8	.9	645	2.5	1180	19	252	.5	2.33	70		.1	4.6									11-16-67		L. Holtan
150-81-31 CAC	618	7.5				8.0	2640	1630	59	23	7.6	1.0	656	2.5	1220	0	127	253	.21	220		1.0	2.7									06-06-67		E. Kohler

MERCER AND OLIVER COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
140-85-3 DDD	980					8.3	2630	1660	68	18	4.7	1.6	659	2.4	1260	18	282	3.8	-.27	940			3.7									04-16-68		W. Rusch
141-89-11 BC	1318	8				8.2	2390	1470	83	10	3.6	.2	601	1.9	1280	0	189	3.3	.02	40			3.9									03-21-67		
141-89-20 CB	1340					8.4	2750	1810	87	14	4.4	.7	750	2.4	1880	24	33	3.3	.53	1800		1.8	1.2									03-21-67		
141-90-9 DB	1300	13				8.3	2560	1690	83	14	3.2	1.5	716	2.6	1840	14	29	2.9	-.16			2.5	1.6									06-03-68		S. Jaeger
141-90-19 CCD	1142	16				8.6	2280	1310	82	9	3.2	.2	563	2.6	1160	30	175	1.6	-.36	400		2.5	4.6									07-10-69	3433	NDSWC
142-82-5 DAA 01	501	9				8.5	2450	1510	62	19	4.9	1.7	619	2.3	1350	35	142	8.7	-.26	1100			.9									04-25-69	3647	NDSWC
142-84-24 BBA						8.6	2820	1680	74	16	4.2	1.3	684	2.5	1170	38	343	4.6	-.13	2100			3.2											
142-89-10 AB	1480	11				8.2	2700	1650	88	11	4.0	.2	671	2.1	1220	0	315	.3	-.98	150			3.8									04-18-67		
142-90-25 BA	960	13				8.3	2900	1970	90	15	5.2	.5	806	20	1970	58	54	11	-.28	1600			.6									08-25-64		F. Schmidt
142-90-25 CB	880	14				8.3	2900	1990	91	15	5.2	.5	810	20	1940	65	63	21	-.32	1100			.7									08-25-64		F. Schmidt
142-90-26 ABB	860	14				8.4	2900	1920	86	16	5.6	.5	790	24	1950	50	56	13	-.34	2500			.8									08-25-64		F. Unruh
143-87-25 BB	1380					8.1	3200	1940	79	17	4.8	1.2	750	2.4	1020	0	561	.7	-.72	1400			3.1									03-28-67		
143-89-19 ACC	1280	17				8.4	2320	1430	78	10	2.8	.7	570	24	1180	29	186	5.8	0	2000			6.0									08-24-64		Hauck Bros.
143-90-24 BA	1280	17				8.2	2420	1520	86	10	2.8	.7	626	24	1520	0	108	11	-.21	1700			2.9									08-24-64		Hauck Bros.
143-90-34 CD	880	12				8.4	2870	1860	86	15	3.9	1.3	767	2.6	1950	19	65	4.1	-1.1				.7									06-17-68		R. Backfish
144-85-10 CCA						8.5	2560	1550	77	12	4.4	.2	613	2.2	1100	43	275	2.1	-.55	100			4.4											
144-86-11 DAA						8.5	2650	1510	74	14	4.4	.7	634	2.2	1140	24	308	1.3	-.50	60			2.9											
144-86-17	940					7.40	2621	1696		72.9	5.1	2.9	622	3.7			794	ND		180.6	13.2	<0.1	1.64			20.9	12.7			-12.45		03-14-77		Hoffman
144-87-20 DDD	1144	13				8.6	2420	1520	77	11	3.6	.5	590	34	1070	50	267	3.3	-.11	1300			5.0											
144-89-14 CDD	1281					8.2	2370	1510	75	12	4.0	.5	601	1.9	1160	0	237	4.9	1.12	50		.2	4.9											
144-90-4 BBA	1265	9				8.6	2360	1510	80	11	4.0	.2	614	10	1350	50	121	2.5	-.13	460			2.7									08-25-64		D. Brecht
144-90-15 DB	1325	17				8.4	2310	1290	74	11	2.4	1.2	567	1.9	1120	38	185	2.0	1.8	240			5.2									06-03-68		Golden Valley
144-90-25 BD	1360	14				8.6	2360	1530	78	12	3.6	.7	626	20	1370	55	124	8.2	-.36	1000			3.2									08-27-64		Hauck Bros.
144-90-29 AD	1400	13				8.5	2230	1300	76	10	2.8	.7	556	1.5	1130	27	166	1.8	.62	120		.6	5.4									04-05-67		V. Entze
145-84-6 CCB						8.5	2470	1500	76	12	4.4	.2	602	1.8	1100	22	264	.1	.51	80		.9	5.2									03-31-67		W. Wiedrich
145-85-22 CAC	891	11				8.5	2420	1480	60	18	4.5	1.7	587	2.1	1100	25	234	8.6	.58			1.0	4.8									05-01-69		E. Zieman
145-85-24 DDA	1058					8.2	2570	1550	78	12	4.0	.4	623	2.0	1130	0	305	.7	.46	100		.8	4.4									03-31-67		H. Galster
145-87-4 DDD	1300					7.36	2621	1600		57.5	4.6	2.2	506	3.9			955			266.7	7.9	0.11	3.63				6.8					03-14-77		A. Oberlander
145-87-6 CBB 03	1370					8.3	2360	1450	67	15	4.0	1.2	593	2.4	1200	22	201	2.1	7.65	3400			3.9									05-09-68		E. Boeckel
145-89-25 DBA	1500					8.7	2330	1420		8	2.8	.2	577	2.3	1060	58	206	3.0	-.30			0.4	5.0									04-06-67		A. Mittelstead[illegible]

MERCER AND OLIVER COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
146-86-14 BBA	1320					7.34	2039	1458		46.3	3.3	1.5	540	4.0			832			109.7	8.1	0.14					16.2			-13.27		03-14-77		H. Miller
146-87-8 DDD 02	1205	14				8.6	2340	1450		11	3.4	.6	583	2.1	1140	47	192	1.8	-.16			.1	4.6									03-23-67		H. Hafner
146-87-8 DDD 02	1205	1	8.4	2400		8.67	2262	1476		39.6	1.9	5.5	742	3.3	1243		8.919	1.638	3.1	831	13.5	4.07	3.25		17.5	0.85	15.6					12-15-76		S. Hafner
146-87-10 DBC	1299	10				8.6	2340	1400	72	12	3.3	1.0	571	2.0	1060	33	234	3.8	-.04	60			5.0									06-12-68		M. Hafner
146-90-20 CCC	1574	19				8.4	2260	1230	82	9	2.5	.7	564	1.7	1100	14	214	2.9	-.30	240		2.5	4.9									07-09-69	3575	NDSWC
147-85-20 DBD 03	1440	10				8.7	2690	1610		14	4.6	.6	653	2.3	1010	49	359	.8	.74	1400			4.8									03-31-67		F. Isaak

MORTON COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
133-82-5 ABC	320	9.5				8.3	2300	1360	60	18	5.8	.9	590	2.2	1170	7	100	170	.75	270	30	.23	2.3									06-27-72		N. Schmidt
133-82-15 ACD 02	260	10.0				8.2	2730	1770	60	24	6.6	1.8	670	7.6	1130	0	42	530	-1.54	860	40	.23	1.6									06-28-72		C. Weinberger
133-82-29 CDD 01	280	10.5				8.3	2240	1370	47	26	3.3	4.4	560	2.0	1150	7	74	230	-1.9	90	10	.23	1.6									06-27-72		J. Meyer
133-82-31 DDA	280	10.0				8.2	2150	1320	55	17	4.3	1.6	530	1.9	1100	0	37	240	-1.1	220	10	.23	1.7									06-27-72		J. Meyer
133-82-32 BAD	200	10.0				8.2	2270	1380	60	17	4.9	1.2	570	2.0	1130	0	93	200	-.22	0	0	.23	1.9									06-27-72		J. Meyer
134-81-6 DAB 01	286	8.0				7.9	3180	2180	49	45	12.0	3.6	750	2.4	820	0	12	900	1.7	680	50	.16	1.0									07-18-72		H. Schmidt
134-81-6 DAB 02	360	12.0				8.1	2700	1940	46	41	9.2	4.4	680	2.6	890	0	41	700	.15	< 20	40	.56	1.4									07-18-72		H. Schmidt
134-81-8 DAD 01	365	9.0				7.9	2540	1840	25	110	25	11	600	3.1	800	0	4.1	690	-.61	310	40	.99	1.0									07-18-72		N. Heinrich
134-81-8 DAD 02	375	8.0				7.9	2520	1760	47	32	6.6	3.8	610	1.8	760	0	1.7	750	-1.7	80	30	.56	.6									07-18-72		N. Heinrich
134-81-30 BCD 02	200	10.0				8.2	2490	1670	63	18	5.0	1.3	610	2.5	1100	0	69	320	-.60	< 20	10	.23	3.2									07-13-72		S. Henderson
134-82-1 AAC	289	9.5				8.1	1800	1190	46	20	3.2	2.9	470	1.5	1000	0	44	140	-.92	90	50	.56	30									07-17-72		C. Fleck
134-82-1 ACA	289	10.0				7.7	1420	958	35	20	2.6	3.3	360	1.1	730	0	8.5	160	1.77	400	50	.23	5.5									07-17-72		C. Fleck
134-83-5 CCD 01	277	12.0				8.1	1530	967	68	6	2.2	.1	380	.9	700	0	0	260	-.63	< 20	10	.23	1.0									07-07-72		M. Stegmiller
134-83-5 CCD 02	277	11.0				8.2	1640	1140	79	5	1.8	.1	400	1.1	740	0	4.6	270	-.99	40	0	.23	1.0									07-08-72		M. Stegmiller
134-84-3 AAD	200	11.5				8.3	2020	1360	71	9	2.5	.7	490	1.2	620	10	.6	550	-.25	230	60	.23	2.7									06-28-72		J. Allen
134-84-3 ADC	200	11.0				8.3	2240	1450	50	20	3.5	2.8	520	1.8	961	8	90	250	-1.3	170	10	.16	3.8									09-19-75		J. Allen
134-84-3 CBA	140	10.0				8.4	2090	1390	50	19	3.4	2.6	500	1.1	599	11	4.8	550	-.86	380	10	.02	2.1									09-19-75		Flasher No. 2
134-84-11 DDD	140	10.0				8.4	2100	1380	46	20	3.3	2.9	470	1.1	598	11	5.4	540	-1.63	370	10	.05	2.1									09-19-75	4564	NDSWC
135-79-10 AAB 01	180	9.5				8.6	2900	1730	58	27	7.0	2.3	690	3.2	1110	36	420	4.9	-1.1	40	40	.23	.7									05-19-75	4769	NDSWC
135-79-10 AAB 02	99	8.5				8.4	2670	1750	53	28	7.0	2.6	650	3.0	1100	16	150	310	-.50	100	20	.23	1.4									05-19-75	4769A	NDSWC
135-80-32 DDA	330					7.9	1770	1180	37	26	5.9	2.8	430	1.9	800	0	0	300	-.23	640	50	.32	.4									08-07-72		M. Howiston
135-81-24 DDD	291	10.5				8.4	1760	1160	29	40	7.9	5.0	420	2.3	798	8	9.4	270	-.21	100	10	.63	.6									08-07-75	9328	NDSWC
135-83-32 CBB 01	466	10.0				8.5	3110	2100	66	24	5.7	2.4	750	2.0	1160	28	14	470	4.8	0	40	.23	2.1									05-27-75	4768	NDSWC
135-83-32 CBB 02	370	11.0				8.6	3870	2990	60	50	13	4.3	980	3.2	1140	44	6.4	1150	-.68	1300	60	.23	1.1									05-27-75	4768A	NDSWC
135-84-23 AAB	310	10.0				8.2	2170	1430	63	13	3.9	.9	530	1.4	930	0	17	370	-.15	300	20	.56	5.9									06-14-72		E. Zimmerman
136-79-5 CCC	200	9.5				8.3	2990	1820	58	29	6.9	2.9	720	3.1	1210	6	340	140	-.84	130	20	.23	1.0									05-19-75	4770	NDSWC
136-79-7 BAD 01	217	9.5				8.0	2070	1330	58	13	3.7	1.0	490	1.5	630	0	3.9	550	-.62	370	20	.56	.8									08-17-72		M. Graner
136-81-7 DDC 01	457	10.0				8.6	1620	1070	40	19	2.0	3.4	400	1.3	377	29	7.0	130	27.8	190	20	.23	2.3									06-02-75	4771	NDSWC
136-81-7 DDC 02	369	9.5				8.5	2230	1380	63	15	3.9	1.3	560	1.9	1070	25	130	110	-.80	150	20	.23	2.7									06-23-75	4771A	NDSWC

MORTON COUNTY

Location	Depth (ft)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
136-81-16 CDD	500	9.5				7.6	1350	893	5.8	270	70	23	220	4.0	490	0	9.1	310	38.1	190	100	.23	.7									10-02-73	4593	NDSWC
136-82-7 CCC 01	517	13.0				8.4	2840	1740	55	30	5.0	4.3	690	2.3	1200	12	380	.4	-.24	460	10	.95	2.3									08-07-75	9305	NDSWC
136-82-7 CCC 02	249	11.0				8.4	2130	1320	40	33	3.4	6.0	530	1.8	1160	12	140	23	-.01	290	0	.72	1.4									08-05-75	9305A	NDSWC
136-82-8 AAB	300	9.0				7.8	2560	1550	56	26	7.9	1.6	660	2.5	1380	0	210	25	-.39	420	30	.00	.4									05-30-72		W. Miska
136-82-22 BBC	300	5.0				8.0	1980	1290	68	10	3.5	.4	500	1.5	1060	0	61	130	-.43	400	0	.56	1.7									05-30-72		E. Morrell
136-83-1 CCC	214	9.5				8.4	2170	1310	52	21	5.3	1.9	550	1.9	1120	20	110	89	-.85	190	60	.23	1.6									10-17-73	4586	NDSWC
136-84-21 BDC	400					7.9	2350	1480	74	12	4.7	.1	590	1.6	1150	0	120	150	2.69	140	10	.23	2.9									06-08-72		G. Pietan
137-80-7 CAD	275	9.0				8.2	2490	1640	63	18	4.4	1.7	610	2.0	1010	0	87	380	.06	<20	0	.07	1.9									08-17-72		L. Bayer
137-81-24 ADB	290	9.0				8.0	2310	1520	65	15	5.8	.1	580	1.8	1170	0	23	300	-.97	200	20	.47	1.2									05-22-72		M. Hille
137-81-25 CAB	305	12.0				7.8	2500	1740	38	49	7.2	7.5	610	1.7	870	0	.4	690	-2.1	90	20	.34	.4									05-22-72		M. Hille
137-81-28 CBC 02	486	4.0				7.5	1220	812	7.9	160	39	15	230	2.7	520	0	0	230	-.49	2000	110	.23	.5									05-22-72		W. Graner
137-83-6 CDD 01	589	12.0					3800	1880	79	17	4.8	1.1	740	2.7	1200		490	6.6	-1.6	100	10		3.2									05-28-75	4763	NDSWC
137-83-6 CDD 02	435	11.5					3400	1820	72	19	5.8	1.1	720	2.6	1210		440	6.4	-.91	310	10		3.5									05-28-75	4763A	NDSWC
137-83-6 CDD 03	284	10.5					2500	1380	75	11	3.1	.8	570	2.0	1210		160	23	-.58	150	0		4.0									05-28-75	4763B	NDSWC
137-86-3 AAD 01	734	10.5				8.8	2600	1670	94	11	3.1	.8	720	2.2	1210	34	330	4.7	2.1	40	10		4.5									11-27-74	4752	NDSWC
137-86-3 ADD 02	672	10.5				8.5	2400	1530	94	10	2.7	.7	670	1.9	1270	37	220	3.7	1.8	60	20		5.2									11-27-74	4752A	NDSWC
138-80-6 BCA 02	360	12.0				8.2	2750	1580	65	20	5.3	1.7	670	2.0	1150	0	360	7.8	-.73	100	0	.23	1.7									08-10-73		G. Borden
138-81-1 CBD	150	10.0				7.7	1350	881	11	130	31	13	280	4.8	620	0	16	210	-.20	210	20	.14	1.0									08-09-73		A. Nelson
138-81-1 CCA	149	12.0				7.6	1230	818	3.2	370	87	37	140	6.6	550	0	29	200	-1.27	250	580	.05	.4									08-09-73		Stewart Dairy
138-81-9 ABB 01	537	9.0				8.4	3800	2270	83	23	6.5	1.5	900	3.1	1120	25	730	4.7	-.39	100	20		.6									12-16-74	4750	NDSWC
138-81-9 ABB 02	348	7.5				8.6	2300	1450	76	11	3.2	.8	590	2.4	1270		200	3.3	-.91	50	10		3.1									01-02-75	4750A	NDSWC
138-81-15 DDC	430	12.0				8.5	1710	1100	16	130	13	24	420	2.4	820	25	18	190	5.57	170	0	.61	3.4									08-08-73		R. Dugan
138-81-17 DDA	432	10.0				8.3	2170	1410	62	15	4.4	1.0	550	3.5	1220	9	140	3.7	-.21	230	10	.56	2.7									08-08-73		J. Taghon
138-81-20 BAA	365	11.0				8.4	2050	1310	58	15	4.1	1.2	520	3.2	1180	12	63	79	-.35	140	0	.32	3.4									08-08-73		E. Kalvoda
138-81-30 ABB	34	8.0				7.8	726	454	.6	330	77	33	26	4.1	330	0	13	76	2.77	60	80	9.3	.2									08-08-73		G. Taylor
138-82-4 BDD 01	183	13.0				8.2	2800	1680	33	78	20	6.8	670	10	1160	0	390	.8	1.52	40	0	.23	3.0									08-06-73		C. Hendrickson
138-82-5 BCA	198	14.0				8.2	2830	1720	71	18	5.0	1.3	690	7.2	1230	0	360	3.3	.28	60	0	.23	3.6									08-06-73		C. Carlson
138-82-5 DBC	200	10.0				8.1	2860	1740	39	61	4.7	12	700	5.8	1230	0	380	1.6	1.45	190	10	.23	3.4									08-02-73		O. Larson
138-82-8 DDD	210	9.0				8.2	2920	1740	58	27	7.4	2.1	700	5.0	1250	0	390	4.5	-.73	560	20	.23	3.4									08-02-73		E. Ellison
138-83-14 ABB	175	9.5				8.3	2850	1740	76	15	3.7	1.5	690	4.2	1270	11	350	13	-1.46	80	0	.23	3.2									07-16-73		M. Nelson
138-83-20 ACC	180	8.5				8.4	2680	1620	77	14	3.0	1.6	660	3.2	1300	19	260	15	-.87	110	20	.23	3.1									07-16-73		
138-83-22 ABA	285	10.0				8.3	2900	1680	81	14	4.2	.9	700	3.5	1190	6	380	17	-.08	570	10	.23	2.9									07-18-73		D. Inglais
138-83-22 BDB	185	10.0				8.3	3100	1830	82	15	4.3	1.1	740	4.0	1230	9	420	18	-.14	0	10	.23	3.0									07-18-73		D. Inglais
139-81-4 BDA 02	680	10.5				8.0	3160	2060	73	22	6.3	1.5	790	3.0	1300	0	520	6.9	-1.76	100	0		1.0									04-25-73		Developers, Inc.
139-81-9 AAA 01	264	10.0				8.1	3250	2060	75	24	6.2	2.1	850	3.0	1300	0	560	3.6	-.52	240	10		.9									12-20-74	4766	NDSWC
139-81-9 AAA 02	412	7.0				8.9	3100	1980	64	30	8.8	1.9	800	2.8	1150	60	500	5.8	.64	50	0		.9									12-20-74	4766A	NDSWC
139-81-9 AAA 03	269	8.0				8.5	2800	1710	65	21	5.1	2.0	680	2.4	1070	31	410	9.9	-.40	110	20		.7									12-20-74	4766B	NDSWC
139-81-16 BCC	40	12.5				8.1	3350	2040	124	8	1.0	1.3	800	2.2	1310	0	500	.8	-.85	100	10	.23	1.3									09-02-75		K. Forsberg

MORTON COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
139-81-16 CCB	860	13.0				7.9	3350	2070	47	52	7.6	8.0	780	2.8	1290	0	500	9.9	-.60	40	0	.23	1.3									09-02-75		Roughrider Est.
139-81-16 CDB	520	42.0				8.1	2730	1560	60	22	5.4	2.1	650	2.3	1200	0	350	13	-1.8	< 20	20	.23	2.3									08-31-72		J. Hepfauf
139-81-30 DDA	270	13.0				8.2	2520	1540	64	17	4.1	1.7	610	3.0	1200	0	260	7.4	-.37	120	10	.23	2.5									08-10-73		S. Markel
139-82-8 BCC	860					8.6	2800	1740	52	31	4.9	4.6	670	1.8	1190	41	310	18	-.28	7400	90	.07	1.9									01-21-72		L. Boehm
139-82-15 ADA	760	12.0				8.2	3070	1840	46	51	5.9	8.9	760	6.9	1290	0	420	1.2	1.86	390	0	.23	2.5									08-06-73		Skelly Truck Stop
139-82-23 DCB	240	10.0				8.3	3020	1800	58	30	8.2	2.3	730	7.0	1190	9	450	1.2	-.49	230	40	.23	1.3									08-06-73		W. Siegel
139-82-24 CCA	400	13.0				8.1	3200	1890	69	24	5.8	2.2	770	7.9	1280	0	470	1.6	-.16	140	0	.23	1.8									08-06-73		M. Koffler
139-83-12 DBA 01	789	10.0				9.0	2800		86	15	3.9	1.1	750	2.3	1220	45	370	4.4	1.5	60	20		3.0									12-09-74	4751	NDSWC
139-83-12 DBA 02	558	10.0				8.4	2600	1680	84	14	3.7	1.1	720	2.2	1220	45	330	4.3	1.2	50	20		2.4									12-09-74	4751A	NDSWC
139-85-30 AAB 01	962	9.0				8.7	2550	1960	85	26	6.6	2.3	800	4.8	1090	40	590	4.9	-.69	1900	160	.23	2.7									06-11-74	4651	NDSWC
139-88-34 BCC 01	1062	10.0					2400	1760	81	16	4.4	1.1	730	2.7	885	186	390	6.5	.62	20	5		3.6									06-17-75	4753	NDSWC
139-88-34 BCC 02	860	9.0				8.7	2550	1560	85	11	3.0	.8	640	1.2	1110	82	240	4.3	-.55	190	0		4.5									11-06-74	4753A	NDSWC
139-90-12 DAA	1165	10.5				8.2	3160	2450	65	28	5.5	3.4	790	4.0	973	0	5.2	1000	-2.66	140	30		1.8									04-25-73		W. Hoenauf
140-81-29 ACC	390	11.0				8.3	2780	1600	68	18	5.0	1.3	660	1.9	1190	7	350	3.7	-.95	60	0	.23	.9									08-09-73		M. Geiser
140-85-3 DDD	980					8.3	2630	1660	68	18	4.7	1.6	640	2.4	1260	18	280	3.8	-1.69	940			3.7									04-16-68		W. Rusch
140-90-17 ACB	1500	10.5				8.1	2680	1710	77	17	3.9	1.8	730	2.3	1870	0	31	8.6	.86	90	10	.45	1.5									05-15-72		N. Underdahl
140-90-20 DBA 01	1200	12.0				8.0	2800	1950	74	20	5.8	1.3	760	2.3	2020	0	38	8.6	-1.2	< 20	70	.23	.6									05-16-72		A. Rehm

GOLDEN VALLEY, SLOPE, AND BILLINGS COUNTIES

Location	Depth (Ft.)	Field Temp °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
133-99-2 CBB	1404	13.0				8.7	1920	1230	60	12	2.4	1.5	480	1.0	891	32	80	150	.17	750	10	1.6	4.0									06-26-75		F. Pierce
133-99-32 BBA	1252					8.7	1830	1160	48	16	2.3	2.6	450	1.2	830	30	64	180	-.37	410	40	2.6	3.2									08-28-74		F. Dilse
133-105-30 CCC	215	14.0				8.7	2570	1720	56	22	5.9	1.8	610	1.5	700	28	9.8	720	-1.3	240	0	.6	.3									07-23-74		Marmarth
133-106-34 BAA		8.5				8.8	1950	1290	70	9	2.8	.4	470	1.5	728	14	5.5	420	-1.5	70	10		.3									10-09-75	4809	NDSWC
134-104-24 DDD	1255	20.0				8.8	1800	1070	40	19	3.1	2.8	400	2.5	653	45	110	150	-1.5	250	10		1.0									10-02-75	4810	NDSWC
134-105-5 AAA	98	14.0				8.6	1690	1080	42	16	2.6	2.3	390	1.4	616	24	12	320	-1.6	0	40	1.0	.8									07-16-75		E. Clark
134-105-9 BAA	463	12.5				8.8	1420	887	38	14	1.9	2.3	330	.8	527	28	23	230	-.94	270	20	2.5	.7									07-16-75		USFS
134-105-26 BAA	530	14.0				8.8	1480	952	59	7	1.8	.6	360	1.5	623	33	9.0	220	-.84	210	10	2.0	.6									07-08-75		A. Henke
135-102-19 DAA	1080	20.0				8.7	1910	1140	57	12	2.1	1.7	460	3.6	822	35	170	56	-.90	350	0	1.0	3.8									07-08-75		H. T. Enterprises
135-104-19 CDD	740	14.0				8.6	1550	964	43	13	2.1	2.0	360	1.2	630	22	14	200	1.2	250	10	2.0	2.3									07-16-75		G. Strom
136-102-11 DAC	1120	17.8				8.4			126	2	.8	0	410	1.6	710	41	25	220	-1.2				2.3									07-02-69		R. Hanson
136-102-15 ACC	1091	15.5				8.6	1760	1060	60	9	2.1	1.0	420	1.3	730	30	88	140	.30	130	20	2.1	3.6									08-21-74		USFS
136-102-20 BBD	1120	18.0				8.6			89	4	.8	.5	410	1.6	700	31	28	220	.84				2.1									07-28-69		R. Hanson
136-102-21 DBD	1100	17.0				8.6			72	6	1.2	.7	400	1.6	730	34	22	220	-2.1				2.8									07-03-69		R. Hanson
136-103-14 ADA	840	15.5				8.5			89	4	.8	.5	410	1.7	720	41	18	220	-1.1				2.5									07-03-69		K. Hafele
136-103-23 ADB	850	14.7				8.5			71	6	1.6	.5	400	1.4	690	46	21	220	-1.2				2.2									07-03-69		V. Jacobson
136-103-24 ABD	840	17.2				8.4			86	4	.8	.5	400	1.6	730	34	22	220	-2.2				2.5									07-03-69		K. Hafele
136-104-12 BAA	987	18.0				8.8	1670	1020	45	14	2.4	2.0	390	3.5	593	32	25	300	-.97	80	10	1.0	1.8									07-23-75		E. Wojohn
137-101-29 CCA	865	17.5				8.5			73	6	1.6	.5	410	1.8	850	41	19	110	-.47				3.3									07-02-69		M. Gerbig

GOLDEN VALLEY, SLOPE, AND BILLINGS COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
137-101-30 ABC	925	18.0				8.9	1610	1010	73	5	1.5	.4	390	1.2	710	37	27	180	-.38	120	20	1.0	3.8									08-13-74		M. Gerbig
137-101-30 BBC	807	16.0				8.5			123	2	.8	0	400	1.8	860	32	15	110	-1.2				3.1									06-24-69		M. Gerbig
137-102-6 CBC	940	18.5				8.7			69	7	.8	1.2	420	1.8	750	31	7.5	240	-.54				3.9									06-20-69		C. Drybread
137-103-12 BAB	950	20.0				8.8			65	7	.4	1.5	400	1.7	620	36	31	280	-1.4				2.0									06-20-69		A. Wosepka
137-105-10 ABB	940	17.0				8.6	2020	1220	50	19	5.9	1.1	500	1.4	770	21	18	370	1.2	210	0	1.0	1.8									09-19-74		M. Bosserman
138-102-20 ADA	777	15.0				8.6		992	67	8	1.6	1.0	440	2.3	1080	32	1.8	41	-.95				3.9									06-24-69		USFS
138-102-34 DDA	988	18.0				8.9	1600	1100	79	3	1.2	.5	410	.9	650	42	28	210	1.8	100	20	1.0	3.0									08-13-74		R. Paasch
138-106-25 DDA	967	17.0				8.7	1780		57	5	1.5	1.6	420	.9	717	24	21	280	-1.3	80	20	2.5	2.1									03-05-75		Golva
139-102-2 DCA	1100	19.5				8.7		1060	83	10	.8	.7	420	1.6	730	40	39	220	-1.5	-			2.5									06-23-69		L. Hellickson
139-102-14 DBD	1096	29.0				8.8		1100	103	5	1.2	0	410	1.8	733	32	41	207	-1.9				2.6									06-23-69		USFS
139-102-17 CAC	1125	17.0				9.0	1720	1100	64	8	2.0	.7	410	1.1	660	39	32	250	-.58	1100	40	1.0	3.6									08-14-74		A. Burkhardt
139-105-11 BBC	1200	14.0				8.6	1840	1150	57	11	3.0	.9	440	1.3	760	27	24	270	-.85	340	0	3.5	3.6									09-19-74		D. Ueckert
140-100-28 CAB	1770	12.0				8.7	1670	1090	49	13	1.6	2.2	410	2.3	794	31	34	160	-.38	230	0	.4	4.6									07-10-75		J. Redmond
140-101-35 DAD	1870	28.0				8.7	1590	1050	79	5	1.5	.4	420	1.5	746	42	67	120	1.2	90	10		3.1									07-25-73		USDI
140-102-18 DCC	1200	14.0				8.6	1490	1110	51	13	2.6	1.6	420	1.2	670	26	44	260	.32	100	10	3.8	4.2									09-20-74		USFS
140-102-22 DCD	1045	21.0					1750	1070	75	6	1.6	.4	410	1.5	738		51	220	-.42	60	0		2.6									08-06-75		D. Backman
140-102-26 ACC	1190								61	10	4.0	.0	440	0	740	50	38	215	-.26				0									09-18-67		Medora
140-102-26 BBB	1040	20.0				8.6	1670	1130	62	8	2.7	.4	410	1.3	677	32	41	220	0.0	0	0		3.0									06-13-73		USDI
140-102-26 BCA	1080	22.0				8.8	1680	1060	59	9	2.9	.5	410	.9	730	33	37	190	-.28	140	20	1.0	4.6									07-18-74		Medora
140-102-27 ACB 01	1120	20.5				8.8			85	5	1.2	.5	440	1.9	780	53	42	170	-.13				3.3									08-01-69		NDSHS
140-102-34 AAD	1100	20.0				8.8			101	3	1.2	0	400	1.7	710	38	31	240	-3.5				2.8									06-23-69		M. Hellickson
140-103-2 CDC	1455	13.0				8.6	1830	1170	49	15	2.1	2.4	440	1.2	710	30	65	220	1.1	230	20	1.9	4.8									09-20-74		R. Meyers
140-104-12 ADB	1350	13.5				8.6	1810	1100	66	8	1.6	1.0	430	1.7	666	23	38	300	-.18	130	10	2.5	3.6									03-06-75		NDSHD
140-104-15 BBD	1400	13.0				8.6	1820	1160	70	7	2.0	.5	430	2.3	674	22	38	310	-1.1	100	10	2.5	3.0									03-05-75		NDSHD
140-105-14 ABA	1553	22.0				8.8	1890	1280	56	12	4.0	.5	450	1.8	708	35	37	320	-1.5	330	0	1.0	2.9									07-01-75		Home on Range
140-106-25 CBB 01	1259	21.5				8.5	2170	1430	59	15	3.6	1.5	530	1.3	790	18	23	430	.60	80	20	.5	1.9									08-07-74		Beach
141-101-2 AAC	1300	8.5				8.0			12	710	170	69	740	15	680	0	6.5	1800	-2.1				1.0									08-30-69		D. Meschke
141-101-21 BCB	1280	11.0				8.4			66	8	2.4	.5	430	0	760	42	33	200	-.32				0									09-20-67		Dakota
141-101-21 CAC	1200	18.0				8.6			81	5	1.6	.2	410	2.0	740	42	42	190	-2.0				3.4									08-31-68		R. Mosser
142-101-33 DBA	1333	19.0				8.6			200	1	.4	0	460	1.9	820	41	35	190	-.70				3.4									08-30-69		USFS
143-102-1 BBD	1250	19.5				8.4			122	3	.8	.2	470	1.8	870	29	48	140	2.3				4.4									10-05-68		J. Connell
143-102-29 AAD	1200	16.5				8.6			38	27	2.4	5.0	450	1.8	750	42	44	250	.20				3.7									08-30-68		USFS
144-99-14 ABB	2106	5.0				8.5	1730	1050	65	8	1.8	.9	430	1.3	969	22	84	7	-.76	270	10	2.1	6.8									03-05-75		
144-100-24 BBD 01	2160	20.5				8.6	1720	1070	81	6	1.8	.2	430	1.7	928	39	77	29	-1.13	500	10		4.1									10-06-75	4814	NDSWC
144-101-15 BCC	1540	11.0				8.7	1740	1070	47	16	1.9	2.8	440	1.6	940	33		3.3	8.0	340	20		7.4									12-19-74		W. Northrup
144-102-27 DCC	1280	19.5				8.4			102	4	1.6	0	470	2.0	890	34	56	160	-.17				4.7									10-05-68		L. Connell
144-102-29 BBA	1200	18.5				8.3			96	4	1.6	0	440	2.0	810	34	49	170	-.18				4.1									08-30-68		J. Teacher

APPENDIX C-III

GROUNDWATER CHEMICAL DATA--

COLEHARBOR FORMATION

(DATA ARRANGED BY COUNTY)

DUNN COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-91-22 DDD	116	9.0				8.2	1650	1090	12	170	42	16	360	5.8	880	0	2.0	210	1.00	530	20	1.0	.8									07-02-74	4695	NDSWC
141-91-26 BCB	81	8.0				7.7	3130	2490	6.3	980	240	92	450	9.1	840	0	3.6	1200	.63	3600	100	1.0	.7									07-01-74	4694	NDSWC
141-91-30 DAD	183	9.0				8.3	3570	2550	43	87	22	7.8	920	4.6	1490	11	9.1	830	-.65	370	60	1.0	2.7									06-26-74	4693	NDSWC
141-92-7 BBA	84	7.0				8.0	3040	2280	10	590	136	61	569	9.2	873	0	2.3	1090	-.01	0	40	2.5	.6									11-23-71	8266	NDSWC
141-92-20 DBD 01	38	9.0				7.9	2330	1620	11	340	82	32	444	6.0	818	0	17	599	-.34	2500	40	2.5	1.2									07-29-71		E. Zimmerman
141-92-28 AAA	51	9.0				8.2	2840	2050	18	240	58	23	630	6.1	1080	0	4.8	740	-.01	3500	140	1.0	1.2									06-26-74	4692	NDSWC
141-93-4 CBB 01	144	8.5				7.9	5900	5030	15	1100	260	120	1200	16	878	0		3000	-.92	5500	230	1.0	.7									12-15-73	4611	NDSWC
141-93-11 BCC	65	7.0				8.1	3220	2320	18	260	66	23	700	9.3	985	0	5.7	960	-.58	380	1000	1.0	.8									12-15-73	4614	NDSWC
141-93-19 DDD	85	7.0				8.1	4040	3080	22	320	75	32	920	14	1150	0	9.0	1400	-.02	500	50	1.3	.8									12-14-73	4609	NDSWC
141-93-20 DCD	55	5.5				8.1	5230	4200	17	800	140	110	1100	7.4	1100	0	6.8	2300	-1.56	400	320	1.0	.7									12-14-73	4610	NDSWC
141-93-22 DCD	112	9.5					1030	688	4.2	240	63	20	150	4.2	475	0	.9	160	1.24	470	40	1.0	1.2									06-10-74	4663	NDSWC
141-93-30 ABA	39	6.7				8.1	1340	880	10	130	31	13	270	4.1	586	0	3.2	240	-.79	3100	160	1.0	.8									12-14-73	4608	NDSWC
141-94-4 BAA	161	9.0					3560	2610	20	290	68	29	780	7.8	1020	0	4.2	1100	-.21	310	20	1.0	1.5									06-12-74	4668	NDSWC
141-94-15 ABB	124	8.5				8.2	2860	2020	19	200	44	22	630	9.4	873	0	4.4	870	-1.39	4700	20	1.0	1.0									12-06-73	4607	NDSWC
141-94-16 AAA	51	8.5				7.9	908	556	3.9	210	36	29	128	6.3	450	0	0	131	-.90	0	200	1.0	.4									09-15-72	4472	NDSWC
141-94-17 BAB	49	7.0				8.0	717	421	1.3	290	61	33	50	5.0	343	0	8.0	110	-.56	230	720	1.0	.5									12-06-73	4606	NDSWC
141-94-20 CCB	70	10.0				7.9	1310	842	4.7	330	53	47	196	6.9	582	0	1.7	254	1.13	730	30	2.0	.5									07-28-71		J. Wanner
141-94-34 AAD	140	8.0				8.0	3010	2100	12	430	93	48	570	5.8	864	0	2.8	960	-1.15	3300	60	1.0	.7									06-12-74	4666	NDSWC
141-94-35 BBC	182	8.0				8.2	3490	2490	18	330	72	36	768	7.0	892	0	1.9	1260	-.94	580	60	1.0	.6									11-24-71	8276	NDSWC
142-91-8 DDA	31	7.0				8.2	1300	843	6.4	220	52	22	219	5.0	549	0	.6	224	1.37	5800	270	1.0	1.0									11-16-71	8256	NDSWC
142-91-14 BBB	51	8.0				8.2	2500	1750	12	330	70	38	500	5.8	670	0	7.0	820	-.48	80	320	1.0	.8									06-02-74	4698	NDSWC
142-91-15 AAD	131	8.5				8.3	2590	1730	32	84	21	7.7	670	4.0	1700	15	10	120	-.35	1200	20	1.0	1.5									06-26-74	4700	NDSWC
142-91-15 CCC	143	7.5				8.3	2490	1610	24	130	31	12	610	4.1	1740	13	8.0	41	-1.45	1000	10	1.0	1.1									11-16-71	8258	NDSWC
142-91-17 AAD	32	7.5				7.9	832	502	2.5	260	53	30	91	4.3	435	0	1.9	78	1.55	0	210	1.0	.5									11-15-71	8254	NDSWC
142-91-17 ADA	25					7.9	1020	623	3.5	290	57	35	138	12	456	0	4.0	195	1.65	0	10	1.0	.4									11-16-71	8257	NDSWC
142-91-33 DCC	81	8.0				8.2	2110	1420	12	260	63	25	440	5.7	1020	0	4.4	370	-.10	1800	40	1.0	1.1									06-27-74	4697	NDSWC
142-92-10 BCC 02	28	7.5				8.0	2710	1810	22	160	26	24	641	6.0	1370	0	23	436	-1.39	0	10	2.0	.5									11-12-71	8253 A	NDSWC
142-93-18 BBB	86	12.5				7.8	3760	3710	2.7	2100	570	160	280	8.7	650	0	4.8	2100	-.47	160	3700	1.0	.4									06-25-74	4690	NDSWC
142-93-28 BBA	94	7.5				7.8	3860	3020	10	870	200	90	710	10	1110	0	10	1400	-.94	850	610	1.0	.8									12-17-73	4620	NDSWC
142-94-9 CDC	94	8.0				8.2	3550	2630	16	440	88	54	750	10	1220	0	4.8	1100	-1.56	160	40	1.0	.6									06-19-74	4689	NDSWC
142-94-9 CDD	163	10.0				8.1	4260	3180	20	410	79	52	950	9.3	1350	0	4.5	1400	-1.60	100	700	1.0	1.1									06-18-74	4688	NDSWC
142-94-35 CCC	68	7.5				8.2	3520	2570	17	390	82	46	768	6.3	1120	0	2.5	1090	.39	0	90	6.7	.6									11-23-71	8273	NDSWC
142-97-24 CCB	60	8.5				7.6	4910	4360	2.0	2600	355	419	235	89	902	0	315	1530	6.05	0	50	681	.5									06-13-72		E. Kukla
142-97-25 CDB	18	13.0				7.9	7840	8170	5.3	4400	628	690	804	5.8	500	0	34	5520	-.35	0	360	117	.4									06-13-72		C. Kadrmas
143-91-8 DCD	60	11.0				7.8	883	557	.7	410	90	45	31	6.8	314	0	19	192	-.10	520	290	2.5	1.0									08-19-71		B. Duttenhefer
143-91-18 BAD	104	8.5				8.4	795	511	7.0	84	14	12	147	7.9	276	7	0	174	-.36	230	30	2.6	.5									06-23-72		J. Schweitzer
143-91-19 AAA 02	66	8.0				8.3	1680	1160	7.1	320	59	42	290	10	620	7	8.3	430	-.77	160	240	1.0	.7									07-18-74	4602 A	NDSWC
143-92-7 DDD	25	7.0				7.7	480	272	.1	260	71	19	4.9	1.8	289	0	1.3	33	-1.02	0	10	1.0	.1									11-03-71	8226	NDSWC

DUNN COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	B_3 µg/L	Date	Well No.	Owner
143-92-8 CCC 02	50	9.5				7.8	557	322	.5	250	72	17	17	3.7	275	0	11	53	-.85	290	450	1.0	.2									06-16-72		P. Paulson
143-92-16 BBA	51	10.0				8.3	1000	681	3.4	280	72	24	130	3.4	380	4	2.9	220	1.25	350	200	1.0	1.1									07-03-74	4716	NDSWC
143-93-9 AAD	152	15.0				8.4	2020	1420	9.6	310	72	32	390	6.0	860	12	6.8	430	-.64	20	200	1.0	1.2									07-18-74	4719	NDSWC
143-93-14 AAD	127	7.0				7.9	1250	789	4.7	310	64	36	190	12	606	0	1.8	213	1.06	200	70	1.0	.3									11-04-71	8228	NDSWC
143-93-14 AAD 02	20					8.3	4050			476	96	57	876	14	1384	0	13	1488	-5.9	300												11-10-75	DC 39-2	UND-EES
143-93-18 ACB	40	10.0				8.1	987	622	4.2	230	64	18	146	3.4	445	0	1.3	183	-.13	4500	140	1.0	1.0									08-18-71		S. Stromme
143-94-8 CCC 02	78					8.09	1120	856		60.8					455		5.6	379.9		180.7	39				10.7	1.8	20.4					11-23-76		L. Steckler
143-94-12 DAD	12					7.8	5790			1996	249	234	920	20	864	0	33	2742*	*													08-19-75		E. Huenke
143-94-17 BBA	102	7.5				7.9	2540	1870	11	390	85	44	480	6.7	709	0	5.0	815	-.31	0	30	2.5	.9									10-20-71	8197	NDSWC
143-94-19 DCD 02	69	7.5				8.0	2180	1500	18	140	28	17	488	7.7	880	0	8.1	491	-1.3	70	30	1.0	.9									10-20-71	8199	NDSWC
143-94-20 DCC	104	8.5				8.1	3710	2690	28	190	44	19	890	7.3	1250	0	4.0	1100	-.97	350	30	1.0	1.0									06-19-74	4683	NDSWC
143-94-21 CCA 02	18	8.5				7.8	2870	2100	10	510	109	58	534	6.1	808	0	6.8	1020	-1.57	0	10	3.4	.8									09-24-71		M. Koller
143-94-28 BBB	26	8.0				8.2	2340	1660	18	170	36	19	530	6.0	880	0	6.4	570	-.17	470	480	1.0	1.2									06-26-74	4684	NDSWC
143-94-31 ADA	124	7.5				7.9	2470	1760	13	270	63	28	506	7.0	741	0	6.7	742	-.27	100	40	1.0	.7									10-21-71	8200	NDSWC
143-94-32 CCC	144	8.0				7.9	2970	2160	17	270	57	32	638	7.8	867	0	12	897	-.29	220	30	1.0	.5									10-21-71	8201	NDSWC
143-95-33 AAD	30	10.0				8.2	4050	3020	22	320	58	43	900	7.6	978	0	3.6	1500	-1.71	60	450	1.0	1.0									06-18-74	4681	NDSWC
143-97-20 DCD	20					7.5	571	337	2.5	140	28	18	69	7.1	252	0	0	104	-1.94	100	520	4.2	.3									06-13-72		S. Steffan
144-91-10 CCA 01	48	11.0				7.9	2390	1720	8.3	460	116	41	410	6.8	724	0	5.6	758	-1.18	0	210	10	.5									08-05-71		E. Ziman
144-91-10 CAA 02	33	9.5				8.1	1100	741	2.2	380	82	43	97	3.5	360	0	18	226	-1.74	0	50	62	.6									08-05-71		R. L. Pederson
144-91-10 CCB	58					7.7	1360	937	2.8	480	133	36	140	6.6	563	0	15	290	.54	100	0	16	.5									08-13-73		S. Sitter
144-91-11 BCA 01	74	10.0				8.1	2650	1740	43	40	6.5	5.8	632	4.5	1230	0	.6	423	-1.01	880	30	1.7	.4									07-17-72		J. Lorenz
144-92-31 DCD	216	8.0				8.2	1220	779	9.6	130	27	15	250	6.0	612	0	2.9	170	-.18	620	160	.2	1.1									12-19-73	4623	NDSWC
144-92-31 DDC	89	7.0				8.2	1460	985	6.6	270	66	26	250	9.3	707	0	2.8	240	-.39	1100	240	1.0	1.1									12-19-73	4622	NDSWC
144-93-8 CBB 01	177					7.6	2256			320	106	14	416	15	705	0	2.5	620	.1			1.3										11-05-75	DC 36-1	UND-EES
144-93-8 CBB 02	50					7.7	1051			252	83	11	192	6.8	508	0	0	230	1.7			.1										11-05-75	DC 36-2	UND-EES
144-93-17 ADD	121	8.5				8.2	2480	1760	16	210	51	20	540	5.7	870	0	3.2	670	-.84	140	640	1.0	1.0									07-19-74	4723	NDSWC
144-93-17 DAA	173	8.0				8.2	2640	1900	13	310	66	35	530	6.1	793	0	4.7	808	3.90	0	110	1.0	.8									10-22-71	8194	NDSWC
144-93-26 BCC	48	18.0				8.2	2130	1480	13	210	36	29	440	6.5	770	0	5.9	540	-8.12	980	60	1.0	.7									07-19-74	4713	NDSWC
144-93-29 ADD	180	9.5				8.1	2050	1420	11	240	56	24	400	5.9	750	0	2.5	510	-1.48	100	200	1.3	2.5									08-06-74	4721	NDSWC
144-93-32 CDD 02	177					8.2	1871			236	56	24	744	11	781	0	2.0	436	26.05			.7										11-20-75	DC 56-2	UND-EES
144-93-32 CDD 03	28					7.9	2594			1600	481	97	276	18	503	0	3.0	2060	-7.1			.2										11-20-75	DC 56-3	UND-EES
144-94-1 BCA 01	102					8.3	2593			40	9.6	3.9	722	7.0	1044	1.2	22	704*	*													10-25-75		E. Trampe
144-94-1 BCB 03	120					7.9	3541			300	67	32	832	14	839	0	.8	1872	-11.			.8										10-24-75	DC 55-3	UND-EES
144-94-1 BCB 04	75					7.4	3242			1640	401	155	556	22	652	0	0	1992	49			.1										10-24-75	DC 55-4	UND-EES
144-94-1 BCB 05	30					7.7	1297			468	113	45	300	11	403	0	6.5	478	15			.2										10-24-75	DC 55-5	UND-EES
144-94-1 CDD 01	95					8.2	2435			174	38	19	600	8.8	893	0	3.0	604	4.4			.1										10-24-75	DC 49-1	UND-EES
144-94-1 CDD 02	57					7.9	1307			452	91	54	286	7.3	461	0	0	384	16			.2										10-24-75	DC 49-2	UND-EES
144-94-1 CDD 03	25					7.7	1461			630	156	59	282	5.3	444	0	1.5	384	24			.4										10-24-75	DC 49-3	UND-EES

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Location	Depth (Ft.)	Field Temp °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 mg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	B_3 µg/L	Date	Well No.	Owner
144-94-1 DCB 01	150					7.8	2294			380	99	32	800	13	776	0.0	4.0	880	16			0.7										10-23-75	DC 57-1	UND-EES
144-94-1 DCB 02	40					7.6	3267			1450	385	119	730	120	573	0.0	3.5	2607*	*			0.7										10-23-75	DC 57-2	UND-EES
144-94-2 DBC 02	28					8.1	748			254	74	17	104	4.5	388	0.0	2.5	160	-0.2			0.1										11-12-75	DC 58-2	UND-EES
144-94-4 ABB	36	8.0				8.1	1330	932	1.1	660	160	63	66	5.0	610	0.0	6.1	310	-1.4	2700	640	1.0	0.4									07-25-74	4727	NDSWC
144-94-6 DAA 01	75	8.0				8.1	1130	764	4.7	260	52	32	175	6.0	536	0.0	3.8	200	-0.27	2300	40	1.0	0.6									10-19-71	8191	NDSWC
144-94-12 AAD 01	168					8.0	2669			118	29	11	676	11	891	0.0	4.0	760	2.4			2.0										10-24-75	DC 59-1	UND-EES
144-94-12 AAD 02	112					7.5	1696			715	210	46	180	9.3	659	0.0	2.0	496	2.7			0.4										10-24-75	DC 59-2	UND-EES
144-94-12 AAD 03	15					8.2	1895			705	146	83	266	11	408	0.0	0.0	896	1.2			0.4										10-24-75	DC 59-3	UND-EES
144-94-12 ABA 03	52					7.8	1564			500	119	49	356	13	600	0.0	4.0	458	17			0.4										10-24-75	DC 52-1	UND-EES
144-94-12 ABA 04	89					7.7	2025			282	59	33	656	12	715	2.5	0.0	516	4.8			0.4										10-24-75	DC 52-2	UND-EES
144-94-12 ABA 04	89					7.9	1736	1458		439.2					690		10.96	506.22		174.5	1400	0.7	0.6		21.3	1.7	6.5					11-19-76	DC 52-2	UND-EES
144-94-16 BBA 02	102					8.3	4230			304	112	5.8	1000	18	944	0.0	4.5	1400	5.5			1.3										10-28-75	DC 27-2	UND-EES
144-94-16 BBA 03	51					7.4	3333			1330	271	159	392	19	612	0.0	11	1720	2.3			0.7										10-28-75	DC 27-3-1	UND-EES
144-94-16 BBA 04	19					7.7	2717			428	171	0.0	350	16	476	0.0	8.0	300	25			0.1										10-28-75	DC 27-3-2	UND-EES
144-94-21 CDC 02	52					7.6	1856			588	204	19	256	7.8	456	0.0	1.0	260	0.5			0.4										10-28-75	DC 20-2	UND-EES
144-95-3 AAD	84	7.5				8.2	1490	995	17	71	17	6.9	333	1.1	691	0.0	2.6	237	-1.21	800	10	1.0	1.6									10-22-71	8206	NDSWC
144-95-5 DCD	78	7.0				7.9	1390	896	7.8	200	36	27	253	3.1	526	0.0	3.8	310	-.26	2300	20	1.0	0.4									10-21-71	8205	NDSWC
144-95-36 AAA	161	9.0				7.8	2140	1530	8.0	410	103	37	371	8.0	708	0.0	2.5	627	14.02	3100	80	1.0	0.6									09-14-72	4473	NDSWC
144-96-1 DDC	75	8.0				8.4	1820	1190	23	71	14	8.8	450	4.0	890	12	2.7	250	1.96	290	520	1.0	0.9									07-30-74	4734	NDSWC
144-97-26 CCA	14	9.0				8.1	484	253	.8	210	40	27	28	11	285	0.	0	40	1.96	580	30	2.5	.6									11-10-71	8237	NDSWC
145-91-30 BBD	31	8.5				8.0	2120	1470	8.6	360	65	48	374	4.2	624	0	78	537	-.08	230	320	1.0	.7									09-13-72	72-3	NDSWC
145-91-30 BDD	26	7.0				7.7	2630	2030	4.5	970	180	126	321	7.3	581	0	6.1	1130	.42	1700	790	1.0	.8									11-10-71	8242	NDSWC
145-91-30 CAA	36	7.0				7.9	2030	1350	7.2	420	73	57	339	5.5	674	0	37	545	-.47	970	270	1.0	1.1									11-11-71	8243	NDSWC
145-92-22 CCC 03	34					7.9	718			258	62	25	100	4.8	415	0	3.0	105	2.9			.6										11-13-75	DC 34-3	UND-EES
145-92-22 CCC 04	19					7.6	513			257	63	24	30	11	322	0	0	200	-18			.2										11-13-75	DC 34-4	UND-EES
145-92-24 CCB	30	7.0				8.1	1800	1160	23	61	13	6.9	410	2.9	725	0	.9	351	-.26	0	80	1.0	1.0									11-15-71	8239	NDSWC
145-92-24 CCC	16	7.0				8.0	1760	1180	5.9	430	81	56	283	4.3	0	785	4.0	375	-23.6	360	450	1.0	1.1									11-12-71	8238	NDSWC
145-92-24 CDD 02	36	9.0				8.2	2670	1790	24	130	15	23	633	3.9	948	0	9.1	690	-.17	240	60	1.0	3.4									11-12-71	8249	NDSWC
145-92-25 BAA 01	14	11.0				8.0	4710	3600	11	1000	92	190	805	6.0	1120	0	75	1660	-.32	0	40	129	1.0									08-04-71		A. Bergstedt
145-92-25 BBA	36	7.0				8.1	2950	2040	18	250	44	35	656	5.5	820	0	7.6	949	.51	1100	60	.30	1.8									11-11-71	8251	NDSWC
145-93-27 ABC 04	16					8.0	1666	352			80	37	300	9.0	659	0	3.0	456	-.15			.6										11-03-75	DC 32-4	UND-EES
145-94-12 BAA	81	8.0				7.9	1580	1200	1.3	780	160	92	83	7.2	580	0	3.1	460	-.42	450	1300	1.0	.6									07-31-74	4744	NDSWC
145-94-27 ABC	30	7.0				7.4	1580	1280	1.8	710	180	63	110	6.5	360	0	11	650	-1.62	13000	1300	1.0	.5									07-31-74	4732	NDSWC
145-94-27 CAB	17					8.01	1336.7	1046		322.7										151	800	0.8	.52		19.8	1.8	5.5					11-19-76	DC 43	UND-EES
145-94-27 CAB	17					8.0	1487			316	64	38	468	4.3	720	0	4.5	330	18			0.0										07-15-75	DC 43-1	UND-EES
145-94-34 CCC 02	40					7.6	11023			2028	286	319	2140	60	1083	0	4.0	6640	-7.2															
145-94-34 CCC 02	40					8.48	1835.2	1396		50.9					895		6.92	345.56		229.4	69	2.0	1.79		16.7	3.6	16					11-19-76	DC 44-2	UND-EES
145-94-35 BAA	45	7.5				8.4	3260	2250	40	74	17	7.7	785	3.7	1110	19	7.4	824	-.65	450	100	1.0	1.7									10-19-71	8190	NDSWC

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Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
145-95-9 AAB	64	8.0				8.0	1250	800	8.6	160	28	21	248	6.2	569	0	25	212	-1.30	940	160	1.0	1.0									11-21-72	4479	NDSWC
145-95-22 DAD 02	160	8.0				8.1	1530	1010	9.0	220	48	23	304	7.3	793	0	3.8	223	-.14	440	200	1.0	.6									08-31-72	4468B	NDSWC
145-95-22 DAD 03	54	8.0				7.9	1400	904	13	110	23	12	311	4.1	691	0	3.0	200	-.67	1300	20	1.0	.9									09-19-72	4468A	NDSWC
145-05-23 AAD	60	8.5				7.8	482	234	3.2	95	15	14	72	4.4	287	0	0	33	-2.37	80	50	.30	.2									07-06-72		C. Wierson
145-95-23 ABB	70	8.0				8.2	1620	1090	11	170	49	11	328	3.7	710	0	6.3	310	-1.56	1600	150	1.0	.9									08-04-71		Killdeer No.6
145-95-29 AAA	143	8.0				7.9	1330	854	8.5	180	34	23	263	4.9	643	0	2.8	211	-.50	0	30	1.0	.3									11-08-71	8232	NDSWC
145-95-29 ADA 01	62	9.0				7.9	867	539	7.1	110	27	9.4	169	6.1	488	0	0	74	-.47	250	240	1.0	.6									09-12-72	4476	NDSWC
145-95-29 ADA 02	74					7.9	760	453	2.0	260	58	29	75	3.7	405	0	3.1	108	-1.99	3200	460	1.0	.1									04-17-73	8623	NDSWC
145-95-29 ADA 03	234					8.2	1450	929	10	160	34	17	295	8.0	720	0	3.4	218	-.95	380	400	.5	1.0									04-18-73	8624	NDSWC
145-95-29 ADA 04	27					8.3	766	447	5.2	130	25	16	135	4.1	475	5	2.9	39	-1.73	0	180	1.0	.4									04-18-73	8264A	NDSWC
145-95-29 ADD 01	74					8.0	686	439	5.6	92	22	9.0	124	3.4	378	0	2.5	61	-2.4	1300	200	1.0	.4									04-16-73	8619	NDSWC
145-95-29 ADD 02	75					8.1	689	441	6.5	82	20	7.8	135	2.4	374	0	3.1	66	-.13	910	160	1.0	.4									04-17-73	8622	NDSWC
145-95-29 ADD 03	110					7.9	701	391	5.4	110	25	11	128	3.4	403	0	3.1	58	-.57	1500	140	1.0	.3									05-27-73	PW	NDSWC
145-95-29 DAA 01	113	7.5				8.3	744	458	8.6	67	16	6.6	161	3.1	408	2	0	70	1.20	180	110	1.0	.6									11-09-71	8233	NDSWC
145-95-29 DAA 02	74					7.9	1090	682	7.1	150	31	18	202	3.0	580	0	2.8	127	-1.37	3400	240	1.0	.3									04-16-73	8618	NDSWC
145-95-29 DAA 03	74	7.0				7.9	776	470	5.0	140	33	13	133	2.9	396	0	3.1	92	-.47	1800	180	1.0	.3									04-17-73	8621	NDSWC
145-95-29 DDD	41	7.0				7.8	1160	742	5.2	240	50	28	186	4.0	473	0	3.2	254	-.54	0	30	1.0	.5									11-09-71	8234	NDSWC
145-95-34 DCC	161	9.0				7.8	1730	1220	7.5	310	73	30	300	5.9	639	0	0	439	-.77	2400	240	1.0	.7									09-14-72	4475	NDSWC
146-91-17 CDC	141	8.0				8.1	953	626	2.1	330	75	35	89	4.3	430	0	2.3	180	-1.21	1600	240	1.0	.7								-	07-23-74	4708	NDSWC
146-91-20 DDD	43	15.0				7.6	1230	806	2.9	380	91	37	129	4.5	420	0	4.4	322	-1.44	0	10	2.5	.8									08-11-71		W. Schaper
146-91-21 CDD 01	192	7.0				7.6	1170	870	3.9	350	94	27	166	7.0	506	0	2.6	287	-.10	1300	160	.30	.8									10-27-71	8216	NDSWC
146-91-21 CDD 02	93	6.0				7.5	811	514	1.0	370	91	34	46	4.1	423	0	1.4	130	-1.47	0	550	1.0	.7									10-27-71	8216A	NDSWC
146-91-28 ABA	94	7.0				8.1	2640	2100	7.9	730	149	86	489	5.5	630	0	5.1	1190	-.96	0	520	1.0	.9									10-28-71	8217	NDSWC
146-91-35 BBC	221	8.0				8.2	988	637	1.8	380	87	40	80	5.9	460	0	3.0	180	-.49	2700	160	1.0	.9									07-23-74	4707	NDSWC
146-93-34 CCC	37	6.0				8.1	433	259	.5	200	49	19	16	3.6	180	0	10	71	-.95	80	100	11	.4									07-24-74	4788	NDSWC
146-94-25 BAA 01	66	7.5				8.0	1070	768	.8	540	140	46	42	5.0	450	0	2.2	260	-.43	960	1000	1.0	.6									07-25-74	4740	NDSWC
146-94-31 DAD	63	10.0				7.4	1550	1160	3.5	480	127	39	177	6.2	441	0	6.0	486	-.31	4000	750	1.0	.3									07-14-72		G. Carlson
146-95-20 CCB	61	7.5				7.9	1130	709	4.4	260	44	37	167	8.0	479	0	4.6	223	-.32	1100	20	1.5	.5									10-18-71	8180	NDSWC
146-96-36 AAA	24	6.0				7.8	895	580	4.3	200	40	24	138	6.1	448	0	4.1	113	1.60	80	20	1.0	.4									04-18-73	4480	NDSWC
146-96-36 BBB	44	8.0				8.0	931	574	2.1	330	72	36	89	6.2	454	0	3.9	127	1.88	2500	170	1.0	.4									09-19-72	4481	NDSWC
148-94-20 DDD	134	-				8.0	1490	1050	6.3	300	74	28	250	4.6	581		2.0	378	-1.37	440		1.5	.6									10-12-50		Tribal

HETTINGER & STARK COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
140-92-1 BAA	101	7.5				7.9	2930	2130	22	189	54	13	689	7.0	1030	0	0	820	-.06	1200		.7	1.6									05-06-69	3550	NDSWC
140-92-6 DAA	278	8.5				8.1	2700	2000	18	220	58	18	612	5.8	1000	0	2.5	697	.27	3400		0	1.4									10-19-67	3549	NDSWC
141-91-25 AAA	35					7.9	683	361	7.1	206	43	24	68	3.8	383	0	.5	41	.28	160		2.5	1.3									06-02-69		E. Eggert

MCLEAN COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-82-17 AAD	41					8.0	2530	1760	15	259	52	31	546	6.4	1010	0	6.3	602	-.36	2700		1.5	.9									07-25-67	2697	NDSWC
144-83-30 DAA	61	7.5				7.8	1230	819	2.5	440	89	54	123	7.4	553	0	12	242	-.07	2800		.5	.8									07-25-67	2698	NDSWC
144-84-4 CDD 01	92	7.5				7.9	1560	1040	6.3	338	90	27	267	5.8	842	0	6.3	215	.03	4200		3.0	.3									05-02-68		C. Reimers
144-84-10 CCC	71	7.5				7.8	1380	909	3.8	410	104	37	175	9.4	659	0	13	230	-.37	3500		2.5	.9									07-26-67	2699	NDSWC
144-84-24 BCD 01	22	7.0				7.9	1270	835	1.4	593	156	49	81	4.9	787	0	8.3	110	-.13	700		3.0	.2									05-01-68		C. Yunker
144-84-24 CBA	62	10.5				8.2	2430	1530	50	28	7.8	2.1	604	2.4	1380		153	14	.59	580		1.0	1.4									08-20-69	2911	NDSWC
145-82-4 CDC	12					8.22	1128	972		583.13	184.4	29.7	62	5.5	463		14.52	251.44	4.5	1100	194				415	.9	607					08-25-76	FA 3-2	UND-EES
145-82-7 DAA	241	7.0				8.1	1320	867	4.5	350	77	38	192	8.3	712	0	2.7	188	-.42	960		.5	.3									04-30-68	2858	NDSWC
145-82-8 ADD 02	251	10	7.0	1550		7.8	1396	910		235	50	27	156	7.7	828		13.2	295	-26.4	11196	658				69.6	0.94	52.9					07-01-76	FA 101-2	UND-EES
145-82-8 ADD 02	251	8	7.32	1675		7.58	1242	919		177	31.7	24.2	309	14.6	797		11.6	170.3	1.28	1800	58	0.49	0.4		8.3	1.2	6.7					08-10-77	FA 101-2	UND-EES
145-82-8 ADD 03	47	10	7.0	850		7.55	752	450		230.8	13.5	47.9	30.6	6.6	467		.63	129	-25.8	381	1116				19.1	3.12	24.3					07-01-76	FA 101-3	UND-EES
145-82-28 ABB	37	4.5				8.3	2430	1640	13	250	66	21	487	4.3	683	3		746	-.96			1.0	.7									11-10-69	3907	NDSWC
145-84-11 ABA	82	9.0				7.9	1000	631	2.3	365	91	33	100	3.7	490	0	9.3	154	-.82	3100		0	.2									08-23-67	2704	NDSWC
145-84-14 CDD	78	11.0				7.8	1330	967	1.3	641	168	54	73	6.1	470	0	4.0	369	2.12	1800		6.0	.3									07-26-67	2701	NDSWC
145-84-15 DDC	101	10.0				8.2	1650	1130	12	168	49	11	344	4.6	781	0	14	263	-.65	3400		0	.4									07-27-67	2702	NDSWC
145-84-23 AAA	60	11.0				8.0	754	456	2.2	259	53	31	81	3.4	433	0	2.9	63	1.79	4800		0	.3									07-26-67	2700	NDSWC
146-81-18 CDD	187	7.0				7.9	1020	631	1.2	479	107	51	58	7.3	546	0	.9	144	1.11	900		0	0									10-04-67	2859	NDSWC
146-82-34 ADD	80	4.5				7.9	701	417	.5	353	89	32	20	3.5	376			85	1.26				.2									11-10-69	3911	NDSWC
146-82-34 CBC 01	51					7.4	2970	240		160	63	1.0	1.2	6.6	187		1.5	18	-.72	6670	730	.16			68.3	1.3	37.1					08-25-76	FA 2-1	UND-EES
146-83-15 CCC	284	9.0				7.9	2620	1730	24	125	33	10	629	4.4	1230		17	464	-.60	80		.9	.6									07-08-70	4036	NDSWC
146-84-8 DBD	28	8.5				8.2	2170	1470	9.9	316	34	56	406	7.3	584	0	55	633	-.29	5100		2.5	0									08-23-67	2713	NDSWC
146-84-17 DAA	121	9.5				7.7	3990	3780	3.9	1930	514	157	394	17	474	0	12	2310	-.06	10000		0	0									08-23-67	2712	NDSWC

MERCER & OLIVER COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-81-13 CCC	54	9				7.8	900	547	1.5	380	93	36	67	5.5	467	0	11	114	.02	3300		2.5	.3									08-28-67		NDGS
141-82-22 CDA	34	8				7.8	1190	720	4.5	285	66	29	174	4.7	518	0	10	222	.00	1300		1.0	.1									07-02-69	3725	NDSWC
141-83-4 ADD	66					8.0	1040	745	5.9	212	48	22	196	5.2	579	0	2.7	160	.00	2800		1.0	.2									08-28-67		NDGS
141-83-4 BDA	48	9				8.4	1070	712	9.2	108	24	12	221	5.5	583	5	2.6	100	.00	3300		3.0	.4									08-29-67		NDGS
141-83-4 BDB	76	8				8.4	1050	645	5.6	194	47	19	179	4.1	531	8	3.8	128	.00	3200			.2									08-29-67		NDGS
141-84-1 CAA	47					7.7	1470	988	4.7	450			218		512	0	20	361		130		10										05-27-76		J. Berger
141-89-5 CBB	162					7.9	4000	2660	18	440	101	46	849	9.9	999	0	3.5	1450	-.71	300		2.5	.1									08-04-69	3763	NDSWC
141-89-23 AA	102	9				8.0	6320	4650	20	872	213	83	1370	7.0	1450	0	3.6	2700	-1.81	18000		1.0	.4									08-07-69	3765	NDSWC
141-89-23 BAA	280					7.9	3080	2320	9.5	628	152	60	551	11	850	0	4.0	1110	-.01	3800		5.6	.4									11-15-68	3663	NDSWC
142-82-5 DAA 02	50					7.9	1290	911	3.0	440	101	46	143	4.7	472	0	4.3	359	-.01	5500		2.0	.1									10-25-68	3648	NDSWC
142-83-19 CCB	16					7.5	1600	1160		647			198		492	0	17	512		200		34										05-27-76		J. Schmidt
142-84-8 AAB	124					8.0	806	527	3.2	206	53	18	107	3.5	416	0	1.2	104	-.89	880		1.0	.1									07-09-69	3732	NDSWC
142-84-8 ABB	81	8				8.0	595	374		214	68	11	51	2.8	334	0	1.8	55	-.68	1200		1.0	.1									07-13-69	3733	NDSWC

MERCER & OLIVER COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	B_3 µg/L	Date	Well No.	Owner
142-84-23 BBB	54					7.8	1330	930	3.5	473			177		460	0	13	366		3260												05-18-76		A. Meyhoff
142-89-13 CBB	40					7.8	5083	4027		1494.2	311	148	598	9.7			20.0	657.3		178.8	144	1.92	0.35		50.4	15.3	51.6			-8.03		03-14-77		Ed Unruh
142-90-23 DCC 02	179					7.8	3990	2860	13	682	170	63	770	12	983	0	1.9	1570	-1.41	6100		2.5	.3									08-06-69	3762	NDSWC
143-84-28 CCC 02	65					7.7	1050	698	2.1	388	103	32	97	4.2	485	0	3.1	186	.79	400		1.0	.1									05-24-69		H. Schultz
143-88-4 DCD	30	7				7.9	1410	962	3.2	458	116	41	159	6.0	574	0	8.0	323	-.43			20	.2									06-12-68		R. Keogh
143-89-11 DDD 02	59	9				7.7	1720	1130	4.2	505	139	38	217	10	695	0	1.2	436	-1.81	2700		1.0	.2									08-07-69	3766	NDSWC
143-90-34 DAC 01	105	10				7.9	2330	1390	10	351	83	35	435	7.1	776	0	4.0	678	-1.56	1900		2.5	.3									08-03-69	3759	NDSWC
143-90-34 DAC 02	79					8.0	3160	1980	17	319	74	33	687	8.4	1260	0	4.0	800	-1.26	980		1.0	.5									08-03-69	3760	NDSWC
144-82-17 CCC	23	12				7.9	1360	883	4.0	389	70	52	180	5.8	540	0	7.0	312	.64	2900		1.0	.2									09-11-67		NDGS
144-82-17 CDD 01	111					7.9	2030	1400	6.3	497	141	35	322	8.8	1060	0	13	334	-1.08	7300			.5									10-04-68	PW	NDSWC
144-82-17 CDD 02	105					8.0	1970	1350	6.9	435	122	32	333	8.8	989	0	14	338	-.45	4800		4.0	.5									09-20-68	3630 No. 1	NDSWC
144-82-17 CDD 03	103					7.9	1800	1230	7.2	485	125	42	271	8.8	910	0	6.8	325	-.34	5200		.5	.4									09-19-68	3631 No. 2	NDSWC
144-82-17 CDD 04	103					7.9	1910	1290	6.5	433	112	37	313	9.7	959	0	8.0	330	-.73	5700		1.0	.4									09-20-68	3632 No. 6	NDSWC
144-82-20 ABB	101					7.9	1770	1200	5.0	480	132	36	254	9.6	900	0	8.4	317	-1.74	5400		.6	.5									09-17-68	3633 No. 4	NDSWC
144-82-20 DCD	85	10				8.0	1110	687	4.4	266	74	21	166	4.6	592	0	5.7	135	.35	340			.2									07-13-67		B. Faimin
144-82-21 CBB	19	9				8.0	1490	960	4.8	384	60	57	215	7.1	661	0	10	288	.29	3300		1.0	.1									09-01-67		NDGS
144-82-21 CDD	104	9				7.8	1600	1000	5.4	386	99	34	245	8.3	780	0	17	263	-.35	3800		.4	.2									07-09-69	3730	NDSWC
144-82-21 DAA	70	7				7.7	1720	1150	3.8	560	128	58	209	7.1	737	0	18	377	-.02	3500		1.0	.1									12-13-67	2903	NDSWC
144-82-23 BBB 01	38	9				7.5	979	585	2.2	352	96	27	94	8.7	578	0	9.3	69	.67	5300		.6	.7									07-18-67	2688	NDSWC
144-82-23 DDD	200	9				8.1	2410	1480	34	61	18	3.9	607	4.8	1380	0	107	95	.22	2400		1.0	.9									07-08-69	3729	NDSWC
144-82-26 ADD	26	7				7.5	2160	1520	3.9	770	184	75	247	8.5	776	0	39	608	-.32	15000		4.9	.1									07-03-69	3728	NDSWC
144-82-16 BBA	60	8				7.5	1600	1070	3.0	590	150	52	168	5.0	800	0	15	281	-.44	5200			.2									07-18-67	2690	NDSWC
144-82-27 BBB 01	50	9				7.1	1480	985	2.8	556	145	47	150	4.0	710	0	11	276	.08	5400		5.0	.3									07-18-67	2689	NDSWC
144-82-28 CBA	120					7.8	1030	695	3.1	315	82	27	125	7.4	485	0	3.0	184	.25	1100		1.0	.3									10-21-68	3638	NDSWC
144-82-29 AB	72	7				8.2	1140	671	4.2	263	66	24	155	3.7	562	0	4.0	123	.88	40			.2									07-21-67		A. Van Oosting
144-83-13 DDD	19	8				7.8	980	741	1.6	405	90	44	72	6.0	384	0	10	214	1.61	3200		3.0	.2									08-30-67		NDGS
144-83-24 CCC	29	8				8.2	1520	892	8.5	213	32	32	284	5.6	902	0	6.3	71	.84	3000		2.0	.2									08-30-67		NDGS
144-83-24 DBA	100	10				8.0	2480	1660	13	305	69	32	527	6.6	1210	0	4.0	444	-.03	4000		2.5	.4									07-21-67		Cullen Bros.
144-83-24 DDD	28	9				8.3	2000	1300	12	215	28	35	412	5.8	789	7	2.4	452	-.13	2800		4.0	.1									08-30-67		NDGS
144-84-27 ADD	140					7.9	1280	860	5.2	303	78	26	207	6.4	691	0	3.8	167	.93	3300		1.0	.2									10-23-68	3639	NDSWC
144-85-1 DDD	70					7.8	939	585	1.4	398	114	28	66	5.5	536	0	2.6	108	-.45	5000		1.0	.2									06-29-67	2687	NDSWC
144-85-2 BCB 01	118	9				7.9	1080	724	1.7	456	130	32	81	4.7	586	0	1.9	153	-.31	2300		1.0	.1									06-26-69	No. 3	NDSWC
144-85-2 BCB 02	116					7.8	1130	745	1.1	539	146	42	60	4.5	513	0	1.5	240	.11	100		.2	.1									06-24-69	No. 4	NDSWC
144-85-2 BCB 03	118	26				7.8	1240	848	1.3	580	164	41	72	4.6	592	0	1.9	273	-2.08	1700		2.0	.1									06-23-69	No. 6	NDSWC
144-85-2 BCB 06	130					7.5	1240	868	1.2	585	165	42	65	4.6	560	0	1.5	274	-.95	6100		2.5	.2									07-11-69	PW-2	NDSWC
144-85-2 BCC	119	26				7.7	1340	964	1.3	645	166	56	74	4.7	502	0	1.2	396	-.86	5800		1.0	.1									06-23-69	No. 5	NDSWC
144-85-3 ADA	112					7.7	1310	908	1.1	649	171	54	64	4.4	523	0	1.7	361	-.88	2100		1.0	.1									06-24-69	No. 2	NDSWC
144-85-3 DAA	123	9				7.8	1200	797	1.4	535	146	41	76	4.8	542	0	1.2	264	-1.12			2.5	.1									06-27-69	5268	NDSWC

MERCER & OLIVER COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error
144-85-6 ABB	51	9				7.7	971	620	.9	474	149	25	46	16	488	0	2.5	161	2.10
144-85-10 AAA	110	7				7.8	1200	765	2.9	405	109	32	136	4.6	649	0	2.1	147	1.26
144-85-11 CCC	100	7				7.3	2120	1740	1.2	1180	339	81	98	4.9	660	0		807	.63
144-86-14 DDD	18					7.6	463	292		201.2	35.3	14.4	37.2	0.9			7.7		
144-86-15 CDC	28					7.02	2873	2284		991	165	80.3	306	11.4			12.3	684.7	
144-86-18 ADA 01	66					7.9	717	431	1.8	260	60	27	66	4.9	457	0	15	26	-1.44
144-86-18 ADA 03	65	10				8.0	1170	774	4.5	293	77	24	178	6.5	647	0	5.3	118	1.89
144-86-18 ADC 02	63	9				7.8	907	539	2.6	303	81	25	105	8.5	580	0	2.3	45	1.78
144-86-18 DAB	164	9				7.9	1280	746	4.4	335	82	32	184	9.4	732	0	2.6	135	.27
144-86-18 DAC	63	9				7.6	753	419	.9	334	94	24	37	7.0	396	0	13	68	1.02
144-86-18 DDC 03	53	9				7.8	837	511	2.2	285	77	23	85	6.4	378	0	1.5	149	1.37
144-86-18 DDC 04	203	9				7.9	1420	742	7.6	227	51	18	263	8.1	828	0	8.2	110	0.25
144-86-19 ABA	224	10				8.1	1540	1040	9.5	198	51	17	307	6.9	876	0	12	143	-.60
144-87-3 A	15.8	11.7				7.46	3650	3178	3	1686	205	249	545	6.1	618		192	894	23.0
144-87-14 AAA	230					7.5	1120	683	3.3	336	93	25	139	9.4	573	0	5.4	153	1.05
144-87-31 ADB	120	12				7.9	1120	722	4.8	256	73	18	176	7.6	638	0	8.9	115	-.05
144-88-2 AAB	241	10				7.8	891	504	2.7	264	73	20	100	5.0	483	0	.8	101	-1.36
144-88-25 CA	114	8				7.9	870	554	2.4	286	80	21	93	5.1	487	0	2.5	94	-.54
144-88-25 CC	23					8.1	588	364		296	79	24	5.4	8.0	294		2.0	76	-.94
144-88-25 CCC 03	161					7.9	1260	858	5.1	296	69	25	196	7.6	656	0	3	168	-.39
144-88-25 CD	126					7.7	1100	706	3.2	327	87	27	133	8.1	600	0	.5	121	.80
144-88-36 BBC 02	104	9				8.2	960	625	3.0	285	72	26	115	4.8	478	0	2.0	141	.09
144-89-14 DC 03	56.5	6.7				7.05	3800	5570	9	1803	400	158	867	19	1093		15	3010	-6.50
144-90-4 DDC	160	7				7.9	1210	802	3.2	373	92	35	142	9.2	498	0	-	270	.40
144-90-16 ABC	141	9				7.8	1270	771	5.1	275	64	28	196	8.8	562	0	.2	254	-.90
144-90-22 DAD	162					8.0	1710	1010	8.7	250	60	24	317	8.7	740	0	2.0	350	-1.33
145-84-20 DDD	103	9				7.5	1680	1100	7.8	288	91	15	306	7.3	775	0	63	228	.10
145-84-28 BAD	103	9				7.7	1280	807	5.1	287	87	17	199	3.0	645	0	11	169	.28
145-84-28 DCC 03	63	9				7.9	893	537	2.7	270	79	18	100	15	447	0	3.2	105	2.73
145-84-29 CCB	70	7				8.0	1720	1140	11	209	54	18	367	7.1	958	0	8.6	178	1.65
145-84-32 BCC	90	7				7.8	901	569	2.5	307	92	19	100	5.2	564	0	1.7	48	1.67
145-84-32 CCC	83	7				7.9	850	542	1.6	339	99	22	69	4.7	494	0	1.0	69	1.54
145-84-33 BDD	134	9				7.9	948	636	2.4	330	96	22	99	5.8	516	0	1.0	103	1.98
145-85-34 CCB	53	9				7.8	842	503	1.9	318			76	8.5	493	0	1.7	74	
145-87-2 ADD	23.8	8.9				7.48	590	491	0.6	350	90	32	26	21	412		2.0	83.2	1.4
145-87-26 AAD	207					7.58	1756	1218		372.6	61.4	32.3	329	11.0	1033		6.8	368.2	-9.95
145-87-32 DC	49	9				8.0	1210	779	3.4	377	92	36	150	5.8	638	0	2.0	171	0.49
145-88-3 ACC	118					7.5	1460	2080	5.5	576	140	55	304	10	1010	0	.5	403	.08

Location	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-85-6 ABB	6900			.3									07-17-67	2681	NDSWC
144-85-10 AAA	4500			.2									05-13-69	5269	NDSWC
144-85-11 CCC	25000		2.5	.1									05-13-69	5270	NDSWC
144-86-14 DDD	133	49.4	0.09	0.47		39.3	0.84	1.2			-12.91		03-14-77		E. Bentz
144-86-15 CDC	7207	668	.31	.20		36.6	15.6	18.0			-13.03		03-14-77		Morgenstern
144-86-18 ADA 01	2800		1.1	.4									05-01-69		N. Pacific RR
144-86-18 ADA 03	3200		5.5	.5									01-23-68		Hazen
144-86-18 ADC 02	5200		.6	.5									07-17-67	2677	NDSWC
144-86-18 DAB	3400		.2	.3									07-23-69	3748	NDSWC
144-86-18 DAC	5300		1.0	.4									07-18-67	2679	NDSWC
144-86-18 DDC 03	5400			.3									07-18-67	2678	NDSWC
144-86-18 DDC 04	2200		.3	.5									07-23-69	3747	NDSWC
144-86-19 ABA	960		.3	.7									07-14-69	3739	NDSWC
144-87-3 A	130												06-20-74	G29	Woodward-Clyde Consult
144-87-14 AAA	5000		8.6	.3									11-02-68	3652	NDSWC
144-87-31 ADB	3300		1.0	.4									06-12-68		A. Sailer
144-88-2 AAB	2000			.3									07-28-69	3755	NDSWC
144-88-25 CA	3200		1.0	.3									01-23-68		Beulah
144-88-25 CC	20			.1									05-13-47		
144-88-25 CCC 03	1200		.5	.4									07-22-69	3743	NDSWC
144-88-25 CD	2000		1.0	.4									05-24-69		Beulah
144-88-36 BBC 02	880		1.0	.2									07-15-69	3741	NDSWC
144-89-14 DC 03	880	60		.72		150	8	55	5	<10			07-10-74	G11	Woodward-Clyde Consult.
144-90-4 DDC	3700			.6									05-09-68	5265	NDSWC
144-90-16 ABC	1800		2.5	.5									07-29-69	3757	NDSWC
144-90-22 DAD	2300		1.0	.6									08-02-69	3758	NDSWC
145-84-20 DDD	2000		0	.5									07-17-67	2684	NDSWC
145-84-28 BAD	6700		2.0	.3									07-17-67	2685	NDSWC
145-84-28 DCC 03	2000			.3									07-17-67	2686	NDSWC
145-84-29 CCB	2200		.5	.6									05-13-69	5273	NDSWC
145-84-32 BCC	4500		.2	.3									05-12-69	5266	NDSWC
145-84-32 CCC	3500		.2	.2									05-12-69	5267	NDSWC
145-84-33 BDD	4300		2.5	.3									07-14-69	3768	NDSWC
145-85-34 CCB	3600			.2									07-17-67	2682	NDSWC
145-87-2 ADD	29800	660		12.5		250	640	230	<5	<10			06-29-74	G13	Woodward-Clyde Consult.
145-87-26 AAD	99.2	176	.26	.63		27.6	2.2	6.8			-15.39		03-14-77		Oster
145-87-32 DC	5000		.5	.4									08-31-67		NDGS
145-88-3 ACC	8600		8.4	.5									05-24-69		L. Eisenbeis

MERCER & OLIVER COUNTIES

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
145-88-25 ABB	216					7.8	656	423	.7	322	90	24	29	4.2	395	0	1.4	.47	2.22	3300		1.0	.5									11-04-68	3653	NDSWC
145-89-14 CAA	57	12	7.61	1500		7.45	1290	1174		760	172	71	33	6.8	416.0		56.2	313.6	3.52	28.6	190	23.8	.62		14	2.0	48					06- -77		O. Lang
145-89-14 CCB	49	12	7.39	650		7.55	657	536		431	87	30	24	1.9	240.3		13.8	140.2	4.29	60	72.2	14.1	.33		24	3.74	7.4					06- -77		O. Lang
145-90-6 DB 02	54					7.6	489	276	.5	228	74	11	17	2.5	260	0	.3	36	3.55	80		6.4	.6									05-22-69		E. Weisz
145-90-8 CBB	236					7.7	1520	1090	5.3	356	103	24	231	5.8	463	0	1.5	465		2900		1.0	.5									11-04-68	3657	NDSWC
145-90-21 AAA 01	200	7				7.8	1150	1000	3.0	360	90	33	132	7.8	429	0		282	.92	2700		.4	.6									05-08-69	5264	NDSWC
145-90-21 AAA 02	80	7				7.9	937	614	3.3	260	70	21	124	4.6	452	0		145	1.42	4000		.1	1.5									05-08-69	5264A	NDSWC
146-86-21 DAD 01	44					7.11	3657	3388		1921	208	215	239	24.8			63.1	682.1		71.4	15.0	> 2.0	0.20		25	7.6	23.1				3±8	03-14-77		D. Reichenberg
146-88-21 DDD	224	10				7.8	1250	786	4.2	325	82	29	174	6.9	638	0	.2	184	-.25	3000		.2	.3									07-25-69	3750	NDSWC
146-88-28 DDD	162	10				7.8	1250	862	5.1	273	73	22	194	5.9	611	0	.8	201	-.74	8500		2.5	.4									07-25-69	3752	NDSWC

MORTON COUNTY

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
139-88-6 DDD	328	10.5				7.7	3790	3070	9.7	910	210	94	670	11	964	0	2.8	1500	.55	2000	60	1.7	.5									08-05-75	9331	NDSWC
139-88-15 CCC	304	8.5				8.0	3400	2600	11	560	140	73	630	9.5	1000	0	5.1	1200	-1.07	0	80	.23	.6									11-08-73	4540	NDSWC
139-88-22 DCB	283	3.0				8.1	3340	2280	34	110	26	12	830	4.5	1530	0	3.7	650	-.25	2000	570	.23	2.3									05-12-76		J. Duppong
139-88-25 BAD	224	8.0				7.9	3330	2450	12	510	110	57	630	11	1150	0	7.8	930	-.75	60	80	.45	.5									11-16-73	4541	NDSWC
139-88-25 BCC	284	7.5				7.9	3110	2210	13	430	90	50	630	8.9	1070	0	5.2	910	-.56	1200	0	.23	.8									11-08-73	4542	NDSWC
139-88-28 DDA	128	8.0				8.0	4240	3230	17	560	130	57	910	6.8	1300	0	6.3	1400	-.29	1800	70	.23	1.2									11-16-73	4539	NDSWC
139-88-31 BBC 01	364	9.0				8.2	2060	1380	20	110	28	9.7	490	5.9	1020	0	5.6	280	2.05	920	40	.45	1.3									11-06-73	4538	NDSWC
139-88-31 BBC 02	99	8.0				8.0	3460	2510	24	210	47	22	800	5.5	1310	0	6.4	890	-1.36	2500	70	.29	1.5									11-06-73	4538A	NDSWC
139-89-8 DDC	244	8.5				8.0	997	635	3.5	260	60	27	130	6.9	574	0	2.8	78	-.32	460	40	.23	.9									10-24-73	4535	NDSWC
139-89-26 CDD 02	141	9.5				7.8	3990	3220	8.5	1100	260	110	650	12	1130	0	6.3	1580	-.98	1700	120	.68	.5									06-20-75	9299A	NDSWC
139-89-27 BCC	74	8.0				8.2	1160	739	5.1	240	53	26	180	4.3	578	0	.4	170	-1.17	3500	110	.23	.6									05-30-74	8959	NDSWC
140-89-15 DCC	163	7.0				7.8	2130	1490	7.2	470	100	54	360	11	1110	0	6.8	330	.24	40	50	.14	.8									11-15-73	4536	NDSWC
140-89-36 ADD 01	349	9.0				7.8	2860	2170	7.0	750	160	85	440	12	816	0	4.7	1000	-.15	2200	80	.23	.7									11-15-73	4537	NDSWC
140-89-36 ADD 02	144	8.5				7.9	1720	1200	5.1	450	110	43	250	7.1	809	0	2.7	340	-.84	2500	80	.18	.6									11-16-73	4537A	NDSWC
140-90-21 BCB 01	381	10.0				7.9	2500	1740	15	230	55	23	530	5.5	894	0	8.2	630	-.32	0	40	.23	3.8									07-11-74	4531	NDSWC
140-90-21 BCB 02	19					7.6	9760	9700	10	4000	490	670	1500	7.3	630	0	4.0	6500	-.26		100	.23	.4									05-17-74		H. Seyler
140-90-34 AAA	204	7.8				8.2	1830	1210	9.4	250	62	23	340	4.1	661	0	3.3	440	-.53	100	40	.23	.8									10-24-73	4533	NDSWC
141-89-36 DCD	338	10.0				7.8	2930	2220	8.4	680	140	80	500	11	817	0	2.5	1100	-1.06	2000	60	.72	.8									08-05-75	9330	NDSWC

APPENDIX C-IV

GROUNDWATER CHEMICAL DATA--GOLDEN VALLEY, SENTINEL BUTTE, BULLION CREEK, SLOPE, CANNONBALL, AND LUDLOW FORMATIONS (DATA ARE ARRANGED STRATIGRAPHICALLY BY LOCATION)

In Standard Error column an
* indicates ion determined by difference

GOLDEN VALLEY FORMATION

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
143-92-22 AAD	64	11.0				6.5	751	463	.4	330	90	25	15	1.9	263	0	1.1	142	-.34	100	90	6.9	0.1									06-23-72		F. Schumacher
144-93-9 DDD 04	55					8.7	9485			4907	1067	539	481	82	129	1.2	31	4600	10			1.2										11-03-75	DC 17-2C-3	UND-EES
145-88-8 BCC 01	54	13	6.72	1950		7.26	1710	1597		991	223	91	68	14.9	592.9		25.7	638.3	-3.87	382	570	4.98	.13		44.4	3.20	22					06-14-77		R Renner
145-90-30 DDA	18					6.55	1334	1005		625.9	117	55.5	65.8	12.6	287.9		8.3	747.7	-20.32	15586	466	.46	.13		4.5	0.32	17.8			-12.83		03-14-77		A. Isaak

SENTINEL BUTTE FORMATION
Harnisch Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-91-22 BCD	75	9		5000		8.04	5727	4946		880.32	161	96.9	1067	34.8	667.34		36.3	690.6	41.23	157.8	96.8	<0.1	.23		59.5	13.8	454			-12.21		03-14-77		Elmer Wolff
144-92-8 CAC 03	81					8.0	3474			220	42	28	842	14	987	0	10	1000	5.2													08-23-75		J. McNamara
144-92-18 CBA	115					7.6	2883				249		352	23	683	0	17	1328	-.5													11-10-75		M. Hellickson
145-88-20 BAB	90	2	7.47	940		8.17	706.3	606		493.82	32.9	87.9	26.9	4.8	452	0	11.48	190.48	-7	106	158.8	5.1	.35		24	1.2	5.3					12-15-76		A. Reinhardt
145-88-20 BAB	90	1	7.16	850		8.04	-	586		484.8	32.5	57.1	37.5	6.8	452		11.48	150.95	-14.5	84	920	4.5	.31		10.2	1.10	4.4					12-15-76		A. Reinhardt
145-88-20 CCC	135	2	6.71	100		8.12	937.4	762		522.06	48.0	58.7	83.2	18.9	451		3.39	312.44	-13.5	800	3160	1.0	.14		10	1.2	7.7					12-15-76		J. Becker
145-88-22 CDC	110	2	7.65	1500		7.46	1344	1226		510.47	54.5	47.7	116.5	9.8	603		3.47	517.23	-12.7	250	280	5.5	.22		35	2.65	5.0					12-15-76		E. Weiss
145-90-20 BAD	115					7.70	1765	1242		154.4	15.9	10.1	404	12.6			4.2	644.7		56	92	.09	.41		31.5	5.1	82.5			-10.23		03-14-77		E. Tschaekofske
145-96-14 BBA	27					7.5	596	316	.8	260	62	26	28	12	327	0	6.6	36	3.5	0	10	13	.2									03-11-71		M. Tachenko
145-97-15 CAD	115	8.5				7.2	341	222	2.8	63	13	7.4	51	2.0	176	0	0.0	25	1.9	180	0	7.6	.2									06-30-72		E. Hovden
145-97-22 DCC	34	9.0				7.3	1050	664	11	71	12	10	217	4.5	456	0	3.4	167	-.32	780	190	1.0	.5									06-29-72		L. Klatt
145-97-30 ADD 02	30	6.5				8.0	2330	1570	11	330	63	41	436	5.4	519	0	55	762	-.60	0	20	25	.4									11-05-71		R. Kostelnak
146-90-13 DCC 01	125					7.34	969	598		491.5	84.2	41.6	35	10.7			5.4	196.3		77	1115	0.1	.43		5	0.28	5.8			-12.17		03-14-77		R. Link
146-90-13 DCC 02	135					7.19	1328	945		721.2	69.1	82.5	47.5	13.6			6.9	328.2		27866	1093	.25	.28		4.8	0.23	16.8			-15.03		03-14-77		R. Link
146-92-30 DAA	70	9.5				7.2	470	256		130	24	16	52	2.4	249	0	0	44		100		1.0										07-12-72		J. Schettler
146-93-19 BDD	140					6.9	934	650		370	73	45	67	3.4	290	0	.3	269	-.1	2100		1.0										07-13-72		R. Krieger
146-93-20 CBC 01	110	8.5				7.8	670	417		300	58	37	37	3.7	312	0	3.9	113	.4	4300		1.0										10-06-71		R. Knutson
146-93-20 CCA	120	10.0				7.2	665	422		250	48	32	49	2.9	324	0	4.3	70	2.4	1300		19										07-13-72		R. Knutson
146-93-22 ADD	85					6.9	196			31	8.0	2.7	34	2.0	57	0	6.5	38	5.7	6200												08-20-75		G. Buehner
146-93-24 DCC 01	115	8.5				7.6	421	284		140	29	16	34	2.3	113	0	0	113	1.1	142		1.										10-06-71		T. Cook
146-93-24 DCC	115					7.6	707	712		354.2	52.8	33.1	50.8	4.6			5.2	363.8		21	1452	.28	.32		20	7.38	10.86					02-02-77		T. Cook
146-93-26 CBB	60	7.5				7.1	887	607	1.6	300	47	45	62	13	53	0	32	191	22.5	40	300	189	.7									10-05-71		C. Pelton
146-93-29 CCC 1	55					7.0	212	192		59	13	6.4	20	2.0	78	0	9.9	27	-.6	4200		1.0										08-08-73		M. Guenther
146-95-7 DDB 02	40	7.5				7.8	2010	1430	6.0	510	99	64	311	7.2	532	0	3.2	728	-.10	70	20	1.0	.9									11-23-71		A. Robinson
146-95-10 ABA 01	35	-				7.8	3680	2780	9.6	860	137	126	647	6.5	762	0	31	1620	-1.7	30	20	2.5	.9									12-01-71		J. Kupper
146-95-22 DCA	100	-				8.3	2080	1390	14	200	25	34	449	7.1	819	4	1.5	510	-.94	200	20	1.0	.4									11-30-71		C. Klatt
146-95-30 DDD	66	8.0				8.3	1030	635	16	40	8.4	4.6	226	3.4	471	2	2.3	149	-1.1	570	20	1.0	.7									10-19-71		F. Skachenko
146-96-6 BAC	140	-				7.1	528	335	.3	270	57	30	12	3.2	232	0	2.6	92	1.0	12000	760	1.0	.1									11-11-71		T. Band
146-96-11 BAC 02	144	6.0				8.0	436	250	1.1	170	43	15	33	3.1	269	0	1.0	26	-.81	720	40	1.0	.1									11-15-71		W. Lubke
146-96-13 ADA	84	8.0				8.6	1580	1020	28	33	7.7	3.4	368	2.4	599	20	6.7	296	-.33	6700	100	1.0	.7									10-13-72	4483	NDSWC
146-96-24 CBB	140	8.0				8.3	1890	1230	21	87	15	12	441	5.2	242	8	3.8	407	10	1300	10	1.0	.4									11-23-71		J. Ryden

SENTINEL BUTTE FORMATION
Harnisch Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
146-97-25 AAC 01	198					8.5	1950	1270	57	13	2.6	1.6	472	2.4	771	18	1.0	338	1.3	300	20	1.0	.7									11-11-71		A. Olson
146-97-26 AAD	30	8.0				7.8	685	361	.7	330	61	43	28	13	356	0	7.5	77	3.1	30	10	11	.4									11-11-71		A. Olson

SENTINEL BUTTE FORMATION
Twin Buttes Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-93-10 DBB 02	70					7.9	8081			1212	191	179	1552	45	1088	0	0	4780	-12			.4										12-10-75		E. Reiersgaard
144-93-12 DAB	110					7.2	2494			694	107	103	352	23	793	0		1010	-6.8			1.6										11-10-75		J. Reiersgaard
144-94-24 BDD	30					6.8	4531			172	43	16	63	1.5	102	0	22	38	33													08-20-75		P. Roschild
145-88-30 ABB	95					7.11	1099	836		594.2	64.3	44.8	39.1	8.4	394.1		2.4	415.3	-26.55	748	2469	<0.1	.30		6.1	0.77	25			-14.51		03-14-77		E. Weiss
145-88-31 BBC	6.16	9.0	7.77	1180				880	2	468	113	49	107	8.6	508		0.4	315	-1.2	430												07-10-74	F05	Woodward-Clyde Consult.
145-94-6 CCC 01	135	10.0				8.2	698	413	6.0	89	16	12	130	2.4	350	0	2.7	86	-.73	110	180	1.0	0.7									12-19-74	4780	NDSWC
146-89-26 BCA	4					7.47	2346	1599		406	83.6	35.0	369	14.7	893.0		7.6	512	-4.32	1853	374	.27	.48		23.3	53.1	12.5			-15.38		03-14-77		R. Pfennig

SENTINEL BUTTE FORMATION
Twin Buttes Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-87-4 DAB	35					7.18	5083	4392		1601	291	147	649	20.5			166	689.9		63	21.0	1.0	.26		110.3	6.8	14.7			-14.27		03-14-77		Skalsky
143-97-9 CDD	70	11.0				7.7	870	528	2.0	310	75	30	80	1.6	426	0	7.5	124	-.21	0	10	11	.7									08-11-71		M. Stroh
143-97-24 DBB	70	10.0				8.1	779	465	5.9	120	22	15	146	2.9	439	0	4.6	74	-.62	120	10	2.0	1.2									08-12-71		A. Stroh
144-94-13 CCC 2	64					8.2	3563			124	43	1.9	852	16	1054	0	2.0	992	2.5			.1										10-28-75	DC 35-1	UND-EES
144-94-14 BCD	8					6.8	3524			1472	270	194	700	22	437	0	15	2539*	*													10-24-75		D. Harris
145-94-10 ABB 2	40	7.0				7.3	7630	7060		3200	366	55.3	992	14	267	0	103	4290	5.2	1300		424										07-22-71		C. Brown
146-93-23 CBB 3	93					7.4	1646			44	10	4.4	52	3.0	81	0	4.0	40	17			.2										11-13-75	DC 8-3	UND-EES
146-93-23 CBB 03	94	9	6.37	190		7.18	129	173		87.9	1.9	1.6	30	1.7	58.44		2.09	66.30	-21.2	179	125	<0.1	.76		9.5	0.50	11					06-10-77	DC 75-8-3	UND-EES
146-93-23 CBB 03	94	9	6.37	190		7.45	150	1390		76.4	1.6	1.4	29	2.0	59.54		2.51	23.16	-.66	137	126	<0.1	.72		6	0.60	16.5					06-10-77	DC 75-8-3	UND-EES

SENTINEL BUTTE FORMATION
Schoolhouse Bed

Location	Depth (Ft.)	Field Temp °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-87-4 DAC	50					7.21	3462	3050		1551	296	142	196	12.7	427		257	667.2	36.0	35.5	97.2	>2.0	.25		6.1	5.0	15.7			-13.03		03-14-77		Skalsky
141-95-2 DCB	40										602	235	363	6.2	956	0	26	2220	2.1	0	90	248	.3											G. Kadrmas
142-88-22 CDD	67					7.78	1416	790		119.7	10.3	11.2	298	7.1	590.5		3.8	525.7	-17.47	143	19.6	.14	.38		41	3.1	83.3			-9.66		03-14-77		Ballinsky
142-88-34 CAD	100					8.22	2712	1459		32.8	3.8	1.8	616	3.2	1389.6		575	445.7	-27.9	163	4.7	.46	3.22		22	0.93	11.6			-13.28		03-14-77		Boeckel
142-95-33 DCC	64	10.5				7.6	5770	4930	12	1500	330	176	1080	7.4	1630	0	82	2440	-1.1	740	250	1.0	.1									06-08-72		A. Godlevsky
142-96-18 BBA	52	10.0				8.2	3390	2550	3.4	1900	131	98	587	6.8	869	0	19	1180	1.2	140	20	83	1.5									08-10-71		H. Froehlich
143-88-34 DAD	135					7.98	2603	1686		62.2	5.6	4.7	596	8.4	897.9		9.5	565	.09	67.5	14	.29	.92		112	8.9	150			-10.42		03-14-77		Kessler
143-92-3 BAA 01	96	9.5				8.2	1080	685	14	54	11	6.4	240	4.4	547	0	0	138	-.85	310	30	2.5	.5									06-22-72		A. Swenson
143-92-20 DBB	132	10.0				8.0	929	565	34	8	2.1	.7	224	2.2	482	0	0	105	-.65	220	10	.70	.4									06-15-72		R. Smith
144-93-2 DCB	180					8.4	2115			25	8.8	.7	600	6.8	1251	5.1	10	140	5.7													08-21-75		S. Pollestad
144-93-9 DDD 5	132					8.3	3076			104	34	4.6	776	14	571	1.2	5.5	1600	-8.5			1.3										11-03-75	DC 17-3-1	UND-EES

SENTINEL BUTTE FORMATION
Schoolhouse Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error
144-93-11 ABC	158					8.3	1888			24	8.0	1.0	562	5.3	1405	0	7.3	70	.8
144-93-18 ADB 1	22					7.6	3600			767	141	101	700	15	572	0	43	1760	-1.1
144-93-18 ADB 2	32					7.2	1460			161	35	18	328	9.0	433	0	5.8	340	11
144-93-18 ADB 1	22					7.86	1951				25.3	32.1	405.4	10.2	443.47		9.5	611.9	3.59
144-94-7 DAA 3	35					8.0	8460			716	208	48	1800	33	1335	0	7.0	3800	4.0
144-94-13 CBB 2	69					7.6	4563			698	156	75	1016	22	476	0	7.5	1600	17
144-94-14 ADD 1	95					7.4	4682			364	93	32	1430	18	554	0	8.0	2912*	*
145-88-12 CCD 4	surface	8.8				6.67	1250	808	4	363	73	35	158	6.5	434		0.8	329	-1.5
145-90-2 BCB	44					7.48	3827	2569		54.1	3.9	2.8	830	4.5	1096		18.2	720.6	4.59
145-91-11 CDD 02	185	9.0				7.5	2490	1790	14	270	51	34	516	11	795	0	0	694	1.04
145-91-11 CDD	185	12	8.69	2600		7.39	2632	1778			54.6	20.9	520	16.0	793		7.2	709.5	0.90
145-91-20 AAA 02	125					7.4	1630	1200					7.4		400	0	4.4	480	
145-92-6 CCC	55					7.23	1061	834		380.4	45.6	39.8	112.9	7.2	348.3		3.7	319.3	-7.88
145-93-2 CBB	44					8.07	1021	804		233.8	24.2	24.7	164.8	5.8	368.5		3.5	282.5	-6.41
145-93-3 AAA 2	53					7.0	1359			710	161	75	85	6.5	154	0	17	744	-1.2
145-93-4 DDD 2	38					7.4	4050	1200		156	57	3.6	300	10	560	4.0	3.1	480	-1.
145-93-9 DAA 3	58					7.5	1072			600	222	11	85	9.0	249	0	30	515	.1
145-93-9 DAA 03	58	8	6.39	1300	0.35	7.04	1095	991		609	107	66	45	7.6	257.4		4.47	378.6	16.72
145-93-10 ACC 2	30					6.5	3197			1785	305	249	232	9.3	183	0	42	1500	13
145-93-14 ADD	40					7.31	913	1440		438.3	59.0	35.4	68.4	3.4	251.4		8.3	317.7	-10.21
146-91-13 BCA 01	200	8.5				7.6	893	557	2.1	310	64	36	84	7.0	433	0	1.7	150	-1.4
146-91-24 BDB	130					6.75	1880	1407		976.9	159	79.1	80	13.4	681.9		2.5	497.2	-8.4
146-92-29 DDC 01	75	8.0				7.7	1100	720	1.8	380	92	37	81	2.3	311	0	36	124	12.6
146-93-17 CBC	150	9.5				7.0	745	516		370	85	38	26	3.8	374	0	0	126	-.9
146-93-23 CBB 2	129					7.8	1372			128	40	6.8	322	13	478	0	17	290	8.1
146-93-23 CBB 02	129	10	8.34	1300		8.32	112.7	904		130	10	9.0	261	6.6	427.0		4.9	299.7	-2.37
146-93-33 ADD 6	55					7.7	848			288	75	24	103	5.5	234	0	5.5	260	4.9
146-93-33 ADD 06	55	8	7.92	975	0.30	7.31	846	646		342	56	29	78	5.5	242.8		4.07	283.4	-6.84
146-93-33 BAA 01	79					7.6	1032			500	117	51	120	6.8	285	0	1.0	515*	*
146-93-33 BAA 02	70					7.6	906			404	82	49	130	6.5	198	0	7.5	501*	*
146-93-33 BAA 01	79					7.5	962	884		410.5	45.1	50.4	61.2	6.3	298.5		3.5	267.4	-6.77
146-93-33 BDD	60					7.7	831			392	104	32	100	6.8	310	0	1.5	347*	*
146-94-35 ABA	21	10.0				7.1	729	483	.5	370	86	38	20	2.4	284	0	1.9	172	.42
143-91-18 BAD	104	8.5				8.4	795	511	7.0	84	14	12	147	7.9	276	7	0	174	-.54
143-93-3 CCB	24					6.10	1228	870		118.5	7.7	10.0	306.9	5.6	653.2		2.4	220	-2.2
143-96-21 BDD	150	9.0				7.3	548	333	.6	250	64	22	22	7.4	294	0	0	65	-1.2
144-91-34 DDB	40	9		1750		7.43	1773	1269		579.5	82.8	51.4	214	10.4	577		6.8	545.0	-7.86
144-93-9 DDD 3	177					8.5	2564			92	30	4.4	666	16	744	4.8	18	856	0.8

Location	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-93-11 ABC													08-21-75		S. Follestad
144-93-18 ADB 1													08-22-75		A. Wermager
144-93-18 ADB 2													08-22-75		A. Wermager
144-93-18 ADB 1	116.7	113.0	> 2	.15		48.7	3.5	50.0					02-16-77		A. Wermager
144-94-7 DAA 3			.1										10-29-75	DC 30-1	UND-EES
144-94-13 CBB 2			1.6										10-28-75	DC 48-1	UND-EES
144-94-14 ADD 1													10-25-75		J. Hueske
145-88-12 CCD 4	5000	110		.33		15	<5	38	<5	<10			07-02-74	FD3	Woodward-Clyde Consult
145-90-2 BCB	400	19.1	.195	.95		65.3	3.6	503			-13.71		03-14-77		N. Sailer
145-91-11 CDD 02	0	300	.50	.4									07-11-72		E. Morast
145-91-11 CDD	954	277	<.1	.35		16.8	13	42			-11.74		03-14-77		E. Morast
145-91-20 AAA 02	7400		.0										10-07-71		O. Flaget
145-92-6 CCC	1392.0	292				33.3	2.7	1.7					02-16-77		McMahen
145-93-2 CBB	178.3	342.5	.1	.53		18.8	5.16	49.2					02-02-77		S. Pelton
145-93-3 AAA 2			0										11-13-75	DC 42-2	UND-EES
145-93-4 DDD 2	200		1.0										11-13-75	DC 41-1	UND-EES
145-93-9 DAA 3			.1										11-13-75	DC 11-3	UND-EES
145-93-9 DAA 03	5300	1300	<0.1	.29		4	0.84	45.0					06-13-77	DC 11-3	UND-EES
145-93-10 ACC 2													08-19-75		A. Hansen
145-93-14 ADD	50.6	25.2	.95	.45		1572.0	7.4	3.0					02-16-77		R. Borth
146-91-13 BCA 01	6700	50	1.0	.5									09-28-71		H. Wiedner
146-91-24 BDB	1175	807	<0.1	.09		5.8	1.90	16.3					03-14-77		Weidner
146-92-29 DDC 01	0	20	181	1.1									09-30-71		J. Schettler
146-93-17 CBC	3100		2.5										07-12-72		R. Knutson
146-93-23 CBB 2			1.1										11-13-75	DC 8-2	UND-EES
146-93-23 CBB 02	55.4	59	<0.1	1.2		50	1.20	64.2					06-09-77	DC 8-2	UND-EES
146-93-33 ADD 6			.4										11-13-75	DC 10-6	UND-EES
146-93-33 ADD 06	1961	645	<0.1	.62		5.4	0.32	15					06-15-77	DC 10-6	UND-EES
146-93-33 BAA 01													10-30-75		H. Eckelberg
146-93-33 BAA 02													10-31-75		H. Eckelberg
146-93-33 BAA 01	3	677.4	.125	.37		11.1	3.16	6.0					02-02-77		G. Eckelberg
146-93-33 BDD													10-30-75		H. Eckelberg
146-94-35 ABA	940	350	1.0	.4									07-14-72		J. Connolly
143-91-18 BAD	230	30	2.6	.5									06-23-72		J. Schweitzer
143-93-3 CCB	1222.0	44.6	.52	.58		74.8	11.5	3.4					02-16-77		C. Nodland
143-96-21 BDD	90	10	2.6	.2									06-14-72		F. Kubik
144-91-34 DDB	468	197	.16	.41		32	1.3	10.7					03-14-77		C. Plotski
144-93-9 DDD 3			.9										11-03-75	DC 17 2C-2	UND-EES

SENTINEL BUTTE FORMATION
Schoolhouse Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-94-24 BDB	190					8.1	2668			56	12	6.3	738	10	606	0	1.5	990	-4.5													08-20-75		P. Roschild
145-91-5 DDD 03	170	8.0				8.2	565	359	2.1	170	36	19	64	4.0	270	0	4.1	83	-.84	20	280	1.0	.8									07-23-74	4604A	NDSWC
145-93-10 AAC 1	91					7.5	1108			370	74	45	148	6.8	350	0	3.3	410	-1.3													08-19-75		A. Hansen
145-93-10 CBC 1	136					6.7	755			316	72	33	20	4.5	125	0	53	210	-4.1													08-19-75		C. Hansen
145-93-10 CCC	161					7.9	2014			221	45	26	426	16	762	0	1.8	630	-4.8													08-19-75		C. Hansen
145-96-21 DDD	79	8.5				8.4	2920	1980	56	32	8.4	2.7	730	3.5	1230	18	5.9	590	-1.1	120	100	1.0	.5									07-30-74	4736	NDSWC
146-85-29 DCD	24	2	6.62	2400		7.61	2260.5	1800		884.3	74.9	145.5	258	4.8	709		9.12	658.39	2.8	567	39.6	5.4	.19		9.3	.60	6.3					12-15-76		E. Oster
146-91-14 DDB	210	13	8.40	900		7.29	739	439		320.5	37.1	34.2	48	4.9	355		3.2	365.6	-32.5	4853	598	.16	.48		5	.20	4.4			-15.43		03-14-77		Gegelman
146-92-27 DDD	58	10				8.1	407	231		140	34	13	37	2.9	220	0	2.9	38	-.34	0		1.0										07-24-74	4709	NDSWC
146-92-32 CDD	80	8.0				7.9	810	506		270	53	33	66	5.0	275	0	25	107	5.7	100		65										09-30-71		C. Christensen
146-93-33 ADD 5	90					7.9	1247			400	82	48	112	14	361	0	14	240	7.8			.7										11-13-75	DC 10-5	UND-EES

SENTINEL BUTTE FORMATION
Beulah-Zap Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-88-10 BBD	100					7.96	2944	1851		118.1	12.5	14.0	431	7.5	753.9		9.5	708.4	-13.87	173	12.2	0.24	0.58		57.2	32.8	187.5			-13.53		03-14-77		Kemmett
142-87-3 DDD	44					7.20	1649	1220		729	60.9	71.6	117	7.3	662.5		51.3	301.9	-13.4	477	18.3	>2.0	0.22		7.9	1.5	14.4			-13.34	83± 10	03-14-77		C. Zuern
142-87-30 BAC	248					7.49	1141	709		580.3	73	48.7	44	6.9	586.8		11.5	478.3	-34.3	60.2	3.2	>2.0	0.21		21.6	0.76	4			-13.76		03-14-77		J. Schutt
142-95-27 BCC	56					8.2	745	473	3.3	180	36	22	101	3.3	371	0	11	82	- .12	0	100	9.9	.7									08-09-71		L. Bahley
143-88-21 CAC	105	9		2000		8.10	2228	1307		113.9	11.6	7.6	485	7.1	890		30.2	475.7	-5.98	165	8.0	> 2.0	0.54		23	6.4	49.3			-13.24		03-14-77		Fetch
143-88-25 DAD	30	14	8.98	1900		7.12	1944	1387		28.9	92.9	62.0	216	12.3	531.9		7.2	615.4	-5.9	14600	202	0.12	0.20		15	2.7	7.8					03-14-77		Orth
143-91-11 CBA	88	8.0				7.1	996	681	.4	530	123	55	19	8.3	445	0	0.0	207	.43	5700	350	1.0	0.2									06-26-72		W. Streifel
143-96-10 DCB	50	10.0				7.9	767	484	1.7	270	60	30	65	2.5	341	0	13	125	-1.2	730	10	1.0	0.9									08-12-71		J. Bullinger
144-88-31 BBC	70					9.06	3038	3390		53.8	28.4	44	985	31.4	1520.1		18.9	1024.7	2.01	243	306	1.6	0.48		1000	9.2	33.9					10-05-77	IH 6	NACCO
144-89-4 BAD	40	1		2000		7.39	2220	1530		752.9	131	91.1	208	18.0	723		20.9	582.8	-2.16	169.7	405.8	<0.1	0.44		12	4	11.8			- 13.63		03-14-77		B. Horning
144-89-35 AAD	70					7.41	4724	3969		colored	31.6	35.8	1090	14.1			17.4	colored		689	63.3		0.17		100.0	8.3	406			-6.17		03-14-77		A. Fuchs
144-89-36 BBB 1	65.2	7	7.66	6250		9.10	4437	3380		37.2	19.4	12.8	1039	31.4	1455.5		25.0	1211.4	-1.81	271	121	0.3	0.42		263	18.4	309					10-06-77	IH 14	NACCO
144-89-36 BBB-2	69	8	7.28	7000		9.03	5587	4390		124.4	63.5	30	1107	35.3	1662.9		37.7	1605.7	-6.05	1642	1283		0.30		164	90	64					10-06-77	IH 117	NACCO
144-89-36 CCC	108	14	7.83	1475		7.61	1508	938		116.1	76.7	29.9	305	21.4	445.3		8.2	408.6	10.6			0.92	0.40									10-13-77	IH 98	NACCO
144-89-36 CCB	121		7.52	1590		8.36	1497	990		121.0	185.9	37.8	278	18.5	414.8		10.0	434.2	21.49	215	395	>3.0	0.39		18.7	1.5	13.3					10-13-77	IH 99	NACCO
144-93-7 AAB 01	80					7.7	1938			267	53	33	392	13	739	0	1.0	550	-1.9													08-21-75		I. Kling
144-93-7 CDD 01	107					8.3	2205			34	14	0.0	600	8.5	805	0	3.0	476	7.6			0.1										10-31-75	DC 23-1	UND-EES
144-93-7 DCD 01	107					8.5	1885			42	6.4	6.3	564	9.5	1305	9.6	7.0	178	0.0			0.2										11-04-75	DC 24-1	UND-EES
144-93-8 ABB 02	140					7.2	3097	2084		103.0					1326		8.4	480.0		668.3	27.8			0.06	41	5.4	63.4					11-23-76		H. Kling
144-93-8 BCB 4	80					9.7	2307			40	2.2	1.8	580	41	722	114	5.0	418	4.0			1.6										11-03-75	DC 16-3C-2	UND-EES
144-93-9 DDD 02	222					8.5	1651			62	6.2	11	446	22	1000	6.0	7.5	50	5.7			0.8										11-03-75	DC 17-2C-1	UND-EES
144-93-17 ADA 01	98	8.5				8.4	2760	1890		95	20	11	670	5.1	1160	14	2.0	560	0.6	200												07-19-74	4724	NDSWC
144-93-23 ADA 02	220	11				8.0	2000	2069		42	8.0	5.3	608	6.3	1548	0	13	145	-2.3	1000		0.0										06-18-75		E. Rohde
144-93-23 ADA 02	220	12				8.3	2060	1595		30	7.2	2.9	658	6.6	1459	0	0.8	130	4.9			0.0										07-22-75		E. Rohde

SENTINEL BUTTE FORMATION
Beulah-Zap Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-93-23 ADA 02	220	10				8.2	2215	1544		26	8.8	1.0	625	6.1	1462	0	7.3	140	1.4	2200		0.0										10-29-75		E. Rohde
144-94-4 ADA	50	10				6.9	1800	1611		880	198	93	135	5.7	417	0	5.2	480	16	1000		0.0										06-18-75		Iverson Brothers
144-94-4 ADA	50	8.0				7.3	1750	1664		905	244	72	138	6.4	421	0	18	860	-2.3			5.8										07-22-75		Iverson Brothers
144-94-4 ADA	50	5.5				6.9	1963	1603		884	248	64	73	6.2	433	0	35	620	-0.3	3000		7.6										10-29-75		Iverson Brothers
144-94-10 DAA 02	60	11				6.6	2000	1960		1188	352	75	60	5.5	373	0.0	3.9	880	3.8	8000		0.2										06-18-75		G. Schmidt
144-94-10 DAA 02	60	9.0				6.5	1725	1784		1100	352	53	58	6.0	332	0.0	33	940	-2.7			0.1										07-22-75		G. Schmidt
144-94-10 DAA 02	60	7.0				6.6	1812	1661		1048	334	52	71	5.9	360	0.0	38	790	1.6	15000		0.6										10-29-75		G. Schmidt
144-94-10 DAA 02	60					6.6	1787			1152	299	98	95	6.0	302	0.0	26	1037 *	*													10-24-75		G. Schmidt
144-94-13 DAD 02	107					8.4	3641			112	30	8.7	900	12	1003	7.2	18	1640	-7.4			1.0										11-19-75	DC 3-2	UND-EES
144-94-23 ADD 02	198					8.5	1795			172	48	13	446	22	776	6.0	14	304	8.7			0.5										10-29-75	DC 18-2C-1	UND-EES
144-94-34 BAB 2	97					8.0	3030	2240	39	64	11	8.9	710	5.8	743	0	6.2	1000	-1.3	410	20	1.0	0.5									08-13-73		B. Trampe
145-86-1 DDD	35	3	5.93	3100		7.30	3318	3664		2033.9	242	383	236.8	12.0	306		52.48	682.86	44.7	90	1320	3.2	0.15		30	3.3	10.5					12-15-76		H. Reichenberg
145-86-12 BBB	40	3	6.73	1400		7.84	1242.6	992		509.9	47.7	40.0	209	10.8	467		5.13	315.46	2.3	67.4	1600	1.2	0.13		16	0.65	6					12-15-76		E. Richter
145-87-19 CCB	114.8	11.2				8.77	650	482	3	143	24	20	99	7.4	242		5.6	123	4.7	10500	160		1.0		390	<5	200	<5	10			07-06-74	G25	Woodward-Clyde Consult
145-87-30 ADB	103	10.9				7.28	1275	1530	5	660	85	71	250	9.2	652		8.8	599	-5.0	8900	160		.63		490	5	390	<5	10			07-06-74	C09	Woodward-Clyde Consult
145-90-16 BBB	14					7.97	1265	817		247.5	44.6	25.6	222	11.8			4.6	405.3		1114	350	<0.1	1.23		11	1.3	5			-14.13		03-14-76		A. Stuhmiller
145-92-12 DCC 01	24	9.0				7.0	672	452		170	30	20	72	4.2	192	0.0	0.0	179	-1.2	4300		2.5										07-11-72		C. Ferebee
145-92-14 BAD	12	6.0				6.7	712	416		230	41	30	70	4.2	238	0.0	3.9	175	0.1			0.1										11-10-71		C. Ferebee
145-92-22 DAA 02	83	8.0				7.8	1760	1180	26	46	6.5	7.3	414	3.8	691	0	0.0	372	2.2	200	20	1.0	0.9									07-11-72		T. Ferebee
145-93-3 AAA 01	114					7.8	1154			536	126	54	103	7.3	371	0.0	8.0	436	-0.1			0.6										11-13-75	DC 42-1	UND-EES
145-93-4 BBC 02	170					7.7	1372			680	205	41	141	13	537	0.0	1.5	470	3.6			0.6										11-13-75	DC 7-2	UND-EES
145-93-4 DDD 01	109	8.0				8.3	1740			280	54	35	40	2.0	98	0.0	2.0	120	8.2			0.5										11-13-75	4776	NDSWC
145-93-9 DAA 02	135					8.0	2544			324	83	29	516	34	869	0.0	18	608	4.2			0.0										11-13-75	DC 11-2	UND-EES
145-93-9 DAA 02	135	9	7.776	2400	0.15	8.06	2379	1877		288	35	36	537	21.8	880.8		5.25	759.2	-3.00	40	136	<0.1	<0.1		28.9	1.7	72.5					06-13-77	DC 11-2	UND-EES
145-93-10 CBC	150					6.96	512	480		194.7	15.3	16.3	22.1	3.0	58.8		23	224.9	-33.4	290	5753	.23	.5		86.4	6.14	5.71					02-02-77		H. Hansen
145-93-14 ADD	140					7.46	1110	812		335.9	32.2	36.1	128.4	8.2	251.4		2.8	314.8	-10.26	772.0	141.7	.28	.22		14.9	9.0	7.2					02-16-77		R. Borth
145-93-16 CBB 03	179					7.4	798			320	80	29	96	18	342	0.0	19	200	3.4			1.0										11-13-75	DC 6-3-1	UND-EES
145-93-29 BCA	75					8.21	1833	1330		64.2					789		5.9	156.3		59.2	10.7			0.35	16	1.5	61.5					11-23-76		G. Lynch
145-93-29 BCA	75					7.88	1818	1538		130.6	8.8	9.7	394.3	8.0	711		2.5	486.4	-8.06	700	35.0	1.43	1.1		21.0	3.4	28.6					02-16-77		G. Lynch
145-93-32 BBB 02	55	8.0				7.3	10000	9090		2700	283	494	1820	14	728	0.0	239	5210	2.7	3900		251										10-21-71		W. Benz
145-93-32 DAA	82					7.4	1888			392	104	32	453	9.0	551	0.0	6.0	891*	*													10-25-75		E. Trampe
145-93-33 BBC	90					8.3	2644			42	14	1.4	712	9.0	1201	0.0	5.0	556	1.0			0.0										11-17-75	DC 66	UND-EES
145-94-19 CCC	145	8.0				9.1	933	575		17	2.2	2.8	220	1.3	430	44	2.3	71	7.3	200		1.0										12-10-74	4781	NDSWC
145-94-22 BCC	78					8.32	1964	1534		41.1	3.7	7.3	501.7	5.6			7.0	392.4		200.0	23.4	.63	1.3		53.3	8.15	12.9				29± 10	02-02-77		L. Grow
145-94-26 AAA 04	26	8.0				6.5	2550	2080		470	88	61	400	10	400	0.0	3.1	1000	-0.7	21000		9.8										12-05-74	4794C	NDSWC
145-94-26 AAA 04	26	8.0					2690	2020		500	83	71	420	13	418		6.4	1100	-2.3	700												01-07-75	4794C	NDSWC
145-94-34 AAD 01	58					8.1	1521			280	61	31	352	15	603	0.0	6.0	384	8.2			2.4										11-20-75	DC 68	UND-EES
145-94-34 DDA 03	70					7.3	1102			358	91	32	146	14	449	0.0	6.0	270	2.6			0.2										10-27-75	DC 33-3	UND-EES

SENTINEL BUTTE FORMATION
Beulah Zap Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
146-86-21 DAD 2	160	14	6.84	1500		7.15	1886	1274		87.2	7.8	5.7	388	30.2	185.4		12.3	335.2	28.2	1552	39.1	< 0.1	0.24		22.3	40.6	28.9			-11.07	-9 + 8	03-14-77		D. Reichenberg
146-86-32 DDD	147	8		1300		8.18	1730	1110		65.3	4.5	6.0	397	6.7	773		9.5	497.9	-12.47	1800	41.7	0.25	0.46		16	1.6	31.8			-14.03		03-14-77		R. Miller
146-87-21 DCC	135.3	9.0				7.88	1000	741	3	369	73	36	126	7.3	564		5.6	142	-.32	7400	230		1.4		750	17	12	< 5	< 1			06-29-74	G23	Woodward Clyde Consult
146-87-27 ACC	160.7	9.2				6.98	1190	934	2	529	87	53	115	9.2	590		15	256	-5.0	10100	360		1.4		630	25	12	< 5	< 1			06-29-74	G16	Woodward Clyde Consult
146-91-22 BBA 02	235	10.0				8.9	2200	1490	91	7	1.8	.6	550	2.3	863	62	0.0	401	-1.0	620	30	1.0	.6									07-12-72		G. Gegelman
146-93-22 CCC	90					7.5	1586			144	34	15	356	8.8	721	0.0	0.8	300	1.4													08-20-75		G. Buehner
146-93-26 CBB 02	66					6.3	906			300	50	43	83	5.0	57	0.0	50	125	33													08-20-75		C. Pelton
146-93-27 ADD 02	94	12	7.06	3000	0.7	7.84	2257	2256		575	97	63	501	16.2	777.1		5.01	1031.9	-3.23	36.5	263	< 0.1	.36		25.8	0.83	33.8					06-07-77	DC 9-2	UND-EES
146-93-27 CCC	76	9.0				8.1	1030			420	95	44	73	5.6	340	0.0	5.2	300	-1.2	0.0												07-24-74	4746	NDSWC
146-93-28 AAA 02	76	8.0				8.0	909			430	100	44	40	4.7	450	0.0	2.0	150	-.38	100												11-22-74	4777A	NDSWC
146-93-28 ADD	100					7.3	7149			280	62	30	116	6.5	268	0.0	2.0	304*	*													10-29-75		E. Buehner
146-93-28 DDB 02	98					7.4	831			248	61	23	148	7.5	320	0.0	1.5	302*	*													10-30-75		W. Eckelberg
146-93-28 DDB 03	90					7.4	831			220	56	19	176	7.0	337	0.0	1.5	318*	*													10-30-75		W. Eckelberg
146-93-33 AAB	110					6.6	1636			956	189	118	112	7.0	398	0.0	16	827*	*													10-29-75		E. Pelton
146-93-33 ADD 04	120					7.7	848			340	91	27	136	7.5	356	0.0	5.5	258	6.3			0.2										11-13-75	DC 10-4	UND-EES
146-93-33 ADD 04	120	8	6.94	925	0.35	7.68	849	664		326	59	29	90	6.9	356.2		5.13	233.5	-7.01	42.7	408	< 0.1	.14		4.1	0.80	10.8					06-14-77	DC 10-4	UND-EES
146-93-34 ADA 01	139					6.7	1963			1194	255	135	107	9.0	211	0.0	9.8	1400	-6.7													08-20-75		C. Buehner
146-93-34 ADD	137					7.4	982			376	87	39	23	6.5	415	0.0	1.0	160	-7.9													08-20-75		G. Buehner
146-94-24 DDD 02	60	9.0				7.9	442	274		130	26	16	53	2.3	249	0.0	1.6	46	-1.1	0.1		2.5										10-07-71		R. Krieger
146-94-25 ABA	89	8.0				8.2	706	429		270	64	27	55	3.6	360	0.0	5.9	87	0.1	0.4		1.0										07-25-74	4741	NDSWC

SENTINEL BUTTF FORMATION
Beulah-Zap Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
143-91-19 AAA 03	149	9.0				7.8	2530	1890	7.0	590	140	58	390	10	590	0	3.1	940	-.60	0	140	3.1	.7									07-02-74	4602B	NDSWC
143-96-27 DBB	175	11.0				8.5	3440	2370	27	170	30	23	821	3.9	1240	21	13	843	.33	500	20	1.0	5.1									08-12-71		R. Schneider
144-94-1 CBC	42					7.9	8729			824	18	190	2615	28	822	0.0	5.5	4850	6.6			4.9										10-21-75	DC 54-1	UND-EES
144-94-1 CCC	48					8.2	5640			456	96	52	1400	22	1010	0.0	5.5	2480	1.6			1.5										10-22-75	DC 28-3-1	UND-EES
144-94-16 AAA 04	169					8.5	2769			46	6.6	7.2	711	17	1047	8.4	6.0	680	0.8			0.2										10-27-75	DC 19-3	UND-EES
144-94-16 ABB	85					8.0	2694			130	47	2.9	652	12	615	0.0	5.0	1030	-0.6			0.1										10-27-75	DC 61	UND-EES
145-93-6 CDC 04	100					8.3	1122			412	97	41	246	8.5	442	1.2	0.0	248	27			0.4										11-14-75	DC 12-3	UND-EES
145-93-21 DAA 04	117					8.6	2282			64	18	4.8	550	11	947	13	7.5	448	0.1			0.2										11-10-75	DC 13-3C-2	UND-EES

SENTINEL BUTTE FORMATION
Spaer Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-88-11 DDD	115			2950		8.12	3209	2091		51.4	3.7	2.4	797	7.1	1779		34.6	390.5	-4.12	89.4	10.2	0.14			33	11.7	81.6			-13.08		03-14-77		Tri-County Imp. Inc.
144-88-30 DDA	43					8.08	6390	4438		84.2	328	231	515	88			5.9			118	1325		0.2		118	17.3	30.0					08-30-77	MSU 17	NDGS
144-92-4 DBB	100	3.0				7.0	2520	2430	.6	1600	390	150	56	11	554	0	17	1200	-.03	100	520	2.5	.3									08-06-73		E. Nordahl
144-93-8 BCB 03	115					8.1	2025			312	24	61	428	14	670	0.0	0.0	644	1.6			1.4										11-03-75	DC 16-3C-1	UND-EES

SENTINEL BUTTE FORMATION
Spaer Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-94-1 CBB	62					8.6	4768			162	63	0.9	1260	26	1000	12	6.5	2780	-12.1			2.0										10-24-75	DC 53-1	UND-EES
144-94-2 DBC 01	71					7.4	1097			356	102	25	212	6.5	405	0.0	0.0	290	13			0.1										11-12-75	DC 58-1	UND-EES
144-94-5 BBC	35					7.36	1606	1184		477.4					606		11.9	150.4		588	675			0.33	39	0.25	233.7					11-23-76		F. Fritz
144-94-7 DAA 08	90					8.2	3128			152	40	7.5	776	14	869	0.0	6.5	1020	2.0			0.4										10-29-75	DC 30-5	UND-EES
144-94-7 DAA 09	133					8.5	2153			53	20	0.5	580	9.0	1030	6.0	5.0	478	-1.2			0.2										10-29-75	DC 30-6	UND-EES
144-94-7 DAA 01	127					8.4	2215			56	13	7.8	630	7.5	1069	3.6	12	530*	*													10-29-75		F. Fritz
144-94-12 AAB	65	10				7.2	2000	1653		600	136	63	324	9.0	795	0.0	36	640	- 2.6	0.5		20										06-18-75		R. Mjolhus
144-94-12 AAB	65	8.0				7.5	1845	1529		810	258	40	204	9.2	650	0.0	56	480	6.2			7.0										07-22-75		R. Mjolhus
144-94-12 AAB	65	6.0				7.0	2265	1612		588	184	31	328	6.0	742	0.0	44	500	4.5	0.6		4.8										10-29-75		R. Mjolhus
144-94-34 BAB 02	100	12				7.8	3000	2190		42	14	1.9	749	7.4	770	0.0	3.5	914	2.9	0.0		0.0										06-18-75		B. Trampe
144-94-34 BAB 02	100	10				8.1	2815	2190		70	14	8.3	758	8.2	733	0.0	3.5	980	3.0	0.0		0.0										07-22-75		B. Trampe
144-94-34 BAB 02	100	12				8.0	2970	2134		73	18	6.6	768	8.3	744	0.0	0.5	1000	3.0	0.0		0.0										10-29-75		B. Trampe
145-85-5 ADA	68	2	7.11	1900		7.98	1708	1316		608.9	73.9	59.0	500	16.6	582		15.85	492.76	20.5	1255	119	7.3	0.18		12.6	0.8	7.0					12-15-76		E. Pischel
145-86-6 CDD	180			2450		8.01	2944	1949		68.7	7.5	5.3	667	7.9	1630		33.1	344.9	-7.4	148.6	19.5	0.50	0.81		31	28.9	3.82			-13.65		03-14-77		E. Wiedrich
145-86-10 AAC	80	1	6.07	1100		7.72	1025.7	890		471.86	31.6	54.1	45.8	6.7	221		39.81	179.18	-1.7	250	195	5.5	0.10		54	0.75	9.4					12-15-76		L. Weisz
145-86-10 DBA	60	4	6.56	5900		8.05	4055	3706		1765.77	201.9	244.6	792	6.4	1346		34.67	706.2	26.4	200	6112	3.9	0.24		18	10.0	10.8					12-15-76		D. Weisz
145-86-11 CDD 01	100	12				7.4	1550	1050	3.8	469	116	44	190	10	720	0	4.3	311	-1.29	3600		0	.2									06-12-68		E. Richter
145-93-16 CBB 01	227					8.5	2319			88	29	3.9	607	16	1166	9.6	32	290	3.8			0.9										11-13-75	DC 6-2C-1	UND-EES
145-93-27 ABC 03	37					7.9	2077			152	32	17	500	9.0	783	0.0	3.5	604	-1.0			0.6										11-13-75	DC 32-3	UND-EES
145-93-27 ABC 03	37	10	7.5	2400	1.2	7.79	1890	1614		276	27	25	501	7.8	843		5.50	552.8	-.18	197	70.7	< 0.1	1.15		16.4	0.7	50.8					06-01-77	DC 32-3	UND-EES
145-93-29 CDB						8.30	1953	1564		85.3					1190		7.9	colored		340	21			col-ored	21	41.3						11-23-75		M. Kling
145-93-33 BAA 02	128					8.6	2694			100	35	2.9	666	13	1047	11	14	710	-2.2			0.1										11-10-75	DC 5-3	UND-EES
145-93-33 BBB 01	80					8.3	2344			136	35	12	600	14	1098	0.0	4.0	496	1.2			2.2										11-10-75	DC 67-1	UND-EES
145-93-33 BCC	155					8.8	2743			42	17	0.0	752	13	1261	30	7.0	320	8.6			0.0										11-12-75	DC 65	UND-EES
145-93-36 BCC 03	167					8.4	2461			44	12	3.4	622	16	1320	7.2	15	172	4.5			1.0										11-04-75	DC 15-3	UND-EES
145-94-10 CCB	238	7.0				8.4	2220	1500		78	21	6.2	565	2.3	1100	18	1.6	322	3.8	0.0		2.5										10-27-71		H. Reiss
145-94-26 AAA 03	68	8.5				7.7	2420	1660		210	41	26	500	5.3	700	0.0	3.8	740	-1.7	0.3		0.9										12-04-74	4794B	NDSWC
145-94-26 AAA 03	68	10					1775	1760		250	50	31	540	6.7	688		4.3	820	0.4	0.3		1.0										12-15-74	4794B	NDSWC
145-94-26 BDD 2	61	8.0				8.0	2110	1470		22	4.2	2.8	500	2.9	713	0.0	0.0	524	-0.7	0.5		1.0										07-11-72		Hinty Bldg.
145-94-32 DCC 01	38					7.5	1873			80	26	3.9	580	7.5	869	0.0	14	596*	*													10-08-75		C. Murphy
146-85-29 DCD	127	3	7.79	1900		8.39	1711.3	1168		47.46	3.0	4.35	418.9	4.8	999		4.47	210.43	-5.1	831	13.5	0.6	0.10		17.5	0.85	15.6					12-15-76		E. Oster
146-93-33 ADD 03	150					8.5	1746			32	8.8	2.4	468	7.0	905	9.6	34	192	2.6			0.4										11-13-75	DC 10-3	UND-EES
146-93-35 BCC	165					7.4	906			374	90	36	78	6.0	399	0.0	1.8	215	-.32													08-20-75		G. Buehner
146-94-25 AAA	143	13				8.3	950	610		64	14	7.1	210	3.9	420	4.0	5.6	150	1.7			1.0										07-25-74	4742	NDSWC

SENTINEL BUTTE FORMATION
Spaer Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
143-93-7 CCC 04	84	9	7.70	5000		7.95	3637	3175		821	133	115	729	18.1			7.08	939.2	13.92	128	194	.409	.51		42.2	0.87	63.3					06-17-77	DC 1-4	UND-EES
143-93-14 AAD 01	245					8.7	2205			99	26	8.2	562	95	1171	22	7.0	236	3.4			0.2										11-10-75	DC 39-1	UND-EES

SENTINEL BUTTE FORMATION
Spaer Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
143-94-20 DCC	104	8.5				8.1	3710	2690		190	44	19	890	7.3	1250	0.0	4.0	1100	-1.0	0.4		1.0										06-19-74	4683	NDSWC
143-94-34 BAD	40	9.0				8.1	748	434	.8	320	63	39	32	2.1	309	0.0	27	79	2.2	70	10	9.1	.8									08-17-71		M. Jordan
144-91-30 AAA 02	516	10.0				8.6	2400	1580	26	110	17	16	610	7.0	1440	40	14	150	-.77	40	30	1.0	1.1									07-02-74	4603A	NDSWC
144-93-7 AAB 02	140					7.1	2417			406	95	41	493	13	671	0.0	14	1000	-3.7													08-21-75		J. Kling
144-93-20 ADA 03	260					8.4	3025			60	20	2.4	790	7.5	1035	3.6	4.0	956	1.9			0.9										11-04-75	DC 29-3	UND-EES
144-94-1 BCB 02	160					7.9	2644			358	80	38	600	14	769	0.0	3.0	880	3.9			1.4										10-24-75	DC 55-2	UND-EES
144-94-1 CCC 05	99					9.6	2538			36	9.6	2.9	646	48	869	134	18	516	0.1			0.2										10-22-75	DC 28-4C-2	UND-EES
144-94-1 CCD 01	114					8.3	3066			60	19	2.9	906	9.0	1227	0.0	8.5	720	7.2			0.4										10-22-75	DC 50-1	UND-EES
144-94-1 DAA	100					8.6	1721			54	17	2.9	492	9.0	746	6.0	5.5	320	8.2			0.5										10-24-75	DC 60-2	UND-EES
144-94-7 DAA 01	127	7.5				8.5	2310	1530	53	22	5.4	2.1	570	3.0	1040	33	.7	370	-1.1	540	10	1.0	4.4									11-30-73		F. Fritz
144-94-12 ABA 02	125					8.4	3066			46	12	3.6	874	7.5	1069	2.4	4.0	856	4.8			0.6										10-24-75	DC 51-2	UND-EES
144-94-35 ADD	158					7.9	1661			288	59	34	464	7.0	795	0.0	23	597*	*													10-22-75		M. Bergurud
144-94-35 ADD	158					6.20	1444	1008		116.6	43.6	26.6	275.1	6.3	744.6		18	232.3	-3.08	646.0	57.0	>2	.82		27.4	4.4	6.0					02-16-77		M. Bergurud
145-91-16 CCC	250					7.2	2520	2200							1530	14	60	24		620		4.0										10-07-71		O. Flaget
145-92-25 AAC	74	10				7.9	5220	4880		2200	415	288	591	12	760	0.0	47	2640	1.2	0.7		211										09-13-72	72-1	NDSWC
145-92-28 DAA 02	164					8.4	2410			88	19	9.7	690	14	1713	6.0	24	120	1.0			0.2										11-10-72	DC 31-2	UND-EES
145-93-6 CDC 02	220					8.4	2394			54	21	0.5	646	5.5	1125	6.0	10	440	2.2			0.4										11-14-75	DC 12-2-1	UND-EES
146-93-33 ADD 02	215					8.6	1905			84	5.4	11	488	23	933	14	12	210	3.5			0.0										11-13-75	DC 10-2	UND-EES

SENTINEL BUTTE FORMATION
Jim Creek Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-92-8 CAC 01	50					7.3	1963			722	140	91	232	14	527	0.0	3.5	950	-6.8													08-22-75		J. McNamara
144-92-8 CAC 02	46					7.6	2240			392	73	51	405	16	624	0.0	13	730	0.1													08-22-72		J. McNamara
144-93-9 DDD	335					8.6	2666			68	26	0.5	700	11	1100	17	9.0	556	2.6			1.0										11-03-75	DC 17-4	UND-EES
144-94-5 BBB	160					8.2	3323			60	16	4.9	900	8.0	944	4.8	3.5	1200*	*													10-10-75		F. Fritz
144-94-5 BBB	160					8.19	3458	2520		84.9					985		8.4	509.8		12.2	60.7			0.06	5	2.2	20.3					11-23-76		F. Fritz
144-94-6 BDB	80					8.3	2039			16	4.8	1.0	614	3.5	947	6.0	12	540*	*													10-09-75		T. Stroh
144-94-6 CBB 01	205					8.4	2307			52	15	3.4	692	7.5	1305	6.0	8.0	218	7.0			0.8										10-29-75	DC 45-1	UND-EES
144-94-6 CBB 01	205					8.68	2380.8	1690		76.9					1565		12.59	225.69		650	650.3	colored	2.27		21	1.8	12.6					11-19-76	DC 45-1	UND-EES
144-94-7 DAA 06	195					8.2	2359			140	42	8.2	666	8.8	1710	0.0	25	1000	-22			0.8										10-29-75	DC 30-4C-1	UND-EES
144-94-16 BAB 02	165					7.9	2999			228	69	14	646	19	786	0.0	5.5	550	15			0.9										10-27-75	DC 26-1-2	UND-EES
144-95-1 BBD	65					7.5	1611			29	8.0	2.2	405	6.8	781	0.0	1.5	260	0.3													08-22-75		J. Schdlmeyer
145-92-30 BBB 01	100	8.0				8.3	2180	1450		10	2.9	0.7	560	2.7	1170	9.0	3.5	254	0.1	0.0		1.0										08-04-71		Peavy Elevator
145-93-21 CDD	100	11.0				8.1	1850	1275		12	4.8	0.0	493	3.7	861	0.0	2.7	370	-0.3	0.0		0.0										06-18-75		G. Lynch
145-93-21 CDD	100	9.0				8.5	1705	1277		20	6.4	1.0	501	4.5	770	28	<1.0	310	6.3	0.0		0.0										07-22-75		G. Lynch
145-93-21 CDD	100	8.0				8.3	1863	1218		30	11	0.5	496	3.8	838	0.0	1.5	275	6.6	0.6		0.0										10-29-75		G. Lynch
145-93-22 DCA 01	130					8.4	1812			10	4.0	0.0	426	4.3	828	2.6	2.8	300	-2.9			-										08-19-75		P. Hausauer
145-93-27 ABC 02	120					8.2	2051			20	7.2	0.5	562	5.0	1049	0.0	2.0	200	7.7			0.7										11-03-75	DC 32-2	UND-EES

SENTINEL BUTTE FORMATION
Jim Creek Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
145-93-27 ABC 02	120	10	8.325	2075	0.1	8.58	1721.1	1292		47.6					986		6.025	292.13		535	156	colored	2.3		15.4	2.3	38					11-19-76	DC 32-2	UND-EES
145-93-27 ABC 02	120					8.39	1710	1392		72.0	1.6	1.4	490	4.4			6.61		-2.96	253	19.5	.289	2.63		47.6	16	65.6					06-02-77	DC 32-2	UND-EES
145-93-27 DBC	138					7.96	2043	1528		94.8					1005		10.6			473.3	18.4			colored	73	6.0	14					11-23-76		A. Johnson
145-93-29 CDB 01	106	8.5				8.4	2250	1530		71	19	5.7	571	2.5	1130	16	0.0	305	2.8	0.0		1.0										10-21-71		M. Kling
145-93-30 CDD 01	127	8.5				8.4	2210	1460		84	14	12	563	2.5	1140	20	0.4	293	1.4	0.0		1.0										10-21-71		W. Pelton
145-93-32 BBB 01	100					8.5	2930	1960		38	6.6	5.2	729	3.7	1070	24	4.0	680	1.2	2.5		1.9										10-21-71		W. Benz
145-94-10 ABB 01	300					8.5	2270	1470		69	14	8.3	565	2.3	1000	21	0.6	409	2.2	0.0		1.0										10-22-71		C. Brown
145-94-10 ABB 01	300					8.45	2027	1608		37.5	4.0	12.9	591.9	4.4	1000		11	388.3	4.49	460.0	36.2	colored	2.5		84	3.61	11.0					02-02-77		C. Brown
145-94-15 DDD 01	174	11				8.5	2190	1490		23	3.2	3.6	530	2.4	900	19	2.9	410	0.4	0.7		1.0										12-20-74	4792	NDSWC
145-94-20 DDB 02	40	8.0				7.4	5820	4890		2100	319	326	789	21	749	0.0	309	2250	7.0	0.1		1.9										10-27-71		J. Saetz
145-94-20 DDC 01	31					7.1	3172			432	69	63	750	14	537	0.0	23	1545*	*													10-10-75		J. Saetz
145-94-20 DDC 02	40					7.6	5135			1600	282	218	1140	39	590	0.0	227	3195*	*													10-10-75		J. Saetz
145-94-26 BDA 02	115					8.1	1722			32	8.0	2.9	622	5.0	710	0.0	3.5	773*	*													10-10-75		Dunn Center Motor
145-94-27 BCC	125					7.0	992			216	46	24	218	7.5	410	0.0	21	342*	*													08-22-75		USBFW
145-94-28 ABB	133					6.0	2114			552	213	5.0	236	9.5	34	0.0	11	993*	*													10-10-75		Dunn Center Cementery
145-94-28 DCD 02	61					8.2	1846			82	24	5.3	876	7.5	739	0.0	2.5	456	30			0.4										10-16-75	DC 47-2	UND-EES
145-94-28 DCD 02	61					8.37	1760.8	1318		100.7					777		4.47	340.3	19.9	650	192	2.6	1.68		2.4	1.6	13.3					11-19-76	DC 47-2	UND-EES
145-94-28 DDB	163					8.3	1812			13	5.2	0.0	516	7.8	914	0.0	4.5	210	7.9													08-22-75		USBFW
145-94-30 AAD 01	106					7.9	1510			100	26	8.8	437	6.0	661	0.0	6.5	488*	*													10-16-75		D. Hutchinson
145-94-34 CBB 01	191					8.3	2041			24	9.6	0.0	950	5.5	886	0.0	2.5	344	32			0.3										10-27-75	DC 46-1	UND-EES
145-94-34 CBB 01	191					8.3	1835.2	1356		44.3					925		9.12	484.78		268.2	57	2.8	2.3		23	1.6	16.4					11-19-76	DC 46-1	UND-EES
145-94-34 CCC 01	112					8.4	1959			28	8.0	1.9	950	5.5	837	4.8	6.0	304	35			0.4										10-16-75	DC 44-1	UND-EES
145-94-34 CCC 01	112					7.9	8763	9906		2150.5					1104		10.0	694.6		3150	400	0.9	0.41		67.5	13.0	512.5					11-19-76	DC 44-1	UND-EES

SENTINEL BUTTE FORMATION
Antelope Creek Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-93-20 BDD	55	10.0				8.0	2690	1790	30	89	16	12	650	3.4	1050	0	2.7	564	2.0	1500	20	2.0	1.1									07-28-71		H. Bernhardt
142-93-18 DBB	55					7.5	1400	977	1.5	590	113	74	82	8.5	482	0	3	221	10.7	0	150	181	0.5									06-07-72		L. Hauger
142-94-19 DDD	50	11.0				8.0	6190	5480	10	1800	238	298	1020	.5	735	0	10	3430	-1.6	470	140	34	.5									06-07-72		N.Dak. State
142-95-2 BCB	84	11.0				8.0	1980	1330	8.0	370	62	53	353	7.0	741	0	1.6	515	.15	250	20	1.0	.7									08-06-71		G. Miller
143-93-7 CCC 02	130					8.5	2968			68	19	4.8	776	12	1244	8.4	0.7	684	3.6													11-04-75	DC 1-7-C	UND-EES
143-93-33 BCC	79	10.5				7.8	5260	4080	16	890	235	74	1070	12	941	0	81	2270	-.23	10000	320	1.0	0.2									06-06-76	4604	NDSWC
143-94-5 BBB	90					8.06	1971	1246		44.6	2.3	2.3	424.5	6.8	730.17		3.7	387.5	-3.1	1660.0	14.5	.36	.78		30.0	11.0	33.3					02-16-77		L. Steckler
144-93-8 BCB 02	252					7.9	2692			88	25	6.1	646	13	835	0.0	3.0	760	1.0			0.6										11-03-75	DC 16-2	UND-EES
144-93-17 ADA 02	278					8.3	2769			43	12	3.2	680	8.0	947	0.0	3.0	840	-3.9			0.7										11-05-75	DC 37-1	UND-EES
144-94-1 CCC 04	165					8.2	3076			52	16	2.9	790	9.5	1205	0.0	17	710	0.9			0.8										10-22-75	DC 28-4C-1	UND-EES
144-94-12 ABA 01	170					9.1	2974			65	26	0.0	832	8.0	1135	54	7.0	320	16			1.3										10-24-75	DC 51-1	UND-EES
144-94-13 DAD 01	255					8.7	2394			145	38	12	646	8.5	1605	30	38	60	2.6			0.2										11-19-75	DC 3-1	UND-EES

SENTINEL BUTTE FORMATION
Antelope Creek Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	CO3 mg/L	Cl mg/L	SO4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO3 mg/L	F mg/L	PO4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	18O µg/L	H3 µg/L	Date	Well No.	Owner
144-94-16 BAB 01	190					8.6	3051			50	3.9	9.8	744	9.3	1308	11	12	500	1 6			1.0										10-27-75	DC 26-1-1	UND-EES
144-94-16 BBA 01	173					8.4	3871			160	45	12	876	16	1010	4.8	5.0	1800	-13			0.6										10-28-75	DC 27-1	UND-EES
144-94-25 CAA 01	280					8.6	2435			64	24	1.0	630	14	1574	12	18	200	3.1			2.0										10-28-75	DC 21-1	UND-EES
144-94-35 DAA 02	205					8.5	2344			64	18	4.8	666	14	1571	11	29	70	1.9			0.6										10-28-75		UND-EES
145-85-4 ADC	124	3	7.16	2000		8.21	1852	1234		200.19	16.2	24.7	596	7.0	882		8.71	357.62	13.3	118	162	9.56	0.37		19	0.8	7.5					12-15-76		E. Oster
145-86-10 AAC	120	1	5.86	700		6.54	625.8	484		296.47	19.0	26.3	45.8	6.7	131		17.78	179.18	-9.5	100	175	6.0	0.13		21	0.65	7.7					12-15-76		L. Weisz
145-86-27 BBC	140	2	8.42	2100		8.26	2166.6	1648		62.13	2.0	4.9	565	7.0	1131		8.51	345.95	-1.4	220	26	4.6	0.47		91.8	1.84	8.0					12-15-76		Wiedrich
145-87-1 CCB	180					7.09	2300	1534		660	100	103	311	16.3	1035		10.9	545.0	-2.16	558	418	< 0.1	0.18		22.7	10.9	5.4			-14.30	0 ± 9	03-14-77		H. Shied
145-91-5 DDD 02	585	10.0				8.5	2960	1864	55	38	7.0	5.0	780	3.7	2060	42	26	6.2	-1.75	60	0	1.0	1.2									04-25-74	4604	NDSWC
145-92-19 CBD	72					8.03	2646	1932		137.2	9.8	11.6	526.4	10.5	761.2		3.7	707.1	-5.18	1654.0	41.6	.29	.91		48.3	5.0	45.0					02-16-77		Bessaw
145-92-22 CCC 02	116					8.6	1923			19	6.4	0.7	500	8.5	1037	12	5.0	230	0.1			0.0										11-13-75	DC 34-2	UND-EES
145-92-24 BCA	105	8.0				6.6	2000	1670		1000	244	102	137	7.9	271	0.0	15	1040	0.4			2.5										10-27-71		Halliday
145-93-16 CBB 05	329					8.5	2419			40	14	1.0	646	5.5	1337	11	23	285	0.3			1.0										11-13-75	DC 6-4P	UND-EES
145-93-21 DAA 03	209					8.5	2256			36	13	1.0	614	6.0	1222	12	46	172	4.3			0.1										11-10-75	DC 13-3C-1	UND-EES
145-93-26 BAD	116	8.0				8.4	1980	1280	30	54	9.8	7.2	499	2.5	1060	17	.0	218	.82	0	10	1.0	3.0									09-23-71		G. Schmidt
145-93-27 ABC 01	155					8.1	1897			16	6.0	0.2	516	5.0	944	0.0	10	230	5.4			0.1										11-03-75	DC 32-1	UND-EES
145-93-27 ABC 01	155	12	8.415	1650	0.2	8.54	1730	1441		196	1.4	1.5	504	4.6	1024.8		6.09	293.2	-1.85	353	33.8	.225	2.69		24.8	0.55	100					06-02-77	DC 32-1	UND-EES
145-93-33 BAA 01	231					8.6	2195			76	19	6.8	607	22	1269	24	30	152	5.3			0.8										11-10-75	DC 5-2	UND-EES
145-93-36 BCC 02	200					8.2	2410			35	11	1.9	614	7.0	1459	0.0	30	234	-3.5			0.8										11-04-75	DC 15-2	UND-EES
145-94-27 ACC	151	12				8.2	2110			73	11	11	544	2.6	1250	0.0	0.0	201	1.0	0.4												07-10-72		T. Ridle
145-94-27 ACC	151	10				8.1	2060			15	3.1	1.7	530	3.1	1230	0.0	1.9	210	-2.0	0.6												05-23-75		T. Ridle
145-94-27 ACC	151	8.3				-	2024			40	9.6	3.9	700	4.8	1171	0.0	4.0	580*	*													10-30-75		T. Ridle
145-94-28 ADB 02	140					8.3	3323			60	16	4.9	556	3.0	1020	3.6	3.5	415*	*													10-08-75		O. Kittelson
145-94-28 DCD 01	138					8.5	1897			16	4.4	1.2	910	4.8	966	7.2	2.5	320	27			0.1										10-16-75	DC 47-1	UND-EES
145-94-28 DCD 01	138					8.47	1723.6	1232		70.3					1007		8.32	228.5		670	66.7	1.1	2.35		27.7	3.4	24.0					11-19-76	DC 47-1	UND-EES
145-94-34 DDA 02	206					8.4	2359			24	8.8	0.5	666	8.5	1645	6.0	13	28	2.7			0.2										10-27-75	DC 33-2	UND-EES
146-87-31 ABA	160	15	7.88	3000		7.3	3288	2452		119.2	13.4	9.9	932	10.2	1503		10.2	605.0	5.96			0.93	0.67		227	49.3	27.5			-13.53	59 ± 10	03-14-77		K. Renner
146-88-22 CSB 1	35.75	6.9				7.7	2850	2200	16	231	49	34	590	8.6	827	0	4.0	1000	-5.0	480	56		.16		27	7	34	< 5	< 10			07-11-74	GOZ	Woodward-Clyde Consult
146-91-21 DCD	69	12.0				8.0	4260	3110	39	140	27	17	1050	6.4	937	0	4.0	1660	-1.5	0	80	2.5	.8									09-28-71		L. Weisz
146-93-27 ADD 03	255					8.4	2818			80	19	7.8	680	18	1191	8.4	14	530	0.7			0.7										11-13-75	DC 9-3	UND-EES

SENTINEL BUTTE FORMATION
Antelope Creek Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	CO3 mg/L	Cl mg/L	SO4 mg/l	Stan-dard Error	Fe µg/L	Mn µg/L	NO3 mg/L	F mg/L	PO4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	18O µg/L	H3 µg/L	Date	Well No.	Owner
143-93-07 CCC 01	205					8.7	2943			108	26	11	730	19	1193	19	22	730	-2.2			1.5										11-04-75	DC 1-1	UND-EES
144-93-9 DDD 01	460					7.8	2384			756	207	58	388	24	586	0	3.0	1098*	*			4.6										11-03-75	DC 17-1	UND-EES
144-94-1 BCB 01	182					7.8	2120			149	44	9.4	580	11	917	0	7.5	400	9.4			0.2										10-24-75	DC 55-1	UND-EES
145-92-25 ADC 02	152	9.5				8.2	3030	2080		32	5.6	4.4	756	3.7	1290	0	6.0	624	-1.0			1.0										09-13-72	72-4	NDSWC
145-93-33 CBC 03	340					8.5	2615			44	15	1.4	630	6.8	1076	8.4	10	320	6.7			0.2										11-18-75	DC 14-3	UND-EES

SENTINEL BUTTE FORMATION
Kinneman Creek Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-84-5 CAA	35					7.6	1890	1060	13	168			389		658	0	10	328		0.96		Trace										06-03-76		W. Mosbrucker
141-84-26 CBB	65					7.3	2150	1730	1.0	1291	248	153	86		633	0	53	610		0.21		168										05-13-76		E. Remke
141-92-9 BBD 01	44	9.0				8.1	2850	1930	33	78	15	9.8	678	4.8	1100	0	3.5	676	-1.64	820	20	1.0	.7									07-29-71		F. Guthmiller
141-93-2 ABB	97	11.0				8.0	3770	2640	29	170	32	22	874	7.2	1290	0	2.9	1050	-3.17	5200	60	2.5	.7									07-28-71		J. Enderle
141-94-2 BBA	75	11.0				7.9	2320	1670	12	290	66	30	471	6.0	745	0	2.8	702	-.94	3900	20	2.5	1.0									07-28-71		A. Sickler
142-84-26 CBB	74	11	7.485	1350	0.5	7.78	863	843		377	64	44	164	13.0	523.4		17.4	254.9	-.38	45.1	259	.108	<0.1		14.0	.22	6.4					05-13-77	Center 371 A	NDGS
142-84-27 CCC	138	9	6.00	2200	0.7	7.28	1606	1539		731	152	63	204	13.6	560.0		7.24	642.7	-1.74	1300	461	< 0.1	<0.1		9.0	.34	13.8					05-13-77	Center 367 A	NDGS
142-84-29 ABB	70					7.2	2520	1840	9.3	500			480		438	0	29	980		0.53		57										06-07-76		V. Ganske
142-84-32 BDD	32					7.8	3310	2850	10	710			536		699	0	47	1180		2.85		124										06-03-76		T. Lipp
142-84-33 ADA	78	10	6.52	2050	0.5	7.95	1909	1499		288	54	29	441	14.3	868.6		3.72	232.6	12.44	562	130	< 0.1	0.1		11.7	.33	11.5					05-13-77	Center 368 A	NDGS
142-84-33 ADA	78					7.67	2320	1631		221	75	54	373	48	1021.1		<1.0	499.1	-2.90	363	95		0.1		21.3	3.0	9.0					08-24-77	Center 368 A	NDGS
142-84-33 BDD	55					7.2	2340	1890	4.1	880			282		348	0	26	1066		2.64		None										05-18-76		J. Bobb
142-84-34 ACC	46					7.3	1130	772	1.2	577			64		440	0	22	207		0.16		36										05-05-76		B. Dresser
142-93-9 BBA	58					8.4	3320	2330	30	140	24	19	800	5.9	1150	17	5.0	910	-1.05	0	20	1.0	.8									06-26-74	4691	NDSWC
142-93-32 DCC	70	7.0				8.4	2020	1310	44	28	6.4	2.9	530	2.6	1290	35	12	51	-.06	390	40	4.1	5.1									12-18-73	4616	NDSWC
142-93-34 DCB	35	11.0				7.8	971	698	2.9	290	57	36	115	4.6	436	0	9.3	160	.83	360	10	4.3	.9									08-05-71		R. Vaagen
142-94-8 DDD	226	11.5				7.8	4410	3260	45	110	20	14	1080	6.5	1320	0	2.4	1430	-2.2	170	80	4.8	.5									06-06-72		D. Webster
143-87-31 BBC	180	14	9.74	2500		7.98	2708	1529		50.2	5.3	2.3	637	6.0	1792		51.3	256.3	-12.18	226	13.2	0.15	1.25		8.7	0.83	3.7			-13.94		03-14-77		G. Clive
143-93-31 ACD	150	9.0				8.4	3110	2080	65	27	6.2	2.8	779	3.5	1190	19	3.5	651	-.25	0	50	1.3	3.5									08-18-71		R. Stein
143-94-21 CCA 01	81	7.5				7.7	3530	2490		150	29	19	835	6.9	1130	0.0	4.9	1040	-1.0	0.8		2.5										09-24-71		H. Koller
143-95-32 ACB	270	14.0				8.4	2660	1730	65	22	4.7	2.6	708	3.6	1870	32	9.5	13	-1.5	200	50	1.0	2.5									08-12-71		E. Kudrna
144-92-10 ADC 01	225					8.4	2700	1820							1260	76	27	230		6000		0.0										09-30-71		F. Loffelbeir
145-86-1 DDD	168	3	6.97	2200		8.16	2136.4	1620		56.09	3.1	3.4	500	6.3	1553		95.50	86.96	-14.6	990	315	>8.9	0.89		10.3	1.2	7.7					12-15-76		H. Reichenberg

SENTINEL BUTTE FORMATION
Kinneman Creek Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
146-82-16 CCB	63					8.29	1113	810		399.3	153.7	3.6	62.8	10.3	446.3		138.4	230.7	-18.8	2800	510	.16			20.6	0.7	30.5					08-25-76	FA 9-1	UND-EES
146-82-20 DDD	73.2	10	7.33	1675		7.75	1257	1473		764	198	67	8.5	1.5	286		57.5	570	-7.0	29.5	810		<0.1		22.6	6.5	9.6					08-02-77	FA 106-3	UND-EES
146-82-21 CCC 01	58					7.84	1230	806		582.03	233.6	0.0	81.0	7.0	700.7		137.09	38.72	-2.5	880	1800				28	0.8	62.2					08-25-76	FA 8-1	UND-EES
146-82-21 CCC	58	9	6.97	900		7.61	744	652		94.6	66	38	39	5.9	417		12.5	159	-11.8	67	659	0.1	0.29		4.0	0.32	2.1					07-07-77	FA 8-1	UND-EES
146-82-21 CCC 02	40	8	7.04	1500	0.5	7.32	1271	992		620	152	53	90	6.7	741.8		306.2	71.4	-16.37	312	1744		<0.1		8.3	0.53	3.7					07-07-77	FA 8-2	UND-EES
146-82-21 CCC 03	19					8.20	847	546		351.27	66.9	44.7	35.6	7.3	387.6	8.76	125.89	12.93	-7.4	2200	530	.28			11.5	0.3	21.8					08-25-76	FA 8-3	UND-EES
146-82-29 DAA	54					7.74	662	366		186					397.0		3.8	87		1838	238				40	1.06	108					06-04-76	FA 109-2	UND-EES
146-82-29 DAA	54					8.39	739	436		365	69.6	39.9	9.5	4.7	418.5		1.2	45.1	-5.58	266	512	1.2	0.2		9.1	1.1	11.2					08-17-77	FA 109-2	UND-EES
146-88-10 DDC	120	8.0				8.1	2520	1670	32	670			606	3.4	881	0	6.9	631	-2.43				.6									06-17-67		J. Renner
146-91-8 CAA	170	7.5				7.8	2860	2250	4.9	1000	206	120	357	5.1	705	0	12	1180	-.89	0	350	1.0	1.3									09-29-71		P. Beko
146-91-22 BBA 02	235	10.0				8.9	2200	1490	91	7	1.8	.6	550	2.3	863	62	0.0	401	-.90	620	30	1.0	.6									07-12-72		G. Gegelman
146-94-8 DAC 01	25	8.0				8.0	4070	3160	9.7	970	219	103	694	10	1060	0	17	1480	1.2	0	180	46	1.7									10-08-71		R. Hammel

SENTINEL BUTTE FORMATION
Hagel Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-94-21 CCD	185	10				8.3	2590	1740	20	170	17	32	603	4.3	982	10	4.7	601	1.3	500	40	1.0										07-28-71		
142-84-33 CCC 02	95.14	11	7.0	900	0.4	7.61	744	652		94.6	12.1	5.7	183	4.2	412.2		12.5	160.0	-6.64	147	598	< 0.1	.29		9.4	1.30	5.2					06-28-77	Center 365A	NDGS
143-87-4 ABC	170	7	7.50	2200				1668		68.3	5.1	4.1	589	5.8	1113		12.6	335.6	1.4	38.4	62.1	0.16	0.25		11.7	3.7	17.1			-13.77		03-14-77		Thompson
143-88-29 DBC	250	16	10.4	2600		8.02	2934	1823		45.9	7.2	2.8	724	6.0	1941		107.1	ND	-4.02	313	11.3	0.16	1.16		156	1.0	7.6			-13.15		03-14-77		Winkler
143-93-7 CCC 03	355					8.3	2220			588	143	56	410	20	754	2.4	20	720	3.6			0.4										11-04-75	DC 1-3	UND-EES
144-87-13 BBA	80	2	7.47	650		8.06	599.6	430		234.95	19.3	14.4	87.2	4.3	392		4.79	48.56	-11.2	125	1250	.53	0.14		24	3.1	4.8					12-15-76		A. Christman
144-94-1 CCC 02	357					8.6	2897			64	24	1.0	810	14	2035	30	32	192	-3.1			1.0										10-22-75	DC 28-2-1	UND-EES
144-94-7 DAA 05	411					8.3	2435			276	87	15	550	13	1027	0.0	13	704	3.4			1.2										10-29-75	DC 30-3	UND-EES
144-94-16 AAA 01	480					8.1	2974			952	115	161	478	53	488	0.0	9.5	1575	0.1			1.6										10-27-75	DC 19-1	UND-EES
145-82-4 DAA	37	9	7.05	1575		7.41	1351	1280		743.0	98.9	120.5	11.5	7.0	539.0		20.4	334.0	-2.6	731	410				36.6	0.3	21.2					07-01-76	FA 37	UND-EES
145-82-5 ADD	54	8		990	0.25	6.97	925	674		370	78.9	33.4	70.4	4.1	453.8		39.3	273.6	-18.26	1214	231	<0.1	.15		4	1.7	12.6					07-15-77	FA 94	UND-EES
145-82-5 CBB	62.66	11.5	7.6	1600		8.08	1607	1102		476.3					575.0		20.5	419.8		>10000	660	0.16		<0.02	650	0.22	263					05-14-76	FA 92	UND-EES
145-82-5 CBB	62.66					7.40	1521	2128		492.3	66.9	79.0	134.5	9.8	546		12.02	340.7	-1.3													07-15-76	FA 92	UND-EES
145-82-5 DAB	57	11	7.1	3800		8.85	3021	4890		2200.9	586.7	178.4	78.7	19.6	109		19.05	1023.0	33.9	847	1189				66.9	0.83	47.5					07-01-76	FA 114	UND-EES
145-82-5 DBA	51	9	7.2	1450		6.31	1249	1308		658.2	195.6	41.1	30.6	10.6	259		15.85	508	-1.8	457	188				74.2	0.23	24.1					07-01-76	FA 113-2	UND-EES
145-82-5 DBB	58	10	7.0	1650		6.35	1529	1506		841.1	243.9	56.2	37.9	10.2	369		21.88	680	-5.4	3171	458				241.1	1.47	54.9					07-01-76	FA 112-2	UND-EES
145-93-21 DAA 01	385		8.4	2948						52	18	1.4	790	11	2108	6.0	41	250	-6.9	·		0.1										11-10-75	DC 13-1	UND-EES
146-82-15 CCC	106.30	9	7.6	1000		7.67	1080	652		259					411.0		14.1	211.0		>10000	>1000 + <10000	0.06		0.01	2	0.94	4.9					05-20-76	FA 45	UND-EES
146-82-20 CBB	112	10	7.9	1100		7.89	1086	748		548.6	40.0	74.5	48.8	9.2	526.0		16.0	148.3	-7.4	2806	770	0.30			72	0.08	400					05-07-76	FA 81	UND-EES
146-82-20 CBB	112					7.45	1052	1608		406.5					600		12.18	162.8														07-15-76	FA 81	UND-EES
146-82-20 CBB	112	7	7.745	1100	0.7	7.59	969	724		445	110	45	68	4.9	571.0		46.9	162.2	-6.76	388	477	0	.5		11.3	0.40	4.0					07-11-77	FA 81	UND-EES
146-82-20 CCC	119	10	8.1	630		7.91	582	344		161.1					338.5		14.0	23.5		1854	255			0.08	146	0.10	152					05-07-76	FA 82	UND-EES
146-82-20 CCC	119					7.52	519	1132		508.6	32.1	104.1	77.5	7.2	571.0		7.08	12.6	16.5													07-15-76	FA 82	UND-EES
146-82-20 CCC	119	8		650	0.3	7.03	867	396.3		120.4	18.6	15.4	79.2	4.3	377.1		71.7	22	-20.1	126	214	< 0.1	.26		8.6	0.31	4.3					07-20-77	FA 82	UND-EES
146-82-20 CDD	161	10	7.5	610		7.78	514	34		123.3	16.7	19.8	78.0	9.3	320		6.31	511	-45.0	6794	470				227.8	0.54	78.9					07-01-76	FA 80	UND-EES
146-82-20 DAD	51	13	6.2	800		7.56	804	492		396					411		78.0	81		422	1116				50	0.92	145					06-10-76	FA 110-1	UND-EES
146-82-20 DAD	92	12	7.8	1650		8.25	1727	1098		60					877.0		8.4	212		4032	277				40	4.86	180					06-10-76	FA 110-2	UND-EES
146-82-21 ADD	120.41	10	7.5	650		7.68	714	448		189					426.0		16.5	64.5		3416	330	0.06		< 0.01	210	0.16	268					05-20-76	FA-43	UND-EES
146-82-21 DDD	120.4	10	7.15	700		7.89	624	446		187	33.3	18.8	79.5	5.0	477		11.1	31.4	-12.7	21.8	110				30	6.0	13.3					07-26-77	FA-43	UND-EES
146-82-21 CBB	90	14.0	8.1							300	73.0	29.0	18.0	3.1	329.0	0.0	15.0	28.0	1.0	0.1	0.0	20.0	0.1									08-26-76	Well # 3	City of Underwood
146-82-21 CCC	82					7.81	1571	1436		960	15.3	50.3	17.5	4.6	292.0		36.5	619.0	-52.8	403	540				61	1.22	50					06-04-76	FA 106-6	UND-EES
146-82-21 CCC	82	10	7.5	490		7.81	457	274		245.17					407		3.16	19.2		725	391				30	1.46	28					06-16-76	FA 106-6	UND-EES
146-82-21 CCC	82	8	7.81	500		8.68	418	301		188	42.6	18.3	17.4	3.6	310		19.1	21.7	-14.96	16.0	303	6.1	0.2		9.8	0.65	4.6					08-02-77	FA 106-6	UND-EES
146-82-22 ADD	79	9.5	7.6	1600		7.83	2086	1758		1185.5					511		43.0	840.1		>10000	>1000 + <10000	0.01		<0.01								05-14-76	FA-77	UND-EES
146-82-22 ADD	79	7	6.87	900		7.11	973	739		461	127	67	128	9.4	440		8.4	274.7	14.56	600	300				8.0	0.44	4.2					08-16-77	FA-77	UND-EES
146-82-22 CCD	99	9	7.4	460		7.56	556	340		216					329.0		6.0	60.2		1397	235	0.08		0.04	95	0.07	99					05-21-76	FA-42	UND-EES
146-82-22 CCD	99	10	7.465	560	0.5	7.60	496	344		205	37	22	38	4.3	363.6		46.9	32.5	-18.98	39	181	0.109	.14		4.8	0.32	2.3					07-16-77	FA-42	UND-EES
146-82-22 DDD 01	72	9.5	7.6	770		7.83	756	460		415.3					415		13.0	97.4		2143	495	0.01		<0.01	760	0.08	530					05-14-76	FA 76-1	UND-EES

SENTINEL BUTTE FORMATION
Hagel Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
146-82-22 DDD 01	72	8		860	0.2			462.7		295.2	81.5	37.4	9.5	5.0	378.1		9.6	61	-0.26	596	267	<0.1	.16		7.2	0.9	51					07-22-77	FA 76-1	UND-EES
146-82-22 DDD 01	72	11	6.81	790		7.65	675	712		359.8	81.2	37.8	10.9	4.0	467		5.6	66	-8.57	203	272				10.8	1.1						07-28-77	FA 76-1	UND-EES
146-82-22 DDD 02	73																			2400	290				297	2.0	975					08-25-76	FA-5	UND-EES
146-82-22 DDD 02	73	8	6.965	600	0.2	7.17	633	438		329	74	35	13	6.8	431.9		30.5	46.5	-9.80	857	306	<0.1	.18		4.7	1.76	4.6					07-22-77	FA-5	UND-EES
146-82-26 BCC	93	9	9.83	600		7.89	623	427		335	55.5	35.9	22	5.9	450		10	94.1	-16.91	550	220				12.2	1.1	12.0					08-12-77	FA-75	UND-EES
146-82-26 BCC	93	10	8.2	710		7.81	703	384		344.6					389		8.1	104.5		>10000	>1000 <10000	0.04			56	0.55	153					05-14-76	FA-75	UND-EES
146-82-27 BBC	59	9	7.6	550		7.5	555	400		287					264.0		8.4	58.8		693	70	0.08		0.06	60	0.07	70					05-21-76	FA-41	UND-EES
146-82-27 BBC	59					7.21	475	1262		162.7	66.4	0.0	1.3	6.7	372		8.90	22.3	-31.6													07-15-76	FA-41	UND-EES
146-82-27 BBC	59	7		630	3.9			343.7		349.0	53.1	23.1	20.8	3.2	454.6					2990	1430	.955	.13		6.4	0.8	43					07-21-77	FA-41	UND-EES
146-82-27 CCC	81.36	9	7.2	520		7.89	650	420.0		334.7					350.0		14.8	43.2		3509	290			0.04	28.5	0.08	28.0					04-21-76	FA-40	UND-EES
146-82-27 CCC	81.36	10	7.8	775		7.29	658	404		282.9	47.8	29.0	11.5	7.2	387		2.11	77.0	-18.9	630	176				88.5	0.24	66.3					07-01-76	FA-40	UND-EES
146-82-27 CCC	81.36					7.63	606.3	1420		338.02							16.60	273.15		240	1000	1.1	.56		18.2	.34	5.2					10-09-76	FA-40	UND-EES
146-82-27 DCC	70.21	10	7.8	700		7.8	679	352		339.4					367		12.0	98.1		4684	35	0.06		<0.01	290	0.10	215					05-14-76	FA-78	UND-EES
146-82-27 DCC	70.2	7	8.93	675		7.28	648	440		335	62.3	41.3	13.2	5.9	431		5.2	130.9	-15.8			<0.1	0.17									08-12-77	FA-78	UND-EES
146-82-28 CCC	61	10	7.4	825		7.67	723	465.2		344.8	6.0	80.1	25.0	7.9	482.0		2.82	52.4	-5.2	1732	391				135	0.80	45					06-16-76	FA 105-6	UND-EES
146-82-28 CDD	71.52	9	7.5	850		7.41	883	562		340					368		17.2	204.0		3416	355	0.08		<0.01	55	0.10	80					05-21-76	FA-79	UND-EES
146-82-28 CDD	71.52					7.45	875	1668		547.9	96.2	74.7	70.6	10.7	678		20.89	118.9	.04													07-15-76	FA-79	UND-EES
146-82-29 DAA	79	11	7.5	590		7.67	681	195		198.3	36.2	20.4	66.2	5.9	388		<1.0	20.6	-2.18	4400	113	< 0.1	0.14		3.8	1.2	2.8					08-18-77	FA 109-3	UND-EES
146-82-30 CCC	108	10	7.7	860		7.67	1065	654		522				·	500.0		14.1	212.0		>10000	>1000 < 10000	0.02		<0.01	36	0.35	140					05-21-76	FA-86	UND-EES
146-82-30 CCC	108					7.54	1015	1572		347.6	58.1	49.2	41.3	8.8	409		2.19	132.4	-3.0													07-15-76	FA-86	UND-EES
146-82-30 DAA	72	7		1500	1.0	6.87	1192	1034.2		655.7	143	75.3	45.2	7.5	607.8		43.7	326	-7.4	576	265	.152		6.0	0.6	35.8						07-20-77	FA 88-1	UND-EES
146-82-31 AAA	57	8		1250	0.85	6.32	1152	1106.5		601.6	96.8	92.6	46.7	6.8	512.0		32.9			125	68	.187	.1		6.4	0.6	6.5					07-18-77	FA-89	UND-EES
146-82-31 CCC	57	10	7.3	1300		7.29	1310	982		620					442		12.0	366.0		5871	>1000 < 10000	< 0.02		<0.01	66	0.30	50					05-21-76	FA-87	UND-EES
146-82-31 DAA	57.74	9	7.4	1850		7.41	1886	1374		738					737.0		8.2	456.0		2289	495	< 0.02		<0.01	56	0.07	66					05-21-76	FA-90	UND-EES
146-82-31 DAA	57.74					7.12	1683	2306		484.4	223.0		99.0	12.3	591.5		8.71	322.7	-2.8													07-15-76	FA-90	UND-EES
146-82-32 ADD	57					7.56	1898	1308		568					619.0		15.1	566.0		>50000	10384				119	215	50					06-09-76	FA 108-2	UND-EES
146-82-33 CDD	103	11	7.2	1090		7.79	1104	644		106					599.0		3.3	135		4760	299				50	1.18	70					06-10-76	FA 111-1	UND-EES
146-82-33 CDD	71	11	7.3	750		7.61	706	422		313					416.0		2.1	77		2348	244				40	0.86	46					06-10-76	FA 111-2	UND-EES
146-82-33 CDD	71					7.73	615	416		318.36							4.27	240.46		217	1250	.49	.11		18.8	.60	6.0					10-09-76	FA 111-2	UND-EES
146-82-34 BCC	50.2	9	7.0	750		8.12	847	584		445.3					411		18.4	97.5		< 50	>1000 <10000			0.04	3.5	0.25	50					04-21-76	FA-39	UND-EES
146-82-34 BCC	50.2	10	7.2	960		7.32	866	558		352.4	32.1	66.1	45.4	9.8	457		10.47	155	-8.7	2748	311				17.0	0.17	120.4					07-01-76	FA-39	UND-EES
146-82-34 BCC	50.2					7.40	726.2	470		402.96							8.3	254.5		214	1350	.69			21.2		10.6					10-09-76	FA-39	UND-EES
146-82-34 CDD	30.18	9.5	7.6	710		7.78	950	536		328.2							12.0	203.9		2672	280	0.05		<0.01	212	0.15	890					05-14-76	FA 74-2	UND-EES
146-83-24 BBB	143.70	9	7.6	2200		7.89	2599	1828		370.6					793.0		25.0	531.1		>10000	>1000 <10000			0.02								05-07-76	FA-83	UND-EES
146-83-24 BBB	143.70		7.78	2371				2006		367.9	56.2	55.2	337.5	13.5	904.5		19.05	142.2	9.9													07-15-76	FA-83	UND-EES
146-83-24 BBB	134.19	7	7.53	2450		7.67	2327	1787		301	83.2	41.3	569	12.3	932.1		13.5	694.2	4.0	350	180	<0.1	<0.1		16.8	1.1	4.0					08-16-77	FA-83	UND-EES
146-83-24 CCC	134.19	10	8.2	1600		7.82	1617	1164		570.4					588.9		18.4	396.9						0.03								05-07-76	FA-84	UND-EES
146-83-24 CCC	134					7.32	1650	2110		694.3	154.2	75.0	115.6	15.2	973		80.12	340.4	-13.4													07-15-76	FA-84	UND-EES

SENTINEL BUTTE FORMATION
Hagel Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
146-83-24 DDD	131																			1100	194				415	0.9	607					08-25-76	FA-6-2	UND-EES
146-83-36 BCC	65	10	7.7	1290		7.81	1338	872		402					548.0		8.8	275.0		>10000	>1000 <10000	0.08		<0.01	240	0.34	278					05-21-76	FA-85	UND-EES
146-83-36 BCC	65					7.33	1310	1798		285.3	7.9	64.5	100.5	11.4	299		20.42	200.6	3.5													07-15-76	FA-85	UND-EES

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SENTINEL BUTTE FORMATION
Hagel Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-84-2 BAA	82	12	8.40	2200		8.29	1599	1443		43.3	3.6	2.8	474	5.5	1195.6		19.9	196.8	-6.78	456	289	.136	1.88		50.2	1.35	12.7					06-29-77	Center 362	NDGS
141-84-3 DDA	82	10	7.925	2500		8.37	1437	1708		48.5	6.2	4.2	559	6.5	1374.9		21.9	256.3	-6.25	190	329	0.12	.91		67.5	1.70	39			-9.66		06-28-77	Center 363	NDGS
141-84-10 ABA	69					7.8	1110	780	2.0	490			101		332	0	22	334		0.32		Trace										05-17-76		K. Reinke
141-91-10 DBC	230	12.0				8.3	2330	1650	19	170	11	35	565	2.7	1070	6	2.9	458	1.30	940	20	1.0	.8									07-29-71		Schwenk
141-92-12 DCC	77	10.0				8.0	5890	4360	27	510	100	64	1410	9.7	1510	0	9.1	2260	-.17	0	80	21	.6									07-29-71		Schwenk
141-93-6 ABA	79	6.5				8.2	4910	3660	35	220	55	20	1200	4.6	1290	0	6.0	1800	-1.8	930	90	1.0										12-18-73	4618	NDSWC
142-84-22 AAA	65					7.8	2960	2320	10.2	610			582		674	0	67	866		0.77		254										05-13-76		O. Light
142-84-23 CCC	45.93	10	8.28	1350		7.73	556	538		128	19.4	7.9	109	8.6	388.0		107.2	31.4	-20.77	96	151	<0.1	.38		5.1	0.28	4					06-29-77	Center 360A	NDGS
142-92-10 BBC	215	9.0				8.1	2780	1820	44	54	14	4.6	750	4.0	1980	0	14	19	.84	500	50	13	1.4									04-18-72		K. Perhus
142-94-34 BBB	305	13.0				8.4	2760.	1730	34	83	6.7	16	712	3.8	1550	23	7.3	338	-1.06	170	20	1.0	1.8									08-04-71		A. Hueske
143-95-34 ACD	360	13.0				8.4	2550	1650	69	18	4.1	1.9	673	3.2	1790	26	8.9	11	-1.6	340	20	1.0	3.4									08-13-71		D. Dvorak
144-86-13 BBB	150	12	7.34	850		7.19	813	506		296	43.1	30.7	79.3	7.5	533		7.7	667.3	-46.6	218	145	<0.1	0.33		10.7		3.1					03-14-77		Weidrich
144-88-24 CCB	160	2	7.07	1750		8.10	1569.6	1128		466.76	30.3	46.3	378.0	12.7	759		11.75	319.97	6.4	663	1510	1.1	0.17		13.4	1.1	4.7					12-15-76		J. Schumaier
144-95-35 ACB 01	380	9.0				8.4	3130	2010	71	25	6.3	2.3	819	4.0	1770	23	7.0	321	-.60	2800	60	1.0	2.7									09-21-71		L. Kubischta
145-82-3 CDD	13					7.68	1445	1206		726.35	261.5	17.6	90.0	9.6	598.9		13.58	388.87	1.0	4000	690	.16			31.9	1.4	52.5					08-25-76	FA 4-1	UND-EES
145-82-4 AAA	67	14	7.3	1395		7.55	1289	940.4		309.1	9.8	69.2	247.9	10.9	838.0		7.76	91.5	4.1	4776	1006				40	2.3	61					06-16-76	FA 107-3	UND-EES
145-82-5 DAA	82	10	7.8	1590		7.50	1287	896		210.7	1.4	50.3	175.0	10.0	791.0		9.55	143.1	-14.6	1209	360				55	0.36	105					06-18-76	FA 102-3	UND-EES
145-91-5 DDD 02	585	10.0				8.5	2960	1864	55	38	7.0	5.0	780	3.7	2060	42	26	6.2	-1.8	60	0	1.0	1.2									04-25-74	4604	NDSWC
146-82-20 DDD	132					7.88	1230	782		37					743.0		8.2	49.0		5891	381				108	42.5	70					06-04-76	FA 106-3	UND-EES
146-82-20 DDD	132	9	8.33	1300		8.56	996	750		49.5	2.3	0.5	241	2.5	719		25.7	71.4	-13.37	167	50	0.48	1.2		52	6.2	32					08-01-77	FA 106-3	UND-EES
146-82-28 CCC	109	10	8.1	700		7.75	678	430		55.9	5.1	10.5	87.5	5.0	427		.94	19.9	-19.1	4882	202				17	0.60	86					06-16-76	FA 105-2	UND-EES
146-82-29 DAA	114	12	7.2	710		7.68	707	414		145					417.0		0.07	89		2812	238				104	1.78	60					06-04-76	FA 109-1	UND-EES
146-82-29 DAA	114					7.88	738	502		73	40	20	271	40	498		9.1	75.7	24.4	600	66	< 0.1	0.3		7.6	1.1	55					08-16-77	FA 109-1	UND-EES
146-82-32 ADD	97	17	8.05	1200		8.08	968	570		33					593.0		1.8	92		9443	576				71	14.01	68					06-09-76	FA 108-1	UND-EES
146-82-32 DDD	105	11	7.0	1510		7.61	1486	974		588					743.0		3.3	320		2076	727				60	0.94	61					06-10-76	FA 104-1	UND-EES
146-82-32 DDD	105	9	6.43	1600		7.17	1308	1020		539	119	50.8	151	10.1	745		7.24	284.4	-3.91	8300	6500				5.7	0.52	24.5					08-09-77	FA 104-1	UND-EES
146-82-34 CDD	72.5	10	8.6	1490		8.9	2520			59.5							35.0			< 50	70				5	0.12	3.1					05-14-76	FA 73-1	UND-EES

BULLION CREEK FORMATION
Tavis Creek Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
145-82-4 AAA	147	12	8.1	1650		7.22	1351	992.0			6.5		36.3	7.2			50.12			48929	2560				65	27.96	12					06-16-76	FA 107-2	UND-EES
145-82-4 CDC	40					7.95	1523	1114		211.7	64.6	12.2	212.5	7.6	865.7		9.4	162.8	-13.3	2400	290.	0.1										08-25-76	FA 3-1	UND-EES

BULLION CREEK FORMATION
Tavis Creek Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-93-14 ABA	360	12.0				8.3	2590	1610	45	45	11	4.3	691	3.1	1850	15	10	9.5	-.42	620	30	.90	3.4									07-28-71		L. Hauck
141-93-16 AAA 02	384	12.0				8.6	2140	1490	56	18	3.9	2.1	550	3.3	1400	45	10	11	1.92	1100	40	1.0	5.5									07-18-74	4662A	NDSWC
143-93-9 BCB	396	7.2				8.9	3140	1990	79	23	4.2	3.0	870	4.0	2100	141	14	9.9	-1.69	80	20	1.0	1.5									04-24-74	4600	NDSWC
145-82-5 DAA	179	10	8.5	2200		8.43	1975	1332.8		58.1	5.6	3.4	361.3	6.5	1174.6		22.91	181.0	-18.0	3864	217				35	0.57	50					06-18-76	FA 102-2	UND-EES
145-82-5 DAA	179					8.24	1852.5	394		46.01							13.18	384.94		232	600	1.2	.12		24.2	.60	12.8					10-09-76	FA 102-2	UND-EES
145-82-5 DAA	179	8	7.825	1850	0.3	8.16	2013	1458		23.7	3.4	1.5	451	3.3	1152.9		105.8	308	-17.19	62.4	66.7	<.1	1.1		17	0.8	28.7					07-13-77	FA 102-2	UND-EES

BULLION CREEK FORMATION
Weller Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-93-8 BCB 01	435					7.3	346			112	26	12	23	28	193	0.0	7.5	20	0.6			6.8										11-03-75	DC 16-1	UND-EES
145-97-28 DAA 01	354					8.2	2794			38	13	1.4	790	11	1976	0.0	34	26	2.2			0.1										11-10-75	DC 31-1	UND-EES

BULLION CREEK FORMATION
Harmon Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	val Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-93-20 ADA 01	882					8.9	2717			60	21	1.9	800	12	1835	50	59	170	-0.9			0.0										11-04-75	DC 29-1	UND-EES

BULLION CREEK FORMATION
Hansen Bed

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-94-21 CDC 01	740					9.1	2077			60	21	1.9	571	15	1386	54	10	54	1.0			0.1										10-28-75	DC 20-1	UND-EES
145-93-36 BCC 01	760					8.5	2871			56	8.0	8.7	722	18	2033	12	61	17	-4.1			1.2										11-04-75	DC 15-1	UND-EES
145-94-34 DDA 01	768					8.6	2794			28	6.4	2.9	750	16																		10-27-75	DC 33-1	UND-EES

BULLION CREEK FORMATION
Hansen Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hardness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Standard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
141-84-4 DDD	250					8.8	1580	1180	35	27			421		693	67	6.0	160		4.66		10										05-13-76		S. Henderscheid
142-88-1 CDC	560	9.0				8.6	3190	2030	71	26	6.1	2.7	828	4.1	1920	49	124	15	-.37	50		.5	1.9									05-24-69	3651	NDSWC
143-91-19 AAA 01	670	10.5				8.7	2830	1830	25	130	33	12	660	7.2	1320	50	12	420	-.93	40	40	1.0	.9									04-19-74	4602	NDSWC
145-81-5 CCB	175	16	7.98	1350		8.83	2700	1629		3.4	7.2	3.0	625	5.0	1294.4		1.9	308	-0.41	206	215	0.4	0.6		22.7	3.0	15.3					08-19-77		Elvrum
145-81-8 CCB	230	15	8.15	2850		8.28	1850	1369		25.8	7.6	2.2	533	3.7	1085		39.8	114.2	5.65	1750	19	< 0.1	0.71		18.7	1.4	6.9					08-12-77		O. Sheldon
145-82-4 AAA	237	10	8.3	1510		7.49	1658	465.2		83.7	13.0	7.9	307.5	9.1	1089		660.69	63.5	-43.4	8403	375				82	13.8	76					06-16-76	FA 107-1	UND-EES
145-82-5 DAA	279	11	8.4	1500		8.01	1371	888		34.3	4.2	2.6	15.6	5.3	819.0		9.33	98.1	-85.4	1483	127				35	1.32	210					06-18-76	FA 102-1	UND-EES
145-82-5 DAA	279					8.38	1425	948		31.91							7.24	295.29		436	65.8	1.4	.27		23.0	.40	14.5					10-09-76	FA 102-1	UND-EES
145-82-5 DAA	279	8	8.235	1500	0.3	8.18	1374	962		35.3	.9	.7	315	1.8	825.9		77.0	215.2	-18.63	119	36	.140	2.1		10.2	1.1	12					07-13-77	FA 102-1	UND-EES
145-82-18 BBC	150	20	7.37	1750		7.82	1589	1198		356	78	60	379	9.3	921		15.9	323.2	6.88	1800	36.5		0.32		7.2	0.43	2.6					08-16-77		L. Hazen
146-81-6 DDD	260	11	7.35	1300		7.78	1696	1021		390	107	52	262	14.2	729.6		<1.0	377	3.76	17244	276	< 0.1	<0.1		3.6	0.8	7.1					08-19-77		E. Schauer
146-81-8 BCB	150	9	8.18	1650		8.25	1426	1000		21.3	32.2	17.4	502	4.7	839		20.4	61.7	23.12	207	14.2	0.11	0.21		17.0	14.6	6.6					08-15-77		M. Seidler
146-81-18 CCA	248	14	7.335	1075		7.68	1010	622		225	51.7	22.1	175	8.7	648		7.24	107.1	-3.24	7000	200	<0.1	<0.1		7.0	0.85	3.1					08-11-77		R. Weisz
146-81-18 DDD	186	17	7.74	1150		7.89	1020	710		79.6	21.4	7.1	278	8.5	660		17.4	512.5	-22.31	1150	33	0.31	<0.1		22.2	0.86	10.8					08-11-77		J. Saylor

BULLION CREEK FORMATION
Hansen Interval

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
146-81-31 CCC	280	20	8.01	1500		8.19	1285	935		37.7	5.8	1.8	383	3.6	854		19.3	136.3	-0.55	2300	19.6	0.1	0.32		10.5	0.64	7.6					08-12-77		R. Saylor
146-82-13 DDB	252	15	7.29	950		7.91	954	632		133	46.2	24.4	308	8.1	656.4		10.0	100.6	-15.45	1100	56	< 0.1	<0.1		10.0	0.65	3.6					08-15-77		H. Mantz
146-82-20 CAD	300	8	8.60	1650		8.69	1668	1041		14.9	2.5	1.2	386	3.3	877.2		2.3	100	1.70	733	12.7	0.3	1.5		5.2	0.62	10.2					08-18-77		Sigurdson
146-82-21 BDC	395	10	8.69	1290		8.73	1402	817		8.5	2.5	1.1	354	1.7	728		1.6	93.1	4.7	131	10.7				4.0	3.7	4.3					08-19-77		City of Underwood
146-82-21 CCC	320-360		8.85	1320			1090	896	44	12	3.1	1.1	350	1.7	762	35	.4	74	.88	900	0	1.0	.2									08-19-77	FA 137	UND-EES
146-82-22 CBC	120	15	7.23	535		8.26	511	228		181	48	30.9	31.8	6.1	409.9		<1.0	67.6	-11.4	2008	204	< 0.1	0.1		3.0	0.4	1.6					08-19-77		E. Schell
146-82-28 CCC	259	11	8.2	1310		8.31	1193	882		45.4	2.3	9.6	225.0	3.8	770.0		9.33	83.9	-15.2	2211	106				30	1.44	45					06-16-76	FA 105-1	UND-EES

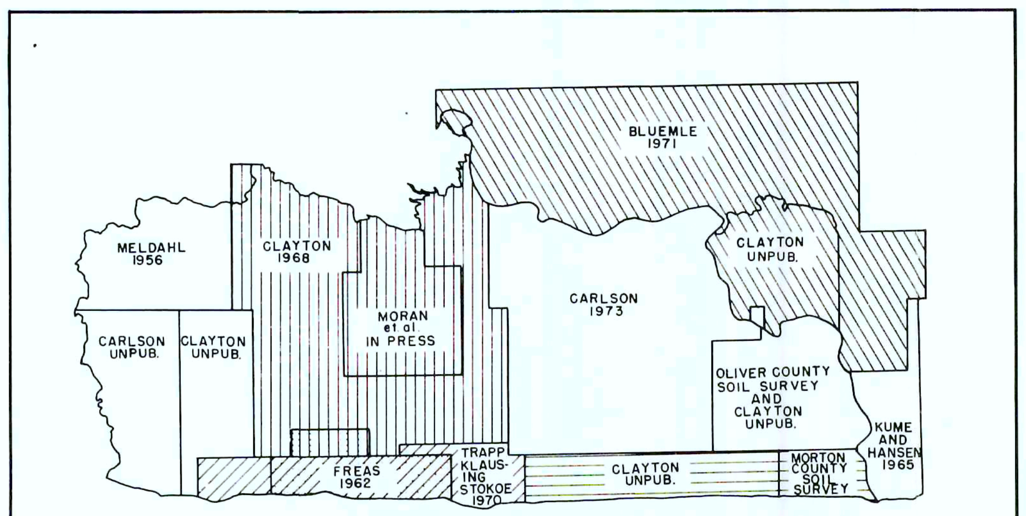
SLOPE-CANNONBALL FORMATIONS

Location	Depth (Ft.)	Field Temp. °C	Field pH	Field Cond.	DO	Lab pH	Lab Cond	TDS	SAR	Total Hard-ness	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	CO_3 mg/L	Cl mg/L	SO_4 mg/L	Stan-dard Error	Fe µg/L	Mn µg/L	NO_3 mg/L	F mg/L	PO_4 µg/L	Cu µg/L	Cd µg/L	Pb µg/L	Se µg/L	As µg/L	^{18}O µg/L	H_3 µg/L	Date	Well No.	Owner
144-87-23 ACC	630	12				8.2	3030	1890	75	19	5.6	1.2	750	2.2	1400	0	356	.4	.11	.060			.8									07-19-67		J. Nelson
145-82-8 ADD	347	11	7.1	1950		8.06	1693	1034		97.7					847		25.70	715		>50000	15773				694.5	20.40	240.2					07-01-76	FA 101-1	UND-EES
145-82-8 ADD	347	8	8.18	2075		8.22	1873	1385		75.7	7.6	3.6	539	5.3	1224		21.3	196.8	-1.0	1150	46.6	0.17	0.71		24.7	3.1	14.5					08-11-77	FA 101-1	UND-EES
146-82-23 BAC	550	11	6.98	1550		7.44	1438	1108		368	99	57	329	13.7	628		10	412	11.83	3100	290	0.16	<0.1		8.4	0.52	9.0					08-16-77		Miller

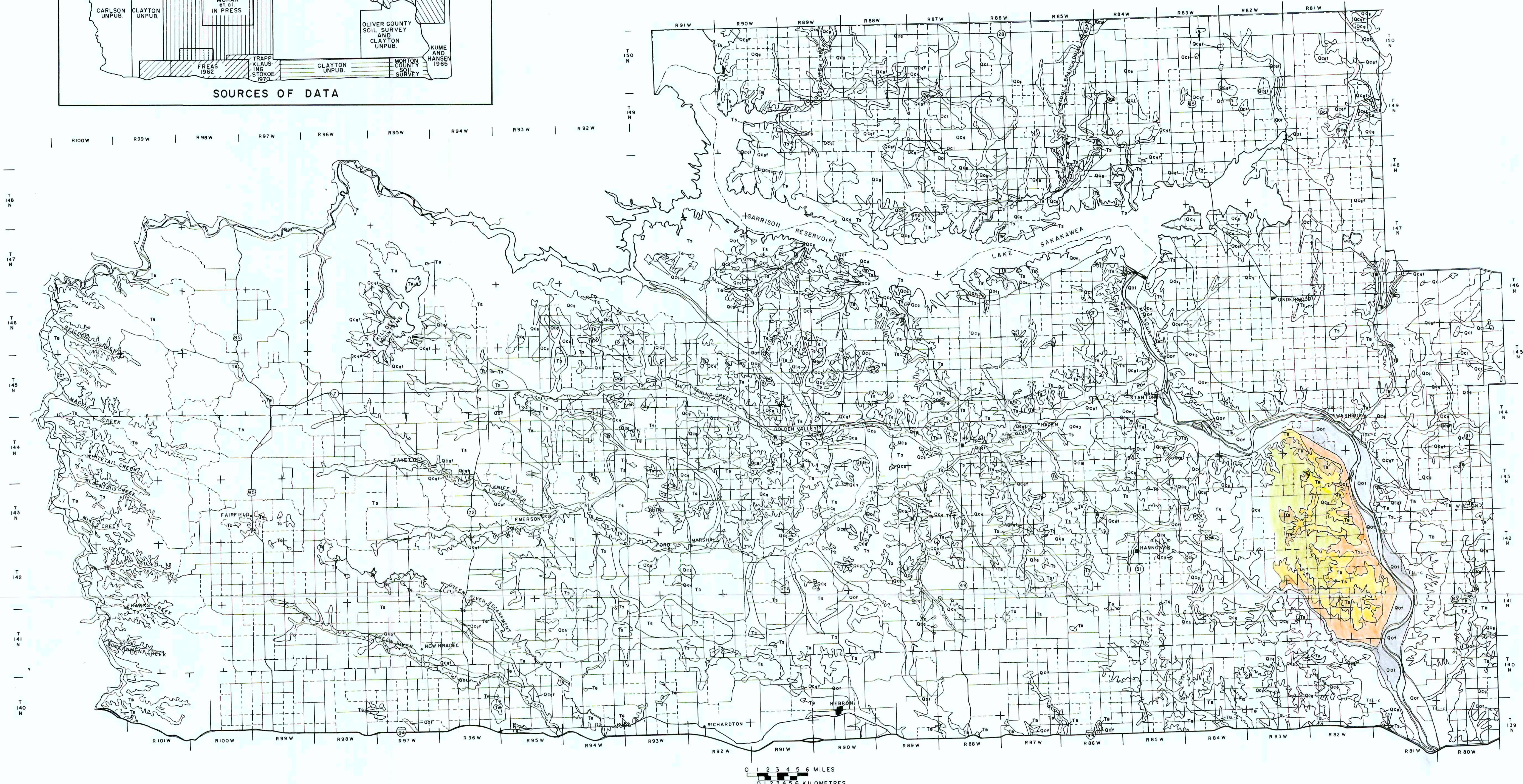
PLATE 1
REPORT OF INVESTIGATION 64

PLATE 1 GEOLOGIC MAP OF THE KNIFE RIVER BASIN AND ADJACENT AREAS

Compiled by William Peterson



SOURCES OF DATA



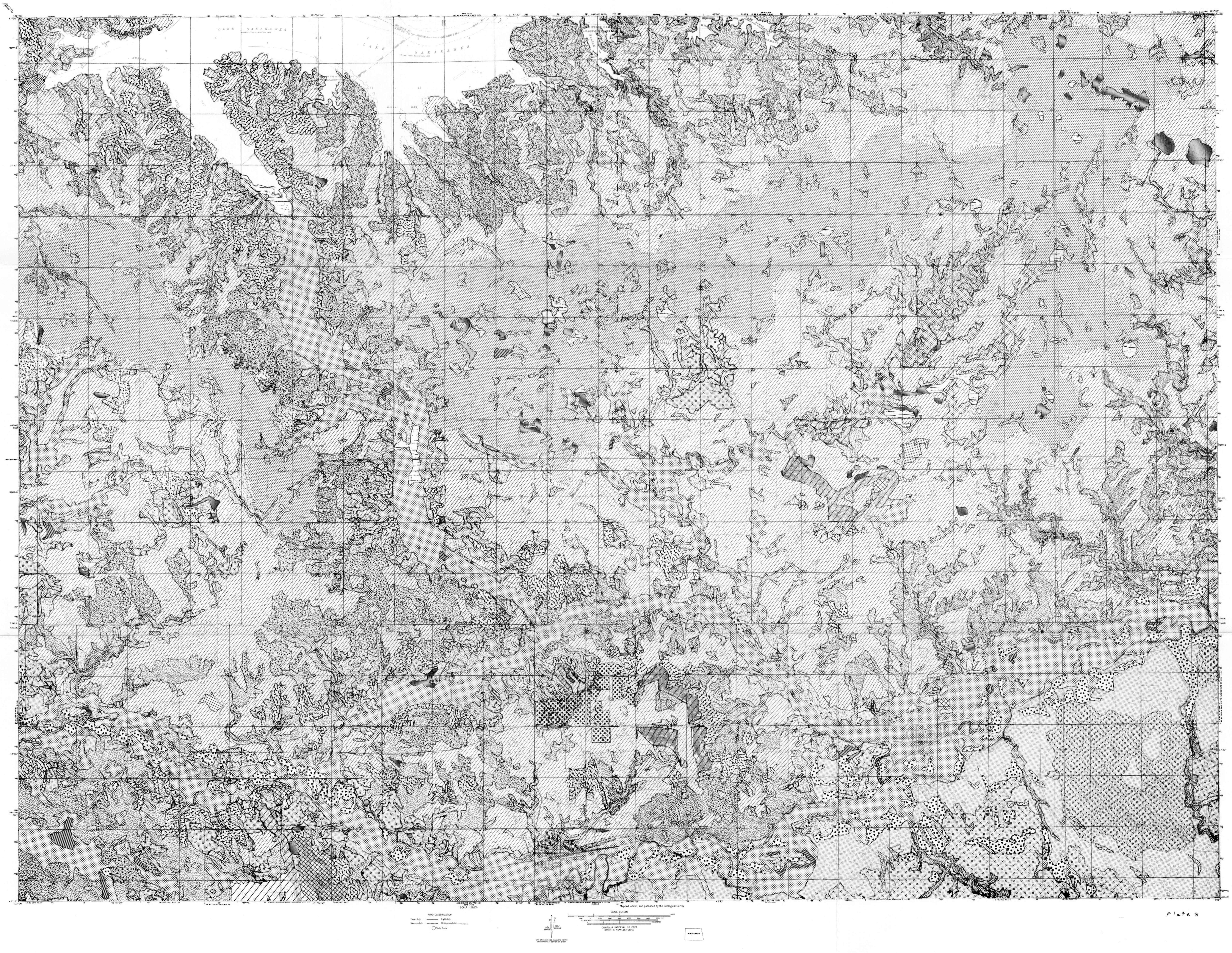
EXPLANATION

Age		Formation		Origin	Lithology
Quaternary	Holocene	Qof		Fluvial	Silt and clay with sand and gravel
		Qoe1	Oahe	Eolian	Silt and very fine sand
	Pleistocene	Qoe2		Eolian	Sand
		Qcgf		Glaciofluvial	Sand, gravel and till
		Qcl	Coleharbor	Lacustrine	Silt and clay
		Qcg		Glacial	Till
Tertiary	Miocene & Oligocene	Tk-A	Killdeer Arikaree	Lacustrine	Limestone and sandstone
		Tw	White River	Fluvial and lacustrine	Conglomerate, sandstone, shale, and limestone
	Eocene	Tg	Golden Valley	Fluvial, lacustrine	Clay, silt, sand, sandstone, and lignite
	Paleocene	Ts	Sentinel Butte	Fluvial, lacustrine	Clay, silt, sand, and lignite
		Tb	Bullion Creek	Fluvial, lacustrine	Clay, silt, sand, and lignite
		Tsl-c	Slope and Cannonball (Undifferentiated)	Slope–fluvial, lacustrine Cannonball–Marine	Clay, silt, and sand

PLATE 2
REPORT OF INVESTIGATION 64

PLATE 2 EAST-WEST DIAGRAMMATIC CROSS SECTION OF THE KNIFE RIVER BASIN AND ADJACENT AREAS

PLATE 3 SURFICIAL MATERIALS IN THE BEULAH - HAZEN AREA, MERCER COUNTY, NORTH DAKOTA



EXPLANATION

UNITS	LITHOSTRATIGRAPHIC	DESCRIPTIVE LITHOLOGIC	MORPHOGENETIC	LITHOGENETIC
	Oahe Formation (Holocene)	Highly organic brown and dark gray clays associated with perennial standing water.	Marshes and sloughs	Standing, shallow water sediment.
	Oahe Formation (Holocene)	Gray and black, organic, laminated silts and clays.	Lake plains, ephemeral ponds and oxbow lake basins.	Pond and lacustrine sediment.
	Oahe Formation (Holocene and Pleistocene)	Predominantly black, gray, and brown silt and clay, locally organic; includes some pebbly sand, FeO concretion fragments and scoria fragments.	Flood plains of streams and hillslope aprons.	Alluvium and colluvium
	Oahe Formation (Holocene and Pleistocene)	1. Well sorted, brown, very fine-to fine-to medium sand and silt. 2. Well sorted, brown, very fine-to fine-to medium sand and silt overlying till to depths generally not more than 0.5 metres.	Sand dunes, sand shadows, and sand-blanketed topography; local relief up to 16 metres.	Eolian deposits.
	Oahe Formation (Holocene and Pleistocene)	Well sorted, slightly sandy, slightly clayey, unbedded brown silt.	Loess–draped topography, generally less than 6 percent slopes.	Loess (Eolian deposits).
	Oahe and Coleharbor Formations (Undifferentiated) (Holocene and Pleistocene)	Fine to medium, bedded, brown and gray sand and silty sand; locally includes some gravel.	Fluvial terraces, point bars, flood plains of streams, and alluvial fans.	Fluvial deposits.
	Coleharbor Formation (Pleistocene)	Unbedded, unsorted mixture of sand, silt and clay with scattered pebbles, cobbles and boulders; locally includes gravel, reworked lignite, and reworked scoria.	1. Draped moraine (till mantling preexisting bedrock topography; constructional relief lacking) 2. Hummocky moraine (relief 6-8 metres in a kilometer; abundant closed depressions).	Till (glacial deposits).
	Coleharbor Formation (Pleistocene)	Gray and black laminated silts and clays.	Lake plains.	Glacial pond and lacustrine sediment.
	Coleharbor Formation (Pleistocene)	Moderately well sorted to poorly sorted, bedded, yellow-brown oxidized sand and gravel composed of a heterogeneous mixture of igneous, metamorphic and sedimentory rock fragments.	Outwash plains, outwash terraces, kames and eskers; includes collapsed outwash plains.	Glaciofluvial deposits.
	Golden Valley Formation (Eocene and Paleocene)	1. White, gray, purple-brown and yellow silt, silty clay, and clay (generally kaolinitic), with carbonaceous shale and lignite. 2. Tan, very fine to fine grained, cross-bedded, micaceous sandstone, sand and silty sand; locally includes white kaolinitic sand.	Flood plains, filled channels, levees, lake plains and swamps.	Fluvial, lacustrine and swamp deposits.
	Sentinel Butte Formation (Paleocene)	1. Drab, gray-brown silt, silty clay, and clay, (montmorillinitic), with carbonaceous shale, lignite and minor limestone. 2. Light brown to brownish-gray, cross-bedded, sandstone, sand and silty sand.	Flood plains, filled channels, levees, lake plains and swamps.	Fluvial, lacustrine and swamp deposits.

Areas underlain by Scoria–various shades of red, yellow, and orange, clay, silt, sand, and pebble-loam, backed and fused by the in situ combustion of lignite.

Spoil piles, abandoned, and active open pit lignite mines.

Areas of subsidence pits overlying abandoned underground lignite mines.

Areas of cut-and-fill; includes recontoured open pit lignite mines.

Gravel pit

Sand dunes, boundary of dune field indicated by dashed lines.

Blowouts

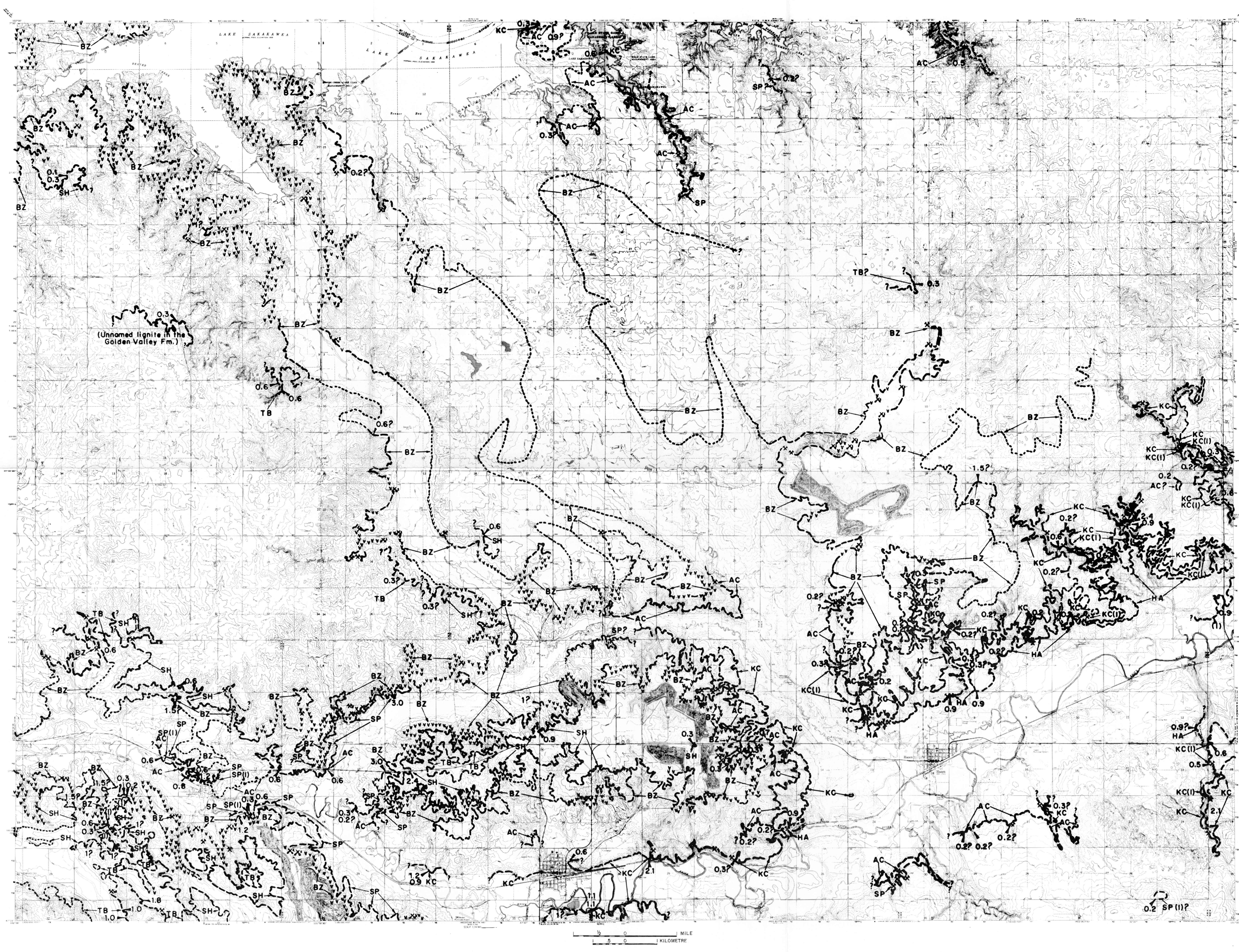
Geologic contact

Spring

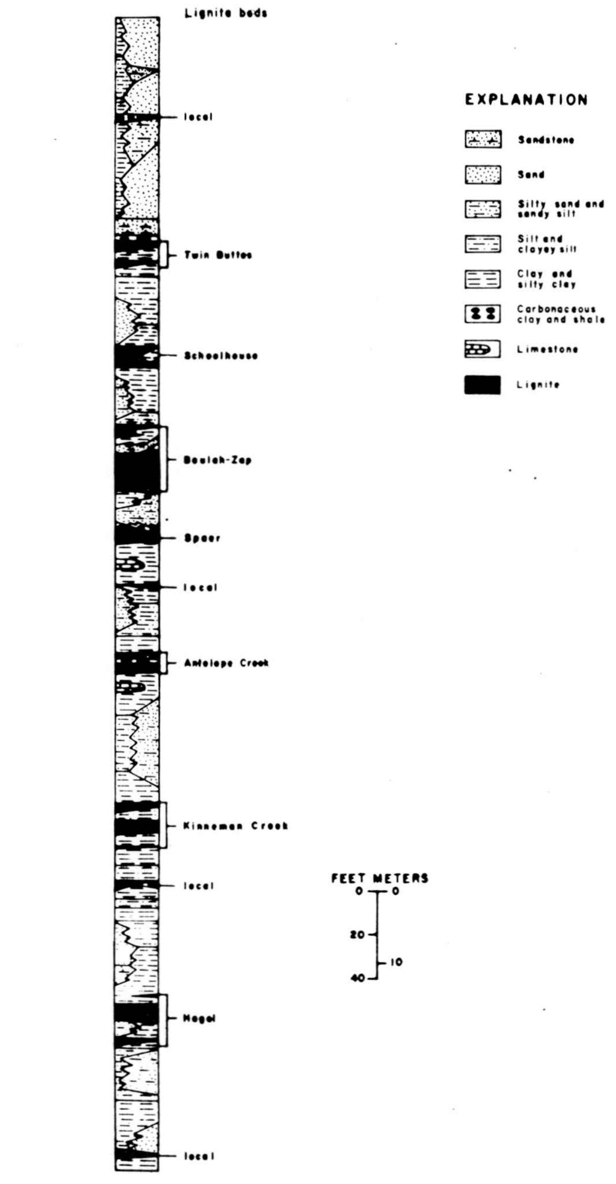
Boundary of the Krem Moraine

PLATE 4
REPORT OF INVESTIGATION 64

PLATE 4 MAP OF THE LIGNITE DEPOSITS IN THE BEULAH - HAZEN AREA, MERCER COUNTY, NORTH DAKOTA



GENERALIZED STRATIGRAPHIC SECTION OF THE PART OF THE SENTINEL BUTTE FORMATION EXPOSED IN THE BEULAH-HAZEN AREA



EXPLANATION

AC / 0.3 — LIGNITE BED–(May include carbonaceous clay locally)–Dashed where approximately located; short dashed where inferred. Letters indicate name of lignite bed; queried where correlation doubtful or location of bed uncertain. Thickness of coal in meters, measured at triangle; queried where bed is not completely exposed, partly eroded, or partly burned and total thickness is uncertain. Where two beds were measured at one outcrop, the thickness of the upper bed is at the top.

VVVVVV — PORCELLENITE (CLINKER)–Areas where rocks overlying the lignite beds have been baked and fused by the in situ combustion of the coal.

ABANDONED LIGNITE MINE–Small operation.

SCORIA PIT

NAME OF LIGNITE BED*

TB = TWIN BUTTES
SH = SCHOOLHOUSE
BZ = BEULAH-ZAP
SP = SPAER
AC = ANTELOPE CREEK
KC = KINNEMAN CREEK
HA = HAGEL
(1) or KC(1) = LOCAL BED OR LOCAL BED ASSOCIATED WITH BED NAMED

*All lignite beds listed are in the Sentinel Butte Formation of Paleocene age.

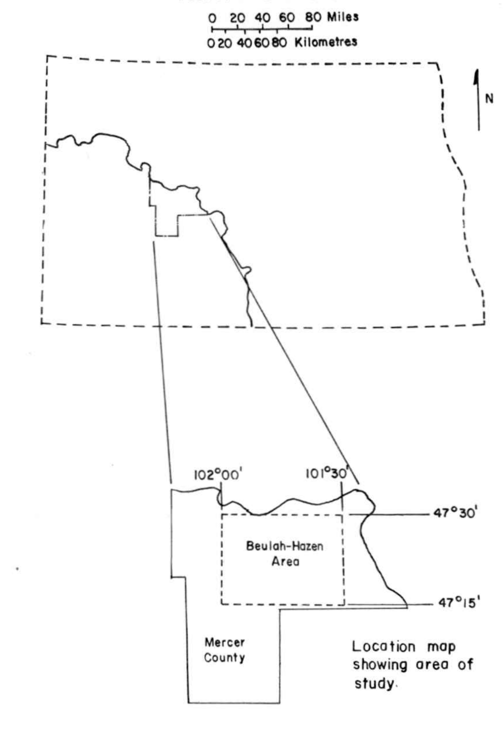
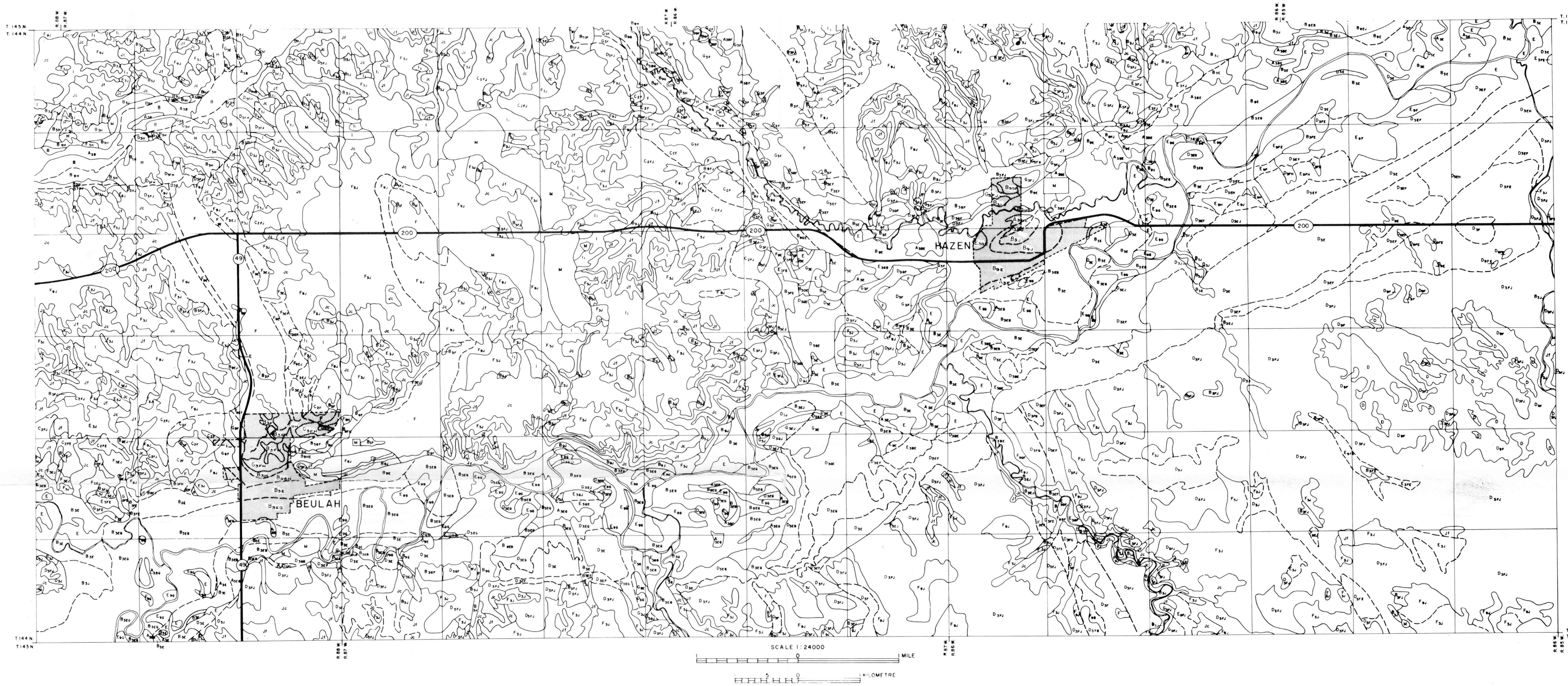


PLATE 5 SURFICIAL AND NEAR-SURFACE MATERIALS MAP OF THE BEULAH-HAZEN DETAILED STUDY AREA



EXPLANATION

A Silty clay and clay, highly organic.

B Sandy silt and clay, organic near surface, with lenses of silty sand and clay.

C Silt, slightly sandy and clayey, unbedded.

D Sand, very fine to medium grained, very well sorted, loose.

E Sand and silty sand, fine to coarse grained, well sorted, with lenses of gravel and clay.

F Silty, sandy, pebbly, bouldery clay (pebble loam), with gravel, sand, silt and clay lenses.

G Sand and gravel, silty, poorly sorted.

H Silt, coarse grained, to very fine grained sand; very well sorted, interbedded with silty clay and silty sand.

I Scoria, with some clay, sand and lignite. Designated where overlain by thin (less than 1 metre) sandy silt and clay.

Jf. Silt, silty clay, and clay; partially consolidated with lignite and carbonaceous beds, and minor limestone.

Jc Sand, silty sand, sandy silt, and sandstone; very fine to medium grained with lignite and carbonaceous beds.

Jf and Jc = J in the subsurface.

Letters and numbers are combined to show relative depths and thicknesses of a maximum of 3 units to a depth of 9 metres. For example A_{3BC} represents a maximum of 3 metres of unit A overlying unit B, unit C at a maximum depth of 9 metres. A_{9B} represents a maximum of 9 metres of unit A overlying unit B. See text for further discussion.

less than

——— ± 30 metres reliability

– – – – ± 60 metres reliability

PLATE 6 CROSS SECTION A - A'

PLATE 7 CROSS SECTION B - B'

EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
REAP__	1976-77	NDGS	Rotary Rig
L__	1976	USGS	Rotary Rig
HB__	1976	NDGS	Auger Rig
B74__	1974	USGS	Rotary Rig
M74__	1974	NACCO	Rotary Rig
NDSWC__	1968-69	NDSWC	Rotary Rig

PLATE 8 CROSS SECTION C - C'

EXPLANATION

Lithostratigraphic units indicated on cross section.
Names of lignite beds indicated on cross section.
Symbols for lithologic units listed below:

- Pebble-loam
- Sand and Gravel
- Sand
- Sandstone
- Silty Sand and Sandy Silt
- Porcellenite (Scoria)
- Silt and Clayey Silt
- Clay and Silty Clay
- Carbonaceous Clay
- Limestone
- Lignite
- Mixed lithology (Spoils)
- Formation Contact

EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
REAP —	1976-77	NDGS	Rotary Rig
L —	1976	USGS	Rotary Rig
HB —	1976	NDGS	Auger Rig
M74 —	1974	NACCO	Rotary Rig
NDSWC —	1968	NDSWC	Rotary Rig

PLATE 9 CROSS SECTION D - D'

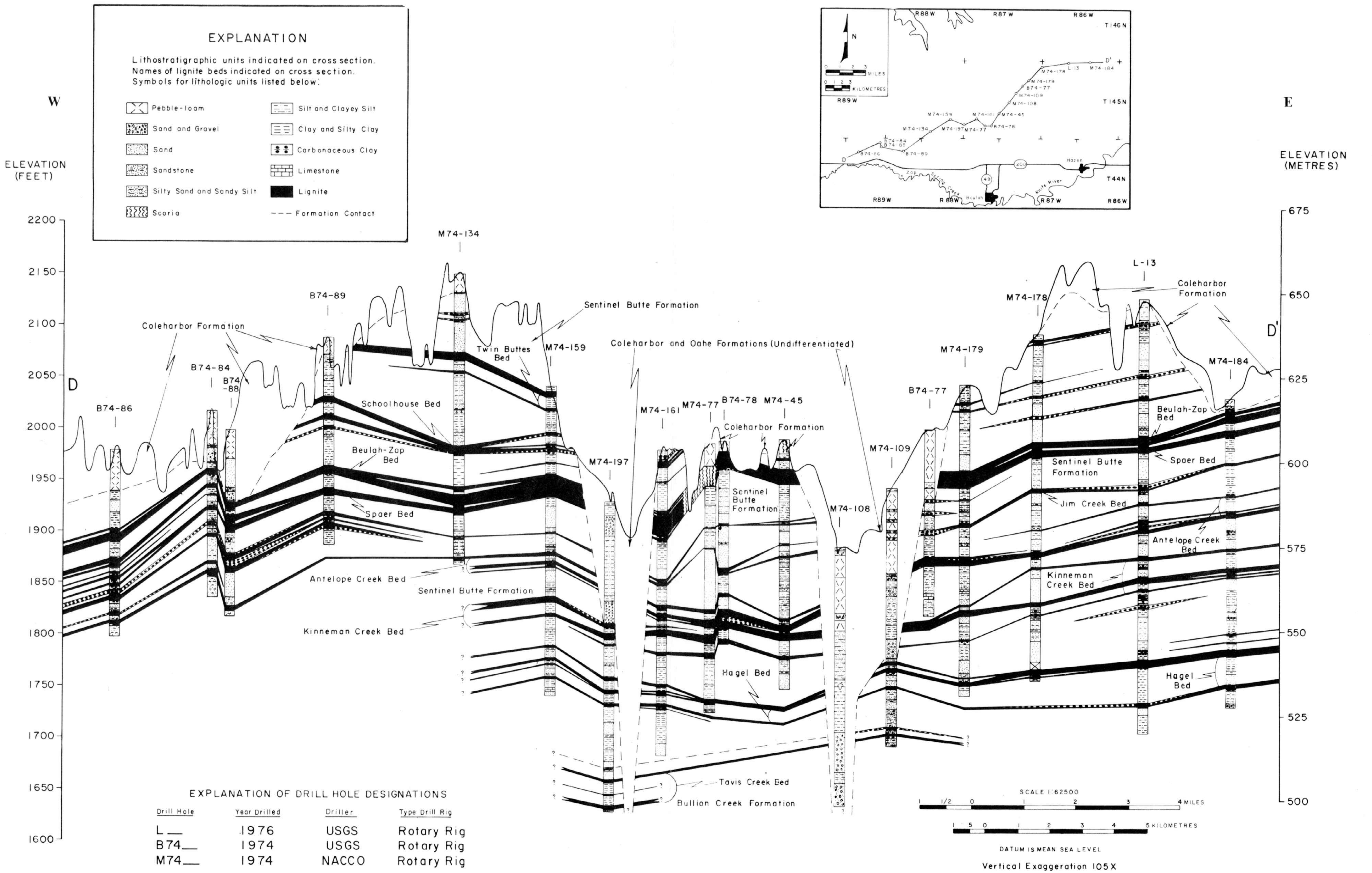


PLATE 10
REPORT OF INVESTIGATION 64

PLATE 10 CROSS SECTION E - E'

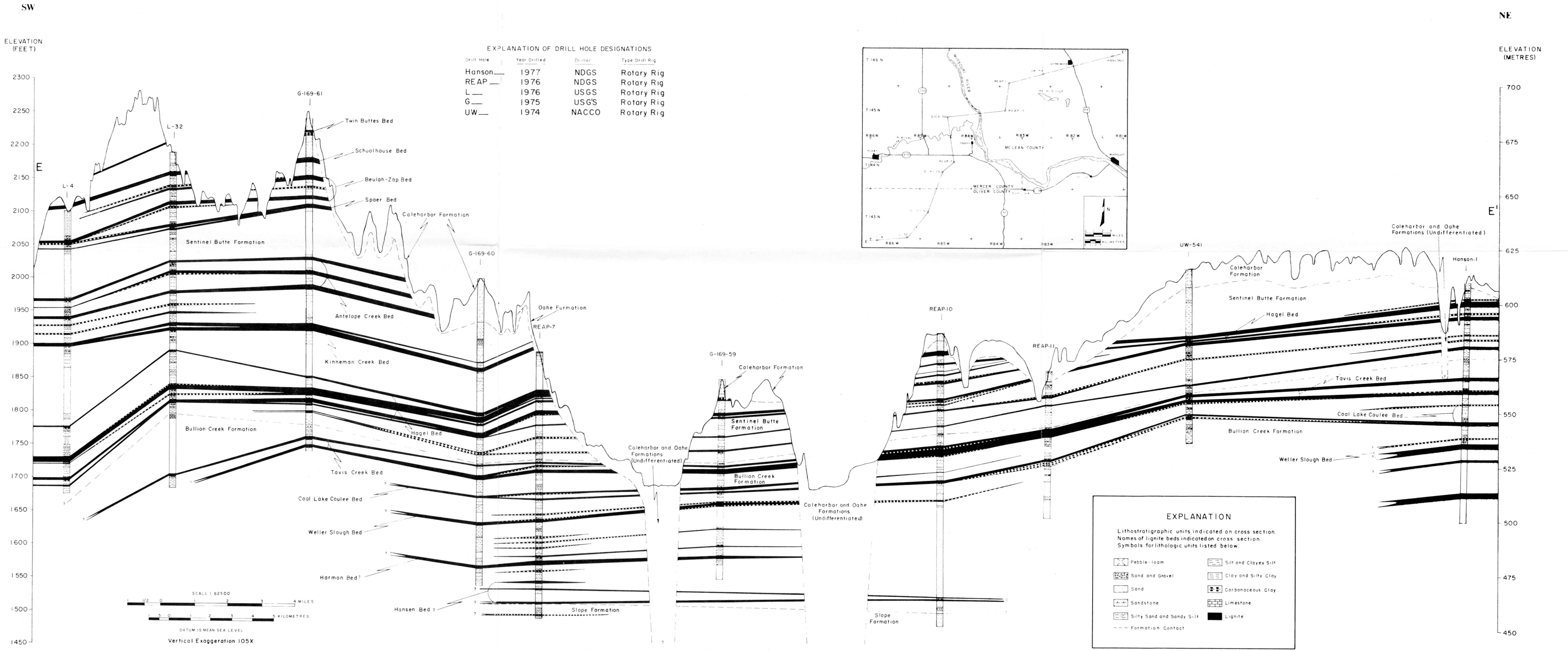


PLATE 11 CROSS SECTION F - F'

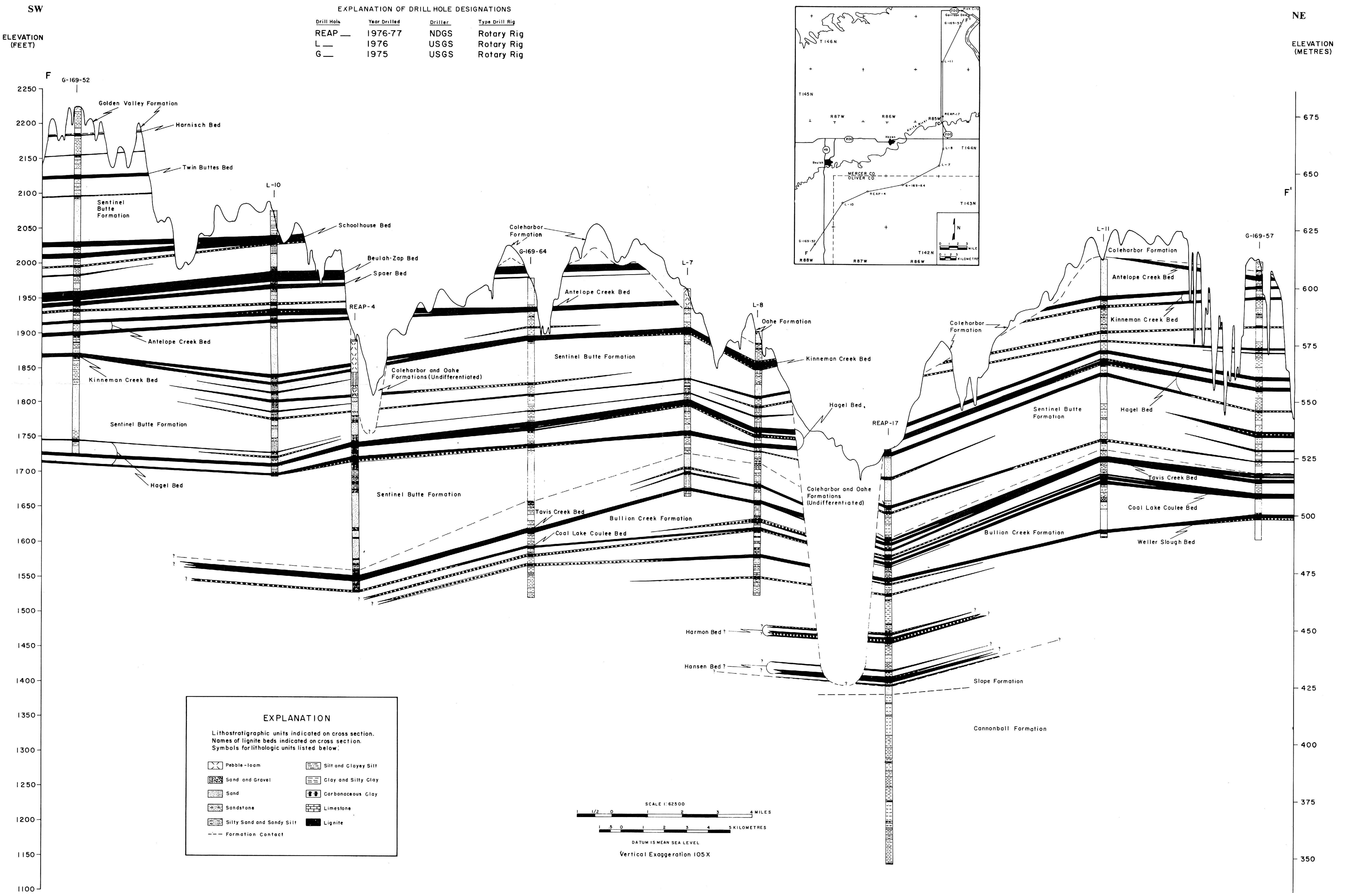


PLATE 12 CROSS SECTION G - G'

PLATE 13 CROSS SECTION H - H'

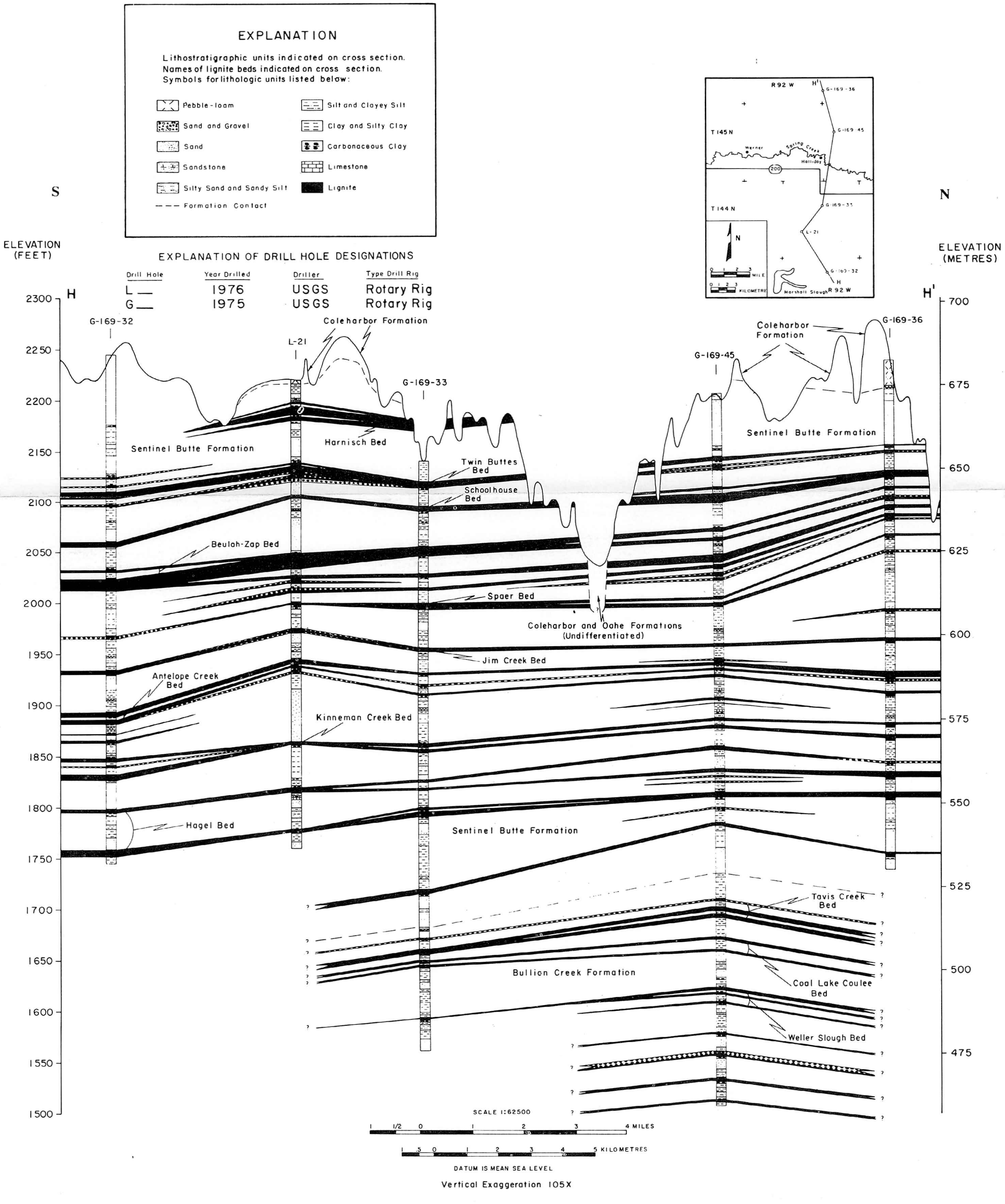


PLATE 14 CROSS SECTION J-J'

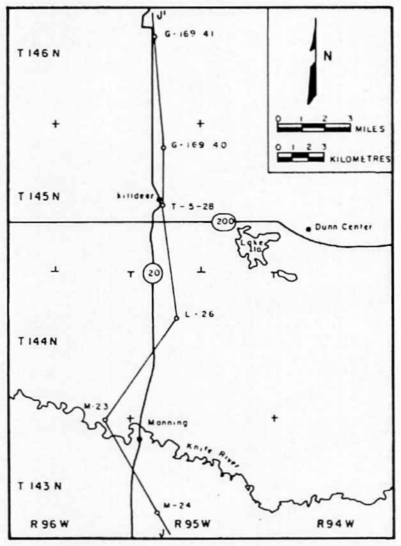
EXPLANATION

Lithostratigraphic units indicated on cross section.
Names of lignite beds indicated on cross section.
Symbols for lithologic units listed below:

- Pebble-loam
- Sand and Gravel
- Sand
- Sandstone
- Silty Sand and Sandy Silt
- Formation Contact
- Silt and Clayey Silt
- Clay and Silty Clay
- Carbonaceous Clay
- Limestone
- Lignite

EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
L___	1976	USGS	Rotary Rig
M___	1976	USGS	Rotary Rig
G___	1975	USGS	Rotary Rig
T___	1958	Thompson Drilling	Rotary Rig



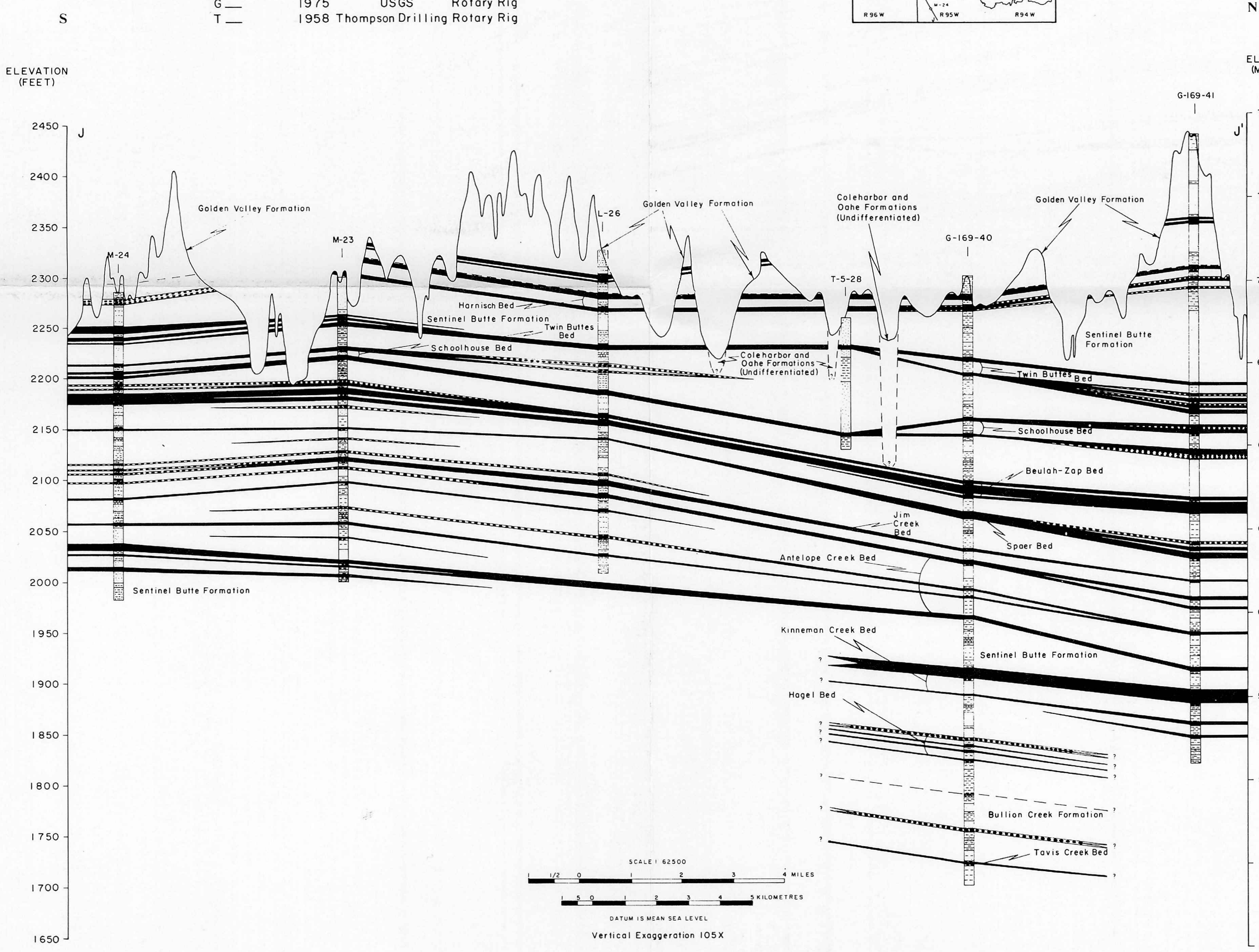


PLATE 15 CROSS SECTION K - K'

EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
REAP___	1976-77	NDGS	Rotary Rig
L___	1976	USGS	Rotary Rig
G___	1975	USGS	Rotary Rig
M74___	1974	NACCO	Rotary Rig

PLATE 16 CROSS SECTION L - L'

EXPLANATION

Lithostratigraphic units indicated on cross section
Names of lignite beds indicated on cross section
Symbols for lithologic units listed below:

- Pebble-loam
- Sand and Gravel
- Sand
- Sandstone
- Silty Sand and Sandy Silt
- Silt and Clayey Silt
- Clay and Silty Clay
- Carbonaceous Clay
- Limestone
- Lignite
- --- Formation Contact

EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
REAP __	1976-77	NDGS	Rotary Rig
L __	1976	USGS	Rotary Rig
M __	1976	USGS	Rotary Rig
G __	1975	USGS	Rotary Rig

PLATE 17 MAP SHOWING LOCATIONS OF CROSS SECTIONS A-A' — L-L'

PLATE 18 CROSS SECTION M-M', BEULAH-HAZEN DETAILED STUDY AREA

PLATE 19 CROSS SECTION N-N', BEULAH - HAZEN DETAILED STUDY AREA

PLATE 20 CROSS SECTION P-P', BEULAH-HAZEN DETAILED STUDY AREA

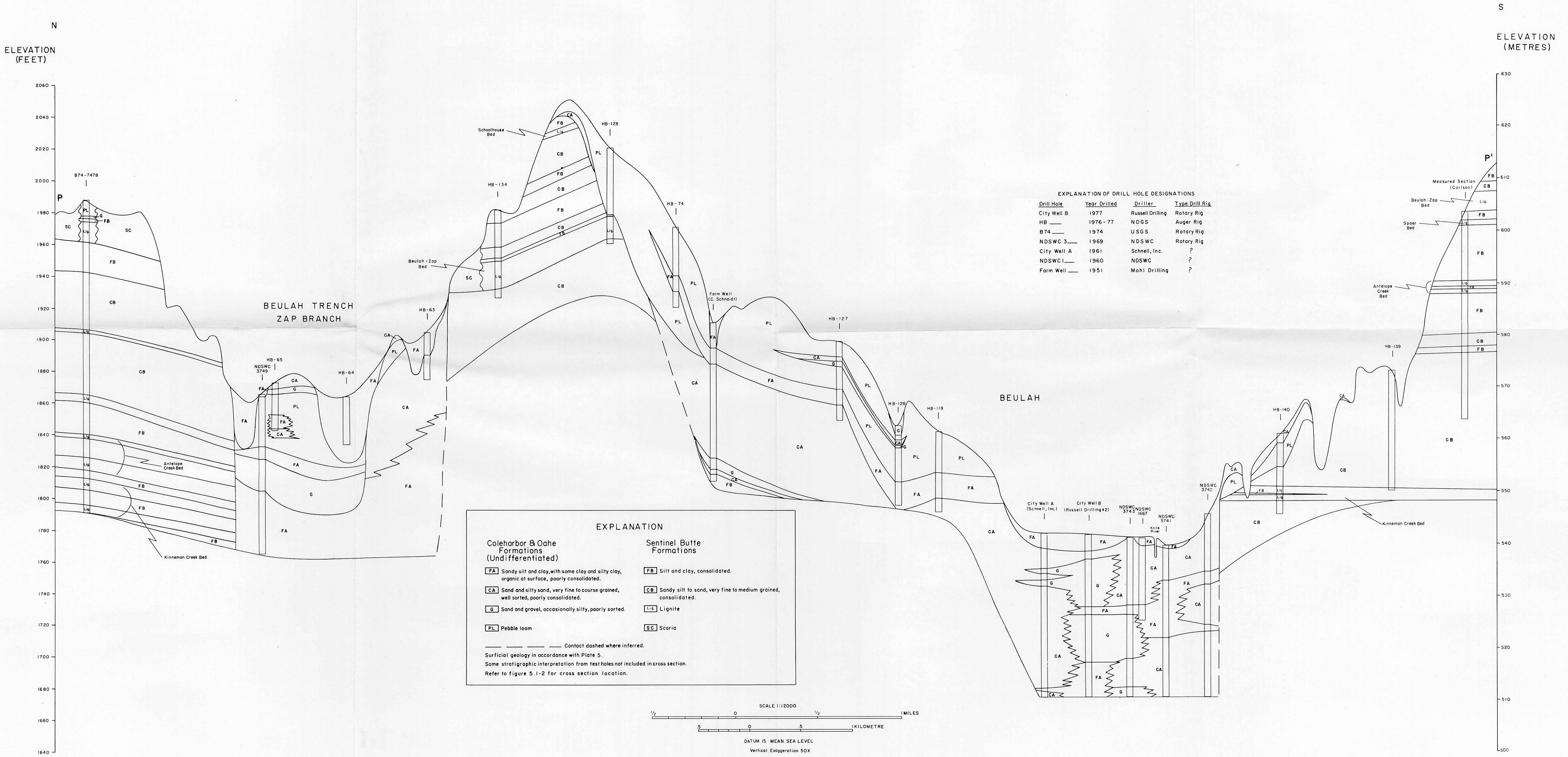


PLATE 21 CROSS SECTION Q-Q', BEULAH-HAZEN DETAILED STUDY AREA

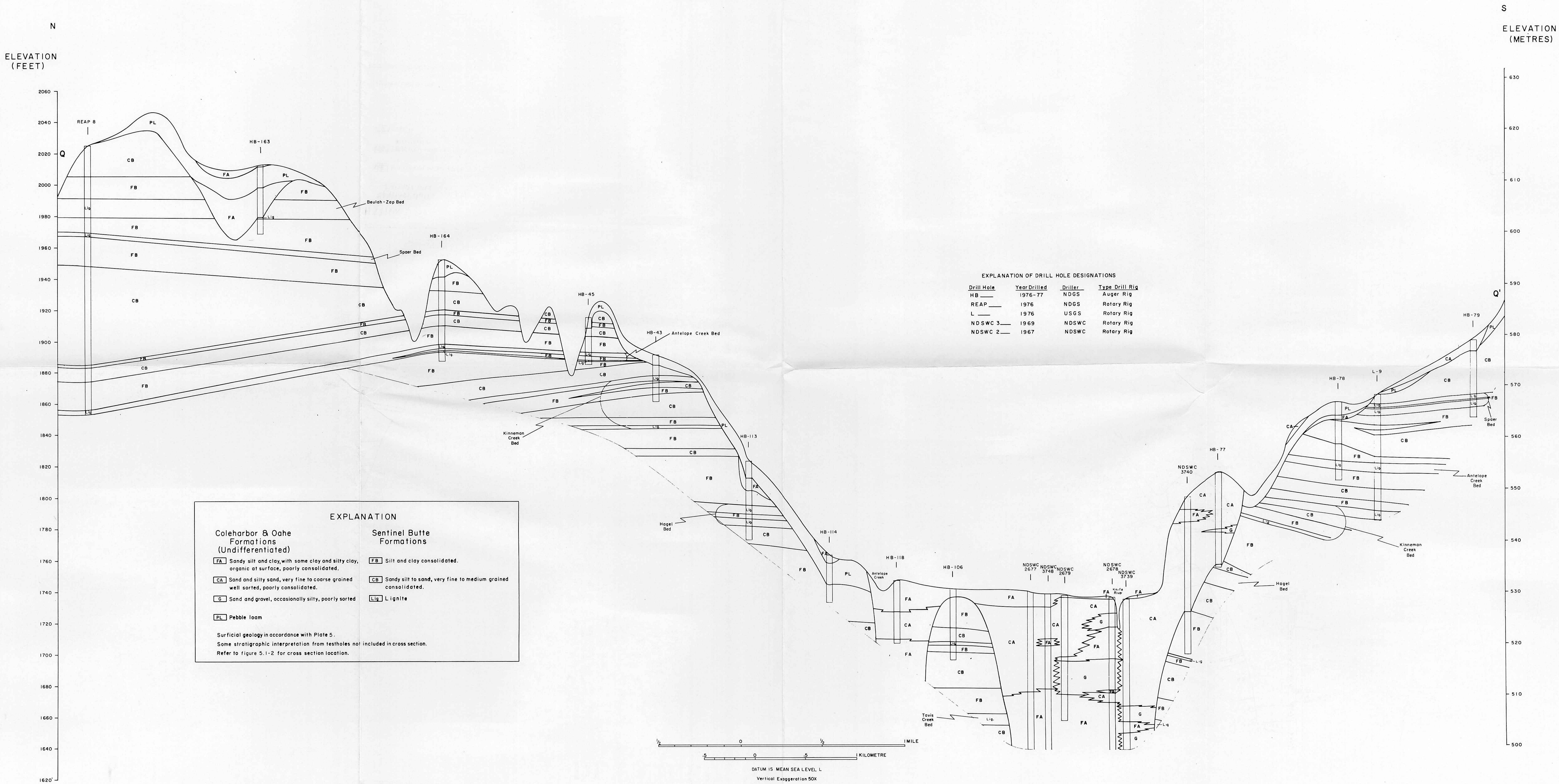


PLATE 22 STRUCTURE CONTOUR OF THE TOP OF THE BULLION CREEK FORMATION

STRUCTURE CONTOUR MAP ON TOP OF THE BULLION CREEK FORMATION

EXPLANATION

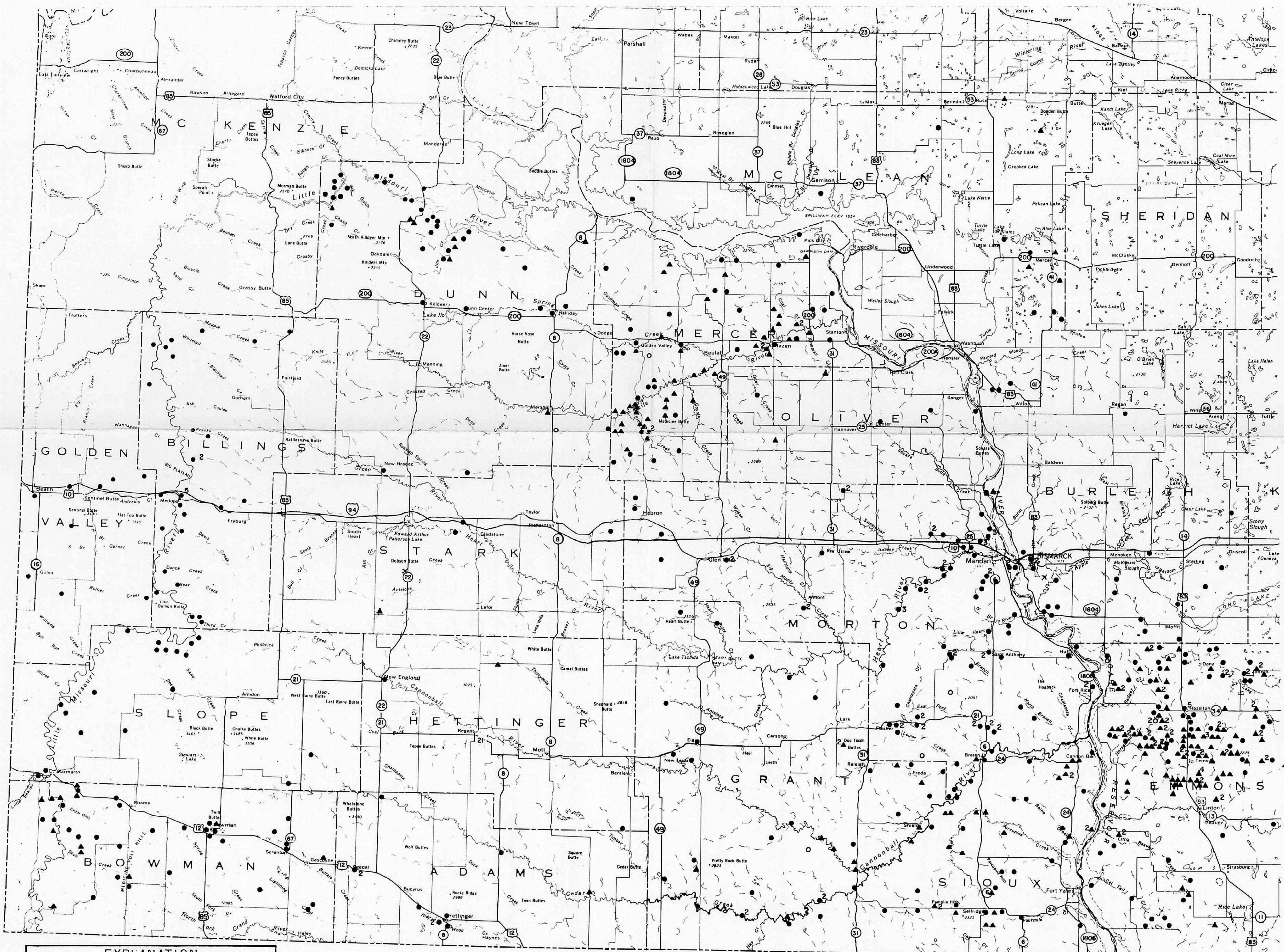
- ● RELIABLE DRILL HOLE DATA
- ◉ QUESTIONABLE DRILL HOLE DATA
- ○ DATA EXTRAPOLATED FROM DRILL HOLE NOT PENETRATING THE BULLION CREEK FORMATION
- \+ DATA FROM OUTCROP
- —— STRUCTURE CONTOUR LINE
- — — INFERRED STRUCTURE CONTOUR LINE
- OUTLINE OF KNIFE RIVER BASIN

0 1 2 3 4 5 6 MILES
0 1 2 3 4 5 6 KILOMETRE

CONTOUR INTERNAL-50 FEET

PLATE 23
REPORT OF INVESTIGATION 64

PLATE 23 LOCATION OF FOX HILLS - HELL CREEK WELLS IN SOUTHWESTERN NORTH DAKOTA [See Appendix C-II for analyses]



EXPLANATION
- ▲ Well without chemical data
- ○ Well with specific conductance only
- ● Well with complete chemical analyses
- 2 Number of wells at a given location

10 0 10 20 30 40 Miles
10 0 10 20 30 40 50 Kilometres

PLATE 24 LOCATION OF COLEHARBOR WELLS IN THE KNIFE RIVER BASIN
[See Appendix C-III for analyses]

PLATE 25
REPORT OF INVESTIGATION 64

PLATE 25 LOCATION OF ALL WELLS (EXCLUDING FOX HILLS - HELL CREEK AND COLEHARBOR) IN THE KNIFE RIVER BASIN FOR WHICH THE INTAKE ZONE WAS IDENTIFIED

PLATE 26 LOCATION OF ALL WELLS (EXCLUDING FOX HILLS-HELL CREEK AND COLEHARBOR) IN THE KNIFE RIVER BASIN FOR WHICH THE INTAKE ZONE WAS IDENTIFIED AND WHICH HAVE COMPLETE CHEMICAL ANALYSES

(See Appendix C-IV for analyses)

PLATE 27 EAST-WEST CROSS SECTION, FALKIRK AREA

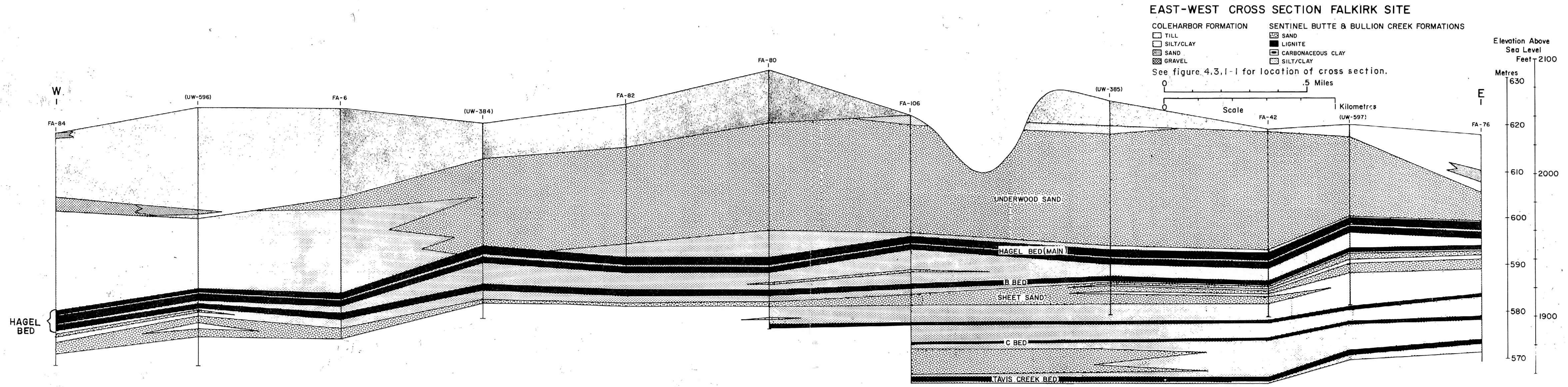


PLATE 28 NORTH - SOUTH CROSS SECTION, FALKIRK AREA

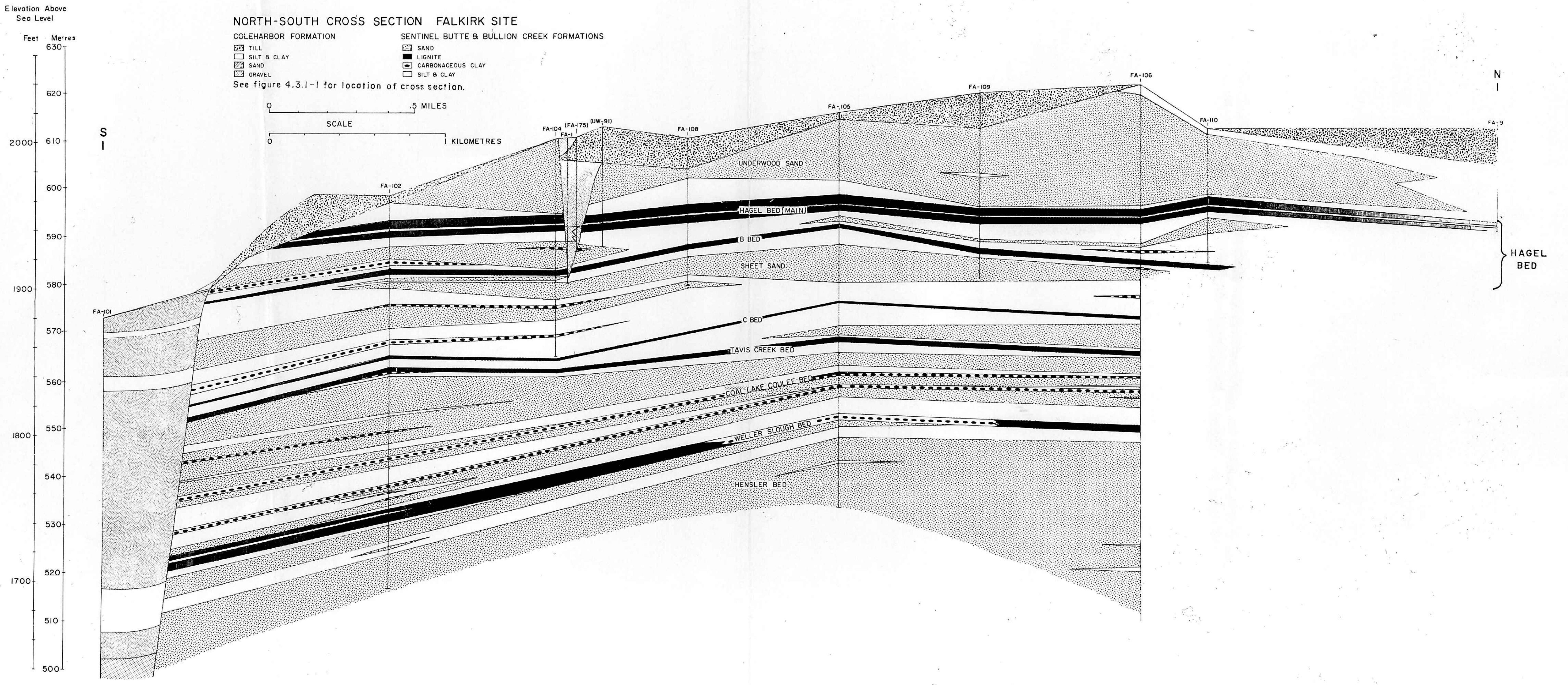
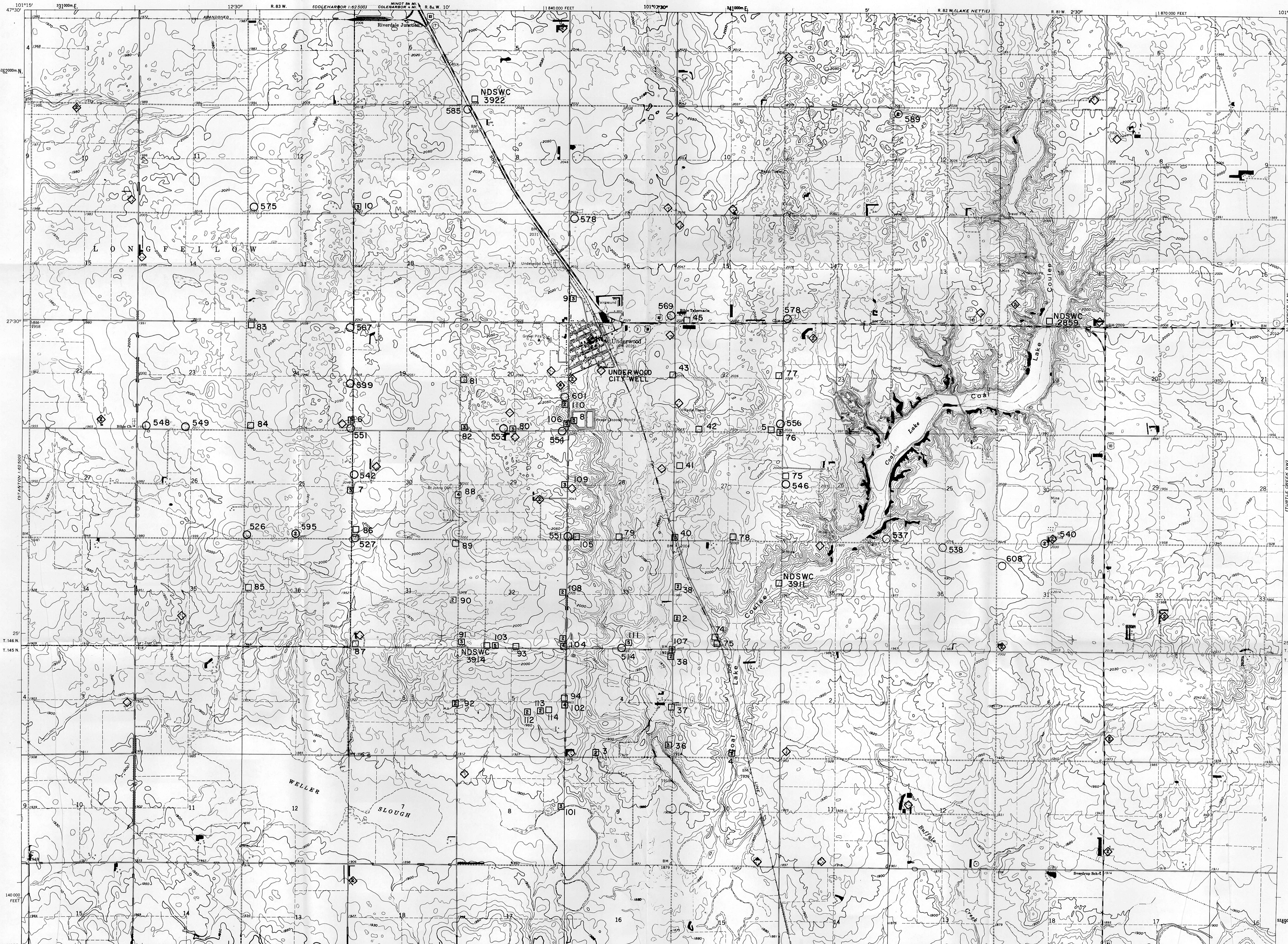


PLATE 29 PIEZOMETER NESTS AND IDENTIFIED FARM WELLS, FALKIRK AREA



- ○ 1 inch (2.5 cm.) piezometers
- □ 2 inch (5 cm.) piezometers
- ◇ Farm wells
- 2 Number of piezometers

Refer to Table 4.3.1-1 for specific intake zone of each piezometer and farm well.

PLATE 30 CROSS SECTION OF THE BEULAH-HAZEN AREA SHOWING GROUNDWATER CHEMICAL VARIABILITY IN SHALLOW STRATIGRAPHIC UNITS

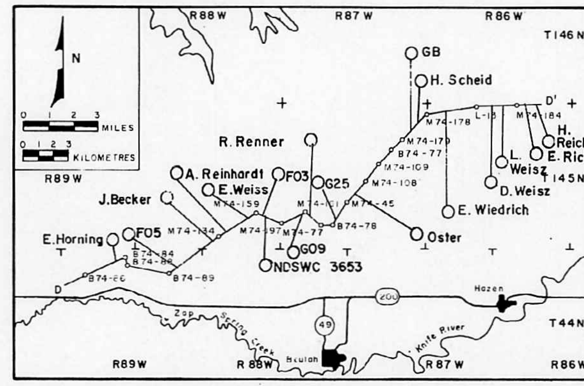
FARM WELLS AND PIEZOMETERS	LOCATION
E. Horning	144-089-04 BAD
F 05	145-088-31 BBC
J. Becker	145-088-20 CCC
A. Reinhardt	145-088-20 BAB
E. Weiss	145-088-30 ABB
F 03	145-088-12 DCD
NDSWC 3653	145-088-25 ABB
G 09	145-087-30 ADB
R. Renner	145-088-08 BCC
G 25	145-087-19 CCB
E. Oster	146-085-29 DCD
G 13	145-087-02 ADD
H. Scheid	145-087-01 CCB
E. Weidrich	145-086-06 CDD
D. Weisz	145-086-10 DBA
L. Weisz	145-086-10 AAC
E. Richter	145-086-12 BBB
H. Reichenberg	145-086-01 DDD

All other numbers refer to testholes used in construction of the cross section.

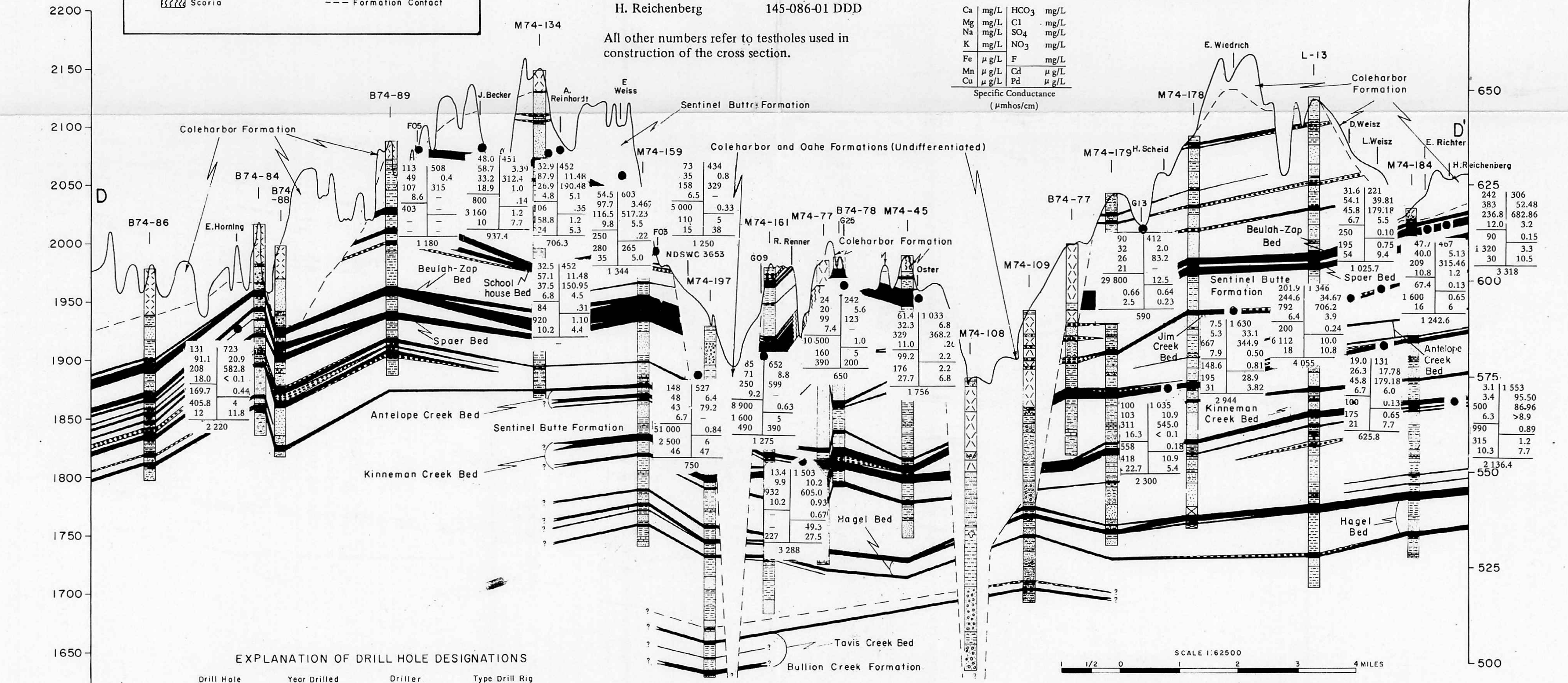
EXPLANATION

Lithostratigraphic units indicated on cross section.
Names of lignite beds indicated on cross section.
Symbols for lithologic units listed below:

- Pebble-loam
- Sand and Gravel
- Sand
- Sandstone
- Silty Sand and Sandy Silt
- Scoria
- Silt and Clayey Silt
- Clay and Silty Clay
- Carbonaceous Clay
- Limestone
- Lignite
- --- Formation Contact



Ca mg/L	HCO3 mg/L
Mg mg/L	Cl mg/L
Na mg/L	SO4 mg/L
K mg/L	NO3 mg/L
Fe μg/L	F mg/L
Mn μg/L	Cd μg/L
Cu μg/L	Pd μg/L
Specific Conductance (μmhos/cm)	



EXPLANATION OF DRILL HOLE DESIGNATIONS

Drill Hole	Year Drilled	Driller	Type Drill Rig
L__	1976	USGS	Rotary Rig
B74__	1974	USGS	Rotary Rig
M74__	1974	NACCO	Rotary Rig

PLATE 31 CROSS SECTION OF THE CENTER AREA SHOWING GROUNDWATER CHEMICAL VARIABILITY IN SHALLOW STRATIGRAPHIC UNITS

Ca mg/L	HCO3 mg/L		
Mg mg/L	Cl mg/L		
Na mg/L	SO4 mg/L		
K mg/L	NO3 mg/L		
Fe µg/L	F mg/L		
Mn µg/L	Cd µg/L		
Cu µg/L	Pd µg/L		

Specific Conductance (µmhos/cm)

0 1000 2000 FT
SCALE

EXPLANATION

Coleharbor Formation

- Pebble-loam
- Silt and clay

Sentinel Butte Formation

- Sand
- Sandy silt - silty sand
- Silt
- Clay
- Lignite

FARM WELLS AND PIEZOMETERS	LOCATION
O. Light	142-084-22 AAA
360 A	142-084-23 CCC
371 A	142-084-26 CBB
E. Reinke	141-084-26 CBB
V. Ganske	142-084-29 BBB
367 A	142-084-27 CCC
368 A	142-084-33 ADA
B. Dresser	142-084-34 ACC
J. Bobb	142-084-33 BDD
T. Lipp	142-084-32 BDD
365 A	142-084-33 CCC
W. Mosbrucker	141-084-05 CAA
362	141-084-02 BAA
363	141-084-03 DDA
K. Reinke	141-084-10 ABA

All other numbers refer to testholes used in construction of the cross section.

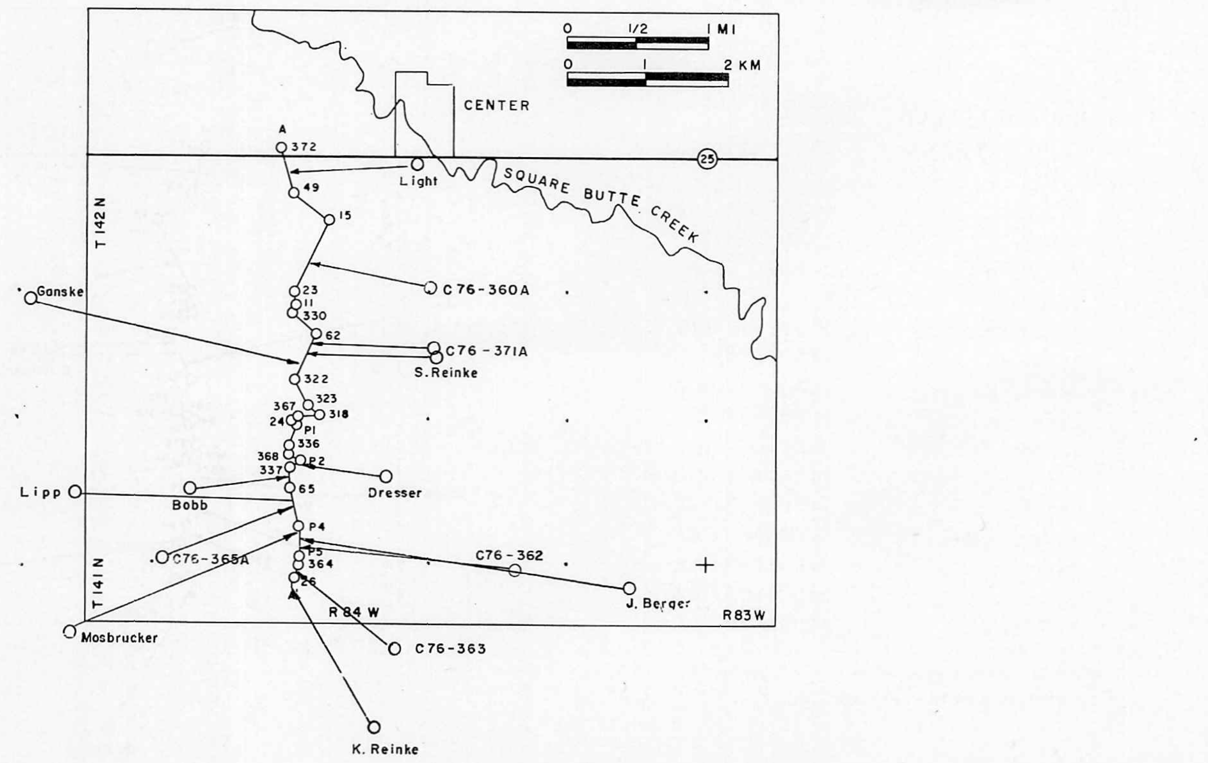


PLATE 32 CROSS SECTION OF THE INDIAN HEAD MINE

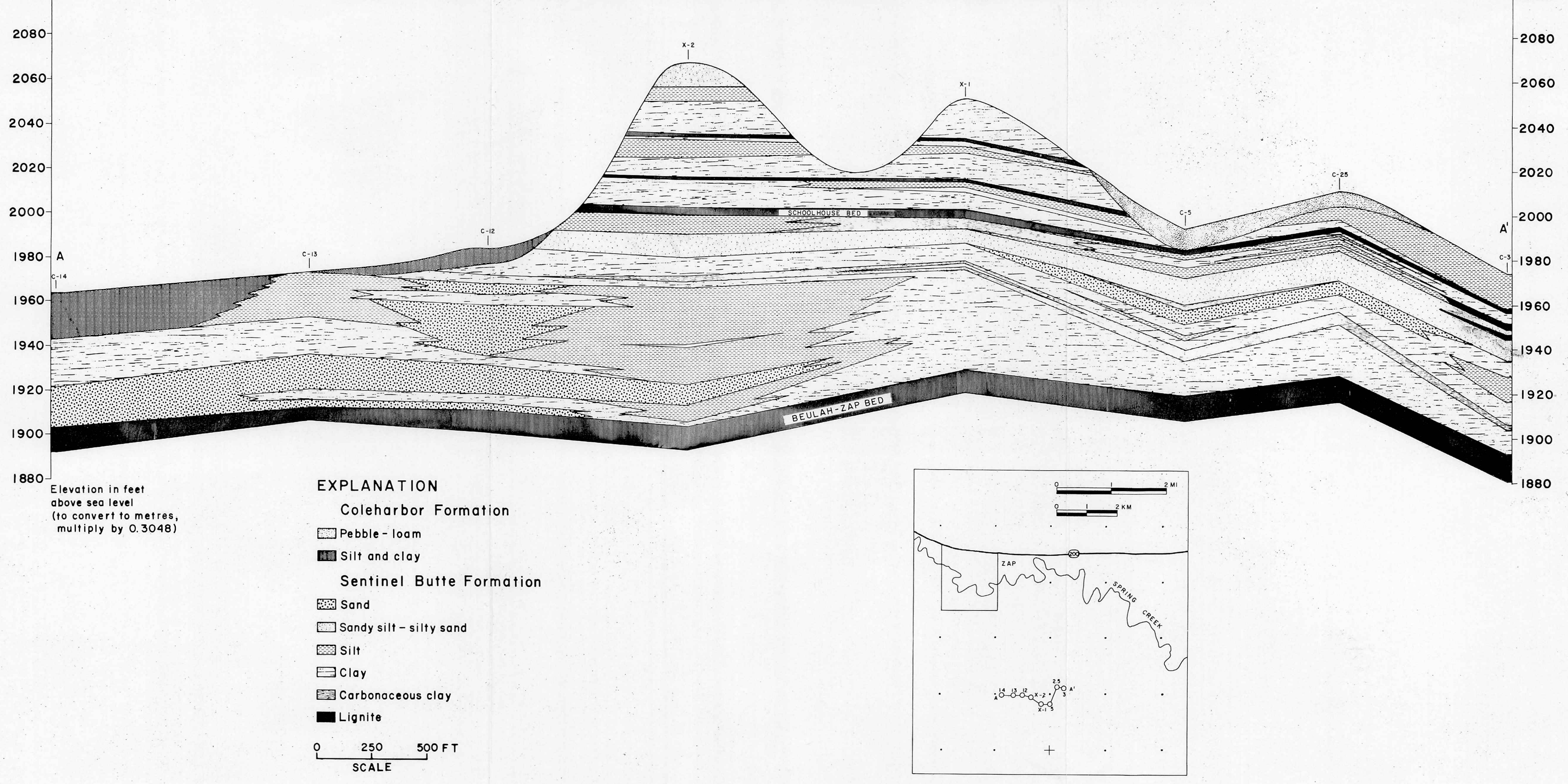


PLATE 33 LOCATIONS OF TESTHOLES AND CROSS SECTION IN THE BEULAH-HAZEN DETAILED STUDY AREA

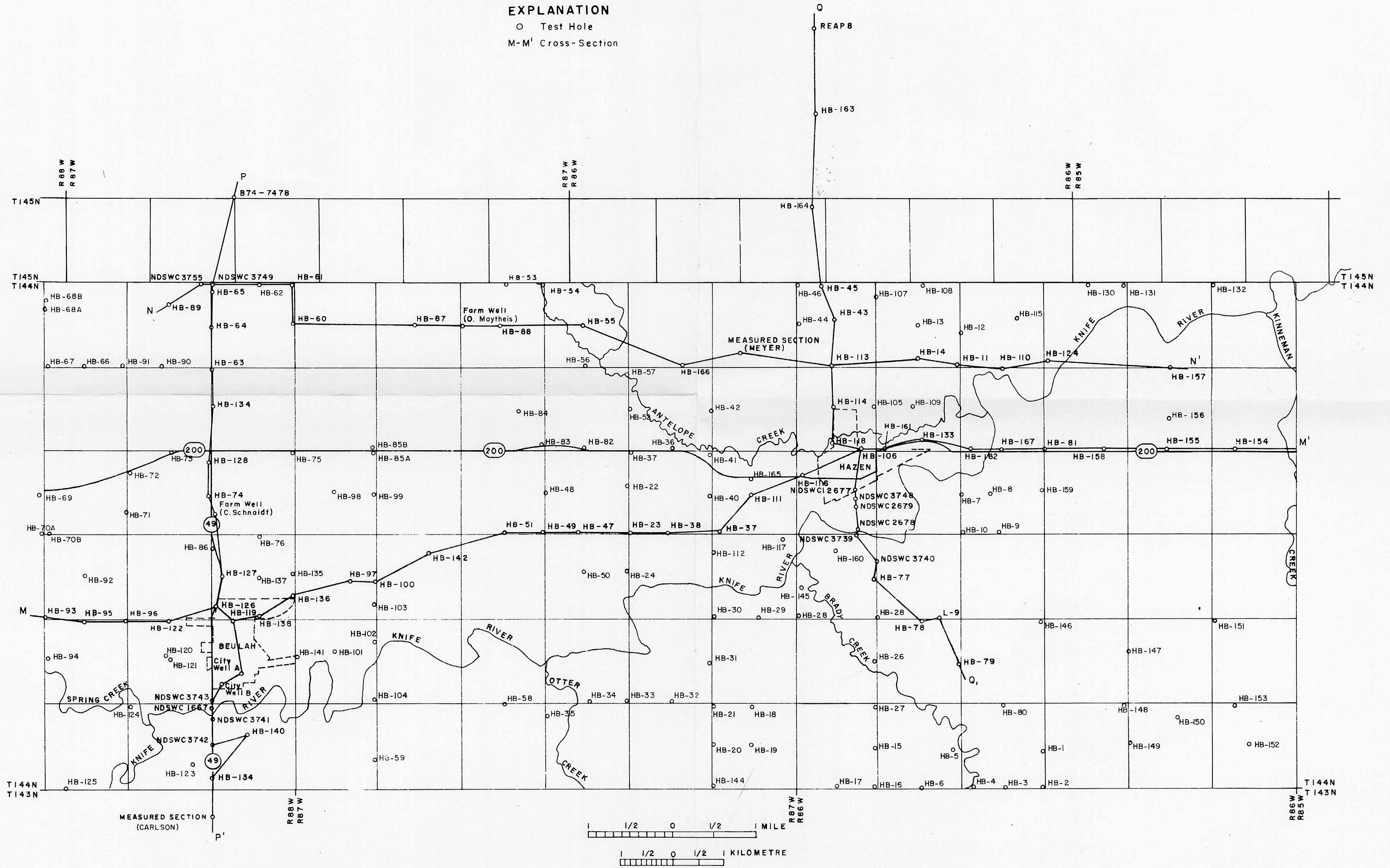
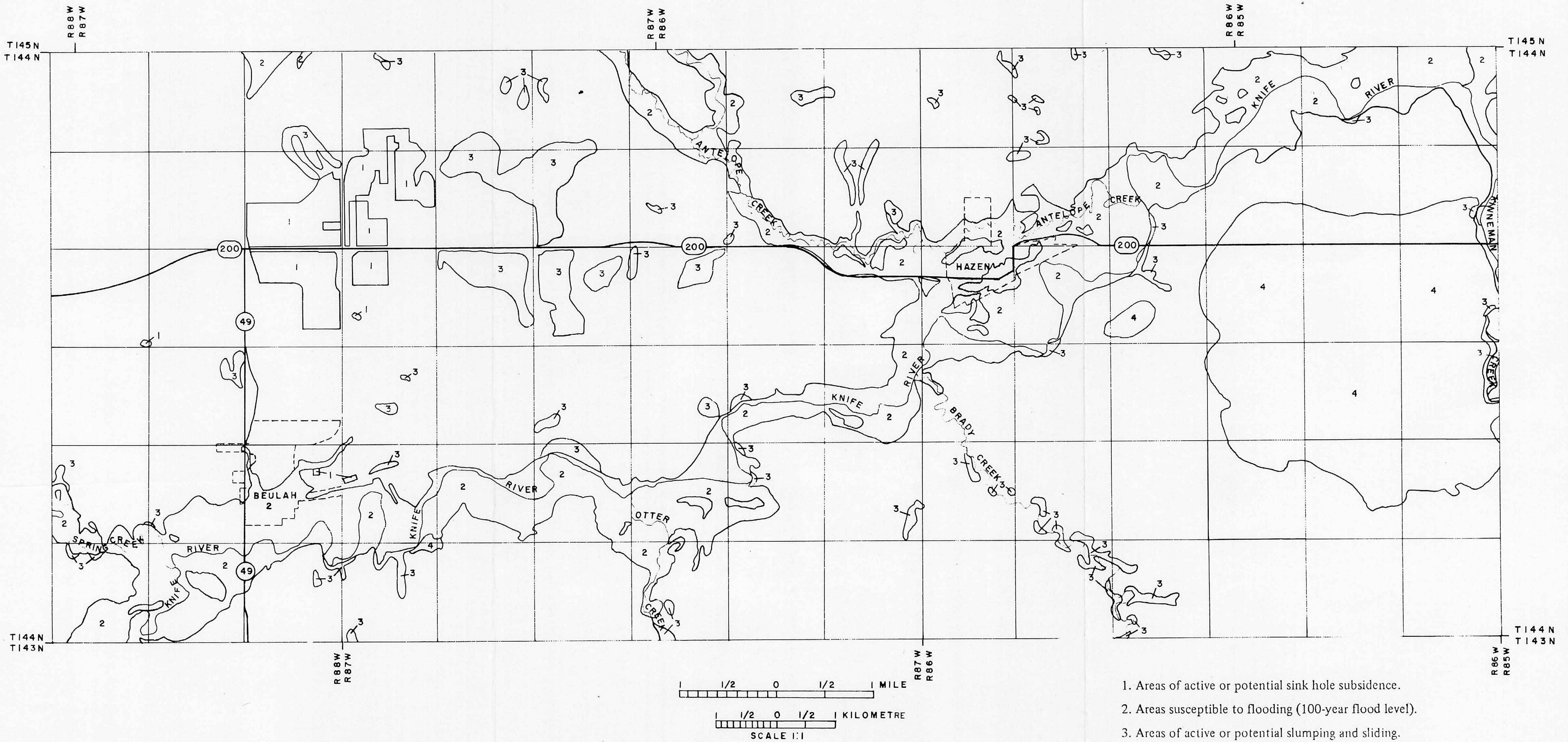
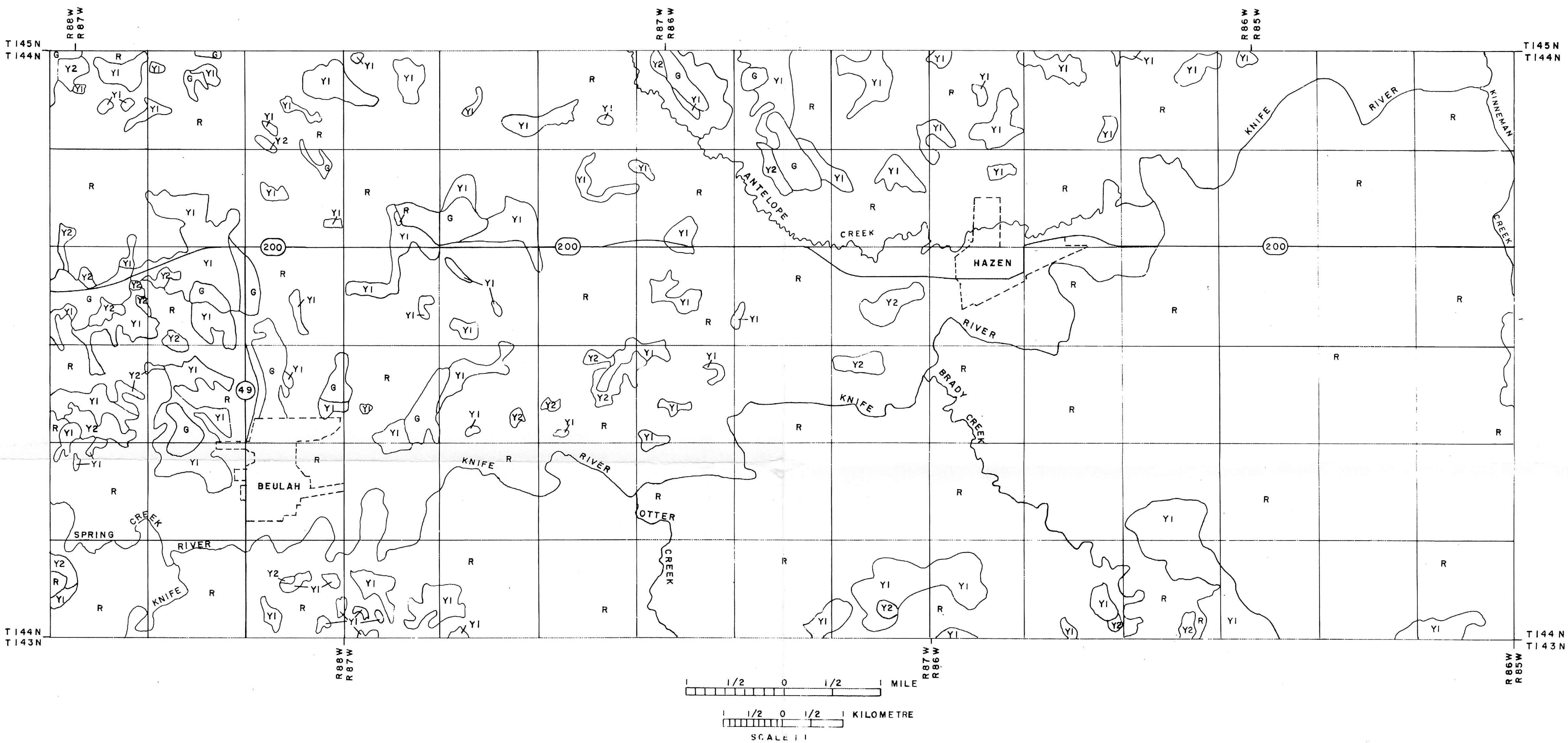


PLATE 34 GEOLOGIC HAZARDS-- BEULAH-HAZEN AREA



1. Areas of active or potential sink hole subsidence.
2. Areas susceptible to flooding (100-year flood level).
3. Areas of active or potential slumping and sliding.
4. Areas of active or potential wind erosion.

PLATE 35 SUITABILITY OF THE BEULAH-HAZEN AREA FOR SANITARY LANDFILLS



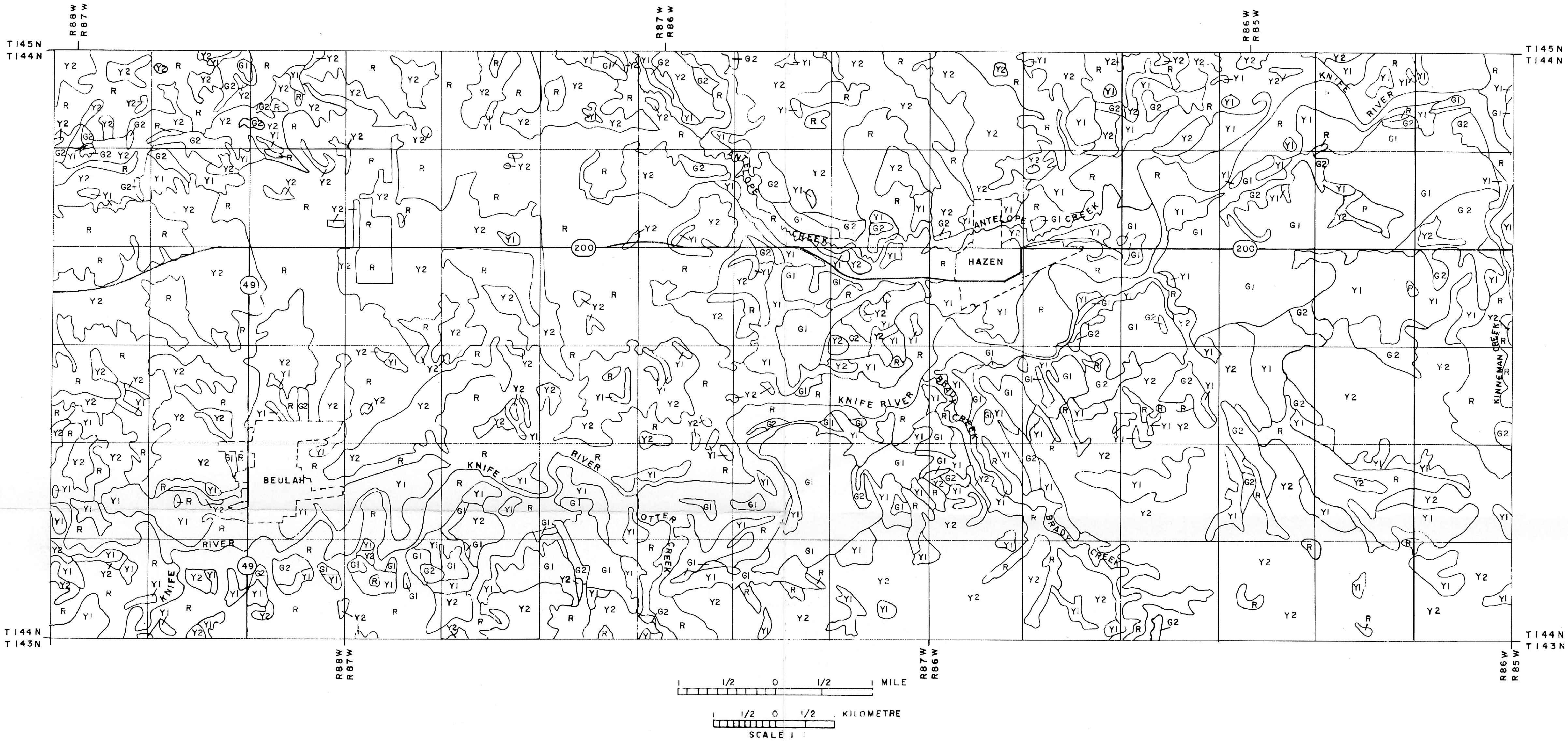
G — Suitable disposal sites are available. These areas are characterized by at least 15 metres of relatively impermeable unsaturated material. Includes areas of pebble loam and loam over pebble loam where there is no evidence suggesting the occurrence of sand and gravel lenses. Boulders at or near the surface may provide some workability problems.

Y1 — Suitable disposal sites probably available; at least 9 metres of relatively impermeable unsaturated material. Includes areas of pebble loam and loam over pebble loam, with possible sand or gravel lenses at depth; pebble loam over relatively impermeable, soft bedrock; and areas underlain directly by relatively impermeable, soft bedrock. Also includes many areas where the principal limiting factor is the slope (9-15%), and areas where up to 1.5 metres of silty fine sand may overlay pebble loam. Clayey bedrock and boulders in some areas may provide some workability problems.

Y2 — Some suitable disposal sites available; at least 9 metres of relatively impermeable unsaturated material. Includes areas of 0.5 to 2 metres of sand or sand and gravel over pebble loam or relatively impermeable, soft bedrock. Sand at the surface provides poor cover, and may cause problems of seepage into the site.

R — Disposal sites likely to pose pollution hazards unless special engineering precautions are taken. Includes areas of less than 9 metres of unsaturated materials, areas of flooding and ponding, areas of steep (greater than 15%) slopes, and areas of materials having moderate to rapid permeability (sand, gravel, scoria, some sandy bedrock).

PLATE 36 SUITABILITY OF THE BEULAH-HAZEN AREA FOR SEPTIC SYSTEMS



G1	Suitable sites available; relatively high permeability, low water table, gentle slopes, and no danger of flooding. Silty, very fine to medium sand, with some areas of silty coarse sand and gravel, and sandy silt. Caution should be exercised, especially in areas of coarser sand and gravel, to insure proper spacing and location of the septic systems.
G2	Suitable sites generally available; moderate to high permeability, low water table, moderate to gentle slopes, and no danger of flooding. Sandy silt and sandy silt over sand, and silty sand on moderate slopes. Pebble loam may occur at depths below 1.5 metres.
Y1	Suitable sites probably available; moderate to high permeability, low to moderately low water table, gentle to moderately steep (15%) slopes. Includes areas of loam and loam over sand, pebble loam, or soft sandy bedrock. Also includes areas of less than 1.5 metres of silty sand over pebble loam or soft sandy bedrock, and areas of silty sand on moderately steep slopes. Rare instances of high water table and flooding could cause problems in those areas lying within floodplains.
Y2	Some suitable sites may be available with proper spacing and design; moderate to low permeability, generally low water table, gentle to moderately steep (15%) slopes. Includes areas of silty clay loam, silt over pebble loam, thin (less than .5 metre) sand over pebble loam, pebble loam, pebble loam over soft bedrock, and soft sandy bedrock. Areas of windblown sand characterized by steep slopes and high permeability are also included. Occasional instances of high water table and flooding places stringent limitations on those areas lying within floodplains.
R	Suitable sites generally not available due to one or more of the following constraints: low permeability, high water table, steep slopes, or severe flooding hazard. Areas of soft clayey bedrock where permeability is the principal limiting factor may be a possible exception; in this case extensive drain-tile fields may provide sufficient drainages.

PLATE 37
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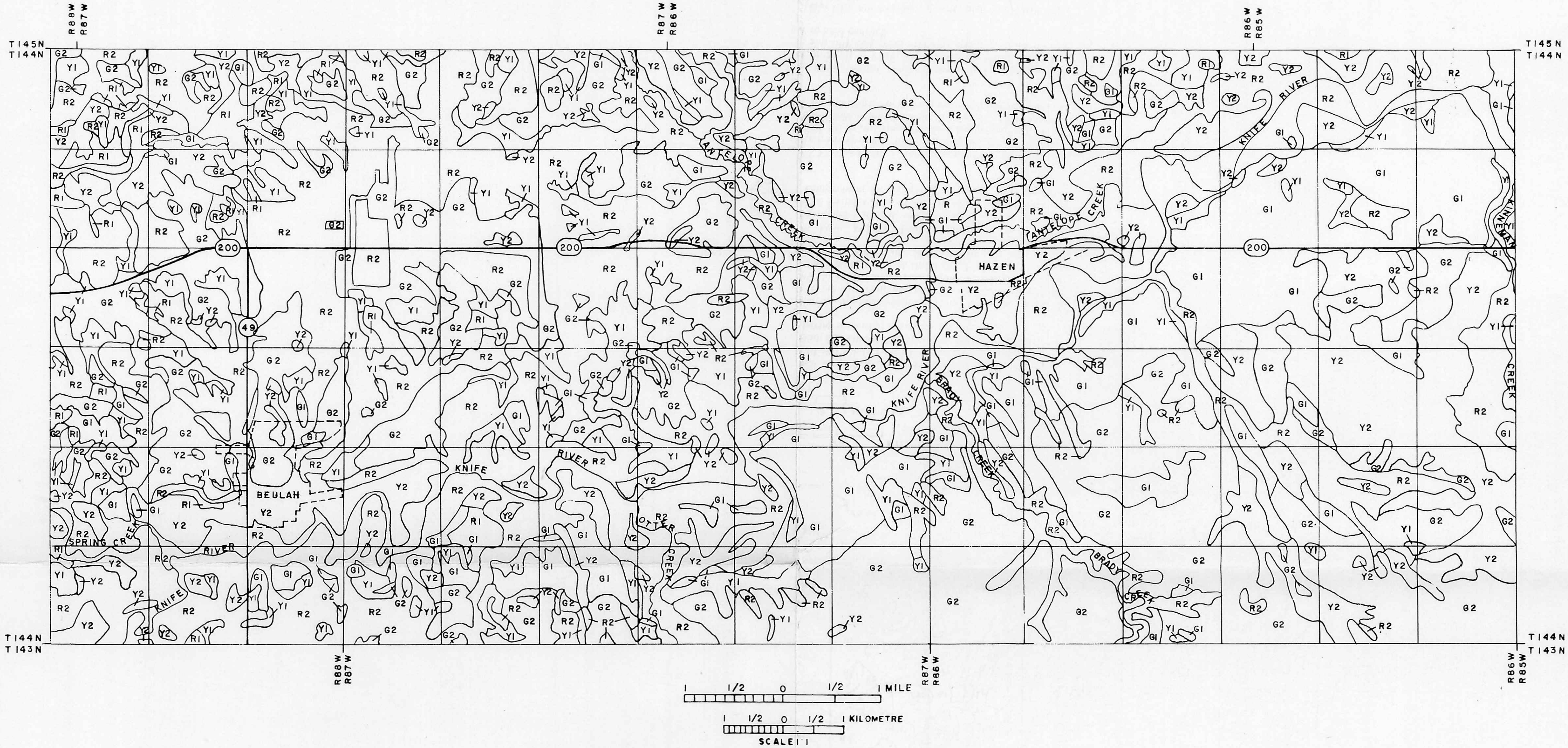
PLATE 37 CONDITIONS EFFECTING GENERAL CONSTRUCTION IN THE BEULAH-HAZEN AREA



G1 — Good construction conditions; high bearing capacity, low compressibility, low water table, good internal drainage, gentle to moderate slopes. Includes upland areas of soft sandy bedrock where the major limitation is workability and lowland areas and terraces of silty sand, sand, and sand and gravel where the major limitation is sidewall instability. Also includes areas of windblown sand having somewhat lower bearing capacities.

G2 — Good to moderate construction conditions; high bearing capacity, low compressibility, low water table, gentle to moderate slopes. Includes areas of pebble loam and areas where silt, loam, and sand and gravel overlie pebble loam. The presence of scattered boulders both at and below the surface may cause problems during excavation, compaction, and pile driving. Susceptibility to frost heave and moderate to high shrink-swell characteristics may cause some foundation problems. Dewatering of sand and gravel lenses may cause slope stability problems.

Y1 — Moderate construction conditions; areas of sand, pebble loam, and soft bedrock limited in construction capabilities mainly by moderate to steep (9 to 15%) slopes. Includes areas of shallow (less than 1 metre) loam over scoria, where workability may be a severe problem. Also includes areas of shallow sandy silt and silt over soft sandy siltstone and siltstone, where fair to poor compaction, moderately low bearing capacity, and susceptibility to frost heave are principal limiting factors.

Y2 — Moderate to poor construction conditions; moderate to low bearing capacity, moderate to low compressibility, fair to poor compaction, moderate shrink-swell characteristics, susceptibility to frost heave, low water table, and gentle to moderate slopes. Materials generally consist of clayey silt to very fine silty sand. Deeper excavations on the uplands may encounter workability problems. Quick conditions common on the floodplain. Clay lenses at depth on the floodplains may cause problems of differential settlement. Some areas are susceptible to flooding and high water tables.

R1 — Poor construction conditions; low bearing capacity, high compressibility, poor internal drainage, moderate to high shrink-swell characteristics, susceptible to frost heave, difficult to work, and sidewall instability. Silty clay loam in swales and on floodplains; silty clay, clay loam, and silty clay loam over soft clayey bedrock on the uplands. Bearing capacity is moderately high where shallow to hard bedrock.

R2 — Very poor construction conditions. Areas of organic-rich clays with low bearing capacity, high compressibility, high water table, poor internal drainage, high to very high shrink-swell potential, high water content, liquid limit, and plasticity index. Includes areas of high water table and poor drainage, areas of severe flood hazard, areas of blowouts and drifting sand, and areas of steep (greater than 15%) slopes.