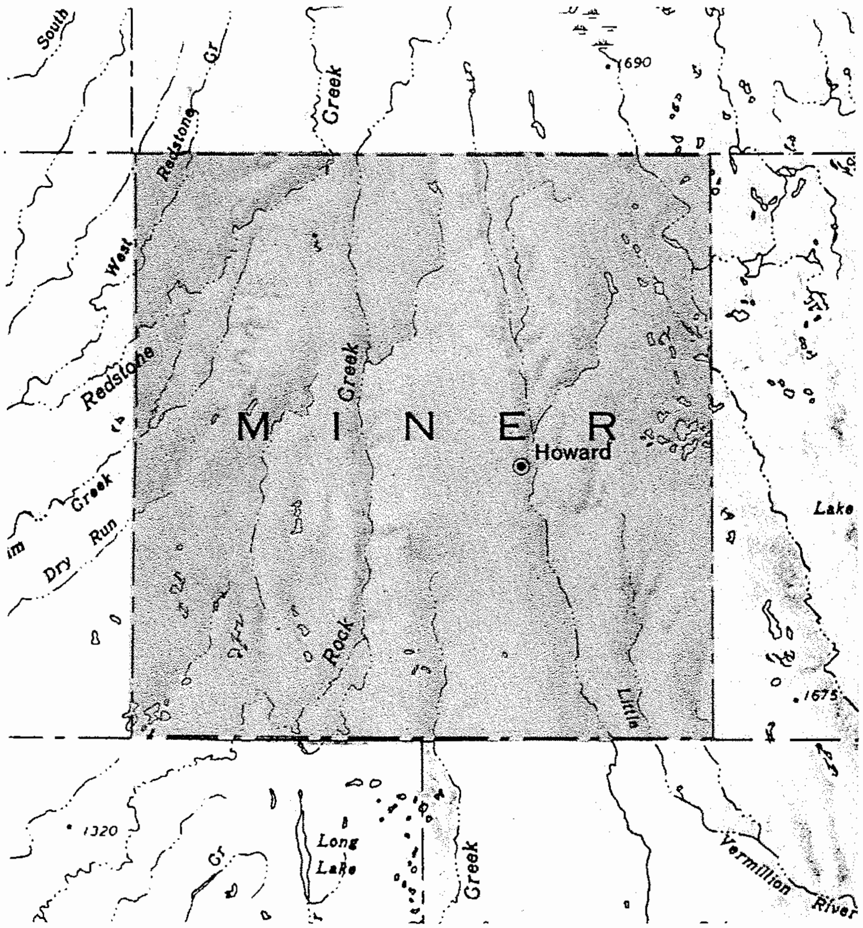
BULLETIN 31

GEOLOGY AND WATER RESOURCES OF MINER COUNTY, SOUTH DAKOTA



PART I: GEOLOGY

by Wayne Schroeder

Prepared in cooperation with the United States Geological Survey, East Dakota Conservancy Sub-District, Lower James Conservancy Sub-District, and Miner County

DEPARTMENT OF WATER AND NATURAL RESOURCES
SOUTH DAKOTA GEOLOGICAL SURVEY-1988

STATE OF SOUTH DAKOTA
George S. Mickelson, Governor

DEPARTMENT OF WATER AND NATURAL RESOURCES
John J. Smith, Secretary

DIVISION OF GEOLOGICAL SURVEY
Merlin J. Tipton, State Geologist

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Science Center
University of South Dakota
Vermillion, South Dakota

1988

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ABSTRACT

Miner County is located in the central part of eastern South Dakota and covers an area of 571 square miles. It is located on the boundary between the Coteau des Prairies and the James Basin divisions of the Central Lowlands physiographic province. Pre-Pleistocene rocks represent Precambrian and Cretaceous time. No outcrops of these formations are present but they do exist at shallow depths in some areas. The bedrock may be Pierre Shale, Niobrara Marl, Carlile Shale, the Codell Member of the Carlile Shale or Sioux Quartzite. Pleistocene age deposits mantle the bedrock surface. Thicknesses vary from a maximum of 535 feet to a minimum of 14 feet and average 165 feet. Most of these sediments are composed of till, outwash, or alluvium. Evidence indicates the presence of three intervals of glaciation. These have been assigned to the Illinoian, early Wisconsin, and late Wisconsin glacial advances. The first two advanced from the east-northeast or northeast and the last from the north or northwest. Present surface deposits only expose late Wisconsin materials. One radiocarbon date suggests deglaciation of the southwest corner of the County around 12,200 years ago. Economic resources include sand, gravel and water.

INTRODUCTION

Purpose

The present program of county-wide studies was started in 1959 due to increasing public concern regarding the availability of water for domestic and irrigation uses. Figure 1 shows the status of this mapping program. The primary purpose of the County study is to evaluate the quantity and quality of existing water resources. Secondary purposes include mapping the distribution of sand and gravel supplies, locating other economic minerals, and determining the geologic development of the area.

Results of the investigation are published in three parts. Part I, this report, contains the geology; Part II - McGarvie, (in preparation) contains the water resources; and Part III (Schroeder, 1982) is an open-file report containing the test-hole logs and well logs acquired during this study.

Location and Area

Miner County is located in the central part of eastern South Dakota (fig. 1). It is bordered on the north by Kingsbury County, on the east by Lake County, on the south by McCook and Hanson Counties, and on the west by Sanborn County. The County covers an area of 571 square miles.

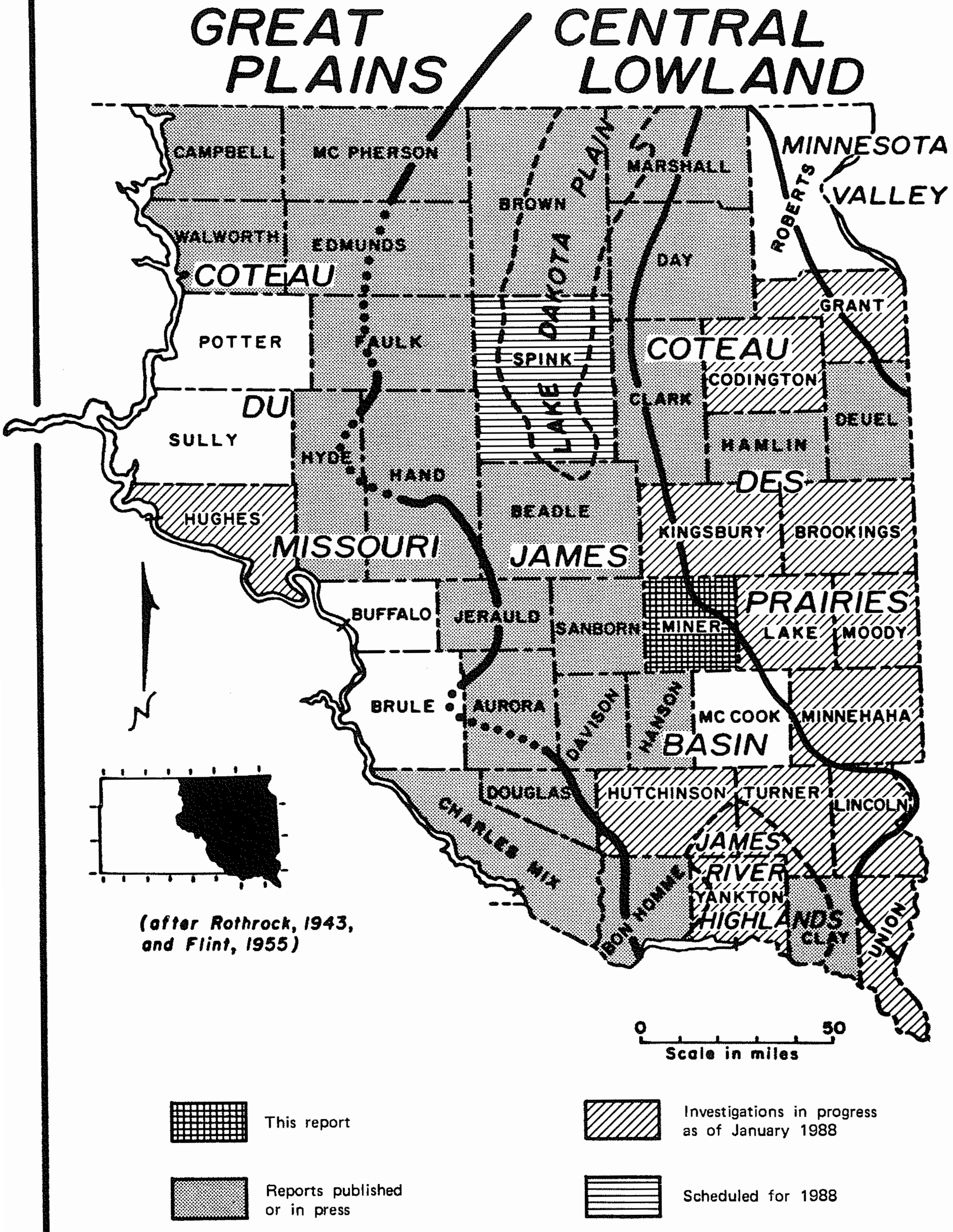


Figure 1. Index map of eastern South Dakota showing area of this report, status of county investigations, and major physiographic divisions.

Physiography

Miner County is located on the boundary between the Coteau des Prairies and the James Basin divisions of the Central Lowlands physiographic province (fig. 1). The Coteau des Prairies portion of the County lies between 1,650 and 1,800 feet elevation and is characterized by an undulating topography with numerous shallow lakes. Local relief, here defined as the difference between the highest and lowest points within a one-half mile radius of any location, averages about 55 feet. The western edge of this division slopes gently toward the James Basin on the west and southwest where the surface is smoother and lakes are smaller and more shallow. Elevations lie between 1,300 and 1,650 feet and the local relief averages about 25 feet.

Previous Investigations

The most detailed reports dealing with the bedrock of the area are those of Todd and Hall (1903, 1904a). Other reports which discuss the geology on a broader scope are Todd (1894), Darton (1896, 1905, 1909), Todd and Hall (1904b) and Rothrock (1943). Two other references concerned primarily with stratigraphy are Agnew and Tychsen (1965) and Schoon (1974).

Glacial geology has been the subject of numerous broad scale reports but again the most detailed work within the County is that of Todd and Hall (1903, 1904a). More recent detailed work has been completed on Sanborn County (Steece and Howells, 1965) and Beadle County (Hedges, 1968). Other reports which include Miner County are those of Chamberlin (1883), Todd (1894, 1899), Visher (1918), Flint (1955), Cox (1962), Lemke and others (1965), and Matsch and others (1972). In addition, there have been three city studies completed for the City of Howard (DeWild, Grant, Reckert and Stevens, 1959; Jorgensen, 1960; and Barari, 1972).

Method of Investigation

Data used to compile this report were derived mainly from the drilling program and field work done during the summers of 1976, 1977, and 1978. During this time, 96 rotary test holes (totaling 19,318 feet) and 273 auger holes (totaling 6,196 feet) were drilled. Sixty percent of the rotary-drill holes were logged with the South Dakota Geological Survey's electric logging unit. Supplementary drill-hole information was obtained from private drillers, prior city studies, adjacent county data, and United States Geological Survey well inventories.

Field mapping was done on conventional black and white aerial photographs at a scale of about 1:63,500 (1 inch = 1 mile) and on 7 1/2 minute topographic maps at a scale of 1:24,000 (1 inch = 2,000 feet). The contents of these two sets of data were later transferred to a base map made to a scale of 1 inch = 1 mile.

Acknowledgements

The investigation and preparation of this report were performed under the supervision of the South Dakota Geological Survey. The author wishes to thank Merlin Tipton, Lynn Hedges, Cleo Christensen, Scott McGarvie, Dennis Beissel, Richard Bretz, Robert Stach, and Robert Schoon for assistance in the preparation of this report. Also, indispensable to the acquisition of these data were Lloyd Helseth, Millard Thompson, Ralph Danzl, Richard Hammond, Carl Cripe, Frank Summers, Randy Marin, John Webster, Les Hirocke, Marti Schockenmaier, Robert Bender, John Fricke, Jon Hangas, Roger Lowe, Dennis Tomhave, Kathleen Stack Goodman, Greg Wallace, Tim Kenyon, Paul Noble, and John Mathews, all of who served in various supporting technical capacities.

Assistance with drafting and typing were provided by Dennis Johnson, Beverly Fortner, and Colleen Odenbrett.

Financial assistance was contributed by the South Dakota Geological Survey, the United States Geological Survey, the East Dakota Conservancy Sub-District, the Lower James Conservancy Sub-District, and Miner County.

STRATIGRAPHY

Stratigraphic Relations

Stratigraphic nomenclature used in this report conforms to that accepted by the South Dakota Geological Survey (Agnew and Tychsen, 1965) with the possible exception of the term "wash," which will be discussed later. Figures 2 and 3 show the subsurface relationships among the Precambrian rocks and younger overlying sediments. Figure 4 shows the configuration of the bedrock surface as well as the distribution of the formations. Throughout most of the County, the surface deposits are underlain by Pierre Shale. Niobrara Marl is second in subcrop abundance followed by Carlile Shale and Sioux Quartzite. Table 1 is a columnar section showing the stratigraphic relationship of the formations underlying Miner County.

Precambrian Rocks

Figure 5 is a map of the Precambrian surface compiled from Steece (1961), Lidiak (1971), samples on file with the South Dakota Geological Survey and numerous test holes and private wells. Across the northern part of the County silicic volcanics are inferred from data in Kingsbury and Sanborn Counties. South of the volcanics there exists a belt of igneous intrusives and metamorphic rocks. The southern half of the County is underlain by Sioux Quartzite.

Figure 2. Cross section A - A'.

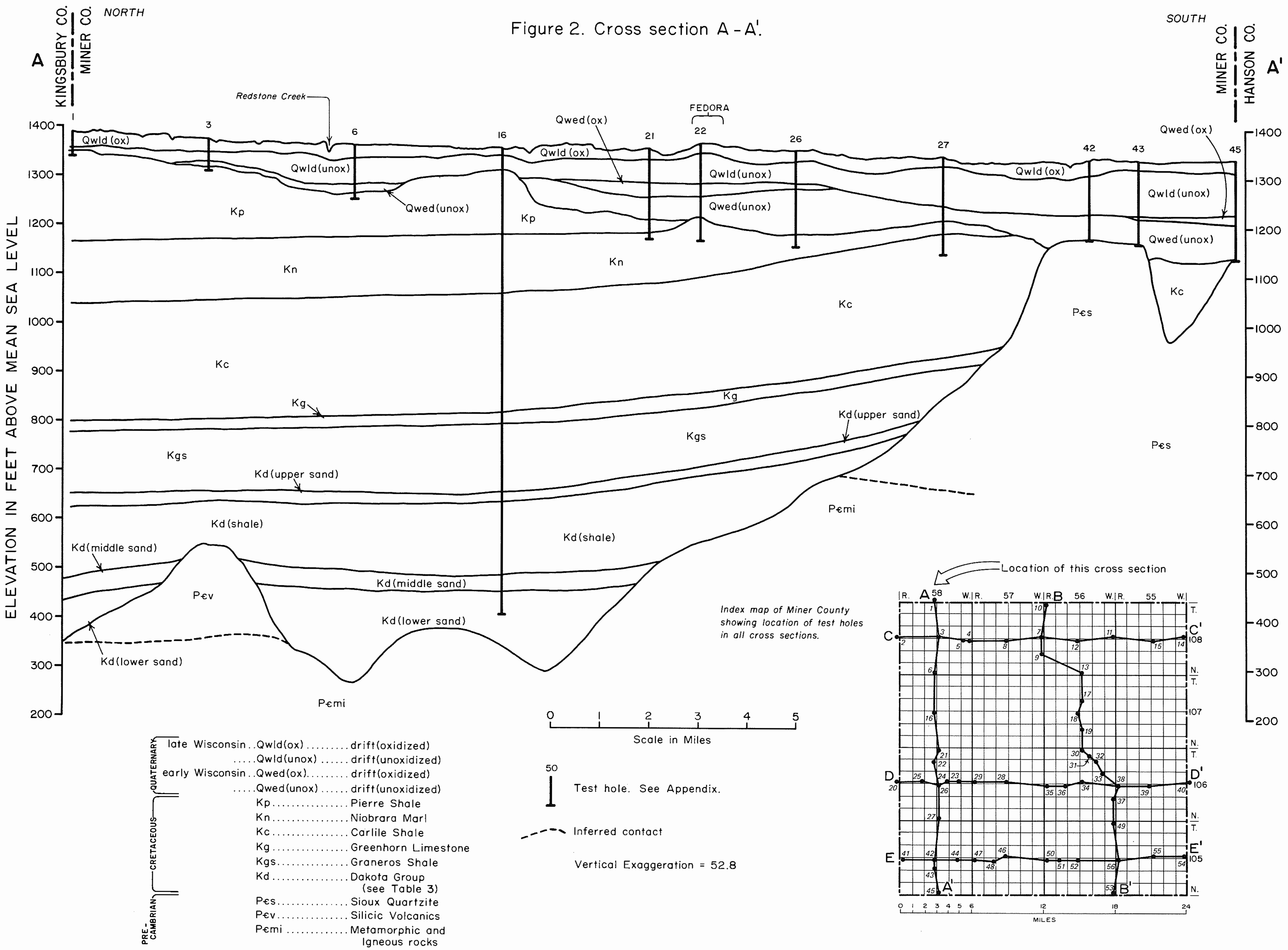
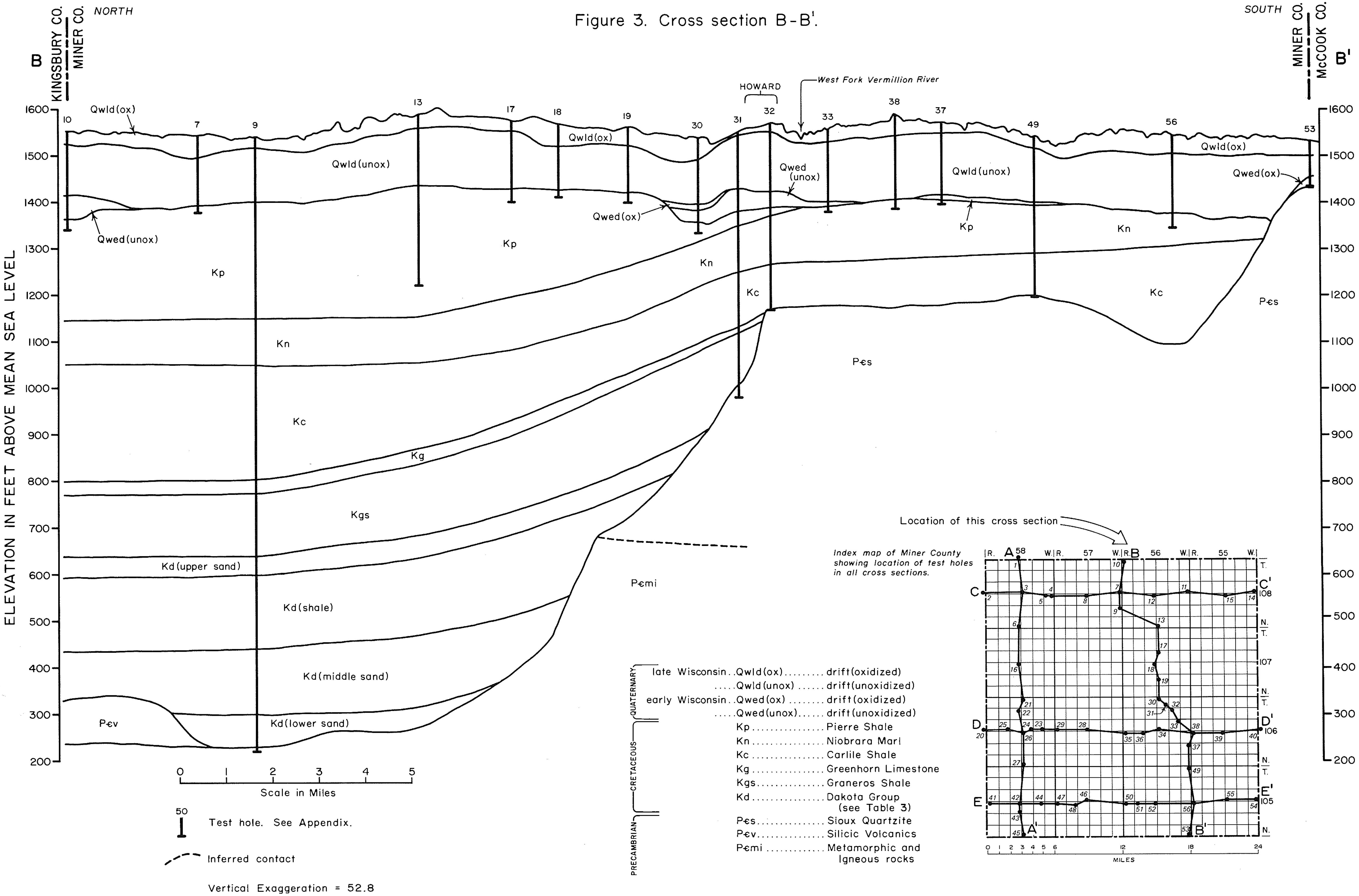
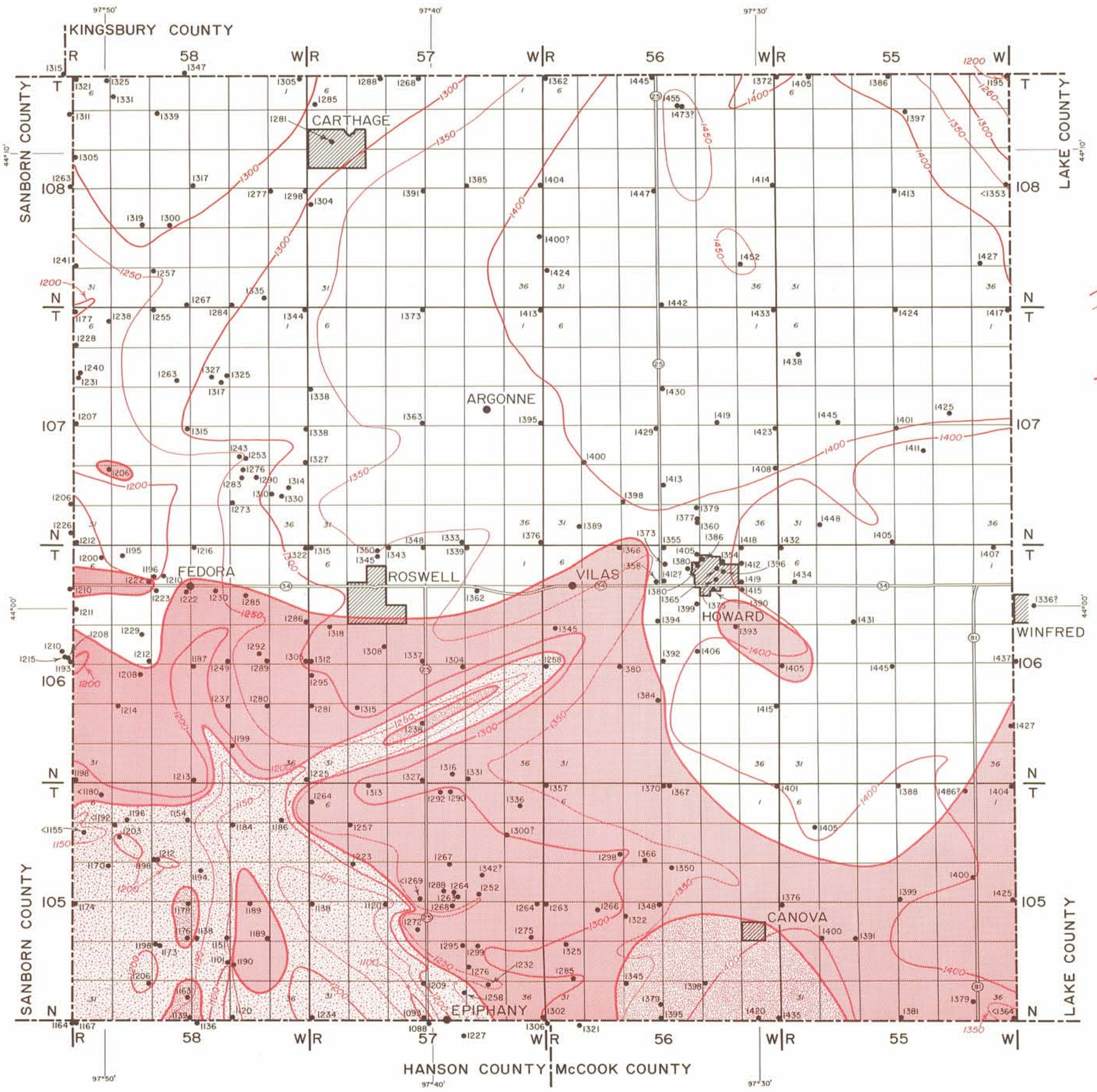


Figure 3. Cross section B-B'.





Data point. Number is elevation of the bedrock surface. Numbers with the symbol (<) indicate maximum elevation of bedrock surface. Numbers with the symbol (?) indicate approximate elevation of bedrock surface.

(<)1377(?)

Contour on bedrock surface. Number is elevation above sea level. Contour interval = 50 feet

1200
1150

Formation contacts

Bedrock Units

☐ Pierre Shale

▨ Carlile Shale

▨ Niobrara Marl

▨ Sioux Quartzite

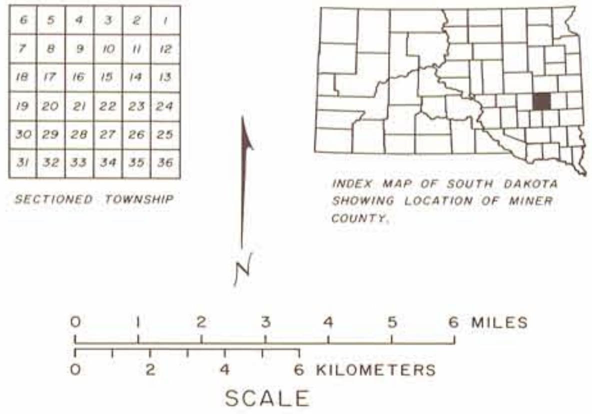
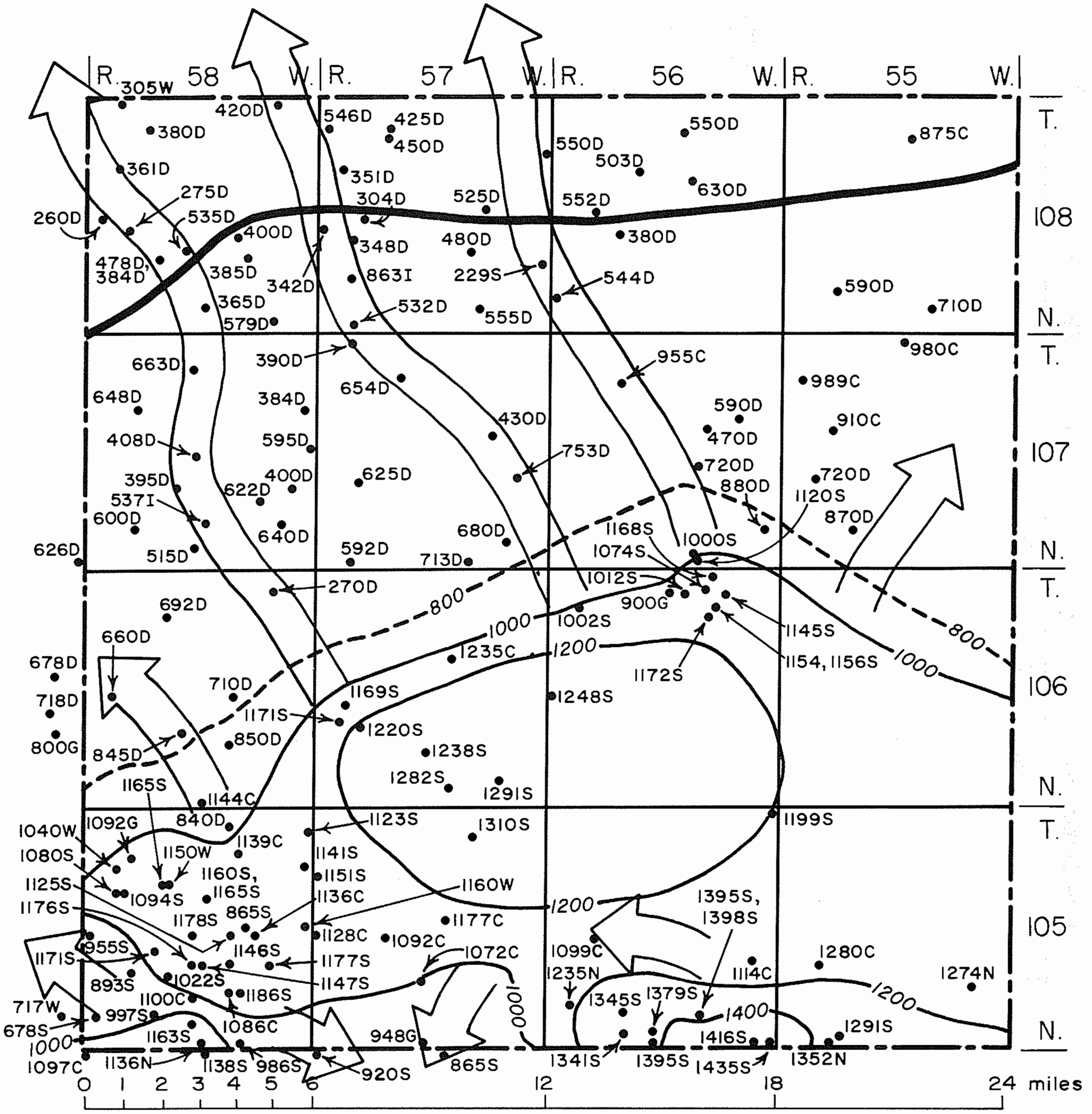


Figure 4. Map showing configuration of the bedrock surface and distribution of bedrock formations.

Era or Period	Stratigraphic Unit	Thickness in feet	Description
Quaternary	Drift	14-535	Clay, pale yellowish-brown or medium gray, silty, sandy, pebbly; and sand and gravel.
Late Cretaceous	Pierre Shale	0-265	Shale, dark-gray, abundant bentonite, speckled marl sequences in upper part.
	Niobrara Marl	0-120	Marl, light-brown to gray-brown and light-gray, speckled, some pyrite, gypsum and shell fragments.
	Carlile Shale: Codell Sandstone Member	0-23 0-102	Sandstone, greenish-yellow to yellow, fine; and shale, gray-brown, silty, sandy, some pyrite.
	Carlile Shale	0-130	Shale, gray-brown to black, greasy, some pyrite.
	Greenhorn Limestone	0-29	Limestone, light-gray, abundant shell fragments.
	Graneros Shale	0-137	Shale, gray, some zones of concretions, silty in spots.
	Dakota Group	0-410	Sandstone, light-brown, pink, and white to gray, medium to fine; and shale, gray, silty.
?	"Wash"	0-71	Sand, pink, medium to coarse, subrounded.
Precambrian	Sioux Quartzite	?	Orthoquartzite, pink to red, massive.
	Igneous Extrusives	?	Andesites and rhyolites.
	Metamorphic rocks and Igneous intrusives	?	Chlorite schist and granite.

Table 1. Generalized columnar section of the subsurface formations.



• 380D	Data point. Number is elevation of the top of the Precambrian when followed by I or S, and bottom hole elevation when followed by other formation symbols.

Formation Symbols

N = Niobrara
C = Carlile
G = Graneros
D = Dakota
W = 'wash'
S = Sioux quartzite
I = Igneous (granite)

━━	Contact between silicic volcanics to the north and older igneous and metamorphic rocks to the south.
- -800- -	Inferred erosional edge of the Sioux Quartzite and the 800 ft. contour.
—1000—	Contour lines drawn on the Precambrian surface. Contours below 800 ft. have been omitted due to lack of data.
⇨	Inferred drainage

Figure 5. Map showing the Precambrian surface.

Cretaceous Deposits

The next younger sequence of units are the late Cretaceous sediments. They span the time interval from about 100 M.Y. (million years) to about 75 M.Y. ago. Figures 2 and 3 show a progressive extension of younger sediments onto the quartzite ridge to the south.

Dakota Group

The Dakota Group is an interbedded series of sandstone, siltstone, and shales. The maximum known thickness in Miner County is 400 feet in the Rocky Ridge No. 1 Hale oil test southeast of Carthage (see app., test hole 9).

The Dakota group lies on either "wash" or Precambrian rocks (figs. 2 and 3). Figure 5 shows the inferred erosional edge of the Sioux Quartzite ridge which also approximately delineates the southern extent of the Dakota. This ridge was a dominant source for much of the earlier Dakota sediments.

Graneros Shale

The Graneros Shale is a gray, silty, shale containing concretionary zones in the middle portion and abundant siltstones and fine sandstones in the lower one-third. The Graneros Shale is very similar to the Dakota shales except for a high percentage of pyrite. This indicates a similar sediment source which was deposited under more reducing conditions associated with deeper, more stagnant waters. Thicknesses are surprisingly consistent at about 136 feet in the northern part of the County; suddenly thinning to zero against the quartzite ridge to the south. The formation lies conformably on top of the Dakota Group except along its southern boundary where it overlaps the Precambrian surface.

Greenhorn Limestone

The Greenhorn Limestone is a light-gray limestone composed of abundant shell fragments. The thickness varies from 24 to 29 feet in the northern portion of the County to zero where it "pinches out" against the quartzite ridge at Howard. It constitutes a key marker bed on electric logs because of its characteristic high resistivity kick and the fact that it occurs between two shales which exhibit low resistivity. The Greenhorn lies conformably on the Graneros Shale and unconformably on the Precambrian surface (figs. 2 and 3).

Carlile Shale

The Carlile Shale can generally be split into three rather distinct units (table 1). The upper unit is a gray, greasy shale which varies in thickness from 20 to 23 feet in the northern part of the County to zero in the extreme southern part. Some workers prefer to include this unit as the basal part of the Niobrara Marl.

The middle unit is the Codell Member of the Carlile Shale. It is a thinly interbedded sequence of fine, yellowish sandstones and gray-brown shales. The thickness varies from 92 to 102 feet in the northern part of the County to zero in the southern part. Test Hole 49 shows Codell type sediments from 236 feet to 277 feet depth giving a thickness of 41 feet. Six miles north of test hole 53 it is absent above the quartzite high.

The lower unit is a gray-brown to black, greasy shale very similar in appearance to the upper unit. Thicknesses vary from 130 feet in the NE 1/4 NE 1/4 NE 1/4 NE 1/4 sec. 21, T. 107 N., R 58 W. to zero on the quartzite ridge near the southern boundary of the County. Test hole 49 shows 33 feet of shales lying on 31 feet of "wash." The unit lies conformably on the Greenhorn Limestone and unconformably on the Precambrian surface.

Niobrara Marl

Rothrock (1931), in discussing the Niobrara Marl, refers to three different zones (an upper white, a middle buff, and a lower blue-black) and attributes these changes to oxidation and leaching. All three of these colors have been noted in drill holes in the southern part of the County. By applying other workers' techniques of microfossil identification, Bolin (1952) separated the Niobrara into an upper Smoky Hill Member and a lower Fort Hays Member. Due to its high clay content, the Niobrara is, in most places, classified as a marl as opposed to a chalk. Where shale is present between the Niobrara and the Codell Member of the Carlile, the upper and lower contacts are easily distinguished on electric logs. The thickness varies from zero on the quartzite ridge, to 90 feet in the vicinity of Howard, to 120 feet 4 miles north of Fedora. This is also the direction of dip of the Pierre-Niobrara contact which, in the vicinity of Fedora, amounts to about 18 feet per mile in a direction of N 24 degrees W.

Pierre Shale

The Pierre Shale is a dark-gray to black shale containing highly calcareous units in the upper part and numerous bentonite beds throughout (table 1). The bentonite beds vary in color from nearly white to cream to light-blue. Maximum thickness of the Pierre Shale in Miner County is 265 feet.

Bedrock Surface

Figure 4 is a map showing the configuration of the bedrock surface and the distribution of bedrock formations. Relief on this surface is less than that of the present land surface. It varies from 1,455 feet in the northeast portion of the County to 1,088 feet west of Epiphany. This represents a total relief of only 367 feet compared to 504 feet of total relief on the present surface.

Successively older bedrock formations are encountered in the southern part of the County due to post depositional erosion. In at least four different locations the Pleistocene deposits are underlain by the Sioux Quartzite.

Pleistocene Deposits

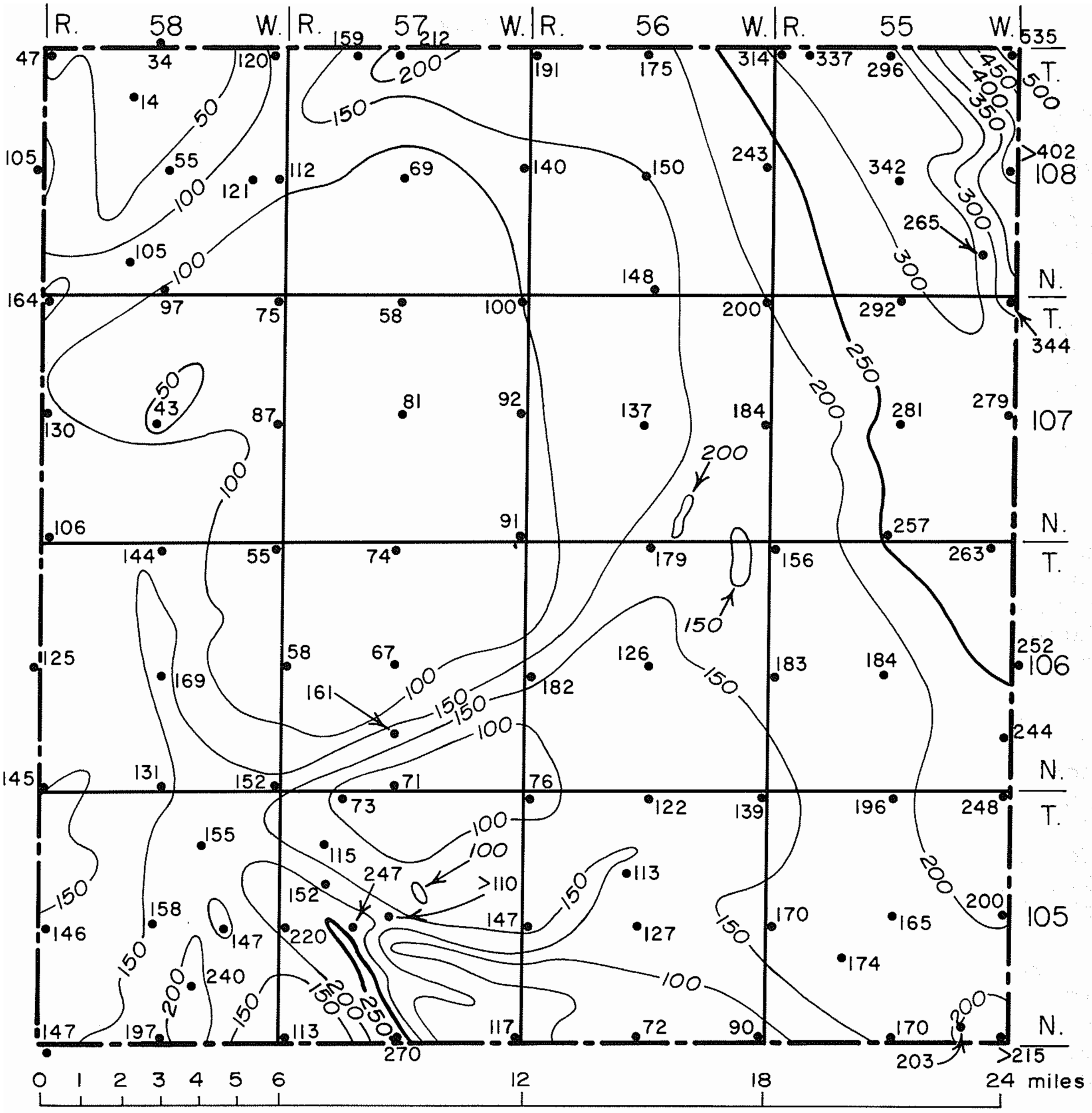
Pleistocene deposits form a continuous covering over the bedrock in Miner County. Collectively these deposits, transported by glaciers and deposited directly by or from the ice, or by running water emanating from the ice, are called drift. Drift in turn can be subdivided into till, which is nonstratified, and outwash and lake deposits, which are stratified.

Figure 6 is a map showing the thickness of the drift in Miner County. Drift completely covers the bedrock surface but an auger test hole, located in the NW 1/4 NE 1/4 NW 1/4 NW 1/4 sec. 9, T. 108 N., R. 58 W., along the West Redstone Creek, encountered Pierre Shale containing abundant bentonite at a depth of only 14 feet. The maximum thickness of drift is 535 feet in the NE 1/4 NE 1/4 NE 1/4 NE 1/4 sec. 1, T. 108 N., R. 55 W. and the average thickness is 165 feet.

No evidence remains in the subsurface of Miner County to indicate the events which occurred between 1 million years ago and 115,000 years ago during Nebraskan and Kansan time. Subsequent glaciations and subaerial erosion have reworked and/or removed all deposits if they were ever present.

Illinoian

Illinoian time is that period between 115,000 years ago and 70,000 years ago (table 2). Tipton (1959) tentatively identified Illinoian till in the vicinity of Sioux Falls. Steece (1965) corroborated this date with evidence in southern Lincoln and northern Union Counties. In Miner County little evidence exists of these deposits. Of 97 test holes with detailed descriptions of the Pleistocene materials, only nine showed evidence of Illinoian ice invasion. All of these holes are located in the northeast part of the County and underlie about 49 square miles (fig. 7). Three of the nine occurrences are illustrated by test holes 11, 14, and 15 on cross section C-C′ (fig. 8). Reasons for assigning



200 — Line of equal thickness. Contour interval = 50 feet

105● Data point showing thickness of glacial drift

>110● Greater than 110 feet

Figure 6. Map showing thickness of glacial deposits.

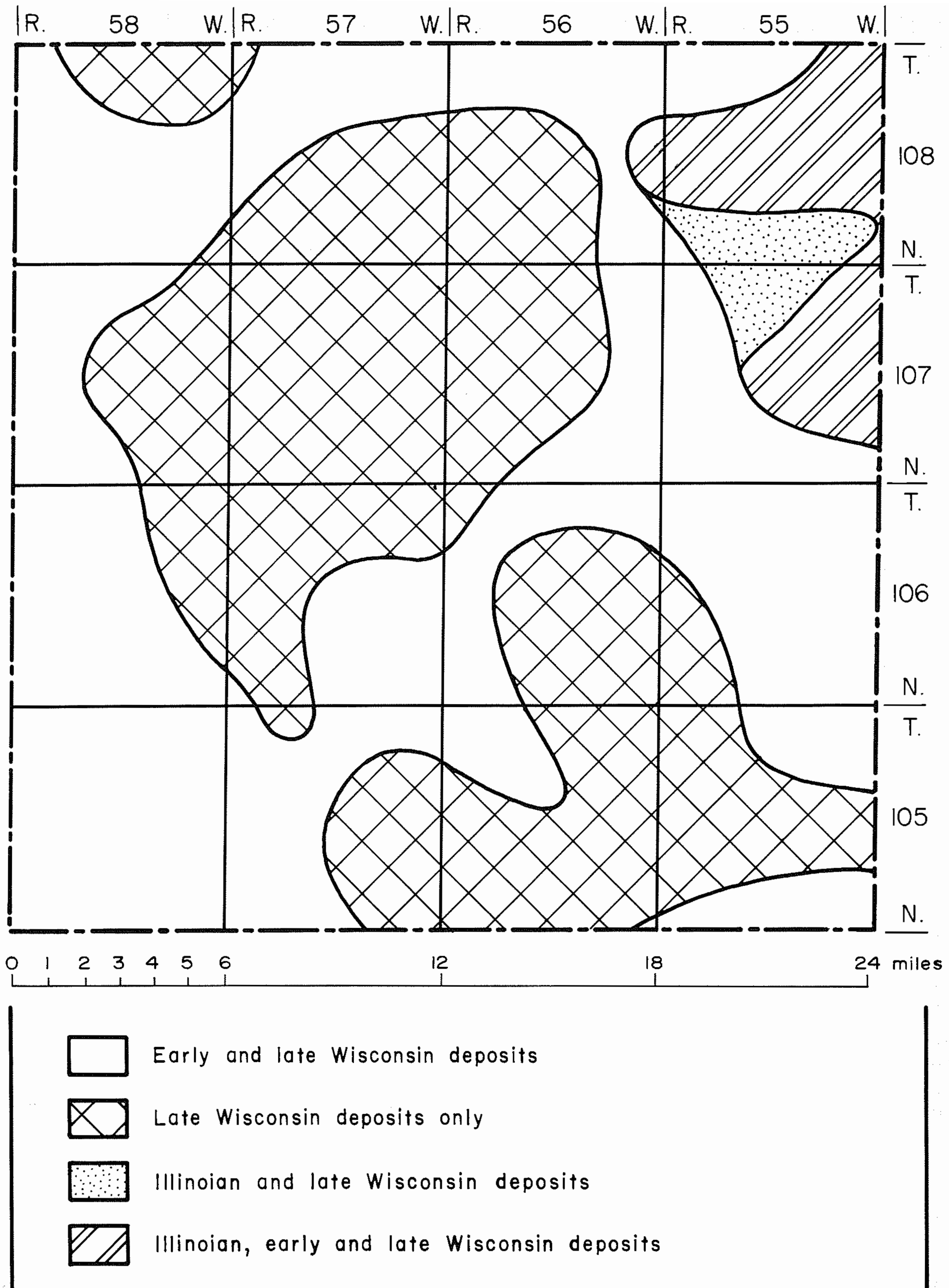


Figure 7. Map showing distribution of glacial deposits.

an Illinoian age to these deposits will be discussed in the next section of the report.

TABLE 2. Pleistocene Timetable

Glacial Stages	**Beginning of stage** (yrs. before present)
Late Wisconsin glacial	22,000 *
Early Wisconsin glacial	70,000 *
Sangamon interglacial	
Illinoian glacial	115,000(?) **
Yarmouth interglacial	
Kansan glacial	400,000(?) **
Aftonian interglacial	
Nebraskan glacial	1,000,000 **

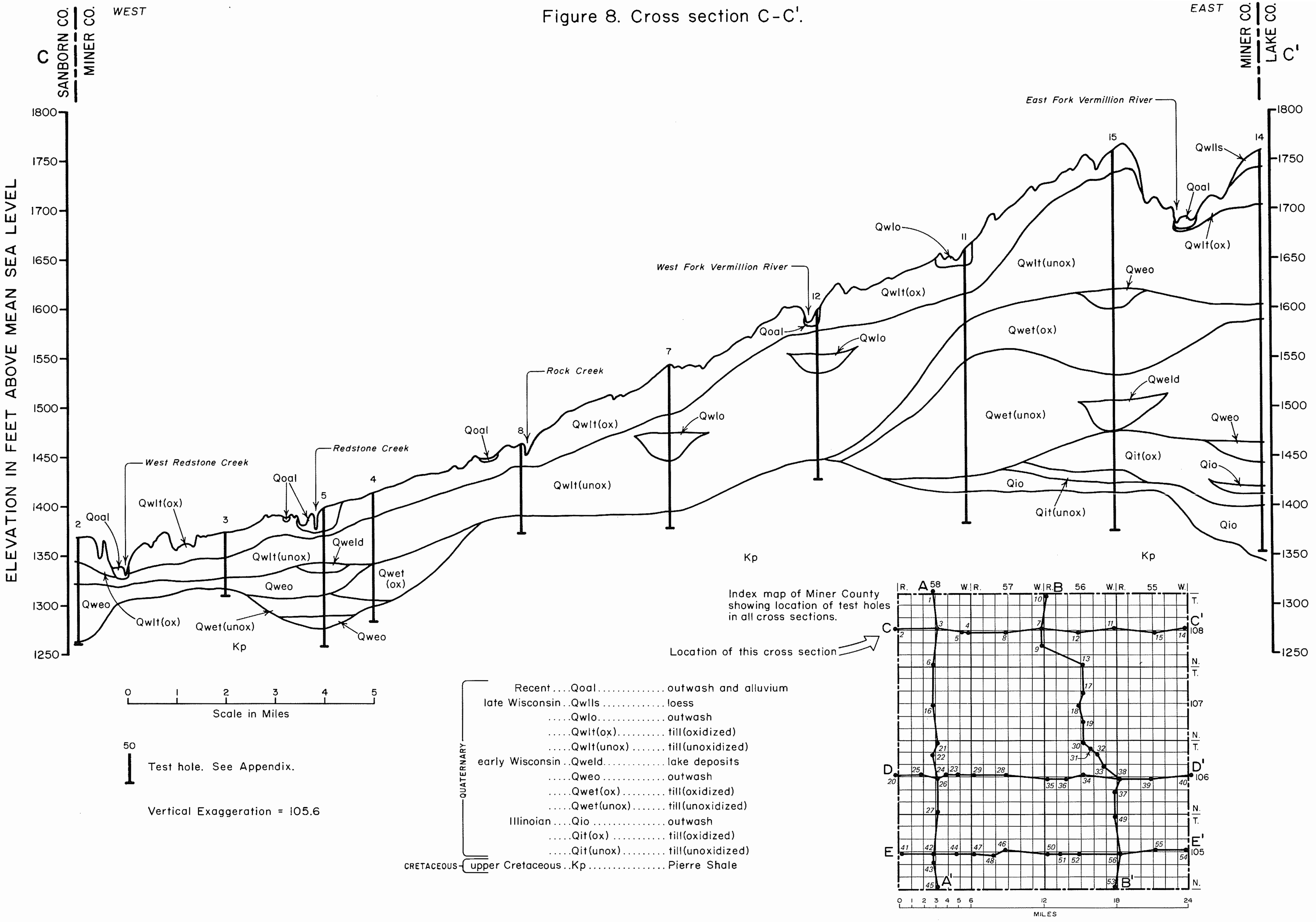
* Frye and Willman, 1963; and Lemke and others, 1965
** Gary and others, 1974

Average thickness of the Illinoian drift is 105 feet; however, it ranges from 16 to 178 feet and accounts for about 6 percent of the total volume of Pleistocene deposits. The average depth of weathering on the Illinoian deposits is 69 feet. This is also a minimum depth because in every instance all traces of the soil profile and an undetermined amount of oxidized material has been removed by glacial and/or subaerial erosion. Depth of weathering of the Illinoian drift can be compared to the average depth of weathering on the early and late Wisconsin drifts which is 31 and 27 feet respectively.

TILL

Till is composed of a heterogeneous mixture of clay, silt, sand, gravel and boulders. Color shades vary from yellow to yellow-brown to brown to gray-brown in oxidized till whereas unoxidized till grades from gray-brown to gray to dark-gray.

Figure 8. Cross section C-C'.



QUATERNARY	Recent	Qoal	outwash and alluvium
	late Wisconsin	Qwlls	loess
		Qwlo	outwash
		Qwlt(ox)	till(oxidized)
		Qwlt(unox)	till(unoxidized)
	early Wisconsin	Qweld	lake deposits
		Qweo	outwash
		Qwet(ox)	till(oxidized)
		Qwet(unox)	till(unoxidized)
	Illinoian	Qio	outwash
		Qit(ox)	till(oxidized)
		Qit(unox)	till(unoxidized)
CRETACEOUS	upper Cretaceous	Kp	Pierre Shale

Illinoian till is generally a gray-brown to gray, silty, pebbly clay and drills harder than most of the younger tills. In only two locations was yellow-brown and brown oxidized till present. The lack of the more intense oxidation colors is due to erosion of the upper part of the weathering profile. The oxidized till ranges from 32 to 123 feet thick and averages 72 feet. The unoxidized till ranges from 6 to 55 feet thick and averages 26 feet.

Three lines of evidence have been used to assign the deposits to the Illinoian glacial stage. First, on the basis of weathering zones, it underlies two till sheets believed to be Wisconsin in age. Second, the depth of weathering on this till is much greater than is generally found on the younger tills throughout the County. Last, very few Nebraskan or Kansan deposits have been identified in South Dakota whereas Illinoian age drift is recognized throughout the southeastern part of the State (Tipton and Steece, 1965).

OUTWASH

Outwash is that portion of the drift which is stratified and sorted by running water. As the water flows away from the glaciated region, silt and clay are transported in suspension, leaving the coarser materials behind. The more turbulent the water, the coarser grained the transported sediments. Therefore, the texture of the outwash is related to the amount of energy expended in transporting the load of the stream.

Most of the Illinoian outwash is medium to coarse, gray, clayey gravel. In a few instances it is brown because of oxidation or reworking of the local weathered bedrock. Some of the gravel contains abundant shale and/or limestone pebbles. Thickness varies from 4 to 54 feet and averages 14 feet.

In most areas there is a veneer of gravel or coarse sand lying on the bedrock at the base of the Illinoian deposits. Its composition shows it to be a combination of locally derived shale or marl from the Pierre Shale and glacially derived granites, dolomites, and limestones.

Early Wisconsin

Early Wisconsin time started about 70,000 years before present and terminated about 22,000 years before present (table 2). Glacial drift composed of till, outwash and lake deposits underlie about 319 square miles of the County. These deposits range from 10 to 188 feet thick and average 71 feet. Their volume constitutes about 28 percent of the Pleistocene drift.

Early Wisconsin drift is generally present throughout the County except for a 12-mile wide strip trending north-northwest to south-southeast across the central portion (fig. 7). Thirty-two test holes drilled in this area did not encounter drift older than late Wisconsin. The reason for this distribution can be seen in figures 8, 9, and 10. Eastward from the James Basin and onto the Coteau des Prairies the bedrock surface rises in elevation faster than the land surface. This results in a zone where the early Wisconsin drift was probably originally thin. By the time of the late Wisconsin advance, much of this may have been eroded and the remainder was thin enough to be reworked by the late Wisconsin ice. Only in places, where this strip is cut by bedrock lows and channels, is early Wisconsin drift present (figs. 4, 7, 8, 9, and 10).

Elsewhere in the County, such as around Fedora, early Wisconsin drift is present but the oxidized upper surface is missing. Here the early Wisconsin drift is outwash and stratigraphically it correlates with similar age and type deposits in Sanborn County (Steece and Howells, 1965), and Beadle County (Hedges, 1968). This relationship is illustrated in figures 8, 9, and 10.

TILL

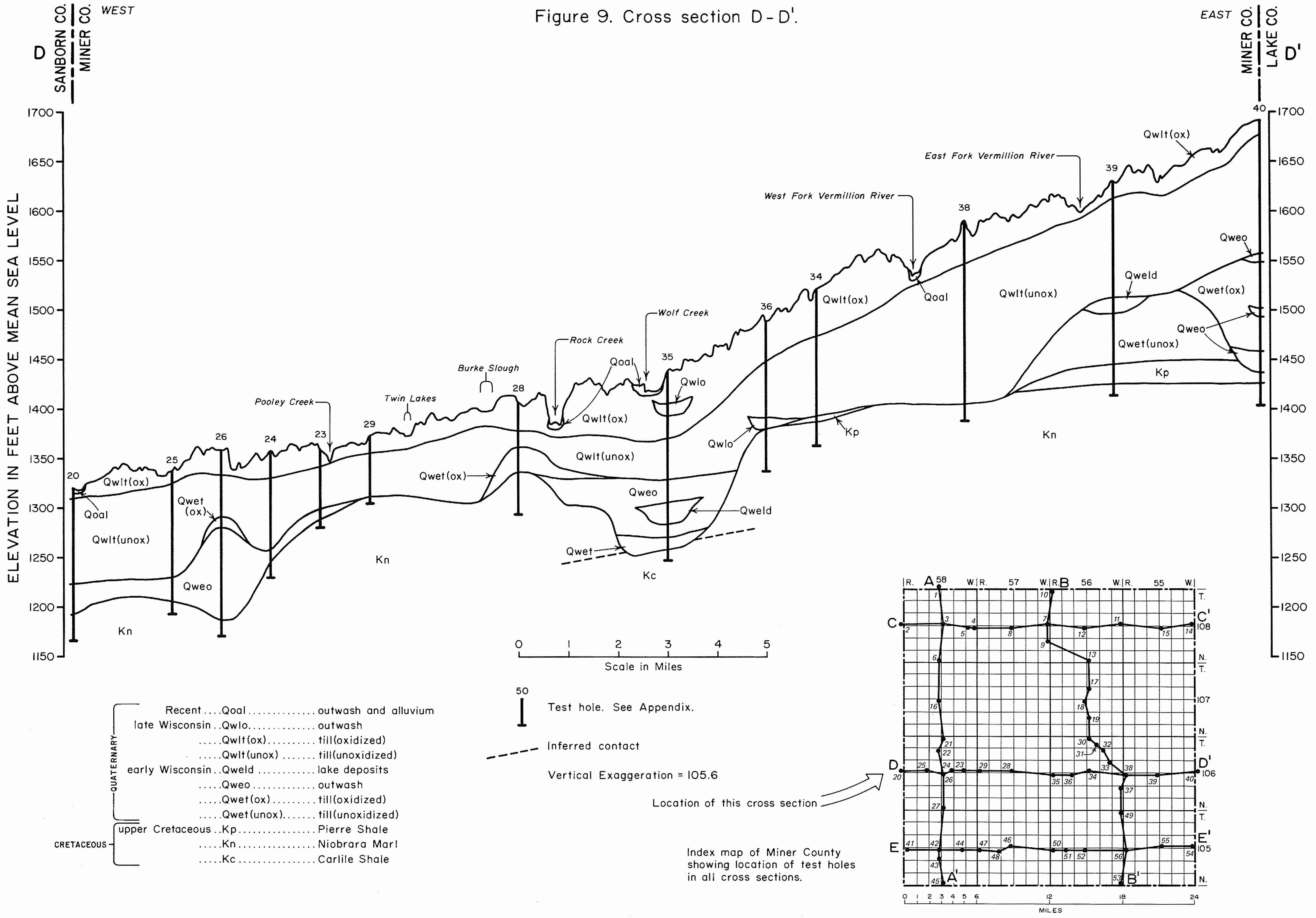
Early Wisconsin till is gray-brown to yellow-brown when oxidized and gray to dark-gray when unoxidized. The early Wisconsin till is a silty, pebbly, sandy clay which is generally calcareous and hard. This texture is similar to most till in the area. The oxidized till ranges from 5 to 81 feet in thickness and averages 32 feet. Unoxidized till ranges from 6 to 129 feet thick and averages 51 feet.

Before the invasion of the late Wisconsin ice, the oxidized zone was thicker. Evidence supporting this statement is that the upper surface of the drift sheet is often gray-brown in color which suggests that only the lowest part of the weathering profile is present. This gray-brown color is so close to that of the unoxidized materials that it is easily missed in the fresh, wet cuttings. Therefore, examination of the cuttings after they have dried will sometimes reveal subtle color differences. The lack of a soil zone also indicates partial removal of weathered material. In addition, test holes at three locations penetrated yellow till indicating that the yellow color was part of the original weathering profile.

OUTWASH

The early Wisconsin outwash is fine to medium gravel and medium to coarse sand with occasional clayey zones. The color varies from brown to gray-brown where oxidized and gray where unoxidized. Sand grains are subangular to subrounded. Shale content is very low. Thickness varies from 3 to 95 feet and averages 18 feet.

Figure 9. Cross section D-D'.



Recent....Qoal..............outwash and alluvium
QUATERNARY
late Wisconsin..Qwlo..............outwash
.....Qwlt(ox)..........till(oxidized)
.....Qwlt(unox).......till(unoxidized)
early Wisconsin..Qweld............lake deposits
.....Qweo..............outwash
.....Qwet(ox).........till(oxidized)
.....Qwet(unox).......till(unoxidized)
CRETACEOUS
upper Cretaceous..Kp................Pierre Shale
.....Kn................Niobrara Marl
.....Kc................Carlile Shale

Test hole. See Appendix.

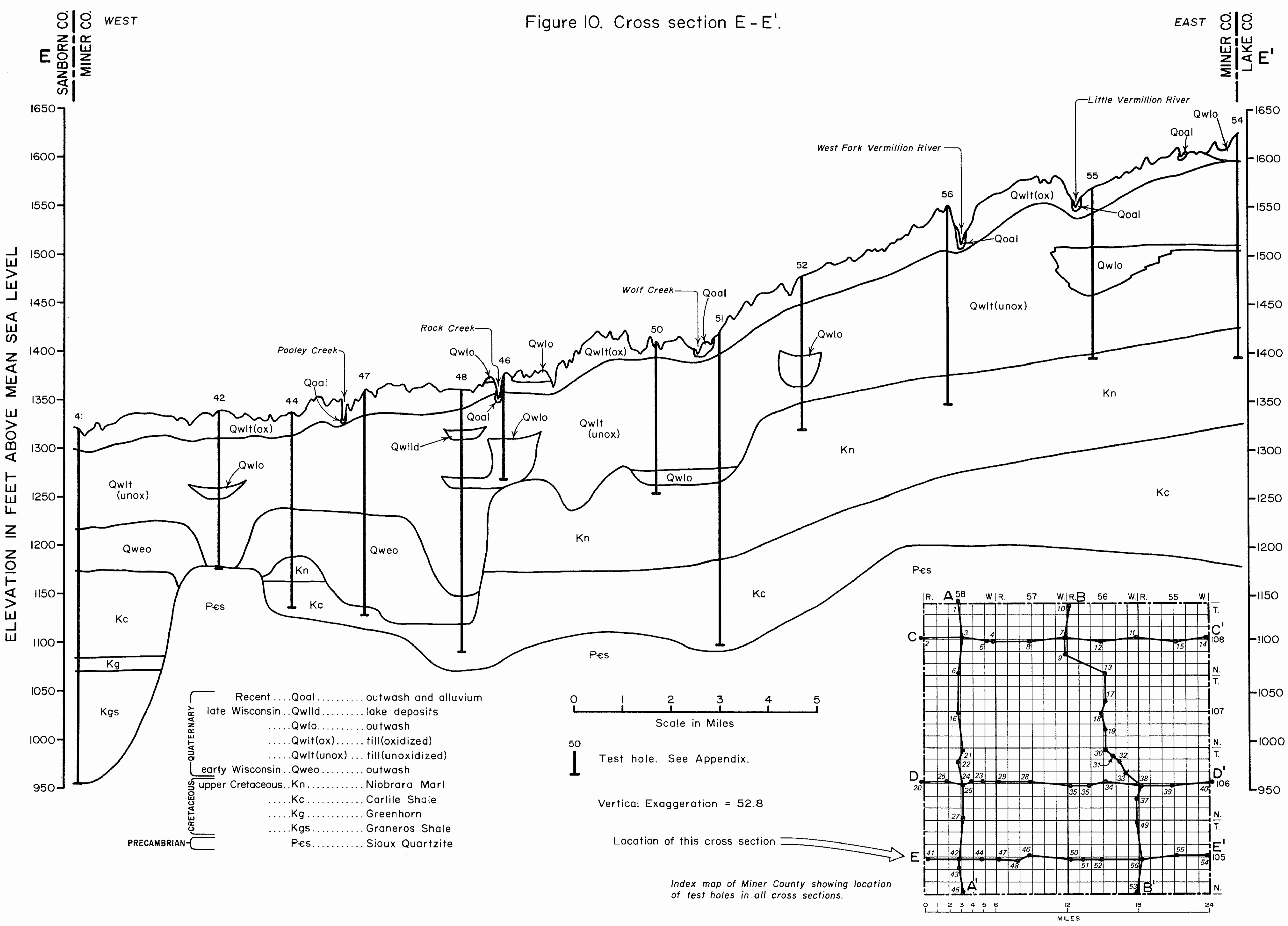
Inferred contact

Vertical Exaggeration = 105.6

Location of this cross section

Index map of Miner County showing location of test holes in all cross sections.

Figure 10. Cross section E-E'.



Most of the outwash encountered in Miner County lies on the bedrock surface and is an extension of the large Floyd aquifer named by Steece and Howells (1965) in Sanborn County. The aquifer name comes from Floyd Township where it attained its maximum thickness. This outwash is present in much of eastern Beadle County (Howells and Stephens, 1968) and in the west-central and southwestern part of Miner County. McGarvie (in preparation) offers a detailed description of the aquifers.

LAKE DEPOSITS

Lake deposits are generally fine sands, silts and clays which were deposited on the floor of temporary glacial lakes. These lakes may be of many different origins which will be discussed in a later section of the report.

The early Wisconsin lake sediments are either gray or black, contain abundant carbonaceous matter and sulfides derived from decay of organisms and they are generally greasy in texture. A drop of 20 percent hydrochloric acid placed on a sample produces hydrogen sulfide gas. Lake deposits range from 2 feet to 36 feet thick and average 14 feet.

Most lake deposits are concentrated along the axis of bedrock lows and are not traceable from one hole to the next. A possible explanation for this is that the isolated lake deposits represent small lakes dammed by the ice as it encroached the higher elevations to the east. Elevations of lake deposits listed on table 3 show progressive higher elevations from west to east. One excellent example of this sequence is illustrated along the axis of the Redstone Creek bedrock low. Traversing from southwest to northwest the lake deposit elevations increase from 1,251 feet to 1,343 feet to 1,412 feet. A similar example can be seen in the vicinity of Howard.

Late Wisconsin

Late Wisconsin glaciation occurred during the time span between 22,000 and about 10,000 years before present. It was during this interval that all the surface deposits in Miner County were formed.

Figure 11 shows the thickness of the late Wisconsin deposits. Values range from a maximum of 200 feet in the southeastern part of the County to a minimum of 14 feet in the northwest and averages 109 feet. By volume, this constitutes approximately 65 percent of the glacial deposits in Miner County. Figure 12 shows the areal distribution of the various late Wisconsin deposits and geomorphic features.

TABLE 3. Locations of lake deposits, their elevations and thicknesses.

LATE WISCONSIN

Location	Elevation (ft)	Thickness (ft)
NE NE NE NE 1-107-55	1661-1655	6
NE NE NE NE 6-108-55	1615-1610	5
SW SW SW SW 34-108-56	1558-1552	6
SW SW SW SW 34-108-56	1534-1530	4
NE NE NE NE 21-106-55	1513-1496	17
NE NW NE NE 4-108-57	1419-1398	21
NW NW NW NW 19-106-56	1407-1402	5
NW NW NW NW 19-106-56	1397-1394	3
NW NE NW NW 17-105-57	1335-1328	7
SE NE NE NE 20-105-57	1320-1312	8

EARLY WISCONSIN

Location	Elevation (ft)	Thickness (ft)
NE NE NE NE 6-108-55	1506-1486	20
SE SE SE SE 33-107-55	1497-1482	15
NE NE NE NE 1-105-55	1491-1486	5
NE NE NE NE 1-105-55	1445-1431	14
NW NW NW NW 6-108-56	1412-1408	4
NW NW NW NW 24-108-58	1343-1333	10
NW NW NW NW 19-106-56	1307-1284	23
NE NE NE SE 27-105-58	1271-1269	2
SW NW NW NW 6-107-58	1251-1215	36

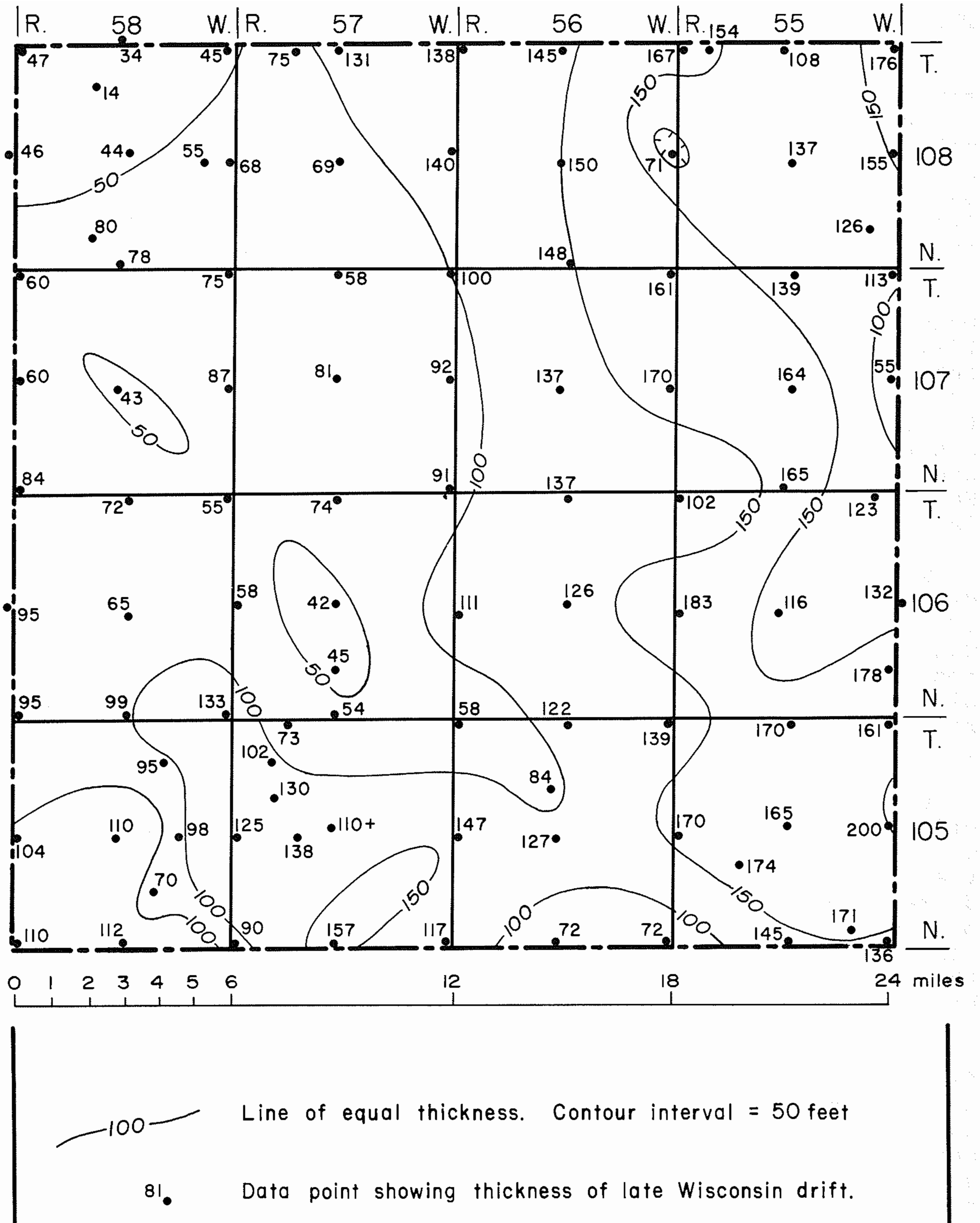


Figure 11. Map showing thickness of late Wisconsin deposits.

TILL

In order of the frequency of occurrence, oxidized late Wisconsin till varies from yellow-brown to brown to yellow to red-brown to gray-brown. Unoxidized till is either gray or dark-gray. The till is a pebbly, silty clay with numerous thin gravel lenses dispersed throughout. It also contains abundant shale, probably derived from local Pierre Shale bedrock. Oxidized till ranges from 2 to 56 feet thick and averages 25 feet. The unoxidized till ranges from 5 to 166 feet in thickness and averages 74 feet.

The high shale content of the late Wisconsin till has been used as a means of differentiating late Wisconsin till from older till in the Des Moines Lobe (Matsch and others, 1972) and on the Coteau des Prairies in southeastern South Dakota (Schroeder, 1979). Based on the work on the Coteau, Schroeder (1979) found the Illinoian till to average 3 percent shale, the early Wisconsin till to average 11 percent and the late Wisconsin till to average 19 percent. Along the axis of the Minnesota River Valley, Matsch (1971) found shale values as high as 59 percent in the late Wisconsin till.

The procedure used for the till analysis in both cases was to dry the samples and crush them until they could pass through a 1/2-inch slotted sample splitter. About 50 grams of this material was then added to about 800 mL of 0.02 M Calgon solution and the resulting slurry occasionally stirred over a 2-hour period. The slurry was then washed through screens to isolate the 1-2 mm size range. These particles were then dried and placed under a binocular microscope for identification.

Using this technique, till samples were collected on a 6-mile grid over the entire County. In the northeastern part of the County four additional samples were collected from each side of the East Fork Vermillion River to determine whether there is a difference in the till composition associated with the presence of loess east of the river and its absence west of the river. Also, three extra samples were collected in the southwest part of the County to determine possible compositional differences between the ground moraine area and the stagnation moraine.

Figure 13 shows the results of the till analysis. Most values fall in the range of high shale composition except for 10.8 percent in the northeast part of the County and 9.1 percent in the southwestern corner. There is a rather obvious decrease in shale composition toward the west. This may be a result of secondary advances over till rather than bedrock. The stagnation moraine east of the East Fork Vermillion River averages 51.4 percent shale whereas the end moraine west of the river averages

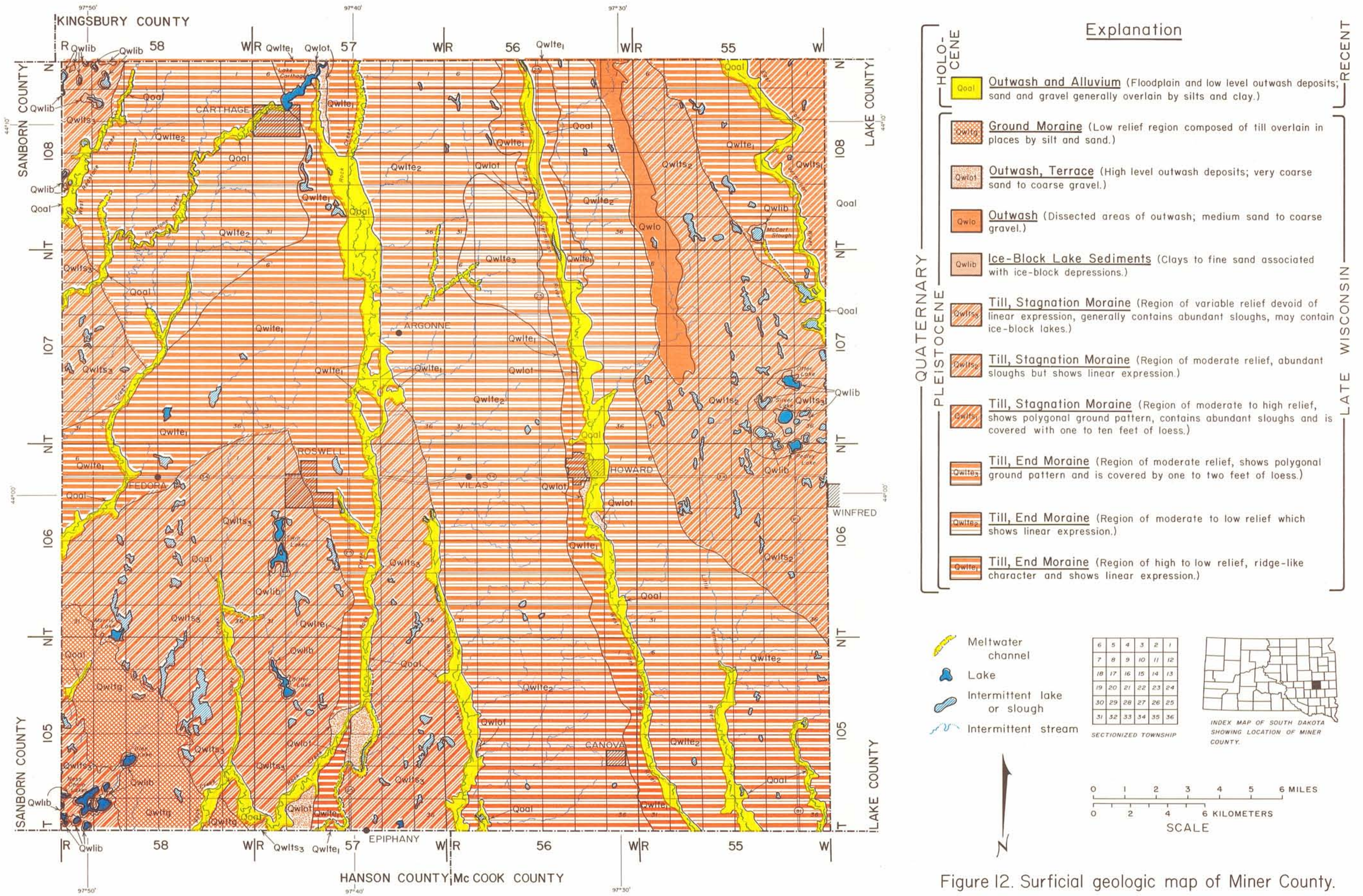


Figure 12. Surficial geologic map of Miner County.

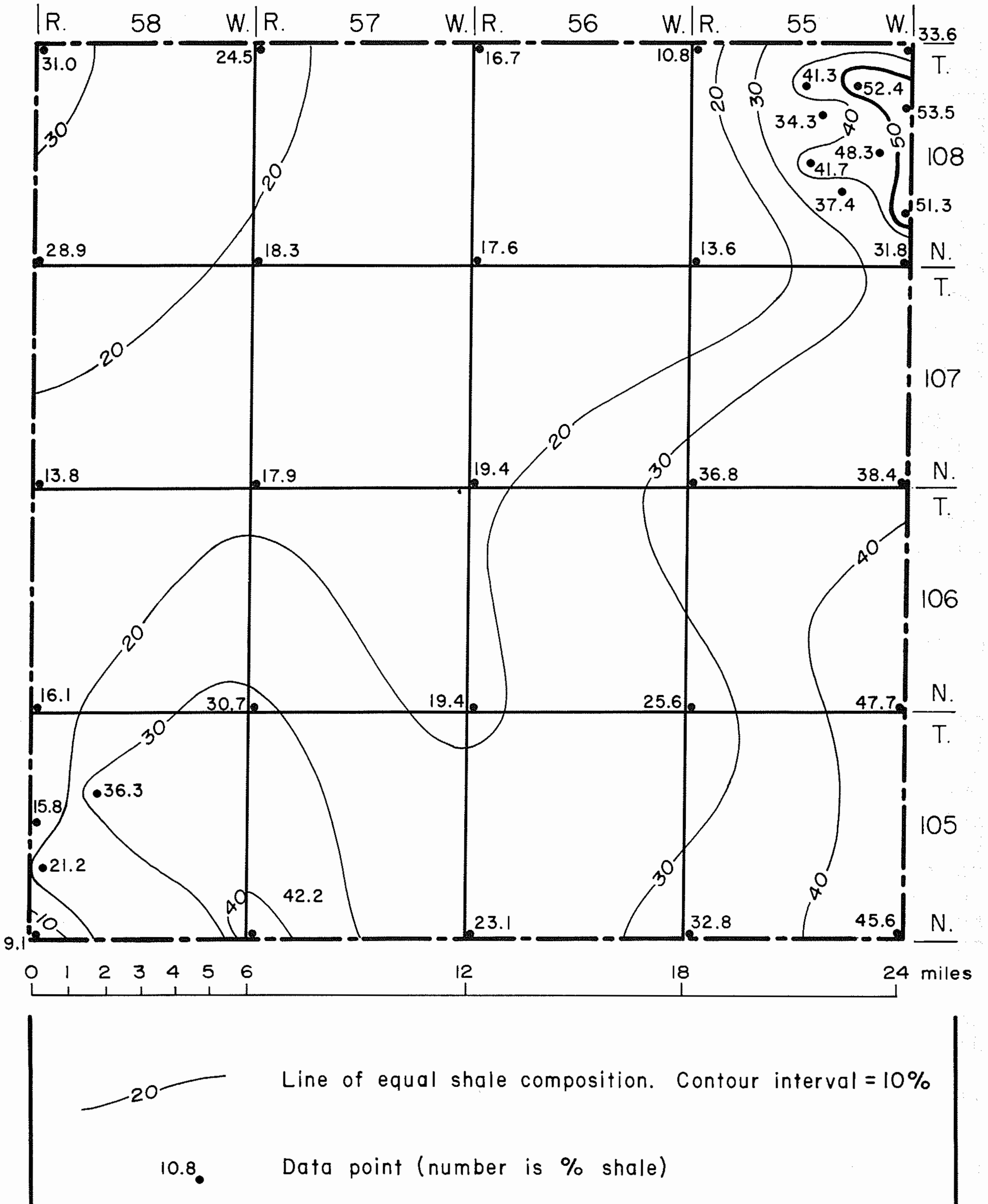


Figure 13. Map showing the percent shale in the 1-2mm fraction of the till.

38.7 percent. This difference may be related to the fact that freeze-thaw and weathering phenomenon does not affect the till below the loess as much as it does the till at the surface. The ground moraine in the southwest corner is composed of 26.2 percent shale as opposed to 15.4 percent for the stagnation moraine.

Except for the two previously mentioned low shale values, all samples appear to correlate with the late Wisconsin glaciation, however, the stratigraphic relationship of the drift sheets strongly indicated that the two samples low in shale must also be late Wisconsin. The shale percent analyses also suggest the possibility of differentiating between ground moraine, stagnation moraine, and end moraine on the basis of shale percent but this would require more detailed work.

The till samples analyzed were mostly pale yellowish-brown in color. They averages 30.1 percent sand of which 8.5 percent fell within the 1-2 mm size range. The full range of the sand extends from 2 mm to 1/16 mm. Average composition of the 1-2 mm fraction was 29.9 percent shale, 18.8 percent carbonates, 33.2 percent igneous rocks, and the remaining 18.1 percent composed of other rock types.

OUTWASH

Late Wisconsin outwash ranges from 4 to 55 feet thick, averages about 10 feet and is composed of about equal volumes of fine to medium gravel and fine to medium sand. Grains of sand are angular to subrounded. Color varies from brown and gray-brown when oxidized to gray where unoxidized. The outwash sand has a relatively high shale content which reflects its derivation from the shale rich late Wisconsin till. Small fragments of coal are common. These are either derived from late Cretaceous formations which once extended across the northern part of the State or reworked older glacial deposits which derived the coal from that same source.

Most buried late Wisconsin outwash deposits are located in the eastern half of the County associated with the edge of the Coteau des Prairies (figs. 8 and 10). Surface outwash deposits are mainly located along Lake Carthage, Rock Creek, West Fork Vermillion River, and the outwash body northeast of Howard (fig. 12).

LAKE DEPOSITS

Lake deposits in the subsurface are mainly gray, brown and black silts and clays and are slightly calcareous. Carbonaceous matter and sulfides are less common in the late Wisconsin than in the early Wisconsin lake sediments. Lake clays average 9 feet in thickness and range from 5 to 21 feet thick. They occur randomly throughout the County as isolated entities.

LOESS

East of the East Fork Vermillion River in the extreme northeast corner of the County, the surface till is overlain by 1 to 10 feet of windblown silt. Most of this loess is yellowish-gray with some streaks of medium gray and is both calcareous and nonstratified. On figure 12 this region is labeled as Type 1 stagnation moraine. This deposit is believed to be late Wisconsin in age as evidenced by the abrupt termination at the river. This is due to the presence of ice to the west and exposed ground to the east at the time of deposition. Polygonal ground patterns displayed on its surface are believed to be indicative of a periglacial environment.

A second region which contains some thin loess (1 to 2 feet thick) is located northeast of Argonne and is labeled as Type 3 end moraine on figure 12. This deposit is also believed to be late Wisconsin in age because the polygonal ground pattern exhibited on air photos is similar to that east of the East Fork Vermillion River. This will be discussed more fully in the section on geomorphology.

Recent

Recent refers to the time span since the end of the late Wisconsin about 10,000 years ago. Geologically, this has been a time of weathering, soil formation, and erosion by wind and water. These processes have all been active in development of the present landscape. Most of the changes tend to smooth out the steeper slopes by erosion from the high areas and deposition of the material in the low areas.

Outwash and Alluvium

The materials deposited in the present-day stream and river valleys are a combination of reworked late Wisconsin outwash and other sediments deposited during Recent time. Outwash is generally a coarse sand to a medium gravel, brown to reddish-brown and silty to clayey.

Alluvium is composed mainly of dark-brown to black, fine to medium sand and is very clayey. Separating outwash from alluvium on a small scale map is difficult so the two have been lumped together into one category.

Thicknesses of the outwash and alluvium are dependent on the size of the stream, mode of formation and time of formation. Some average figures for different stream systems include: West Redstone Creek, 6 feet of sand and gravel; Redstone Creek, 8 feet of clay over 10 feet of sand and gravel; Jim Creek, 7 feet of clay over 8 feet of sand and gravel; Pooley Creek, 3 feet of sand and gravel; Rock Creek, 3 feet of clay over 16 feet of sand and gravel; Wolf Creek, 3 feet of clay over 4 feet of sand and gravel; West Fork Vermillion River, 6 feet of clay over 15 feet of sand and gravel; Little Vermillion River, 4 feet of clay over 7 feet of sand and gravel; and East Fork Vermillion River, 4 feet of clay over 6 feet of sand and gravel.

Lake Deposits

Recent lake deposits usually consist of a basal fine sand grading upwards to black, organic-rich silts and clays. The basal sand probably started accumulating at the close of the late Wisconsin. Accretion of organic-rich silt and clay has continued to the present time, slowly filling the lake beds. The combination of deposition in the lake bed and a changing hydrologic regime has transformed the lakes of yesterday to the sloughs of today.

GEOMORPHIC DEVELOPMENT

Pre-Pleistocene

Prior to 2.5 billion years (B.Y.) ago, the area was receiving sediments from surrounding higher areas. Silts and clays composed the greatest part of these deposits. With thicker and thicker accumulations, these sediments were converted to siltstones and shales. Approximately 2.5 B.Y. ago, due to great pressures and possibly some new sources of internal heat in the area, these deposits were slowly changed to schists, granitic gneisses and granites. By 1.8 B.Y. ago, new activity was taking place in the form of granitic intrusions which involved the emplacement of molten rock of granitic composition. This mass of magma caused uplift of the surrounding area but never actually reached the surface. Instead it cooled at great depth forming a rock similar to the Milbank granite or the Harney Peak granite. Possibly, as a late phase of development of the previous activity, about 1.64 B.Y. ago, the andesite and rhyolite porphyries formed. These are extrusive igneous rocks which means that the magma reached the surface and flowed in the form of lava. Most likely this filled in some of the valleys that existed at that time. As this material cooled, it formed the silicic volcanics indicated in figure 5.

Sometime between 1.64 and 1.47 B.Y. ago, there was a period of subsidence in the area or uplift of the surrounding area during which coarse sands and gravels were initially deposited. Subsequently medium sands were deposited over the whole County. Little is known of the time between 1.47 and 1.2 B.Y. ago but the sediments were eventually cemented by silica to form the conglomerates and quartzites of the Sioux Quartzite. When this cementing took place is in doubt but it may have occurred about 1.2 B.Y. ago in association with intrusives and extrusives in the surrounding area. Later, uplift again took place starting an erosional cycle on the quartzite. Erosion continued to be the dominant force acting on the Sioux Quartzite until the beginning of the late Cretaceous. By this time the land surface had become rather rugged because of erosion. Steep cliffs and incised drainage were probably quite common. Figure 5 shows a wide range of elevations on the quartzite surface in the vicinity of Howard and west of Epiphany. It also implies a rapid decrease in elevation north of the 1,000-foot contour. The Sioux Quartzite was probably missing in the northern half of the County. The weathered and reworked material was strewn over the surface in the form of "wash."

By about 100 M.Y. ago the Cretaceous Seaway, which existed to the north and west, had expanded to the north edge of what is now Miner County. The sea extended from northern Canada to the Gulf of Mexico and from central Utah to eastern South Dakota. The environment was that of a shoreline or near shoreline in the vicinity of Carthage and a high landmass about 1,200 feet higher around Epiphany. Weathered quartzite was eroded off the highlands and deposited as "wash" in deltas in the lowlands. This covered the old "wash" which already existed in the lowlands. The old "wash" may constitute the lower 84 feet of the Dakota Sandstone in test hole 9. This interval contains a high percentage of iron carbonates. The newly deposited "wash" material would then represent the next 139 feet of the Dakota Formation. As sea level rose, the shoreline continued to shift farther south onto the highlands. As the water deepened, clays were deposited instead of sands. This constitutes the next 129 feet of the Dakota. At this point a change in source took place because the upper 58 feet of the Dakota is a clear, quartz sand rather than the pink sands deposited earlier. At this time the sea still had not reached the vicinity of Howard (fig. 3).

The sea continued spreading southward onto the quartzite ridge, resulting in a transgressive depositional sequence. It was not until deposition of the Niobrara Marl that the sea completely submerged the Sioux Quartzite ridge. Test hole 45 had to be abandoned in chalk due to a severe loss of water. Later drilling, across the road in Hanson County, showed the chalk to be lying on quartzite. Reported outcrops to the southeast along the East Fork Vermillion River also show chalk lying on the quartzite surface. The subsequent deposition of Pierre Shale also extended over the Sioux Ridge.

Younger Cretaceous and/or Tertiary formations were probably deposited on the Pierre Shale but, if so, they were totally removed by erosion during and after the regression of the Cretaceous Seaway. What was a sea, became land. Drainages developed on this surface in response to the slope of the surface and the varying degrees of resistance to erosion. By Pleistocene time, a well developed drainage system existed. Flint (1955) traced the pre-Pleistocene drainage of eastern South Dakota and has shown that all the rivers west of the present Missouri River flowed into eastern South Dakota. The Missouri and the James Rivers, however, did not exist at that time. The Cheyenne River and all rivers north of it eventually turned north at about the axis of the present James Basin and drained into Hudson Bay. Those south of it turned south in about the same general area, forming the White River system, and drained south to the Gulf of Mexico. Miner County was part of this later drainage system.

Pre-Late Wisconsin

Events taking place in Miner County during the Nebraskan and Kansan glaciations are in doubt. If glaciers did cover the area, they would have advanced from the east-northeast and northeast. Even if the glaciers did not invade the County, there would have been some periglacial activity and drainage modifications.

The Illinoian glacial advance began about 115,000 years ago. This advance approached from the east-northeast into southeastern South Dakota. Apparently it extended as far north as Miner County because Illinoian deposits occur in the northeast corner of the County (fig. 7). If it covered the quartzite ridge in southern Miner County, the evidence is now missing.

A long period of weathering followed the Illinoian glaciation. This is evident from the thick sequence of oxidized till underlying early Wisconsin drift. Ice again advanced into Miner County sometime after 70,000 years ago. This time it approached from the northeast and eventually covered the entire County. Steece and Howells (1965) identified early Wisconsin till in western Sanborn County and Hedges (1968) identified early Wisconsin till in western Beadle County. Early Wisconsin drift derived from the northeast should be low in shale content (Matsch and others, 1972). The reason for this is two-fold. First, northeast is the direction of depositional thinning and extinction of the Pierre Shale either due to nondeposition or erosion. Second, all previous glacial advances had been from this same general direction, so the shale that still existed would have been mantled with older till. Laboratory analysis of the surface till showed no shale-free material. This supported the conclusion that no early Wisconsin deposits are exposed in Miner County.

The early Wisconsin glacial advance eventually halted and a new period of weathering began. This weathering interval lasted for a shorter period of time than the previous one, or the climatic conditions were colder and drier, because depth and intensity of oxidation of the early Wisconsin drift was less than that of the Illinoian drift.

Late Wisconsin Advance

Between the recession of the early Wisconsin ice and the advance of the late Wisconsin, some major changes in glacier regimen must have taken place in Canada. These changes involved both the source area for the continental glaciation and the flow pattern of the ice. As a result, ice advanced down the course of the present James River for the first time. The glacier, advancing from the north to north-northwest, was split into two lobes by an already existing highland on the Coteau des Prairies. The lobe that covered Minnesota, Iowa, and northeastern South Dakota is called the Des Moines Lobe and the one covering east-central South Dakota is called the James Lobe. The consequence of this split was to modify the Coteau des Prairies into what we see today.

As the lobe of ice advanced toward the south, it also spread laterally to the east and west. Lakes were formed at the margin of the advancing ice sheet due to impoundment of water from the blocked regional drainage outside the boundaries of the ice. With continued advance, these deposits were later buried. In the vicinity of Miner County the ice advanced as far east as the western quarter of Moody County (South Dakota Geological Survey, Educational Series, Map Two). Thus, Miner County was again covered by ice. A large end moraine was deposited at the terminus or edge of the glacier in Moody County.

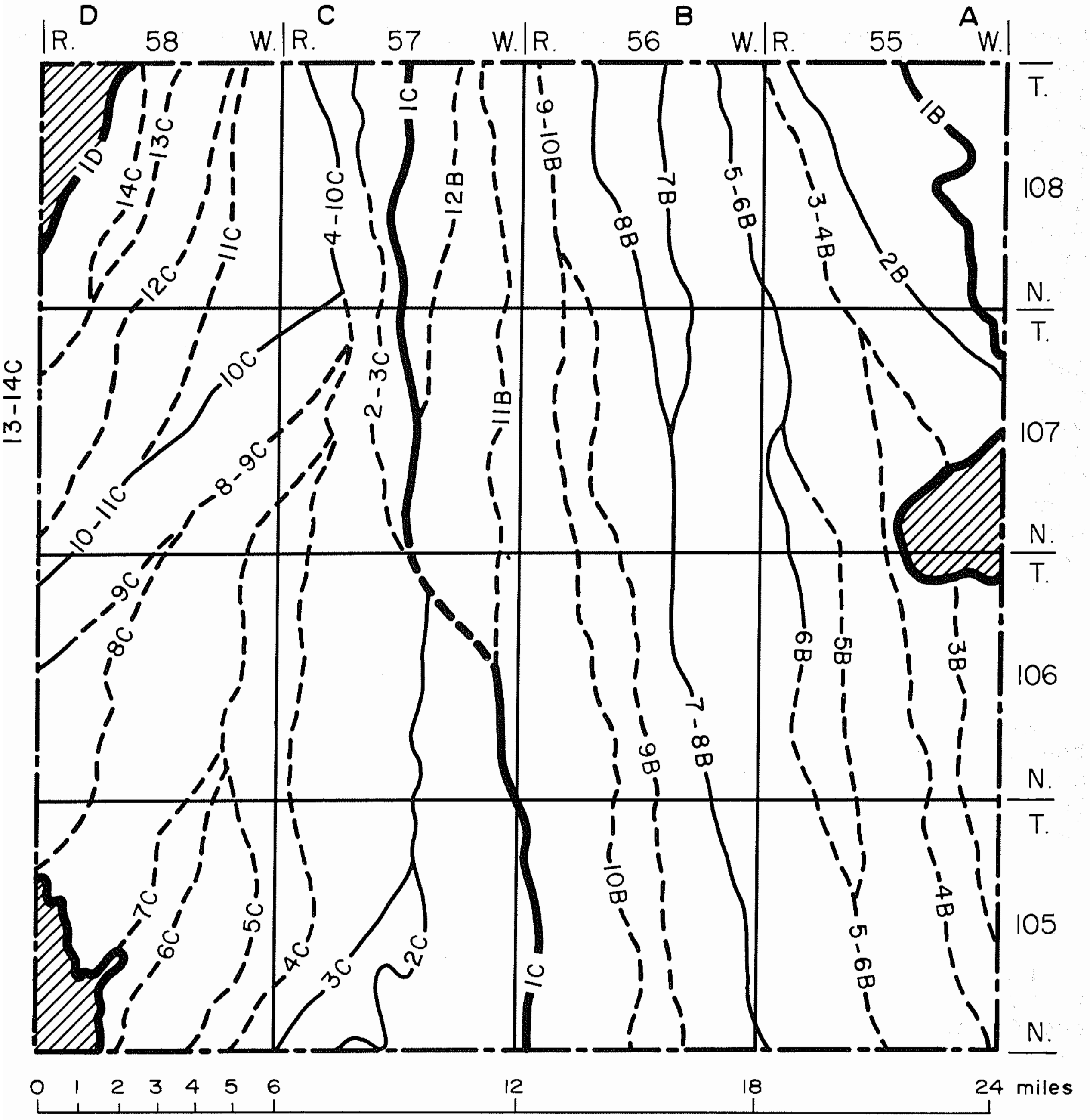
Late Wisconsin Recession

At the time of the beginning of the recession, the terminus of the ice was about 30 miles east of Miner County and the area was covered by ice to a depth of between 300 and 1,000 feet. It was thickest around Ness Chain Lakes and thinner in the northeast part of the County.

Phase A

Figure 14 shows the inferred recessional positions of the ice front. The region marked A is in the extreme northeast part of the County and corresponds with the Type 1 stagnation moraine on figure 12. The surface to the east in Lake County is also stagnation moraine. Figure 15 shows the configuration of the surface over which the late Wisconsin ice was flowing. Note the similarities between the pre-late Wisconsin surface on figure 15 and the configuration of the bedrock surface on figure 4. Figure 15 indicates a buried end moraine ridge just west of the East Fork Vermillion River. This may be the barrier which caused stagnation of the ice to the east. In Miner County the stagnation moraine has 1 to 10 feet of loess cover. Local relief is 47 feet which is quite high compared to the maximum value of 64 feet and minimum value of 13 feet in the County (fig. 16).

Air photos and topographic maps show a polygonal ground pattern in the area covered by Phase A. This pattern extends into Lake and Kingsbury Counties where it is even better developed. These four- to seven-sided polygons may have a slightly raised or depressed center, a ridge or rim defining the sides, and a low



— 10C — Line indicates relative positions of ice front during recessional phases. Lines are dashed where inferred. Heavy lines indicate phase boundaries.

Letters designate ice phases from oldest (A) to youngest (D) and numbers indicate relative position of ice front (1 is youngest in each phase).

▨ Stagnation Moraine with numerous ice-block lakes

Figure 14. Map showing recessional positions of the ice front.

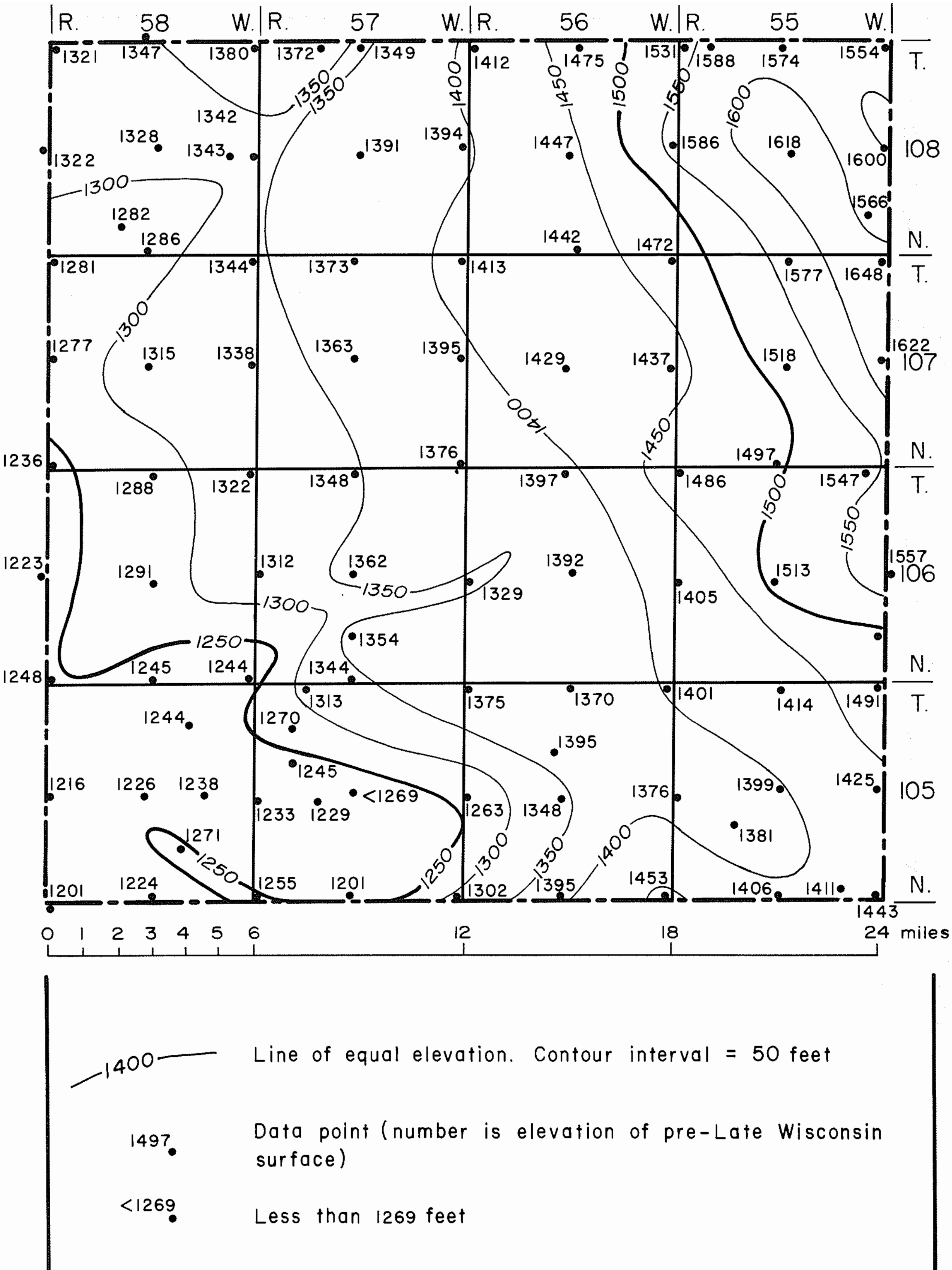


Figure 15. Map showing the pre-late Wisconsin surface.

STREAM VALLEYS	LOCAL RELIEF (FEET)	GEOMORPHIC UNITS	STREAM VALLEYS	LOCAL RELIEF (FEET)	GEOMORPHIC UNITS
East Fork Vermillion River	64		Redstone Creek	35	
	58	Qwle$_1$ - along East Fork Vermillion River		33	Qwle$_2$ - East of Howard
	49	Qwls$_3$ - North of Winfred	Little Vermillion River	32	
	47	Qwls$_1$ - along East Fork Vermillion River	Pooley Creek	31	
Northeast of Argonne Meltwater Channel	46		Jim Creek	30	
West Fork Vermillion River	42			28	Qwls$_3$ - along Wolf Creek
	41	Qwle$_1$ - along West Fork Vermillion River		26	Qwle$_1$ - along Rock Creek
West Redstone Creek	40			26	Qwle$_1$ - North of Fedora
	39	Qwls$_2$ - Northeast of Howard		26	Qwls$_3$ - North of Fedora
Rock Creek	39			23	Qwle$_2$ - along Redstone Creek
	39	Qwle$_3$ - along West Fork Vermillion River		23	Qwls$_3$ - West of Pooley Creek
Wolf Creek	38			22	Qwls$_3$ - East of Pooley Creek
	37	Qwle$_2$ - Vilas		20	Qwls$_3$ - Ness Chain Lakes
	36	Qwls$_3$ - along West Redstone Creek		13	Qwlg - Northeast of Ness Chain Lakes

Figure 16. Comparison of local reliefs.

area surrounding the structure. Lakes developed in this type of topography commonly have straight shorelines where they follow the edge of the polygons. There seems to be some correlation between the presence of loess and the development of polygonal ground pattern because a similar relationship exists in the Type 3 end moraine area northeast of Argonne. Explanation for the mode of formation is left to a more detailed study of loess-ground pattern relationship. The source of the loess cover will be explained in the next section.

Phase B

With the detachment of the ice east of Position 1B (fig. 14) the glacier was able to establish stability. The ice front maintained this position building an end moraine while the detached stagnant ice was slowly melting. To the north in Kingsbury County there was a large, low, flat area which now contains Lakes Thompson, Henry, Whitewood, and Preston. This was the ponding area for much of the meltwater draining north from the East Fork Vermillion River north of sec. 13, T. 108 N., R. 55 W. During this time interval the lake levels fluctuated exposing vast areas of unvegetated shoreline. Winds out of the northwest produced large scale dust storms which deposited silt downwind. This was the source of the loess covering much of the stagnation moraine.

The glacier remained in a relatively stable condition and built a massive end moraine composed of till as far west as Position 2B (fig. 14). The highest elevation in the County, about 1,803 feet, is found within this area in the NW 1/4 NE 1/4 NW 1/4 NW 1/4 sec. 15, T. 108 N., R. 55 W. Local relief on the end moraine is 58 feet and is the highest local relief on constructional topography in the area (fig. 16).

The ice then receded in a series of steps to the 5-6B Position (fig. 14). Intermediate positions such as 3-4B and the southern half of 5-6B are determined by abrupt changes in stream directions in response to minor ridges, alignment of elongated lakes or depressions and alignment of stream drainages. In this interim of time two types (fig. 14) of stagnation moraine formed. Type 2 contains many elongated lakes and sloughs characteristic of end moraine but resembles stagnation moraine on air photos. The local relief is 39 feet. Type 3 contains abundant ovate ice block lakes and sloughs, and lacks other linear features characteristic of end moraine. Local relief in the type 2 and 3 stagnation moraine is 49 feet.

Also, associated with the 5-6B Position is the large collapsed outwash plain, northeast of Howard, composed of medium sand and coarse gravel. Concurrently meltwater from the stagnation moraine continued flowing north into the Lake Thompson area. Because of the coarse texture of the outwash material and the collapsed nature of its surface, it is thought that this stream formed in contact with the ice on the west. Since that time erosion has sculptured it into low flat-topped mounds distributed throughout a lower relatively flat erosional surface. The mounds often contain gravel and exhibit a relief of about 15 to 20 feet.

The West Fork Vermillion was established at Position 8B with an outwash apron forming along the length of the ice margin. Subsequent erosion has left remnants of this outwash apron as gravel terraces elevated above the present flood plain. The glacier was stable in this position for a period of time as indicated by the presence of outwash and Type 1 end moraine. The remainder of Phase B is dominated by continued recession.

Phase C

From the northern border of Miner County and southward for 3 miles Position 1C follows an old meltwater channel containing present-day Rock Creek. The next 10 miles also follow Rock Creek to the vicinity of Roswell, however, the valley is wider and shallower than the first 3 miles. From Roswell south, the 1C Position shifts east and follows Wolf Creek. The ice occupied this position long enough to establish a well developed stream drainage net along the eastern edge.

At Position 2-3C outwash was deposited in the Carthage area. This was later dissected to form terraces. The fine-grained materials which were transported during the process of forming the outwash were redeposited in the wide valley of Rock Creek north of Argonne. Storms containing fine-grained material originating from this outwash plain redeposited the material as loess overlying the Type 2 end moraine to the east. Presently only 1 to 2 feet of loess exists in the area. Polygonal ground patterns are poorly developed because of the thin loess deposits. The meltwater channels shown on the geologic map associated with Position 2-3C have a polygonal shape. This may be a secondary effect resulting from the ground pattern or, possibly, these deeply incised streams are Recent drainage development on the loess surface rather than meltwater channels.

The ice retreat from Position 1C to 2C has resulted in Type 3 stagnation moraine near Epiphany. At the 2C Position the meltwater channel west of Epiphany developed along with associated terrace outwash deposits. Successive development of Rock Creek is as follows: the northern part has maintained approximately the same course throughout its development while the southern segment has shifted west from Wolf Creek to the 2C Position forming the meltwater channel, then to the 3C Position after abandoning the meltwater channel. For some unexplained reason, it was later diverted to the 5C Position in its southernmost stretch.

During the time that the glacier occupied the 5C Position, there was a minor readvance as indicated by the sequence of sediments in the dugout described in 1958 (Flint and Deevey, 1960). From the surface down it shows: alluvium, 2 feet; alluvium with many pebbles, 1 foot; brown, oxidized till, 5 feet; gray, unoxidized till, 3 feet; silt with wood fragments, 1 foot plus. The wood was dated by radiocarbon at 12,200±400 years (sample W-801, Flint and Deevey, 1960). The presence of 8 feet of till over the wood may indicate that ice readvanced over the site and therefore records the existence of active ice in the vicinity after that date. Other interpretations for this data are possible. The site is located in what is mapped as a meltwater channel. Slump along the sides of this channel may have buried the wood or collapse may have occurred in superglacial drift. These interpretations would mean that the ice had already retreated outside the area by 12,200 years ago.

From Position 5C to 9C (fig. 14), Type 3 stagnation moraine and ground moraine were formed. Regionally the glacier had receded to the point where Miner County was located in more of a terminal than a lateral position. The ice front was receding more rapidly and lobation was taking place.

Type 1 end moraine was deposited from 9C to 11C at and north of Fedora. Till with local relief of 26 feet is the major material composing the moraine. Linear features are broader on this surface than on any of the other end moraines in the County. This is best seen by comparing the width of the end moraine (fig. 12) versus their local relief (fig. 16). The end moraine is 3 times wider and yet displays the same local relief.

The remainder of Phase C was a period of recession to Position 1D and resulted in stagnation moraine and end moraine. Throughout Phase C a proportionally larger area was covered by stagnation moraine. The reason for this is probably best illustrated by viewing figures 8, 9, and 10 and relating the early Wisconsin surface to the geometry of the James Lobe. The bedrock surface and the pre-late Wisconsin surface (fig. 4 and fig. 15) rise rapidly along the east edge of the James Basin. This ridge acted as a barrier to ice flow and caused stagnation. Also, by this time, the area was in a terminal rather than lateral position with respect to the James Lobe. These two mechanisms produced an environment prone to stagnation.

Phase D

Subsequent to Position 1D stagnation was again the predominant process. The area indicated as D is quite different from the stagnation to the south as indicated by the increased number of ice-block lakes. One lake on the County line, mostly in Kingsbury County (sec. 32, T. 109 N., R. 58 W.) is quite spectacular for this region. It has a high local relief (50 feet), is up to a half mile across, and has a very flat bottom.

Recent

A number of changes have taken place since the ice retreated. The East Fork Vermillion River, by headward erosion, has cut back into the end moraine (secs. 12, 14, and 23, T. 108 N., R. 55 W.) and captured the previously north flowing upper segment. The tributaries to the West Fork Vermillion River north of Howard have, by headward erosion, drained some of the ground water from the outwash area. Also, headward erosion by Redstone Creek has cut through the end moraine at Carthage and captured the drainage which once flowed into the Rock Creek System. Rock Creek in its lower reaches has shifted west to occupy the previous Pooley Creek drainageway.

During the recession of the late Wisconsin ice, large amounts of meltwater were available. Stream valleys were wide and prone to frequent flooding during the summer months. The present climate with its limited precipitation has modified the drainage to intermittent streams or dry stream beds. Flooding is infrequent and predominant deposition is fine-grained alluvium.

Other changes taking place involve removal of the thin loess deposits, reworking of outwash along the streams, deposition of silt in lakes to yield sloughs, weathering of all surface deposits to form soils and a general lowering of the land surface by erosion.

ECONOMIC GEOLOGY

Sand and Gravel

Figure 12 shows the locations of existing sand and gravel pits. Numerous test holes drilled to determine thickness and areal extent of these deposits. The most productive areas are along the north shore of Lake Carthage, that portion of Rock Creek in T. 105 N., R. 57 W., along the West Fork Vermillion River extending 5 miles north and south of Howard, and the outwash northeast of Howard. Shale and iron-manganese concretions are quite abundant in the outwash material.

Oil and Gas

The only oil and gas test attempted in Miner County is the Rocky Ridge No. 1 Hale test southeast of Carthage. This test penetrated to the Precambrian surface without encountering any economic accumulations.

Water

As part of the county-wide investigation, a complete hydrologic study was made. The results of these findings are available as Part II of this Bulletin (McGarvie, in preparation). A short summary of the overall quality and quantity of ground water and its distribution can be obtained by reading Major Aquifers in Miner County, South Dakota (McGarvie, 1982).

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APPENDIX

Legal descriptions of test-hole logs

The following list contains the test hole numbers and legal descriptions of all test holes shown on the cross sections. These logs are available from the computer files of the South Dakota Geological Survey. Any request for logs should contain the legal description.

TEST HOLE	LEGAL DESCRIPTION
1	SE SE SE SE sec. 33, T. 109 N., R. 58 W.
2	SE SE SE SE sec. 13, T. 108 N., R. 59 W.
3	SW SW SW SW sec. 15, T. 108 N., R. 58 W.
4	NE NE NE NE sec. 24, T. 108 N., R. 58 W.
5	NW NW NW NW sec. 24, T. 108 N., R. 58 W.
6	SE SE SE SE sec. 33, T. 108 N., R. 58 W.
7	SE SE SE SE sec. 13, T. 108 N., R. 57 W.
8	NE NE NE NE sec. 21, T. 108 N., R. 57 W.
9	SW SE NE NE sec. 25, T. 108 N., R. 57 W.
10	NW NW NW NW sec. 6, T. 108 N., R. 56 W.
11	SE SE SE SE sec. 13, T. 108 N., R. 56 W.
12	NE NE NE NE sec. 21, T. 108 N., R. 56 W.
13	SW SW SW SW sec. 34, T. 108 N., R. 56 W.
14	SW SE SE SE sec. 13, T. 108 N., R. 55 W.
15	NW NW NW NW sec. 22, T. 108 N., R. 55 W.
16	NE NE NE NE sec. 21, T. 107 N., R. 58 W.
17	NW NW NW NW sec. 15, T. 107 N., R. 56 W.
18	NE NE NE NE sec. 21, T. 107 N., R. 56 W.
19	SW SW SW NW sec. 27, T. 107 N., R. 56 W.
20	SE SE SE SE sec. 13, T. 106 N., R. 59 W.
21	NW NW NW NW sec. 3, T. 106 N., R. 58 W.
22	SW NE NE NE sec. 9, T. 106 N., R. 58 W.
23	SE SE SE SE sec. 14, T. 106 N., R. 58 W.
24	SE SE SE SE sec. 15, T. 106 N., R. 58 W.
25	SE SE SE SE sec. 17, T. 106 N., R. 58 W.
26	NW NW NW NW sec. 22, T. 106 N., R. 58 W.
27	SW SW SW SW sec. 34, T. 106 N., R. 58 W.
28	SE SE SE SE sec. 16, T. 106 N., R. 57 W.
29	SW SW SW SW sec. 18, T. 106 N., R. 57 W.
30	NW NW NW NW sec. 3, T. 106 N., R. 56 W.
31	SW NE NW SE sec. 3, T. 106 N., R. 56 W.
32	NE NE NW NW sec. 11, T. 106 N., R. 56 W.

TEST HOLE	LEGAL DESCRIPTION
33	NE NE NE NE sec. 14, T. 106 N., R. 56 W.
34	SW SW SW SW sec. 15, T. 106 N., R. 56 W.
35	NW NW NW NW sec. 19, T. 106 N., R. 56 W.
36	NE NE NE NE sec. 20, T. 106 N., R. 56 W.
37	NE NE NE NE sec. 25, T. 106 N., R. 56 W.
38	NW NW NW NW sec. 19, T. 106 N., R. 55 W.
39	NE NE NE NE sec. 21, T. 106 N., R. 55 W.
40	SW SW SW SW sec. 18, T. 106 N., R. 54 W.
41	NE NW NW NW sec. 19, T. 105 N., R. 58 W.
42	NE NE NE NE sec. 21, T. 105 N., R. 58 W.
43	SE SE SE SE sec. 21, T. 105 N., R. 58 W.
44	NW NW NW NE sec. 23, T. 105 N., R. 58 W.
45	SW SW SW SW sec. 34, T. 105 N., R. 58 W.
46	SE SW SE SE sec. 16, T. 105 N., R. 57 W.
47	NW NW NW NW sec. 19, T. 105 N., R. 57 W.
48	SE NE NE NE sec. 20, T. 105 N., R. 57 W.
49	NE NE NE NE sec. 1, T. 105 N., R. 56 W.
50	NW NW NW NW sec. 19, T. 105 N., R. 56 W.
51	SW SW NE NW sec. 20, T. 105 N., R. 56 W.
52	NE NE NE NE sec. 21, T. 105 N., R. 56 W.
53	SE SE SE SE sec. 36, T. 105 N., R. 56 W.
54	SE SE SE SE sec. 13, T. 105 N., R. 55 W.
55	SW SW SW SW sec. 15, T. 105 N., R. 55 W.
56	NW NW NW NW sec. 19, T. 105 N., R. 55 W.