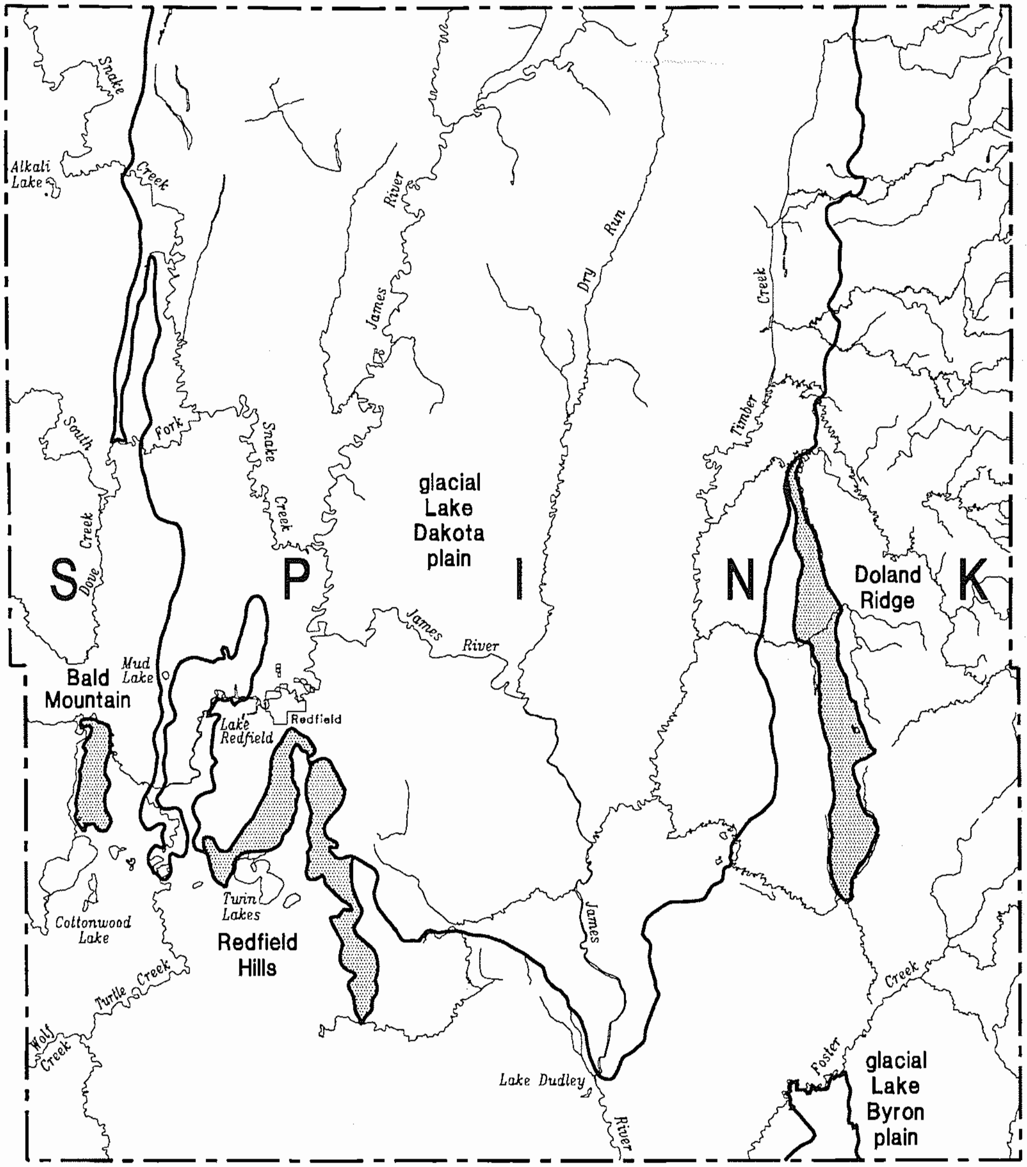
BULLETIN 38

GEOLOGY OF SPINK COUNTY, SOUTH DAKOTA

Dennis W. Tomhave



Prepared in cooperation with the
United States Geological Survey,
James River Water Development District,
Mid-Dakota Water Development District,
and Spink County

Department of Environment and Natural Resources
Division of Financial and Technical Assistance
Geological Survey
Akeley Science Center, University of South Dakota
Vermillion, South Dakota
1997

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WN036 May 1997.

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ABSTRACT

Spink County is located in east-central South Dakota and covers an area of about 1,512 square miles. The entire county lies within the James Basin division of the Central Lowland Physiographic Province. Major geomorphic features include the James River valley, glacial Lake Dakota plain, Doland Ridge, Redfield Hills, and Bald Mountain.

Pre-Pleistocene rocks range in age from Precambrian basement rocks to the Cretaceous Pierre Shale. Over most of the county, Cretaceous sediments are found directly over the Precambrian basement. Little is known about the pre-Cretaceous rocks which would have been deposited from the Cambrian through the Jurassic Periods. Occurrences of these rocks in Spink County are very scarce, probably due to nondeposition or removal by erosion.

The Cretaceous-aged rocks found in Spink County include from oldest to youngest: Inyan Kara Group, Skull Creek Shale, Dakota Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, and Pierre Shale. Only the latter crops out at the surface. Sediments of the Carlile Shale, Niobrara Formation, and Pierre Shale are found in subcrop beneath Quaternary deposits.

Spink County is covered by Pleistocene and Holocene deposits except for the few small areas where the Pierre Shale is exposed. Late Wisconsin-aged sediments comprise most of the surficial deposits. Recent deposits include stream alluvium, lake sediments, and some wind-blown material.

INTRODUCTION

Purpose

The primary intent of this investigation is the location and evaluation of the mineral and water resources available in Spink 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 Spink County is one of a series of cooperative county wide studies conducted in eastern South Dakota (fig. 1). The Spink County study was financed by the South Dakota Department of Environment and Natural Resources – Geological Survey, U.S. Geological Survey, James River Water Development District, Mid-Dakota Water Development District, and Spink County.

The findings of the investigation are published in four parts:

1. *Sand and gravel resources in Spink County, South Dakota*: South Dakota Geological Survey Information Pamphlet 48, Schulz, Layne D., 1995.

2. *Major aquifers in Spink County, South Dakota*: South Dakota Geological Survey Information Pamphlet, Benson, Rick D., U.S. Geological Survey, in preparation.

3. *Geology of Spink County, South Dakota*: South Dakota Geological Survey Bulletin 38, Tomhave, Dennis W. (this report).

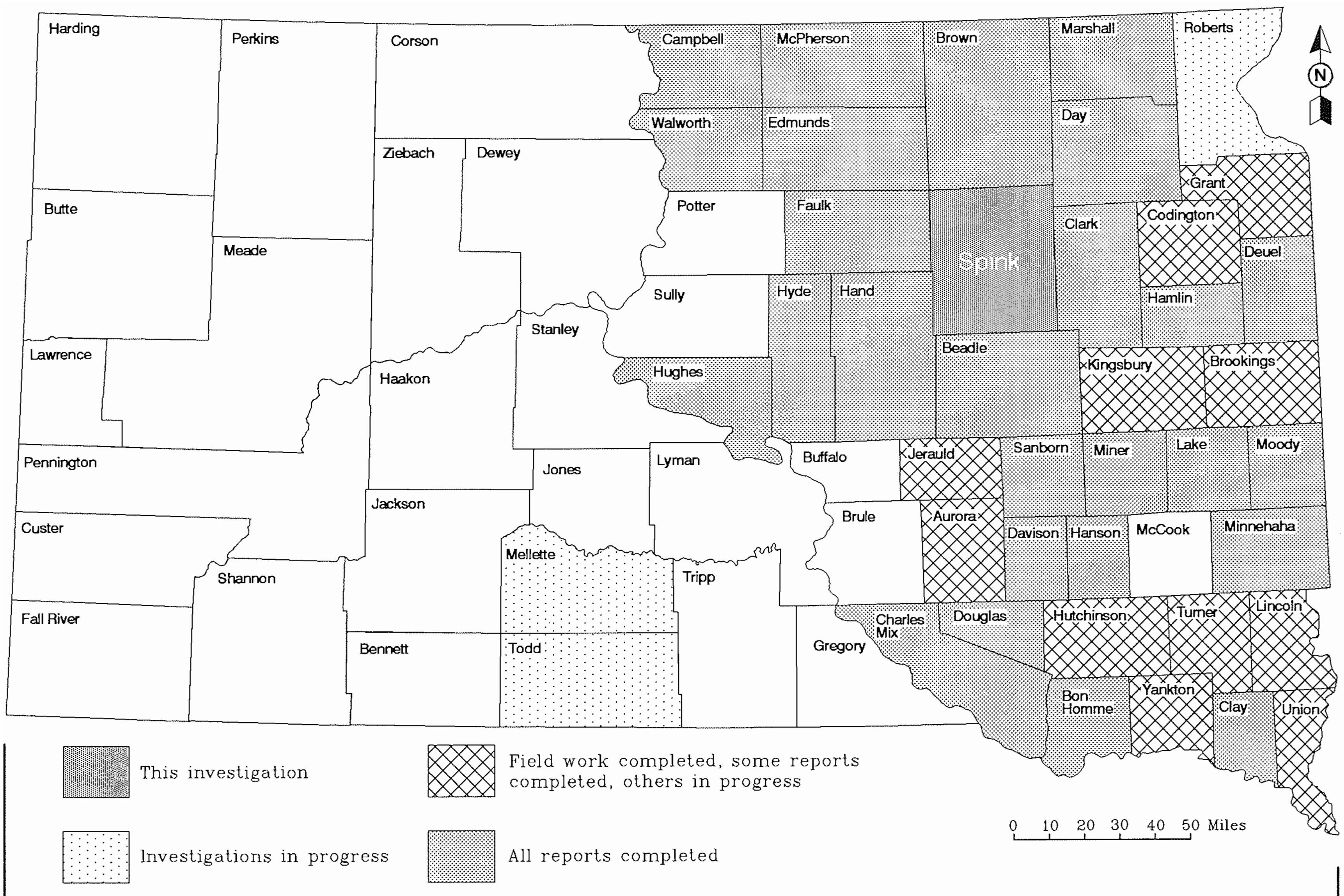


Figure 1. Status of county-wide investigations in South Dakota.

4. *Water resources of Spink County, South Dakota*: U.S. Geological Survey Water-Resources Investigations Report 96-4056, Hamilton, Louis J., and Howells, Lewis W., 1996.

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 Spink 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

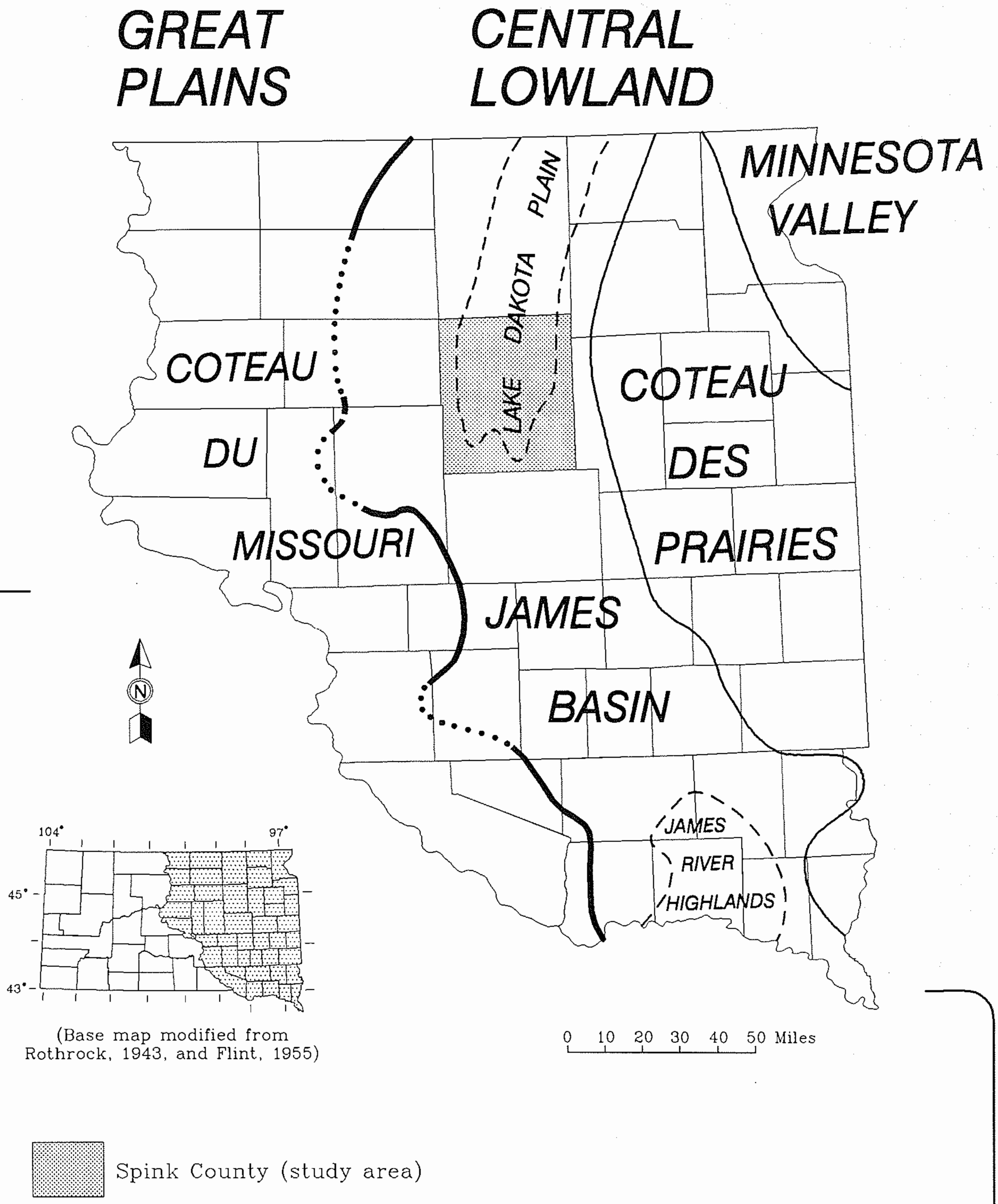
Spink County (fig. 2), covering an area of about 1,512 square miles, is located entirely within the James Basin division of the Central Lowland Physiographic Province (Fenneman, 1931). The county is bordered by Brown County on the north, Hand and Faulk Counties on the west, Clark and Day Counties on the east, and Beadle County on the south.

Several prominent geomorphic features are found within the county including: the glacial Lake Dakota plain, the glacial Lake Byron plain, Doland Ridge, Redfield Hills, Bald Mountain, and the James River valley (fig. 3). The bed of glacial Lake Dakota dominates the central portion of the county, covering an area of over 700 square miles. The glacial Lake Dakota plain is the bed of a large lake (figs. 2 and 3) formed by glacial meltwater trapped between the receding ice and the surrounding highlands. The surface of the lake plain generally lies at an elevation between 1,290 and 1,305 feet above mean sea level. It is nearly flat, with relief seldom exceeding 10 feet, except where incised by stream erosion.

From the glacial Lake Dakota plain, the land surface rises to the east to an elevation of about 1,430 feet along the eastern county border. This area of the county is fairly flat to gently undulating, with the exception of Doland Ridge which is more rugged with several hilltops reaching an elevation of 1,420 feet. The area is well dissected by many small tributary streams of Timber and Foster Creeks which flow from the Coteau des Prairies highland just east of the county.

West of the glacial Lake Dakota plain the land surface is very undulating with many boulder-strewn hills. Several lakes and many sloughs are found within this area. This area is also well dissected by streams flowing from the Coteau du Missouri highland west of the county including: South Fork Snake Creek, Snake Creek, Medicine Creek, Dove Creek, Turtle Creek, and Wolf Creek. Redfield Hills and Bald Mountain reaching elevations of 1,375 feet and 1,480 feet, respectively, are located here.

Streams flowing from the Coteau des Prairies to the east and the Coteau du Missouri to the west eventually reach the glacial Lake Dakota plain, where they ultimately enter the James River. The James River and its tributaries have incised through the lake sediments to expose older sediments below. The James River flows south out of the glacial Lake Dakota plain through a relatively flat, boulder-strewn area and exits the county at an elevation of about 1,235 feet.



(Base map modified from Rothrock, 1943, and Flint, 1955)

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

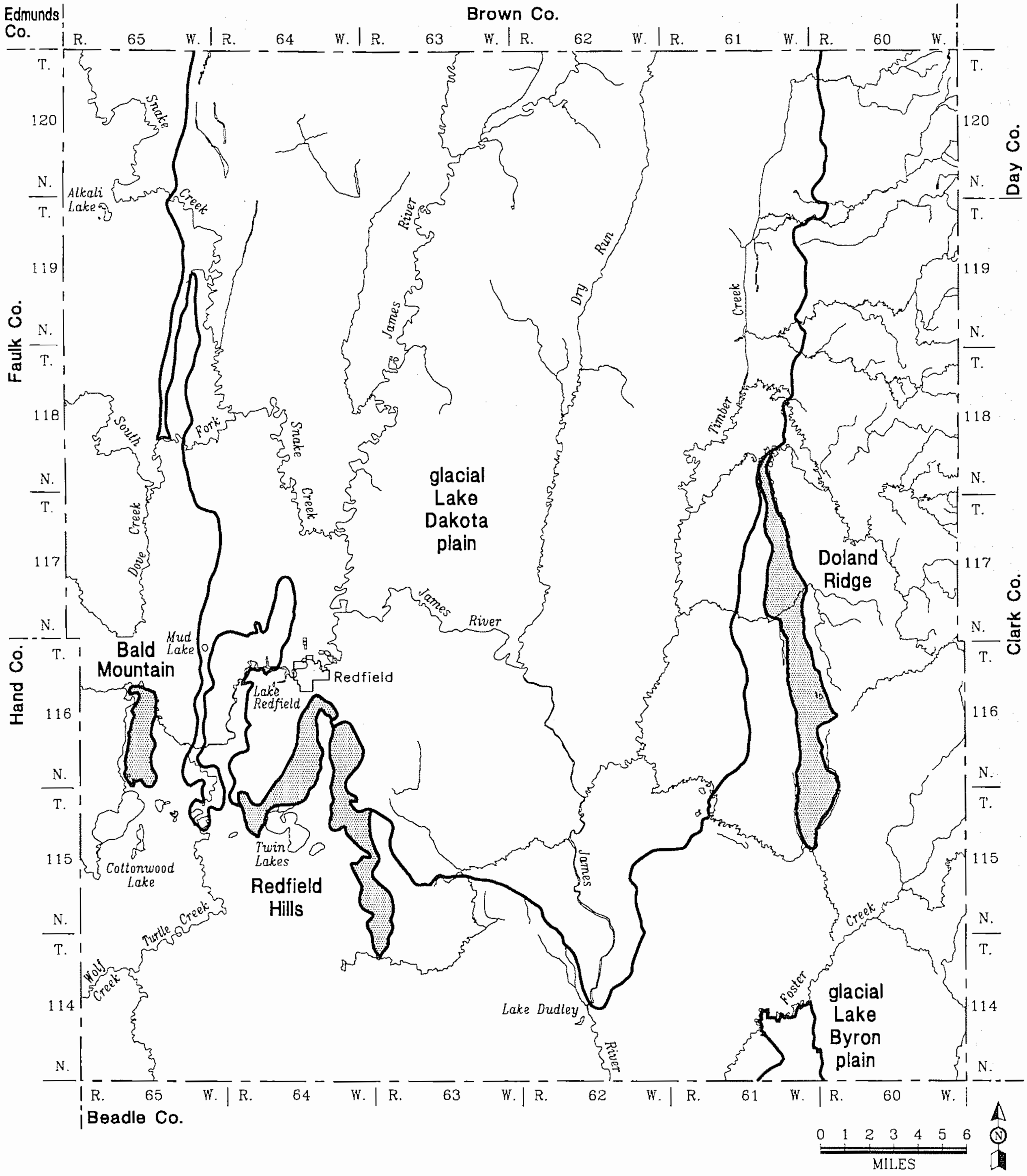


Figure 3. Map showing the locations of major geomorphic features in Spink County, South Dakota.

Previous Investigations

Prior to this investigation the Spink County area has been included in a number of reconnaissance studies dealing primarily with the bedrock and general geology of South Dakota (Todd, 1894; Darton, 1909; and Rothrock, 1943 and 1944). There were also several studies which dealt specifically with the Spink County area (Todd and Hall, 1904; Todd, 1909; Rothrock, 1946; and Hopkins and Petri, 1963).

Todd (1909), working for the U.S. Geological Survey, mapped nearly all of Spink County. The mapping was part of a large project to be incorporated in an atlas of the United States. Each portion of the project was issued in parts called folios. Spink County was included in the Aberdeen-Redfield folio which covers an area a degree in latitude by a degree in longitude (approximately 1,690 square miles).

Todd (1909) described in great detail the glacial geology of the Aberdeen-Redfield district. Several other studies were conducted that were primarily concerned with glacial geology (Chamberlin, 1883; Gwynne, 1951; Leverett, 1932; Flint, 1955; and Lemke and others, 1965).

Many of the early studies investigated the water resources of the area, specifically the artesian waters (Darton, 1896 and 1909; Todd, 1909; Erickson, 1954 and 1955; and Schoon, 1971). In addition, more recent ground water supply studies have been conducted for Redfield (Christensen, 1963; and Iles and Barari, 1978), Southern Spink-Northern Beadle Municipal Water Council (Burch, 1981), and eastern South Dakota (Hedges and others, 1981). Spink County is also included in a preliminary assessment of the hydrologic characteristics of the James River in South Dakota (Benson, 1983).

All of the surrounding counties have been the subject of investigations similar to this cooperative study. Reports from the surrounding counties include: Beadle County (Howells and Stephens, 1968; and Hedges, 1968), Faulk County (Christensen, 1973 and 1977; and Hamilton, 1974 and 1982), Day County (Leap, 1972 and 1988), Brown County (Koch and others, 1973; Koch and Bradford, 1976; and Leap, 1986), Hand County (Koch, 1976 and 1980; Schroeder, 1976; and Helgerson and Duchossois, 1987), and Clark County (Hamilton, 1978 and 1986; Schroeder, 1977; and Christensen, 1987).

Acknowledgements

The investigation and preparation of this publication were performed under the supervision of Merlin J. Tipton, former State Geologist, and C.M. Christensen, 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 drillers, Gary Jensen, Millard Thompson, Jr., and Duane Jacobson, and all of the summer field assistants. Without their much appreciated efforts this investigation would not have been possible.

The cooperative efforts of Louis Hamilton, Lewis Howells, Frank Amundson, and other staff members of the U.S. Geological Survey; staff and board members of the Mid-Dakota Water Development District; staff and board members of the James River Water Development District; and the Spink County commissioners are gratefully acknowledged. Much thanks also goes to the residents of Spink County and the private well drillers of the area who contributed useful information.

Financial assistance for the Spink County Study was provided by the South Dakota Department of Environment and Natural Resources – Geological Survey, U.S. Geological Survey, James River Water Development District, Mid-Dakota Water Development District, and Spink County.

Methods of Investigation

Information contained in this report derived from the compilation of preexisting data and data collected during the 1988 through 1992 field seasons. Preexisting data were plotted on both 7½-minute topographic maps and ½ inch to the mile county highway maps. A test drilling program was set up to obtain data where lacking and to ensure at least a 3-mile grid of test holes across the county. Test holes generally penetrated through Pleistocene-aged sediments to the underlying Cretaceous-aged sediments. Additional test holes were drilled and observation wells installed to better define the extent and thickness of various aquifers and geologic formations. In all, 782 test holes were drilled and 99 observation wells installed for the Spink County Study. To date, approximately 1,800 Spink County test hole logs are on file in the computer database and are available from the office of the South Dakota Geological Survey in Vermillion, South Dakota.

Subsurface geologic data were collected from test holes logs, bore hole cuttings, and geophysical logs. There are 152 test hole sites in Spink County that have an available geophysical log (electric resistivity, natural gamma, and/or spontaneous 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, and previous investigations. The geology was mapped on 7½-minute topographic maps, transferred to a base map with a scale of 1:100,000 (approximately 1 inch equaling 1½ miles), and later reduced for publication.

BEDROCK GEOLOGY

Introduction

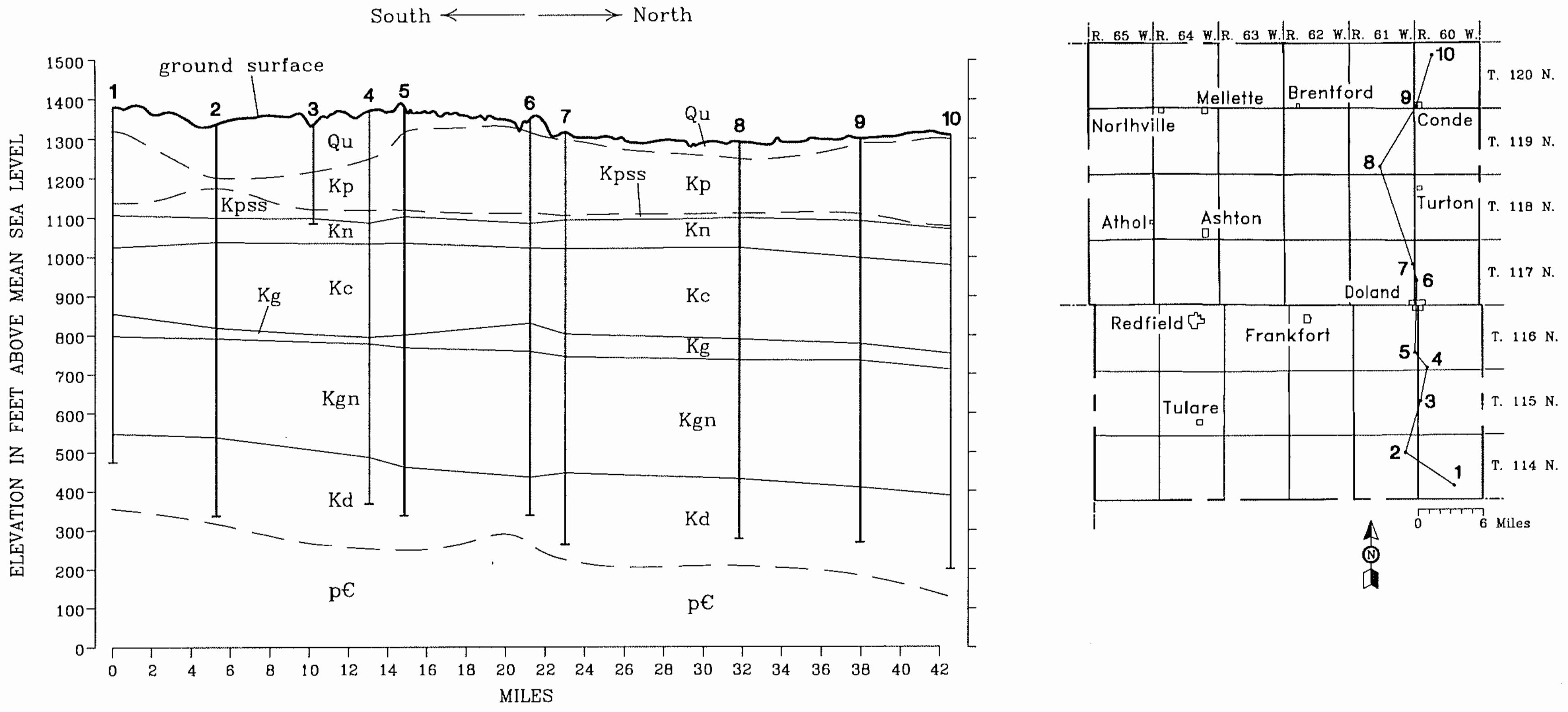
Bedrock refers to Precambrian- to Tertiary-aged rocks which underlie Quaternary-aged rocks. Table 1 lists the bedrock units recognized in Spink County. The cross section in figure 4 shows the stratigraphic relationships and structure of the various geologic units in eastern Spink County. Plate 1 shows the configuration of the bedrock surface and indicates which bedrock unit occurs at this surface.

The only bedrock unit exposed at the land surface in Spink County is the Pierre Shale (pl. 2). No attempt was made to differentiate which member of the Pierre Shale, discussed below, occurs at the land surface. In addition to the Pierre Shale, the Niobrara Formation and Carlile Shale were found to subcrop beneath the various Pleistocene and Holocene deposits (pl. 1). The Niobrara Formation is found in subcrop over a large portion of southern Spink County and along other deep drainageways that have been cut into the bedrock surface. Several test holes, drilled in these deep drainage channels, encountered the Carlile Shale below Pleistocene deposits.

Era	Period		Rock Units		Description	Thickness in Feet	Cretaceous Cyclothem
Cenozoic	Quaternary	Holocene	See Table 2		See text pages 34 to 38	0 - 400	▨
		Pleistocene					
	Tertiary		None		None	0	
Mesozoic	Cretaceous	Upper	Pierre Shale	undifferentiated	Gray to dark-gray, noncalcareous claystone; with concretions and bentonite layers.	0 - 240	Bearpaw
				DeGrey Member	Gray claystone; with numerous bentonite layers.	(0 - ?)	
				Crow Creek Member	Light-gray; calcareous sand, chalk, and calcareous shale.	(0 - 35)	
				Gregory Member	Gray, noncalcareous claystone.	(0 - 110)	Claggett
				Sharon Springs Member	Black, highly organic noncalcareous, bentonitic claystone.	(0 - 60)	
			Niobrara Formation		Dark-gray; calcarenite, chalk, and calcareous shale; pyritic, burrowed, containing some bentonite.	0 - 130	Niobrara
			Carlile Shale	unnamed member	Gray shale.	190 - 240	Greenhorn
				Codell Sandstone Member	Fine- to coarse-grained sandstone; cross-bedding; abundant sharks teeth and phosphatic nodules.		
				Blue Hill Shale Member	Dark-gray, pyritic, concretionary mudstone.		
				Fairport Chalky Member	Grayish-brown, chalky, organic-rich shale.		
			Greenhorn Limestone		Grayish-brown calcareous claystone; with thin shelly, argillaceous limestone layers.	20 - 75	
			Graneros Shale		Dark-gray, noncalcareous, pyritic, poorly fossiliferous claystone; with abundant thin sand layers near base.	250- 360	
			Dakota Formation		White to light-gray, fine-grained, quartz sandstone; with some claystone layers.	100 - 200	
		Lower	Skull Creek Shale		Dark-gray to black claystone.	0 - 50	Kiowa-Skull Creek
			Inyan Kara Group		Undifferentiated sandstone and claystone.	0 - ?	
	Jurassic				?	0 - ?	▨
	Triassic				?	0 - ?	
Paleozoic					?	0 - ?	
Precambrian			Precambrian		Variable igneous and metamorphic rocks.	?	

═══ Period of erosion or nondeposition (unconformity)

TABLE 1. Generalized stratigraphic column of geologic units in Spink County, South Dakota



Cretaceous

Qu ...... Quaternary, undifferentiated

Kp ...... Pierre Shale

Kpss ... Sharon Springs Member – Pierre Shale

Kn ...... Niobrara Formation

Kc ...... Carlile Shale

Kg ...... Greenhorn Limestone

Kgn .... Graneros Shale

Kd ...... Dakota Formation

p€ ...... Precambrian

| Test hole or well

Vertical exaggeration = 106x

Lines dashed where approximate. (Based on data interpreted from geophysical logs and test hole logs on file at the Geological Survey in Vermillion, South Dakota.)

Figure 4. Cross section showing stratigraphic relationships and structure of geologic units in eastern Spink County, South Dakota.

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).

Precambrian Deposits

The Precambrian is an era of geologic time which includes rocks deposited from several billion to about 570 million years ago. It is equivalent to about 90 percent of geologic time (Bates and Jackson, 1987).

The Precambrian deposits of Spink County are undoubtedly exceedingly complex, containing a wide variety of igneous and metamorphic rocks with many different structures about which relatively little is known. From 900 to over 1,100 feet of Cretaceous and Quaternary sediment overlie Precambrian rocks in Spink County.

Most of what is known about the Precambrian in this area was obtained from borings conducted from the late 1800's through the mid-1900's. Most of the wells installed during this time were completed to the Dakota Formation. Some of the borings penetrated through the Dakota Formation to the Precambrian basement. Todd (1909) reported occurrences of quartzite, granite, and schist from these deep borings. A chlorite schist was also reported at a depth of 1,024 feet in the NE¼ of section 26, T. 115 N., R. 64 W. by geologist Bruno Petsch in 1953 (Bolin and Petsch, 1954).

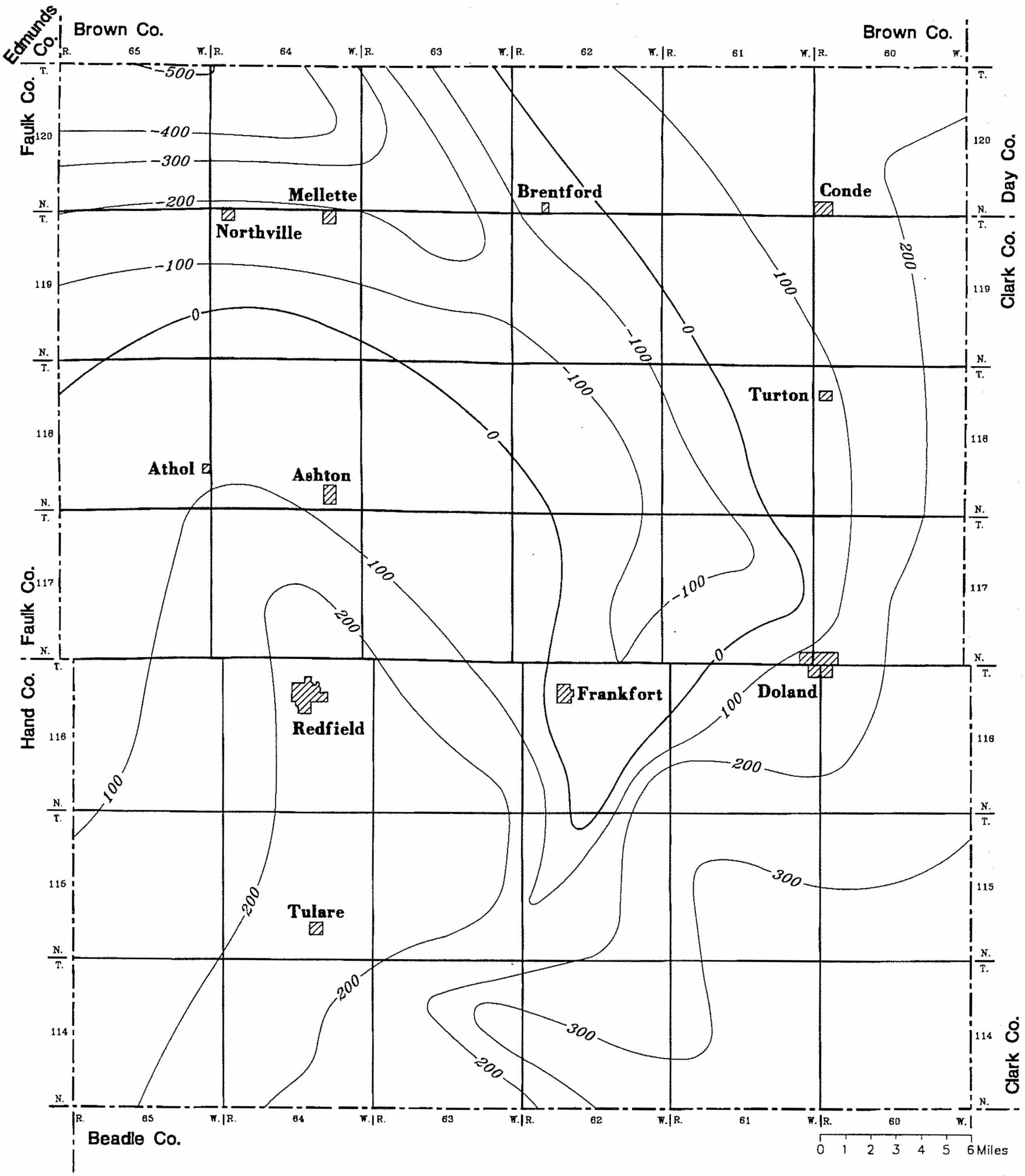
Robert A. Schoon, a geologist with the South Dakota Geological Survey, contributed a great deal of work on the Precambrian "basement" rocks of South Dakota before his retirement in 1994. Figure 5 showing the configuration of the Precambrian surface in Spink County was obtained from Schoon's unpublished data.

No attempt was made in this report to prepare a map showing the distribution of the various Precambrian-aged rocks. For an interpretation of the Precambrian rocks of South Dakota, the reader is referred to Lidiak (1971).

Paleozoic Deposits

The Paleozoic is an era of geologic time following the Precambrian which includes the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian Periods. The Paleozoic includes the group of rocks that were deposited from about 570 to 225 million years ago (Bates and Jackson, 1987).

Paleozoic-aged rocks which were deposited to the west in what is known as the Williston Basin have not been positively identified in Spink County (table 1). A Precambrian surface low which extends into Spink County from the northwest (fig. 5) may have been an area of Paleozoic deposition, however, deposits found in this area have not been differentiated.



Structure contour of the Precambrian surface. Contour interval is 100 feet. Number is elevation in feet above or below (−) mean sea level. The number zero (0) indicates mean sea level.

(Taken from R.A. Schoon, unpublished Precambrian surface map of South Dakota.)

Figure 5. Structure-contour map of the Precambrian surface in Spink County, South Dakota.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

sectionized township

Mesozoic Deposits

The Mesozoic is an era of geologic time following the Paleozoic which includes the Triassic, Jurassic, and Cretaceous Periods. The Mesozoic includes the group of rocks that were deposited from about 225 to about 65 million years ago (Bates and Jackson, 1987). Triassic- and Jurassic-aged rocks have not been positively identified in Spink County but may also be found in topographically low areas of the Precambrian surface (table 1). Cretaceous-aged rocks make up the majority of bedrock deposits which overlie the Precambrian surface in Spink County and are discussed in detail below.

Cretaceous Deposits

The Cretaceous rocks of Spink County were deposited during five major cycles of sedimentation (cyclothems, see table 1) that occurred when inland seas transgressed and regressed across the Western Interior of North America between 135 and 65 million years ago (Dyman and others, 1994). An example of the sea's extent during part of the late Cretaceous Period is shown in figure 6. The reader is referred to Shurr and others (1994) which contains many of the current perspectives on the eastern margin of the Cretaceous Western Interior Basin.

INYAN KARA GROUP

This unit is comprised of sandstones and mudstones deposited during a transgressive sequence of the Kiowa-Skull Creek cyclothem (a global cycle of transgression and regression). The Kiowa-Skull Creek cyclothem is the first major cyclothem which occurred during the Cretaceous Period (table 1) in the Western Interior Seaway.

A thin portion of the Inyan Kara Group may be found overlying Precambrian-aged rocks along the far western edge of the county and in the previously mentioned Precambrian low (fig. 5) in the northwestern corner of the county.

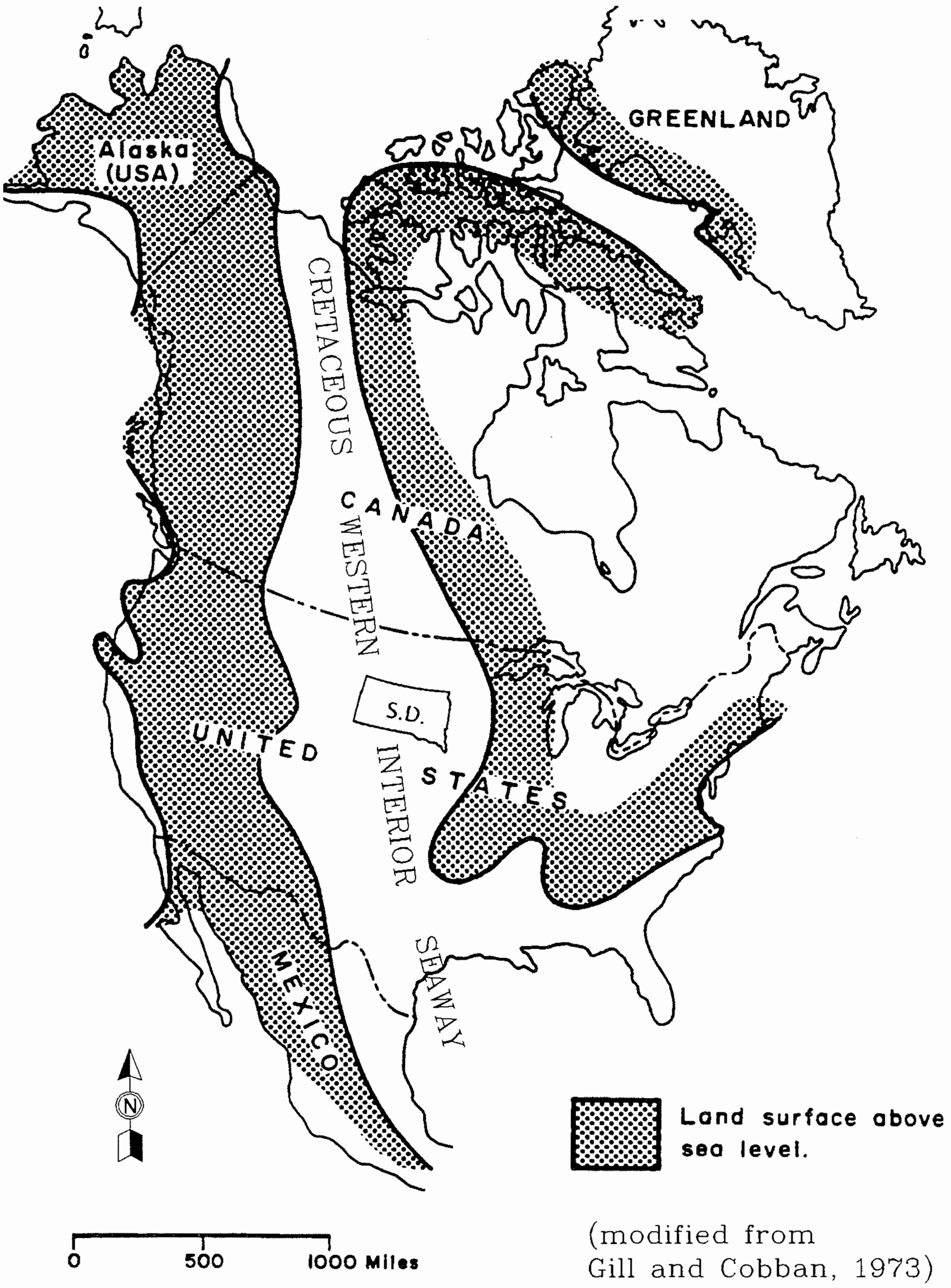
SKULL CREEK SHALE

The Skull Creek Shale was named from exposures along Skull Creek in Wyoming by Collier (1923). The Skull Creek Shale is a dark-gray to black shale with a thin glauconitic siltstone layer in the middle of the unit. Concretions may be found throughout the formation.

The shale was deposited in a marine environment during Kiowa-Skull Creek cyclothem of the Cretaceous Period (table 1). Up to 50 feet of Skull Creek Shale may be found along the western edge of Spink County.

DAKOTA FORMATION

The Dakota Formation was first described by Meek and Hayden (1861) from an exposure in Dakota County, Nebraska. The Dakota Formation extends downward from the first relatively continuous sandstone below the Greenhorn Limestone, to the top of the Skull Creek Shale, in the



(modified from
Gill and Cobban, 1973)

Figure 6. Map showing probable extent of the Western Interior Seaway during a portion of the late Cretaceous Period.

extreme western portion of Spink County. Over the rest of the county it unconformably overlies Precambrian-aged rocks.

The Dakota Formation (Kd, fig. 4) can usually be subdivided into three units. The upper unit, locally known as the "first flow," consists of light-brown to reddish-brown, fine- to medium-grained, quartz sandstone interbedded with minor gray to dark-gray shale layers. The middle unit is a gray silty clay interbedded with minor sandstone layers. The lower unit, locally known as the "second flow," is a medium- to coarse-grained sandstone (Schoon, 1971).

The top of the Dakota Formation, as described above, is typically found at depths ranging from 700 to 1,000 feet below land surface and at elevations of 300 to 600 feet above mean sea level (fig. 7). In Spink County the Dakota Formation thickness typically ranges from 100 feet to over 200 feet.

The lower portion of the Dakota Formation was deposited in a continental environment (Schoon, 1971) at the end of the Kiowa-Skull Creek cyclothem. The middle portion was deposited in a near-marine environment and the upper unit in a marine environment (Schoon, 1971) at the onset of the Greenhorn cyclothem (table 1).

GRANEROS SHALE

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

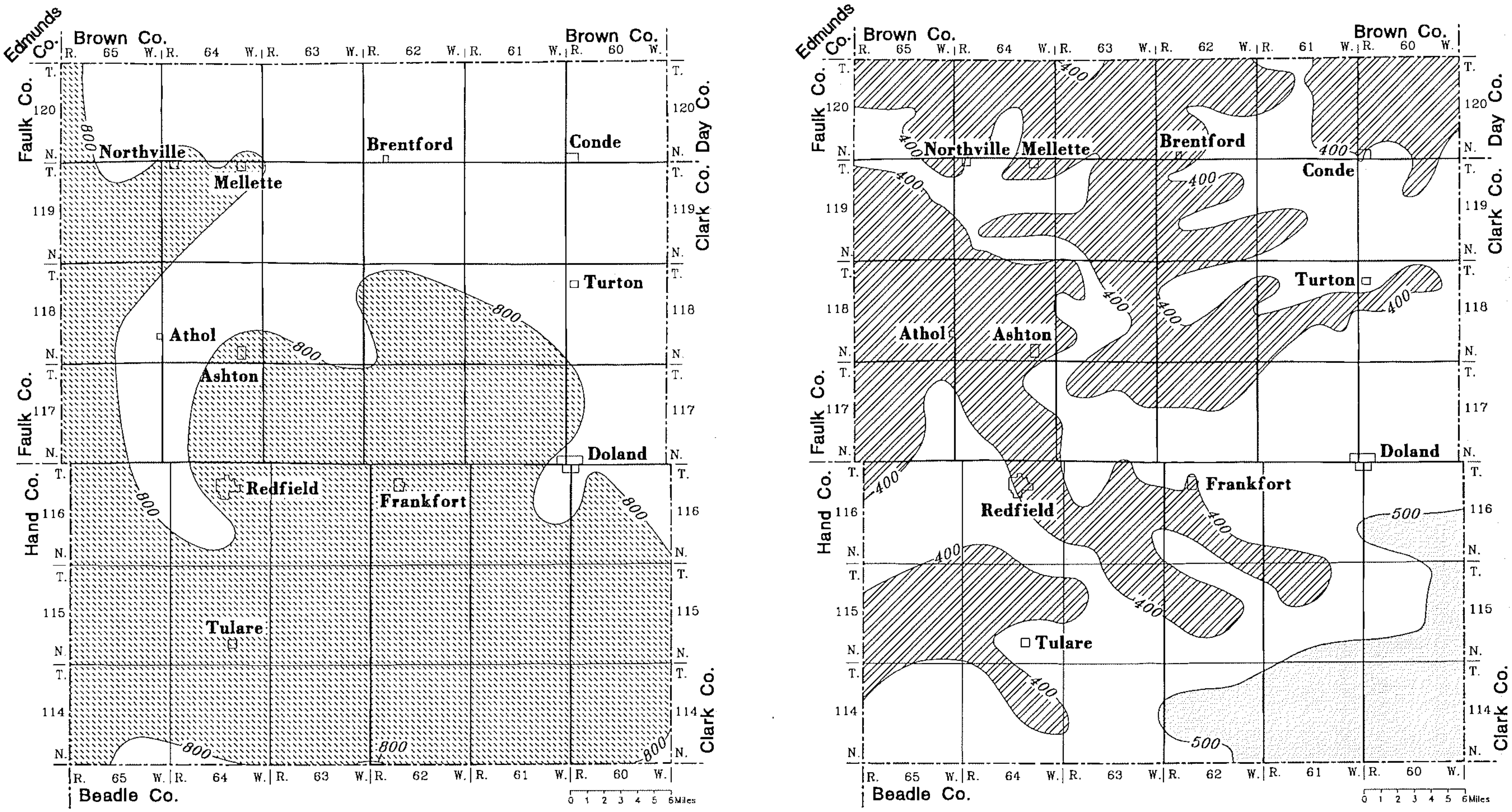
The Graneros Shale (Kgn, fig. 4) is a medium- to dark-gray, noncalcareous, pyritic, poorly fossiliferous silty shale with thin silt and sand layers. The sand layers commonly become thicker and more abundant near the base of the formation. Interpretations of formation thickness may vary because of the gradational contact between the Graneros Shale and underlying Dakota Formation. In Spink County the Graneros Shale thickness varies from about 250 feet to 360 feet.

The gradational contact between the Graneros Shale and the Dakota Formation results from the gradual replacement of a marginal marine environment to offshore marine conditions (Witzke and others, 1983).

GREENHORN LIMESTONE

Gilbert (1896) first described the Greenhorn Limestone from an exposure near Greenhorn Station, 14 miles south of Pueblo, Colorado.

The Greenhorn Limestone (Kg, fig. 4) is a gray to brown, calcareous claystone interbedded with thin fossiliferous limestone and argillaceous limestone layers. The most common fossil is a bivalve clam, *Inoceramus labiatus*, fragments of which are found throughout the unit. An areally extensive cherty limestone layer marks the top of the formation making it one of the best Cretaceous marker beds in South Dakota. This layer gives a very distinctive electric log signature and is quite noticeable by the rough manner in which it drills.



Greenhorn Limestone

☐	750 to 800 feet above mean sea level
▨	800 to 845 feet above mean sea level
—800—	Structure contour of the formation surface. Number is feet above mean sea level.

(Based on data interpreted from geophysical logs and test hole logs on file at the Geological Survey in Vermillion, South Dakota)

Dakota Formation

▨	320 to 400 feet above mean sea level
☐	400 to 500 feet above mean sea level
░	500 to 565 feet above mean sea level
—500—	Structure contour of the formation surface. Number is feet above mean sea level. Contour interval = 100 feet.

(Based on data interpreted from geophysical logs and test hole logs on file at the Geological Survey in Vermillion, South Dakota, and from Todd, 1909)

Figure 7. Structure-contour maps of the Greenhorn Limestone and Dakota Formation in Spink County, South Dakota.

The top of the Greenhorn Limestone is typically found at depths ranging from 760 to 845 feet below land surface and at elevations of 750 to 845 feet above mean sea level (fig. 7). In Spink County the Greenhorn Limestone thickness typically ranges from 15 feet to 75 feet.

The Greenhorn Limestone was deposited in an open-marine environment during the maximum transgressive phase of the late Cretaceous Greenhorn cyclothem (Witzke and others, 1983) (table 1).

CARLILE SHALE

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

Over much of eastern South Dakota, the Carlile Shale can be divided into several distinct members including from bottom to top, the Fairport Chalky Member, the Blue Hill Shale Member, the Codell Sandstone Member, and an unnamed shale member. The Fairport Chalky Member is a slightly calcareous, brownish-black claystone containing numerous "white specks" or fecal pellets and abundant fine-grained pyrite. The Blue Hill Shale Member is a pyritic dark-gray to black shale containing numerous concretionary horizons. The Codell Sandstone Member consists of an upward-coarsening succession of shales and sandstones (Ludvigson and others, 1994). The Fairport Chalky and Blue Hill Shale Members are found extensively across Spink County, while the Codell Sandstone and unnamed shale members occur only sporadically in the southeastern portion of the county.

The Carlile Shale (Kc, fig. 4) is found in subcrop beneath Quaternary-aged sediment in several deep bedrock channels (pl. 1). In the deepest portions of these channels, the Carlile Shale may in fact be completely removed. In Spink County, in areas not incised by these deep channels, the Carlile Shale thickness typically ranges from 190 feet to 240 feet.

The Carlile Shale was deposited in a marine environment during the regressive phase of the late Cretaceous Greenhorn cyclothem (Witzke and others, 1983). The lower portion of the formation was deposited in an offshore marine environment. The upper sands were deposited in nearshore marine to coastal environments.

NIOBRARA FORMATION

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

The Niobrara Formation (Kn, fig. 4) is made up of light- to dark-gray, pyritic, calcarenite, chalk, and calcareous shale, with some bentonite. The Niobrara Formation, also locally known as the "Niobrara Marl" or "Niobrara Chalk," consists of large accumulations of coccoliths and foraminifera resulting in a high calcium carbonate content and a speckled appearance. Macrofossils have also been found in the formation including *Ostrea congesta* and *Inoceramus gigantica*.

The Niobrara Formation is found in subcrop beneath Quaternary-aged deposits (pl. 1 and figs. 8 through 23). In the deep bedrock channels it has been completely removed by subsequent erosion.

Figure 8. Configuration of the Niobrara Formation surface in Spink County, South Dakota.

▨ Approximate Niobrara Formation subcrop area.

1154 ● Data point. Number is Niobrara Formation surface elevation, in feet above mean sea level. A "less than" symbol (<) indicates surface elevation is less than number shown.

909 Kc ● Data point. Number is Carlile Shale surface elevation, in feet above mean sea level.

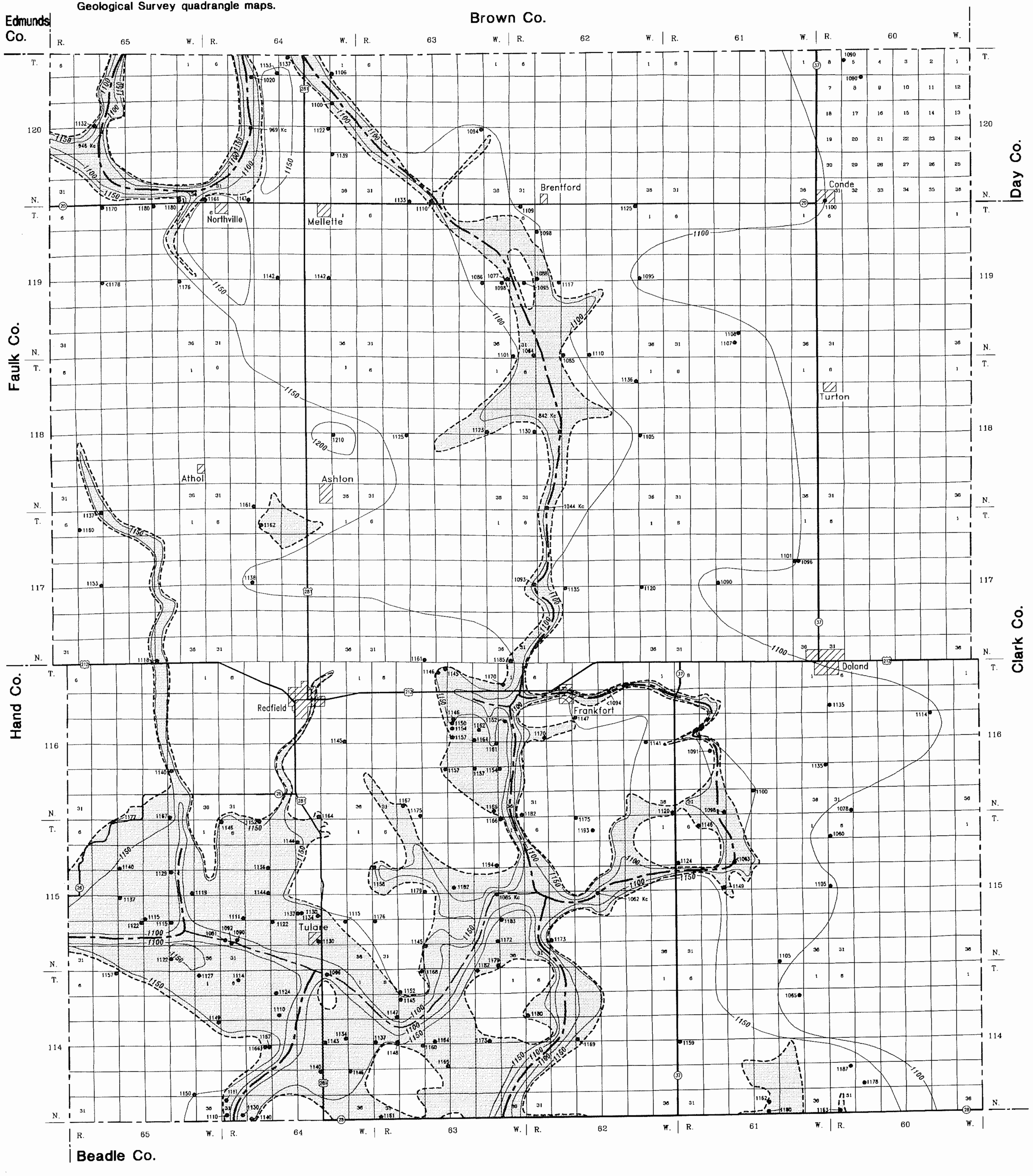
1100 Contour line connecting points of equal Niobrara Formation surface elevation, in feet above mean sea level. Contour interval = 50 feet.

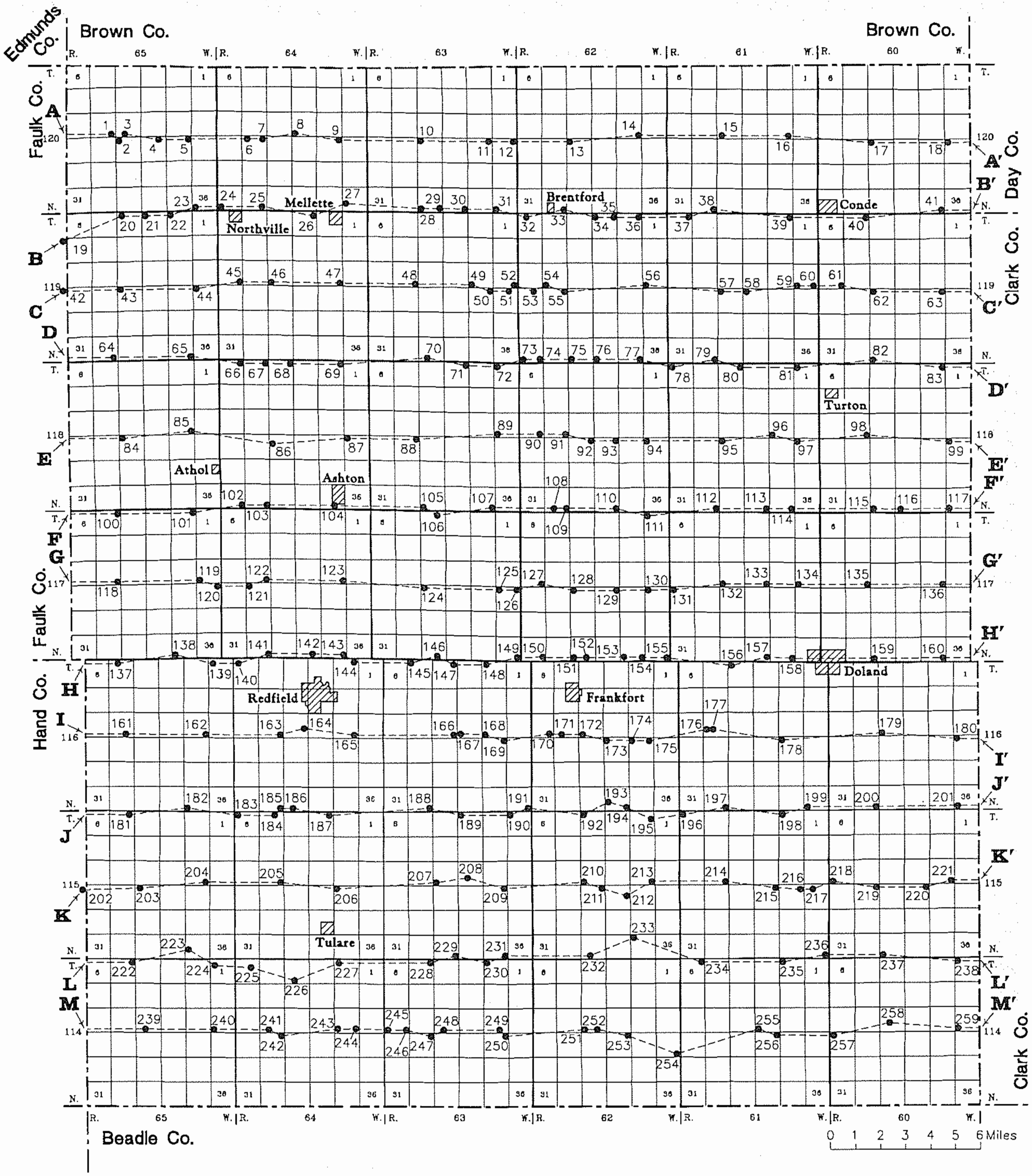
-- Approximate Carlile Shale subcrop area.

For township section numbering system, see T. 120 N., R. 60 W.

Map digitized from Aberdeen, Redfield, Watertown, and Webster 1:100,000-scale United States Geological Survey quadrangle maps.

0 1 2 3 4 5 6 Miles





● Test hole

- - - - - Line of cross section

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

Figure 9. Location of the geologic cross sections (figs. 11 through 23) in Spink County, South Dakota.

N

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

sectionized township

Figure 10. Legend for the geologic cross sections (figs. 11 through 23) in Spink County, South Dakota.

QUATERNARY	Qwloa	late Wisconsin outwash and/or Holocene alluvium, undifferentiated
	Qwll$_2$(ox)	late Wisconsin lacustrine sediments (oxidized), glacial Lakes Dakota and Byron
	Qwll$_2$(unox)	late Wisconsin lacustrine sediments (unoxidized), glacial Lakes Dakota and Byron
	Qwll$_1$(ox)	late Wisconsin lacustrine sediments (oxidized), other surface deposits
	Qwll(ox)	late Wisconsin lacustrine sediments (oxidized), buried deposits
	Qwll(unox)	late Wisconsin lacustrine sediments (unoxidized), buried deposits
	Qwlo	late Wisconsin outwash
	Qwlt$_2$(ox)	late Wisconsin till 2 (oxidized)
	Qwlt$_2$(unox)	late Wisconsin till 2 (unoxidized)
	Qwlt$_1$(ox)	late Wisconsin till 1 (oxidized)
	Qwlt$_1$(unox)	late Wisconsin till 1 (unoxidized)
	Qo	Quaternary outwash, undifferentiated
	Qs	Quaternary silts, undifferentiated
	Qu	Quaternary sediment, unknown channel deposits
CRETACEOUS	Kp	Pierre Shale, undifferentiated
	Kpd	Pierre Shale, DeGrey Member
	Kpcc	Pierre Shale, Crow Creek Member
	Kpg	Pierre Shale, Gregory Member
	Kpss	Pierre Shale, Sharon Springs Member
	Kn	Niobrara Formation
	Kc	Carlile Shale

⊥	Test hole. Number is map location number (MLN). See appendix for legal description. See figure 9 for test hole location.
——— – –	Lithologic contact. Dashed where approximate.
▒	Outwash (Qwlo and Qo)

Figure 11. Geologic cross section A-A'

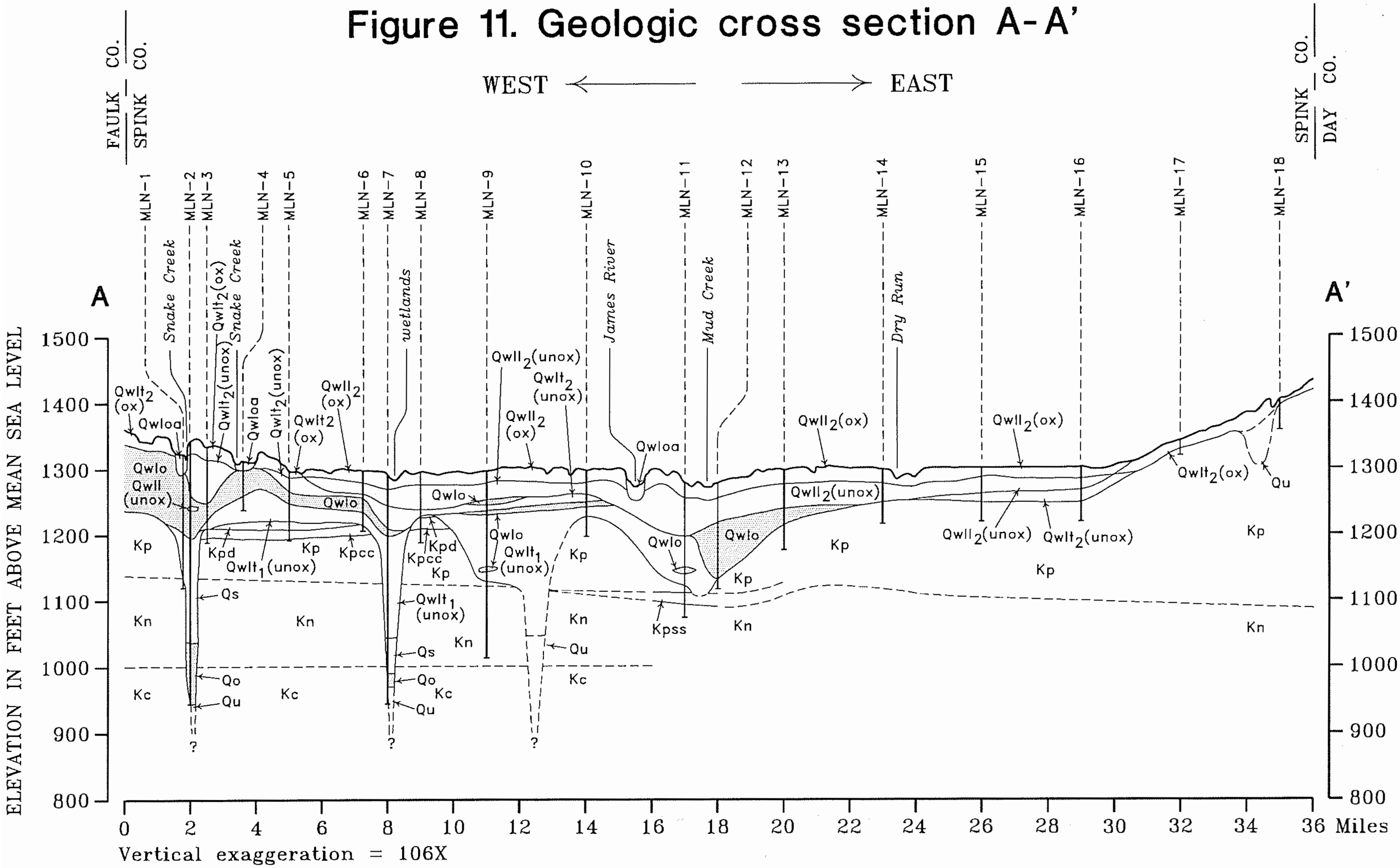


Figure 12. Geologic cross section B-B'

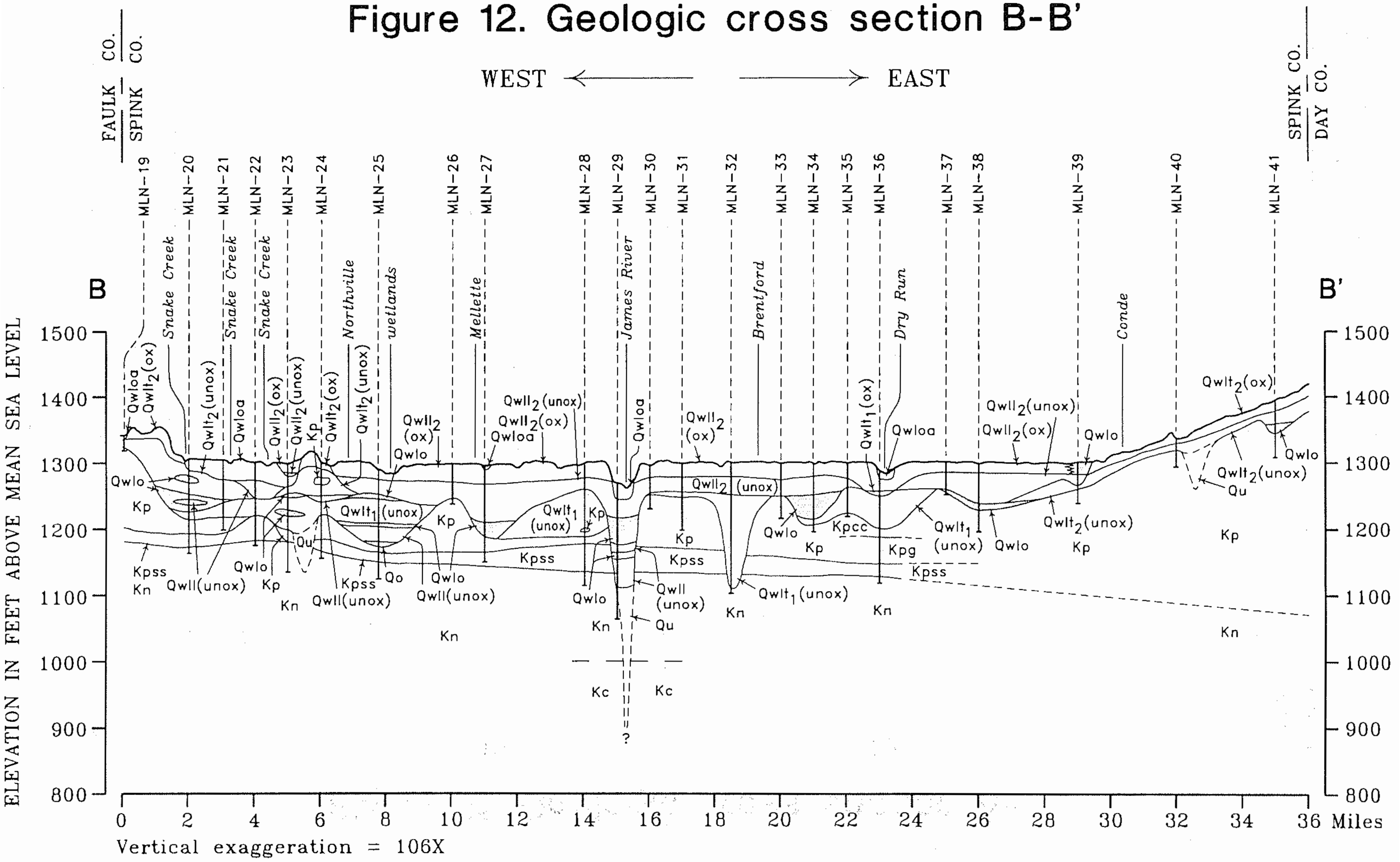


Figure 13. Geologic cross section C-C'

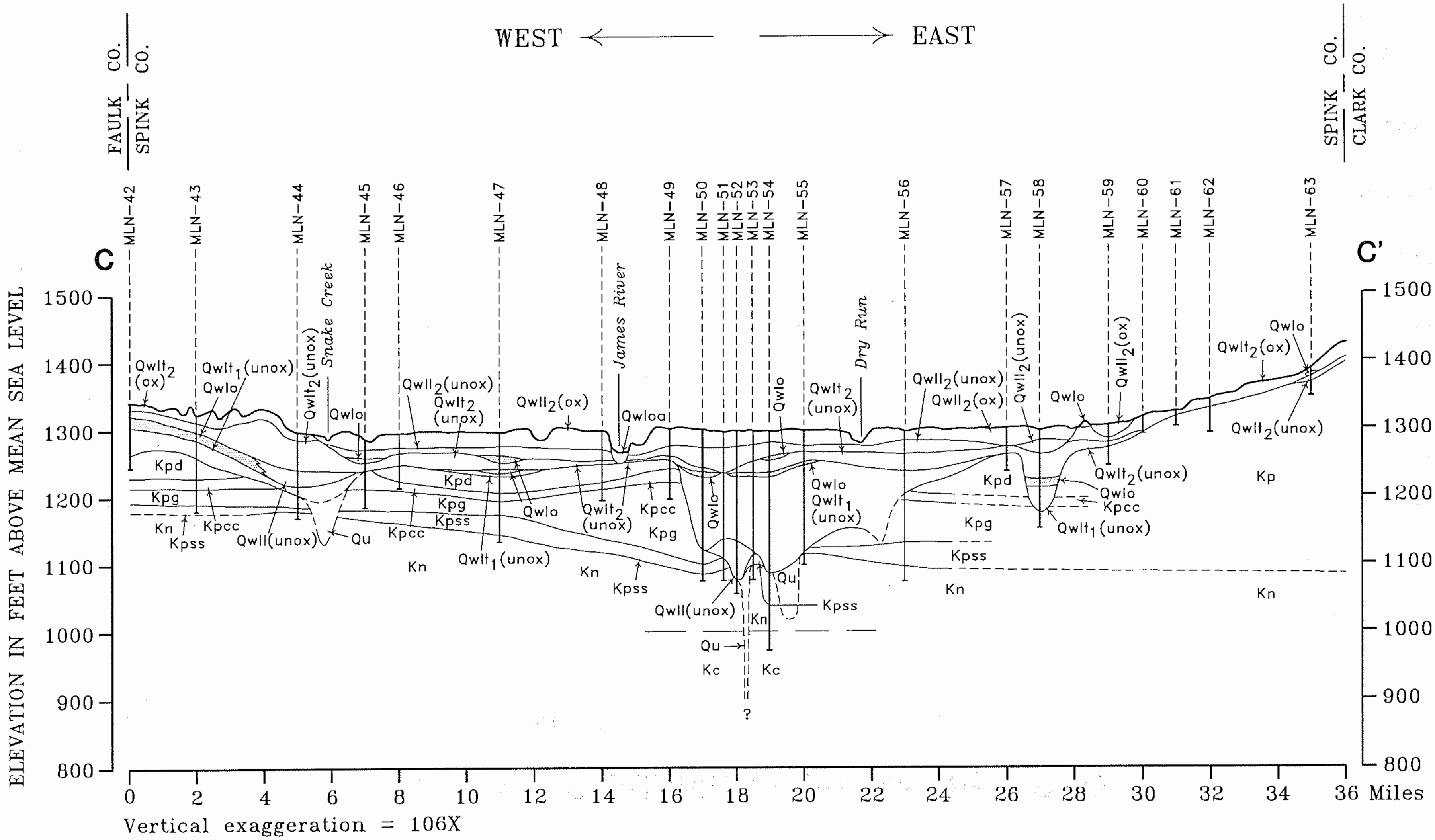


Figure 14. Geologic cross section D-D'

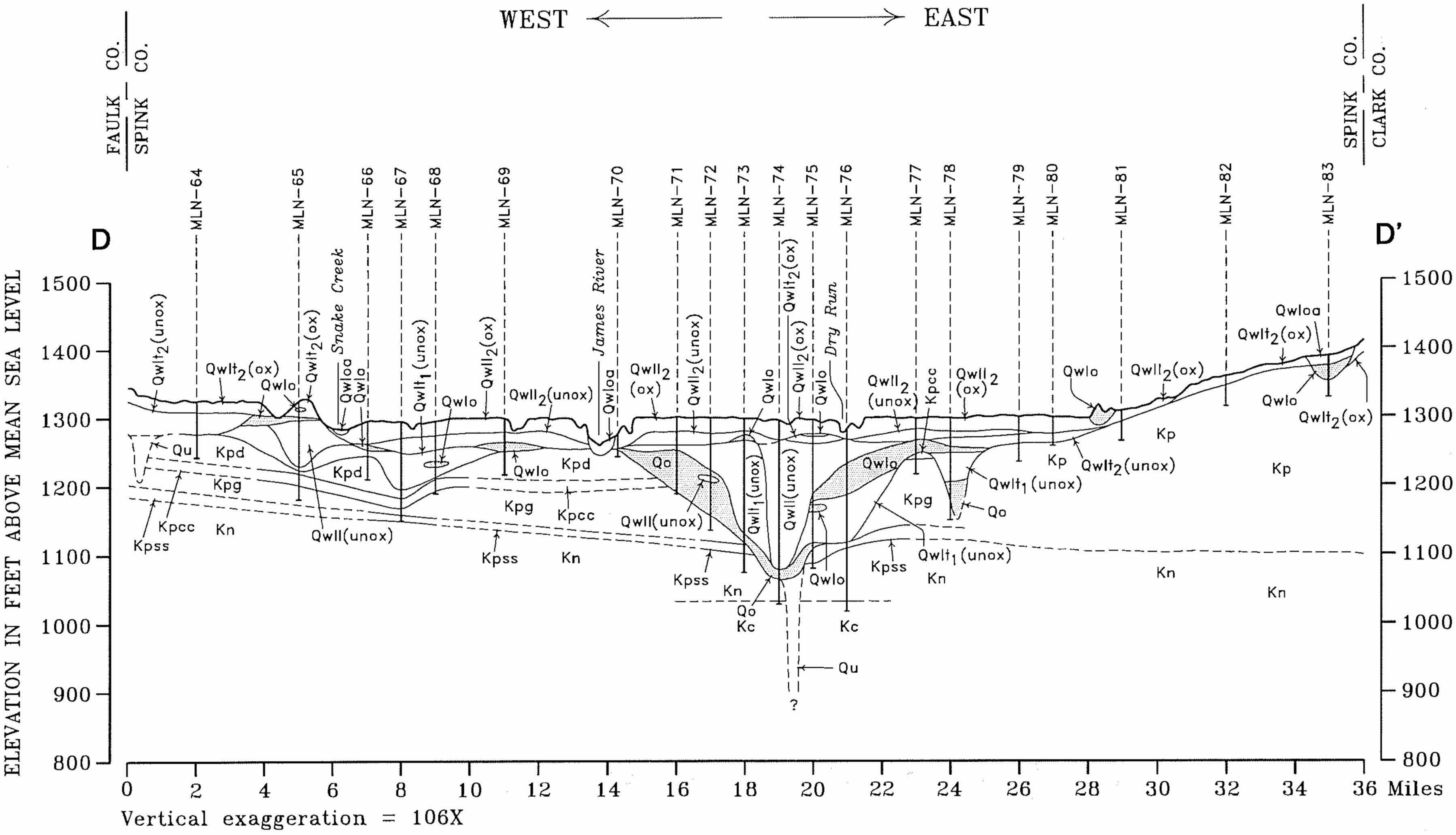


Figure 15. Geologic cross section E-E'

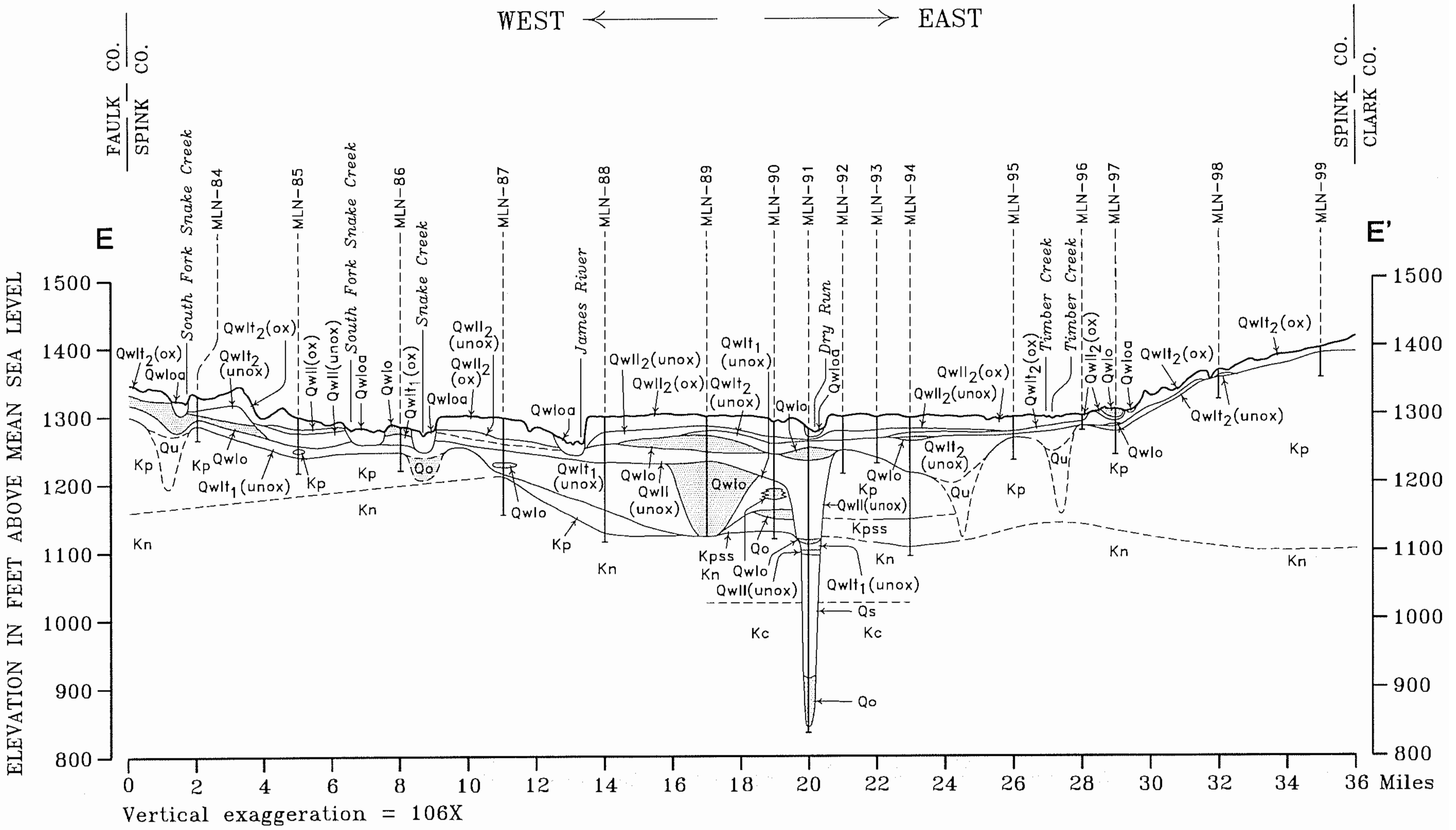


Figure 16. Geologic cross section F-F'

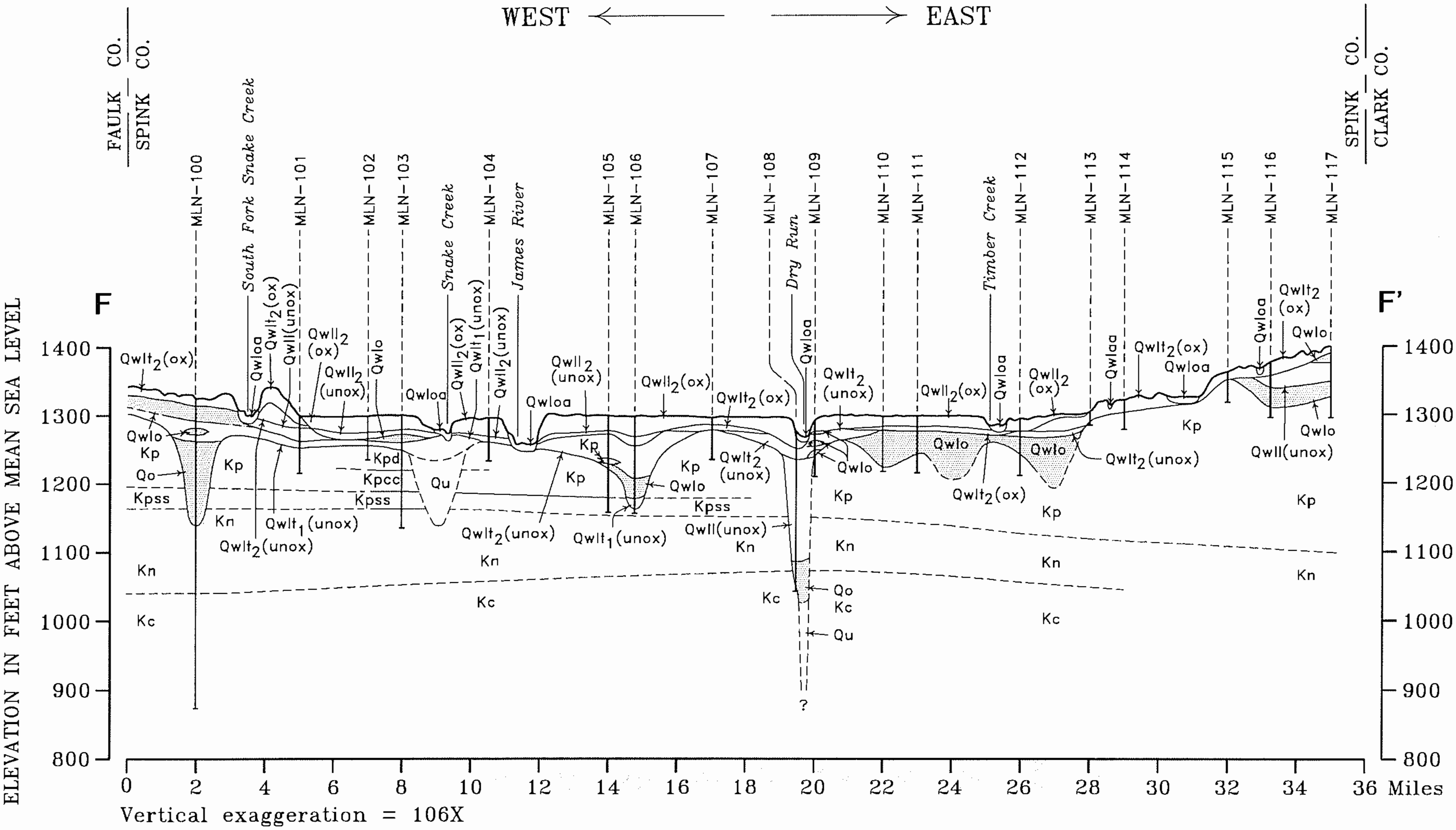
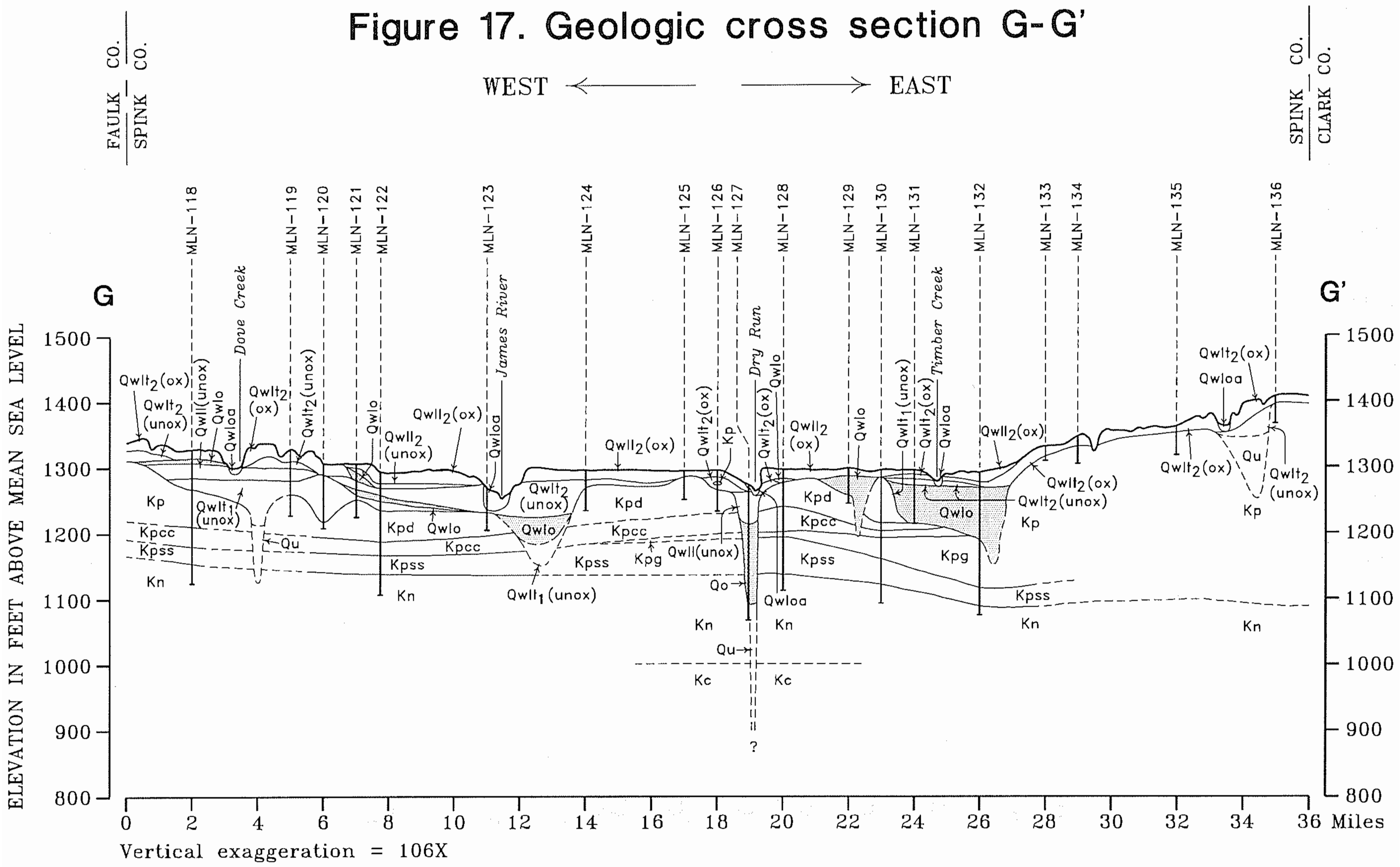


Figure 17. Geologic cross section G-G'



Vertical exaggeration = 106X

Figure 18. Geologic cross section H-H'

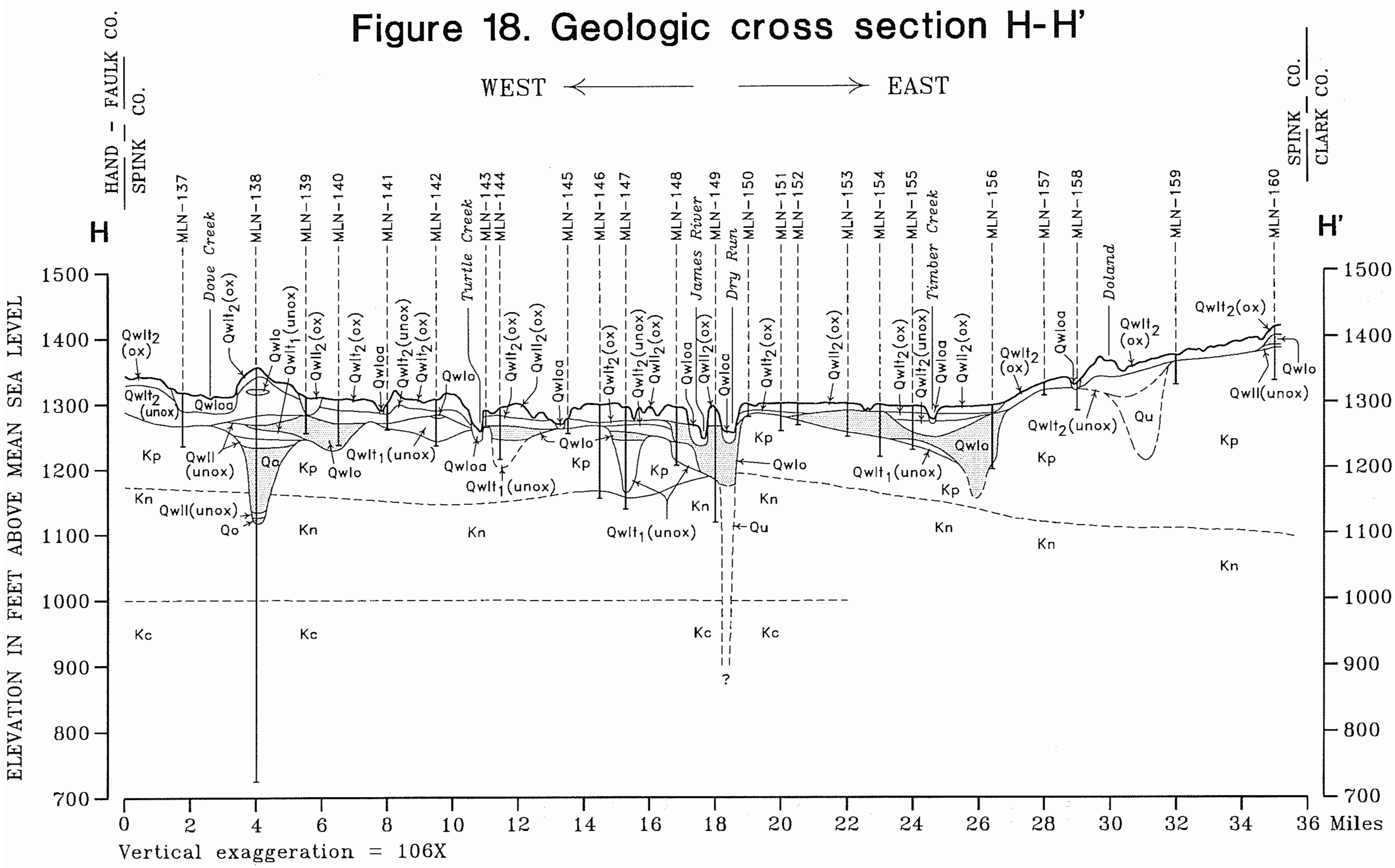
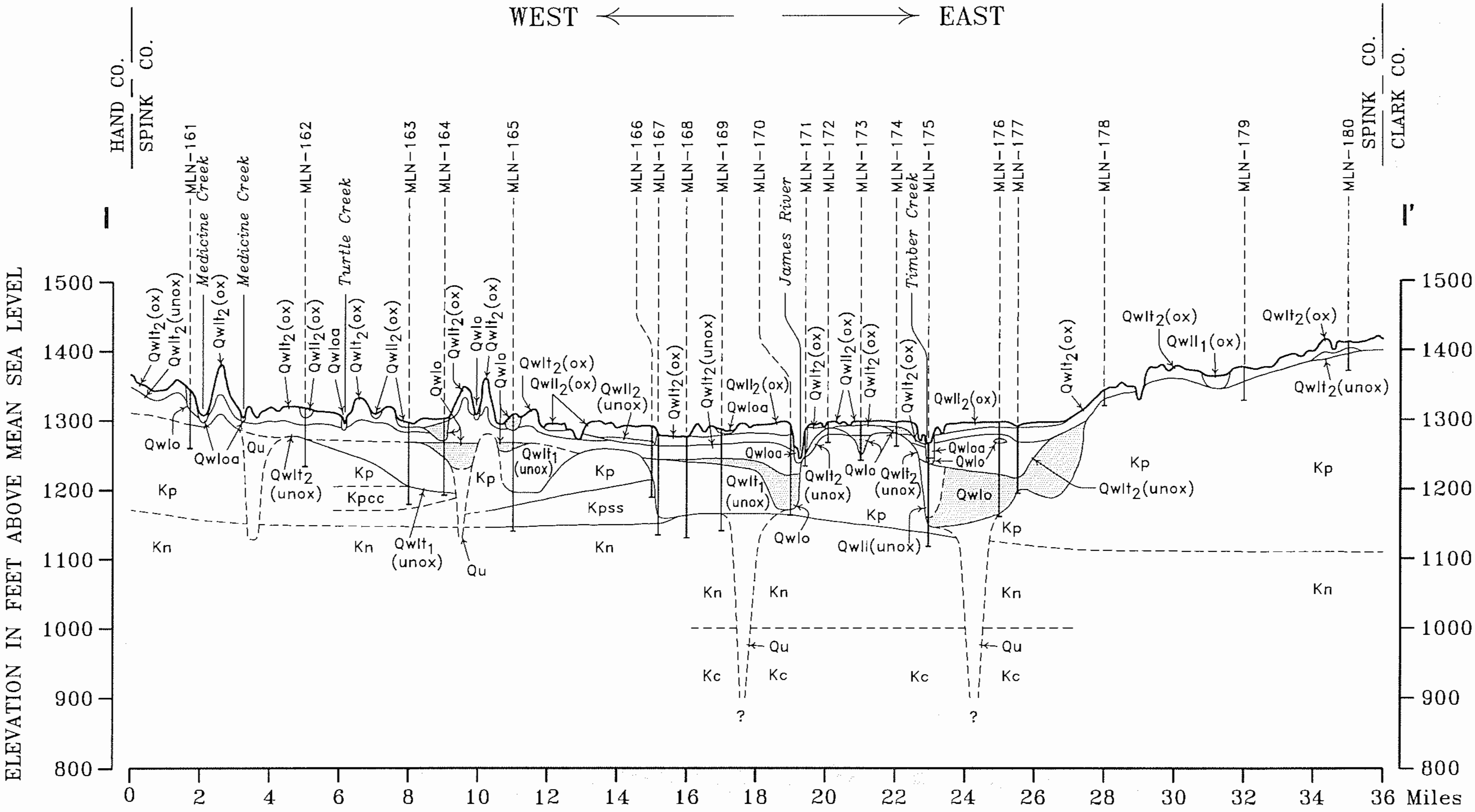
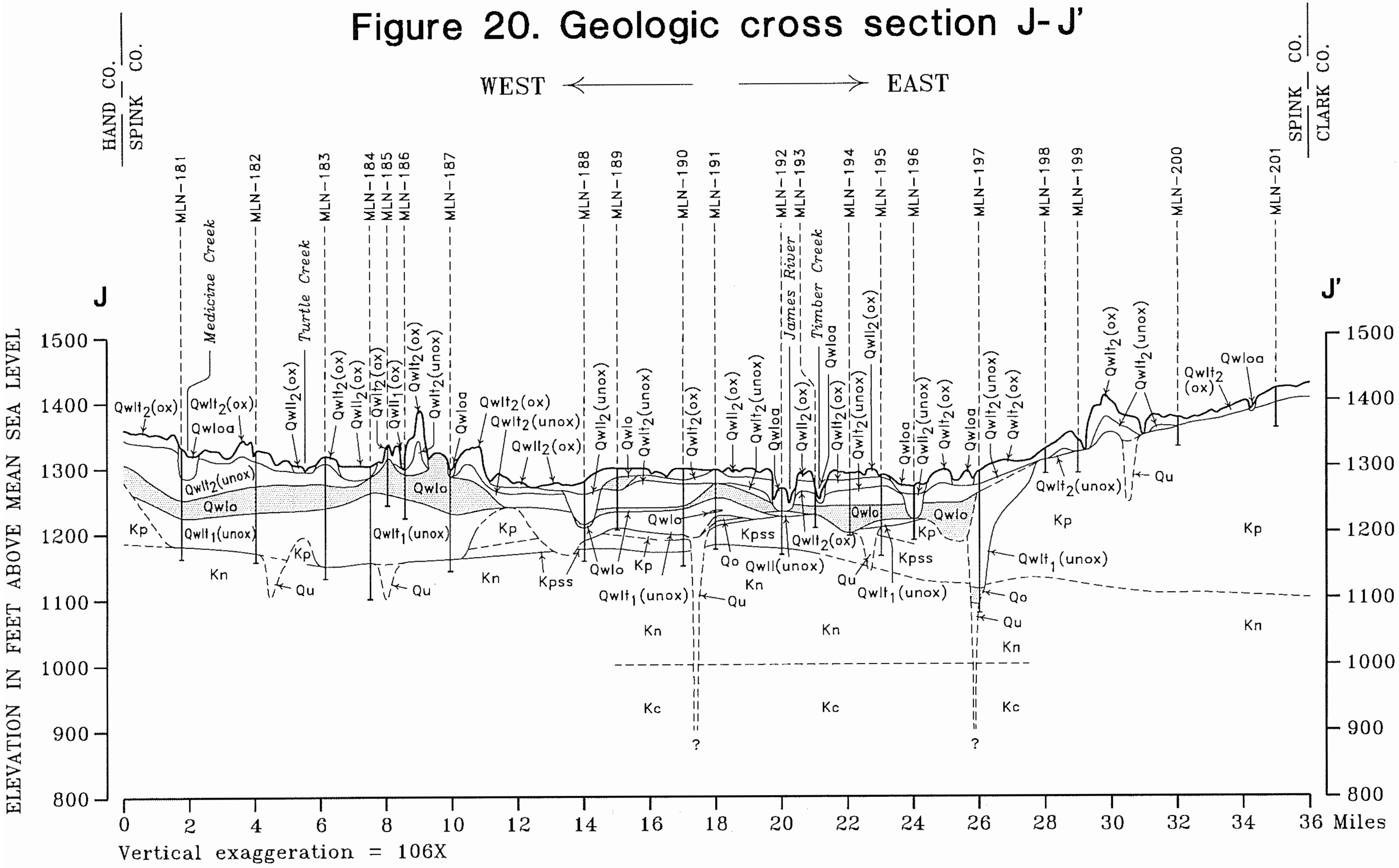


Figure 19. Geologic cross section I-I'



Vertical exaggeration = 106X

Figure 20. Geologic cross section J-J'



Vertical exaggeration = 106X

Figure 21. Geologic cross section K-K'

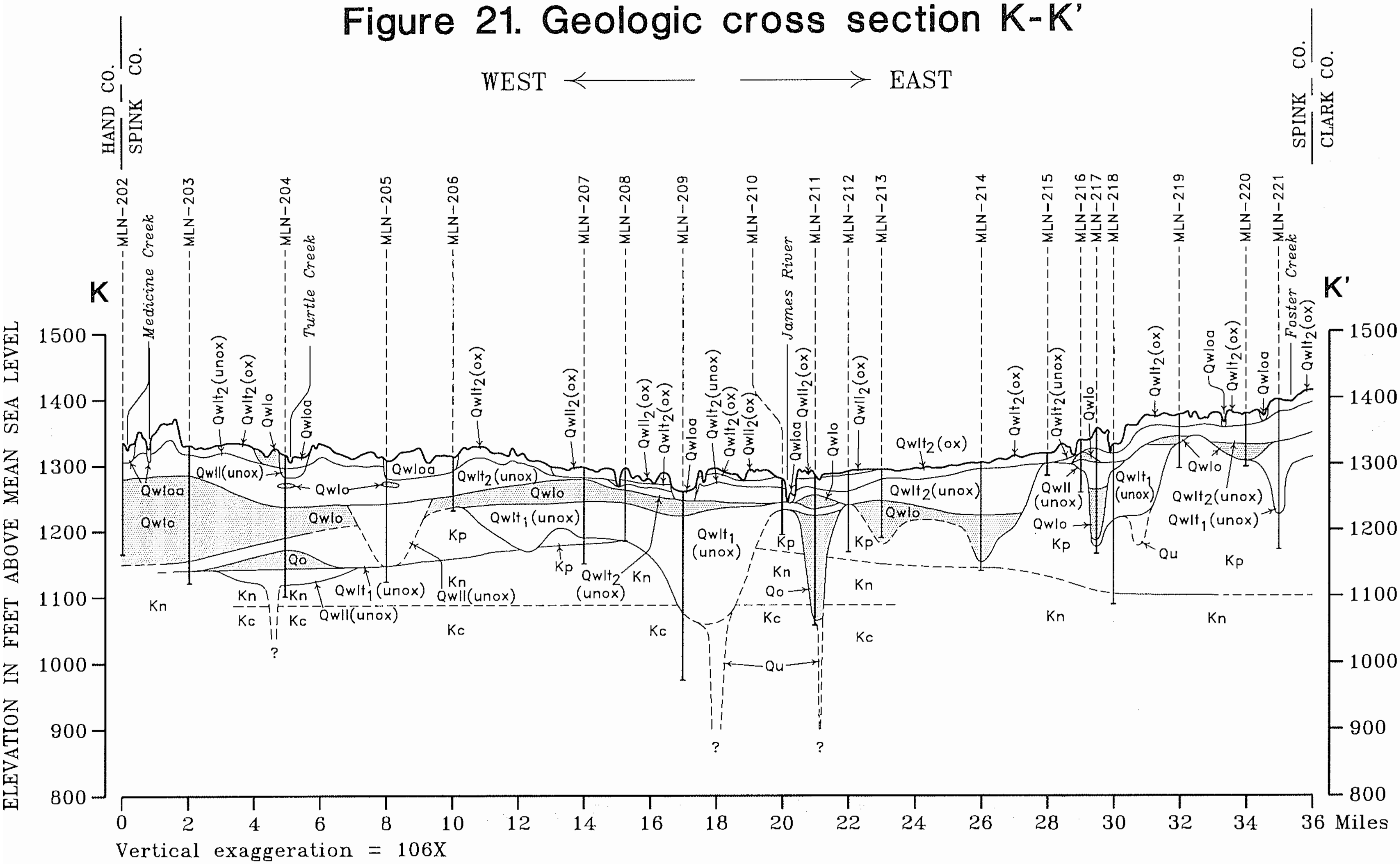
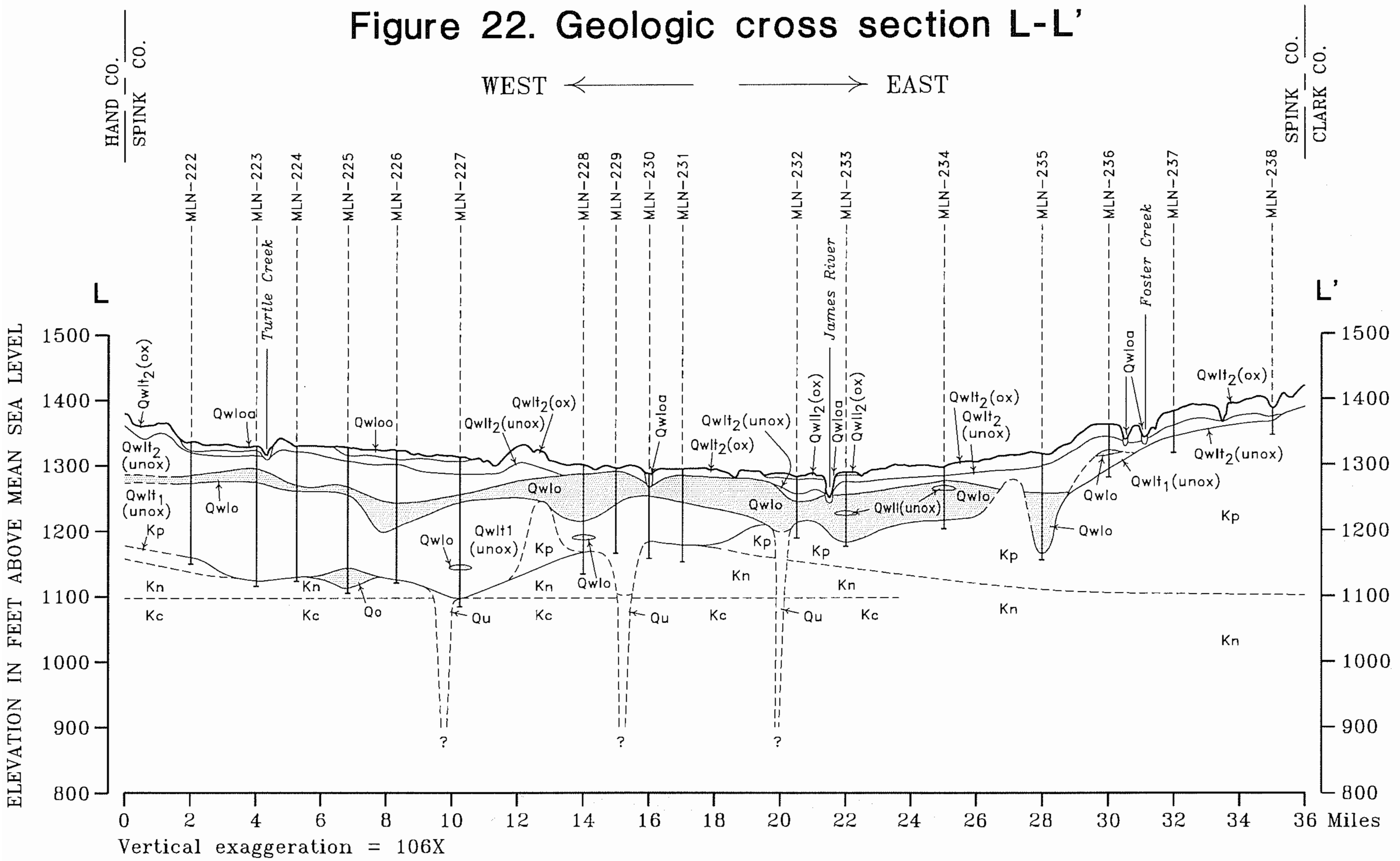
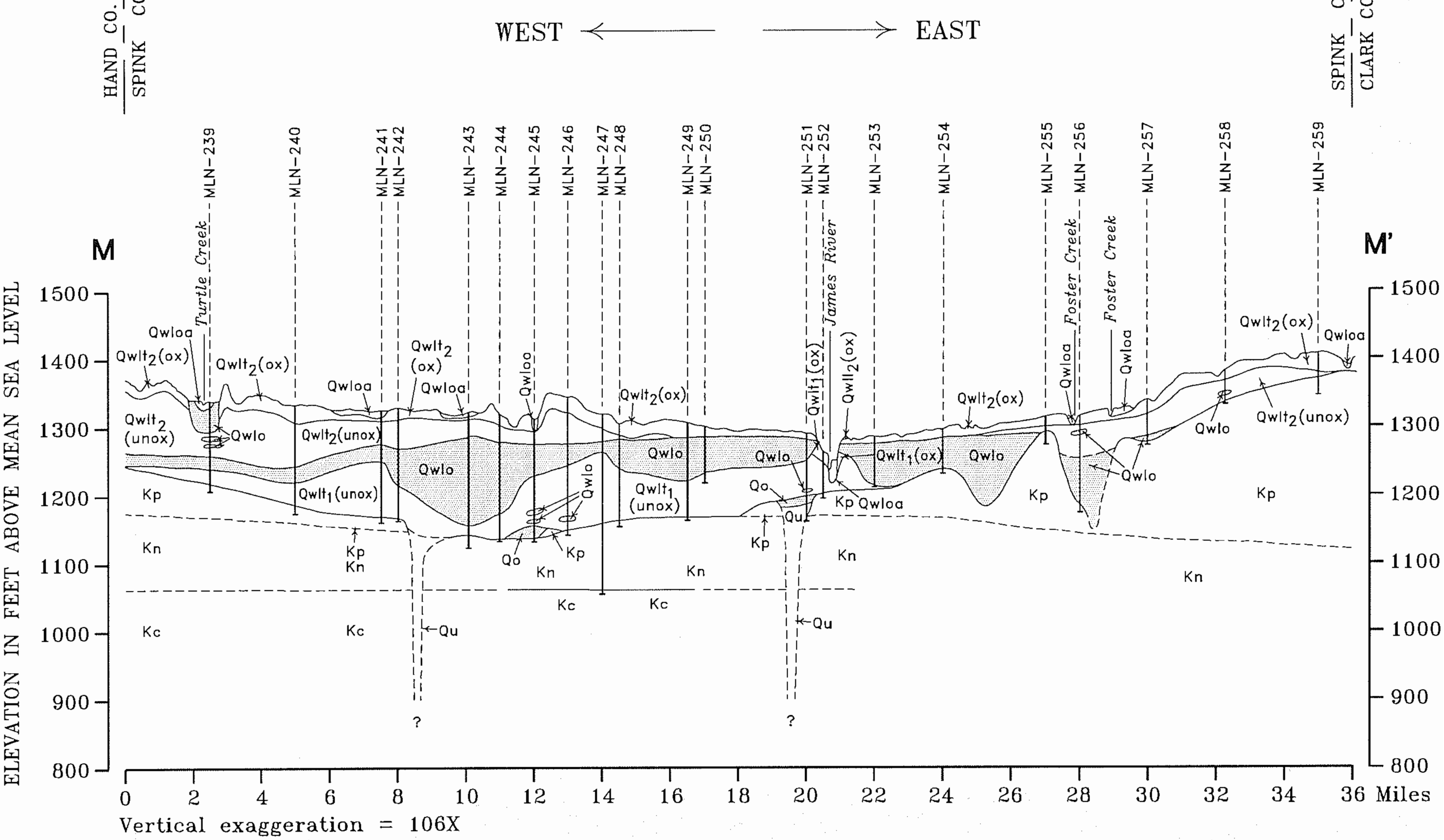


Figure 22. Geologic cross section L-L'



Vertical exaggeration = 106X

Figure 23. Geologic cross section M-M'



Vertical exaggeration = 106X

Figure 8 shows the configuration of the Niobrara Formation surface in Spink County. In Spink County, in areas not incised by these deep channels, the Niobrara Formation thickness typically ranges from 60 feet to 160 feet.

The Niobrara Formation was deposited in a shallow, open-marine environment (Witzke and others, 1983). The Niobrara Formation is bounded above and below by major unconformities, both of which are postulated to be sequence boundaries bracketing the late Cretaceous Niobrara cyclothem (table 1). The top of the Niobrara Formation in Spink County is found as high as 1,210 feet to as low as 1,060 feet above mean sea level.

PIERRE SHALE

The Pierre Shale was first named the Fort Pierre Formation by Meek and Hayden (1861) and was shortened to Pierre by Darton (1896). The formation was first described in detail by Searight (1937) and later by Crandell (1950 and 1958).

The Pierre Shale (Kp, figs. 4, and 11 through 23) is a noncalcareous, light-gray to black, claystone with scattered layers of marl, bentonite, calcareous claystone, and siliceous shale. The formation has been divided into eight members from outcrops along the Missouri River (Searight, 1937; and Crandell, 1950 and 1958) including from top to bottom: Elk Butte Member, Mobridge Member, Virgin Creek Member, Verendrye Member, DeGrey Member, Crow Creek Member, Gregory Member, and Sharon Springs Member. Up to 300 feet of Pierre Shale may be encountered along the eastern edge of Spink County.

The DeGrey, Crow Creek, Gregory, and Sharon Springs Members of the Pierre Shale were recognized in some of the deep borings conducted for this study (figs. 11 through 23). The members of the Pierre Shale were differentiated only when recognized. No attempt was made to completely differentiate all of the members. Some of the uppermost members have been removed by subsequent glacial erosion. For a detailed discussion of the members, the reader is referred to Crandell (1958).

The Sharon Springs Member (Kpss, figs. 11 through 23) is a black, noncalcareous shale to silty claystone with bentonite layers and local phosphatic concretions. Its lower portion is an organic-rich shale that includes bituminous shale and abundant fish debris. Up to 60 feet of Sharon Springs Member was encountered in Spink County. The Sharon Springs Member is a very good Cretaceous marker bed because of its very high gamma radiation signature.

The Gregory Member (Kpg, figs. 11 through 23) is a gray to dark-gray noncalcareous shale with a few thin bentonite layers. The Gregory Member is differentiated only where the overlying Crow Creek Member and underlying Sharon Springs Member were recognized. From 0 to 110 feet of the Gregory Member was encountered.

The Crow Creek Member (Kpcc, figs. 11 through 23) consists of up to 30 feet of gray to light-gray calcareous siltstone. The Crow Creek Member has been erroneously identified as Niobrara Formation in some of the historical data. The Niobrara Formation, however, is usually a darker gray, more cemented, and more calcareous than the Crow Creek Member of the Pierre Shale.

The DeGrey Member (Kpd, figs. 11 through 23) is a gray to dark-gray shale. The basal portion contains numerous bentonite layers, concretions, and macrofossils, and the upper portion is moderately siliceous and contains no macrofossils (Crandell, 1958).

The Verendrye Member is a gray to dark-gray, unfossiliferous shale, with many sideritic concretions (Crandell, 1958).

The Virgin Creek Member is a gray to dark-gray shale that contains concretions, layers of bentonite, and a variety of fossils.

The DeGrey Member was identified in only those areas where the Crow Creek Member was encountered. The Gregory Member was identified in those areas where the Sharon Springs and/or Crow Creek Members were present. In all other areas the Pierre Shale was not differentiated and is designated as Kp (figs. 11 through 23).

The Pierre Shale was deposited in marine environments in the last inland sea of the Cretaceous Period. Two cyclothems, the Claggett cyclothem and the Bearpaw cyclothem (table 1), caused the stratigraphic variations within the formation. The Sharon Springs Member was deposited during the first transgression, and the Gregory Member during the regressive phase of the Claggett cyclothem. Submarine erosion occurred at the maximum regression forming an unconformity. As the sea again transgressed at the onset of the Bearpaw cyclothem, the Crow Creek Member was deposited over the unconformity. During this final Cretaceous transgression, the inland sea was again extensive and rapid deposition of clays occurred. The DeGrey, Verendrye, and Virgin Creek Members of the Pierre Shale were deposited during this time (Schultz and others, 1980). The uppermost members of the Pierre Shale were deposited during the final regression, but have been removed by subsequent erosion.

Bentonite layers found throughout the late Cretaceous result from volcanic activity in the northern Rocky Mountains during deposition. Eruptions ejected ash into the atmosphere, which fell onto the inland sea and became incorporated with the sediment, forming the bentonite layers.

Cenozoic Deposits

The Cenozoic is an era of geologic time which includes the Tertiary and Quaternary Periods. The Cenozoic includes the group of rocks deposited from about 65 million years ago to the present (Bates and Jackson, 1987).

No Tertiary-aged rocks were identified in Spink County (table 1). If indeed Tertiary-aged rocks were deposited in the Spink County area, they have been subsequently removed by post-Cretaceous drainage development and/or glacial erosion.

Sediment deposited during the Quaternary Period is not considered part of the bedrock and is discussed in detail in the sections under Quaternary Geology which follow.

Bedrock Topography

Prior to glaciation, the area that is now Spink County probably consisted of rolling hills dissected by numerous streams, comparable to the landscape currently found west of the Missouri River. The present-day bedrock surface (pl. 1) is the result of post Cretaceous drainage development, as well as subsequent modification by glaciers and glacial meltwater.

As a result of the various cooperative county-wide studies which have been completed in eastern South Dakota, a likely portrayal of the glacially modified post Cretaceous drainage system is proposed (fig. 24). Spink County lies to the north of a major continental drainage divide which separated water flowing to the north from water flowing to the south. Spink County occupied an area of the northern drainage basin which received drainage from western ancient rivers including the Grand, Moreau, Cheyenne, and Bad Rivers, along with some drainage from the south and some from a bedrock highland to the east. Drainage from the east, west, and south merged in the area now occupied by Spink County and flowed in a northerly direction out of the county, most likely to an area occupied by the present-day Hudson Bay.

Pleistocene meltwater streams occupied the channels in which the ancient rivers once flowed. The erosive action of Pleistocene meltwater had a significant effect on the ancient valleys. In Spink County, most of the sediment deposited by post Cretaceous drainage has subsequently been removed by glacial meltwater streams. The valleys themselves once carved into the Cretaceous Pierre Shale were also subsequently deepened. The resulting channels were extremely difficult to locate during the test drilling portion of this investigation. The channels carved by the meltwater streams may be as narrow as a quarter of a mile in width, are incised over 400 feet into the bedrock, and wind back and forth across the ancient valleys. In Spink County a test hole drilled in the southeast corner of section 17, T. 118 N., R. 62 W. penetrated the central channel to an elevation of 842 feet (fig. 15 and pl. 1). Plate 1 and figures 11 through 23 show the channel has been deepened completely through the Pierre Shale and Niobrara Formation and into the Carlile Shale. Assuming this may not be the deepest portion of the channel it may be incised as deep as the Greenhorn Formation, as may have been encountered to the south in Beadle County (Hedges, 1968). Because the channels are so narrow and deep, no attempt was made to contour them below 1,100 feet above mean sea level (pl. 1). Lack of data also made it impossible to determine the direction of flow of the meltwater stream which occupied the main central channel.

QUATERNARY GEOLOGY

The Quaternary is the second period of the Cenozoic era following the Tertiary and includes the Pleistocene and Holocene epochs. The Quaternary includes rocks deposited from about two to three million years ago to the present (Bates and Jackson, 1987).

Pleistocene Deposits

The Pleistocene is an epoch of the Quaternary period sometimes referred to as the "Ice Age" and includes rocks deposited from about two to three million to 10,000 years ago (Bates and Jackson, 1987). In Spink County, the Pleistocene includes rocks deposited by multiple advances of continental glaciers and by glacial meltwater.

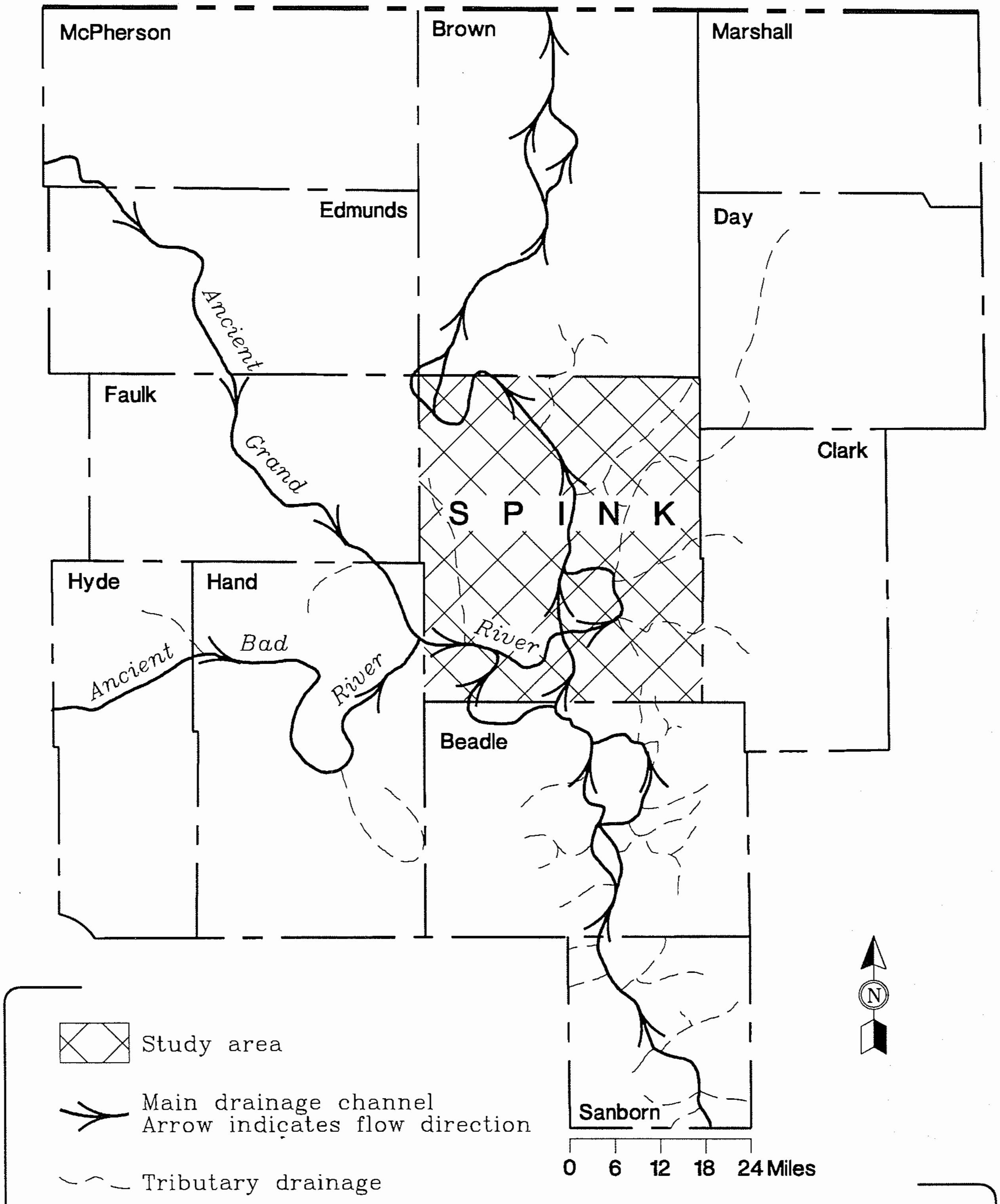


Figure 24. Map showing the inferred pre-late Wisconsin drainage for a portion of eastern South Dakota.

Pre-late Wisconsin Deposits

BASAL OUTWASH

Overlying the bedrock in the deep buried channels is a basal outwash (Qo, figs. 11 through 23). The lower portion of the basal outwash is very coarse grained and made up of a variety of rock types. The unit grades upward to a fine- to medium-grained, predominantly quartz, sand. The contact between the basal outwash and overlying lacustrine silt is gradational.

SILT

Up to 150 feet of silt (Qs, figs. 11 through 23) overlies the basal outwash in the deep buried channels. This unit is a gray, calcareous, clayey to sandy silt. At times it resembles the Niobrara Formation but is much less consolidated. With depth the unit coarsens and increases in quartz content.

Late Wisconsin Deposits

Late Wisconsin-aged deposits cover a large portion of the surface in Spink County (pl. 2). The thickness of these deposits varies from zero, where bedrock is exposed, to over 300 feet at the highest point on Bald Mountain in southwestern Spink County.

TILL

Till is the nonsorted, nonstratified sediment deposited directly from glacial ice. Till is usually composed of two units generally termed lodgement till and ablation till. Lodgement till, usually more compact, is deposited by meltout from the base of actively moving glacial ice. Ablation till, deposited during glacial recession, is more loose, noncompact and its clasts are less strongly abraded. Although these two types of till were noticed during test drilling and in geophysical logs, no attempt was made to differentiate the two.

In Spink County, the tills deposited during each glacial advance are very similar in composition. They usually consist of a very compact, slightly calcareous, silty, clay-rich matrix, reflecting the predominance of Pierre Shale and Niobrara Formation in the local Cretaceous bedrock. Sand- to boulder-sized clasts of many different rock types are found throughout the matrix. The till is generally a gray to near black, depending on the abundance and color of shale it contains. Surface till deposits usually oxidize to a grayish-brown, yellowish-brown, or reddish-brown color to depths of up to 30 feet.

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 Spink County are composed of round to subangular sand grading to a fine- to medium-grained

Figure 25. Areal extent and thickness of glacial Lake Dakota sediments in Spink County, South Dakota.

Sediment Thickness

░ >50 Feet

▩ 25 to 50 Feet

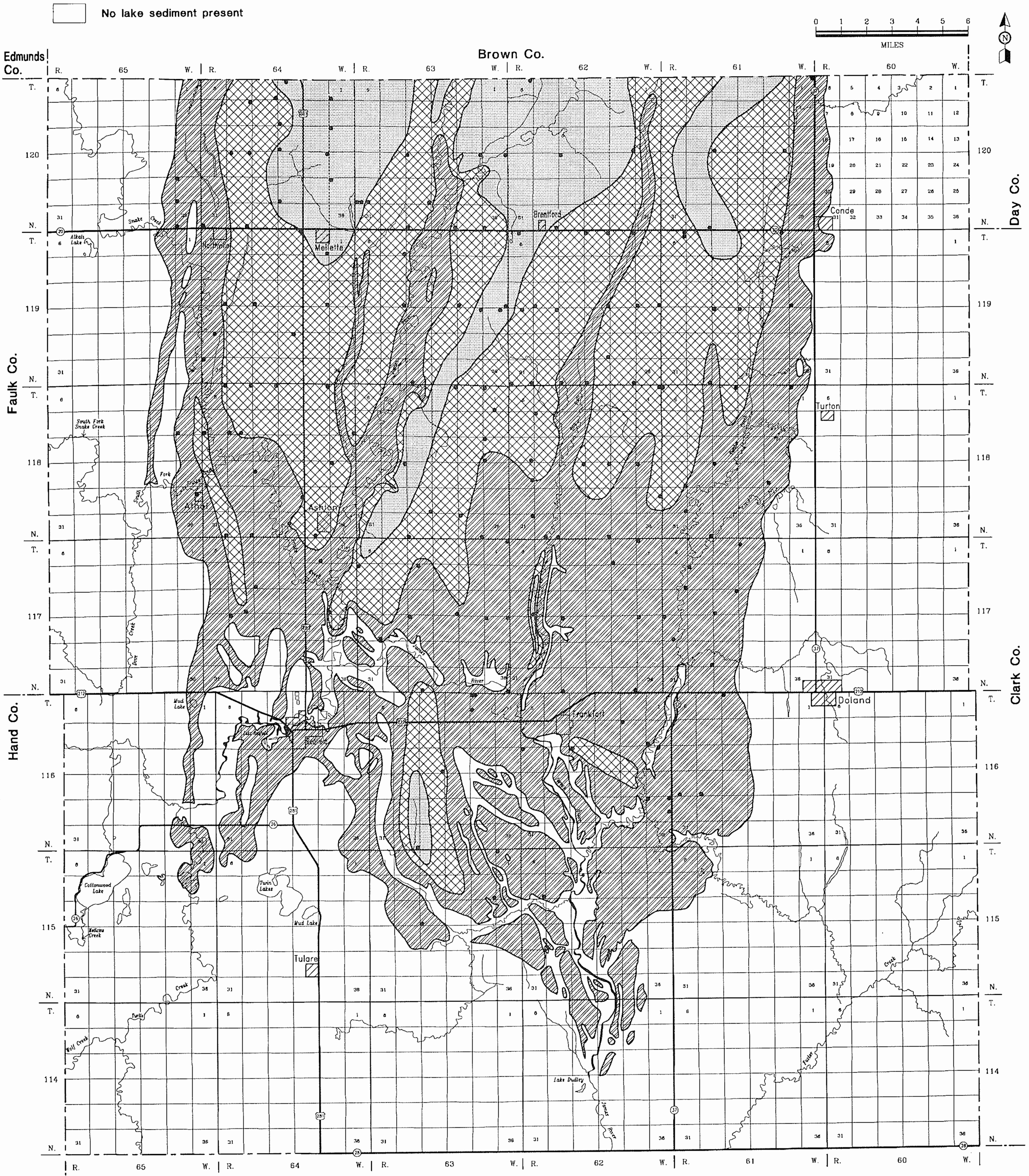
▨ 1 to 25 Feet

☐ No lake sediment present

• Data point.

╱ Line of equal sediment thickness.

For township numbering system see T. 120 N., R. 60 W.



gravel. Some coarse gravel may also be encountered, generally near the base of the deposit. Outwash usually contains a variety of grain types including quartz, limestone, dolomite, shale, and granite.

Outwash associated with each glacial advance has very similar characteristics, making it extremely difficult to distinguish its age. The age of each outwash deposit 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.

LACUSTRINE SEDIMENT

Lacustrine sediment consists of the finer products of glacial erosion, chiefly silt and clay, which have been laid down on the floors of lakes. Lacustrine sediment found at the land surface over much of central Spink County was deposited on the floors of glacial Lakes Dakota and Byron, and has been designated $Qwll_2$ (pl. 2). Lacustrine sediment was also encountered at relatively higher elevations on both sides of the glacial Lake Dakota plain, and has been designated $Qwll_1$ (pl. 2).

Lacustrine sediment ranges in grain size from a clay to a fine sand. The sediment color can be quite variable, from green to gray to black and occasionally white. Some lacustrine sediments contain horizontal bedding. Shell fragments may be encountered.

In Spink County, up to 84 feet of lacustrine sediment was encountered within the glacial Lake Dakota plain. Figure 25 shows the thickness of glacial Lake Dakota sediment which was encountered in Spink County. The glacial Lake Dakota sediment is usually a gray silty clay to clayey silt at depth. From the land surface downward, up to 30 feet has been oxidized to a cream to tan to reddish-brown color. In some areas the entire thickness of lacustrine sediment has been oxidized (figs. 11 through 23).

LOESS

Loess is a windblown deposit consisting of predominantly silt with some clay and fine sand. Loess is generally buff to yellow-brown to light-gray in color. The chief source of this windblown sediment is exposed areas of till and outwash, prior to cover by vegetation.

A thin discontinuous blanket of loess was deposited after the retreat of the late Wisconsin II ice. The loess is typically less than 5 feet thick. In most areas of Spink County it was not considered a mappable unit. Loess was observed in several areas of the county where the vegetation cover was thin or had been removed by agricultural practices. Loess was observed mantling areas east of the glacial Lake Dakota plain and mantling a recessional end moraine to the east of the outwash deposits in the southwestern corner of the county. The placement of the observed loess indicates that the predominant wind direction was probably from the west-northwest. The loess observed in southwestern Spink County is part of a much larger deposit which was mapped in Beadle County to the south (Hedges, 1968) and was therefore mapped for this study (Qes, pl. 2).

Holocene Deposits

The boundary between the Pleistocene and Holocene sediments are time transgressive. Sediment carried in streams and by wind was deposited continuously throughout deglaciation and continues to the present. Alluvial, lacustrine, and eolian sediment deposited during the Pleistocene are, for the most part, indistinguishable from those deposited during the Holocene. Therefore, the boundary between the Pleistocene and Holocene is not definite and has been designated by a dashed line in the legend of plate 2.

Alluvium

Downcutting by recent streams, since the late Wisconsin, has removed some of the outwash leaving terrace remnants along the valley walls. With their floodplains established at a lower position, these streams continue their gradual headward erosion and deposition of alluvium.

Alluvial deposits range in color from brownish-black to grayish-black to black and consist primarily of organic-rich silt, clay, and fine-grained sand. Some medium- to coarse-grained sand and fine-grained gravel may also be encountered.

Lacustrine Sediment

Glacial lakes, such as glacial Lakes Dakota and Byron and other minor lakes, remained long after the ice had retreated from the area. Running water and wind continued to carry sediment to these areas. This process lead to the infilling of glacial lakes, reverting them to sloughs, swamps, and eventually dry lake beds, such as the glacial Lake Dakota plain. This same process continues in present-day lakes such as Cottonwood Lake, Twin Lakes, and others.

Lacustrine sediment typically is a silty clay to a clayey silt, with minor amounts of fine sand. The sediment color can be quite variable, from green to gray to black and occasionally white. Some lacustrine sediments contain horizontal bedding. Shell fragments may be encountered.

Eolian Deposits

Wind has continued to blow sediment from sparsely vegetated areas and redeposit it elsewhere. In some areas, very recent wind-blown deposits can be found partially burying fence lines and other artifacts. These deposits are up to several feet thick, and range in color from yellowish-brown to dark-brown to grayish-black. For the most part recent eolian deposits are indistinguishable from Pleistocene eolian deposits. More recent eolian sediment, however, contains a significant amount of topsoil.

Quaternary Landforms

Landforms Associated with Stagnant Ice

Stagnant ice or dead ice is ice that has been detached and left behind by the retreating glacier. It is ice that is no longer flowing or receiving material from the active glacier (Bates and Jackson, 1987).

STAGNATION MORAINE

Moraine resulting from the stagnation of late Wisconsin ice is found both east and west of the glacial Lake Dakota plain and in the southwestern portion of Spink County (Qwls, pl. 2). Stagnation moraine is composed almost entirely of ablation till. It was deposited when debris-rich blocks of ice became detached from the active glacier and gradually melted. During the melting process, blocks of ice became buried beneath the ablation till. As these blocks melted, the covering blanket of till collapsed forming numerous closed depressions, lakes, and sloughs. The resulting knob and kettle topography is typical of stagnation moraine.

COLLAPSED OUTWASH

An area south of the city of Redfield is mapped as collapsed outwash (Qwloc, pl. 2). In this area, sediment-laden water from the melting ice sheet flowed over and through stagnant ice. When the stagnant ice finally melted, the sediment had collapsed leaving an undulating surface. Sand and gravel deposits are found blanketing the knobs as well as the lows.

DISINTEGRATION RIDGES

Several disintegration ridges (Qwlodr, pl. 2) have been mapped along the eastern side of the glacial Lake Dakota plain. Meltwater emanating from the stagnant ice to the east on the Coteau des Prairies (fig. 2) flowed toward and over the ice which occupied Spink County. Sediment carried by the meltwater was deposited in crevasses in the ice. Eventually, as the ice melted from the area, the crevasse-fill collapsed leaving a ridge on the land surface. As a result of the collapse, these ridges contain a poorly sorted mixture of sand, gravel, and boulders, with minor amounts of clay and silt.

Landforms Associated with Active Ice

Active ice is that part of a glacier which has an accumulation area and is flowing (Bates and Jackson, 1987).

RECESSIONAL END MORAINE

As the late Wisconsin ice was retreating from South Dakota, it would periodically become stable. During this time the ice was neither advancing nor retreating. Long-term stability of the ice margin can result in the accumulation of significant sediment thicknesses. The resulting constructional topography is rugged, relatively elevated, and shows some lineation. Land surface features such as Doland Ridge, Redfield Hills, and Bald Mountain are mapped as recessional end moraine (Qwle, pl. 2). Todd (1909) referred to these features as members of the Antelope moraine.

To the south in Beadle County, Hedges (1968) mapped a rather large area of end moraine. He combined features such as "smooth ridges," "hummocky ridges," and the undulating lowlands between the ridges, into what he called an "end-moraine complex." In Spink County the undulating lower land surface between the recessional end moraine crests has been mapped as stagnation moraine.

GROUND MORAINE

Ground moraine has been mapped in northwestern, eastern, and southern Spink County (Qwlg, pl. 2). Ground moraine is also found in some areas beneath the lake plain deposits. Subsequent stream erosion near the southern end of the glacial Lake Dakota plain has exposed these buried deposits.

Ground moraine consists mainly of lodgement till deposited beneath the glacier as it advanced, covered by a lesser amount of ablation till deposited as the glacier was retreating. In southern Spink County the ablation deposits include thousands of boulders which cover the land surface.

Ground moraine differs in appearance from the other types of moraine, in that it is much less hummocky, usually relatively flat to gently sloping. The relative smoothness is due to the rather rapid and steady rate the ice sheet receded.

WASHBOARD MORAINE

Washboard moraine, sometimes called minor moraines, has been mapped rather extensively in Edmunds, Faulk, and Hand Counties (Christensen, 1977; and Helgerson and Duchossois, 1987). A small portion of this broad area extends into western Spink County (Qwlw, pl. 2). The term, washboard moraine, originates from a pattern of small linear ridges which can be seen when viewed from the air or with the aid of aerial photographs. Gwynne (1951) proposed that they were formed by seasonal advance and retreat of the ice margin as the ice sheet receded from the area.

RECESSIONAL MORAINE

A small portion of northeastern Spink County has been mapped as recessional moraine (Qwlr, pl. 2). Recessional moraine has been mapped rather extensively in Brown and Day Counties (Leap, 1986 and 1988). Leap describes this area as containing quasi-parallel bands of rough and hummocky topography generally running northeast-southwest. In this area, lacustrine deposits are occasionally found between the recessional crests.

VALLEY TRAIN

Valley train is a long narrow body of outwash confined within a valley (Qwlov, pl. 2). The outwash is composed of sand and/or gravel deposited by braided meltwater streams. This type of deposit occurs in the valleys of present-day Medicine Creek, Turtle Creek, and Wolf Creek in southwestern Spink County.

OUTWASH TERRACES

Outwash terraces (Qwlot, pl. 2) are remnants of former valley train deposits. Subsequent downcutting by post-glacial streams has removed much of the outwash that was originally deposited. Flat to gently sloping remnants of the former valley train are found at relatively higher elevations than the present-day stream valley floors.

Landforms Associated with Glacial Lakes Dakota and Byron

LAKE PLAIN

The lake plains associated with glacial Lakes Dakota and Byron ($Qwll_2$, pl. 2) are nearly flat surfaces underlain by lacustrine sediment carried to the lakes by meltwater streams. The near-shore lacustrine deposits within the glacial Lake Dakota plain are sandier and have been worked by wave action. These areas were delineated with the use of aerial photographs and depicted on plate 2.

DELTAS

In Spink County, deltas are found in several areas where meltwater streams emptied into glacial Lakes Dakota and Byron (Qwlod, pl. 2). Deltas are typically very flat features distinguished from the lake plain only by the material they contain. Deltaic deposits contain more of the coarser products of erosion. Typically, the sediment ranges from a sandy silt to a silty sand, but may contain some clay and occasionally gravel.

Quaternary Stratigraphy and Geologic History

Pleistocene

Portions of eastern South Dakota were glaciated many times during the Pleistocene epoch. The reader is referred to Richmond and Fullerton (1986) for more information on the Quaternary glaciations of the area. Prior to the late Wisconsin, glaciers are thought to have approached South Dakota from a northeast direction. As individual glaciers advanced into eastern South Dakota, they became stalled against a bedrock topographic high. This resulted in thick accumulations of till near the ice margin. The net result of this stacking of glacial moraine was a very prominent topographic feature now known as the Coteau des Prairies.

PRE-LATE WISCONSIN

There is no certain evidence that any of the Pleistocene deposits in Spink County are in fact pre-late Wisconsin in age. No buried oxidation zones or paleosols (soils) were encountered during test drilling. Stratigraphic relations and previous investigations, however, suggest that the basal outwash and overlying lacustrine silts in the deep channels are probably pre-late Wisconsin in age. Similar deep channel deposits were encountered to the south in Beadle County (Hedges, 1968) and to the north in Brown County (Leap, 1986) and Stutsman County, North Dakota (Winters, 1963).

Hedges (1968) presented several lines of evidence which seem to indicate a pre-late Wisconsin age for the channel-fill deposits. First of all, the presence of a basal outwash underlying the lacustrine silts places the deposits within the Pleistocene Epoch. Secondly, a significant time lapse is indicated prior to the deposition of late-Wisconsin sediment. In Spink County, over 400 feet of downcutting occurred. This was followed by a significant period of time in which the meltwater outlet was dammed by ice and backwater filled the channel. It is during this period of time that the silts were deposited. Thirdly, a peaty material, lying stratigraphically between the lacustrine silts and late-Wisconsin deposits, gave a radiocarbon date of greater than 32,000 years before present (Levin and others, 1965). Hedges (1968), therefore, stated that the basal outwash and lacustrine silts are at least as old as the early Wisconsin.

More recent studies such as Clark (1986) and Hallberg (1986) subsequently re-evaluated the extent of early-Wisconsin glaciation and suggest that no early-Wisconsin ice advanced to this area. Therefore, the previously mentioned radiocarbon date would seem to indicate the basal outwash and lacustrine silts are older than Wisconsin in age and may in fact be much older. Much older deposits tentatively Illinoian and pre-Illinoian in age have been recognized to the east on the Coteau des Prairies (Tomhave, 1994).

LATE WISCONSIN

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).

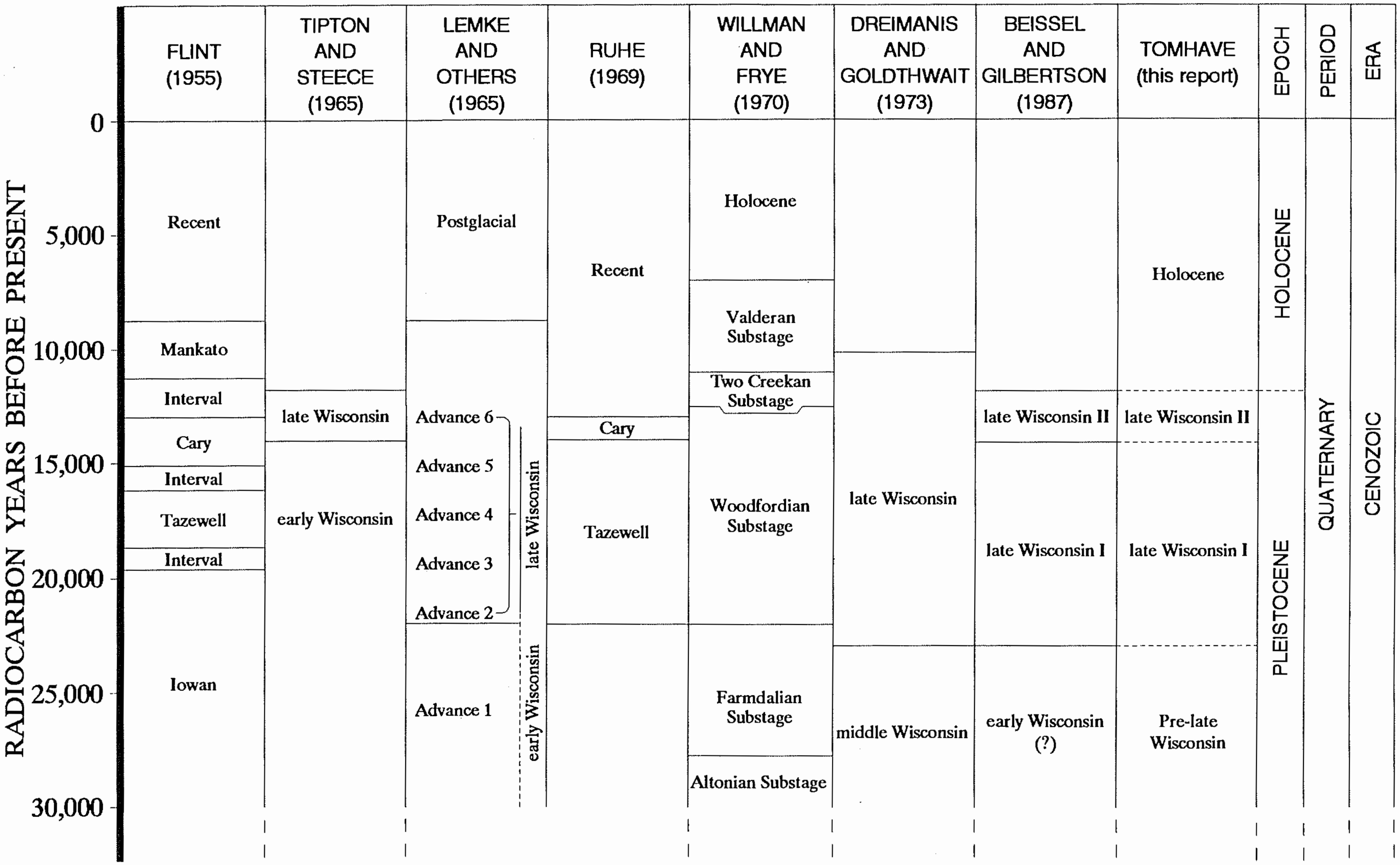
The ice mass was split by the Coteau des Prairies highland and continued as two distinct lobes, now known as the Des Moines lobe and the James lobe. The Des Moines lobe was diverted to the southeast into southern Minnesota and Iowa and had no effect on the Spink County area. The James lobe moved into a topographic lowland west of the Coteau des Prairies highland. The ice flowed in a southerly direction and also spread westward toward the present-day Missouri River and eastward encroaching on the Coteau des Prairies highland.

Lemke and others (1965) postulated that five distinct glacial advances occurred during the late Wisconsin in South Dakota (table 2). Two distinct advances of the James lobe were identified during this investigation and have been designated late Wisconsin I and late Wisconsin II.

As the late Wisconsin I ice approached the Spink County area, meltwater flowed from the ice margin. This meltwater was responsible for the deposition of some of the basal sand and gravel, designated Qo (figs. 11 through 23).

Table 2. Classification and correlation of Wisconsin glaciations in the Midwestern and North-Central United States.

(Modified from Lemke and others, 1965; Dreimanis and Goldthwait, 1973; and Beissel and Gilbertson, 1987)



The late Wisconsin I ice continued to advance, completely covering the area which is now Spink County. The areal extent of the late Wisconsin I advance, outside of Spink County, is not known. In the surrounding counties only one late Wisconsin advance was identified. On the eastern side of the Coteau des Prairies, however, Beissel and Gilbertson (1987) identified two separate periods of late Wisconsin glacial activity (table 2). There is no certain evidence that can be used to correlate the late Wisconsin I and II from the eastern side of the Coteau des Prairies to the western side. Because of this uncertainty, dashed lines are used to indicate the constraints of the separate glacial advances for this report (table 2). The late Wisconsin I advance is responsible for the deposition of the till designated $Qwlt_1$ (figs. 11 through 23).

Eventually, the late Wisconsin I ice began to retreat from the Spink County area. The ice margin retreated northward to some unknown point, north of what is now Spink County. As the ice retreated, meltwater flowed from the ice front and from stagnating ice left behind. This meltwater is responsible for the deposition of a large volume of sand and gravel, designated Qwlo (figs. 11 through 23). This body of outwash contains considerable quantities of water. In Spink County, aquifer names such as the Tulare, Elm, Middle James, and Altamont refer to the water held in outwash bodies deposited at this time.

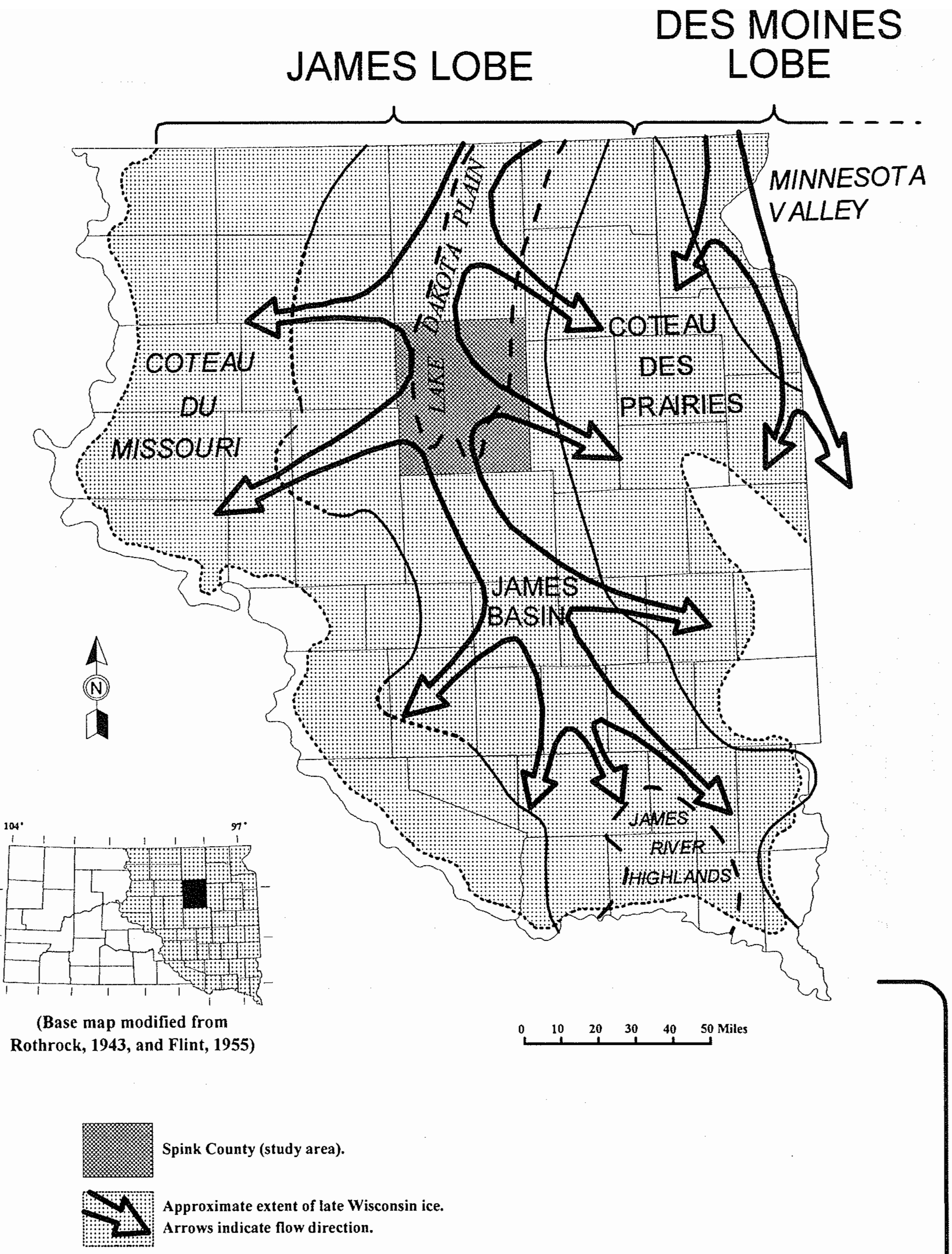
As the late Wisconsin I ice retreated, an ice marginal lake, similar to glacial Lake Dakota, formed. Sediment deposited in this lake has been designated Qwll(unox) (figs. 11 through 23).

The second period of glacial advance began about 14,000 years ago. The ice of the James lobe flowed in a southerly direction, spreading westward toward the present-day Missouri River and eastward encroaching on the Coteau des Prairies highland. Late Wisconsin II ice completely covered the Spink County area and advanced southward to what is now the South Dakota-Nebraska border (fig. 26). This advance is responsible for the deposition of the till designated $Qwlt_2$ (figs. 11 through 23; and pl. 2).

Ice covered all of Spink County until the final retreat of active ice. As the James lobe retreated northward from the South Dakota-Nebraska border, there were periods when the retreat paused or there was a minor readvance of the ice. During these periods, a ridgelike accumulation of debris is produced at the ice margin, referred to in this report as a recessional end moraine. Two such recessional positions (figs. 27 and 28) were recognized in Spink County, which Todd (1909) referred to as stages of the Antelope Moraine.

The western margin of the James lobe receded to a position near Spink County's border with Hand and Faulk Counties (fig. 27), while the eastern margin still extended east of the county to the Coteau des Prairies. A portion of the resultant recessional end moraine extends south from Bald Mountain into Beadle County (pl. 2), where it becomes the western portion of a large end moraine complex (Hedges, 1968).

Eventually the James lobe ice continued to retreat to a point where it paused again. This time, however, the pause was followed by a minor readvance of the ice, in which it split into two minor lobes (fig. 28). Debris accumulation at the ice margin during this readvance again resulted in recessional end moraine, in which mass was added to Bald Mountain. The Redfield Hills, Doland Ridge, and the eastern portion of the Beadle County end moraine complex (Hedges, 1968) were deposited at this time.



(Base map modified from Rothrock, 1943, and Flint, 1955)

Figure 26. Generalized relationship of James lobe and Des Moines lobe ice to eastern South Dakota.

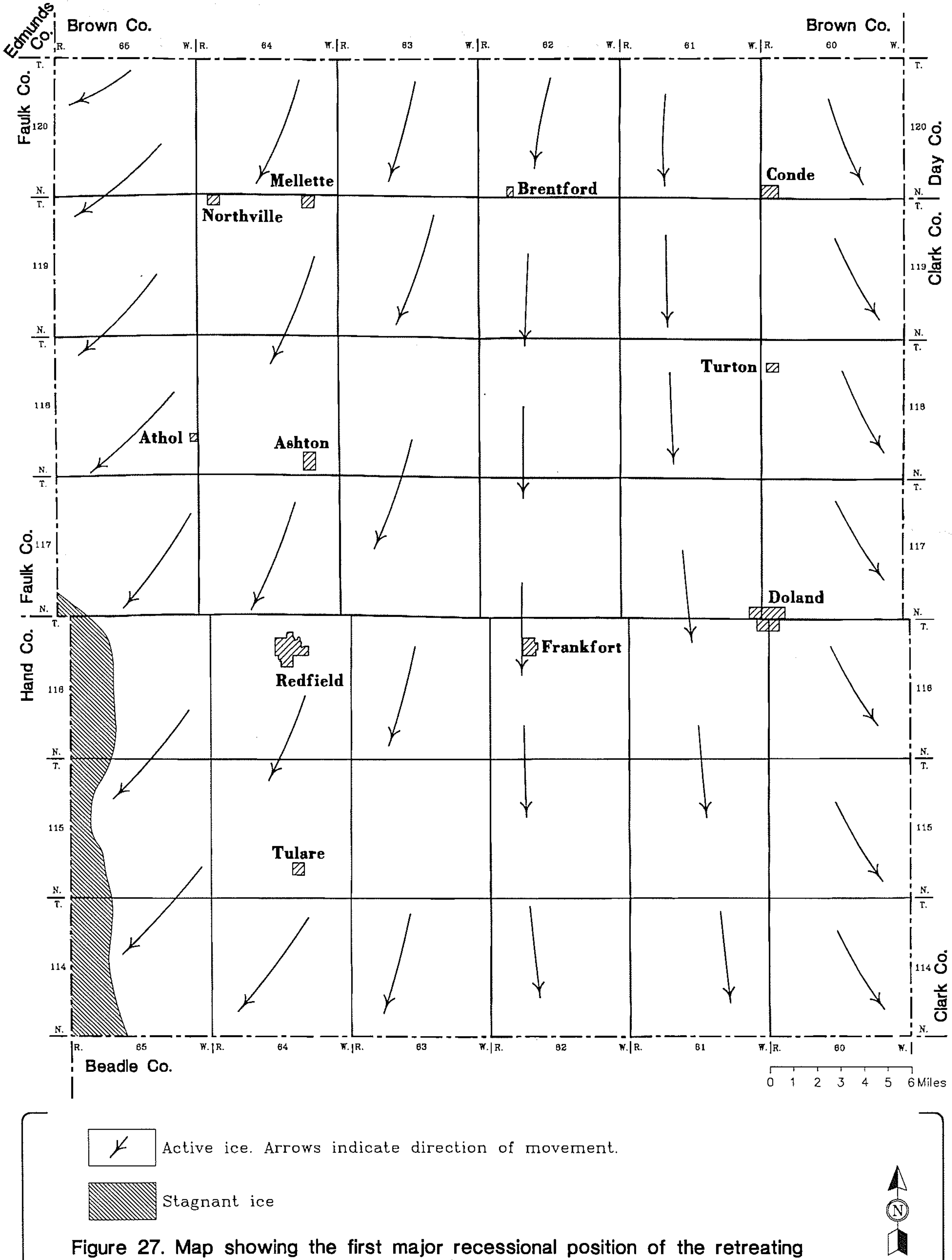


Figure 27. Map showing the first major recessional position of the retreating late Wisconsin II ice in Spink County, South Dakota.

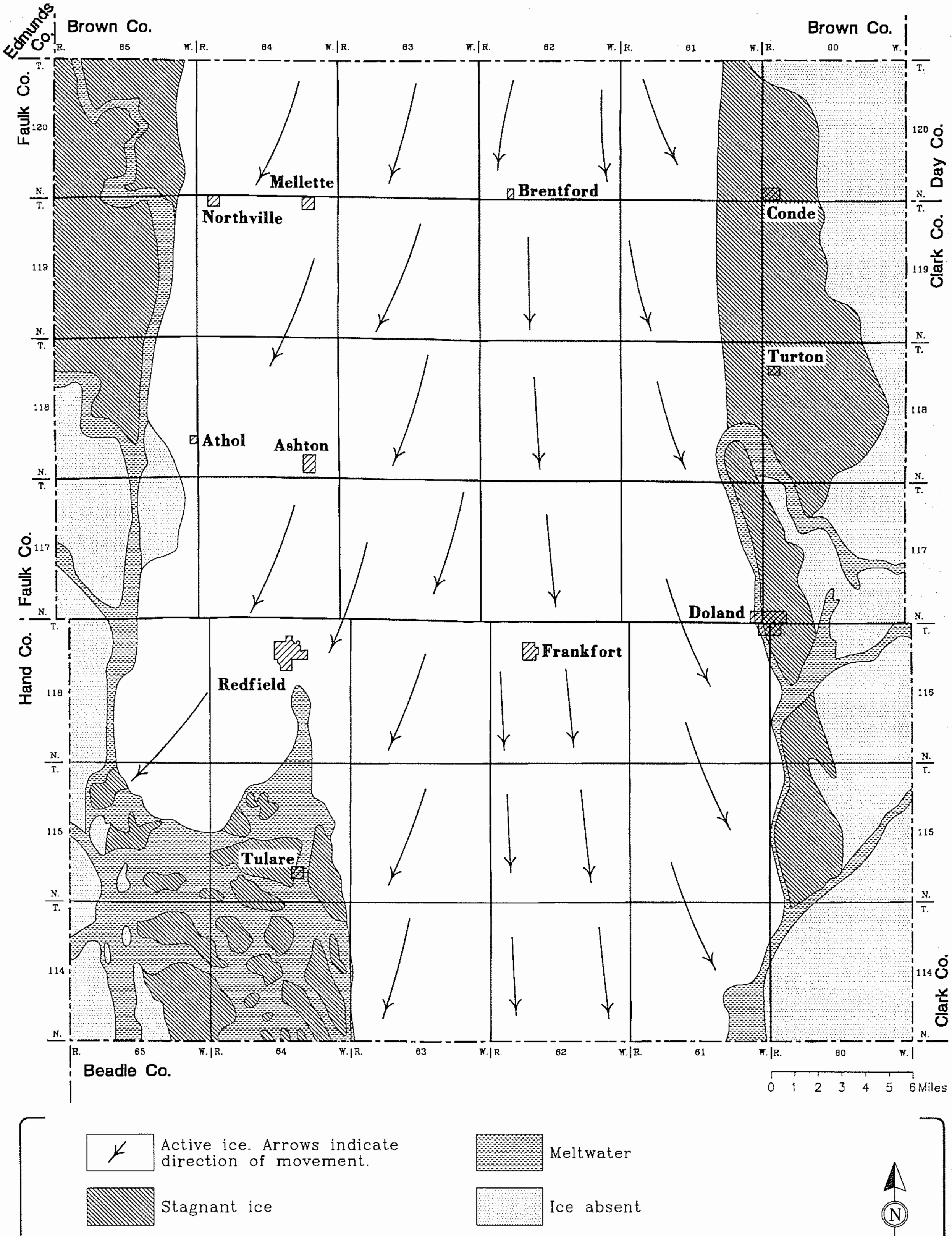


Figure 28. Map showing the second major recessional position of the retreating late Wisconsin II ice in Spink County, South Dakota.

After this minor readvance, the James lobe continued its retreat. As the southern edge of the James lobe retreated northward, meltwater ponded between the ice margin and the end moraine complex in northern Beadle County. During the retreat there were several minor pauses in which recessional end moraine was deposited. These minor recessional end moraines formed morainal dams, which resulted in a succession of small glacial lakes, such as glacial Lake Byron.

During this period and as the James lobe ice resumed its retreat, meltwater flowed from the ice front and from stagnant ice left behind. Much of the surficial outwash found in Spink County was deposited at this time. Partially buried ice blocks, detached from the ice front, are responsible for the formation of Cottonwood Lake and Twin Lakes. On the eastern side of the county, meltwater originating from Coteau des Prairies flowed across stagnant ice depositing sediment in crevasses. Disintegration ridges found near the cities of Conde and Turton are the remnants.

As the James lobe ice receded northward to a point north of what is now Spink County, meltwater became ponded in the low area between the ice front and proximal slope of a minor recessional end moraine creating glacial Lake Dakota. Glacial Lake Dakota, at its maximum, extended from southern Spink County, through Brown County, and into North Dakota. Long after the active ice had retreated from South Dakota, glacial Lake Dakota continued to receive water from melting stagnant ice on the Coteau des Prairies to the east, the Coteau du Missouri to the west, and from North Dakota. This stagnant ice persisted, slowly melting, until as late as 9,000 years ago (Christensen, 1977). As sediment laden meltwater flowed into glacial Lakes Dakota and Byron, the coarse material, primarily sand, was deposited as deltas at the mouths of the meltwater streams. Finer material such as silt and clay was deposited in large quantities on the lake floors. From its inception overflow from glacial Lake Dakota spilled southward down the James River valley.

Prevailing winds blowing from west-northwest to east-southeast across the unvegetated outwash, till, and lake plain surfaces picked up some of the fine material and redeposited it elsewhere (Qes, pl. 2).

Holocene

The Holocene is an epoch of the Quaternary period. It is sometimes defined as beginning at the end of the Pleistocene, approximately 10,000 years ago, and continuing to the present. The boundary between Pleistocene and Holocene sediments is, however, time transitional. Sediment carried in streams and by wind was deposited continuously throughout deglaciation and continues to the present. Therefore, the boundary between the Pleistocene and Holocene is not definite and has been designated by a dashed line in the legend of plate 2 and on table 2.

With time the outflow from glacial Lake Dakota down the James River valley had created an increasingly deeper trench. As the lake shrank, tributary streams extended themselves across the emerged lake bed to the main discharge down the James River valley. Trenching by the James River and its tributaries continued long after the lake had disappeared. After the demise of the lake, a large inflow of water continued down the James River valley from the north. The lake sediments are trenched along the entire length of the lake plain. Silt deposited on the lake floor was very easily eroded. At the southern end of the glacial Lake Dakota plain, the lake silts were completely removed exposing the underlying, boulder strewn, till surface.

In recent times, most of the streams occupying meltwater channels cut during the Pleistocene have become small, underfit, and intermittent. This is due to the fact that today there is less water supplying them than the large volume of meltwater available during the Pleistocene and early Holocene. Downcutting by recent streams has removed some of the outwash leaving outwash terrace remnants along the valley walls. With their floodplains established at a lower position, these streams continue their gradual headward erosion and deposition of alluvium. Stream erosion is gradually moving sediment from the highlands to topographically lower areas. Lakes are continuously being filled with sediment, creating sloughs, marshy areas, and eventually dry lake beds.

Wind continues to blow sediment from sparsely vegetated areas and redeposit it elsewhere. Weathering of the land 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 Spink County. Ground water resources are found in numerous glacial outwash aquifers throughout the county. The "Tulare aquifer," one of the more important glacial outwash aquifers, is found extensively in southern Spink County and supplies large quantities of water for irrigation, domestic, and livestock purposes. Ground water is also found in several of the deep bedrock aquifers within the county. The main source of bedrock ground water is the Dakota Formation, its combined sandstone units referred to as the "Dakota aquifer," supply significant quantities of water for livestock and domestic use.

This cooperative study of the geology and water resources of Spink County included a complete hydrologic investigation. A short summary discussing the major aquifers in Spink County is in preparation (Benson, in preparation). A more technical evaluation of the water resources of Spink County has been published by the U.S. Geological Survey (Hamilton and Howells, 1996). All questions regarding the water resources of Spink County are referred to the office of the U.S. Geological Survey, Water Resources Division, 111 Kansas Avenue SE, Huron, South Dakota 57350 or phone (605) 353-7176.

Sand and Gravel

Another important part of this investigation dealt with the availability of sand and gravel resources within the county. These resources are used primarily for the maintenance of area roads. A separate report summarizing this portion of the investigation was compiled by Schulz (1995).

Other Mineral Resources

At the present time there are no other mineral resources which have proved to be economically feasible for mining in Spink County. Exploration for various mineral commodities other than those previously mentioned has however taken place in the past.

Oil and Gas

Todd (1909) reported on several encounters of unidentified gas in water wells drilled in Spink County. He reported on several encounters of gas from shallow glacial sediments in the vicinity of the city of Ashton and from several deep Dakota Formation artesian wells.

In 1964, two tests were made for oil and gas in section 28, T. 117 N., R. 63 W. to depths of 993 feet and 1,120 feet, respectively (Schoon, 1965). No significant shows of oil and/or gas were reported.

Clay

Clay has been mined in the past from the sediment of the glacial Lake Dakota plain (Todd, 1909). The clay was used to make bricks for building purposes.

Coal

Todd (1909) also made mention of fragments of lignite encountered in water wells drilled in Spink County. During the test drilling conducted for this study, fragments of coal were encountered quite often. The coal fragments were usually noticed when drilling through fine-grained glacial outwash. The coal fragments were undoubtedly incorporated into the till as the ice moved over lignite beds which are prominent to the north in North Dakota. As meltwater flowed across the area from the north, fragments of coal picked up and carried along with the sediment load of the stream. The coal fragments, being fairly light weight, were carried for some distance and deposited with similar weight fine-grained sand.

Manganese

The existence of low grade manganese deposits in the Missouri River Valley region of South Dakota has been known for quite some time (Hewitt, 1930). A report by Gries and Rothrock (1941) focused on the nodule-rich Oacoma Manganiferous Shale facies of the DeGrey member of the Pierre Shale between Chamberlain and Pierre, South Dakota. Interpretations made by the author during this investigation show the DeGrey member of the Pierre Shale as being in subcrop below Quaternary sediment over a large area of Spink County (figs. 11 through 23). Schoon and Hedges (1990) in a reconnaissance study of manganese potential in South Dakota reported the occurrence of manganese nodules at several localities in Spink County. In T. 117 N., R. 60, 61, 62, and 63 W. weathered nodules were obtained from shale which was excavated from numerous dug stock dams. These weathered nodules averaged 23.8 percent manganese (Schoon and Hedges, 1990). Manganese-rich gravels were also reported at several localities including: NW¼ of section 14, T. 114 N., R. 62 W. (3.91 percent manganese), SE¼ of section 8, T. 115 N., R. 62 W. (6.65 percent manganese), and SE¼ of section 15, T. 115 N., R. 61 W. (6.77 percent manganese) (Schoon and Hedges, 1990).

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APPENDIX

Legal description of test hole log locations

The following list contains the map location numbers and legal descriptions of all the test hole logs used to construct the cross sections (figs. 11 through 23). The map location numbers refer only to this report. Any request for logs should contain the legal descriptions, however, more than one test hole log may exist at a given legal description.

MAP LOCATION NUMBER	LEGAL DESCRIPTION
Geologic cross section A-A′ (fig. 11)	
MLN- 1	SE SE SW SE sec. 17, T. 120 N., R. 65 W.
MLN- 2	SW NW NW NW sec. 21, T. 120 N., R. 65 W.
MLN- 3	SE SE SE SW sec. 16, T. 120 N., R. 65 W.
MLN- 4	NE NW NW NE sec. 22, T. 120 N., R. 65 W.
MLN- 5	NE NE NE NE sec. 23, T. 120 N., R. 65 W.
MLN- 6	NE NE NW NW sec. 20, T. 120 N., R. 64 W.
MLN- 7	NE NW NE NE sec. 20, T. 120 N., R. 64 W.
MLN- 8	SW SW SW SW sec. 15, T. 120 N., R. 64 W.
MLN- 9	NE NE NE NE sec. 23, T. 120 N., R. 64 W.
MLN- 10	NW NW NW NW sec. 21, T. 120 N., R. 63 W.
MLN- 11	NE NE NE NE sec. 23, T. 120 N., R. 63 W.
MLN- 12	NE NE NE NE sec. 24, T. 120 N., R. 63 W.
MLN- 13	NW NW NW NW sec. 21, T. 120 N., R. 62 W.
MLN- 14	SE SE SE SE sec. 14, T. 120 N., R. 62 W.
MLN- 15	SE SW SW SW sec. 16, T. 120 N., R. 61 W.
MLN- 16	SW SW SE SE sec. 14, T. 120 N., R. 61 W.
MLN- 17	NW NW NW NW sec. 21, T. 120 N., R. 60 W.
MLN- 18	NW NW NW NW sec. 24, T. 120 N., R. 60 W.
Geologic cross section B-B′ (fig. 12)	
MLN- 19	NE NE NE NE sec. 12, T. 119 N., R. 66 W.
MLN- 20	NE NW NW NW sec. 4, T. 119 N., R. 65 W.
MLN- 21	NW NW NW NW sec. 3, T. 119 N., R. 65 W.
MLN- 22	NW NW NW NW sec. 2, T. 119 N., R. 65 W.
MLN- 23	SW SW SW SW sec. 36, T. 120 N., R. 65 W.
MLN- 24	SW SW SW SW sec. 31, T. 120 N., R. 64 W.
MLN- 25	SE SE SW SE sec. 32, T. 120 N., R. 64 W.
MLN- 26	SE NE NE NE sec. 3, T. 119 N., R. 64 W.
MLN- 27	SW SW NW SW sec. 36, T. 120 N., R. 64 W.
MLN- 28	SW SW SW SW sec. 33, T. 120 N., R. 63 W.

Geologic cross section B-B′ (fig. 12) — continued.

MLN- 29	NE SE SE SE sec. 33, T. 120 N., R. 63 W.
MLN- 30	SE SE SE SE sec. 34, T. 120 N., R. 63 W.
MLN- 31	SW SW SW SW sec. 36, T. 120 N., R. 63 W.
MLN- 32	NE NE NE NW sec. 6, T. 119 N., R. 62 W.
MLN- 33	SE SE SE SE sec. 32, T. 120 N., R. 62 W.
MLN- 34	NW NW NW NW sec. 3, T. 119 N., R. 62 W.
MLN- 35	NE NE NE NE sec. 3, T. 119 N., R. 62 W.
MLN- 36	NE NE NE NE sec. 2, T. 119 N., R. 62 W.
MLN- 37	NE NE NE NE sec. 6, T. 119 N., R. 61 W.
MLN- 38	SE SE SE SE sec. 32, T. 120 N., R. 61 W.
MLN- 39	NE NE NE NE sec. 2, T. 119 N., R. 61 W.
MLN- 40	NE NE NE NE sec. 5, T. 119 N., R. 60 W.
MLN- 41	SE SE SE SE sec. 35, T. 120 N., R. 60 W.

Geologic cross section C-C′ (fig. 13)

MLN- 42	NE NE NE NE sec. 24, T. 119 N., R. 66 W.
MLN- 43	NW NW NW NW sec. 21, T. 119 N., R. 65 W.
MLN- 44	NW NW NW NW sec. 24, T. 119 N., R. 65 W.
MLN- 45	SE SE SE SE sec. 18, T. 119 N., R. 64 W.
MLN- 46	SW SW SW SW sec. 16, T. 119 N., R. 64 W.
MLN- 47	SE SE SE SE sec. 14, T. 119 N., R. 64 W.
MLN- 48	SE SE SE SE sec. 17, T. 119 N., R. 63 W.
MLN- 49	SW SW SW SW sec. 14, T. 119 N., R. 63 W.
MLN- 50	NE NE NE NE sec. 23, T. 119 N., R. 63 W.
MLN- 51	NE NW NW NE sec. 24, T. 119 N., R. 63 W.
MLN- 52	SE SE SE SE sec. 13, T. 119 N., R. 63 W.
MLN- 53	NW NW NW NE sec. 19, T. 119 N., R. 62 W.
MLN- 54	SW SW SW SW sec. 17, T. 119 N., R. 62 W.
MLN- 55	NE NE NE NE sec. 20, T. 119 N., R. 62 W.
MLN- 56	SW SW SW SW sec. 13, T. 119 N., R. 62 W.
MLN- 57	NW NW NW NW sec. 21, T. 119 N., R. 61 W.
MLN- 58	NW NW NW NW sec. 22, T. 119 N., R. 61 W.
MLN- 59	SW SW SW SW sec. 13, T. 119 N., R. 61 W.
MLN- 60	SW SE SE SE sec. 13, T. 119 N., R. 61 W.
MLN- 61	SE SE SE SE sec. 18, T. 119 N., R. 60 W.
MLN- 62	NW NW NW NW sec. 21, T. 119 N., R. 60 W.
MLN- 63	NE NE NE NE sec. 23, T. 119 N., R. 60 W.

Geologic cross section D-D′ (fig. 14)

MLN- 64	SW SE SE SE sec. 32, T. 119 N., R. 65 W.
MLN- 65	SE SE SE SE sec. 35, T. 119 N., R. 65 W.
MLN- 66	NE NE NE NE sec. 6, T. 118 N., R. 64 W.
MLN- 67	NE NE NE NE sec. 5, T. 118 N., R. 64 W.
MLN- 68	NE NE NE NE sec. 4, T. 118 N., R. 64 W.

Geologic cross section D-D′ — continued.

MLN- 69	NE NE NE NE sec. 2, T. 118 N., R. 64 W.
MLN- 70	SW SW SE SW sec. 33, T. 119 N., R. 63 W.
MLN- 71	NE NE NE NE sec. 3, T. 118 N., R. 63 W.
MLN- 72	NW NW NW NW sec. 1, T. 118 N., R. 63 W.
MLN- 73	SW SW SW SW sec. 31, T. 119 N., R. 62 W.
MLN- 74	SE SE SE SE sec. 31, T. 119 N., R. 62 W.
MLN- 75	SW SW SW SW sec. 33, T. 119 N., R. 62 W.
MLN- 76	SW SW SW SW sec. 34, T. 119 N., R. 62 W.
MLN- 77	SE SE SE SE sec. 35, T. 119 N., R. 62 W.
MLN- 78	NW NW NW NW sec. 6, T. 118 N., R. 61 W.
MLN- 79	SE SE SE SE sec. 32, T. 119 N., R. 61 W.
MLN- 80	NE NE NE NE sec. 4, T. 118 N., R. 61 W.
MLN- 81	NW NW NW NW sec. 1, T. 118 N., R. 61 W.
MLN- 82	SW SW SW SW sec. 33, T. 119 N., R. 60 W.
MLN- 83	NE NE NE NE sec. 2, T. 118 N., R. 60 W.

Geologic cross section E-E′ (fig. 15)

MLN- 84	NW NW NW NW sec. 21, T. 118 N., R. 65 W.
MLN- 85	SE SE SE SE sec. 14, T. 118 N., R. 65 W.
MLN- 86	SW SW SW NW sec. 21, T. 118 N., R. 64 W.
MLN- 87	NW NW NW NW sec. 24, T. 118 N., R. 64 W.
MLN- 88	NE NE NE NE sec. 20, T. 118 N., R. 63 W.
MLN- 89	SW SW SW SW sec. 13, T. 118 N., R. 63 W.
MLN- 90	SW SE SE SE sec. 18, T. 118 N., R. 62 W.
MLN- 91	SE SE SE SE sec. 17, T. 118 N., R. 62 W.
MLN- 92	NE NE NE NE sec. 21, T. 118 N., R. 62 W.
MLN- 93	NE NE NE NE sec. 22, T. 118 N., R. 62 W.
MLN- 94	NW NW NW NW sec. 24, T. 118 N., R. 62 W.
MLN- 95	NW NW NW NW sec. 21, T. 118 N., R. 61 W.
MLN- 96	SW SW SW SW sec. 14, T. 118 N., R. 61 W.
MLN- 97	NW NW NW NW sec. 24, T. 118 N., R. 61 W.
MLN- 98	SE SE SE SE sec. 17, T. 118 N., R. 60 W.
MLN- 99	NW NW NW NW sec. 24, T. 118 N., R. 60 W.

Geologic cross section F-F′ (fig. 16)

MLN-100	NE NE NE NE sec. 5, T. 117 N., R. 65 W.
MLN-101	NE NE NE NE sec. 2, T. 117 N., R. 65 W.
MLN-102	SE SE SE SE sec. 31, T. 118 N., R. 64 W.
MLN-103	SE SE SE SE sec. 32, T. 118 N., R. 64 W.
MLN-104	SE SE SE SW sec. 35, T. 118 N., R. 64 W.
MLN-105	SW SW SW SW sec. 33, T. 118 N., R. 63 W.
MLN-106	SE NE NW NE sec. 4, T. 117 N., R. 63 W.
MLN-107	SE SE SE SE sec. 35, T. 118 N., R. 63 W.
MLN-108	SE SE SE SW sec. 32, T. 118 N., R. 62 W.
MLN-109	SE SE SE SE sec. 32, T. 118 N., R. 62 W.