

GEOLOGY

of

**SHERIDAN COUNTY,
NORTH DAKOTA**

by

John P. Bluemle
North Dakota Geological Survey
Grand Forks, North Dakota
1981

BULLETIN 75—PART 1

North Dakota Geological Survey

Don L. Halvorsen, *Acting State Geologist*

COUNTY GROUNDWATER STUDIES 32—PART 1

North Dakota State Water Commission

Vernon Fahy, *State Engineer*

Prepared by the North Dakota Geological Survey
in cooperation with the U.S. Geological Survey,
North Dakota State Water Commission,
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ABSTRACT

Sheridan County, located on the eastern side of the Williston Basin, is underlain by 6,000 to 8,500 feet of Paleozoic, Mesozoic, and Cenozoic rocks that dip to the west toward the center of the basin a hundred miles west of Sheridan County. The Cretaceous Pierre, Fox Hills, and Hell Creek Formations and the Tertiary Cannonball and Bullion Creek Formations lie directly beneath the glacial drift. The Hell Creek and Cannonball Formations are exposed in parts of northern Sheridan County. The Pleistocene Coleharbor Group, which covers most of the area, averages between 300 and 400 feet thick, reaching a maximum thickness of over 700 feet east of McClusky. This is probably the thickest accumulation of glacial sediment anywhere in North Dakota. The Holocene Oahe Formation occurs in many sloughs throughout the county, on river bottomland, and in small dunes.

The southern two-thirds of Sheridan County is part of the Missouri Coteau, an area characterized by hilly, collapsed glacial sediment with numerous sloughs, lakes, and closely spaced hills. Ice-thrust topography and collapsed flood plains and lake plains are also common on the Missouri Coteau.

The northern third of Sheridan County is part of the Glaciated Plains, an area characterized by undulating topography. Rolling to steep land is found on the Glaciated Plains along the Sheyenne River Valley and in areas of ice thrusting. The Missouri Escarpment, which separates the Glaciated Plains from the Missouri Coteau, is a dissected, 200- to 400-foot high, north-facing escarpment.

Several distinct till layers can be identified in test holes that have been drilled through the glacial drift in Sheridan County. These layers attest to repeated glacial advances, both prior to and during Wisconsinan time.

INTRODUCTION

Purpose

This report is published by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the United States Geological Survey, and the Sheridan County Water Management District. It is one of a series of county reports on the geology and groundwater resources of North Dakota. The main purposes of these studies are: 1) to provide a geologic map of the area; 2) to locate and define aquifers; 3) to determine the location and extent of mineral resources in the counties; and 4) to interpret the geologic history of the area. This volume describes the geology

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of Sheridan County. Readers interested in groundwater should refer to Part II of this bulletin, which includes detailed basic data on the groundwater, and Part III, which is a description and evaluation of the groundwater resources of Sheridan County.

Parts of this report that are primarily descriptive include the discussions of the topography, rock, and sediment in Sheridan County. This information is intended for use by anyone interested in the physical nature of the materials underlying the area. Such people may be water-well drillers or hydrologists interested in the distribution of sediments that might produce usable groundwater; civil engineers and contractors interested in such things as the gross characteristics of foundation materials at possible construction sites, criteria for selection and evaluation of waste disposal sites, and the locations of possible sources of borrow material for concrete aggregate; industrial concerns looking for possible sources of economic minerals; residents interested in knowing more about the area; and geologists interested in the physical evidence for the geologic interpretations.

Previous Work

All or portions of Sheridan County have been included in several previous studies. In 1883, Chamberlin presented a map of the Missouri Coteau in "Terminal Moraines of the Second Glacial Epoch." Todd (1896) described the moraines of the Missouri Coteau. Leonard (1916) described the "pre-Wisconsin drift" of North Dakota. He placed the western limit of the Wisconsinan drift at the front of the "Altamont Moraine." Andrews (1939) discussed the development of several spillways that drained water from glacial Lake Souris into the Sheyenne River. Lemke (1960) briefly discussed the northwest corner of Sheridan County in a report on the Souris River area.

Several geologic reports of the present county series are now available for the area near Sheridan County. They include Kidder County (Rau and others, 1962); Burleigh County (Kume and Hansen, 1965); McLean County (Bluemle, 1971); Pierce County (Carlson and Freers, 1975); and Wells County (Bluemle and others, 1967). Fieldwork has also been completed in McHenry County and a report is now under way on that area.

Unpublished geologic studies that have included parts of Sheridan County include two masters' theses done by students at the University of North Dakota. A study of the glacial geology of western Sheridan County was completed by N. R. Sherrod in 1963, and a similar study of the glacial geology of eastern Sheridan County was completed by T. C. Gustavson in 1964. An unpublished study of a part of the Lincoln Valley area

in central Sheridan County was completed in 1962 by John Brophy of North Dakota State University.

In addition, four circulars describing samples from exploratory oil wells have been published, and various general studies of North Dakota have included all or parts of Sheridan County.

Methods of Study

During the 1962 field season, N. R. Sherrod and T. C. Gustavson, then graduate students at the University of North Dakota, mapped the geology of Sheridan County for their Master of Science degree theses. They traversed every passable road in the county by automobile, and some inaccessible areas on foot, checking the lithology with hand auger or shovel at 0.2-mile intervals. Data were plotted on aerial photographs (1:20,000 scale). Numerous samples of glacial sediment and fossiliferous material were collected by Sherrod and Gustavson for later laboratory analysis.

During the 1969 field season, I checked Sherrod's and Gustavson's maps and made several corrections and revisions. Most of the lithologic information on the students' maps was accepted. However, at that time, the Sheridan County groundwater study was not under way and no decision was made to proceed with publishing a report on the geology of the county.

In 1978, a formal study was undertaken and the State Water Commission initiated its test drilling program. Over 36,000 feet of test drilling was completed in Sheridan County in 1978 and 1979. I rechecked the surface geology of the county during the 1979 field season and compiled the geologic map (pl. 1).

Regional Topography and Geology

Sheridan County, in central North Dakota, has an area of 1,008 square miles in Townships 145-150 North and Ranges 74-78 West. It is located between 100° 01' 57" West Longitude on the east and 100° 40' 21" West Longitude on the west; 47° 19' 39" North Latitude on the south and 47° 50' 52" North Latitude on the north.

The Missouri Escarpment extends from northwest to southeast across northern Sheridan County, dividing it into the Missouri Coteau (southwestern two-thirds of the county) and the Glaciated Plains (northeastern third) (figs. 1 and 2). The Glaciated Plains of Sheridan County include about 175 square miles of nearly level to undulating glacial topography with poorly developed drainage. The Sheyenne River meltwater trench crosses this area. Local relief is less than five feet in many places, although it is greater than 150 feet near the Sheyenne River trench. Elevations range from about 1,600 feet to about 1,700 feet.

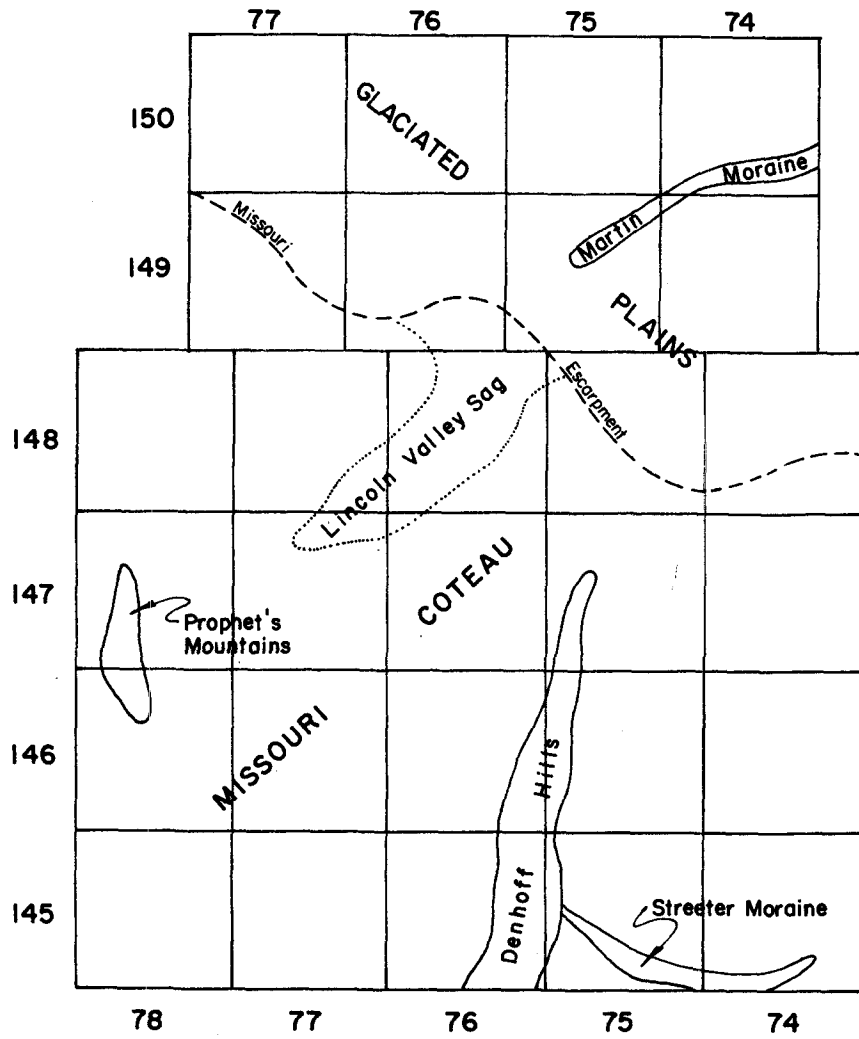


Figure 1. Physiographic map of Sheridan County.

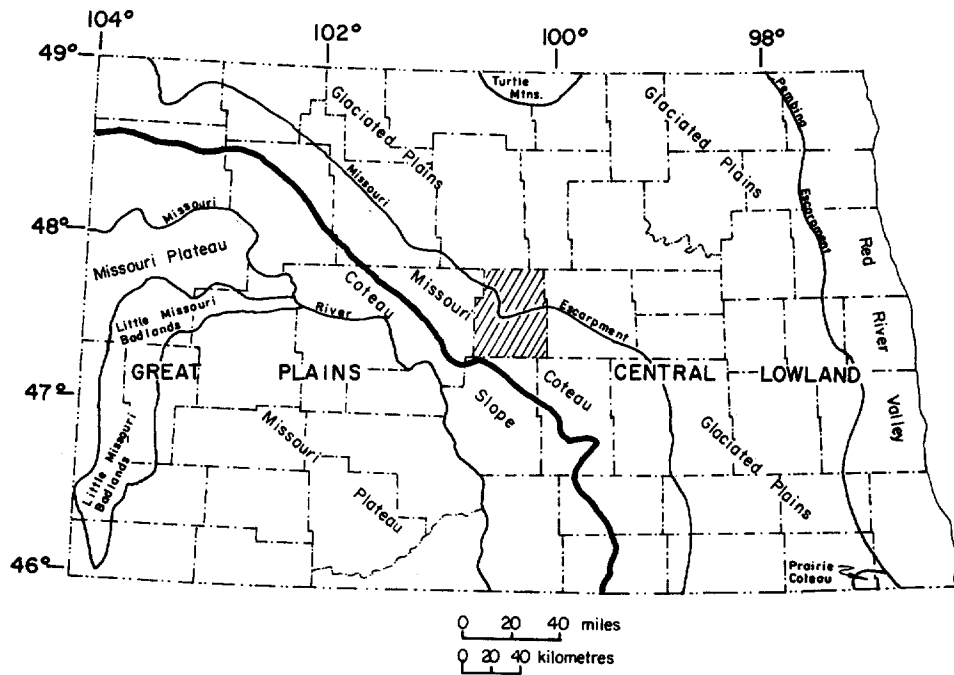


Figure 2. Physiographic map of North Dakota showing the location of Sheridan County.

The Missouri Coteau, which covers the remainder of Sheridan County, is a 15- to 50-mile-wide band of grass-covered hills that resulted from large-scale glacial stagnation. This area is undrained or poorly drained and is characterized by numerous sloughs, lakes, and closely spaced hills. Many depressions on the Missouri Coteau receive runoff water from nearby higher areas. The Missouri Coteau in Sheridan County forms the Continental Divide between Hudson Bay drainage on the northeast and Gulf of Mexico drainage on the southwest.

Elevations on the Missouri Coteau average about 200 to 400 feet higher than on the Glaciated Plains of Sheridan County, ranging from about 1,800 feet over much of the area to over 2,200 feet in the Prophets Mountains northwest of McClusky.

Sheridan County is situated on the east flank of the Williston Basin, an intracratonic, structural basin containing a thick sequence of sedimentary rocks (fig. 3). All the formations below the Coleharbor have a westerly regional dip that ranges from less than 25 feet per mile in the Upper Cretaceous sediments to about 60 feet per mile in the lowermost Paleozoic rocks.

STRATIGRAPHY

General Statement

As much as 8,300 feet of Paleozoic, Mesozoic, and Cenozoic sedimentary rocks lie on the Precambrian basement in Sheridan County. The discussion that follows is mainly a description of the composition, sequence, and correlation of the geologic units that lie at and immediately beneath the surface in Sheridan County. The description proceeds from the oldest known materials, which are discussed briefly, to the younger materials. The younger, more easily accessible geologic units are described in much greater detail than are the older units. All of the landforms that occur at the surface in Sheridan County are composed of Pleistocene materials, which were deposited mainly by glacial action. Considerable attention will be given to the configuration and origin of these landforms.

Precambrian Rocks

No wells have yet been drilled in Sheridan County that penetrated Precambrian basement rocks. Based on data from McLean, Pierce, and Wells Counties, it seems likely that the Precambrian surface ranges in depth from about 6,000 feet at the eastern edge of the county to about 8,500 feet in the west. In Burleigh County, to the south, Precambrian rocks have been penetrated in several holes. There, they consist of altered


AGE	SEQUENCE	UNIT NAME	DESCRIPTION	THICKNESS (feet)	
Holocene	Tejas	Oahe Formation	Sand, silt, and clay	0-30	
Quaternary		Coleharbor Group	Till, sand, gravel, silt, and clay	0-750	
Tertiary	Zuni	Bullion Creek Formation	Sandstone, shale, and lignite	0-100	
		Cannonball Formation	Marine sandstone and shale	0-225	
Cretaceous		Hell Creek Formation	Sandstone, shale, and lignite	0-250	
		Fox Hills Formation	Marine sandstone	0-275	
		Pierre Formation	Shale	800-1000	
		Niobrara Formation	Calcareous shale	175-250	
		Carlile Formation	Shale	360-410	
		Greenhorn Formation	Calcareous shale	100-140	
		Belle Fourche Formation	Shale	175-250	
		Mowry Formation	Shale	25-100	
		Newcastle Formation	Sandy silt	0-35	
		Skull Creek Formation	Shale	120-200	
		Inyan Kara Formation	Sandstone and shale	200-300	
		Jurassic	Swift Formation	Shale	75-250
			Rierdon Formation	Shale	150-225
Piper Formation	Limestone		190-220		
Triassic	Absaroka	Spearfish Formation	Siltstone and sandstone	0-250	
Permian			(absent in Sheridan County)	----	
Pennsylvanian		Tyler Formation	Shale and limestone	0-125	
Mississippian	Kaskaskia	Big Snowy Group	Shale, sandstone, and limestone	0-360	
		Madison Group	Limestone, evaporites, and shale	900-1320	
		Bakken Formation	Siltstone and shale	0-20	
Devonian		Three Forks Formation	Shale, siltstone, and dolomite	0-60	
		Birdbear Formation	Limestone	60-70	
		Duperow Formation	Dolomite and limestone	200-300	
		Souris River Formation	Dolomite and limestone	100-200	
		Dawson Bay Formation	Dolomite and limestone	60-100	
		Prairie Formation	Halite	20-60	
		Winnipegosis Formation	Limestone and dolomite	20-150	
Silurian	Tippecanoe	Interlake Formation	Dolomite	210-300	
		Stonewall Formation	Dolomite and limestone	75-85	
Ordovician		Stony Mountain Formation	Dolomite, limestone, and shale	140-150	
		Red River Formation	Limestone	610-660	
		Winnipeg Group	Siltstone, sandstone, and shale	190-210	
Cambrian	Sauk	Deadwood Formation	Limestone, dolomite, shale, and sand	210-260	
Precambrian basement rocks			Unknown	----	

Figure 3. Stratigraphic column for Sheridan County. Wavy horizontal lines represent unconformities.

granitic and gneissic rocks. The same is true in Wells and McHenry Counties, where granitic and gneissic rocks rich in biotite and muscovite occur.

Paleozoic Rocks

Paleozoic rocks range in thickness from about 2,800 feet in southeastern Sheridan County to about 4,000 feet in the southwest. For purposes of discussion, the Paleozoic rocks can be subdivided into four sequences (fig. 3). A sequence is defined as the preserved sedimentary rock record bounded by regional unconformities (Sloss, 1963). In ascending order, the sequences are the Sauk, Tippecanoe, Kaskaskia, and Absaroka.

Sauk Sequence

The Sauk Sequence is represented by the Deadwood Formation. The part of the formation preserved in Sheridan County is of Upper Cambrian age. The Deadwood is an onlap depositional sequence consisting primarily of a basal sandstone overlain by shale and carbonate and then by another sandstone. The upper part of the Deadwood Formation was probably removed by erosion in central North Dakota. Four exploratory wells have penetrated Deadwood sediments in Sheridan County. The Deadwood Formation ranges in thickness from about 210 feet in the northeast to 260 feet in the southwest part of the county. Over the southeast quarter of the county, an area of thinning in the Deadwood results in a thickness of about 210 feet for the formation.

Tippecanoe Sequence

The Williston Basin began to be a slightly negative area during deposition of the Tippecanoe Sequence. This sequence is the result of a transgressive event during which the seas invaded from the south and east, and the Williston Basin became part of a much more extensive epicontinental sea. The Tippecanoe Sequence is represented in Sheridan County by rocks of Middle Ordovician to Silurian age. The initial deposits of the sequence were the clastics of the Winnipeg Group. These were followed by carbonates with minor amounts of evaporites of the Red River, Stony Mountain, Stonewall, and Interlake Formations.

In Sheridan County, the thickness of the Tippecanoe ranges from about 1,150 feet in the southeast to about 1,350 feet in the west. Only four exploratory oil wells have been drilled as deep as the Interlake Formation in Sheridan County.

Kaskaskia Sequence

During deposition of the Kaskaskia Sequence, the Williston Basin was slightly more tectonically negative than during the previous two sequences. The initial deposits of the Kaskaskia

Sequence represent a transgressive sea that spread over the area from the north and west during Devonian time.

Devonian formations that have been recognized in Sheridan County include, in ascending order, the Winnipegosis (mainly carbonates), Prairie (mainly salt with some limestone and anhydrite), Dawson Bay (limestone and dolomitic limestone), Souris River (alternating limestone and thin argillaceous beds), Duperow (cyclical carbonates and shales), Birdbear (limestone), and Three Forks (shale, anhydrite, siltstone, and dolomite). The overlying Mississippian rocks were deposited mainly during normal marine conditions. They include rocks of the Bakken Formation (fine-grained clastics), the Madison Group (carbonates), and Big Snowy Group (shale, carbonates, and sandstones).

The Kaskaskia Sequence in Sheridan County ranges in thickness from about 1,350 feet in the southeast to about 2,400 feet in the southwest. In addition to the four wells that have penetrated formations below the Kaskaskia, 5 additional wells have penetrated the Kaskaskia to varying depths. A total of 9 oil exploratory holes have been drilled in Sheridan County.

Absaroka Sequence

Sheridan County was flooded by a sea in Early Pennsylvanian time and the Tyler Formation beds of shale and limestone were deposited. If additional Pennsylvanian sedimentary rocks were deposited, they were later eroded away during a period of erosion that probably extended throughout Late Pennsylvanian and most of Permian time. Deposition of redbed clastics of the Spearfish Formation began in Early Triassic time; no beds of Permian age have been identified in Sheridan County. The Absaroka Sequence ranges up to about 400 feet thick in western Sheridan County.

Mesozoic and Tertiary Rocks

Mesozoic rocks range in thickness from about 2,100 feet in eastern Sheridan County to about 4,000 feet along the western edge of the county. All of these rocks are part of the Zuni Sequence, with the exception of the previously discussed Spearfish Formation, which is part of the Absaroka Sequence. Tertiary rocks are not present in much of eastern Sheridan County, but they are up to about 400 feet thick in the west.

Zuni Sequence

Mesozoic rocks of the Zuni Sequence in the Williston Basin consist mainly of clastic rocks that were deposited in widespread Jurassic and Cretaceous seas. Jurassic strata range from about 450 to 650 feet thick in Sheridan County, southeast to northwest, and consist of evaporites, shale, and limestone of

the Piper Formation, and fine-grained clastics of the Rierdon and Swift Formations. Cretaceous rocks include well-developed sandstone in the Inyan Kara Formation and a thin, poorly developed sandy facies in the Newcastle Formation. The rest of the Cretaceous rocks, below the Fox Hills Formation, are gray shales with some calcareous shales and thin bentonites. They include the Skull Creek, Mowry, Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre Formations. The Pierre Formation subcrops beneath the glacial deposits in a small area in central Sheridan County (pl. 2).

The Fox Hills Formation conformably and gradationally overlies the Pierre Formation. It is a marine sandstone and shale sequence that ranges up to about 275 feet thick in Sheridan County with the greatest thickness occurring in the eastern part of the county. The Fox Hills Formation subcrops beneath the glacial deposits over much of central Sheridan County (pl. 2). The Hell Creek Formation, the youngest Cretaceous formation, conformably overlies the Fox Hills Formation in Sheridan County. It is of continental origin and consists of interbedded gray, greenish-gray, and brown sandstone, mudstone, siltstone, carbonaceous shale, and thin lignite seams. The Hell Creek Formation directly underlies the glacial deposits over much of Sheridan County (pl. 2). It ranges up to about 250 feet thick in places.

The remaining Zuni Sequence sediments in Sheridan County are included in the Tertiary Cannonball and Bullion Creek Formations. The Cannonball Formation consists of marine sediments. It is largely olive black, carbonaceous and lignitic siltstone and shale, and micaceous, friable sandstone. The Cannonball Formation is probably as much as 225 feet thick in parts of western Sheridan County where it may be conformably overlain by the Bullion Creek Formation. In most areas where it is present, the upper part of the Cannonball Formation has been removed by erosion and it is overlain by glacial deposits. Elevations on the bedrock surface in parts of westernmost Sheridan County are high enough that the Bullion Creek Formation may be present beneath the glacial deposits, probably at elevations above about 1,800 feet. However, positive identification of the several Tertiary formations, as well as the Fox Hills and Hell Creek Formations, can be difficult unless a sufficiently thick section is sampled. Those test holes that may have penetrated Bullion Creek Formation sediments bottomed only a few feet beneath the base of the glacial deposits. None of the test holes drilled in Sheridan County during the course of this study penetrated materials that were definitely identified as Bullion Creek Formation sediments. To the west of Sheridan County, in McLean County, the Bullion Creek Formation consists of interbedded sandstone, shale, claystone, siltstone, and lignite. Where they are exposed, these beds are generally buff

to orange buff. In the subsurface, they are commonly yellowish brown, olive gray, and brownish black.

Several outcrops of what appear to be Cannonball Formation shale occur in T148N, R74W along road cuts at the edge of the Sheyenne River Valley. In every case, the lithologies are similar. They include poorly indurated, silty to sandy, black mudstone that is plastic when wet and fractures into small blocks. Unconsolidated buff to gray calcareous sandstone beds with discontinuous lignitic stringers also occur. Sharks' teeth are found in the material.

The largest outcrop of what is probably Cannonball Formation material is about 150 feet long and 40 feet thick in the E $\frac{1}{2}$ sec 35, T148N, R78W. However, the bedrock here is probably an ice-thrust block that is not in place. It occurs in an area in which the glacial sediment is generally between 200 and 300 feet thick. Surface elevations are about 2,100 feet at the outcrop, and in-place bedrock at such an elevation would be considerably above the top of the Cannonball Formation, well up in the Bullion Creek Formation. At the base of this outcrop is an 18-inch thick clay unit that contains thin sandy layers $\frac{1}{2}$ to 1 inch thick. These sandy layers weather to a rusty brown color. The clay unit clearly shows the folding developed in the bedrock due to glacial deformation. About 5 feet above the clay layer, large gray sandy concretions that range from 2 to 4 feet in diameter are found.

Pleistocene Sediment

All the sediment related to glacial deposition in Sheridan County, that is, all the materials that were deposited by the glacial ice as well as by flowing and ponded water associated with the ice, are collectively referred to as the Coleharbor Group. The Coleharbor Group has been subdivided into a large number of informal units and formally named formations by various geologists. Some of these units are apparently regionally correlatable, but others seem to have local extent at best. I have generally avoided using the many formally named Coleharbor Group Formations, referring instead to informal units.

Sediment of the Coleharbor Group is exposed throughout Sheridan County. The Coleharbor Group sediment in Sheridan County apparently ranges up to over 700 feet thick a few miles east of McClusky. Figure 4 is a thickness map of the Coleharbor Group in Sheridan County. The Coleharbor Group sediment consists of three main facies in Sheridan County: till; sand and gravel; and silt and clay.

Till Facies

The till of the Coleharbor Group found at and near the surface in Sheridan County (map units Qcch, Qccr, Qccu,

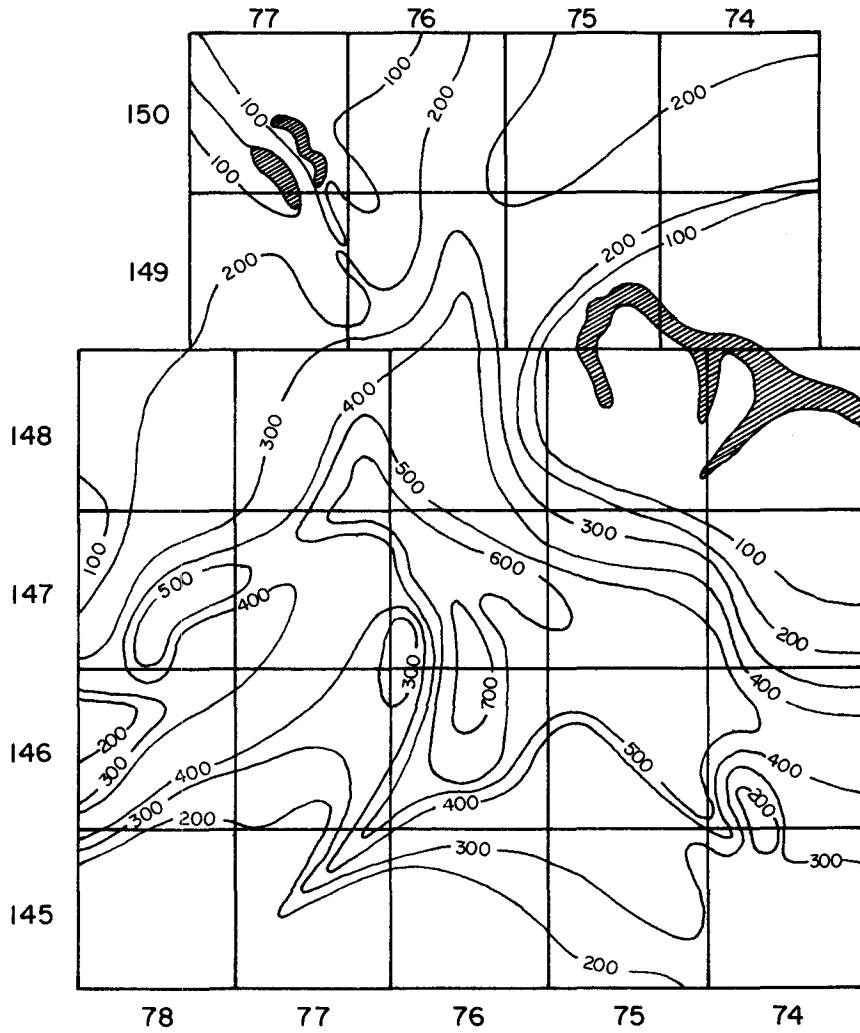


Figure 4. Map of Sheridan County showing the thickness of glacial and related deposits on top of the preglacial bedrock surface. Shaded areas are covered by a discontinuous veneer of glacial sediment and have numerous exposures of bedrock. The 700+ thickness of glacial sediment in Tps146-147N, R76W is the thickest glacial sediment yet found in North Dakota.

Qccg, Qct, Qces, Qcdg, and Qcer) is typically a mixture of varying proportions of sand, silt, clay, pebbles, cobbles, and boulder-sized particles. The matrix, composed mostly of silt- and clay-sized particles is, in oxidized exposures, generally pale to medium yellowish brown when dry, or olive brown when moist. Fresh, unoxidized samples of till, taken during test-hole drilling, are medium to dark olive gray, tight, cohesive, and brittle. The depth of oxidation of the surface till throughout Sheridan County ranges from about 14 to 48 feet. The till found near the surface is commonly poorly indurated, and it may be crudely jointed locally with gypsum crystals oriented parallel to the joint faces. It generally has no other recognizable structure, except for occasional dessication polygons, which can be seen in fresh road cuts.

In the northern part of Sheridan County, in the area of the Glaciated Plains, the till tends to be sandier in the west, more clayey in the east. Over the area of the Missouri Coteau, no significant textural differences were noted in the surface till county-wide.

The coarser grained materials in the till are generally angular to subrounded. Samples of near-surface till taken by Sherrod (unpublished Master's thesis) and Gustavson (unpublished Master's thesis) had average coarse-grain compositions of 38 percent carbonate particles; 28 percent granitic, metamorphic, and basic igneous particles; 17 percent lignite particles; 13 percent shale particles; and 7 percent other constituents, including sandstone, chert, and iron concretions (based on a total of 25 pebble counts of 100 or more pebbles each). Sherrod and Gustavson were unable to distinguish individual till sheets or determine different sources for the surface tills based on their pebble counts. Their sieve analyses of the tills were also inconclusive as the sand-silt-clay ratios of near-surface samples tended to be quite diffuse. Sherrod (unpublished Master's thesis) determined that the fine-grained particles of the tills in western Sheridan County consisted of 40 percent sand, 30 percent silt, and 30 percent clay; he noted no major differences in textures of the surface till throughout the county.

In general, the igneous and metamorphic rock fragments in the till were ultimately derived from the Precambrian rocks of the Canadian Shield, to the east and northeast of Sheridan County, and from the Tertiary sandstone formations of western North Dakota. Carbonate rock fragments were derived from Paleozoic rocks in Canada to the north and northeast of Sheridan County, and the shale, sandstone, and lignite were derived from local bedrock formations. Many of the grains in the till were not transported directly from their outcrop areas to their present locations during a single advance of the

glacier. An undetermined proportion of the sediment from each glacial advance was derived from older glacial sediment.

Sand and Gravel Facies

The sand and gravel facies of the Coleharbor Group covers the surface area of about 15 percent of Sheridan County (areas of Qcrf, Qcrh, and Qcot). It amounts to about the same fraction of the total thickness of the Coleharbor Group sediments in the county. (Approximately 29,000 feet of glacial deposits were penetrated during test drilling; of this, 5,000 feet were in gravel and sand.) The sand and gravel facies consists largely of river channel sediment, with little or no overbank sediment. The deposits occur both as thin layers and lenses within the till and as thick, continuous sequences independent of the till. Gravel and sand deposits are as much as 50 feet thick at the surface. Buried layers, penetrated during test drilling, are as much as 100 feet thick.

The sand and gravel facies is composed of subangular to subrounded, moderately well-sorted sand and pebble-sized detritus with small-scale and large-scale cross bedding and poorly sorted gravel with plane bedding. Locally, however, silt, cobble, and boulder beds are found. Minor folding and slumping occurs in sand and gravel pits in areas where the material was deposited in contact with stagnant glacial ice. In most good exposures of sand and gravel, beds with a small percentage of organic detritus occur in thicknesses ranging from less than an inch to several inches. This material is largely finely divided lignite, although some of it may be finely divided organic debris interbedded with fine sand. Ice-contact deposits, such as eskers and kames, are composed largely of fine to medium, well-sorted sand and gravel.

The sand and gravel facies of the Coleharbor Group has a mineralogic composition similar to that of the till. The mineralogy indicates that it is a combination of locally derived materials and materials that were ultimately derived from the north in Canada. The sand-sized fraction is largely quartz and feldspar with minor amounts of shale and carbonates. The gravel-sized fraction is commonly about half carbonates and the remainder granitics, shale, and western-derived siliceous rocks. Some of the gravel has a high percentage of shale. Near the surface, caliche (CaCO_3) coats the undersides of pebbles and cobbles. Generally, the sand is loose, but in some local occurrences, it is cemented with iron-oxide and forms a conglomerate. In areas where the sand and gravel is loose and uncemented, it is also highly permeable. The sand and gravel facies is generally the largest and most dependable source of high-quality groundwater in Sheridan County.

The sand and gravel facies includes the deposits of both meltwater rivers and nonmeltwater rivers. Except for a small

area of sand and gravel in northeastern Sheridan County (Qcrf in T149-150N, R74W), where the fluvial material is almost surely glacial outwash, it is difficult or impossible to distinguish meltwater from nonmeltwater fluvial deposits. Much of the material that has been referred to as "outwash" on previous maps was deposited by rivers consisting largely of runoff from precipitation rather than from meltwater. For example, the youngest "collapsed outwash" (Qcrh on pl. 1) of the Missouri Coteau was deposited thousands of years after the glacier stagnated, when less than a tenth of the runoff was derived from melting ice (Clayton, 1967, p. 36, fig. A-7). Even the "outwash" deposited by some meltwater rivers is not really outwash. For example, the sand and gravel deposited by the Sheyenne meltwater river in Sheridan County, after it left glacial Lake Souris, was washed out of pre-existing glacial sediment in the river cutbanks, not out of the glacier.

Silt and Clay Facies

The silt and clay facies of the Coleharbor Group consists of materials that were deposited in lakes. Such deposits are designated on the geologic map (pl. 1) as Qcoe (elevated, ice-contact lake deposits) and Qcoc (collapsed lake deposits). Most surface deposits of the silt and clay facies are boulder-free areas that are generally less than a square mile in area. The largest single surface occurrence of the silt and clay facies is a seven-square-mile area of lake silt and clay in the Goodrich area (pl. 1). Gustavson (unpublished Master's thesis) referred to this area as the Lake Goodrich plain. The surface silt and clay deposits range up to 40 feet thick, but most of them are probably less than 10 feet thick.

The ice-contact lake deposits (Qcoe on pl. 1) consist of flat-bedded sediment of flat lake plains elevated above the surrounding glacial topography. They were deposited in lakes bottomed on solid ground, but surrounded by stagnant glacial ice. Collapsed lake deposits (Qcoc on pl. 1) consist of folded and contorted sediment with hummocky topography. They were deposited in lakes bottomed on stagnant ice.

Generally, where it is exposed, the silt and clay facies consists of about two-thirds silt and one-third clay and fine sand. The sediment is typically horizontally laminated except in areas of hilly or undulating topography where the laminations are commonly tilted or contorted, but not usually faulted.

Buried layers of silt and clay interpreted to be lake sediment were penetrated in about two dozen test holes in Sheridan County. In a few instances, it was possible to correlate these silt and clay layers for distances of up to 4 or 5 miles, but usually the silt and clay layer occurred in only a single hole. Buried lake deposits that could be correlated between two or more test holes and shown to have some lateral extent occur in

buried valleys south of McClusky and near Pickardville (T146N, R77-78W), and near Martin (T150N, R74W). They probably formed when glaciers dammed the northeast-trending drainages, forming proglacial lakes. Thicknesses of buried layers of silt and clay ranged between 110 and 140 feet in several test holes.

Fossils

Pleistocene and Holocene fossils were collected and identified by Sherrod (1963; unpublished Master's thesis) and Gustavson (unpublished Master's thesis) at 10 places in Sheridan County. Most of the fossil-bearing sediments are Late Wisconsinan and Holocene lake deposits. The locations of the fossil sites and identifications of the species found at each location are listed below.

1) sec 1, T150N, R74W. Numerous fossil gastropod shells, ostracode carapaces, and Stonewort (*Chara*) zygospore cases were found here. The listing of species is as follows: Helisoma sp., Promenetus exacuus, Pisidium sp., Lymnaea humilis, Valvata tricarinata, Spaerium sp., Gyraulus sp., Gyraulus parvus, Vallonia gracilicosta, Armiger crista, Ostracoda, and *Chara*. The fossil-bearing sediment is a marl bed, which was exposed in a portion of a slough that had been excavated to provide water for cattle.

2) sec 12, T150N, R77W. Specimens of the gastropod Succinea grosvenori in calcareous organic sediment on the shore of Krueger Lake.

3) sec 8, T150N, R77W. Specimens of the gastropod Succinea grosvenori in calcareous organic slough sediments on the east edge of a slough.

4) NE $\frac{1}{4}$ sec 13, T148N, R76W. Two gastropod species were found: Gyraulus sp. and Valvata tricarinata. The fossil-bearing sediment is mainly silty lake sediments, but no lake outline is discernable.

5) SW $\frac{1}{4}$ sec 19, T148N, R77W. A fragment of a gastropod was found here. The collection site is in hilly lake sediment that was deposited on stagnant glacial ice.

6) SW $\frac{1}{4}$ sec 28, T147N, R78W. Four species of gastropods were found: Gyraulus parvus, Armiger crista, Lymnaea humilis, and Lymnaea sp. One pelecypod shell, genus Pisidium, was found. Three species of fossil fish were found at this site: Catostomus commersoni (white sucker), Semotilus atromaculatus (creek chub), and Chrosomus neogaeus (finescale dace). The collection site is located in the Prophets Mountains. The fossil-bearing sediments consist of rhythmically bedded, silty lake sediments found in a dump pile beside a stock pond.

7) sec 18, T147N, R74W. Freshwater gastropod shells, ostracode carapaces, and stonewort zygospore were found here. The listing of species is as follows: Promenetus

exacuus, Helisoma sp., Pisidium sp., Physa sp., Lymnaea humilis, Valvata tricarinata, Ostracoda, and Chara. The fossils were collected from lake sediments that occur immediately below recent organic slough sediment.

8) SE $\frac{1}{4}$ sec 28, T147N, R77W. The species of gastropod, Valvata tricarinata, was found at this site, which is located at the edge of an area of collapsed gravel deposits (ice-contact fluvial sediment).

9) NE $\frac{1}{4}$ sec 31, T147N, R77W. Two species of gastropods, Valvata tricarinata and Gyraulus sp., and one species of the pelecypod Pisidium were found here. The fossil-bearing sediment is clay, presumably of lacustrine origin, but no lake plain is noticeable.

10) SE $\frac{1}{4}$ sec 34, T147N, R77W. Five gastropod species found here were Valvata tricarinata, V. lewisi, Gyraulus parvus, Gyraulus sp., and Promenetus exacuus. One pelecypod shell of the genus Pisidium was collected. The fossils here were found in lake sediments at the edge of a collapsed gravel deposit.

11) NW $\frac{1}{4}$ sec 15, T146N, R77W. Four species of gastropods, Amnicola limosa, Valvata tricarinata, Gyraulus parvus, and Gyraulus sp., along with one pelecypod shell of the genus Pisidium, were collected. The fossils were found in clayey silt, presumably of lacustrine origin, although no lake plain is noticeable.

12) sec 9, T146N, R75W. One unidentified pelecypod fragment was found at this site, which is an elevated lake plain covered by a silt deposit.

All of the fossils just described are known to have lived in streams and lakes that were, in part at least, supported by stagnant glacial ice between about 11,500 and 9,500 years ago (Clayton and Cherry, 1967; Clayton, Moran, and Bluemle, 1980). Generally, superglacial and ice-walled lakes were characteristic of Late Wisconsinan stagnant glaciers in North Dakota. Similar lakes occur today on modern stagnant glaciers.

Sherrod (1963) contends that the evidence for a Late Wisconsinan age for the Prophets Mountains site (site number 6, above) is strong, although not conclusive. He points out that the only way in which postglacial age fish could have reached the top of the Prophets Mountains would be in the beaks of pelicans or other birds that prey on fish. The large number of fish specimens found at site 6 argues against, but does not disprove, this possibility. The fish presumably reached the area of the Prophets Mountains during a time when stagnant glacial ice, covered by glacial sediment, existed on the Missouri Coteau. The fish could then have swum up meltwater streams from ice-free areas and established successful populations in the ice-contact lakes that existed in the area of the Prophets Mountains at that time.

Holocene Sediment

All the postglacial sediment in Sheridan County is included in the Oahe Formation (Clayton and Moran, 1979; Clayton, Moran, and Bluemle, 1980), which consists of a clay facies and a silt and sand facies. The clay facies is composed mainly of pond and slough sediment, and the silt and sand facies is mainly river sediment and wind-deposited sediment.

Clay Facies

The Oahe Formation clay facies is present on the floors of sloughs throughout the county; such sloughs are especially numerous on the Missouri Coteau where as many as 75 of them may occur in a square mile. North of the Missouri Escarpment, on the Glaciated Plains, sloughs are less numerous, but they tend to be larger than do those on the Missouri Coteau. Although several thousand small areas of Oahe Formation clay facies (ponds and sloughs) occur in Sheridan County, only a few of the larger ones are shown on the geologic map (Qos on pl. 1); many of the ones that are shown were taken off aerial photographs.

The clay facies consists of as much as 20 or 30 feet of tough, black clay, silty clay, and clayey silt that fills the bottoms of sloughs. It contains several percent of organic material, which gives it its black color.

Water frequently stands in the ponds and sloughs, but the depressions that are floored by glacial till beneath the Holocene sediment commonly are dry much of the time. In contrast, the sediment in the bottoms of intermittent or perennial ponds, lakes, or marshes is always moist; this condition is more common where the material beneath the Holocene sediment is gravel or sand. As a result of the fact that such ponds and sloughs are always moist, the sediment there has a much lower compressive strength and a greater content of organic material.

The clay facies of the Oahe Formation can usually be distinguished from clay in the Coleharbor Formation. It contains several percent organic material and is generally free of calcium carbonate, whereas Coleharbor Formation clay has little or no organic material and generally at least several percent calcium carbonate.

Silt and Sand Facies

The silt and sand facies of the Oahe Formation is found largely as stream sediment on valley floors and as scattered areas of wind-blown sediment. Stream sediment in the Oahe Formation (Qor) consists of poorly sorted, obscurely bedded silt with some thin layers of sand, weak paleosols, scattered mammal bones and teeth, terrestrial snail shells, and fragments of wood. In the Sheyenne River Valley, the underlying, poorly

exposed Coleharbor Formation stream sediment in most places consists of cross-bedded sand. Other stream valleys were not examined in much detail, but it is presumed a similar situation exists in them. The thickness of the Oahe Formation stream sediment is generally less than 20 feet.

Wind-blown silt was not mapped in Sheridan County, although a veneer of wind-blown silt does occur in many places, especially on and near areas of Coleharbor Formation gravel and sand. Where it does occur, it is generally a gray to black silt. A small area of low dunes (Qod) occurs in secs 8, 9, 16, and 17, T150N, R75W. The wind-blown sand in this area is less than 10 feet thick.

GEOMORPHOLOGY

General Description

The modern landscape in Sheridan County is the surface that was formed during the time that Wisconsinan glaciers covered the area. The county can be subdivided into two well-defined areas, the Missouri Coteau, which covers about 750 square miles in the southern three-quarters of the county, and the Glaciated Plains, which covers the remaining quarter of the county in the north. These areas are separated by the Missouri Escarpment.

Most of the landforms on the Missouri Coteau in Sheridan County formed due to the collapse of glacial sediment that covered a nearly continuous sheet of stagnant glacial ice, which melted between about 12,500 and 9,000 years ago. Typical landforms of the Missouri Coteau include collapsed moraine, collapsed flood plains and lake plains, elevated lake plains, and various types of disintegration ridges. Glacial sediment on the Missouri Coteau in Sheridan County averages from 200 to 500 feet thick, reaching over 700 feet just east of McClusky (fig. 4). This is the greatest reported thickness of glacial sediment in North Dakota.

Surface elevations rise as much as 200 to 300 feet along the Missouri Escarpment in Sheridan County. Although elevations on the buried bedrock surface beneath the escarpment do rise southwestward, no pronounced "escarpment" was present on the bedrock surface in this area prior to glaciation. The Missouri Escarpment in Sheridan County is formed largely of glacial sediment, in contrast to parts of northwestern North Dakota where it is built of preglacial bedrock.

It appears that the modern Missouri Escarpment formed as the glacier flowed southward, up the gradual rise in elevation on the bedrock surface. The upslope movement of the glacier caused compressive flow within the ice and resulted in large-

scale thrusting near the glacier terminus. Thrusting was intense in the Sheridan County area, and areas of ice-thrust topography are unusually prominent in the area. Quarrying that occurred near the center of the county north of McClusky resulted in especially thick glacial deposits and numerous areas of ice-thrust topography. Repeated stagnation of the glacier terminus over the higher elevations of the area now known as the Missouri Coteau resulted in a progressively steeper slope for succeeding glaciers to flow over. Possibly, glacier flow directions northeast of the Missouri Escarpment shifted to more southeasterly directions as portions of the glacier on the Coteau stagnated.

The face of the modern Missouri Escarpment is deeply channeled in places by numerous deep gullies (fig. 5). Materials that washed from the slopes during both Pleistocene and Holocene time are found at the base of the escarpment as fans and, in some places, as accumulations of colluvial debris, although most of these deposits are small and not mapped. Most of the gullies that head into the Missouri Escarpment do not extend any appreciable distance into the Missouri Coteau.

The Glaciated Plains include the northern quarter of Sheridan County northeast of the Missouri Escarpment. Landforms in that area were formed by the active, moving glacier. They range from pre-last glacial till-draped topography through ice-thrust features and various degrees of collapsed moraine, although large-scale glacial stagnation was not a significant land-forming process on the Glaciated Plains as it was on the Missouri Coteau.

The glacial landforms of the Glaciated Plains have been modified by running water, which has washed the surfaces in some places and deposited gravel and sand in other places. The uppermost reach of the Sheyenne River Valley, a major meltwater trench farther east in North Dakota, is cut into the Glaciated Plains of Sheridan County. It borders immediately on the base of the Missouri Escarpment in several places. The Sheyenne River meltwater trench is not large in this area, generally less than a half mile wide and only 40 to 60 feet deep.

Glacial Landforms

Collapsed Glacial Topography

Hilly and hummocky glacial topography results from the lateral movement of supraglacial sediment as it subsides (collapses; is let down) when the underlying ice melts out from under it (Clayton, 1967; Clayton and Moran, 1974; Clayton, Moran, and Bluemle, 1980). Although this is the generally accepted explanation for the origin of hummocky glacial topography, two alternatives have been suggested. Stalker (1960)

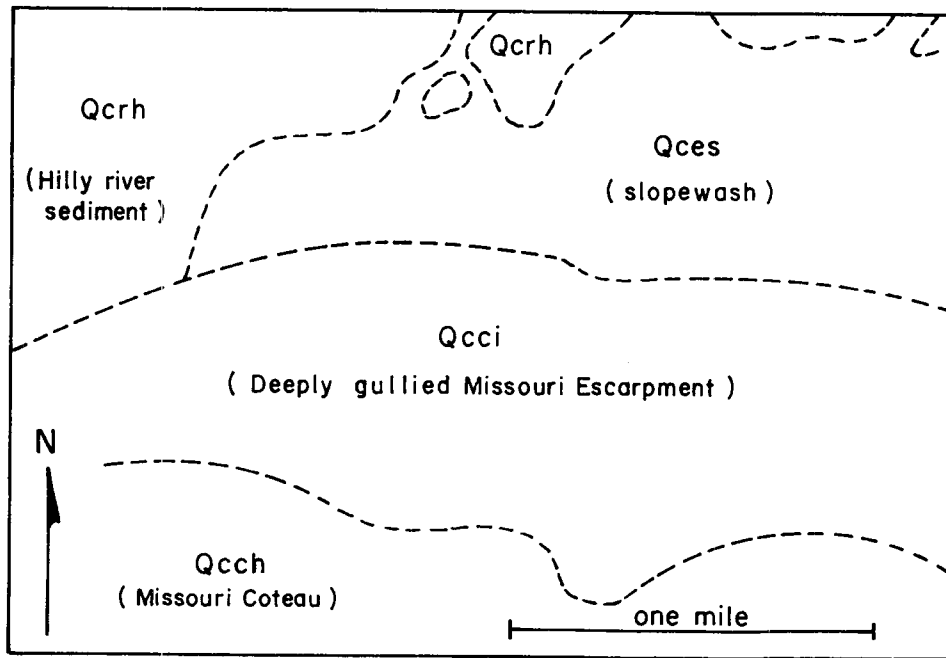
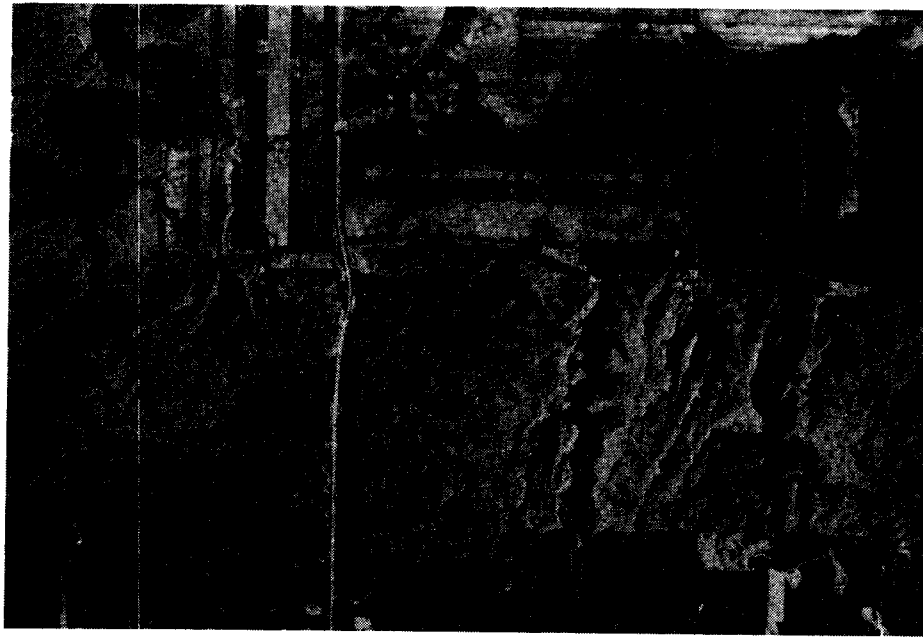


Figure 5. Airphoto of deeply gullied Missouri Escarpment in secs 15, 16, 21, and 22, T148N, R74W.

suggested that hummocks resulted from the squeezing of sub-glacial sediment into irregularities in the base of a stagnant glacier. However, hummocks composed of glacial sediment are essentially identical to hummocks composed of collapsed supra-glacial fluvial and lacustrine sediment that lacks evidence of ever having been under a glacier. Bik (1967) suggested that hummocks resulted from the movement of sediment during the growth and decay of permafrost (relict pingos). However, in North Dakota, hummocks were generally formed at a time when paleoecologic evidence indicates a climate too warm for permafrost, and hummocks are generally absent in North Dakota in areas known to have had permafrost (Clayton, Moran, and Bluemle, 1980).

On the geologic map of Sheridan County (pl. 1), the collapsed glacial topography (Qcch, Qccl, Qccr, Qccu) is subdivided on the basis of its most conspicuous variables: slope angles, overall relief, presence or absence of ring-shaped hummocks, and presence or absence of transverse ridges. The most widespread glacial landform in Sheridan County is hilly collapsed glacial topography with steep slopes, generally over 8° (Qcch on pl. 1). This landform will be referred to here as "hilly collapsed moraine." Hilly collapsed moraine has commonly been referred to as "dead-ice moraine" or "hummocky moraine" in most previous North Dakota Geological Survey publications. It should be noted that the names used in this report for many of the glacial landforms are modified somewhat from previous North Dakota Geological Survey usage. Although this may cause some initial confusion, the modified terminology is more closely in step with names used on the new Geologic Map of North Dakota (Clayton, Moran, Bluemle, and Carlson, 1980) and, hopefully, we will eventually have a terminology acceptable to a majority of people working on North Dakota glacial geology.

The hilly collapsed moraine in Sheridan County has relief of 50 to 200 feet locally. Relief is greatest in the north-central part of the county. Large kettle holes, commonly containing lakes or sloughs, are abundant in areas of hilly collapsed moraine.

The topography in areas of hilly collapsed moraine is apparently the result of large-scale glacial stagnation and most of the landforms are ultimately the direct result of mudflows. As the stagnant glacier melted, topography on the surface of the ice was continually inverted. When sinkholes in the stagnant glacier finally melted through to the solid ground beneath, circular holes formed in the glacier. Material flowing down the sides of these holes completely filled many of the holes, resulting in hills of material occupying the positions of the former sinkholes when all the ice finally melted. If the amount of material flowing into a hole was not enough to completely fill it, the material formed a doughnut-shaped ridge at the base of the

sides of the hole; ridges such as these are commonly called "circular disintegration ridges" or "doughnuts" (fig. 6). If, in the final stages of topographic inversion, thick deposits of material in the bottom of sinkholes caused them to invert into ice-cored cones, the material may have flowed down the sides of the cones, producing, when all the ice had melted, doughnut-shaped ridges, also called "circular disintegration ridges." Any ridges formed by material moving down ice slopes and collecting at the base of the slopes are called "disintegration ridges." The ridges generally form random patterns and they may be any shape, from circular to straight, depending on the shape of the former ice slope and the fluid content of the sediment as it slid into place.

In Sheridan County, closed disintegration ridges average about 500 feet in diameter. Linear (straight) disintegration ridges average less than 0.3 mile long. Both the closed and linear ridges average about 15 feet high. Differences in the steepness of hillslopes in hilly collapse topography are probably mainly the result of differences in the viscosity of the supraglacial sediment. As the grain size and clay mineralogy of all of the Late Wisconsinan till in Sheridan County was probably essentially the same everywhere, the variable that produced the largest differences in flowability was water content. Water content was related to the rate of ice melting, which, in turn, was related mainly to the thickness of the insulating cover of supraglacial sediment. Thicker supraglacial sediment has less water in it, is more viscous, and produces hummocks with steeper sides. As a result, local relief in collapse topography is related to the thickness of supraglacial sediment.

Areas of collapsed glacial topography in Sheridan County that are not so hilly as the hilly collapsed moraine, but which are marked by abundant glacial stagnation features, are referred to as "rolling collapsed moraine" (Qccr on pl. 1). This landform has sometimes been referred to as "low relief dead-ice moraine" in previous North Dakota Geological Survey publications. Rolling collapsed moraine is found in the north-central part of the county. It has poorly integrated drainage and local relief of less than 50 feet in most places. In Sheridan County, the rolling collapsed moraine has a regional northeasterly slope. Slopes are generally less than 8°.

The largest single area of rolling collapsed moraine is in an area known as the "Lincoln Valley Sag," located just west of the village of Lincoln Valley. This broad, rolling area is a sort of reentrant in the Missouri Escarpment. It may coincide with a preglacial or intraglacial river valley (the Knife River Valley?) that trended northeastward from the Missouri Coteau upland onto the lower areas northeast of the escarpment.

Collapsed glacial topography with low relief (generally less than 10 feet locally) and poorly integrated drainage is found on

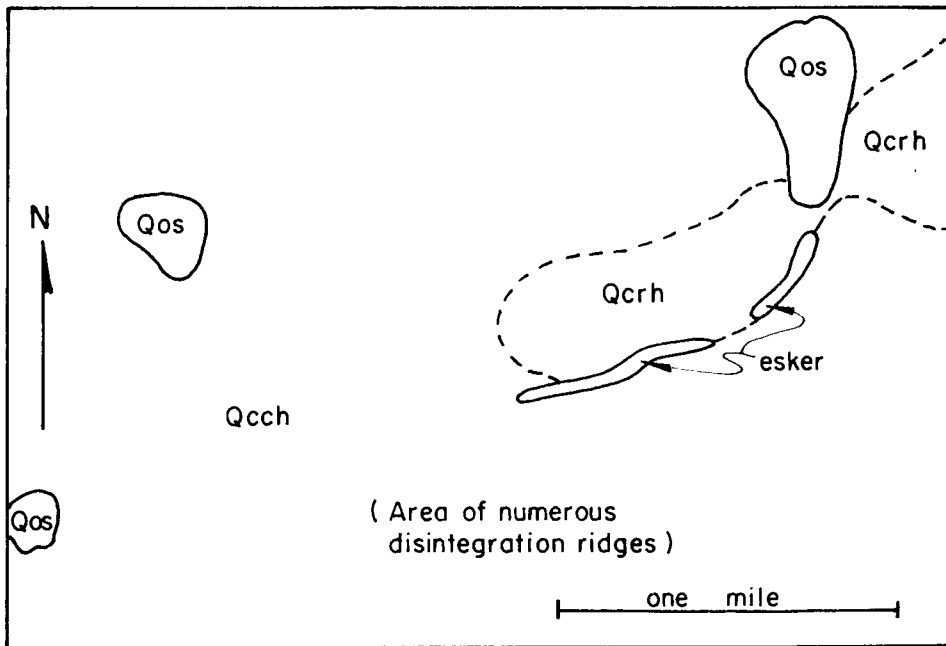


Figure 6. Airphoto of typical high relief collapsed moraine in southeastern Sheridan County (secs 29 and 30, T145N, R74W). At least one esker occurs in two segments. Similar-appearing ridges in the collapsed moraine are disintegration features. Area of high relief collapsed river sediment has a smoother appearance on the airphoto.

the Glaciated Plains of northern Sheridan County (Qccu on pl. 1). These areas are referred to as "undulating collapsed moraine." Essentially similar areas with comparable topography and relief have been termed "ground moraine" in many previous North Dakota Geological Survey publications. However, undulating collapsed moraine is more narrowly defined than is ground moraine. Undulating collapsed moraine differs from rolling collapsed moraine (discussed above) primarily in that it does not have the abundant stagnation markings typical of rolling collapsed moraine; the relative relief of the two landforms is not the diagnostic characteristic, although maximum slope angles are commonly less than 4° on the undulating collapsed moraine.

The most characteristic markings on the undulating collapsed moraine in Sheridan County are washboard ridges, which are quite prominent in places (pl. 1). Areas of washboard ridges consist of series of low transverse ridges and shallow trenches spaced about 650 feet apart and with local relief of 5 to 10 feet. They are best seen on airphotos. The ridges and trenches are gently curved, with a radius of curvature of 15 to 20 miles, concave upglacier (to the northwest). The ridges may have formed as the result of greater concentrations of glacial sediment along periodically spaced transverse shearing zones near the margin of the glacier.

The overall pattern of disintegration features--ridges, potholes, and other markings--is mainly random in collapsed glacial topography. However, certain areas, otherwise similar to hilly collapsed moraine, do have either an overall linear pattern or internal linearity, or both. These linear patterns are typically obvious on airphotos, but they are difficult for the ground-based observer to perceive. The linear elements (ridges and rows of potholes) generally parallel the overall linear configuration of the areas. Areas of linear collapsed moraine are found in several places in Sheridan County, both on the Missouri Coteau and on the Glaciated Plains (Qccl on pl. 1). Relief on the linear collapsed moraine may exceed 200 feet locally (Denhoff area). Maximum slope angles are commonly greater than 8° .

Presumably, the linear collapsed moraine was deposited by a combination of shearing at the ice margin (see the discussion of thrust moraine), glacial stagnation, and ablation while the active ice margin remained in the same location for a relatively prolonged time, melting at about the same rate as the glacier advanced. Landforms of this type have commonly been termed "end moraine." Although some of the linear features probably did form at the margin of the active glacier and in the manner just described, others are merely narrow areas of hilly or rolling collapsed topography, unrelated to significant ice-margin positions. One area of linear collapsed moraine that probably did form as a true "end moraine" is the range of hills that

extends northeast-southwest through T150N, R74W in the Martin area. This feature is often referred to as the Martin Moraine. It extends northeastward into Wells County (Bluemle and others, 1967) and northwestward along the face of the Missouri Escarpment in Sheridan County. The presence of an outwash plain southeast (ahead) of the range of hills in T150N, R74W and to the east in Wells County is typical of an end moraine.

Areas on the Missouri Coteau, such as the Denhoff Hills in Tps 145-147N, Rs 75 and 76W and the Woodhouse Lake loop of the Streeter Moraine in T145N, Rs 74 and 75W have usually been referred to as end moraines (Gustavson, 1964; Rau and others, 1962). An apron of outwash abuts on the south side of the Woodhouse Lake loop of the Streeter Moraine in southeastern Sheridan County and northern Kidder County (fig. 7). The Streeter Moraine can be followed, as a series of connected loops, for several hundred miles, to Logan and McIntosh Counties in south-central North Dakota (Clayton, 1962). Even so, the topography on either side of the Streeter Moraine is the same (hilly collapsed moraine) and the feature probably does not represent a significant ice margin and is therefore not a true end moraine (Clayton, Moran, and Bluemle, 1980). The same is true of the Denhoff Hills and several other small areas of linear collapsed moraine (shown on pl. 1). These features are probably the result of ice thrusting, but conclusive evidence of their origin was not found.

Kettle Chains

Numerous chains of kettles in low areas were noted in several places in Sheridan County. Two kettle chains occur in southwestern Sheridan County near Pickardville. One of these follows a winding path for about 15 miles from sec 21, T146N, R78W into Burleigh County. The other is about 7 miles long and trends north-south through Tps 146-147N, R77W. The kettle chains are from one half mile to a mile wide and from 20 to 75 feet lower than surrounding areas of hilly collapsed moraine. They contain numerous lakes and sloughs and associated esker ridges.

The kettle chains probably mark the route of a valley that became filled with stagnant ice before being covered with glacial sediment. No evidence for such a valley was found on the bedrock surface, however (pl. 2); so it is likely that the valley was an interglacial one, cut in pre-Wisconsinan glacial sediment.

Ice-Thrust Materials

Ice thrusting near the terminus of the active glacier in many parts of North Dakota resulted in compressional folds and thrusts of the subglacial sediment. Vertical displacement was typically tens of feet and the individual folds or thrust masses are commonly about 600 feet across. The folds are commonly

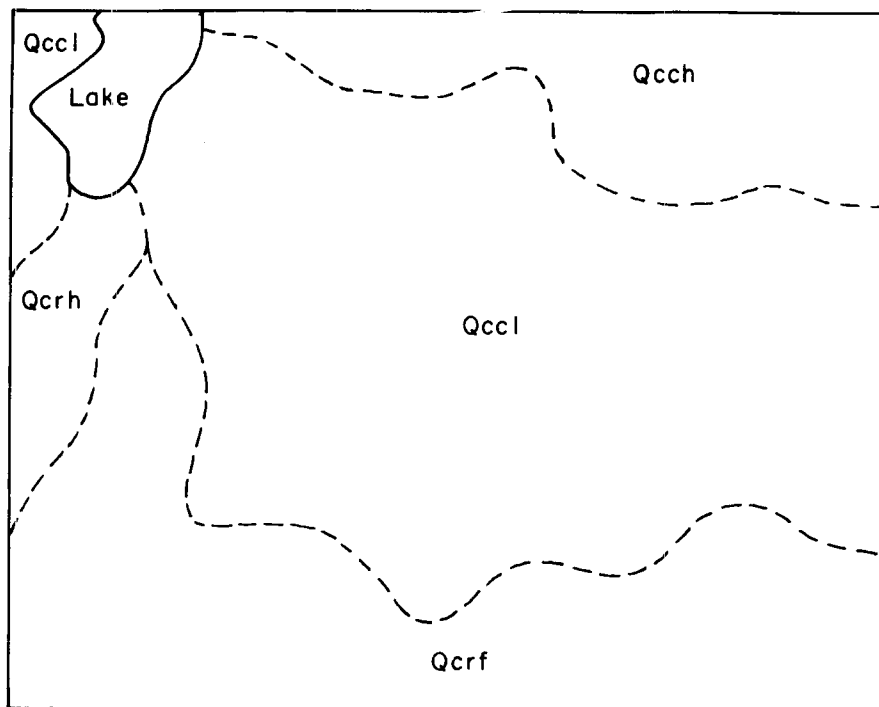
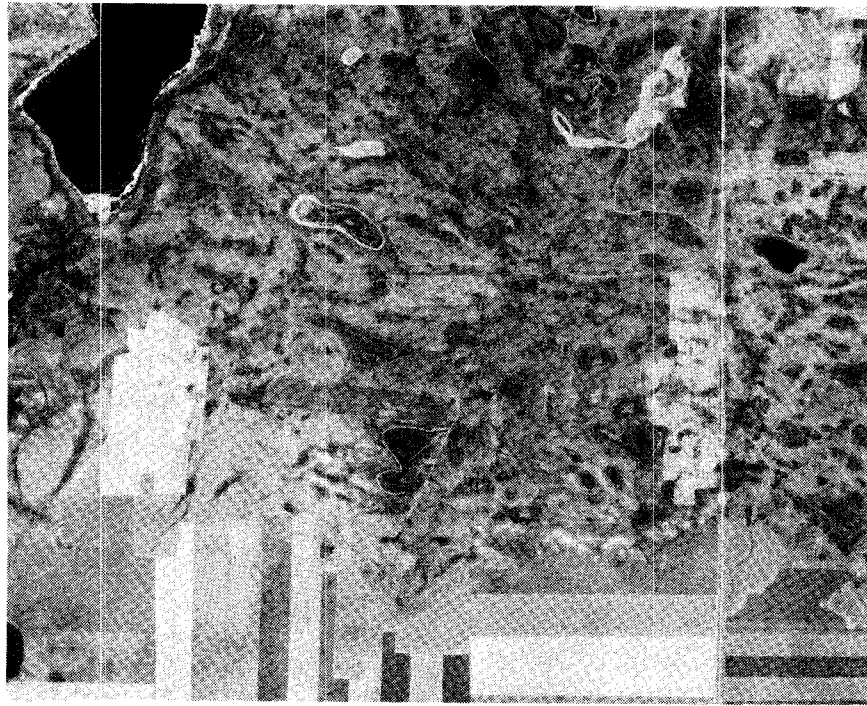


Figure 7. Area of linear collapsed moraine (Streeter moraine) in southeastern Sheridan County (secs 26, 27, 28, 33, 34, and 35, T145N, R75W). The Streeter moraine probably formed at the ice margin and, in that respect, it is an end moraine. A flat, fluvial gravel plain (glacial outwash) lies in front (south) of the area of linear collapsed moraine.

overturned. Their axial plane and the thrust faults dip up-glacier at 30° to 60°. The strike is parallel to the ice margin. In map view, the thrust masses are concave upglacier, commonly with a radius of curvature of about three miles.

Ice thrusting was probably more intense in the Sheridan County area than anywhere else in North Dakota, and, in fact, the first evidence that ice thrusting was a major land-forming process in North Dakota came from Sheridan County (Bluemle, 1970). Three general forms of ice-thrust masses have been recognized: transverse ridges above overturned folds or at the ends of intricate thrust slabs; roughly equidimensional hills containing thrust masses downglacier from a source depression of similar size and shape; and irregular forms (Clayton, Moran, and Bluemle, 1980). All three forms are found in Sheridan County.

Apart from the variety of landforms found in Sheridan County that owe their origin to ice thrusting processes, it is probable that the preglacial surface (pl. 2) has been substantially modified by ice thrusting. At least three test holes (North Dakota State Water Commission test holes #5265, #5266, and #5334) in the area north and northeast of McClusky penetrated to depths as much as 175 feet below the presumed surrounding preglacial valley floor. These three test holes help identify a closed depression on the bedrock surface of about 30 square miles in Tps147-148N, Rs76-77W (pl. 2), where the glacial sediment is as much as 729 feet thick (sec 33, T147N, R76W; NDSWC test hole #5265). The most likely explanation for this area of exceptionally thick glacial sediment is that repeated large-scale ice thrusting occurred in the area, resulting in quarrying of the preglacial bedrock and the building of ice-thrust masses to the west in T147N, R78W in the area of the Prophets Mountains and in the area to the southeast of the depression (see areas of ice-thrust materials identified on pl. 1). Such large-scale ice thrusting has been reported from other places. In the Sand River area of northwestern Alberta, Fenton and Andriashek (1978) describe a depression quarried by glacial thrusting that covers about 126 square miles and is over 130 feet deep.

Some of the individual ice-thrust features are noteworthy. The Prophets Mountains, an area of about 8 square miles in T147N, R78W, is an example of the first of the three types of ice-thrust masses (transverse ridges above overturned folds). The Prophets Mountains have local relief exceeding 300 feet, strong north-south linearity indicating imbricate thrusting from the east, and associated ice-contact fluvial deposits (figs. 8 and 9). A road cut on the south end of the Prophets Mountains (sec 34, T147N, R78W) exposes folded and contorted Hell Creek and Cannonball sandstone, shale, and lignite beds. About 50 feet of Hell Creek Formation section and 40 feet of Cannonball Formation

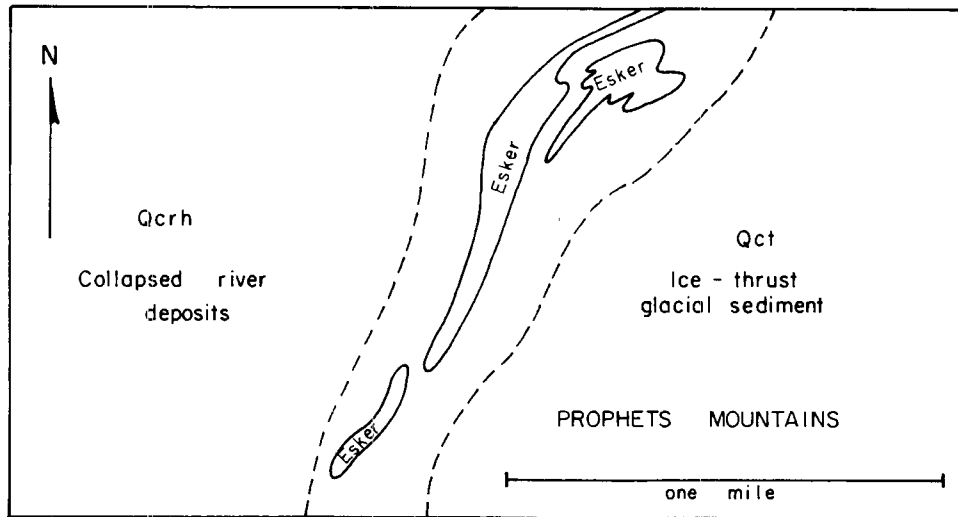
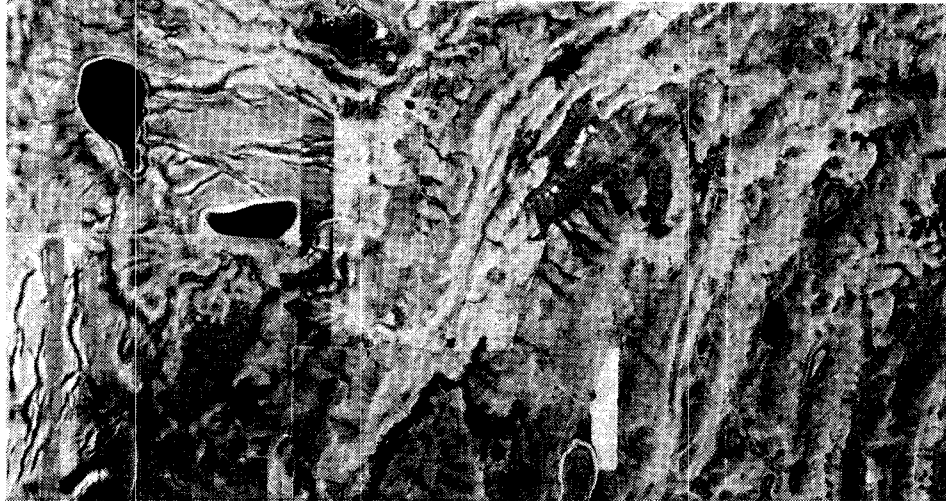


Figure 8. Airphoto of a part of the Prophets Mountains in western Sheridan County (parts of secs 28, 29, 30, 31, 32, and 33, T147N, R78W). Eastern half of area is ice-thrust ridges that average about 80 feet between troughs and crests, but local relief exceeds 300 feet in places. The area west of the Prophets Mountains (left half of photo) is mainly collapsed river deposits that are quite hilly.

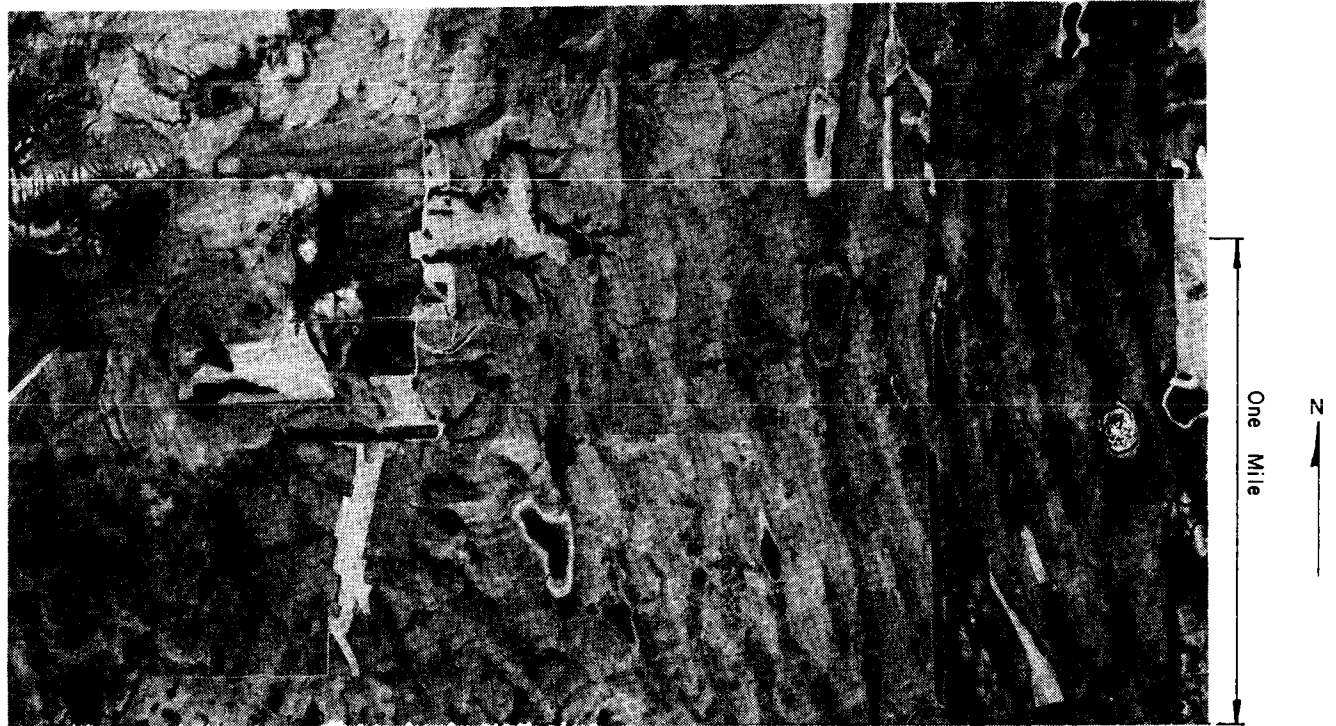


Figure 9. Airphoto of a part of the Prophets Mountains in western Sheridan County (parts of secs 28, 29, 30, 31, 32, and 33, T147N, R78W). The eastern half of the area consists of ice-thrust ridges that average about 80 feet between adjacent troughs and ridge crests, but local relief exceeds 300 feet in places. The area west of the Prophets Mountains (left half of photo) is mainly collapsed river deposits that are quite hilly.

is exposed at the road cut. The elevation of the exposure is about 1,975 feet and the contact between the two formations in this area is found in nearby test holes at a depth of about 1,650 feet. The bedrock found in the exposure has been lifted, as a result of glacial thrusting, at least 300 feet above its in-place position.

Another outstanding example of an ice-thrust mass of the first of the three types is found mainly in secs 2, 3, 4, 9, 10, 15, and 16 (and extending into small parts of adjoining sections) T147N, R76W. Here, about a dozen 0.1-to 0.2-mile-wide, northeast-southwest trending ridges indicate imbricate thrusting from the northwest. Local relief between ridges and intervening troughs is as much as 200 feet. The Lincoln Valley Sag is located immediately northwest of the area of ice thrusting.

Examples of ice-thrust masses of the second type (roughly equidimensional hills containing thrust masses downglacier from a source depression of similar size and shape) are the hills adjacent to Wolf Lake (secs 15, 16, 21, and 22, T150N, R74W); the hill adjacent to an unnamed lake a mile to the north of Wolf Lake; and the hill in sec 1, T150N, R74W adjacent to Clear Lake, which is located in Pierce County. Ice-thrust masses of this type are abundant in nearby adjoining areas of Pierce, McHenry, and Wells Counties. Smaller ice-thrust masses (0.2 mile across, or even less) are common in the Martin area; most of these were not mapped. The thrust masses of this type are sometimes immediately adjacent to the source depression, although typically they are located a half mile or more downglacier from the depression. Commonly, an esker may originate in the source depression and wander downglacier around one side of the thrust mass.

The ice-thrust mass adjacent to Wolf Lake is about 100 feet high, with a steep slope along the lake (fig. 10). It covers an area of about 3/4 mile by one mile and it is bordered by a small esker on its southern edge (pl. 1).

The third type of ice-thrust mass (irregular forms) are the most common in Sheridan County. These are gradational with the two previously discussed types, and consist of a jumble of hills with no obvious transverse ridges and no obvious source depression. They are more difficult to identify than the two other types, although test holes or road cuts often provide conclusive evidence of their origin. Some have been recognized by the presence of displaced or deformed fluvial, lacustrine, cretaceous, or Tertiary sediment. At least one of the ice-thrust masses of this type recognized in Sheridan County consists largely of gravel (secs 8, 17, and 18, T148N, R76W). Most of the other features of this type recognized in the county consist of glacial deposits or displaced preglacial sediment.

One of the better documented ice-thrust masses of this type is in T149-150N, R75W and covers an area of about seven

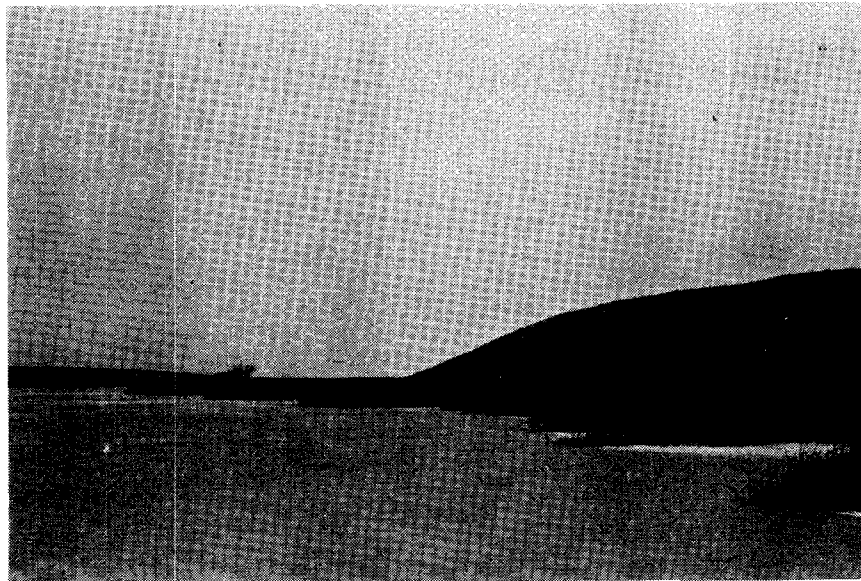
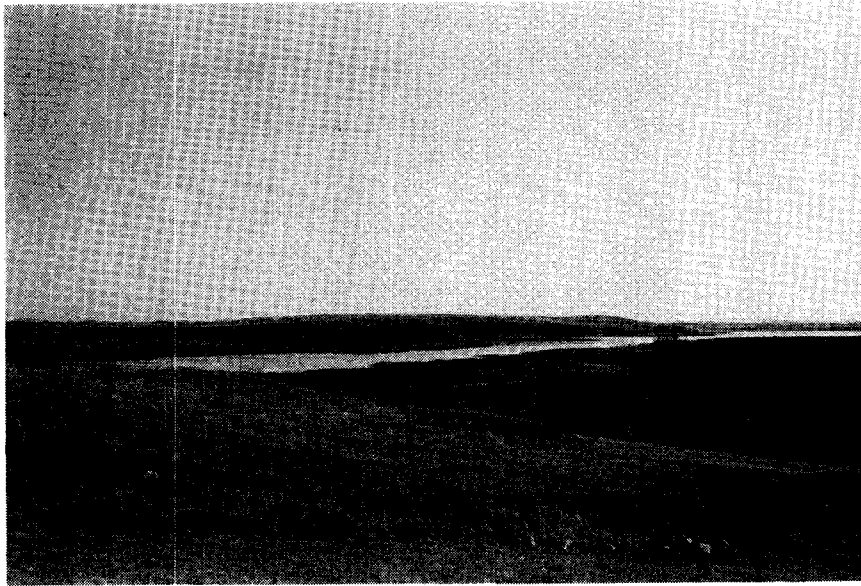


Figure 10. Two photos of a depression occupied by Wolf Lake (secs 15, 16, 21, and 22, T150N, R74W) and ice-thrust hill to the southeast of the lake. Upper photo shows lake in foreground, ice-thrust hill beyond (view to the southeast). Lower photo shows steep slope at edge of ice-thrust hill (sec 16) adjacent to Wolf Lake (view north).

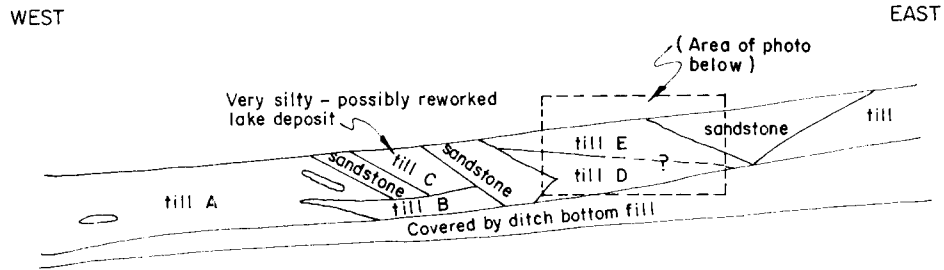


Figure 11. Drawing of an exposure in a road cut. This exposure is located along the south side of an east-west road (northwest corner of sec 3, T149N, R75W). The fresh, 420-foot-long cut, located near the easternmost (downglacier; leading) edge of a large ice-thrust mass, exposed intricately thrust layers of glacial and preglacial sediment. The bedrock sandstone layers are probably from the Fox Hills Formation. This exposure occurs between the elevations of 1,750 feet and 1,800 feet, about 280 feet above the top of the Fox Hills Formation in this area.



Figure 12. Photo of ice-thrust sediment and bedrock. A small part of the exposure diagrammed on figure 11 is shown here. Location is at the northeast corner of sec 3, T149N, R75W.

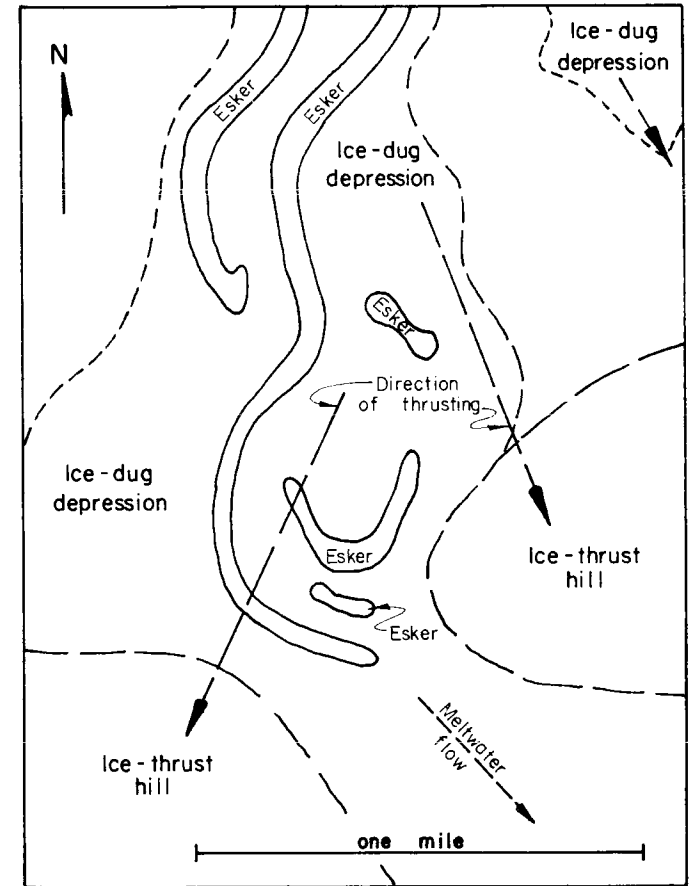
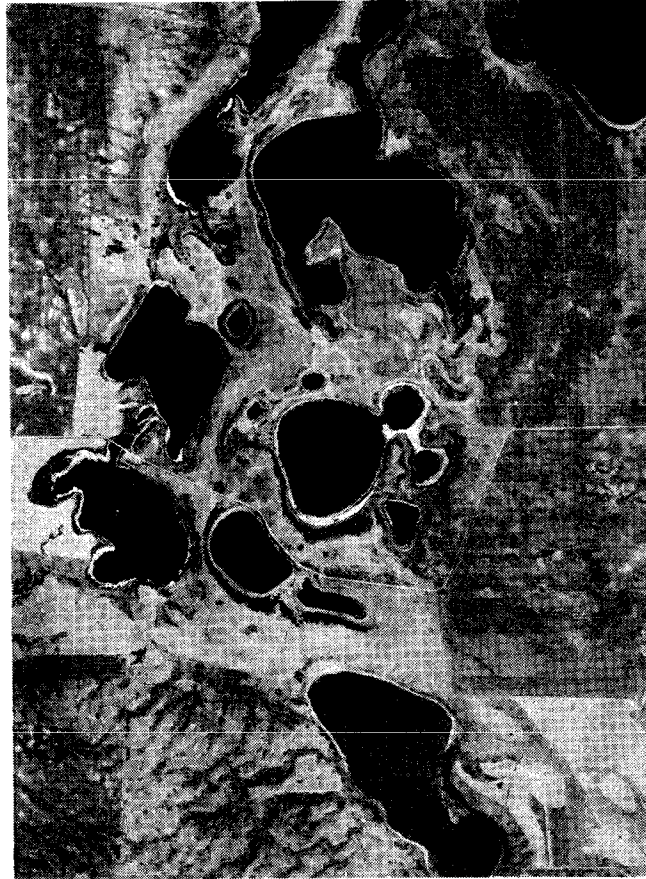


Figure 13. Frankhauser Lake area (T150N, Rs 75-76W). Several eskers occur in a depression along with several ponds and sloughs. The depression formed as a result of ice thrusting. Ice-thrust hills that occur adjacent to the depression are from 150 to 200 feet higher than are the areas from which they were derived.

Many of the streamlined ridges in this part of North Dakota contain some fine-grained glacial or lacustrine sediment, but fluvial gravel and sand seems to be the most common constituent. The sand in the small northwestern Sheridan County flutings is interpreted to have been deposited prior to the last glacial advance. The glacial sediment of the last advance in most areas is a thin layer, generally less than 3 feet thick, draped over streamlined ridges and grooves. Where the glacial sediment of the last advance is thicker than about 3 feet, but thinner than about 10 feet, collapsed hummocks partly obscure the streamlined ridges.

It is probably significant that the long, streamlined ridges (Hogback Ridge and others) are found in close association with a great number of ice-thrust masses. The long ridges seem to occur on divide areas between nearly parallel (northwest to southeast) drainages. In fact, this entire area (northwestern Sheridan, southern McHenry, and southwestern Pierce Counties) is one in which a readvance deposited a thin layer of till over everything. Fenton and Andriashek (1978) also noted that the fluting process appears to be closely associated with ice thrusting. They stated that the sediment in the depressions upglacier from ice-thrust masses in the Sand Hills area of northwestern Alberta is commonly fluted and, in places, the thrust masses themselves are fluted.

Large amounts of water must have been present beneath the ice in the drainages that were overridden by the last advancing glacier. It seems logical to expect that this water resulted in a "supersaturated" till, one which was easily molded as the glacier "floated" over it. In fact, it seems probable that the controlling factor responsible for both the ice thrusting and the streamlining was water content--water that was present in the drainages and subglacial till.

In areas where impermeability (freezing of some of the sedimentary layers, for example, or some other factor such as the speed with which the ice advanced or the type and amount of clay in the overridden material) limited water migration in the subglacial material, ice thrusting of the subglacial materials, not streamlining, resulted. It is likely that essentially the same original conditions existed in both thrust areas and streamlined areas--large amounts of subglacial water--and a minor, but critical, change in the permeability determined whether the subglacial materials were thrust or streamlined.

Slopewash-Eroded Till Slopes and Colluvial Fans

The face of the Missouri Escarpment in T148N, R74W and in Tps149-150N, R77W has been deeply incised by erosion (areas of Qcci on pl. 1) (figs. 5 and 14). Relief on the bouldery till surface in these areas ranges up to 100 feet locally and drainage is mostly integrated. A similar incised till slope occurs

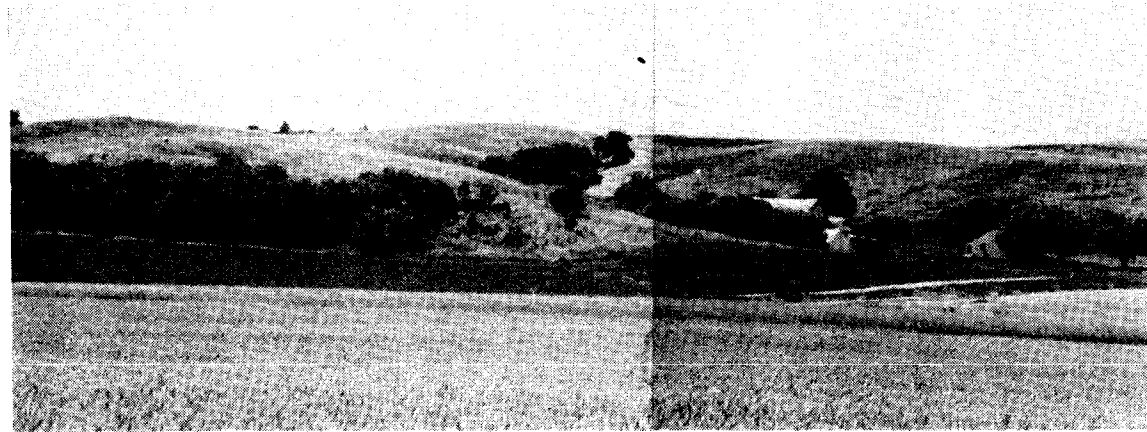


Figure 14. View southwest over a part of the Sheyenne River Valley at the Missouri Coteau Escarpment (T148N, R74W). Photo by T. C. Gustavson.

along the Sheyenne River Valley in sec 34, T149N, R74W. At the base of the gullied escarpment in easternmost Sheridan County, a sharp break in slope marks the upper edge of a fan of colluvial debris that consists of a mixture of sandy gravel along with some gravelly sand, clay, and boulders (Qces on pl. 1). A similar fan is not apparent at the base of the eroded escarpment face in northwestern Sheridan County, probably because the slopewash material there was covered by thin till during a brief southeastward readvance of the glacier along the escarpment in that area.

River-Eroded Till Surfaces

Areas of scoured till in northern Sheridan County were washed by running water that had already dumped most of its bedload of gravel and sand farther north in McHenry County. These scoured areas (Qcer on pl. 1) are found in association with the undulating collapsed glacial topography (Qccu). They have a channeled appearance on airphotos and local relief of only a few feet. The scoured areas are largely till, although scattered patches of gravel and sand left by the water that washed the surface do occur in some places; and, just north of the county line in McHenry County, gravel amounts are sufficient for commercial use (sec 28, T151N, R76W). In some places, large numbers of boulders occur. These boulders were left behind as a lag deposit when the running water that washed the surface removed the finer materials that had been associated with the boulders (fig. 15).

Along the eastern shore of Krueger Lake (sec 26, T150N, R77W), Cretaceous Hell Creek Formation sandstone is exposed along the edge of the river-eroded surface (figs. 15 and 16). However, this bedrock has been disturbed by the glacier as the sandstone beds have nearly vertical dips and they strike in all directions.

Lacustrine Landforms

Collapsed Lake Plains

In places where silt and clay were deposited in lakes that flooded areas of stagnant glacial ice, collapsed lake plains resulted (Qcoc on pl. 1). Several small collapsed lake plains occur on the Missouri Coteau in Sheridan County. The topography in such areas is hilly, much like surrounding areas of hilly glacial sediment, and the surface is free of boulders. The collapsed lake plains have numerous undrained depressions, much like the hilly collapsed glacial sediment and collapsed flood plains. In contrast to these landforms, the sediments of a collapsed lake plain are folded and contorted, rather than faulted.



Figure 15. Two photos of a bouldery surface on Hell Creek Formation sandstone along the shore of Krueger Lake (sec 26, T150N, R77W). Erosion of this surface has removed everything from the bedrock surface except the boulder lag shown here. The Hell Creek beds exposed in this area (lower left, bottom picture) have been disturbed by glacial action and dip in all directions.

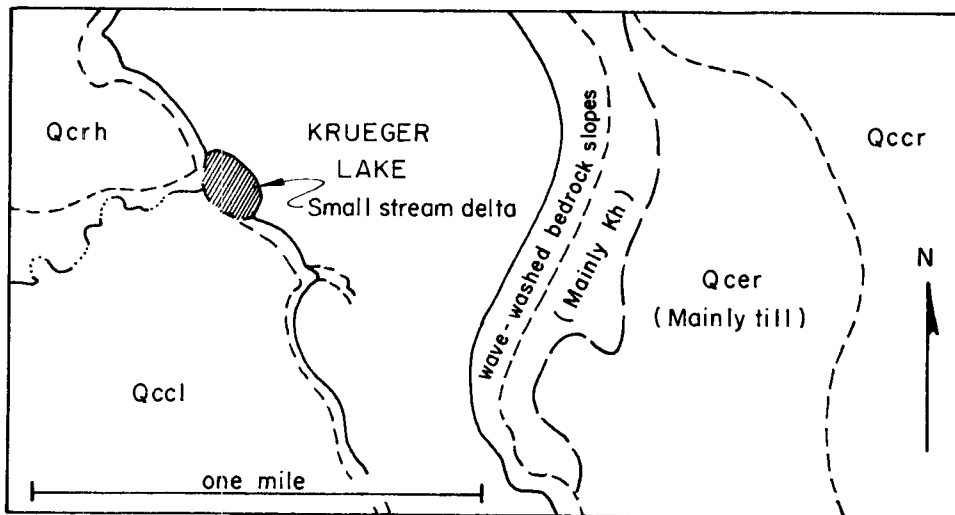
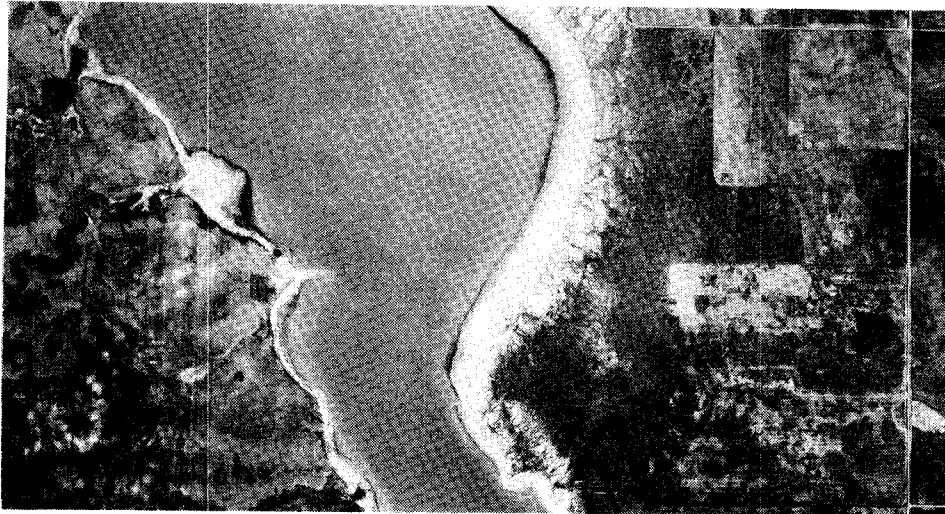


Figure 16. Airphoto of a part of Krueger Lake in northwestern Sheridan County (secs 33 and 34, T150N, R77W). This area was washed by water flowing southeastward, probably from the glacial Lake Souris. Intense washing of the surface, east of the lake on this photo, resulted in an area of scoured bedrock (Cretaceous Hell Creek sandstone) with only small amounts of glacial sediment. A covering of boulders is all that remains in places (see fig. 15). Notice the small delta (shaded area) being built along the west shore of the lake by an ephemeral stream.

Areas of collapsed lake sediment are commonly cultivated and therefore easy to identify on airphotos. Some of the collapsed lake plains in Sheridan County are slightly higher than the surrounding glacial sediment, or they are bordered by a low rim of till or gravel and sand. These lake plains formed in lakes that were ice-walled prior to the time the underlying stagnant ice melted, causing the flat lake floor to collapse.

Elevated Lake Plains

Elevated lake plains (Qcoe on pl. 1) resulted when lakes flooded depressions in the stagnant ice surface on the Missouri Coteau. They are covered by laminated silt and clay that washed into and settled to the bottoms of these ice-walled lakes. The surfaces are free of boulders. The elevated lake plains formed in lakes that were surrounded by stagnant glacial ice and floored by solid ground, commonly till. A few of them flooded areas of stagnant ice, resulting in partial collapsing of the lake plain floor, so some of the elevated lake plains are also collapsed features. Some of the elevated lake plains have margins of till that are raised as much as 15 feet above the center of the plain (fig. 17).

Most of the elevated lake plains are not larger than a half mile across, but southwest of Goodrich, a seven-square-mile lake plain occurs. A few miles northeast of Goodrich, about twenty closely associated, but unconnected, small, rimmed, elevated lake plains occur. Each is surrounded by a till rim that is from one to five feet high.

Sloughs

Sheridan County has several thousand sloughs. Only a few of the larger ones are shown on the geologic map (pl. 1) and these were identified mainly by examining airphotos. The density of sloughs on the Missouri Coteau associated with hilly and rolling collapsed moraine is considerably greater than on the glaciated plains area of northern Sheridan County. As many as 75 small lakes and sloughs can occur in a square mile on the Missouri Coteau. Even so, many sloughs do occur north of the Missouri Escarpment, too. Most of the sloughs in Sheridan County occur in potholes, depressions left when buried blocks of stagnant glacial ice melted from the glacial sediment.

Lakes in depressions in outwash gravel and sand are usually the same level as the groundwater table (Clayton, 1962). As a result of the smaller amount of evaporation at the surface of the underground part of the groundwater reservoir, these lakes and sloughs have fresh water and a stable water level. Fish, pelicans, ducks, and gulls frequently occupy these gravel-bottomed lakes, and trees and shrubs grow along their shores. In contrast, lakes floored entirely by impermeable till or lake clay usually have a high salt concentration and a rapidly fluc-

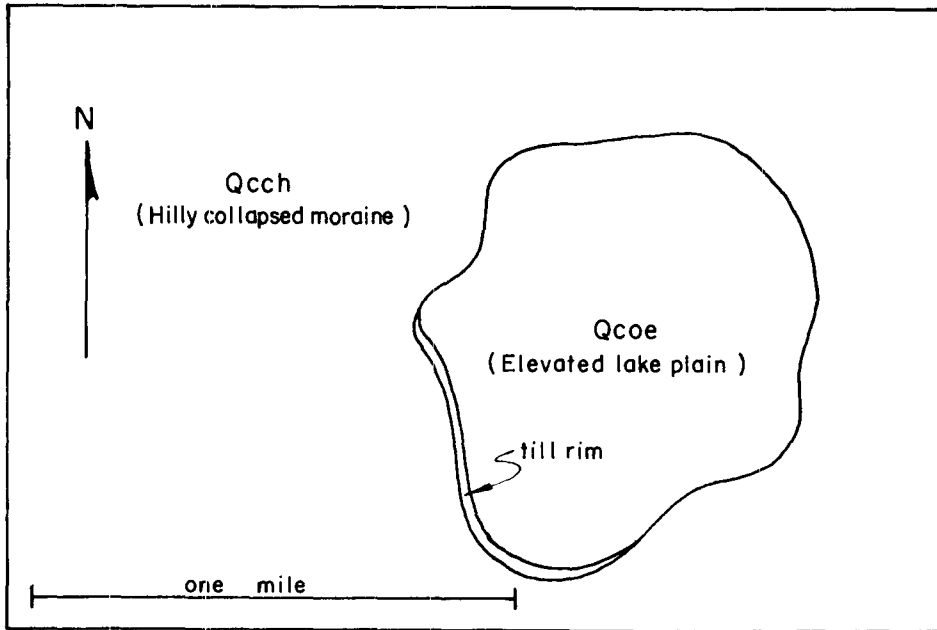


Figure 17. Elevated lake plain about a mile northeast of Denhoff (secs 4, 5, 8, and 9, T146N, R75W). The lake plain has a till rim that is especially prominent on the southern margin. The elevated lake plain stands about 50 feet above the surrounding hilly collapsed moraine.

tuating water level, so many of these are intermittent. Fewer fish and water birds live in these lakes.

In some places, deposits of peat and decomposed peat ("muck") are found in sloughs. This material is generally less than three feet thick. Sediment in the sloughs has been derived largely from adjacent hillslopes. It consists of dark, clayey material alternating with layers of lighter colored, more silty beds.

Fluvial Landforms

Landforms resulting from the action of running water include deposits of both meltwater rivers and nonmeltwater rivers. They were left undifferentiated because no consistent way of distinguishing them is known. Much of the material called "outwash" on previous maps was deposited by rivers consisting largely of runoff from precipitation rather than from meltwater. For example, the youngest "collapsed outwash" of the Missouri Coteau was deposited thousands of years after the glacier stagnated, when less than a tenth of the runoff was derived from melting ice (Clayton, 1967, p. 36). Even the "outwash" deposited by some meltwater rivers is not really outwash. For example, the sand and gravel deposited by the Sheyenne meltwater river in Sheridan County, after it left glacial Lake Souris, was washed out of pre-existing glacial sediment in the river cutbanks, not out of the glacier. In Sheridan County, the fluvial landforms include several meltwater trenches; glacial river flood plains and stream terraces including both flat and hilly (collapsed) surfaces; and various ice-contact deposits including eskers and kames.

Meltwater Trenches

Meltwater trenches are abandoned river channels, true channels, that were once filled bank to bank by flowing water. They are shaped like channels, with consistent bank heights, uniform channel widths, and regular meander shapes. Roughly, a third to a half of the greater discharge during Late Wisconsinan time was the result of greater runoff during that time resulting from a mean annual temperature a few degrees cooler than present and a mean annual precipitation a few hundred millimeters greater than present (Schumm, 1965). The remainder was glacial meltwater (Clayton, Moran, and Bluemle, 1980).

The meltwater trenches of southern Sheridan County, on the Missouri Coteau, are poorly defined due to collapse of the stagnant ice over and through which they were cut. Areas shown as collapsed river flood plains (pl. 1) are in places confined to fairly well defined valleys that are most likely segments of older meltwater trenches. In other places (secs 4, 9, and 16,

T146N, R77W is an example), separate areas of collapsed river flood plain are connected by eskers that probably once served as meltwater routes and remained as ridges of gravel when the surrounding areas collapsed on melting of the stagnant glacial ice.

In northern Sheridan County, the meltwater trenches are more obvious. The longest trench enters Sheridan County in the northwest corner (sec 7, T150N, R77W) and trends southeastward. Moesner and Krueger Lakes are located in the trench. The Sheyenne River flows within the trench, beginning at Krueger Lake, and it crosses the county, entering Wells County in T148N. Parts of this meltwater trench are poorly defined, especially in areas where it is bordered by fluvial sediment where it is much wider and more shallow, as in the area of Sheyenne Lake and Coal Mine Lake in T149N, Rs74 and 75W. Other parts are well defined, up to 80 feet deep, and about a quarter to a half mile wide (T149N, R76W) where it is cut through rolling collapsed moraine. The surface sediment on the floor of the trench is mainly modern alluvium, fine gray sand and silt.

A well defined meltwater trench enters Sheridan County in sec 4, T150N, R77W and trends southeastward. In sec 24, T150N, R76W, it joins an area of collapsed river sediment and eskers and turns southward. Several small lakes occupy the trench in sec 31, T150N, R75W and secs 6 and 17, T149N, R75W. The surface sediments in this trench, like the already-described Sheyenne River trench, are mainly modern alluvium.

A third meltwater trench enters Sheridan County in sec 6, T150N, R74W, trends southeastward through the Martin area, and enters Wells County in sec 31, T150N, R73W. Wolf Lake (secs 16 and 21, T150N, R74W) occupies a portion of this trench which, like the two already discussed, has a floor of modern alluvium.

The three meltwater trenches described above all served as drainage ways for water that had its main source to the northwest. Some drainage from the Missouri Coteau contributed to the Sheyenne River trench, but this was probably a small amount of water. Lake Souris, in the counties to the north, probably provided most of the water that flowed through the trenches.

River Flood Plains and Terraces

The sediment of proglacial rivers occurs as broad, flat fluvial plains (Qcrf on pl. 1); as valley side terraces (Qcot) (fig. 18); or as a hummocky topography (Qcrh) almost identical to that of hilly collapsed glacial topography (Qcch) or collapsed lake plains (Qcoc). Nearly all of the flat areas of fluvial sediment in Sheridan County are located north of the Missouri Escarpment; an exception is in southeastern Sheridan County

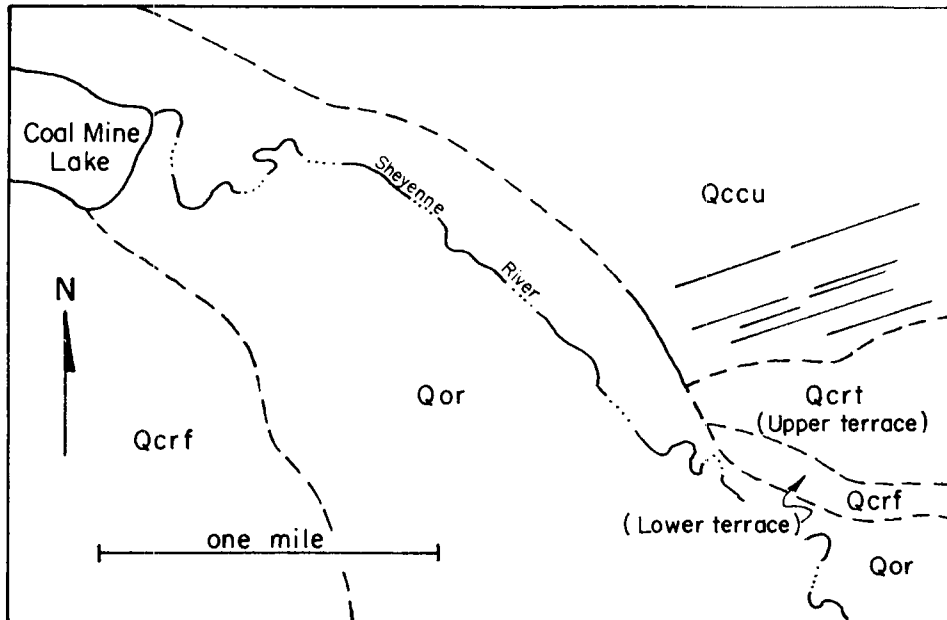
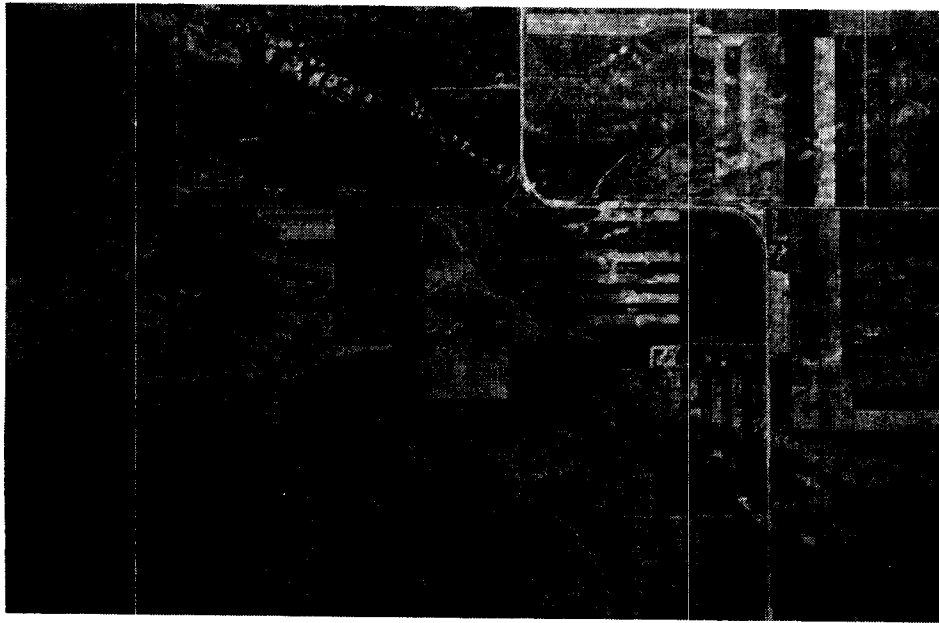


Figure 18. Sheyenne River valley flood plain and terraces (secs 33 and 34, T149N, R74W, and secs 4, 5, and 6, T148N, R74W). Washboards north of the valley indicate glacial movement from the northwest.

south of the "Streeter moraine" (T145N, R75W). In most places, the original channel pattern has been destroyed by wind erosion or hidden by a blanket of wind-blown sediment as in T150N, R75W where an area of dunes (Qod) occurs.

Extensive areas of collapsed fluvial sediment occur on the Missouri Coteau in Sheridan County. They can be distinguished on airphotos by the sharper tonal boundaries on the collapsed sand and gravel. Lithologically, collapsed river sediment is identical to uncollapsed river sediment, except that its bedding is faulted and tilted. Relief is commonly a hundred feet or less and, typically, the areas of collapsed fluvial sediment are located at elevations slightly lower than the surrounding hummocky collapsed moraine.

Eskers

Only a few of the many small eskers that occur in Sheridan County are shown on the geologic map (red lines on pl. 1). Most of them were identified largely by airphoto interpretation (fig. 19). The eskers are composed of gravel, sand, and some till. The mixture is poorly sorted and rather "dirty" with a ratio of silt and clay of about 3:1. The shale content is high in some of the eskers. Some of the gravel is used locally for road material, but, in general, the quality of the fluvial sediment in the eskers is too poor for commercial use.

The largest and best developed eskers occur north of the Missouri Escarpment in association with old valleys or other low areas that became partly filled with stagnant ice during the last glaciation. Meltwater flowing over the low areas cut valleys in the stagnant ice. The best examples are in the Frankhauser-Moorehead Lake area (T150N, Rs75-76W). The esker ridges in this low area, a depression that resulted from ice thrusting, are about 60 feet high, and about 500 feet wide. The longest one, which begins in sec 2, T150N, R76W at the end of Lake Richard, is about 4 miles long.

Eolian Landforms

Dunes

Although scattered patches of wind-blown silt occur throughout Sheridan County, the only deposit that was mapped is an area of dunes in secs 8 and 17, and parts of adjacent sections in T150N, R75W (Qod on pl. 1). This small area of dunes and associated blowouts has relief ranging from 10 to 40 feet.

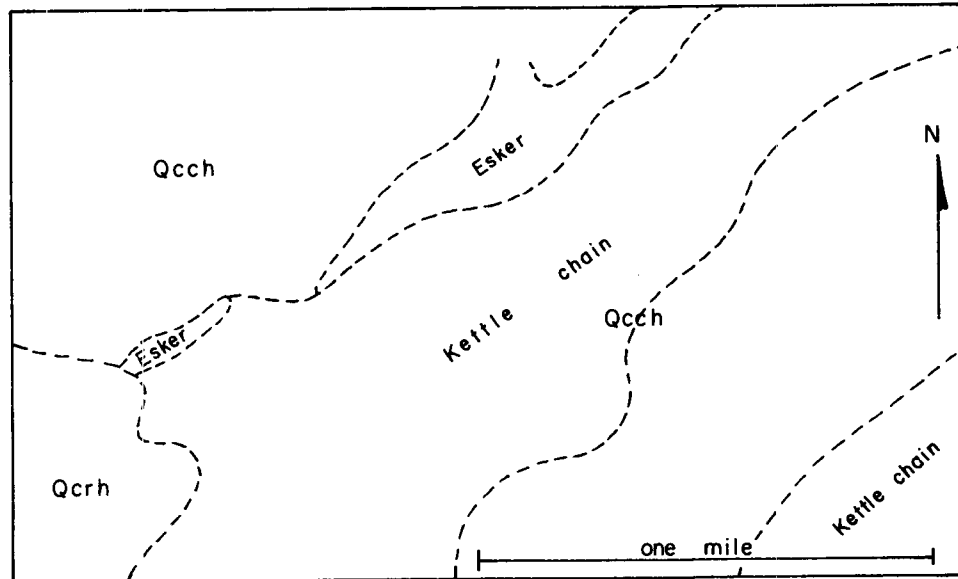
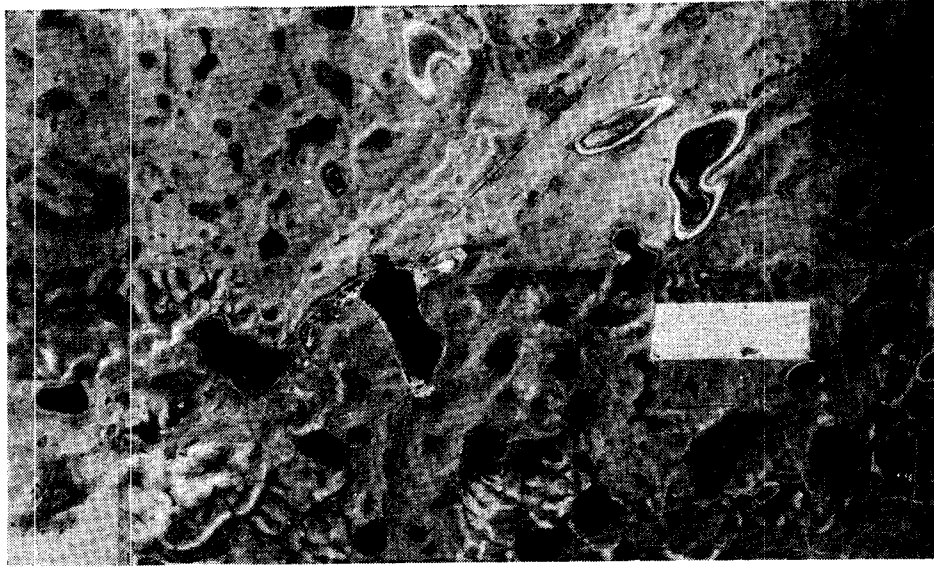


Figure 19. Airphoto of hilly collapsed moraine in southwestern Sheridan County (parts of secs 15, 16, 17, 20, 21, and 22, T145N, R78W). A part of a 5-mile-long esker and a part of a 15-mile-long kettle chain are shown. Local relief on the collapsed moraine here is about 50 feet; about 100 feet in the kettle chain.

SYNOPSIS OF GEOLOGIC HISTORY

Preglacial History

The Precambrian, Paleozoic, and Mesozoic history of Sheridan County is summarized earlier in this report, in the section dealing with stratigraphy. During early Tertiary time, some marine sediments were deposited in the Cannonball sea, and it is possible that later some nonmarine Bullion Creek Formation sandstone and shale may have been deposited over part or all of Sheridan County. If any younger materials were deposited, they were later removed by post-Paleocene erosion.

Erosion probably continued, intermittently, during much of Tertiary time in Sheridan County, through most of Pliocene time. By the end of the Pliocene Epoch, a gently rolling landscape had developed on the Late Cretaceous and early Paleocene sands and shales of the Fox Hills, Hell Creek, Cannonball, and possibly the Bullion Creek Formation. The land surface sloped gently northeastward from about 1,800 feet in the south and west to perhaps 1,500 feet in the northeast part of the county. It does not appear that any prominent escarpment corresponding to the modern Missouri Escarpment existed on the preglacial bedrock surface.

At least one major river valley crossed Sheridan County, from southwest to northeast (fig. 20). This valley may have been part of the preglacial route of the Knife River through central North Dakota. The river drained all of Sheridan County. Other deep valleys that are cut into the bedrock surface probably formed as a result of the diversion of the drainage by early glaciers. A deep valley that extends southeastward into southern Wells County, from T146N, R76W, was probably eroded by glacially-diverted water.

Glacial History

From three to six separate layers of glacial till were found in the test holes that have penetrated the entire thickness of glacial sediment in Sheridan County. It is not known how many separate glaciations are represented by these till layers; some of the deeper ones are almost surely of pre-Wisconsinan age. The preglacial Knife River Valley in southwestern Sheridan County contains layers of sand, till, and gravel indicating that the valley was probably partly filled with fluvial sediment and glacial till during an early glacial advance (see cross section, pl. 3). The lowermost till is overlain by a gravel deposit that consists, in part, of western-derived gravel, so it seems likely that the early glaciations did not result in permanent diversion of the drainage direction, at least not in Sheridan County.

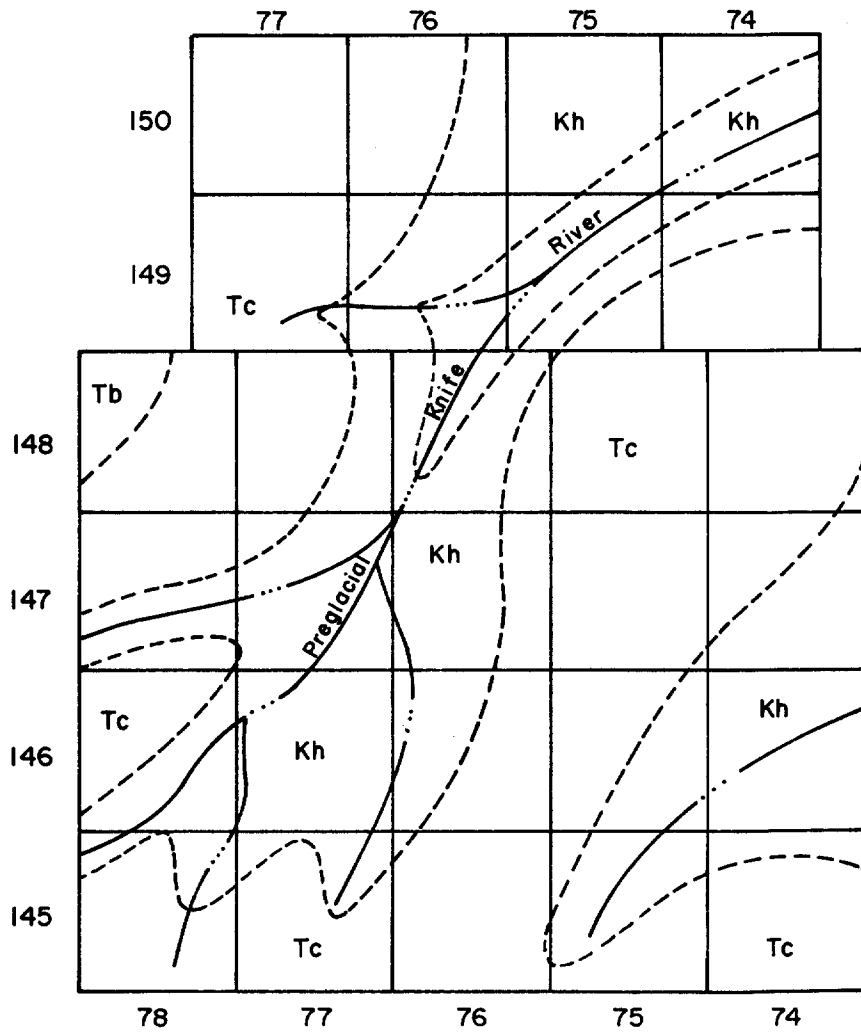


Figure 20. Possible drainage and generalized bedrock outcrop pattern in Sheridan County prior to the earliest glaciation. The major drainage was the now buried Knife River and its tributaries.

Each time glaciers advanced into the Sheridan County area, and also when they receded, damming of water occurred in the valleys ahead of the ice. Sediments that were deposited in these ice-dammed lakes were identified in about 25 test holes. These lake deposits occur at several horizons, but not enough test holes were drilled in them to accurately delineate the extent of the ice-dammed lakes in which they were deposited. Based on a study of the available data, it appears that an extensive lake dammed the Knife River Valley in northern Sheridan County early during the glacial epoch. The early age is postulated because this deposit lies, in part at least, directly on Fox Hills Formation bedrock. As much as 70 feet of sandy lake sediment occurs at elevations ranging between 1,480 and 1,550 feet near Martin in T150N, R74W.

Another lake deposit occurs in the Knife River Valley near Pickardville at elevations between 1,650 and 1,700 feet at depths over 200 feet. This deposit lies above thick layers of till and gravel and must therefore have been deposited sometime in mid-Pleistocene time.

The most extensive area of buried lake deposits is south of McClusky, mainly in T146N, R77W. These deposits are as much as 135 feet thick and buried from 100 to 300 feet deep. In one test hole (NDSWC test hole #5256), three separate layers of lake sediment were penetrated. These layers of lake sediment have a total thickness exceeding 200 feet.

It appears that the Sheridan County area was a focus for large-scale thrusting by the glacier throughout the entire Pleistocene Epoch, continuing through latest Wisconsinan time. Although it is not immediately clear why so much thrusting occurred here, it is possible that the now buried Knife River Valley acted as a major aquifer, carrying large amounts of groundwater through the valley-fill sand and gravel toward the advancing glacier. This may have resulted in hydrologic conditions favorable for thrusting.

The earliest glaciers that advanced over Sheridan County apparently produced large-scale thrusting in the area north of McClusky. Blocks of ice-thrust sandstone and shale have been identified at various levels in all parts of the county in several of the test holes that penetrate the glacial sediments. The late Wisconsinan surface is characterized by an unusually diverse array of ice-thrust features (pl. 1).

The Late Wisconsinan glacial history can be better understood by examining the way the last glacier melted from the area (figs. 21 through 24). The southeasternmost part of the county was the first area to be deglaciated, about 12,300 years ago (Clayton, Moran, Bluemle, 1980). At that time, the main glacier movement was still almost due south over the whole county. The range of hills extending from near North Lake (sec 18, T145N, R75W) to the Wells County line was formed during

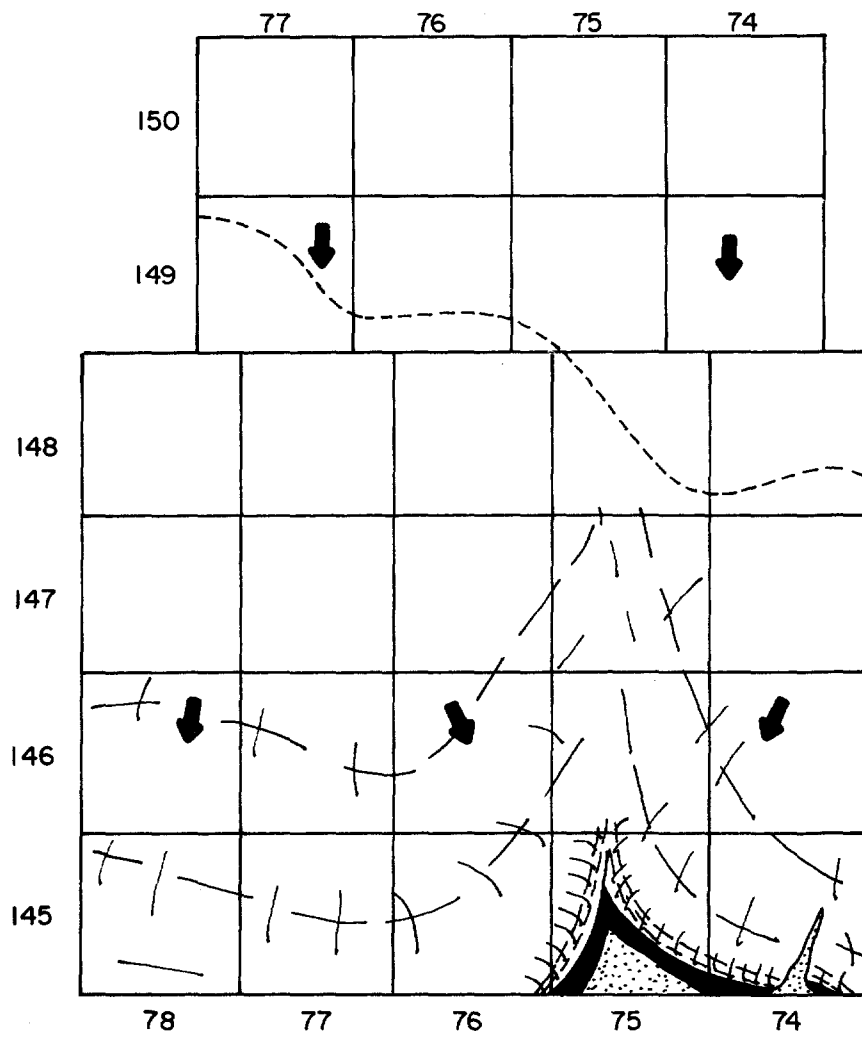


Figure 21. Formation of the Streeter moraine in southern Sheridan County about 12,300 years ago. The dashed line represents the Missouri Escarpment. Glacial ice flowed southward (arrows) over the entire county, although it was relatively thin south of the escarpment and tending to become more lobate on the Missouri Coteau. Dotted area is gravel and sand; black area is constructional glacial relief (Streeter moraine).

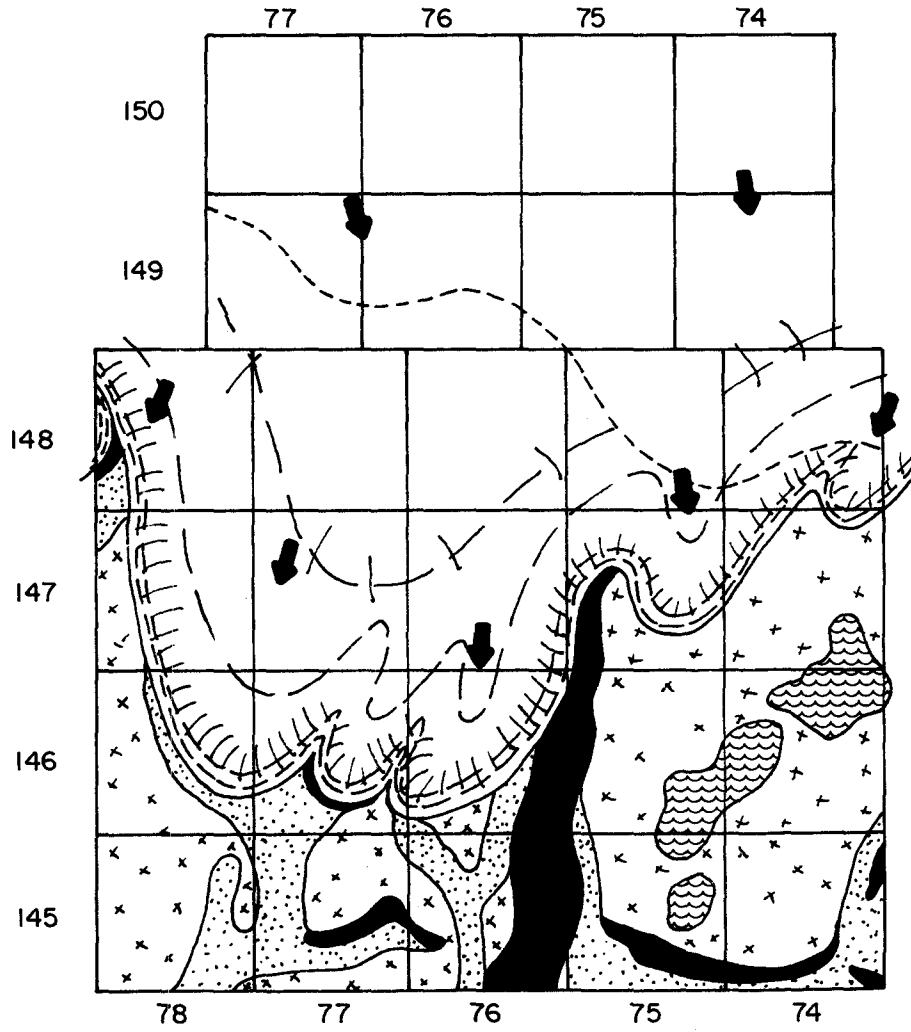


Figure 22. An intermediate phase in the withdrawal of the glacier from Sheridan County. The ice north of the Missouri Escarpment is somewhat thicker than it is to the south. Much of the glacier on the Coteau has stagnated (cross pattern). Lakes (wave pattern) existed on the stagnant ice in southeastern Sheridan County.

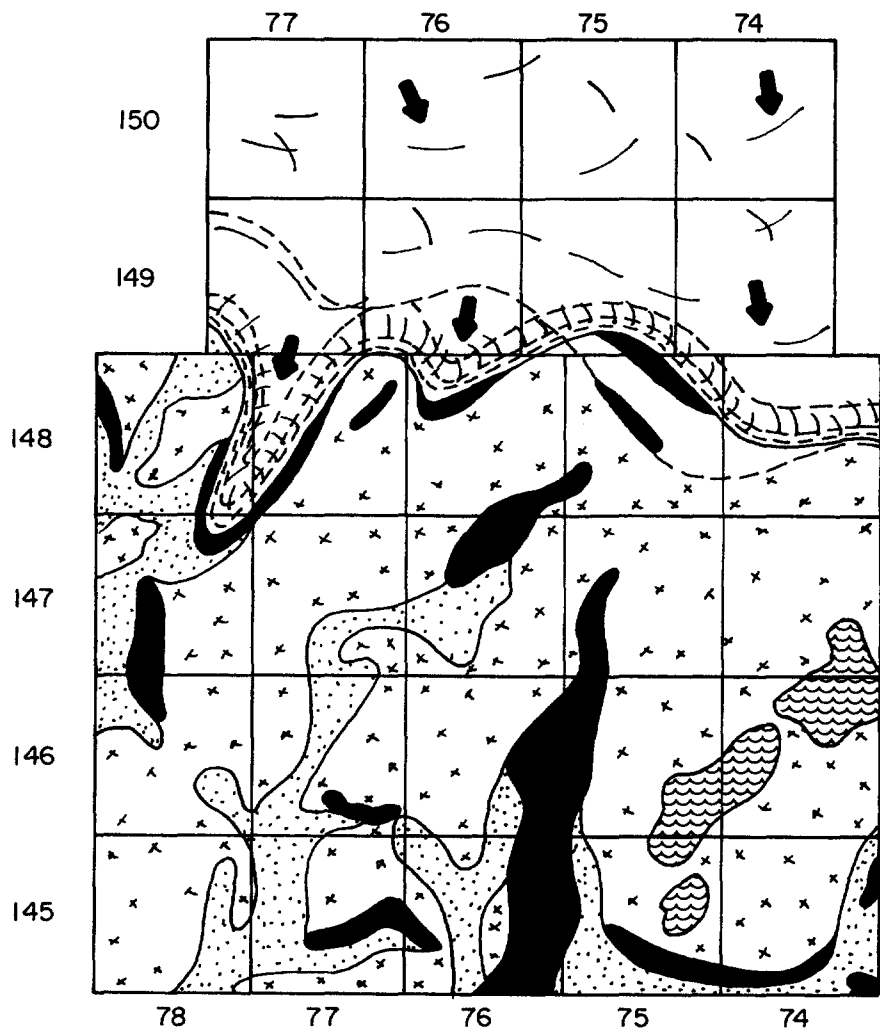


Figure 23. Final phase in the withdrawal of the glacier from the Missouri Coteau in Sheridan County. The ice on the Coteau is thin and active only in the western part of the county. It became increasingly lobate as it thinned on the Coteau. The main ice flow was probably shifting to a more southeasterly direction by this time, and in areas to the southeast of Sheridan County, the ice flow was already southeast, parallel to the Missouri Coteau.

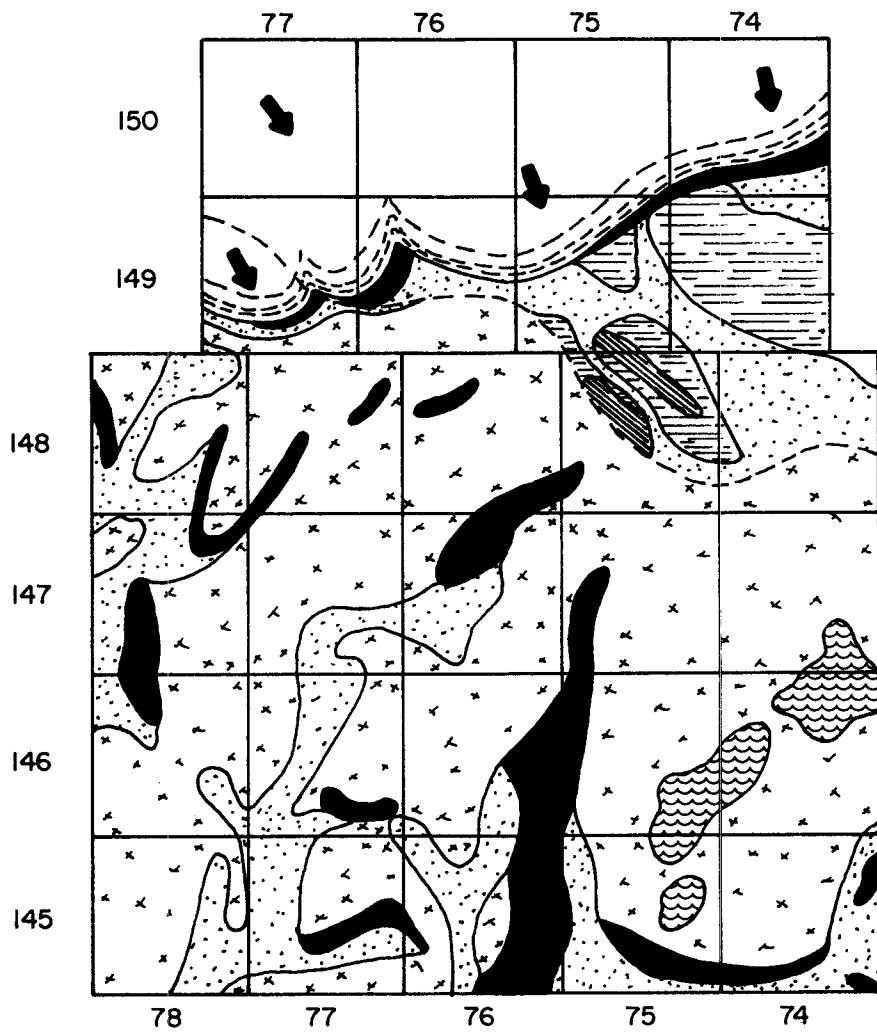


Figure 24. Deposition of the Martin moraine in northeastern Sheridan County. The glacier on the Missouri Coteau has stagnated.

the time the ice margin stood at this position (fig. 21). This range of hills has been referred to as the "Streeter Moraine," (fig. 1) and it may be in part an ice-marginal feature (an "end moraine") and in part a series of ice-thrust blocks. While the glacier stood along the position of the Streeter Moraine, an outwash plain of gravel and sand developed in the area immediately south, in Sheridan, Burleigh, and Kidder Counties.

At a somewhat later stage in the Late Wisconsinan deglaciation, when the edge of the glacier crossed Sheridan County entirely on the Missouri Coteau, the ice margin became considerably more lobate (fig. 22). Large-scale thrusting by the glacier resulted in the formation of surface features such as the Denhoff Hills, Prophets Mountains (fig. 1), and other large hills and groups of hills, all shown on the geologic map (pl. 1). It is difficult to accurately determine the rate of deglaciation. Probably, less than a hundred years elapsed between the time conditions were as shown on figure 21 and the time they became similar to the situation shown on figure 22 (Clayton, Moran, Bluemle, 1980). In eastern Sheridan County, such a withdrawal of the ice margin, assuming it was an orderly, year-by-year retreat, would have had to have averaged nearly 100 feet per year. It seems likely, however, that as the glacier melted, large portions of it became detached, resulting in broad areas of stagnant ice. The glacier withdrawal was therefore not an orderly process. Ice-contact lakes formed in the Goodrich area and broad areas of outwash were deposited in other areas (fig. 22; pl. 1) as the glacier receded.

By between 12,100 and 12,200 years ago, the glacier had stagnated nearly everywhere on the Missouri Coteau in Sheridan County and active glacial ice was restricted to the area north of the Missouri Escarpment (fig. 23). As the glacier became thinner, its direction of flow changed from a southerly to a more southeasterly direction, parallel to the Missouri Escarpment in northern Sheridan County.

The Martin Moraine probably formed about 12,100 years ago (Clayton, Moran, and Bluemle, 1980). The Martin Moraine appears to be a true "end moraine," formed along the edge of the glacier. It has an extensive plain of outwash gravel and sand ahead (southeast) of it (fig. 24). A large number of ice-thrust blocks are also associated with the Martin Moraine, and it is difficult to differentiate ice-thrust topography in the area from end moraine topography.

ECONOMIC GEOLOGY

Hydrocarbons

Nine exploratory oil wells have been drilled in Sheridan County as of July 1, 1980. None of these has produced any oil and no oil shows were reported from any of the wells.

Sand and Gravel

Sand and gravel are found in a variety of situations in Sheridan County. The best quality gravel, with a relatively low percentage of shale, is found on the terraces of the Sheyenne River. Good quality gravel is also found in some of the fluvial plain deposits; an area of hummocky fluvial deposits (Qcrh) has been utilized as a source of gravel for several years. Most of the gravel found in ice contact deposits (eskers, etc.) is poor in quality.

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