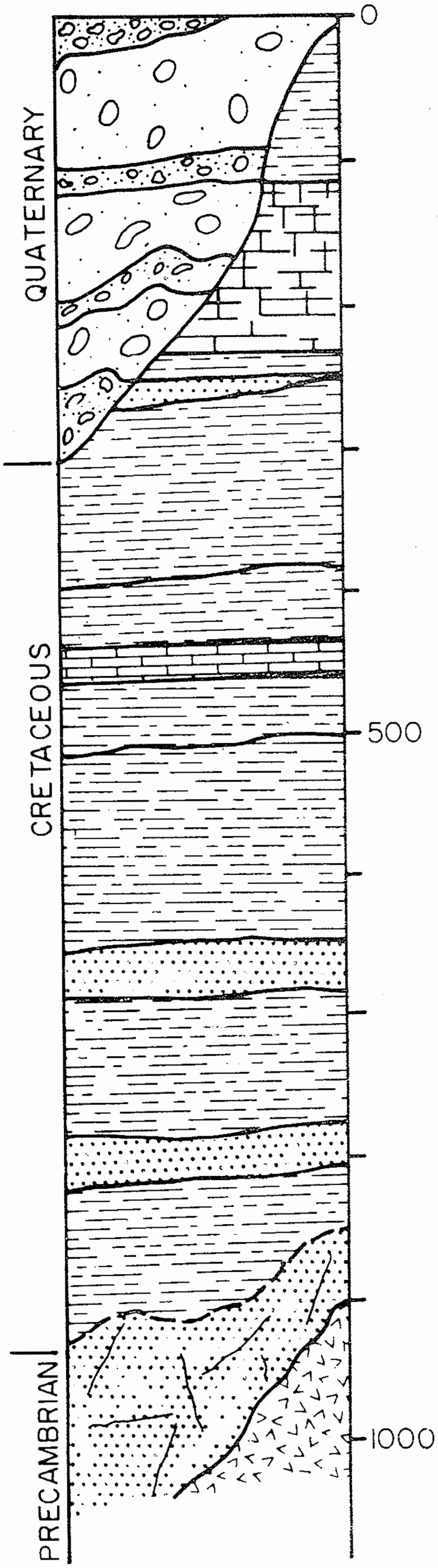

GEOLOGY AND WATER RESOURCES OF BON HOMME COUNTY SOUTH DAKOTA

Part I; Geology

by

Cleo M. Christensen

South Dakota Geological Survey

Prepared in cooperation with the United States Geological Survey, Fort Randall Water Conservancy Sub-District, and Bon Homme County.

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DEPARTMENT OF NATURAL RESOURCE DEVELOPMENT – GEOLOGICAL SURVEY

1974

STATE OF SOUTH DAKOTA
Richard Kneip, Governor

DEPARTMENT OF NATURAL RESOURCE DEVELOPMENT
Vern W. Butler, Secretary

GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

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Science Center
University of South Dakota
Vermillion, South Dakota
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ABSTRACT

Bon Homme County is located in southeastern South Dakota and has an area of 570 square miles. The major topographic features present within the County are the Coteau du Missouri, James Basin, James River Highlands, and the Missouri River.

Pre-Pleistocene rocks ranging in age from Precambrian to Pliocene are found in the subsurface but only those from Upper Cretaceous to Pliocene are exposed. Included in these exposures are the Cretaceous Niobrara and Pierre Formations and the Pliocene Ogallala Group.

Deposits of Pleistocene age mantle the bedrock throughout most of the mapped area and in some areas reach a thickness of over 300 feet. These deposits consist of both glacial and nonglacial sediments including till, outwash, loess, and fluvial deposits not derived from the melting ice.

Because materials commonly used for absolute dating are lacking in the County, most age relationships are based on the use of topography, physical characteristics, and stratigraphic associations. Pleistocene sediments range in age from Kansan through late Wisconsin. Two new formations, the Bon Homme Gravel and the Tyndall Sand, both of late Kansan age have been described in Bon Homme County.

Resources of economical value include large reserves of both surface and ground water as well as substantial reserves of sand and gravel. Other materials which may have potential economic value are the chalk areas within the Niobrara Marl. Evidence to date indicates no significant metallic or fossil fuel resources within the County.

INTRODUCTION

Purpose

Investigation of the geology and water resources of Bon Homme County is fifth in a series of cooperative studies conducted through the combined efforts of the South Dakota Geological Survey and the United States Geological Survey. Each study is conducted with several goals in mind. Of primary concern is the location and evaluation of the mineral and water resources available in each of the counties being studied. In addition, the knowledge gained from each study will be a most important contribution to understanding the overall geology of South Dakota.

Results of the Bon Homme County investigation are published in three parts. Part I contains the geology, with special emphasis on deposits of Pleistocene age; Part II (Jorgensen, 1971) contains the water resources; and Part III is a compilation of all basic data resulting from the investigation.

Location

Bon Homme County is located in southeastern South Dakota and has an area of 570 square miles (fig. 1). It is bordered on the west by Charles Mix County, on the north by Hutchinson County, on the east by Yankton County, and on the south by the Missouri River which forms the border with Nebraska (fig. 2).

Previous Investigation

Although French fur traders probably visited Bon Homme County in the late seventeen hundreds, the earliest written account of the geology of the area is found in the writings of Lewis and Clark (Thwaites, 1959). About 60 years after the Lewis and Clark expedition, Meek and Hayden (1861) briefly described the stratigraphy and landforms of the area while making a survey of the Nebraska Territory.

Bon Homme County has been included in a number of reconnaissance studies dealing primarily with bedrock and general geology of South Dakota (Todd, 1894; Darton, 1909; and Rothrock, 1943). Flint (1955) made a reconnaissance survey of the Pleistocene deposits of eastern South Dakota which included Bon Homme County, and Simpson (1952, 1960) studied a small portion of the County in detail. In addition, shallow ground-water investigations were conducted for the municipalities of Tyndall (Bruce, 1962) and Scotland (Christensen, 1963).

Method of Procedure

Information contained in this report results in part from geologic work done during the three field seasons of 1965, 1966, and 1967. The geology was mapped on aerial photographs having a scale of approximately 1:70,000 (about 1 inch = .9 miles) and was later transferred to a base map of the same scale. The base map was reduced to a scale of ½" = 1 mile.

Information obtained from natural outcrops and man-made exposures of rock material was supplemented by numerous power auger holes, rotary holes, and hand auger holes. Most subsurface information was obtained from examination of well cuttings and electric logs from holes drilled by the South Dakota and United States Geological Surveys. However, supplemental information was obtained from the files of local well drillers and from a well inventory which was conducted in the County for Part II (Jorgensen, 1971) of this report.

Acknowledgements

The investigation and preparation of this report

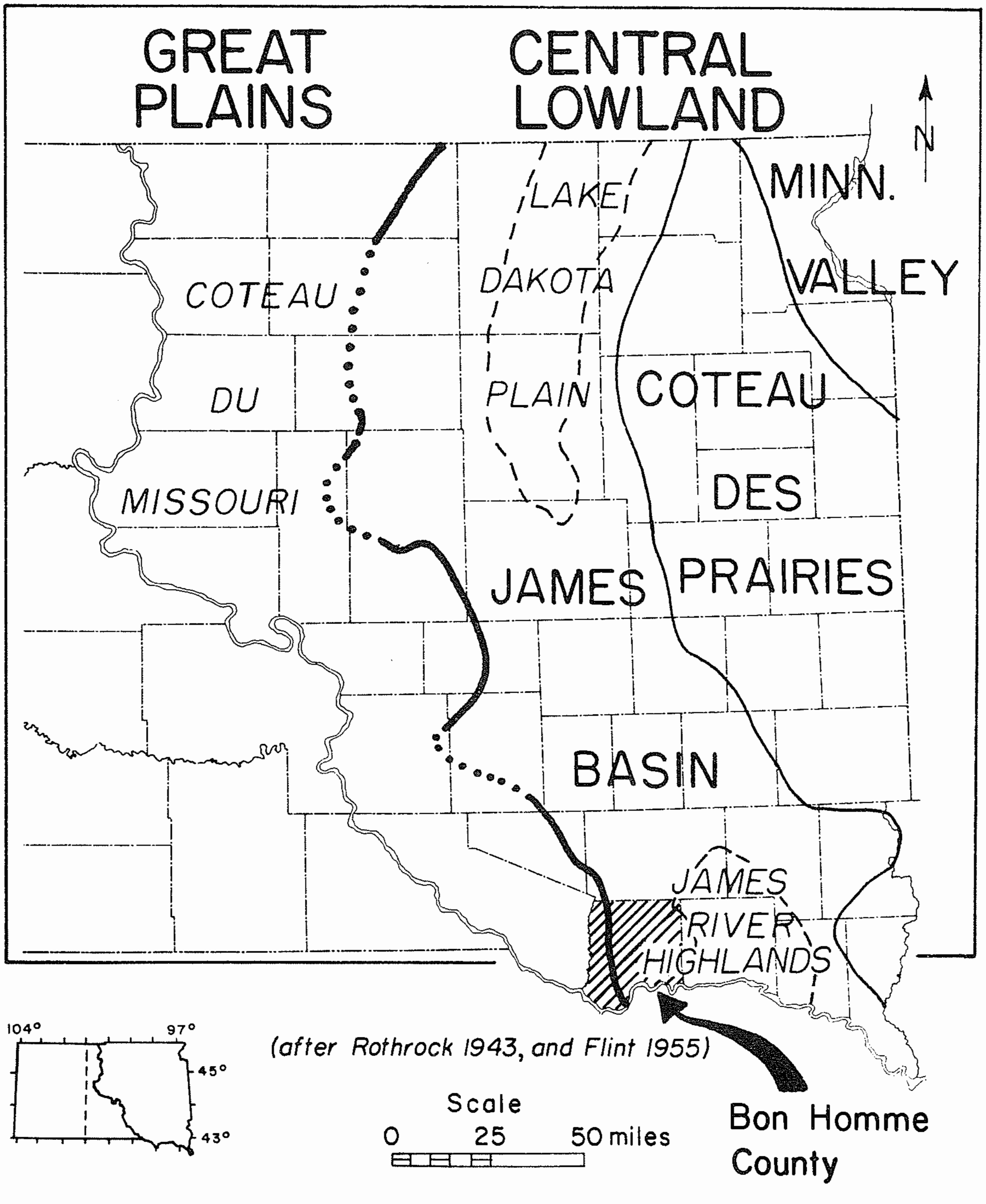


Figure I. Index map of eastern South Dakota showing the physiographic divisions and the location of Bon Homme County.

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

were performed under the supervision of Dr. 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 Lynn S. Hedges, Darrell I. Leap, and Donald G. Jorgensen, for their participation in numerous field conferences with the writer. Also performing a valuable service by assisting in the field and drilling test holes were Charles Cipperley, Tom Paulson Robert Dutcher, Lloyd Helseth, Robert Stach, Ron Helgerson, and Millard Thompson, Jr.

Financial assistance for the project was contributed by the South Dakota Geological Survey, United States Geological Survey, Fort Randall Water Conservancy Sub-District, and Bon Homme County.

The study was initiated at the request of the County Commissioners, and the cooperation of the Commissioners and the residents of the County is gratefully acknowledged.

Geography

Soils

At present no detailed soils map exists for Bon Homme County. It is possible, however, to determine the general type of soil that may be present at specific localities by close inspection of: (1) topography, and (2) geology.

Table 1 shows the various types of soils that exist within the County. The first group of soils mentioned in table 1 are basically loams, silt loams, and clay loams developed on clay-rich glacial till. Differences in topography will cause these soils to be excessively drained, well drained, or poorly drained and the soil series will vary accordingly.

Group 2 soils are upland soils developed in loess and are primarily silty loams because the loess consists of a mixture of windblown silts and clays.

Soils of group 3 are intermediate between groups 1 and 2 and are developed under similar circumstances. Soils of this group are primarily silty clay loams.

Group 4 soils are usually somewhat excessively drained. They are formed on eolian sands and are nearly level to undulating depending on the amount of dune topography that has developed.

Soils classified in group 5 are developed in loamy material overlying coarse sand and gravel deposits. These soils are well drained to excessively drained and are usually found along major streams.

The soils of group 6 are usually well drained to moderately well drained. They have developed over clay-rich and silt-rich alluvium along both major and minor streams.

Physiography

Three major topographic features are present in the mapped area (fig. 3). The most impressive of these features is the Coteau du Missouri (Missouri Hill Country). This vast dissected highland, which was probably named by early French traders, occupies an area nearly 200 miles long between the Missouri River and the James River lowland, extending north-south through North Dakota and South Dakota. The Coteau du Missouri is nearly 75 miles wide at the northern border of South Dakota, and narrows to less than 25 miles where it crosses the Missouri River near the Charles Mix-Bon Homme County boundary. The Coteau du Missouri extends along the western edge of Bon Homme County from the northern boundary to

TABLE 1. -- Soil Types of Bon Homme County

Group	Parent Material	Soil Type
1	Glacial till	Loams, silty loam, clay loam
2	Loess	Silty loam
3	Loess over till	Silty clay loams
4	Eolian sand	Sandy loams
5	Coarse sand and gravel	Sandy loams
6	Alluvium	Clay loam, silty clay loam, silt loam

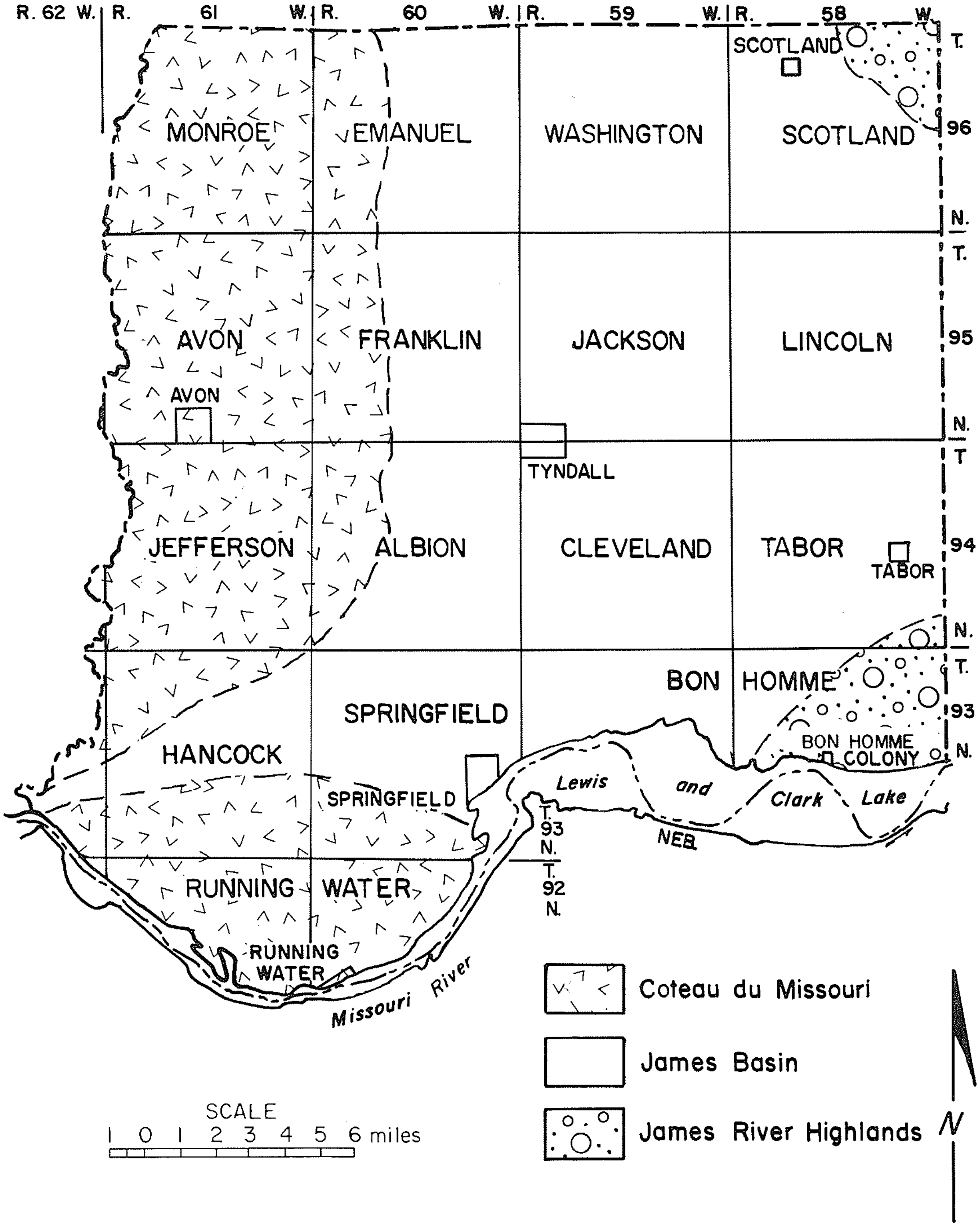


Figure 3. Generalized township map of Bon Homme County showing major physiographic features.

Figure 4. Photograph showing topography of Coteau du Missouri north of Avon.

the Missouri River (fig. 3), but is better developed in the northern part of the County north of Avon (fig. 4).

Bordering the Coteau du Missouri on the east in Bon Homme County is the James Basin (fig. 3). This broad lowland occupies most of Bon Homme County and extends northward into North Dakota. Characterized by gently undulating topography, the James Basin does not portray the rugged and highly dissected appearance of the Coteau du Missouri. In general, the Basin is 200 to 300 feet lower in elevation than the Coteau which it borders.

Immediately to the east of the James Basin in extreme northeastern and extreme southeastern Bon Homme County, lies the James River Highlands. Even though the Highlands cover only a small portion of the County, they are readily discernible. They extend northward a short distance into Hutchinson and Turner Counties, entirely comprise Yankton County, and extend eastward into Clay County.

From west to east the Highlands are locally called Yankton Ridge, James Ridge, and Turkey Ridge. Most prominent of these in the mapped area is Yankton Ridge, the northern border of which is about 3 miles south of Tabor. Yankton Ridge reaches a height of nearly 500 feet above the waters of Lewis and Clark Lake. The southern side of the ridge is steep where it abuts the Lake; however, the northern side slopes gently to an ancient stream valley in the James Basin, now abandoned and filled with glacial debris.

STRATIGRAPHY

Stratigraphic Relations

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 Bon Homme County in the order of their occurrence from the youngest deposit at the top of the list to the oldest at the bottom.

- **Quaternary System**
  - **Recent Series**
    - **Landslide deposits**
    - **Alluvium**
      - **Bar deposits**
    - **Dune sand**
  - **Recent and Pleistocene Series**
    - **Loess**
  - **Pleistocene Series**
    - **Wisconsin glaciation**
      - **Late Wisconsin**
      - **Early Wisconsin**
    - **Illinoian Glaciation**
    - **Yarmouth Interglaciation**
    - **Kansan Glaciation**
  - **Pliocene Series**
    - **Ogallala Undifferentiated**
- **Cretaceous System**

Upper Cretaceous Series
Pierre Shale
Niobrara Marl
Carlile Shale
Greenhorn Limestone
Graneros Shale
Upper and Lower Cretaceous Series
Dakota Formation
Precambrian System
Sioux Quartzite and older rocks

The basement rock most commonly encountered in the subsurface of southeastern South Dakota is the Sioux Quartzite. Although termed a quartzite and referred to locally in some areas of the State as granite, the Sioux Quartzite is actually an orthoquartzite because of its sedimentary origin (Baldwin, 1951). The Sioux is composed of pink, very tightly-cemented sand grains. Interbedded with the orthoquartzite are layers of conglomerate, mudstone, and red to purple shale. Layers of pipestone from the Sioux Quartzite of southwestern Minnesota were examined for age determination by Goldich and others (1961) and found to have an age of 1.2 billion years.

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

Although test holes have not been drilled to the basement rock in Bon Homme County, information from private wells in the area indicate that the Sioux Quartzite is the first basement rock present. The Sioux Quartzite is probably underlain by older granitic rocks similar to those described above. The Sioux Quartzite should be encountered in Bon Homme County at an elevation of about 500 feet above sea level.

Cretaceous Rocks

The bedrock of Bon Homme County is primarily of Cretaceous age and consists of shales, marls, limestones, and sandstones. In ascending order they are the Dakota Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale (including the Codell Sandstone), Niobrara Marl, and the Pierre Shale.

Dakota Formation

The Dakota Formation 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 Formation is composed of alternating beds of siltstone, sandstone, and shale; is varicolored and attains a maximum thickness of over 125 feet in Bon Homme County. Locally the Dakota Formation is sometimes referred to as the "artesian basin" because of the abundance of flowing wells it feeds. The water potential of the Dakota is discussed in detail in Part II (Jorgensen, 1971) of this report.

Graneros Shale

Graneros Shale overlies the Dakota Formation in Bon Homme County and is characteristically a medium- to dark-gray, noncalcareous, silty shale interbedded with thin silt and sand layers.

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).

The Graneros Shale is widespread throughout South Dakota and varys greatly in thickness. In Bon Homme County the Graneros has a maximum thickness of over 50 feet.

Greenhorn Limestone

Greenhorn Limestone overlies the Graneros Formation and is one of the best marker beds within the Cretaceous deposits of South Dakota. The Greenhorn 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. Other characteristics of the Greenhorn that make it such a good marker are its diagnostic "kick" on the electric and radioactive logs and the "rough" manner in which it drills.

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

Greenhorn Limestone does not crop out in Bon Homme County but underlies the entire County in the subsurface. It 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. The Greenhorn has a thickness of about 75 feet in Bon Homme County.

Carlile Shale

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

Carlile Shale underlies the Niobrara Marl and consists of a medium-gray noncalcareous, plastic, fissile shale.

In the mapped area the Carlile contains a layer of

Figure 5. Photograph of Niobrara Marl west of Springfield, South Dakota.

sandstone up to 100 feet thick named the Codell Sandstone Member. Usually the Codell occurs near the top of the Carlile, but it may be covered by over 20 feet of shale. In Bon Homme County the Codell is a gray to green, fine to medium sandstone. It may be very tightly cemented or noncemented and is sometimes cross bedded. The Codell constitutes a major ground-water aquifer in the County and is discussed in detail in Part II (Jorgensen, 1971) of this report.

Maximum thickness of the Carlile Shale including the Codell Sandstone Member is over 200 feet in the mapped area.

Niobrara Marl

The Niobrara Marl crops out extensively in Bon Homme County (pl. 1 and fig. 5) and underlies much of the County in the subsurface (pl. 2 and fig. 6).

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

In Bon Homme 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. At some localities a dark- to medium-gray marl is also found below the limestone.

The Niobrara Marl is locally called "Niobrara Chalk" or "Chalk Rock" because of the chalky appearance of the limestone layers of the formation.

Fossils are abundant in the Niobrara, with microfossils sometimes comprising most of the material found in the limestone layers. Among the common planktonic forms found are *Globigerina, Planomalina,* and *Heterohelix*. Macrofossils are also found in the Niobrara and the two most common are *Ostrea congesta* and *Inoceramus gigantica*. Other fossils such as barnacles, fish, and mosasaur have been collected from exposures of Niobrara throughout the area.

The Niobrara averages about 160 feet thick in eastern South Dakota and has a maximum thickness of over 200 feet in northwestern Bon Homme County.

Pierre Shale

Pierre Shale is exposed in several areas of Bon Homme County mostly in the southwestern and southeastern sections. Very limited exposures are found at several other localities (pl. 1). In addition, the Pierre Shale underlies the glacial drift in several areas (fig. 6).

The Pierre Shale was first named the Ft. Pierre Formation by Meek and Hayden (1861) and the name was shortened to Pierre by Darton as early as 1896.

In Bon Homme County several members, or at least parts of several members, of the Pierre Shale are present. For the purposes of this report, these

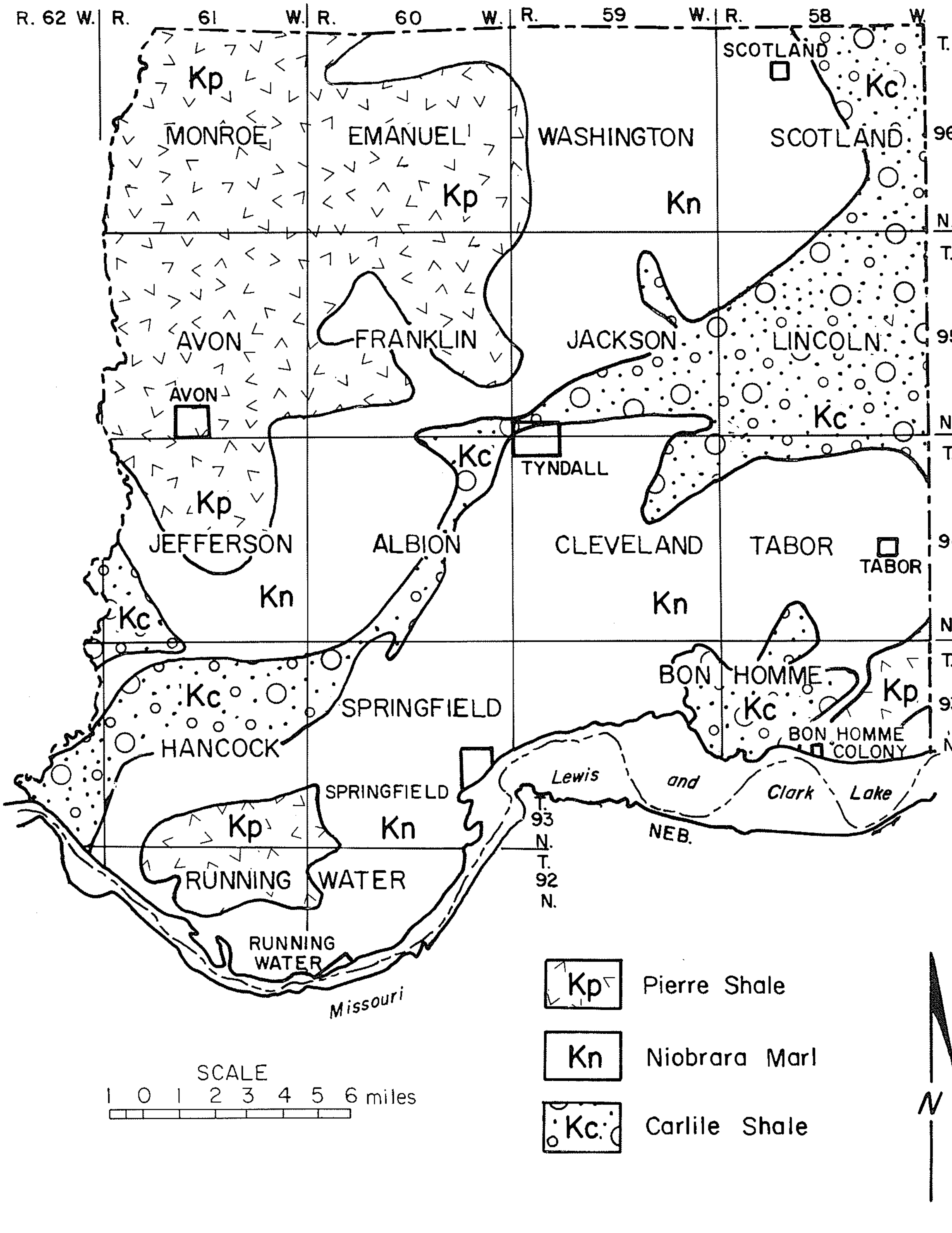


Figure 6. Generalized township map of Bon Homme County showing approximate areal distribution of first Cretaceous Formation beneath the drift.

Figure 7. Photograph of banded Pierre Shale 6 miles south of Tabor.

members have not been differentiated and are simply referred to collectively as the Pierre Shale.

Depending on the particular member encountered, the Pierre Shale in the mapped area may vary from a highly banded, varicolored clay shale (fig. 7) containing abundant belemnites to a dark-gray to nearly black organic clay shale. Maximum thickness of the Pierre in Bon Homme County is about 330 feet.

Pliocene Rocks

Ogallala Undifferentiated

At several isolated localities in west-central Bon Homme County (pl. 1) Pliocene age rocks of the Ogallala Group crop out. Generally this sequence of rocks is capped by a very hard greenish quartzite approximately 1 to 4 feet thick which is underlain by up to 59 feet of varicolored shales and clean white quartz sand.

The Ogallala was first described by Darton (1899) and the type section designated "near Ogallala Station" in western Nebraska. Although widespread in the northern and southern parts of western South Dakota, only scattered outcrops are present east of the Missouri River. The exposures in Bon Homme County probably represent the easternmost exposures of the Ogallala in South Dakota.

Pleistocene Deposits

Deposits of Pleistocene age mantle the bedrock throughout most of the mapped area (pl. 1) and consist of sediments of both glacial and non-glacial origin. The glacial deposits are primarily made up of till with minor amounts of ice-contact stratified drift. Non-glacial sediments consist of loess and fluvial deposits not derived from the melting ice.

Because materials commonly used for absolute dating are lacking in the County, most age relationships are based on the use of topography, physical characteristics, and stratigraphic relationships.

Discussion of the Pleistocene is divided into two sections. The first section contains the description of the deposits (table 2), whereas, the second section represents the writer's attempt to reconstruct the geomorphic events from the beginning of the Pleistocene Epoch up to the present time.

Kansan Glacial Deposits

Kansan Till

Till of Kansan age is probably the oldest till present in Bon Homme County. As one might expect exposures of Kansan till are not present within the area because of a nearly complete mantle of younger

Table 2. Generalized stratigraphic section of the Pleistocene deposits of Bon Homme County.

AGE			DEPOSIT	THICKNESS (IN FEET)	DESCRIPTION
PLEISTOCENE	WISCONSIN	LATE	*Loess*	*0 to 15+*	Light yellow-brown to light-gray silt and fine sand; locally fossiliferous.
			Ice-contact stratified drift	*0 to 30?*	Fine to coarse gravel with numerous large cobbles and boulders and varing amounts of sand.
			Outwash	*0 to 125+*	Fine sand to coarse gravel to boulders, varying amounts of silt and clay; locally stratified.
			Till	*0 to 200+*	Light yellow-brown to dark olive-gray boulder clay, friable; locally sandy and silty, locally contains large boulders, calcareous.
		EARLY	*Loess*	*0 to 15±*	Light yellow-brown to medium-gray fine to coarse silt and fine sand, calcareous, friable, locally mottled with a variety of colors.
	PRE-WISCONSIN	ILLINOIAN	*Till*	*0 to 80±*	Light yellow-brown to dark olive-gray boulder clay till, blocky and hard, highly jointed with oxidation and mineralization associated with the joint pattern, calcareous.
			Outwash	*0 to 120±*	Fine sand to coarse gravel and boulders, unoxidized, water saturated.
		KANSAN	*Tyndall sand (new name)*	*0 to 27+*	Light-colored Arkosic stratified sand composed predominately of quartz, feldspar, and granite fragments; grains rounded and polished.
			Bon Homme Gravel (new name)	*0 to 25±*	Light to dark-colored pebbly gravels composed predominately of granites, quartz, and feldspar; grains are rounded and polished; grains are locally strained with iron-maganese coating.
			Till	*0 to 160±*	Dark olive-gray boulder clay till, calcareous, found only in the subsurface.
			Outwash	*0 to 20±*	Fine sand to coarse gravel and boulders unoxidized, water saturated.

Pleistocene and Recent deposits. The presence of Kansan till has been established through the correlation of test hole logs and samples. Because Kansan till is not exposed, a physical description would be difficult to relate and misleading at best.

Late Kansan Non-Glacial and Yarmouthian Deposits

Bon Homme Gravel (new name)

Sands and gravel of late Kansan(?) fluvial deposition are exposed in extreme southeastern Bon Homme County and are here named the Bon Homme Gravel. The name Bon Homme was taken from Bon Homme Colony which is located in extreme southeastern Bon Homme County near the type section of the Bon Homme Gravel. Intended use of the name was filed with the Chairman of the Geologic Names Committee on April 24, 1968, and its reservation for use at a later date was noted by George V. Cohee (written communication, April 30, 1968).

An exposure in extreme southwestern Yankton County (fig. 8a and b) is here established as the type section of which the location and description are as follows:

Measured section 15 - SW¼SW¼SW¼SW¼ sec. 7, T. 93 N., R. 57 W., Yankton County. Gravel pit on west side of road, east side of section line; approximate altitude 1600±25 feet. Exposed in 1967.

Unit	*Thickness (feet)*
3. Till, clay, pale yellowish-brown, pebbly calcareous	*5*
2. Sand, light colored, quartz, feldspar and granite fragments, subangular to subrounded, moderate to high sphericity, horizontal bedding, some cross bedding, gravelly	*9*
1. Gravel, pink, feldspar, quartz and granite fragments, cross bedded and horizontal bedding; some zones of gravel are entirely stained with iron and manganese oxides. Contains inclusions of green- to reddish-brown clayey silt occurring in spherodial masses up to 2 feet in diameter (fig. 8b). Also contains silicified wood and Mammalian fossils	*up to 25*

Base of exposure concealed

These gravels have previously been studied by Flint (1955) and Simpson (1952, 1960). Flint referred to the gravels as "alluvium of western origin," whereas, Simpson mapped them as the Grand Island Formation of Lugn and Condra (Lugn, 1932).

Much additional study is needed before any definite age can be assigned to the Bon Homme Gravel or before any precise correlations can be made. Gravels of similar composition and supposedly "western origin" occur at many localities in South Dakota and correlation of these gravels is difficult. The Bon Homme Gravel may be time equivalent, at least in part, to the Herrick (Stevenson and Carlson, 1952), Atchison (Tipton, 1958), Newton Hill (Baird, 1957), "older alluvium" (Flint, 1955) or they may in fact correlate (temporally) with the Grand Island Formation as proposed by Simpson (1952).

Much of the problem with correlation arises from the fact that very little significant fossil material is present. Simpson (1952) states, "Correlation of coarse alluvium of western provenience in the Yankton area, with the Grand Island Formation is based on fossil content, stratigraphic relations, and lithology." Of the fossils collected by Simpson and identified by C. Bertrand Schultz, University of Nebraska State Museum (Simpson, 1952, p. 75), none can be considered diagnostic. Stratigraphic relationships are also lacking where the Bon Homme Gravel is concerned because in all known exposures in Bon Homme County the gravel is overlain by till of probable late Wisconsin age and underlain by Cretaceous shale or marl. Likewise, lithologic factors cannot be used to correlate the Bon Homme Gravel with the Grand Island Formation.

Fossil material collected by the writer was identified by J. C. Harksen (oral communications, January 9, 1970) as simply *Equus* sp. and *Titanotylopus* sp. and are not considered diagnostic.

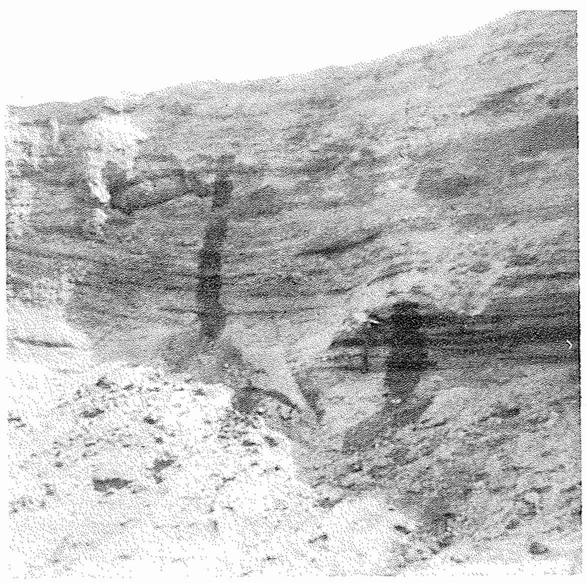
It is for the above stated reasons that these gravels have been named the Bon Homme Gravel. It must be understood that this is not an attempt to cloud the literature with another name but is instead an attempt to not confuse the literature with another erroneous correlation based on circumstantial evidence.

Tyndall Sand (new name)

Additional fluvial deposits of possible late Kansan or Yarmouthian age exist at other localities within the County. These deposits, here named the Tyndall Sand, occur both at the surface and in the subsurface in south-central Bon Homme County, west of the town of Springfield (pl. 1). The name Tyndall Sand which was reserved by the Chairman of the Geologic Names Committee, George V. Cohee, (written communication, April 30, 1968) is taken from the town of Tyndall in central Bon Homme County.

The following description is taken from the type section (fig. 9):

A



B

Figure 8. Photographs of the Bon Homme Gravel at the type locality.

Figure 9. Photograph of the Tyndall Sand at the type locality.

Measured section 13 – SW¼SE¼NE¼SE¼ sec. 13, T. 92 N., R. 61 W., Bon Homme County, Natural exposure along creek valley. Approximate altitude 1350±25. Exposed in 1967.

Unit	*Thickness (feet)*
2. Till slope, grass covered	*6*
1. Sand, white, quartz, feldspar, granite fragments, generally subrounded, moderate to high sphericity, interbedded with gravel beds up to 1-inch thick. Good horizontal bedding, good cross bedding, gravels generally oxidized	*27*

Base of exposure concealed

No fossils have been discovered in any of the exposures of the Tyndall Sand in the County, therefore, no age determinations can be made on the basis of fossil content. A late Kansan(?) age has been assigned to the deposit strictly on the basis of stratigraphic evidence. In several areas west of Springfield test drilling has shown the Tyndall Sand to be overlain by two tills (see app., test hole 12). Other test holes show the Tyndall Sand to also be underlain by yet another till (see app., test hole 2). If, as proposed later in this report the upper two tills represent the late Wisconsin and Illinoian tills and the underlying till is Kansan, the stratigraphic evidence for assuming the Tyndall Sand to be late Kansan is indeed sound. However, if both the Tyndall Sand and Bon Homme Gravel are of late Kansan age, the fact that they are found at considerably different elevations presents a problem. This problem is discussed in the section of this report dealing with Pleistocene and Recent history.

Illinoian Deposits

Illinoian Till

Till of Illinoian age crops out at several locations in the southern part of the County (pl. 1) and is also found in the subsurface (see app., test holes 1, 3, and 24).

Where exposed the Illinoian till is generally dark gray (unoxidized), hard, blocky, pebbly, and calcareous. Joints are common within the till and oxidation extends outward from the joints for a distance of 2 to 6 inches in either direction. The joints usually portray some degree of separation with the opening being filled with either gypsum or carbonate. In general, when broken, the till has a blocky fracture unlike the roughly conchoidal fracture of older tills or the platy, crumbly type of disintegration associated with tills of Wisconsin age.

Illinoian till is best exposed in several localities along the north shore of Lewis and Clark Lake in secs. 13 and 14, T. 93 N., R. 59 W. In these exposures the characteristic physical features of the till can be readily observed.

Pre-Illinoian Outwash

The existence of pre-Illinoian outwash in Bon Homme County is evidenced by the fact that a substantial thickness of outwash occurs in the subsurface and is overlain by Illinoian till (pl. 3). Because the outwash does not occur at the surface its exact age is difficult to determine. It may in fact have been deposited by ice from several different advances between Nebraskan and early Illinoian times.

No visible oxidation zones or other identifiable markers were discovered within the outwash. Because all of the test holes penetrating the outwash were drilled with rotary drilling equipment, it is quite possible that any thin marker zone may not have been discovered. In the absence of conclusive stratigraphic evidence with regard to the age of the outwash, an age grouping based on the appearance of the outwash with respect to other geologic units as they appear on the cross sections (pl. 3) has been assigned. The writer is first to admit that this assignment is purely speculative and cannot be substantiated.

In general, the outwash is composed of fine sand to coarse gravel with minor amounts of cobbles and boulders, and consists of a wide variety of igneous, metamorphic, and sedimentary rock fragments. As is the case with most outwash in eastern South Dakota, the grains are usually subangular to subrounded. However, chalk and shale pebbles are common. The sand portion of the outwash consists primarily of quartz.

Early Wisconsin Deposits

Early Wisconsin Loess

Loess is the only early Wisconsin deposit known to be present in Bon Homme County. Although only a very few exposures exist in the west-central part of the County (pl. 1), several test holes have penetrated early Wisconsin loess (see app., test holes 1, 3, 6, and 24).

Where exposed the loess is generally light yellow-brown and grades downward in some instances to a medium gray. Locally this deposit is mottled with a variety of colors. In Bon Homme County the early Wisconsin loess consists of fine to coarse silt and fine sand with very minor amounts of clay. It is calcareous and friable and attains a maximum thickness of about 10 feet in the County.

Late Wisconsin Deposits

Till

Till of late Wisconsin age exists immediately below the soil throughout most of Bon Homme County (pl. 1) and exposures of the till in road and stream cuts are abundant.

Where exposed the till is usually light yellow-brown near the surface and grades downward to a dark olive-gray. The upper oxidation zone may be only a very few feet thick; however, it averages about 30 feet in thickness and oxidation to a depth of more than 50 feet is not uncommon (pl. 4).

The till consists primarily of silty, sandy clay with minor amounts of pebbles, cobbles, and boulders and is moderately to highly calcareous. Unlike the older tills, the late Wisconsin till does not portray a distinct jointing pattern and can best be described as friable or crumbly.

Outwash

Late Wisconsin outwash and outwash terraces exist at several localities within the County (pl. 1) and, with the exception of isolated areas in northwestern and east-central Bon Homme County, are confined to the major stream and creek valleys. Substantial thicknesses of outwash (up to 150 feet) are located beneath the alluvium along Choteau Creek, Emanuel Creek, and the Missouri River.

Grain size of the outwash and outwash terraced sediments varies greatly; ranging in size from fine silty sand to large cobbles and boulders. Individual particles are generally subangular to subrounded with the greater degree of roundness being associated with the smaller grains.

The finer portion of the outwash consists mostly of quartz whereas the coarser sediments are fragments of a wide variety of crystalline and sedimentary rocks. Chalk and shale are common especially in the pebble size and larger fragments. Where cobble-size shale is found the original fissility is still visible and the cobbles break along the planar structures.

Horizontal bedding is common in all of the exposures of late Wisconsin outwash; whereas cross bedding exists in only a few of the exposures.

Ice-Contact Stratified Drift

A relatively small area of ice-contact stratified drift of late Wisconsin age exists in west-central Bon Homme County (pl. 1) on the highland east of Choteau Creek.

This deposit consists of fine to coarse gravel and contains many cobbles and boulders. In some instances the entire deposit consists of very coarse gravel and large boulders.

Thickness of the deposits is difficult to determine because of the difficulty in penetrating the extremely coarse sediments with any type of drilling equipment. Indications are, however, that the deposit probably does not exceed 25 to 30 feet in thickness.

Most of the ice-contact stratified drift is composed of igneous and metamorphic rocks with many of the large boulders being derived from nearby exposures of Ogallala and consisting of hard dense orthoquartzite.

Loess

Late Wisconsin loess is located at the surface in southeastern Bon Homme County (pl. 1). Hand auger holes were used to determine the thickness and distribution of loess within the mapped area. In all cases if another geologic unit was encountered beneath the loess and within 5 feet of the surface, the loess was not mapped. For this reason, isolated areas of loess less than 5 feet thick may exist within the County and not be identified on plate 1.

In general, the loess is composed of light yellow-brown to light-gray silt and fine sand. It is locally fossiliferous, however, no diagnostic fossils were found. Thickness of the loess ranges from less than 3 feet to over 15 feet; however, the average thickness is less than 10 feet.

Recent Deposits

Deposits of Recent age (table 3) are widely dispersed throughout Bon Homme County and are shown on plate 1 as dune sand, sand bars, alluvium, and landslide deposits. They are either confined to drainageways or are in some way related to drainageways and associated topography.

Dune Sand

An area of eolian sand with local dune topography exists in the northeastern part of the County near the town of Scotland (pl. 1). The deposits, made up of fine to medium sand probably derived from the nearby James River trench, are very local in extent and seldom reach a thickness of more than 10 feet. Dune topography is only developed on the thickest part of the deposit.

Bar Deposits

Sand bars exist at many localities in the Missouri River in the southwestern section of the County (pl. 1). Although numerous, the bars are intermittent because of fluctuations in water level and constantly changing river conditions. Great seasonal variations in the outline and position of an individual bar is common.

The bars are composed of very fine to medium sand with minor but varying amounts of silt and clay and are usually bedded.

Alluvium

Recent alluvium exists along all of the major streams and most minor tributaries in the mapped area (pl. 1). The alluvium consists of very dark-gray to black, humic stratified clay and silt with minor amounts of sand and gravel.

Thickness of the deposits varys from one locality to another; however, thickness up to 40 feet are not uncommon along the Missouri River, Emanuel Creek, and Choteau Creek. In association with smaller tributary creeks, alluvium is much thinner and generally does not exceed 15 feet.

Landslide Deposits

In extreme southeastern Bon Homme County mass movement of surficial material under the influence of gravity has been widespread (pl. 1). The

TABLE 3. -- Generalized Stratigraphic Section of the Recent Deposits of Bon Homme County

AGE	DEPOSIT	THICKNESS (feet)	DESCRIPTION
Recent	Landslide Deposits	?	Undifferentiated deposits of glacial debris and bedrock moved downslope as a result of gravity.
	Alluvium	0-40	Black humic stratified clay and silt with minor amounts of sand and gravel; fossiliferous.
	Bar Deposits	?	Very fine to medium sand with minor amounts of silt and clay; usually bedded.
	Dune Sand	0-10	Fine to medium wind-blown sand, local dune topography.

majority of the area is masked by a variety of slumps and slides. Much of the slide material is glacial debris; however, some slide material is composed of shale. Rather than attempt to unravel the lithology of the deposits, it was decided to map them as a group under the heading of landslide deposits.

GEOMORPHIC DEVELOPMENT

Pre-Pleistocene Land Surface

At the beginning of the Pleistocene Epoch the surficial deposits of the area that is now Bon Homme County consisted primarily of Cretaceous shales and marls. Pierre Shale occupied the northwestern one-fourth of the area as well as isolated highlands in the southwestern and southeastern corners (pl. 2). Much of the remainder of the County was covered by Niobrara Marl that had been exposed by stream erosion. Although some Carlile Shale may have been exposed it is doubtful if these exposures were widespread at the beginning of the Pleistocene. The only non-Cretaceous rocks at the surface, other than alluvium, were the small areas of Pliocene Ogallala in the west-central part of the area (fig. 10).

Pre-Pleistocene Drainage

Although the pre-Pleistocene topography of the area was probably very similar to that shown on plate 2, several important differences did exist.

The ancient Niobrara-Missouri River system occupied a position somewhat south of the present-day Missouri River in southwestern Bon Homme County and flowed in an eastward direction until it reached a point several miles east of the present-day site of Springfield. Here the River changed to a northeasterly direction (fig. 10) and flowed north of the Pierre Shale highlands in the southeastern corner of the County. The River crossed what is now the Bon Homme County-Yankton County boundary, approximately 6 miles north of the present north shore of Lewis and Clark Lake. It then continued its easterly course and re-entered what is now the Missouri River trench in the vicinity of Yankton.

Pre-Illinoian Time

Although Nebraskan till has been recognized in eastern Nebraska (Reed and Dreeszen, 1965) it is doubtful if the Nebraskan glacier entered the Bon Homme County area. Likewise there is no evidence of a major diverson channel of Nebraskan age in the area even though the presence of Nebraskan ice in the mid-continent region must have had some effect on the drainage. The position of the ancient Niobrara-Missouri drainage during the Aftonian interglacial age is also unknown. However, it is thought by the writer to have occupied a position very similar to that shown on figure 10 throughout Nebraskan and Aftonian times.

Indications are that the Kansan glacier did cover at least part of the mapped area. The ice was probably confined to the eastern two-thirds of the County. However, the exact extent of the drift border is impossible to discern because of the mantle of younger deposits.

Kansan drift has been discovered in the subsurface in several areas within the County (pl. 5 and app., test hole 2), and it was Kansan drift that first choked the channel of the ancient Niobrara-Missouri River. During the period when Kansan ice occupied the ancient Niobrara-Missouri trench, the River was diverted along what is now the course of the Missouri River in Lewis and Clark Lake (fig. 11). Throughout this period of diversion the new channel was cut downward to an elevation of about 1450 feet. Immediately after Kansan ice receded from the ancient Niobrara-Missouri channel, the channel was again occupied by the River because of its lower elevation (approximately 1250 feet).

This theory is supported by the discovery of a substantial thickness of what is thought to be Kansan drift in the ancient trench (pl. 5) and the portion of the Bon Homme gravel that rests on the Pierre Shale on Yankton Ridge at a contact elevation of between 1475 and 1550 feet. The gravel was deposited as alluvium by the ancient Niobrara-Missouri River during late Kansan time.

An additional fluvial deposit, the Tyndall Sand, also of probable late Kansan age exists in Bon Homme County (pl. 1) at an elevation up to 100 feet lower than the elevation of the Bon Homme Gravel. In order to explain the depositional history of the Tyndall Sand it is necessary to set the stage by discussing ancient Ponca Creek, another Kansan and Yarmouthian drainageway.

Ancient Ponca Creek

Another lowland area exists in the southwestern corner of Bon Homme County and has a surface elevation of less than 1450 feet. This lowland was first interpreted by Todd (1912) as representing the continuation of ancient Ponca Creek which flowed northward from Knox County, Nebraska. Todd's interpretation of the Ponca Creek ancient drainage has been substantiated by later workers (Flint, 1955, and Simpson, 1960) and the writer also believes the theory to be correct.

It is not known if ancient Ponca Creek existed in Bon Homme County before Kansan time, however, if it did, it was certainly diverted farther southward by Kansan ice. The writer believes that the portion of ancient Ponca Creek that once occupied the

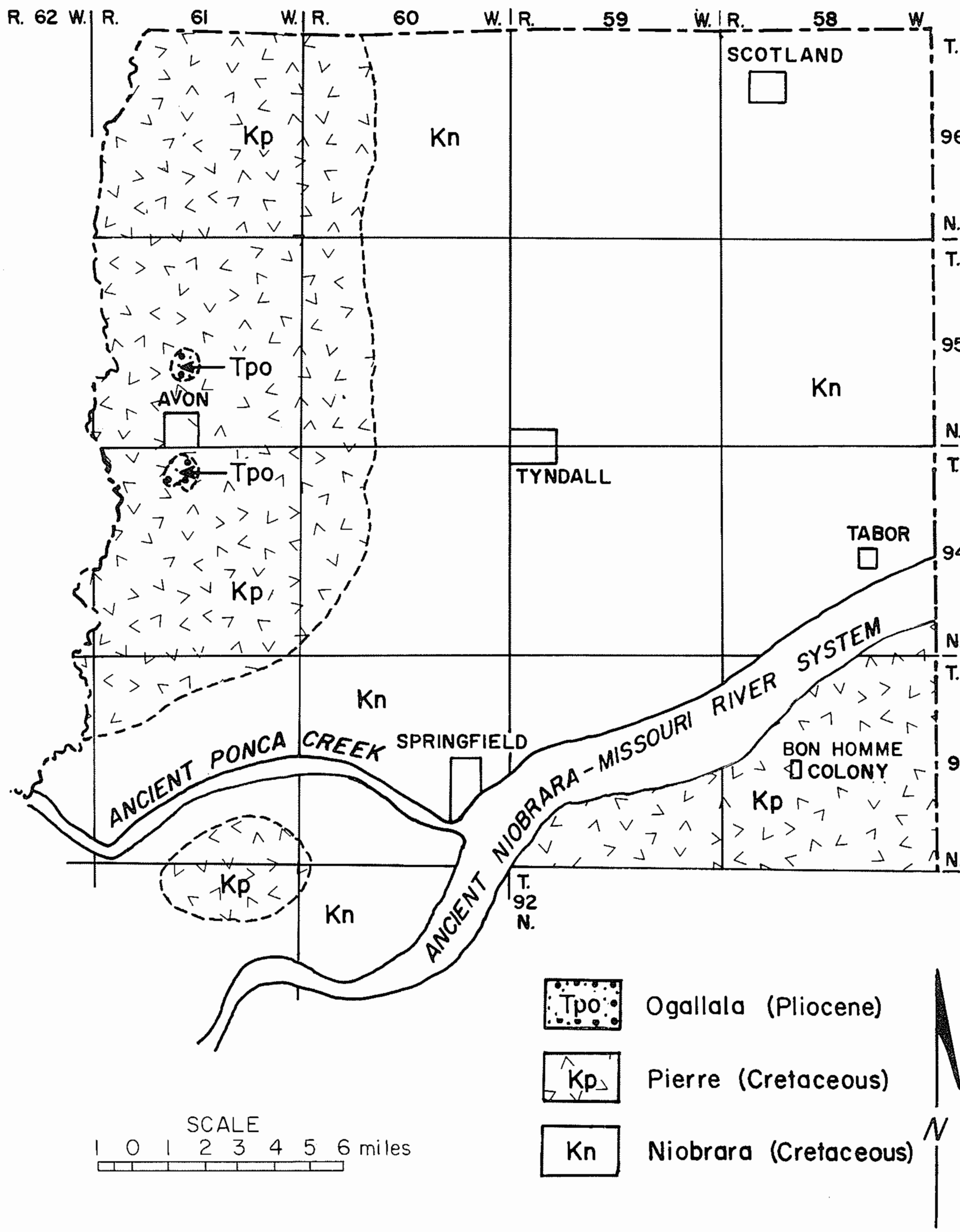


Figure 10. Generalized paleogeologic map of Bon Homme County.

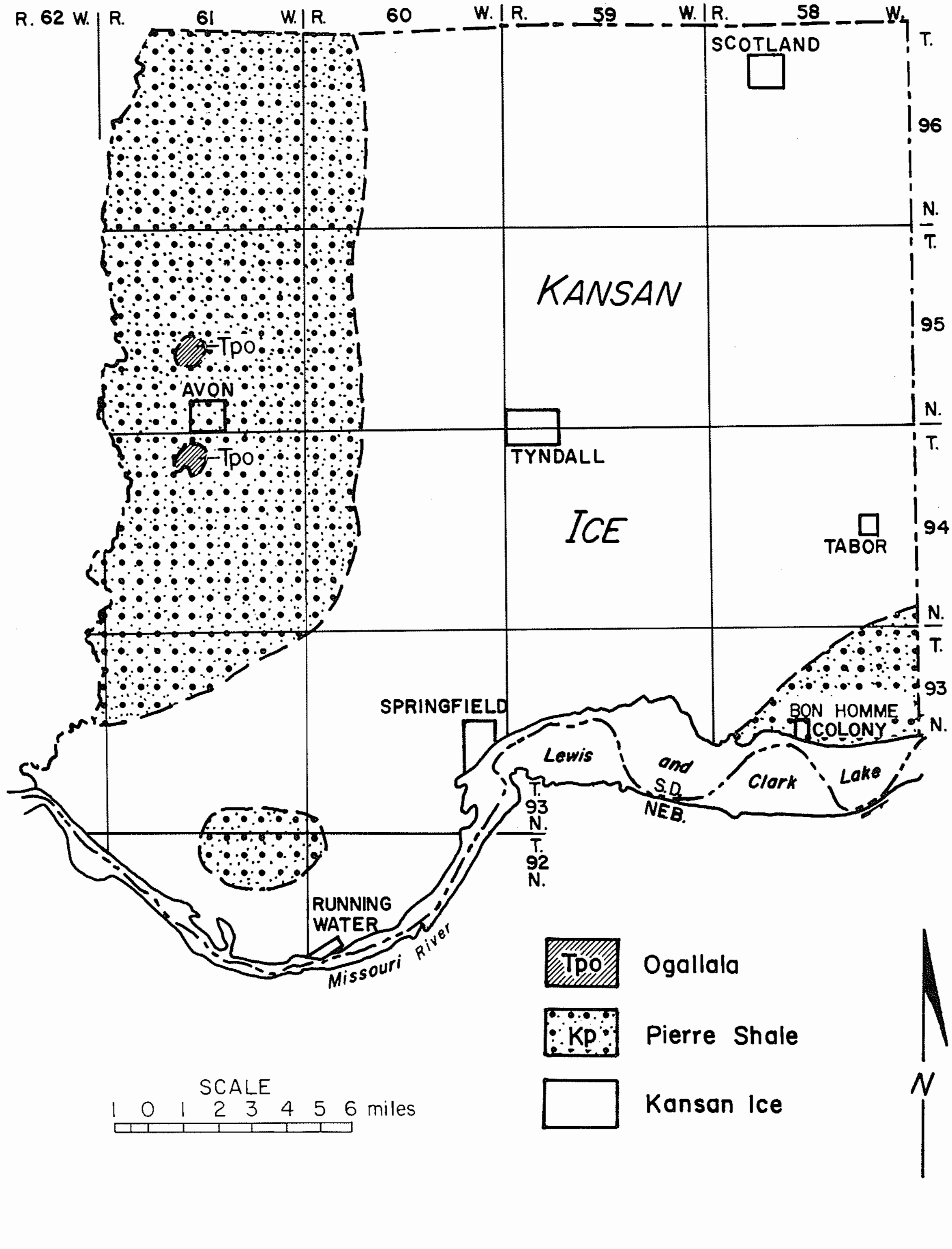


Figure 11. Generalized map showing position of Kansan ice at glacial maximum.

southwestern corner of Bon Homme County (fig. 12) did in fact develop prior to Kansan time. During very late Kansan and early Yarmouthian time, after the ancient Niobrara-Missouri had returned to the original channel north of Yankton Ridge, the Tyndall Sand was deposited as alluvium by ancient Ponca Creek.

The writer thus believes that both the Bon Homme Gravel and Tyndall Sand are of late Kansan age. However, the Tyndall Sand, which is at a lower elevation than the Bon Homme Gravel, was deposited by ancient Ponca Creek after the ancient Niobrara-Missouri had returned to its original channel. Therefore, the Tyndall Sand represents a later Kansan deposition than does the Bon Homme Gravel. This reasoning is further substantiated by the fact that the Tyndall Sand is a much finer-grained deposit than the Bon Homme Gravel, indicating less water velocity. To be sure less water would be available as Kansan glaciation gave way to the Yarmouthian interglacial period and the streams returned to the original pre-Kansan positions.

Illinoian Glaciation

Immediately prior to the advance of Illinoian ice into the mapped area the ancient Niobrara-Missouri River and ancient Ponca Creek maintained positions similar to those shown on figure 13.

Cretaceous shale still occupied most of the highlands and Kansan drift covered nearly two-thirds of the area. Isolated remnants of the Pliocene Ogallala Formation existed in the west-central section. Deposition of the late Kansan fluvial deposits (Bon Homme Gravel and Tyndall Sand) was complete (fig. 13).

Illinoian ice probably covered most of what is now Bon Homme County although no Illinoian drift is present today on any of the highlands. Plates 3, 4, and 5 show widespread deposits of Illinoian till and outwash confined to the lowland areas of the County. Although by no means numerous, Illinoian drift exposures are found in Bon Homme County (pl. 1) especially in the southern part along the north shore of Lewis and Clark Lake.

During the Illinoian, the ancient valleys of the Niobrara-Missouri and Ponca Creek were filled with ice and later with glacial drift (pls. 4 and 5). The writer believes this diversion to have been the permanent diversion from the ancient Niobrara-Missouri trench to the present-day Missouri trench that bisects Yankton Ridge. At the end of the Illinoian glacial period a substantial thickness of drift choked the ancient channels. The present-day Missouri was well entrenched and continued to flow in the diversion channel.

Sangamon Interglacial Stage

With the end of the Illinoian glaciation and the beginning of the warmer Sangamon interglacial stage came a period of time dominated by erosion and weathering. Downcutting was predominate in the major stream valleys and the Missouri River was no exception. During this time the River became further entrenched in the new channel bisecting Yankton Ridge.

No deposits have been found in Bon Homme County to mark the Sangamon interglacial stage, and those deposits that must have existed have either been removed by erosion or covered by younger sediments. Soils of Sangamon age do occur, however, in extreme eastern South Dakota (Steece and Tipton, 1965) substantiating the occurrence of a relatively long period of weathering following the retreat of the Illinoian ice.

Early Wisconsin Glaciation

Early Wisconsin ice did not invade Bon Homme County and indeed the southern limit of early Wisconsin ice was probably in the vicinity of Dell Rapids, South Dakota, a distance of over 100 miles to the northeast (Steece, 1959; Tipton 1959).

Evidence of the exact extent of the ice sheet in South Dakota, especially the western boundary is not conclusive. It is certain, however, that all easterly flowing streams that had not been disrupted by earlier ice sheets must have been diverted by the early Wisconsin ice. Meltwaters from the ice must have traveled down the major drainageways and destroyed much of the valley fill. Later as the velocity and volume of water decreased, early Wisconsin outwash was deposited in the earlier formed troughs.

Evidence of early Wisconsin outwash is inconclusive in Bon Homme County. One possible outwash of this age is shown on plates 3 and 5. Here an outwash of substantial thickness and extent is located between Illinoian till and late Wisconsin till. It is more probable, however, that this outwash was deposited in front of the advancing late Wisconsin glacier and later covered by till from the same ice sheet.

In order for the outwash to be labeled early Wisconsin an unlikely series of events would had to have occurred.

1. Meltwater would have to travel from the early Wisconsin ice front a distance of some 100 miles to the southwest during a period of time when the normal drainage was to the east and south.

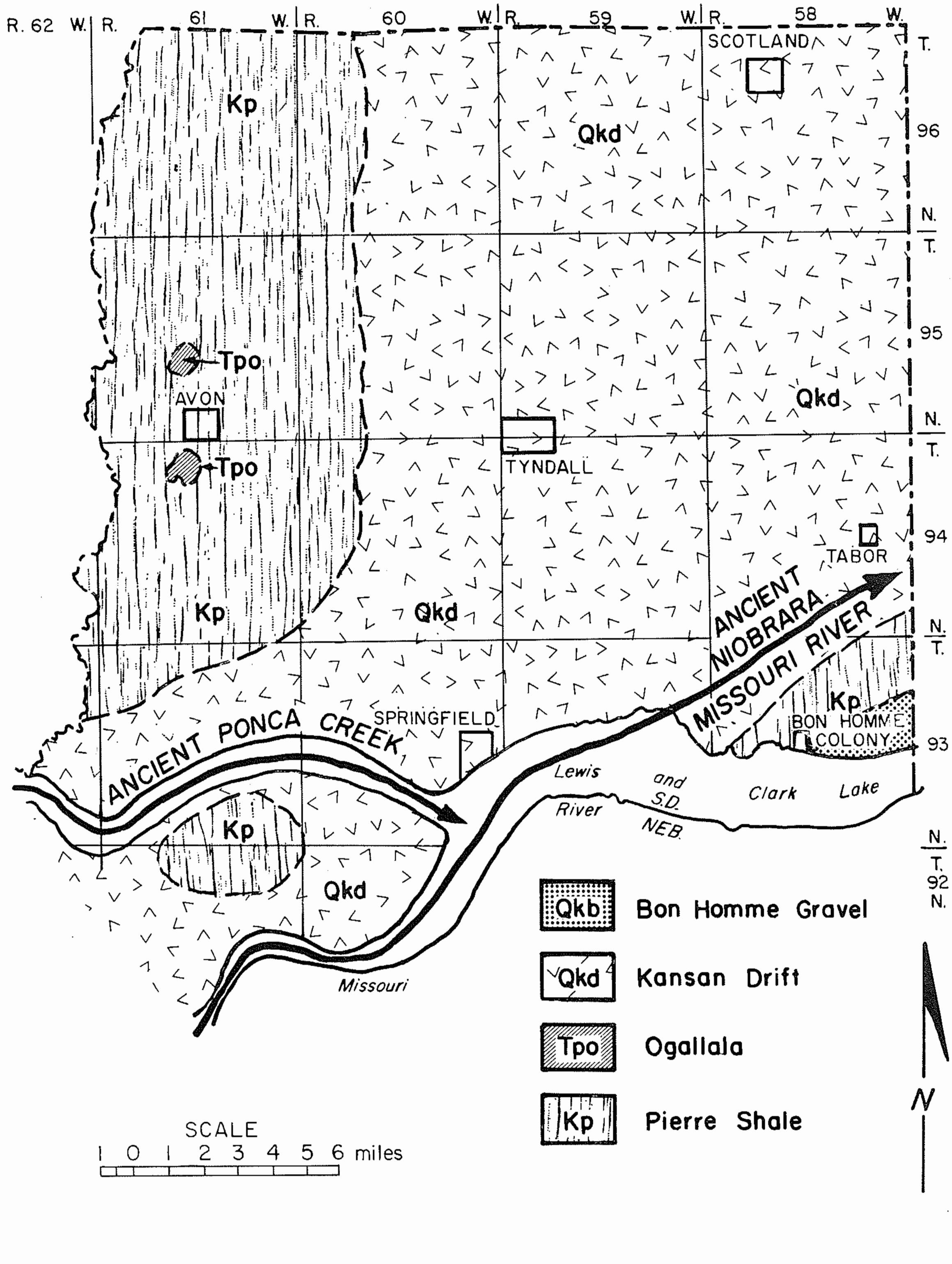


Figure 12. Map showing location of major drainage in Bon Homme County after retreat of the Kansan ice.

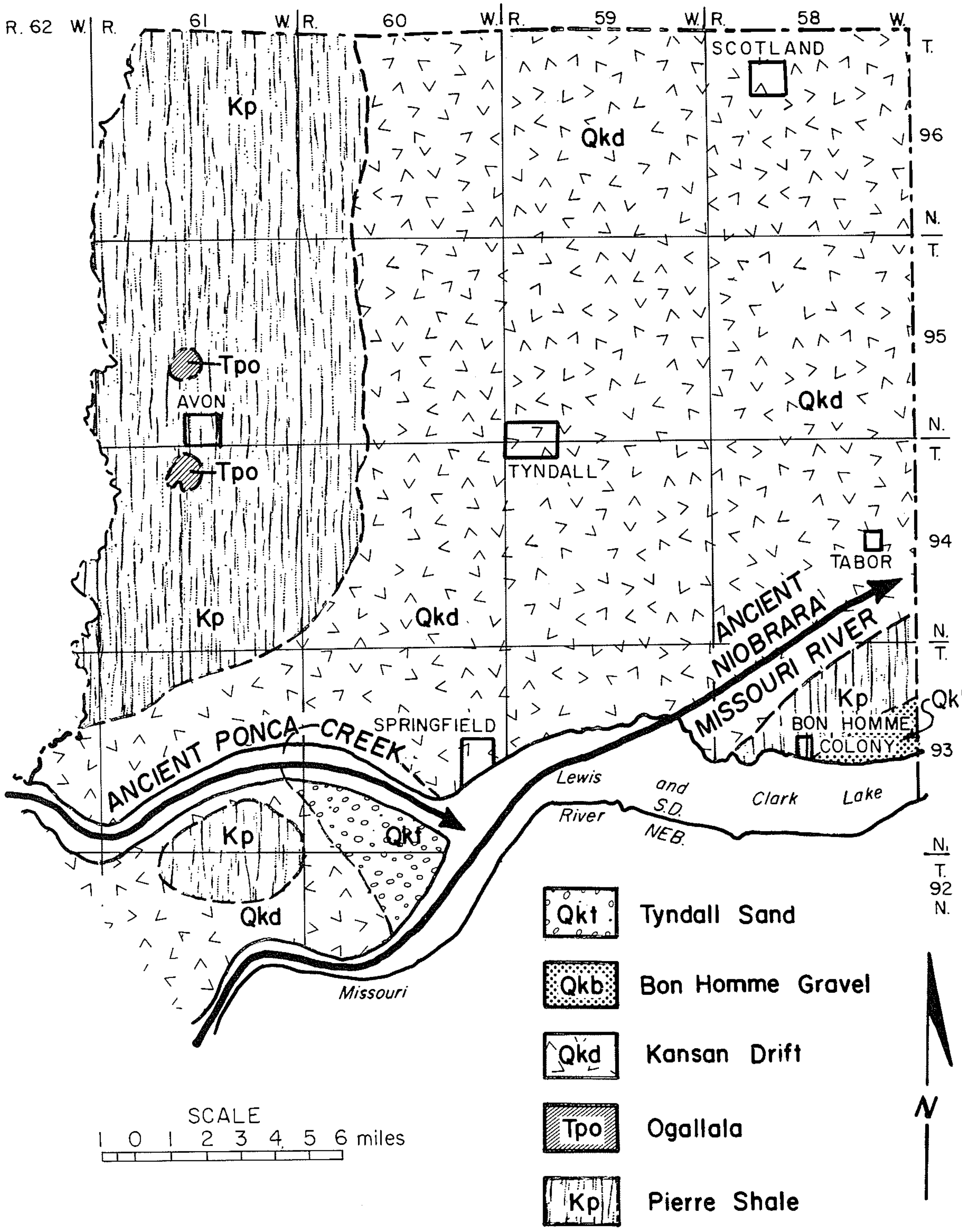


Figure 13. Generalized map of Bon Homme County immediately prior to Illinoian glaciation.

2. This meltwater would then flow "up" a valley from northeast to southwest in Bon Homme County (pl. 2) and across what is now a ground-water divide near sec. 10, T. 93 N., R. 60 W. (pls. 2 and 4) and into the Missouri near the Charles Mix-Bon Homme County boundary.

The writer feels that instead of the unlikely route proposed above, meltwaters from the early Wisconsin ice followed the ancient White River (Christensen, 1966) through what is now Clay County and entered the Missouri near the town of Vermillion (Christensen and Stephens, 1967).

The possibility of early Wisconsin loess existing in Bon Homme County is much greater. Loess believed to be of early Wisconsin age was found at several localities both at the surface (pl. 1) and in the subsurface (see app., test holes 1, 3, 6, and 24). The loess is covered by late Wisconsin drift and rests directly on Illinoian drift, and stratigraphically could be early Wisconsin or Illinoian in age. In no instances, however, was any substantial thickness of soil associated with the upper part of the loess or found overlying the loess. For this reason the loess has been assigned to the early Wisconsin. This loess is not widespread in the mapped area and was probably derived from the floodplain of the Missouri River.

Late Wisconsin Glaciation

Ice of late Wisconsin age completely covered Bon Homme County and was the first ice sheet to completely override all of the highland areas including Yankton Ridge and the Coteau du Missouri. At least if it was not the first to cover these high bedrock areas, it was the first to leave behind now recognizable deposits of drift.

The late Wisconsin ice entered the mapped area from the northeast generally following the low broad topographic depression marking the ancient Niobrara-Missouri River north of Yankton Ridge. Pro-glacial outwash was deposited in this depression and continually overridden by the advancing ice. As the ice moved over the ground-water divide in sec. 10, T. 93 N., R. 60 W., meltwaters flowed in a southwesterly direction a distance of less than 20 miles to the Missouri River. Outwash was deposited in this rather narrow channel (pl. 2) and again overridden by the advancing ice (pl. 6). Figure 14 shows the general configuration of the advancing ice. Although confined initially to the topographic low, the ice eventually covered the entire County as shown by the complete cover of late Wisconsin drift (pl. 1).

Late Wisconsin Till

Till of late Wisconsin age is widespread throughout the mapped area and in fact comprises the major surficial deposit. With regard to method of deposition, this till sheet has been divided for mapping purposes into stagnation moraine, end moraine, and ground moraine.

Avon Moraine

The Avon Moraine, which is named after the town of Avon in western Bon Homme County, constitutes a sizeable mass of stagnation moraine in the western one-third of the area (pl. 1). Its western boundary is in Charles Mix and Douglas Counties and the eastern boundary is in part marked by Emanuel Creek. Size and shape of the Avon Moraine is nearly the same as the underlying bedrock high previously mentioned in the report (fig. 3).

The moraine results from the stagnation of the late Wisconsin ice on the bedrock high; consequently no active ice features are present. The entire area is devoid of any end-moraine type ridges usually associated with active ice and is composed of a random series of knobs and kettles. Many of the higher knobs are topped by unsorted deposits of sand and gravel and were deposited as meltwaters running over the ice surface entered holes and cracks in the ice.

Kettles resulting from ice blocks buried or partly buried in the till are numerous as are isolated sand and gravel ridges and small areas of collapsed outwash.

Late Wisconsin ice advancing toward the southwest in Bon Homme County followed a topographic low at a minimum elevation of about 1200 feet (base of the ice). As the ice moved down the low it was able to expand outward in all directions and move onto the topographic high in the western section of the County which had an elevation of nearly 1700 feet (pl. 7). Although able to surmount the nearly 500 feet difference in elevation the ice was not able to continue movement along the high and stagnation occurred.

Emanuel Creek, which marks the eastern edge of the Avon Moraine along nearly half of its distance in Bon Homme County, received meltwaters from the Avon Moraine as well as from the Tripp Moraine and now marks the boundary between the two moraines (pl. 1).

Late Wisconsin ice probably did not cross the Missouri River, at least it did not do so for any length of time, because remnants of late Wisconsin till across the River are few. Most of the material that would have been used to build a terminal moraine was either carried away by meltwater and the Missouri River or has since been removed by the Missouri. At any rate only a small amount of end moraine can be found in southern Bon Homme County.

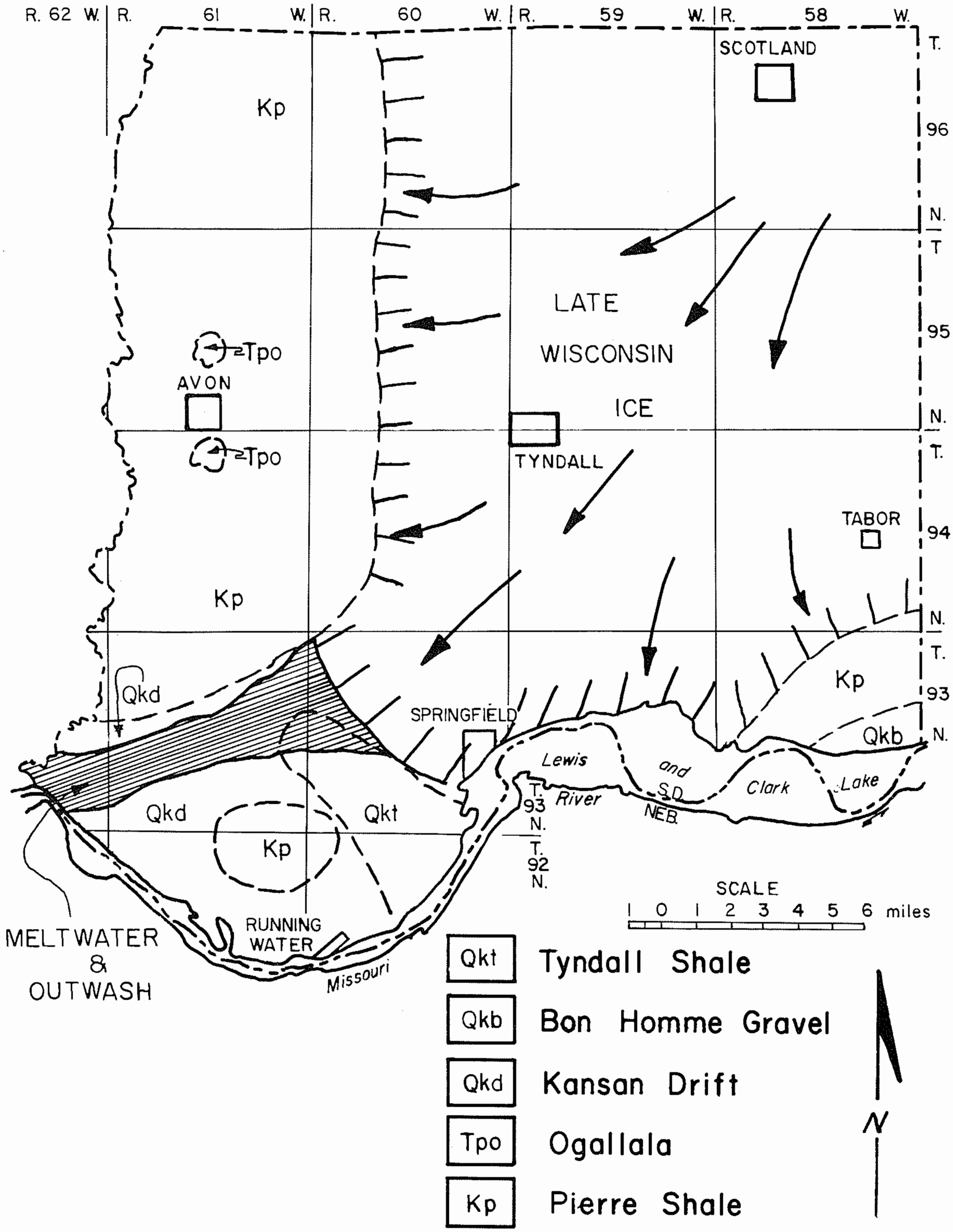


Figure 14. Generalized map of Bon Homme County during advance of the late Wisconsin ice. (arrows show direction of ice advance.)

Colony Moraine

A minor amount of end moraine, called the Colony Moraine and named for Bon Homme Colony, exists in the extreme southeastern part of the mapped area (pl. 1). This moraine forms the north flank of what is now Yankton Ridge and is discontinuous over the Ridge, covering the bedrock and much of the Bon Homme Gravels.

Along the north flank of the Ridge the Colony Moraine portrays distinct lineation from northeast to southwest and the moraine ridges act as interfluves for local southwest flowing tributaries to the Missouri River.

Tabor Moraine

This moraine results from a very isolated mass of drift left in the topographic low as the late Wisconsin ice receded and is relatively small in size (pl. 1). Unmistakable stagnation features such as numerous kettles and sandy, gravelly knobs are found in this area in southeastern Bon Homme County and the area is devoid of any till ridges. For these reasons the Tabor Moraine, named for the nearby town of Tabor, was mapped as stagnation moraine.

The writer believes that a block of ice existed in the topographic low and was covered by drift. After recession of the main ice body, differential melting occurred causing the resulting knob and kettle topography. Although some may question the validity of calling the Tabor Moraine stagnation drift, the geomorphic features are very similar to those found on the Avon Moraine, and it was on this basis that the decision was made.

Tripp Moraine

The Tripp Moraine, named for the town of Tripp in Hutchinson County, represents the largest end moraine in the area. Even though it does not represent the farthest advance of the late Wisconsin ice and cannot therefore be considered as a terminal moraine, the Tripp Moraine does represent a still-stand of relatively long duration.

Sometime after the late Wisconsin ice had reached the vicinity of the Missouri River it began to recede. This retreat was at first slow and erratic as evidenced by numerous recessional morainal ridges within the Tripp Moraine complex (pl. 1). The ice was melting back from the highlands leaving masses of dead ice on the highlands to the west and a small mass of drift-covered ice in the topographic low to the southeast.

Meltwater from the Tripp Moraine and the Avon Moraine was funneled between the two and down the valley of Emanuel Creek. This creek contains evidence of outwash from these two ice masses in the form of many remnants of terrace gravel sometimes as much as 30 feet above the present floodplain (pl. 1). Emanuel Creek exists today as a very insignificant intermittent stream; however, its valley averages nearly one-fourth of a mile in width and at some places reaches a width of over one mile. The valley width coupled with the present size of the stream clearly indicates the importance of the stream as a meltwater channel during the late Wisconsin. Other features such as abandoned channels and abrupt change in channel size and configuration (pl. 1) indicate its direct association with the ice boundary.

As was mentioned earlier the late Wisconsin ice must have remained for some time with its boundary in northeast-central Bon Homme County. It was during this time that the Tripp Moraine was built, with minor fluctuations in the ice front causing numerous small crests on the end moraine complex (pl. 1).

During the early part of the still-stand, meltwaters issuing from the late Wisconsin ice front were channeled down what are now the valleys of Snatch and Tabor Creeks. This fact is substantiated by the numerous outwash remnants along these creeks and outwash buried beneath their most recent alluvial fill, plus the occurrence of one abandoned meltwater channel in association with Snatch Creek.

At a later time, when the southern boundary of late Wisconsin ice was positioned along the north flank of the topographic low, most of the meltwater was flowing in an easterly direction along the southern boundary of the ice. This meltwater channel was the beginning of Beaver Creek.

Simpson (1960) experienced some difficulty in explaining the east-west trend of Beaver Creek.

However, his problem does not arise when the following points are considered:

1. Late Wisconsin ice occupied the area immediately to the north and west of Beaver Creek.

2. Yankton Ridge formed a barrier along the southern edge of the topographic low in which Beaver Creek is located.

3. The Tabor Moraine and associated stagnant ice occupied the southwestern part of the low.

With these three facts in mind, it can easily be seen that meltwater from the ice front, of necessity, was diverted in an easterly direction down Beaver Creek, thence into the James River, and finally into the Missouri. Outwash terraces and abandoned meltwater channels associated with Beaver Creek (pl. 1) substantiate this fact.

Ground Moraine

Ground moraine deposited beneath the late Wisconsin ice has been subdivided on plate 1 in the interest of clarity. That ground moraine labeled $Qwltg_1$ is what now exists as a surficial deposit on most of the area southwest of the Tripp Moraine. This ground moraine occupies most of the lowland areas in southwestern Bon Homme County and was probably deposited in part as lodgement till beneath the advancing ice and in part of ablation till as the ice receded. All of the drainage from this ground moraine is directly to the Missouri River and everywhere the topography slopes toward the River.

Ground moraine in northeastern Bon Homme County is labeled $Qwltg_2$ on plate 1 and is confined to an area northeast of the Tripp Moraine. Here again it is impossible to determine how much of the deposit is lodgement till and how much is ablation till. This ground moraine is extremely flat with stream dissection causing most of the noticeable relief. All drainage from this area was blocked to the south by the Tripp Moraine and consequently trends northeasterly into the James River by way of Dawson Creek and its tributaries.

Late Wisconsin Loess

Loess of late Wisconsin age is not widespread in the area and is mostly located along the southern boundary of the County. Deposition was most predominate in the southwestern end of the topographic low in that area (pl. 1). Source of the loess was almost certainly the floodplain of the Missouri River. Loess deposition occurred along the River both in Bon Homme County and Nebraska; however, in neither case was loess deposited more than a very few miles in either direction.

Recent Development

Since the close of the Pleistocene Epoch the land surface of Bon Homme County has changed only to a slight degree.

Major changes have occurred only in the Missouri River trench where lateral cutting has essentially replaced downcutting. The River has meandered over the floodplain changing channels and leaving many cut off meanders. With the construction of Gavin's Point Dam and the resultant filling of Lewis and Clark Reservoir in the late 1950's most of the Missouri River floodplain is now covered by water and the evidence of the shifting Missouri River channel cannot be seen. Sand bars still exist in the backwater areas of the Lake (pl. 1) and although more stable than before are still subject to rapid change in size, shape, and position.

Siltation in Lewis and Clark Lake is presently a problem of major importance and primarily results from sediments deposited from the waters of the Niobrara River.

Alluvial deposits along all of the major streams (pl. 1) and most minor tributaries are primarily the result of recent deposition. These alluvial deposits cover most of the outwash earlier deposited in the stream valleys.

Some dune sand is present in the extreme northeastern corner of the County. The source of this sand is most likely the floodplain of the James River. Although mapped as a Recent deposit, deposition probably began during the final stages of the late Wisconsin. The area is now stable and covered with vegetation although some movement of the particles still occurs in open plowed fields.

Most of the major drainage visible today in Bon Homme County began as a direct result of glacial meltwaters. The drainage pattern is well developed, primarily because of the close proximity of the Missouri and James Rivers.

A dendritic drainage pattern has developed since the close of the Pleistocene and most tributaries are still exhibiting headward erosion.

Various types of mass movement are constantly working to change the shape of the landscape (pl. 1).

ECONOMIC GEOLOGY

Mineral Resources of Bon Homme County

Water

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

In addition, ground water is available from several sources within the County. Glacial aquifers, primarily buried beneath the late Wisconsin till cover a major area of the County (fig. 15) and the Niobrara Marl constitutes a sizeable aquifer throughout most of the area (fig. 16). In addition artesian water from the Dakota Formation is available throughout nearly the entire County.

The various aspects of all of the aquifers in Bon Homme County, including quantity, quality, and general availability of water, are discussed in Part II (Jorgensen, 1971) of the report and by Christensen (1970a).

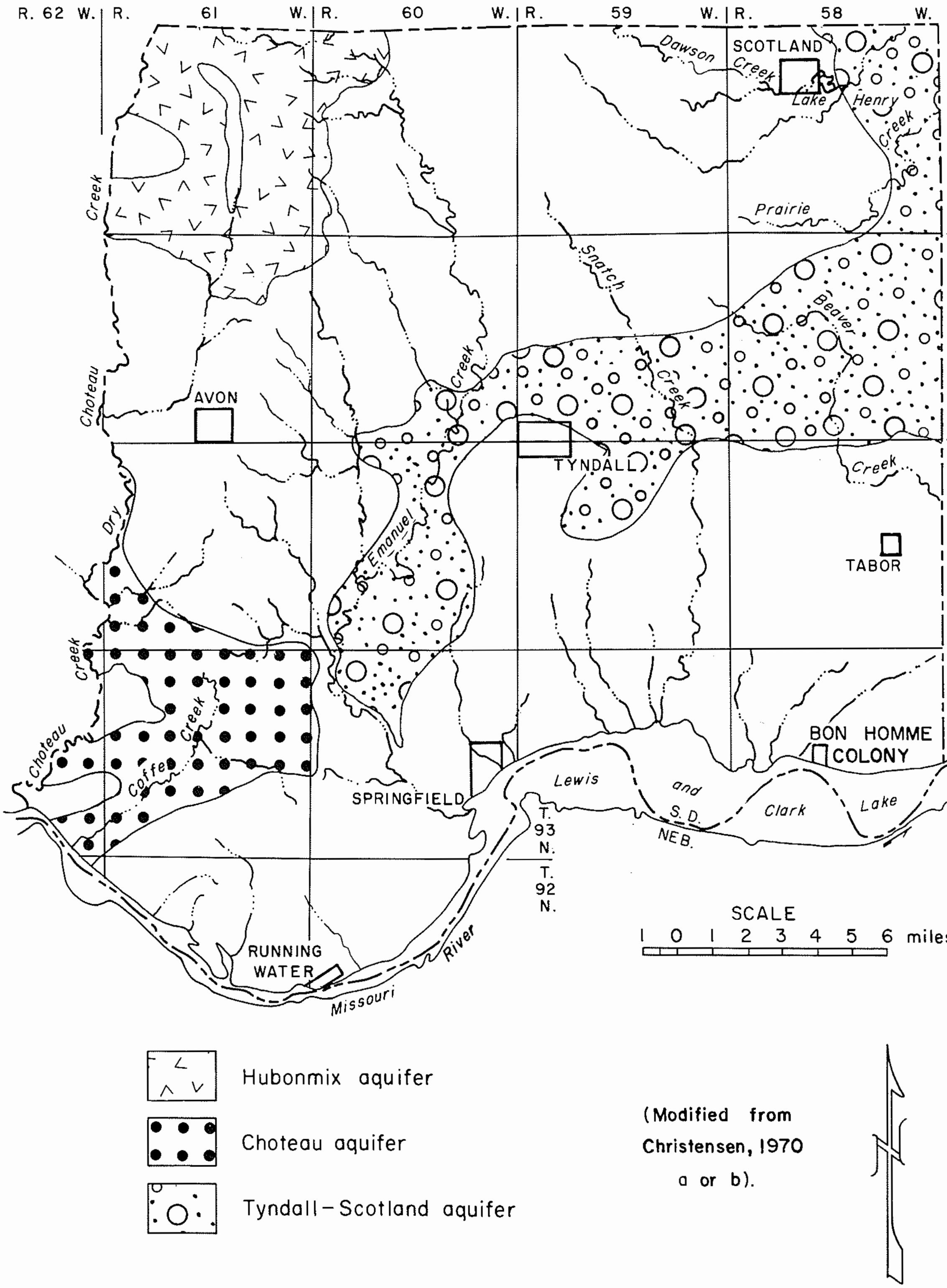


Figure 15. Map of Bon Homme County showing locations of the major glacial aquifers.

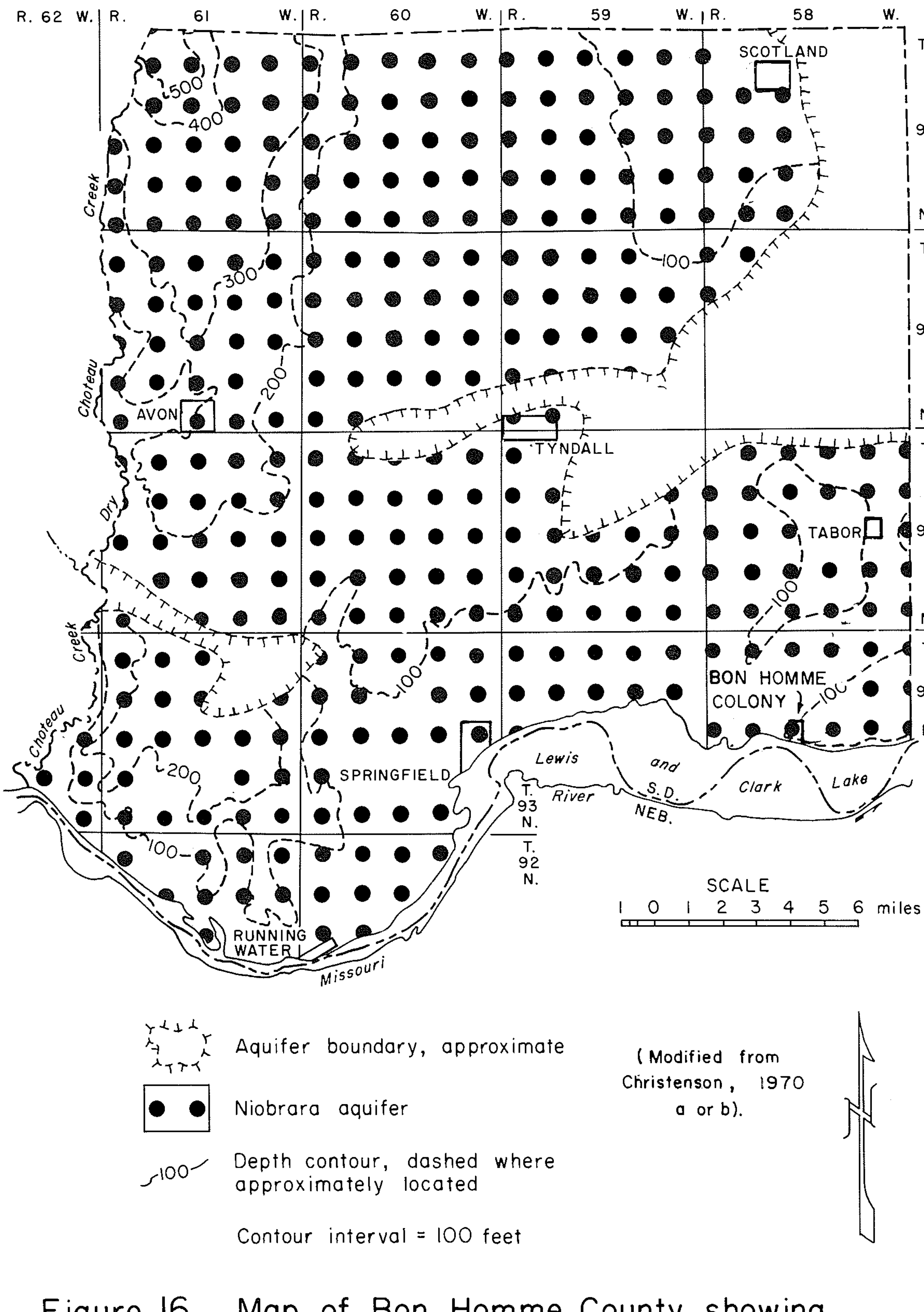


Figure 16. Map of Bon Homme County showing location and depth to Niobrara aquifer.

Sand and Gravel

Sand and gravel is a valuable resource in Bon Homme County although used primarily for road construction and concrete aggregate.

Most minable sand and gravel deposits in the area consist of outwash along the major and minor streams; however, large amounts of gravel are extracted each year from borrow pits in the Bon Homme Gravel in the extreme southeastern corner of the County.

For the more detailed information concerning the sand and gravel resources the reader is referred to Christensen (1970b). This report deals exclusively with the subject and contains information on past, present, and future aggregate localities.

Chalk

Chalky areas within the Niobrara Marl crop out extensively along the Missouri River and the Lewis and Clark Lake in the mapped area.

In general, chalk can be used for building stone, lime, in the manufacture of paints, whiting, kalsomine, putty, oil cloth, gun powder, rubber, leather, and roofing cement.

During the present study no tests were made to determine the qualities of the chalk from Bon Homme County; however, in the past these tests have been made at many localities in southeastern South Dakota. The main objectional feature of South Dakota chalk is its color. Industry requires a pure white chalk for manufacturing purposes. Because chalk from the Niobrara Marl is light-gray to cream-colored, if used, it would surely command a lower price than the natural white chalk from other areas of the country. However, South Dakota chalk is suitable for use in the manufacturing of putty and rubber. The deposits of Niobrara Marl exposed at the surface in Bon Homme County are shown on plate 1.

Other Mineral Commodities

To date no other economically minable mineral deposits such as oil, gas, ceramic clays, or metals have been located in Bon Homme County.

SUMMARY

The investigation of Bon Homme County was designed and undertaken with a two-fold purpose in mind. Of primary importance was the location of all available ground-water supplies of major importance. These deposits have been discussed in this report from a purely geologic standpoint in order to show their mode of occurrence and relationship to the remainder of the deposits in the area. All hydrological data collected is reported in Part II (Jorgensen, 1971) of this report. Included is a discussion on quality, quantity, and availability of ground water from all the known aquifers within the County.

The second major purpose of the investigation was to prepare a geologic map and report that would include all geological information available for the County. This section of the report (Part I) has been aimed at fulfilling that goal. Emphasis has been placed on the Pleistocene age deposits because these sediments are the major surficial deposits present.

In addition, it is hoped that this study will contribute some information useful in the overall understanding of the geology and hydrology of South Dakota and may serve as a starting point for later observers.

REFERENCES CITED

Agnew, A. F., and Tychsen, P. C., 1965, A guide to the stratigraphy of South Dakota: S. Dak. Geol. Survey Bull. 14, 195 p.

American Commission on Stratigraphic Nomenclature, 1961, Code of stratigraphic nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 650-652.

Baird, J. K., 1957, Geology of the Alcester quadrangle, South Dakota-Iowa: unpubl. master's thesis, Univ. of S. Dak., Vermillion, 136 p.

Baldwin, Brewster, 1951, Geology of the Sioux Formation: Ph.D. thesis, Columbia Univ., 156 p.

Bruce, R. L., 1962, Shallow water supply for the city of Tyndall: S. Dak. Geol. Survey Spec. Rept. 13, 23 p.

Christensen, C. M., 1963, Water supply for the city of Scotland: S. Dak. Geol. Survey Spec. Rept. 20, 27 p.

------ 1966, Pleistocene stratigraphy of Clay County, South Dakota: Unpubl. master's thesis, Univ. of S. Dak., Vermillion, 102 p.

Christensen, C. M., and Stephens, J. C., 1967, Geology and hydrology of Clay County, South Dakota: Part I, Geology: S. Dak. Geol. Survey Bull. 19, 86 p.

Christensen, C. M., 1970a, Major ground-water aquifers in Bon Homme County, South Dakota: S. Dak. Geol. Survey Water Inf. Circ. 4, 7 p.

------ 1970b, Sand and gravel resources in Bon Homme County, South Dakota: S. Dak. Geol. Survey Circ. 39, 5 p.

Darton, N. H., 1896, Preliminary report on the artesian waters of a portion of the Dakotas: U.S. Geol. Survey Ann. Rept. 17, Part II, p. 609-694

------ 1899, Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U.S. Geol. Survey 19th Ann. Rept., 1897-98, p. 719-785.

------ 1909, Geology and underground waters of

South Dakota: U.S. Geol. Survey Water-Supply Paper 227, 156 p.

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U.S. Geol. Survey Prof. Paper 262, 173 p.

Goldich, S. S., and others, 1961, The Precambrian geology and geochronology of Minnesota: Minn. Geol. Survey Bull. 41, 193 p.

Jorgensen, D. G., 1971, Geology and water resources of Bon Homme County, South Dakota: Part II, Water Resources: S. Dak. Geol. Survey Bull. 21, 61 p.

Lugn, A. L., 1932, Pleistocene formations of southern Nebraska [abs.]: Geol. Soc. America Bull., v. 43, p. 190.

Meek, F. B., and Hayden, F. V., 1861, Description of new lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska territory, ***; with some remarks on the rocks from which they were obtained: Acad. Natl. Sci., Philadelphia Proc., p. 415-447 (1862).

Petsch, B. C., 1962, Magnetometer survey of southeastern South Dakota: S. Dak. Geol. Survey Mineral Resources Inv. Map 3.

Reed, E. C., and Dreeszen, V. H., 1965, Revision of the classification of the Pleistocene deposits of Nebraska: Neb. Geol. Survey Bull. 23, 65 p.

Rothrock, E. P., 1943, A geology of South Dakota: Part I, The surface: S. Dak. Geol. Survey Bull. 13, 88 p.

Simpson, H. E., 1952, Geology of an area about Yankton, South Dakota: U.S. Geol. Survey open-file report, in Washington, D. C. and Denver, Colo. libraries.

------ 1960, Geology of the Yankton area South Dakota and Nebraska: U.S. Geol. Survey Prof. Paper 328, 124 p.

Steece, F. V., 1959, Geology of the Sioux Falls quadrangle: S. Dak. Geol. Survey map and text.

------ 1962, Precambrian basement rocks of South Dakota: S. Dak. Acad. Sci. Proc., v. 41, p. 51-56.

Steece, F. V., and Tipton, M. J., 1965, Introduction to Pleistocene of Big Sioux River basin in South Dakota: 7th Internat. INQUA Field Conf. C., South Dakota part, p. 11-29.

Stevenson, R. E., and Carlson, L. A., 1952, Areal geology of the Bonesteel quadrangle: S. Dak. Geol. Survey quad. map.

Thwaites, Ruben, 1959, Original journals of the Lewis and Clark expedition: New York, Antiquarian Press Ltd., v. 1, p. 88-164; v. 5, p. 337-395.

Tipton, M. J., 1958, Geology of the Akron quadrangle, South Dakota-Iowa: unpubl. master's thesis, Univ. of S. Dak., Vermillion, 80 p.

------ 1959, Geology of the Dell Rapids quadrangle, South Dakota: S. Dak. Geol. Survey map and text.

Todd, J. E., 1894, Preliminary report of the geology of South Dakota: S. Dak. Geol. and Nat. Hist. Survey Bull. 1, 172 p.

------ 1912, Pre-Wisconsin channels in southeastern South Dakota and northeastern Nebraska: Geol. Soc. America Bull., v. 23, p. 463-470.

APPENDIX — LOGS OF TEST HOLES

Logs listed in this appendix were used to compile the cross sections (pls. 3, 4, 5, 6, and 7) that are located in the map pocket. Additional logs that were used for descriptive purposes within the text are also listed.

Following is a list of abbreviations used on the test hole logs.

Geologic Units

Qal	Recent Alluvium
Qwll	Late Wisconsin Loess
Qwlt	Late Wisconsin Till
Qwlo	Late Wisconsin Outwash
Qwlu	Late Wisconsin deposits undifferentiated
Qwel	Early Wisconsin Loess
Qit	Illinoian Till
Qiu	Illinoian deposits undifferentiated
Qkt	Tyndall Sand (Late Kansan)
Qku	Kansan deposits undifferentiated
Qo	Outwash undifferentiated
Tpo	Ogallala deposits undifferentiated
Kp	Pierre Shale
Kn	Niobrara Marl
Kc	Carlile Shale
Kcc	Codell Sandstone Member of Carlile Shale
Kd	Dakota Formation

Drilled by

USGS	United States Geological Survey
SDGS	South Dakota Geological Survey
Pd	Private Driller

Test Hole 1
Location: 92-60-7cddd
Drilled by: USGS
Elevation: 1307 feet

Test Hole 1 -- continued.

Geologic Unit	Description	Depth Feet
Qwll	Clay and silt, brown	0- 10
Qwlt	Clay, brown, silty, sandy, and gravelly	10- 17
Qwel	Clay, yellow, saturated	17- 27
Qit	Clay, gray, silty, sandy, and pebbly	27- 42
Kn	Marl, gray-brown, crumbly	42- 57

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Test Hole 2
Location: 92-60-19bbab
Drilled by: USGS
Elevation: 1420 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, light-brown to brown, with pebbles	0- 23
	Clay, gray, with pebbles	23- 30
Qkt	Sand, fine to medium, mostly feldspar and quartz, some fine to medium gravel of same composition from 50 to 60 feet	30- 60
Qit	Clay, gray with pebbles	60-117

* * * * * *

Test Hole 3
Location: 92-61-3baaa
Drilled by: SDGS
Elevation: 1520 feet

Geologic Unit	Description	Depth Feet
	Topsoil, black, noncalcareous	0- 1

Test Hole 3 -- continued.

Qwlt	Clay, yellow-brown, pebbly	1- 20
Qwel	Silt, yellow-brown, sandy	20- 30
Qit	Clay, yellow-brown, some large rocks	30- 40
	Clay, medium-gray, pebbly	40- 65

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Test Hole 4
Location: 92-61-4aaaa
Drilled by: SDGS
Elevation: 1537 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly	0- 45
	Clay, gray	45- 50
Kn	Marl, light-gray, abundant white, calcareous, specks	50- 60

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Test Hole 5
Location: 92-61-4ddda
Drilled by: SDGS
Elevation: 1610 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, with pebbles	0- 1
Qwlo	Gravel and sand	1- 10
Kp	Shale, multi-colored, brown to dark-gray with yellow streaks, fissle	10- 27

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Test Hole 6
Location: 92-61-12dddc

Test Hole 6 -- continued.

Drilled by: USGS
Elevation: 1426 feet

Geologic Unit	Description	Depth Feet
Qwll	Clay and silt, brown	0- 2
Qwlt	Clay, silty, medium-brown, pebbly	2- 15
Qwel	Clay, light yellow-brown, caliche	15- 17
Qit	Clay, reddish-brown, pebbly	17- 35
Qkt	Sand, very fine- to medium-grained, composed of quartz and feldspar	35-117

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Test Hole 7
Location: 93-58-1cccc
Drilled by: SDGS
Elevation: 1492 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, with pebbles and sand	0- 32
	Clay, gray, with pebbles and sand	32- 42
	No sample; easy drilling	42- 47
Kp	Shale, medium dark-gray	47- 57

* * * * * *

Test Hole 8
Location: 93-58-10aaaa
Drilled by: SDGS
Elevation: 1442 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, with pebbles	0- 37

Test Hole 8 -- continued.

Geologic Unit	Description	Depth Feet
	Clay, medium-gray, with pebbles	37- 62
Kp	Shale, dark-gray	62- 77

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Test Hole 9
Location: 93-59-2dddd
Drilled by: SDGS
Elevation: 1286 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, light-brown, with pebbles	0- 17
Qwlo	Gravel, coarse	17- 32
Qwlt	Clay, gray, with pebbles.	32- 47
Qit(?)	Clay and silt, brown	47- 52

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Test Hole 10
Location: 93-59-7bbbb
Drilled by: SDGS
Elevation: 1372 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, with pebbles	0- 27
Qwel	Clay and silt, yellow, saturated	27- 32
Qit	Clay, yellow-tan	32- 62
	Clay, gray, with pebbles	62-110
Kn	Marl, light-gray, calcareous	110-112

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Test Hole 11
Location: 93-59-10aabb
Drilled by: SDGS
Elevation: 1265 feet

Test Hole 11 -- continued.

Geologic Unit	Description	Depth Feet
Qwll	Clay and silt, brown	0- 2
Qwlo	Gravel, coarse, and brown sand	2- 7
	Gravel, coarse with brown sand and clay	7- 12
Qwlt	Clay, gray, sandy, damp	12- 17
	Clay, gray, with pebbles	17- 57
Qit(?)	No sample (gray till on auger flights and bit	57-112

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Test Hole 12
Location: 93-59-11bbab
Drilled by: SDGS
Elevation: 1236 feet

Geologic Unit	Description	Depth Feet
Qwll	Clay, silty, brown with trace of sand	0- 7
Qwlt	Clay, sand, and gravel, brown	7- 12
	Clay, light-tan, with pebbles becoming gray	12- 17
	Clay, light-gray, with pebbles	17- 37
Qit(?)	Clay, sand, silt, dark-gray to black	37- 52
Qku(?)	Sand, fine, white	52- 77
Kn(?)	No sample, tight drilling	77- 82

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Test Hole 13
Location: 93-60-1cccd
Drilled by: SDGS
Elevation: 1368 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly	0- 19

Test Hole 13 -- continued.

Geologic Unit	Description	Depth Feet
	Clay, gray, pebbly	19- 38
Kn	Shale, dark-gray	38- 50
	Shale, dark-gray saturated	50- 87

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Test Hole 14
Location: 93-60-4cccc
Drilled by: SDGS
Elevation: 1365 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, buff-brown, pebbly	0- 28
	Clay, gray, with some sand layers	28- 43
Qwlo	(Hard formation, used pull-down all the way, no cuttings)	43- 65
	Gravel stringers and fine sand	65-155
Kn	Marl, gray	155-170

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Test Hole 15
Location: 93-60-7aaaa
Drilled by: SDGS
Elevation: 1346 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown with iron stains and pebbles	0- 12
	Clay, brown, with pebbles	12- 27
	Clay, brown, sandy	27- 37
Qwlo	Sand, medium-brown, with clay	37- 47
	Sand, brown, fine to medium	47- 57
	Sand, brown, fine	57- 77
	Sand, brown, fine, saturated	77- 82
	Sand, gray, fine, with clay	82- 92

Test Hole 15 -- continued.

Geologic Unit	Description	Depth Feet
Qwlu	Clay, silty	92- 97

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Test Hole 16
Location: 93-60-9baaa
Drilled by: SDGS
Elevation: 1360 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay	0- 10
Qwlo	Sand	10-136
Kn	Chalk	136-145

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Test Hole 17
Location: 93-60-10babd
Drilled by: SDGS
Elevation: 1370 feet

Geologic Unit	Description	Depth Feet
Qwlt	Sand and clay	0- 45
	Clay, blue	45- 60
Kn	Marl	60-120
	Chalk	120-160
	Shale with chalk layers (with flow at 225 feet)	160-280
	Sandstone	280-301

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Test Hole 18
Location: 93-60-11aaaa
Drilled by: SDGS
Elevation: 1370 feet

Test Hole 18 -- continued.

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, with chalk pebbles	0- 37
Kn(?)	Clay, gray (takes water easily)	37- 50
	No return	50-125
	(Bit sample of calcareous shale)	

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Test Hole 19
Location: 93-60-11bbbb
Drilled by: SDGS
Elevation: 1357 feet

Geologic Unit	Description	Depth Feet
Qwll	Clay and silt, tan	0- 5
Qwlt	Clay, brown, with pebbles	5- 47
	Clay, yellow-brown, silty	47- 88
Kn	Shale, dark-gray, with chalk specks	88- 97

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Test Hole 20
Location: 93-61-1cccc
Drilled by: SDGS
Elevation: 1368 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, sandy	0- 45
	Clay, gray	45-100
	Clay, gray, with gravel stringers	100-120
Qwlo	Gravel, medium	120-132
	(Fairly easy drilling)	132-138
	(Lost circulation, plugged bit and found black till)	138-140

Test Hole 20 -- continued.

Geologic Unit	Description	Depth Feet
	Clay, gray	140-160
Kn(?)	(Lost circulation)	160-240

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Test Hole 21
Location: 93-61-5bccc
Drilled by: SDGS
Eelvation: 1395 feet

Geologic Unit	Description	Depth Feet
	Topsoil, black	0- 5
Qwlt	Clay, yellow-brown, pebbly	5- 31
	Clay, gray, sandy and gravelly, with few thin gravel stringers	31-170
Qwlo	Gravel	170-190
Kn	Chalk	190-200

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Test Hole 22
Location: 93-61-10bbbb
Drilled by: SDGS
Elevation: 1443 feet

Geologic Unit	Description	Depth Feet
	Topsoil, black	0- 5
Qwlt	Clay, light-gray turning brown	5- 23
	Clay, gray, with a few gravel stringers	23-206
Qwlo	Gravel (takes water easily)	206-230
Kn	Clay, hard (takes water very easily)	230-238

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Test Hole 23
Location: 93-61-15cccc

Test Hole 23 -- continued.

Drilled by: SDGS
Elevation: 1438 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, sandy	0- 45
	Clay, gray	45- 90
	Clay, gray with thin gravel layers	90- 95
	Clay, gray, sandy, and gravelly	95-138
	Gravel, pea-size	138-142
	Clay, gray, sandy with some gravel stringers	142-168
Qwlo	Gravel, fine to coarse (Lost circulation at 220 feet)	168-220

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Test Hole 24
Location: 93-61-31aaaa
Drilled by: SDGS
Elevation: 1420 feet

Geologic Unit	Description	Depth Feet
Qwll(?)	Clay, silty, reddish-brown, loess(?)	0- 3
Qwlt	Clay, yellow-brown to light-brown, pebbly, chalky, mottled with white, brown from 20 to 35 feet	3- 35
Qwel	Silt, yellow-brown to brown, some clay and fine sand	35- 42
Qit	Clay, brown, pebbly, silty, chalky, mottled with white, brown, and black specks	42- 67
Qiu	Sand and gravel containing wide variety of rock types, abundant chalk and shale pebbles	67- 78
Qku(?)	Alluvium(?), composed of sand and some fine gravel, silt and shale particles, light-gray to black	78-128

Test Hole 24 -- continued.

Geologic Unit	Description	Depth Feet
	Gravel, fine to medium and some coarse sand, mostly quartz and feldspar but also some limestone and other rock types	128-177
Kn	Marl, medium-gray, abundant white calcareous specks. (Lost circulation).	177-185

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Test Hole 25
Location: 94-57-6bbbb
Drilled by: SDGS
Elevation: 1375 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown	0- 28
	Clay, gray, sandy, drills easier	28- 35
	Clay, gray, sandy, drills very easy	35- 50
	Same with rocky spots	50- 65
	Same; toughened up at 75 feet	65- 80
Qwlo	Sand	80- 90
Qit	Clay, gray, sandy, drills very easy	90-110
	Clay, gray, drills tough first 5 feet, rocky	110-125
	Clay, gray, rocky, and gravelly	125-140
	Clay, gray, with a few gravel stringers	140-155
	Clay, gray, gravelly	155-185
	Clay, gray, gravelly; drills a little easier	185-200
	Clay, gray, with few gravel stringers	200-229
Qo	Gravel	229-255
Kc	Shale, gray	255-270
Kcc	Sandstone chips and shale, gray	270-275
	Sandstone	275-290
Kc	Shale, very tough, no samples, sandstone stringers	290-305

Test Hole 25 -- continued.

Geologic Unit	Description	Depth Feet
	Shale, medium-gray, very soft	305-320

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Test Hole 26
Location: 94-58-3aaaa
Drilled by: SDGS
Elevation: 1375 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, pale, yellow-brown, silty, sandy, pebbly, some light-gray to whitish clay, calcareous	0- 17
	Clay, medium-gray, silty, slightly sandy, pebbly, calcareous	17- 63
Qwlo	Sand, fine to coarse, some fine to medium gravel. Medium to coarse gravel from 84 to 88 feet	63- 88
	Sand and gravel interbedded with medium-gray till. Some beds up to 5 feet thick	88-112
Qit	Clay, medium-gray, silty, sandy, pebbly, calcareous. Several gravel stringers and a few rocks	112-348
Kc	Shale, dark-gray, plastic, very hard, non-calcareous	348-365

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Test Hole 27
Location: 94-58-6aaaa
Drilled by: SDGS
Elevation: 1395 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown	0- 25

Test Hole 27 -- continued.

Geologic Unit	Description	Depth Feet
	Clay, gray	25- 35
	Lost and regained circulation, getting gray clay	35- 50
	Clay?, gray, still getting a lot of brown clay	50- 65
	Clay, gray, rocky and gravelly in spots	65-105
Qwlo	Sand	105-115
Qit	Clay, gray, sandy	115-140
	Same, very tough	140-170
	Clay, gray, drills easier	170-200
	Same, drills like a few coal seams	200-215
	Drills like gravelly till, think that is what it was above also	215-243
Kcc	Sandstone	243-260

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Test Hole 28
Location: 94-59-2aaaa
Drilled by: SDGS
Elevation: 1340 feet

Geologic Unit	Description	Depth Feet
	Gravel and yellow clay	0- 10
	Silt	10- 20
Qwlt	Clay, medium-gray, very silty, pebbly, two thin gravel stringers from 40 to 42 feet	20- 50
Qwlo	Sand and gravel, some clay stringers, some coal	50- 65
Qit	Clay, medium-gray, silty, and pebbly	65-100
	Sand and gravel, some clay	100-125
	Clay, some poor clayey gravel	125-140
	Clay, gray	140-148
Kcc	Sandstone	148-168
Kc	Shale, black, waxy, noncalcareous	168-185

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Test Hole 29
Location: 94-59-4bbbb
Drilled by: SDGS
Elevation: 1400 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown	0- 17
	Clay, gray	17- 50
	Same, drills easy	50- 80
	Same, drills very easy	80-140
	Clay, gray, gravelly in spots, toughened up at 150 feet	140-165
	Gravel, poor	165-173
	Clay, gray, tough, gravelly in spots	173-185
Qwlo	Gravel, very poor	185-200
	Drills like gravel, getting soft white (Kn); but not much	200-215
	Drills like Codell or gravel, and we are getting some sandstone	215-230
Kcc	Sandstone, poorly consolidated, some of the cuttings are very dirty yellow	230-245

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Test Hole 30
Location: 94-60-5aaaa
Drilled by: SDGS
Elevation: 1449 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown	0- 40
	Clay, gray, with silt and gravel stringers	40-219
Qwlo	Sand and fine gravel	219-355
Kc	Clay, light-gray	355-380

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Test Hole 31
Location: 94-61-2bbbb
Drilled by: USGS
Elevation: 1598 feet

Geologic Unit	Description	Depth Feet
Qwlt	Topsoil and gray clay	0- 7
	Clay, yellow-brown, with pebbles	7- 12
	Clay, brown, with pebbles	12- 22
	Clay, gray, with pebbles	22- 32
	Clay, gray, with silt, sand, and gravel lenses	32- 87

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Test Hole 32
Location: 94-61-3bbbb
Drilled by: SDGS
Elevation: 1637 feet

Geologic Unit	Description	Depth Feet
	Road fill	0- 6
Qwlt	Clay, creamy-brown, sandy, rocky, and more sandy from 15 to 24 feet	6- 24
	Clay, medium-gray, silty, sandy, pebbly, some rocks	24- 95
	Silt, gray, sandy	95-110
	Clay, medium-gray, pebbly, sand stringers, silty, rocky in spots	110-190
Kp	Black shale	190-215

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Test Hole 33
Location: 94-61-4dddd

Test Hole 33 -- continued.

Drilled by: USGS
Elevation: 1643 feet

Geologic Unit	Description	Depth Feet
	Clay, light-brown with pebbles	0- 27
	No sample (drills tight)	27- 32
	No sample (drills easy)	32- 47
	Clay, gray, with silt and sand, saturated	47- 80
	Clay, gray, with sand, silty, and pebbles, tight	80- 87
	Clay, gray, with silt, saturated	87-113
	Shale, black, indurated	113-117

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Test Hole 34
Location: 94-61-5abcc
Drilled by: SDGS
Elevation: 1728 feet

Geologic Unit	Description	Depth Feet
Qwlt	Till, yellow-brown, silty, pebbly, calcareous	0- 25
	Gravel	25- 31
Tpo	Silt, white- to light-gray, sandy, some very fine sand	31- 37
	Sand and clay, sand is very fine, green, silty, clay is multicolored brown, white, light-gray, and green	37- 94
Kp	Shale, medium- to dark-gray, noncalcareous, some lighter colored fragments	94-187
	Shale, dark-gray to black, slightly calcareous	187-265
	Shale, medium- to dark-gray, noncalcareous	265-371
Kn	Marl, light-gray, extremely calcareous	371-380

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Test Hole 35
Location: 94-61-10cccc
Drilled by: USGS
Elevation: 1606 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, with silt and pebbles	0- 7
	Clay, brown, with silt and pebbles, saturated	7- 37
	Clay, brown, with silt, sand, and gravel	37- 42
	Clay, gray, with silt, sand, and gravel	42-108
Kp	Shale, medium- to dark-gray	108-112

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Test Hole 36
Location: 94-61-15cccc
Drilled by: SDGS
Elevation: 1556 feet

Geologic Unit	Description	Depth Feet
	Topsoil, black	0- 2
	Clay, light-gray	2- 5
	Gravel	5- 6
	Clay, brown	6- 25
	Clay, gray	25- 40
	Shale, dark-gray, fissile	40- 85

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Test Hole 37
Location: 94-61-22cccc
Drilled by: USGS, Denver, Colorado
Elevation: 1553 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly	0- 40

Test Hole 37 -- continued.

	Clay, gray, pebbly	40- 60
	Clay, gray and water	60-110
	Clay, gray, pebbly	

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Test Hole 38
Location: 95-58-1aaaa
Drilled by:
Elevation: 1342 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown	0- 16
	Clay, gray	16- 20
	Silt, gray	20- 25
	Clay, gray, very silty, sandy	25- 50
	Same; little tougher	50- 65
	Clay, gray, sandy, tough in spots, a few sand stringers	65- 90
	Clay, gray, gravelly, tough	90- 95
	Clay, gray, drilled little easier towards bottom	95-109
	Sand, good	109-112
Qit	Clay, gray	112-125
	Clay, gray, gravelly in spots	125-140
	Same, tougher	140-170
	Same, drills little easier	170-195
Qo	Gravel	195-215
	Clay, gray, very gravelly	215-230
	Dirty sand, with some gravel stringers, I think above may be same	230-260
	Same, getting cleaner towards bottom	260-290
	Gravel, interbedded with sandy gray clay	290-315
	Gravel	315-325
Kc(?)	Bedrock	325-355

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Test Hole 39
Location: 95-59-1aaaa
Drilled by: USGS, Denver, Colorado
Elevation: 1405 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly	0- 25
	Clay, gray, pebbly	25- 35
	Sand, with silt and clay	35- 47
	Clay, gray, tight	47- 50
Qwlo	Sand to medium gravel, some clay	50- 74
Qit	Clay, gray, tight, pebbly	74- 75

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Test Hole 40
Location: 95-59-5aaaa
Drilled by: SDGS
Elevation: 1467 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, yellow-brown, pebbly	0- 28
	Clay, gray, pebbly	28- 35
	Clay, gray, silty, pebbly, gravelly	35- 50
	Clay, gravelly	50- 80
	Same, with some gravel stringers	80-110
	Clay, gray, silty, pebbly	110-140
	Same, with some coal and wood	140-167
Qwlo	Drilled like sand and gravel, getting some organic clay	167-178
Kn	Bedrock	178-200

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Test Hole 41
Location: 95-60-2aaaa
Drilled by: SDGS
Elevation: 1506 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, tan, pebbly	0- 20
	Clay, tan turning to brown clay, pebbly	20- 32
	Clay, gray, pebbly	32- 50
	Clay, gray, silty, pebbly down to 61 feet, then light-gray clay	50- 65
	Clay, gray, silty, pebbly	65- 80
	Clay, gray, very silty down to 88 feet, then drilled tougher, pebbly	80- 95
	Clay, gray, silty, gravelly, some light-gray chalk or marl cuttings	95-110
Kp	Shale, black	110-115
Kp	Marl, light-gray	115-128
Kp	Shale, black	128-140

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Test Hole 42
Location: 95-60-3aaaa
Drilled by:
Elevation: 1448 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown	0- 21
	Clay, gray	21- 31
Kp	Shale, dark-gray, noncalcareous, bentonitic	31- 65

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Test Hole 43
Location: 95-60-6bbbb

Test Hole 43 -- continued.

Drilled by:
Elevation: 1604 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown	0- 25
	Clay, gray	25- 35
	Silt, brownish-gray, gravelly in spots	35- 50
	Clay, gray, drills very easy	50- 65
	Same; gravelly in spots	65- 80
	Same	80- 95
	Same; tougher in spots	95-110
	Clay, gray, tougher	110-125
Qwlo	Sand, very good	125-135
Kp	Black clay (organic), shale	135-140

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Test Hole 44
Location: 95-60-32cccd
Drilled by: SDGS
Elevation: 1415 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, light yellow-brown, pebbly, sandy	0- 8
Qo	Gravel, fine to coarse, sandy oxidized, numerous chalk pebbles	8- 16
Qwlt	Clay, medium-gray, silty, pebbly, calcareous	16- 42
	Sand, fine to medium	42- 55
	Clay, medium-gray, calcareous, some gravel stringers, silty, pebbly	55-180
Qwlo	Rocks and very coarse gravel	180-183
Kn	Marl, abundant white specks and chalk	183-200

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Test Hole 45
Location: 95-60-34ccac
Drilled by: Pd
Elevation:

Geologic Unit	Description	Depth Feet
Qwlt	Clay	0-160
	Sand	160-170
	Clay, dark	170-205
Qwlo	Sand and gravel	205-296
Kc	Shale	296-306
	"Hard layer"	306-310
	Shale, hard	310-520
Kd(?)	"First flow" sandstone	520-565
	Shale	565-690
	"Second flow" fine white sand with shale layers	690-743

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Test Hole 46
Location: 95-60-35cccc
Drilled by: SDGS
Elevation: 1368 feet

Geologic Unit	Description	Depth Feet
	Topsoil and road fill	0- 5
Qal	Clay, medium-brown	5- 7
	Black material containing some wood	7- 14
	Sand and clay stringers, getting green material and shells	14- 20
Qwlt	Clay, medium-gray, pebbly, sandy, and silty, some gravel and sand stringers	20-185
Qwlo	Sand and gravel, coarse gravel from 200 214 feet	185-272
Kc	Shale	272-290

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Test Hole 47
Location: 95-61-9dddd
Drilled by: SDGS
Elevation: 1615 feet

Geologic Unit	Description	Depth Feet
Qal	Clay, very black	0- 9
	Clay, light-gray, marly, pebbly	9- 16
Qwlt	Till, gray, pebbly, silty	16- 46
Kp	Shale	46- 80

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Test Hole 48
Location: 95-61-27bbbb
Drilled by: USGS, Denver, Colorado
Elevation: 1595 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown pebbly	0- 25
	Clay, gray, pebbly	25- 82

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Test Hole 49
Location: 95-61-33cccc
Drilled by: USGS
Elevation: 1666 feet

Geologic Unit	Description	Depth Feet
	Clay, gray, silt	0- 7
	Clay, brown with pebbles	7- 32
	Clay, gray with pebbles	32- 67
	Shale, dark-gray, tight	67- 72

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Test Hole 50
Location: 95-61-36cccc
Drilled by: SDGS
Elevation:

Geologic Unit	Description	Depth Feet
Qwlt	Clay, yellow to 13 feet, light-yellow to 16 feet, dark-brown to 17 feet, silty, sandy, pebbly, calcareous	0- 17
	Clay, medium-gray, some weathered chalk, silty, pebbly. Still getting about one-third to one-half yellow and brown cuttings	17-105
	Clay, medium-gray as above, many sand and gravel stringers, coal and shale pebbles, some large rocks below 120 feet	105-125
	Clay, medium-gray, pebbly, silty, a few rocks	125-192
Kn	Marl, abundant white specks, very calcareous	192-200

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Test Hole 51
Location: 96-58-3ddb
Drilled by: SDGS
Elevation: 1225 feet

Geologic Unit	Description	Depth Feet
Qal	Alluvium	0- 5
Qwlt	Clay, buff, sandy	5- 20
Qwlo	Sand, very coarse; fine gravel	20- 39
	Alluvium(?)	39- 45
	Gravel, pea- to nut-size; sand	45- 82
Kc	Carlile Shale	82- 95

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Test Hole 52
Location: 96-58-2dd
Drilled by: SDGS
Elevation: 1295 feet

Geologic Unit	Description	Depth Feet
	Topsoil	0- 5
Qwlt	Clay, buff, sandy	5- 25
	Clay, gray, sandy, pebbly	25- 35
	Gravel, nut-size	35- 40
	Clay, gray, sandy, thin gravel lenses	40- 80
Qwlo	Gravel, pea- to nut-size, coarse sand	80-130
Kc	Carlile Shale	130-140

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Test Hole 53
Location: 96-58-4cc
Drilled by: SDGS
Elevation: 1355 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, buff, sandy	0- 31
	Clay, gray, sandy	31- 55
Kn	Niobrara Chalk (lost circulation at 65 feet)	55- 70

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Test Hole 54
Location: 96-58-4cd
Drilled by: SDGS
Elevation: 1337 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, buff, sandy	0- 26

Test Hole 54 -- continued.

Geologic Unit	Description	Depth Feet
	Clay, gray, sandy; many thin sands and gravels	26- 55
	Clay, gray, sandy	55- 78
Kn	Niobrara Chalk(?) — samples badly mixed	78-115
Kcc	Codell Sandstone	115-125

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Test Hole 55
Location: 96-58-6dddd
Drilled by: USGS
Elevation: 1354 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly	0- 23
	Clay, gray, pebbly	23- 33
	Gravel with clay	33- 35
	Clay, gray, pebbly	35- 73
Kn	Marl, medium-gray	73- 83

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Test Hole 56
Location: 96-59-1dddd
Drilled by: SDGS
Elevation: 1355 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, buff, sandy	0- 30
	Clay, gray, sandy	30- 40
	Clay, gray with sandy streaks	40- 55
Kn	Marl	55- 60
	Marl	60- 80
	Marl, white	80-150
Kcc	Codell	150-185

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Test Hole 57
Location: 96-59-5dccc
Drilled by: SDGS
Elevation: 1425 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, buff, sandy	0- 20
	Clay, gray, sandy	20- 70
Qwlo	Sand and gravel with little clay stringers	70- 80
	Silt, clayey, alluvium	80-122
	Sand and fine gravel	122-137
Kn	Marl	137-170

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Test Hole 58
Location: 96-59-7aaaa
Drilled by: SDGS
Elevation: 1435 feet

Geologic Unit	Description	Depth Feet
Qwlt	Light-gray gravelly clay, turning to brown pebbly clay	0- 20
	Grayish-brown pebbly clay	20- 32
	Gray clay, pebbly, getting about one-half brown cuttings	32- 50
	Same as above except gravel and gravel stringers from 54 feet	50- 65
	Silty, sandy, pebbly gray clay	65- 80
	Gray clay, pebbly	80- 95
Qwlo(?)	Very silty or sandy, some gray clay	95-110
	Silty, sandy, gravelly, some chalky clay	110-125
Kn(?)	Chalk, hard white	125-200
	Shale, gray, soft	200-225
Kcc(?)	Sand stringers interbedded with shale	225-230
	Sandstone, poorly consolidated	230-260
	Sandstone, consolidated	260-290

Test Hole 58 -- continued.

Geologic Unit	Description	Depth Feet
	Shale, interbedded with sandstone	290-325
	Shale, soft, gray	325-345

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Test Hole 59
Location: 96-59-11aaaa
Drilled by: SDGS
Elevation: 1380 feet

Geologic Unit	Description	Depth Feet
Qwlo	Gravel	0- 3
Qwlt	Clay, yellow-brown, pebbly, sandy	3- 16
	Clay, gray, pebbly, sandy, some rocks	16- 42
	Clay, brown-gray, some rocks	42- 49
Qwlo	Sand, medium to coarse, about 50 percent chalk pebbles	49- 55
	Drills very easy and soft. Getting weathered chalk, sand, and gray clay	55- 63
Kn	Marl, dark brown-gray, very calcareous, numerous white specks	63- 72
	Chalk, very light-gray to white, very calcareous	72- 80

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Test Hole 60
Location: 96-59-12baaa
Drilled by: SDGS
Elevation: 1357 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, buff, sandy	0- 30
	Clay, gray, sandy	30- 40
	Gravel and sand	40- 45

Test Hole 60 -- continued.

Geologic Unit	Description	Depth Feet
	Clay, gray, sandy	45- 80
Kn	Chalk	80-140
Kcc	Sandstone	140-175

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Test Hole 61
Location: 96-60-7bbbb
Drilled by: USGS, Denver, Colorado
Elevation: 1597 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly	0- 34
	Clay, gray, pebbly	34- 78

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Test Hole 62
Location: 96-60-8aaaa
Drilled by: SDGS
Elevation: 1476 feet

Geologic Unit	Description	Depth Feet
Qal	Alluvium, black, humic, noncalcareous to calcareous	0- 3
Qo	Gravel, fine to very coarse, subrounded to angular, some rocks	3- 24
Qwlt	Clay, light- to medium-gray, pebbly, silty, calcareous, harder and more clayey from 78 to 86 feet	24-106
	Gravel and sand, clayey	106-111
	Clay, gray, sandy, calcareous	111-119
Qwlo	Sand, some gravel, clayey	119-132
	Clay(?), gray, very sandy	132-138
	Gravel and sand (several large rocks from 146 to 147 feet)	138-147

Test Hole 62 -- continued.

Geologic Unit	Description	Depth Feet
Kp	Shale, black, partly fissile, noncalcareous, earthy	147-170

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Test Hole 63
Location: 96-60-11bbbb
Drilled by: SDGS
Elevation: 1540 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly	0- 14
	Coarse gravel	14- 17
	Clay, brown, pebbly, silty	17- 39
	Clay, gray, silty, pebbly	39-155
	Clay, tough, gray, pebbly	155-230
Kn	Chalk	230-290
	Could be in Codell now, cannot tell for sure, no circulation, rattles quite a bit but drills easy	290-305
	Drills same as above, could be a shale between the chalk and sandstone	305-345
Kcc	Sandstone	345-425

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Test Hole 64
Location: 96-60-32dddd
Drilled by:
Elevation: 1529 feet

Geologic Unit	Description	Depth Feet
	Clay, brown	0- 26
	Clay, gray	26- 35
	Clay, gray, drills very easy	35- 59

Test Hole 64 -- continued.

Geologic Unit	Description	Depth Feet
	Shale, black, blocky	59- 67
	Shale, dark-gray	67- 80

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Test Hole 65
Location: 96-60-34cccc
Drilled by: SDGS
Elevation: 1476 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown	0- 41
Kp	Clay, brownish-gray, weathered shale with bottom few feet being regular shale, getting bentonite	41- 50
	Shale, few concretions or lime edges	50- 65

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Test Hole 66
Location: 96-61-4aaaa
Drilled by: USGS, Denver, Colorado
Elevation: 1705 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly with thin gravel layers	0- 50
	Clay, gray, pebbly	50- 78

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Test Hole 67
Location: 96-61-5cccb
Drilled by: USGS
Elevation: 1851 feet

Test Hole 67 -- continued.

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, with pebbles	0- 15
	Clay, dark-gray, with pebbles	15- 82
	Clay, dark-gray, with pebbles, saturated	82-117

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Test Hole 68
Location: 96-61-9aad
Drilled by: SDGS
Elevation: 1765 feet

Geologic Unit	Description	Depth Feet
Qwlt	Shale, hard black, blocky (block in the till)	0- 4
	Clay, medium-brown, silty, pebbly	4- 28
	Clay, medium-gray, silty, pebbly	28-148
Kp	Shale, yellow, white, green, gray, some white to cream bentonite	148-165
Kp	Shale, black, waxy, greasy, noncalcareous	165-185

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Test Hole 69
Location: 96-61-11bbbb
Drilled by: USGS
Elevation: 1693 feet

Geologic Unit	Description	Depth Feet
	Clay, brown, with pebbles	0- 12
	Clay, brown, with pebbles and trace of sand	12- 32
	Clay, gray, with pebbles	32-117

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Test Hole 70
Location: 96-61-28aaaa
Drilled by: SDGS
Elevation: 1730 feet

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, drills easy	0- 20
	Clay, brown, rocky	20- 25
Qwlu	Silt, brown, sandy, may be loess	25- 42
	Clay, steel-gray, clean, (lacustrine?)	42- 51
	Silt, gray, sandy, and some gray clay, drilled like sand except for a couple of tough spots	51- 65
	Silt, gray, very sandy, some gravel stringers	65- 80
Qwlt	Clay, gray, pebbly, some rocks	80-102
Qo	Gravel, fine to very coarse, clayey from 102 to 110 feet	102-120
	Clay, gray, sandy, silty, some gravel stringers	120-138
Kp	Shale	138-185

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Test Hole 71
Location: 96-61-32dcc
Drilled by: USGS
Elevation: 1653 feet

Geologic Unit	Description	Depth Feet
Qwlo	Sand, medium	0- 4
	Gravel, small and medium sand	4- 13
	Gravel, large and medium sand	13- 18
Qwlt	Sand, dirty, clayey, (till?)	18- 55
	Clay, gray, pebbly	55- 57
Qwlo	Sand, fine to medium	57- 88
	Gravel, large, and coarse sand	88- 98

Test Hole 71 -- continued.

	Sand, gravel with clay	98-105
Kp(?)	Clay, gray	105-112

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Test Hole 72
Location: 96-61-34cccc
Drilled by: USGS, Denver, Colorado
Elevation: 1694 feet

Test Hole 72 -- continued.

Geologic Unit	Description	Depth Feet
Qwlt	Clay, brown, pebbly	0- 8
	Gravel	8- 10
	Clay, brown, pebbly	10- 35
	Clay, gray, pebbly	35- 70
Qwlo	Sand, medium	70- 78
Kp	Clay, gray	78- 82

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