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GEOLOGY AND SHALLOW GROUND WATER RESOURCES OF THE MISSOURI VALLEY BETWEEN NORTH SIOUX CITY AND YANKTON, SOUTH DAKOTA

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ABSTRACT

The North Sioux City–Yankton area of southeastern South Dakota is drained by the Missouri River and its tributaries the Big Sioux, the Vermillion, and the James Rivers.

Precambrian unnamed granite and Sioux quartzitic sandstone form the basement rocks of the area; they are overlain by lower Paleozoic and Cretaceous sedimentary rocks and by Pleistocene deposits that include drift of Kansan(?), Illinoian(?), and Wisconsin ages.

In 1958 an estimated 1,375 billion gallons of shallow ground water occupied the glacial outwash deposits, which contain 22 billion cu yd of sand and gravel. In addition, in 1958 an estimated 875 billion gallons of shallow ground water occupied 13 billion cu yd of sand in alluvial deposits. The quality of this ground water is satisfactory for human consumption, for irrigation, and for industrial use.

INTRODUCTION

General Description of the Area

The North Sioux City–Yankton area is in the Central Lowlands physiographic province (Fenneman, 1938) of southeastern South Dakota (fig. 1). The area is in the southeastern part of the Coteau des Prairies (Prairie Hills) upland, and in the southeastern part of the James Basin lowland (Rothrock, 1943). The area contains about 400 square miles in parts of Union, Clay, and Yankton Counties (fig. 1).

The climate of the North Sioux City–Yankton area is characterized by long cold winters and short hot summers, with rapid fluctuations in temperature. Daily fluctuations in temperature are commonly 30° F. or more. The average annual temperature between 1940 and 1957 was 48.2°F. (fig. 2). The maximum annual precipitation recorded by the United States Weather Bureau at Yankton and Vermillion between 1940 and 1957 was 38.60 inches (1951), and the minimum was 12.76 inches (1956). However the average rainfall was 24.98 inches (fig. 2).

The rural population is dense, averaging 3-4 families per square mile. Cities, towns, and villages are numerous (table 1).

Table 1.–Population of Towns
in North Sioux City–Yankton area

Town	Population
Burbank (unincorporated)	75 est.
Elk Point	1367
Gayville	271
Jefferson	466
Meckling	111
Mission Hill	169
North Sioux City	657 est.
Richland (unincorporated)	55 est.
Vermillion	5337
Volin	197
Yankton	7709

The North Sioux City–Yankton area is served by U. S. Highways 77 and 81, and by State Routes 19 and 50. In addition to the main highways, there are many gravel and hard-surface county roads, and nearly every section line is marked by a gravel road.

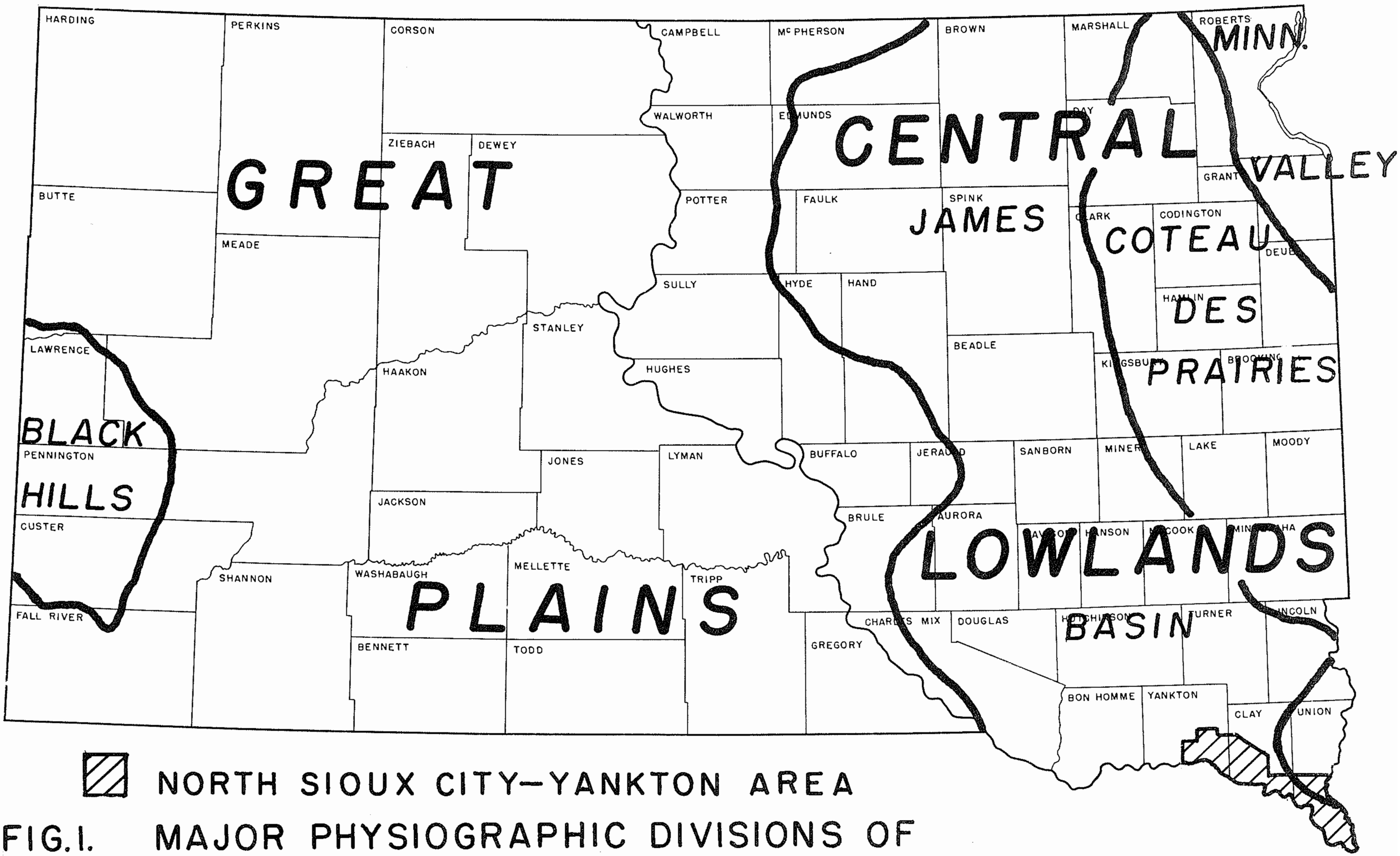
The character of the soil ranges from a sandy clay on the bluffs, to a clay on the flood plain, to a sandy soil along the Missouri River itself. The agriculturally productive sandy clay soil on the upland consists predominantly of clay, with minor amounts of sand and gravel. This soil is nearly impermeable to water.

The flood plain soil ranges from clay or "gumbo" near the bluffs, to predominantly sandy soil along the Missouri River. The sandy soil is very permeable and porous and retains moisture well, but generally lacks humus. Because the precipitation occurs mainly during the growing season from April through September (fig. 2), crops suitable to a semi-humid climate, such as corn, soybeans, small grain, and alfalfa, can be raised.

The main industries of the area are grain farming and the raising of livestock. Yankton and Vermillion have meat-packing plants.

Topography and Drainage

Four types of topography are present in the North Sioux City–Yankton area. The regional topographic features range from the nearly flat flood plain to gently undulating glacial ground moraine, to rough glacial end moraine; the ridges and high bluffs contain



NORTH SIOUX CITY—YANKTON AREA

FIG. I. MAJOR PHYSIOGRAPHIC DIVISIONS OF SOUTH DAKOTA (ROTHROCK, 1943)

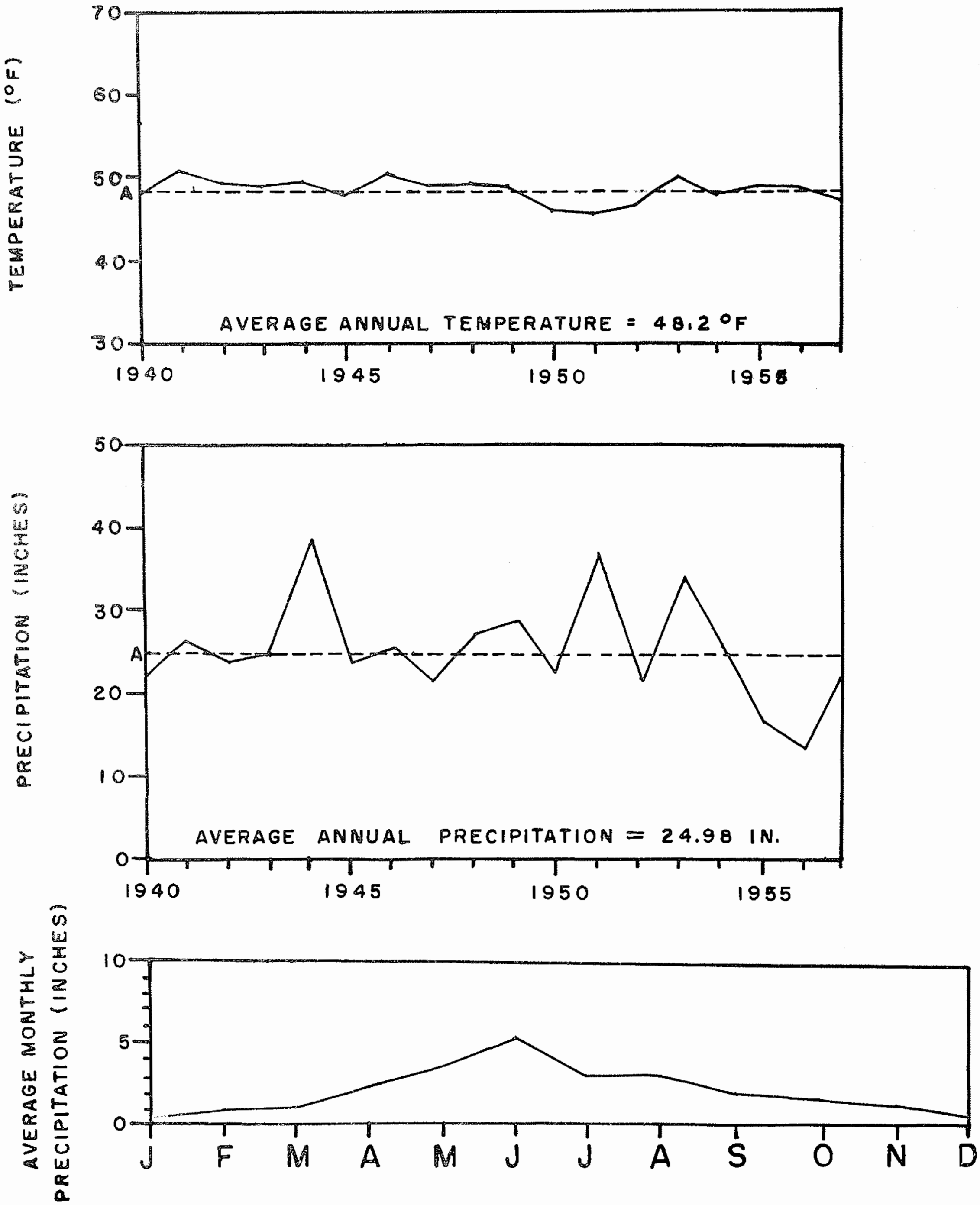


FIG.2 AVERAGE DISTRIBUTION OF TEMPERATURE AND PRECIPITATION AT VERMILLION AND YANKTON, 1940-1957. (U.S. WEATHER BUREAU)

cores of resistant bedrock.

Bedrock topographic highs occur at Spirit Mound and farther north along Turkey Ridge (pl. 1), where the Niobrara chalk is exposed. These two topographic highs represent preglacial hills which were later mantled with glacial deposits except in the highest parts of the hills. The maximum relief of these two highs above the surrounding country is 145 feet.

Moraine is an accumulation of clay, sand, and boulders that were deposited by an ice sheet. According to topographic expression, moraine is subdivided into ground moraine and end moraine. **End moraine** is a ridgelike accumulation of till built chiefly along the margin of the ice sheet by the conveyor-belt action of the moving ice, and by deposition of debris from the ice when melting occurred. The end moraine has relatively rough topography, and has greater relief than does ground moraine.

In the North Sioux City–Yankton area an end moraine covers Turkey Ridge (pl. 1) except where the bedrock is exposed. Thus Turkey Ridge is a bedrock high that is almost completely mantled by end moraine.

The Turkey Ridge end moraine extends southeastward across the northeastern corner of the mapped area (pl. 1). Turkey Ridge averages six miles in width, and is characterized by stoney knobs and undrained depressions. The gentle northeastern slope and the steeper southwestern slope of the ridge are cut by numerous intermittent streams which have not yet dissected the central mass of the drift-mantled bedrock (Sevon, 1958, p. 6). Local relief on the ridge averages 20-50 feet, and a maximum relief of 145 feet is attained.

Ground moraine is a relatively thin accumulation of till compared to its areal extent, and was deposited by the main body of ice; it usually has a gently undulating surface.

Ground moraine extends southeastward from Turkey Ridge to near the Big Sioux River. The Vermillion River dissects the southwestern side of the ground moraine. The area is characterized by an undulating plain with gently sloping swells and shallow depressions. Local relief ranges from 5 to 15 feet.

A **flood plain** is a broad relatively flat surface along a stream, caused by the deposition of alluvial material during flood stage, and is generally restricted to a belt which includes the streams meanders.

The flood plain lies between the bluffs and the Missouri River. It is nearly flat except for meander scars which vary in relief from 2-20 feet. The meander scars represent abandoned channels of the Missouri River. The surface of the flood plain slopes southeastward from Yankton to North Sioux City at the rate of about a foot per mile.

The alluvial materials consist of sand, clay and silt which were deposited by the Missouri River when its waters covered the flood plain.

Stratified sands and gravels laid down by glacial meltwater streams as **outwash deposits** underlie the floodplain; at Yankton, Volin, and Richland (pl. 1), the outwash deposits are exposed in gravel pits.

The drainage in this area is controlled by the Missouri River and its tributaries the Big Sioux, the Vermillion, and the James Rivers. The Missouri River flows to the southeast across the North Sioux City–Yankton area.

Previous Investigations

Chamberlin (1883) made reconnaissance studies of the moraine systems of eastern South Dakota. Later Todd (1908) mapped part of this area as the Elk Point quadrangle, in the southeastern part of the North Sioux City–Yankton area. Flint (1955) prepared a reconnaissance map of the glacial geology of the eastern part of the State. Rothrock (1957) reported on an investigation of the alluvial deposits in the Elk Point area. The most recent geologic work was by Tipton (1958), who mapped the Akron quadrangle, just north of the Elk Point quadrangle.

Present Investigations

The area was mapped in the summer of 1958 by the writer and David Valandry. The geology was plotted on air photos and on U. S. Army Corps of Engineers maps of the Missouri River. Surface elevations were determined by plane table and alidade. The thicknesses of the alluvial and glacial outwash deposits were determined by 35 electrical resistivity stations and by 37 jeep-mounted auger drill holes (pl. 2).

Water levels in 46 irrigation wells, in 11 observation wells of the South Dakota Water Resources Commission, and in several test holes of the South Dakota Geological Survey were measured by steel tape. Studies of the physical properties of alluvial and glacial moraine material were made in the laboratory of the State Geological Survey. Analyses of water samples were made in the State Chemical Laboratory at the University of South Dakota, Vermillion.

Reserves of sand and gravel were determined by combining the total amount of gravel and sand for the alluvial and outwash deposits.

Acknowledgments

The geologic work on which this report is based was done under the supervision of Dr. A. F. Agnew, State Geologist. The writer profited by conferences with F. V. Steece. Charles Douglas helped in mapping alluvial sediments and contributed useful information from sample studies. The assistance of geophysicist Daniel Lum, and field assistants Robert Benson, Spencer Brooks, and Howard Loitwood is gratefully acknowledged. The writer also wishes to express his thanks to the residents of the area, for contributing information and otherwise aiding in the completion of this work.

GENERAL GEOLOGY

Exposed Rocks

Two bedrock units are exposed in the North Sioux City–Yankton area, the Greenhorn Formation and the Niobrara Formation, both of Cretaceous age.

Cretaceous System

(Greenhorn Formation)

The Greenhorn limestone is exposed in a small area in the loess-covered hills in the SW¼ sec. 18, T. 92 N., R. 49 W. and the NE¼ sec. 29, T. 92 N., R. 49 W., north of Richland (pl. 1). The formation is a light- to dark-gray fossiliferous limestone interbedded with thin chalk, calcareous shale, and bentonitic beds. Large pelecypods, identified by Todd (1908) as *Inoceramus labiatus* Schlotheim, are prevalent throughout the exposure, which measures 11.7 feet thick. The Greenhorn at this locality is overlain by 21 feet of Kansan(?) till.

(Niobrara Formation)

The Niobrara chalk is exposed about a mile northeast of Volin on Turkey Ridge (pl. 1), on a slumped talus slope along an intermittent stream. The chalk is bluish-gray but weathers white or cream, and is thin-bedded, in two- to six-inch layers. Another exposure of Niobrara chalk is on Spirit Mound, about 6 miles north of Vermillion. This exposure is similar to that at Volin. Larger exposures of Niobrara chalk occur farther north, outside the mapped area.

Surficial Deposits

Pleistocene Series

During the Pleistocene epoch, eastern South Dakota was repeatedly the scene of continental glaciation. During this time four stages of major ice advance, and three major interglacial stages have been recognized. The last major glacial stage is further subdivided into four glacial substages and three interglacial substages that are represented by loess (table 2). Perhaps not all of these stages and substages are represented in this area.

Table 2.–Classification of Pleistocene Glacial Deposits
(After Tipton, 1958, Table 1)

SERIES	STAGE	DEPOSIT
Pleistocene	Wisconsin Glacial and Interglacial	Mankato Drift
		Cary Loess
		Cary Drift
		Tazewell Loess
		Tazewell Drift
		Iowan Loess
		Iowan Drift
	Sangamon Interglacial	Loveland Loess
	Illinoian Glacial	Illinoian Drift
	Yarmouth Interglacial	Fossiliferous clays and loess(?)
	Kansan Glacial	Pearlette Ash Kansan Drift "Atchison" Sand
	Aftonian Interglacial	Alluvial Silt(?) "Western" Sand and gravel
	Nebraskan Glacial	Nebraskan Drift

(Kansan(?) till)

Kansan(?) till is exposed in one locality (NE¼ sec. 20, T. 92 N., R. 49 W., near Richland). At this locality a 21-foot thickness of till is present below an undetermined thickness of Wisconsin loess. The till is light-tan, compact, blocky, and jointed. The joint faces are stained a dark-rust color by iron oxide.

The till was identified as Kansan(?) by Tipton (1958), because it contains a slightly larger concentration of greenstone pebbles than the Cary till. The exposure of till lies on the Greenhorn limestone and is covered by Wisconsin loess. The till corresponds to other nearby exposures of Kansan(?) till lying directly on Cretaceous formations (Tipton, 1958, p. 35-36).

(Pearlette Ash and Atchison(?) Sand)

A three-inch bed of Pearlette ash, and a two-foot layer of Atchison(?) sand are exposed in the SW¼ sec. 18, T. 92 N., R. 49 W. along the west bank of Brule Creek, in Union County. At this location a sequence of Wisconsin loess (highest), Pearlette ash, Atchison(?) sand, and Greenhorn limestone is exposed.

The ash is white to gray, fine-grained, and unconsolidated; it is characterized by translucent and curved shards, and fibrous shards are abundant. It was identified as Pearlette, of Kansan age, by Tipton (1958) because:

> "The refractive index lies between 1.487 and 1.500. This index could not be determined any closer owing to the lack of standard oils. According to Frye, Swineford and Leonard (1948), the refractive index for the Pearlette ash should be between 1.499 and 1.501, for Pliocene ash between 1.500 and 1.505."

The sand called Atchison(?) is composed of well-sorted, subround, nearly pure quartz sand grains. This sand can be traced in drill holes and exposures for 30 miles to the northeast, where a thick section is exposed in Newton Hills State Park in Lincoln County.

In the Newton Hills area the Atchison(?) sand (named Newton Hills by Baird, 1957, p. 68) is overlain and underlain by till; thus the sand is Pleistocene in age because of its lithologic character and stratigraphic position. The sand consists of about 65 percent quartz and 35 percent feldspar. The sand is similar to other Pleistocene sands found south and west of the area, and therefore probably has the same source.

(Illinoian(?) Outwash)

Although no Illinoian glacial material is exposed in this area, the 5- to 10-mile wide valley-outwash deposit lying beneath the Missouri River flood plain is believed to contain some material of Illinoian age (pl. 2). The Illinoian glacier in South Dakota probably extended to approximately the present site of the Missouri River (Warren, 1952). As the Illinoian ice sheet melted, large amounts of gravel were deposited by the meltwaters. The depth to the bottom of the valley-outwash deposit ranges from 110 to 200 feet, with a cover of alluvium ranging between 43 and 90 feet.

The valley outwash consists of layers of sand and gravel up to 10 feet thick, with occasional boulders in the gravel layers. The outwash is believed to be not entirely Illinoian in age; possibly the upper layers of sand and gravel are Iowan, Tazewell and Cary. Many of the gravel layers contain fragments of lignitic coal, which may give the false appearance of a bedrock coal seam.

The samples of the Illinoian(?) valley-outwash deposit used for petrographic and size analyses were badly contaminated because they were obtained with an auger drill, and mixing of the alluvial sand with the outwash sands occurred. Therefore it was impossible to determine accurately either the texture or the lithologic composition of the outwash sands.

Because of the contamination of the sample, especially by the finer material, an analysis was made on only the gravel fraction of the samples. This analysis indicates that igneous and metamorphic fragments are abundant, but shale and chalk fragments are lacking; shale and chalk are abundant, however, in younger tills and outwash deposits (fig. 3).

(Wisconsin Loess)

Loess of Wisconsin age covers Kansan(?) till near Richland, and covers Pearlette ash and Atchison(?) sand along the west bank of Brule Creek in Sec. 18, T. 92 N., R. 49 W., Union County. This loess is dark olive-gray and slightly calcareous, and weathers to vertical cliffs.

(Wisconsin Stage; Cary Substage)

General Statement.--The Cary drift in this area consists of till and outwash material. Till is defined as an unstratified accumulation of material deposited by glacial ice, and consists largely of particles of clay and silt, with varying amounts of sand, pebbles, and cobbles. The Cary till is compact, blocky, and well jointed, and has a light-tan color. The joints are stained with iron oxide, and the till crumbles rather easily.

Ground Moraine.--The Cary ground moraine extends from near Brule Creek westward and northwestward to the Cary end moraine at Turkey Ridge. This ground moraine has typical swell and swale topography, but with small relief--less than 10 feet. The drainage is poorly developed except for pre-Cary creeks. The southern part of this ground moraine is nearly flat, in Sections 13-15, 22, 23, 26, and 27, T. 92 N., R. 50 W. Residents of this flat area report the presence of water from a 30-60 foot sand layer below the till at a depth of approximately 90 feet. The sand layer and the flat ground surface indicate possibly that a pre-Cary stream valley exists beneath the till.

A second area of Cary ground moraine extends from the Cary end moraine at Turkey Ridge northwestward to the boundaries of the mapped area. This moraine is continuous except where it has been dissected by the James River. The moraine is relatively rougher and appears more youthful than the Cary ground moraine east of Turkey Ridge. The roughness can be attributed partially to higher and more resistant bedrock here, but the writer believes that this ground moraine is younger than the ground moraine east of Turkey Ridge. This ground moraine might thus be Late Cary in age.

End Moraine.--Turkey Ridge northwestward from Volin is capped with Cary end moraine; this end moraine has high stoney hills and small round depressions, a typical knob and kettle topography. Undrained depressions are not uncommon, although drainage is generally good. Exposures of the Niobrara Formation near the crests of several hills show that a bedrock high exists under the end moraine. This end moraine was formed by the Cary ice as it moved southeastward along the James River lowland. The bedrock high acted as a lateral barrier which halted the ice, causing an end moraine to be deposited chiefly along the west side of the bedrock. This end moraine was probably formed at the same time as the Late(?) Cary ground moraine to the west.

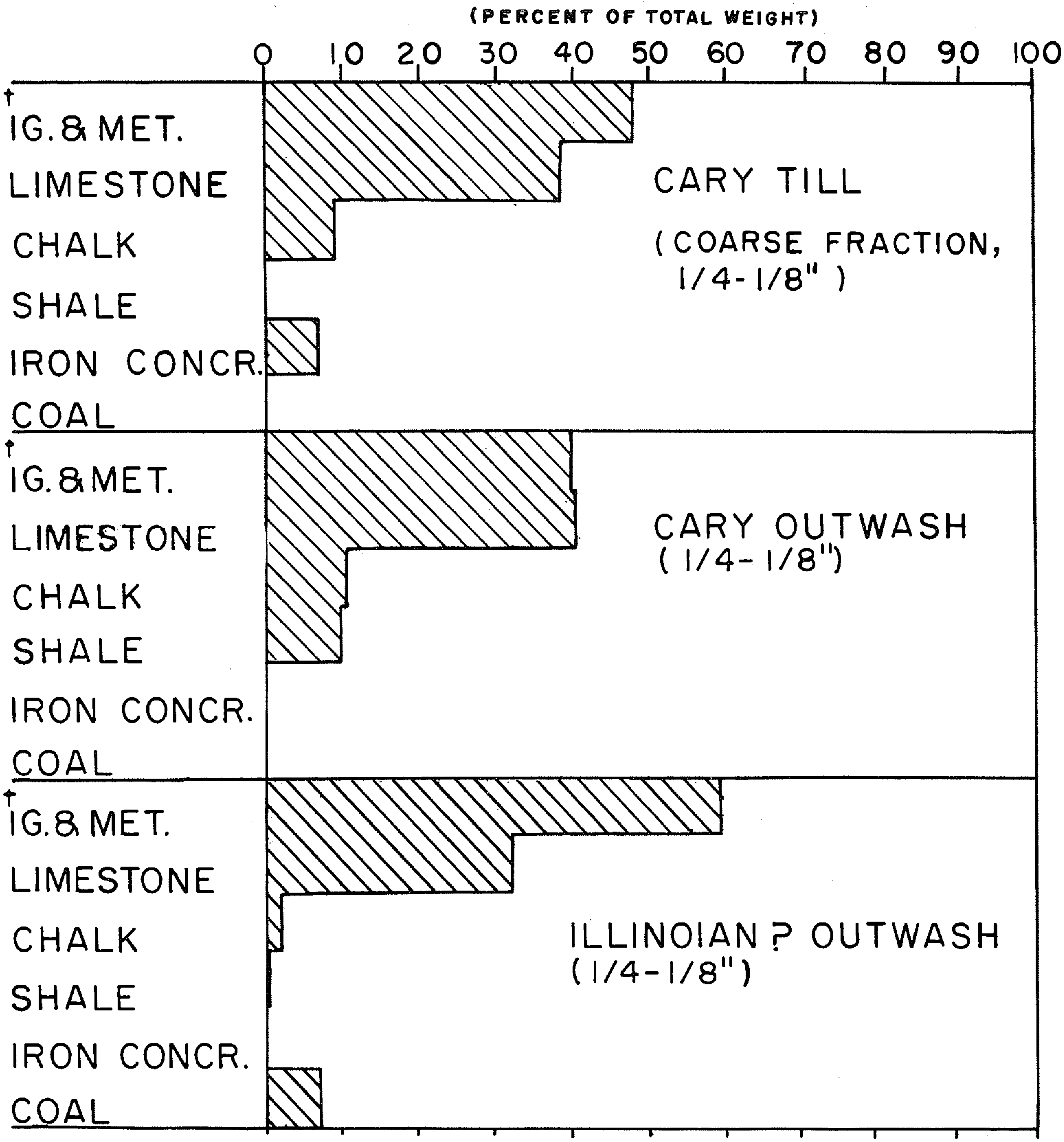
Outwash Deposits.--Cary outwash deposits occur below the alluvium in the present floodplains of the James, the Vermillion, and the Big Sioux Rivers. These valley-outwash deposits are younger than the Illinoian(?) valley-outwash materials beneath the Missouri River floodplain because their delta-fan sediments spread into the lower stream valley of the Missouri River over the older outwash material (see pl. 2).

Small areas of Cary outwash deposits are northwest of Richland, at Volin, and at the eastern edge of Yankton. These outwash deposits possess little alluvial cover, but do have thin topsoils.

The Cary outwash deposits are poorly sorted, with relatively large percentages of shale and chalk (fig. 3). The abundance of chalk and limestone is caused by the outcrops of these materials just north of the mapped area.

Recent Deposits

Alluvium is a detrital deposit resulting from deposition by rivers; thus it includes the



† Igneous, Metamorphic, and all other rocks.

Figure 3 Lithology of coarse glacial deposits in the North Sioux City-Yankton area.

sediments deposited in river-beds, flood plains, lakes, fans, and estuaries.

Alluvial material in the North Sioux City–Yankton area is present in the flood plains of the Missouri, the Big Sioux, the Vermillion, and the James Rivers, and along nearly all the intermittent streams.

A flood plain is a strip of relatively smooth land bordering a stream, built of sediment carried by the stream and deposited in slack water beyond the influence of the swiftest current. The limits of most well-developed flood plains are defined by the meander belt of the stream. Alluvial plains or flood plains are built by deposition on the inside of river curves, and deposition from overbank flow of flood water; therefore the entire flood plain consists of meander belt deposits and overbank deposits (Wolman and Leopold, 1957, p. 91-103).

(Meander Belt Deposits)

Meander belt deposits can be subdivided into channel fill, and bar material. These deposits can be distinguished by origin, physiographic expression, and size of sediments.

Channel fill deposits consist chiefly of clay and silt size particles. Channel fill deposits occur in abandoned meander channels and in narrow channels called swales or sloughs. Abandoned meander channels are caused by shortening of the stream course by chute cut-off or neck cut-off. Fisk (1947, p. 36) described the chute cut-off and its origin:

> "The chute cut-off takes place as a part of the normal development of a meander where the alignment of the upstream arm is fixed and where the bend can expand in the direction determined by this alignment. Such expanding bends leave ridge and swale accretions in point bars which are oriented more or less parallel with the direction of flow in the river. At some stage in the development of the meander the river during high stage may scour a shorter channel down one of the old swales and eventually isolate the longer course it previously occupied."

Lake Goodenough, O'Connors Lake, and Mud Lake south of Jefferson (pl. 1) occupy abandoned channels caused by chute cut-off.

Neck cut-offs occur late in the development of a meander loop, when the lateral migration of the downstream arm has been retarded so that the upstream arm of the meander has migrated downstream until cut-off occurs. McCook Lake near North Sioux City (pl. 1) is an oxbow lake occupying an abandoned channel caused by a neck cut-off. Slough fillings are associated with bar and point bar deposits. The sloughs are remnants of small abandoned channels.

Point bars and sloughs are caused by the gradual changes in stream alignments accompanying bend migration, resulting in the formation of a bar on the point or convex side of the meander. **Point bar** deposition begins as a bar, forming at water-level during low-water stages. Later high-water deposition takes place on the bar area, and a ridge-like mass of fine-grained sand is deposited upon the arcuate shape of the low-stage bar. Erosion by scouring takes place during high-water stages, causing the formation of a deep narrow channel behind the bar ridge. These deep narrow channels are the sites of sloughs or channel-filling. After the formation of several point bars and sloughs, the topography shows sandy arcuate ridges divided by narrow clay-filled depressions.

The formation of **bar** and slough deposits is nearly identical to point bar and slough formation. Bars are the result of small meanders which cut into either the convex or concave bank of a larger meander, and are later abandoned. The resulting physiographic expression is a bar composed of sand separated from the bank by a narrow clay-filled slough which marks the position of the deep channel when cutting occurred. Bars may also develop in a manner similar to that which causes a braided stream deposit, and if the channel is abandoned they will be preserved.

(Overbank Deposits)

Overbank deposits consist of backswamp deposits and natural levee deposits.

Natural levees are composed of silt and clay, resulting from deposition during flooding. The muddy water overflows the banks where its velocity is lessened, causing deposition along the banks.

Backswamp deposits are formed behind **natural levees**. Backswamp deposits consist of clay and very fine silt which are deposited by the river during stages of very high water causing extensive flooding.

No identifiable backswamp deposits or natural levees are present in the North Sioux City–Yankton area, but undifferentiated **overbank** deposits do occur. The overbank deposits are caused by river deposition during flood stages. The overbank deposits have masked or concealed nearly all the meander belt deposits except for those in the very recent meander belts.

Average size analyses of alluvial deposits shown in Figure 4 were derived from sample analyses by Douglas (1959).

(Dunes)

Dunes are accumulations of wind-blown sand. Dunes are generally located on bars or point bars. The loose sand for the dunes is derived from bars or point bars, or it may be derived from sand deposited on these features during high-water stages. The sand dunes southwest of Elk Point (pl. 1) were derived in the latter manner.

Subsurface Rocks

The alluvial and glacial deposits of the North Sioux City–Yankton area are underlain with Mesozoic and Paleozoic rocks that rest on a basement of Precambrian rocks (table 3). The Niobrara chalk, Carlile shale, and Greenhorn limestone are present near Yankton, but are missing at North Sioux City because of erosion before Pleistocene time. The upper sandstone of the Dakota sequence has likewise been eroded in the area between Elk Point and North Sioux City. The lower sandstone of the Dakota is present in the area, but pinches out to the north.

Below the Cretaceous rocks lie limestone, dolomite, shale, and sandstone of early Paleozoic age. The Paleozoic sediments thin to the northwest and pinch out against the Sioux Ridge north of the area.

The Precambrian basement rocks consist of granite except at Vermillion where Sioux quartzitic sandstone was reported in a well. The Sioux quartzite is believed to overlie the granite.

Structure

The North Sioux City–Yankton area lies on the northern edge of the so-called northern extension of the Forest City Basin, whose western boundary extends northward along the Kansas-Missouri and Nebraska–Iowa State lines at least as far north as Omaha. The regional dip of the Cretaceous strata in this area is 6 feet per mile southeasterly.

The Cretaceous strata are draped over the surface of the Precambrian rocks; thus variable dips and strikes are present in the bedrock, reflecting the irregular surface of the Precambrian below.

The Lower Paleozoic strata dip slightly to the south-southeast, thus forming an angular unconformity with the Cretaceous strata above.

The Precambrian basement rocks possess an irregular surface (fig. 5), which dips generally southeastward. A possible fault in the Precambrian granite is present at Jefferson, where an oil test was drilled 1725 feet into an apparent shear zone (Bolin and Petsch, 1954).

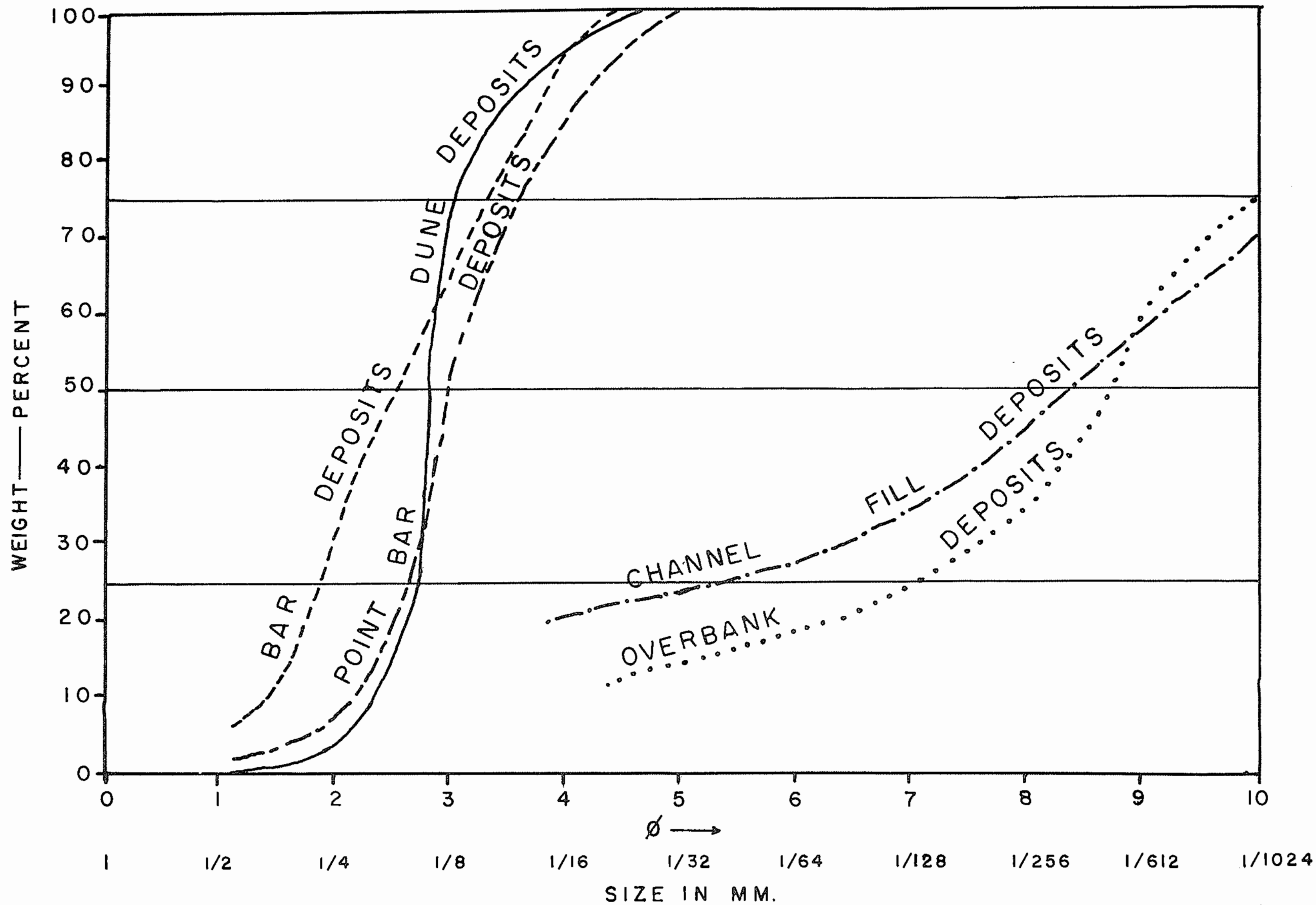


FIG. 4 AVERAGE CUMULATIVE CURVES OF ALLUVIAL DEPOSITS IN THE NORTH SIOUX CITY — YANKTON AREA (AFTER DOUGLAS, 1959)

Table 3.--Subsurface Stratigraphy
of the North Sioux City—Yankton Area

ERA	SYSTEM	FORMATION	THICKNESS (feet)	LITHOLOGY AND REMARKS
Mesozoic	Cretaceous	Niobrara	170	Impure chalk, (exposed)
		Carlile	70-100	Dark-gray shale
		Greenhorn	35-50	Impure limestone, (exposed)
		Graneros	50-90	Medium and dark-gray shale and sandy shale
		Dakota	145?-210	Upper Unit largely sandstone alternating with shale Middle Unit largely shale alternating with sandstone Lower Unit largely sandstone alternating with shale
		Unconformity		
Paleozoic	Younger Paleozoic	Undifferentiated	30-387	Dolomite, limestone, and sandstone
	?			
	Ordovician	Galena	50?-147	Cherty dolomite and shale
		Decorah-Platteville	60-185	Green shale, dolomite, and limestone
		Unconformity?		
		St. Peter	25-56	Quartz sandstone
		Unconformity		
	Cambrian	Jordan-St. Lawrence	60+-125	Dolomite and glauconitic sandstone
		Undifferentiated	70-114	Sandstone, shale, and limestone
		Unconformity		
Precambrian		Sioux	?	Siliceous quartzitic sandstone and claystone
		Unconformity		
		Granite	1725+	Granite, schist, and pegmatite

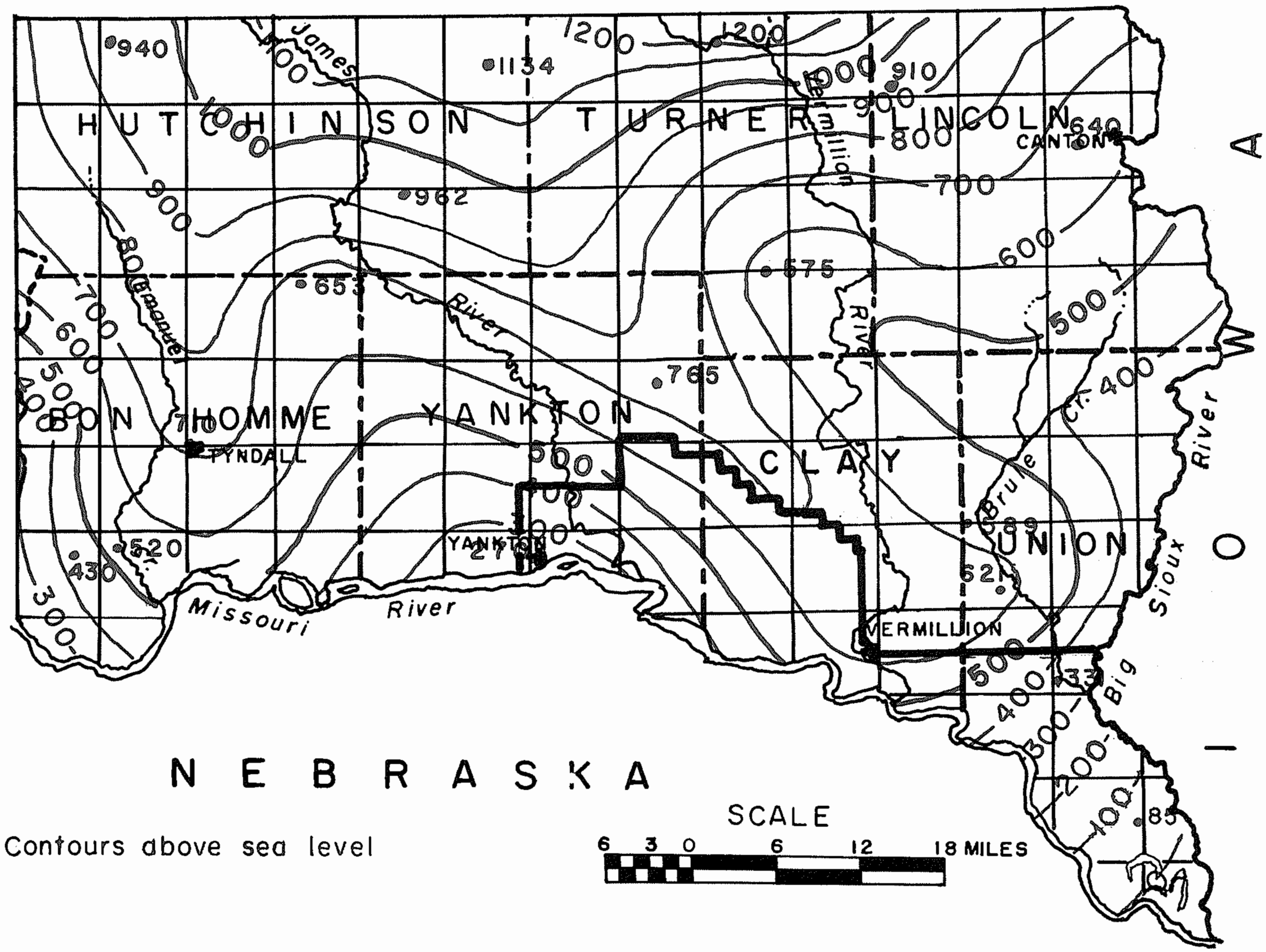


Figure 5 Map of Southeastern South Dakota showing topography of Buried Precambrian Surface in the North Sioux City-Yankton Area.

ECONOMIC GEOLOGY

Shallow Ground Water Resources

Principles of Occurrence of Ground Water

Ground water in the North Sioux City–Yankton area is furnished almost entirely by precipitation in the form of rain or snow. A large part of the water seeps downward through the soil to the water table, where it joins other water in storage in the zone of saturation. If the upper surface of the ground water is free to rise and fall with seasonal changes in recharge, flow is unconfined or free; thus the water surface, or ground water table, has a slope similar to that of the surface of the ground. Under these conditions, the ground water moves at right angles to the water-table contours. If the water-bearing stratus (aquifer) dips below an impervious layer, the flow becomes constricted as in a pipe that dips below the hydraulic grade line, and artesian water will rise under hydrostatic pressure when tapped (Fair and Geyer, 1958, p. 98). (A city water system which uses standpipes or water towers to cause hydrostatic pressure for water distribution operates on the same principle as artesian water.) Water trapped above a lens of impervious material is called perched water. Ground water moving from the intake area to the discharge area is said to be in transient storage.

Ground water occurs in all the interstitial openings of unconsolidated deposits in the zone of saturation, and partially fills nearly all the interstices above the zone of saturation or above the water table.

The quantity of the water in the zone of saturation depends on several factors, among which are porosity, permeability, and the volume of the material.

The quantity of water stored in a given volume of material is dependent upon the porosity of the material. Porosity is the ratio of the volume of voids to the volume of the material. The porosity is dependent upon sorting, sphericity, and the amount of consolidation. In general a well-rounded, well-sorted, unconsolidated material will have a high porosity (fig. 6). The size of the grains has no affect on porosity if the material is well-sorted and rounded.

Permeability is a measure of the amount of fluids that will pass through a certain thickness of material under a certain pressure. A material may have a high porosity, but may produce only a small amount of water because the pores are not interconnected and the water will thus not move easily. A well-sorted sand and gravel deposit has a high permeability. A poorly sorted gravel has a lower permeability because the finer material will fill the openings and block the flow of water. Till is poorly sorted and unstratified, and is relatively impermeable.

Recharge is the addition of water to the reservoir, and is accomplished in the following manner:

1. Percolation of water derived from rainfall and snow melt
2. Infiltration from surface bodies of water
3. Underflow of water into the reservoir along the hydrostatic gradient or by hydrostatic pressure
4. Leakage through confining layers, or water displaced from them by compression
5. Water derived from water-spreading operations

Discharge is the loss of water from the reservoir, and is accomplished in the following manner (Fair and Geyer, 1958, p. 104):

1. Evaporation and transpiration (water-loss by plants)
2. Seepage into surface bodies of water
3. Underflow from the reservoir along the hydraulic gradient or by hydrostatic pressure

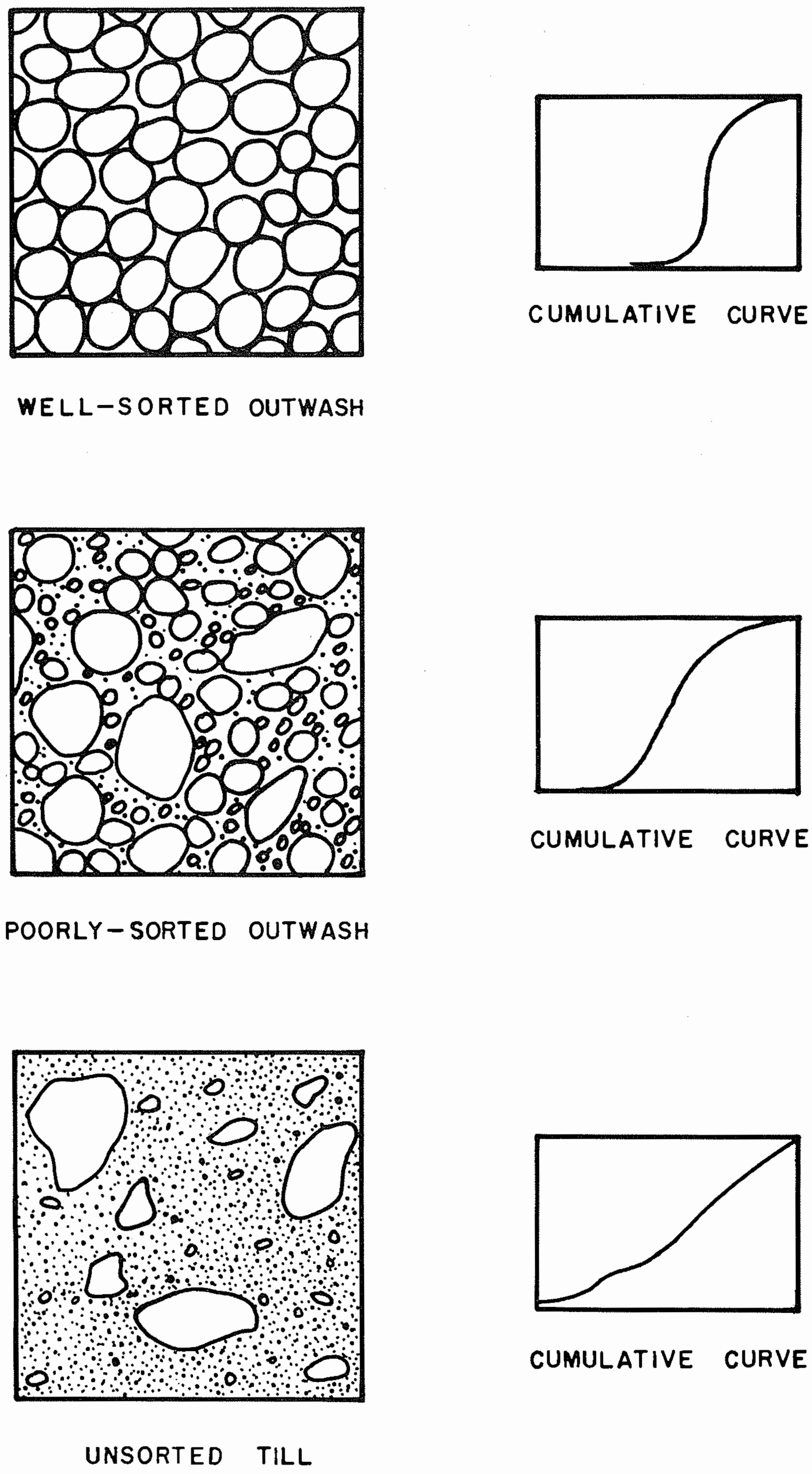


FIG. 6. PARTICLE SORTING AND ARRANGEMENT IN THREE IDEALIZED GLACIAL DEPOSITS. (AFTER STEECE, 1958, FIG.5)

4. Leakage through confining layers or absorbed by them by reduction of compressive force
5. Water withdrawn through wells, basins and galleries

Recovery is the speed or rate at which the water level returns to normal after the cessation of discharge by pumping. Recovery depends upon rate of recharge, permeability, thickness, and volume of the reservoir.

The factors governing the availability of ground water–discharge, recharge, recovery, permeability, and porosity–are often diffidult to evaluate. Therefore a field method of determining these factors has been developed so that proper well-design and well-spacing may be achieved. The method employs pumping a test well at different rates for a specified period of time. As the test well is pumped, drawdown is measured at specified intervals of time in observation wells spaced at different distances from the test well. This method determines the hydraulic factors of (T) and (S).

(T) is the coefficient of transmissibility and is expressed as the number of gallons which would flow through an opening 1 foot wide from the top to the bottom of the reservoir or aquifer in one day, under the hydraulic gradient of 1 foot per foot. (T) is related to permeability and can be determined from the formula:

$$T = \frac{(264)\,(Q)}{\Delta s}\text{, where} \qquad (1)$$

Q = rate of pumping in gallons per minute,
Δs = rate of drawdown of water level in feet per log cycle, of the straight line part of the curve as plotted on semilog paper.

(S) is the coefficient of storage and is a measure of the quantity of water given up by a column of the aquifer with a cross-sectional area of 1 sq ft and equal in height to the thickness of the saturated formation when the hydraulic head is lowered 1 ft. (S) is related to porosity and can be expressed by the formula:

$$S = \frac{(T)\,(to)}{(4790)\,(r^2)}\text{, where} \qquad (2)$$

T = coefficient of transmissibility in gal per day per ft,
to = time in minutes when the straight-line portion of the curve extended instersects the value of zero drawdown, and
r = radius or distance in feet from the center of the pumped well to the center of the observation well.

The values of (S) and (T) are used in the nonequilibrium formula:

$$u = \frac{(1.87)\,(r^2)\,(S)}{(T)\,(t)}\text{, where} \qquad (3)$$

T, S, and r have the same meaning as in formulas (1 and 2), and t = time of pumping in days

The value for (u) is then used to find the safe yield(s) for the well by the formula:

$$s = \frac{(114.6)\,(Q)\,(W)\,(u)}{T}\text{, where} \qquad (4)$$

T and Q have the same meaning as used in formula (1), and W (u) = the well function of (u), determined from calculated tables for each value of (u).

Besides determining the safe yield rating for an isolated well, this method can be used in determining interference between wells, and in determining well spacing (Miller, 1957).

Ground Water in Glacial Outwash Deposits

Glacial outwash deposits constitute the largest reservoir of ground water in the North Sioux City–Yankton area. Outwash deposits are present in 370 sq mi of the 395 sq mi mapped in this report. Porosity in unconsolidated sands and gravels ranges from 25 to 65 percent. A conservative estimate of porosity of the outwash deposits is 30 percent; therefore a total of 1,375 billion gallons or 4,210,000 acre feet of water is present in the outwash deposits.

Because of the character of the soil on the flood plain, large amounts of water are available for recharge by downward percolation of water to the outwash deposits. If there was no loss of precipitated water by evaporation, transpiration, or runoff, more than 155 billion gallons of water would be available for recharge annually. An estimate of runoff used by water engineers is slightly more than one-half the total precipitated water. Depsite this loss, the runoff still furnishes about one-tenth of the amount of water needed to recharge the outwash reservoirs.

Large quantities of water are also available from seepage from surface bodies of water. The Missouri River, the James River, the Vermillion River, and the Big Sioux River all discharge tremendous amounts of water daily. An average of 228,000 gallons or 30,370 cu ft of water per second is discharged daily by these rivers (Wells, 1957). All of this water is potentially available for recharge of the ground water reservoirs.

The water-table gradient slopes southeastward at the rate of slightly more than 1 foot per mile. This slope is slightly more than the slope of the land, and is nearly identical to the slope of the surface water in the Missouri River. The slightly higher water-table slope at the mouths of the tributaries is due to a rise in the water table caused by the steeper gradient of two of the tributary streams. The gradient of the water table in the Vermillion River Valley is about 4 feet per mile; in the Big Sioux Valley, 3 feet per mile; and in the James River Valley, 1¼ feet per mile. Therefore the underflow water in the first two tributaries has a faster rate of flow than the underflow water in the Missouri River Valley. When the underflow water from the tributaries reaches the Missouri River flood plain and underlying outwash, the water velocities are lessened, causing a rise in the water level. The rise of the water level causes water to be discharged into the Missouri River, thus maintaining a hydraulic equilibrium in the reservoir.

Another source of recharge is seepage from artesian aquifers.

Underflow is the major method of discharge from the outwash reservoir. Pumping from wells, runoff, seepage, and evaporation and transpiration by plants are minor means of discharge. The total quantity of water discharged is not known, except that it does not exceed the quantity of water available for recharge.

Domestic, city, and irrigation wells account for a large amount of discharge. Although large amounts of water are pumped from reservoirs in this manner, much of the water is returned to the soil and then percolates downward to the outwash reservoir.

There were 46 operational irrigation wells in the area in the summer of 1958. Nearly all of the irrigation wells are used during the summer. Each well pumps water at the rate of 350-1500 gallons per minute. The towns of Elk Point, Jefferson, Gayville, and Vermillion obtain their water supply from the outwash materials. Nearly every farm has two small wells, one used for domestic purposes and the other for stock; however, these wells pump water largely from alluvial deposits instead of the deeper outwash deposits.

Wells to be used for irrigation or for public water supply should be located at least a quarter of a mile from the margins of the outwash reservoir. The wells should penetrate the entire thickness of the outwash deposits to insure the maximum thickness of water being available to the well, and to be less affected by drawdown due to pumping. The average depth of an irrigation and public water supply well will be about 125 feet, allowing 65 feet for alluvial cover and 60 feet for the average thickness of the outwash deposit. The average water level of 14 feet below ground level is not a significant factor, because all the outwash deposits occur below or nearly below the water table.

Ground Water in Alluvial Deposits

Abundant water is present in the alluvial deposits. The average thickness of the alluvium is 65 feet. In most of the flood plain the alluvium consists of sand with clay lenses; in these sites the alluvial deposits possess the same water level as the underlying outwash deposits. In a 2½ - 3½ mile wide area bordering the Big Sioux River or the till bluffs, the surface alluvial sediments consist predominantly of clay with water-bearing lenses of sand. In this border region the alluvial deposits possess a separate water table with a water level about 12 feet below the ground surface.

The alluvial sands and silts have a relatively high permeability and porosity, and therefore constitute a good ground-water reservoir. Sand makes up more than 52 percent of the total alluvial deposits. The clay part of the alluvial deposits contains water in small quantities, but this water cannot be effectively discharged by pumping because the clay has low permeability.

The total quantity of water in transient storage in the alluvial sands is 875 billion gallons, or 2,610,000 acre feet of water, or approximately 30 percent of the total water stored in the combined alluvial and outwash deposits.

The ground water in the alluvial deposits has the same means of recharge as the ground water in the outwash deposits. Therefore recharge is available chiefly by precipitation, underflow, and seepage from surface bodies of water.

Discharge of ground water from the alluvial deposits is largely by evaporation, pumping and underflow, whereas discharge of ground water from the outwash deposits is chiefly by underflow.

Ground Water in Glacial Till

Small quantities of water are present in stratified sand lenses in the till. The sand lenses are generally composed of well-rounded medium to coarse sand with a high degree of sorting. Therefore these lenses of sand have good permeability and porosity, but because of their small volume they normally do not contain enough water for irrigation or public water supplies. Ground water stored in the stratified lenses is usually adequate for domestic stock wells.

Continued pumping of water from these small reservoirs will generally seriously deplete the water supply.

Recharge of ground water to the small lenses of sand is very slow, because the reservoirs are surrounded by till which is relatively impermeable to water movement.

Ground Water in Buried Alluvial Deposits

In the nearly flat area in Sections 13 and 14, T. 92 N., R. 50 W., Union County, ground water is derived from a 30-60 foot sand layer at a depth of approximately 90 feet. Because of the flat topographic expression of the ground surface, and the thickness and the width of the sand deposit, it is believed that this sand represents a pre-Cary alluvial deposit.

Residents whose wells penetrate the sand deposit report that they have an adequate supply of water for domestic and stock purposes.

Ground Water in Artesian Aquifers

The upper and lower sandstones of the Dakota sequence in southeastern South Dakota contain artesian water. These sandstones are commonly used to produce water for livestock. The Codell sand member of the Carlile Formation also produces artesian water, but it is limited in extent to the northern part of the mapped area, near Volin.

Discharge of the artesian water is by flowing wells, pumping wells, natural springs, and seepage.

Water for recharge to the upper and lower sandstones of the Dakota Group is thought to be derived from the Black Hills area, where several of the sandstones of the Dakota sequence crop out. Although these sandstones are probably not laterally equivalent in age to the upper and lower sandstones present in southeastern South Dakota, they probably converge in the central part of the state, allowing a continuous flow of artesian water.

The artesian water level (piezometric surface) between Yankton and North Sioux City has been lowered because the outwash material at North Sioux City lies directly on the upper sandstone of the Dakota Group and therefore the artesian water is rapidly discharged upward into the outwash.

Quality of Water

Meteoric or precipitated water is nearly pure and has a very low mineral content. Part of the meteoric water after reaching the earth's surface percolates downward and dissolves mineral constitutents, and can become highly mineralized in a short distance. The amount of mineral matter dissolved depends upon the distance that the water travels, the solubility of the minerals, the length of time that the minerals are in contact with the water, and the pressure and temperature. Standards of quality of public water supplies have been established by the United States Public Health Service (table 4).

Table 4.--United States Public Health Service Standards for Drinking Water (1946)

Constituent	Standard Limits (ppm)
Copper (Cu)	3.0
Iron and Manganese (Fe) and (Mn)	0.3
Magnesium (Mg)	125
Zinc (Zn)	15
Chloride (Cl)	250
Sulfate (SO_4)	250
Lead (Pb)	0.1
Fluoride (F)	1.5
Nitrate (NO_3)	10.0
Arsenic (As)	0.05
Selenium (Se)	0.05
Hexavalent Chromium (Cr)	0.05
Phenolic Compounds	0.001
Total Solids	500*

*Total solids may exceed 500 ppm to a maximum of 1000 ppm if the water having this concentration is the only water available.

The chemical quality of a water is an important factor in evaluating its usefulness for irrigation. Factors of the chemical composition that need to be considered include the concentration of individual constituents, the relative proportions of some of the constituents, and the total amount of dissolved matter. Whether a particular water may be used successfully for irrigation depends upon many factors not directly associated with composition, however.

The water consumed by plants and then evaporated is essentially free from dissolved salts, but the growing plants retain part of the mineral matter originally dissolved in this water. Thus, continued collection of minerals by plants and evaporation causes a disposal problem.

The problem of the disposal of excess soluble salts in any irrigated area is dependent upon several factors. These factors include the chemical composition of the water supply, the topography of the land, the method of irrigation, the type of crops grown, the drainage, the water level, the amount of rainfall, the permeability of the soil, and the chemical composition of the soil (Hem, 1959, p. 241-243).

In this area most of the excess soluble matter left in the soil is removed from the soil by leaching, caused by the downward percolation of rain water. This does not mean that an accumulation of salts in the soil is not a problem in this area; however, intermittent irrigation during dry periods probably would not create a serious problem in the accumulation of salts in the soil. During longer periods of irrigation the concentration of salts in the soil becomes abnormally high, and can become harmful to plant growth if preventive measures are not used. Therefore during the period of irrigation, water samples should be taken periodically.

Common elements that are especially detrimental to plants in small quantities are boron, sodium, calcium, magnesium, carbonate and bicarbonate radicles.

To evaluate if a water supply will be harmful to plant growth or the soil, arbitrary limits on certain mineral quantities have been determined (table 5).

Nine samples were taken from water derived from outwash deposits or from combined alluvial and outwash deposits; (table 6, samples 1, 3-10). The water from the outwash reservoirs is highly mineralized, but most samples are of quality adequate for irrigation, and satisfactory for domestic and stock use.

Water sample 2 (table 6) was taken from the isolated alluvial reservoir bordering the Big Sioux River. The water from this reservoir has the lowest mineral content and is of excellent quality for nearly any purpose; however, the alluvial reservoir does not possess the quantity of water needed for irrigation or public water supply.

The water derived from artesian sources is adequate for stock but is usually not used for irrigation or human consumption without treatment because of the hardness, taste, and high mineral content.

The hardness and taste of the water varies without any particular geographic pattern. This condition may be due to the circulation of water in the sandstone. In places where there is good permeability and slope, the water is kept circulating. Where the sandstone is more impermeable and flat-lying, the water becomes stagnant because the circulation of the water is lessened (Barkley, 1955, p. 34).

Sand and Gravel Resources

Of the 395 sq mi covered by this report, more than 90 percent is underlain with sand and gravel deposits of outwash origin. The average thickness of the outwash sands and gravels is 61 feet, and a total of 22,000,000,000 cu yd of sand and gravel is present in the area. Of the 370 sq mi, only 10 sq mi of the area has a cover of alluvium less than 12 feet, where the gravel is easily accessible. Most of these deposits are located beneath the alluvial flood plains of the James River, the Vermillion River, and the Big Sioux River; however, small areas are exposed at Volin and at Yankton. The outwash deposits in the 10 square mile area have an average thickness of 42 feet and contain 475,000,000 cu yd of gravel.

The composition of the outwash sands and gravels is chiefly limestone, dolomite, granite, shale, ironstone, and metamorphic rocks such as quartzite and schist. Shale, ironstone concretions, and chalk are considered impurities if the gravel is to be used for high-strength concrete. Therefore the gravel in the North Sioux City—Yankton area is not suitable for high-strength concrete, but is excellent for road surfacing. Sand is the predominant constituent of alluvial deposits, constituting 52 percent of the alluvial deposits of 13,000,000,000 cu yd. The sand is fine to medium in size, and consists chiefly of quartz. Because of the small grains and impurities, the sand is of little value as a fine aggregate in plaster or concrete.

Table 5.–Qualitative Classification of Irrigation Waters
(After Steece, 1958, Table 3)

Classification	Percent Sodium	Boron (ppm)*		Chloride (ppm)	Sulfate (ppm)
		Sensitive Plants	Tolerant Plants		
Class 1 Excellent to Good	0- 40	Under 0.4	Under 1.00	Under 71	Under 192
Class 2 Good to Injurious	40- 70	0.40-1.00	1.00-2.00	71-213	192-576
Class 3 Injurious to Unsatisfactory	70-100	1.00+	2.00+	213+	576+

*ppm – parts per million

Table 6.--Analyses of Shallow Ground Water
in the North Sioux City—Yankton Area

SAMPLE NUMBER	1	2	3	4	5	6	7	8	9	10
CONTENTS	Parts Per Million									
Calcium (Ca)	124	129	164	317	284	205	188	102	213	277
Magnesium (Mg)	38	55	42	62	49	37	55	31	55	63
Sulfates (SO_4)	147	120	437	935	756	336	400	136	564	795
Chloride (Cl)	4	1	2	78	32	17	31	0.2	17	52
Alkalinity										
Phenolphthalein	21	40	21	15	16	14	16	14	13	16
Methyl Orange	364	404	216	148	171	204	212	275	256	163
Hardness ($CaCO_3$)	467	547	581	1048	909	666	696	383	755	950
Fluoride (F)	Trace	0.30	0.4	1.3	1.0	2.4	0.3	0.2	0.3	0.8
Iron (Fe)	7.1	none	Trace	8.1	3.9	6.2	Trace	Trace	7.4	none
Manganese (Mn)	1.0	0.5	1.1	1.7	1.4	0.7	1.1	1.2	1.9	2.6
Nitrate (NO_3)	0.4	1.60	0.3	Trace	none	0.4	none	2.0	3.4	1.5
Sodium (Na)	63.0	38.0	80	90	73	40	43	67	108	70
Total Solids	828	696	1143	1783	1528	976	1138	708	1428	1762
Class for Irrigation	1	1	2	3	2	2	2	1	2	3

Analyst: D. J. Mitchell, State Chemist, State University of South Dakota, Vermillion, 1958.
Sample location and owner:

1. M. E. Jorgensen, NE¼NE¼ sec. 11, T. 89 N., R. 49 W.
2. I. Mollet, NW¼SE¼ sec. 20, T. 90 N., R. 48 W.
3. D. Chicoine, NW¼ sec. 9, T. 90 N., R. 49 W.
4. A. Wagner, NE¼SW¼ sec. 35, T. 92 N., R. 50 W.
5. L. Cusick, NW¼SW¼ sec. 26, T. 92 N., R. 51 W.
6. R. D. Hill, SW¼NW¼ sec. 22, T. 93 N., R. 53 W.
7. F. Yagie, NW¼NE¼ sec. 9, T. 93 N., R. 54 W.
8. L. Holzbauer, NW¼NE¼ sec. 12, T. 93 N., R. 55 W.
9. D. Weaverstad, NE¼NW¼ sec. 13, T. 93 N., R. 55 W.
10. B. Anderson, NW¼NE¼ sec. 8, T. 93 N., R. 55 W.

Clay

Clay is abundant in the till, loess, and alluvial deposits.

The clay contains many impurities such as iron and calcium, which cause staining detrimental for ceramic purposes. The till contains rock fragments of sand and gravel size, which must be removed if the clay is to be used for ceramics, tile or bricks.

The clay in the loess contains iron which is detrimental in ceramics, but is not harmful if the clay is to be used for brick and tile manufacture.

Limestone

Calcium carbonate is present as chalk in the Niobrara Formation and as limestone in the Greenhorn Formation.

The Niobrara chalk and the clay present in the area could be used together for the manufacture of portland cement, or the chalk could be used to manufacture lime or quicklime.

Both the Greenhron limestone and the Niobrara chalk are suitable for use as agriculture fertilizer because the $CaCO_3$ content is greater than 95 percent.

The limestones can also be crushed and used as rock surfacing for roads.

Oil and Gas

Oil or gas accumulations of economic importance are possibly present in the North Sioux City–Yankton area because of the existence of potential reservoir beds and stratigraphic traps.

Potential reservoir beds consist of the sandstones of the Dakota sequence, the chalk of the Niobrara Formation, and the undifferentiated Paleozoic sandstones, limestones, and dolomites.

Pinchouts and buried-hill traps are likely to be associated with the irregular Sioux quartzite Ridge. The Sioux Ridge in South Dakota was an erosional feature apparently since at least early Paleozoic time. During the Paleozoic era sediments overlapped the periphery of the ridge, but during the Mesozoic era (especially Cretaceous time) the Dakota sandstones and shales, the Graneros shale, the Greenhorn limestone, the Carlile shale, and the Niobrara chalk successively covered the ridge. Each deposit covered more of the ridge than the underlying one. Either or both the Niobrara chalk or the overlying Pierre shale completely covered the ridge in Late Cretaceous time. Therefore, two types of oil or gas traps were formed: (1) a pinch-out or a reservoir truncated against the unconformable surface of the Sioux Ridge, and (2) a buried-hill trap caused by uneven compaction of the soft rocks on the harder rocks that compose the Sioux Ridge.

In many locations a "wash" is present near the contact between the overlying deposits and the Sioux quartzite or Precambrian granite. The "wash" is composed of rock fragments of sand to pebble size derived from the Sioux quartzite or granite, intermixed with the overlying sediments. It could have served as an avenue of escape for oil and gas. The escaping oil or gas may have migrated updip to the erosional surface of the ridge and may have been trapped there against a buried-hill.

Oil shows were present in the Wagner No. 1 Peterson oil test (SW¼NW¼ sec. 30, T. 92 N., R. 49 W., Union County), in a brown silty shale at 580-585 feet depth. The 5 foot zone showing oil is in the undifferentiated Paleozoic strata (App. D).

The Wagner No. 1 O'Connor oil test, just north of the mapped area (SE¼NW¼ sec. 31, T. 94 N., R. 50 W., Union County) showed oil-stained sand in the upper sandstone of the Dakota sequence (App. D).

SUMMARY

The North Sioux City–Yankton area in southeastern South Dakota covers about 395 sq mi, of which the Missouri River flood plain occupies 360 sq mi.

Alluvium, along with glacial till, outwash and loess, mantle most of the area; Cretaceous bedrock is exposed only locally.

The till is chiefly clay with rock fragments of sand to cobble size, and contains only small amounts of water.

The outwash deposits are sand and gravel that contain large quantities of water. The total reserve of outwash sand and gravel is more than 22,000,000,000 cu yd, containing approximately 1,375,000,000,000 gallons of water.

Recent alluvial deposits cover the flood plains and consist of sand, silt and clay. An estimated 13,000,000,000 cu yd of sand is present in the alluvium, containing 875,000,000,000 gallons of water in the summer of 1958.

The potential recharge of the water to the outwash and alluvial deposits exceeds the discharge. The quality of the water is satisfactory for human consumption, for industrial use, for domestic use, and for periods of continued pumping.

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APPENDIX A
(see pl. 2)

Logs of Test Holes and Irrigation Wells in the Alluvial and Outwash Sediments

Hole C-1

Location: NW¼SW¼ sec. 23, T. 92 N., R. 51 W., Clay County
Elevation: 1137 feet
Total Depth: 120 feet
Depth to water: 9.7 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay	0- 9
Silt and clay	9- 19
Sand, fine	19- 49
Sand, medium	49- 99
Outwash deposits	
Sand, coarse	99-120

Hole C-2

Location: SW¼SW¼ sec. 26, T. 92 N., R. 51 W., Clay County
Elevation: 1137 feet
Total depth: 109 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay	4- 19
Sand and clay	19- 24
Sand, medium	24- 99
Outwash deposits	
Sand, coarse	99-109

Hole C-3

Location: NW¼SW¼ sec. 34, T. 92 N., R. 51 W., Clay County
Elevation: 1144 feet
Total depth: 116 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Sand, fine	0- 9
Sand, fine, and clay	9- 19
Sand, fine	19- 39
Sand, medium	39-104

Hole C-3 – Continued

Outwash deposits	
Sand, coarse	104-112
Sand, coarse, and fine gravel	112-116

Hole C-4

Location: NE¼NE¼ sec. 3, T. 91 N., R. 51 W., Clay County
Elevation: 1131 feet
Total depth: 112 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 1
Sand, fine	1- 9
Clay, yellow	9- 14
Clay, dark gray, and fine sand	14- 24
Sand and silt	24- 29
Sand, fine	29- 39
Sand, medium	39- 64
Sand, medium and coarse	64- 79
Sand, medium	79- 84
Sand, medium and coarse	84- 94
Outwash deposits	
Sand, coarse	94- 99
Sand, coarse and fine gravel	99-112

Hole C-5

Location: SW¼SW¼ sec. 1, T. 93 N., R. 53 W., Clay County
Elevation: 1153 feet
Total depth: 49 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay	4- 14
Clay and silt	14- 24
Sand and silt	24- 44
Outwash deposits	
Gravel, coarse	44- 49

Hole C-6

Location: NE¼NE¼ sec. 14, T. 93 N., R. 53 W., Clay County
Elevation: 1150 feet
Total depth: 69 feet
Depth to water:
Source of Data: S. Dak. Geol. Survey

Hole C-6 – Continued

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay, tan	4- 19
Clay, blue	19- 29
Clay, tan	29- 54
Sand, medium	54- 64
Outwash deposits	
Gravel, coarse	64- 69

Hole C-7

Location: NE¼NE¼ sec. 26, T. 93 N., R. 53 W., Clay County
Elevation: 1150 feet
Total depth: 136 feet
Depth to water: 9 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 2
Clay, yellow	2- 9
Clay, gray and medium sand	9- 24
Silt and clay	24- 29
Clay, yellow, sandy	29- 34
Sand, medium-coarse and clay	34- 74
Outwash deposits	
Sand, medium-coarse	74- 79
Sand, coarse	79- 84
Sand, coarse and fine gravel	84- 89
Gravel, medium	89- 99
Gravel, fine	99-109
Sand, coarse-medium and medium-fine gravel	109-136

Hole C-8

Location: SW¼NE¼ sec. 35, T. 93 N., R. 53 W., Clay County
Elevation: 1153 feet
Total depth: 99 feet
Depth to water: 12.0 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay, yellow	4- 19
Clay, dark gray	19- 29
Clay, tan	29- 39
Clay, and silt	39- 64
Outwash deposits	
Silt and sand	64- 99

Hole C-9

Location: SW¼SW¼ sec. 15, T. 92 N., R. 53 W., Clay County
Elevation: 1154 feet
Total Depth: 112 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay, yellow	0- 4
Sand, very fine	4- 9
Clay, dark	9- 10
Sand, very fine	10- 14
Sand, very fine and clay	14- 19
Sand, fine	19- 79
Outwash deposits	
Sand, fine and medium	79-109
Cretaceous	
Carlile? shale	
Shale, black	109-112

Hole C-10

Location: SE¼SE¼ sec. 3, T. 92 N., R. 53 W., Clay County
Elevation: 1153 feet
Total depth: 106 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay, yellow	0- 4
Sand, very fine	4- 9
Clay, dark gray	9- 10
Sand, very fine	10- 14
Sand, fine	14- 44
Sand, medium	44- 69
Outwash deposits	
Sand, coarse	69-104
Cretaceous	
Carlile? shale	
Shale, hard, dark	104-106

Well I-3

Location: NE¼NW¼ sec. 23, T. 90 N., R. 49 W., Union County
Elevation: 1115 feet
Total depth: 116 feet
Depth to water: 12.5 feet
Source of data: test hole

Depth
(feet)

Well I-3 – Continued

Alluvium	
Topsoil	0- 1
Clay, light yellow	1- 16
Sand, fine	16- 48
Outwash deposits	
Gravel, very coarse	48- 50
Sand and gravel	50- 75
Gravel, coarse	75- 76
Gravel, coarse and sand	76- 82
Gravel, very coarse	82- 83
Gravel and sand	83-116

Well I-7

Location: SE¼NW¼ sec. 17, T. 90 N., R. 48 W., Union County
Elevation: 1110 feet
Total depth: 116 feet
Depth to water: 10.9 feet
Source of data: test hole

	Depth (feet)
Alluvium	
Clay, dark gray	0- 11
Clay, yellow	11- 21
Clay, blue gray	21- 27
Clay, yellow	27- 53
Outwash deposits	
Sand and gravel	53- 61
Gravel and sand	61-106
Sand and gravel	106-116

Well I-10

Location: SW¼NW¼ sec. 5, T. 90 N., R. 48 W., Union County
Elevation: 1110 feet
Total depth: 104 feet
Depth to water: 7.4 feet
Source of data: test hole

	Depth (feet)
Alluvium	
Clay, gray	0- 48
Sand and clay	48- 65
Sand	65- 68
Outwash deposits	
Sand and gravel	68- 74
Gravel coarse	74-104

Hole I-12

Location: SE¼ sec. 31, T. 91 N., R. 48 W., Union County
Elevation: 1108 feet
Total depth: 117 feet

Hole I-12 – Continued

Depth to water: 11.6 feet
Source of data: Irrigation test well

	Depth (feet)
Alluvium	
Clay, dark gray	0- 32
Clay, blue gray	32- 54
Clay and sand	54- 66
Outwash deposits	
Sand and fine gravel	66- 83
Gravel, coarse	83- 85
Sand and gravel	85- 98
Gravel, coarse	98-106
Sand and gravel	106-117

Well I-13

Location: SW¼SE¼ sec. 25, T. 90 N., R. 49 W.
Elevation: 1111 feet
Total depth: 97 feet
Depth to water: 12.5 feet
Source of data: test hole

	Depth (feet)
Alluvium	
Clay, dark gray	0- 11
Clay, tan	11- 16
Clay, gray	16- 55
Sand and clay	55- 64
Outwash deposits	
Sand and gravel	64- 88
Gravel, coarse	88- 90
Sand and gravel	90- 97

Well I-14

Location: NE¼SW¼ sec. 25, T. 91 N., R. 49 W., Union County
Elevation: 1112 feet
Total depth: 116 feet
Depth to water: 13.5 feet
Source of data: test hole

	Depth (feet)
Alluvium	
Clay, tan	0- 6
Clay, gray	6- 31
Clay, tan	31- 43
Clay, gray	43- 60
Outwash deposits	
Sand and gravel	60- 67
Gravel, coarse	67- 72
Gravel, fine and sand	72- 75

Well I-14 – continued

Gravel, coarse	75- 77
Gravel, fine and coarse	77- 82
Gravel, medium	82- 91
Sand, coarse	91-104
Sand, coarse and fine gravel	104-112
Gravel	112-116

Well I-17

Location: SE¼SW¼ sec. 18, T. 91 N., R. 49 W., Union County
Elevation: 1124 feet
Total depth: 111 feet
Depth to water: 13.6 feet
Source of data: test hole

	Depth (feet)
Alluvium	
Clay and fine sand	0- 63
Outwash deposits	
Gravel, fine and coarse	63- 68
Gravel, medium and coarse	68- 98
Gravel, medium	98-111

Test Hole I-20

Location: NE¼SW¼ sec. 35, T. 92 N., R. 50 W., Union County
Elevation: 1129 feet
Total Depth: 104 feet
Depth to water: 9.5 feet
Source of data: test hole

	Depth (feet)
Alluvium	
Clay	0- 10
Clay and silt	10- 21
Sand, fine and silt	21- 42
Clay, blue gray and silt	42- 52
Sand, fine and silt	52- 63
Outwash deposits	
Sand and fine gravel	63- 95
Gravel, very coarse	95-104

Well I-21

Location: SW¼SE¼ sec. 14, T. 91 N., R. 50 W., Union County
Elevation: 1123 feet
Total depth: 93 feet
Depth to water: 15.8 feet
Source of data: test well

	Depth (feet)
Alluvium	

Well I-21 – continued

Sand and clay	0- 18
Sand, fine and silt	18- 38
Sand, fine	38- 53
Clay, blue gray	53- 55
Sand	55- 57
Clay, blue gray	57- 67
Outwash deposits	
Gravel, medium-coarse	67- 76
Gravel and clay	76- 78
Gravel, medium-coarse	78- 93

Well I-22

Location: SW¼NE¼ sec. 22, T. 91 N., R. 50 W., Union County
Elevation: 1132 feet
Total depth: 87 feet
Depth to water: 15.2 feet
Source of data: test hole

	Depth (feet)
Alluvium	
Sand, fine	0- 57
Outwash deposits	
Sand, coarse and gravel, fine	57- 87

Well I-29

Location: NW¼NE¼ sec. 15, T. 92 N., R. 53 W., Clay County
Elevation: 1156 feet
Total depth: 125 feet
Depth to water: 15.3 feet
Source of data: test well

	Depth (feet)
Alluvium	
Clay and medium sand	0- 12
Sand, fine	12- 22
Sand, medium-coarse	22- 52
Outwash deposits	
Sand, medium and fine gravel	52- 65
Sand, medium	65- 85
Sand, medium and fine gravel	85- 95
Sand, coarse and fine gravel	95-116
Cretaceous, Carlile shale	
Shale, dark gray	116-125

Well I-38

Location: SE¼SE¼ sec. 11, T. 93 N., R. 55 W., Yankton County
Elevation: 1166 feet
Total depth: 123 feet
Depth to water: 11.8 feet
Source of data: test well

Well I-38 – Continued

	Depth (feet)
Alluvium	
Clay, dark-gray	0- 12
Sand, fine	12- 26
Sand, coarse	26- 40
Outwash deposits	
Gravel	40- 43
Gravel, coarse	43- 52
Gravel, fine	52- 65
Gravel	65- 76
Sand, coarse	76-123

Hole M-1

Location: SE¼SE¼ sec. 21, T. 94 N., R. 54 W., Yankton County
Elevation: (Top of Casing): 1163.8 feet
Total depth: 80 feet
Depth to water: 5.2 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 1
Clay, gray	1- 21
Outwash deposits?	
Gravel, medium	21- 80

Hole M-2

Location: SW¼SW¼ sec. 7, T. 93 N., R. 52 W., Clay County
Elevation: (Top of casing)
Total Depth: 80 feet
Depth to water: 8.0 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 2
Clay, gray	2- 29
Outwash deposits	
Gravel, coarse	29- 80

Hole M-3

Location: NW¼NW¼ sec. 15, T. 92 N., R. 53 W., Clay County
Elevation (Top of Casing): 1156.2 feet
Total depth: 100 feet
Depth to water: 14.9 feet
Source of data: S. Dak. Water Resources Commission

Depth
(feet)

Hole M-3 -- continued

Alluvium	
Topsoil	0- 15
Sand, fine	15- 85
Outwash deposits	
Sand, coarse	85- 90
Gravel, coarse	90-100

Hole M-4

Location: SW¼SW¼ sec. 14, T. 92 N., R. 52 W., Clay County
Elevation: (Top of casing)
Total depth: 112 feet
Depth to water: 14.8 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 13
Sand, fine	13- 38
Clay, gray	38- 40
Sand, fine	40- 48
Clay, gray	48- 50
Sand, medium	50- 70
Sand, coarse	70- 77
Clay, gray	77- 80
Outwash deposits	
Sand, coarse	80- 93
Gravel, medium	93-112

Hole M-5

Location: NW¼SW¼ sec. 27, T. 92 N., R. 51 W., Clay County
Elevation (Top of Casing): 1138.9 feet
Total depth: 70 feet
Depth to water: 12.4 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 2
Clay, brown	2- 9
Sand, fine	9- 54
Clay, gray	54- 56
Gravel, medium	56- 63
Clay, dark gray	63- 70

Hole M-6

Location: SW¼NE¼ sec. 9, T. 91 N., R. 50 W., Union County
Elevation: (Top of Casing): 1128.6 feet
Total depth: 60 feet
Depth to water: 10.9 feet
Source of data: S. Dak. Water Resources Commission

Hole M-6 – Continued

	Depth (feet)
Alluvium	
Topsoil	0- 2
Clay, gray	2- 5
Clay, brown	5- 11
Sand, fine	11- 52
Clay, blue	52- 60

Hole M-7

Location: NW¼NW¼ sec. 33, T. 91 N., R. 49 W., Union County
Elevation: (Top of Casing): 1123.1 feet
Total depth: 35 feet
Depth to water: 16.4 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 3
Clay, brown	3- 7
Clay, gray	7- 25
Sand, very fine	25- 35

Hole M-8

Location: NE¼NE¼ sec. 35, T. 90 N., R. 49 W., Union County
Elevation (Top of Casing): 1112.0 feet
Total depth: 40 feet
Depth to water: 14.5 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay, gray	4- 7
Sand, very fine	7- 27
Clay, gray	27- 29
Sand, coarse	29- 40

Hole S-38

Location: NE¼NE¼ sec. 28, T. 92 N., R. 49 W., Union County
Elevation (Top of Casing): 1121.0 feet
Total depth: 70 feet
Depth to water: 9.2 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 10
Clay, yellow	10- 20

Hole S-38 – Continued

Sand, fine	20- 28
Clay	28- 30
Outwash deposits	
Gravel, medium	30- 65
Alluvium	
Clay	65- 70

Hole S-39

Location: SE¼SW¼ sec. 9, T. 90 N., R. 48 W., Union County
Elevation (Top of Casing): 1107.0 feet
Total depth: 50 feet
Depth to water: 8.9 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 1
Clay	1- 10
Sand, very fine	10- 23
Clay	23- 24
Sand, fine	24- 39
Clay, brown	39- 50

Hole S-40

Location: NE¼NE¼ sec. 10, T. 89 N., R. 48 W., Union County
Elevation (Top of Casing): 1108.5 feet
Total depth: 60 feet
Depth to water: 14.0 feet
Source of data: S. Dak. Water Resources Commission

	Depth (feet)
Alluvium	
Topsoil	0- 1
Clay	1- 20
Sand, fine and clay	20- 55
Clay, blue	55- 60

Hole U-3

Location: SE¼NW¼ sec. 21, T. 92 N., R. 49 W., Union County
Elevation: 1122 feet
Total depth: 49 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay	4- 19

Hole U-3 – Continued

Outwash deposits	
Sand, coarse	19- 24
Clay	24- 49

Hole U-4

Location: NW¼NW¼ sec. 21, T. 92 N., R. 49 W., Union County
Elevation: 1123 feet
Total depth: 96 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Outwash deposits	
Gravel, medium	4- 6
Sand, medium	6- 9
Gravel, medium	9- 14
Clay	14- 15
Gravel, medium	15- 44
Gravel, coarse	44- 64
Clay	64- 96

Hole U-5

Location: SW¼SE¼ sec. 21, T. 92 N., R. 49 W., Union County
Elevation: 1122 feet
Total depth: 94 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay, dark	4- 29
Silt	29- 34
Clay	34- 39
Silt	39- 44
Silt and very fine sand	44- 49
Sand, medium and silt	49- 64
Sand, medium	64- 69
Outwash deposits	
Gravel, fine	69- 79
Sand, coarse	79- 84
Alluvium	
Clay	84- 94

Hole U-6

Location: SW¼SW¼ sec. 6, T. 91 N., R. 49 W., Union County
Elevation: 1124 feet
Total depth: 49 feet

Hole U-6 – Continued

Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil, dark	0- 4
Clay	4- 49

Hole U-7

Location: SE¼SE¼ sec. 11, T. 91 N., R. 50 W., Union County
Elevation: 1125 feet
Total depth: 54 feet
Depth to water: 13.9 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay, yellow	0- 4
Clay, gray	4- 24
Clay, yellow	24- 29
Fine sand	29- 39
Clay, gray	39- 54

Hole U-8

Location: NE¼SW¼ sec. 23, T. 91 N., R. 50 W., Union County
Elevation: 1125 feet
Total depth: 64 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 1
Sand, fine	1- 39
Clay	39- 64

Hole U-9

Location: NE¼NE¼ sec. 28, T. 91 N., R. 49 W., Union County
Elevation: 1121 feet
Total depth: 108 feet
Depth to water: 13.8 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Sand, fine, and silt	4- 24

Hole U-9 – Continued

Clay, dark	24- 29
Silt and sand	29- 39
Clay	39- 44
Silt and clay	44- 49
Clay	49- 69
Clay and fine sand	69- 74
Clay	74- 84
Sand, medium, and clay	84- 94
Outwash deposits	
Gravel, fine	94-104
Gravel, medium	104-108

Hole U-10

Location: SE¼SW¼ sec. 32, T. 90 N., R. 48 W., Union County
Elevation: 1114 feet
Total depth: 107 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Toposil	0- 4
Sand, fine, and clay	4- 24
Clay, dark	24- 29
Silt and sand	29- 39
Clay and silt	39- 49
Sand, medium	49- 64
Outwash deposits	
Sand, coarse	64- 69
Gravel, fine	69- 74
Gravel, medium	74- 84
Gravel, fine	84- 99
Gravel, medium-fine, and sand	99-107

Hole U-11

Location: NE¼NE¼ sec. 9, T. 90 N., R. 49 W., Union County
Elevation: 1119 feet
Total depth: 94 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay	4- 34
Sand, fine, and clay	34- 59
Sand, medium, and clay	59- 84
Outwash deposits	
Sand, coarse	84- 89
Gravel, coarse	89- 94

Hole U-12

Location: NE¼NE¼ sec. 18, T. 90 N., R. 49 W., Union County
Elevation: 1121 feet
Total depth: 107 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay, yellow	0- 4
Sand, fine	4- 29
Sand, medium	29- 99
Outwash deposits	
Sand, coarse and medium	99-107

Hole U-13

Location: SW¼SE¼ sec. 18, T. 90 N., R. 49 W., Union County
Elevation: 1122 feet
Total depth: 79 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay	0- 1
Sand, fine	1- 4
Clay	4- 16
Sand, fine	16- 19
Clay and fine sand	19- 29
Sand, medium	29- 74
Outwash deposits	
Gravel, coarse	74- 79

Hole U-14

Location: NW¼SE¼ sec. 10, T. 89 N., R. 48 W., Union County
Elevation: 1114 feet
Total depth: 107 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 1
Clay	1- 29
Silt and clay	29- 44
Silt, coarse, and fine sand	44- 54
Clay and silt	54- 74
Clay, silt, and sand	74- 84
Silt and medium sand	84- 94
Outwash deposits	
Sand, coarse	94-107

Hole U-15

Location: SW¼NE¼ sec. 21, T. 89 N., R. 49 W., Union County
Elevation: 1095 feet
Total depth: 107 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay	0- 4
Sand, medium	4-107

Hole Y-1

Location: SW¼SW¼ sec. 16, T. 94 N., R. 54 W., Yankton County
Elevation: 1164 feet
Total depth: 79 feet
Depth to water: 6.6 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay	4- 9
Clay, and fine sand	9- 29
Sand, medium	29- 74
Outwash deposits	
Sand, coarse	74- 76
Gravel, coarse	76- 79

Hole Y-2

Location: NW¼NW¼ sec. 16, T. 94 N., R. 54 W., Yankton County
Elevation: 1170 feet
Total depth: 93 feet
Depth to water: 13.0 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay and medium sand	4- 9
Clay and fine gravel	9- 14
Gravel, fine, and silt	14- 49
Sand, medium	49- 74
Outwash deposits	
Sand, coarse, and coarse gravel	74- 93

Hole Y-3

Location: SW¼SW¼ sec. 4, T. 94 N., R. 54 W., Yankton County
Elevation: 1177 feet

Hole Y-3 – Continued.

Total depth: 19 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay and medium sand	4- 9
Clay and coarse sand	9- 19

Hole Y-4

Location: NE¼NE¼ sec. 32, T. 94 N., R. 54 W., Yankton County
Elevation: 1164 feet
Total depth: 93 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay	0- 4
Clay and fine sand	4- 7
Sand, fine	7- 93

Hole Y-5

Location: SW¼SW¼ sec. 33, T. 94 N., R. 54 W., Yankton County
Elevation: 1164 feet
Total depth: 79 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay, silty	0- 4
Sand, fine and clay	4- 9
Sand, fine	9- 79

Hole Y-6

Location: SW¼SW¼ sec. 4, T. 94 N., R. 54 W., Yankton County
Elevation: 1165 feet
Total depth: 93 feet
Depth to water: 8.0 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Sand, fine and clay	0- 4
Clay, tan	4- 14
Clay, dark gray	14- 39

Hole Y-6 – Continued.

Sand, fine	39- 84
Outwash deposits	
Sand, medium	84- 93

Hole Y-7

Location: SE¼SE¼ sec. 8, T. 93 N., R. 54 W., Yankton County
Elevation: 1169 feet
Total depth: 79 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay and fine sand	0- 14
Sand, fine	14- 64
Outwash deposits	
Sand, medium-coarse	64- 79

Hole Y-8

Location: NE¼NE¼ sec. 20, T. 93 N., R. 54 W., Yankton County
Elevation: 1164 feet
Total depth: 93 feet
Depth to water: 11 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay and fine sand	0- 4
Clay	4- 9
Sand, fine and clay	9- 14
Sand, medium	14- 79
Outwash deposits	
Sand, coarse	79- 93

Hole Y-9

Location: SW¼SW¼ sec. 34, T. 94 N., R. 55 W., Yankton County
Elevation: 1174 feet
Total depth: 79 feet
Depth to water: 16.3 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay	0- 4
Clay and fine sand	4- 24
Sand, very fine	24- 39
Clay and silt	39- 49
Clay, silty and fine sand	49- 59

Hole Y-9 – Continued.

Outwash deposits	
Gravel, coarse	59- 79

Hole Y-10

Location: NW¼NW¼ sec. 10, T. 93 N., R. 55 W., Yankton County
Elevation: 1176 feet
Total Depth: 79 feet
Depth to water: 12.0 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Topsoil	0- 4
Clay and fine sand	4- 29
Sand, fine and clay	29- 59
Clay, silt and fine sand	59- 74
Outwash deposits	
Gravel, coarse	74- 79

Hole Y-11

Location: NW¼SW¼ sec. 10, T. 93 N., R. 55 W., Yankton County
Elevation: 1171 feet
Total depth: 93 feet
Depth to water: 9.0 feet
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Clay and fine sand	0- 9
Clay	9- 12
Sand, fine	12- 69
Outwash deposits?	
Sand, medium	69- 93

Hole Y-12

Location: NE¼NE¼ sec. 16, T. 93 N., R. 55 W., Yankton County
Elevation: 1170 feet
Total depth: 79 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Alluvium	
Sand, fine	0- 19
Sand, medium	19- 59
Outwash deposits	
Sand, coarse	59- 69
Gravel, fine	69- 79

Hole Y-13

Location: NE¼SE¼ sec. 4, T. 93 N., R. 55 W., Yankton County
Elevation: 1175 feet
Total depth: 29 feet
Depth to water:
Source of data: S. Dak. Geol. Survey

	Depth (feet)
Clay	0- 19
Clay and fine sand	19- 29

APPENDIX B

Depth to Bottom of Sand and Gravel Based on Resistivity Measurements

Station Plate 2	Location	Alt. above sea level (feet)	Depth to bottom of sand and gravel (feet)
M1	SW¼SW¼ sec. 18, T. 90 N., R. 49 W.	1120	130
M2	NW¼NE¼ sec. 18, T. 90 N., R. 49 W.	1121	165
M3	SE¼SE¼ sec. 8, T. 90 N., R. 49 W.	1116	140
M4	NW¼NE¼ sec. 9, T. 90 N., R. 49 W.	1118	170
M5	SW¼SW¼ sec. 3, T. 90 N., R. 49 W.	1117	160
M6	NW¼NW¼ sec. 2, T. 90 N., R. 49 W.	1113	130
M7	SE¼NW¼ sec. 27, T. 89 N., R. 48 W.	1094	120
M8	SE¼SE¼ sec. 2, T. 91 N., R. 50 W.	1127	165
M9	NE¼NW¼ sec. 15, T. 91 N., R. 50 W.	1126	102
M10	SE¼SE¼ sec. 26, T. 92 N., R. 50 W.	1125	150
M11	NE¼SW¼ sec. 16, T. 91 N., R. 50 W.	1133	155
M12	NE¼NE¼ sec. 33, T. 90 N., R. 49 W.	1114	110
M13	SE¼SW¼ sec. 26, T. 90 N., R. 49 W.	1116	90
M14	SE¼SE¼ sec. 30, T. 91 N., R. 49 W.	1126	100
M15	NW¼NW¼ sec. 17, T. 90 N., R. 49 W.	1120	140
M16	SW¼SW¼ sec. 15, T, 90 N., R. 49 W.	1116	145
M17	NE¼NW¼ sec. 12, T. 90 N., R. 49 W.	1114	175
M18	SW¼SW¼ sec. 27, T. 91 N., R. 49 W.	1116	145
M19	NW¼SW¼ sec. 25, T. 91 N., R. 49 W.	1134	155
M20	NE¼SE¼ sec. 27, T. 92 N., R. 51 W.	1137	93
M21	NW¼SW¼ sec. 23, T. 92 N., R. 51 W.	1135	150
M22	NW¼SE¼ sec. 10, T. 92 N., R. 53 W.	1151	90
M23	NW¼SW¼ sec. 1, T. 93 N., R. 53 W.	1153	88
M24	SE¼NE¼ sec. 14, T. 93 N., R. 53 W.	1153	160
M25	NE¼NE¼ sec. 10, T. 92 N., R. 53 W.	1151	130
M26	NE¼NW¼ sec. 2, T. 92 N., R. 53 W.	1150	160
M27	NW¼NE¼ sec. 35, T. 93 N., R. 53 W.	1153	100
M28	SW¼NE¼ sec. 26, T. 93 N., R. 53 W.	1147	150
M30	NE¼SE¼ sec. 8, T. 93 N., R. 54 W.	1166	160
M31	NW¼NW¼ sec. 9, T. 93 N., R. 54 W.	1164	165
M32	SE¼SE¼ sec. 32, T. 94 N., R. 54 W.	1164	100
M33	SE¼SE¼ sec. 29, T. 94 N., R. 54 W.	1166	160
M34	SE¼NE¼ sec. 8, T. 94 N., R. 54 W.	1177	155
M35	SW¼NW¼ sec. 16, T. 94 N., R. 54 W.	1168	150
M36	SW¼NW¼ sec. 21, T. 94 N., R. 54 W.	1166	155

APPENDIX C

Log of Water Well in Glacial Till

Location: NE¼NE¼ sec. 19, T. 92 N., R. 51 W., Clay County
(domestic well on plate 2)
Owner: Allen F. Agnew
Total Depth: 161 feet
Source of data: S. Dak. Geological Survey

	Depth (feet)
No sample	0- 10
Pleistocene: Wisconsin Cary? Ground Moraine	
Till, mainly gray clay with coarse fraction (sand and gravel size rocks) consisting of chalk and quartz and chert.	10- 20
Till, mainly gray ironstained clay with coarse fraction consisting of rounded quartz and mica flakes.	20- 40
Till, mainly light gray clay with coarse fraction of rounded rock fragments of quartz, limestone, silicates and granite.	40- 50
Till, mainly light gray clay with coarse fraction consisting of limestone, chalk and silicates.	50- 60
Till, mostly gray ironstained clay with coarse fraction consisting of granite, quartz, schists and chalk.	60- 70
Till, clay and large fraction of sand.	70- 80
Till, chiefly gray clay with coarse fraction consisting of granite, limestone,	80- 90
chalk, pebbles and coarse sand.	90-100
Till, chiefly gray clay with coarse fraction of schists, granite, limestone and chalk.	100-120
Sand and gravel mainly of medium sub-angular sand and pebbles of limestone and igneous and metamorphic rocks.	120-130
Sand, medium and coarse	130-138
Sand, medium and coarse.	138-142
Till, chiefly of gray clay and medium sand.	142-157
Sand, well sorted, medium-grained.	157-161

APPENDIX D

Logs of Deep Borings (Oil Tests)

Name: Sioux Valley No. 1 LaFleur
Location: SE¼SW¼ sec. 18, T. 90 N., R. 48 W., Union County, South Dakota (Number 1 on plate 2)
Elevation (G. L.): 1112 feet
Source of data: S. Dak. Geol. Survey files, logs by writer and tops by A. F. Agnew and writer

Formation	Depth to top (feet)
Alluvium	0
Outwash, gravels and sands	70
Sample gap	125
Dakota, sandstones and shales	243
Paleozoic strata, limestones	390
Galena, cherty dolomite and limestone	518
Decorah-Platteville, green shales and dolomites	665
St. Peter, sandstone	765
Jordan-St. Lawrence, dolomites and glauconitic sandstone	805
Cambrian strata, sandstones	957?
Precambrian rocks, "granite"	1027
Total Depth	2752

Name: Wagner No. 1 Blanchard
Location: NE¼NE¼ sec. 29, T. 92 N., R. 49 W., Union County, South Dakota (Number 2 on plate 2)
Elevation: (G. L.): Approximately 1170 feet
Source of data: S. Dak. Geol. Survey files, logs by E. E. Lutzen, tops by writer

Formation	Depth to top (feet)
Talus	0
Greenhorn, limestone	10
Graneros, shale	23
Dakota, sandstone and shales	100
Paleozoic strata, sandstones, shales, cherty dolomites (Galena formation is at least partially present)	355?
Decorah-Platteville, green and gray shale	505
St. Peter, sandstone	640
Jordan-St. Lawrence, glauconitic sandstones	665
Cambrian strata, shale, limestone and sandstones	725
Precambrian rocks, granite?	839
Total Depth	846

Name: Wagner No. 1 Peterson
Location: NW¼NW¼ sec. 30, T. 92 N., R. 49 W., Union County, South Dakota
(Number 3 on plate 2)
Elevation (G.L.): 1125 feet

Formation	Depth to top (feet)
Alluvium and Outwash	0
Dakota, sandstones and shales	154
Paleozoic strata, sandstones	305
Decorah-Platteville, green shale	485?
St. Peter, sandstone	545
Cambrian strata including Jordan-St. Lawrence sandstones	585
Total Depth	698

APPENDIX E

Irrigation Well Data

Well	Owner or Tenant	Location	Well Depth (feet)	Height Above Sea Level (top of casing)	Water Level
1	Claussen, E.	NW¼ sec. 7, T. 89 N., R. 48 W.	100	1096.4	9' 0"
2	Chicoine, D.	NW¼ sec. 9, T. 90 N., R. 49 W.	107	1121.8	15' 3"
3	Curran, W. J.	NW¼ sec. 23, T. 90 N., R. 49 W.	82	1118.2	14' 6"
4	Bamesbotham, V.	SE¼ sec. 20, T. 90 N., R. 48 W.	94	1112.9	15' 6"
5	Mollet, V.	NW¼ sec. 20, T. 90 N., R. 48 W.	80	1113.1	15' 1"
6	Fornia, H.	NW¼ sec. 21, T. 90 N., R. 48 W.	94	1110.2	12' 10"
7	Anderson, M.	NW¼ sec. 17, T. 90 N., R. 48 W.	82	1111.7	12' 5"
8	Bosse, D.	SE¼ sec. 18, T. 90 N., R. 48 W.	100	1115.3	13' 2"
9	LaBreche, M.	NE¼ sec. 19, T. 90 N., R. 48 W.	96	1115.9	18' 1"
10	Curran, J.	NW¼ sec. 5, T. 90 N., R. 48 W.	80	1113.5	11' 5"
11	Bosse, D.	NE¼ sec. 11, T. 90 N., R. 49 W.	80	1114.7	16' 5"
12	Tracy, E.	SE¼ sec. 31, T. 91 N., R. 48 W.	82	1108.3	11' 7"
13	Steckle, F.	SE¼ sec. 25, T. 91 N., R. 49 W.	80	1112.2	14' 6"
14	Shearon, C.	SW¼ sec. 25, T. 91 N., R. 49 W.	116	1114.0	16' 6"
15	Lyle, R.	NW¼ sec. 36, T. 91 N., R. 49 W.	110	1114.3	13' 2"
16	Lyle, R.	SE¼ sec. 23, T. 91 N., R. 49 W.	100	1111.0	16' 1"
17	Curry, J. J. & Sons	SE¼ sec. 18, T. 91 N., R. 49 W.	111	1124.7	16' 7"
18	Curry, J. J. & Sons	SE¼ sec. 7, T. 91 N., R. 49 W.	106	1116.9	11' 9"
19	Curry, J. J. & Sons	NW¼ sec. 8, T. 91 N., R. 49 W.	109	1114.5	10' 0"
20	Wagner, A. H.	SW¼ sec. 35, T. 92 N., R. 50 W.	104	1130.3	9' 6"
21	Jorgenson, F.	SE¼ sec. 14, T. 91 N., R. 50 W.	94	1128.2	17' 1"
22	Chaussee, C.	NE¼ sec. 22, T. 91 N., R. 50 W.	87	1131.6	15' 2"
23	Benjamin, H.	SW¼ sec. 8, T. 91 N., R. 50 W.	90	1133.9	15' 1"
24	Donnley, L.	NE¼ sec. 7, T. 91 N., R. 50 W.	97	1132.3	13' 4"
25	Donnley, B.	NW¼ sec. 31, T. 92 N., R. 50 W.	106	1132.7	
26	Jorgensen, A.	NE¼ sec. 6, T. 91 N., R. 50 W.	87	1135.8	
27	Cusick, L.	SW¼ sec. 26, T. 92 N., R. 51 W.	103	1138.2	
28	Knutson, N.	NE¼ sec. 13, T. 92 N., R. 53 W.	108	1152.5	16' 1"
29	Myron, D.	NE¼ sec. 15, T. 92 N., R. 53 W.	116	1156.6	16' 3"
30	Bremer, H.	NE¼ sec. 4, T. 92 N., R. 52 W.	74	1145.0	

Well	Owner or Tenant	Location	Depth (feet)	Height Above Sea Level (top of casing)	Water Level
31	Rayman, W.	SW¼ sec. 21, T. 93 N., R. 52 W.	76	1145.6	11' 2"
32	Steel & Tiahrt	SW¼ sec. 24, T. 93 N., R. 53 W.	86	1151.9	13' 10"
33	Hill, R. D.	NW¼ sec. 22, T. 93 N., R. 53 W.	108	1153.8	9' 9"
34	Moore Bros.	NE¼ sec. 9, T. 93 N., R. 54 W.		1164.7	11' 5"
35	Thorson	SE¼ sec. 5, T. 93 N., R. 54 W.	72	1167.2	12' 4"
36	Thorson	NW¼ sec. 5, T. 93 N., R. 54 W.	68		11' 8"
37	Weaverstad	NW¼ sec. 13, T. 93 N., R. 55 W.		1173.1	15' 6"
38	Gigge, A.	SE¼ sec. 11, T. 93 N., R. 55 W.	100	1167.3	12' 8"
39	Holzbauer, L.	SE¼ sec. 12, T. 93 N., R. 55 W.	100	1169.6	
40	Yaggie, F.	SE¼ sec. 2, T. 93 N., R. 55 W.		1173.5	18'
41	Klassi, E.	NW¼ sec. 9, T. 93 N., R. 55 W.	58	1190.1	
42	Branbaugh, B.	NE¼ sec. 8, T. 93 N., R. 55 W.	48	1184.2	18' 5"
43	Gurney	NW¼ sec. 8, T. 93 N., R. 55 W.	40	1183.1	17' 9"
44	Gurney	SE¼ sec. 8, T. 93 N., R. 55 W.	24*	1180.7	15' 6"
45	Schenk & Sattler	SE¼ sec. 8, T. 93 N., R. 55 W.	50	1176.3	9' 4"
46	Schenk & Sattler	SW¼ sec. 9, T. 93 N., R. 55 W.	45	1172.4	11' 7"

* 36-inch diameter; otherwise 18-inch