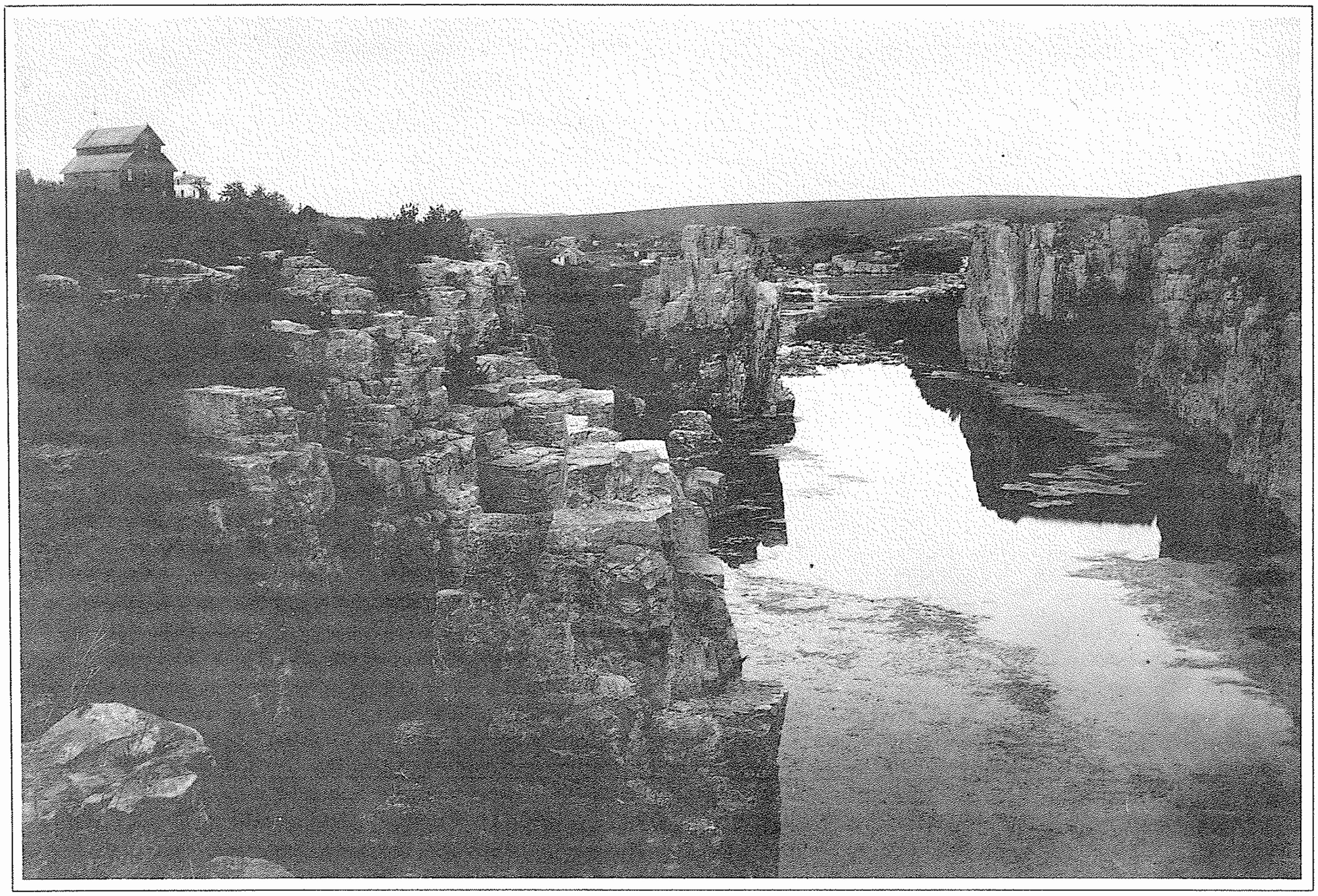
BULLETIN 37

GEOLOGY OF MINNEHAHA COUNTY, SOUTH DAKOTA

Dennis W. Tomhave



Prepared in cooperation with the
United States Geological Survey,
East Dakota Water Development District,
and Minnehaha County

Department of Environment and Natural Resources
Division of Geological Survey
Science Center, University of South Dakota
Vermillion, South Dakota
1994

SOUTH DAKOTA GEOLOGICAL SURVEY
SCIENCE CENTER
414 EAST CLARK STREET
VERMILLION, SOUTH DAKOTA 57069-2390
605-677-5227

COVER: An 1885 photo of Palisades, South Dakota, taken from the files of J.E. Todd, geologist for the U.S. Geological Survey who later became South Dakota's first State Geologist.

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DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
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DIVISION OF GEOLOGICAL SURVEY
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by

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ABSTRACT

Minnehaha County is located in southeastern South Dakota and covers an area of about 816 square miles. It lies primarily within the Coteau des Prairies physiographic province except for the extreme southwestern corner which lies in the James Basin physiographic province.

Precambrian-aged rocks underlie the entire county. The Sioux Quartzite and to a lesser extent the intrusive Corson Diabase are exposed in many places across the county. The Cretaceous-aged Split Rock Creek Formation lies unconformably in the topographic lows of the Precambrian surface and is exposed along the Big Sioux River, Slip-up Creek, and Split Rock Creek. Mantling these bedrock deposits is a complex sequence of Pleistocene-aged glacial deposits. In general, the area east of Skunk Creek is composed of various deposits of older pre-Illinoian and Illinoian(?) drift, covered by highly variable thicknesses of loess. West of Skunk Creek, late Wisconsin deposits are found at the surface, and are underlain by deposits of pre-Illinoian drift.

INTRODUCTION

Purpose

The primary intent of this investigation is the location and evaluation of the mineral and water resources available in Minnehaha County. In addition, the geologic and hydrologic data obtained provide a framework for further exploration and development of the natural resources of the area.

The investigation of the geology and water resources of Minnehaha County is one of a series of cooperative county wide studies in eastern South Dakota (fig. 1). The Minnehaha County Study is also one of several counties within the Big Sioux basin included under the Big Sioux Hydrologic Study (fig. 1). The Big Sioux Hydrologic Study was conducted through the combined efforts of the South Dakota Geological Survey and the U.S. Geological Survey to provide a general assessment of the mineral and water resources available in the Big Sioux basin. The Big Sioux Hydrologic Study was financed by the South Dakota Geological Survey, U.S. Geological Survey, East Dakota Water Development District, and individual counties involved.

The findings of the Minnehaha County Study portion of the Big Sioux Hydrologic Study are published in four parts:

1. *Aggregate resources in Minnehaha County, South Dakota*: South Dakota Geological Survey Information Pamphlet 42, Jarrett, Martin J., 1990.

2. *Major aquifers in Minnehaha County, South Dakota*: South Dakota Geological Survey Information Pamphlet, Lindgren, Richard J., and Niehus, Colin A., in preparation.

3. *Geology of Minnehaha County, South Dakota*: South Dakota Geological Survey Bulletin 37, Tomhave, Dennis W., 1994 (this report).

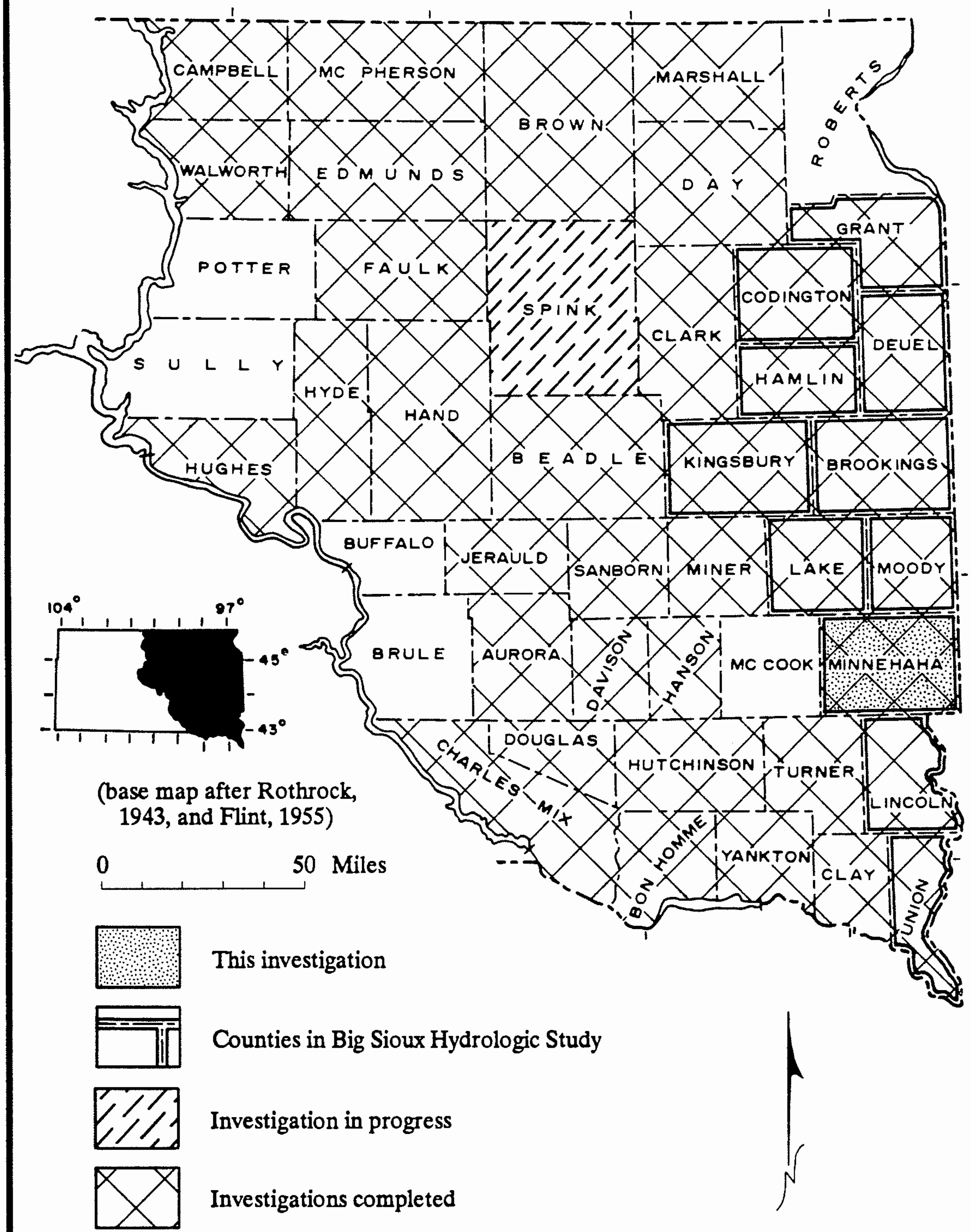


Figure 1. Status of county-wide investigations in eastern South Dakota.

4. *Water resources of Minnehaha County, South Dakota*: U.S. Geological Survey Water-Resources Investigations Report 91-4101, Lindgren, Richard J., and Niehus, Colin A., 1992.

The first two publications contain a generalized summary of the surficial sand and gravel deposits and the aquifer data, in short, easy-to-read pamphlets. The latter are more technical and exhaustive evaluations of the geology and water resources of Minnehaha County. All basic data used to compile these publications are available at the offices of the South Dakota Geological Survey in Vermillion, South Dakota, and the U.S. Geological Survey in Huron, South Dakota.

Location and Physiography

Minnehaha County (fig. 2) is located in southeastern South Dakota on the southern flank of the Coteau des Prairies division of the Central Lowland Physiographic Province (Fenneman, 1931). A small portion of the southeastern corner of the county is part of the James Basin physiographic province. The county covers an area of about 816 square miles.

The Coteau des Prairies is an impressive topographic feature, a highland that extends some 200 miles in length and up to 75 miles in width across eastern South Dakota.

The topography of Minnehaha County is characterized by well-dissected loess covered uplands to the east of Skunk Creek and poorly drained uplands to the west of Skunk Creek. The Big Sioux River and Skunk Creek cross the county in broad flat valleys. The Precambrian-aged Sioux Quartzite, which crops out in many places across the county, has been eroded to form some very striking topographic features. The maximum relief of the county is about 550 feet, ranging from an elevation of greater than 1,820 feet in the northwest to an elevation of less than 1,270 feet where the Big Sioux River exits the southeastern part of the county.

Previous Investigations

The diversity in geologic settings has made Minnehaha County the site for many previous investigations. Native American tribes undoubtedly were the first to show interest in the area for its geologic resources, such as pipestone. In the 1830's, George Catlin, an American artist who painted Indian life, was the first to bring the area to general attention (Bretz, 1981). The Nicollet-Fremont expeditions of 1838 and 1839, led by Joseph LaFramboise, were the first truly scientific expeditions to the area (Bretz, 1981). The earliest accounts of the landforms and geology of the area are found in the writings of Hall and Meek (1856) and Meek and Hayden (1862) while making a survey of the Nebraska Territory. Later, Minnehaha County was included in many reconnaissance studies dealing primarily with the bedrock geology of South Dakota (Todd, 1894; Darton, 1909; and Rothrock, 1943, 1944). Meanwhile, other studies dealt with more detailed aspects of the area's geology.

The Precambrian-aged Sioux Quartzite was mentioned in many of the early reconnaissance studies. White (1870) formally named the Sioux Quartzite from exposures near the Big Sioux River in northwest Iowa. It was first studied in detail by Beyer (1895, 1896) and later by Baldwin (1949,

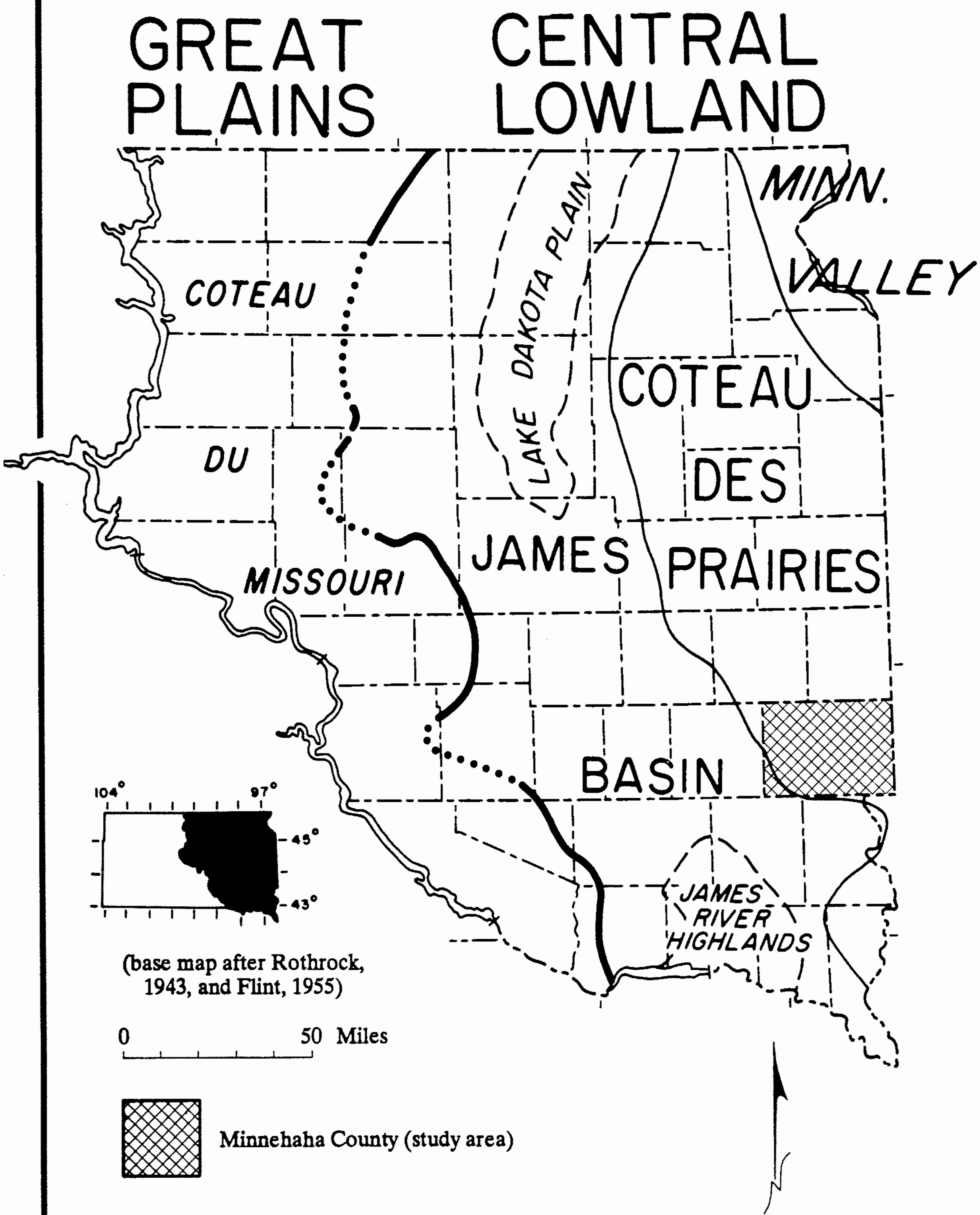


Figure 2. Map of eastern South Dakota showing physiographic divisions and location of the study area

1950). More recent studies by Ojakangas and Weber (1984) and Southwick and others (1986) describe the Sioux Quartzite and discuss its probable origins.

The presence of intrusive rocks, now known as the Corson Diabase, was first noted by Culver and Hobbs (1892). Beyer (1895, 1896) and Todd (1904) presented more detailed studies of these rocks. Keyes (1914) named the Corson Diabase from outcrops found along Split Rock Creek. Bendrat and Spencer (1904) were the first to make mention of "slate," a contact metamorphic product of the mudstone beds of the Sioux Quartzite, now locally known as the "Corson Slate." Recent studies of the Corson Diabase include: Stach (1970), Stach and others (1981), Bretz (1981, 1984), and Sklar (1982).

Rocks now considered to be part of the Cretaceous-aged Split Rock Creek Formation were first mentioned by Upham (1885). The "chalk rock" was also noted by Bain (1895), Beyer (1896), Todd (1899), Darton (1909), and Rothrock and Newcomb (1926). These rocks were first given the name Pathfinder Formation from test-hole data obtained during studies for the Pathfinder Nuclear Power Plant, sec. 31, T. 102 N., R. 48 W. (Dienhart, 1958 and Rothrock, 1958). Ludvigson and others (1981) formally named the Split Rock Creek Formation from exposures along Split Rock Creek in Minnehaha County. Other investigations include: Stach (1970), Brenner and others (1981), McKay and Ludvigson (1981), Merewether and Cobban (1981), Shurr (1981), Cobban and Merewether (1983), Witzke and others (1983), Hammond and Ludvigson (1985), Hammond (1987), Holtzheimer (1987), Setterholm and Morey (1987), and Kairo (1987).

Early studies of the glacial geology of the Minnehaha County area include: Chamberlin (1883), Upham (1885), Todd (1899), Shimek (1912), Carman (1913), Leverett (1932), and Flint (1955). More detailed work was completed during the South Dakota Geological Survey's 15-minute geologic mapping program. Geologic quadrangles, which are found entirely or in part within Minnehaha County, include: Dell Rapids Quadrangle (Tipton, 1959a), Chester Quadrangle (Tipton, 1959b), Sioux Falls Quadrangle (Steece, 1959a), and Hartford Quadrangle (Steece, 1959b). Several papers, including Steece (1960), Tipton (1960), and Steece (1965), discuss in more detail the findings of the quadrangle mapping. The first detailed study of the sand and gravel resources of the county was made by Rothrock and Newcomb (1926).

Numerous investigations dealing with the water resources of the area have been conducted by Rothrock and Otton (1947), Barkley (1952), Adolphson and Ellis (1964), Ellis and others (1968), Ellis and Adolphson (1964, 1969), Jorgensen and Ackroyd (1973), Hedges and others (1981), Koch (1982), and Iles and Frykman (1991). Ground water supply studies have also been conducted for Sioux Falls (Ranney Water Systems Inc., 1956), Dell Rapids (Barari, 1967), Baltic (Barari, 1972), Brandon (Barari, 1979), Wall Lake (Carter and Barari, 1981), Garretson (Barari and Hilton, in preparation), and the Sioux Falls-Brandon area (Iles, in preparation).

Other relevant studies conducted in the area include the Minnehaha County Soil Survey (Nestrud and others, 1964), a study on environmental geology around Sioux Falls (Buehrer, 1971), and a ground-water contamination study (Iles and others, 1987).

With the exception of McCook County, all of the surrounding South Dakota counties have been the subject of investigations similar to those which resulted in this report. Reports from the surrounding counties include: Lake and Moody Counties (Hammond, 1991), Lincoln and Union Counties (Hammond, in preparation), and Hutchinson and Turner Counties (Jarrett and Duchossois, in preparation) .

Acknowledgements

The investigation and preparation of this publication were performed under the supervision of Merlin J. Tipton, former State Geologist, and C.M. Christensen, present State Geologist. The writer wishes to thank the entire staff of the South Dakota Geological Survey for their advice and assistance throughout the project.

A special thanks to Derric Iles, Martin Jarrett, Richard Hammond, Assad Barari, Robert Schoon, Louis Frykman, Joanne Holtzheimer, and Suzanne Kairo, whose recent studies within the area added much to the understanding of the geology and water resources of Minnehaha County.

Also appreciated are the efforts of the drillers: Millard Thompson, Jr., E. Thomas McCue, Lloyd Helseth, Gary Jensen, Carol Schmig, Duane Jacobson, Dennis Iverson, Stewart Mitchell, Robert Gravholt, and Larry Merriman.

The cooperative efforts of Neil Koch, Rick Lindgren, Wendell Bradford, and other staff members of the U.S. Geological Survey; Jerry Siegel, staff and board members of the East Dakota Water Development District; and the Minnehaha County commissioners are gratefully acknowledged.

Much thanks also goes to the residents of Minnehaha County and the private well drillers of the area who contributed useful information.

Financial assistance for the Minnehaha County Study was provided by the South Dakota Geological Survey, U.S. Geological Survey, East Dakota Water Development District, and Minnehaha County.

Methods of Investigation

Extensive test drilling throughout Minnehaha County actually began as part of a ground-water study for the Sioux Falls-Brandon area (Iles, in preparation), which was conducted from July 1978 through August 1980. The study area chosen had a radius of approximately 20 miles from the center of Sioux Falls and was limited by the South Dakota border. Test holes were drilled on a 3-mile grid across this area, which included a large portion of Minnehaha County. Grid-test holes generally penetrated through Pleistocene- and Cretaceous-aged sediments and were completed to the Precambrian surface. In all, 188 test holes were drilled and 45 observation wells installed in Minnehaha County for the Sioux Falls-Brandon Study.

Data collection for the Minnehaha County Study portion of the Big Sioux Hydrologic Study was obtained during the 1984, 1985, 1986, and 1987 field seasons. Initially, test holes were drilled to the Precambrian surface to complete the 3-mile grid across the county. Additional test holes were drilled and observation wells installed to define the extent and thickness of the various aquifers and geologic formations. In all, 481 test holes were drilled and 152 observation wells installed for the Minnehaha County Study.

Other preexisting data were also compiled and entered into the computer database. To date, approximately 1,500 test-hole logs comprise the database for Minnehaha County and are available at the office of the South Dakota Geological Survey in Vermillion, South Dakota.

Subsurface geologic data were obtained from the examination of the test-hole logs, well cuttings, and geophysical logs. There are 160 test-hole sites in Minnehaha County that have an available geophysical log (electric resistivity, natural gamma, and/or specific potential). Photocopies of the geophysical logs are available from the office of the South Dakota Geological Survey in Vermillion, South Dakota.

Surface geologic data were collected from test holes, natural and man-made exposures, interpretation of topographic maps and aerial photographs, soil survey information (Nestrud and others, 1964), and previous investigations.

The geology was mapped on 7½-minute topographic maps and then transferred to a base map with a scale of 1:100,000 (approximately 1 inch equaling 1½ miles).

STRATIGRAPHY

Stratigraphic nomenclature used in this report 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, 1983).

Table 1 lists the pre-Pleistocene stratigraphy identified in Minnehaha County in comparison with the pre-Pleistocene stratigraphy that has been identified over much of eastern South Dakota. The youngest rocks appear at the top of the list.

Only those pre-Pleistocene rocks that are exposed at the surface or found directly beneath the Pleistocene deposits in Minnehaha County will be discussed in this section. From oldest to youngest, these are the Sioux Quartzite, Corson Diabase, Split Rock Creek Formation, and undifferentiated silts. For information regarding other stratigraphic units in eastern South Dakota, the reader is referred to Agnew and Tychsen (1965).

Precambrian Lithologies

Sioux Quartzite

The Precambrian-aged Sioux Quartzite underlies all of Minnehaha County and is exposed at the surface in many areas (pl. 1). Exceptional exposures can be found at the Dells of the Sioux River near Dell Rapids, at Palisades State Park near Garretson, and at Falls Park in Sioux Falls.

TABLE 1. Pre-Pleistocene stratigraphy of the study area

SYSTEMS	ROCK UNITS	
	Eastern South Dakota (Schoon, 1974)	Minnehaha County
		??Undifferentiated silts??
Cretaceous Systems		
Late Cretaceous Series	Montana Group	
	Pierre Shale	Split Rock Creek Formation
	Colorado Group	↓
	Niobrara Formation	↓
	Carlile Shale	↓
	Codell Sandstone	↓
	Greenhorn Limestone	↓
	Graneros Shale	↓
		↓
Early Cretaceous Series	Dakota Sandstone	Split Rock Creek Formation
Precambrian		Corson Diabase
	Sioux Quartzite	Sioux Quartzite
	Igneous and Metamorphic rocks	

The Sioux Quartzite consists of predominantly orthoquartzite with minor conglomerate and mudstone layers. The orthoquartzite portion of the formation, typically pale red to moderate red in color, consists predominantly of pink-colored, fine grains of quartz sand cemented to a nonporous quartzite by silica (Baldwin, 1949). Since both the grains and the cement are silica, the rock is homogeneous, tough, hard, and pure.

Scattered layers of claystone to silty mudstone are found within the Sioux Quartzite. These mudstone beds, commonly called pipestone or catlinite, are usually less than 30 feet thick. The mudstone ranges in color from a red to a dark purple and is composed predominantly of sericite, quartz, and hematite (Berg, 1938). Several different horizons are exposed along Split Rock Creek. Mudstone beds also crop out in other parts of Minnehaha County including: along Skunk Creek in sec. 11, T. 102 N., R. 51 W.; on Cliff Avenue, near Rice Street in Sioux Falls, sec. 16, T. 101 N., R. 49 W.; and in a gully a mile south of East Sioux Falls in secs. 28 and 29, T. 101 N., R. 48 W. Mudstone beds were also encountered in several of the test holes drilled.

The Sioux Quartzite is thought to be of an inferred Early Proterozoic age, 1,760 to 1,630 million years old (Bergstrom and Morey, 1985). Most of the Sioux Quartzite is interpreted to have been of fluvial origin, deposited in a distal braided river-alluvial plain environment to a shallow, tidally influenced environment (Ojakangas and Weber, 1984). Sedimentary structures that are common within the Sioux Quartzite include: trough, planar, and herringbone cross bedding; parallel bedding; asymmetrical and symmetrical ripple marks; and mud cracks (Ojakangas and Weber, 1984). The Sioux Quartzite is broken into blocks by well-developed jointing, both vertical and horizontal. Spacing of the joints varies greatly in exposures from a few inches to several feet apart.

The Sioux Quartzite is found in a east-west trending belt or ridge extending from southwestern Minnesota and northwestern Iowa to central South Dakota. In Minnehaha County, however, test drilling has shown that the Sioux Quartzite ridge is actually made up of a series of northwest-southeast trending ridges (pl. 1). This same pattern of northwest-trending blocks is also found to the east in Minnesota where they have been named from west to east: the Pipestone basin, Fulda basin, Cottonwood County basin, and New Ulm basin (Southwick and others, 1986). Southwick and others (1986) state that these "basins" are depositional and probably fault bounded, because they are aligned parallel to the fault trends of the Central Plains orogen. Erosional remnants of similar depositional basins make up the ridges present in the subsurface across Minnehaha County.

Over the years there has been much speculation about the thickness of the Sioux Quartzite. Estimates have ranged anywhere from about 1,000 feet to almost 15,000 feet. Baldwin (1950) calculated a thickness of over 5,000 feet, assuming an average constant dip of the beds. Gries (1983) approximated the thickness at about 1,000 feet. He argued that Baldwin's approach was not very precise due to the difficulty correlating beds over sparse exposures and the possibility that they were deposited on a sloping surface. Test drilling in Minnehaha County encountered the Sioux Quartzite at a maximum elevation of 1,545 feet above mean sea level (SE SE SE SE sec. 16, T. 103 N., R. 47 W.) and at a minimum elevation of about 660 feet above mean sea level (SE SE SE SE sec. 34, T. 102 N., R. 47 W.).

Corson Diabase

The Corson Diabase is a black to greenish-black rock containing plagioclase feldspar, pyroxenes, and olivine, with minor amounts of biotite, amphiboles, apatite, chlorite, and zircon (Sklar, 1982).

The Corson Diabase is believed to be a sill-like intrusion of late Precambrian age, 1470±50 million years old or younger (Sklar, 1982). It is found as erosional remnants along the walls of valleys found between the northwest-southeast trending ridges in the Sioux Quartzite. The Corson Diabase is exposed in two localities in Minnehaha County: along Split Rock Creek in secs. 10, 15, and 22, T. 102 N., R. 48 W., and at an old quarry site northeast of Sioux Falls in sec. 11, T. 101 N., R. 49 W. (pl. 1). The Corson Diabase was also encountered in several test holes drilled in the county.

Intrusion of the Corson Diabase has created some contact metamorphism of the Sioux Quartzite. In the outcrop area in secs. 15 and 22, T. 102 N., R. 48 W., a dark-gray to purple, spotted, slatey argillite is found and has been informally referred to as the "Corson Slate" (Stach, 1970). The "Corson Slate" in this area is interpreted to be altered mudstone beds of the Sioux Quartzite. Test-hole data in other areas have revealed other altered rocks near known Corson Diabase intrusions.

Cretaceous Lithologies

Split Rock Creek Formation

Rocks now considered part of the Split Rock Creek Formation have been noted during many of the early studies of the area. Upham (1885), Bain (1895), Beyer (1896), Todd (1899), Darton (1909), Rothrock and Newcomb (1926), Baldwin (1949, 1950), Flint (1955), and Steece (1959b) all refer to outcrops of a "chalk rock" of Cretaceous(?), or Tertiary(?) age. Rothrock (1958), in a study of the geology and water supplies in the vicinity of the Pathfinder steam plant, informally called these rocks the Pathfinder Formation. Rothrock subdivided the Pathfinder Formation into an Upper Clay Member, a Black Rock Member, and a Lower Clay Member, all of probable Cretaceous age. Ludvigson and others (1981) proposed the name Split Rock Creek Formation for outcrops located along Split Rock Creek in Minnehaha County.

The Split Rock Creek Formation is a suite of embayment fill and other nearshore facies deposited along the irregular paleoshore of the Sioux Ridge (Ludvigson and others, 1981). The formation is possibly the lateral equivalent to all of the marine Cretaceous formations of eastern South Dakota, listed in table 1.

Three major embayments were encountered in Minnehaha County and informally given the names the Herman Embayment, Trent Embayment and Brandon Embayment (pls. 1 and 2). The Herman Embayment and the Trent Embayment are located in the northwestern and northeastern corners of the county respectively (Holtzheimer, 1987). The Brandon Embayment (Kairo, 1987) is located in the southeastern corner of the county.

The lower portion of the Split Rock Creek Formation consists of up to 240 feet of Sioux Quartzite wash. Sioux Quartzite wash is a term locally used to describe the fine- to medium-grained pink sands derived from the Sioux Quartzite. The Sioux Quartzite wash is a time-transgressive deposit. In Minnehaha County, it is found lying stratigraphically above the Sioux Quartzite as nearshore facies of Cretaceous formations. These fine- to coarse-grained pink sands are separated by several beds of siltstones, laminated claystones, and lignite, which are up to 20 feet thick. The lower portions of these sands may correlate in age to the Dakota Sandstone (table 1).

A distinct lithology of opaline spiculites, carbonaceous claystones, bedded cherts, calcium bentonites, pink quartz sandstones, and sandy siltstones make up the next portion of the formation. Abundant, well preserved, terrestrial plant and animal fossils suggest that certain parts of the Sioux Ridge were above sea level during the deposition of these sediments. In the area of the type section, along Split Rock Creek, the upper portion of these sediments has been age correlated to the Niobrara Formation (Ludvigson and others, 1981) (table 1). It is these sediments that make up the "Lower Clay Member" and the "Black Rock Member" of Rothrock (1958).

In the Brandon Embayment, overlying the previous described sediments, are up to 90 feet of gray silty clays and gray shales, which Rothrock (1958) referred to as the "Upper Clay Member." In the Trent Embayment the uppermost Split Rock Creek sediments consist of alternating beds of white to tan carbonaceous claystones and pink quartz sands. This part of the Split Rock Creek Formation may, in part, correlate in age to the Pierre Shale (table 1).

Laterally, from the quiet-water embayments, the Split Rock Creek Formation shows a range of depositional environments, from wave battered shoreline to shallow marine shelves. The contact between the Split Rock Creek Formation and its equivalents away from the Sioux Ridge (table 1) is typically picked where the normal marine sequence can first be recognized in hand samples or electric logs (Hammond, 1991).

In the southwestern corner of Minnehaha County, the Split Rock Creek Formation was deposited in a shallow marine shelf environment. Overlying the Sioux Quartzite, in ascending order, is up to 100 feet of Sioux Quartzite wash, gray calcareous, silty claystone, and oxidized white to yellow, calcareous, silty claystone, with interbedded pink quartz sands. The oxidized claystone crops out to the west along the East Fork Vermillion River in McCook County and has been age correlated to the Pierre Formation (Iles, in preparation). The lower sediments may, however, be correlated in age to the Niobrara Formation or even older.

Undifferentiated Silts

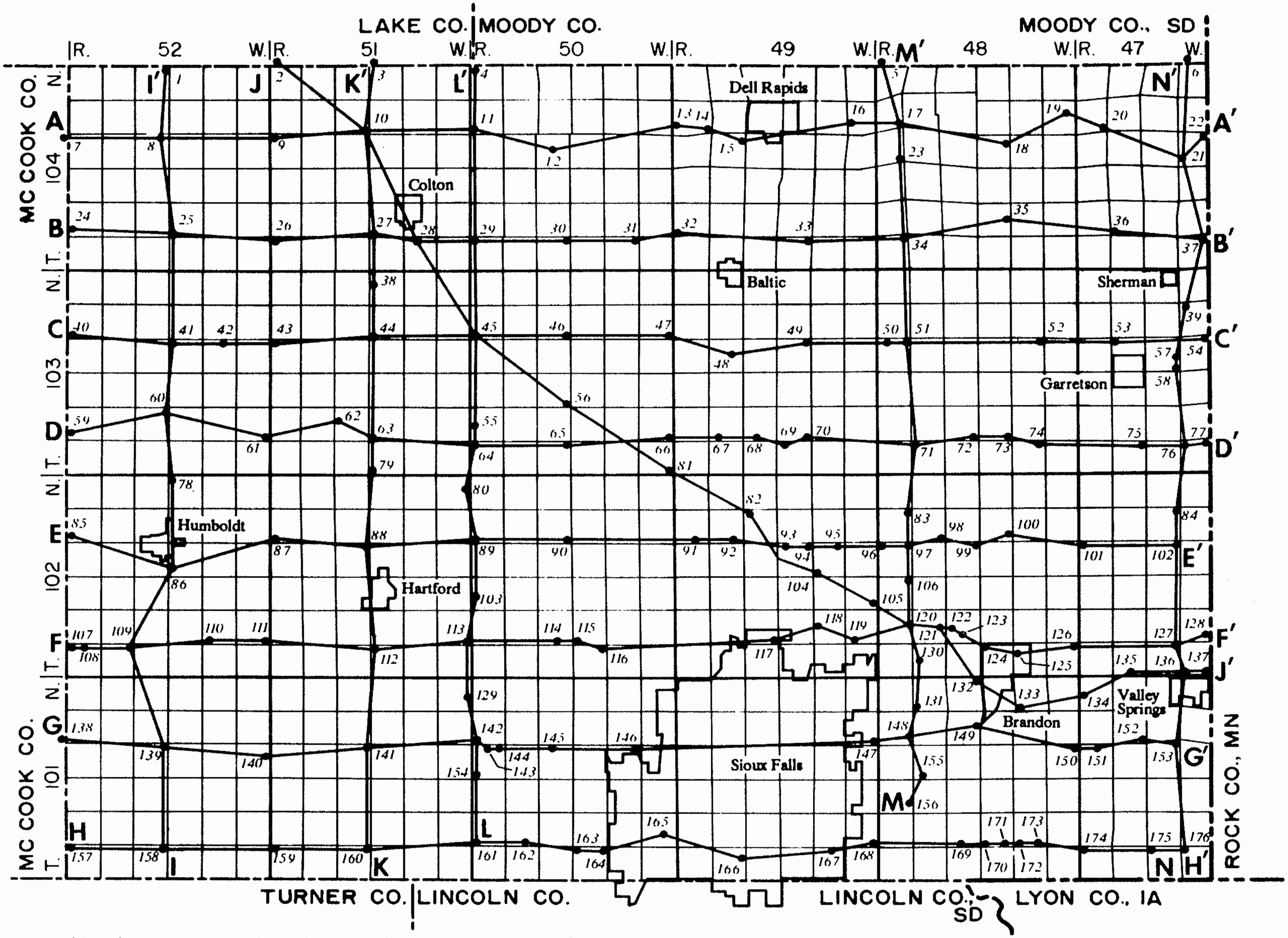
An unnamed deposit of pale-green, pale-gray, pale-pink, and white silts, silty clays, and fine sand mantles the surface of the Split Rock Creek Formation in northeastern Minnehaha County. These sediments lie between Late Cretaceous-aged deposits and deposits of Pleistocene age and their age is only poorly constrained. These deposits may represent stream and lake deposition during the early Pleistocene but may indeed be much older (Hammond, 1991). For this report, this deposit was mapped as part of the bedrock topography and designated Q-Kus (pl. 2).

Bedrock Surface Topography

The Sioux Quartzite highland has greatly influenced deposition of sediment since Precambrian time. There is approximately 320 feet of relief on the bedrock surface in Minnehaha County, mostly due to the Sioux Quartzite's resistance to erosion. In many areas the Sioux Quartzite erodes to form near vertical cliffs, as seen along Split Rock Creek. Cliffs such as these also occur in subcrop below the glacial sediments. This fact must be taken into account when interpreting the contour maps of the Precambrian surface (pl. 1), and the bedrock surface (pl. 2), and the cross sections (figs. 3 through 18). Rocks of the Corson Diabase, Split Rock Creek Formation, and undifferentiated silts make up the remainder of the bedrock surface (pl. 2). With the exception of the undifferentiated silts, all are found to crop out within Minnehaha County. Much of the bedrock relief has resulted from the action of Cretaceous seas and from pre-Pleistocene drainage development. However, erosion by glacial ice and meltwater has also modified the bedrock surface.

Pleistocene Stratigraphy

Pleistocene-age sediments make up most of the surface deposits in Minnehaha County. The thickness of these sediments varies from a thin veneer covering the bedrock to more than 300 feet in the northwestern portion of the county. Plate 3 shows the thickness of Quaternary deposits, most of which are Pleistocene in age, but also includes Holocene alluvium and loess.



Numbers are map location numbers (MLN) and refer to locations of logs on the cross sections and in the appendix.

Figure 3. Location of the geologic cross sections (figs. 5 through 18) in Minnehaha County, South Dakota.

Figure 4. Legend for the geologic cross sections (figs. 5 through 18) in Minnehaha County, South Dakota.

QUATERNARY

- Ql .... Holocene through pre-Illinoian 3 loess, undifferentiated
- Qwll .... late Wisconsin lacustrine sediments
- Qwloa .... late Wisconsin outwash and/or Holocene alluvium, undifferentiated
- Qwlo .... late Wisconsin outwash
- Qwlt(ox) .... late Wisconsin till (oxidized)
- Qwlt(unox)..... late Wisconsin till (unoxidized)
- Qo .... late Wisconsin and/or pre-Illinoian outwash, undifferentiated
- Qit(ox) .... Illinoian(?) till (oxidized)
- Qit(unox) ...... Illinoian(?) till (unoxidized)
- Qio .... Illinoian(?) outwash
- Qpwo.......... pre-Wisconsin outwash, undifferentiated
- Qpitu .... pre-Illinoian till, undifferentiated
- Qpill .... pre-Illinoian lacustrine sediments, undifferentiated
- Qpio .... pre-Illinoian outwash, undifferentiated
- Qpi_3l .... pre-Illinoian 3 loess
- Qpi_3t(ox) ...... pre-Illinoian 3 till (oxidized)
- Qpi_3t(unox).... pre-Illinoian 3 till (unoxidized)
- Qpi_3o .... pre-Illinoian 3 outwash
- Qpi_2l .... pre-Illinoian 2 loess
- Qpi_2t(ox) ...... pre-Illinoian 2 till (oxidized)
- Qpi_2t(unox).... pre-Illinoian 2 till (unoxidized)
- Qpi_2o .... pre-Illinoian 2 outwash
- Qpi_1l .... pre-Illinoian 1 loess
- Qpi_1t .... pre-Illinoian 1 till
- Qpi_1o .... pre-Illinoian 1 outwash

?

- Q-Kus .... undifferentiated silts

CRETACEOUS ?

- Ksrcu .... Split Rock Creek Formation, undifferentiated
- Ksrcc .... Split Rock Creek Formation, clay and shale
- Ksrco .... Split Rock Creek Formation, opaline spiculite, etc.
- Ksrcs .... Split Rock Creek Formation, sand

PRECAMBRIAN

- p€c .... Corson Diabase
- p€s .... Sioux Quartzite

Test hole. Number is map location number (MLN). See appendix for explanation. See figure 3 for test-hole location.

Lithologic contact. Dashed where approximate.

Figure 5. Geologic cross section A-A'.

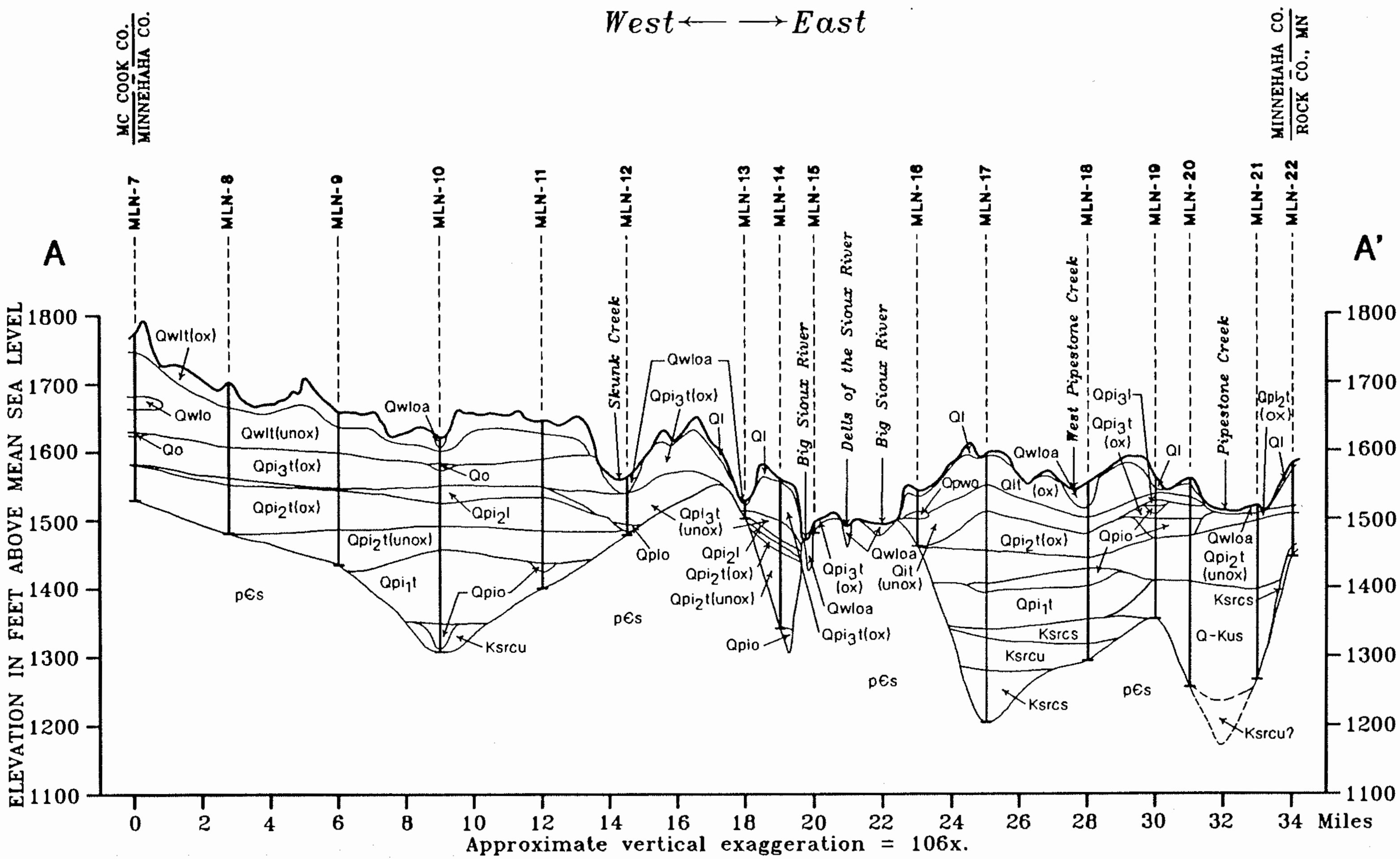


Figure 6. Geologic cross section B-B'.

West ⟵ ⟶ *East*

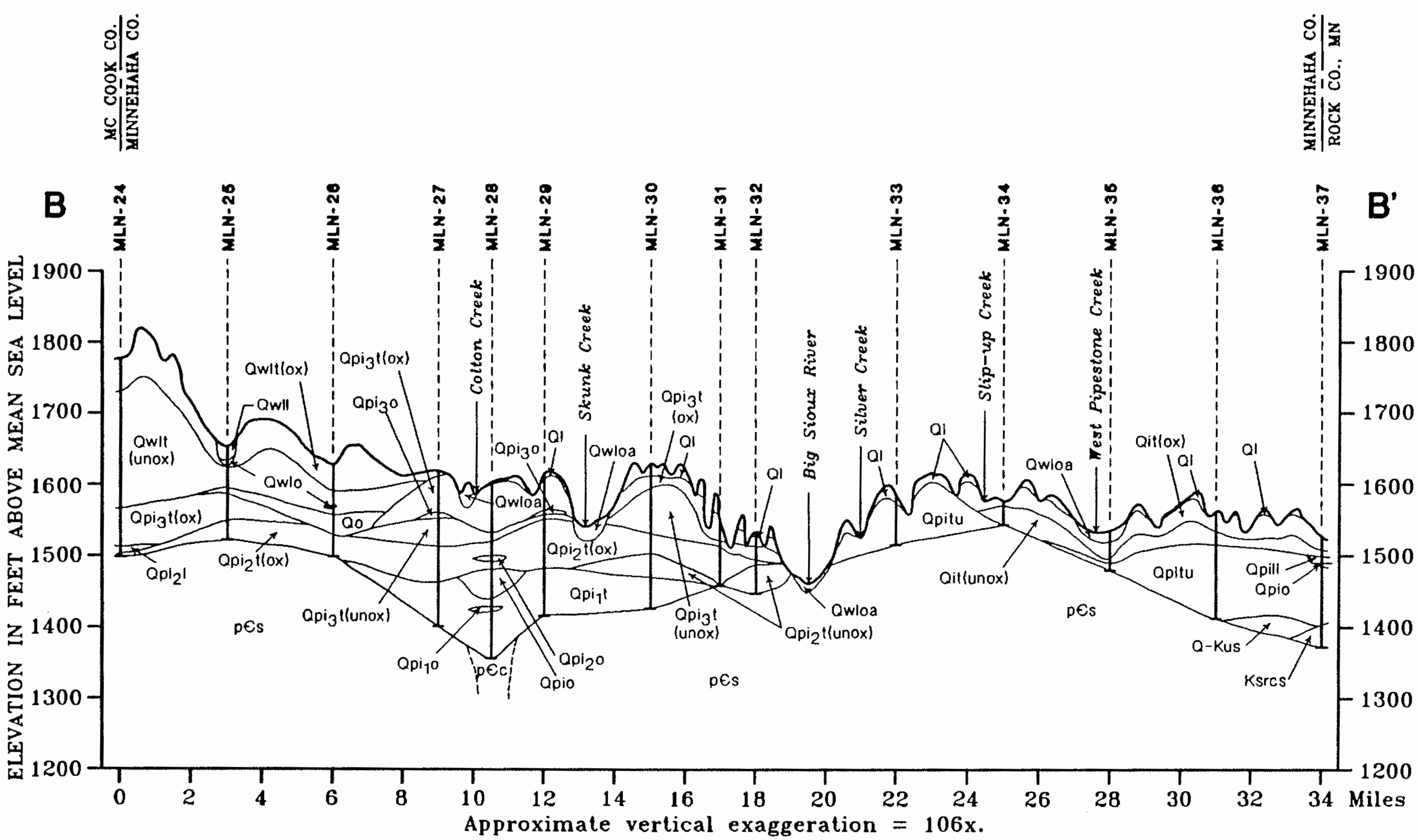
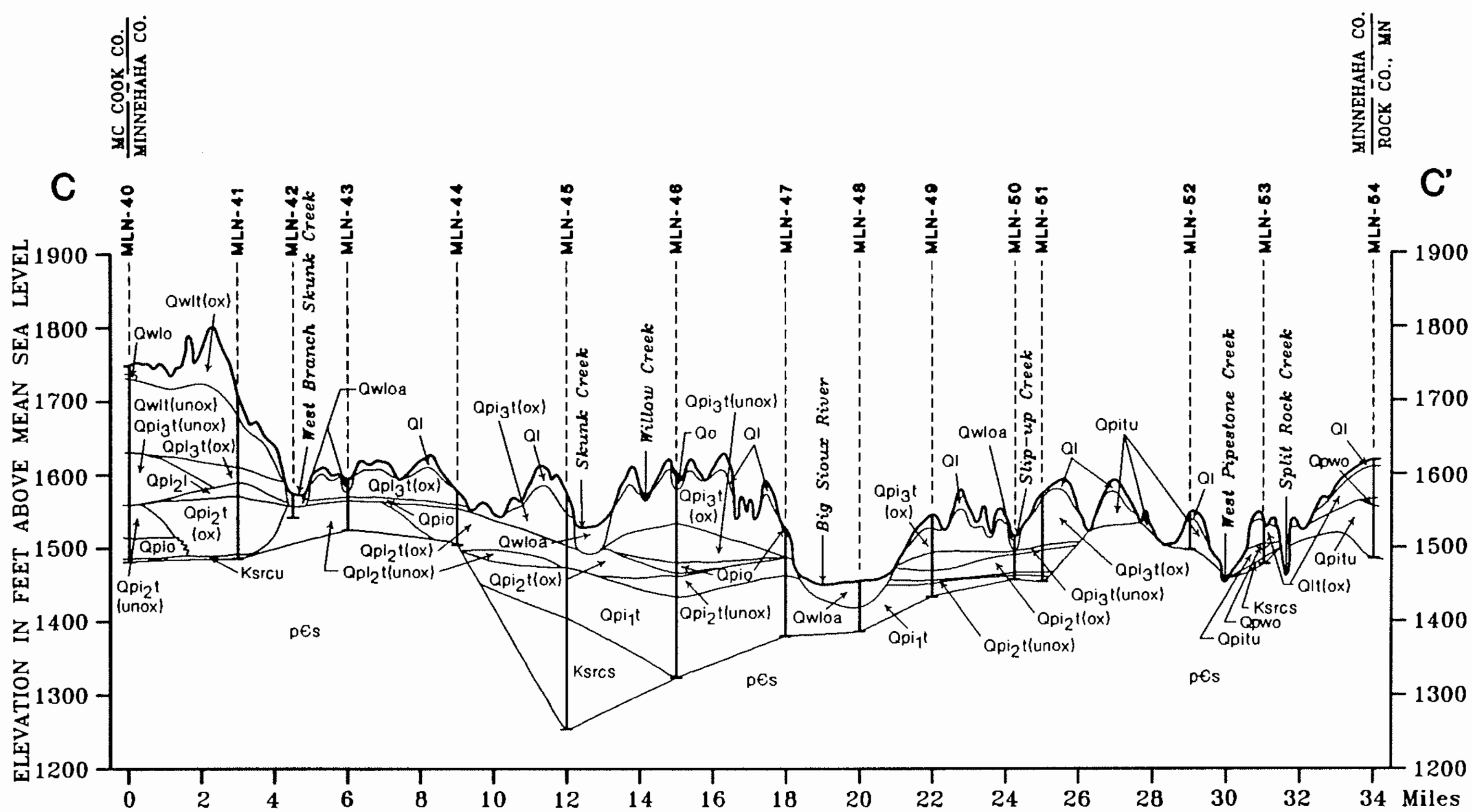


Figure 7. Geologic cross section C-C'.

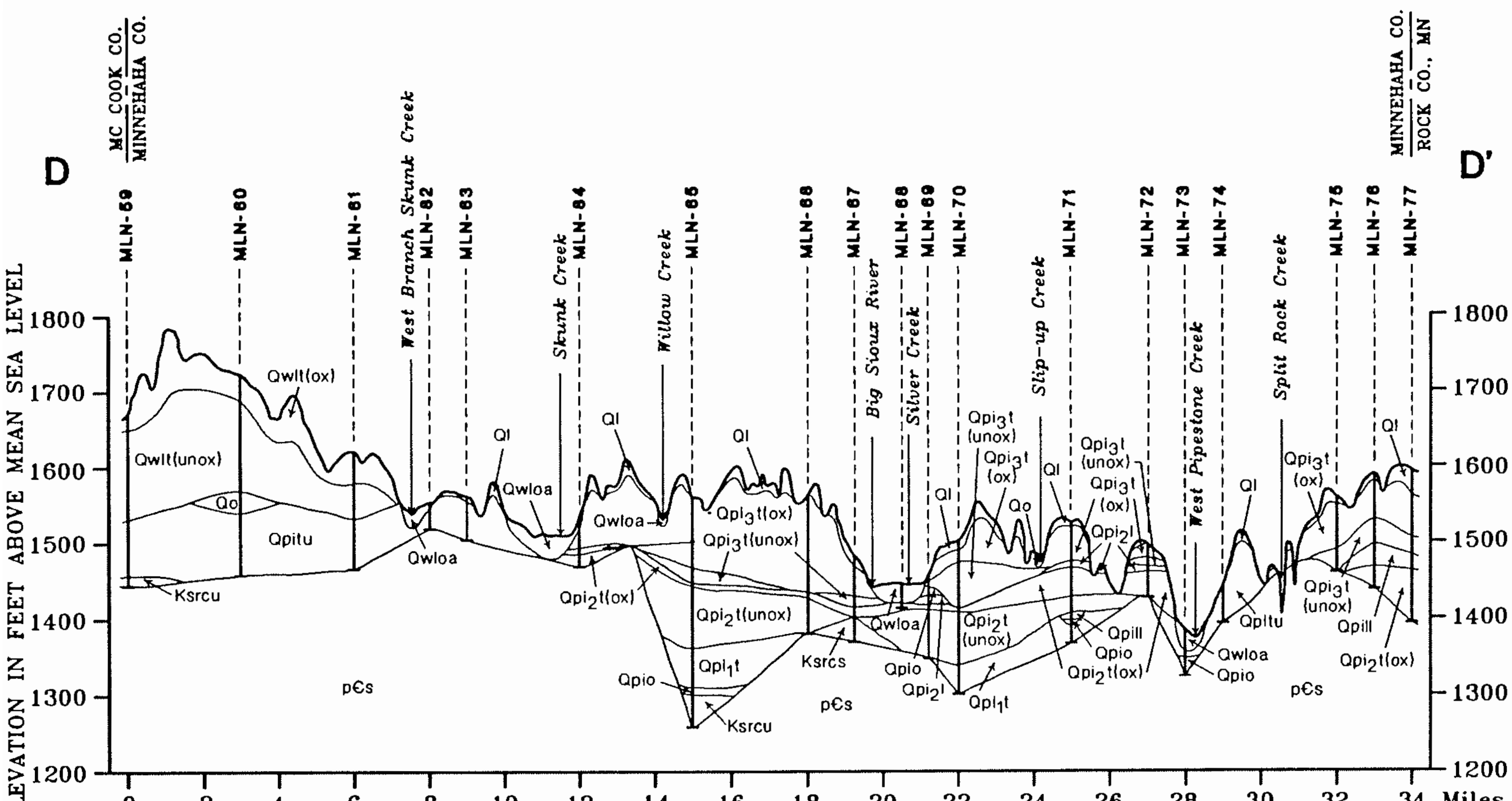
West ⟵ ⟶ *East*



Approximate vertical exaggeration = 106x.

Figure 8. Geologic cross section D-D'.

West ⟵ ⟶ East



Approximate vertical exaggeration = 106x.

Figure 9. Geologic cross section E-E'.

West ⟵ ⟶ *East*

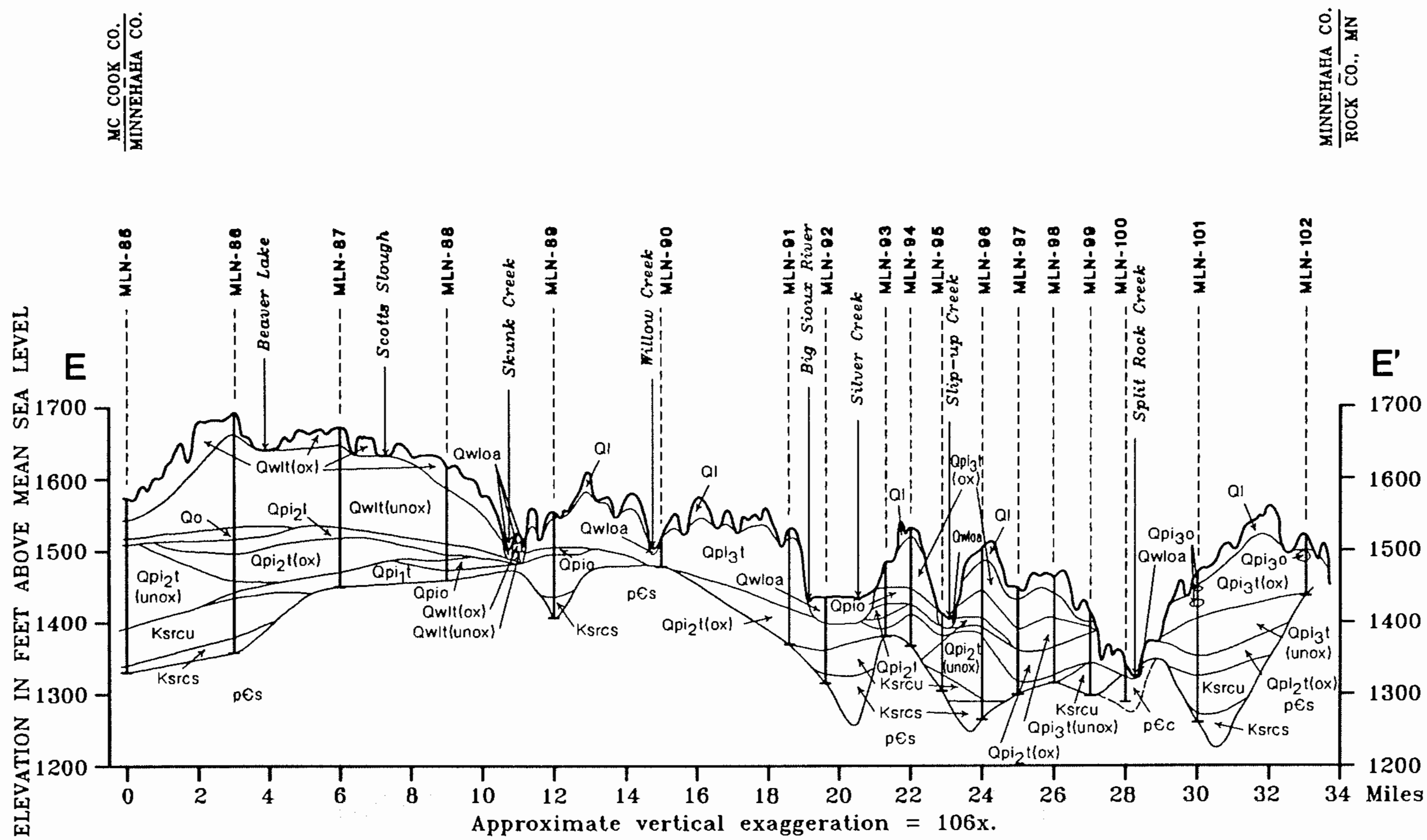


Figure 10. Geologic cross section F-F'.

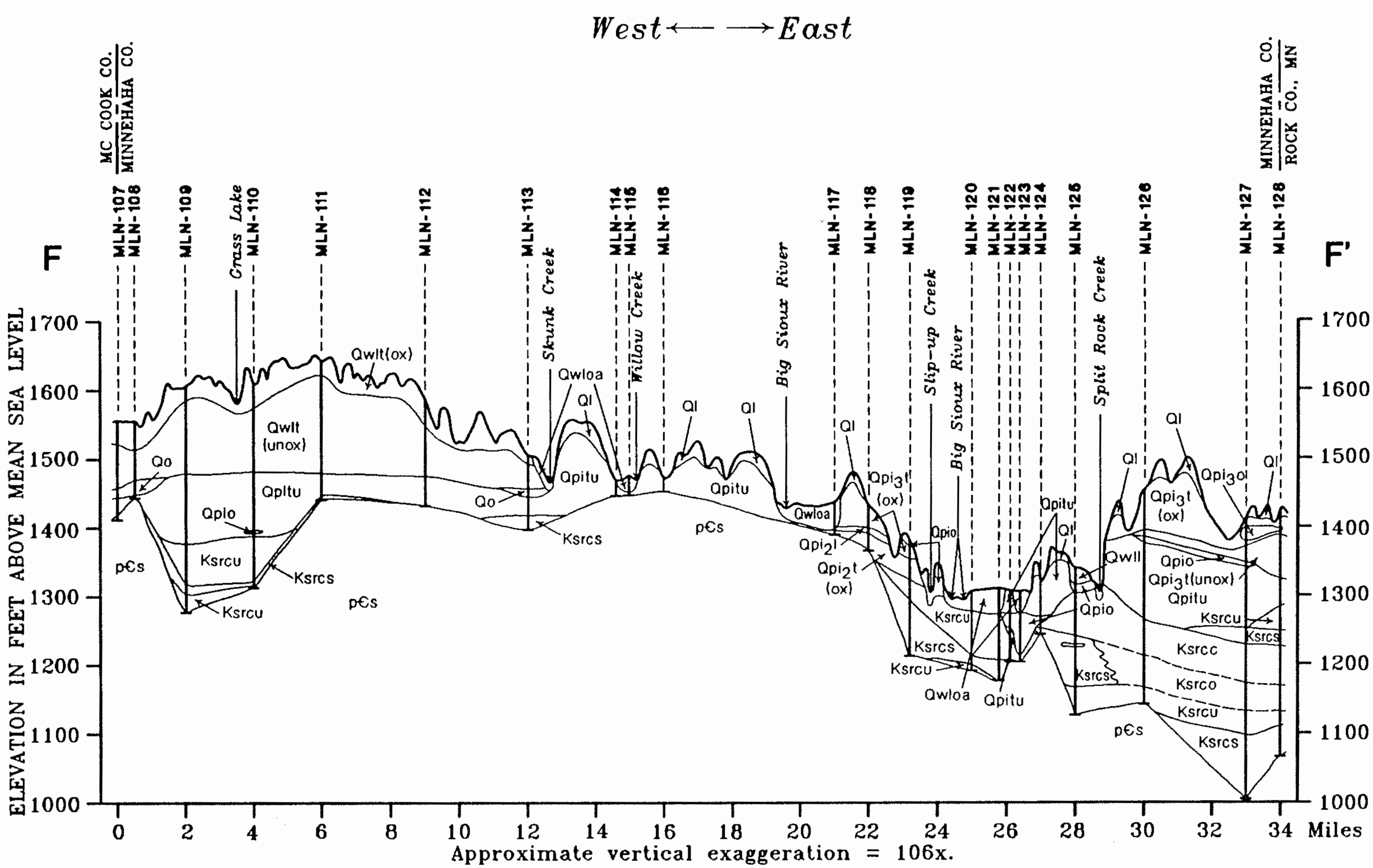
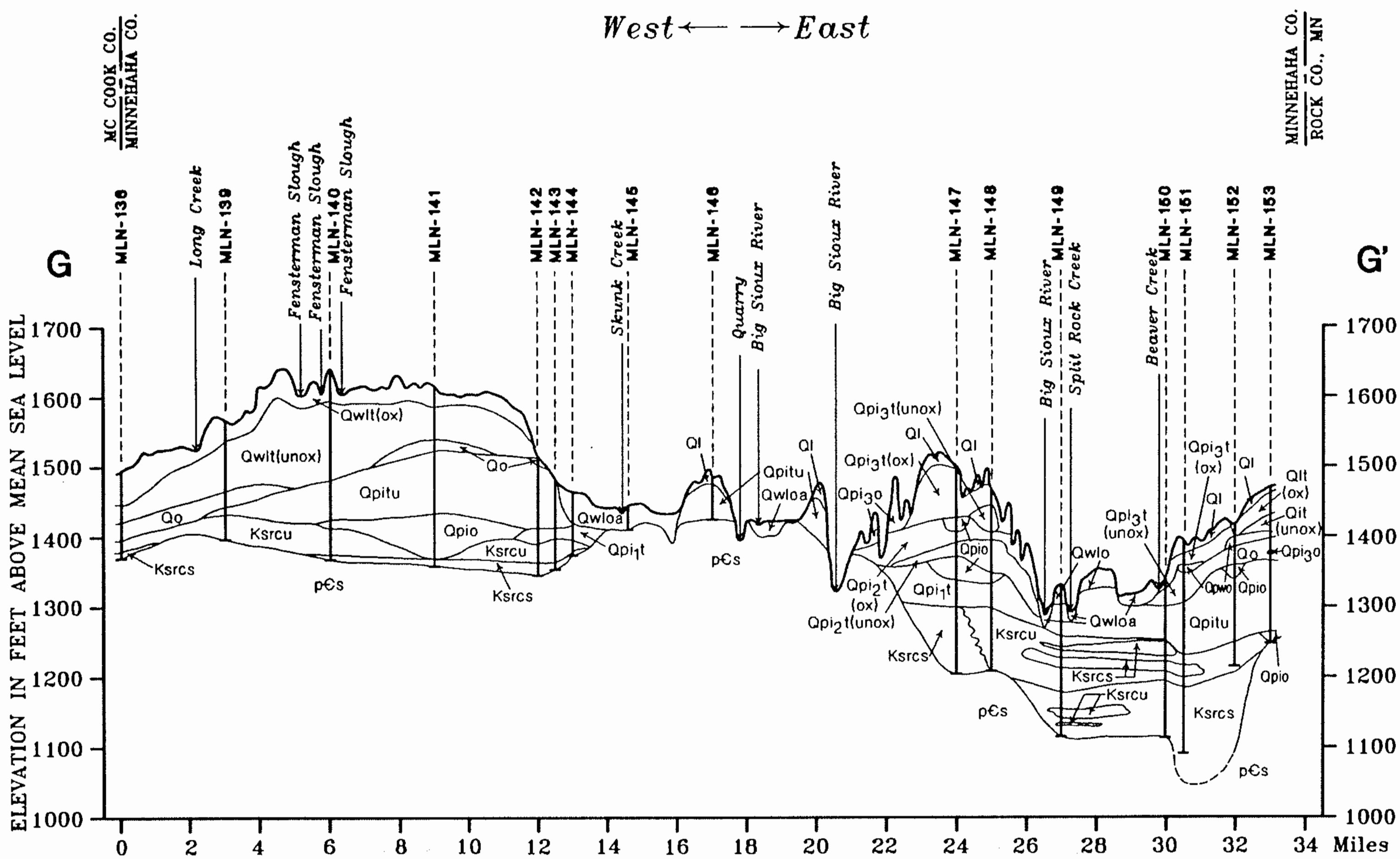


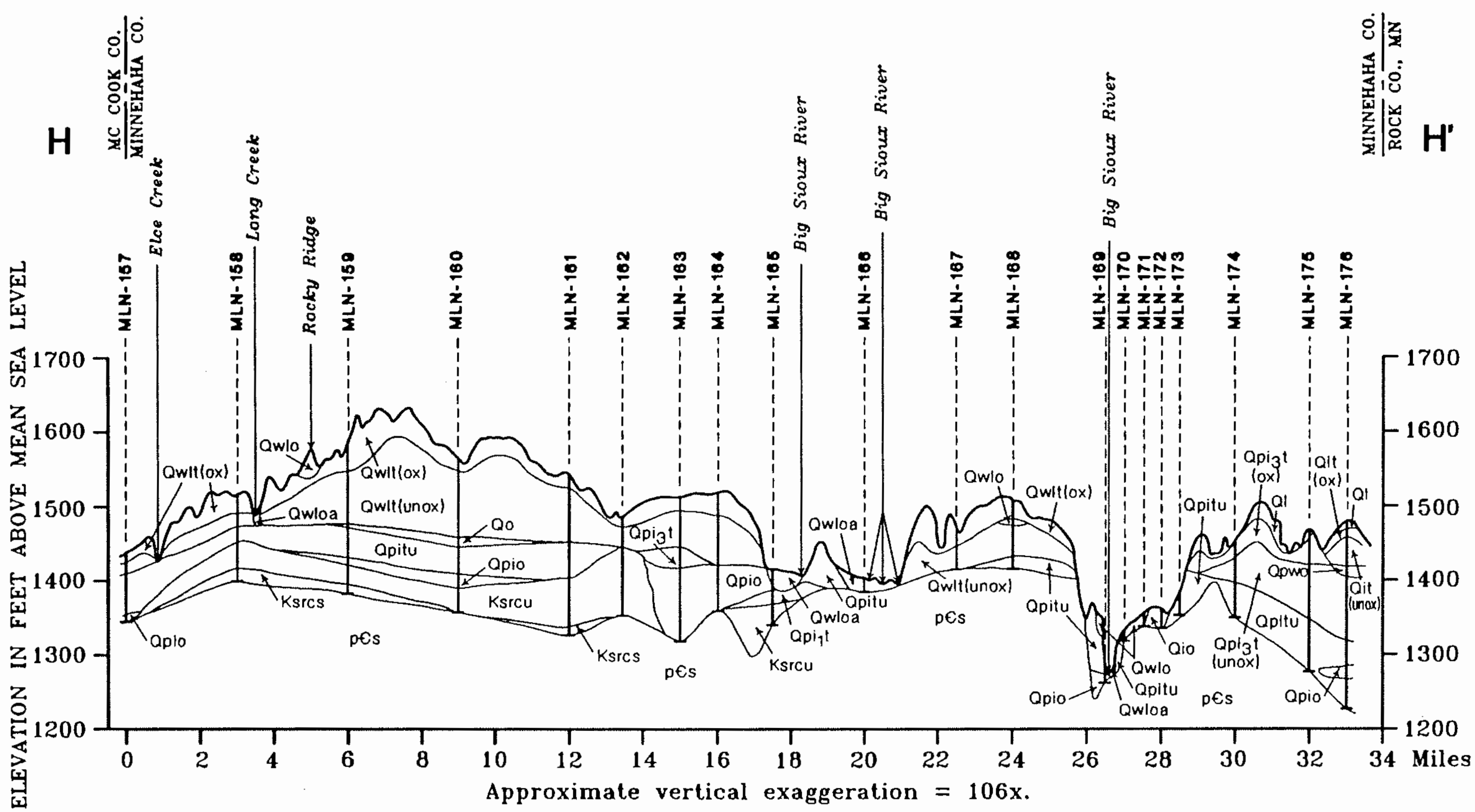
Figure 11. Geologic cross section G-G'.



Approximate vertical exaggeration = 106x.

Figure 12. Geologic cross section H-H'.

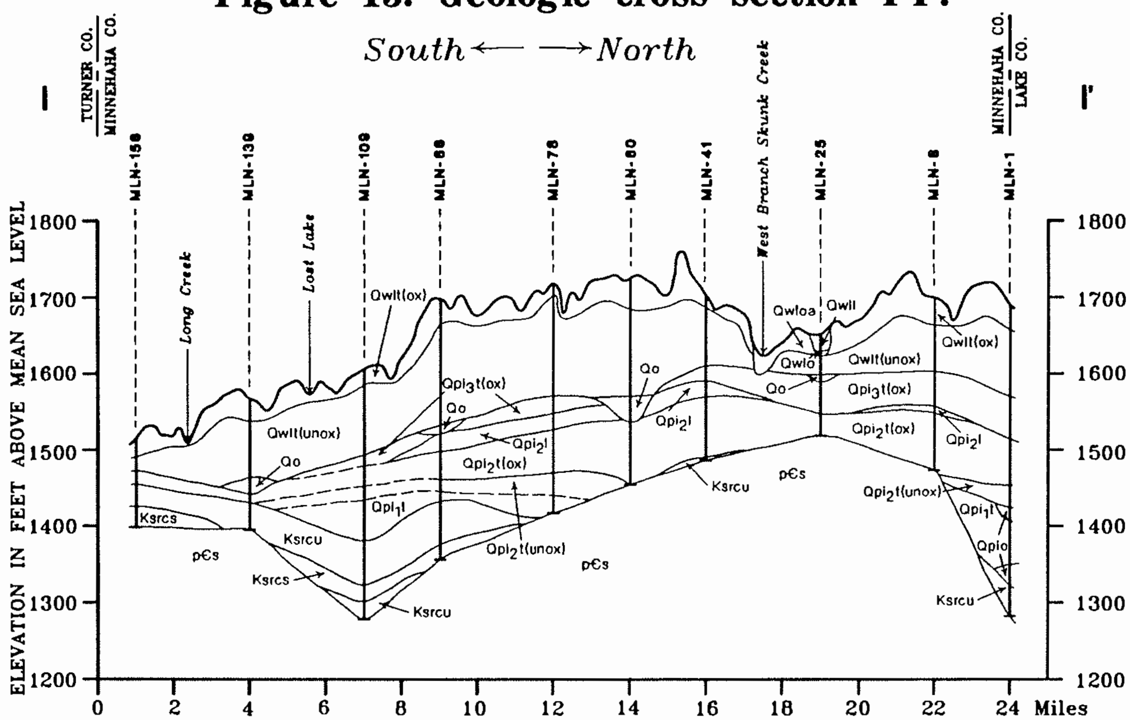
West ⟵ ⟶ East



Approximate vertical exaggeration = 106x.

Figure 13. Geologic cross section I-I'.

South ← → *North*



Approximate vertical exaggeration = 106x.

Figure 14. Geologic cross section J-J'.

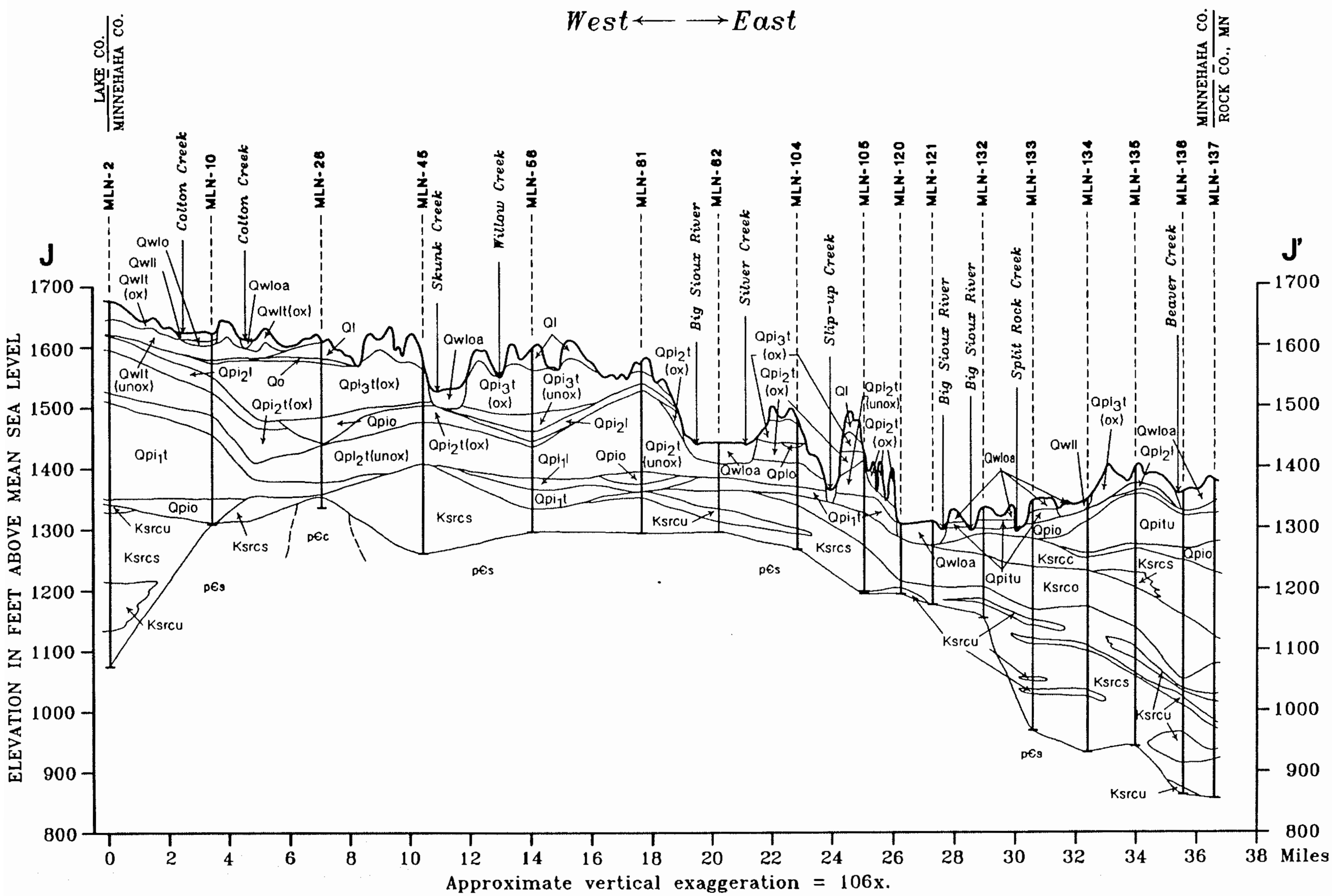


Figure 15. Geologic cross section K-K'.

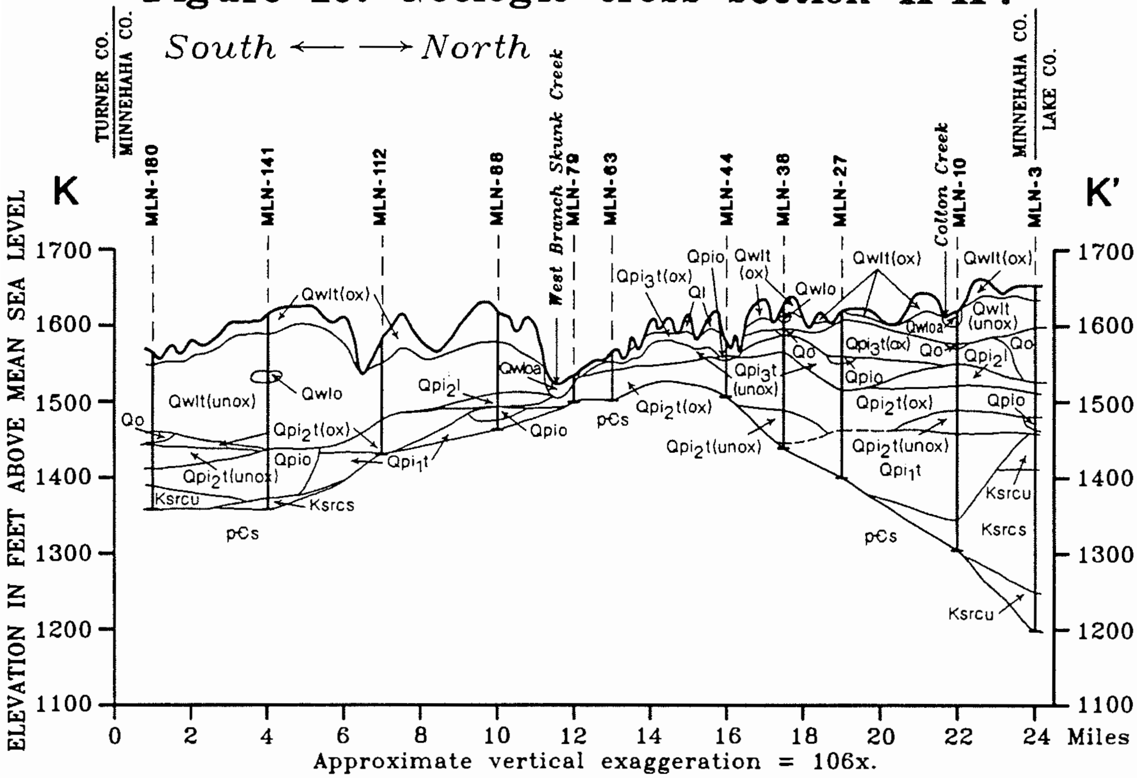


Figure 16. Geologic cross section L-L'.

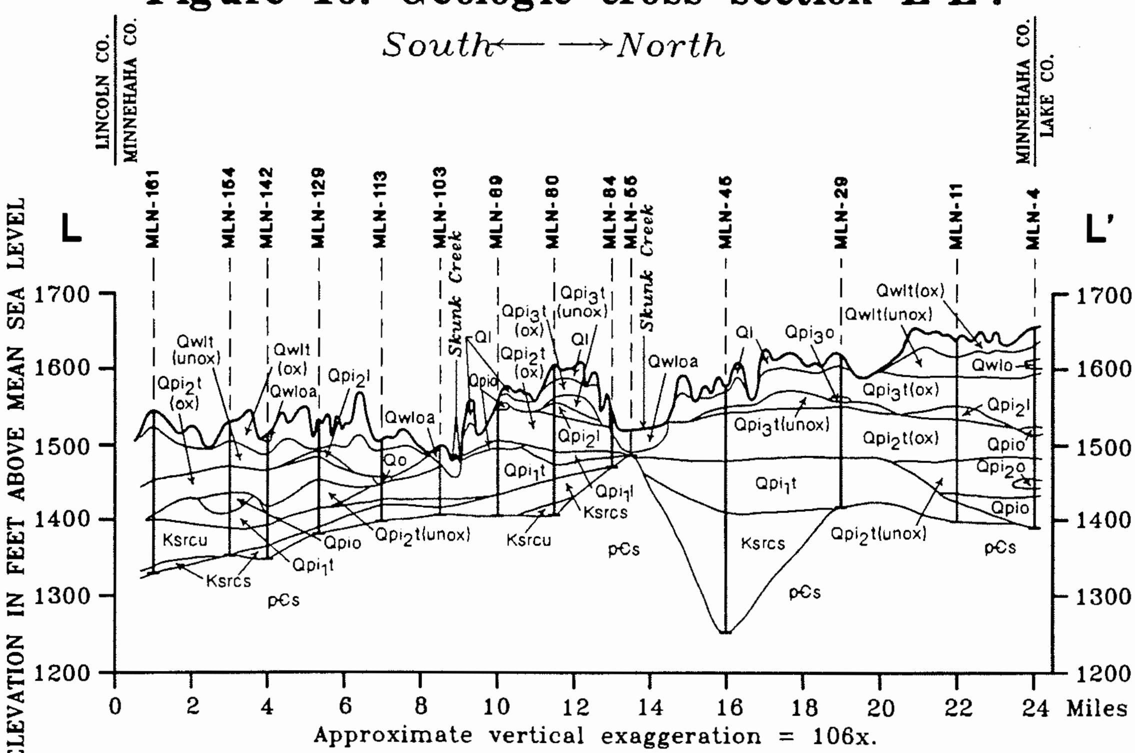


Figure 17. Geologic cross section M-M'.

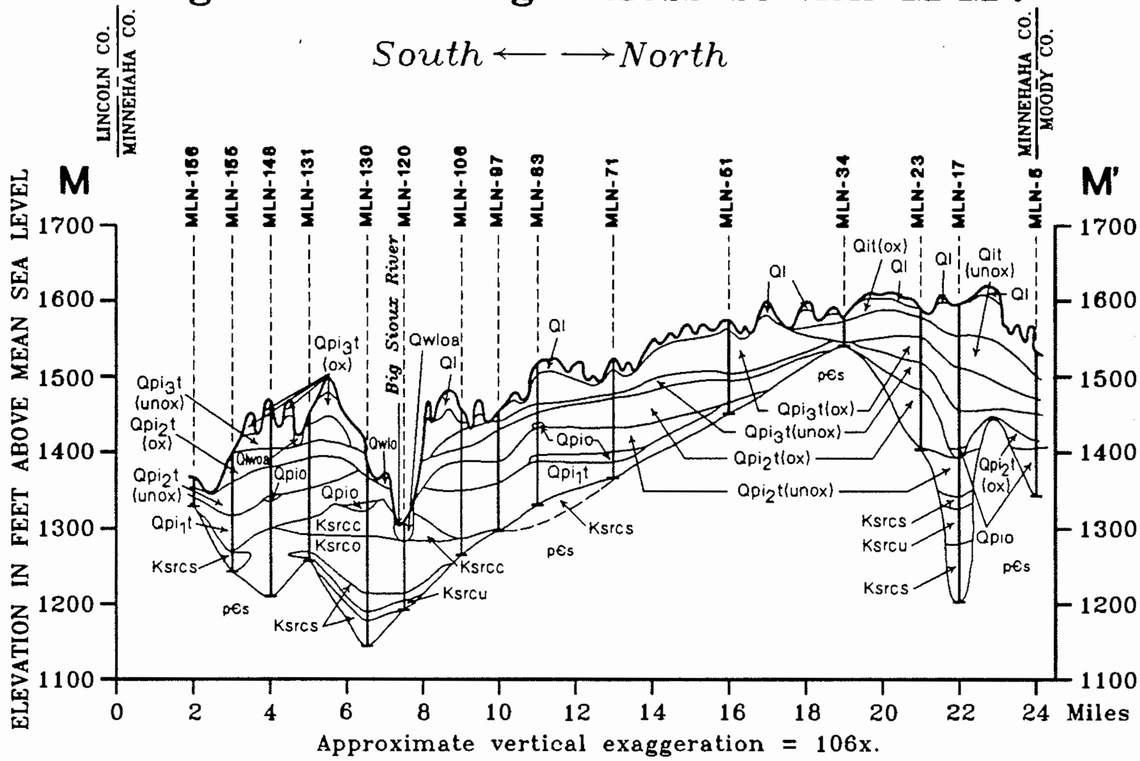
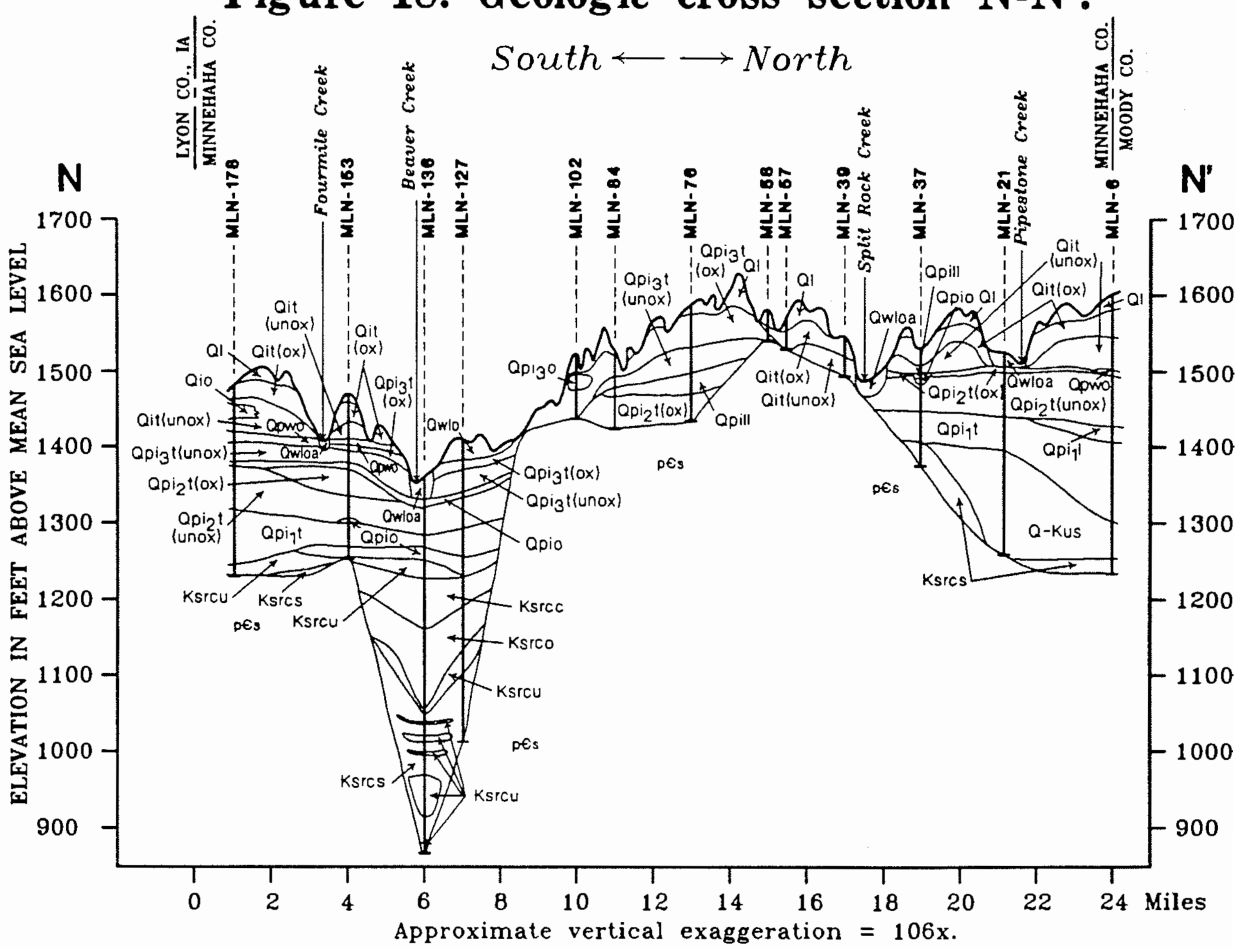


Figure 18. Geologic cross section N-N'.



The glacial history of the region has been substantially reinterpreted in recent years and is now known to be more complex than was envisioned in previous studies. Presently, 11 distinct glacial cycles have been identified on the North American continent, which have been matched with 11 major cold cycles recorded in ocean sediments deposited during the past 900,000 years. At least eight temporally distinct drift sheets have been noted in the upper midwest (Richmond and Fullerton, 1986). The recognition of multiple volcanic ash beds in the region has also been of major importance in the redefinition of glacial chronology. The Pearlette Ash, a regionally important marker bed to early stratigraphers, was discovered to be three distinct beds, representing volcanic events separated by more than 1.3 million years (Boellstorff, 1978). The Pearlette Ash beds have been fission-track dated at .61 (Pearlette "O"), 1.27 (Pearlette "S"), and 2.01 (Pearlette "B") million years old (Izett, 1981). This recent work has shown that many of the previous correlations using a single ash bed were erroneous.

In this study, five distinct glacial advances were recognized in Minnehaha County. From oldest to youngest they include: pre-Illinoian 1, pre-Illinoian 2, pre-Illinoian 3, Illinoian(?), and late Wisconsin.

Pre-Illinoian Stratigraphy

The youngest of the Pearlette Ash markers, now known as the Pearlette "O" Ash bed (Izett and Wilcox, 1982), crops out about 2 miles northeast of the town of Hartford in sec. 11, T. 102 N., R. 51 W. This ash, locally known as the Hartford Ash, separates drift previously interpreted as Illinoian from the underlying drift sheets thought to be Kansan and Nebraskan in age (Steece, 1965). Hallberg (1986) reinterpreted the ages of these older tills using Izett's .61 Ma date for the Hartford Ash. The Nebraskan, Kansan, and Illinoian of Steece (1965) were correlated with the A_3, A_2 and A_1 tills, respectively, of western Iowa, all of which occurred during pre-Illinoian time (table 2). This study will therefore refer to the tills of these three advances as pre-Illinoian 1, pre-Illinoian 2, and pre-Illinoian 3, respectively (table 2).

In Minnehaha County very few test holes revealed the presence of all three distinct drifts. The pre-Illinoian 1 drift was usually restricted to the topographically low areas of the bedrock surface. In some areas, large thicknesses of oxidized drift were encountered making delineation of individual drift sheets extremely difficult.

Illinoian(?) Stratigraphy

In northeastern and southeastern corners of Minnehaha County, overlying the aforementioned drift sheets, is another pre-late Wisconsin drift. Tipton and Steece (1965) suggested that this drift may be early Wisconsin in age because of its position between the late Wisconsin drift margin and drift then interpreted to be Illinoian. Subsequent re-evaluations of the extent of early Wisconsin glaciation, for example (Clark, 1986), have cast doubt upon the proposed age of these sediments.

In northeastern and southeastern Minnehaha County these sediments are found overlying pre-Illinoian 2 and 3 sediments. Several test holes also encountered a paleosol between the older pre-

TIME DIVISIONS (RICHMOND and FULLERTON, 1986)		TIME SCALE	IOWA SECTION (HALLBERG, 1986)	HARTFORD SECTION (BOELLSTORFF, 1978)	HARTFORD SECTION (STEECE, 1965)	LAKE & MOODY CO. (HAMMOND, 1991)	THIS STUDY
HOLOCENE							nonglacial sediment
LATE PLEISTOCENE	LATE WISC.	10,000	Dows Fm.			late Wisc. till	late Wisc. till
		14,000	loess				
	MIDDLE WISC.	35,000	Yarmouth-Sangamon Paleosol				
	E. WISC.	65,000				?	?
		79,000					
LATE MIDDLE PLEISTOCENE	ILLINOIAN	132,000				early Wisconsin(?) till	Illinoian(?) till
MIDDLE MIDDLE PLEISTOCENE	PRE-ILLINOIAN	302,000				?	? Yarmouth? Paleosol
			A_1 tills Classic "Kansan"	A_1 till	Illinoian till	pi-2 till	pre-Illinoian 3 till
EARLY MIDDLE PLEISTOCENE		610,000	Pearlette "O"	Pearlette "O"	Hartford Ash	not found	Pearlette "O"
			A_2 tills	A_2 till	Kansan till	pi-1 till	pre-Illinoian 2 till
			A_3 till	A_3 till	Nebraskan till	not found	pre-Illinoian 1 till
EARLY PLEISTOCENE		788,000					
			A_4 tills				
			B tills				
		1,270,000	Pearlette "S"				
PLIOCENE		2,010,000	Pearlette "B"				
		2,140,000	C tills				
		2,480,000					

Table 2. Classifications and correlation of Pleistocene-Pliocene glaciations.

Illinoian drift and this surface drift. This paleosol may correlate stratigraphically to the paleosols of the Yarmouth interglacial period. This stratigraphic position and the fact that no early Wisconsin-age sediments have been recognized in the region (Hallberg, 1986) has led to the tentative interpretation that these sediments are Illinoian in age (table 2).

Late Wisconsin Stratigraphy

Overlying the pre-Illinoian 2 and 3 drift in western Minnehaha County are sediments of the late Wisconsin. Five distinct glacial advances were postulated to have occurred during the late Wisconsin in South Dakota (Lemke and others, 1965). However, only a single advance has been detected in Minnehaha County.

LANDFORMS

Glacial Landforms

The majority of landforms observed in Minnehaha County are the direct result of glaciation during the Pleistocene. They result both from the construction of various types of morainic deposits related to ice movement and from the erosive powers of meltwaters flowing from the melting ice. The deposition of sediment that comprises each unique landform was controlled by the position of the ice in relation to high and low areas in the surrounding topography.

Stream Dissected Till Plain

The areas of Minnehaha County with pre-late Wisconsin drift at the surface were mapped as stream dissected till plain. The land surface in these areas has been subject to the erosive action of running water and wind for a great length of time. On aerial photographs and topographic maps, these areas are easily distinguished from the areas where late Wisconsin deposits make up the surface. Two distinct stream dissected till plains were observed in Minnehaha County. In this report they will be referred to as the Minnehaha till plain and the Brookings till plain (pl. 4).

MINNEHAHA TILL PLAIN

The Minnehaha till plain is made up of loess-covered deposits of pre-Illinoian advances 3, 2, and possibly 1. Because of the similarity in these sediments and the amount of erosion that has occurred, the exact till unit found at the surface at any given location has not been determined during this investigation. Drift of the pre-Illinoian 3 advance is, however, very likely the surface drift with the underlying pre-Illinoian 2 exposed in topographically lower areas along streams and rivers. Drainage within the Minnehaha till plain is very well integrated. The major waterways traversing the area include the: Big Sioux River, Skunk Creek, Split Rock Creek, Slip-up Creek, and Beaver Creek. The till surface is mantled with loess, commonly about 20 to 30 feet thick. Erosion has formed the loess into northwest-southeast trending ridges which show up very distinctly on aerial photographs. Most constructional or depositional features directly related to action by glacial ice are either covered by loess or have been destroyed by headward erosion of streams.

BROOKINGS TILL PLAIN

The Brookings till plain is made up of loess-covered deposits of the Illinoian(?) advance and is thus younger than the Minnehaha till plain. A loess cover of 10 to 15 feet is common.

Drainage within the Brookings till plain is also well integrated, however, remnants of constructional and depositional features such as end moraine, recessional moraines, kames, kame terraces, and outwash terraces are still distinguishable and will be discussed further below.

Landforms Associated with Stagnant Ice

STAGNATION MORAINE

Moraine resulting from the stagnation of late Wisconsin ice is found in western Minnehaha County. The land surface in this area, mapped as stagnation moraine (pl. 4), has the typical knob and kettle topography. Numerous lakes, sloughs, and closed depressions are found within this area.

COLLAPSED OUTWASH

There are three areas mapped as collapsed outwash on plate 4: one near the town of Colton, one southwest of Ellis, and another along the upstream portion of West Branch Skunk Creek. These areas are all associated with the late Wisconsin ice margin. Sediment-laden waters from the melting ice flowed over and through stagnant ice to outlets along what is now Skunk Creek. When the ice had finally melted, the sediment collapsed leaving an undulating surface. Sand and gravel deposits are found blanketing the knobs as well as the lows.

DISINTEGRATION RIDGE

Several disintegration ridges were mapped within the area of stagnation moraine. As the ice melted, sediment was carried into crevasses in the stagnant ice. The resulting crevasse fill is a poorly sorted mixture of sand, gravel, and boulders, with minor amounts of clay and silt. Eventually the ice completely melted from the area leaving the crevasse fill as a positive ridge. Rocky Ridge, located in southwestern Minnehaha County, is a good example of this type of feature (pl. 4).

ICE-WALLED LAKE PLAIN

Two ice-walled lake plains were observed in northwestern Minnehaha County. They are roughly circular, flat-topped features elevated above the surrounding countryside. Ice-walled lake plains are commonly found within stagnation moraine, immediately adjacent to an area of end moraine (Christensen, 1987). Meltwater transports and deposits sediments in the topographic depressions on the stagnating ice. The sediment, ranging in grain size from a fine sand to clay, is left as a positive feature once the surrounding ice melts.

KAMES AND KAME TERRACES

Kames and/or kame terraces were observed within the Minnehaha till plain, Brookings till plain, and late Wisconsin stagnation moraine. Kames and kame terraces are ice-disintegration features composed of sand and gravel. Kames originate when sediment is deposited in crevasses and other openings in or on the surface of stagnant ice. When the ice melts away, it leaves the sediment in the form of isolated mounds. Kame terraces originate as accumulations of sediment laid down by meltwater between the glacier and the side of a valley. A constructional terrace is left after the ice melts away.

Landforms Associated with Active Ice

END MORAINE

End moraine is a ridge-like accumulation of drift that develops along the stable margin of an active glacier. End moraines of the Illinoian(?) and the late Wisconsin advances were recognized within Minnehaha County (pl. 4). The Illinoian(?) end moraine is found along the margin of the Brookings till plain. It has been subject to considerable erosion and is covered with loess, but some lineation can still be recognized. The late Wisconsin end moraine extends from the Big Sioux River near East Sioux Falls, west along the southern border of the county and along the western sides of Skunk Creek and West Branch Skunk Creek. It contains numerous boulder-strewn areas and far less sloughs and closed depressions than the adjacent stagnation moraine.

RECESSIONAL MORAINE

Two linear ridges can be recognized within the Brookings till plain. As the Illinoian(?) ice retreated, it stopped for a time at these two positions leaving an accumulation of glacial debris. These recessional moraines run parallel to the Illinoian(?) end moraine and are indicated on the map (pl. 4) by a dotted line.

VALLEY TRAIN

Valley train is a long, narrow body of outwash confined within a valley. The outwash is composed of sand and gravel deposited by braided meltwater streams. Within Minnehaha County, this type of deposit occurs in the valleys of the present-day Big Sioux River, Skunk Creek, West Branch Skunk Creek, Slip-up Creek, Split Rock Creek, Pipestone Creek, and Beaver Creek (pl. 4).

OUTWASH TERRACE

Outwash terraces are remnants of former valley-train outwash. Outwash associated with the Illinoian(?) glaciation remains as terrace remnants along the valley walls of Split Rock Creek, Beaver Creek, and Big Sioux River (Qiot on pl. 4). Late Wisconsin outwash terraces ($Qwloa_1$ and Qwlot on pl. 4) are found along the valley walls of the Big Sioux River, Skunk Creek, West Branch Skunk Creek, and Beaver Creek. Along the Big Sioux River, the outwash terraces of the Illinoian(?) glaciation lie at higher elevations than the late Wisconsin terraces.

MELTWATER CHANNELS

Meltwater channels are valleys cut by water flowing from melting glaciers. The meltwater channels are usually filled with valley-train outwash. Some of these channels, however, contain very little sediment left by the meltwater. This type of meltwater channel was formed by meltwater containing very little sediment. These channels may contain thin alluvial deposits left by the present streams that flow within them.

LAKE DEPOSITS

Several areas along Beaver Creek and Split Rock Creek were found to contain deposits of lake clay and silt. These sediments were deposited when meltwater was ponded within each of these valleys. Subsequent erosion by meltwater streams has left these deposits as remnants along the valley walls.

Nonglacial Landforms

Recent Stream Channels

Since the retreat of the glaciers, streams have been modifying the land surface. The channels cut by these streams contain alluvial deposits consisting of primarily sand to clay-sized sediments. Streams flowing across the older surfaces of the Minnehaha and Brookings till plains have been depositing sediment for a much longer time. These stream channels contain a thicker sequence of alluvial sediments than the stream channels of the late Wisconsin surface. In these areas recent alluvium is found overlying Pleistocene outwash and alluvial deposits.

Bedrock Exposures

The Sioux Quartzite, Corson Diabase, and Split Rock Creek Formation are all exposed within Minnehaha County (pls. 1 and 2). Typically these outcrops are located in areas where streams have worn away the overlying sediments. Exposures of Sioux Quartzite are the most common across the county. The well-developed vertical and horizontal jointing of the Sioux Quartzite commonly causes exposures to erode to near vertical cliffs. The Dells of the Sioux River, near Dell Rapids; Devils

Gulch and Palisades Park, near Garretson; and Falls Park in the city of Sioux Falls are some of the more spectacular exposures.

Exposures of the Corson Diabase occur along Split Rock Creek and at an old quarry site along the Big Sioux River. The Split Rock Creek Formation is exposed along Slip-up and Split Rock Creeks and along the Big Sioux River.

QUATERNARY DEPOSITS

Pleistocene Deposits

Till

Till is the nonsorted, nonstratified sediment deposited by a glacier. The composition of till is a result of the material over which the glacier traveled. In Minnehaha County the differing-aged tills are all very similar in composition. They usually consist of a very compact, silty, clay-rich matrix, reflecting the predominance of shale in the local Cretaceous bedrock. Sand- to boulder-sized clasts of many different rock types are found throughout the matrix. The tills in Minnehaha County are usually brownish-gray to gray with a yellowish-brown to reddish-brown upper oxidized zone. Since the tills are very similar in composition, distinguishing each till unit is very difficult. In this study, the till units (Qpi_1t, Qpi_2t, Qpi_3t, Qit, and Qwlt, figs. 5 through 18) were separated using oxidation zones, outwash and loess deposits, electric log signatures, and stratigraphic position. Separation of the pre-Illinoian tills using this method was not always accomplished. In areas where data were lacking or separations were very difficult, the till is referred to as undifferentiated pre-Illinoian and designated Qpitu (figs. 5 through 18).

Outwash

Outwash is the sorted, stratified sediment deposited by water flowing from melting glacial ice. These sediments are laid down in front of the advancing glacier, often become incorporated within the till, and are deposited as the glacier retreats. The majority of the outwash deposits encountered in Minnehaha County are composed of round to subangular sand grading to a fine to medium gravel. Some coarse gravel may also be encountered, generally near the base of the deposit. The outwash usually contains a variety of grain types including quartz, limestone, dolomite, shale, quartzite, and granite.

Outwash associated with each glacial advance has very similar characteristics, making it extremely difficult to distinguish its age. The age of the outwash is constrained only by the age of the sediments surrounding it. Outwash lying stratigraphically between two tills may be correlated in age to the overlying till, the underlying till, or may be a combination of both. For this study, only the surface outwash and outwash completely surrounded by a single till have been correlated to an associated glacial advance (Qpi_1o, Qpi_2o, Qpi_3o, Qio, Qwlo, and Qwloa on figs. 5 through 18). Outwash which lies below the youngest pre-Illinoian till (Qpi_3t), and lies stratigraphically between pre-Illinoian 3 and 2 deposits, between pre-Illinoian 2 and 1 deposits, or below pre-Illinoian 1 till is referred to as pre-

Illinoian outwash, undifferentiated, and designated Qpio (figs. 5 through 18). Outwash lying stratigraphically between Illinoian(?) till and pre-Illinoian till is referred to as pre-Wisconsin, undifferentiated and designated Qpwo (figs. 5 through 18). Outwash lying stratigraphically between late Wisconsin till and pre-Illinoian till is referred as Quaternary, undifferentiated and designated Qo (figs. 5 through 18).

Loess

Loess is a sediment composed dominantly of silt-sized particles, with minor amounts of clay and sand, and that was deposited by wind. Loess consists mainly of quartz, with very small variable proportions of clay minerals, feldspars, micas, hornblende, and pyroxene (Flint, 1955). The color of most exposed loess ranges through various hues of yellow, orange, and brown. Where loess is unoxidized, it may be grayish.

The chief source of sediment transported by the wind is exposed areas of till and outwash uncovered by deglaciation. Deposits of loess accumulate after the deglaciation of each glacial advance. For this study, subsurface deposits of loess have been correlated to the sediments of the underlying glacial advance (Qpi_1l, Qpi_2l, and Qpi_3l on figs. 5 through 18). The older drift surfaces, like that of the Minnehaha and Brookings till plains, have been exposed since deglaciation of the pre-Illinoian 3 and Illinoian(?) advances, respectively. Accumulations of loess in these areas are therefore a combination of material deposited following deglaciation of each successive glacial advance. Since the source of sediment was very similar following each deglaciation, the differing-aged loesses have similar characteristics and are difficult to separate. For this study, these accumulations of loess are referred to as Quaternary loess, undifferentiated and designated Ql (figs. 5 through 18).

Lake Sediments

Lake sediments accumulate in areas containing ponded meltwater. Lake sediment ranges in grain size from clay to fine sand. The sediment color can be quite variable, from green to gray to black and occasionally white. Some lake sediments contain horizontal bedding. Shell fragments may be encountered.

Pre-Illinoian 1 Deposits

In Minnehaha County, the oldest pre-Illinoian till (Qpi_1t) occurs in topographically low areas of the bedrock surface (figs. 5 through 18). This till ranges up to 150 feet thick in the test holes drilled. An upper oxidized zone is not always present, probably due to erosion by subsequent glaciations. In some localities, oxidized fractures or joints occur throughout the till. When drilling these sediments, many oxidized-unoxidized contacts are encountered.

Some of the outwash found below the pre-Illinoian 1 till contains a significant amount of well-sorted quartz sand. This sand may be Pleistocene age but could be much older.

Widely scattered deposits of loess were encountered overlying the pre-Illinoian 1 till. Much of the original loess cover was probably removed by subsequent glacial erosion.

Pre-Illinoian 2 Deposits

Till of the pre-Illinoian 2 advance (Qpi_2t) was encountered over much of the county, with a maximum thickness of 120 feet in the test holes drilled (figs. 5 through 18). Exposures of this till are found along Skunk Creek, the Big Sioux River, and within the Minnehaha till plain where erosion has removed the overlying pre-Illinoian 3 till. In some areas, the entire thickness of pre-Illinoian 2 till (up to 70 feet) has been oxidized.

A large body of outwash, locally known as the Wall Lake aquifer (Iles and Frykman, 1991), reaches a thickness of over 80 feet in sec. 34, T. 101 N., R. 50 W. This deposit of outwash lies above pre-Illinoian 1 till and was possibly laid down by southerly flowing meltwater of pre-Illinoian 2 ice. This deposit is part of a large buried outwash plain which extends to the south into Lincoln County.

Up to 25 feet of loess (Qpi_2l) overlies the pre-Illinoian 2 drift (figs. 5 through 18). In northwestern Minnehaha County, this loess forms an almost continuous blanket and is an ideal marker bed between the pre-Illinoian 2 till and the overlying pre-Illinoian 3 till. It is exposed along Skunk Creek (the Hartford site) and along the Big Sioux River from Dell Rapids to Sioux Falls. Over the remainder of the county, this loess is very scattered or has been removed by subsequent glacial erosion. It is within this interval that the Pearlette "O" Ash (Hartford Ash), dated at 610,000 years old, occurs (Izett, 1981). In areas away from the Hartford site (sec. 11, T. 102 N., R. 51 W.), the ash was extremely difficult to identify in drill-hole cuttings.

Pre-Illinoian 3 Deposits

Till of the pre-Illinoian 3 advance is the uppermost till of the Minnehaha till plain. It is also usually the first till encountered when drilling through the Illinoian(?) and late Wisconsin tills. In some locales, however, subsequent glacial erosion has removed the pre-Illinoian 3 sediment. This till reaches a maximum thickness of over 120 feet. Up to 90 feet has been oxidized, which in some areas makes up the entire thickness. The unweathered portion of the till is usually less than 50 feet thick.

There are several notable pre-Illinoian 3 outwash deposits in Minnehaha County. A line of kames and kame terraces (Qpi_3ok) extends northeast from Sioux Falls toward Garretson (pl. 4). These features are commonly found near the terminus of the active ice and may be an indication of a terminal position of the pre-Illinoian 3 advance. The sorting in the kames is typically poor, however, each deposit has its own characteristics, ranging from well-sorted sand to poorly sorted gravel or boulders. A great deal of silt and clay may also occur within these deposits. The largest deposit is a kame terrace found just northeast of Sioux Falls on both sides of the Big Sioux River (pl. 4). This deposit has considerably better sorting than the other kames and has been greatly utilized for sand and gravel resources.

A mantle of loess covers the pre-Illinoian 3 till within the Minnehaha till plain. The thickness of the loess is highly variable. Thicknesses of 10 to 30 feet are common, with up to 50 feet encountered in drill holes. Subsequent erosion has washed some of the loess from the hilltops to the valleys. Much of this loess was deposited following pre-Illinoian 3 deglaciation, however, part of the thickness may also be attributed to loess deposition following both the Illinoian(?) and late Wisconsin deglaciations.

In several areas, a thin paleosol was noted in exposures, developed on loess deposited following pre-Illinoian 3 deglaciation and underlying loess deposited following Illinoian(?) deglaciation (Rothrock and Newcomb, 1926). A paleosol developed on the pre-Illinoian 3 drift and underlying Illinoian(?) deposits was also encountered in several test holes (up to 4 feet thick). The paleosol is typically a brownish-black to black, organic-rich silty clay. Because of its thin and discontinuous nature, no attempt was made to separate pre-Illinoian 3 loess from Illinoian(?) loess using this paleosol.

Illinoian(?) Deposits

Till of the Illinoian(?) advance (Qit) is the uppermost till within the Brookings till plain. In Minnehaha County, this till has a maximum thickness of about 90 feet with an upper oxidized zone up to 50 feet thick.

There are several notable Illinoian(?) outwash deposits in Minnehaha County. Outwash terrace remnants (Qiot) of former valley-train deposits occur along the valley walls of West Pipestone Creek Split Rock Creek, Slip-up Creek, Fourmile Creek, Beaver Creek, and the Big Sioux River (pl. 4). Thicknesses of 20 to 40 feet are common, with up to 90 feet encountered near Brandon. A large kame terrace (Qiok) occurs south of Garretson and many kames are scattered across the Brookings till plain in the northeastern and southeastern corners of the county (pl. 4).

A mantle of loess covers most of the Illinoian(?) till. Thicknesses of 5 to 15 feet are common, with up to 20 feet encountered in some areas.

Late Wisconsin Deposits

Late Wisconsin till (Qwlt) reaches thicknesses of over 200 feet (figs. 5 through 18). Late Wisconsin till typically has a thinner oxidation zone than the older tills, seldom exceeding 30 feet. In the areas mapped as end moraine (pl. 4), cobbles and boulders are found scattered across the land surface.

Late Wisconsin surface outwash is found in a variety of landforms such as valley trains, terraces, and ice-contact features, including collapsed areas, disintegration ridges, and kames (pl. 4). Changes in base level and source area during the late Wisconsin have created three distinct levels of valley-train outwash. Remnants of the oldest stage, occur as terraces (Qwlot) along the valley walls of West Skunk Creek and Skunk Creek (pl. 4). Outwash deposits of the middle stage remain as valley train in the Skunk Creek valley and as terrace remnants along the Big Sioux River ($Qwloa_1$ on pl. 4).

Outwash deposits of the youngest stage remain as valley train in the valleys of the Big Sioux River, Beaver Creek, Pipestone Creek, and Split Rock Creek ($Qwloa_2$ on pl. 4). The latter two deposits are designated $Qwloa_1$ and $Qwloa_2$ because they may be covered with a thin veneer of Holocene alluvium.

Late Wisconsin lake sediments were found in two ice-walled lake plains in northwest Minnehaha County and near the confluence of the Big Sioux River, with Split Rock and Beaver Creeks (Qwlli and Qwll, respectively, on pl. 4). Over 20 feet of lake sediment was encountered in test drilling in each of these areas.

A thin discontinuous blanket of loess covers the late Wisconsin till. Where found, the loess is typically less than 5 feet thick and rarely exceeds a thickness of 10 feet. Because of its thin patchy nature, the late Wisconsin loess was not considered a mappable unit.

Holocene Deposits

Alluvium

The various creeks and rivers in the county have been depositing alluvial sediments since the retreat of the last glaciers. Within the Minnehaha till plain, alluvial sediments have been accumulating since the retreat of the pre-Illinoian 3 ice and within the Brookings till plain since the retreat of the Illinoian(?) ice (pl. 4). These older alluvial sediments are covered by alluvial sediments deposited during Holocene time. Up to 30 feet of alluvium may be found in some of the older stream valleys of the Minnehaha and Brookings till plains. In the late Wisconsin meltwater channels, stream erosion has removed some of the outwash and replaced it with 10 to 20 feet of black to brownish-black organic-rich silt, clay, and fine sand. The floodplains also are covered with a thin veneer of alluvial material deposited at times of flooding. These flood deposits were not considered mappable units.

Lacustrine Sediments

From the end of the Pleistocene to the present, erosional forces have been at work. Running water has carried sediment from the hilltops to topographically lower areas. This process leads to the infilling of glacial lakes, reverting them to sloughs, swamps, and eventually dry lake beds. These deposits, consisting of dark-gray to black silt and clay, are very minor in areal extent and were not considered mappable units.

Eolian Deposits

Wind has continued to blow sediment from sparsely vegetated areas and redeposit it elsewhere. In some areas over 3 feet of loess can be found burying fence lines and other artifacts. These yellowish-brown to dark-brown to grayish-black sediments are at times indistinguishable from older loess deposits in the area.

GEOLOGIC HISTORY

Pre-Pleistocene

During Middle Proterozoic time, quartz sand was deposited on an extremely irregular surface of older rocks. Over time these sediments were subject to consolidation, deformation, and some low-grade metamorphism, creating the rock now known as the Sioux Quartzite. The last event of the Middle Proterozoic in the area was the intrusion of the Corson Diabase into the Sioux Quartzite. Some contact metamorphism occurred during this event causing alteration of some of the fine-grained sediments within Sioux Quartzite.

During the Paleozoic Era and into the Mesozoic Era, sedimentation in the area was controlled by the Transcontinental Arch. In general, major transgressions flooded the arch during the early Paleozoic. From late Paleozoic time to the Late Cretaceous Epoch, Minnehaha County was generally an emergent area. Much erosion occurred during this time which removed large portions of the Corson Diabase intrusive and created deeply incised valleys in the Sioux Quartzite (pl. 1).

During Late Cretaceous time, the Western Interior Sea repeatedly covered the area. The topographically high areas of the Sioux Quartzite, however, remained as islands in the sea and locally controlled sedimentation. It was during this time that the sediments of the Split Rock Creek Formation were deposited in the low areas of the Sioux Quartzite surface. Several transgressive-regressive cycles have been noted in the Split Rock Creek sediments (Kairo, 1987).

From Late Cretaceous time to Pleistocene time, the area remained emerged and subject to erosion. The Sioux Quartzite highlands were again the controlling factor in the development of the pre-Pleistocene drainage network. Drainage development occurred in the topographic lows, primarily on the surface of the Split Rock Creek Formation. These areas received runoff from the surrounding highly fractured Sioux Quartzite highlands. The undifferentiated silts were deposited during this time period.

Plate 2 shows the present configuration of the bedrock surface in Minnehaha County. This is probably a close approximation of the topography just before the onset of Pleistocene glaciation. The glaciations did very little in modifying the Sioux Quartzite surface but certainly had some effect on the Cretaceous sediments found in the topographically low areas.

Pleistocene

Early Pleistocene glaciations are thought to have approached South Dakota from a northeast direction, as evidenced by glacial striations found on the surface of the Sioux Quartzite (Baldwin, 1949).

Pre-Illinoian 1 Glaciation

Sediments of the pre-Illinoian 1 glaciation are found partially filling pre-Pleistocene valleys. Widely scattered remnants of loess on the pre-Illinoian 1 surface indicate a period of wind erosion existed after the retreat of glacial ice from the area. A long period of weathering occurred after the glacial retreat forming a thick oxidation zone and oxidation along fractures and joints throughout the thickness of the deposit.

Pre-Illinoian 2 Glaciation

Glaciation during the pre-Illinoian 2 advance probably modified the older drift surface to some extent. Sediments of the pre-Illinoian 2 advance are found over most of Minnehaha County, indicating the ice probably completely overrode the Sioux Quartzite highlands. The pre-Illinoian 2 glaciation significantly modified the drainage patterns within the study area. Sediments were deposited over the Sioux Quartzite highlands, filling in the topographic lows, and adding considerable mass to the development of the Coteau des Prairies. Meltwaters from the retreating ice flowed generally to the south carrying significant amounts of sand and gravel. These sediments are now part of what is known as the Wall Lake aquifer.

After the retreat of the pre-Illinoian 2 ice, loess deposition resumed over the area. In the western part of the county, the remnants of this loess are fairly continuous and served as a good marker bed between the pre-Illinoian 2 and 3 glaciations.

During the period of loess deposition, there was some volcanic activity occurring far to the west of the study area. This volcanic activity led to the deposition of the Hartford Ash (Pearlette "O" Ash), about 610,000 years old (Izett, 1981). A long period of weathering again followed creating a thick oxidation zone. In some localities, the entire thickness of pre-Illinoian 2 drift has been oxidized.

Pre-Illinoian 3 Glaciation

Glaciation during the pre-Illinoian 3 advance modified the land surface to some extent, although the loess remnants found overlying the pre-Illinoian 2 drift seem to indicate this modification was very slight. Sediments of the pre-Illinoian 3 glaciation are found over most of the county, covering the older glacial sediments. The pre-Illinoian 3 ice, like the pre-Illinoian 2 ice, probably covered most of the Sioux Quartzite highlands. The pre-Illinoian 3 advance also contributed a considerable mass of sediment to the development of the Coteau des Prairies. These highlands greatly influenced the movement of later glaciations.

A line of kames and kame terraces trending northeast of Sioux Falls toward Garretson may indicate a possible terminal position for the pre-Illinoian 3 advance. The ice front in this area was blocked by a Sioux Quartzite high which extends from Sioux Falls to Rowena. The large kame terrace, remnants of which are found on both bluffs of the Big Sioux valley just northeast of Sioux Falls, was deposited by meltwater flowing between the ice and the Sioux Quartzite high. Cross bedding within the deposit dips to the southwest indicating a southwest flow of meltwater.

After the retreat of the pre-Illinoian 3 ice, loess deposition resumed over the area. A long interglacial period followed during which considerable weathering occurred. A very thick oxidation zone was created in some localities encompassing the entire thickness of pre-Illinoian 3 sediment. Several test holes encountered remnants of a thin paleosol that had developed over this surface. It is this erosional surface that has been mapped as the Minnehaha till plain. Along many of the present-day drainages, erosion has removed the pre-Illinoian 3 sediments to reveal pre-Illinoian 2 sediment.

Illinoian(?) Glaciation

The Illinoian(?) glacial advance is also thought to have encroached upon eastern South Dakota only from a northeasterly direction. As ice entered Minnehaha County from the north, it became stalled against a Sioux Quartzite high that trends southeast from Dell Rapids to Garretson. The ice moved south around the highland into Minnesota and encroached upon the very southeastern corner of the county. Here again it was halted by a Sioux Quartzite high. The ice was relatively thin and only minor modification of the local landscape occurred.

Much of the depositional history of the Illinoian(?) glaciation is difficult to interpret. Most of the constructional features have been altered by erosion and masked by subsequent loess cover. In northeastern Minnehaha County, however, there is a topographically high area that contains some linear features that appear to be remnants of end moraine. To the north of these highlands, there are also two parallel linear ridges that appear to be loess covered recessional moraines.

Many kames are found in both the northeast and southeast corners of the county indicating portions of the ice were possibly stagnant. Meltwater flowing between the stagnant ice and the highland to the south deposited a large kame terrace just south of Garretson. Meltwater flowed south in the valleys now occupied by Split Rock and West Pipestone Creeks and west along the valley now occupied by Beaver Creek. Just south of Brandon these meltwaters converged and flowed south out of the county in the valley now occupied by the Big Sioux River. Many remnants of this valley-train outwash are found at topographically high levels along these creek valleys.

Meltwater flowing down the Split Rock and West Pipestone Creek valleys eventually eroded through the older glacial sediments to the Sioux Quartzite surface. As the meltwater flowed over the fractured surface of the Sioux Quartzite, blocks of quartzite were lifted out and carried downstream. This type of erosive action helped create the near vertical cliffs that occur in these valleys.

Loess deposition and erosion of the drift surface again followed deglaciation of the area. The loess-covered surface of the Illinoian(?) drift is referred to in this report as the Brookings till plain.

Loess was also deposited over the older loess-covered drift of the Minnehaha till plain. Erosion of these older surfaces has continued to the present, except where covered by late Wisconsin sediments.

Late Wisconsin Glaciation

During late Wisconsin time, the center of glaciation shifted westward from earlier glacial advances. Late Wisconsin ice approached eastern South Dakota from the north rather than the northeast (Hallberg and Kemmis, 1986). The ice mass was split by the Coteau des Prairies highland and continued as two distinct lobes, now known as the Des Moines lobe and the James lobe (fig. 19).

The Des Moines lobe was diverted to the southeast into southern Minnesota and Iowa. The Des Moines lobe ice did not enter Minnehaha County (fig. 19). Water from the melting Des Moines lobe ice, however, eroded channels now occupied by Pipestone Creek, Split Rock Creek, and Beaver Creek. The meltwater deposited a large volume of outwash in these valleys as well as the valley now occupied by the Big Sioux River.

The James lobe moved into a lowland now occupied by the James River. The ice flowed southward eventually reaching the southern edge of the state. The valley of the present-day Missouri River marks, very nearly, the maximum extent of late Wisconsin glaciation within South Dakota (Gilbertson and Lehr, 1989) (fig. 19).

In Minnehaha County, the valley of Skunk Creek roughly marks the eastern extent of the James lobe ice (pl. 4). A narrow band of rough, hummocky topography, mapped as end moraine on plate 4, marks this ice margin. The majority of the land surface affected by late Wisconsin ice contains stagnation features. Closed depressions, many containing lakes or sloughs, as well as disintegration ridges, collapsed areas, and ice-walled lake plains are found in this stagnation area.

Meltwater flowing from the stagnant ice made its way eastward to the valley now occupied by Skunk Creek. In several areas, the meltwater flowed over the stagnant ice leaving sediment which later collapsed as the ice melted. Meltwater flowing down the Skunk Creek valley then merged with meltwater flowing down the Big Sioux valley. During the pre-Illinoian 2 and pre-Illinoian 3 glaciations, meltwater flowed generally from the north-northeast to the south and out of the county. Late Wisconsin ice, however, blocked this southern route creating the big bend in the Big Sioux River. The meltwater flowed along the edge of the ice until it found an outlet to the north. The meltwater moved across older glacial sediments, in a direction opposite of that in which the pre-Illinoian 3 waters had flowed. The meltwater must have flowed over a low divide near Brandon and into a channel which was formed by meltwater of the Illinoian(?) advance. South of Brandon the meltwater merged with meltwater flowing down the Split Rock and Beaver Creek valleys and continued south out of the county.

The outwash in the Big Sioux valley is a remnant of an interlobate drainage between the ice of both the Des Moines and James lobes. The erosive action of the late Wisconsin meltwater removed some of the outwash that had been deposited during the pre-Illinoian 3 and Illinoian(?) advances. Only high level terrace remnants remain.

Three levels of late Wisconsin outwash occur within the study area, indicating several changes in the base level and source area of meltwater during the late Wisconsin. Initially, meltwater flowed from the stagnating ice down the West Skunk Creek valley and other unnamed channels to the Skunk Creek valley. As the late Wisconsin ice retreated, the source area of meltwater changed. The majority

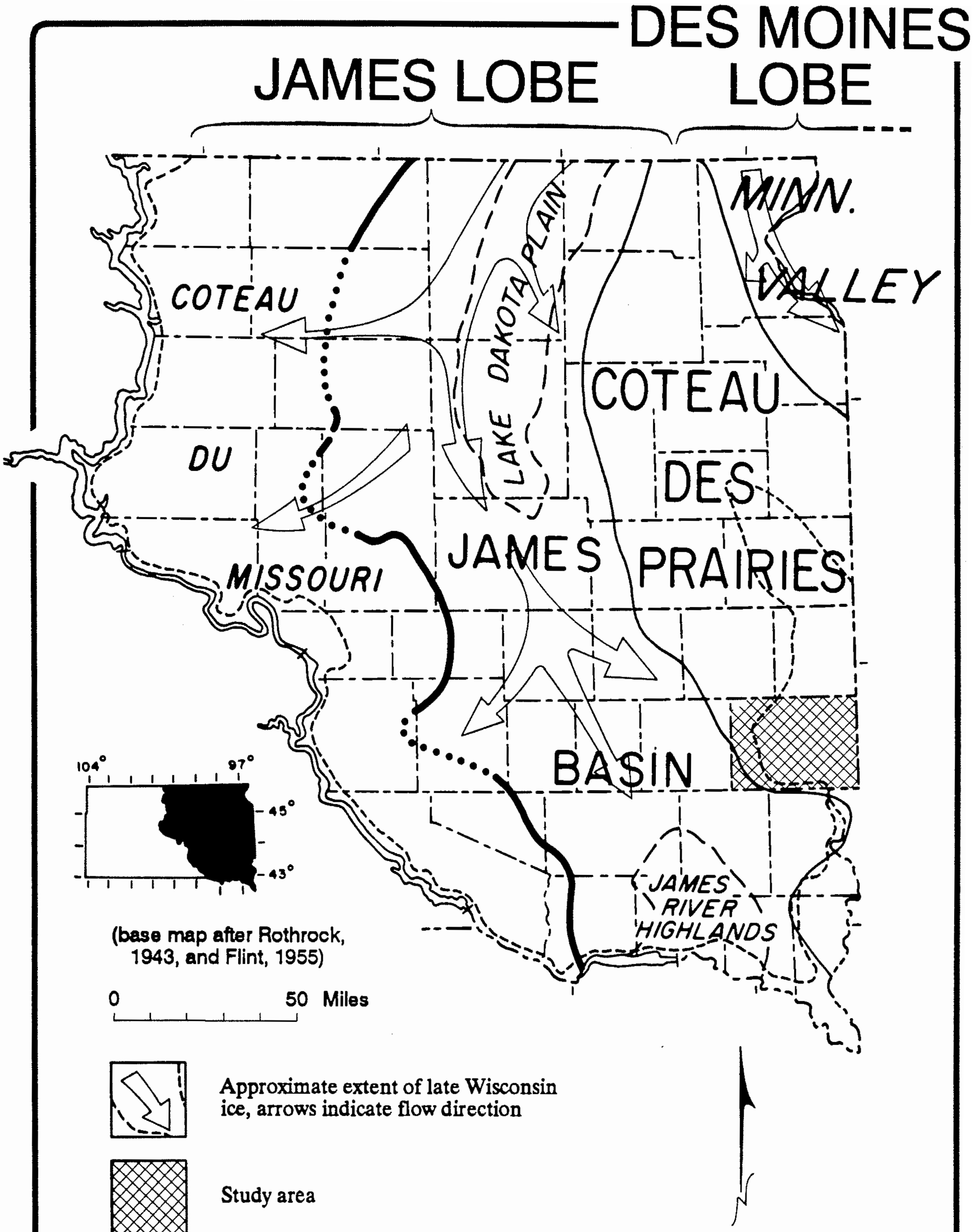


Figure 19. Generalized relationship of James lobe and Des Moines lobe ice to eastern South Dakota.

of meltwater subsequently flowed down the Skunk Creek valley. With a lowering of the base level, this middle stage of meltwater dissected the deposits left by the earlier stage leaving terrace remnants along West Skunk Creek and the western wall of the Skunk Creek valley. Meltwater flowed down the Skunk Creek valley to the Big Sioux River valley, where it followed the big bend until it became partially blocked by a narrow bedrock passage, located between East Sioux Falls and Rowena. A bottle neck occurred which ponded meltwater to the north, back into the Split Rock and Beaver Creek valleys. As the late Wisconsin ice continued to retreat, the meltwater source area changed so that the primary flows were within the Big Sioux River valley and the Beaver Creek, Pipestone Creek, and Split Rock Creek valleys. With another change in base level, this meltwater flow dissected the deposits left by the middle meltwater stage, leaving remnants of the valley-train deposits within the Skunk Creek valley and terrace deposits along the walls of the Big Sioux River valley. Lake deposits (Qwll) left by the ponded meltwater in the Beaver Creek and Split Rock Creek valleys were also dissected leaving them as terraces in the lower ends of these valleys (pl. 4). The outwash deposits left by the three stages of late Wisconsin meltwater flow have been designated, from oldest to youngest, Qwlot, $Qwloa_1$, and $Qwloa_2$ (pl. 4).

Late Wisconsin meltwater eventually eroded through older glacial deposits to reveal the Sioux Quartzite surface. Just as during previous glaciations, the meltwater flowed over the fractured Sioux Quartzite surface eroding blocks of quartzite and carrying them downstream. The near vertical cliffs created by this action can be seen at the Dells of the Sioux River, near Dell Rapids; Palisades Park and Devil's Gulch, near Garretson; and at Falls Parks in Sioux Falls.

After the retreat of the late Wisconsin ice, some loess deposition occurred. A very thin layer of loess overlies the late Wisconsin drift surface, making it very easy to distinguish from the thick loess-covered surfaces of the Minnehaha and Brookings till plains.

Holocene

The geologic history of Minnehaha County since the end of the Pleistocene Epoch has been dominated by processes still active today. Erosion by running water is gradually moving sediment from the highlands to topographically lower areas. Lakes are continuously being filled with sediment, creating sloughs and marshy areas. Wind continues to blow sediment from sparsely vegetated areas and redeposit it elsewhere. Weathering of the late Wisconsin surface is creating a thick oxidation zone on which soils have developed. Landslides and other forms of mass movement, both natural and man-made, continue to shape the land surface.

ECONOMIC GEOLOGY

Water Resources

Water is a very important resource in Minnehaha County. Due to the large population within the county, a large supply is needed to meet the demand. As part of this investigation into the geology and water resources of Minnehaha County, a complete hydrologic investigation was completed. A short summary of the available water resources can be found in Lindgren and Niehus (in preparation) and a more technical evaluation can be found in Lindgren and Niehus (1992).

Sand and Gravel

Another important part of this investigation dealt with the availability of sand and gravel within the county. These resources are used chiefly in the maintenance of area roads. A separate report summarizing this portion of the investigation was compiled by Jarrett (1990).

Oil and Gas

No commercial quantities of oil or gas have been found in the area. Slight traces of low-grade hydrocarbons were encountered when drilling the organic-rich portions of the Split Rock Creek Formation (R.A. Schoon, South Dakota Geological Survey, personal communication, 1988). Also, an observation well installed near the NE NE NE NE sec. 16, T. 102 N., R. 51 W. was found to be emitting small quantities of methane gas from a buried glacial outwash.

Quartzite

The hardness, uniformity, and attractive appearance of the Sioux Quartzite makes it suitable for many uses. Major present-day uses for quartzite include: concrete aggregate, railroad ballast, road construction and sanding, rip-rap for dams and river-bank stabilization, and production of ferro-silicon for the steel industry. Minor and historical uses include: gannister, abrasives, building stone, grinding pebbles and tube mill liners, monument stone, paving blocks, filter beds for sewage lagoons, poultry grit, foundry sand, and filler in certain building and cosmetic products. The portion of this investigation dealing with the availability of quartzite within the county is included in the report on aggregate resources compiled by Jarrett (1990).

Other Mineral Resources

Although no economic mineral deposits have yet been found, the area has attracted considerable exploration in recent years. The Sioux Quartzite has been suggested as a possible host for unconformity vein-type uranium deposits (Cheney, 1981; Ansfield and Stach, 1981), and paleoplacer gold deposits (Southwick and others, 1986). Some test coring has been done in Minnehaha County, however, no economic deposits have been reported. Minnehaha County is also within an area suggested as an exploration target for stratiform-manganese deposits (Cannon and Force, 1983). Cretaceous-age sediments surrounding the Sioux Ridge have traits similar to other manganese-rich sediments found elsewhere (Hammond, 1988). Exploration for manganese is currently under way in eastern South Dakota.

REFERENCES CITED

Adolphson, D.G., and Ellis, M.J., 1964, *Basic hydrologic data, Skunk Creek-Lake Madison drainage basin, South Dakota*: South Dakota Geological Survey Basic Data Report 3.

Agnew, A.F., and Tychsen, P.C., 1965, *A guide to the stratigraphy of South Dakota*: South Dakota Geological Survey Bulletin 14.

American Commission on Stratigraphic Nomenclature, 1983, *North American stratigraphic code*: American Association of Petroleum Geologists Bulletin, v. 67, no. 5, p. 841-875.

Ansfield, V.J., and Stach, R.L., 1981, *Uranium ore possibilities associated with the unconformity beneath the Sioux Quartzite*: Geological Society of America Abstracts with Programs, v. 13, no. 4, p. 189.

Bain, H.F., 1895, *Cretaceous deposits of the Sioux Valley*: Iowa Geological Survey, v. 3, p. 99-114.

Baldwin, Brewster, 1949, *A preliminary report on the Sioux Quartzite*: South Dakota Geological Survey Report of Investigations 63.

____1950, *The geology of the Sioux Formation*: New York, Columbia University, unpublished Ph.D. dissertation.

Barari, A., 1967, *Ground-water supply for the city of Dell Rapids, South Dakota*: South Dakota Geological Survey Special Report 39.

____1972, *Ground-water investigation for the city of Baltic, South Dakota*: South Dakota Geological Survey Special Report 56.

____1979, *Ground-water study in the vicinity of Brandon*: South Dakota Geological Survey Open-File Report 27-UR.

Barari, A., and Hilton, J., in preparation, *Ground-water study for the city of Garretson*: South Dakota Geological Survey Open-File Report.

Barkley, R.C., 1952, *Artesian conditions in southeastern South Dakota*: South Dakota Geological Survey Report of Investigations 71.

Bendrat, T.A., and Spencer, M.S., 1904, *The geology of Lincoln County, South Dakota and adjacent portions*: American Geologists, v. 33, p. 65-94.

Berg, E.L., 1938, *Notes on catlinite and the Sioux Quartzite*: American Mineralogist, v. 23, p. 258-268.

Bergstrom, D.J., and Morey, G.B., 1985, *Correlation of stratigraphic units in North America, Northern mid-continent region correlation chart*: Tulsa, Oklahoma, American Association of Petroleum Geologists.

Beyer, S.W., 1895, *The Sioux Quartzite, near Sioux Falls in South Dakota, with special reference to an intrusive diabase*: Baltimore Maryland, John Hopkins University, unpublished Ph.D. dissertation.

____1896, *The Sioux Quartzite and certain associated rocks*: Iowa Geological Survey Annual Report, v. 6, p. 67-112.

Boellstorff, J., 1978, *A need for redefinition of North American Pleistocene stages*: Transactions of the Gulf Coast Association of Geological Societies, v. 19, p. 65-74.

Brenner, R.L., Bretz, R.F., Bunker, B.J., Iles, D.L., Ludvigson, G.A., McKay, R.M., Whitley, D.L., and Witzke, B.J., 1981, *Cretaceous stratigraphy and sedimentation in northwest Iowa, northeast Nebraska, and southeast South Dakota*: Iowa Geological Survey Guidebook Series 4.

Bretz, R.F., 1981, *Geology of the Sioux Falls, South Dakota area*, in Brenner, R.F., and others, 1981, *Cretaceous stratigraphy and sedimentation in northwest Iowa, northeast Nebraska, and southeast South Dakota*: Iowa Geological Survey Guidebook Series 4, p. 129-147.

____1984, *Metamorphic, igneous and sedimentary relationships on the Sioux Quartzite ridge*: South Dakota Geological Survey unpublished report.

Buehrer, D.W., 1971, *Environmental geology of Sioux Falls, South Dakota, and its relation to urban and industrial development*: Vermillion, South Dakota, University of South Dakota, unpublished Master's thesis.

Cannon, W.F., and Force, E.R., 1983, *Potential for high-grade shallow-marine manganese deposits in North America*, in Shanks, W.C., ed., *Cameron volume on unconventional mineral deposits*: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 175-189.

Carman, J.E., 1913, *The Wisconsin drift-plain in the region about Sioux Falls, South Dakota*: Iowa Academy Science Proceedings, v. 20, p. 237-250.

Carter, K., and Barari, A., 1981, *Hydrology of Wall Lake*: South Dakota Geological Survey Open-File Report 30-UR.

Chamberlin, T.C., 1883, *Preliminary paper on the terminal moraine of the second glacial epoch*: U.S. Geological Survey 3rd Annual Report, p. 291-402.

Cheney, E.S., 1981, *The hunt for giant uranium deposits*: American Scientist, v. 69, p. 37-48.

Christensen, C.M., 1987, *Geology and water resources of Clark County, South Dakota; Part I, Geology*: South Dakota Geological Survey Bulletin 29.

Clark, P.U., 1986, *Reappraisal of early Wisconsin glaciation in North America*: Geological Society of America Abstracts with Programs, v. 18, p. 565.

Cobban, W.A., and Merewether, E.A., 1983, *Stratigraphy and paleontology of mid-Cretaceous rocks in Minnesota and contiguous areas*: U.S. Geological Survey Professional Paper 1253.

Culver, G.E., and Hobbs, W.H., 1892, *On a new occurrence of olivine diabase in Minnehaha County, South Dakota*: Transactions of the Wisconsin Academy of Science, Arts and Letters, v. 8, p. 206-210.

Darton, N.H., 1909, *Geology and underground waters of South Dakota, United States of America*: U.S. Geological Survey Water-Supply Paper 227.

Dienhart, A.V., 1958, *Geology of the Pathfinder Steam Plant site (preliminary report)*: Minneapolis, Minnesota, Northern States Power Company Engineering Department Report E-4366.

Ellis, M.J., and Adolphson, D.G., 1964, *Hydrogeology of the glacial drift in the Skunk Creek-Lake Madison drainage basin, southeastern South Dakota*: U.S. Geological Survey Hydrologic Atlas 195.

____1969, *Basic hydrologic data, for a part of the Big Sioux drainage basin, eastern South Dakota*: South Dakota Geological Survey Basic Data Report 5.

Ellis, M.J., Adolphson, D.G., and West, R.E., 1968, *Hydrology of a part of the Big Sioux drainage basin, eastern South Dakota*: U.S. Geological Survey Hydrologic Atlas HA-311.

Fenneman, N.M., 1931, *Physiography of western United States*: New York, New York, McGraw Hill Book Company.

Flint, R.F., 1955, *Pleistocene geology of eastern South Dakota*: U.S. Geological Survey Professional Paper 262.

Gilbertson, J.P., and Lehr, J.D., 1989, *Quaternary stratigraphy of northeastern South Dakota*, in Gilbertson, J.P. ed., *Quaternary geology of northeastern South Dakota*: South Dakota Geological Survey Guidebook Series 3, 57 p.

Gries, J.P., 1983, *Geometry and stratigraphic relations of the Sioux Quartzite*: South Dakota Academy of Science Proceedings, v. 62, p. 64-74.

Hall, J., and Meek, B., 1856, *Descriptions of new species of fossils from the Cretaceous formations of Nebraska*: Memoirs American Arts and Science, v. 5, pt. 17, p. 379-411.

Hallberg, G.R., 1986, *Pre-Wisconsin stratigraphy of the central Plains region in Iowa, Nebraska, Kansas, and Missouri*: Quaternary Science Reviews, v. 5, p. 11-15.

Hallberg, G.R., and Kemmis, T.J., 1986, *Stratigraphy and correlation of the glacial deposits of the Des Moines and James lobes and adjacent areas in North Dakota, South Dakota, Minnesota, and Iowa*: Quaternary Science Reviews, v. 5, p. 65-68.

Hammond, R.H., 1987, *Inner shelf facies of Upper Cretaceous rocks near the Sioux Ridge of southeast South Dakota*: Geological Society of America, North Central Section, Abstracts with Programs, v. 19, no. 4, p. 202.

____1988, *A preliminary evaluation of the potential for manganese deposits, Sioux Ridge area, South Dakota*: Unpublished report to the U.S. Geological Survey (grant no. 14-08-0001-A0327).

____1991, *Geology of Lake and Moody Counties, South Dakota*: South Dakota Geological Survey Bulletin 35.

____in preparation, *Geology of Lincoln and Union Counties, South Dakota*: South Dakota Geological Survey Bulletin.

Hammond, R.H., and Ludvigson, G.A., 1985, *Shoreline facies of the Upper Cretaceous Niobrara Formation fringing the Sioux Quartzite ridge in southeastern South Dakota*: Society of Economic Paleontologists and Mineralogists, Abstracts with Programs, v. 2, p. 38.

Hedges, L.S., Burch, S.L., Iles, D.L., Barari, A., and Schoon, R.A., 1981, *Evaluation of ground-water resources, eastern South Dakota and the upper Big Sioux River, South Dakota and Iowa*: Final Report for Planning Division, U.S. Army Corps of Engineers.

Holtzheimer, J.M., 1987, *Paleoenvironmental analysis of Upper Cretaceous strata deposited on the northern flank of the Precambrian Sioux Quartzite, Lake and Moody Counties, eastern South Dakota*: Rapid City, South Dakota, South Dakota School of Mines and Technology, unpublished M.S. thesis.

Iles, D.L., in preparation, *Ground-water study for the Sioux Falls-Brandon area*: South Dakota Geological Survey Open-File Report 34-UR.

Iles, D.L., and Frykman, L.J., 1991, *Hydrogeology of the Southern Skunk Creek management unit of the Big Sioux aquifer*: South Dakota Geological Survey Open-File Report 63-UR.

Iles, D.L., Meyer, M.R., Baron, L.R., and Markley, W.E., 1987, *Assessment of hydrogeologic and ground water contamination data in the vicinity of the Hayward Elementary School, West 12th Street, Sioux Falls, South Dakota*: South Dakota Geological Survey Open-File Report 44-UR.

Izett, G.L., 1981, *Volcanic ash beds: Recorders of Upper Cenozoic silicic pyroclastic volcanism in the western United States*: Journal of Geophysical Research, v. 86, p. 1200-1222.

Izett, G.L., and Wilcox, R., 1982, *Map showing localities and inferred distribution of the Pearlette family ash beds of Pliocene-Pleistocene age in the western United States and southern Canada*: U.S. Geological Survey Miscellaneous Investigations Map I-1325, scale 1:5,000,000, text.

Jarrett, M.J., 1990, *Aggregate resources in Minnehaha County, South Dakota*: South Dakota Geological Survey Information Pamphlet 42.

Jarrett, M.J., and Duchossois, G.E., in preparation, *Geology of Hutchinson and Turner Counties, South Dakota*: South Dakota Geological Survey Bulletin.

Jorgensen, D.G., and Ackroyd, E.A., 1973, *Water resources of the Big Sioux River valley near Sioux Falls, South Dakota*: U.S. Geological Survey Water-Supply Paper 2024.

Kairo, S., 1987, *Sedimentology, stratigraphy, and depositional history of the Cretaceous Split Rock Creek Formation, Minnehaha County, South Dakota*: Lafayette, Indiana, Purdue University, unpublished M.S. thesis.

Keyes, C.R., 1914, *Iowa's great period of mountain making*: Proceedings of the Iowa Academy of Science, v. 2, p. 181-187.

Koch, Neil C., 1982, *Digital computer model of the Big Sioux aquifer in Minnehaha County, South Dakota*: U.S. Geological Survey Water Resources Investigation 83-4064.

Lemke, R.W., Laird, W.M., Tipton, M.J., and Lindvall, R.M., 1965, *Quaternary geology of the northern Great Plains*, in Wright, H.E., and Frye, D.G., eds., *The Quaternary of the United States*: Princeton, New Jersey, Princeton University Press, p. 15-27.

Leverett, F., 1932, *Quaternary geology of Minnesota and parts of adjacent states*: U.S. Geological Survey Professional Paper 161.

Lindgren, Richard J., and Niehus, Colin A., 1992, *Water resources of Minnehaha County, South Dakota*: U.S. Geological Survey Water-Resources Investigations Report 91-4101.

____in preparation, *Major aquifers in Minnehaha County, South Dakota*: South Dakota Geological Survey Information Pamphlet.

Ludvigson, G.A., McKay, R.M., Iles, D.L., and Bretz, R.F., 1981, *Lithostratigraphy and sedimentary petrology of the Split Rock Creek Formation, Late Cretaceous of southeastern South Dakota*, in Brenner, R.L., and others, 1981, *Cretaceous stratigraphy and sedimentation in northwest Iowa, northeast Nebraska, and southeast South Dakota*: Iowa Geological Survey Guidebook Series 4, p. 77-104.

McKay, R.M., and Ludvigson, G.A., 1981, *Sedimentary petrology and depositional environment of the Late Cretaceous Split Rock Creek Formation, South Dakota*: Geological Society of America Abstracts with Programs, v. 13, p. 309.

Meek, F.B., and Hayden, F.V., 1862, *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*: Philadelphia Academy of Natural Science Proceedings, v. 13, p. 415-447.

Merewether, E.A., and Cobban, W.A., 1981, *Mid-Cretaceous formations in eastern South Dakota and adjoining areas; stratigraphic, paleontologic, and structural interpretations*: Iowa Geological Survey Guidebook Series 4, p. 43-56.

Nestrud, L.M., Bourne, W.C., Wennblom, J., and Wiesner, W., 1964, *Soil survey of Minnehaha County, South Dakota*: U.S. Department of Agriculture Soil Conservation Service and South Dakota Agricultural Experiment Station Series 1958, no. 30.

Ojakangas, R.W., and Weber, R.E., 1984, *Petrography and paleocurrents of the Lower Proterozoic Sioux Quartzite, Minnesota and South Dakota*, in Southwick, D.L., ed., *Shorter contributions to the geology of the Sioux Quartzite (Early Proterozoic), southwestern Minnesota*: Minnesota Geological Survey Report of Investigations 32, p. 1-16.

Ranney Water Systems, Inc., 1956, *Preliminary report on a hydrogeological survey for the city of Sioux Falls, South Dakota*: City of Sioux Falls, South Dakota, unpublished report.

Richmond, G.M., and Fullerton, D.S., 1986, *Introduction to Quaternary glaciations in the United States of America*: Quaternary Science Reviews, v. 5, p. 3-11.

Rothrock, E.P., 1943, *A geology of South Dakota, Part I, The surface*: South Dakota Geological Survey Bulletin 13.

____1944, *A geology of South Dakota, Part III, Mineral resources*: South Dakota Geological Survey Bulletin 15.

____1958, *Geology and water supplies in the vicinity of the Pathfinder Steam Power Plant project in Minnehaha County, South Dakota*: Minneapolis, Minnesota, Technical report prepared for Northern States Power Company.

Rothrock, E.P., and Newcomb, R.R., 1926, *Sand and gravel deposits of Minnehaha County*: South Dakota Geological and Natural History Survey Circular 26.

Rothrock, E.P., and Otton, E.G., 1947, *Ground water resources of the Sioux Falls area, South Dakota, Parts I and II*: South Dakota Geological Survey Report of Investigations 56.

Schoon, R.A., 1974, *Generalized stratigraphic column of central and northwestern South Dakota*: South Dakota Geological Survey Educational Series South Dakota Map 6.

Setterholm, D.R., and Morey, G.B., 1987, *Stratigraphy and distribution of the Cretaceous rocks of southwestern Minnesota*: Geological Society of America, North Central Section, Abstracts with Programs, v. 19, no. 4, p. 244.

Shimek, B., 1912, *Pleistocene of Sioux Falls, South Dakota and vicinity*: Geological Society of America Bulletin, v. 23, p. 125-154.

Shurr, G.W., 1981, *Cretaceous sea cliffs and structural blocks on the flanks of the Sioux Ridge, South Dakota and Minnesota*, in Brenner, R.F., and others, 1981, *Cretaceous stratigraphy and sedimentation in northwest Iowa, northeast Nebraska, and southeast South Dakota*: Iowa Geological Survey Guidebook Series 4, p. 25-41.

Sklar, P.J., 1982, *Petrologic, petrographic and paleotectonic investigation of Precambrian mafic intrusives in eastern South Dakota*: Iowa City, Iowa, University of Iowa, unpublished M.S. thesis.

Southwick, D.L., Morey, G.B., and Mossler, J.H., 1986, *Fluvial origin of the Proterozoic Sioux Quartzite, southwestern Minnesota*: Geological Society of America Bulletin, v. 97, p. 1432-1441.

Stach, R.L., 1970, *A weathering surface and associated sedimentary rocks near Sioux Falls, South Dakota*: South Dakota Geological Survey unpublished report.

Stach, R.L., Ansfield, V.J., and Iles, D.L., 1981, *Diabase occurrences associated with the Precambrian Sioux Quartzite, eastern South Dakota*: Geological Society of America Abstracts with Programs, v. 13, no. 4, p. 227.

Steece, F.V., 1959a, *Geology of the Sioux Falls quadrangle, South Dakota*: South Dakota Geological Survey Geologic Quadrangle Map, scale 1:62,500, text.

____1959b, *Geology of the Hartford quadrangle, South Dakota*: South Dakota Geological Survey Geologic Quadrangle Map, scale 1:62,500, text.

____1960, *Pleistocene volcanic ash in southeastern South Dakota*: South Dakota Academy of Science Proceedings, v. 38, p. 41-44.

____1965, *Illinoian age drift in southeastern South Dakota*: South Dakota Academy of Science Proceedings, v. 44, p. 62-71.

Tipton, M.J., 1959a, *Geology of the Dell Rapids quadrangle, South Dakota*: South Dakota Geological Survey Geologic Quadrangle Map, scale 1:62,500, text.

____1959b, *Geology of the Chester quadrangle, South Dakota*: South Dakota Geological Survey Geologic Quadrangle Map, scale 1:62,500, text.

____1960, *A new glacial drift sheet in South Dakota?*: South Dakota Academy of Science Proceedings, v. 38, p. 45-48.

Tipton, M.J., and Steece, F.V., 1965, *Reprint of South Dakota part of INQUA guidebook and supplemental data for Field Conference C, Upper Mississippi Valley*: South Dakota Geological Survey Guidebook Series 1.

Todd, J.E., 1894, *A preliminary report on the geology of South Dakota*: South Dakota Geological Survey Bulletin 1.

____1899, *The moraines of southeastern South Dakota and the attendant deposits*: U.S. Geological Survey Water-Supply Paper 34.

___1904, *Discovered rock at Sioux Falls, South Dakota*: American Geologist, v. 33, p. 35-39.

Upham, W., 1885, *Notes on the geology of Minnehaha County, South Dakota*: Minnesota Geological and Natural History Survey 13th Annual Report, p. 88-97.

White, C.A., 1870, *Report on the Geological Survey of Iowa*: Iowa Geological Survey, v. 1, p. 167-171.

Witzke, B.J., Ludvigson, G.A., Poppe, J.R., and Ravn, R.L., 1983, *Cretaceous paleogeography along the eastern margin of the Western Interior Seaway, Iowa, southern Minnesota, and eastern Nebraska and South Dakota*, in Reynolds, M.W., and Dolly, E.D., eds., *Mesozoic paleogeography of west-central U.S.*: Denver, Colorado, The Rocky Mountain Section Society of Economic Paleontologists and Mineralogists, p. 225-252.

APPENDIX

Legal descriptions of test-hole logs

The following list contains the numbers and legal descriptions of all the test-hole logs used to construct the cross sections (figs. 5 through 18). These logs are available from the computer files of the South Dakota Geological Survey. The map location numbers refer only to this report. Any request for logs should contain the legal descriptions.

MAP LOCATION NUMBER	LEGAL DESCRIPTION
MLN- 1	NW NE NE NE sec. 4, T. 104 N., R. 52 W.
MLN- 2	SW SW SW SW sec. 31, T. 105 N., R. 51 W.
MLN- 3	SW SW SW SW sec. 34, T. 105 N., R. 51 W.
MLN- 4	NE NW NW NW sec. 6, T. 104 N., R. 50 W.
MLN- 5	SE SE SE SE sec. 36, T. 105 N., R. 49 W.
MLN- 6	SW SW SW SW sec. 34, T. 105 N., R. 47 W.
MLN- 7	NE NE NE NE sec. 13, T. 104 N., R. 53 W.
MLN- 8	NE NE NW NE sec. 16, T. 104 N., R. 52 W.
MLN- 9	NW NW NW NW sec. 18, T. 104 N., R. 51 W.
MLN- 10	SE SE SE SE sec. 9, T. 104 N., R. 51 W.
MLN- 11	SW SW SW SW sec. 7, T. 104 N., R. 50 W.
MLN- 12	NE NE SW sec. 16, T. 104 N., R. 50 W.
MLN- 13	NW NW SW SW sec. 7, T. 104 N., R. 49 W.
MLN- 14	SE SE SE SE sec. 7, T. 104 N., R. 49 W.
MLN- 15	NE SE NE sec. 17, T. 104 N., R. 49 W.
MLN- 16	SW SW NW SW sec. 12, T. 104 N., R. 49 W.
MLN- 17	SE SE SE SE sec. 7, T. 104 N., R. 48 W.
MLN- 18	SE SE NE NE sec. 15, T. 104 N., R. 48 W.
MLN- 19	SW SE SE NE sec. 12, T. 104 N., R. 48 W.
MLN- 20	SE SE SE SE sec. 7, T. 104 N., R. 47 W.
MLN- 21	SW NW SW SW sec. 15, T. 104 N., R. 47 W.
MLN- 22	NE NE NE NE sec. 15, T. 104 N., R. 47 W.
MLN- 23	SE SE SE SE sec. 18, T. 104 N., R. 48 W.
MLN- 24	NW SW SW SW sec. 30, T. 104 N., R. 52 W.
MLN- 25	SE SW SW SW sec. 27, T. 104 N., R. 52 W.
MLN- 26	SW NW NW NW sec. 31, T. 104 N., R. 51 W.
MLN- 27	SW SW SW SW sec. 27, T. 104 N., R. 51 W.
MLN- 28	NE NE NE NW sec. 35, T. 104 N., R. 51 W.
MLN- 29	NW NW NW NW sec. 31, T. 104 N., R. 50 W.
MLN- 30	NE NE NE NE sec. 33, T. 104 N., R. 50 W.
MLN- 31	NE NE NE NE sec. 35, T. 104 N., R. 50 W.
MLN- 32	SW SW SW SW sec. 30, T. 104 N., R. 49 W.
MLN- 33	NE NE NE NE sec. 34, T. 104 N., R. 49 W.
MLN- 34	NE NE NE NE sec. 31, T. 104 N., R. 48 W.
MLN- 35	NE NE NE SE sec. 27, T. 104 N., R. 48 W.
MLN- 36	SW SW SW SW sec. 29, T. 104 N., R. 47 W.
MLN- 37	NE NW NE NE sec. 34, T. 104 N., R. 47 W.
MLN- 38	SW SW SW NW sec. 3, T. 103 N., R. 51 W.
MLN- 39	NE NW NW NW sec. 10, T. 103 N., R. 47 W.
MLN- 40	SW SW SW SW sec. 7, T. 103 N., R. 52 W.

MAP LOCATION NUMBER	LEGAL DESCRIPTION
MLN- 41	NW NW NW NW sec. 15, T. 103 N., R. 52 W.
MLN- 42	NW NW NW NE sec. 14, T. 103 N., R. 52 W.
MLN- 43	NW NW NW NW sec. 18, T. 103 N., R. 51 W.
MLN- 44	SW SW SW SW sec. 10, T. 103 N., R. 51 W.
MLN- 45	SW SW SW SW sec. 7, T. 103 N., R. 50 W.
MLN- 46	SE SE SE SE sec. 9, T. 103 N., R. 50 W.
MLN- 47	SE SE SE SE sec. 12, T. 103 N., R. 50 W.
MLN- 48	NW NE NW SE sec. 17, T. 103 N., R. 49 W.
MLN- 49	NE NE NE NE sec. 15, T. 103 N., R. 49 W.
MLN- 50	NE NE NW NW sec. 18, T. 103 N., R. 48 W.
MLN- 51	NE NE NE NE sec. 18, T. 103 N., R. 48 W.
MLN- 52	NE NE NE NE sec. 14, T. 103 N., R. 48 W.
MLN- 53	NW NW NW NW sec. 17, T. 103 N., R. 47 W.
MLN- 54	NE NE NE NE sec. 15, T. 103 N., R. 47 W.
MLN- 55	NW NW NW SW sec. 30, T. 103 N., R. 50 W.
MLN- 56	SE SE SE SE sec. 21, T. 103 N., R. 50 W.
MLN- 57	NE NE NE SE sec. 16, T. 103 N., R. 47 W.
MLN- 58	SE SE SE SE sec. 16, T. 103 N., R. 47 W.
MLN- 59	NW NW SW SW sec. 30, T. 103 N., R. 52 W.
MLN- 60	SE NE NE NE sec. 28, T. 103 N., R. 52 W.
MLN- 61	SE SE SE SE sec. 25, T. 103 N., R. 51 W.
MLN- 62	NW NW NW SW sec. 28, T. 103 N., R. 51 W.
MLN- 63	SW SW SW SW sec. 27, T. 103 N., R. 51 W.
MLN- 64	NW NW NW NW sec. 31, T. 103 N., R. 50 W.
MLN- 65	NE NE NE NE sec. 33, T. 103 N., R. 50 W.
MLN- 66	SW SE SE SE sec. 25, T. 103 N., R. 50 W.
MLN- 67	SW SW SE SW sec. 29, T. 103 N., R. 49 W.
MLN- 68	SE SE SW sec. 28, T. 103 N., R. 49 W.
MLN- 69	NE NE NW NW sec. 34, T. 103 N., R. 49 W.
MLN- 70	SE SE SE SE sec. 27, T. 103 N., R. 49 W.
MLN- 71	NW NW NW NW sec. 32, T. 103 N., R. 48 W.
MLN- 72	SW SE SE SE sec. 28, T. 103 N., R. 48 W.
MLN- 73	SE SE SE SE sec. 27, T. 103 N., R. 48 W.
MLN- 74	NW NE NE NE sec. 35, T. 103 N., R. 48 W.
MLN- 75	NE NE NE NE sec. 32, T. 103 N., R. 47 W.
MLN- 76	NW NW NW NW sec. 34, T. 103 N., R. 47 W.
MLN- 77	NE NE NE NE sec. 34, T. 103 N., R. 47 W.
MLN- 78	NW NW NW NW sec. 3, T. 102 N., R. 52 W.
MLN- 79	SW SW SW SW sec. 34, T. 103 N., R. 51 W.
MLN- 80	NE SE SE NE sec. 1, T. 102 N., R. 51 W.
MLN- 81	SE SE SE SE sec. 36, T. 103 N., R. 50 W.
MLN- 82	NW NE NW NW sec. 9, T. 102 N., R. 49 W.
MLN- 83	NE NE NE NE sec. 7, T. 102 N., R. 48 W.
MLN- 84	NE NE NE NE sec. 9, T. 102 N., R. 47 W.
MLN- 85	NW SW SW SW sec. 7, T. 102 N., R. 52 W.
MLN- 86	SW NW SW SW sec. 15, T. 102 N., R. 52 W.
MLN- 87	SW SW SW SW sec. 7, T. 102 N., R. 51 W.
MLN- 88	NE NE NE NE sec. 16, T. 102 N., R. 51 W.

MAP LOCATION NUMBER	LEGAL DESCRIPTION
MLN- 89	SW SW SW SW sec. 7, T. 102 N., R. 50 W.
MLN- 90	SE SE SE SE sec. 9, T. 102 N., R. 50 W.
MLN- 91	SW SE SW SE sec. 7, T. 102 N., R. 49 W.
MLN- 92	SW SE SW SE sec. 8, T. 102 N., R. 49 W.
MLN- 93	NE NE NW NW sec. 15, T. 102 N., R. 49 W.
MLN- 94	NE NE NE NE sec. 15, T. 102 N., R. 49 W.
MLN- 95	NW NE NE NE sec. 14, T. 102 N., R. 49 W.
MLN- 96	NW NW NW NW sec. 18, T. 102 N., R. 48 W.
MLN- 97	NE NE NE NE sec. 18, T. 102 N., R. 48 W.
MLN- 98	SE SE SE SE sec. 8, T. 102 N., R. 48 W.
MLN- 99	NE NE NE NE sec. 16, T. 102 N., R. 48 W.
MLN-100	NE NE SE SE sec. 10, T. 102 N., R. 48 W.
MLN-101	NW NW NW NW sec. 18, T. 102 N., R. 47 W.
MLN-102	NE NE NE NE sec. 16, T. 102 N., R. 47 W.
MLN-103	NW NW NW SW sec. 19, T. 102 N., R. 50 W.
MLN-104	SW SW SW SW sec. 14, T. 102 N., R. 49 W.
MLN-105	NE SE SE SE sec. 24, T. 102 N., R. 49 W.
MLN-106	NE NE NE NE sec. 19, T. 102 N., R. 48 W.
MLN-107	NW NW NW NW sec. 31, T. 102 N., R. 52 W.
MLN-108	NW NE NE NW sec. 31, T. 102 N., R. 52 W.
MLN-109	NE NE NE NE sec. 32, T. 102 N., R. 52 W.
MLN-110	SE SW SW SW sec. 26, T. 102 N., R. 52 W.
MLN-111	SE SE SE SE sec. 25, T. 102 N., R. 52 W.
MLN-112	NW NW NW NW sec. 34, T. 102 N., R. 51 W.
MLN-113	SE SE SE SE sec. 25, T. 102 N., R. 51 W.
MLN-114	SW SE SW SE sec. 28, T. 102 N., R. 50 W.
MLN-115	SW SW SW SW sec. 27, T. 102 N., R. 50 W.
MLN-116	NE NE NE NE sec. 34, T. 102 N., R. 50 W.
MLN-117	SE SE SE sec. 28, T. 102 N., R. 49 W.
MLN-118	SW SW SW NW sec. 26, T. 102 N., R. 49 W.
MLN-119	SE SE SW SW sec. 25, T. 102 N., R. 49 W.
MLN-120	SE SE SE NE sec. 30, T. 102 N., R. 48 W.
MLN-121	NW NW NE SE sec. 29, T. 102 N., R. 48 W.
MLN-122	NW NW SW sec. 28, T. 102 N., R. 48 W.
MLN-123	NW SW NE SW sec. 28, T. 102 N., R. 48 W.
MLN-124	NW NW NW NW sec. 34, T. 102 N., R. 48 W.
MLN-125	SW SW NW NW sec. 35, T. 102 N., R. 48 W.
MLN-126	NE NE NE NE sec. 36, T. 102 N., R. 48 W.
MLN-127	NE NE NE NE sec. 33, T. 102 N., R. 47 W.
MLN-128	NE NE SE SE sec. 27, T. 102 N., R. 47 W.
MLN-129	SE NE NE SE sec. 1, T. 101 N., R. 51 W.
MLN-130	SW SE SW NW sec. 32, T. 102 N., R. 48 W.
MLN-131	SW SW SW SW sec. 5, T. 101 N., R. 48 W.
MLN-132	NE NE NE NE sec. 4, T. 101 N., R. 48 W.
MLN-133	SW SW SW SW sec. 2, T. 101 N., R. 48 W.
MLN-134	NW NW NW SW sec. 6, T. 101 N., R. 47 W.
MLN-135	SW SW SW SE sec. 32, T. 102 N., R. 47 W.
MLN-136	SW SW SW SW sec. 34, T. 102 N., R. 47 W.

MAP LOCATION NUMBER	LEGAL DESCRIPTION
MLN-137	SE SE SE SE sec. 34, T. 102 N., R. 47 W.
MLN-138	NE NE NE NE sec. 13, T. 101 N., R. 53 W.
MLN-139	NE NE NE NE sec. 16, T. 101 N., R. 52 W.
MLN-140	NE NE SE NE sec. 13, T. 101 N., R. 52 W.
MLN-141	NE NE NE NE sec. 16, T. 101 N., R. 51 W.
MLN-142	SW SW SW SW sec. 7, T. 101 N., R. 50 W.
MLN-143	NE NE NE NW sec. 18, T. 101 N., R. 50 W.
MLN-144	NE NW NE NE sec. 18, T. 101 N., R. 50 W.
MLN-145	NE NE NE NW sec. 16, T. 101 N., R. 50 W.
MLN-146	NE NE NE NE sec. 14, T. 101 N., R. 50 W.
MLN-147	NE SE SE SE sec. 12, T. 101 N., R. 49 W.
MLN-148	SE NE SE SE sec. 7, T. 101 N., R. 48 W.
MLN-149	SE SE SE NE sec. 9, T. 101 N., R. 48 W.
MLN-150	NE NE NE NE sec. 13, T. 101 N., R. 48 W.
MLN-151	NE NW NW NE sec. 18, T. 101 N., R. 47 W.
MLN-152	SE SE SE SE sec. 8, T. 101 N., R. 47 W.
MLN-153	NE NE NE NE sec. 16, T. 101 N., R. 47 W.
MLN-154	SW SW SW SW sec. 18, T. 101 N., R. 50 W.
MLN-155	SW SW SE SW sec. 17, T. 101 N., R. 48 W.
MLN-156	SE SE NE SE sec. 19, T. 101 N., R. 48 W.
MLN-157	NW NW NW NW sec. 31, T. 101 N., R. 52 W.
MLN-158	NE NE NE NE sec. 33, T. 101 N., R. 52 W.
MLN-159	NW NW NW NW sec. 31, T. 101 N., R. 51 W.
MLN-160	NE NE NE NE sec. 33, T. 101 N., R. 51 W.
MLN-161	SW SW SW SW sec. 30, T. 101 N., R. 50 W.
MLN-162	NW SW SW SE sec. 29, T. 101 N., R. 50 W.
MLN-163	NW NW NW NW sec. 34, T. 101 N., R. 50 W.
MLN-164	SE NE NE NE sec. 34, T. 101 N., R. 50 W.
MLN-165	NE SW NW SE sec. 25, T. 101 N., R. 50 W.
MLN-166	NE SE SE NE sec. 32, T. 101 N., R. 49 W.
MLN-167	NW NW NW NE sec. 35, T. 101 N., R. 49 W.
MLN-168	SW SE SE SE sec. 25, T. 101 N., R. 49 W.
MLN-169	SE SE SE SW sec. 28, T. 101 N., R. 48 W.
MLN-170	SW SW SW SW sec. 27, T. 101 N., R. 48 W.
MLN-171	SW SE SW SE sec. 27, T. 101 N., R. 48 W.
MLN-172	SE SW SW SW sec. 26, T. 101 N., R. 48 W.
MLN-173	SE SW SW SE sec. 26, T. 101 N., R. 48 W.
MLN-174	NW NW NW NW sec. 31, T. 101 N., R. 47 W.
MLN-175	NW NW NW NW sec. 33, T. 101 N., R. 47 W.
MLN-176	NW NW NW NW sec. 34, T. 101 N., R. 47 W.