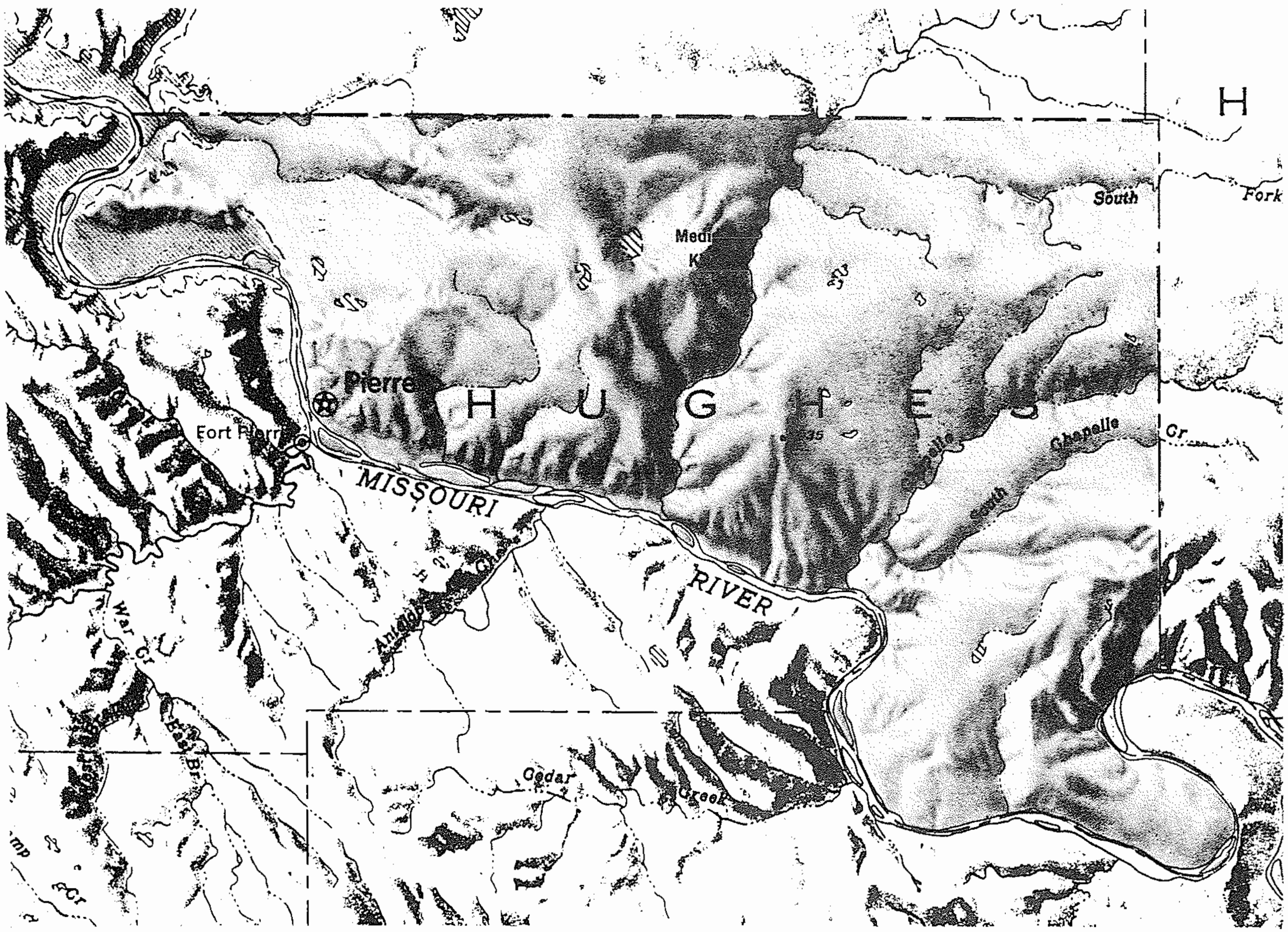
BULLETIN 36

GEOLOGY OF HUGHES COUNTY, SOUTH DAKOTA



by George E. Duchossois

Prepared in cooperation with the
United States Geological Survey,
Mid-Dakota Water Development District,
and Hughes County.

DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY - 1993

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STATE OF SOUTH DAKOTA
Walter D. Miller, Governor

DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
Robert E. Roberts, Secretary

DIVISION OF GEOLOGICAL SURVEY
C.M. Christensen, State Geologist

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Science Center
University of South Dakota
Vermillion, South Dakota

1993

CONTENTS

QUANTERNARY GEOLOGY -- continued. Page

QUATERNARY GEOLOGY -- continued. Page

ILLUSTRATIONS

PLATES (Plates are in pocket)

FIGURES Page

FIGURES -- continued. Page

TABLES

ABSTRACT

Hughes County is located in central South Dakota and has an area of 784 square miles. Prominent surface features in the county are the Coteau du Missouri and the Missouri River valley.

Bedrock underlying the county ranges in age from Precambrian to Cretaceous and consists of basal metamorphic rocks overlain by interbedded limestones, shales, and sandstones. Only the Cretaceous Pierre Shale is exposed at the surface.

Sediments deposited by late Wisconsin glaciation mantle the Pierre Shale in most of the county and have a maximum thickness of 370 feet. At least two glacial advances flowed over the county depositing shale rich lodgement till. Subsurface outwash deposits, although uncommon, are found primarily in the buried Gray Goose valley.

The surface of Hughes County is the result of glaciation and consists mostly of ablation till. Major surface outwash deposits are in terraces along the Missouri River valley.

The major economic resources found in the county are ground water and sand and gravel. There is a good potential for use of low temperature geothermal resources. Present evidence indicates no significant fossil fuel or metallic mineral resources. Slumping in the Pierre Shale may pose a geologic hazard to roads or structures.

INTRODUCTION

Purpose

Findings of the geological investigation of Hughes County are presented in this report. The study is one of a series of county-wide studies in the eastern half of the state conducted by the South Dakota Geological Survey in cooperation with the U.S. Geological Survey. The primary purpose of the study is to provide a geologic and hydrologic framework on which subsequent use of water and geologic resources can be based. Major components of the study include mapping the geology, interpreting the geologic history, delineating the aquifers, and compiling basic data. The study will also contribute to the understanding of the regional geology of South Dakota.

The results of this study are published in four separate publications: *Major aquifers in Hughes County, South Dakota* (Hamilton, 1986a); *Water resources of Hughes County, South Dakota* (Hamilton, 1986b); *Sand and gravel resources in Hughes County, South Dakota* (Tomhave, 1986); and *Geology of Hughes County, South Dakota* (this report). Additionally, basic data compiled for this study are available upon request from the South Dakota Geological Survey in Vermillion, South Dakota.

Location and Topography

Hughes County is in the Coteau du Missouri division of the Great Plains Physiographic Province (fig. 1). It is in the center of the state and has an area of 784 square miles. The county is bordered by the Missouri River on the west and south, Sully County on the north, and Hyde County on the east.

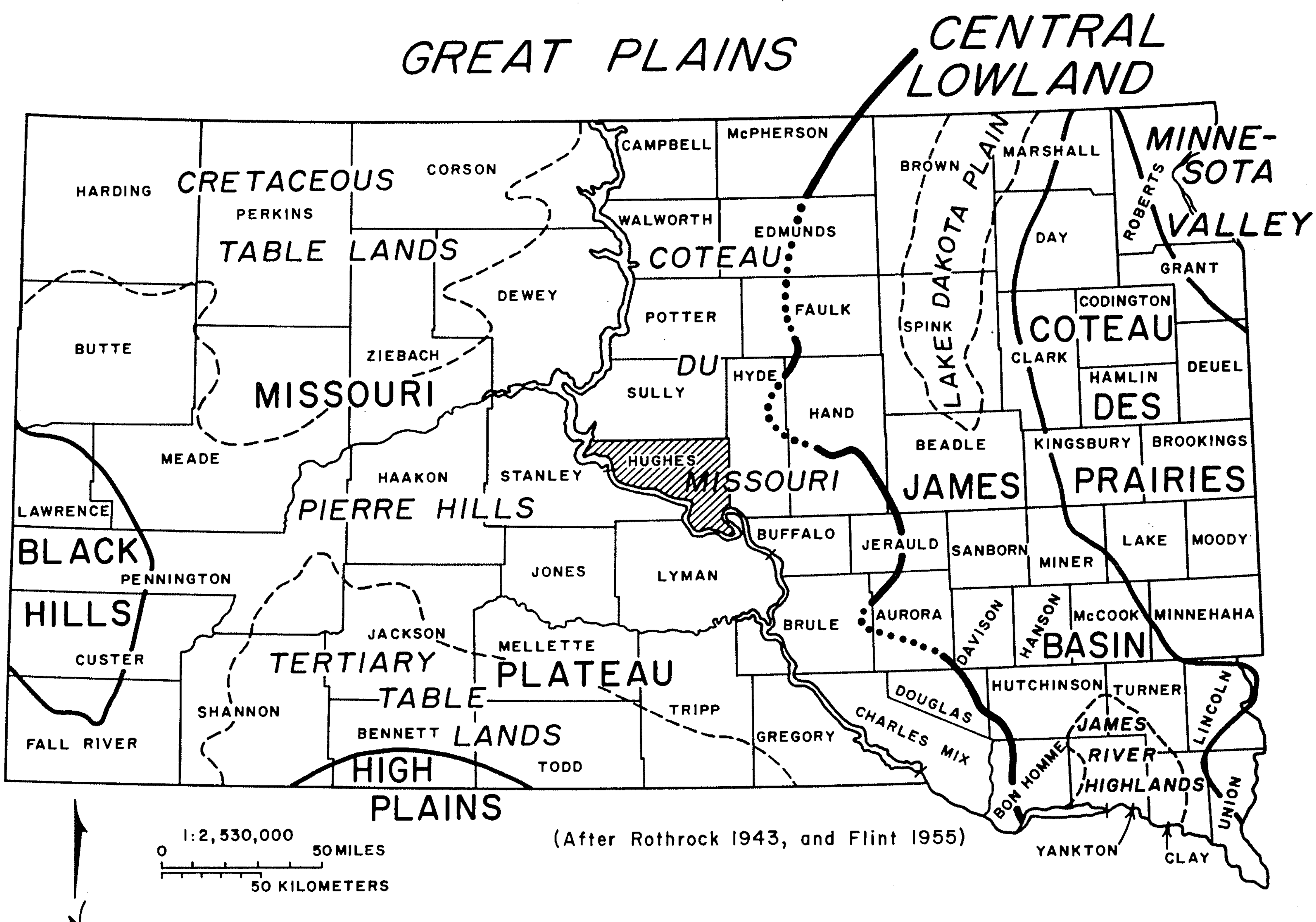


Figure I. Map of physiographic divisions of South Dakota.

The two prominent physiographic features in the county are the Coteau du Missouri and the Missouri River valley. The highest elevation is approximately 2,050 feet on Ree Hills. The lowest is in the southeastern part of the county along Lake Sharpe, which has a normal pool elevation of 1,420 feet. Most land surface in the county is between 1,600 and 2,000 feet above mean sea level (fig. 2).

Hughes County typically has a flat to gently-sloping surface and low local relief except for the steep Missouri River valley walls. There are highlands along the edge of the Missouri River valley and along the border with Hyde County in addition to Medicine Knoll and Canning Hill. Medicine Knoll Creek is the only major, well-developed valley in the county other than the Missouri River valley, and much of the county is poorly drained except near the creeks and near the Missouri River valley.

Previous Investigations

The first geologic investigation to include part of Hughes County was by Lewis and Clark, who described the geology and landforms along the Missouri River (Thwaites, 1959). Early reconnaissance studies of the area were done by Meek and Hayden (1861), Todd (1894), Darton (1909), and Rothrock (1943). During this time other workers completed studies that were primarily concerned with Pleistocene deposits, including Chamberlin (1883) and Todd (1885 and 1896). Later Flint (1955) made a reconnaissance study of the Pleistocene deposits in eastern South Dakota that included Hughes County. Crandell (1958) studied Pleistocene deposits in the Pierre area, including part of Hughes County. Exposures of the Pierre Shale in the Missouri River valley were examined by Searight (1937), Petsch (1946), and Crandell (1950 and 1958).

Detailed reports of the ground-water resources for the towns of Pierre and Harrold were completed by Brinkley (1971) and Helgerson (1975) respectively. In the 1950's, geologic maps were completed for most of the county by a variety of workers, as indicated on figure 2.

Method of Investigation

Much of the information contained in this report was obtained from geologic work completed in Hughes County from 1980 to 1982. Additional test drilling was conducted in the spring of 1983. The geology was mapped on 7½-minute topographic maps at a scale of 1:24,000 (approximately 1 inch = 0.4 mile) and later reduced to 1 inch = 2 miles. Sites referred to in this report are located using the U.S. Public Land Survey System. See figure 3 for an explanation of site location designations used in illustrations.

Information was obtained for this report from natural outcrops, hand-auger holes, test drilling, observations of the land surface, and interpretations of aerial photographs. Most subsurface data were obtained from drill-hole cuttings and electric logs of 427 rotary and auger holes drilled for the study. Approximately 40 percent of these reached the Pierre Shale. Additional subsurface information was obtained from test-hole records on file at the South Dakota Geological Survey, including logs from the Oahe Dam project and private drillers.

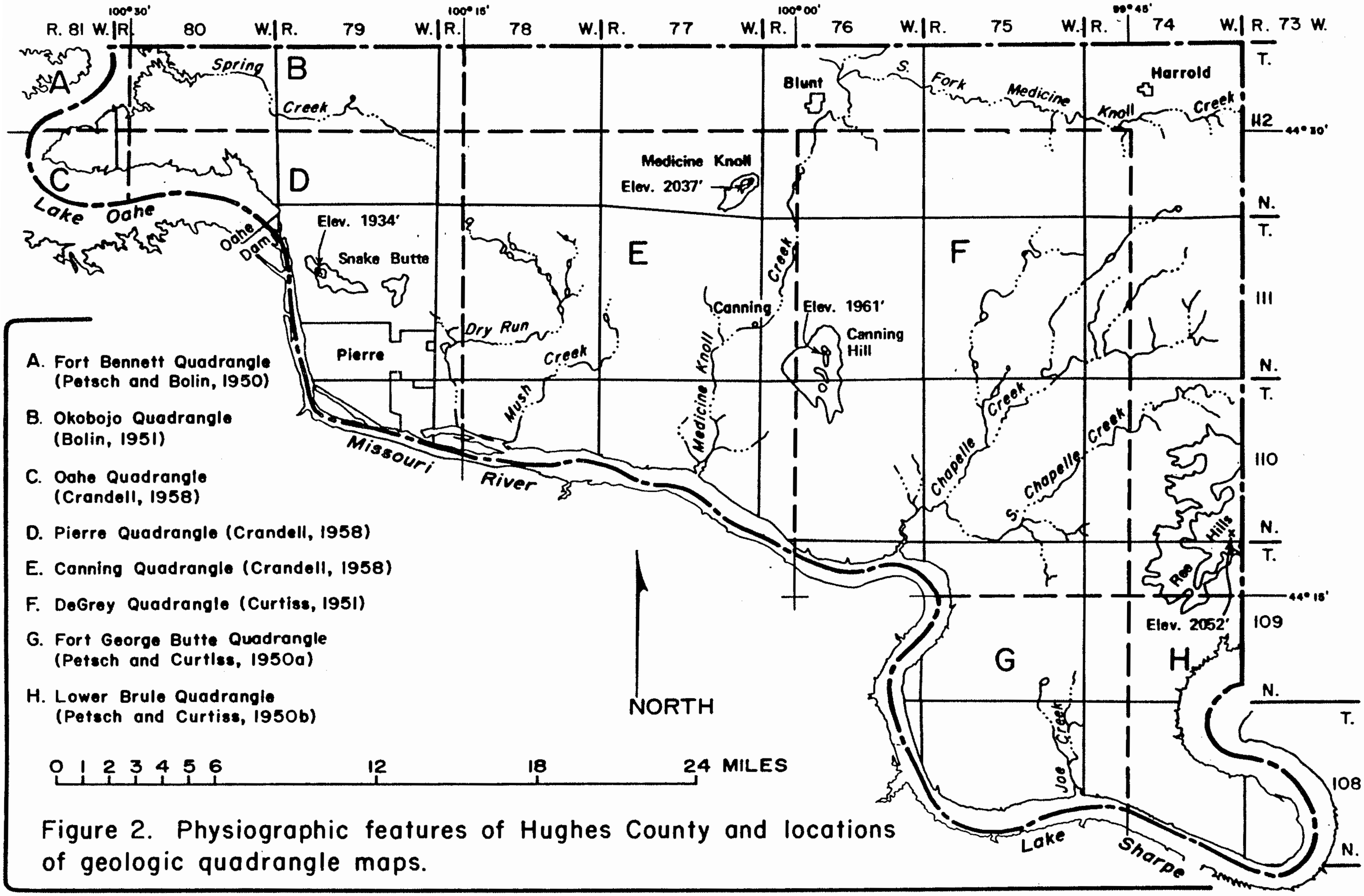
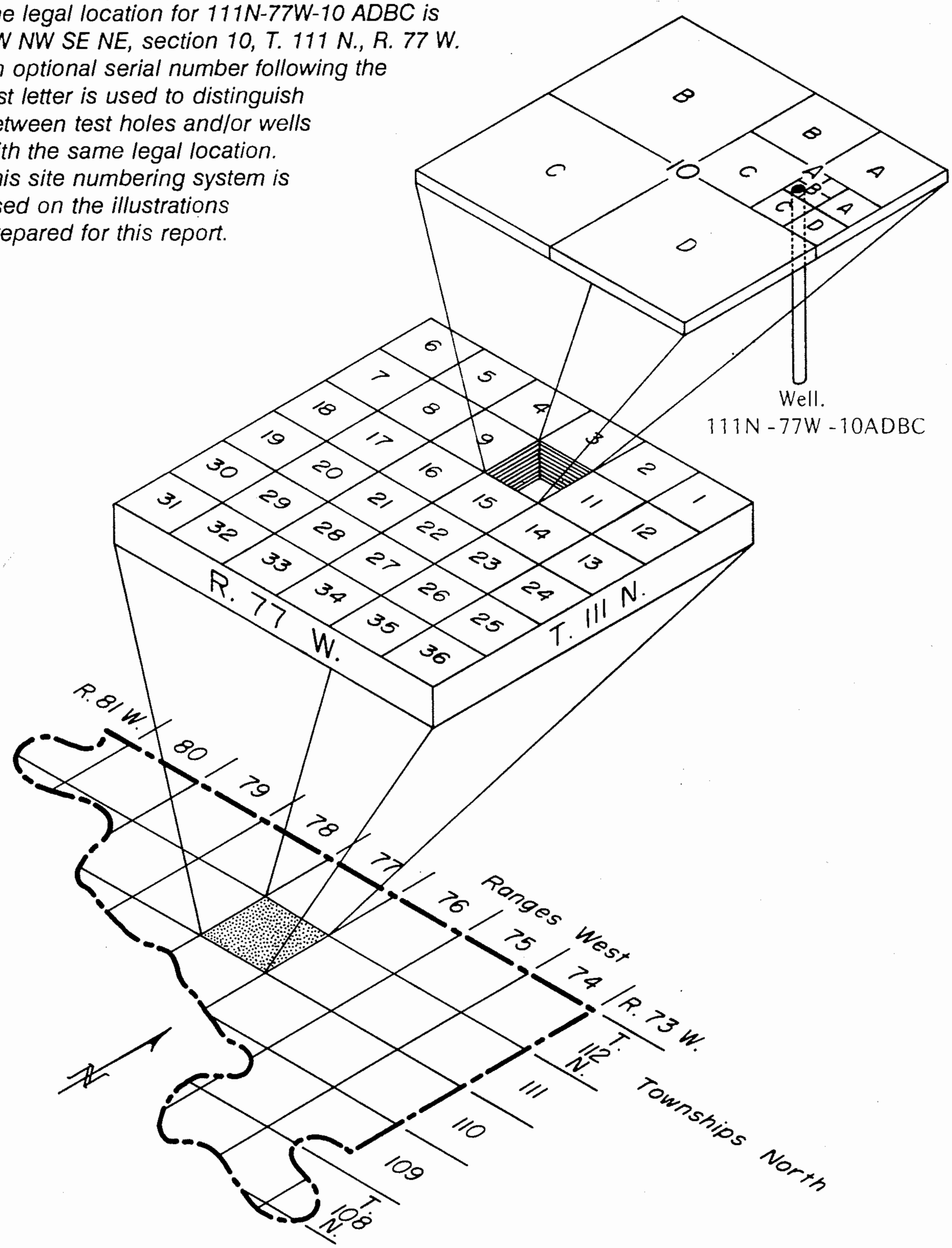


Figure 2. Physiographic features of Hughes County and locations of geologic quadrangle maps.

Figure 3. Site-location diagram. (U.S. Public Land Survey System) *The site number consists of township number followed by "N" for north, range numbers followed by "W" for west, section number, and a maximum of four uppercase letters that indicate, respectively, the 160, 40, 10 and 2 1/2-acre tracts in which the site is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast corner*
The legal location for 111N-77W-10 ADBC is SW NW SE NE, section 10, T. 111 N., R. 77 W. An optional serial number following the last letter is used to distinguish between test holes and/or wells with the same legal location. This site numbering system is used on the illustrations prepared for this report.



Acknowledgements

This investigation was performed under the supervision of Merlin J. Tipton, State Geologist. The writer wishes to thank the entire staff of the South Dakota Geological Survey for their advice and assistance throughout the project. Special thanks go to Jay Gilbertson, Cleo Christensen, Richard Bretz, and Stephen Burch for their comments and ideas, and to Robert Schoon for assistance in interpreting the bedrock stratigraphy. Doris Minnerath and Timothy Ryherd assisted in the field, and drilling equipment was operated by Millard Thompson, Eric Koglin, Carol Schmig, and Martin Jarrett. Many additional people, too numerous to mention, assisted throughout the project.

Financial assistance was contributed by the South Dakota Geological Survey, U.S. Geological Survey, Mid-Dakota Water Development District, and Hughes County. The study was initiated at the request of the Hughes County Commissioners, and their cooperation, as well as that of all the residents of the county, is gratefully acknowledged.

BEDROCK GEOLOGY

Introduction

Bedrock units ranging in age from Precambrian to Cretaceous underlie the unconsolidated surficial sediments (Quaternary) in Hughes County. Table 1 lists the bedrock units recognized in the study area and figure 4 shows them in cross section.

The only bedrock unit exposed at the surface, or found to subcrop beneath the Quaternary deposits, is the Pierre Shale (pl. 1). Regional structure and isopach (thickness) maps for many of the older units can be found in Hedges and others (1982) and Allen and others (1984).

The recognition of rock units was primarily based on geophysical logs (gamma, single point resistivity and/or spontaneous potential) on file at the South Dakota Geological Survey and other published descriptions of rocks in the region. 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 (North American Commission on Stratigraphic Nomenclature, 1983). Deviations from these are pointed out in the text because nomenclature in central and eastern South Dakota differs slightly from that in western South Dakota.

Precambrian and Paleozoic Rocks

The Precambrian basement rocks underlying Hughes County consist of a variety of metamorphic and igneous rocks (Klasner and King, 1986). They are part of a transition zone between two major Precambrian rock terrains. In the southern portion of the county, the Precambrian Sioux Quartzite, a pink orthoquartzite, overlies the crystalline rocks, forming part of the western edge of the Sioux Ridge.

Overlying the Precambrian rocks are a variety of Paleozoic units that range from approximately 200 feet thick in eastern Hughes County to approximately 1,200 feet in the northwestern part of the

ERA	PERIOD		ROCK UNITS	DESCRIPTION	THICKNESS IN Ft. (Avg.)
1					
MESOZOIC	CRETACEOUS	UPPER	Pierre Shale	*Dark-gray claystone with thin layers of whitish bentonite*	60–690 (240)
			Niobrara Formation	*Light- to dark-gray chalk*	100–205 (135)
			Carlile Shale	*Medium-gray claystone with thin sandstone layers in the upper portion*	270–340 (300)
			Greenhorn Limestone	*Medium-gray calcareous claystone with thin limestone layers*	90–110 (100)
			Graneros Shale	*Medium- to dark-gray claystone with abundant thin sand layers in the lower portion*	210–320 (260)
		UPPER / LOWER	Dakota Formation	*White to light-gray quartz sandstone, poorly to well cemented, with claystone layers*	315–355 (330)
		LOWER	Skull Creek Shale	*Dark-gray to black claystone*	85–160 (120)
			Inyan Kara Group: Fall River Sandstone	*White to light-gray quartz sandstone*	140–310 (200)
			Inyan Kara Group: Fuson Shale	*Vari-colored claystone*	
			Inyan Kara Group: Lakota Formation	*Massive sandstone with thin coal, limestone, and claystone layers*	
1					
PALEOZOIC	CARBONIFEROUS	PENNSYLVANIAN	Minnelusa Formation	*Varied lithology: limestones, dolomites, shales, and sandstones*	70–250 (125)
		MISSISSIPPIAN	Madison Group	*White to tan limestone*	0–300 (130)
	1				
	DEVONIAN		[2] Devonian Sandstone	*Light-colored quartz sandstone*	0–130(60)
	1				
	ORDOVICIAN		Red River Dolomite	*Light-colored limestone*	0–80(30)
			Winnipeg Formation	*Quartz sandstone*	0–110(40)
1					
PRECAMBRIAN			———	[3] *Variable metomorphic rocks*	———

[1] Major period of erosion or nondeposition
[2] R. Schoon (personal communication, 1986)
[3] Klasner and King (1986)

Table 1. Generalized stratigraphic column of bedrock units in Hughes County.

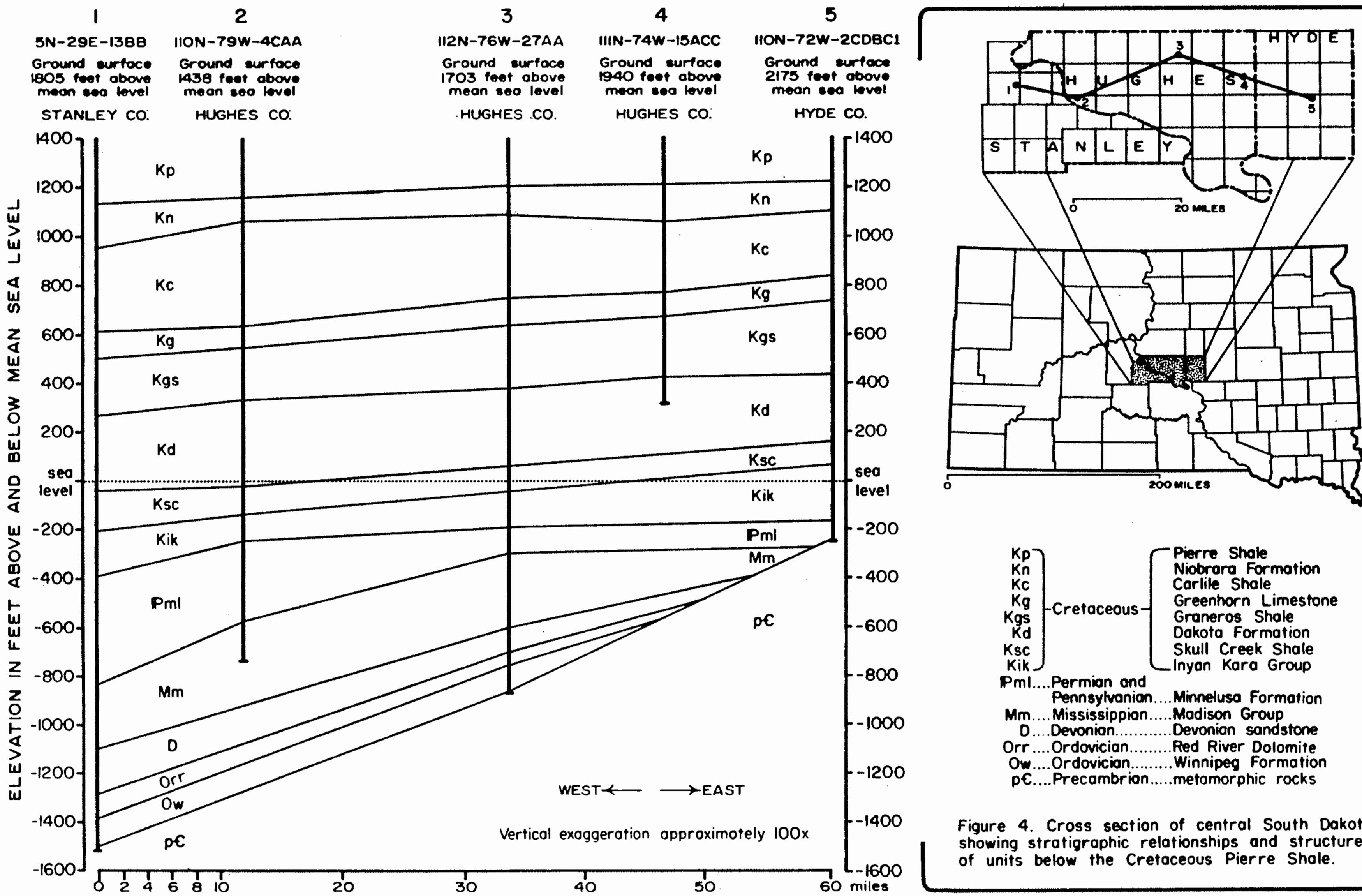


Figure 4. Cross section of central South Dakota showing stratigraphic relationships and structure of units below the Cretaceous Pierre Shale.

county (fig. 4). The rocks include shales, limestones, dolomites, and sandstones (table 1). Because there is relatively little drill-hole data pertaining to these rocks in the county, they will not be discussed here. General descriptions of all Precambrian and Paleozoic rocks that occur beneath Hughes County can be found in Agnew and Tychsen (1965).

Cretaceous Rocks

Cretaceous rocks in South Dakota were deposited in five major cycles of sedimentation (cyclothems) that occurred when inland seas transgressed and regressed across the Western Interior of North America. An example of the sea's extent during part of the late Cretaceous Period is shown in figure 5. The depositional history of these rocks is summarized by Kauffman (1977) and Rice (1983). All of the rocks described underlie the entire Hughes County area.

Inyan Kara Group

This unit is comprised of sandstones and mudstones of a transgressive sequence of the first major cyclothem in the Cretaceous Period (fig. 6). The group, described in detail by Bolyard and McGregor (1966) and Schoon (1971), is divided into the following three formations (discussed in ascending order).

The Lakota Formation is a massive sandstone with thin layers of shale and limestone, and local lenses of coal and conglomerate. The unit consists of fluvial and flood-plain facies that were deposited in a continental environment.

The Fuson Shale consists of varicolored mudstones that were also deposited in a continental environment. The claystones and siltstones that comprise most of this unit contain abundant plant fossils and include local limestone layers. In Hughes County, the Fuson Shale is primarily claystone.

The Fall River Sandstone, which is the youngest formation in the Inyan Kara Group, is a white to light-gray quartz sandstone with interbedded layers of gray claystone and siltstone. The sandstone is fine grained and friable. This unit was deposited in a marginal marine environment of the first inland sea of the Cretaceous Period.

Both the Lakota Formation and the Fall River Sandstone are locally referred to as the "Sundance Sandstone." The Sundance Formation, as defined by the South Dakota Geological Survey, is a Jurassic-age sandstone that is generally found west of the Missouri River below the Inyan Kara Group and above the Minnelusa Formation. An examination of geophysical logs in Hughes, Sully, Hyde, Hand, and Stanley Counties on file at the South Dakota Geological Survey indicates that the unit is present in western Stanley County, but the formation could not be documented as far east as Hughes County (fig. 4). This was confirmed by R. Schoon (South Dakota Geological Survey, personal communication, 1986). Hamilton (1986a,b) mapped the "Sundance Sandstone" in Hughes County, based on unpublished maps prepared by L. Howells of the U.S. Geological Survey (L. Hamilton, U.S. Geological Survey, personal communication, 1986). However, a comparison of the two interpretations indicates that Howells' "Sundance Sandstone" in Hughes County is equivalent to the Lakota Formation in this report.

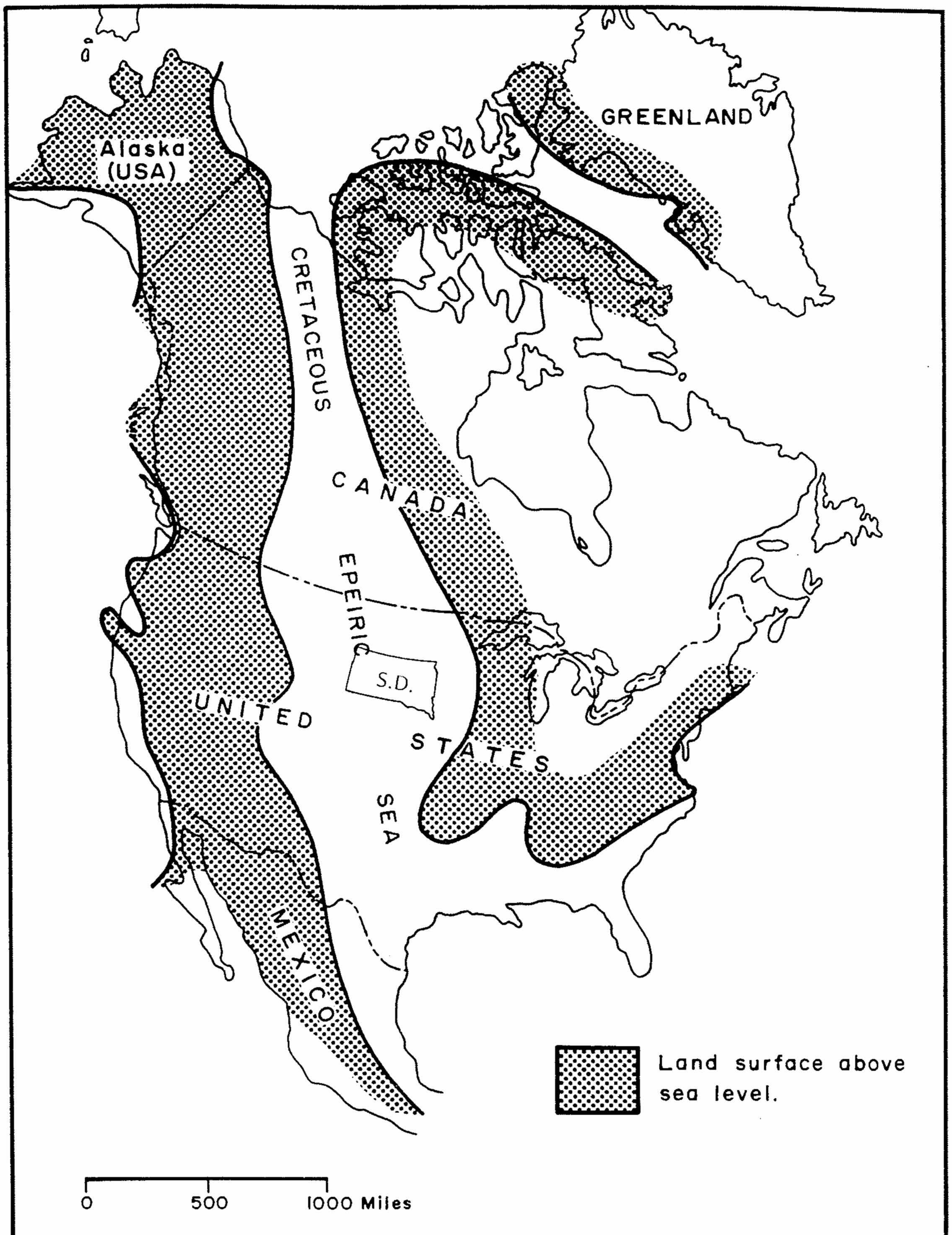
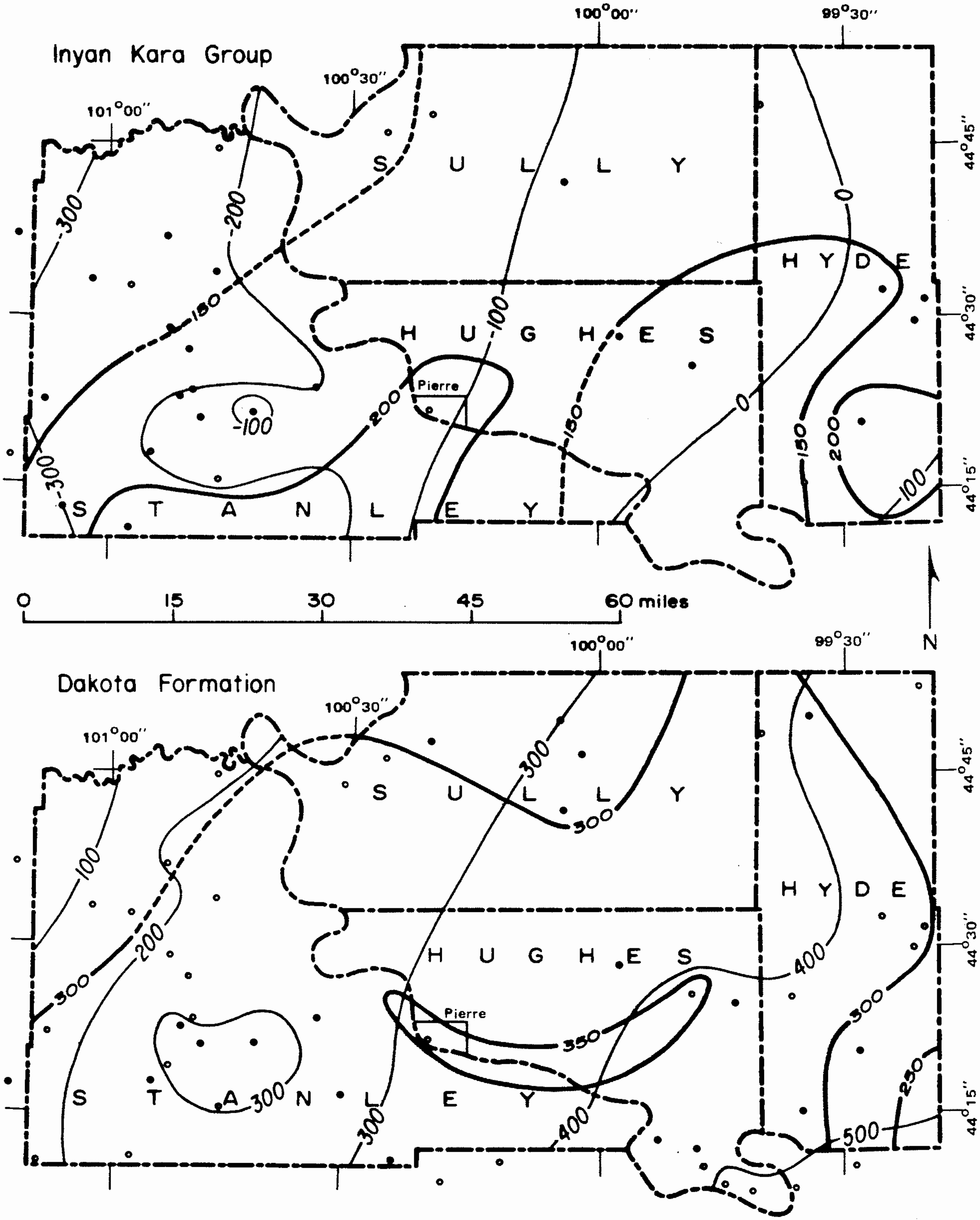


Figure 5. Map showing probable extent of epeiric seaway during a portion of the late Cretaceous Period *(modified from Gill and Cobban, 1973).*



—200 Structure contour of top of rock units. Contour interval = 100 feet. 0 = sea level.

—300— Isopach for rock units. Dashed where approximate. Isopach interval = 50 feet.

° Control point.

Based on data interpreted from geophysical logs on file at South Dakota Geological Survey.

Figure 6. Structure-contour and isopach maps of Inyan Kara Group and Dakota Formation in central South Dakota.

Skull Creek Shale

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 and is sometimes referred to as the Thermopolis Shale. It marks the end of the first cyclothem that occurred in South Dakota during the Cretaceous Period.

Dakota Formation

The Dakota Formation (Witzke and others, 1983) consists of a sequence of mudstones and sandstones, the latter of which consists primarily of fine- to coarse-grained, cemented to poorly cemented, quartz sandstone (fig. 6). Schoon (1971) discusses this formation in detail. It is generally divided into three units: a lower sandstone that includes several thin shale layers, a middle claystone unit with several sandy layers, and an upper sandstone unit with minor shale and lignite beds. The lower unit is not always recognizable in the Hughes County area.

The base of the Dakota Formation marks the beginning of the second Cretaceous cyclothem in South Dakota. The lower unit was deposited in a continental environment, the middle unit in a near-marine environment, and the upper unit in a marine environment. The cycle of sedimentation was the result of post-Skull Creek epeirogenic downwarping of the area which initiated the migration of an inland sea (Schoon, 1971).

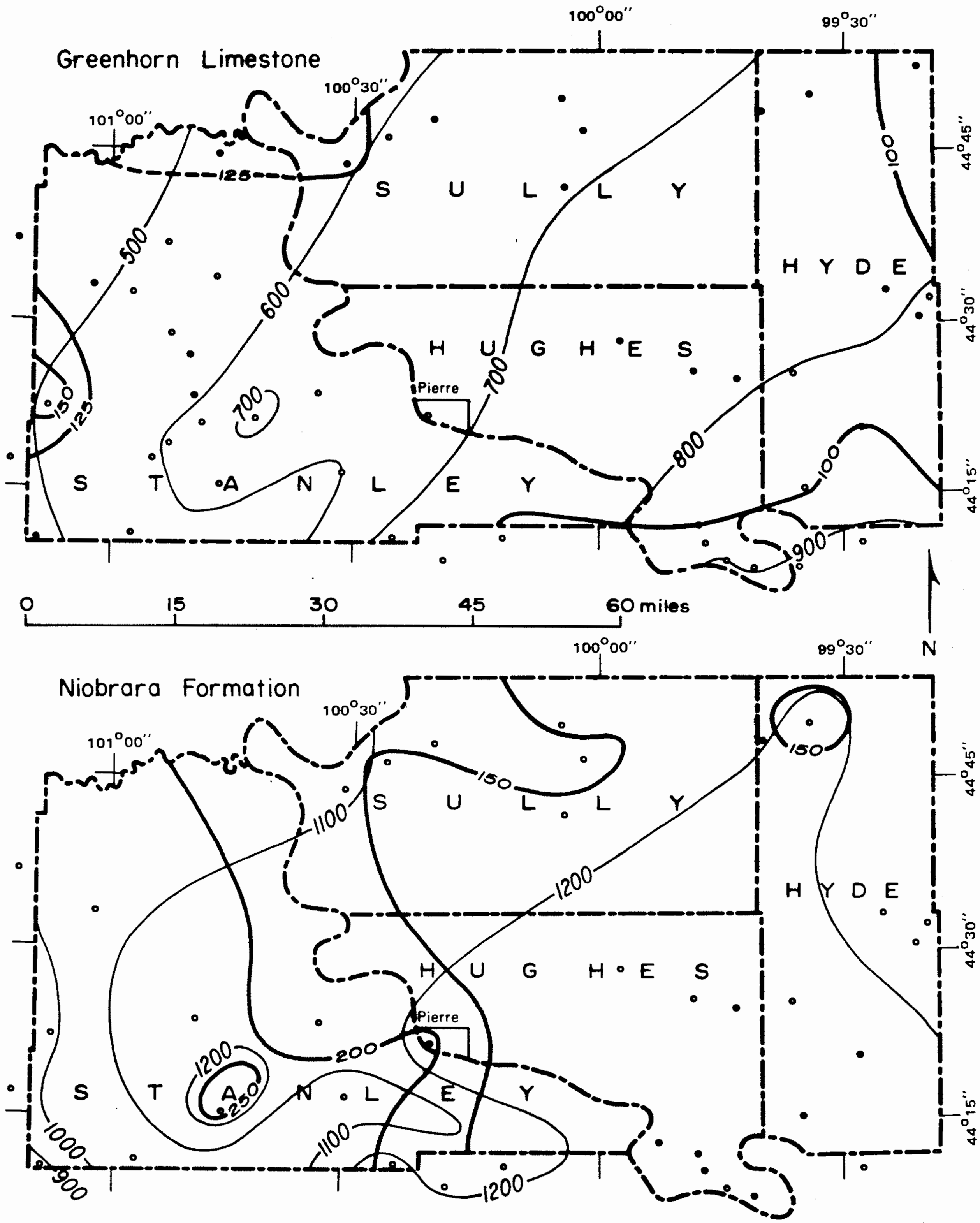
Graneros Shale

The Graneros Shale is a gray, noncalcareous claystone interbedded with thin silty layers. It contains several thin bentonite layers in addition to local concretionary and fossiliferous zones. In eastern South Dakota the interval becomes increasingly calcareous upsection. In many places contact with the underlying Dakota Formation is gradational. In these instances, the top of the first sandstone layer with the thickness of 5 or more feet was chosen as the contact between the two formations. The gradational contact results from a gradual replacement of the marginal marine environment of the upper Dakota Formation by offshore marine conditions of the lower Graneros Shale.

In Hughes County the claystone is divided into two distinct units that are separated by the Clay Spur Bentonite Bed, which is up to 2 feet in thickness. The distinguishing feature between the two units is the presence of sandstone layers in the lower unit. The lower unit of the shale "was probably deposited in brackish to marine environments in nearshore and delta-front areas" (Witzke and others, 1983, p. 238) and is laterally equivalent to the Mowry Shale in western South Dakota. The upper part of the Graneros Shale is laterally equivalent to the Belle Fourche Shale in western South Dakota.

Greenhorn Limestone

The Greenhorn Limestone is a gray, calcareous claystone interbedded with thin fossiliferous limestone and argillaceous limestone layers (fig. 7). Locally it may contain thin bentonite layers. The most common fossil is a bivalve clam, *Inoceramus labiatus*, fragments of which are found throughout the unit. White specks also occur throughout the claystone. These highly calcareous specks are less



—900— Structure contour of top of formations. Contour interval = 100 feet.

—250— Isopach for formations. Dashed where approximate. Isopach interval = 50 feet with supplemental 25 foot isopach for Greenhorn Limestone.

• Control point.

Based on data interpreted from geophysical logs on file at South Dakota Geological Survey.

Figure 7. Structure-contour and isopach maps of Greenhorn Limestone and Niobrara Formation in central South Dakota.

than 0.1 inch in diameter and include foram tests and possible fecal pellets (Witzke and others, 1983). An areally extensive limestone layer, that averages 9 feet thick, marks the top of the formation in the Hughes County area. A bentonite layer, immediately below the lowest limestone layer, marks the base of the formation.

The limestone was deposited in an open-marine environment during the maximum transgressive phase of the second major Cretaceous cyclothem. In Hughes County it is more shaley and less calcareous than the Greenhorn Limestone in southeastern South Dakota "due to an influx of western-derived clasts into the seaway that covered that part of the state" (Witzke and others, 1983, p. 239).

Carlile Shale

The Carlile Shale is a soft, medium-gray to black claystone with discontinuous layers of silty shale and sandstone. It also contains a variety of fossils and calcareous concretions and is noncalcareous to slightly calcareous. In eastern South Dakota the formation has a basal chalky member, but no such unit is recognized in Hughes County. One to three sandstone layers are observed in the upper portion of the formation, and both electric and driller's logs indicate that these are muddy sands that average 13 feet thick. They are probably equivalent to marginal deposits of the Codell Sandstone Member of the Carlile Shale of southeastern South Dakota. Some of the layers, however, could be extensions of the Turner Sandy Member of the Carlile Shale from the Black Hills region. These two members are not believed to be connected.

The Carlile Shale was deposited in a marine environment during the regressive phase of the second Cretaceous cyclothem (Witzke and others, 1983). The lower portion of the formation was deposited in an offshore marine environment. The sands were deposited in nearshore marine environments which resulted from the seaward migration of nearshore environments from both the eastern and western shores.

Niobrara Formation

The Niobrara Formation (Witzke and others, 1983) in Hughes County consists of two chalk units separated by a calcareous shale, with the entire formation varying from light- to dark-gray (fig. 7). The chalk consists of large accumulations of coccoliths and foraminifera resulting in a high calcium carbonate content. Macrofossils have also been found in the formation and the two most common are *Ostrea congesta* and *Inoceramus gigantica*. South of South Dakota, the Niobrara Formation is divided into two members, but they are not found in the state (Shurr and Reiskind, 1984).

The Niobrara Formation was deposited in a shallow, open-marine environment. The deposition was initiated by a rise in sea level which marked the beginning of the third Cretaceous cyclothem, a global cycle of transgression and regression. The formation was deposited on a carbonate ramp on the eastern side of the inland seaway (Shurr and Reiskind, 1984), but the Transcontinental Arch was between the ramp and the eastern shore, blocking the influx of detrital sediments to the ramp and resulting in the high concentrations of microfossils (Witzke and others, 1983).

Unconformities, which mark both the top and bottom of the formation in Hughes County, are exposed near Chamberlain, South Dakota. Both unconformities result from submarine scour in shallow seas and are probably associated with low stands of sea level that occurred at the beginning and end of the cyclothem.

Pierre Shale

The Pierre Shale is a noncalcareous, light- to dark-gray, concretion-bearing claystone with scattered layers of marl, bentonite, calcareous claystone, and siliceous shale. The formation is divided into the following eight members:

Elk Butte	(uppermost member)
Mobridge	
Virgin Creek	
Verendrye	
DeGrey	
Crow Creek	
Gregory	
Sharon Springs	(lowermost member)

All of the members are exposed in Hughes County except the Elk Butte Member, which was removed by fluvial and glacial erosion, and the Sharon Springs Member which subcrops the Gregory Member. Most of the outcrops occur in the Missouri River valley, as shown on plate 1. Individual members of the Pierre Shale were not mapped for this study; the reader is referred to the published geologic quadrangles (fig. 2) for locations of outcrops of the individual members.

The formation was first described in detail in central South Dakota by Searight (1937), and later by Crandell (1950 and 1958), who set the terminology of the members and described their exposures in the Pierre area in detail. More recent regional studies of the Pierre Shale have been done by Tourtelot (1962) and Schultz and others (1980), while Nichols and others (1986 and 1989) and Collins and others (1988) described the geotechnical properties of the formation. A summary of the members exposed or subcropping the study area is presented in this report. For a detailed discussion of the members, the reader is referred to Crandell (1958), from which the following summaries were taken.

The Sharon Springs Member is a dark-gray to black, noncalcareous shale with bentonite layers and local phosphatic concretions. Its lower portion is an organic-rich shale that includes bituminous shale and abundant fish debris. It is approximately 115 feet thick near the Oahe Dam.

The Gregory Member consists of two parts in the Pierre area: a basal portion of interbedded claystone and marl and an upper portion of gray noncalcareous claystone. The member contains a few thin bentonite layers and is 177 feet thick at Oahe Dam.

The Crow Creek Member consists of 7 to 10 feet of gray marl. It is underlain by approximately 1 foot of gray, laminated, calcareous siltstone in the Pierre area.

The DeGrey Member consists of 160 feet of light-olive-gray claystone at Pierre. The basal portion contains numerous bentonite layers, concretions, and macrofossils, and the upper portion is moderately siliceous and contains no macrofossils.

The Verendrye Member consists of 140 to 160 feet of olive-gray, unfossiliferous claystone in the Pierre area. Sideritic concretions are common in this unit.

The Virgin Creek Member is an olive-gray, noncalcareous claystone that contains concretions, layers of bentonite, and a variety of fossils. The lower portion of this member is distinguished by its high concentration of bentonite beds. Its thickness varies from 120 feet south of Blunt along Medicine Knoll Creek to 230 feet west of Oahe Dam along the Missouri River.

The Mobridge Member is a highly calcareous shale with high concentrations of selenium. It is 25 feet thick near Medicine Knoll.

The Pierre Shale was deposited in marine environments in the last inland sea of the Cretaceous Period. Two cyclothems caused stratigraphic variations within this formation. The Sharon Springs Member was deposited during the first transgression, and the Gregory Member was deposited during the regressive phase of that cyclothem. Submarine erosion occurred at the maximum regression forming an unconformity on the top of this member. At the beginning of the next transgression, carbonates were deposited in a shallow sea forming the Crow Creek Member. During this transgression, the inland sea reached its maximum extent forming a deep, wide sea in which rapid deposition of clays occurred forming the DeGrey, Verendrye, and Virgin Creek Members. The Mobridge Member was deposited during the initial stages of the final recession (Schultz and others, 1980).

Bentonite layers found throughout the formation 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 clays, forming the bentonite layers.

Tertiary Rocks

No Tertiary rocks were found in Hughes County, but evidence from the western half of the state suggests that rocks of this age were deposited in the county and subsequently eroded. Tertiary sediments are found on butte tops in the Pierre Hills region of western South Dakota (fig. 1) and Bijou Hills in Brule and Charles Mix Counties. Additionally, clasts of Tertiary sediments were found in Stanley County by Crandell (1958). Harksen (1969) projected the surface of the Ogallala Group (Tertiary) into Hughes County, based on exposures of the group in the southwestern quarter of the state. Regional uplift during the late Pliocene Epoch exposed the rocks to erosion and established a west-to-east drainage system in central South Dakota. Collins and Nichols (1987) determined that 1,100 to 1,300 feet of sediment from the Ogallala Group and the upper Pierre Shale was removed from the present shale surface in western Stanley County. Similar estimations, based on Harksen's (1969) paleotopographic map, suggest that 600 to 700 feet of sediment from the Ogallala Group and the upper Pierre Shale was removed from Medicine Knoll during the Pliocene Epoch and Quaternary Period, of which 500 to 600 feet were probably Tertiary.

Geologic Structures

The major structural feature that influences the geology of Hughes County is the Williston Basin (fig. 8), a 700 mile-long basin which extends northwest into southern Saskatchewan. Hughes County is near the southeastern edge of this feature. In South Dakota sediments within the basin dip to the west or northwest and thicken in the same direction (fig. 4).

Although the Sioux Uplift and the Transcontinental Arch did not influence the structure of rocks in Hughes County, they did influence the deposition of several of formations that are found there. The Sioux Uplift was the source of much of the material deposited in the Inyan Kara Group (Bolyard and McGregor, 1966), and the Transcontinental Arch blocked the influx of eastern-derived terrigenous material during several phases of the inland sea. Additionally, an east-west trending fault in the Precambrian rocks near the southern edge of the county influenced sedimentation in the area from the Paleozoic through most of the Mesozoic era (Nichols and others, 1986 and 1989).

Maps of subsurface bedrock formations in central South Dakota (figs. 6 and 7) indicate that there are no major structures in the Cretaceous formations of Hughes County. Undoubtedly small, local structures exist, such as those described in Stanley County by Nichols and others (1989), but these were not mapped as part of this study. Local structures in the Pierre Shale exposed at the surface in the Pierre area were described by Crandell (1958), Collins and others (1988), and Nichols and others (1989). These structures are characterized by gentle folds, small faults, and joints.

Bedrock Topography

Prior to glaciation, the area that is now Hughes County probably consisted of a series of rolling hills bisected by numerous streams, comparable to the landscape currently found west of the Missouri River. However, present-day relief on the bedrock surface (pl. 2) is the result of both late Pliocene/early Quaternary fluvial drainage development, as well as subsequent modification by the glaciers that covered the area and the resultant diversion of drainage systems.

There are three prominent low areas on the bedrock surface in Hughes County (pl. 2): the modern Missouri River valley, and two informally described lowlands, the Gray Goose and Chapelle buried valleys. The Chapelle buried valley extends from approximately the northeast part of T. 108 N., R. 75 W., north to the Sully County line, approximately 4 miles east of Blunt. The Gray Goose buried valley extends from the northwest corner of the county to a point 3 miles east of Canning where it joins the Chapelle buried valley. All three of these lowlands had an important influence on the routing of glacial meltwaters and contain significant thicknesses of glacial and fluvial sediments.

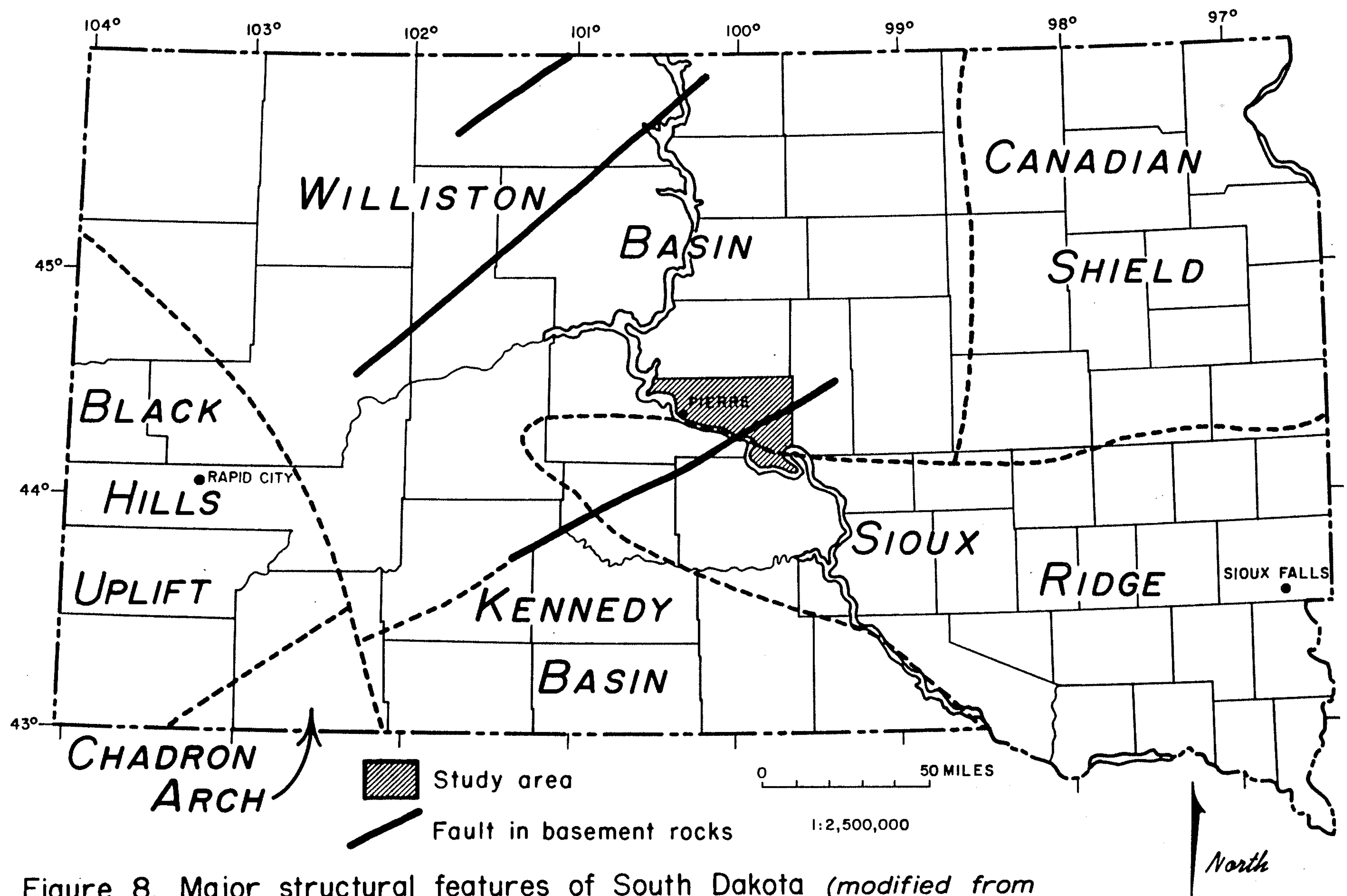


Figure 8. Major structural features of South Dakota *(modified from Steece, 1975, and Klasner and King, 1986).*

QUATERNARY GEOLOGY

Quaternary Deposits

Terminology

A variety of Quaternary sediments were encountered during this investigation, but no detailed study of the units was attempted. The Quaternary terminology used in this report (table 2) is modified from Beissel and Gilbertson (1987).

Pre-Late Wisconsin Deposits

There is no evidence of Quaternary deposits older than late Wisconsin in Hughes County or in counties to the north and east (Helgerson and Duchossois, 1987; Christensen, 1977; and Hedges, 1987). In western South Dakota numerous erratic boulders are found on interflues, generally within 20 miles of the Missouri River. These are thought to be remnants of an earlier glaciation. Similar deposits in North Dakota are thought to be pre-Wisconsin (Bluemle, 1984), but there is no conclusive evidence for the exact age of the deposits.

Late Wisconsin Deposits

AGE CORRELATION

The absolute age of the sediments in Hughes County has not been determined because of the absence of datable material. Correlation of the glacial sediments in the county to those in other north-central counties of the state establishes an age of late Wisconsin for the glacial sediments in Hughes County (Hedges, 1972; Christensen, 1977; and Helgerson and Duchossois, 1987).

TILL

Till is the most common Pleistocene sediment in Hughes County. It is composed of a heterogeneous mixture of silt, sand, pebbles, and boulders in a calcareous clay matrix and contains fragments of rocks that were transported by the glacier. Some fragments are several feet in diameter and one block of shale 24 feet thick was found in a test hole at SW¼SW¼SW¼SW¼ sec. 34, T. 112 N., R. 76 W. The till has a high shale content because the glacier flowed over several hundred miles of bedrock composed almost entirely of Pierre Shale before reaching Hughes County. Typically till contains relatively thin, discontinuous lenses of clay, silt, sand or gravel (pl. 3).

Unweathered (unoxidized) till is gray and weathered (oxidized) till is yellowish-brown. The average depth of oxidization in the county is approximately 40 feet. The maximum depth observed in drilling for the study was 106 feet at SE¼SE¼SE¼SE¼ sec. 8, T. 112 N., R. 79 W. Although there was no discernible pattern, the depth of oxidization is generally greater west of Medicine Knoll Creek, probably due to either thicker loess accumulations, more outwash interbedded with the till, or the presence of aquifers that may influence the water table. Weathered till may be highly

Table 2. Wisconsin classifications in South Dakota and other areas.

Time Scale (Radiocarbon years before present): 0, 5,000, 10,000, 15,000, 20,000, 25,000, 30,000

Crandell (1958) and Flint (1955)	Lemke and others, (1965)	Willman and Frye (1970)	Beissel and Gilbertson (1987)	Duchossois (this report)
Recent	Postglacial	Holocene		Holocene
Mankato		Valderan Substage	Late Wisconsin II	Late Wisconsin
Interval	Advance 6 (Late Wisconsin)	Two Creekan Substage	Late Wisconsin I	Early Wisconsin
Cary	Advance 5 (Late Wisconsin)	Woodfordian Substage	Early Wisconsin (?)	
Interval	Advance 4 (Late Wisconsin)	Farmdalian Substage		
Tazewell	Advance 3 (Late Wisconsin)	Altonian Substage		
Interval	Advance 2 (Late Wisconsin)			
Iowan	Advance 1 (Early Wisconsin)			

Modified from Beissel and Gilbertson (1987).

fractured, such as at SW¼SW¼SW¼SW¼ sec. 32, T. 111 N., R. 76 W., where fracturing was so extensive that the till could not be penetrated with rotary drilling due to loss of drilling circulation.

Till is deposited either directly or indirectly by the glacier. Lodgement till is deposited directly by the base of the ice flow, while ablation till is deposited when ice melts and material in and on the glacier is let down onto the land surface. When till is deposited in association with meltwater, deformed bedding may result, as observed at the large exposures at NW¼NW¼SW¼NW¼ sec. 8, T. 112 N., R. 80 W. The term till is sometimes confused with the term drift, which is used to include all sediments that were deposited by either glacial or glaciofluvial processes.

Till covers most of the surface in Hughes County. The areas of the county where till is at or near the surface are indicated on plate 1 as map units Qwltg, Qwlta, Qwlts, and Qwlte. It probably covered the entire county at one time, but subsequent fluvial processes have removed the till in some areas, especially along the Missouri River valley. Till is thickest in the Chapelle buried valley (fig. 9), where the maximum observed thickness is 370 feet at SE¼SE¼SE¼SW¼ sec. 33, T. 112 N., R. 75 W. The eastern portion of the Gray Goose buried valley also has till thicknesses exceeding 300 feet (fig. 9). Where it has not been completely eroded, the thinnest deposits of till are observed on top of bedrock highs (pl. 2).

OUTWASH

Outwash consists of sand and gravel deposits that were deposited by glaciofluvial processes. It is subdivided into three types based on the deposit's relative position in the drift: basal, intermediate, and surficial. Major outwash deposits identified in Hughes County are shown on figures 10 and 11. Surficial outwash deposits are also shown on plate 1.

Basal Outwash

Basal outwash is primarily medium- to coarse-grained, quartzose sand deposited directly on bedrock or on a thin layer of till that overlies the bedrock. The quartz grains are commonly transparent and colorless, although some have a grayish tint. They were derived from the western part of the state and were transported to Hughes County by east-flowing rivers. Most of the basal outwash deposits were likely eroded by the glaciers, and the only remaining deposits are in Gray Goose buried valley. These deposits have an average thickness of 30 feet and are overlain by either till or intermediate outwash (outwash body A, fig. 10 and pl. 3).

Intermediate Outwash

Intermediate outwash consists of a variety of sediments ranging in size from fine sand to medium-pebble gravel. It is composed of shale, quartz, concretion fragments from the Pierre Shale, and a wide variety of glacially derived igneous and metamorphic rock fragments. The outwash was deposited by meltwater flowing in and under the ice or by proglacial streams during minor recessions. The deposits were then later covered with till as the ice readvanced. Hughes County has many discontinuous deposits of intermediate outwash, but most of these are less than 5 feet thick and are not shown on the cross sections (pl. 3). Deposits thicker than 5 feet underlie a small portion of the county (fig. 11).

Surficial Outwash

Surficial outwash consists of the same sediments as intermediate outwash: fine sand to medium-pebble gravel composed of shale, quartz, concretion fragments from the Pierre Shale, and a variety of glacially derived igneous and metamorphic rock fragments. It is commonly oxidized. Surficial outwash was deposited on previously deposited drift as the ice front receded. Meltwater flowing away from or along the ice front and meltwater flowing in the Missouri River valley deposited most of this outwash. Meltwater flowing in and on the ice itself also deposited sediments that are now exposed at the surface. Surficial outwash covers approximately 12 percent of the county, and except for the Missouri River outwash terraces, most of the deposits are relatively thin (fig. 10). Tomhave (1986) discusses these deposits in more detail.

LACUSTRINE DEPOSITS

Lacustrine deposits consist of layered silts and clays that are composed primarily of quartz and shale fragments. These sediments cover only a small portion of Hughes County (pl. 1) and are approximately 10 feet thick. They were deposited by runoff into shallow bodies of ponded water that temporarily occupied abandoned meltwater channels.

EOLIAN DEPOSITS

Loess is the only eolian deposit observed in Hughes County. It is a yellowish-brown, homogeneous deposit consisting primarily of wind-blown silt with lesser amounts of clay and fine sand. It is composed almost entirely of quartz grains. After the glaciers receded, loess was deposited by northwesterly winds that transported fine-grained sediment east from the Missouri River valley to the exposed surface east of the river. Transportation and deposition continued until vegetation became established on the surface.

Loess covers a large portion of the surface in Hughes County, especially near the Missouri River, but it is generally thin with an uneven distribution. Approximately 25 percent of the test-hole logs for the county on file at the South Dakota Geological Survey indicate a presence of loess, and the average thickness is only 6 feet with a maximum of 18 feet. Due to the thin nature of the deposits and its uneven distribution, loess deposits are not shown on plate 1.

Holocene Deposits

ALLUVIUM

Alluvium deposits consist mostly of silt and fine sand, with lesser amounts of clay and medium- to coarse-grained sand, and are composed of shale, quartz, and other material derived from the drift and Pierre Shale. Alluvium was deposited in flood plains by post-glacial streams and has a relatively flat surface. Most of the alluvium in Hughes County is in the Missouri River valley where deposits average 35 feet in thickness, but alluvium can be found in every drainage in the county. In some of the stream valleys, the alluvium is 100 percent shale debris, while in the Missouri River valley quartz

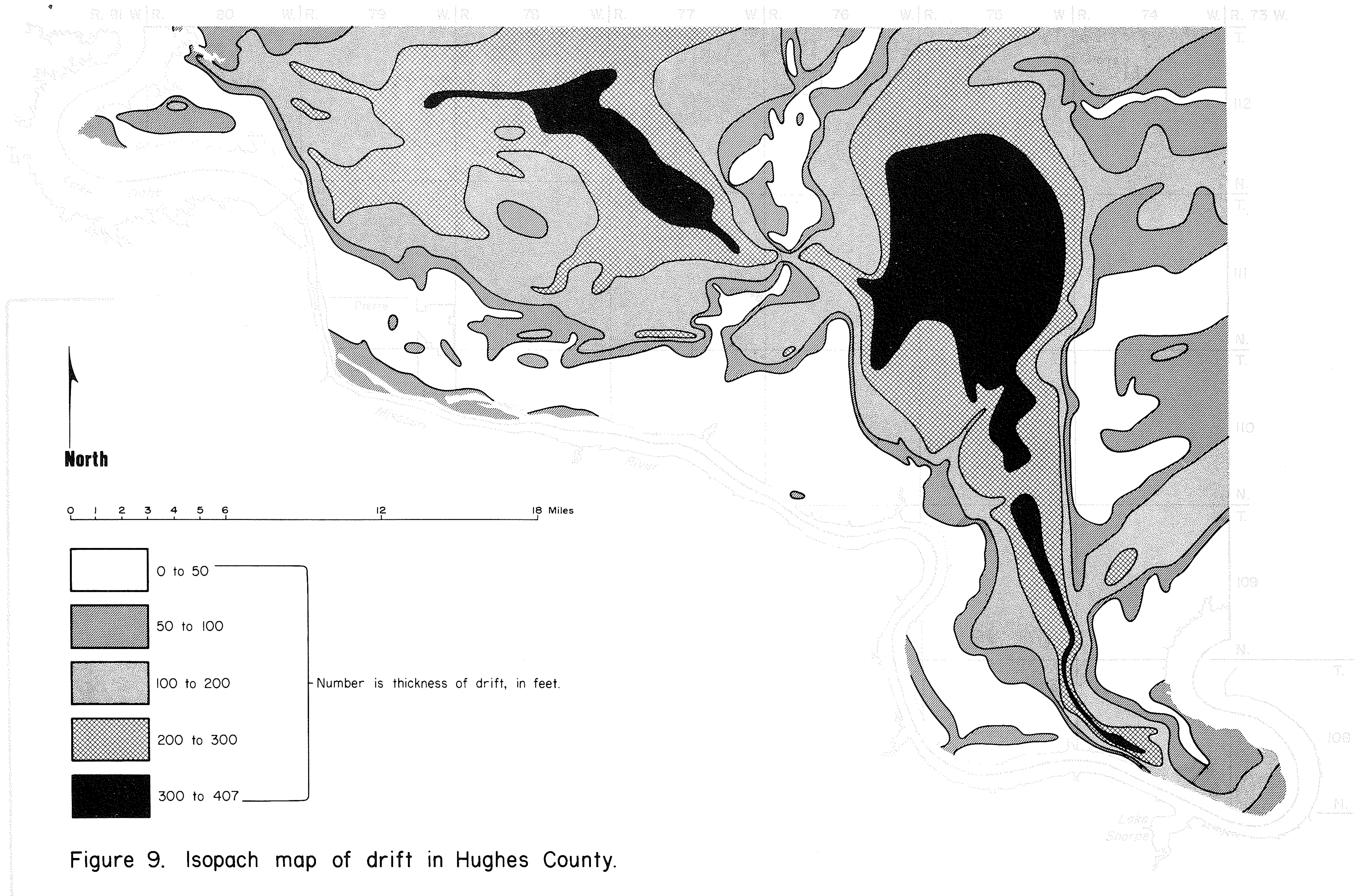


Figure 9. Isopach map of drift in Hughes County.

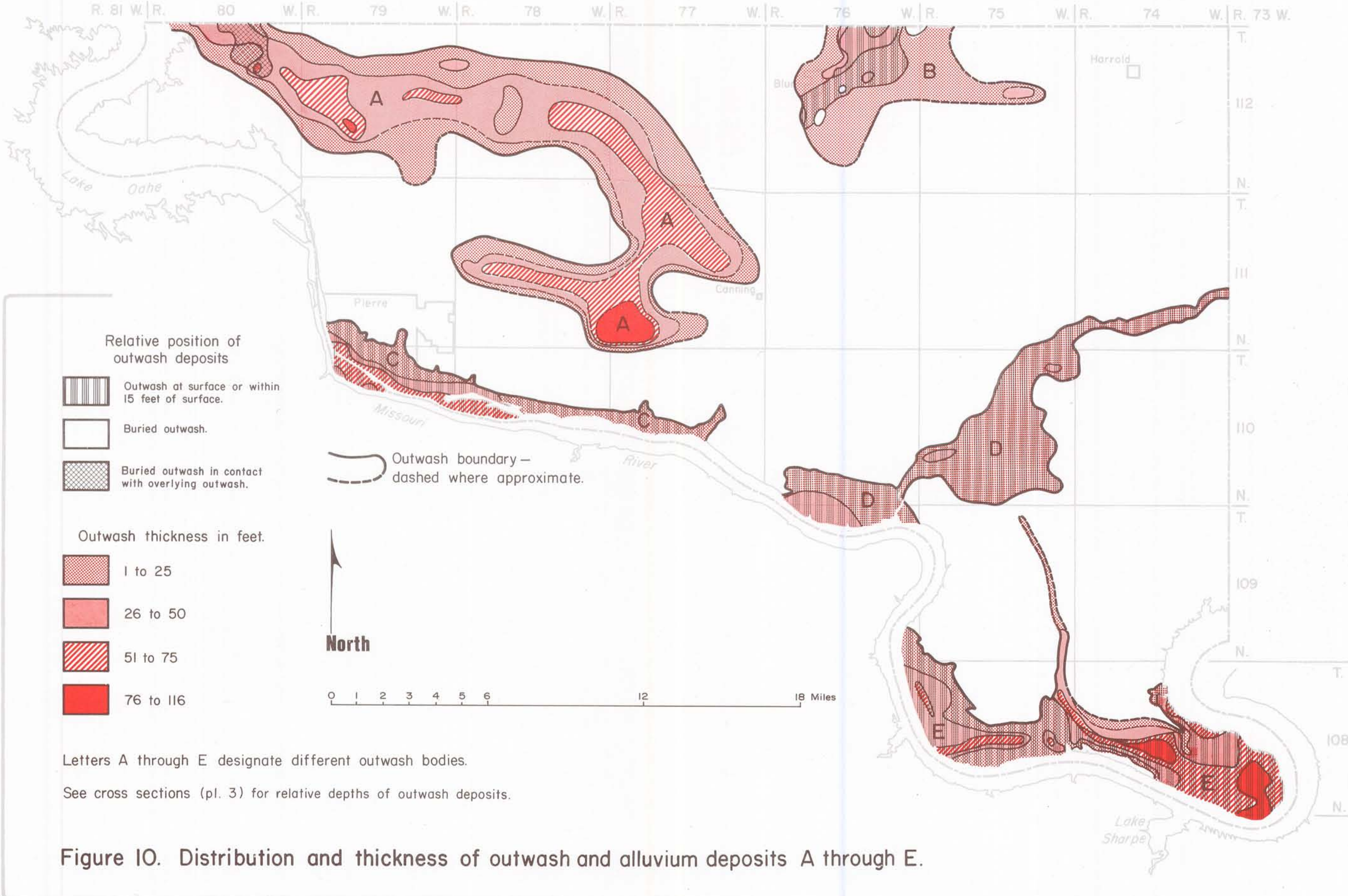


Figure 10. Distribution and thickness of outwash and alluvium deposits A through E.

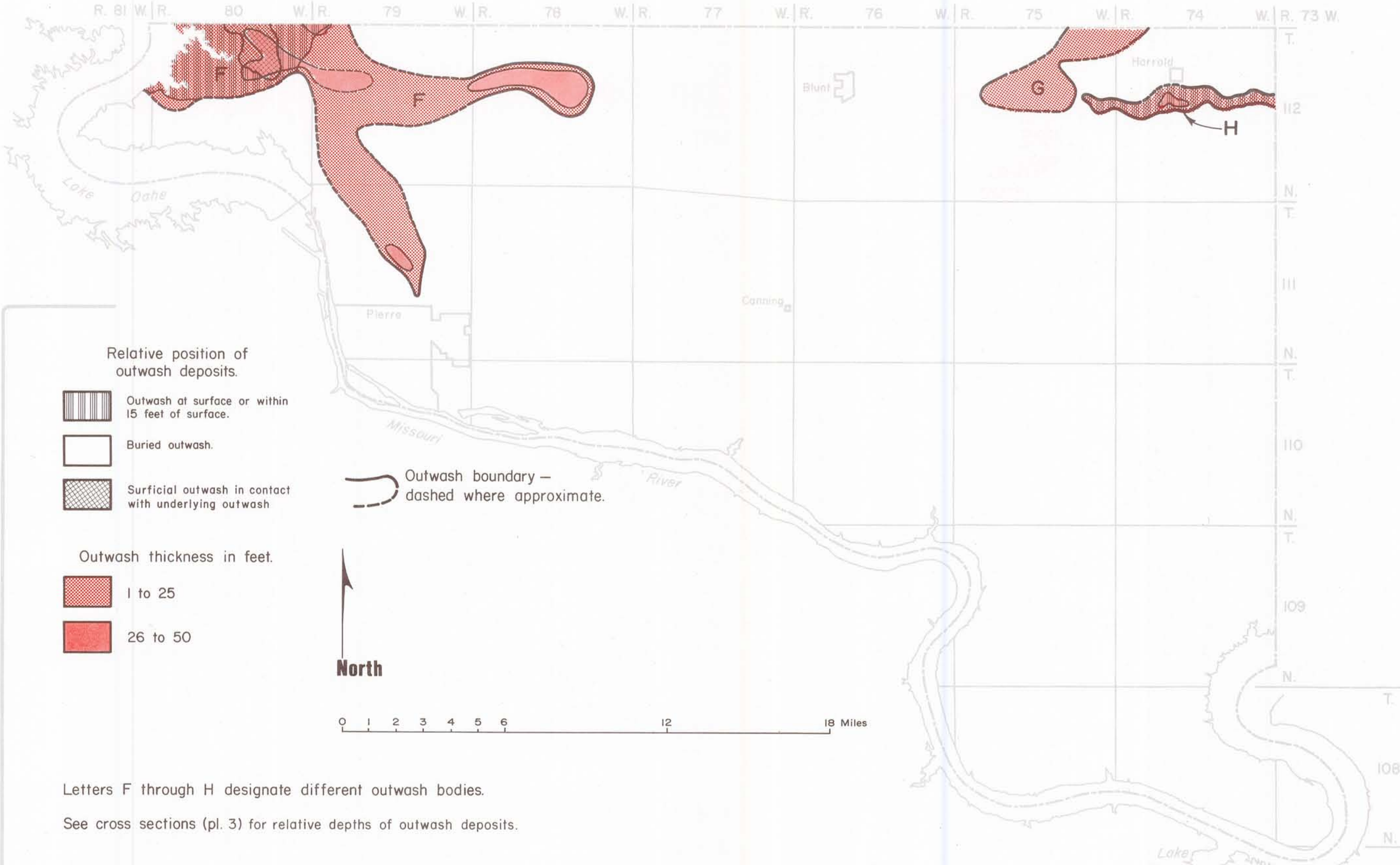


Figure 11. Distribution and thickness of outwash and alluvium deposits F through H.

is the most common component. Alluvial deposits are relatively thin in the tributaries (generally less than 10 feet) and are completely absent (eroded) when the stream is degrading.

COLLUVIUM

Colluvium consists primarily of debris that has been deposited as a result of landslides in the Pierre Shale. Material ranging from clay-size particles to blocks several feet in diameter make up colluvium. Landslides are discussed in greater detail later in the text. Most slumps occur along the Missouri River valley, but other deposits occur wherever slopes are steep and Pierre Shale is exposed. Colluvium deposits range in thickness from several feet to several tens of feet.

Quaternary Landforms

Glacial Landforms

INTRODUCTION

All surficial features in Hughes County are the result of late Wisconsin glaciation which extensively modified the preexisting surface. The features reflect the nature of the glacier as it covered the area. Landscape modification in the county has been relatively minor since the glaciers receded from the region. This is due to the relatively little time that has elapsed since the glaciers receded from the county and due to the low amounts of precipitation that fall on the county. The underlying bedrock influenced the general form of the surface, but drift deposited by the ice has smoothed the bedrock features, obscuring some completely.

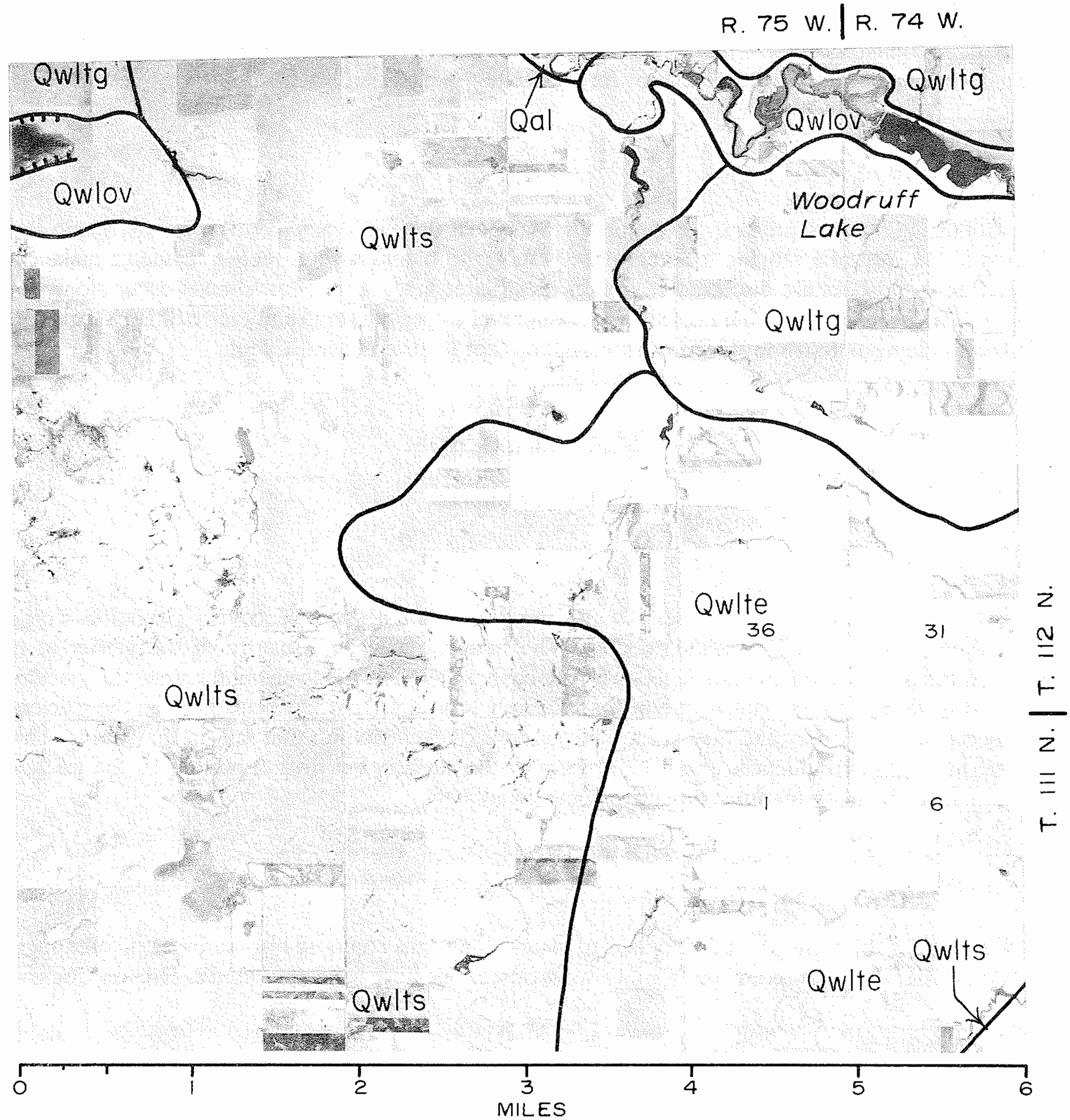
MORAINES

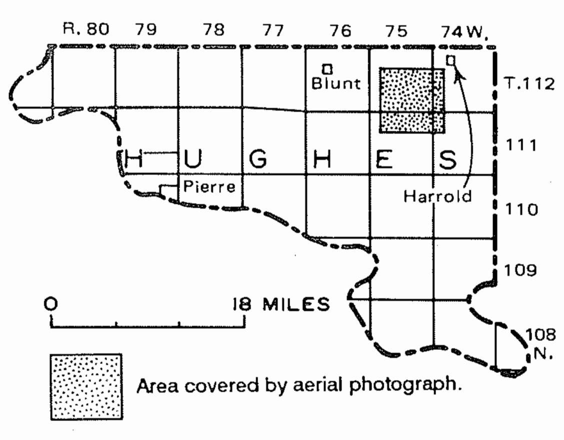
Moraine is the term generally applied to glacial landforms composed primarily of till, although sorted sediments are also common. Various types of moraine have been identified in Hughes County.

Stagnation Moraine

Stagnation moraine is the most common landform in Hughes County and 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.

Stagnation moraine has a generally subdued topographic expression in Hughes County and varies from an essentially flat surface to one with low relief (fig. 12). The surface is either poorly drained or has no drainage, with many areas having only local internal drainage. Close depressions, or kettles, are the most distinct feature of stagnation moraine. These were formed when blocks of ice were buried in the drift during the melting of a mass of inactive ice. The blocks remained buried after the ice mass completely melted, and slowly melted under the till. As the blocks melted, the till that covered the blocks collapsed, forming closed depressions. The kettles (also called sloughs) vary in size from less than 1 acre to several tens of acres.





Qal..........Alluvium
Qwltg......Ground moraine
Qwlts......Stagnation moraine
Qwlte......End moraine
Qwlov......Valley-train outwash
Meltwater channel

Figure 12. Aerial photograph showing typical glacial landforms in northeastern Hughes County.

Other features observed on stagnation moraine in the county are kames and eskers. Kames are deposits of sand and gravel that formed when sediments accumulated in a depression on the ice surface. As the ice melted, sediments collapsed onto the land surface forming a mound. Kames in the area are typically 10 to 30 feet high and several tens to a few hundred feet in diameter. Although common in areas of stagnation moraine, individual kames are too small to be mapped. Eskers are sand and gravel deposits deposited by meltwater flowing under the ice. There is one discontinuous esker in Hughes County extending from sec. 3, T. 110 N., R. 75 W. to sec. 6, T. 110 N., R. 74 W. (pl. 1). It forms a sinuous ridge that is 10 to 30 feet high.

Ground Moraine

Ground moraine consists of lodgement till and forms gently sloping surfaces with low to moderate relief and poor to moderate drainage. No other distinguishing features were observed on ground moraines in Hughes County.

End Moraines

End moraines consist primarily of ablation till with local concentrations of boulders and minor sand and gravel deposits. These moraines were formed at the margin of the glacier when the ice was neither advancing nor receding. Long-term stability of the ice margin can result in the accumulation of significant drift thicknesses in end moraines.

In Hughes County end moraines have moderate relief and are generally well drained, although some local internal drainage does exist (fig. 12). The moraines are poorly developed features with some small linear ridges that roughly parallel the former ice front. The end moraines in the county are equivalent to the Artas moraine mapped by Hedges (1972) in Campbell County, but further mapping in the counties between Hughes and Campbell Counties must be completed to confirm this theory. The Bowdle moraine (Hedges, 1972) is not recognized in Hughes County.

ATTENUATED DRIFT

Attenuated drift consists of thin deposits of till overlying Pierre Shale. The deposits are generally less than 50 feet thick with occasional bedrock exposures. The surface has moderate to well-developed drainage and has low to high relief reflecting the underlying bedrock surface.

OUTWASH FEATURES

Valley-Train Outwash

Valley-train outwash consists of surficial outwash that was deposited by meltwater as it flowed away from the ice front in agrading streams. Where continuous, the outwash has low relief and is well drained. In many places the valley-train outwash has been partially eroded by post-glacial stream flow, so that the underlying drift is locally exposed. This results in discontinuous deposits such as those along the South Fork of Medicine Knoll Creek. The deposits are generally less than 15 feet thick.

Outwash Terraces

Outwash terraces are observed in the Missouri River valley and along major drainages. They consist of fine-grained outwash that was deposited as flood-plain sediments. Gradual lowering of the river level resulted in the entrenchment of early levels and deposition of new sediments at lower levels. Three terrace levels were recognized along the Missouri River in Hughes County (pl. 1). Terraces are flat to gently sloping with low local relief and are well drained.

Collapsed Outwash

Collapsed outwash consists of surficial outwash that was deposited over a broad plain by meltwater flowing adjacent to a stagnant ice mass. Due to the close proximity of the glacier, ice blocks were transported by meltwater and deposited with the outwash. When the blocks melted, closed depressions were formed as the sediment surrounding the block collapsed into the space vacated by the ice. These depressions may be several hundred feet in diameter. Between depressions the outwash surface is relatively flat and is poorly drained with local internal drainage. The outwash is generally less than 15 feet thick and is locally absent due to post-glacial stream erosion.

MELTWATER CHANNELS

Meltwater channels are valleys containing underfit streams that were formed by meltwater flowing away from the ice front. There are two types of channels found in Hughes County. The first are channels formed by degrading meltwater streams that cut into the land surface eroding the drift, but not depositing any outwash. An example is the channel that extends from sec. 10, T. 111 N., R. 78 W. to sec. 26, T. 111 N., R. 78 W. (pl. 1). The second are channels that showed evidence of degradation and agradation. Meltwater streams initially cut into the land surface, but later sediment was deposited (outwash), as shown by the channel that extends from sec. 23, T. 112 N., R. 76 W. to sec. 8, T. 111 N., R. 76 W. (pl. 1).

LAKE PLAINS

There are two lake plains in the county in closed depressions. They formed in depressions in abandoned meltwater channels, and sediments deposited in them are locally derived. The lakes in which deposition occurred were temporary and intermittent.

Nonglacial Landforms

STREAM ERODED BEDROCK TOPOGRAPHY

Where the drift has been completely removed from an area and the Pierre Shale has been exposed to erosion, the result is stream eroded bedrock topography. The areas have moderate to high local relief (gullies that are up to 8 feet deep) and are well drained. This topography is found along the Missouri River valley and the east end of Medicine Knoll.

SLUMPS

Slumps consist of colluvium that was deposited by mass movement of the Pierre Shale. They have a rough topographic expression with high local relief and have poor (often internal) drainage. Slumps are located on exposures of Pierre Shale in the Missouri River valley and the east end of Medicine Knoll.

Quaternary Geologic History

Pre-Late Wisconsin

The surface of Hughes County was formed during the last glaciation and modified by subsequent erosion. However, geologic processes during earlier portions of the last geologic era -- the Cenozoic -- have influenced the formation of the regional land surface in central South Dakota and will be discussed briefly.

During most of the Tertiary Period, poorly consolidated sediments, mostly sands, were being deposited in the western and central portions of the state. These sediments were deposited by eastward-flowing streams originating in the Rocky Mountains and the Black Hills, which were undergoing periodic stages of uplift. Continued uplift of the region, and subsequent lowering of the base levels of the streams, caused erosion of these deposits during the latter part of the Tertiary, prior to the Pleistocene.

The land surface near the end of the Tertiary Period was probably similar to that presently found in western South Dakota, with eastward-flowing drainages dissecting Pierre Shale. Interfluves and buttes were likely capped with Tertiary rocks.

Erratic boulders found on the west side of the Missouri River are the only known evidence of pre-late Wisconsin glaciation in the north-central portion of the state. These deposits have not been studied extensively in South Dakota and their absolute age is unknown. Similar deposits have been recognized in North Dakota, where they are attributed to the pre-Wisconsin Dunn glaciation (Bluemle, 1984). By contrast, numerous pre-late Wisconsin tills have been identified on or within the Coteau des Prairies in eastern South Dakota (Gilbertson and Lehr, 1989) and at least six pre-Illinoian and two Illinoian glaciations are documented in Iowa and Nebraska (Richmond and Fullerton, 1986).

Presumably the eastward-draining rivers in western North and South Dakota were diverted southward around the ice sheet during this glaciation. However, there is no evidence of a proglacial channel west of the Missouri River in South Dakota or North Dakota (Bluemle, 1984). Additionally, there are no glacial landforms in the areas covered by erratic boulders in the western part of the state. A long period of erosion must have followed the ice advance(s) to remove all evidence of glacial landforms, till, and proglacial channels. Clayton and Moran (1982) estimated that there were 200 feet of erosion in North Dakota after the Dunn glaciation. Similar erosion must have occurred in South Dakota. As in the late Tertiary, most of the surface was covered with a thin soil overlying the Pierre Shale, and buttes were capped with Tertiary rocks.

Drainage for the north-central portion of South Dakota prior to the late Wisconsin glaciation has been estimated using a contour map of the bedrock surface beneath the glacial drift (fig. 13). The

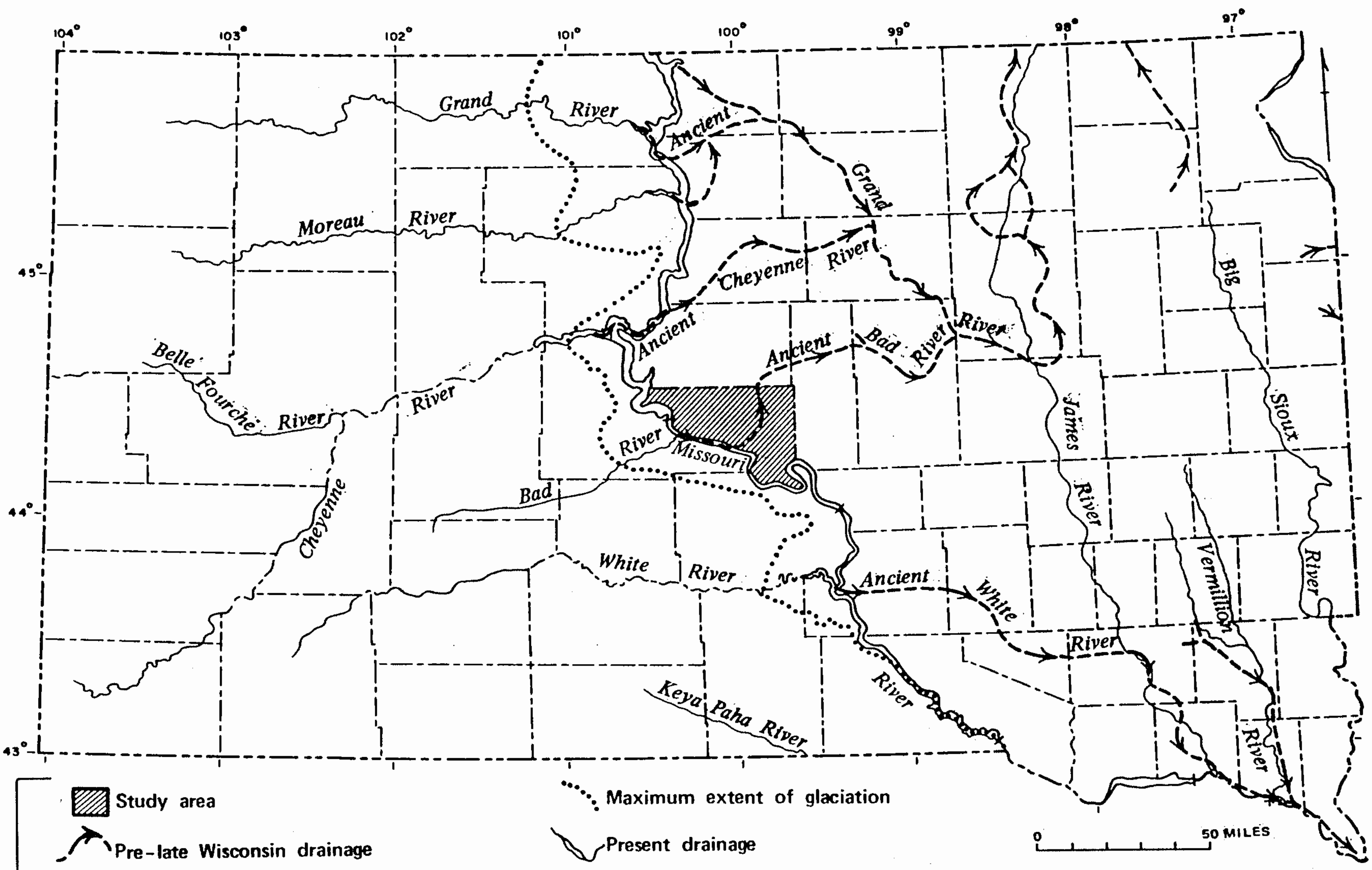


Figure 13. Map showing western extent of glaciation and inferred pre-late Wisconsin drainage in eastern South Dakota *(modified from Lemke and others, 1965; Hedges and others; 1982 and Duchossois, 1985).*

Missouri River and other modern streams were not yet in existence. In Hughes County, the ancient Bad River entered what is now the Missouri River valley near Pierre and flowed eastward to the Chapelle buried valley. From there the river flowed north out of the county and eventually drained into the ancient Grand River which flowed northward to Hudson Bay (fig. 13). The study area was a few tens of miles north of the continental divide (Duchossois, 1985).

Late Wisconsin

Late Wisconsin glaciers first entered north-central South Dakota by way of the James River lowland. As the thickness of ice increased in the lowland, the glacier (the James Lobe) expanded laterally and began to override the bedrock highlands to the west. Ice movement was influenced by preexisting topography and its movement into Hughes County from the east was slowed by the highlands along the Hyde County border. Ice initially moved into the county from the northeast, via the Chapelle buried valley (fig. 14). As the ice flowed up the regional slope and up the valley, a proglacial lake formed in Chapelle buried valley and the flow of the ancient Bad River was diverted to the south through what is now the valley of Joe Creek. At the same time, the drainage of the east-flowing rivers north of Hughes County was also diverted to the south by glacial advances. These rivers coalesced to form the ancient Missouri River, which flowed southward along the ice margin. It flowed across Hughes County in the Gray Goose buried valley. The ancient Missouri and ancient Bad Rivers converged in T. 110 N., R. 75 W. (fig. 14).

As the glacier continued to advanced, it flowed into northwestern Hughes County from the northeast and into the northeastern part of the county from the east, over the northern portion of the eastern highland (fig. 15). Ice advancing in Chapelle buried valley eroded the lacustrine deposits in the valley and blocked the drainage in Gray Goose buried valley. The ancient Missouri River was diverted into the southern portion of what is now the Medicine Knoll Creek valley and a small valley to the west.

The glacier continued to move southward over the Gray Goose buried valley to the southern end of the Chapelle buried valley (fig. 16). Because the Chapelle buried valley is oriented in the same direction as the ice flow, the glacier eroded the valley more than in the surrounding area, carving out the broad, flat valley that is observed on the bedrock surface (pl. 2). Glacial erosion also removed any fluvial deposits that resulted from the ancient Bad River drainage through the valley. In the western part of the county, glacial flow over the Gray Goose buried valley eroded all or most of the sediments previously deposited by the ancient Missouri River and deposited till in the valley. The ancient Missouri River drainage was diverted to a variety of temporary positions south of the margin of the glacier (fig. 16), which resulted in the deposition of alluvial sands in T. 111 N., R. 77 W. The ice front may have extended as far west as the Missouri River. During this time the flow through Joe Creek valley was abandoned by the main drainage due to stream capture, and the ancient Missouri River flowed in the valley of the present Missouri River southeast of sec. 1, T. 109 N., R. 76 W. to the eastern edge of the county.

At this time a minor recession of the ice front occurred, allowing flow to resume in Gray Goose buried valley. Till that had been deposited in the valley was partially eroded by fluvial action and alluvial sediments were deposited in the valley (pl. 3, cross section A-A'). East of Hughes County, a layer of intermediate outwash was deposited in Hyde and Hand Counties during this recession (Helgerson and Duchossois, 1987, pl. 2). There is no evidence of the duration of the recession, but

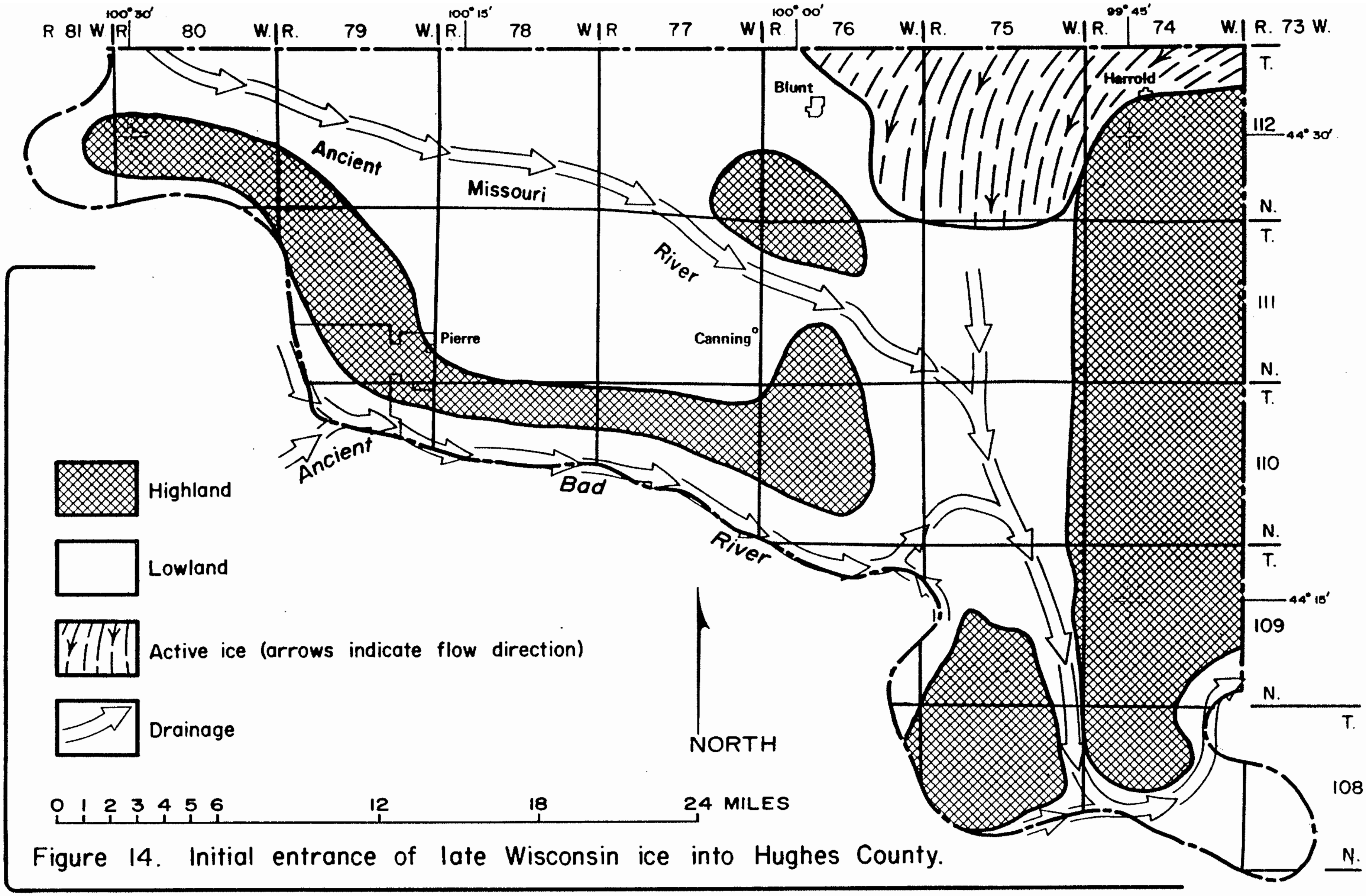


Figure 14. Initial entrance of late Wisconsin ice into Hughes County.

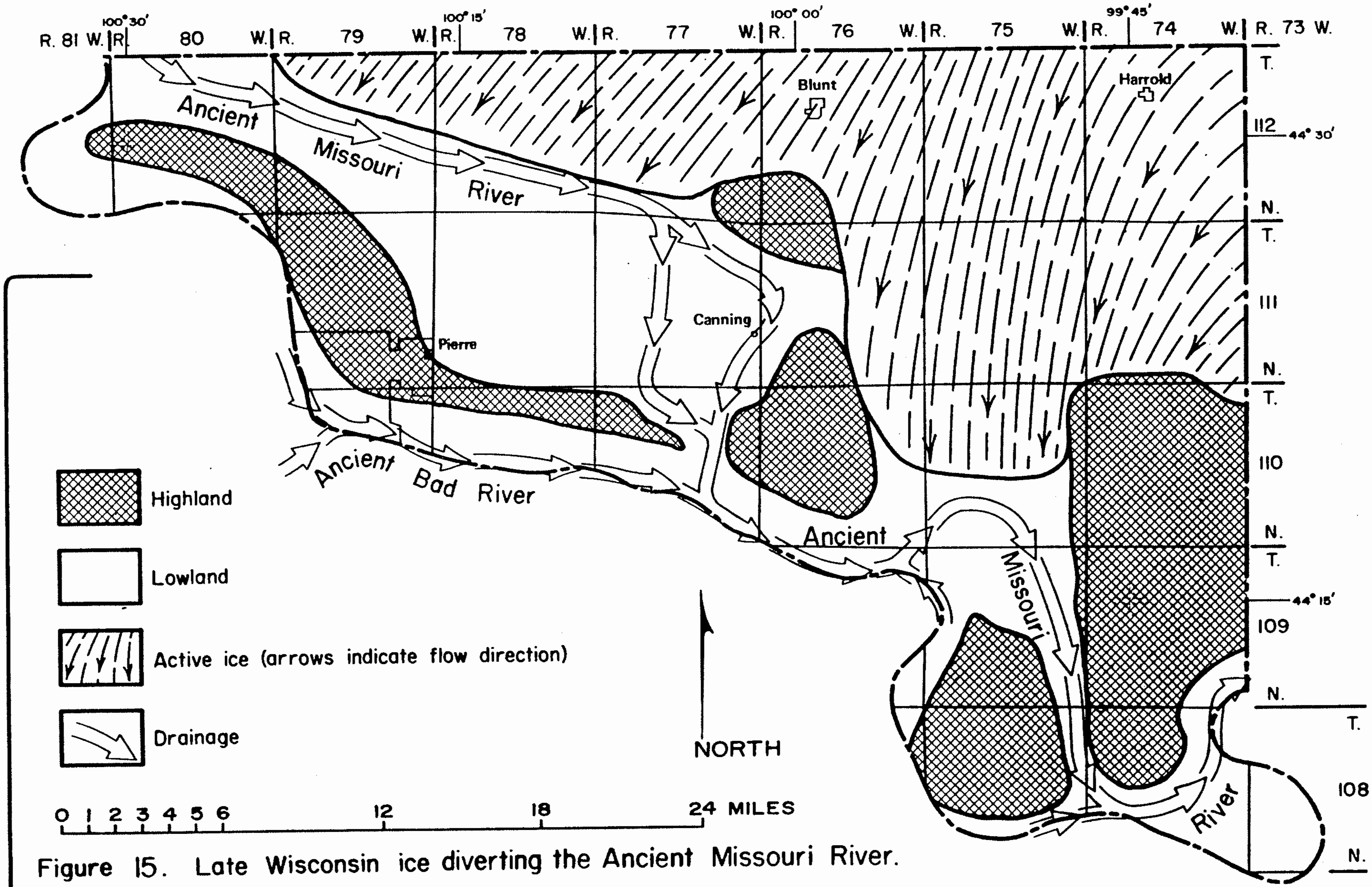


Figure 15. Late Wisconsin ice diverting the Ancient Missouri River.

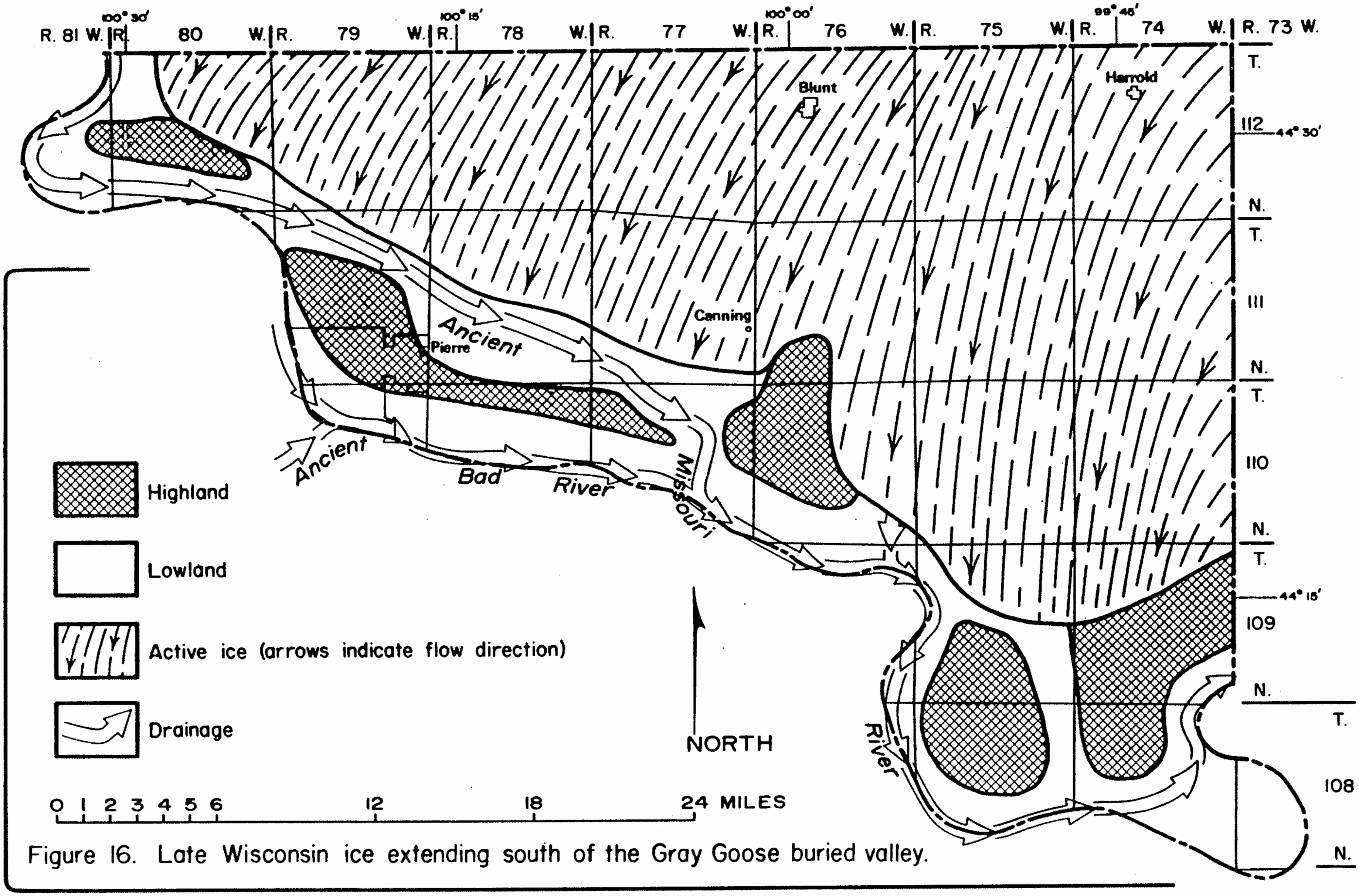


Figure 16. Late Wisconsin ice extending south of the Gray Goose buried valley.

no buried oxidized zones have been observed in Hughes, Sully, Hyde, or Hand Counties, so it was not a major recession. Hedges (1987) also noted the recession in Walworth County with "two phases" of late Wisconsinan glaciation. The ice front receded at least as far east as the Hand-Spink County line before the glacier again advanced over Hughes County covering the alluvial deposits in the Gray Goose buried valley and in T. 111 N., R. 77 W. with till.

The glacier readvanced, covering the entire county with ice. The modern Missouri River valley was now being used along the entire western and southern borders of the county, and the flow through it drained the unglaciated areas northwest of Hughes County and east of the Rocky Mountains. Ice near the glacial margin was probably much thinner than the ice that covered most of the county, as indicated by minimal erosion of the bedrock surface and the thinner drift thickness near the Missouri River valley. The ice front probably did not extend west of the Missouri River valley for any significant period of time during the late Wisconsin, but two small till exposures were observed along the Missouri River valley in Stanley County (T. 7 N., R. 30 E.). These deposits appeared to be similar to exposures on the eastern side of the river and indicate that the ice front advanced across the river for a short period of time. Further evidence that the ice front pulsated at the Missouri River valley is indicated by the multiple till and outwash layers in T. 108 N., R. 74 W. that filled the outlet of Joe Creek valley (pl. 3, cross section F-F').

As the ice receded from the Missouri River valley, deposition of outwash terraces began in the valley. Largest accumulations were on the inside parts of curves in the valley (fig. 17). When the ice front remained in one position for a period of time, end moraines equivalent to the Artas moraine formed. When blocks of ice became separated from the ice flow, they began to stagnate. Meltwater from the ice front formed meltwater channels that eroded previously deposited material.

Continued recession resulted in the formation of a meltwater channel, now occupied by Spring Creek, in which was deposited a thin layer of outwash on the till and on the exposed Gray Goose buried valley outwash (fig. 18). Meltwater also flowed in Dry Run and Medicine Knoll Creek. Erosion of exposed land surfaces continued as did construction of terraces in the Missouri River valley. Downcutting of the valley by erosion caused a gradual lowering of the base level and lower terraces were formed.

Later, large blocks of ice became separated from the active ice and began to stagnate (fig. 19). Meltwater continued to flow away from the ice front in Medicine Knoll Creek and began to flow in the modern Chapelle Creek valley. Meltwater in the latter valley carried blocks of ice from the stagnant ice mass to the north. These blocks of ice were deposited with outwash sediments and an uneven surface was formed.

When the ice front receded to the edge of the county, the only meltwater flow was in Medicine Knoll Creek. Meltwater flowing in the South Fork of Medicine Knoll Creek deposited a layer of outwash along its course, while the main branch of Medicine Knoll Creek began to degrade and the stream began to cut into the land surface removing previously deposited sediments.

After complete recession of the glacier from the county, gradual erosion of the surface continued. In Hyde and Sully Counties the Herreid and Bowdle moraines were formed as the glacier remained within a few miles of Hughes County for a period of time. Meltwater flowed down Medicine Knoll Creek, and the South Fork of Medicine Knoll Creek was captured at sec. 2, T. 112 N., R. 76 W. Flow in the abandoned channel soon ceased. Downcutting and terrace deposition continued in the

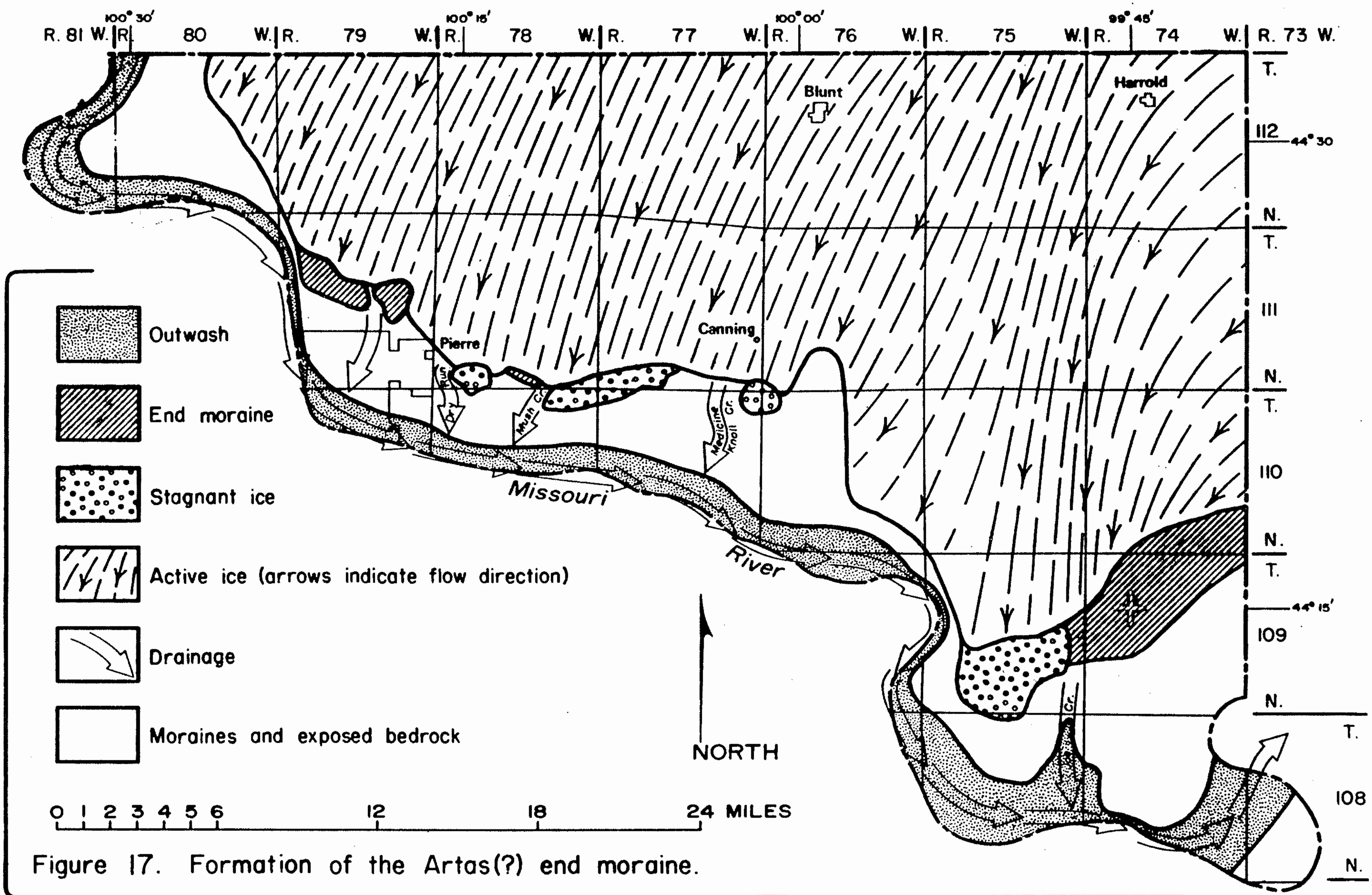


Figure 17. Formation of the Artas(?) end moraine.

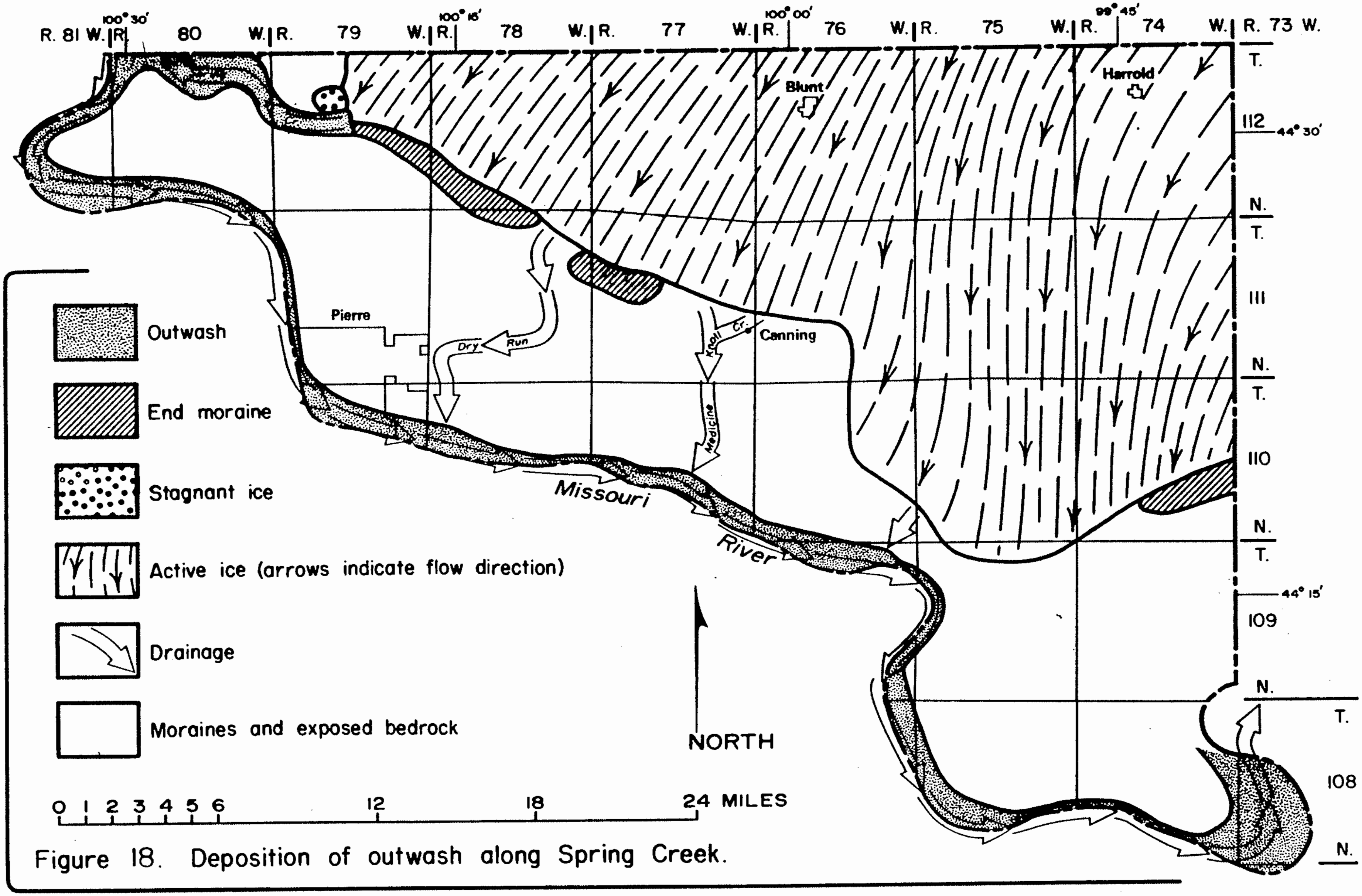


Figure 18. Deposition of outwash along Spring Creek.

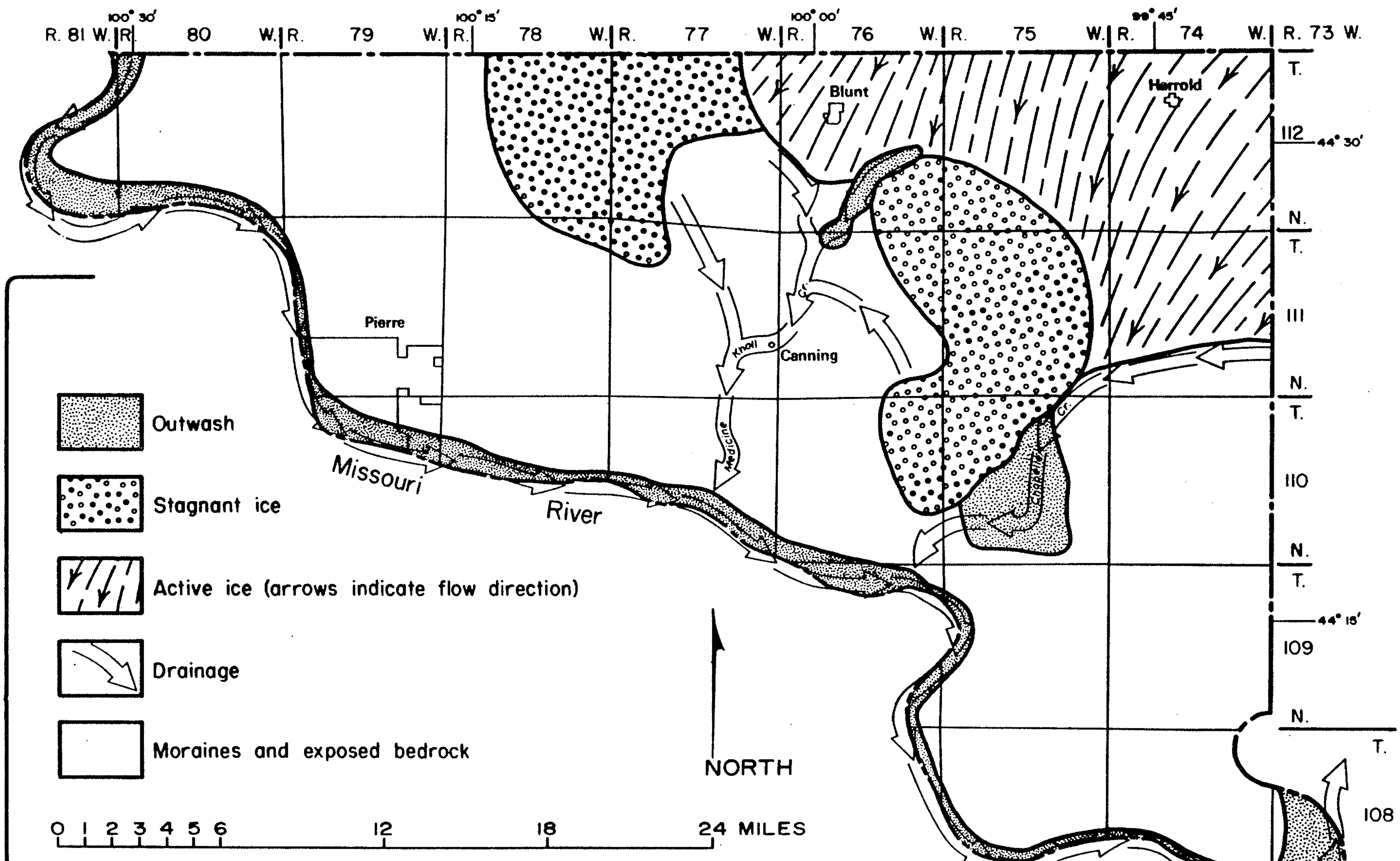


Figure 19. Deposition of outwash along Chapelle and Medicine Knoll Creeks.

Missouri River valley, which lowered the base level of Medicine Knoll Creek. A large amount of meltwater from the glacier still flowed in the creek, and this, combined with the lower base level, accounts for the deep incisement of the stream into the land surface. During this time wind-blown loess was also being deposited over the county.

Holocene Epoch

After the glacier receded from the region, wind-deposited silt derived from the sediment in the Missouri River valley began to accumulate. Flow rates in the Missouri River and its tributaries decreased when meltwater stopped flowing through the county. Relatively low rates of precipitation during this period resulted in low rates of erosion, and there has been little change in the landscape of the county since the ice receded from the area.

ECONOMIC GEOLOGY

Geologic Resources

Petroleum and Natural Gas

Accumulations of petroleum are found in the Minnelusa Formation and Red River Formation in South Dakota, but production wells are located primarily in the northwestern and southwestern corners of the state (Petres, 1989). There is no evidence to suggest the presence of commercially viable deposits of petroleum in Hughes County. Downey (1984, p. 92) states, "The eastern edge of the Williston basin contains no major petroleum accumulations . . ." due to geologic and hydrologic conditions.

In South Dakota natural gas is found primarily in the Inyan Kara Group and the Dakota and Niobrara Formations (Bretz, 1981, and Petres, 1989). Gas from the Dakota Formation was utilized locally in Pierre at the turn of the century. However, no formations are currently thought to contain economical quantities of this resource in central South Dakota, with the possible exception of the Niobrara Formation. Shurr and Reiskind (1984) state that the Niobrara Formation has the best exploration potential for natural gas in this region of the state.

Water

Water is the most important and most abundant resource in Hughes County. Most surface water is limited to the Missouri River, while geology controls the availability of ground water. Ground water underlies the entire county in bedrock aquifers, but shallow, glacial aquifers have an uneven distribution throughout the county. As part of this investigation, a complete hydrologic study of Hughes County is available (Hamilton, 1986b), in addition to a brief summary of the aquifers (Hamilton, 1986a).

Sand and Gravel

The availability of surficial sand and gravel resources is another important part of this investigation. Sand and gravel deposits occur as outwash deposits, including kames and eskers. The distribution of these deposits is discussed and mapped by Tomhave (1986).

Other Resources

Rip rap may be obtained from concentrations of boulders on the land surface. They occur discontinuously throughout the county. Lithology of the boulders varies widely, although most of the glacially transported boulders are either igneous or metamorphic.

Manganese-enriched deposits of Pierre Shale, which are currently under investigation by the South Dakota Geological Survey, occur along the Missouri River valley in the southeast part of Hughes County (R. Hammond, South Dakota Geological Survey, personal communication, 1991). Other mineral resources, such as coal and uranium, may exist in the county, but not in large enough quantities to be economically important.

Geothermal Potential

Hughes County has a good potential for use of low temperature geothermal resources (Schoon and McGregor, 1974). Ground water in the bedrock aquifers is warmed by natural geothermal heat and can be put to use as space heating or hot water when it reaches the surface.

Geologic Hazards

Pierre Shale Landslides

The major geologic hazards in Hughes County are landslides in the Pierre Shale. Landslides, or slumps, are the downslope movement of a land mass caused by slope failure. They may be initiated by earthquakes or gravity and are influenced by a number of geologic factors, including rock composition and ground water. The Pierre Shale is more susceptible to slumping than most rocks because of the numerous thin bentonite layers that occur throughout the formation. Bentonite has a large swelling potential in addition to having a greasy texture when wet. These and other properties of the formation, such as joints, fractures, and faults, combine to make the Pierre Shale very susceptible to slumping, as the slump at NW¼SW¼NE¼ sec. 36, T. 112 N., R. 80 W. demonstrates (pl. 1). Referring to major construction projects, Nichols and others (1986, p. 193) state ". . .physical properties (of the Pierre Shale) can severely affect other construction and use of excavations in the shale." Crandell (1958) and Scully (1973) discuss landslides in the Pierre Shale in greater detail, and Nichols and others (1986) discuss the engineering properties of the formation.

Other Geologic Hazards

Faults in the Pierre Shale may adversely affect roads which are constructed on the formation. Roads constructed on the shale in Stanley County have been damaged by reactivation of Cretaceous faults in the formation (Collins and others, 1988), and similar damage could be expected in Hughes County.

Although no earthquakes have occurred in Hughes County in recorded history, they have occurred throughout the state. Four have been recorded within 20 miles of the county since 1872 (Arney and others, 1987). The closest epicenter to the county occurred in 1876 when an earthquake in Lyman County was centered approximately 1 mile east of the Hughes County line in T. 108 N., R. 73 W. (Arney and others, 1987). All the earthquakes in the state were relatively small in magnitude, and there is no reason to believe that a major earthquake will occur in or near Hughes County.

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