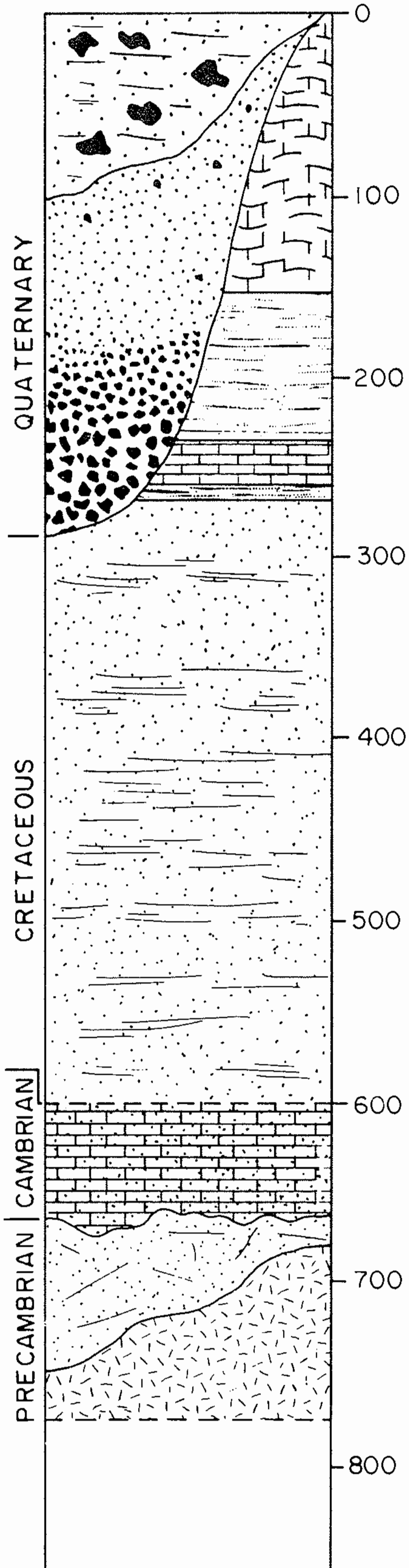

GEOLOGY AND HYDROLOGY OF CLAY COUNTY SOUTH DAKOTA

by

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South Dakota Geological Survey

and

Jerry C. Stephens,

United States Geological Survey

Bulletin 19

South Dakota Geological Survey

1967

STATE OF SOUTH DAKOTA
Nils Boe, Governor

SOUTH DAKOTA GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

Bulletin 19

GEOLOGY AND WATER RESOURCES OF CLAY COUNTY, SOUTH DAKOTA

by
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PART I, GEOLOGY

by
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Prepared in cooperation with the
United States Geological Survey
and Clay County

Science Center
University of South Dakota
Vermillion, South Dakota
1967

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ABSTRACT

Clay County is in southeastern South Dakota in the James Basin, James River Highlands and Coteau des Prairies divisions of the Central Lowlands physiographic province. The area occupies 403 square miles and is drained by the Vermillion and Missouri Rivers.

Surficial sediments of Clay County consist of Pleistocene glacial deposits of Wisconsin and pre-Wisconsin ages and Recent deposits of wind-blown sand, alluvium and colluvium. The Pleistocene and Recent deposits have a maximum thickness of over 300 feet in the county.

Cretaceous sedimentary rocks underlie the Pleistocene and Recent deposits and rest directly on Cambrian and Precambrian rocks. The Cretaceous rocks are the Niobrara Marl, Carlile Shale, Greenhorn Limestone, Graneros Shale, and the Dakota Group. The Cretaceous sequence has a maximum thickness of over 700 feet. At several locations in central Clay County the Niobrara Marl and Carlile Shale are exposed at the surface.

Dolomitic siltstones and sandstones represent the Cambrian age rocks in the subsurface. Thickness of these rocks probably does not exceed 100 feet. The Sioux Quartzite is thought to be the main Precambrian subcrop basement rock that is underlain by older granitic rocks.

Outwash present in Clay County is in part buried, and constitutes a major aquifer.

Ground water, sand, and gravel comprise the most important mineral resources of the county.

INTRODUCTION

Purpose

The investigation of Clay County is the third in a series of cooperative studies conducted by the South Dakota Geological Survey and the United States Geological Survey. These studies are conducted to add to the overall understanding of the geology of South Dakota, and to determine the availability of ground water and other mineral resources within the State. The results of this investigation are published in two parts: Part I contains the geology, with special emphasis on the Pleistocene, Part II contains the hydrology. Also a compilation of all basic data resulting from the investigation will be made available (Christensen and Stephens, in preparation).

Location

Clay County includes an areal extent of 403 square miles in southeastern South Dakota (fig. 1). It is bordered on the north by Turner and Lincoln Counties, on the east by Union County, on the south by the Missouri River, which forms the border with Nebraska, and on the west by Yankton County (fig. 2).

Previous Investigation

The earliest accounts of the geology of the area, which is now Clay County, are found in the writings of Lewis and Clark that describe their expedition of 1804-1806 (Thwaites, 1959). Later, Meek and Hayden (1861) briefly described the landforms and geology of the area while making a survey of Nebraska Territory. Since the time of the earliest explorers, Clay County has been included in a number of reconnaissance studies dealing primarily with the bedrock of South Dakota (Todd, 1894, 1899; Darton, 1909; and Rothrock, 1943). Portions of Clay County have been studied in some detail with regard to artesian water supplies and general geology (Todd, 1903, 1908). Flint (1955) made a reconnaissance study of the Pleistocene deposits of eastern South Dakota which included Clay County. Increased interest in irrigation in southeastern South Dakota resulted in studies of the Missouri River floodplain by Douglas (1959) and Jorgensen (1960a, b). A shallow water investigation was conducted for the city of Vermillion (Bruce, 1963).

Method of Procedure

The information in this report has resulted in part from the geologic work of two field seasons, during the summers of 1963 and 1964. The geology was mapped on aerial photographs (scale approximately 1:70,000) and was later transferred to a base map of the same scale. The original base map was reduced from the standard highway map (scale 1:63,360) prepared by the South Dakota Department of Highways. Because natural outcrops are not abundant within the mapped area, numerous power and hand auger holes were drilled for supplementary information.

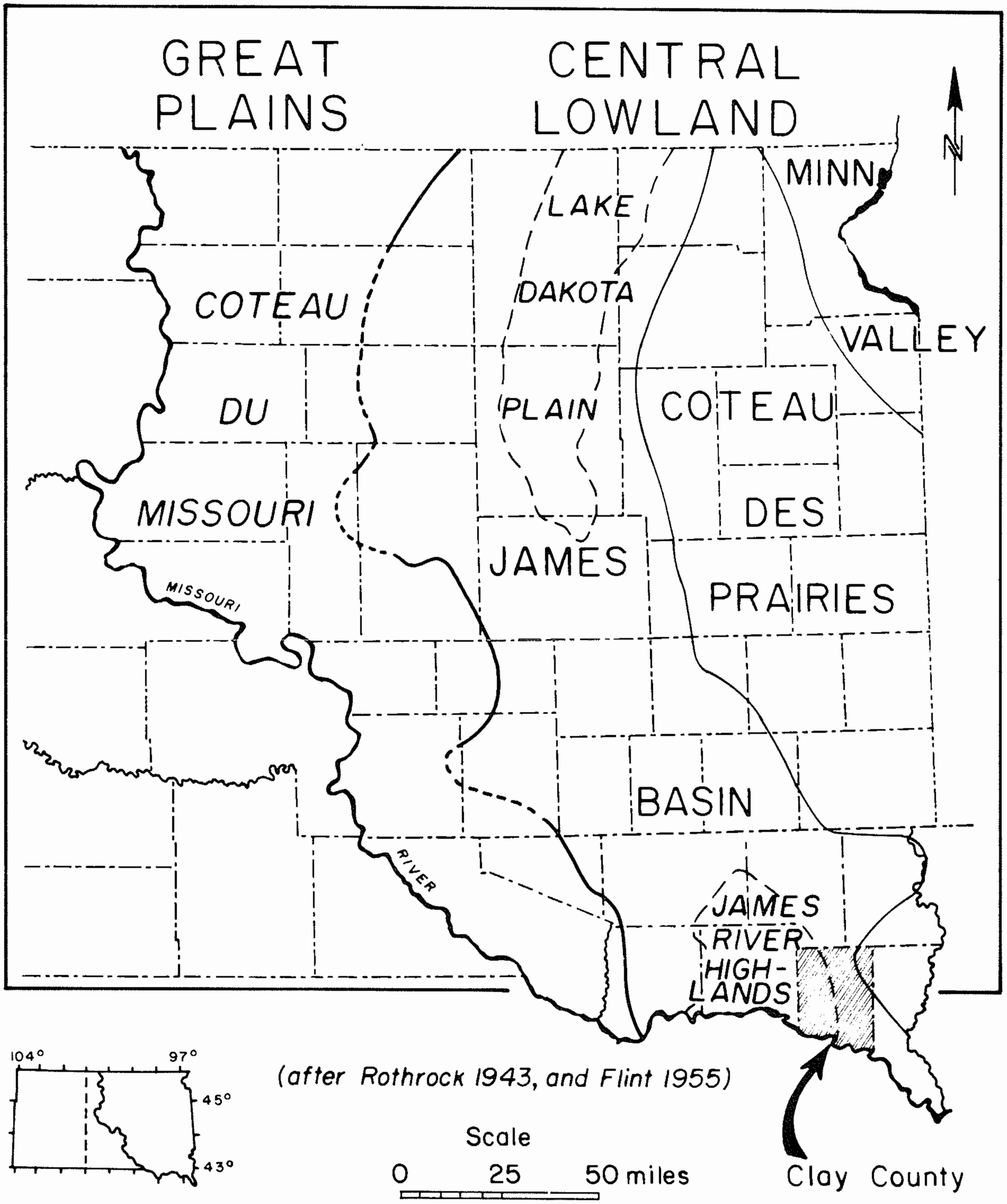

Figure 1. Index map of eastern South Dakota showing the physiographic divisions and the location of Clay County.

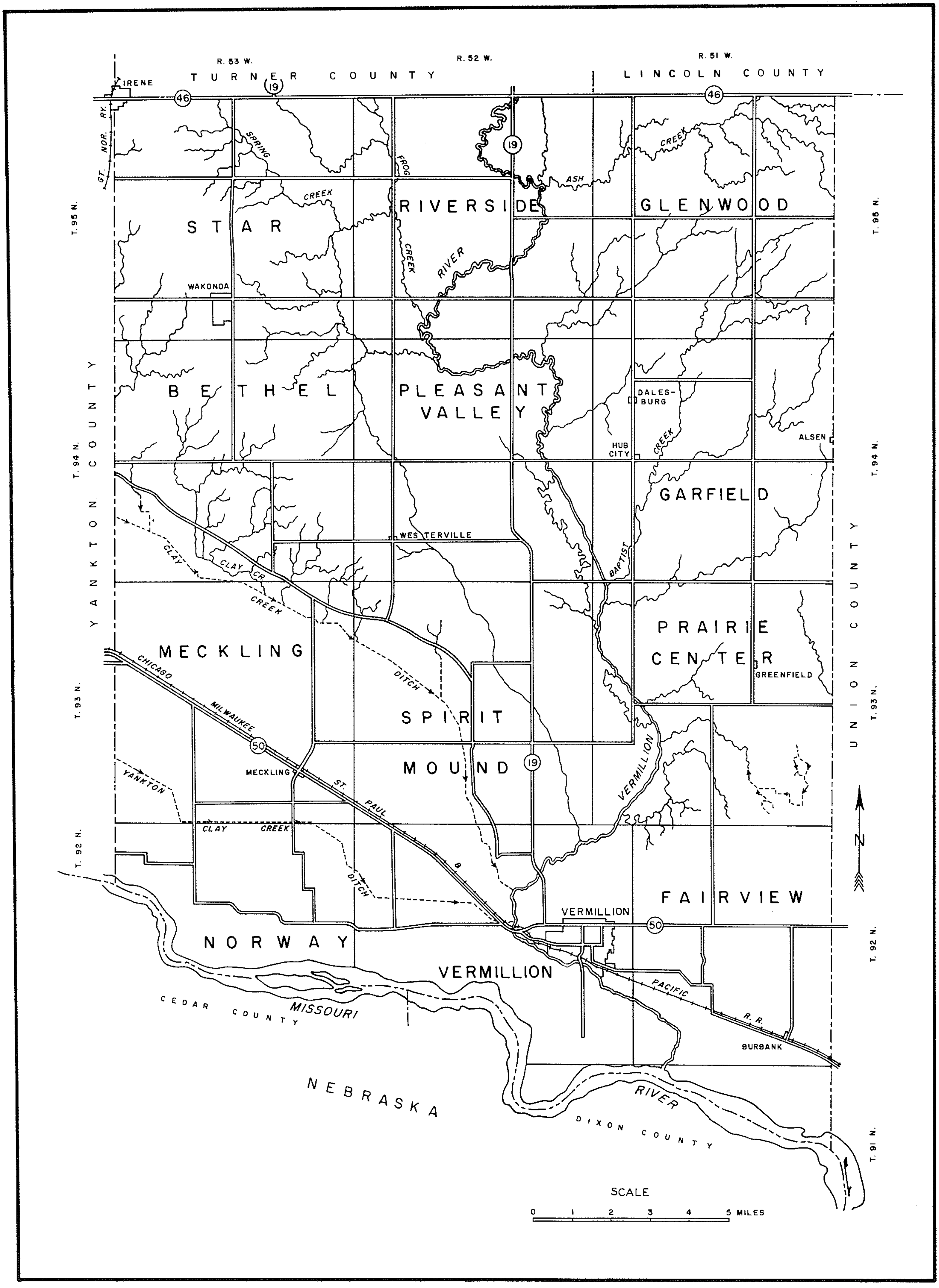

Figure 2. Map of Clay County showing major cultural features and streams.

Subsurface information was obtained from examination of well cuttings and electric logs from rotary and power auger holes drilled by the Bureau of Reclamation, U. S. Geological Survey, South Dakota Geological Survey and private drillers. Also, a well inventory was conducted in the county (see part II of this report) and provided additional subsurface information. Figure 3 shows the location of wells and test holes for which geologic data are available.

Acknowledgments

This investigation and the preparation of the report were performed under the supervision of Duncan J. McGregor, State Geologist. The writer wishes to thank the entire staff of the South Dakota Geological Survey for their advice and assistance throughout the project. Special thanks go to Fred V. Steece of the South Dakota Geological Survey, and Jerry C. Stephens of the U. S. Geological Survey for their participation in numerous field conferences with the writer. Also performing a valuable service by assisting in the field were Kerry Bartlett, Dwight Brinkley, Dean Fickbohm, Robert Stach, and Lloyd Helseth.

The cooperation of the County Commissioners and other residents of Clay County, especially County Agricultural Extension Agent R. L. Venard and Extension Irrigation Specialist Fred Schmer, is gratefully acknowledged.

Financial assistance for the project was contributed by the South Dakota Geological Survey, the U. S. Geological Survey (part II of the report), the U. S. Bureau of Reclamation, and Clay County. The study was initiated at the request of the Clay County Commissioners.

Well-Numbering System

Wells and test holes in this report are numbered in accordance with the U. S. Bureau of Land Management's system of land subdivision. The first numeral of a well designation indicates the township; the second, the range; and the third, the section. Lowercase letters following the section number indicate the position of the well within the section: the first letter indicates the 160-acre tract; the second, the 40-acre tract; the third, the 10-acre tract; and the fourth, the $2\frac{1}{2}$-acre tract. The letters a, b, c, d are assigned to the tracts in a counterclockwise direction beginning in the northeast corner of each tract. For example, well 92-52-14aaaa is in the $NE\frac{1}{4}NE\frac{1}{4}NE\frac{1}{4}NE\frac{1}{4}$ sec. 14, T. 92 N., R. 52 W. (fig. 4). If two or more wells are within the same tract, consecutive numbers beginning with 1 are added as suffixes to designate the order in which the wells are listed.

Geography

History and Population of Clay County

The earliest visitors to Clay County were fur traders who established trading stations along the Missouri River near the close of the eighteenth century. The first written record of this area was furnished by Lewis and

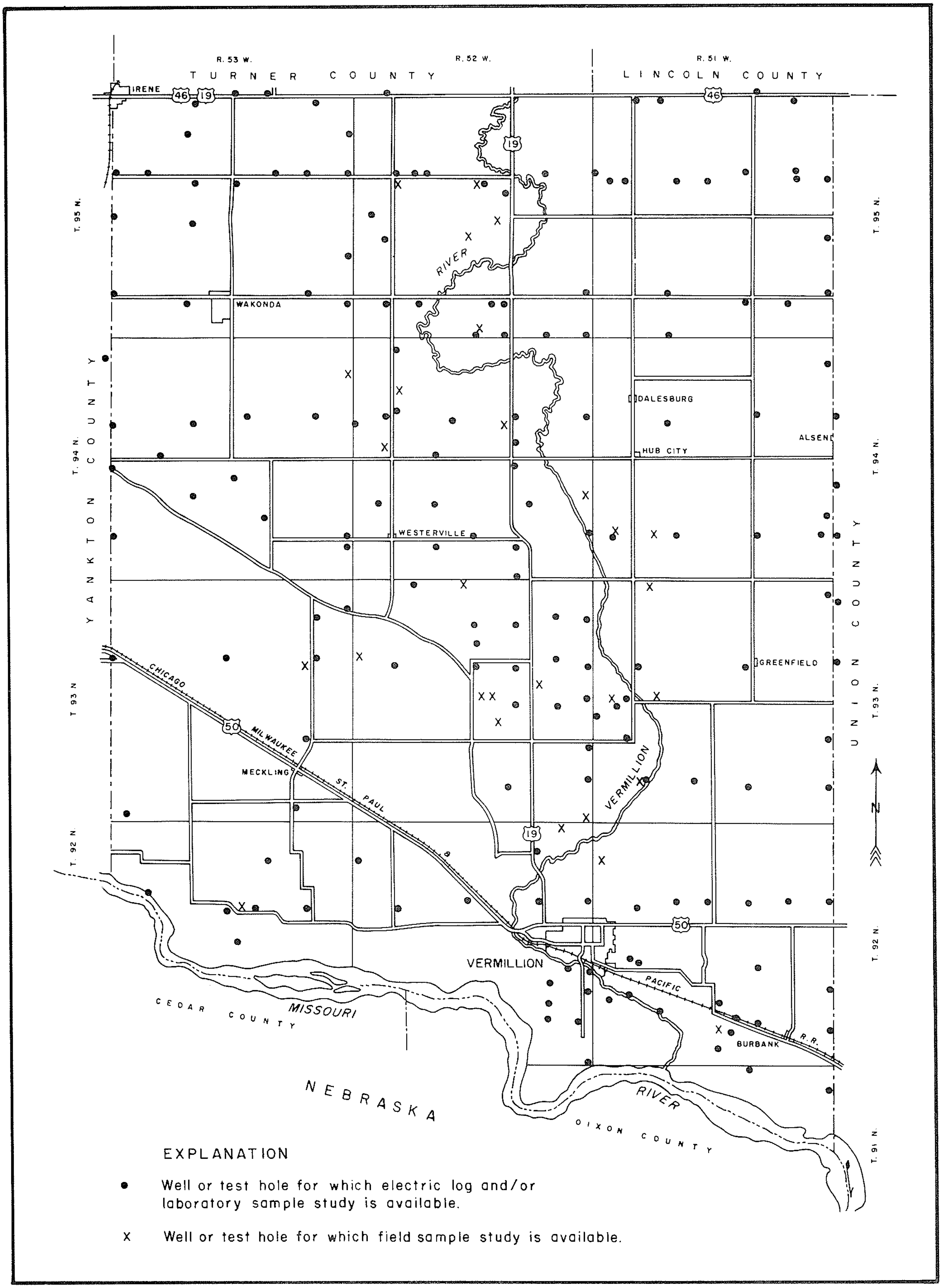

Figure 3. Map of Clay County showing location of wells and test holes for which geologic data are available. (modified from Christensen and Stephens, 1965)

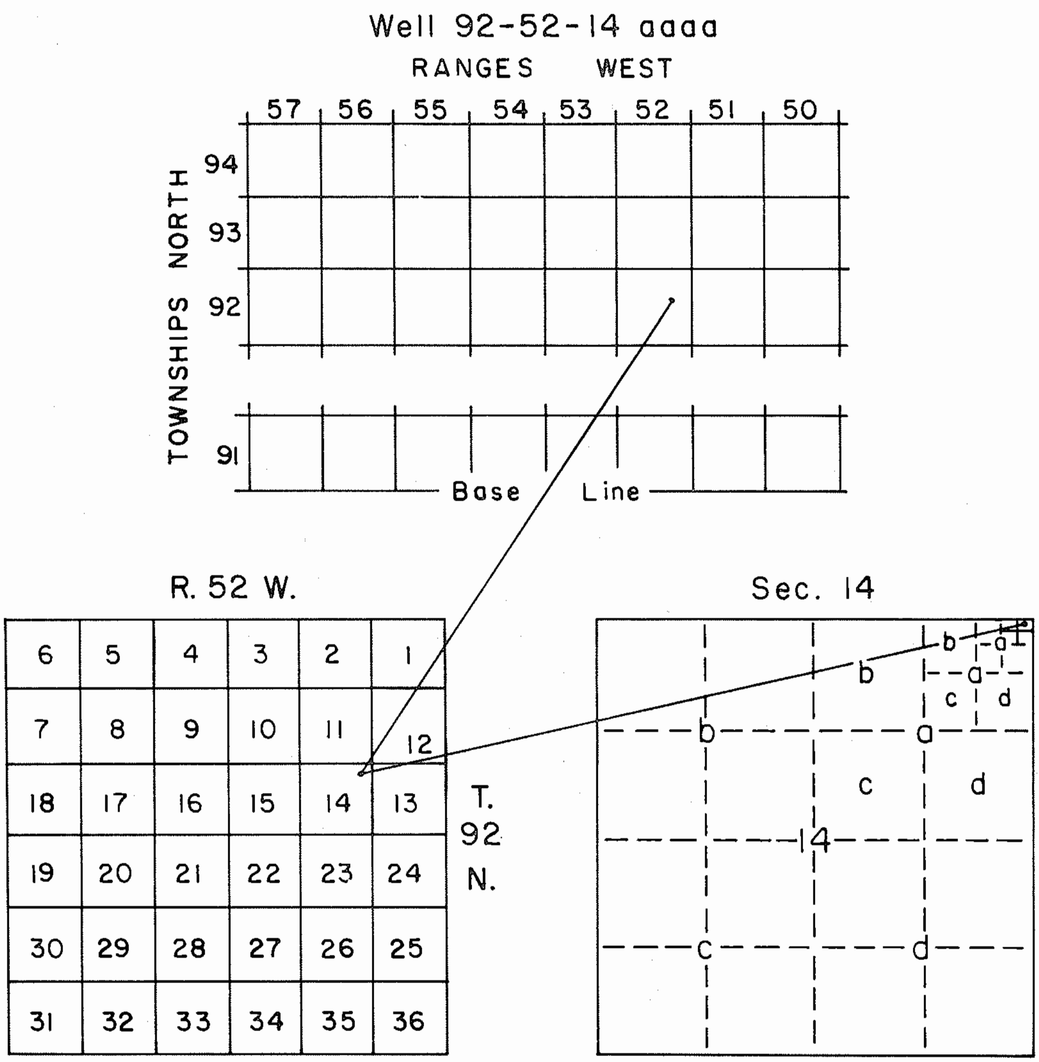

Figure 4. Well-numbering system.

Clark after their expedition of 1804-1806. Clay County was settled as early as 1859 and was officially organized by an act of the Legislature approved April 10, 1862 (Briggs, 1926). The first settlements within the county were in the vicinity of Vermillion, and the city was incorporated as the county seat in 1873. After being nearly completely destroyed by the flood of 1881, Vermillion was relocated on the bluff above the Missouri River floodplain. At least 21 small communities existed in Clay County during its early history. Those still remaining are Vermillion, Wakonda, Irene, Meckling, Burbank, Hub City, Alsen, Westerville and Dalesburg. Of these settlements only Vermillion, Wakonda and Irene are presently incorporated. In 1880, the population of Clay County was 5,001 and its total assessed valuation was $1,543,525; whereas, Clay County presently has 10,810 residents (1960 census) and a total assessed valuation of $42,148,930.

Climate

The climate of Clay County is typically continental--temperate with large daily and seasonal temperature fluctuations--and is characterized by long, cold winters and short, hot summers. The mean annual temperature is 49.3 degrees Fahrenheit at the U. S. Weather Bureau station at Vermillion. The highest temperature recorded at the Vermillion station during the period 1897-1963 was 114 degrees in July, 1936, and the lowest temperature during the same period was -38 degrees in January, 1912. The growing season (consecutive days with the temperature above 32 degrees) is 156 days, and occurs on an average between May 4 and October 7. Figure 5 is a graph of the average annual precipitation at the Vermillion and Centerville U. S. Weather Bureau stations from 1897-1957. The average annual precipitation during this period was 25.06 inches. The longest period of below average precipitation was from 1921-1942. During this period the average precipitation was slightly less than 22 inches.

Soils

Table 1 shows the various soil types that are present in Clay County as classified by Buntley and others (1953). The first types of soils mentioned in table 1 are basically loams and silty loams developed on Clay-rich glacial till. The Barnes loam soils are well drained, the Buse loams excessively drained, and the Parnell and Hamerly loams are poorly drained (Buntley and others, 1953).

Upland soils developed in deep loess are primarily silty loams, because the loess consists of a mixture of windblown silts and clays. The soil series of this group includes Moody, Trent, Olsen and Wakonda, with gradations between the individual types.

Group 3 soils are primarily silty clay loams in association with the Barnes loam, are intermediate between groups 1 and 2, and are developed under similar circumstances.

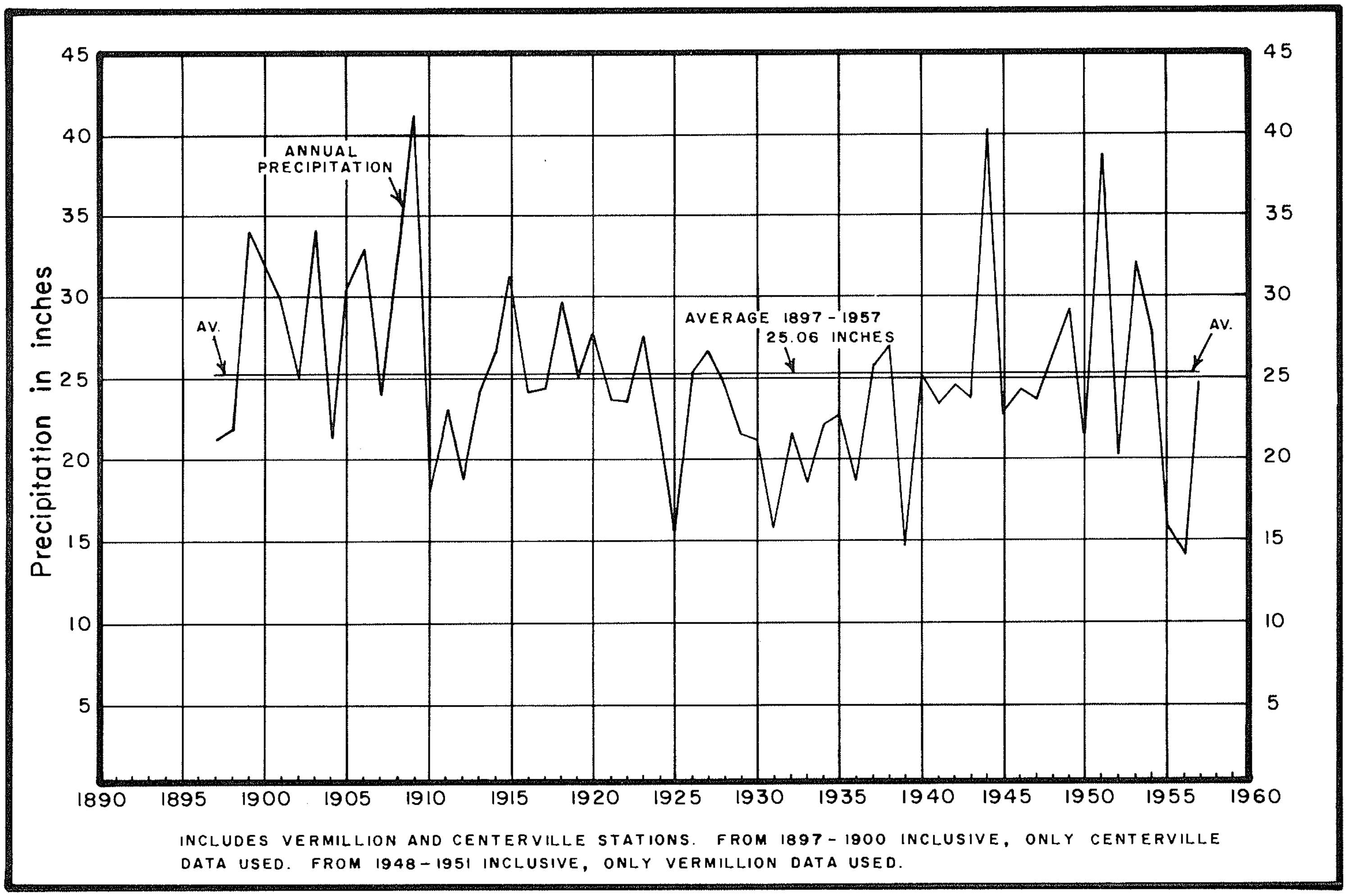

Figure 5. Clay County Annual Precipitation. 1897-1957.
(Palmer and Skow, 1958.)

Table 1.--Soil types of Clay County.

Group Number	Parent Material	Soil Type	Soil Series
1	Glacial till	Loams, silty loam, clay loam	Barnes, Buse, Parnell, Hamerly
2	Loess	Silty loam	Moody, Trent, Alsen, Wakonda
3	Loess over till	Silty clay loams	Barnes loam (intermediate)
4	Eolian sand	Sandy loam	Maddock
5	Coarse sand and gravel	Sandy loam	Fordville, Flandreau
6	Colluvium and alluvium	Silt loam	Alcester-Judson, Alcester-Lamoure, McPaul
7	Alluvium	Clay loam, silty clay loam, silt loam	Onawa, Luton, Luton-Solomon, Napa Complex, Blencoe, Blencoe-Gayville, Blencoe-Lamoure, Lamoure, Volin, Haynic, Wann-Leshara, Sarpy
8	Riverwash (Coarse-textured alluvium)	Same as parent material	No name

The soils of group 4 are developed in eolian sands and are nearly level to undulating Maddock soils, that are usually somewhat excessively drained fine sandy loam.

Soils developed in loamy material over sand and gravel and classified in group 5 are well drained to excessively drained. These are found overlying coarse sand or gravel deposits along major streams; the soil series includes Fordville and Flandreau.

The soils of group 6 are all well drained to moderately well drained silt loams, and include the Alcester-Judson, Alcester-Lamoure, and McPaul soils.

Bottomland soils, such as those classified in group 7, are all clay, silty clay, or silt loams developed on nearly level to level surfaces. The drainage is usually poor, but may be moderate on the more sloping surfaces. The soil series are Onawa, Luton, Luton-Solomon, Napa Complex, Blencoe, Blencoe-Gayville, Blencoe-Lamoure, Volin, Haynie, Wann-Leshara, and Sarpy.

Riverwash, the last group of soils, has no series name and consists of recently-deposited, unstabilized sediments that are mainly coarse-textured alluvium. This type of soil occurs along higher portions of the Missouri River floodplain.

A detailed soils map is available for Clay County (Buntley et al, 1953) and can be obtained from the Extension Division of South Dakota State University at Brookings.

Physiography

A variety of topographic features is present in the mapped area, with the most impressive of these features being the floodplains of the Vermillion and Missouri Rivers, and Spirit Mound.

The Vermillion River enters the county nearly in the center of the northern border at an elevation of 1170 feet above sea level, flows across the county in a southerly direction, and enters the Missouri River at an elevation of 1125 feet, about 4 miles southeast of the city of Vermillion. The Vermillion River floodplain averages about one mile in width and is about 50 to 100 feet deep.

The Missouri River marks the southern border of the county, and also serves as the State boundary between South Dakota and Nebraska. The floodplain of the Missouri River varies greatly in width and averages about 5 miles. The elevation of the Missouri River at its entry point in west-central Clay County is 1145 feet; whereas its elevation as it leaves the southeast tip of the county is 1115 feet, thus the river has a gradient of about one foot per mile.

In its present course, the Missouri River flows close to a high bluff on the Nebraska side of the river, leaving most of the floodplain area located in South Dakota. The surface of the Missouri River floodplain is about 100 feet below the bluff on the South Dakota side of the river, and about 220 feet below the bluff on the Nebraska side.

Other topographic features are less prominent than the trenches of the major rivers, but are certainly conspicuous. End moraine of late Wisconsin age is located in the western and southern parts of the county. The end moraines are 30 to 225 feet above the adjacent ground moraine, and are primarily bedrock controlled. Ground moraine has been subdivided into high and low relief according to respective land surface elevations. Because of the undulating topography of the bedrock, the ground moraine in the northeastern part of the area is at a higher elevation than the ground moraine and end moraine in the central and southern parts. Ground moraine of high relief is located in the northeastern section of the area and rises about 150 feet above the adjacent ground moraine of low relief. Streams tributary to the Vermillion River have dissected the moraines and form a dendritic drainage pattern.

One of the most striking topographic features is Spirit Mound. Located about 6 miles north of Vermillion, the Mound rises abruptly to an elevation of 1295 feet and is about 90 feet above the surrounding ground moraine. It has a north-south length of nearly 1/4 mile and a width of approximately 1/8 mile. The core of Spirit Mound is Niobrara Marl that has been shaped by glacial sculpturing. Late Wisconsin till partly covers the Mound, but Niobrara Marl is exposed at the summit.

STRATIGRAPHY

Stratigraphic Relations

The stratigraphic nomenclature used herein conforms to that accepted by the South Dakota Geological Survey (Agnew and Tychsen, 1965) and to the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961).

The following stratigraphic section lists all of the deposits that are present in Clay County in the order of their occurrence from youngest at the top of the list to oldest at the bottom.

- Quaternary System
  - Recent Series
    - Colluvium
    - Alluvium
      - Meander belt deposits
        - Bar deposits
        - Point bar deposits
        - Channel fill deposits
        - Overbank deposits
    - Dune sand
  - Pleistocene and Recent Series
    - Loess
  - Pleistocene Series
    - Wisconsin Glaciation
      - Late Wisconsin
      - Early Wisconsin
    - Illinoian Glaciation
    - Yarmouthian Interglaciation
    - Kansan Glaciation
    - Nebraskan Glaciation

Cretaceous System
- Upper Cretaceous Series
  - Niobrara Marl
  - Carlile Shale
  - Greenhorn Limestone
  - Graneros Shale
- Upper and Lower Cretaceous Series
  - Dakota Group

Cambrian System
- St. Croixan (?) Series

Precambrian System
- Sioux Quartzite and older rocks

Pre-Pleistocene Deposits

Precambrian Sioux Quartzite and Older Rocks

The basement rock commonly encountered in the subsurface of southeastern South Dakota is the Sioux Quartzite. Although termed a quartzite, the Sioux is actually an orthoquartzite because of its sedimentary origin (Baldwin, 1951). The Sioux is composed of pink, tightly-cemented sand grains, and interbedded with the quartzite are layers of red to purple shale, conglomerate and mudstone. Pipestone layers in the quartzite in southwestern Minnesota have been found to have an average age of 1.2 billion years (Goldich and others, 1961).

Older Precambrian rocks underlie the Sioux Quartzite in southeastern South Dakota (Steece, 1962). These older rocks are pink, red, and gray granites which are intruded by gabbro dikes (Petsch, 1962).

It is not known definitely that the Sioux Quartzite is present as far south as Clay County, since no wells within the county have reached the Precambrian. However, the Sioux is believed to be present at least in the northern part of the county. Petsch (1962) has postulated that a magnetometer high trending east-west through central Clay County marks the southern limit of the Sioux Quartzite.

Where the Sioux Quartzite is absent, the basement rocks of Clay County are probably older granites and the gabbro dikes previously mentioned. Gabbro dikes were cored in two test borings by the South Dakota Geological Survey, one in Yankton County, (93-55-12cabc) and one in Union County, (93-50-25cb). These will be discussed in more detail in a later section of this report.

Cambrian (?) Rocks

Cambrian (?) rocks are thought to be present in the subsurface of Clay County, because rocks of this age were encountered in several wells and test holes beneath Cretaceous rocks in Union County. A test boring by the South Dakota Geological Survey of a magnetometer high in Union County (S. D. Geological Survey-Huebner #1, 93-50-25cb) showed approximately 170 feet of Cambrian (?) rocks between the bottom of the Cretaceous and the top of the Precambrian. These rocks are arbitrarily assigned to the St. Croixan (?) Series and may correlate with the Franconia and Dresbach Formations that have been identified in Iowa (Hale, 1955). Other test holes in Union County, including Sioux Valley #1 La Fleur, Wagner #1 Larson and Wagner #1 Blanchard, have also shown Paleozoic rocks to be present in the subsurface. Sediments of the Cambrian in southeastern South Dakota consist of glauconitic siltstones, sandstones and dolomites. Cambrian rocks are not known to exist in Turner County or Yankton County and if present in Clay County probably lie mainly in the southeast part of the county.

Cretaceous Rocks

The bedrock of Clay County is primarily of late Cretaceous age and consists of shales, marl, limestone and sandstones. In ascending order they are the Dakota Group and the Graneros, Greenhorn, Carlile, and Niobrara Formations.

Dakota Group

The Dakota was first described by Meek and Hayden (1861) from an exposure in Dakota County, Nebraska, and was designated by them as Formation No. 1 of the Cretaceous. The Dakota consists of alternating beds of shale, siltstone, and sandstone. The entire section is varicolored, and has a maximum thickness of over 300 feet in Clay County.

Graneros Shale

The Graneros Shale underlies the Greenhorn Limestone in much of eastern South Dakota; in Clay County it is characteristically a medium- to dark-gray, noncalcareous, silty shale interbedded with thin silt and sand. The Graneros is very thin in Clay County and test holes penetrating it are few in number. On the basis of those holes it is estimated that the Graneros has a maximum thickness of less than 30 feet.

Gilbert first described the Graneros from an exposure near Graneros Creek, Pueblo County, Colorado, in 1896, and the name was suggested by R. C. Hill (Agnew and Tychsen, 1965).

Greenhorn Limestone

The Greenhorn Limestone underlies the Carlile Shale and is the first bedrock unit encountered beneath the Pleistocene deposits of the western part of the Missouri River floodplain in Clay County (pl. 2).

Gilbert first described and named the Greenhorn from an exposure near Greenhorn Station, 14 miles south of Pueblo, Colorado (Agnew and Tychsen, 1965).

In Clay County, the Greenhorn consists of 20 to 25 feet of gray limestone that is overlain and underlain by medium to dark-gray shale containing abundant white specks of calcite. Maximum thickness of the entire Greenhorn section is more than 125 feet. Where exposed, the limestone weathers light cream to white; however, no exposures of the Greenhorn are present in Clay County.

The Greenhorn Limestone is fossiliferous, and the most common fossil is Inoceramus labiatus. Aggregates of calcite prisms from the shells of this fossil aid in the recognition of the Greenhorn in well samples. The Greenhorn is widely used as a marker bed in the Upper Cretaceous of South Dakota because of its characteristic "kick" on the electric and radioactivity logs and the "rough" manner in which it drills.

Carlile Shale

The Carlile Shale underlies the Niobrara Marl and is exposed at several localities in west-central Clay County (pl. 1).

The Carlile was first described and named from an exposure near Carlile Spring and Carlile Station, 21 miles west of Pueblo, Colorado by G. K. Gilbert in 1896 (Agnew and Tychsen, 1965).

In the mapped area, the Carlile consists of a medium-gray, noncalcareous, plastic, fissile shale. Although the shale is fossiliferous, fossils are not abundant; those most commonly found are fish scales. The Carlile averages about 100 feet in thickness in the county.

Niobrara Marl

The Niobrara Marl crops out in several localities (pl. 1) and where present in the subsurface, it is the first Cretaceous formation to be encountered beneath the Pleistocene deposits of Clay County.

Although the Niobrara was first described from an exposure along the Missouri River near the mouth of the Niobrara River, Knox County, Nebraska (Meek and Hayden, 1861), no type locality has been designated for this formation (Agnew and Tychsen, 1965).

In Clay County the Niobrara consists of an upper section of medium- to dark-gray calcareous marl which weathers to a light yellow, and a lower section of gray chalky limestone which weathers white to cream-colored. Because of the chalky appearance of the lower part of the Niobrara, it is locally called "Niobrara Chalk," or "Chalk rock."

The Niobrara Marl is fossiliferous and contains a wide variety of microfossils. Among the common planktonic forms are "Globigerina," Planomalina and Heterohelix. Microfossils are also found in the Niobrara and the two most common are Ostrea congesta and Inoceramus gigantica. Other fossils (marine invertebrates such as barnacles, and marine vertebrates such as fish and mosasaur) have been reported from Niobrara exposures in southeastern South Dakota.

At one locality along the Missouri bluff in Clay County (93-52-8abca) a calc-tufa deposit was found at the base of the Niobrara Marl. This deposit, which averages about 2 feet in thickness, marks the contact of the Niobrara Marl and the underlying Carlile Shale. Although this calc-tufa deposit is probably much younger than Cretaceous, it is discussed here because of its close relationship to the Niobrara and Carlile. Highly mineralized ground water seeping downward through joints in the Niobrara encountered the impervious Carlile Shale, left the Niobrara as springs and deposited the calc-tufa along the Carlile-Niobrara contact.

The Niobrara averages about 160 feet thick in eastern South Dakota (Agnew and Tychsen, 1965), and has a maximum thickness of over 200 feet in Clay County.

Pleistocene Deposits

General Statement

Table 2 shows the generalized stratigraphic section of the Pleistocene deposits of Clay County. The distribution of these deposits is shown on plate 1. Correlation and age determinations of the Pleistocene deposits are given on the following pages.

Early Pleistocene Drainage and Pre-Yarmouthian Till

Ancient White River

In order to set the stage for the correlation of the Pleistocene stratigraphic units, it is necessary to discuss briefly the location of a major bedrock channel that existed in Clay County.

Questions concerning the location of pre-Pleistocene and early Pleistocene drainage in South Dakota have been pondered by geologists for many years. Flint (1955) constructed a Pleistocene drainage map of eastern South Dakota, and postulated that the ancient White River flowed from north to south through Clay County. Drill hole data gathered by the author for this report substantiates the fact that a Pleistocene river of major proportions did exist in the location suggested by Flint. This river had a floodplain that averaged approximately 5 miles in width and was comparable in size to the present-day Missouri or Mississippi River floodplains. Plate 2 shows the location of the ancient White River Valley in Clay County after its modification by glacial meltwaters. Because Flint was first to recognize the fact that this major bedrock channel existed, the name ancient White River has been retained for the purposes of this report.

It is the author's belief that the ancient White River existed in the very earliest of Pleistocene time and may in fact be pre-Pleistocene in origin. This theory is substantiated by the fact that pre-Yarmouthian till is located in the trench of this ancient river. The till is found only in isolated drill holes, is not widespread, and in all cases has been found along the sides or base (pl. 3, sections B-B', C-C') of the trench. The till is dark olive-gray in color and composed of calcareous pebbly clay. Pebbles within the till are scarce and represent mostly siliceous rocks, and the till contains intermixed shale similar in appearance to the shale that forms the underlying bedrock. Because the till is found below the Illinoian till and is separated from the Illinoian till by outwash (pl. 3, section B-B') it is assumed to be of Kansan or Nebraskan age; however, the exact age relationship cannot be determined from the evidence thus far available. It is reasonable to assume that tills of Kansan and Nebraskan ages do exist in the subsurface of Clay County because tills of these ages occur to the south of the county in Nebraska (Reed and Dreeszen, 1965).

Table 2.--Generalized stratigraphic sections of the Pleistocene deposits of Clay County

Age			Deposit	Thickness (feet)	Description
Pleistocene	Wisconsin	Late	Loess	0-15	Light yellow-brown to light-gray silt and very fine sand with minor amounts of clay; locally fossiliferous.
			Terrace outwash	0-10±	Fine to coarse sand with minor amounts of fine gravel and clay; locally stratified.
			Terrace valley outwash	0-50?	Fine sand to coarse gravel to boulders; sometimes covered by as much as 10 feet of alluvial deposits; oxidized in upper part; locally stratified.
			Till	0-136	Light yellow-brown to dark olive-gray calcareous boulder clay; locally sandy; locally contains large chalk boulders.
		Early	Loess	0-43	Buff to light-gray silt to very fine sand; found only in the subsurface.
			Buried outwash	*	Fine sand to very coarse gravel; unoxidized; water saturated and locally stratified.
	Pre-Wisconsin	Illinoian	Till	0-120	Light yellow-brown to dark olive-gray calcareous boulder clay; hard and blocky; highly jointed with oxidation and mineralization associated with the joint patterns where exposed.
			Buried outwash	*	Fine sand to very coarse gravel; unoxidized; water saturated and locally stratified.
		Kansan-Yarmouthian	Silts and clays (Sappa)	0-60±	Varicolored banded clays interbedded with light to dark silts; not exposed at surface.
			Fluvial sand & gravel (Grand Island)	0-28	Light-colored pebbly arkosic stratified sands and gravels composed predominantly of quartz, pink feldspars, granite and chert; grains are well rounded and highly polished; exposures locally contain fossil teeth.
			Buried outwash	*	Fine sand to very coarse gravel; unoxidized; water saturated and locally stratified.
		Nebraskan-Kansan	Till	?	Dark olive-gray, calcareous, pebbly boulder clay; found only in subsurface.

* Maximum composite thickness - 170 feet

Because specific evidence is not available, the older till has been called pre-Yarmouthian till to designate that it may represent either Kansan, Nebraskan, or both glaciations.

Ancient Niobrara River

Another major bedrock valley may have existed in Clay County in very early Pleistocene time. This valley, here referred to as the ancient Niobrara River valley, is located in approximately the same position as the present Missouri Valley.

The age of the Missouri River has never been satisfactorily established in South Dakota. Warren (1952) postulates that part of the Missouri near Chamberlain, in central South Dakota, had its beginning during Illinoian time. The evidence cited by Warren is convincing but takes into consideration only a small segment of the river, thus it is possible that the Missouri River valley may represent several different periods of development.

Topographic maps available for the Missouri Valley show the trench to maintain a rather steep-walled characteristic from the northern border of South Dakota to a point where it turns east in Bon Homme County. Here the trench widens to 3-6 miles. This width is maintained until it reaches Yankton, where a constriction is apparent, and the valley narrows slightly for a distance of several miles. Immediately to the east of Yankton, the trench again widens and maintains a width of 5-10 miles through Clay and Union Counties.

At the point where the Missouri Valley first widens in Bon Homme County, the Niobrara River enters the valley from the southwest. Earlier workers have speculated that the Missouri River, from this point eastward, may be flowing in a valley previously occupied by the Niobrara River.

In Clay County an eastward-flowing stream of some prominence did at one time join the ancient White River at a point near Vermillion. The bedrock map (pl. 2) shows the configuration of these two valleys after modification by glacial ice and meltwaters. Each valley has been filled with outwash sediments (pl. 4). The sediments were studied from drill hole samples and without prior knowledge, it is impossible to discern from which valley a sample was collected.

No buried till, soil or material other than outwash and alluvium has been recovered from the ancient Niobrara River trench. Because of this, no definite age can be assigned to the trench or the sediments it contains.

Cross-section D-D' (pl. 3) shows the valley floor of the ancient Niobrara to be somewhat higher than the floor of the ancient White, and for this reason it is felt that the ancient Niobrara was a tributary to the ancient White. It is possible, however, that the ancient Niobrara represents a major river that was formed at a later date than the ancient White. However, evidence to prove or disprove either of these theories is not available.

In the absence of conclusive evidence of the age of the ancient Niobrara, it is the author's belief that the ancient Niobrara is nearly the same age as the ancient White, i. e. early Pleistocene. Furthermore, the ancient Niobrara represents an eastward extension of the present Niobrara River trench which is older than the present Missouri River trench north of Bon Homme County.

Late Kansan Non-Glacial and Yarmouthian Deposits

Location and Thickness of Exposure

One exposure (pl. 1) of late Kansan fluvial sand and gravel is present in Clay County. The exposure located in the extreme northwestern part of the county in 95-53-27, is overlain by late Wisconsin till and underlain by the Niobrara Marl and has a maximum exposed thickness of 28 feet.

Description of Exposure

The exposure was extensively studied by Lutzen (1957) with regard to texture and composition of the sediments. The deposit is well sorted, having a sorting coefficient of 1.27, and has been found to contain 74.24 percent sand, 24.93 percent pebbles, and 0.82 percent silt and clay (Lutzen, 1957). A study of 4-8 mm. size pebbles showed the following composition: granite, 51.86 percent; feldspars, 23.23 percent; quartz, 15.16 percent; chert, 1.34 percent; and sandstone, 5.76 percent; while other miscellaneous material was responsible for the remaining 3.20 percent. It is important to note the complete absence of carbonates, chalk, shale, and Sioux Quartzite from the deposit, in contrast to the presence of these rocks and mineral types in the glacial deposits of the county.

In general, it can be said that the late Kansan fluvial sand and gravel is a pebbly arkosic sand. It is light colored and stratified, and individual grains are well rounded and highly polished. Pebbles are concentrated primarily in the upper one-third of the section with a dissemination of pebbles in the lower two-thirds. Although cross bedding is seen throughout the entire section, it is generally more fully developed in the upper half.

Correlation of Exposure

Fluvial sands and gravels similar in texture and composition to that described above have been studied by several authors at a number of localities in South Dakota and Nebraska.

Stevenson and Carlson (1952) mapped a deposit of similar nature in Gregory County, South Dakota, near the town of Burke. At that time, the informal name of Herrick was proposed by Stevenson. Similar deposits have been described by Baird (1957) and referred to as Newton Hills sand, and by Tipton (1958) who correlated them with the Atchison sand.

Lutzen (1957) postulated that the deposit exposed at 95-53-27 in Clay County was of Yarmouthian age and correlated it with the Herrick as mapped by Stevenson and Carlson (1952). Lutzen further proposed this deposit to correlate with Simpson's (1952) and Flint's (1955) alluvium of western origin.

Fossil teeth collected from the exposure in Clay County (Lutzen, 1957) were identified as Equus excelsus Leidy....and Equus sp. On the basis of this discovery, Lutzen stated that the deposits were Yarmouthian in age. He also stated that by Yarmouthian he meant, "not older than Grand Island, but probably Sappa (or even later, i. e., early Illinoian)."

The Herrick gravels of Gregory County contain fossil teeth of Pleishippus sp., which according to J. C. Harksen (oral communication, 1966), are common to early Nebraskan deposits. However, according to Hibbard (personal communication to R. E. Stevenson, 1957), fossil teeth of Pleishippus sp. also occur in Kansan non-glacial deposits.

The author is left with a choice as to what name to attach to the fluvial sands and gravels in Clay County. Because the name Grand Island has been extensively used in Nebraska (Reed and Dreeszen, 1965) and is now being used in South Dakota (Steece, in preparation) to refer to late Kansan fluvial deposits, it seems to be the most logical choice. The name Herrick has not been widely used, is the younger of the two names, and enjoys only informal standing since no type locality has been designated. For these reasons, the late Kansan fluvial deposits of Clay County are here designated as Grand Island sands and gravels. These may be equal, at least in part, to the Herrick (Stevenson and Carlson, 1952), Atchison (Tipton, 1958), Newton Hills (Baird, 1957), and the older alluvium of Flint (1955) and Simpson (1952), however, the validity of these assumptions must be proven or disproven by later workers after much additional information has been obtained.

Correlation of Subsurface Deposits

Subcrops of Grand Island sand and gravel occur adjacent to the single exposure of the deposit, and similar deposits are found in the subsurface of northeastern Clay County (pl. 3). Because these sands and gravels are similar in all respects to those in the northwestern part of the county and occur at nearly the same position stratigraphically, they too have been called Grand Island. No fossils have been recovered from samples of the buried portion of the Grand Island so correlation is not definite.

In association with the Grand Island sand and gravel in the subsurface of northeastern Clay County is a relatively thick section of silt and clay (see Appendix A - test hole 39). The clay, which is a greenish-gray to green plastic clay, is interbedded with dark-reddish to greenish-brown clayey silt. This clay-silt sequence overlies the Grand Island in the subsurface of northeastern Clay County (pl. 3), and the entire sequence is very similar to a section at Sherman Park in the city of Sioux Falls at 101-49-19ca, where the clay-silt sequence has been found to contain mollusks. One of the mollusks, Gyraulus labiatus, is considered to be an index fossil restricted to Yarmouth in Kansas (Leonard, 1950). The silts and clays overlying the Grand Island sands and gravels at Sherman Park have been designated as Sappa silts and clays by Steece and Tipton (1965).

Because of the similarity of these deposits to the silts and clays overlying the Grand Island in northeastern Clay County, the author believes the same geologic unit is involved. For this reason, the silts and clays overlying the Grand Island in northeastern Clay County have been designated as Sappa silts and clays.

Pre-Illinoian Outwash

Outwash of pre-Illinoian age exists in Clay County in the valleys of the ancient White and Niobrara Rivers. This fact is evidenced by the location of Illinoian till above a substantial thickness of outwash sediments (pl. 3, sections B-B', and C-C'). The exact age of the outwash cannot be determined from evidence now available. An attempt has been made to assign the outwash an approximate age based on the general appearances of the cross sections of plate 3. The author is the first to admit that these correlations are highly speculative and cannot be substantiated.

In no instance is the pre-Illinoian outwash exposed at the surface in Clay County, and in most cases the outwash is overlain by younger outwash, making even the upper limit impossible to discern.

The outwash consists of fine sand to coarse gravel and is often extremely coarse near the base. The sediment consists of a wide variety of igneous, metamorphic and sedimentary rock fragments that are generally subangular to subrounded. Shale and chalk pebbles are common, whereas the sand fraction consists predominantly of quartz, feldspar, granite, and limestone. Lignite is common throughout the outwash and sometimes makes up as much as 50 percent of the sample obtained by rotary drilling methods.

No buried oxidized zones were found in the outwash, and bedding and gradation according to size was impossible to determine because of the drilling methods used.

Illinoian Till

Location and Description

Illinoian till exists at several localities on the surface (pl. 1) and in the subsurface (pl. 3) of Clay County. Where exposed, the Illinoian till is hard and blocky and contains abundant joints. The till is very compact and varies in color from dark yellowish-brown (10YR 4/2) to light olive-gray (5Y 5/2). Where the till is gray the joints are easily recognized because a yellowish-brown (10YR 4/2) zone of oxidation extends outward from them for 3-6 inches in either direction. Generally, the joints have no preferred orientation and are filled with gypsum or calcite.

The Illinoian till is composed of silty clay which is weakly to strongly calcareous and contains an abundance of pebbles. The pebbles consist of quartzite, basalt, sandstone, quartz, limestone and chalk.

Correlation

Most of the proof that the Illinoian till in Clay County is, in fact, Illinoian has been obtained from work presently being completed by Steece (in preparation) along the lower Big Sioux River valley in Union and Lincoln Counties.

Illinoian till is widespread in the Big Sioux Valley and can be shown to overlie the Sappa silts and clays (Steece and Tipton, 1965). In addition, the till is overlain by early Wisconsin loess (Steece and Tipton, 1965). This sequence of till over loess over till is found only in the subsurface in Clay County, and the following drill-hole log shows the sequence.

Test hole 93-51-1adda

Age	Description	Depth below land surface
Late Wisconsin	Till, light yellow-brown, very silty from intermixed loess, pebbly	0- 20
Early Wisconsin	Loess, silt, light yellow-brown to light-brown, some gray and green silts at base	20- 63
Illinoian (ox.)	Till, light yellow-brown, pebbly, hard, dry, tenacious; some dark-brown streaks from 90-120	63-120
Illinoian (unox.)	Till, medium-gray, silty, pebbly, very hard and dry	120-210
Greenhorn Limestone	Shale, dark-gray, sticky, greasy, speckled-white, calcareous	210-230

The till referred to as Illinoian by Steece and Tipton (1965) can be traced into east-central Clay County (pl. 1), where the above drill log was recorded and the continuity of the till throughout Union County and into Clay County is definite.

No attempt will be made in this report to prove or disprove the presence of the Illinoian till in southeastern South Dakota. Let it suffice to say that evidence cited by Steece in the area along the Big Sioux River is convincing. Because no evidence to the contrary can be found in Clay County, the author has no choice but to respect the correlation made by Steece (in preparation), and refer to what is obviously the same till in Clay County as Illinoian.

Subsurface correlations of the Illinoian till in the mapped area are shown on plate 3. On section B-B' the correlations are based on oxidized zones and the occurrence of approximately 30 feet of outwash that separates the Illinoian from the overlying late Wisconsin till. On section C-C' Illinoian till is shown to exist in the eastern part of the county. This correlation is based on the fact that oxidized till presumed to be the upper part of the Illinoian was encountered beneath the unoxidized late Wisconsin, and above the unoxidized Illinoian till. Drill hole logs used in the foregoing correlations are listed in Appendix A.

Topography

A "nose" of Illinoian till projects into east-central Clay County from the east (pl. 1). This is the only instance where the Illinoian shows a definite surface expression within the county (fig. 6). At this locality the Illinoian is covered by younger loess and has been partly overridden by late Wisconsin ice. No late Wisconsin till is present on the Illinoian highlands in the adjacent area east of this locality. The fact that the Illinoian highlands were only partly covered by late Wisconsin till will be discussed in more detail in the section of this report dealing with the late Wisconsin till.

Illinoian and Early Wisconsin Outwash

Because the ancient White River probably existed as a major drainage way throughout all of Pleistocene time, part of the outwash deposited in the trench is thought to be Illinoian and early Wisconsin in age. Most of the Illinoian till has been removed from the ancient White River trench (pl. 3, sections B-B' and C-C'), and outwash deposited in its stead.

Although early Wisconsin ice did not occupy Clay County, meltwaters from the ice flowed southward through the county in the ancient White River, and were responsible for removing most of the Illinoian till. Steece (1959) and Tipton (1959) postulated that the early Wisconsin ice terminated just north of Sioux Falls. In this area, which is about 60 miles north of the northern border of Clay County, early Wisconsin end moraine remnants have been mapped.

As stated earlier, the author believes the ancient White River trench represented a major channel during most of Pleistocene time. If the early Wisconsin drift border occupied a position near Sioux Falls, as postulated by Steece and Tipton, the logical route for the meltwaters would have been down the ancient White River. These meltwaters must have removed part of the valley fill which consisted of pre-Illinoian deposits. Later, early Wisconsin outwash was deposited in the trench.

Meltwaters from the early Wisconsin ice may also have occupied the ancient Niobrara trench. The writer can only speculate as to the sequence of events and the age of the outwash deposited in the two valleys. No evidence has yet been found to definitely establish the age or correlation of the outwash.

Early Wisconsin Loess

Thickness and Distribution

Loess of early Wisconsin age exists in the subsurface of Clay County where as much as 43 feet of this loess was encountered in a drill hole in 93-51-1adda.

Figure 6. Photograph showing surface expression of Illinoian till.
(High releif area across center of photograph.)

Correlation

The loess is overlain by late Wisconsin till and underlain by Illinoian till (see Appendix A, test hole 15) and it was on this basis that it was assigned an early Wisconsin age. The possibility exists that the loess may be as old as Illinoian or may represent continuous deposition from Illinoian through early Wisconsin; however, evidence contributed by Steece (1965) in Union County favors an early Wisconsin age for the loess.

Exposures of Illinoian till in Union County exhibit ice wedge pseudomorphs common to periglacial regions. These features are wedge shaped and widest at the top, and are filled with well-sorted medium to coarse sand. The wedges have a width of one inch to one foot at the top and reach a depth of over three feet, and where the wedges and oxidation joints are found together the wedges bisect the joints. In addition, the wedges are truncated at the top by the loess previously cited as early Wisconsin. Steece (1965) believes the wedges were formed in perennially frozen Illinoian till, while the early Wisconsin ice occupied the region near Sioux Falls. The fact that the wedges are truncated by the loess and do not extend into the loess would then make the loess Wisconsin in age. Because the loess is overlain by late Wisconsin till and truncates ice wedges formed during the early Wisconsin ice advance, it is assumed to be early Wisconsin.

Origin and Description

Origin of the early Wisconsin loess was most likely from the outwash deposits that existed in the ancient White and Niobrara River valleys. These two valleys were close to the areas where loess accumulated and could have contributed much sediment through the action of westerly and southwesterly winds.

The early Wisconsin loess of Clay County is found only in the subsurface and descriptions are based on rotary drill cuttings. The loess grades downward from light-brown (5YR 6/4) silt and becomes a medium-gray (N5) silt toward the base. No fossils were found in the loess samples.

Late Wisconsin Till

Distribution and Thickness

Till of late Wisconsin age is the major surficial deposit of Clay County, and covers more than 50 percent of the county (pl. 1). The till ranges in thickness from a few feet to 136 feet, and has an average thickness of about 75 feet.

Description of Deposit

Late Wisconsin till consists of pale yellowish-brown (10YR 6/2) to olive-gray (5Y 4/1) boulder clay. Common boulders are chalk and quartzite, and the till is generally sandy and very calcareous. Most exposures in the county show oxidation throughout the entire section.

The lithology of the late Wisconsin till of Clay County has been studied by Stevenson but the results are unpublished. The results of fourteen samples studied by Stevenson are summarized in the following tables.

Table 3 gives the percent by weight of clay, silt, sand, and gravel-size particles reported from the samples.

It can be seen from table 3 that sand comprised the major percentage of sediment in the till. An average of the fourteen samples investigated is given at the bottom of table 3.

Composition of the pebble-size particles in the same fourteen samples was also determined by Stevenson. The percentage of each rock type is shown in table 4.

Sedimentary rocks are most abundant in the pebble-size portion of the late Wisconsin till. In the samples tested, these rocks have a percentage range from 35.8 to 83.8 with an average of 58.5. Crystalline (igneous and metamorphic) rocks average 41.5 percent of the sample, and carbonates 48.3 percent.

The late Wisconsin till of Clay County shows little compaction in comparison to the Illinoian. This may be caused by the relative youth of the deposit or the abundance of sand that it contains. Randomly-oriented joints are sometimes present in the late Wisconsin till. Although no joint fillings of gypsum or calcite are present, the joint faces are often stained black. This staining probably results from mineralization by percolating ground water.

Topography

Late Wisconsin till exhibits topography common to glacial end moraine and ground moraine and the deposits have been mapped according to this topography (pl. 1). Deposition of late Wisconsin till was controlled in part by the topography of the bedrock (pl. 3). Because of this, end moraine in one area of the county may occur at a lower elevation than ground moraine in another area. To aid in delineating these deposits, end moraine and ground moraine were divided into high and low relief (pl. 1) on the basis of their relative surface elevations.

Ground Moraine.--Ground moraine of low relief covers the central part of the county. The ground moraine ranges in thickness from 75-136 feet and has an average thickness of about 100 feet. The ground moraine in central Clay County is very flat and devoid of an abundance of closed depressions (fig. 7). This fact is due in part to a discontinuous loess cover, ranging in thickness from a few inches to over 5 feet, that has subdued the topography.

Ground moraine of high relief occurs in the northeastern part of the county, and has an average thickness of 40 feet. This moraine slopes to the west and south, and gradually merges with the ground moraine of low relief. Plate 1 shows the distribution of the high and low relief ground moraine and its relationship to the other surficial deposits.

Table 3.--Particle size determinations from late Wisconsin till.

Location of Sample	Percent of Sample by Weight			
	Gravel	Sand	Silt	Clay
94-52-10a	3.4	66.6	15.0	25.0
95-52-35bc	7.6	40.3	22.2	29.9
95-52-24bc	6.0	47.1	16.5	30.4
95-52-11c	5.7	52.6	18.2	23.5
95-52-2b	11.6	52.7	12.3	23.4
95-52-14bd	.5	45.0	21.5	33.0
92-51-21aa	.8	47.8	24.7	26.7
92-51-21aa	5.2	33.6	24.7	37.5
92-51-22ba	3.6	27.8	22.3	36.3
92-51-14cc	7.0	40.9	27.7	24.4
92-51-24bb	7.5	37.5	26.0	29.0
92-51-24ba	3.4	48.6	22.5	25.5
93-51-21cb	11.6	29.5	20.6	38.3
93-51-28ba	11.4	23.8	31.9	32.9
Average of fourteen samples tested	6.1	42.4	21.9	29.6

Table 4.--Composition of late Wisconsin till.

Composition (given in percent of total sample)	Location of Sample														Average of Fourteen Samples Tested
	94-52-10a	95-52-35bc	95-52-24bc	95-52-11c	95-52-2b	95-52-14bd	92-51-21aa	92-51-21aa	92-51-22ba	92-51-14cc	92-51-24bb	92-51-24ba	93-51-21cb	93-51-28ba	
Granite	25.4	26.3	23.6	25.0	28.2	25.0	26.3	27.1	12.0	27.2	29.1	34.5	25.8	34.0	26.4
Greenstone	6.1	11.4	6.8	9.1	4.8	7.8	9.0	6.8	2.3	12.0	8.8	7.0	6.2	10.4	7.7
Other Crystalline	10.2	2.8	4.5	3.0	8.2	5.2	8.1	3.1	1.9	5.3	4.5	7.4	18.9	19.8	7.4
Total Percent Crystalline	41.7	40.5	34.9	37.1	41.2	38.0	43.4	37.0	16.2	44.5	42.4	48.9	50.9	64.2	41.5
Limestone	19.4	22.9	27.2	28.8	20.8	25.2	22.7	20.3	38.1	19.9	18.7	24.0	42.3	33.0	25.9
Dolomite	30.4	26.3	28.2	25.0	34.5	25.0	22.3	33.4	14.1	23.6	26.5	19.4	5.1	0.0	22.4
Other Sedimentary	8.5	10.3	9.7	9.1	3.5	11.8	11.6	9.3	31.6	12.0	12.4	7.7	1.7	2.8	10.2
Total Percent Sedimentary	58.3	59.5	65.1	62.9	58.8	62.0	56.6	63.0	83.8	55.5	57.6	51.1	49.1	35.8	58.5

Figure 7. Photograph showing surface expression of late Wisconsin ground moraine.

End Moraine.--End moraine occupies several areas in the county (pl. 1) and generally trends northwest-southeast. Rugged end moraine covers the northwestern and west-central areas (fig. 8), is hummocky in nature, portrays high local relief, and has an easily-recognizable crest (pl. 1). Although essentially undrained, the moraine does have some drainage because of its proximity to the Missouri River.

Associated with the end moraine is a meltwater channel that extends southward from the Turner-Clay County boundary to the Vermillion River (pl. 1). This channel marks the approximate boundary between the end moraine on the west and the ground moraine on the east, is about $\frac{1}{4}$ mile wide and contains a variety of sediments. The lower part of the channel (approximately 5 miles) has a flat bottom and contains alluvial sediments (pl. 1). Upstream from the section that contains alluvium, the channel has a rounded appearance, and may locally contain alluvial or colluvial sediments, outwash, till, or loess. The significance of the meltwater channel will be discussed in more detail in the section of this report dealing with Pleistocene history.

End moraine is also present along the Missouri River bluff in the south-central and southeastern parts of the mapped area (pl. 1). This moraine is of very low relief and could easily be mistaken for ground moraine. The low relief is caused by a nearly-complete blanket of loess that covers the moraine to a thickness of up to 15 feet; however, constructional topography is not completely masked and is especially well developed along the section line road from the north edge of Vermillion east to the county boundary.

Although a recognizable crest could not be discerned on the low relief end moraine, remnants exhibiting a higher topography do exist. It was on the basis of these remnants and the presence of numerous closed depressions that the deposit was recognized as end moraine.

Age and Correlation

The age and correlation of late Wisconsin till is based on radiocarbon dates from the surrounding area. Spruce wood from a depth of 26 feet in till at 99-53-28bb in Turner County was collected by C.A. Avery in 1956. This sample was found to have a date of 12,330±180 years B. P. (sample no. Y-452), making it late Wisconsin in age (Barendson et. al., 1957). This till can be traced on the surface from the area dated into Clay County.

Late Wisconsin Outwash

Distribution and Thickness

Late Wisconsin outwash occurs as a valley train deposit along the Vermillion River trench through the central part of the county (pl. 1). In most cases the outwash is covered by younger overbank deposits but in isolated instances it has not been covered and exists at the surface. Where the outwash is exposed at the surface it is shown on plate 1 with the symbol Qwltvo.

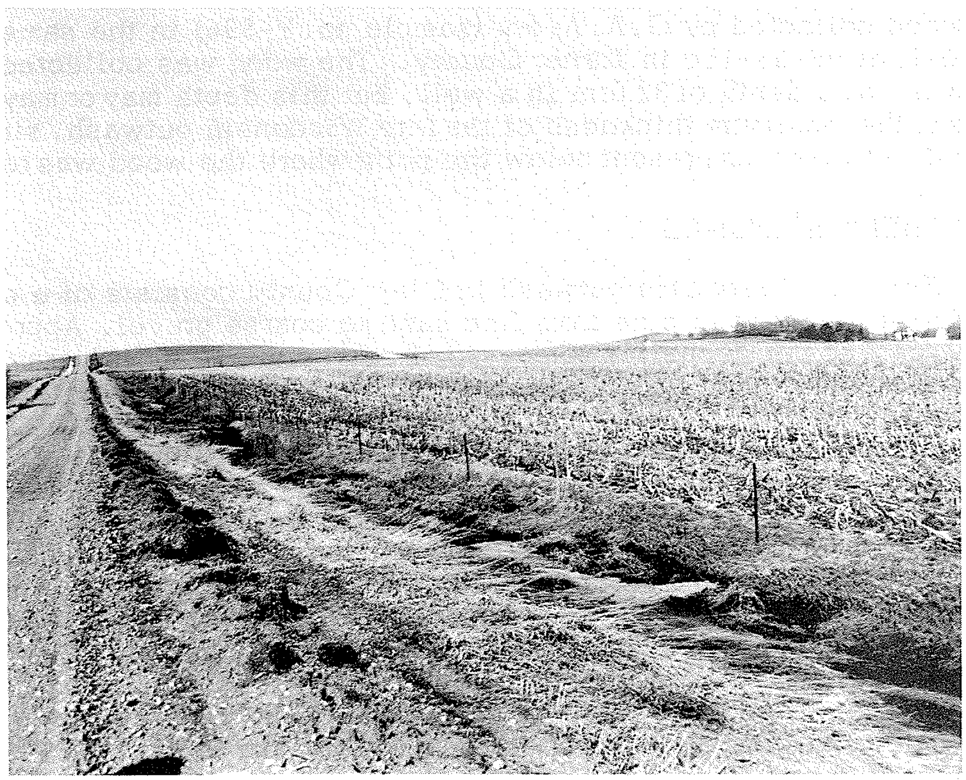

Figure 8. Photograph showing surface expression of late Wisconsin end moraine.

Because the late Wisconsin outwash overlies outwash of an earlier age and similar lithology, it is impossible to determine its true thickness. The author has assigned an approximate thickness of 50 feet to the outwash and used this figure in the construction of the cross section on plate 3. The thickness of 50 feet is based in part on a radiocarbon date of 12,760±120 on wood collected by G.A. Avery (sample no. Y-595) in the same outwash deposit at 98-53-15c in Turner County. The wood was collected from the outwash at a depth of 32 feet in a well, but this depth may or may not represent the maximum thickness of the late Wisconsin outwash, since additional outwash was present below the point where the wood was recovered.

Description of Deposit

The late Wisconsin outwash in Clay County consists of a mixture of sediments ranging in size from fine sand to coarse gravel. Approximately 75 percent of the deposit is composed of coarse sand and fine gravel, while fine to medium sand and coarse gravel together make up the remaining 25 percent. The finer portion of the outwash consists predominantly of quartz, feldspar and limestone, whereas the coarse portion of the outwash is composed of approximately 50 percent crystalline rock fragments including quartzite, and 50 percent sedimentary rock fragments. The sedimentary rocks are primarily shale, chalk, and other limestones, and sandstone is present in only minor amounts. Individual particles in the outwash are subangular to subrounded with the smaller particles being more rounded than the larger ones. Shale pebbles are usually flat sided and have an elliptical shape.

Horizontal bedding is common in all exposures of the late Wisconsin outwash in the Vermillion trench, and it is assumed that this bedding is present in the subsurface.

Age and Correlation

The fact that the outwash presently being discussed is late Wisconsin is based on a radiocarbon date about 50 miles north of Vermillion, near Parker, South Dakota. This date (mentioned earlier in this report, sample no. Y-595) is based on an examination of wood from a depth of 32 feet in the outwash at 98-53-15 c. The date of 12,760±120 years B. P. shows it to be late Wisconsin. The outwash from which the wood was recovered is a northward extension of the Vermillion valley outwash into Turner County, and is continuous along the entire Vermillion River trench.

Late Wisconsin Loess

Distribution and Thickness

Late Wisconsin loess occurs in several areas in Clay County (pl. 1) and is thickest along the bluff of the Missouri River near Vermillion and east of the rugged end moraine. Scattered patches of loess also occur near the center of the county and east of the Vermillion River.

Hand auger holes were used to determine thickness and distribution of the loess in Clay County. In most instances, if another geologic unit were encountered below the loess and within 5 feet of the surface, the loess was not mapped. The distribution of the loess mapped by this method is shown on plate 1.

Description of Deposit

The loess is generally light brown (5YR6/4) to medium gray (N5) and is sometimes fossiliferous in the lower gray part. Fossils collected from the gray lower zone at 92-52-14cdaa were tentatively identified by Steece (oral communication) as Succinea grosvenori, Vallonia gracilicosta, and Vertigo modesta; however, the identification of these fossils lends little to correlation because of their wide range of occurrence in Pleistocene and Recent time.

Age and Origin

Because the loess overlies late Wisconsin till, deposition must have begun after the till was deposited. No upper age limits can, however, be assigned to the loess on the basis of field evidence. It is therefore possible that loess deposition may have started during late Wisconsin time and continued into Recent time.

Origin of the loess was probably from sediments in the Missouri River trench. Transportation by westerly winds would then account for the thicker accumulations along the Missouri River bluff, immediately to the east of the widest part of the Missouri River floodplain. The absence of thick loess on the end moraine adjacent to the Missouri Valley in the western part of the county is at first puzzling, because substantial thicknesses of loess do occur behind the moraine (pl. 1). It is the author's belief that the end moraine acted as a windbreak, and loess was deposited behind it due to the decreased velocity of the westerly winds. Loess does occur discontinuously on the moraine itself, but is usually thin. Thus, the possibility exists of complete covering of the moraine by loess, and later removal of the greater share of the loess by erosion.

Recent Deposits

General Statement

Recent sediments were deposited along most major streams and tributaries in Clay County after the retreat of the glaciers. Most of the Recent sediments result directly from stream activity but other minor deposits are the result of other forces such as wind and gravity.

Table 5 lists the Recent sediments that exist in Clay County and the distribution of the sediments is shown on plate 1.

Colluvium

Colluvial deposits occur principally near the base of slopes along the valley walls of the Vermillion and Missouri Rivers (pl. 1). These deposits

Table 5.--Generalized stratigraphic section of the Recent deposits of Clay County

Age	Deposit	Thickness (feet)	Description
Recent	Colluvium	0-15	Light yellow-brown to black clay interbedded with dark-gray soil; developed on slopes from uplands; locally contains silt, sand, gravel, and boulders.
	Alluvium	0-10	Generally black but sometimes varicolored clay and silt with minor amounts of sand and gravel; locally fossiliferous.
	Bar deposits	?	Very fine to medium well-sorted sand with minor amounts of silt and clay; usually bedded.
	Point bar deposits	?	Silt and fine sand with minor amounts of medium sand; usually bedded.
	Channel fill deposits	0-10	Dark clay and silt with minor amounts of sand; deposited in abandoned meander channels.
	Overbank deposits	0-50±	Dark clay and silt with minor amounts of sand; locally stratified.
	Dune sand	0-20	Reddish-brown, fine to medium, wind-blown sand located on uplands adjacent to Vermillion and Missouri Rivers; local dune topography.

have a maximum thickness of about 15 feet. The colluvium is derived from the uplands and consists of pale yellowish-brown (10YR 6/2) to black (N1) clay and silt interbedded with dark-gray (N3) soil. Colluvium is absent where streams flow near the valley walls. Because of steeper slopes in these instances, colluvial material continues to move downward under the influence of gravity and is finally swept away by the stream.

Alluvium

Alluvium in the tributaries to the Vermillion River is primarily black (N1) humic stratified clay and silt with minor amounts of sand and gravel. These deposits have an average thickness of about 5 feet, and a maximum thickness of about 10 feet. Because the deposits are primarily the result of flooding, the grain size and the amount of stratification may vary considerably, both laterally and vertically.

In the valleys of the Vermillion and Missouri Rivers, the alluvium is divided into meander belt deposits and overbank deposits.

Meander Belt Deposits

Meander belt deposits can be subdivided into bar, point bar, and channel fill material. Each of these deposits is readily distinguishable on aerial photographs or in the field if close attention is given to its topographic expression, texture and relative position within the overall meander belt complex. Bars occur at several locations on the Missouri River floodplain (pl. 1) in Clay County, and were formed in two ways. Many bars are the result of small stream meanders that cut into a larger abandoned meander. When stream erosion occurs, a deep channel is formed adjacent to the stream "cut bank." This channel separates the bank from the slack-water area on the opposite side of the main channel, and sand is deposited in association with the slack-water area and forms a bar. Abandonment of the new channel results in a narrow clay-filled trough between the bank and the sand bar (Jorgensen, 1960b). Bars may also result from the abandonment of a channel containing sediments deposited by braided streams.

Point-bar deposits are formed in much the same manner as bar deposits and also occur on the Missouri River floodplain (pl. 1). The deposits result from slight changes in stream alignment during lateral channel migration, and are located on the convex side of the meander.

Channel-fill deposits consist primarily of clays and silts deposited in abandoned meander channels. These abandoned meander channels are the result of stream channel shortening by chute or neck cutoff (Fisk, 1947). Channel-fill sediments in Clay County are found on the floodplain of both the Missouri and Vermillion Rivers.

Overbank Deposits

Undifferentiated overbank deposits occur in Clay County in the valleys of the Vermillion and Missouri Rivers. These sediments are deposited by rivers during flood stage when sediment-laden water moving at a relatively high velocity overflows the stream banks. The velocity of the overflowing water is decreased and the suspended clays and silts are deposited beyond the banks.

Figure 9 shows the average sediment size of each type of meander-belt and overbank deposit on the Missouri River floodplain in Clay County.

Dune Sand

Eolian sand exists in several areas in Clay County (pl. 1) adjacent to the major drainages. The sand is always found to the east or northeast of the source area, indicating prevailing westerly winds during the time of deposition. The sands are fine to medium and are composed predominantly of quartz. Most grains are frosted, angular to subrounded, and well sorted. Often the grains are stained a pale reddish brown (10 R 5/4) causing the entire deposit to have a dirty appearance. The average thickness of these deposits is 10 feet. In areas where the sand is thickest, dune topography results which aids in the delineation of the deposit in the field and on aerial photographs. The dunes are presently stable and grass covered.

GEOLOGIC HISTORY OF CLAY COUNTY

Sequence of Pre-Pleistocene Events

In extreme southeastern South Dakota a "low" persisted through at least part of the Cambrian. This low was a westward extension of the Paleozoic basin that existed in western Iowa. As this basin was subsiding, sea water covered the area and the glauconitic siltstones, sandstones, and dolomites that make up the Cambrian (?) rocks of Clay County were deposited.

After deposition of these sediments, the land rose and the sea retreated. The region which now includes Clay County was emergent for many millions of years. During this time, erosion removed part of the Cambrian (?) rocks that had previously been deposited. When the land again subsided in southeastern South Dakota in Late Cretaceous time, more than 400 million years had passed. This period of geologic history is thus missing in the area, with only an unconformity separating the Cambrian and Cretaceous sediments.

The shales and sandstones of the Dakota Group represent a repeatedly-shifting strand during Late Cretaceous time. After a period of subsidence near the end of Dakota deposition, stable conditions prevailed during the deposition of Graneros Shale and continued throughout the deposition of Greenhorn, Carlile, and Niobrara. Slight differences in sea-bottom conditions, water level and salinity, tides, currents and other factors are shown, however, by the changes in fossils and the sedimentary sequence from the silty shales of the Graneros through the marls of the Niobrara.

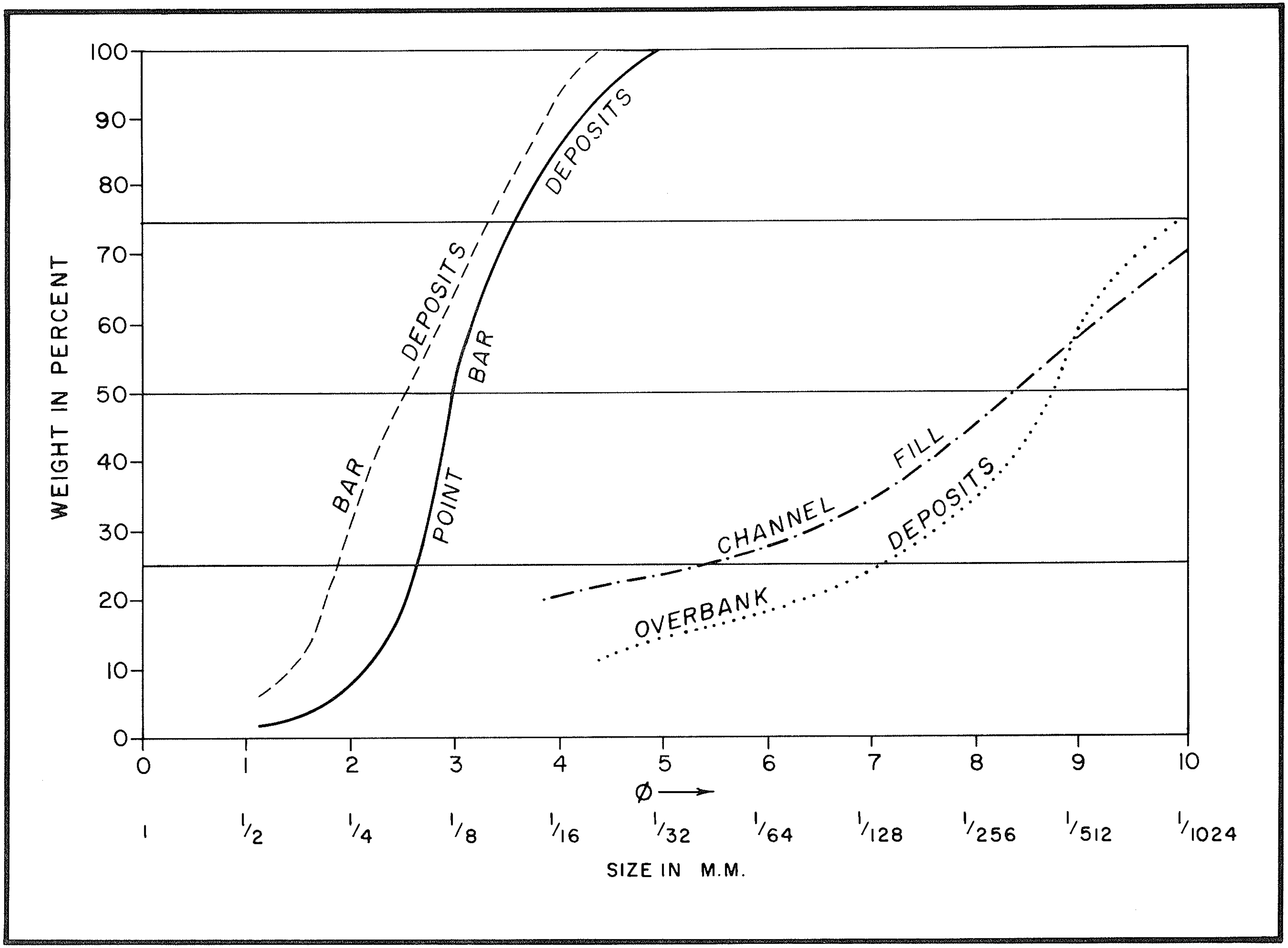

Figure 9. Average size distribution of alluvial deposits of Missouri River floodplain in Clay County. *(after Douglas, 1959)*

After the deposition of the Late Cretaceous sediments, the seas again abandoned Clay County to erosion. Throughout the remainder of the Cretaceous and the whole of the Tertiary Periods weathering acted on the land and a substantial amount of erosion took place.

Sequences of Pleistocene and Recent Events

At the beginning of the Pleistocene Epoch two large rivers were confluent in Clay County. The ancient White River, flowing in a deep valley through the central part of the county from northwest to southeast, was joined by a tributary stream just east of the present site of Vermillion. This tributary stream was probably a continuation of the ancient Niobrara River.

Cretaceous marls, shales, limestone and sandstones formed high bluffs along the ancient White and Niobrara Rivers and formed the interfluve between them (pl. 2). These bluffs were steep walled and well dissected by minor tributary streams.

The earliest continental ice sheets to enter Clay County were the Nebraskan and Kansan. These ice sheets modified the existing topography to an unknown degree. As the early ice sheets melted and retreated north of Clay County, meltwaters from the ice poured in torrents down the ancient White and Niobrara River valleys. These meltwaters destroyed much of the till left by the Nebraskan and Kansan glaciers. As the torrential meltwaters from the Nebraskan and Kansan glaciers subsided, outwash was deposited in the ancient White and Niobrara River valleys. The amount of outwash deposited cannot be determined because it has since been partially removed by later meltwaters and covered by younger outwash.

Because only isolated deposits of Nebraskan and Kansan till are found in Clay County, it is impossible to assign them to a definite age. The tills may represent either Nebraskan or Kansan glaciation or both. Because tills of Nebraskan and Kansan ages are found in Nebraska, it is reasonable to assume that each of these ice sheets did, at one time, occupy Clay County. Likewise, weathered zones and soils formed during the warm Aftonian Interglaciation that separated the Nebraskan and Kansan Glaciations must have formed in Clay County. These deposits have long since been destroyed by erosion or covered by more recent sediments.

Late Kansan and Yarmouthian time in the area that is now Clay County was characterized primarily by erosion and weathering. Some deposition did occur, however, and it was during this period that the Sappa silts and clays and Grand Island sands and gravels were deposited.

At the beginning of the Illinoian Glaciation, the surficial deposits of Clay County consisted of Upper Cretaceous shales and marl, Kansan drift and non-glacial deposits and soils formed during the Yarmouthian Interglaciation. The valleys of the ancient White and Niobrara Rivers contained Kansan and Nebraskan outwash sediments.

Illinoian ice covered most of Clay County and modified the existing topography. Illinoian till was deposited over much of the county. It is impossible to determine the thickness or extent of the Illinoian ice in Clay

County, but since Illinoian till is found in Nebraska to the south and west of Clay County (Reed and Dreeszen, 1965), it is believed that Illinoian ice must have covered the entire county. Illinoian till exists today in Clay County both at the surface (pl. 1) and in the subsurface (pl. 3).

As the Illinoian glacier wasted, meltwaters traveled down the valleys of the ancient White and Niobrara Rivers. At first these waters removed much of the existing deposits, deepening and widening the river channels. Later, the channels were at least partly refilled with Illinoian outwash.

With the advent of the warm Sangamon Interglaciation following the retreat of the Illinoian ice, erosion and weathering were again predominant in the area that is now Clay County. Although this relatively long period of weathering and soil formation followed the retreat of Illinoian ice, no Sangamon age deposits have been found in Clay County. It is assumed that they have been removed by erosion or buried by Wisconsin drift. Buried soils of Sangamon age do occur, however, in Union County immediately to the east of Clay County (Steece and Tipton, 1965).

Early Wisconsin ice probably never covered Clay County, but stopped about 60 miles north of the northern boundary of the county. Meltwaters from early Wisconsin ice flowed through the county and had a profound effect on the topography. Any east-flowing streams in eastern South Dakota that had not been disrupted by pre-Wisconsin ice sheets were probably dammed by the early Wisconsin ice and diverted southward. These streams removed much of the valley fill that existed in the ancient Niobrara and White River valleys.

As the volume and velocity of the early Wisconsin meltwaters decreased, outwash of early Wisconsin age was deposited in the earlier-formed troughs. As much as 170 feet of pre-Wisconsin and early Wisconsin outwash sediments have been reported in one drill hole located in 93-51-34aaaa (pl. 4).

During and after deposition of the early Wisconsin outwash, a vast amount of loess was blown from the outwash plain and deposited on the surrounding highlands. As much as 43 feet of early Wisconsin loess was deposited in the east-central part of the county.

Figure 10 is an idealized paleogeologic map of southeastern South Dakota just prior to the advance of the late Wisconsin ice. As the late Wisconsin ice entered Clay County it conformed to the existing topography. This is shown by the fact that the tip of the Illinoian highlands projecting westward from Union County into Clay County was only partly overridden by the late Wisconsin ice (pl. 1). Also subsurface information from test holes indicates that the late Wisconsin till is draped over the older deposits (pl. 3).

An ice tongue, thickest in the center, advanced down the valley of the ancient White River. At the same time, marginal ice partly or completely overrode the surrounding highlands. During the maximum stage of the late Wisconsin advance, ice pushed at least as far south as the floodplain of the Missouri River (fig. 11). If ice actually reached Nebraska there is no evidence of the fact because no late Wisconsin till can be found south of Clay County (Reed and Dreeszen, 1965). No remnants of late Wisconsin till remain in the present-day Missouri trench in Clay

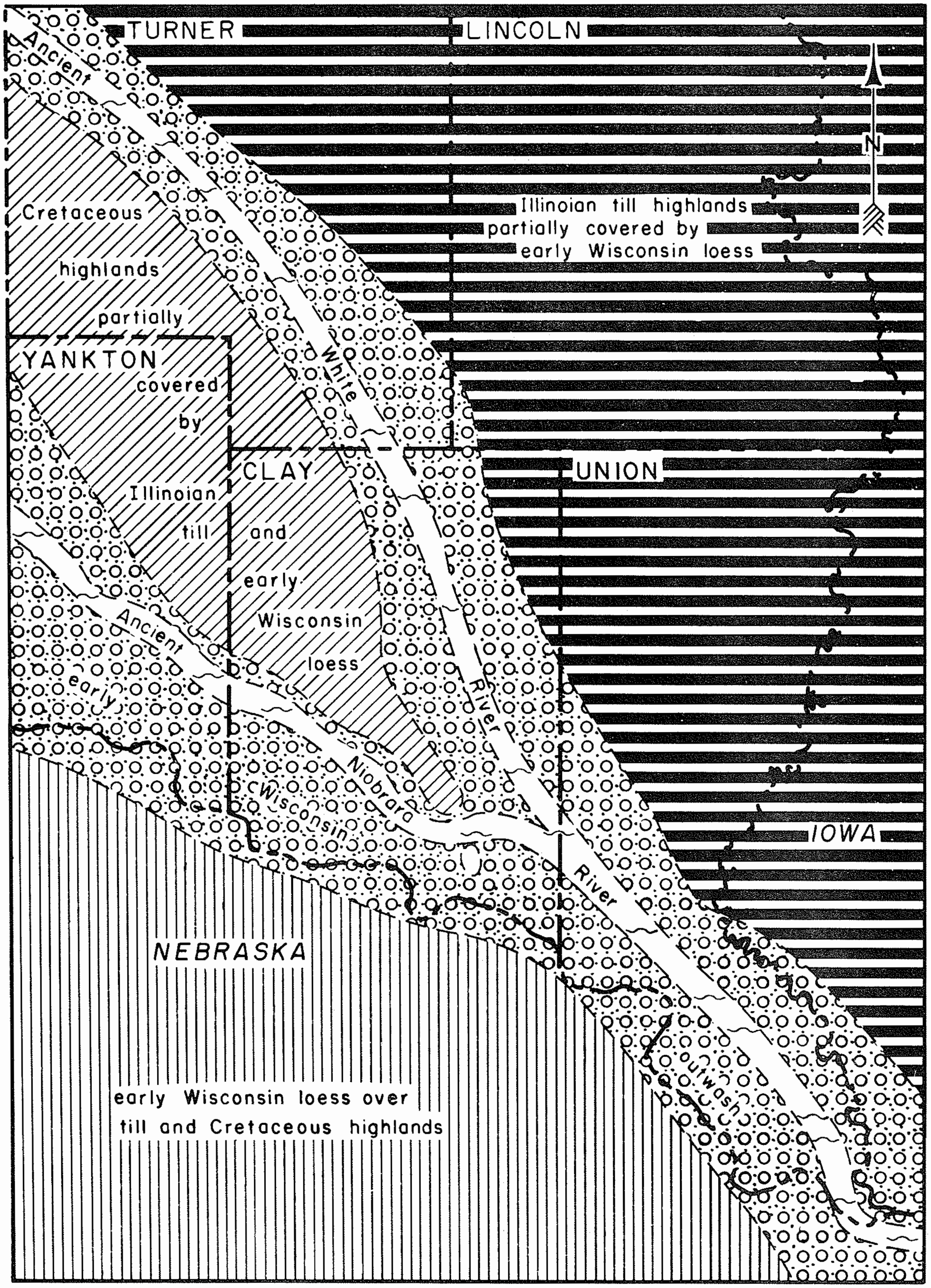

Figure 10. Idealized paleogeologic map of southeastern South Dakota at the beginning of late Wisconsin time.

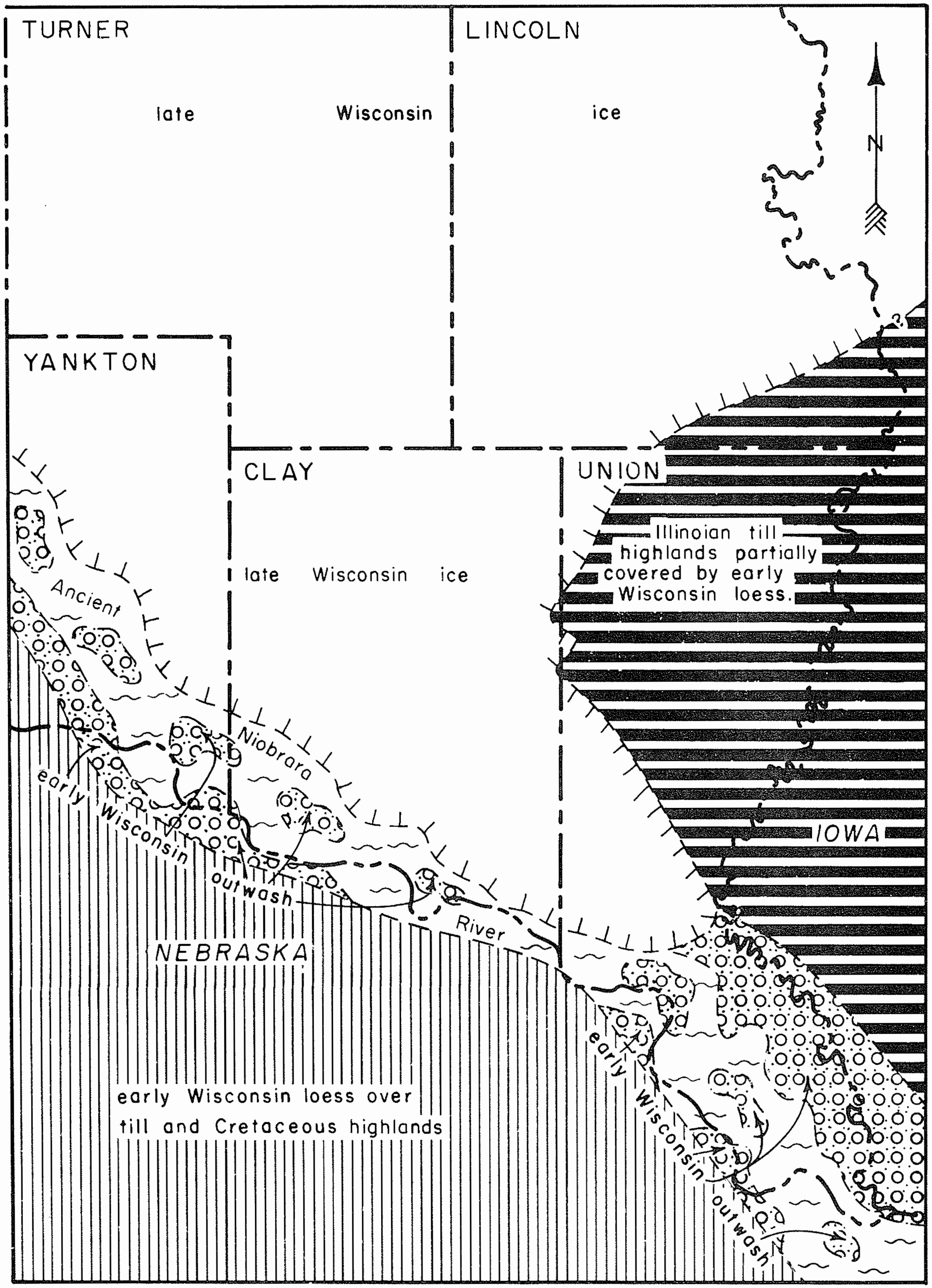

Figure 11. Idealized paleogeologic map of southeastern South Dakota during maximum late Wisconsin ice advance.

County; however, the north bluff of the Missouri trench is made up almost entirely of late Wisconsin till. Much of the ice and debris that would have formed end moraine on the floodplain of the Missouri probably was removed by meltwaters coming from the glacier during the ablation season. End moraine may have actually existed beyond the north bluff (fig. 12). Some end moraine was built on the former floodplain causing a constriction in the Missouri trench near Vermillion. To either side of this constriction the valley again resumes its normal width in the area.

The late Wisconsin ice remained in the ancient White River trench longer than elsewhere in the county (fig. 13). This hypothesis is supported by the fact that as much as 136 feet of late Wisconsin till is found in the central part of the county above the former valley floor while only about 50 to 60 feet is found on the highlands to either side of the valley. As the ice stood in this position (fig. 13), minor fluctuations probably occurred along its margin. These slight fluctuations may have contributed to construction of the end-moraine complex in the western part of the county. It is possible also that poorly-developed end moraine may exist in the northeastern section of the county in the area mapped as high relief ground moraine (pl. 1 and fig. 13). The author believes, however, that most of the high moraine in northeastern Clay County is best classified as ground moraine because it is devoid of any ridge-like trends or crests.

Formation of the present-day Vermillion River trench (pl. 1) probably began during the retreat of the late Wisconsin ice when meltwaters from the wasting glacier carved a deep trench through the late Wisconsin ground moraine (figs. 13 and 14). This trench was cut into the underlying early Wisconsin outwash, and late Wisconsin meltwaters probably removed some of the older outwash and later partly refilled the trench with outwash of late Wisconsin age. That the younger outwash is late Wisconsin is corroborated by a radiocarbon date in the Vermillion valley outwash near Hurley, Turner County, South Dakota, approximately 14 miles north of the Clay County boundary. Wood recovered at a depth of 32 feet from a well in 98-53-15c was dated at 12,760±120 years B. P. (sample no. Y-595).

After the retreat of the late Wisconsin ice, westerly winds carried vast amounts of silt and fine sand from the Missouri and Vermillion River outwash and deposited this material as loess and dune sand on the adjacent uplands. Alluvium has been deposited in the valleys of Recent streams and the constantly shifting channels of the Vermillion and Missouri Rivers have left evidence of erosion and deposition in the valleys in which they flow.

Since the retreat of the late Wisconsin ice sheet more than 12,000 years ago, the topography of Clay County has been sculptured by wind and water into its present-day form. Erosional forces work continuously to destroy the highlands, while alluvial and colluvial sediments are deposited along the drainageways.

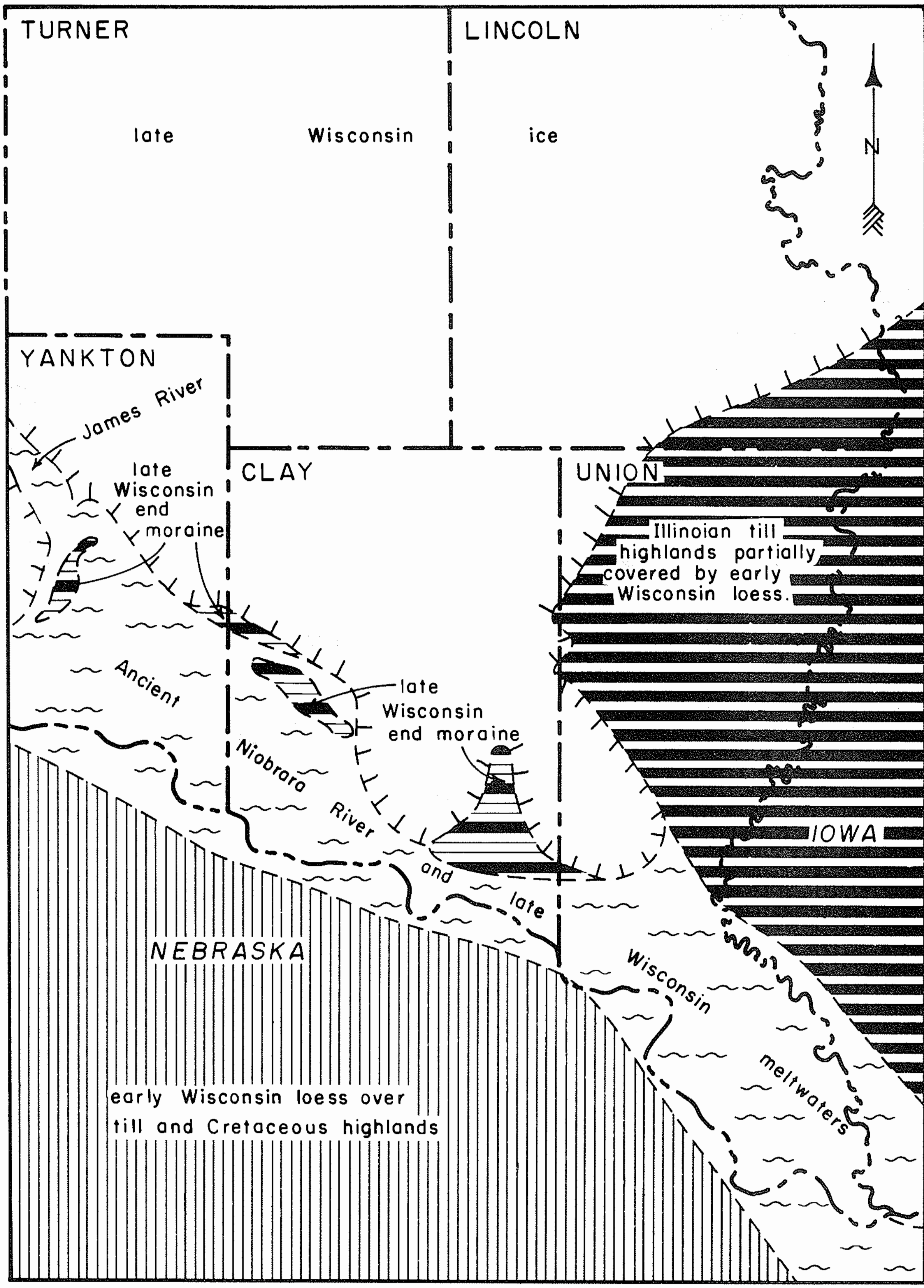

Figure 12. Idealized paleogeologic map of southeastern South Dakota during early stage of retreat of the late Wisconsin ice.

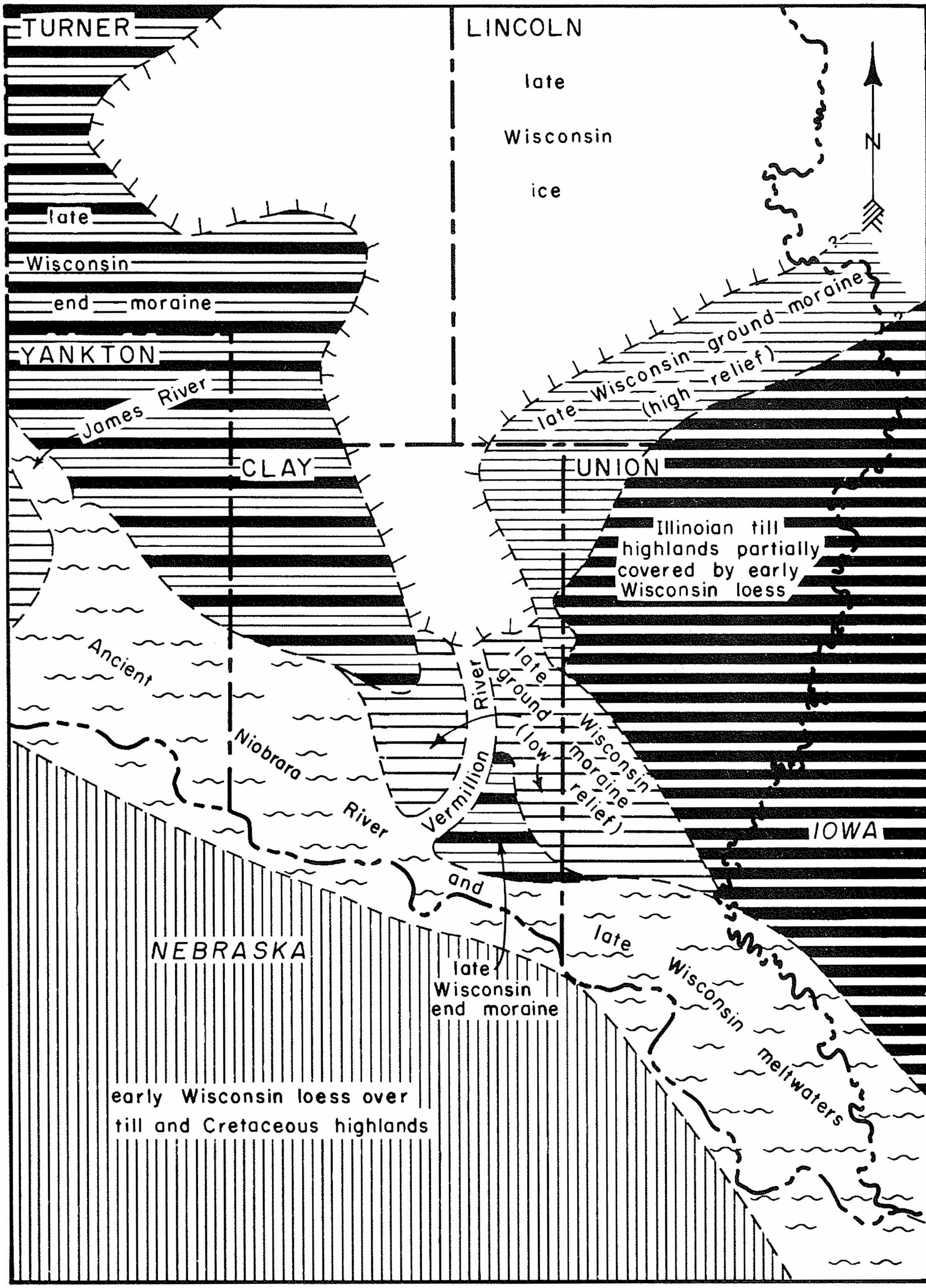

Figure 13. Idealized paleogeologic map of southeastern South Dakota during retreat of the late Wisconsin ice.

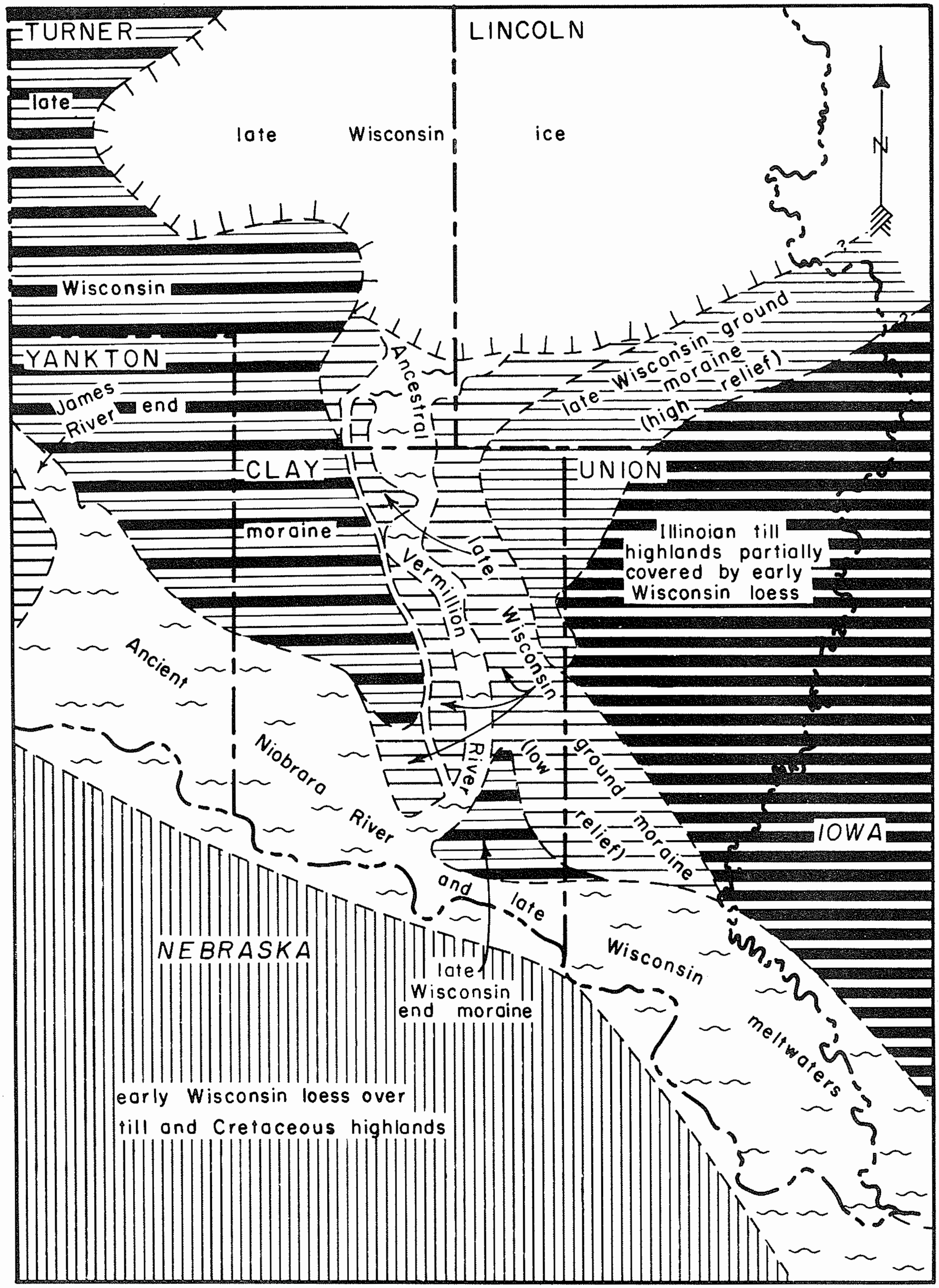

Figure 14. Idealized paleogeologic map of southeastern South Dakota after late Wisconsin ice has retreated from Clay County.

ECONOMIC GEOLOGY

Exploration and Development of Mineral Deposits

Mineral resources are considered to be those minerals within the ground that are minable today or may be minable in the future. The minability of a specific mineral depends primarily on its usefulness to man. Understandably, this usefulness may change as man advances in his capabilities and technology. For this reason, a mineral which perhaps 100 years ago was considered of little value may now contribute greatly to man's economy. Thus, any mineral deposit that is easily accessible and of substantial extent is worthy of notation.

Geologic Factors

Many geologic factors play an important role in mineral exploration and govern the ultimate removal of the mineral from the ground for use by man. Such factors as the amount of overburden that must be removed, the size of the deposit and the purity of the mineral being considered, are of prime importance. Often a very pure mineral deposit may be passed by, and a less pure deposit chosen for development because the latter deposit is larger and nearer the surface. When minerals are extracted from beneath the surface, other factors, such as the static ground-water table and artesian head, must be considered. These factors may govern the maximum depth at which the deposit can be mined.

Economic Factors

In addition to the geologic factors mentioned above, a number of economic aspects must be considered during exploration and development of a mineral deposit. Of primary importance is the economic desire for a specific mineral commodity, and the availability and location of suitable markets. Transportation and labor are among other economic factors that may exercise control over exploration and development of mineral deposits.

In Clay County, transportation would present little problem. Good roads exist throughout the county and rail service is available. In addition, the Missouri River offers a convenient waterway to mid-western and southern markets.

Mineral Resources of Clay County

Water

The largest single mineral commodity available in Clay County is water. In the form of surface water or ground water, this commodity is available in abundance. The Missouri River offers nearly an unlimited supply of fresh water for use by a variety of consumers, and nearly any desired capacity could be withdrawn from the Missouri for industrial, municipal, irrigation or domestic use.

In addition, ground water is available from several sources within the county. The major buried outwash shown on plate 4 constitutes a portion of one of the largest fresh-water aquifers in southeastern South Dakota. The aquifer underlies approximately 75 percent of the county (fig. 15), and is composed of outwash sands and gravels deposited in the ancient White and Niobrara River valleys by meltwaters from several glaciers. The aquifer is capable of supplying large-yield wells with up to 2000 gallons per minute of fresh water.

Smaller yields of ground water are available from isolated glacial aquifers, the Niobrara Marl and sandstones of the Dakota Group. The various aspects of these aquifers, including quantity, quality, and general availability of water, are discussed in part II of this report.

Sand and Gravel

Sand and gravel is a valuable resource in Clay County. Although many industries make use of sand and gravel, its chief use in South Dakota is in road construction and concrete aggregate. A total of sixteen samples of sand and gravel from Clay County have been tested by the South Dakota Department of Highways and their possible uses in various aspects of road construction have been reported. These reports, as well as several showing test results from sand and gravel areas in surrounding counties, are tabulated by Christensen and Stephens (in preparation).

The most accessible sand and gravel in Clay County is found beneath the floodplains of the Vermillion and Missouri Rivers (pl. 1). In the Vermillion River trench the sand and gravel is part of the glacial outwash deposits. The outwash is close to the surface and in some places is exposed at the surface. Where the outwash is exposed, it is shown on plate 1 by the symbol Qwltvo. In these places no stripping is required before the sand and gravel is mined. Throughout the rest of the Vermillion trench the outwash is buried beneath overbank sediments deposited while the Vermillion River was in flood stage. In these areas, shown by the symbol Qo on plate 1, approximately 10 feet of stripping would be required before the outwash could be mined.

There is an estimated 4,770,304,000 cubic yards of sand and gravel in the Vermillion trench. Not all of this material is accessible to man, however, because of its depth and the high ground-water table that exists in the deposit. The water table ranges between 7 and 15 feet below land surface in the Vermillion trench. This high water table must be considered when a sand or gravel pit is being studied for development, because dredging or drag-line equipment would be necessary to recover sand and gravel from below the water table. This type of equipment has been used with success to recover sand and gravel to a depth of 40 feet in the Vermillion trench.

The deposits in the Vermillion trench range in size from fine sand to extremely coarse gravel containing cobbles and boulders. In general, they contain a certain percentage of coarse gravel (probably less than ten percent) commonly referred to as oversize material.

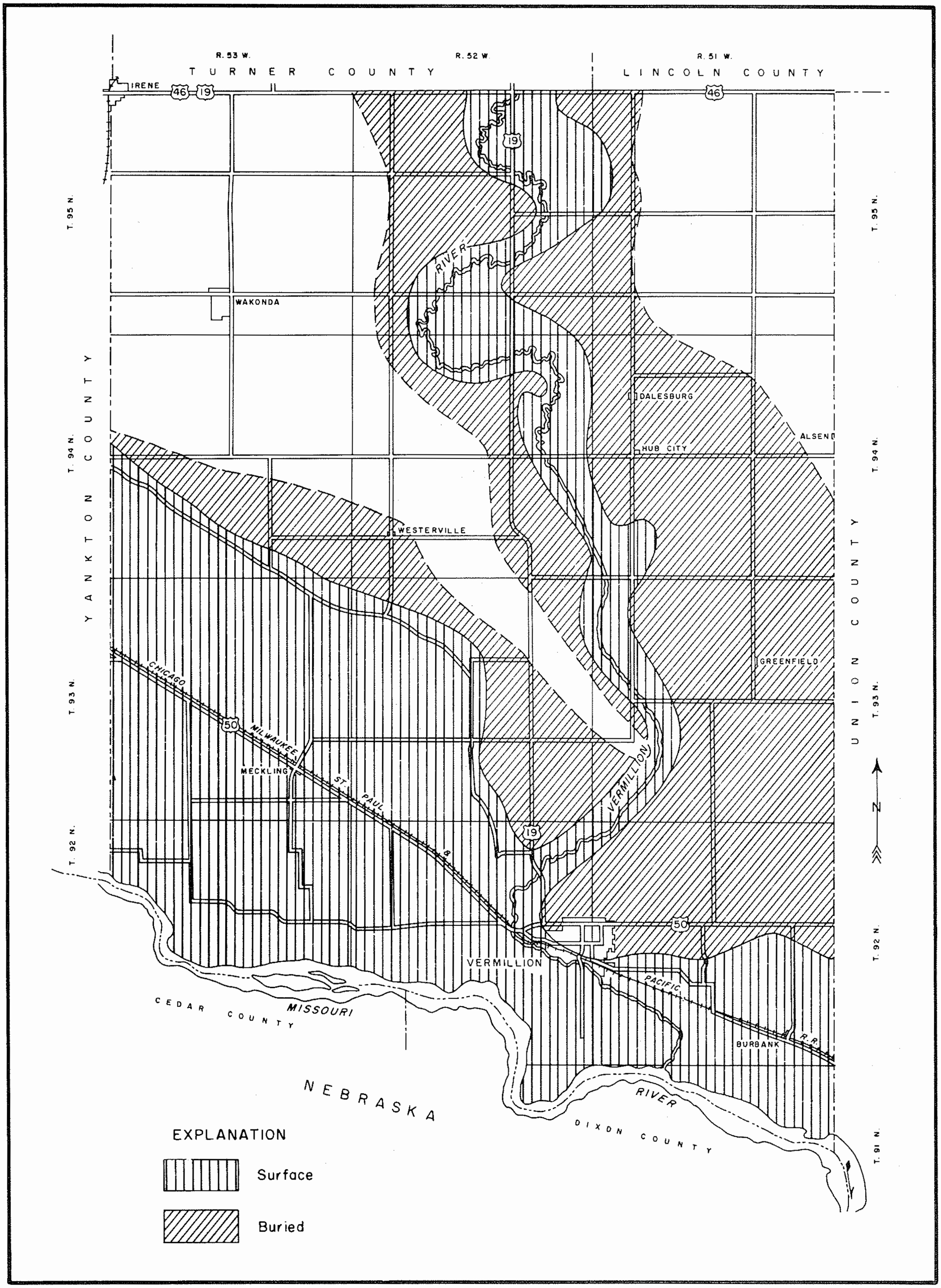

Figure 15. Map showing distribution of the major glacial aquifer in Clay County. (modified from Christensen and Stephens, 1965.)

The materials in the Missouri trench are generally much finer than those in the Vermillion trench, and consist primarily of fine to coarse sand with varying amounts of silt and fine gravel.

The areas shown on plate 1 as Qpb and Qb offer excellent areas for sand excavation. In these areas sand is present at, or very near, the surface. The water table must also be considered when excavating sand from the Missouri trench because, like the water table in the Vermillion trench, it ranges from 7 to 15 feet below the surface.

The areas shown on plate 1 as Qcf and Qo in the Missouri trench do not contain sand and gravel in substantial quantities near the surface. In these areas, 30 to 90 feet of overburden must be removed before outwash material could be mined.

Other deposits of sand and gravel, in addition to those on the floodplains, are present in Clay County, but in most instances they are too thin or too small to be economically important. It would be possible, however, to use these deposits for conditioning farm lanes or short distance roads. These deposits are shown on plate 1 by the symbols Qds and Qwlto.

Chalk

Chalky areas within the Niobrara Marl crop out in several areas in Clay County and are represented on plate 1 by the symbol Kn.

Chalk can be used for building stone and lime and in the manufacture of paint, putty, whiting, kalsomine, oil cloth, roofing cement, gunpowder, rubber and leather.

No tests to determine the qualities of the chalk from Clay County have been made, but chalk from exposures in the surrounding areas have been tested for various purposes. In general, South Dakota chalk is suitable for the manufacture of putty and rubber. The main objectionable feature of South Dakota chalk is its color. Industry prefers a pure white chalk for the manufacture of whiting, putty and rubber and the chalk from the Niobrara Marl is usually light gray to cream colored. If this chalk were to be used for industrial purposes, it would surely command a lower price than the natural white chalk from other areas of the country.

The deposits of chalk in Clay County that are exposed at the surface crop out along the "bluff road" about 8 miles northwest of Vermillion and at "Spirit Mound" about 6 miles north of Vermillion. Under the present economic circumstances the deposits in these areas are considered too small to be mined commercially. Elsewhere in the county, the chalk is overlain by up to 50 feet of glacial drift.

Clay and Boulders

Approximately 50% of the surficial deposits of Clay County consists of boulder clay (till) deposited by the glaciers. The possibility exists that some of this clay could be used in the manufacture of ceramic products. No information is presently available regarding the industrial qualities of the clay.

Boulders and cobbles can be found scattered over the surface of the high relief end moraine in western Clay County (pl. 1). Where these boulders are abundant, they could be stripped from the surface of the end moraine for use as riprap.

Oil and Gas

Despite the fact that several oil tests have been drilled in southeastern South Dakota (Schoon, 1965), no commercial quantities of oil or gas have been discovered in that part of the State. Oil and gas may occur within the bedrock formations of southeastern South Dakota, however, and only additional investigation will prove or disprove the presence of these mineral commodities.

Metals

No metallic mineral deposits of major importance have been found in southeastern South Dakota; however, several areas have been test-drilled as a direct result of reconnaissance surveys made in search of such deposits.

A magnetometer survey has been made of the entire State and several areas near Clay County have been further investigated. The magnetometer is an instrument used to measure magnetic intensities of buried deposits. During the investigations in southeastern South Dakota a magnetic high, or anomaly, was discovered to lie in an east-west direction through central Clay County (fig. 16). The most favorable position on this anomaly for further investigation was 93-50-25b in Union County and at 93-55-12 cba in Yankton County. These two areas were test-drilled by the South Dakota Geological Survey and a core taken from the Precambrian basement rock. An analysis was made of the 54-inch long core taken from a depth of 796 feet at 93-50-25b in Union County with the following results:

	"Unaltered Rock" *	"Altered Rock" **
Iron	14.47%	13.61%
Titanium dioxide	6.76	3.60
Magnesium oxide	1.89	5.29
Calcium oxide	10.39	4.40
Silica	33.43	41.05
Combined oxides	40.19	33.54
Loss on ignition	11.22	12.23

* Gabbro, as from 39-54 inches
** Clay, as from 28-39 inches

A similar core with similar analytical results was obtained from a South Dakota Geological Survey test boring of the Willowdale magnetometer high in Yankton County.

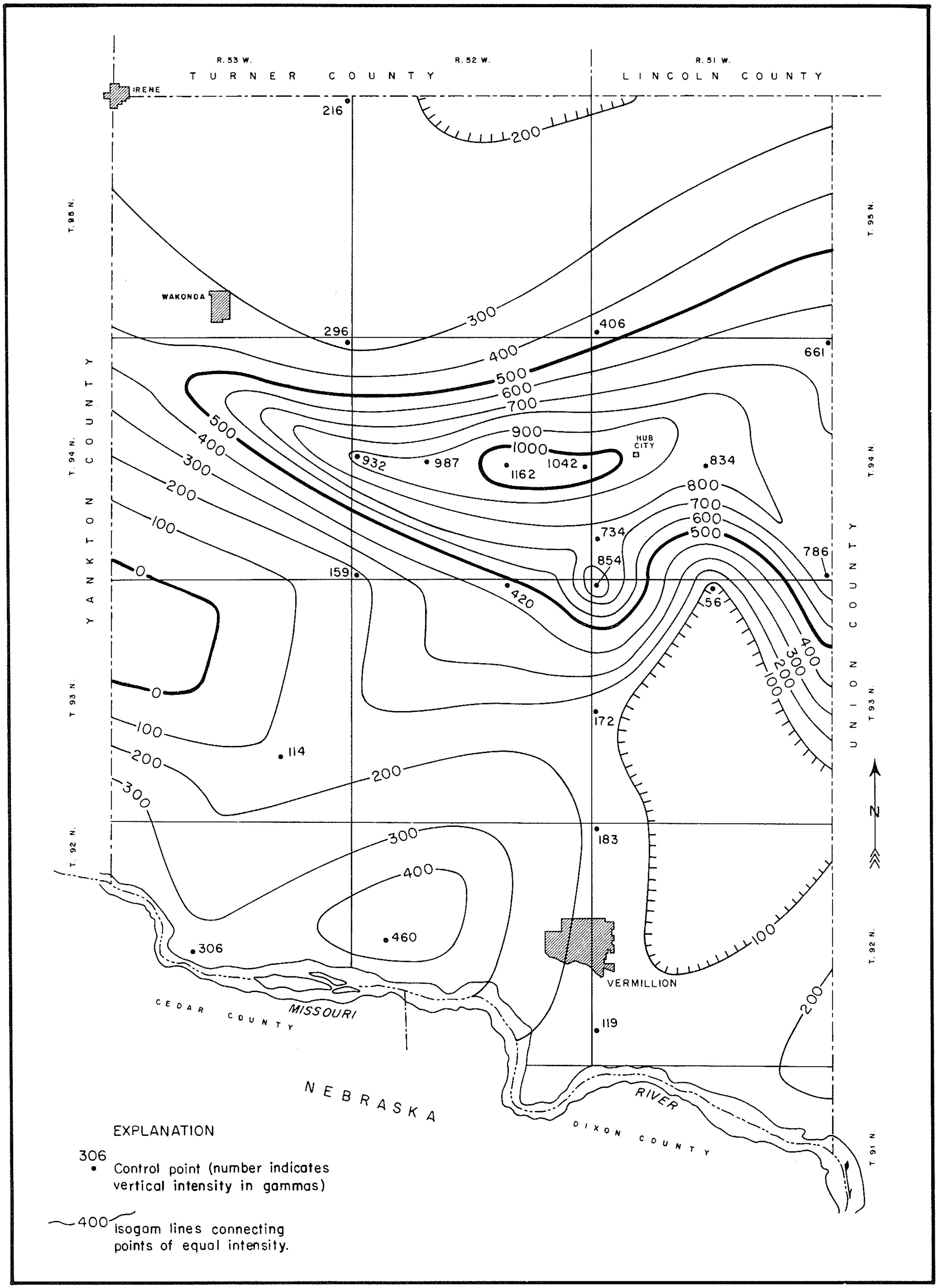

Figure 16. Magnetometer map of Clay County. *(from Petsch, 1962.)*

SUMMARY

The investigation of Clay County was designed and undertaken with a two-fold purpose in mind. Of primary importance was the location of available ground-water supplies that would support high-yield wells necessary for irrigation and industrial expansion. The high-yield glacial aquifer was discussed in the foregoing pages from a geologic standpoint. Included were the physical aspects and character of the material comprising the aquifer. The hydrological information obtained from the study will be reported in part II of this report. Included will be a discussion on quantity, quality and availability of ground water from all the known aquifers in the county.

The second major purpose of the investigation was to prepare a geologic map and report that would include all of the geological information available for Clay County. The geology of the county is discussed in part I. Special emphasis has been placed on the Pleistocene sediment because these sediments are the major surficial deposits present.

It is hoped that the report has contributed to the overall understanding of the geology and hydrology of South Dakota and may serve as a starting point for later observers.

GLOSSARY OF GEOLOGIC TERMS

Altitude.--The vertical distance between a point and a datum surface, such as sea level.

Aquifer.--A formation, group of formations, or part of a formation that can serve as a useful source of water.

Arkosic sand.--A sand deposit essentially composed of nearly-equal amounts of grains of quartz and feldspar.

Artesian.--Refers to ground water under sufficient pressure to rise above the top of the aquifer containing it.

Artesian head.--Artesian pressure, expressed as the height above the base of the overlying confining bed, to which water from an artesian aquifer would rise in a tightly cased well that had no discharge. May sometimes be given with reference to some datum, as "artesian head of 10 feet above land surface."

Basalt.--An extrusive rock composed primarily of calcic plagioclase and pyroxene. A fine-grained, dark-colored, igneous rock.

Basin.--The drainage or catchment area of a stream or lake.

Bedrock.--Any solid rock underlying the looser materials of the earth's surface.

Bentonite.--A clay formed by the decomposition of volcanic ash and largely composed of the clay minerals montmorillonite and beidellite.

Calcareous.--Containing calcium carbonate.

Calcite.--A mineral composed of calcium carbonate; similar to aragonite; a very common mineral; the principal constituent of limestone.

Calc-tufa.--Calcium carbonate soil cement formed by evaporation of calcium carbonate-rich water brought to the surface by springs.

Chalk.--A very soft, white to light-gray, porous, friable limestone composed of the shells of floating microorganisms and some bottom dwelling forms in a mass of microscopic calcite crystals.

Chert.--A compact form of silica composed of chalcedonic or opaline silica; of organic or precipitated origin; hornstone.

Colluvium.--Loose or incoherent deposits, usually at the foot of a slope, brought there chiefly by gravity.

Conglomerate.--Rounded water-worn fragments of rock or pebbles, cemented together by another mineral substance.

Constructional topography.--A surface whose form, position, orientation, or general character is the result of building-up processes, such as deposition by glacial ice.

Cross bedding.--The arrangement of stratification transverse or oblique to the main planes of stratification of the strata concerned.

Coteau.--A term used by early French travelers in North America to signify a range of hills or a dissected escarpment, such as the Coteau des Prairies.

Dike.--A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks.

Dolomite.--A rock similar to limestone but whose chemical composition approximates that of the mineral dolomite (a calcium magnesium carbonate).

Drift.--All rock material transported by glacial ice, all material predominantly of glacial origin deposited in the sea or in bodies of glacial meltwater, whether rafted in icebergs or transported in the water itself; includes till, stratified drift, and scattered rocks.

Dune sand.--Windblown sand that has drifted to form low hills or dunes.

Electric log.--The log of a well or bore hole obtained by lowering electrodes in the hole and measuring various electrical properties of the geological formations traversed.

Elevation.--Generally refers to the height in feet above mean sea level.

Epoch.--A subdivision of a period.

Erosion.--The group of processes whereby earth material or rock material is loosened and moved from place to place; includes weathering, corrasion, and transportation.

Feldspar.--A group of abundant rock-forming minerals including microcline, orthoclase, plagioclase and anorthoclase.

Fissility.--The property of splitting easily along closely spaced parallel planes.

Floodplain.--That part of a river valley adjacent to the river channel, which is built of sediments during the present regimen of the stream and which is covered with water when the river overflows its banks at flood stage.

Fluvial.--Deposited by the action of rivers.

Fossil.--The remains or traces of animals or plants that have been preserved by natural causes in the earth's crust, exclusive of organisms buried since the beginning of historic time.

Fresh water.--Water containing less than 1,000 ppm (parts per million) dissolved solids.

Gabbro.--A plutonic rock consisting of calcic plagioclase and clinopyroxene.

Gamma-ray log.--The log of a well or bore hole made by measuring variations in the natural radioactivity of the rocks through which the hole passes.

Glacial drift.--See drift.

Glaciation.--A glaciation was a climatic episode during which extensive glaciers developed, attained a maximum extent, and receded.

Glauconite.--A green mineral, closely related to the micas, that commonly occurs in sedimentary rocks of marine origin.

Granite.--An igneous, coarsely crystalline rock consisting essentially of alkalic feldspar, quartz; usually contains small amounts of muscovite, biotite, hornblende, or, rarely, pyroxene.

Gypsum.--A common mineral of evaporites used in the manufacture of plaster of paris.

Humus.--Dark-colored, organic, well-decomposed soil material consisting of the residues of plant and animal materials together with organic and inorganic compounds.

Igneous.--Rocks formed by solidification from a molten or partially-molten state.

Interglaciation.--An episode during which the climate was incompatible with the wide extent of glaciers that characterized a glaciation; time period between glaciations.

Limestone.--A bedded sedimentary deposit consisting chiefly of calcium carbonate.

Lithology.--Physical character of a rock, generally as determined megascopically or with the aid of a low power magnifier.

Loess.--A homogeneous, nonstratified, unconsolidated deposit consisting predominantly of silt with small amounts of very fine sand and/or clay; eolian in origin.

Magnetic anomaly.--Any departure from the normal magnetic field of the earth as a whole. May be high or low, subcircular, ridge- or valley-like, or linear or dikelike.

Magnetometer.--An instrument used for measuring magnetic intensity; in ground magnetic prospecting usually an instrument for measuring the vertical intensity.

Marl.--A calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells. Also calcareous deposits of lakes which contain 30 to 90 percent of calcium carbonate.

Metamorphic.--Rocks formed in the solid state in response to pronounced changes of temperature, pressure and chemical environment.

Mudstone.--A sedimentary rock consisting of indefinite amounts of clay, silt and sand.

Orthoquartzite.--A clastic sedimentary rock composed of silica-cemented quartz sand.

Outwash.--Stratified drift deposited by meltwater streams beyond the margin of active glacier ice.

Overburden.--Useless material of any type that overlies a useful deposit of minerals, ore, coal, etc.

Oxidation.--Process of combining with oxygen; an increase in positive valence or decrease in negative valence.

Oxidized zone.--That portion of a deposit which has been subjected to the action of surface waters carrying oxygen, carbon dioxide, etc.

Periglacial.--Refers to an area of nearly perennially frozen ground peripheral to an ice sheet.

Period.--The fundamental unit of the standard geologic time scale, the time during which a standard system of rocks was formed.

Physiography.--The study of the surface of the earth--its physical form and the processes and forces that mold and change that surface.

Pipestone (Catlinite).--Indurated sericitic claystones and siltstones; deposits in southeastern South Dakota, southwestern Minnesota, and northwestern Iowa are interbedded with Sioux Quartzite. Used by the Dakota Indians for making pipes, tools, and ornaments.

Planktonic.--Floating.

Quartz.--A mineral, silicon dioxide (silica), having hexagonal crystals and a Mohs hardness of 7; most abundant mineral in earth's crust.

Quartzite.--1. A granulose metamorphic rock consisting essentially of quartz. 2. Sandstone cemented by silica which has grown in optical continuity around each fragment.

Radiocarbon dating.--Determination of the age of a material by measuring the proportion of the isotope C^{14} (radiocarbon) in the carbon it contains. The method is suitable for the determination of ages of as much as 30,000 years.

Riprap.--Rock or broken rock used for protection of bluffs or structures exposed to wave action.

Sandstone.--A cemented or otherwise compacted detrital sedimentary rock composed predominantly of sand-size quartz grains.

Schist.--A medium or coarse-grained metamorphic rock with sub-parallel orientation of the micaceous minerals which dominate its composition.

Sedimentary.--Term used to classify rocks formed by the accumulation of sediment in water (aqueous deposits) or from air (eolian deposits).

Sericite.--A fine-grained variety of mica; occurs in small scales, especially in schists.

Series.--A time-stratigraphic unit ranked next below a system.

Shale.--A laminated sedimentary rock, in which the constituent particles are predominantly of the clay grade.

Siliceous.--Of or pertaining to silica; containing silica, or partaking of its nature.

Siltstone.--A very fine-grained consolidated fragmental sedimentary rock composed predominantly of particles of silt grade.

Soil series.--A group of soils having soil horizons similar in characteristics and arrangement in the soil profile, and developed from a particular type of parent material.

Sorting coefficient.--A mathematical measure of the degree of sorting of a sediment.

Stratification.--Layering of rock produced by deposition of sediments in beds or layers (strata), laminae, and other essentially tabular units.

Surficial.--Characteristic of, pertaining to, formed on, situated at, or occurring on the earth's surface; especially alluvial or glacial deposits lying on the bedrock.

System.--The fundamental unit of world-wide time-stratigraphic classification of Phanerozoic rocks; contains strata deposited during the corresponding geologic period.

Terrace.--A relatively flat, horizontal or gently inclined surface, usually long and narrow, that is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side; when typically developed is steplike in character.

Texture.--Geometric aspects of the component particles of a rock, including size, shape, and arrangement.

Till.--Non-sorted, non-stratified sediment carried and/or deposited by a glacier. Commonly called boulder clay.

Topography.--The physical features of the land surface, especially the relief and contour.

Unconformity.--A surface of erosion or nondeposition that separates younger strata from older rocks.

Valley.--An elongate depression in the earth's surface, usually with an outlet, ordinarily occupied by a stream or river.

Water table.--The upper surface of the zone of saturation, except where that surface is formed by an impermeable boundary.

Weathering.--The group of processes whereby rocks on exposure to the weather change in character, decay, and finally crumble into soil.

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APPENDIX A.--SELECTED LOGS OF WELLS AND TEST HOLES IN CLAY COUNTY, AND VICINITY

Drilled by: USBR, U. S. Bureau of Reclamation; USGS, U. S. Geological Survey; SDGS, South Dakota Geological Survey; P. C., private contractor.

Source of data: D, drillers log; S, sample study.

Elevation: To the nearest foot; obtained by instrument.

Geologic unit: Qu, Pleistocene and Recent undifferentiated; Qow, outwash undifferentiated; Qal, alluvium undifferentiated; Qt, till undifferentiated; Qwlt, late Wisconsin till; Qwlo, late Wisconsin outwash; Qwel, early Wisconsin loess; Qit, Illinoian till; Qks, Sappa silt and clay; Qkg, Grand Island sand and gravel; Qkt, Kansan till; Kn, Niobrara Marl; Kc, Carlile Shale; Kg, Greenhorn Limestone; Kgs, Graneros Shale; Kd, Dakota Group.

Test Hole 1
Location: 92-51-9cccc
Drilled by: USBR
Source of data: S
Elevation: 1243 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, light yellowish-brown, oxidized, sandy, silty, calcareous, some reworked carbonates and chalk balls	0- 10
	Glacial till, yellowish-gray (5Y8/1), highly calcareous, sandy, silty, chalky	10- 20
	Glacial till, light brownish-gray (5YR6/1), sandy, silty, highly calcareous	20- 30
	Glacial till as above, sample is 50% medium- to coarse-grained quartz sand	30- 40
	Glacial till, light brownish-gray (5YR6/1), sandy, silty, highly calcareous, becoming very sandy in 110-120 sample	40-120
Qow	Sand, medium to very coarse and fine gravel, predominantly quartz, some igneous and some siltstone pebbles, much coal	120-130
	As above, less coal	130-180
	As above, coarser grained (very coarse sand to medium gravel)	180-190
	As above, grain size smaller (fine sand to fine gravel)	190-200
	Gravel, medium to coarse grained, subangular to rounded igneous; some shale pebbles	200-220
	Sand as described from 120-130	220-250
Kd	Bedrock-shale, medium-gray, silty, slow effervescence, banded, massive. Hard. Banding caused by silty zones. Some pyrite.	250-260
	Driller has bedrock at 241	

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Test Hole 2
Location: 92-51-9dddd
Drilled by: USBR
Source of data: S
Elevation: 1251 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, yellowish-gray (5Y7/2), silty, sandy, highly calcareous, contains many chalk fragments	0- 10
	Glacial till, yellowish-gray (5Y8/1), silty, contains much chalk, highly calcareous	10- 20
	Glacial till, yellowish-gray (5Y7/2), silty, sandy, contains pebbles of chalk and igneous rocks, highly calcareous	20- 30
	Glacial till, medium light-gray, highly calcareous, silty, sandy	30-100
Qow	Sand, medium to gravel, medium, consists of limestone and shale pebbles with fraction of granite and other igneous materials. Trace of coal; subangular to subrounded.	100-150
	Sand, medium to very coarse to gravel, fine, subangular to rounded, primarily quartz with trace of igneous materials and shale and limestone pebbles and calcite	150-252
Kd	Shale, gray	252-265
	Driller has bedrock at 252 (gray shale)	

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Test Hole 3
Location: 92-51-10dddd
Drilled by: USBR
Source of data: S
Elevation: 1251 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, yellowish-gray (5Y8/1), highly calcareous, contains much chalk	0- 10
	Glacial till, yellowish-gray (5Y7/2), highly calcareous, contains much chalk	10- 30
	Glacial till, medium light-gray (N6), highly calcareous, gravelly, little chalk present, very sandy from 90-110	30-110
Qow	Sand, coarse to gravel, fine, subangular to subrounded, consists of quartz and igneous rock fragments, shale and limestone pebbles and minor amounts of coal and feldspar	110-160
	Sand, medium to very coarse, primarily quartz and igneous rock fragments, subangular to subrounded	160-170
	Sand, medium to gravel, fine, primarily quartz and igneous rock fragments, subangular to rounded, some limestone and shale fragments	170-265

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Test Hole 4
Location: 92-51-12dddd
Drilled by: USBR
Source of data: S
Elevation: 1235 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, yellowish-gray (5Y8/1), silty and sandy, highly calcareous	0- 10
	Glacial till, light-gray (N7), as above	10- 20
	Glacial till, medium light-gray (N6), as above, very sandy from 110-120	20-120
Qow	Sand, coarse to gravel, fine, consists of quartz, igneous rock fragments, limestone and shale pebbles and trace of coal	120-260
	Driller has bedrock at 245	

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Test Hole 5
Location: 92-51-14aaaa
Drilled by: USBR
Source of data: S
Elevation: 1242 feet

Qwlt	Glacial till, yellowish-gray (5Y8/1), contains much chalk, silty, highly calcareous	0- 20
	Glacial till, light-gray (N7), silty, chalky, highly calcareous	20- 30
	As above, medium light-gray (N6), very sandy from 100-130	30-130
Qow	Sand, medium to gravel, fine, consists of quartz, igneous rock fragments, shale and limestone pebbles with minor amounts of coal and calcite, angular to subrounded, much coal from 160-170	130-260
Kd	Bedrock-silt (quartzose) loosely cemented, slightly calcareous, very light-gray (N8), partly banded	260-265
	Driller has bedrock at 228	

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Test Hole 6
Location: 92-51-17bbbb
Drilled by: USBR
Source of data: S
Elevation: 1229 feet

Geologic Unit	Description	Depth Feet
	No sample	0- 30
Qwlt	Glacial till, light-gray clay, silty, highly calcareous, trace of fine to coarse quartz sand, subangular and rounded, trace coal and other rock fragments	30-110
	As above, more sand and rock fragments	110-120
Qow	Sand, very coarse to fine gravel (70%> 2mm), quartz, feldspar, various igneous rock fragments, trace coal, some limestone and other calcareous rocks. Quartz is subrounded to round, other fragments angular to subrounded	120-130
	Sand, as above with about 25-35% coal, less rock fragments; primarily coal and quartz	130-140
	Sand, as above, less coal (5-10%), quartz> 50%, remainder of sample is rock fragments as above	140-150
	Sand, as above, trace of coal, 80% quartz, remainder is rock fragments	150-160
	Sand, as above, coarse to fine gravel (1/2 to 3mm), >80% quartz	160-200
	Gravel, medium to coarse sand, >80% quartz, more calcareous material, trace Kn (not cuttings)	200-260
	No bedrock in cuttings	
	Bedrock from E-log 255 (Dakota Group)	

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Test Hole 7
Location: 92-52-9dddd
Drilled by: SDGS
Source of data: D
Elevation: 1147 feet

	Road fill	0- 4
Qal	Clay, brown-gray, very silty, fine	4- 14
	Clay, brown-gray, partly saturated, very fine	14- 19
Qow	Sand, fine, clayish, silty, brown-gray to light-gray, water at 20 feet	19- 70
	Sand, gray-brown to light-gray, very fine	70-122
Kg	Bedrock	122-124

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Test Hole 8
Location: 92-52-14abaa
Drilled by: USBR
Source of data: D
Elevation: 1219 feet

Geologic Unit	Description	Depth Feet
Qwlt	Loam, black, sandy	0- 2
	Silt, brown, sandy	2- 13
	Till, brown	13- 20
	Till, gray, sand lenses	20-118
Qow	Sand, fine to medium, fine gravel	118-130
	Sand, medium to coarse, gray, gravel, lignite	130-165
	Sand, gray, medium, gravel, lignite	165-218
Kgs	Shale, gray	218-224
	Shale, gray, silty seams (2" to 2.5" thick)	224-230
	Shale, gray, lignite seam	230-237
Kd	Sand, gray, fine, silty	237-249

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Test Hole 9
Location: 92-53-7ddaa
Drilled by: SDGS
Source of data: D
Elevation: 1150 feet

Qal	Very fine material, gray-white, very powdery (river silt)	0- 10
Qoa	Sand, fine, gray-brown, saturated	10- 90
	Sand, coarse, to gravel, gray-brown	90-122
Kg	Bedrock at 122'	122-125

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Test Hole 10
Location: 92-53-14aaaa
Drilled by: SDGS
Source of data: D
Elevation: 1154 feet

	Silt, brown, clayey, fine	0- 9
Qal	Clay, yellow-brown to sand, very fine, silty, water at 18'	9- 19
Qow	Sand, yellow-brown, fine, with clay, very sticky	19- 49
	Sand, fine, yellow-brown to brown	49- 85
	Gravel, yellow-brown to gray-brown	85-109
Kg	Bedrock	109-113

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Test Hole 11
Location: 92-53-15ab
Drilled by: P. C.
Source of data: D
Elevation: 1155 feet

Geologic Unit	Description	Depth Feet
Qal	River fill--clay to medium sand, mostly very fine sand, mostly quartz, some feldspar and a little dark igneous material	0- 12
Qow	Sand, very fine to fine, loose; mostly angular quartz grains, well sorted	12- 22
	Sand, loose, medium to coarse, mostly quartz with some feldspar; granite and greenstone, mostly angular to subrounded with a few well-rounded grains	22- 32
	As above with a little more rounding to the grains	32- 52
	Sand, medium to fine gravel, loose, quartz, feldspar, granite, dark igneous, and some limestone; angular to subrounded grains; clay parting	52- 65
	Sand, medium loose, subrounded to round, mostly quartz	65- 85
	Sand, medium loose; subrounded to round, mostly quartz, some coal fragments	85- 95
	Sand, coarse, to fine gravel, angular, quartz, granite, limestone with some greenstone, chert and dark igneous pebbles	95- 99
	Sand, coarse to fine gravel, angular quartz, granite, limestone with some greenstone, chert, and dark igneous pebbles; mostly coarse sand	99-116
Kg	Dark-gray shale	116-125

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Test Hole 12
Location: 92-53-16aaaa
Drilled by: SDGS
Source of data: D
Elevation: 1155 feet

Geologic Unit	Description	Depth Feet
Qal	Sand, fine, yellow-brown, water at 19'	0- 19
Qow	Sand, coarse, brown-gray, to fine sand	19- 64
	Sand, coarse, deep-brown, saturated	64- 87
	Gravel, brown-yellow to brown-gray	87-113

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Test Hole 13
Location: 93-50-6cbbb
Drilled by: SDGS
Source of data: S
Elevation: 1284 feet

Geologic Unit	Description	Depth Feet
Qwlt	Till, clay pale yellowish-brown (10YR6/2), silty, sandy, abundant chalk pebbles, calcareous, some iron staining	0- 20
	Till, clay, light brownish-gray (5YR6/1), silty, sandy, chalky, some iron staining, calcareous	20- 40
	Till, clay, pale-olive (10Y6/2) mottled with light brownish-gray (5YR6/1), calcareous, silty, sandy, chalky	40- 50
Qit	Till, clay, dusty-yellow (5Y6/4), calcareous, silty, sandy, chalky	50- 90
	Till, shale, medium-gray (N5), calcareous, silty, mottled oxidation	90-100
	Till, composed almost entirely of shale, medium-gray (N5), pebbly, calcareous, contains many white calcareous specks	100-150
	Till, consisted entirely of shale except for a number of small pebbles, and sand grains	150-160
Kg	Shale, medium-gray (N5), calcareous, hard, banded in part, contains abundant white calcareous specks	160-200

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Test Hole 14
Location: 93-50-18bbbb
Drilled by: USBR
Source of data: S
Elevation: 1254 feet

Geologic Unit	Description	Depth Feet
Qwlt	Chalk, white (N9) to very pale-orange (10YR8/2), highly calcareous	0- 10
	Glacial till, very pale-orange (10YR8/2), to light bluish-gray (5B7/1), chalky, silty, highly calcareous	10- 20
	Glacial till, light bluish-gray (5B7/1) to light-gray (N7), silty, highly calcareous	20- 30
	Glacial till, light bluish-gray (5B7/1), silty, highly calcareous	30- 40
	Glacial till, very pale-orange (10YR8/2) to light bluish-gray (5B7/1), chalky, silty, highly calcareous	40- 50
	Glacial till, light bluish-gray (5B7/1), silty, highly calcareous	50- 60
	Glacial till, light-gray (N7), silty, highly calcareous, becomes sandy from 120-130	60-130
Qow	Sand, medium to gravel, fine, consists of quartz grains, igneous and metamorphic rock fragments, some siltstone and limestone pebbles. Trace of coal. Grains angular to rounded.	130-240
Kd	Siltstone, light-gray (N7), very slightly calcareous, bentonitic	240-261

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Test Hole 15
Location: 93-51-1adda
Drilled by: SDGS
Source of data: S. D.
Elevation: 1318 feet

Qwlt	Till, clay, light yellow-brown, very silty from intermixed loess, pebbly	0- 20
Qwel	Loess, silt, light yellow-brown to light-brown, some gray and green silt at bottom (core 40-45, early Wisconsin loess)	20- 63
Qit	Till, light yellow-brown, pebbly, hard, dry, tenacious (core from 65-70 Illinoian till); some dark-brown streaks from 90-120	63-120
	Till, clay, medium-gray, silty, pebbly, very hard and dry. Rock at 209-210	120-210
Kg	Shale, dark-gray, sticky, greasy, calcareous, very slow drilling	210-230

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Test Hole 16
Location: 93-51-15aaaa
Drilled by: USBR
Source of data: S
Elevation: 1230 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, yellowish-gray (5Y7/2), silty, sandy, highly calcareous	0- 20
	Glacial till, light-gray (N7), silty, highly calcareous	20- 70
Qow	Sand, medium to gravel, medium, much quartz and granite fragments, other igneous and metamorphic rock fragments, some carbonates and siltstone pebbles, trace of coal. Grains subangular to rounded	70-220
	Silt, very light-gray (N8), quartzose, calcareous cement, crumbles easily, bentonitic	
	Sand, medium to gravel, fine, quartz, granite and other igneous and metamorphic rock fragments. Some carbonates, siltstone, and coal. Subangular to subrounded	230-240
Kd	Shale, medium dark-gray (N4), silty, non-calcareous, massive, permeable	240-250
	Siltstone, medium light-gray (N6), banded, non-calcareous	250-260

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Test Hole 17
Location: 93-51-17bbbb
Drilled by: USBR
Source of data: S
Elevation: 1185 feet

Qwlt	Glacial till, yellowish-gray (5Y7/2), silty, highly calcareous, chalky	0- 30
	Glacial till, light-gray (N7), silty, highly calcareous	30- 70
Qow	Sand, coarse to gravel, medium, subangular to rounded, much quartz, granite and other igneous and metamorphic rock fragments, siltstone, carbonate and shale pebbles	70- 90
Qit?	Glacial till, light-gray (N7), silty, calcareous	90-100
Qow	Sand and gravel as above	100-130
Qkt?	Glacial till, clay, silty and sandy, light-gray (N7), calcareous	130-150
	Driller has bedrock at 129	

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Test Hole 18
Location: 93-52-12cccc
Drilled by: USBR
Source of data: S
Elevation: 1214 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, silty, sandy, yellowish-gray (5Y7/2), highly calcareous	0- 10
	Glacial till, clay, light-gray (N7), silty, sandy	10- 50
Kc	Shale, medium light-gray (N6), massive, noncalcareous, non-bentonitic	50- 70

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Test Hole 19
Location: 93-52-13aaaa
Drilled by: USGS
Source of data: D
Elevation: 1145 feet

Geologic Unit	Description	Depth Feet
Qal	Clay, light- to dark-gray, brown streaks. Scattered sand grains	0- 6
Qow	Sand, very coarse to fine, very clayey from 8-10, clean below. Scattered gravel streaks. Gravelly throughout.	6- 30
	Gravel, coarse, sandy	30- 32
	Sand and gravel	32- 76
Kg	Silt, gray-brown, tight, dense	76- 79

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Test Hole 20
Location: 93-52-14bbbb
Drilled by: USGS
Source of data: D
Elevation: 1219 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, dark-brown, silty, sandy, gravelly	0- 10
	Clay, medium-brown to yellow-brown, very silty, sandy, gravelly	10- 15
	Clay, very sandy, to very clayey sand, silty, soupy	15- 21
	Sand, coarse to fine, gravelly, with streaks, very sandy, gravelly yellow-brown clay	21- 30
Kc	Shale, blue-black, tough	30- 34

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Test Hole 21
Location: 93-52-16aaaa
Drilled by: USBR
Source of data: S
Elevation: 1241 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, yellowish-gray (5Y7/2), silty, sandy, highly calcareous, very sandy, from 20-30 feet	0- 30
	Glacial till, clay, light-gray (N7), silty, very sandy, highly calcareous	30-110
Qow	Sand, medium to gravel, fine, composed of quartz, feldspar, igneous and metamorphic rock fragments, some siltstone and carbonate pebbles. Grains subangular to rounded. Trace of coal.	110-170
Qt	Clay, medium light-gray (N6), silty, sandy, highly calcareous	170-180
Kc-Kg	Shales, medium light-gray (N6), massive, contains many small white specks, non-fissile, highly calcareous.	180-190
	Driller has shale at 169	

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Test Hole 22
Location: 93-52-18aaaa
Drilled by: SDGS
Source of data: D
Elevation: 1149 feet

Qal	Clay, gray, very fine, silty, water at 18'	0- 19
Qwlo	Sand, very fine mixed with clayish material, highly saturated, brown-gray	19- 40
Qal	Clay, brown-gray, mixed with gravel, highly saturated	40- 90
Qow	Gravel, with fine sand, brown- to yellow-brown	90-113
Kg	Shale, medium-gray, calcareous, speckled with carbonate	113-114

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Test Hole 23
Location: 93-53-7cccc
Drilled by: SDGS
Source of data: D
Elevation: 1162 feet

Geologic Unit	Description	Depth Feet
	Road fill	0- 4
Qal	Clayish material, very fine, gray-brown	4- 19
	Clayish material, dark-gray, silty with fine sand, water at 20'	19- 89
Qow	Gravel mixed with clay, gray, fine	89-132
Kg	Bedrock	132-135

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Test Hole 24
Location: 93-53-9dddd
Drilled by: SDGS
Source of data: D
Elevation: 1153 feet

Geologic Unit	Description	Depth Feet
Qal	Sand, very fine, silty, brown-gray to yellow-gray	0- 14
	Clayish material, very fine, gray-yellow to yellow-brown, water at 18'	14- 30
Qow	Sand, fine, to gravel, yellow-brown to brown-gray, highly saturated	30-130
Kg	Bedrock	130-131

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Test Hole 25
Location: 93-53-12cccc
Drilled by: SDGS
Source of data: D
Elevation: 1151 feet

Geologic Unit	Description	Depth Feet
Qal	Clayish material, brown-gray, very fine, silty	0- 21
	Clay, brown-gray, very fine, water at 21'	21- 53
Qow	Gravel, mixed with clay, gray-brown, saturated	53- 69
	Sand, fine to gravel, brown-yellow, highly saturated	69- 90
	Gravel, with fine sand, yellow-brown	90-125
Kg	Bedrock	125-126

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Test Hole 26
Location: 94-50-7cccc
Drilled by: USBR
Source of data: S
Elevation: Not recorded

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, yellowish-gray (5Y8/1), silty, sandy, highly calcareous	0- 50
Qwel	Loess, yellowish-gray (5Y7/2), sandy silt, very hard, calcareous	50- 80
	Loess, light-gray (N7), sandy silt, very hard, calcareous	80- 90
Qit	Glacial till, yellowish-gray (5Y7/2), to light-gray, silty, sandy and pebbly, highly calcareous, mostly oxidized	90-150
	Glacial till, light-gray (N7), clay, silty, sandy and pebbly, highly calcareous, very sandy from 180-200	150-200
Kg	Shale, medium-gray (N5), massive, many small white calcareous specks, highly calcareous	200-220

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Test Hole 27
Location: 94-50-19cbcb
Drilled by: SDGS
Source of data: D
Elevation: 1294 feet

Qwlt	Till, clay, light-brown (5YR6/4), sandy, silty, pebbly, calcareous	0- 10
	Till, clay, light olive-gray (5Y6/1), sandy, silty, pebbly, calcareous	10-130
Qu	Silt, light olive-gray (5Y6/1), sandy, scattered pebbles, calcareous. Probably loess but may be old alluvium or very silty till	130-160
Kg	Shale, medium-gray, speckled, calcareous, banded	160-185

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Test Hole 28
Location: 94-50-30cccc
Drilled by: USBR
Source of data: S
Elevation: 1317 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, yellowish-gray (5Y7/2), silty, sandy, highly calcareous	0- 40
	Glacial till, clay, light-gray (N7), silty, sandy, highly calcareous	40- 70
Qow	Sand, coarse to gravel, medium, consists of igneous and metamorphic rock fragments, siltstone, sandstone and limestone pebbles, some quartz grains, subangular to rounded, some pyrite	70-110
Qit	Glacial till, light-gray (N7), very silty and sandy, highly calcareous	110-170
Qow	Sand, medium to gravel, fine, as above from 40-110	170-190
Qt	Glacial till as above from 110-170	190-220
Kg	Shale, alternating light (chalky) and dark (shaley) bands, medium light-gray, highly calcareous	220-230

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Test Hole 29
Location: 94-51-1dada
Drilled by: USBR
Source of data: S
Elevation: 1383 feet

Qwlt	Till, clay, grayish-yellow (5Y8/4), sandy and silty, calcareous	0-10
	Till, clay, light olive-gray (5Y6/1), sandy and silty, calcareous. Trace of grayish-yellow till from above	10- 20
	Till, clay, greenish-gray (5G6/1), sandy, silty, calcareous	20- 40
	Till, clay, light brownish-gray (5YR6/1), calcareous, slightly sandy, becoming very silty	40- 70
Qwel	Loess, silt, light brownish-gray (5YR6/1), trace sand	70- 90
Kc	Shale, medium dark-gray (N4), hard, fissile, non-calcareous, mottled oxidation and staining from 90-110	90-125

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Test Hole 30
Location: 94-51-26cccc
Drilled by: USBR
Source of data: S
Elevation: 1249 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, yellowish-gray (5Y8/1 to 5Y7/2), silty sandy, highly calcareous	0- 10
	Glacial till, clay, light-gray (N7), silty, sandy, highly calcareous. Sandy and gravelly from 30-40	10-100
Qow	Sand, medium to gravel, fine, subangular to rounded, composed of quartz grains and igneous and metamorphic rock fragments. Some siltstone, shale, and limestone pebbles. Trace of coal	100-180
Kg	Shale, medium light-gray (N6), massive, highly calcareous, hard, contains many white calcareous specks	180-200

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Test Hole 31
Location: 94-51-29dddd
Drilled by: USBR
Source of data: S
Elevation: 1230 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, yellowish-gray (5Y7/2), silty, sandy, pebbly, highly calcareous	0- 20
	Glacial till, clay, light-gray (N7), silty, sandy, highly calcareous	20- 80
Qow	Sand, medium to gravel, fine, subangular to rounded, composed of quartz grains, igneous and metamorphic rock fragments, some siltstone and limestone pebbles. Medium gravel at 110-120	80-190
	Glacial till, clay, medium light-gray (N6), silty, sandy, pebbly, highly calcareous, chalky	190-240
Kd	Siltstone, medium light-gray (N6), micaceous, quartzose, non-calcareous to slightly calcareous	240-250
	Driller has bedrock at 226	

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Test Hole 32
Location: 94-52-33bbbb
Drilled by: USBR
Source of data: S
Elevation: 1235 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, yellowish-gray (5Y7/2), silty, sandy, highly calcareous	0- 20
	Glacial till, clay, light-gray (N7), silty, sandy, highly calcareous	20- 30
	Glacial till, clay, yellowish-gray (5Y7/2), silty, sandy, highly calcareous	30- 40
Kc	Bentonite, light-gray (N8-N7), slightly silty, slightly calcareous in spots	40- 50
	Shale, medium light-gray (N6), massive non-calcareous	50-150
Kg	Shale, medium light-gray (N6), massive, speckled, calcareous. Some speckled light-gray limestone	150-160

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Test Hole 33
Location: 94-52-35bbbb
Drilled by: USBR
Source of data: S
Elevation: 1215 feet

Qwlt	Glacial till, clay, yellowish-gray (5Y7/2), silty, sandy, highly calcareous	0- 20
	Glacial till, clay, light-gray (N7), silty, sandy, highly calcareous	20- 90
Qow	Sand, medium to gravel, fine, subangular to rounded, consists of quartz grains, igneous and metamorphic rock fragments, siltstone and limestone pebbles, trace of coal. Medium gravel at 110-120	90-200
Qt	Glacial till, clay, medium-gray (N5), silty, sandy, chalky, highly calcareous	200-210
Kg	Shale, medium-gray (N5), contains many white calcareous specks, hard, massive, highly calcareous. Contains some crystalline limestone	210-220

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Test Hole 34
Location: 94-53-27addd
Drilled by: USBR
Source of data: S
Elevation: 1277 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, yellowish-gray (5Y7/2), silty, sandy, mottled oxidation, noncalcareous	0- 10
	Glacial till, as above only calcareous	10- 30
	Glacial till, clay, light-gray (N7), very silty and sandy, highly calcareous	30-120
Qow	Sand, medium to gravel, fine, subangular to subrounded, contains igneous and metamorphic rock fragments, quartz grains, and siltstone and carbonate pebbles and coal	120-180
Kg	Shale, medium dark-gray (N4), massive, hard, contains many small white calcareous specks, highly calcareous, becoming silty and sandy at 190'	180-200

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Test Hole 35
Location: 94-53-30cccc
Drilled by: SDGS
Source of data: D
Elevation: 1161 feet

	Road fill	0- 4
Qal	Clayish material, brown-yellow to brown-gray, and sand, very fine, silty, water at 18'	4- 19
Qow	Sand, very fine, brown-gray to gray, saturated	19- 63
	Gravel, gray-brown, with fine sand	63- 95
Kg	Bedrock	95-105

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Test Hole 36
Location: 94-53-36aaaa
Drilled by: USBR
Source of data: S
Elevation: 1331 feet

Geologic Unit	Description	Depth Feet
Qwlt	Glacial till, clay, yellowish-gray (5Y7/2), silty, sandy, highly calcareous	0- 20
	Glacial till, clay, light-gray (N7), silty, sandy, highly calcareous	20- 90
Qow	Sand, medium to gravel, medium, subangular to rounded, contains igneous and metamorphic rock fragments, quartz grains, limestone and siltstone pebbles	90-120
Kc	Shale, medium light-gray (N6), massive to banded, slightly calcareous to non-calcareous	120-140

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Test Hole 37
Location: 95-51-10dddd
Drilled by: USGS
Source of data: D
Elevation: 1371 feet

	Road fill	0- 4
Qwlt	Clay, yellow-brown to brown, very gravelly, sandy; slightly moist	4- 27
	Clay, dark red-brown, gravelly, sandy, silty	27- 31
	Clay, brown, very gravelly, very sandy; thin streaks light-gray and tan fine sand	31- 36
Kn	Claystone, light cream-tan at top to light-gray with dark-gray streaks at bottom	36- 42

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Test Hole 38
Location: 95-51-13aaaa
Drilled by: SDGS
Source of data: D
Elevation: 1460 feet

Qwlt	Clay, buff, pebbly, sandy	0- 35
	Clay, buff and gray mottled sandy	35- 65
	Clay, gray, sandy	65- 90
	Clay, light tan-white	90- 95
	Gravel, fine, western?	95-115
Kn	Clay, white, Kn, weathered	115-145
	Clay, gray, Kn, fresh	145-160

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Test Hole 39
Location: 95-51-12cccc
Drilled by: SDGS
Source of data: S
Elevation: 1432 feet

Geologic Unit	Description	Depth Feet
Qwlt	Till, clay-rich, brown-yellow, sandy, calcareous, oxidized (rocks 16-19 feet)	0- 18
Qks	Clay, olive-gray, smooth, compact; tougher drilling below 18 feet; occasional small pebble or sand grain; calcareous interbedded with medium dark-gray and light green-gray (some sandy) compact, weakly calcareous, clay, (Core: From 35-40 dark green-gray sandy, clay, wet; weakly calcareous; resembles alluvium beds in section at Newton Hills.)	18- 45
Qks-Qkg	Clay, light olive-gray to tan, sandy, with stringers of western sand below about 46 feet; mainly sand below 60 feet; some gravelly zones	45- 75
Kn	Marl, yellow, soft, oxidized, easy drilling; white chalk at 100; rougher drilling at 108 feet	75-112
	Chalk or marl, gray, choppy drilling	112-115

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Test Hole 40
Location: 95-51-16aaaa
Drilled by: SDGS
Source of data: D
Elevation: 1315 feet

	Road fill	0- 4
Qwlt	Till, yellow-brown, with small pebbles	4- 35
	Till, brown-gray, with few pebbles, water at 41'	35- 50
Qow	Sand, fine, grayish, to almost clay (50% sand) saturated	50- 70
	Sand, gray, highly saturated	70- 95
	Sand, very fine, grayish	95-131
Kc	Bedrock	131-135

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Test Hole 41
Location: 95-51-16bbbb
Drilled by: SDGS
Source of data: D
Elevation: 1301 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, buff, sand, carbonaceous	0- 10
Kn	Kn, weathered	10- 20
	Kn, unweathered	20- 50
	May be about 10' of Carlile	

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Test Hole 42
Location: 95-51-18aaaa
Drilled by: USGS (Phillips)
Source of data: D
Elevation: 1259 feet

Qwlt	Clay, dark red-brown, slightly gravelly, sandy, silty	0- 7
	Clay, dark yellow-brown, streaks light-gray, gravelly, very sandy, silty	7- 15
Qks(?)	Clay, dark-brown, light-brown, gray, black, tan streaks. Very gravelly, very sandy. Streaks clayey sand and gravel. Much Fe-staining. (Alluvium-colluvium?)	15- 27
Qit(?)	Clay, dark-brown, very gravelly, very sandy, silty	27- 32
	Clay, dark gray-black, gravelly, very sandy, silty	32- 97

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Test Hole 43
Location: 95-51-18baaa
Drilled by: USBR
Source of data: D, S
Elevation: 1248 feet

Qwlt	Till, clay, light-brown (5YR6/4), sandy, silty, pebbly, calcareous	0- 20
	Till, clay, light olive-gray (5Y6/1), pebbly, sandy, silty, calcareous	20- 50
Qow	Outwash, sand, medium to gravel, medium, angular to subrounded wide variety of rock types, clayey, 2% clay 50-60, 50% clay 60-70, 75% clay 70-80	50- 80
Qit(?)	Till, clay, light olive-gray (5Y6/1), sandy, pebbly, silty, calcareous	80-110
Kc-Kg	Shale, medium dark-gray (N4) fissile, plastic waxy, non-calcareous to partly calcareous. Some till caving in 110-120 sample	110-125

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Test Hole 44
Location: 95-51-24daaa
Drilled by: SDGS
Source of data: D
Elevation: 1435 feet

Geologic Unit	Description	Depth Feet
Qwlt	Till, clay, light-brown (5YR6/4), sandy, silty, calcareous. Becoming unoxidized in 20-30 foot sample	0- 30
Qow	Outwash, gravel, fine to coarse, subangular to subrounded, extreme variation in composition, sandy. Very clayey (50%) from 40-90'	30- 90
Qit(?)	Till, clay, light brownish-gray (5YR6/1), very sandy, calcareous	90-100
	Till, clay, light brownish-gray (5YR6/1), silty, sandy, pebbly, calcareous	100-130
	Till, clay, light brownish-gray (5YR6/1), silty, sandy, pebbly, calcareous and Niobrara Marl	130-140
Kn	Driller has bedrock at 133	

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Test Hole 45
Location: 95-52-8cccc
Drilled by: USGS
Source of data: D
Elevation: 1197 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, dark-brown with light-tan carbonate nodules. Sandy, gravelly	0- 8
	Clay, light-brown, gravelly, sandy; wet	8- 14
	Clay, dark-gray, slightly gravely, very sandy	14- 30?
Qow	Sand, coarse to fine, slightly gravelly, silty, slightly clayey	30?- 52?
	Gravel, fine, and very coarse to medium sand. Some medium gravel, streaks of very coarse gravel. Clean, loose. Abundant lignite	52?- 97

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Test Hole 46
Location: 95-52-8dccc
Drilled by: SDGS
Source of data: S
Elevation: 1233 feet

Geologic Unit	Description	Depth Feet
Qwlt	Till, clay, yellowish-gray (5Y7/2), sandy, silty, calcareous	0- 30
	Till, clay, light olive-gray (5Y6/1), very sandy--sample is 50% coarse sand and fine gravel	30- 60
Qow	Outwash, coarse sand to medium gravel, subangular to subrounded, consists of igneous metamorphic and sedimentary rock fragments; sand fraction is mostly quartz; some pyrite present	60- 90
Kg(?)	Hole goes through gravel and into bedrock at 150. Samples not available below 90'	

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Test Hole 47
Location: 95-52-8dddd
Drilled by: SDGS
Source of data: D
Elevation: 1229 feet

Qwlt	Clay, buff, sandy, pebbly	0- 23
	Clay, gray, sandy, pebbly	23- 37
	Gravel, pea size	37- 42
	Clay, gray, sandy	42- 65
Qow	Sand, coarse and gravel, fine	65- 80
	Sand, coarse and granular	80-140
	Gravel, fine to coarse	140-155

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Test Hole 48
Location: 95-52-11dddd
Drilled by: SDGS
Source of data: S
Elevation: 1187 feet

Qow	Gravel, fine to medium, oxidized to 40 feet, subangular to subrounded, sandy, silty, trace of alluvium; gravel composed of igneous, metamorphic and sedimentary rock fragments. Trace of 3% coal	0- 80
	Sand, medium to very coarse, mostly subrounded, wide variety of mineral and rock fragments. Trace to 2% fine gravel. Trace to 5% coal.	80-140
	Hole abandoned at 145' because of rocks and lost circulation	

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Test Hole 49
Location: 95-52-15bbaa
Drilled by: SDGS
Source of data: S
Elevation: 1231 feet

Geologic Unit	Location	Depth Feet
Qwlt	Till, clay, pale-olive (10YR6/2), very sandy, silty, calcareous	0- 10
	Till, clay, light brownish-gray (5YR6/1), very sandy, silty, calcareous. Gravelly from 30-50 feet	10- 60
Qow	Outwash, coarse sand to medium gravel, sub-angular to subrounded, gravel is igneous, metamorphic and sedimentary rock fragments, (much limestone, granite, shale fragments), some pyrite	60- 80
	Hole finished in gravel at 110, abandoned due to caving	

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Test Hole 50
Location: 95-53-5dddd
Drilled by: SDGS
Source of data: D
Elevation: 1432 feet

Qwlt	Till, yellow-brown to brown clay, silty, pebbly, some small rocks, dry	0- 53
Qwel	Loess, clayey silt, very fine, yellow-brown, dry	53- 60
	Loess, brown, silt, clayey, very fine, dry	60- 80
Kn	Kn, weathered, yellow	80- 85
	Kn, unweathered	85- 95

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Test Hole 51
Location: 95-53-7cccc
Drilled by: SDGS
Source of data: D
Elevation: 1415 feet

Qwlt	Clay, buff, silty	0- 3
Qkg	Sand, coarse to fine gravel, quartzite and feldspar	3- 30
Kn	Kn, weathered	30- 35

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Test Hole 52
Location: 95-53-7dddd
Drilled by: SDGS
Source of data: D
Elevation: 1446 feet

Geologic Unit	Description	Depth Feet
	Road fill	0- 4
Qwlt	Till, yellow-brown, pebbles and cobbles	4- 34
	Till, brown-gray, pebbles and cobbles	34- 49
Qow	Sand, gray-brown to gray, fine, clayish material, moist, water at 49'	49- 59
	Sand, gray-brown to gray, very fine, saturated	59-135

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Test Hole 53
Location: 95-53-11cccc
Drilled by: SDGS
Source of data: D
Elevation: 1296 feet

Qwlt	Clay, buff, sandy, much chalk	0- 15
	Clay, gray, sandy, much chalk	15- 25
Kn	Kn, unweathered	25- 60

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Test Hole 54
Location: 95-53-11dddd
Drilled by: USGS
Source of data: D
Elevation: 1266 feet

Qwlt	Clay, light yellow-brown to tan, very gravelly, sandy	0- 7
	Clay, medium-brown, very gravelly, very sandy, plastic	7- 30
Kn	Shale, medium-gray, very tough. Abundant pyrite and some fragments of <u>Inoceramus</u>(?)	30- 35

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Test Hole 55
Location: 95-53-12dddd
Drilled by: USGS
Source of data: D
Elevation: 1261 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, dark-brown, gravelly, very sandy, very silty	0- 7
	Clay, light yellow-brown, gravelly, very sandy, silty; very sticky	7- 27
	Clay, dark-gray, very gravelly, very sandy, silty; tough	27- 48
Kn	Shale, light-gray, very sticky but soft	48- 52

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Test Hole 56
Location: 95-53-15bbbb
Drilled by: SDGS
Source of data: D
Elevation: 1373 feet

	Road fill	0- 4
Qwlt	Till, yellow-brown, with small pebbles	4- 44
Qow(?)	Sand, fine, gray, to silty material, moist	44- 87
Kn	Bedrock	87- 95

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Test Hole 57
Location: 95-53-16bbbb
Drilled by: SDGS
Source of data: D
Elevation: 1456 feet

	Road fill	0- 4
Qwlt	Till, yellow-brown, pebbles and cobbles	4- 14
	Till, yellow-brown to brown, pebbles	14- 19
	Till, brown, moist, pebbles and cobbles	19- 53
Kn	Bedrock	53- 55

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