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GEOLOGY OF
RENVILLE AND WARD COUNTIES
NORTH DAKOTA

by

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COUNTY GROUNDWATER STUDIES 11 - PART 1
NORTH DAKOTA STATE WATER COMMISSION

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ABSTRACT

Renville and Ward Counties, located in north-central North Dakota on the northeast side of the Williston Basin, are underlain by as much as 11,000 feet of Paleozoic, Mesozoic, and Cenozoic rocks that dip gently to the southwest. The uppermost Paleocene rocks, the Cannonball, Bullion Creek, and possibly the Sentinel Butte Formations, lie directly beneath the Pleistocene glacial deposits, which overlie most parts of the two counties. Isolated exposures of the Bullion Creek and Cannonball Formations occur in the Des Lacs and Souris River valleys. The glacial deposits in the two-county area range from 0 to 800 feet thick and average about 165 feet thick.

Renville County and about a third of Ward County are located on the Glaciated Plains, an area of undulating to flat topography. The southwestern two-thirds of Ward County lies within the Missouri Coteau and Coteau Slope part of the Great Plains. This area is characterized by high-relief collapsed hummocky topography. Associated landforms include numerous ice-contact deposits, lake plains, and collapsed fluvial plains. Surficial deposits throughout the two counties are predominantly till and glaciofluvial deposits, but lake sediments, colluvium, and recent alluvium and landslide deposits are also present.

The most important economic resources in Renville and Ward Counties, other than soil and water, are lignite, sand and gravel, and petroleum. Although no potash or halite are currently being produced, beds of these materials do underlie the area.

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, the Renville County Board of Commissioners, and the Ward 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 geologic maps of the areas; (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 areas. This volume describes the geology of Renville and Ward Counties. Readers interested in groundwater should refer to Part II of this bulletin (Pettyjohn, 1968), which includes detailed basic data on the groundwater, and Part III (Pettyjohn and Hutchinson, 1971), which is a description and evaluation of the groundwater resources of Renville and Ward Counties.

Parts of this report that are primarily descriptive include the discussions of the topography, rock, and sediment in Renville and Ward Counties. 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 concerned about the distribution of sediments that have potential to produce usable groundwater; state and county water managers; consultants to water users; water users in the development of groundwater supplies for municipal, domestic, livestock, irrigation, industrial, and other uses; 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

Parts of Renville and Ward Counties were studied by Upham (1895) during his study of glacial Lake Souris. Wilder and Wood (1902) and Wood (1902) made early studies of lignite in the area; Leonard (1916) and Todd (1923) investigated the drainage systems of northwestern North Dakota, an area that included Renville and Ward Counties. An early study of the geology and groundwater resources of the two counties was made by Simpson (1929). Alden (1932) described the glacial deposits of the area; Andrews (1939) published a generalized geologic map of southwestern Ward County and evaluated the lignite resources of the region. The glacial history of North Dakota and the Souris River Lobe were described by Lemke (1958) and Lemke and Colton (1958). An exposure of two drift sheets in Ward County was described by Lemke and Kaye (1958). Lemke (1960) provided a comprehensive report on the geology of Renville and Ward Counties (except for the Missouri Coteau area). Colton and others (1963) mapped the general glacial features of North Dakota and, later, Clayton and others (1980) provided a considerably more detailed map of the geology of North Dakota. Pettyjohn (1967a, 1967b) described the stagnant ice features and stratigraphy of multiple-layered glacial deposits on the Missouri Coteau. Kehew presented evidence for Late Wisconsinan catastrophic flooding in the Souris River area, including parts of Renville and Ward Counties (Kehew, 1979, 1982; Kehew and Clayton, 1983).

Akin (1947, 1951), Jensen (1962), Armstrong (1963), Randich (1963), Schmid (1963), LaRocque and others (1963a, 1963b), Froelich (1964), Pettyjohn and Hills (1965), and Pettyjohn (1967c) described the geology of small areas of the counties or provided basic data related to groundwater supplies. Kehew (1983) described the geology and geotechnical conditions in the Minot area.

Several of the nearby county studies in the present series of county geologic studies have been completed. Bluemle (1971, 1982, 1985) reported on the geology of McLean, McHenry, and Bottineau Counties. Clayton (1972) described the geology of Mountrail County, and Freers (1973) described the geology of Burke County.

Methods of Study

Fieldwork for the geologic study of Renville and Ward Counties was accomplished over a long period of time by several people. Wayne Pettyjohn mapped the geology of the southwestern part of Ward County during the summer of 1965. Alan Kehew mapped the 16 townships in the northeastern quarter of Ward County in the early 1980s.

John Bluemle spent part of the field season in 1987 checking the geology of Renville County and parts of Ward County.

Field mapping was done on aerial photographs (scale 1:20,000) and county road maps (1:126,720). Test holes drilled during the early part of the study were logged by Larry Froelich and Alain Kahail of the North Dakota State Water Commission. Dan Walker and Randy Rickford operated the North Dakota Geological Survey auger during the test drilling. Garth Anderson provided data from his mapping and drilling in the Minot area (results included in Kehew, 1983). Unpublished geological and groundwater data were provided by the North Dakota State Water Commission. Test-hole logs and engineering lab test data were provided by the North Dakota State Highway Department, the U.S. Army Corps of Engineers, and Soil Exploration Company. Grain-size analyses were made in the Hydrologic Laboratory; fossil wood was identified by the Paleontology and Stratigraphy Branch, and the carbon-14 age determinations were made by the Isotope Geology Laboratory--all of the U.S. Geological Survey.

Acknowledgments

I acknowledge the efforts of Wayne A. Pettyjohn, who initiated this study in the 1960s and who mapped a considerable part of the two-county area at that time. Special thanks are due to Alan Kehew, who mapped a sixteen-township area of Ward County in the early 1980s.

Regional Topography and Geology

Renville and Ward Counties, in north-central North Dakota, have a combined area of 2,915 square miles in Tps151 to 164N, and Rs 81 to 89W. The area is located between 47° 50' 52" North Latitude on the south, 49° North Latitude (the U.S.-Canadian border) on the north, 100° 58' 12" West Longitude on the east and 102° 14' 2" West Longitude on the west.

The surface deposits in Renville and Ward Counties consist almost entirely of Pleistocene sediments of Late Wisconsinan age overlying deposits of older glaciations and bedrock of Cretaceous and Tertiary age. The Paleocene Bullion Creek Formation is exposed along the slopes of the Des Lacs valley and along the Souris River valley, especially southeast of Burlington. It is also exposed in the many small tributary valleys bordering the Des Lacs and Souris Rivers, particularly the tributaries that enter the larger valleys from the southwest. The Bullion Creek Formation exposures consist of alternating beds of sand, silt, clay, and lignite. Marine sediments of the Paleocene Cannonball Formation are exposed in road cuts just east of Sawyer. The Cretaceous Fox Hills and Hell Creek Formations, which subcrop beneath the glacial deposits in the northeasternmost part of the area, are not exposed in either county.

The slope on the preglacial bedrock surface in Renville and Ward Counties is northeastward, generally down the bedrock surface beneath the modern Missouri Coteau. The dip of the preglacial bedrock layers is toward the southwest, reflecting the position of the two-county area on the eastern side of the Williston Basin, a cratonic basin, the center of which is in western North Dakota.

Renville County is in the Central Lowland Province and Ward County lies in both the Central Lowland and Great Plains physiographic provinces. In the report area, the Central Lowland is subdivided into the Western Lake District and the Missouri Escarpment District of the Glaciated Plains. The Great Plains in Ward County consist of the Missouri Coteau and the Coteau Slope (fig. 1).

The Western Lake District consists mainly of low-relief plains that slope gently to the northeast. The glacial deposits range up to 750 feet thick, possibly 800 feet thick in northwestern Renville County. Generally, the thickness of the glacial sediment increases to the northeast, but the thickest glacial deposits are in the buried river valleys.

The Missouri Escarpment extends from the Des Lacs and Souris River valleys to the eastern margin of the Missouri Coteau (fig. 1). The surface of the escarpment, which is controlled in part by the underlying bedrock, is inclined rather steeply to the northeast. The northeast-facing escarpment is an abrupt feature along most of its length in Ward County, and local relief may exceed 300 feet.

The Missouri Coteau is a belt of collapsed glacial topography that has nonintegrated drainage and higher elevation than adjacent areas. Locally, bedrock of the Fort Union Group of Paleocene age crops out; however, the glacial deposits on the Missouri Coteau exceed 250 feet in thickness in places. The southwestern margin of the

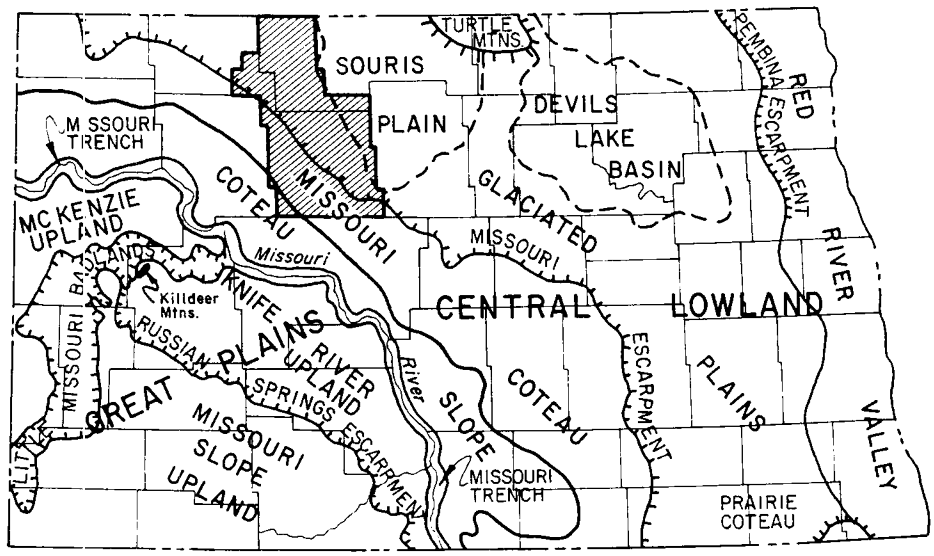

Figure 1. Physiographic map of North Dakota showing the location of Renville and Ward Counties.

Missouri Coteau separates an area with nonintegrated drainage (northeast of the margin) from one that has integrated drainage (southwest of the margin).

Most of the two-county area is drained by the Souris and Des Lacs Rivers, which nearly bisect the area of study. These streams are in the drainage of the Red River of the North, which empties into Hudson Bay. Only two tributaries of the Missouri River traverse southwesternmost Ward County. The remainder of the area is poorly drained and is characterized by numerous prairie potholes. The northeast-flowing tributaries of the Souris and Des Lacs Rivers are relatively long and deeply incised, compared to the southwest-flowing tributaries, which are generally only a mile or two long. Long, narrow ice-marginal channels trend parallel to the Souris River in a wide arc and empty into the Souris River in Bottineau and McHenry Counties. Most of these channels carry only intermittent flow. Local relief northeast of the Missouri Escarpment is only a few feet and the area is poorly drained. An average of nine closed depressions occur per square mile. These depressions collect runoff from small areas and contain water for at least six months of the year. In addition to the larger depressions, thousands of small ponds or prairie potholes contain water for only a few days or weeks at a time after a rain or in the spring when the snow melts.

Only two waterways on the Missouri Coteau drain into the Missouri River system. Lakes and intermittent streams lie in an elongate sag that extends from Rice Lake through Douglas and into McLean County. During some wet periods, the lakes overflow and may drain into Middle Branch Douglas Creek.

Several tributaries enter the Hiddenwood Lake drainage, which is blocked by glacial deposits in McLean County. During the spring and in wet seasons, the lakes may overflow into swampy areas prior to gaining access to the Missouri River by way of Deep Water Creek in McLean County.

With the exceptions noted above, drainage on the Missouri Coteau and the Coteau Slope in Ward County is interior. Potholes are abundant and collect runoff and precipitation throughout the year.

STRATIGRAPHY

General Statement

Renville and Ward Counties lie within the Williston Basin, one of the largest structural troughs in North America. The center of the basin is in McKenzie County, to the southwest of the study area. Rocks near the surface in the area are flat-lying or dip only a few degrees to the southwest into the basin.

Most of the rock and sediment exposed at the surface in Renville and Ward Counties was deposited by glaciers during Pleistocene time. Marine and nonmarine sedimentary rocks underlie the glacial deposits. Several hundred oil and gas tests drilled in the two-county area indicate that the sedimentary sequence there is between 8,000 and 11,000 feet thick, generally thickest in the western areas. Crystalline rocks of Precambrian age underlie the sedimentary rocks; a total of 12 test holes have penetrated as deep as the Precambrian.

The rocks deposited in the Williston Basin during the Paleozoic Era and during Triassic and Jurassic time, generally consist of evaporites and carbonates interbedded with some clastic rocks (fig. 2). Deposition of clastic

AGE	SE-QUENCE	UNIT NAME	DESCRIPTION	THICKNESS (feet)
Holocene	TEJAS	Oahe Formation	Sand, silt, and clay	0-50
Quaternary		Coleharbor Group	Till, sand, gravel, silt, and clay	0-500
Tertiary	ZUNI	Ft. Union: Sentinel Butte/ Bullion Creek	Shale, sandstone, and lignite	0-700
		Ludlow/Cannonball	Shale, sandstone, marine sand, clay, and lignite	0-360
Cretaceous		Hell Creek Formation	Sandstone, shale, and lignite	0-400
		Mont.: Fox Hills Formation	Marine sandstone	0-400
		Pierre Formation	Shale	1,200±
		Colorado: Niobrara Formation	Calcareous shale	900 to 1,500
		Carlile Formation	Shale	
		Greenhorn Formation	Calcareous shale	
		Belle Fourche Fm.	Shale	
		Dakota: Mowry Formation	Shale	270 to 360
		Newcastle Formation	Sandstone	
		Skull Creek Formation	Shale	
		Inyan Kara Formation	Sandstone	250±
Jurassic		Undifferentiated	Shale, sandstone, carbonates, and gypsum	700-900
Triassic	ABSAROKA	Spearfish Formation	Siltstone and sandstone (redbeds)	180-300
Permian			(Absent in Renville-Ward)	0
Pennsylvanian		Amsden and Minneulsa Fm.	Sandstone, shale, and carbonates	0-400
Mississippian	KASKASKIA	Big Snowy Group	Shale, sandstone, and carbonates	0-400
		Madison Group	Limestone, dolomite, and anhydrite	1,200-1,800
Devonian		Bakken Formation	Siltstone and shale	20-70
		Three Forks Formation	Shale, siltstone, and dolomite	100-220
		Birdbear Formation	Limestone	80-100
		Duperow Formation	Dolomite and limestone	300-420
		Souris River Fm.	Dolomite and limestone	250-300
		Dawson Bay Fm.	Dolomite and limestone	100-150
		Prairie Formation	Anhydrite, halite, and potash	100-500
		Winnipegosis Fm.	Limestone and dolomite	200-300
Silurian	TIPPECANOE	Interlake Formation	Dolomite	500-800
		Stonewall Formation	Dolomite and limestone	70-120
Ordovician		Stony Mountain Fm.	Dolomite, limestone, and shale	120-160
		Red River Formation	Limestone	550-650
		Winnipeg Group	Siltstone, sandstone, and shale	200-275
Cambrian	SAUK	Deadwood Formation	Limestone, dolomite, shale, and sand	200-550
Precambrian basement rocks				

Figure 2. Stratigraphic column for Renville and Ward Counties.

rocks, however, predominated from the latter part of the Paleozoic. Throughout the Paleozoic, the Williston Basin was at times a cratonic basin or a shelf area that bordered a miogeosyncline farther west. At other times, the area was flooded by seas that followed a trough extending eastward from the miogeosyncline across the area of the central Montana uplift and the central Williston Basin. At times, the entire Williston Basin area was above sea level and subjected to subaerial erosion for relatively short intervals of time.

The oldest rocks that subcrop directly beneath the glacial deposits are shales of Cretaceous age. During the Cretaceous Period, shale and sandstone were the principal deposits throughout the Williston Basin. These sediments were deposited in a huge epicontinental seaway that extended southward through Canada and the western conterminous United States. During the Laramide orogeny, in Late Cretaceous and early in Tertiary time, the area of the Williston Basin was, for the most part, above sea level and continental deposits of sandstone, shale, and lignite were deposited. However, early in the Tertiary Period, a narrow arm of a sea did exist in some parts of the basin and marine sediments of the Cannonball Formation were deposited.

Cretaceous and Tertiary Rocks

The Cretaceous has traditionally been subdivided into three main groups: the Dakota Group, the Colorado Group, and the Montana Group. The lowermost of these is the Dakota, which includes the Inyan Kara, Skull Creek, Newcastle, and Mowry Formations. The Inyan Kara Formation is an interbedded shale and sandstone unit, which in Renville and Ward Counties averages about 250 feet thick. The lower part of the Inyan Kara is nonmarine in origin, while the upper part of the formation is partly marine. Drillers commonly report a "first artesian flow" and a "second artesian flow," which are separated by a predominantly shale section.

The sandy marginal marine characteristics of the upper Inyan Kara are overlapped by siltstone and shale of the Skull Creek Formation. The overlying Mowry Formation consists of dark-gray to black shale and is similar to the Skull Creek. The Mowry and Skull Creek generally range from 220 to 360 feet thick in Renville and Ward Counties. Locally, a lenticular sandy zone is present at the base of the Mowry. Where present, this sandstone is called the Newcastle Formation.

The Colorado Group, of Late Cretaceous age, consists of as much as 900 to 1,050 feet of light-gray to dark-gray, limy shale that overlies the Dakota Group. It is divided into four formations (in ascending order): the Belle Fourche, Greenhorn, Carlile, and Niobrara.

The Colorado Group is overlain by the Montana Group, which consists of about 1,200 feet of gray, locally bentonitic, Pierre Formation shale, and more than 400 feet of fine-grained clastics of the Fox Hills Formation. The Montana Group shales, in turn, may be overlain by as much as 400 feet of clastic sediments of the Hell Creek Formation.

The Fort Union Group was deposited during early Tertiary time. The continental and marine beds of the Fort Union Group are commonly divided into the Cannonball, Ludlow, Bullion Creek, and Sentinel Butte Formations. The Cannonball and Ludlow Formations, which form the basal part of the Fort Union Group, were deposited contemporaneously--the Cannonball as a marine deposit and the Ludlow as the equivalent continental strata. The Cannonball Formation crops out along the walls of the Souris River valley in the vicinity of Sawyer, where the formation consists of sandy shale. Elsewhere, the Cannonball generally consists of alternating beds of sand and shale. The Ludlow Formation is not exposed in Renville and Ward Counties, although it underlies the area. The Ludlow generally consists of interbedded fine sand and lignitic shale where it is exposed in other parts of North Dakota. The Cannonball and Ludlow Formations probably interfinger in the subsurface of the report area as they do in other parts of the Dakotas. Consequently, these formations are difficult to differentiate by drill-hole cuttings. The combined thickness of the Cannonball and Ludlow Formations in Renville and Ward Counties is about 360 feet.

The Bullion Creek and Sentinel Butte Formations in the two-county area consist of about 700 feet of interbedded shale, siltstone, sandstone, and lignite in the western part of the area, but they thin to almost nothing where the Cannonball Formation crops out near Sawyer. The sediments were deposited in rivers, streams, swamps, and shallow lakes on an alluvial plain. The Bullion Creek Formation crops out at many places along the Des Lacs River valley and along the Souris River valley below

Burlington (pl. 1). On the Missouri Escarpment south of Sawyer, the glacial deposits thin appreciably and lignite seams interbedded with sandstone and siltstone are exposed.

After the Sentinel Butte Formation was deposited and before the first period of glaciation, the Fort Union Group was gently warped. Erosion removed the Sentinel Butte Formation and much of the Bullion Creek Formation in the central and northern parts of the two counties and produced a near-badlands topography throughout the area. This rugged topography was modified considerably by subsequent glacial action.

It is generally difficult or impossible to distinguish the various formations in the Fort Union by examining the test-hole cuttings. In fact, the rocks from the base of the glacial sediments, downward to the top of the Pierre Formation, are so similar that even tentative correlations are difficult. The Ludlow Formation appears to underlie the Cannonball Formation in the Carpio area, but elsewhere the Cannonball beds intertongue with the Ludlow and Bullion Creek Formations. The Fort Union Group has a total thickness of about 615 feet in the Carpio area where the Ludlow and Cannonball have a total thickness of 360 feet and the Bullion Creek is about 255 feet thick.

Configuration of the Bedrock Surface

The topography on the bedrock surface underlying the glacial deposits in Renville and Ward Counties is shown on figure 3. This generalized map is based mainly on test-hole data, although a few outcrops of bedrock provided additional control. In general, the eroded preglacial surface sloped toward the northeast at approximately 16 feet in a mile. The valleys of the Des Lacs and Souris Rivers are deeply incised on the regional slope as are the glacial diversion trenches.

Southwest of the Des Lacs River and near the lower Souris River, downstream from Burlington, the regional slope is considerably greater than to the northeast. This slope, which is particularly steep in the vicinity of Kenmare (T160N, R88W), reflects the more abrupt rise of the preglacial elevation of the Missouri Escarpment and the Missouri Coteau along the Coteau Slope. The northeastward slope there is 50 feet or more in a mile. The remainder of the two-county area has a bedrock

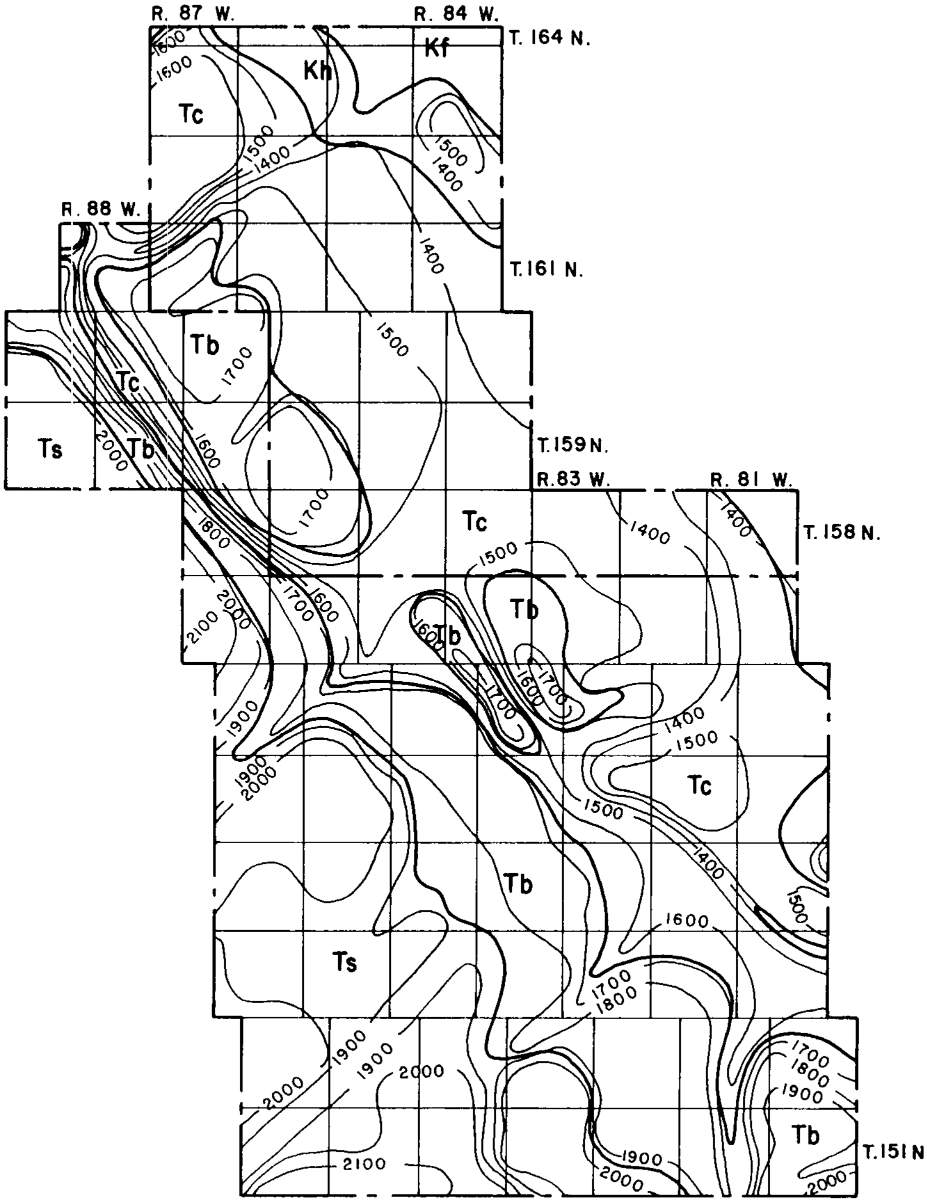

Figure 3. Subglacial geology and topography of Renville and Ward Counties. The highest bedrock elevations and youngest formations occur in the western part of the area, which slopes generally northeastward. Kf = Fox Hills Fm.; Kh = Hell Creek Fm.; Tc = Cannonball Fm.; Tb = Bullion Creek Fm.; Ts = Sentinel Butte Fm.

surface that is flat to gently sloping at about 13 feet per mile to the northeast. The Des Lacs and lower Souris Rivers have eroded narrow, steep walls nearly 200 feet below the slope of the regional bedrock surface.

Major bedrock topographic features probably were formed by Tertiary weathering and erosion. In a few places, particularly on the Missouri Coteau, a weathered zone on the bedrock was penetrated by test holes. Throughout most of the area, however, glacial erosion stripped off most or all of the Tertiary soil and weathered zone, and modified the topographic features, including the existing drainage system.

Pleistocene Sediment

Renville and Ward Counties are covered by glacial and glaciofluvial sediment, except in places where the Fort Union Group sandstones and shales (mainly the Bullion Creek Formation) crop out in a few small and local exposures. The thickness of the glacial deposits generally ranges from absent at the bedrock outcrops to about 400 feet (fig. 4). The greatest thickness of glacial deposits penetrated in the two-county area was 800 feet in a test hole in section 27, T162N, R87W, about 12 miles northeast of Kenmare. This test hole was drilled after the basic-data report was published (Pettyjohn, 1968). Another test hole in the same section penetrated 655 feet of glacier sediment. Test holes drilled in sections 4 and 9, T155N, R83W, penetrated 432, 430, and 422 feet of glacial sediment. In most places, however, the glacial deposits are fairly uniform in thickness, except where the major streams and meltwater valleys have removed them. The average thickness of the glacial deposits penetrated by 178 test holes drilled during the test-drilling program was 165 feet.

All the sediment related to glacial deposition in Renville and Ward Counties, 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 formal formations by various geologists. However, most of the detailed stratigraphic work has been done in eastern North Dakota where the glacial sediments were deposited by glaciers that advanced southward, up the Red River Valley (the Des Moines Lobe) and around

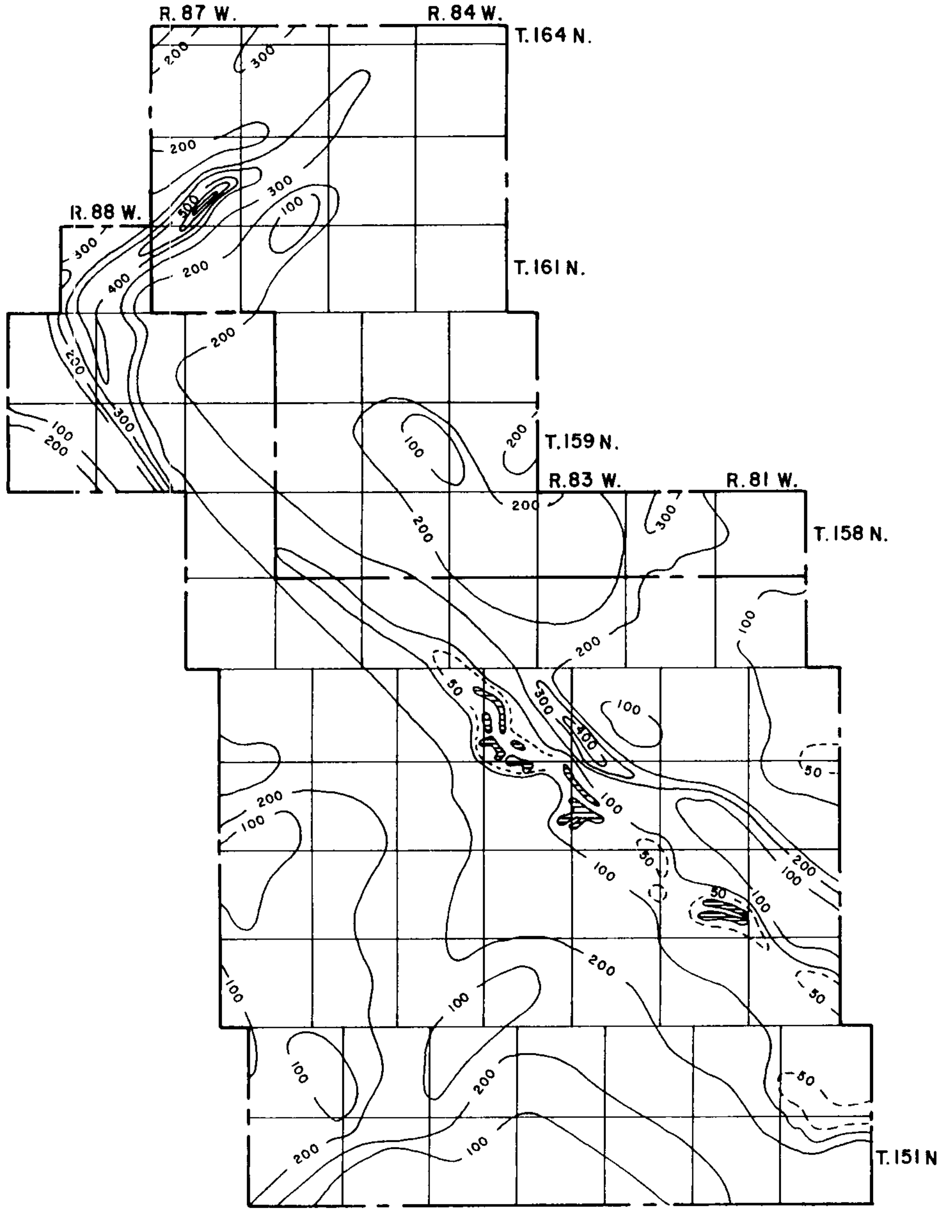

Figure 4. Thickness of the Coleharbor Group deposits in Renville and Ward Counties. The thickest glacial deposits are in the northwest part of the area, in a buried valley, where more than 600 feet of sediments occur; one test hole in T162N, R87W reported over 800 feet of sediment. The shaded areas represent discontinuous glacial deposits with numerous exposures of pre-Coleharbor formations. Thicknesses given in feet.

the east side of the Turtle Mountains (the Leeds Lobe). The glacial sediments in Renville and Ward Counties were deposited by glaciers that advanced around the west side of the Turtle Mountains (the Souris Lobe), and although some stratigraphic work has been done along Lake Sakakawea in McLean County (Ulmer and Sackreiter, 1973), the formal glacial stratigraphy in this part of North Dakota is not yet well understood. Some of the formal units that have been described for the eastern North Dakota glacial sediments may be regionally correlatable with units in Renville and Ward Counties. However, since the present study did not include any specific effort to formally describe the discrete units of glacial sediment that can be attributed to specific units of differing ages, no attempt has been made to compare the glacial stratigraphy in the two-county area with that in any other area.

Kehew (1983) studied the geology and geotechnical conditions in a 16-township area of eastern Ward County that includes the Minot area and he later studied a part of southwest Ward County (Kehew, 1984). Much of the discussion of till stratigraphy included in this report comes from his studies. Kehew's are the only studies that have dealt in any detail with the specific physical characteristics of the glacial till units. One of Kehew's objectives was to characterize and differentiate till units using quantitative lithologic parameters (table 1) and to relate tills to ice-marginal positions representing specific glacial advances. Differences in lithology are to be expected in tills deposited during glacial advances of different ages and from ice moving in different directions. The methods used for till characterization by Kehew included hand-specimen appearance, field stratigraphic relationships, weight percentages of sand, silt, and clay fractions of the till matrix, and lithology of the very coarse-sand fraction (1-2 mm).

Laboratory grain-size analyses were done by standard sieve and hydrometer methods. The specific laboratory procedure used by the North Dakota Geological Survey for till samples is described by Perkins (1977). The very coarse-sand lithology is determined by counting individual grains under the binocular microscope. These were divided into groups including Precambrian igneous and metamorphic, carbonate, shale, lignite, secondary precipitates, and miscellaneous categories. Percentages of lignite, secondary precipitates, and miscellaneous groups were

Table 1. Very Coarse Sand Percentages

Unit	n	Ig/Met. $\bar{x}$	Ig/Met. SD	Carb. $\bar{x}$	Carb. SD	Sh. $\bar{x}$	Sh. SD	Lig. $\bar{x}$	Lig. SD
A	63	68.5	4.3	28.3	7.3	3.3	1.4	0	0
B	94	74.3	4.1	21.3	3.8	4.3	2.5	3.8	6.2
Martin	4	49.9	5.5	28.7	4.3	21.4	3.9	4.1	2.2
Ryder	6	34.6	3.6	30.1	4.1	35.5	5.4	0.5	1.2
Makoti	13	40.9	8.2	22.8	2.4	36.3	9.1	7.7	5.6
Blue Mtn.	22	33.4	5.6	24.1	4.1	42.6	7.4	0.3	1.1
Snow School	6	43.6	5.0	35.0	3.0	21.4	3.2	*	*

* - abundant lignite in sample

based on the total grain count. Percentages of igneous and metamorphic, carbonate, and shale grains were calculated by normalizing the sum of these groups as 100 percent. Finally, the ratio of igneous and metamorphic to igneous and metamorphic plus carbonate grains was calculated. Of the two laboratory techniques, grain-size distribution is most useful for tills of vastly different provenances. This technique was of limited usefulness for differentiating tills in Ward County. Very coarse-sand lithology has proven to be an effective stratigraphic tool in localized stratigraphic studies in areas such as northeastern North Dakota (Harris and others, 1974; Hobbs, 1975) and has been used as an aid to regional stratigraphic correlation (Moran and others, 1976). In Ward County as well, coarse-sand lithology is an effective stratigraphic tool.

The very coarse sand grain counts indicate a combination of local and distant sources. Igneous and metamorphic grains include Canadian Shield Precambrian sources as well as local sources derived from Fort Union bedrock. Carbonate grains are derived from distant exposures of Paleozoic limestone and dolomite formations. The shale content of the till is probably derived mainly from Cretaceous marine shales exposed east and northeast of central North Dakota. Some grains derived from Fort Union bedrock may be included in this fraction. The source of the lignite is the Paleocene Fort Union Group. The relative proportions of the various very coarse-sand groups give a relative indication of the direction of glacial advance. For example, tills with high shale content were probably derived from glaciers advancing from the east or northeast. In contrast, tills low in shale must have been deposited by south- or southeast-moving glaciers.

The most current compilation of ice-marginal correlations in North Dakota (Clayton and others, 1980) indicates 13 ice-marginal positions in the state. Although age dating of most North Dakota glacial deposits is lacking, it appears that most of the ice margins represent advances and readvances of the Late Wisconsinan Laurentide ice sheet. During the late phases of Late Wisconsinan deglaciation, glacial advances and readvances occurred by the movement of thin ice lobes into low-lying areas. Two such lobes may have flowed southward around the Turtle Mountains into North Dakota, the Leeds Lobe east of the Turtle Mountains, and the Souris Lobe around the west side. Renville and Ward Counties lie entirely within the extent of the Souris Lobe. Several ice-marginal positions cross the two-county area (Clayton and others, 1980) and, consequently, several different till units occur in the area (fig. 5).

Samples for laboratory analysis were taken from surface exposures and auger holes drilled during the study. Auger samples included samples brought to the surface during auger rotation as well as split-barrel penetration samples. The maximum depth reached was usually about 75 feet. Therefore, only the upper portion of the glacial section could be studied by this method. Some samples obtained during drilling for the county groundwater study were analyzed. These rotary-drilled samples were often contaminated by overlying material, particularly in places where a sand layer was penetrated.

Glacial Stratigraphy

Preliminary studies of the stratigraphy of the glacial deposits of the Coleharbor Group have been restricted to the eastern part of Ward County and to southwestern Ward County (Kehew, 1983, 1984). No studies have been conducted in Renville County, but the results of the eastern Ward County area should be generally applicable to Renville County because all of Renville County lies within--behind--ice margin 13, the most recent margin recognized in North Dakota (fig. 5) (Clayton and others, 1980). In southwestern Ward County, at least three discrete layers of glacial sediment can be recognized. Each glacial advance resulted in a new layer of sediment, but during each subsequent advance, much of the older glacial material probably was incorporated into the advancing glacier and redistributed. The separate layers of glacial deposits are lithologically similar, but they can be distinguished by the presence of buried oxidized zones, boulder pavements, and widespread buried sand and gravel deposits. Kehew (1984) found that the older tills can be differentiated by a study of their very coarse-sand lithology.

As the glaciers advanced and retreated, the underlying bedrock surface was eroded and subdued, and in most areas buried under thick deposits of glacial sediment. Much of the glacial ice that covered the Missouri Coteau stagnated there and left characteristic topographic features that will be discussed later.

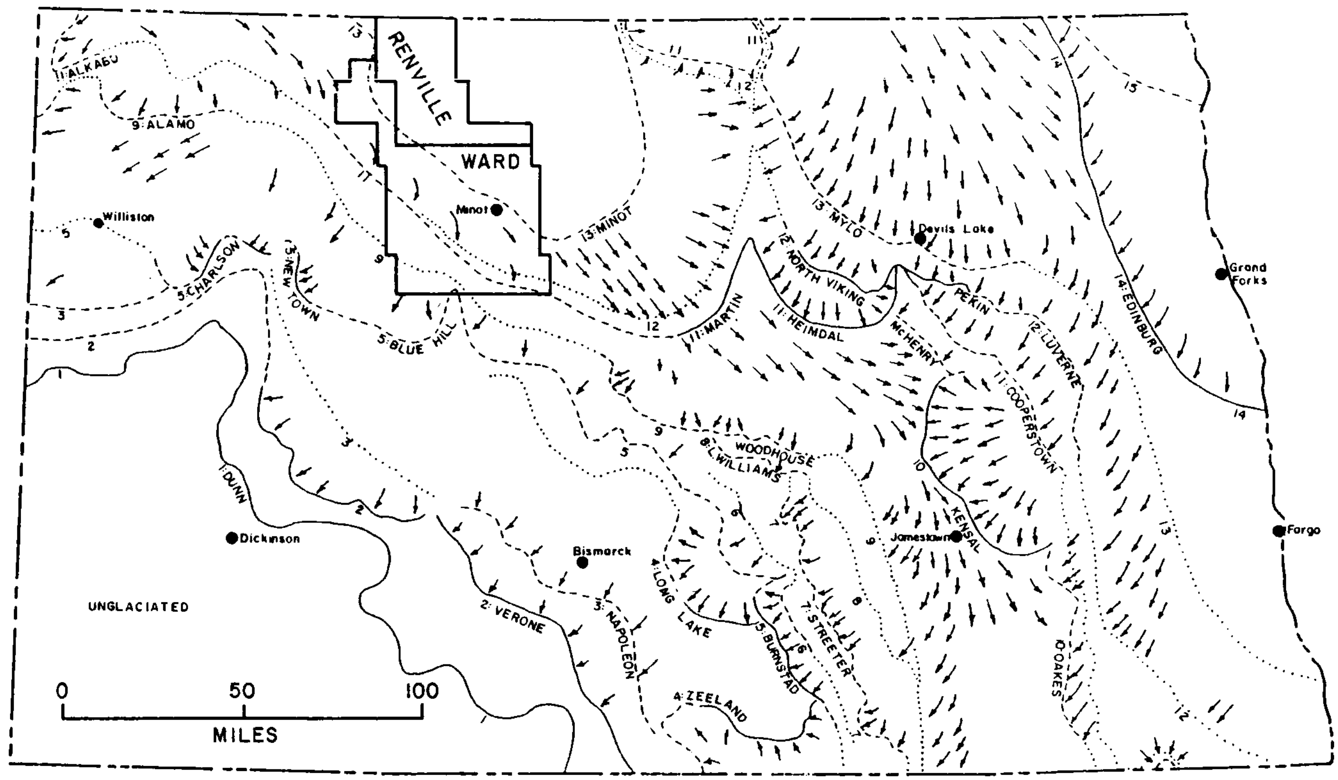

Figure 5. Ice-movement directions (arrows) and outer margins of glacial advances.

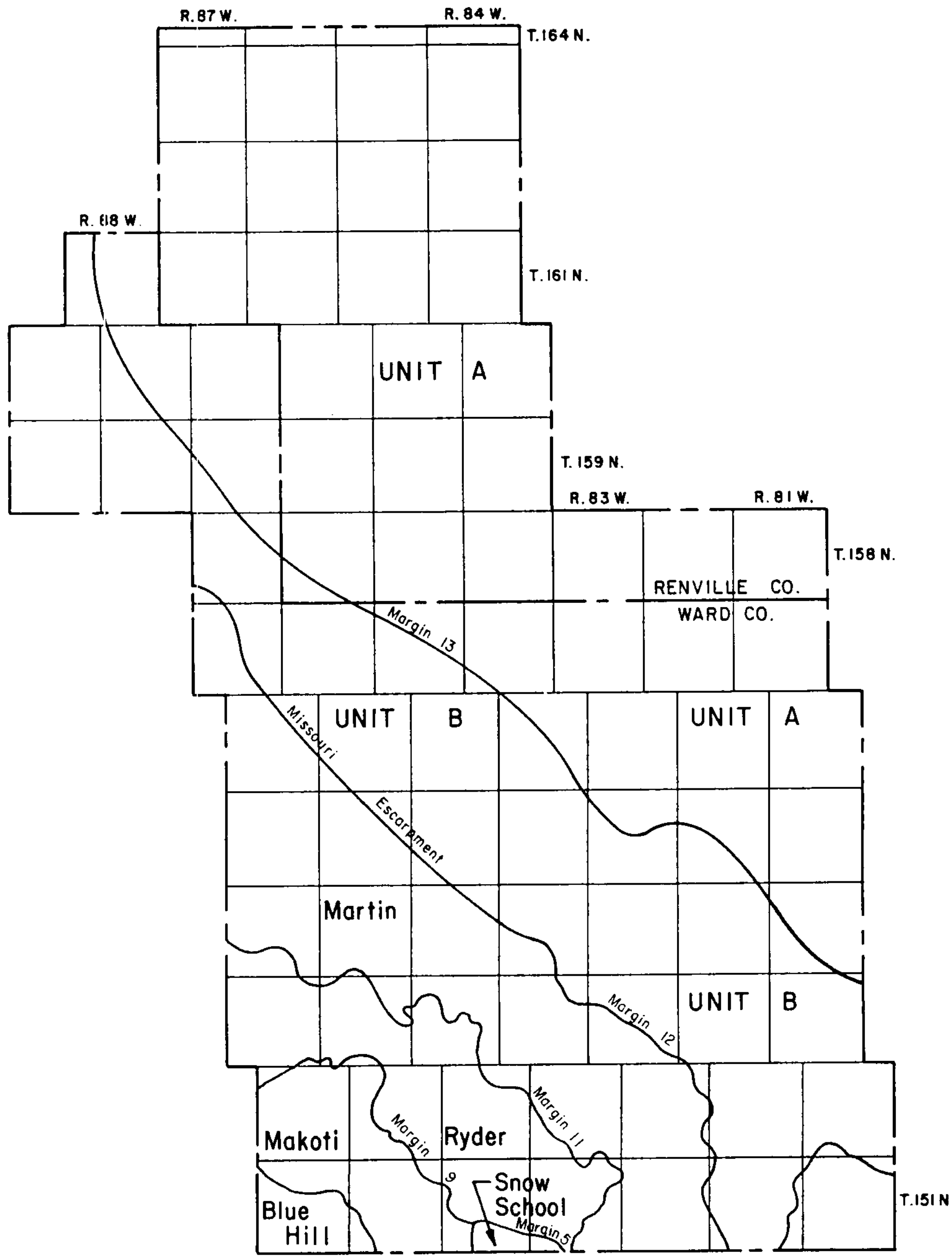

Figure 6. Surface till units in Renville and Ward Counties. The oldest till unit, the Snow School, occurs only at the southern edge of the area and is probably early Wisconsinan in age. The Blue Hill, Makoti, and Ryder units are all probably Late Wisconsinan in age, as are Units A and B.

Snow School Formation

The oldest glacial deposits exposed in the two-county area cover a small area in the south-central part of Ward County, in the southeast part of T151N, R85W (fig. 6). This small area of collapsed glacial topography is bounded on the west by the Blue Hill moraine and on the north and east by younger glacial deposits and by outwash. The older glacial deposits cover wide areas to the south in McLean County where they were identified as belonging to the early Wisconsinan Napoleon Glaciation (Bluemle, 1971). Clayton and Moran (1982) correlated the Napoleon deposits in this area with the Snow School Formation (Ulmer and Sackreiter, 1973). This formally named unit will be used here to refer to these deposits. The Snow School deposits were penetrated beneath the Makoti moraine at a depth of 173 to 190 feet in a test hole in section 15, T151N, R87W. Here, they lie directly on the Sentinel Butte Formation and are overlain by stream gravel and younger glacial deposits.

The Snow School glacial deposits consist of silty and sandy till that is relatively high in carbonates with an abundance of lignite chips (table 1). Pebbles in the till are coated with manganese oxide. Well data indicate that the entire thickness of the till, which may be as much as 30 feet, is oxidized.

The undulating surface of the Snow School deposits probably reflect the topography of the underlying preglacial surface. Drainage on the Snow School Formation deposits is integrated.

Blue Hill Deposits

An area in southwestern Ward County is surfaced by Late Wisconsinan glacial deposits that have been informally called "Blue Mountain" (Colton and others, 1963; Pettyjohn, 1967a) or "Blue Hill" (Clayton and others, 1980). The deposits will be referred to here as Blue Hill (fig. 6). In the extreme southwestern part of Ward County, where the Blue Hill deposits are at the surface, the entire thickness is oxidized to shades of red, yellow, and brown. The till is generally silty to sandy and slightly cohesive with a relatively high percentage of shale (table 1). Associated surficial sand and gravel is commonly a poorly sorted mixture of sand and angular to subangular gravel composed of carbonates and chips of shale and lignite. Lake silts and sands that occur in association with the Blue Hill deposits are found mainly on elevated lake plains.

Pettyjohn (1967a) considered the Blue Hill deposits of southwestern Ward County to be of Early Wisconsinan age. This is unlikely in view of the fact that stagnation features present on the Blue Hill glacial deposits form an interlocking pattern with similar stagnation features all the way to the Missouri Escarpment. Such an interlocking pattern could result only if a continuous sheet of stagnant ice covered the Missouri Coteau and melted everywhere over that area at about the same time. Pettyjohn states that the Blue Hill deposits are oxidized to an average depth of 26 feet and that he has traced this oxidized zone nearly 40 miles north and more than 30 miles east of the Blue Hill moraine in Ward County. However, it is more likely that he was actually drilling into the oxidized zone on top of the Snow School Formation; certainly there is no reason to believe the oxidized zone is necessarily developed entirely on the Blue Hill deposits. The unusually thick oxidized zone (44 feet) on the Blue Hill deposits in southwestern Ward County is probably a composite of oxidized Blue Hill deposits lying on oxidized Snow School deposits.

The Blue Hill deposits crop out along the valley walls of the Des Lacs River in the Donnybrook area and along the Souris River valley from Minot nearly to Verendrye in McHenry County. Presumably, the oxidized material in the upper part of the Blue Hill deposits in the area was, in most places, incorporated into glacial ice during the subsequent advance of the Souris Lobe.

Lemke and Kaye (1958) described an exposure of two glacial drift sheets near Donnybrook. In that area, the older layer of glacial sediment, the Blue Hill deposits, consists of till and associated glaciofluvial deposits that are at least 30 feet thick. Although the upper and lower layers are lithologically similar, the older material shows a greater degree of oxidation. The two deposits are separated by a boulder pavement that is generally less than 3 feet thick and that grades laterally into a lime-rich zone. The younger layer of glacial sediment is as much as 50 feet thick. Along both walls of the Souris River valley and along several of its tributaries, the older material is overlain by 10 to 80 feet of younger till.

Younger Glacial Deposits

The Blue Hill glacial deposits are overlain in most of Renville and Ward Counties by younger glacial till that tends to be somewhat more pebbly and bouldery than the underlying Blue Hill deposits. These materials were deposited by several minor pulsations of the Souris Lobe over a relatively short period of Late Wisconsinan time. They include materials that were deposited by glacier lobes that have been variously referred to as Martin (Lemke, 1960; Colton and others, 1963; Clayton, 1966; Pettyjohn, 1967a; Bluemle and others, 1967; and Clayton and others, 1980), Makoti and Ryder (Pettyjohn, 1967a), and Minot (Clayton and others, 1980). These Late Wisconsinan glacial deposits cover the surface over most of the two-county area.

The relatively few samples that have been analyzed from the Makoti, Ryder, and Martin tills suggest that they can be differentiated by a study of their very coarse-sand lithology (table 1). Oxidized zones were not present at the tops of the Makoti and Ryder tills when these tills were encountered in the subsurface beneath younger tills. Contacts between these till units are commonly marked by boulder concentrations.

Kehew (1983; 1984), in a study of eastern Ward County, was able to recognize two stratigraphic units in the upper portion of the till section. Laboratory data for these units are shown in table 1. Unit A, the uppermost unit, is assumed to be the till deposited by the glacier that advanced to ice margin 13. Unit B consists of surface till samples beyond (south and west of) margin 13 and samples of the till below unit A behind (north and east of) margin 13. The contact between units A and B in the subsurface is usually recognized by the presence of a sand lens or boulder concentration between the two units. Although units A and B are similar in texture, small but consistent differences were noted in the two tills. Unit B is higher in igneous and metamorphic grains, lower in carbonate, and slightly higher in shale. Unit B also contains more lignite. The lignite percentage cannot be used as a precise indicator because of the tendency of lignite fragments to easily break apart during sieving and other laboratory procedures. Lignite is useful as a general indicator of till lithology and the difference in lignite content between units A and B is real although the percentages are not accurate. Although unit A does contain lignite, the percentages were less than 0.5 and they are therefore rounded off to zero on table 1.

The basic similarity between units A and B in both texture and coarse-sand lithology suggests that unit A represents a readvance of the same glacier that deposited unit B after only a short retreat. Unit B is correlated with ice margin 11 or 12 (Clayton and others, 1980). These margins represent the maximum advance of the Souris Lobe in North Dakota. Ice margin 13, correlated with unit A, forms a lobate shape behind margins 11 and 12, indicating a readvance of the Souris Lobe.

One explanation for the differences in very coarse-sand lithology between units A and B can be formulated from the stratigraphic relations in the Minot area. Exposures near the bottom of the Souris River valley near Minot indicate that unit B commonly rests directly upon bedrock. This suggests that, as the Souris Lobe was advancing to margins 11 and 12, it incorporated material from the local bedrock into the till. Sand and lignite from the Fort Union Group increased the crystalline and lignite percentages in the very coarse-sand fraction and diluted the carbonate content to some extent. After retreat of the Souris Lobe, the glacier began to advance to margin 13. During this advance, the glacier would have travelled over the thick till of unit B and therefore it would not have been influenced as much by local bedrock. Consequently, unit A is lower in crystalline and lignite grains and slightly higher in carbonate content.

In several places in the Souris and Des Lacs valleys, small amounts of older till crop out above bedrock. These exposures are common in the northwestern part of Ward County in the vicinity of Donnybrook (see previous discussion). Average values of nine samples from these older tills are shown in table 1 for comparison with units A and B. While textures again are not significantly different, a major difference in shale content is apparent. The older tills contain much more shale in the very coarse-sand fraction. The high variation in the older tills indicates that more than one till is present. These tills have not been differentiated by the laboratory studies, but we do have a reasonable idea of the overall regional relationships (see previous discussion of Napoleon and Blue Hill tills). The shale percentages do suggest that the advances that deposited the older tills (at least some of the older tills) came from the east and northeast, where they obtained a high content of shale from the Cretaceous bedrock formations. During deglaciation, the ice sheet thinned and became segmented into topographically controlled lobes near the ice margin (Bluemle, 1965). As the lobes flowed around topographic obstacles, they advanced over different bedrock formations and therefore deposited lithologically different tills. The Souris Lobe flowed around the west side of the Turtle Mountains and deposited the shale-deficient tills of units A and B in the Renville-Ward County area. These tills contrast with those of the Leeds Lobe, which flowed around the east side of the Turtle Mountains and deposited shale-rich tills (Hobbs, 1975; Hobbs and Bluemle, 1987).

Holocene Sediment

The Holocene sediment in Renville and Ward Counties is designated Oahe Formation. The Oahe Formation includes material deposited during Holocene time, the geologic time period beginning at the end of glaciation about 10,000 years ago, and continuing until the present. The Oahe Formation consists largely of organic clay and silt deposited in sloughs and in shallow channels eroded during deglaciation. This sediment, which may overlie sand and gravel of the Coleharbor Group, was deposited by Holocene streams, intermittent runoff from valley sides, and wind. The Oahe Formation deposits are generally thin and confined to valley and slough bottoms.

The most extensive Oahe Formation deposits include Holocene alluvium deposited by the Souris and Des Lacs Rivers and their major tributaries (map unit Qor). This unit is restricted to valleys that contain a recognizable flood plain. The sediment is dark, fossiliferous, obscurely bedded material of clay to sand size representing both channel and overbank deposition. The valleys of the Souris and Des Lacs Rivers contain a maximum of 150 feet of this type of sediment in combination with Coleharbor Group fluvial sediment. As is typical with fluvial environments, the surface and subsurface sediment is highly variable both laterally and vertically. Some test holes in the valleys indicate the presence of more uniform fine-grained sediment suggesting that shallow lakes occupied portions of the valleys from time to time. An example is the Souris River valley upstream from its confluence with the Des Lacs River. Test holes drilled for the Burlington Dam project and for Kehew's study of the geology and geotechnical conditions in the Minot area (Kehew, 1983) penetrated thick silty clay deposits of possible lacustrine origin.

Some sediment was deposited in the Souris and Des Lacs valleys by intermittent streams flowing in gullies or coulees tributary to the main valleys. These fan-like deposits formed where the tributary coulee meets the main valley. The sediment is generally coarser in grain size than that found beneath the flood plains. This type of deposit constitutes a significant part of the thick alluvial valley fill in the Souris and Des Lacs valleys. As the modern rivers meander laterally across their flood plains, they can erode and rework alluvial fan sediment. Alluvial fan deposition, on the other hand, from large coulees, can force the river toward the opposite side of the valley and occasionally dam the main valley. The Souris River may have been dammed intermittently during Holocene time in this manner.

Fine-grained, organic-rich sediment in sloughs is mapped as Qos (slough sediments). Closed depressions (sloughs) occur in collapsed glacial topography as a result of the uneven subsidence of supraglacial debris as the stagnant glacial ice beneath slowly melted. Runoff from surrounding higher ground transports sediment to the slough basin. Additional sediment is contributed by wind and by the decomposition of the abundant vegetation, which grows in the wet environment.

The last Oahe Formation unit, Qol, consists of landslide deposits involving material from the Coleharbor and Fort Union Groups. Landslides have occurred along the valley sides, especially where the bedrock-glacial contact is close to the surface. Most of the landslides occurred during or soon after the rapid erosion of the Souris and Des Lacs valleys as the bedrock materials were subjected to a loss of lateral support. Because the geologic history of the Fort Union Group sediments has resulted in a condition known as overconsolidation, exposure during erosion or excavation causes rebound or volume expansion of the sediments with accompanying loss of strength. Other factors, such as bedding composed of alternating coarse- and fine-grained sediments and aspects of groundwater flow, influence the stability of slopes in the Fort Union Group. In the Des Lacs valley, in the western part of the area, the bedrock-till contact occurs well above the present valley floor. Abundant landslides and slumps, ranging from old to presently active, characterize the valley and tributary slopes. Smaller landslides in till are rare, but they do occur in places.

The landslides mapped commonly consist of parallel slump ridges and slump blocks. Material within the slump blocks remained mostly intact and relatively undisturbed. With several exceptions, landslides in the area appear to be inactive. Cuts or excavations in these deposits could cause reactivation of old planes of failure.

GEOMORPHOLOGY

General Description

The modern landscape in Renville and Ward Counties was formed by the Wisconsinan glacier that covered the area, by meltwater that flooded the land when huge glacial lakes to the north periodically burst, and by meltwater that carved the valleys of the Souris and Des Lacs River valleys. The northeastern two-thirds of the two-county area--the part of the area northeast of the Missouri Escarpment--is primarily low-relief collapsed glacial topography (fig. 7). Over much of the northern part of this area large numbers of low-relief, ring-shaped hummocks ("doughnuts") can be seen on aerial photographs. The Des Lacs and Souris Rivers have carved 100- to 200-foot-deep valleys across the two counties, through the glacial deposits, and into the underlying Tertiary rocks. As a result, the Paleocene Bullion Creek Formation is extensively exposed along the valley walls, especially along the Des Lacs River valley. To the east of the Souris River, repeated floods of glacial meltwater scoured the surface extensively (Kehew, 1982) when glacial Lake Regina, to the northwest of the two-county area, drained repeatedly, releasing huge volumes of water in short periods of time.

The Missouri Escarpment, a 200- to 300-foot-high rise to the southwest, separates the Glaciated Plains from the Missouri Coteau, an area of hummocky, irregular plains that resulted primarily from collapse of superglacial sediment. Areas of collapsed fluvial sediment are found in places on the Missouri Coteau, along with collapsed lake plains. Relief is highest in the areas of high-relief collapsed glacial topography. It is less pronounced in areas of rolling collapsed glacial topography, but in general, the glacial topography southwest of the Missouri Escarpment is considerably more rugged than is the relief

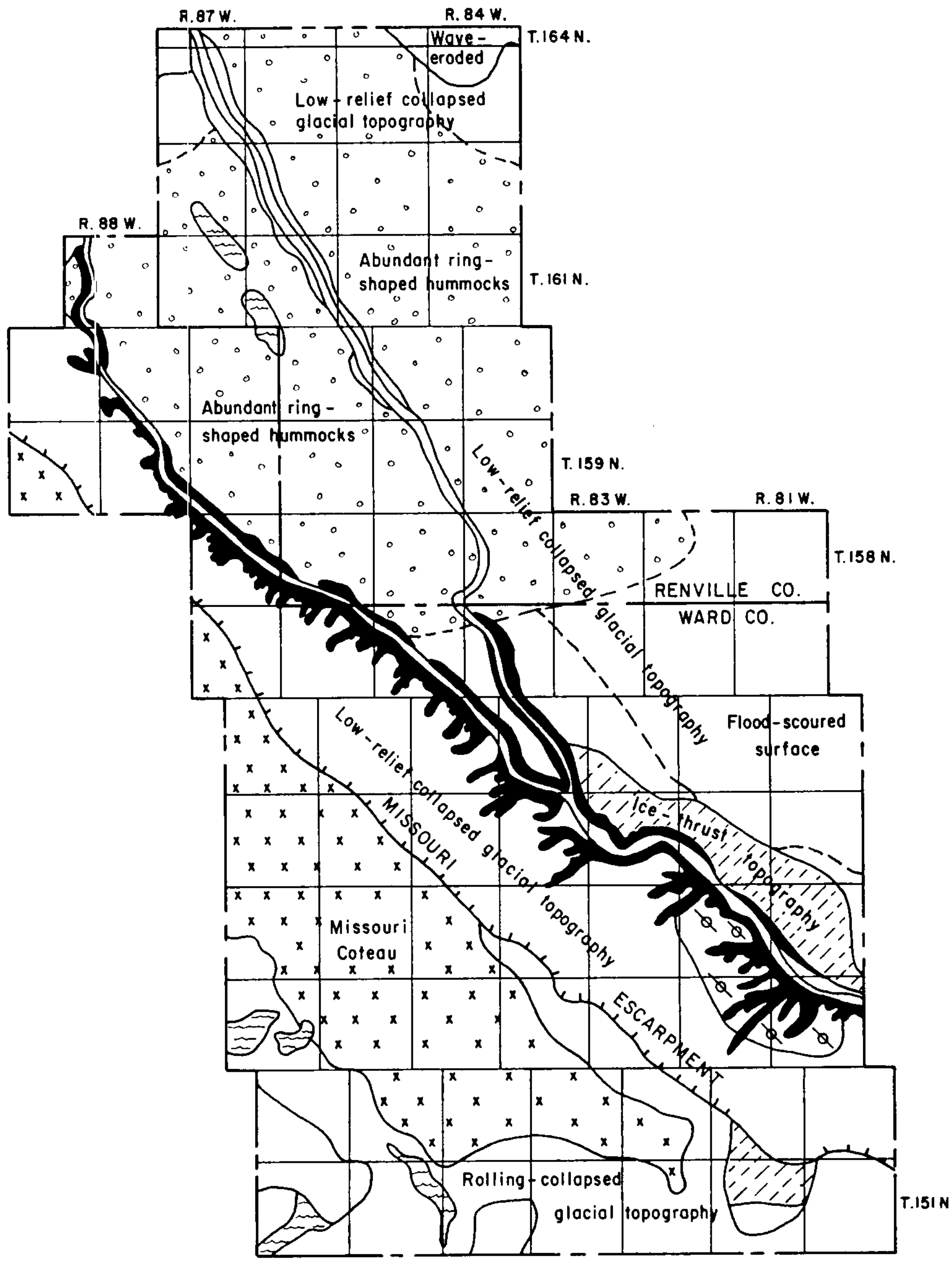

Figure 7. Generalized map of the landform types in Renville and Ward Counties.

over the areas of collapsed topography northeast of the escarpment.

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, or slides to lower elevations in the form of mudflows) when the underlying ice melts out from under it (Clayton, 1967; Deal, 1971; 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) suggested that hummocks resulted from the squeezing of subglacial sediment into irregularities in the base of a stagnant glacier. However, hummocks composed of glacial sediment are essentially identical to hummocks composed of collapsed supraglacial 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; he considered them to be relict pingos. 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).

In Renville and Ward Counties, collapsed glacial topography occurs in two different settings: on the glaciated plains northeast of the Missouri Escarpment, and on the Missouri Coteau. Much of the area of the Glaciated Plains northeast of the Missouri Escarpment to the international boundary is mainly nearly flat-surfaced collapsed glacial topography that has been referred to as ground moraine (Qccu on pl. 1). It is the most extensive topographic unit in the two-county area. This area has low relief, generally less than 10 feet locally, poorly to moderately well integrated drainage, and numerous small, shallow undrained depressions. Maximum slope angles are generally less than 4°. Many of the shallow, undrained depressions are rimmed by low, indistinct, circular disintegration ridges that are best seen on aerial photographs. South of Sawyer several transverse ridges ("washboards" or "washboard moraines") occur. These are especially well developed south and southeast of Velva in McHenry County (Bluemle, 1982). The surface has been washed in places, especially in the eastern part of the area, by running water--by periodic floods from rapidly draining glacier-dammed lakes (Kehew, 1982). These areas are designated Qces on plate 1. The numerous, small channel scars indicate that the water flowed mainly eastward or southeastward over the surface in this area. In other places, conspicuous, although low-relief, ring-shaped hummocks can be seen on airphotos; much of Renville County is marked by abundant hummocks that are, however, not apparent to the observer on the ground. Areas with abundant hummocks are shown with a ring pattern on plate 1 (Qccu).

The boundary between the hilly collapsed glacial topography of the Missouri Coteau and the undulating collapsed glacial topography of the Glaciated Plains is abrupt in many places. In other places, though, the change is gradational and is most easily mapped on the basis of the presence or absence of integrated drainage; drainage on the Missouri Coteau is unintegrated whereas off the Coteau, it is integrated. The abrupt nature of the boundary probably corresponds to bedrock escarpments, knobs, or hills, and where the boundary is indistinct the bedrock surface tends to rise more gently.

The thickness of glacial sediment in areas of undulating collapsed glacial topography ranges from 0 to (possibly) more than 800 feet. It is thin near the Missouri Escarpment in the southeastern part of Ward County and thin or absent along the walls of the Souris and Des Lacs Rivers.

Hilly collapsed glacial topography (Qcch on pl. 1) is well developed on the Missouri Coteau where local relief may exceed 100 feet and slope angles greater than 7° are common. Through drainage is essentially lacking on the Missouri Coteau. The landforms in much of the southwestern third of the two-county area are the result of large-scale glacial stagnation, most of them ultimately the result of mass movement, mainly flowage and sliding. A few disintegration ridges may have formed by upward flowage of saturated material into openings in the base of the ice. Although most of the disintegration ridges on the Missouri Coteau in Ward County are either relatively straight or roughly circular "doughnuts," in several areas they are braided or meandering. These probably originated in stream channels in the stagnant ice. Most disintegration ridges consist almost entirely of till whereas others, located mainly in extensive outwash regions, are draped by gravel. It is difficult to distinguish this type of disintegration ridge from an esker. Figure 8 illustrates two ways circular disintegration ridges can form.

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." Doughnuts are best developed over areas of the Makoti and Ryder glacial units (fig. 6), which have low to medium relief.

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. Ridges formed by material moving down ice slopes and collecting at the base of 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.

Dump ridges are another type of disintegration ridge on the Missouri Coteau in Ward County. They are related to widespread deposits of collapsed outwash and sub-ice channels at the edge of the Martin Glacier. Dump ridges consist of esker-like ridges of coarse gravel and boulders that were deposited at the edges of stagnant ice fields. The ridges were formed by dumping of coarse outwash at the margin of the ice after meltwater carried the finer material downslope forming adjacent outwash deposits. A typical dump ridge is 20 to 45 feet wide at the base, 5 to 20 feet high, and it may be as long as a mile.

Clayton (1967) presented theoretical reasons why most of the circular disintegration ridges are about 500 to 600

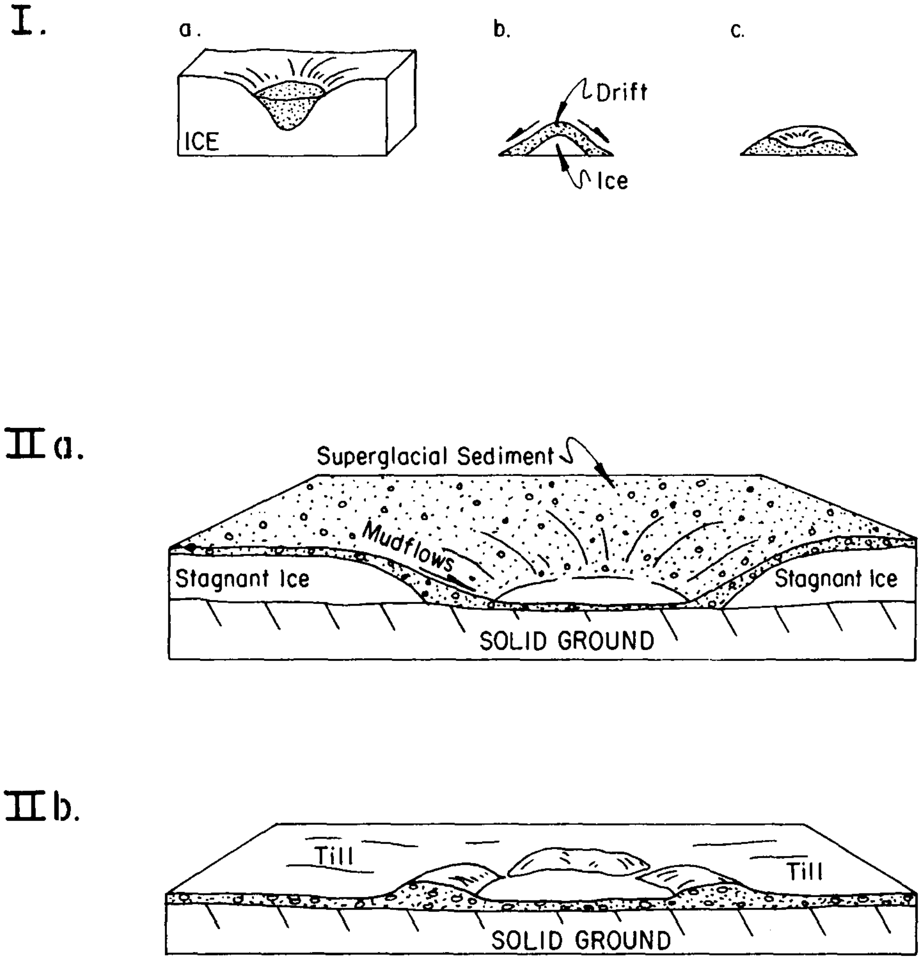

Figure 8. Diagrams showing how circular disintegration ridges form in areas of collapsed glacial topography. Small "doughnuts" (500 to 600 feet across) might form in three stages, as shown in the uppermost series of diagrams (Ia, Ib, and Ic). Large "doughnuts" (1,000 feet or more in diameter) might have formed as shown in the lower two diagrams (IIa and IIb). Diagram I is adapted from Clayton, 1967. Figure A-2; diagram II is adapted from Deal, 1971, Figure 13.

feet across. He pointed out that, beneath a depth of about 150 feet, ice of temperate glaciers tends to become plastic; ice depressions deeper than about 150 to 200 feet are unlikely. If maximum probable ice slopes were about 40 degrees, and maximum depression depths were about 200 feet, the average ice depression would have been about 550 feet in diameter. These values are close to the equivalent values for depressions in modern stagnant glaciers.

In two areas along the Missouri Escarpment in Ward County, areas of glacial topography with internal linearity occur (areas designated Qccl on pl. 1). These areas have up to 100 feet of local relief and numerous chains of potholes. The southern area (Tps151-153N, R82W) appears to represent a lateral or terminal moraine that was deposited as a lobe as the glacier receded from the re-entrant in the Missouri Coteau in that area.

Waterworn Topography

Areas shown as Qces, Qcep, and Qcet are waterworn surfaces with relatively low relief (as opposed to areas of Qcer, described below) that may be cut from till or preglacial materials and may or may not be veneered or covered by fluvial deposits. In places east of Minot, where water spilled out of the Souris spillway and flowed east to glacial Lake Souris, an intricate system of braided and anastomosing channels was cut (Qces on pl. 1). Similar broad areas of washed till that may be veneered by discontinuous patches of sand and gravel, occur in the northeastern part of the area near Kenmare. The topography in these areas is characterized by numerous shallow channels and by a lack of typical collapsed topography adjacent to the channels. This eroded or washed topography is distinct and unmistakable in places, but in other areas, the evidence of erosion is less evident as washed topography grades into unwashed topography.

Along the edge of the Missouri Escarpment, washed areas of till, along with some preglacial bedrock, slope toward the northeast (Qces on pl. 1). In places, however, especially flat, apron-like surfaces occur that are covered by angular gravel deposits up to 5 feet thick. These are considered to be pediments (Qcep on pl. 1). Pediments are especially well-developed in the southeastern part of Ward County in Tps 152 and 153N, Rs 81, 82, and 83W.

Slopewash-Eroded Topography

Slopewash-eroded topography occurs along the sides of the Souris and Des Lacs valleys and along the valleys of their major tributaries (Qcer on pl. 1). These steeply sloping valley sides have been dissected by water flowing in rills, gullies, and coulees, which have developed since the spillways formed during deglaciation. The erosion of these slopes is a discontinuous process most evident during heavy showers or thunderstorms when sediment is eroded and transported through the system of gullies and coulees by intermittently flowing streams. With time, the gullies become deepened and lengthened by headward erosion. This process has been more active southwest of the Souris and Des Lacs valleys because the land slopes northeastward from the higher elevations of the Missouri Coteau to the river valleys, thus forming a natural topographic gradient for the intermittent streams.

Glacial Lake Landforms

Glacial lake deposits cover wide areas on the Missouri Coteau. Sediment deposited in lakes that existed on stagnant glacial ice is designated Qcle and Qclc on plate 1. Two major types of glacial lake deposits are evident: ice-walled and supraglacial. Ice-walled lakes were bottomed on solid ground and surrounded by stagnant ice that in most places was no more than a few tens of feet thick. The materials deposited on the former floors of these lakes are designated Qcle on plate 1. Superglacial lakes were bottomed on stagnant ice. The surrounding or adjacent ice melted slowly due to relatively thick accumulations of sediment on the ice. The sediment underwent collapse at least once, possibly several times, as the underlying ice melted. The collapsed materials deposited in these lakes are designated Qclc.

Several unstable ice-walled lakes (Qclc) formed on the surface of the Makoti deposits. These lake plains are of limited extent and encompass an area smaller than a square mile. Modern evidence of the lakes consists of thin deposits of laminated silt and clay about 2 to 10 feet thick; they are barely distinguishable on aerial photographs. The sediment in unstable-environment lakes tends to be siltier and sandier than that in the stable-environment lakes. Most of the water in the stable-environment lakes was derived from rainfall, not from melting of the underlying ice, and, as a result, they probably contained less sand and more clay than the unstable-environment lakes. One example of an unstable-environment lake deposit, in sections 12, 13, and 14, T151N, R87W, is rimmed by till and is probably a supraglacial type.

Evidence for five large ice-walled lake deposits occurs at the distal margin of the Ryder deposits (Qcle on pl. 1). Locally, these deposits are collapsed. Probably only two lakes are represented, the deposits having been modified by glacial erosion. The three distinct elevated deposits at Ryder are extensively collapsed over wide areas and are dissected by moats or valleys. The lake deposits at Ryder consist of sand and gravel and the largest segment is distinctly rimmed with sand. This deposit was formed by stagnant ice damming the meltwater flowing south and west from the melting Ryder ice mass. The other ice-walled lake deposit, about six miles northwest of Makoti, is collapsed over a wide area, although a large segment of it is nearly intact. Both large segments are surrounded by moats and locally by sand or gravel rims. This lake was fed by meltwater from the Martin ice mass only a few miles to the northeast.

The three ice-walled lake deposits mapped on the Ryder deposits are represented by elevated surfaces and two are partly rimmed by sand and gravel. The rims of these lake deposits represent disintegration ridges.

The most prominent glacial lake deposits occur between the Martin ice-margin border and the Missouri Coteau Escarpment (pl. 1). These supraglacial lake deposits, which exceed three square miles in area, are extensively collapsed around the margins. They consist of finely laminated clay. Fifty-four feet of lake clay was penetrated in a test hole in section 3, T153N, R85W. The lake deposits have smooth, boulder-free surfaces and nearly all of the deposits are cultivated. Many of the lakes illustrated on plate 1 apparently were combined to form larger lakes at one time, but now they appear as separate deposits owing to subsequent collapse. Apparently, those segments of the lakes that were bottomed on ice collapsed as the debris-covered Martin ice melted.

A 12-square-mile lake plain (Qcln on pl. 1) in the Tolley area (Tps160-162N, Rs86-87W) represents the former extent of a lake that existed for a time after the ice melted. This boulder-free area is underlain by less than 10 feet of fine sand and laminated silt.

Fluvial Landforms

Landforms resulting from the action of running water include deposits of meltwater rivers on and near the glacier and deposits of non-meltwater 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 fluvial deposits of the Missouri Coteau (Qcrs on pl. 1) was deposited thousands of years after the glacier there stagnated, when less than a tenth of the runoff was derived from melting ice (Clayton, 1967). Even the fluvial materials deposited by some of the meltwater rivers is not really outwash. For example, much of the sand and gravel in the eastern part of the area (Qcrf) was deposited by floods of water flowing from glacial Lake Regina to the northwest of the two-county area.

Spillways

Alan Kehew has described the landforms and fluvial deposits associated with catastrophic drainage of glacial Lake Regina through the Souris and Des Lacs valleys (refer to fig. 9). The next several paragraphs are taken largely from his descriptions of these spillways (Kehew, 1982). The Souris spillway begins as a broad, shallow five-mile wide channel that merges upvalley with the floor of glacial Lake Regina near Weyburn, Saskatchewan. Immediately downvalley from this outlet, the spillway consists of an inner trench that is about a half mile wide and as much as 150 feet deep. Both sides of the inner trench are flanked by erosional, terrace-like surfaces that are up to four miles wide (Qces). These upper surfaces, which are continuous upvalley with the floor of the Lake Regina outlet, contain conspicuous longitudinal grooves parallel to the inner channel. The grooves have been modified in some places by Holocene erosion and they now comprise segments of intermittent tributaries to the inner channel of the spillway. The lower part of the upper erosional surface is mantled by a discontinuous lag deposit of coarse sand and gravel (Christiansen, 1956). This bouldery, lag-covered area is less suitable for farming than the adjacent land, and the resulting difference in land use makes a striking contrast on aerial photographs.

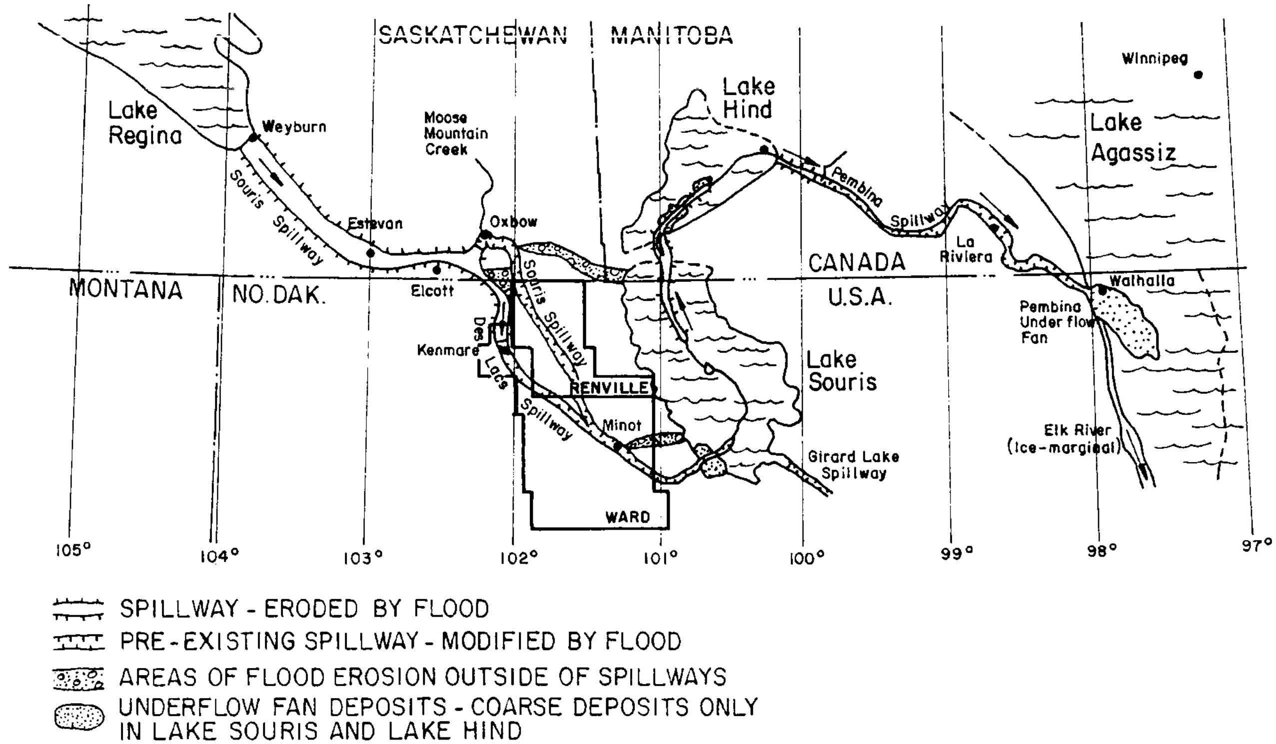

Figure 9. Area affected by catastrophic floods. Floods of water from Lake Regina and lakes north of there carved large channels including those of the Des Lacs, Souris, and Sheyenne Rivers. The erosion of the channels resulted in great amounts of find-grained sediment, much of which settled into the various lakes along the path of the floods. Diagram is adapted from Kehew and Clayton, p. 189 (1983).

The inner channel generally maintains a regular channel shape along its course, with nearly constant width and depth. In places, the inner channel bifurcates into two parallel trenches separated by a narrow ridge. About midway between the Lake Regina outlet and the international border, the inner channel becomes broad and shallow for a short distance. In this area, glacial sediment is thin, and the inner channel is cut entirely into the Paleocene bedrock. Drill holes on the floor of the inner channel near Minot indicate a thickness of 135 to 165 feet of mostly fine-grained, dark-colored, fossiliferous alluvium, colluvium, and lacustrine sediment. Coarse sand and gravel at the bottom of the Holocene valley fill, which could have been deposited by the glacial spillway flood, is either thin or totally lacking in some places. The original erosional depth of the inner channel, prior to deposition of Holocene sediment, was as much as 350 feet.

In the vicinity of the international border, the spillway splits into two branches. One branch consists of a continuation of the broad upper surface across a low drainage divide to the south. For several miles, no inner channel exists in the broad, grooved surface; however, over a distance of about 25 miles, an inner channel a mile wide and 135 feet deep develops. This spillway, the Des Lacs spillway, rejoins the Souris spillway north of Minot. The Des Lacs spillway has two topographically different segments. The valley sides of the lower segment are much more deeply dissected by gully erosion than those in the upper segment. In addition, the lower segment has no scoured upper surface. Non-eroded, hummocky topography extends to the edge of the spillway. Therefore, it is apparent that floodwater from the Lake Regina discharge was channeled into a pre-existing drainageway and that bankfull flow in the lower Des Lacs spillway was never achieved.

Downstream from the point where the Souris spillway bifurcates at the international border, the main branch of the spillway makes several relatively tight meanders and then trends southeastward to the point where it is rejoined by the Des Lacs spillway near Minot. This segment of the spillway consists of a trench one to two miles wide and 150 feet deep and, like the Des Lacs spillway, it has an upper level. Because both the lower reaches of the Souris and Des Lacs spillways lack erosional surfaces and are larger than the inner channel near Lake Regina, it is likely that the lower segments of both spillways were pre-existing drainageways that were scoured and deepened by discharge from glacial Lake Regina.

Along the path of the Souris spillway downvalley from the main bifurcation, water spilled out of the channel and flowed eastward in several locations. The most spectacular example of such overflow can be seen downvalley from the point where the Souris and Des Lacs spillways join. Just west of Minot, the spillway makes a sharp bend to the east, and then, east of Minot, it makes another sharp bend to the southeast. At this second bend, a large part of the flow from the main channel breached the east wall of the channel and continued eastward along a more direct path to the glacial Lake Souris basin. While flowing out of the channel, the water eroded the channel wall to about a third of its normal height in that area. Just beyond the breakout point on the channel, the water eroded a plexus of anastomosing channels in the glacial sediment adjacent to the spillway (area of Qces on pl. 1). Streamlined fluvial erosional forms are present in this area, but the anastomosing channels contain no fluvial channel deposits near their heads. Farther along the flood path, the channels diverge around obstacles that must have been higher than the flood-water surface. Channel deposits consisting of coarse gravel in point-bar positions in channel meanders are more common with increasing distance from the Souris spillway. The water continued to flow eastward to the glacial Lake Souris basin.

Depositional features of the massive discharge from glacial Lake Regina and associated spillway erosion include huge point bars located at the inside of each spillway meander. The flat to gently undulating upper surfaces of the bars are mantled with boulders up to ten feet in diameter. The boulders are probably a lag deposit that formed as discharge and velocity dropped, causing their deposition. The bars project as much as 80 feet above the present valley floor. Test-hole lithologic logs indicate that coarse sand and gravel extend into the subsurface along the valley wall.

One of the largest bars in either spillway occurs just west of Minot. This bar, which has been extensively quarried for sand and gravel, consists of an upper level of moderately well-sorted and cross-bedded sand and gravel that looks much like most normal outwash deposits in the area. The lower section of the bar, however, is composed of poorly sorted, nonbedded gravel containing very large boulders. Some of the boulders are nonresistant lithologic types such as glacial till and Tertiary sandstone, shale, and lignite, which must have been deposited quite near their source. One chunk of lignite weighing two tons was removed from this deposit and burned for fuel (Laird and Hansen, 1958). This lower part of the bar suggests a rapid decrease in current velocity, resulting in dumping of material eroded just upstream. Such deposition could be the result of a flood terminating with a rapid drop in discharge soon after peak discharge had been achieved.

Overridden Fluvial Deposits

Stratified deposits of sand and gravel covered by glacial till are locally exposed along the walls of the Souris River between Minot and Verendrye, in McHenry County. These fluvial deposits crop out about a third of the way up the valley walls and locally they form indistinct benches, the result of recent differential erosion. The deposits range up to about 30 feet thick. Bedding is indistinct in most exposures. The finest material generally shows the greatest degree of bedding. Where exposed, these deposits are dirty with iron stains, although bedded layers of sand are generally clean and contain little or no iron oxide. These rather extensive deposits of sand and gravel were formed prior to the last glacial advance. In areas where the deposits are exposed, they are commonly overlain by several tens of feet of younger glacial deposits.

Other Glaciofluvial Deposits

Stratified deposits of sand and gravel of glacial origin are scattered at the surface throughout the mapped area (Qcrf and Qcrs on pl. 1). Generally, these deposits are only a few hundred feet across and they rise 15 feet or less above the surrounding till plain. Most of the deposits are only a few feet thick and the lithologic composition is similar to outwash and stratified ice-contact deposits in the area. Most of these deposits are probably ice-contact in origin.

One rather extensive deposit is in a low topographic sag on the till plain half a mile southwest of Tolley in northern Renville County. It consists predominantly of sand and fine gravel, and in most places it is less than ten feet thick.

Eskers and Kames

Eskers and kames are found throughout the area of the glaciated plains northeast of the Missouri Escarpment in Renville and Ward Counties (red lines on pl. 1). Typically, they are mounds or sinuous ridges of various size, and shape. They consist predominantly of poorly sorted gravel, sand, and silt. Their bedding is commonly deformed by collapse along the margins of the deposits.

Kames range in height from less than 5 feet to large, well-defined hills as much as 115 feet high. They are generally irregular in shape, although most are nearly round or oval. Black Butte, which may be a kame, is located about a mile and a half northeast of Sawyer. It consists of sand and gravel with smaller amounts of cobbles and boulders. The bedding is considerably deformed in all exposures, possibly because of subsequent collapse following melting of the supporting ice. It is also possible that Black Butte is actually a block of ice-thrust material, but if it is, it is not a typical example of such a feature. There is no apparent source depression associated with the butte, and although sand and gravel are sometimes the dominant material in ice-thrust masses, other, more competent materials are more common.

Most eskers are sinuous ridges of ice-contact material consisting mainly of sand and gravel; glacial sediment is locally common. Eskers are locally abundant on the glaciated plains, but they are much smaller than the ones found on the Missouri Coteau. Eskers on the glaciated plains are generally less than 5 feet high, whereas those on the Missouri Coteau stand 10 to 25 feet above the surrounding terrain.

PLEISTOCENE FOSSILS

Only a few fossils have been collected from Pleistocene deposits in Renville and Ward Counties. Those that have been recovered consist mainly of grasses, wood fragments, cones, gastropod and pelecypod shells, ostracods, and a few small bone fragments.

Wood fragments have been recovered from a number of test holes or wells, but in all but two cases they were very small. However, a sample of wood fragments, cones, and grasses was collected from a test hole located in the NE¼NE¼SE¼sec 3, T153N, R86W from a depth of 137 feet (Pettyjohn, 1967b, p. 128). The wood fragments were used for a radiocarbon age determination and dated at 10,350±300 B.P. The grasses were not studied, but the cones were identified as white spruce or Picea glauca (Moench) Voss. A white spruce log, nearly 2 feet long, was collected from a depth of 12 feet from collapsed glacial topography 8 miles west of Berthold (NW¼SE¼sec 181, T157N, R83W). This wood (W-1818) was dated at 10,330±300 B.P.

Several fossil gastropods were collected from collapsed superglacial lake deposits in the NE¼NE¼NW¼sec 32, T151N, R83W. Dr. Aurele LaRocque, Ohio State University, studied the forms and found one or more species of ostracods in addition to the following snails: Pisidium sp., Helisoma anceps striatum (F. C. Baker), Valvata tricarinata (Say), and Gyraulus parvus (Say).

Dr. LaRocque suggested that these forms indicate a warm, shallow, freshwater environment that contained an abundance of vegetation. This implies that the ice-contact lake in which the forms lived was well insulated from the underlying ice. Although meltwater fed the lake and carried in large amounts of sand, the water was relatively free of silt and suspended clay--as indicated by the presence of the prosobranch or gill-breathing snail Valvata. Consequently, it can be assumed that the fossils collected from the collapsed superglacial lake deposits inhabited a nonglacial environment.

Two genera of pelecypods were collected from samples of coarse sand and fine gravel penetrated at depths of 5 to 40 feet in many places in the Souris River valley. These fossils were not identified. A few bone fragments were collected from test-hole cuttings in the Souris River valley, but these fragments were too small for identification.

GEOLOGIC HISTORY

The oldest glacial deposits exposed in the two-county area consist of a thin layer of till on the distal (southeast) side of the Blue Hill surface till (fig. 5) (secs. 33, 34, 35, and 36, T151N, R85W) near Douglas. This, the Snow School till, was deposited by a glacial advance that probably occurred during early Wisconsinan time. The thin, deeply oxidized till sheet probably extends at least as far south as the Missouri River. Following deposition of the Snow School till sheet, the glacier retreated to the north and the upper part of the till sheet was thoroughly weathered.

The series of diagrams (figs. 10-16) show how the Late Wisconsinan glacier shaped the landforms in the Renville and Ward County area. All but a small part of southern Ward County was covered by the Late Wisconsinan glacier, which at its maximum extent sometime prior to 13,000 years ago, deposited the Blue Hill moraine and Blue Hill deposits in the southwest corner of the county and in northern McLean County (fig. 10). The pre-Late Wisconsinan glaciers had covered the entire two-county area and broad areas to the south. It is possible that, by 13,000 years ago, the glacier had already stagnated over the Turtle Mountains upland to the northeast, and by that time the flow directions of the glacier in the region were being influenced by the upland in the Renville and Ward County area.

The recession of the glacier from the area was a complex and irregular process with numerous readvances interrupting the overall deglaciation. About 12,300 years ago, a readvance of the Late Wisconsinan glacier from the northeast, over the Missouri Coteau, truncated the Blue Hill moraine (fig. 11). This advance from the northeast deposited the Makoti till. As the glacier advanced up the northeastern margin of the Missouri Coteau, extensive imbricate thrusting occurred and great quantities of glacial sediment were incorporated in, and on top of the ice. When the glacier ceased to advance, the debris-laden ice on the Coteau separated from the major glacier and slowly melted during the next 2,000 to 4,000 years. The Makoti moraine is well developed four and a half miles south of the village of Makoti where it blocks the Hiddenwood Lake valley in T151N, R87W. The distal margin of the Makoti moraine trends northwest-southeast across a ten-mile stretch in Ward County. It continues southeast into McLean County, but becomes indistinct near the Blue Hill moraine. The Makoti moraine has not been traced northwest into Mountrail County; it is indistinct on airphotos.

The Makoti moraine consists of discontinuous, generally elongate, isolated ridge-like masses of glacial sediment. Most of the gaps between the ridges appear to represent areas in which no real moraine was built

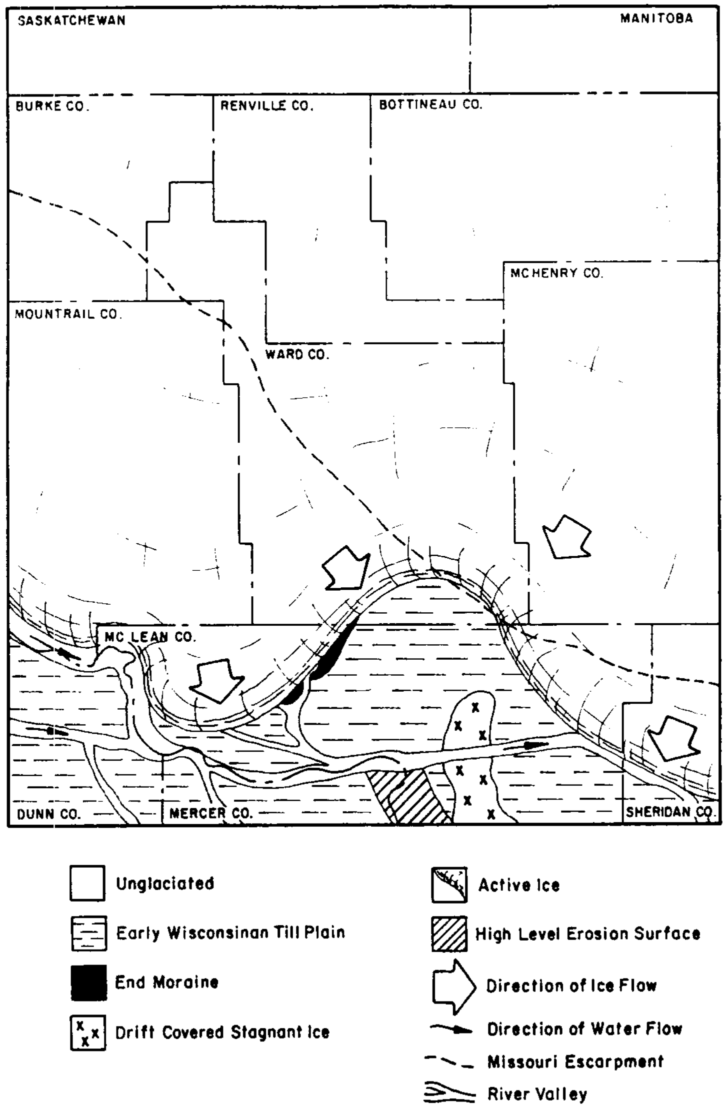

Figure 10. Maximum extent of Late Wisconsinan ice in Renville and Ward Counties. All but the southernmost part of Ward County was covered by ice in Late Wisconsinan time, probably prior to 13,000 years ago. This diagram illustrates the deposition of the Blue Hill moraine in southern Ward and northern McLean Counties.

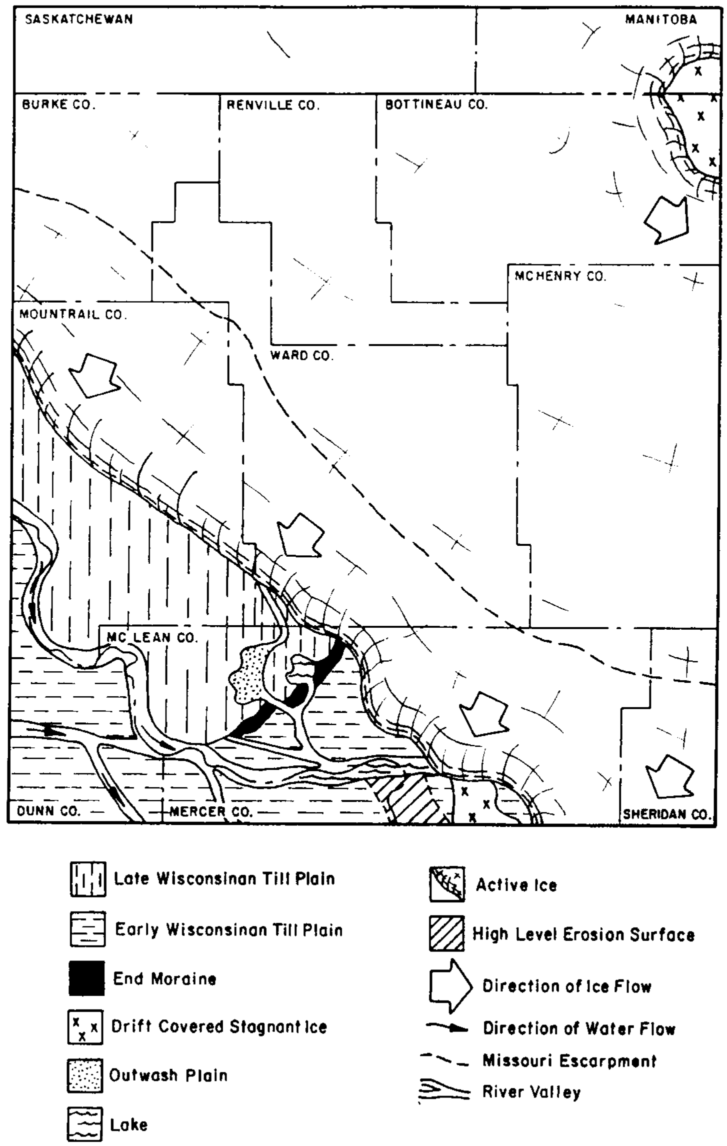

Figure 11. Readvance of the Late Wisconsinan glacier. About 12,300 years ago, after it had receded from the Blue Hill maximum, the glacier advanced again from the northeast, over the Missouri Coteau. This, the Makoti advance, truncated the Blue Hill moraine.

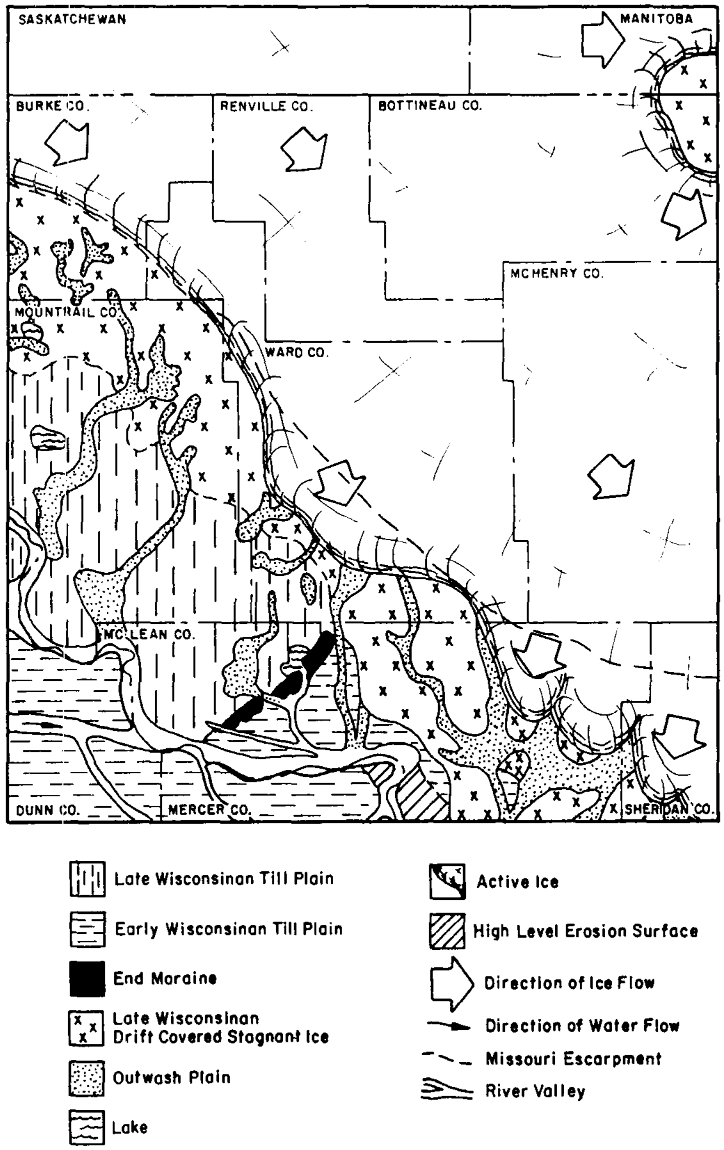

Figure 12. Recession of the glacier. As the glacier receded from its Makoti position, it paused briefly or may have readvanced slightly to the Ryder position (between 12,200 and 12,000 years ago). As it then continued to waste from the Ryder position, it stagnated over the Missouri Coteau and its active flow became restricted to the lowland northeast of the Missouri Escarpment.

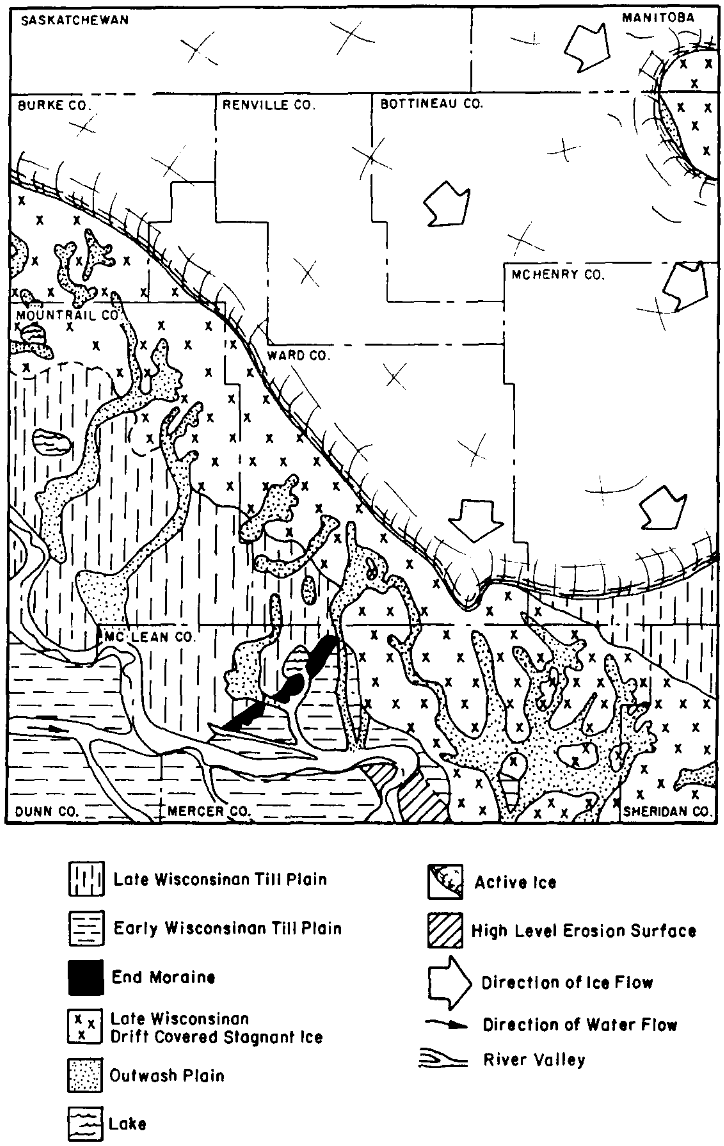

Figure 13. Recession of the glacier. Continued withdrawal of the active glacier margin through the area between the Missouri Escarpment and the Turtle Mountains probably exposed portions of Ward, possibly southeastern Renville County before 12,000 years ago.

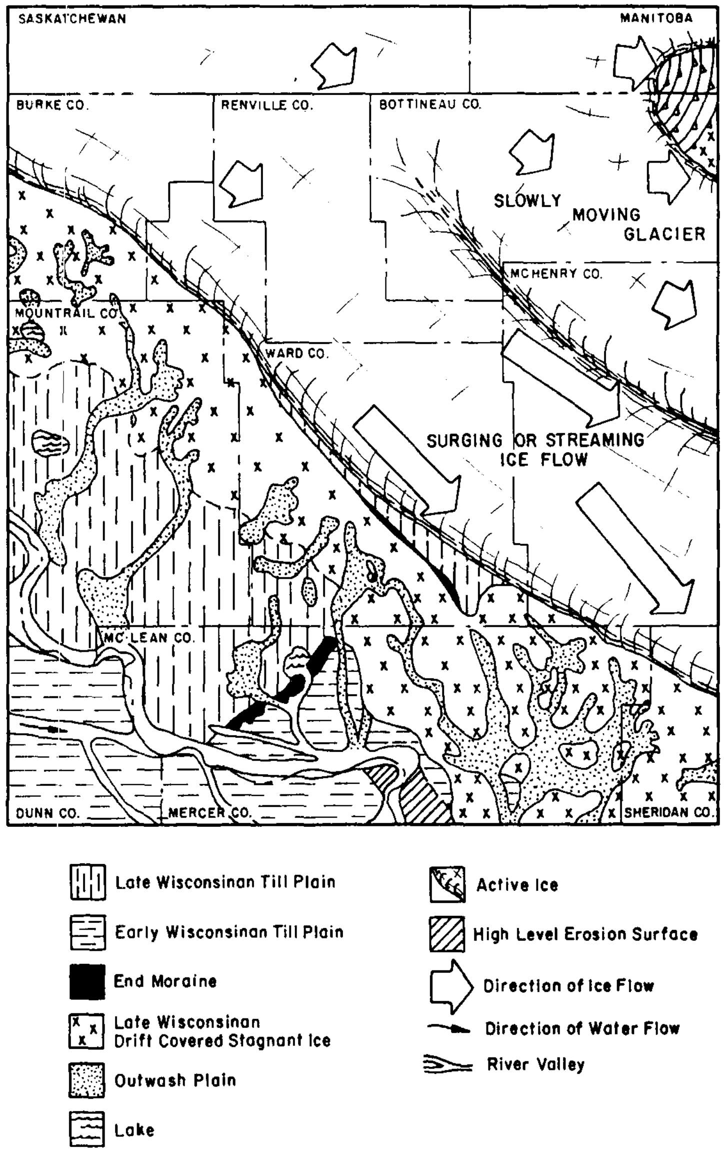

Figure 14. Readvance and shearing in the glacier. During this same period of time (about 12,000 years ago), the Souris ice lobe surged--advanced rapidly southeastward. Evidence to the east indicates it "sheared," with the southern part advancing much more rapidly than the part nearer the Turtle Mountains. It was during this period of surging or streaming flow that the Hogback Ridge and other streamlined features in McHenry County were formed, as well as large-scale thrusting in the area of northern Sheridan County and in the Turtle Mountains.

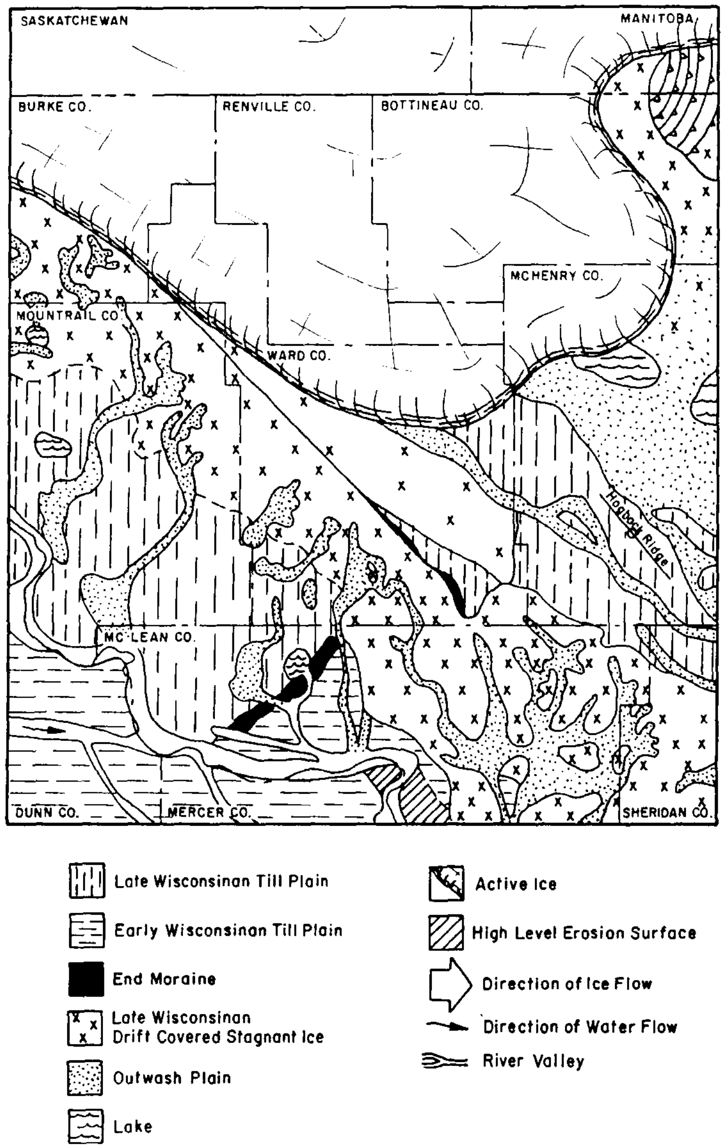

Figure 15. Final withdrawal of the glacier. After 12,000 years ago, the glacier finally began its last withdrawal. As the ice melted back, glacial Lake Souris flooded the area ahead of it.

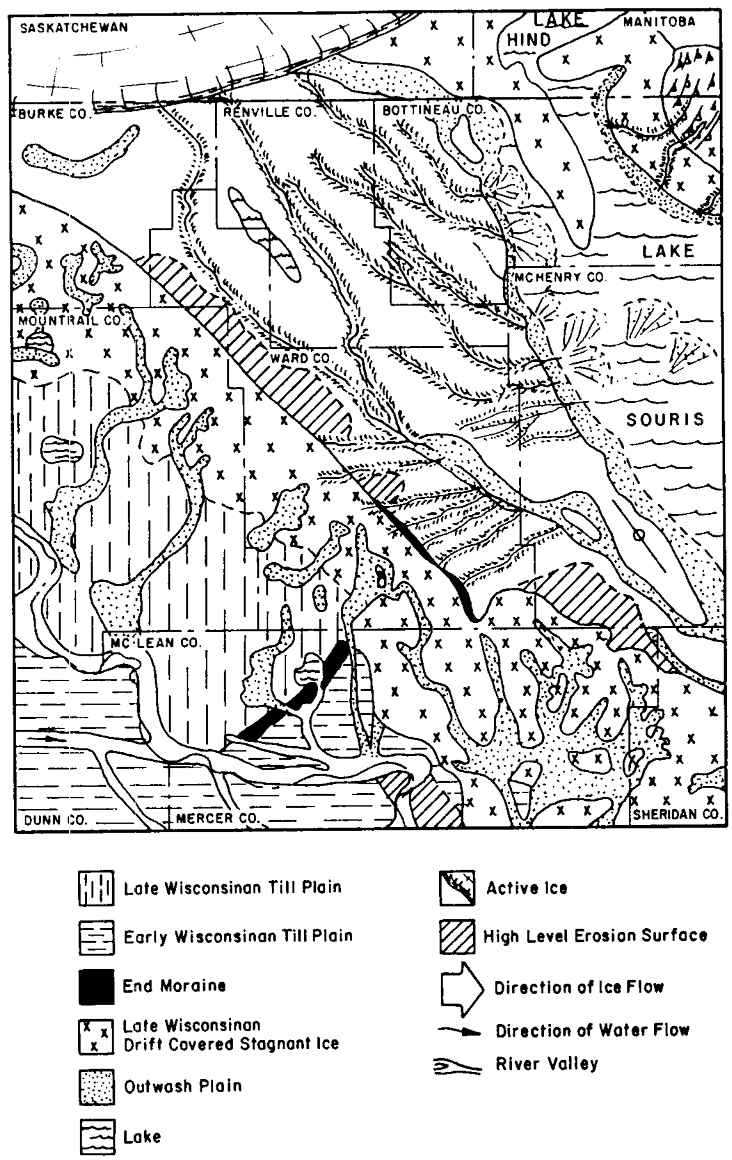

Figure 16. Flooding and the formation of glacial Lake Souris. Even after the active glacier had melted back into Canada, broad areas of stagnant glacial ice remained on the Missouri Coteau in Ward County. Meltwater from the melting glacier to the north carved numerous small meltwater trenches. About 11,500 years ago, as glacial Lake Regina formed, huge volumes of water were periodically, catastrophically released, carving the Des Lacs and Souris River valleys and transporting large volumes of sediment into Lake Souris.

because of the small load of debris in the ice, or because the terminal part of the glacier had become stagnant by that time. The larger ridge-like masses of the Makoti moraine average about a mile wide with maximum local topographic relief of about 40 feet. The distal margin generally has the steepest slopes, which contrasts with the very low relief of the older moraine to the south. The proximal slope of the moraine is gentle in most places.

The till plain behind the Makoti moraine grades imperceptibly into the moderate-relief hummocky collapsed moraine forming the border of the Ryder moraine (fig. 6). In the Ryder area, the Makoti moraine is covered by perched and collapsed sandy lake deposits that formed at or near the border of the Ryder ice margin. North of Makoti, the till plain is locally covered by collapsed outwash. The Ryder deposits consist of typical undulating collapsed hummocky moraine. The Ryder till plain has greater relief than the Makoti till plain and less relief than the Martin deposits to the northeast. No active-ice features occur in the area of the Ryder deposits. Slopes of the hills and depressions are low to moderately steep and generally range from 4 to 7 degrees. The drainage is entirely unintegrated. Scattered throughout the Ryder area are several types of ice-disintegration features, including collapsed outwash, glacial lake deposits, and ice-contact deposits such as kames and eskers.

As the glacier withdrew from its Makoti-Ryder position, about 12,200-12,000 years ago, much of the ice on the Missouri Coteau stagnated and most of the active-ice movement was then restricted to the lowland northeast of the Missouri Escarpment. The flow of the glacier about this time shifted to a southeasterly direction, with the Souris Lobe flowing between the Turtle Mountains on the northeast and the Missouri Escarpment on the southwest (figs. 12, 13).

The most rugged glacial landforms on the Missouri Coteau in Ward County are those associated with the Martin advance. The Martin deposits consist of rolling, high-relief, collapsed glacial topography that grades imperceptibly into the lower-relief of the Ryder deposits. The boundary is readily distinguishable, however, in areas where large collapsed-outwash aprons or partly filled outwash trenches terminate or grade into kame-esker fields. This boundary commonly coincides with marked differences in relief.

There are no active-ice features in areas where Martin deposits form the land surface on the Missouri Coteau. Slopes of the hills and depressions are moderately steep to very steep and generally range from 5 to 15 degrees. Drainage is entirely unintegrated. Large-scale ice-disintegration features typify the Martin deposits. Large ice-walled superglacial lake deposits, eskers, kames, and kame-esker-outwash fields are common. Narrow, elongate collapsed-outwash deposits, some of which grade into ice-walled lake deposits, cover several square miles.

The glacier continued to thin and recede northwestward, exposing areas to the southeast. As the ice melted, the early glacial Lake Souris formed ahead of the glacier, although because the extent of the glacier was still fluctuating, it repeatedly readvanced southeastward into the lake. The readvances of the glacier may have been fast; in fact, surging or streaming ice flows almost certainly occurred (fig. 14). During at least one of these surges, shearing apparently took place in the ice mass, with a segment of the glacier to the south readvancing quickly while, at the same time, the ice to the north, nearer the Turtle Mountains, either stagnated or simply continued to advance southeastward too, although at a much slower rate. It was during this surge that the array of megaflutes that includes the Hogback Ridge in McHenry County formed. Large-scale thrusting occurred to the southeast of the megaflute field, east of the area shown on figures 14 and 15.

After 12,000 years ago, the Souris Lobe finally receded from the area. Glacial Lake Souris flooded the areas ahead of the receding ice and broad areas of outwash were deposited by the water flowing from the melting ice (fig. 15). The meltwater carved numerous valleys in the area west of glacial Lake Souris (fig. 16; pl. 1). Water flowing off of the Missouri Coteau carved pediments, particularly in the area between the Missouri Escarpment and the Des Lacs River valley, and the Souris River valley, downstream from the confluence of the two rivers.

Sometime after the active-glacial ice northeast of the Missouri Escarpment had melted from Renville and Ward Counties perhaps about 11,500 years ago, glacial Lake Regina, in southeastern Saskatchewan, drained suddenly and repeatedly, by releasing a huge volume of water in a short time, resulting in a catastrophic flood (Kehew, 1982). This flood poured southeastward, overland into glacial Lake Souris, and then, in domino fashion, to Lake Hind and, through southern Manitoba, to glacial Lake Agassiz (Kehew and Clayton, 1983). The volumes of water were too large for the existing valleys and, as a result, floods of water left the valleys in several places. Water flowed overland east of Minot, carving an array of anastomosing channels and eroding the till surface, leaving a lag of boulders and patches of gravel in places.

ECONOMIC GEOLOGY

Lignite

Lignite coal was mined throughout Renville and Ward Counties beginning in about 1900. Most of the mining was along the Souris and Des Lacs Rivers where underground mines were opened into the valley walls. About 1930, strip mining began along the Missouri Escarpment south of Minot and Sawyer. No lignite has been mined in the two counties since 1986, when the Velva Mine, operated by Consolidation Coal Company, produced about 63,000 tons. During the four years prior to 1986, the Velva Mine produced about 250,000 tons of lignite coal annually.

Renville County has estimated reserves of 780 million tons of lignite and Ward County has 10,286 million tons (Brant, 1953; p. 2, table 1). However, reserves that can be removed by strip mining in the two counties are relatively small and limited to the area along the Missouri Escarpment south of Sawyer.

Three major lignite seams have been mined in Renville and Ward Counties. The stratigraphically lowest zone is the Burlington bed, which outcrops at an elevation of about 1,620 feet along the Souris and Des Lacs Rivers northwest of Minot. The Burlington bed was mined extensively by underground methods in the vicinity of Burlington (Brant, 1953). Lignite in the Burlington bed may be as much as 11 feet thick (Andrews, 1939). Test-hole data indicate that this bed is overlain by as much as 200 feet of glacial deposits and Tertiary sedimentary rocks southwest of its outcrop. Original reserves in the Burlington bed are estimated at over 725 million short tons.

The Des Lacs lignite bed crops out along the Des Lacs River valley in the vicinity of Kenmare at an elevation between 1,830 and 1,860 feet. It may be as thick as 6 feet (Leonard and others, 1925). The Des Lacs bed, which was mined by underground methods, is covered in many places by at least 200 feet of overburden. It has not been mined for many years.

The Coteau bed is stratigraphically the highest minable lignite seam in Ward County. It outcrops over relatively extensive areas south of Sawyer where, until 1986, Consolidation Coal Company mined it by stripping. Apparently, this bed is correlative with the Garrison Creek bed in McLean County. The Coteau bed, which is as much as 16 feet thick in the area of the Velva Mine, crops out between elevations of 1,820 and 1,900 feet. Brant (1953) estimated original reserves in the Coteau bed at 4,111 million short tons.

Gravel and Sand

Numerous deposits of gravel and sand occur in Renville and Ward Counties; the locations of major surficial deposits are shown on plate 1. The best quality and most extensive deposits are found on terraces along the Souris and Des Lacs River valleys. Extensive deposits are also found in the collapsed outwash gravels on the Missouri Coteau, although these are generally poorer in quality. Isolated ice-contact deposits are also mined for gravel from time to time, but these too are of poor quality. Over the past five years, reported production has ranged from 60,000 cubic yards of gravel to 400,000 cubic yards, but small gravel pits operate as the need arises and dozens of these pits are found throughout the two-county area. During most years, five or six operators report production.

Generally, the river-terrace deposits contain the coarsest material, much of which exceeds four inches in diameter. In places, these deposits are stratified and well sorted, whereas elsewhere they are poorly sorted. Ice-contact deposits, on the other hand, generally contain a large percentage of iron oxide and shale or claystone, and are commonly poorly sorted.

Hydrocarbons

Oil production began in the two-county area in the 1950s. Currently (early 1988), about 300 wells produce in Renville County at a total annual rate of about 1.5 million barrels, while Ward County has about 20 wells, producing about 175,000 barrels of oil a year. Production is from the Madison Group, with wells ranging in depth from about 4,000 to 7,000 feet, the greater depths being in the western and southwestern parts of the area. One well in Renville County (Newporte Field) produces from Cambro-Ordovician rocks.

Potash

Potash deposits are being mined in southeastern Saskatchewan by solution and underground methods. The mines produce potash from several beds within a thick unit of halite. Rocks of equivalent age occur in northwestern North Dakota in the Devonian Prairie Formation. In Renville and Ward Counties, the Prairie Formation ranges up to 450 feet thick, and within the formation from one to six potash beds occur; these beds have a combined thickness of up to 40 feet.

Conventional underground methods of mining potash in Canada appear to be limited to depths of less than 3,600 feet. At greater depths, solution methods are practiced. In extreme northeastern Renville County, the top of the shallowest potash bed is approximately 6,000 feet below the land surface. The deposits become progressively deeper toward the southwest and are more than 10,000 feet deep in the southwest corner of Ward County. Consequently, mining techniques in North Dakota will be limited to solution methods if the potash is to be removed economically.

Halite

Extensive deposits of salt occur in the subsurface in Renville and Ward Counties. Anderson and Hansen (1957) and Anderson (1964) described 11 separate halite units in the western part of the state. Six halite deposits underlie Renville or Ward Counties. One deposit is present in the Prairie Formation of Devonian age, three are in the Madison Group of Mississippian age, and two beds are in the Triassic Spearfish Formation.

Salt deposits in the Prairie Formation underlie most of Renville and Ward Counties, except in the extreme eastern part, at depths greater than 6,000 feet. These salt deposits may exceed 350 feet in thickness in northwestern Ward County. The Madison Group contains a stratigraphically lower "X" salt, a higher "F" salt, and an upper "D" salt. The "X" salt underlies eastern Renville and Ward Counties. It is as much as 20 feet thick and deeper than 3,600 feet. The "F" salt trends northwest across the central part of Ward County and thickens to the southwest. It ranges from 0 to 35 feet thick and occurs at depths greater than 5,500 feet. The "D" salt underlies generally the same areas as the "F" salt, ranges from 0 to 20 feet in thickness, and is at depths greater than 5,200 feet. The Spearfish Formation contains an upper "A" or "Dunham" salt and a lower "B" or "Pine" salt. Both deposits underlie the southwestern part of Ward County. The Pine salt is less than 50 feet thick, whereas the Dunham salt ranges from 0 to 100 feet thick. The lower unit lies at depths greater than 5,400 feet and the upper unit may be penetrated at depths greater than 5,200 feet (Anderson and Hansen, 1957).

In eastern Renville and Ward Counties, salt could conceivably be mined most economically from the relatively shallow Mississippian "X" bed. Salt mining in this area could be a dual-purpose operation: (1) the brine could be processed, and (2) the resulting cavity in the rocks could be used for underground storage of gas or possibly for the disposal of certain types of waste materials.

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