GEOLOGY

of

BOTTINEAU COUNTY, NORTH DAKOTA

by
John P. Bluemle
North Dakota Geological Survey
1985

BULLETIN 78–PART I
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

COUNTY GROUNDWATER STUDIES 35–PART I
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

Prepared by the North Dakota Geological Survey
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Sidney B. Anderson, *Acting State Geologist*

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This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. This report is in three parts: Part I describes the geology of Bottineau County; Part II presents groundwater basic data for Bottineau and Rolette Counties; and Part III describes the groundwater resources in Bottineau and Rolette Counties. In addition, North Dakota Geological Survey Bulletin 58 describes the geology of Rolette County.

Additional copies of this bulletin are available from the North Dakota State Water Commission, Bismarck, North Dakota 58501.

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ABSTRACT

Bottineau County, located in north-central North Dakota on the eastern side of the Williston Basin, is underlain by 6,000 to 9,000 feet of Paleozoic, Mesozoic, and Cenozoic rocks that dip west-southwestward toward the center of the basin about 100 miles away. The Cretaceous Pierre, Fox Hills, and Hell Creek Formations and the Tertiary Cannonball Formation lie directly beneath the glacial drift. Exposures of Hell Creek Formation sandstone and Cannonball Formation siltstone are found on the western edge of the Turtle Mountains near Carbury. The Pleistocene Coleharbor Group covers the entire county, averaging about 50 to 100 feet thick in the central part of the county, 200 to 250 feet in the west, and 200 to 300 feet thick over the Turtle Mountains. It reaches a maximum thickness of 400 to 500 feet in places over the Turtle Mountains.

Bottineau County is located mainly on the Glaciated Plains, an area of undulating to flat topography. The central part of the county was flooded by Glacial Lake Souris and is covered by thin lake and lake shore sediments and wave-planed glacial sediment. Western Bottineau County is mainly low-relief collapsed glacial topography. The northeastern part of the county is part of the Turtle Mountains, an area of high-relief collapsed glacial topography and ice-thrust topography.

Oil production began in Bottineau County in 1953 from the Madison Formation. Currently, about 600 wells produce between 2 and 3 million barrels of oil annually from Mississippian and Triassic age rocks.

INTRODUCTION

Purpose

This report is published by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the United States Geological Survey, and the Bottineau 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 Bottineau County. Readers interested in groundwater should refer to Part II of this bulletin (Kuzniar and Randich, 1982), which includes detailed basic data on the groundwater, and Part III (Randich and Kuzniar, 1984), which is a description and evaluation of the groundwater resources of Bottineau and Rolette Counties.

Parts of this report that are primarily descriptive include the discussions of the topography, rock, and sediment in Bottineau County. This information is intended for use by anyone interested in the physical nature of the materials underlying the area. Such people may be water-well drillers or hydrologists 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

The earliest geologic report that included a discussion of Bottineau County was by Upham (1895, p. 267-272), who described the area covered by glacial Lake Souris. Simpson (1929) included a brief description of the geology of Bottineau County in his report on the geology and groundwater resources of North Dakota. Greenlee (1942) described the Turtle Mountains as a project he worked on for a Master's degree in geology. A geologic report by Lemke (1960) describes the Souris River area, including most of Bottineau County. Deal (1971) described the geology of Rolette County, immediately to the east of Bottineau County. Bluemle (1982) reported on the geology of McHenry County, immediately south of Bottineau County, and Carlson and Freers (1975) described the geology of Benson and Pierce Counties. The reports on McHenry, Benson, and Pierce Counties were completed as part of the same series of county reports as the present report.

Local groundwater studies have been made in several parts of Bottineau County. Akin (1951) described the geology and groundwater conditions in the Mohall area, which includes parts of Renville and Bottineau Counties. Powell (1959) discussed the geology and occurrence of groundwater in the vicinity of Westhope. Froelich (1963) investigated the groundwater conditions near Bottineau, and he also (Froelich, 1966) conducted a water-supply survey for the city of Lansford in the southwestern part of the county. Beeks (1967) reported on groundwater conditions at Metigoshe State Park. Naplin (1968) reported on a groundwater survey of the Willow City area in southeastern Bottineau County.

Numerous studies of the subsurface geology and oil-producing horizons have been completed in the Bottineau County area. Anderson and Nelson (1956) reported on a study of the Madison Formation in Bottineau County. Folsom, Hansen, and Anderson (1958) conducted a magnetometer study of the Westhope-Newburg area. Anderson and Carlson (1958) prepared a detailed subcrop map of the pre-Triassic surface in the Bottineau County area. Hunt (1962) prepared gravity maps for a part of north-central North Dakota, including a part of Bottineau County.

Methods of Study

Fieldwork for the present study was accomplished over a long period of time by several people. S. R. Moran began field studies in Bottineau County in the late 1960s and mapped much of the area at that time. Parts of eastern Bottineau County were mapped, along with all of Rolette County, by D. E. Deal in 1969. In 1978, K. L. Harris compiled all the previous work onto a single map and he augered several shallow test holes to gather near-surface stratigraphic information. J. P. Bluemle field-checked the county in 1984, making only minor changes from the previous maps except for remapping parts of the Turtle Mountains.

Almost all roads and trails in the county were traveled by the several geologists who have mapped there. Many trails in the Turtle Mountains are nearly impassable and some relatively large areas have no trails. By following all available trails on foot, it was possible to map the area with reasonable thoroughness. I walked to and hand-augered many features which, as a result of something I had seen on airphotos or topographic maps, I suspected might contain lithologies different from their surroundings.

Subsurface information for the upper part of the Pierre Formation and younger units was provided by 1,268 wells and test holes drilled mainly by the North Dakota State Water Commission. The results of this drilling were published as a groundwater basic data report (Kuzniar and Randich, 1982). These data include lithologic and geophysical logs of 1,158 test holes and wells. The oil exploration files of the North Dakota Geological Survey provided information for the subsurface stratigraphic section of this report.

Regional Topography and Geology

Bottineau County, in north-central North Dakota, has an area of 1,707 square miles in Tps 160 to 164N and Rs 74 to 83W. It is located between 48° 32' 39" North Latitude on the south, 49° North Latitude (the U.S.-Canadian border) on the north, 100° 8' 44" on the east and 101° 30' on the west.

The surface deposits in Bottineau County consist almost entirely of Pleistocene sediments of Late Wisconsinan age laid down on deposits of older glaciations and on bedrock of Cretaceous and Tertiary age. A few small exposures of sandstone and shale of the Cretaceous Fox Hills and Hell Creek Formations and the Tertiary Cannonball Formation can be found north of Carbury along the west flank of the Turtle Mountains. The slope on the preglacial bedrock surface in all but the northeastern part of the county is northward; in the northeast, the preglacial surface consists of upper Cretaceous and Tertiary sediment that is part of a large mesa now known as the Turtle Mountains. The dip of the preglacial bedrock layers is toward the southwest, reflecting the position of the county on the eastern side of the Williston Basin, an intracratonic basin, the center of which is in western North Dakota.

Bottineau County lies within the Central Lowland Province (fig. 1). It is contained mainly within the Glaciated Plains with the northeast part of the county in the Turtle Mountains. It is characterized mainly by undulating to gently rolling glacial sediment in the west, the gently rolling to nearly flat glacial Lake Souris plain in the central part, and the hilly areas of stagnant glacial features in the Turtle Mountains in the northeast. The maximum relief is about 1,135 feet in Bottineau County, ranging from an altitude of 1,410 feet at the Souris River on the boundary between North Dakota and Manitoba to 2,545 feet at Boundary Butte west of Lake Metigoshe. The most prominent land feature in the area is the Turtle Mountains, which stand about 500 feet above the surrounding area. The

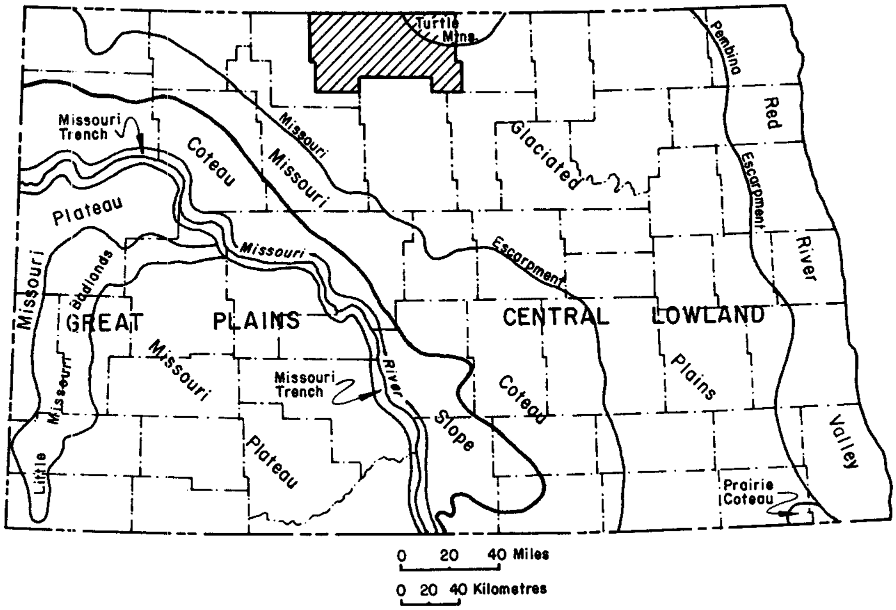

Figure 1. Physiographic map of North Dakota showing the location of Bottineau County.

major drainage in most of Bottineau County is the Souris River. Much of the area of the Turtle Mountains has no through drainage, but numerous lakes and sloughs are found.

Acknowledgments

I gratefully acknowledge the efforts of Stephen R. Moran in mapping most of the surface geology of Bottineau County in 1968 and 1969. Dwight Deal mapped parts of the Turtle Mountains in northeastern Bottineau County in 1969 when he was studying the geology of nearby Rolette County. Kenneth Harris reviewed the data collected by these two people and was most directly responsible for synthesizing the surface geology into a coherent geologic map. The final geologic map (pl. 1, in the pocket at the back of this report) is therefore a result of the combined efforts of several geologists. Kenneth Harris also contributed to the study of the near-surface glacial stratigraphy by conducting extensive soil probing throughout the county.

STRATIGRAPHY

General Statement

As much as 9,000 feet of Paleozoic, Mesozoic, and Cenozoic sedimentary rocks lie on the Precambrian basement in Bottineau County. The discussion that follows is mainly a description of the composition, sequence, and correlation of the geologic units that lie at and immediately beneath the surface in Bottineau County. The description proceeds from the oldest known materials, which are discussed briefly, the younger materials, which, because they are more easily accessible, are described in greater detail than are the older units. All of the landforms that occur at the surface in Bottineau County are composed of Pleistocene materials, which were deposited mainly by glacial action and by water ponded in glacial lakes and in streams flowing from the melting glacier. The emphasis of this report will be on the configuration and origin of the landforms.

Precambrian Rocks

A total of seven wells have penetrated Precambrian rocks in Bottineau County. The buried Precambrian surface in Bottineau County ranges from a depth of about 6,000 feet in the east to about 9,000 feet in the west. It slopes west-southwestward at about 50 to 60 feet in a mile. Elevations on the Precambrian surface range from about 4,000 feet below sea level in northeasternmost Bottineau County to about 7,500 feet below sea level in the southwest corner of the county.

Samples of cuttings from wells that have penetrated Precambrian rocks in Bottineau County were examined by E. G. Lidiak, whose findings have not been published. Lidiak named several rock-type "terranes" in North Dakota. Easternmost Bottineau County is part of his Towner granite terrane, which extends southward from the Canadian border to south-central North Dakota. The remainder of the county is included within an undifferentiated western North Dakota area where Precambrian rocks are generally deep, and not much data are available on them.

The easternmost sample of Precambrian rock from Bottineau County was taken from the Lion Oil Co.--#1 Huss (NW¼NW¼sec 23, T163N, R77W) at a depth of 6,422 feet. It consisted of coarse-grained granite with most of the individual cuttings composed entirely of a single mineral. Other samples from the central and western parts of the county included hornblende schist from two wells (the California Oil Co.--#1 Blanche Thompson Well, located in sec 31, T160N, R81W and the California Oil Co.--#4 Bert Henry Well, located in sec 6, T161N, R79W). Another sample was of granofels composed of quartz and sodic oligoclase with some microcline (Hunt Oil Co.--#1 Olson Well, located in sec 18, T163N, R77W). The metamorphic rocks identified in these wells may be part of a much larger metamorphic belt as they lie in a broad zone of gravity anomalies which extend south from Canada into North Dakota. This gravity feature joins the Nelson River high which approximately coincides with a prominent gneissic belt situated between the Superior and Churchill provinces on the Canadian Shield.

One well, the Amerada Petroleum Corp.--Lillestrand #1 Well, located in the SE¼SW¼sec 31, T162N, R78W, drilled 550 feet into the Precambrian rocks. It penetrated a serpentine-rich schist.

Paleozoic Rocks

Paleozoic rocks range in thickness from about 2,800 feet in eastern Bottineau County to about 4,500 feet in the west. At least part of the variation in thickness is the result of episodes of erosion that resulted in unconformities, especially at the top of the Mississippian section; most of the Paleozoic formations tend to thicken westward, toward the depositional center of the Williston Basin. For purposes of discussion, it is convenient to divide the stratigraphic section into sequences, a sequence being the preserved sedimentary record bounded by major regional unconformities (fig. 2). Paleozoic sequences recognized in Bottineau County are the Sauk, Tippecanoe, and Kaskaskia.

Sauk Sequence

All the rocks of the Sauk Sequence are included in the Deadwood Formation, which consists of interbedded clastics and carbonates. The eastern depositional edge of the Deadwood Formation is at about the Bottineau-Rolette County line and the formation thickens westward to about 170 feet at the Bottineau-Renville County line.

Tippecanoe Sequence

Rocks of the Tippecanoe Sequence range in thickness from about 1,000 feet in the northeast corner of Bottineau County to about 1,450 feet in the southwest corner of the county. The relatively uniform thickness of these rocks reflects stable conditions during their deposition and a location where the depositional thickness of all the formations, except the Interlake, has been preserved. The Tippecanoe Sequence began with clastics of the Winnipeg Group, followed by carbonates and minor evaporites of the Red River, Stony Mountain, and Interlake Formations.

AGE	SEQUENCE	UNIT NAME	DESCRIPTION	THICKNESS (feet)
HOLOCENE	TEJAS	OAHE FORMATION	Sand, silt, and clay	0- 50
QUATERNARY	TEJAS	COLEHARBOR GROUP	Till, sand, gravel, silt, and clay	0- 500
TERTIARY	ZUNI	CANNONBALL FORMATION	Marine sandstone and shale	0- 130
CRETACEOUS	ZUNI	HELL CREEK FORMATION	Sandstone, shale, and lignite	0- 225
CRETACEOUS	ZUNI	FOX HILLS FORMATION	Marine sandstone	0- 300
CRETACEOUS	ZUNI	PIERRE FORMATION	Shale	800-1500
CRETACEOUS	ZUNI	NIOBRARA FORMATION	Calcareous shale	150- 200
CRETACEOUS	ZUNI	CARLILE FORMATION	Shale	160- 220
CRETACEOUS	ZUNI	GREENHORN FORMATION	Calcareous shale	80- 120
CRETACEOUS	ZUNI	BELLE FOURCHE FORMATION	Shale	140- 200
CRETACEOUS	ZUNI	SKULL CREEK-MOWRY FORMATION	Shale	150- 260
CRETACEOUS	ZUNI	INYAN KARA FORMATION	Sandstone and shale	30- 410
JURASSIC	ZUNI	UNDIFFERENTIATED	Shale, sandstone, carbonates, and gypsum	500- 800
TRIASSIC	ABSAROKA	SPEARFISH FORMATION	Siltstone and sandstone (redbeds)	80- 275
PERMIAN	ABSAROKA		(Absent in Bottineau County)	0
PENNSYLVANIAN	ABSAROKA			
MISSISSIPPIAN	KASKASKIA	MADISON GROUP: POPLAR INTERVAL	Anhydrite	0- 100
MISSISSIPPIAN	KASKASKIA	MADISON GROUP: RATCLIFFE INTERVAL	Limestone and dolomite	0- 200
MISSISSIPPIAN	KASKASKIA	MADISON GROUP: FROBISHER-ALIDA INTERVAL	Limestone and anhydrite	0- 300
MISSISSIPPIAN	KASKASKIA	MADISON GROUP: TILSTON INTERVAL	Limestone	0- 220
MISSISSIPPIAN	KASKASKIA	MADISON GROUP: BOTTINEAU INTERVAL	Cherty carbonates	350- 640
MISSISSIPPIAN	KASKASKIA	BAKKEN FORMATION	Siltstone and shale	15- 50
DEVONIAN	KASKASKIA	THREE FORKS FORMATION	Shale, siltstone, and dolomite	25- 150
DEVONIAN	KASKASKIA	BIRDBEAR FORMATION	Limestone	90- 110
DEVONIAN	KASKASKIA	DUPEROW FORMATION	Dolomite and limestone	340- 420
DEVONIAN	KASKASKIA	SOURIS RIVER FORMATION	Dolomite and limestone	235- 280
DEVONIAN	KASKASKIA	DAWSON BAY FORMATION	Dolomite and limestone	130- 170
DEVONIAN	KASKASKIA	PRAIRIE FORMATION	Anhydrite, halite, potash	40- 90
DEVONIAN	KASKASKIA	WINNIPEGOSIS FORMATION	Limestone and dolomite	150- 220
SILURIAN	TIPPECANOE	INTERLAKE FORMATION	Dolomite	250- 500
ORDOVICIAN	TIPPECANOE	STONEWALL FORMATION	Dolomite and limestone	70- 90
ORDOVICIAN	TIPPECANOE	STONY MOUNTAIN FORMATION	Dolomite, limestone, and shale	110- 130
ORDOVICIAN	TIPPECANOE	RED RIVER FORMATION	Limestone	545- 630
ORDOVICIAN	TIPPECANOE	WINNIPEG GROUP	Siltstone, sandstone, and shale	160- 210
CAMBRIAN	SAUK	DEADWOOD FORMATION	Limestone, dolomite, shale, and sand	0- 170
Precambrian basement rocks				

Figure 2. Stratigraphic column for Bottineau County.

Kaskaskia Sequence

Rocks of the Kaskaskia Sequence range in thickness from about 1,800 feet in easternmost Bottineau County to as much as 3,000 feet in the southwest corner of the county. The Devonian rocks are mostly carbonates with minor amounts of evaporites (the Prairie Formation) and shales (the Three Forks Formation). The Bakken Formation siltstone and shale ranges from 15 to 50 feet thick in Bottineau County. It is considered to be Devonian to Mississippian in age. In Bottineau County, only the upper part of the Bakken is present, lying unconformably on the Three Forks, so it is probably mainly Mississippian in this area.

The geology of the Mississippian rocks in Bottineau County is of particular interest because of the hydrocarbons these rocks produce. The Madison Group in Bottineau County ranges from about 350 feet thick in the northeast to about 1,500 feet in the southwest. It includes three distinct facies or formations: the Lodgepole at the base (mainly cherty limestone); the Mission Canyon (a massive-bedded, fragmental, and oolitic limestone); and the Charles at the top (an evaporite consisting of halite and anhydrite). However, these three facies have such a complex intertonguing relationship that, for study purposes, petroleum geologists have divided the Madison strata into several para-time rock units referred to informally as "intervals." These intervals are bounded or contain persistent evaporite beds that are easily recognized by their characteristic electric-log and gamma-ray signatures. In ascending order, the intervals of the Madison are the Bottineau, Tilston, Frobisher-Alida, Ratcliffe, and Poplar. Subintervals, such as the Rival at the top of the Frobisher-Alida interval and the Midale at the base of the Ratcliffe, are also recognized in places.

The Madison Group intervals are all truncated in Bottineau County by the major pre-Mesozoic unconformity, which is overlain by Triassic Spearfish Formation siltstone and sandstone. Some of the hydrocarbon reservoirs in the several Madison Group intervals occur at the pre-Mesozoic unconformity, where the porosity pinches out against the impermeable Spearfish sediments (fig. 3). In places, the oil from the Madison has drained into sand beds in the Spearfish Formation so that several oil fields in Bottineau County produce from the Spearfish.

Mesozoic Rocks

Mesozoic rocks are mainly fine-grained clastics that range in thickness from about 2,400 feet in northeastern Bottineau County to about 4,400 feet in the southwest. These rocks are divided into two sequences, the Absaroka and the Zuni (fig. 2).

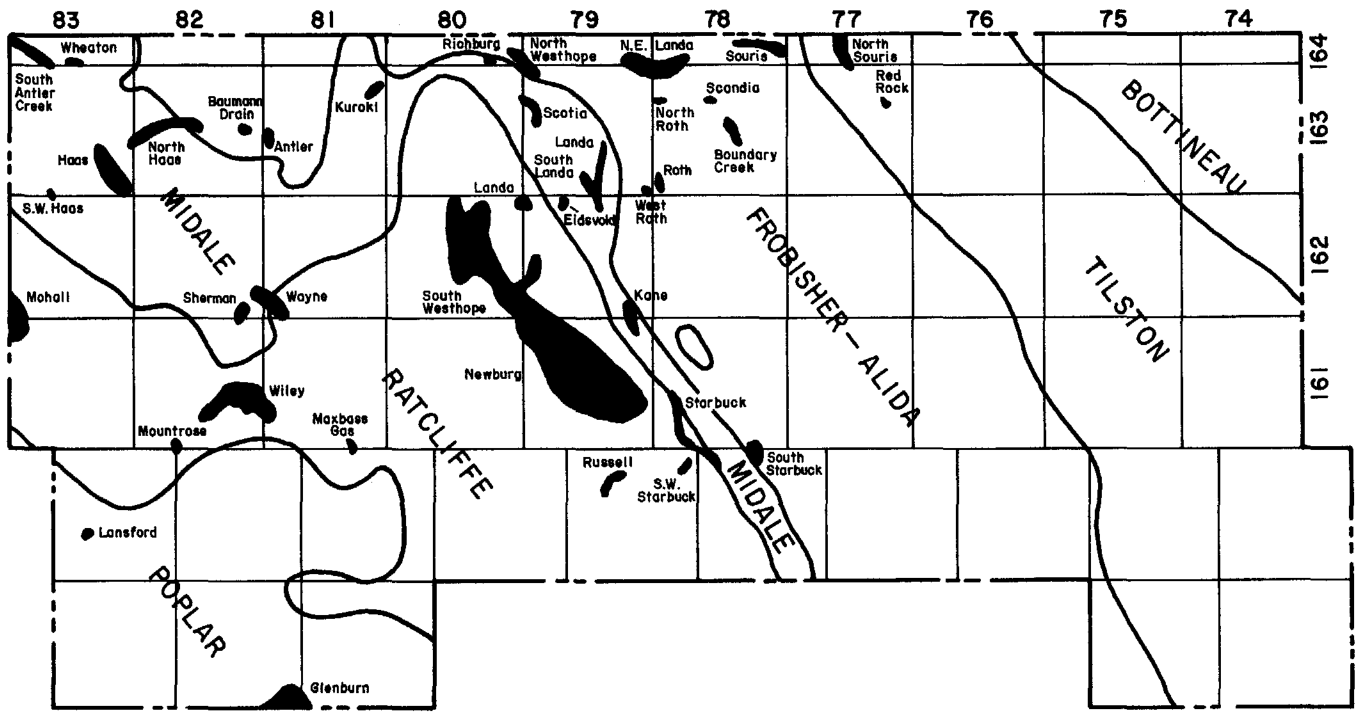

Figure 3. Pre-Mesozoic paleogeology of Bottineau County. Shaded areas represent the locations of the oil fields. Map is adapted from Anderson (1974).

Absaroka Sequence

The Spearfish Formation directly overlies the unconformity at the top of the Mississippian rocks in Bottineau County. The Spearfish in this area is probably entirely Triassic in age as only the upper part of the formation is preserved here; in the deeper parts of the Williston Basin, farther west, lower Spearfish sediments of Permian age occur. The continental redbeds of the Spearfish Formation are quite variable in both thickness and texture, consisting of sand, siltstone, and shale ranging in thickness from perhaps 80 feet in northeastern Bottineau County to about 275 feet in the southwest, although local variations in thickness are considerable.

Zuni Sequence

The Zuni Sequence includes rocks of Jurassic and Cretaceous age, which reach a combined total thickness ranging from about 2,300 feet in eastern Bottineau County to more than 4,000 feet in the southwest part of the county. The Jurassic rocks, which consist mainly of shale with some fine-grained sandstone and lesser amounts of carbonates and gypsum, range from about 500 feet thick in extreme eastern Bottineau County to about 800 feet in the west.

Cretaceous rocks in Bottineau County range from about 1,800 feet thick in the east to about 3,300 feet in the southwest. The lower Cretaceous Inyan Kara clastics unconformably overlie the Jurassic section throughout the county. The Inyan Kara consists of interbedded shale and sand of variable thickness, ranging from about 80 feet thick in parts of eastern Bottineau County to over 400 feet thick in some western parts of the county (fig. 4). Although water from the Inyan Kara constitutes one of the most widely known aquifer systems in the state, the water from the Inyan Kara in Bottineau County is generally saline and undesirable for domestic and irrigation purposes. Water produced with oil in some Bottineau County oil fields is reinjected into the Inyan Kara and water from the Inyan Kara is used for repressurizing purposes in the Newburg and North Westhope oil fields.

The Cretaceous section above the Inyan Kara consists mainly of gray, marine shale formations. These are mainly noncalcareous, except for the Greenhorn and Niobrara, and they contain isolated bentonitic layers. The only area where preglacial formations are exposed in Bottineau County is around the flank of the Turtle Mountains. Isolated exposures of the Cretaceous Fox Hills and Hell Creek Formations and the Tertiary Cannonball Formation are found in this area. The Fox Hills Formation can be seen in several places near Souris. It consists of massive to interbedded sandstone, siltstone, claystone, and

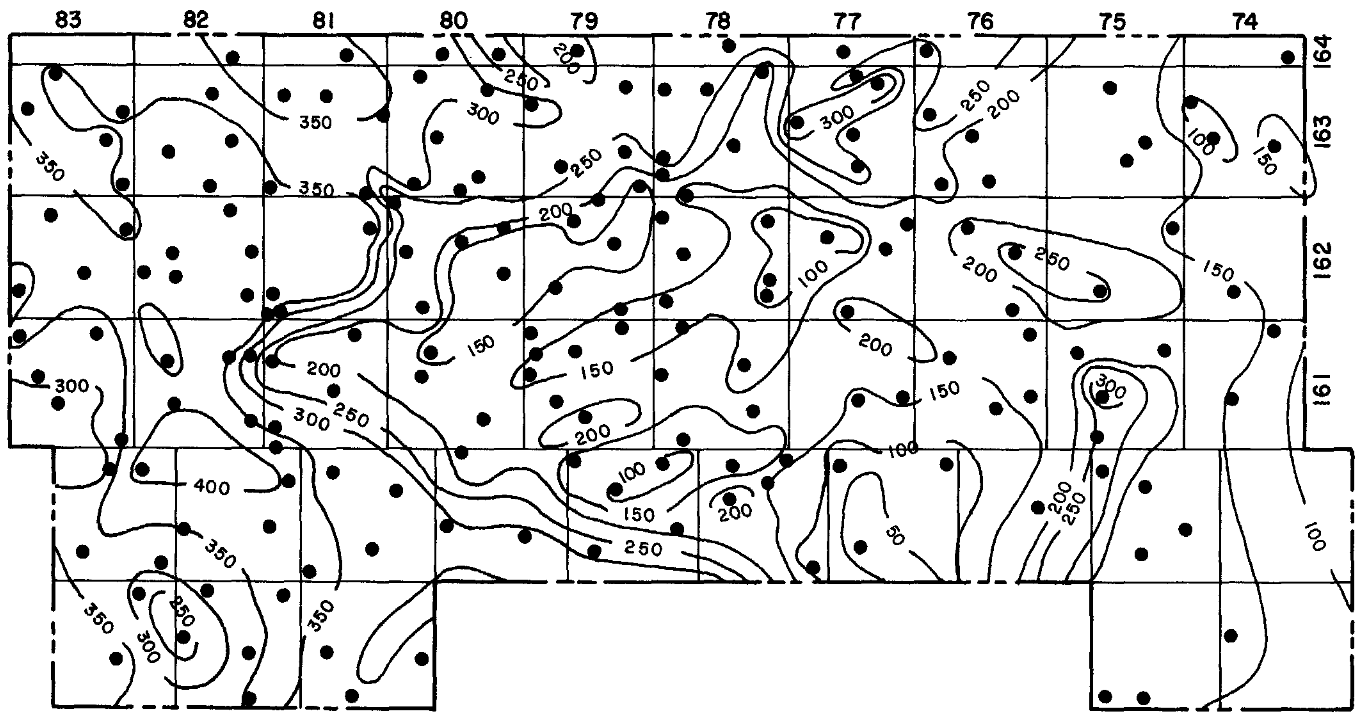

Figure 4. Thickness of the Cretaceous Inyan Kara Formation in Bottineau County. This map is modified slightly from an unpublished map drawn by S. B. Anderson and W. L. Moore. Black dots indicate well control. Contour interval is 50 feet.

Figure 5. Striated boulder of Fox Hills Formation at the SW¼sec 10, T163N, R77W. The striae trend N 12° W.

shale. Where it is present, it can be an important aquifer system. The Fox Hills Formation ranges from 0 to as much as 230 feet thick in the Turtle Mountains area where it is conformably overlain by Hell Creek Formation sediments. In southwestern Bottineau County, the Fox Hills sediments are as much as 300 feet thick in places (the formation is known only from test holes in that area). Through most of Bottineau County, the upper surface of the Fox Hills Formation has been eroded, and it is unconformably overlain by glacial deposits (fig. 5).

The Cretaceous Hell Creek Formation is found in southwest Bottineau County where as much as 226 feet has been measured in test holes. The formation is not exposed in that area. In the Turtle Mountains, as much as 200 feet of Hell Creek sediments have been measured in places where the formation is conformably overlain by the Tertiary Cannonball Formation sediments.

Figure 6. Steeply dipping Hell Creek Formation beds in the foreground; undisturbed beds beyond. The bedrock, which consists of gray sandstone, siltstone, and soft silt with pods of micritic mudstone, is dipping at about 45° to the east, striking N 35° W. This is apparently a thrust block, possibly related to the nearby, intensely ice-thrust area in the western portion of the Turtle Mountains (pl. 1). Exposure is along Highway 14, NW¼NW¼sec 8, T163N, R76W.

The Hell Creek is exposed along the southwest flank of the Turtle Mountains north of Carbury, where it consists of interbedded to massive sandstone, siltstone, claystone, and shale (fig. 6). Like the Fox Hills Formation, the Hell Creek may act as an aquifer in areas where it occurs.

The Tertiary Cannonball Formation subcrops beneath the glacial sediment along the Canadian border in the Turtle Mountains. This marine, sandy siltstone is yellowish brown where it is oxidized in exposures along State Highway 43 in sections 16 and 17, T163N, R76W. Fresh, unoxidized samples are greenish-gray sandy siltstone with limonite concretions. The Cannonball Formation rests conformably on the Hell Creek Formation. It is overlain by glacial sediment and its upper surface has been extensively weathered and eroded. As much as 130 feet of Cannonball sediments were noted in a test hole located in section 34, T164N, R75W; the formation thins southward from there.

The first glaciers advanced over a relatively flat bedrock surface in Bottineau County (fig. 7). The most prominent feature was a large mesa in the northeast corresponding to the modern Turtle Mountains. Tertiary Cannonball Formation beds covered much of the Turtle Mountain area with Cretaceous Hell Creek beds around the margins of the Turtle Mountains. Hell Creek beds also occurred at the surface in western Bottineau County. Elsewhere, the Cretaceous Fox Hills Formation was at the surface, except for patches of Pierre Formation shale in some lower places.

Pleistocene and Holocene Sediment

All the sediment related to glacial deposition in Bottineau County, that is, all the materials that were deposited by the glacial ice as well as by flowing and ponded water associated with the ice, are collectively referred to as the Coleharbor Group. Holocene materials are referred to as the Oahe Formation. The Coleharbor Group has been subdivided into a large number of informal units and formal formations by various geologists. However, most of this 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 the east side of the Turtle Mountains (the Leeds Lobe). Some stratigraphic work has been done along Lake Sakakawea in McLean County. Although some of the formal units that have been described for the eastern North Dakota glacial sediments may be regionally correlatable with units in Bottineau County, the present study did not include any effort to differentiate discrete units of glacial sediment that can be attributed to specific events of differing ages. For this reason, no attempt has been made to compare the glacial stratigraphy in Bottineau County with that in any other area.

Sediment of the Coleharbor Group is exposed throughout Bottineau County and only a few scattered exposures of preglacial sediment are found, these in the area along the southwest edge of the Turtle Mountains where only a veneer of glacial sediment is present on the bedrock surface. The Coleharbor Group sediment has been measured in test holes to thicknesses exceeding 300 feet in the Maxbass area in western Bottineau County and to about the same thickness at the edge of the Turtle Mountains a few miles north of Bottineau (fig. 8). However, the rugged local relief in the Turtle Mountains causes the covering of glacial deposits there to be quite variable in

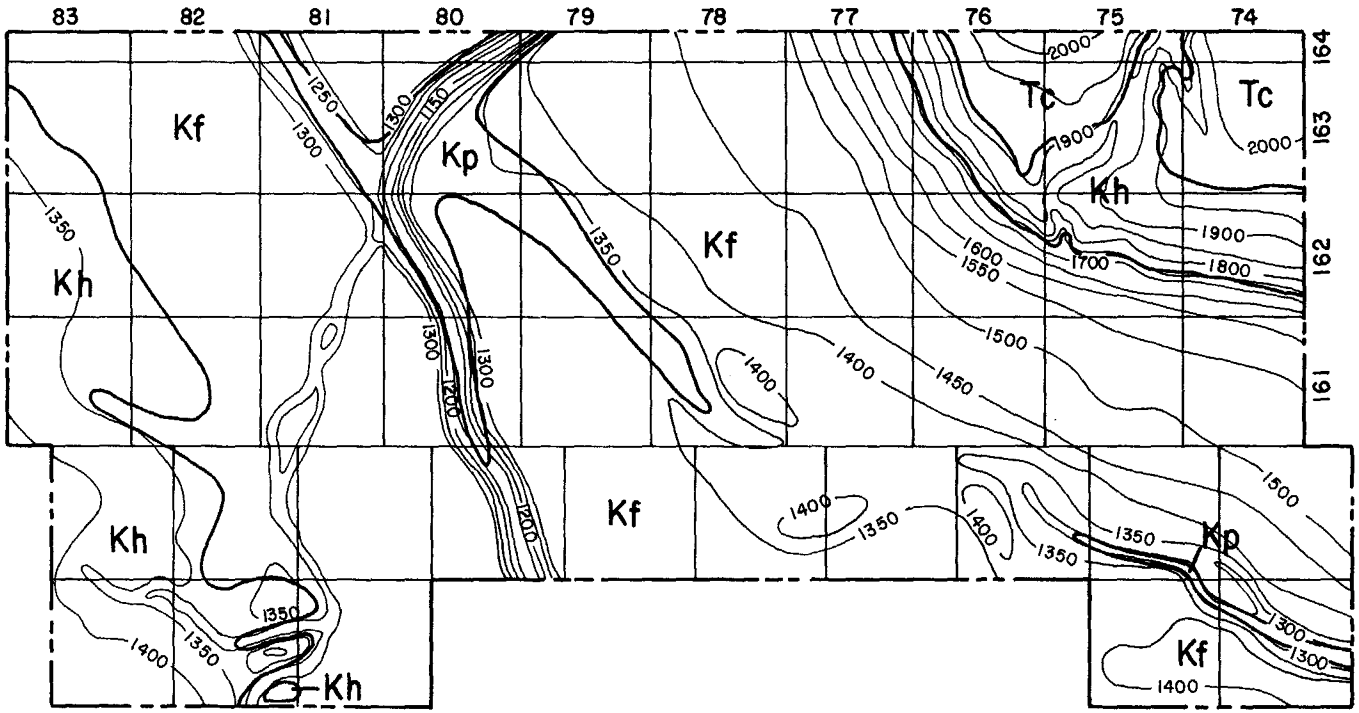

Figure 7. Subglacial geology and topography of Bottineau County. The central part of the county is mainly a lowland developed on Cretaceous Fox Hills Formation sediments with scattered areas of Pierre Formation in the lowest areas. Cretaceous Hell Creek Formation sediments subcrop beneath the glacial deposits in western Bottineau County, where the bedrock surface rises, and along the margin of the Turtle Mountains. Tertiary Cannonball Formation sediments lie beneath the glacial deposits in the higher portions of the Turtle Mountains.

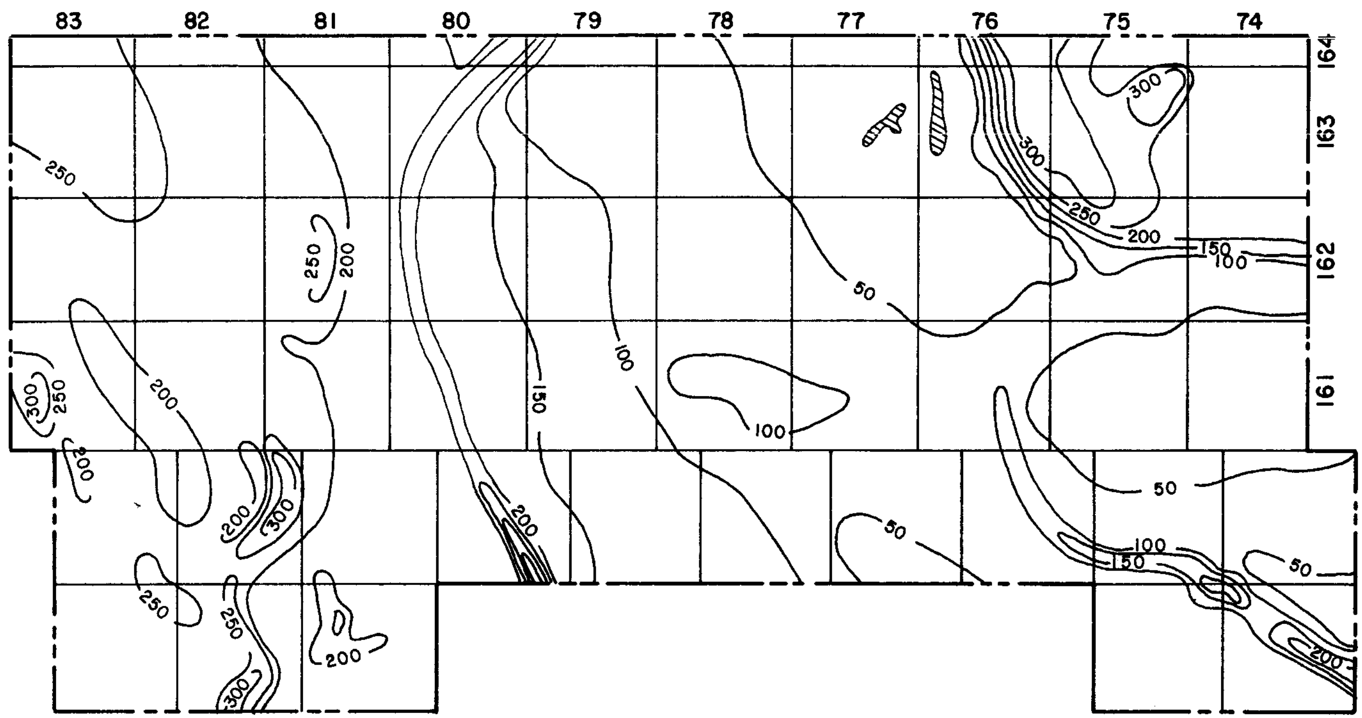

Figure 8. Thickness of the Coleharbor Group deposits in Bottineau County. This map is generalized, especially in the area of the Turtle Mountains where thicknesses are quite variable over short distances due to the rugged topography. The shaded area represents discontinuous glacial deposits with numerous exposures of pre-Coleharbor formations. The thicknesses are given in feet. The contour interval is 50 feet. Shaded areas show where preglacial deposits are commonly exposed at the surface.

thickness and it is likely that thicknesses between 400 and 500 feet are common. Three main facies of the Coleharbor Group sediment are recognized in Bottineau County: till; sand and gravel; and silt and clay.

Till Facies

The till of the Coleharbor Group found at and near the surface in Bottineau County (map units Qcer, Qcct, Qcch, Qces, Qccu, and Qcew on pl. 1) is typically a mixture of varying amounts of clay, silt, sand, pebbles, cobbles, and boulder-size particles. In oxidized exposures, the matrix material, which is composed mostly of sand and silt-size particles, is generally pale to medium yellowish brown when dry, or olive brown when moist. Fresh, unoxidized samples of till, taken during test-hole drilling, are typically medium to dark olive gray in color. The depth of oxidation of the surface till in most of Bottineau County generally ranges between 10 and 25 feet, except in the Turtle Mountains where it may be oxidized to 50 feet or more in areas of higher relief.

Most of the surface till in the Turtle Mountains is generally more shaly than that on the lower land south and west of there. It is a slightly stony mixture of clay, silt, and sand in approximately equal proportions with silt usually predominating. Many lithologies are present in the stony fraction of the till (pebbles, cobbles, and boulders). Most are igneous and metamorphic rock types; some limestone, dolomite, shale, sandstone, and lignite occur, although large fragments of sandstone and lignite are less common in the Turtle Mountains than in the till found on the nearby lowlands. Sand-size particles are also highly varied in composition, but are dominantly quartz and feldspar with some limestone, dolomite, shale, and a large variety of igneous and metamorphic rock-forming minerals. The silt-size particles are mostly quartz and feldspar with some limestone, dolomite, and shale. Clay-size particles are mostly montmorillonite with some fine-grained calcite, dolomite, quartz, and feldspar.

Most of the near-surface till found in Bottineau County away from the Turtle Mountains is more sandy than that found in the Turtle Mountains and that found farther east, in eastern North Dakota. This near-surface till was deposited by glacial ice that advanced southeastward, around the west side of the Turtle Mountains, over areas of Upper Cretaceous and Tertiary sediment including the Fox Hills, Hell Creek, Cannonball, and Bullion Creek Formations, all of which are much sandier than the older Cretaceous shale formations found in eastern North Dakota.

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

Sand and Gravel Facies

The sand and gravel facies consists largely of river-channel sediment, with only minor amounts of overbank sediment. The deposits occur both as thin layers and lenses within the till and as thick, continuous sequences independent of the till. The sand and gravel facies of the Coleharbor Group covers the surface area of about 15 percent of Bottineau County (areas of Qcsl, Qcst, Qcrf, Qcrs, Qcrw, and Qcrz). Modern stream deposits belong to the Oahe Formation (Qor). Areas of fine- to medium-grained, wind-blown sand (Qod) also occur in places.

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

The sand and gravel facies of the Coleharbor Group has a mineralogic composition similar to that of the till. The mineralogy indicates that it is a combination of locally derived materials as well as materials that were ultimately derived from the north in Canada. The sand-size fraction is largely quartz and feldspars with minor amounts of shale and carbonates. The gravel-size fraction is commonly about half carbonates and the remainder granitics, shale, and western-derived siliceous rocks. Some of the gravel has a high percentage of shale; this is common in the Carbury area where the bedrock is at shallow depths. The sand and gravel facies is generally the largest and most dependable source of high-quality groundwater in Bottineau County.

Silt and Clay Facies

Deposits of silt and clay that were laid down in lakes are found at the surface over much of Bottineau County. This material typically consists of yellowish-brown to olive-gray, cohesive to sticky, clay or silt that is sandy or even gravelly in places. Nearly all of the lake sediments found over the central and southeastern parts of the county were deposited as offshore turbidity-current sediment in glacial Lake Souris. Only small amounts of lake sediment occur outside the area that was flooded by Lake Souris. The areas of clay, silt, and fine sand are designated mainly Qclo, Qcln on the geologic map. In some areas, thin deposits of lake sediment overlie till; these are designated Qclt on the geologic map. In addition to the areas of lake silt and clay, some areas are covered by fine nearshore sand that has been designated Qcsl or, where it veneers glacial till, Qcst. In places, areas of Qcsl are gradational in texture with areas of Qcln, and areas of Qcst are gradational in texture with areas of Qclt; in many cases it would have been logical, perhaps, to lump these units together.

In the Turtle Mountains, several fairly extensive areas of lake clay with some silt occur. Pleistocene-age lake deposits are designated Qcle on the geologic map and Holocene deposits are designated Qos (slough sediments). The surface materials in these areas are mainly tough, black, slightly sandy, slightly silty clay containing several percent of organic material. These sediments were deposited in elevated lakes or in lakes that were otherwise surrounded by or in contact with stagnant glacial ice.

The silt and clay that was deposited in glacial Lake Souris ranges up to 60 feet thick in places, although thicknesses of 15 to 30 feet are more common. The thickness is a function of the relief on the underlying till surface as the upper surface of the lake deposits is generally quite flat.

GEOMORPHOLOGY

General Description

The modern landscape in Bottineau County was formed by the Wisconsinan glacier that covered the area and by the glacial Lake Souris, which flooded the central and southeastern parts of the county when the glacier melted (fig. 9). The Souris River has modified the lake plain considerably, depositing broad areas of fine fluvial sand and silt in places, and eroding away the covering of lake sediment in other places. The lake plain surface has been modified by the wind in some places. Dunes are found on the lake plain in the southern part of the county,

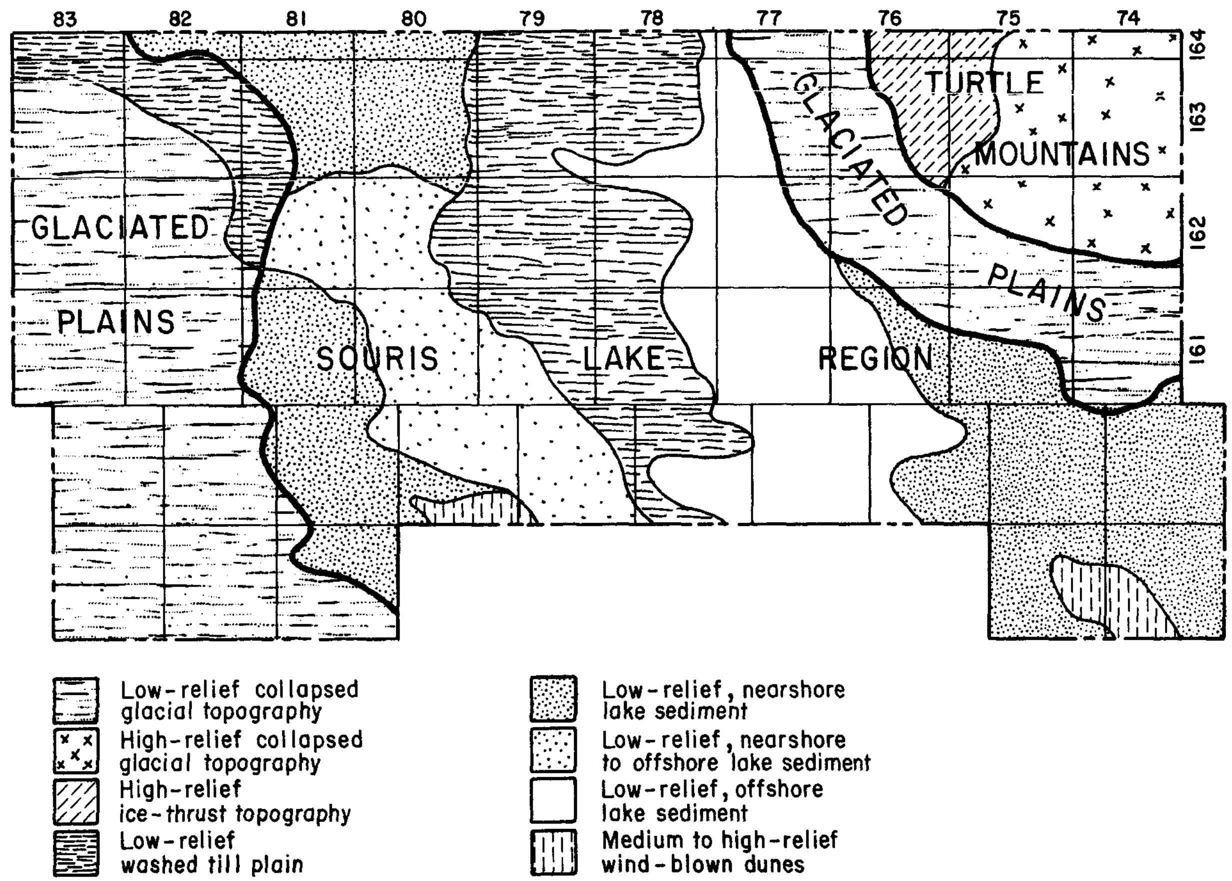

Figure 9. Landforms found in Bottineau County. This generalized map shows the major landforms and the major topographic areas in the county.

although they are not so large or so numerous as those in McHenry County to the south.

The western part of Bottineau County (the "Glaciated Plains" on fig. 9; mainly unit Qccu on pl. 1) is a plain of glacial sediment (till) with low to moderate local relief. This till plain formed when glacial ice melted there about 12,000 years ago, depositing glacial sediment. The till surface was later modified by stream erosion and probably also by periodic flooding so that it is veneered in many places by fluvial sediment, and it is scoured and bouldery in other places.

The Turtle Mountains are the most rugged part of the county. They resulted from the melting of sediment-covered, stagnant glacial ice. The glacial ice on the Turtle Mountains in northeastern Bottineau County probably melted somewhat later than did the ice in the remainder of the county. The west end of the Turtle Mountains is notable for the unusually well-developed, large, glacial thrust feature there (fig. 9).

Much of the remainder of Bottineau County has landforms that resulted largely from the action of glacial Lake Souris. An area of offshore silt occurs just to the east of the center of the county. Much of the remainder of the lake plain has sandy, nearshore topography although few identifiable beach ridges were seen. An extensive portion of the lake plain in the central part of the county is surfaced mainly by till. The pre-lake topography in this area was too high to allow the deposition of much lake sediment here. If any lake sediment was deposited in this area, it may have been eroded away by catastrophic floods, which flowed northward.

Surface elevations in Bottineau County rise about 1,135 feet from the lowest point (1,410 feet elevation) where the Souris River flows into Manitoba to the top of Boundary Butte in the Turtle Mountains (elevation 2,545 feet). The sharpest rise in elevation is at the scarp to the Turtle Mountains where elevations rise from as much as 500 to 600 feet in a distance of about two miles. The rise in surface elevation is due in part to a rise on the preglacial surface at that location of about 300 feet and in part to a thickening of the glacial-sediment covering on the Turtle Mountains.

The valley of the Souris River has been carved as much as 80 feet deep at the Canadian border where it is bordered on either side by a water-worn till surface. To the south, the valley is less deep. At the point where the river enters Bottineau County from McHenry County for example, the valley is only about 20 feet deep. The valley ranges from about three-quarters of a mile wide in the central part of the county to a mile and a half wide at the Canadian border.

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 relect pingos. However, in North Dakota, hummocks were generally formed at a time when paleoecologic evidence indicates a climate too warm for permafrost, and hummocks are generally absent in North Dakota in areas known to have had permafrost (Clayton, Moran, and Bluemle, 1980).

In Bottineau County, two areas of collapsed glacial topography are recognized and they are quite different from one another. Western Bottineau County (the "Glaciated Plains" area on fig. 9) is designated mainly Qccu on plate 1. This area has low relief, generally less than 10 feet locally, poorly to moderately well integrated drainage, and maximum slope angles of less than 4°. It has been washed in places by running water, perhaps by periodic floods of water from rapidly draining glacier-dammed lakes (Kehew, 1982). 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 (fig. 10).

Small, discontinuous areas with topography similar to that just described occur along the margin of the Turtle Mountains in the areas northwest and southeast of Bottineau (fig. 11). These areas, however, are more dissected by small valleys heading in the Turtle Mountains. They are also obscured in places by a veneer of fluvial sediment so that ice-disintegration markings are harder to see.

Hilly collapsed glacial topography (Qcch on pl. 1) is well developed in the Turtle Mountains where local relief may exceed 100 feet and slope angles greater than 7° are common. Through drainage is essentially lacking in the Turtle Mountains. The

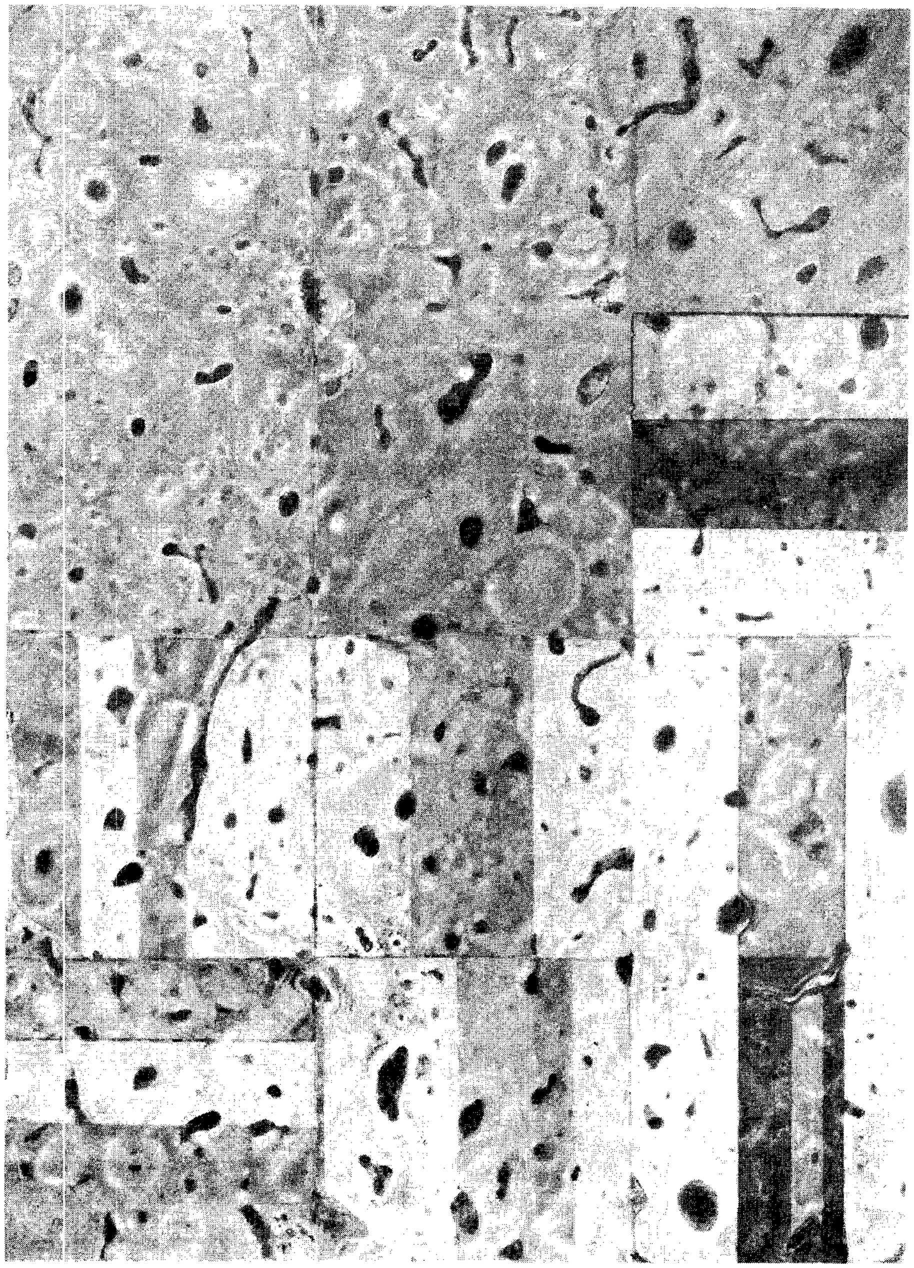

Figure 10. Airphoto of typical collapsed glacial topography in western Bottineau County (parts of secs 27, 28, 33, and 34, T161N, R83W). Local relief in this area is generally less than 5 feet. Even so, circular disintegration ridges ("doughnuts") are well developed and apparent on the photo.

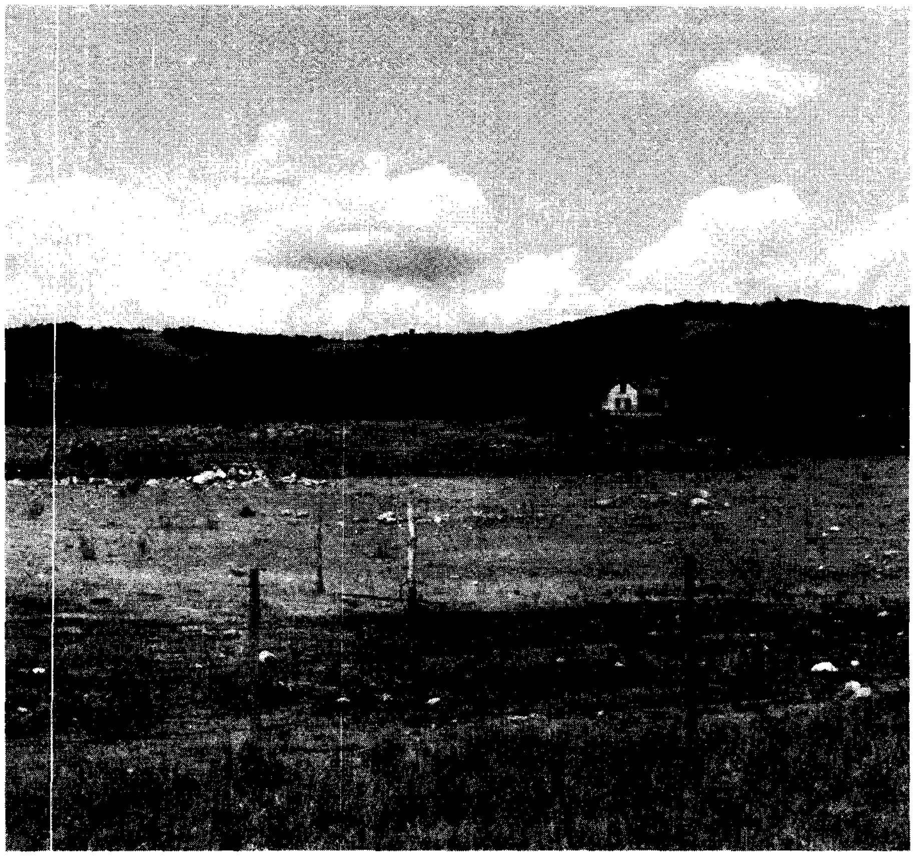

Figure 11. Southwest slope of the Turtle Mountains. The view is to the northeast over sec 27, T163N, R76W. A lag of boulders remains as a result of extensive washing by slopewash from the Turtle Mountains.

landforms in the area are the result of large-scale glacial stagnation, most of them ulitmately the result of mudflows. As the stagnant glacier melted, topography on the surface of the ice was continually inverted. When sinkholes in the stagnant glacier finally melted through to the solid ground beneath, circular holes formed in the glacier. Material flowing down the sides of these holes completely filled many of the holes, resulting in hills of material occupying the positions of the former sinkholes when all the ice finally melted (fig. 12). 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." If, in the final

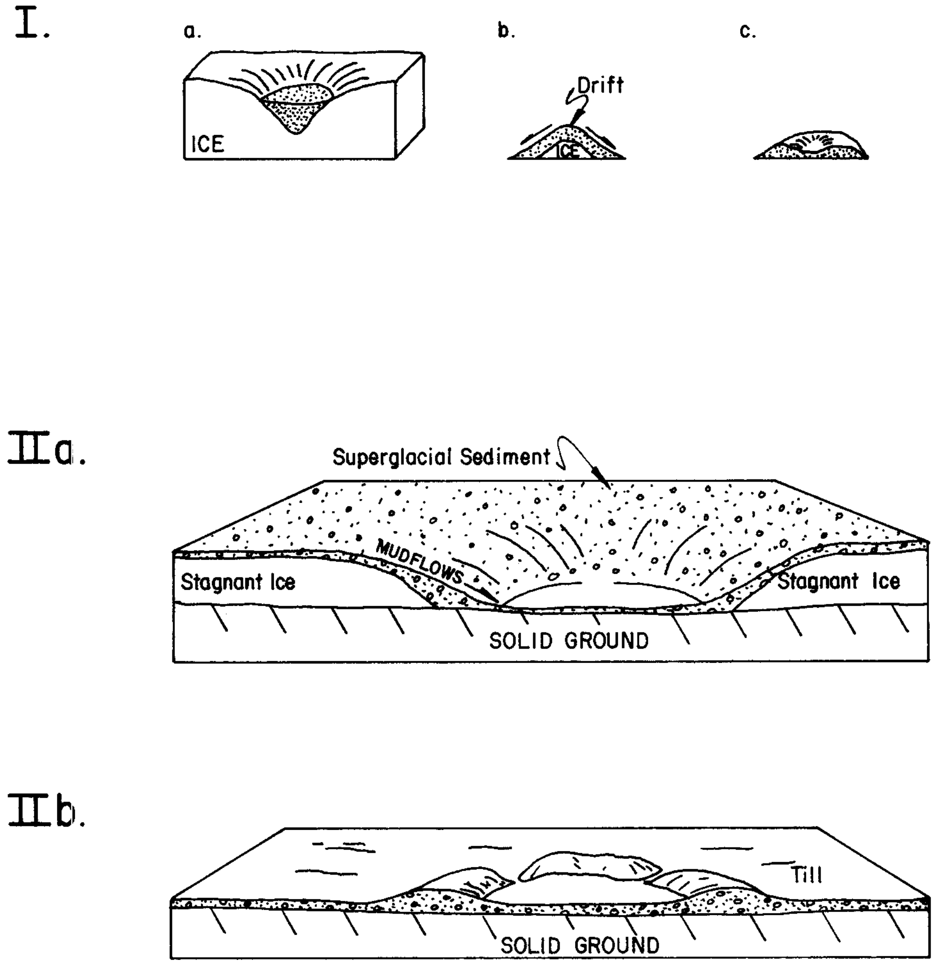

Figure 12. Diagrams showing how circular disintegration ridges form in areas of collapsed glacial topography. Small "doughnuts" (500 to 600 feet across) might form in three stages, as shown in the uppermost series of diagrams (I-a, I-b, and I-c). Large "doughnuts" (1,000 feet or more in diameter) might 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.

stages of topographic inversion, thick deposits of material in the bottom of sinkholes caused them to invert into ice-cored cones, the material may have flowed down the sides of the cones, producing, when all the ice had melted, doughnut-shaped ridges, also called circular disintegration ridges. Any ridges formed by material moving down ice slopes and collecting at the base of 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 (figs. 13 and 14).

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

Ice-Thrust Topography

Ice-thrusting near the terminus of the active glacier in the westernmost part of the Turtle Mountains (fig. 15), immediately west of the Turtle Mountains, and in many other parts of North Dakota, resulted in large compressional folds and thrusts of the subglacial sediment (Bluemle, 1970; Bluemle and Clayton, 1984) (areas designated Qcct on pl. 1). Vertical displacement was typically tens of feet, and the individual folds or thrust slabs are commonly about 600 feet across. However, the individual slabs in the ice-thrust topography in the western Turtle Mountains (Tps 163-164N, Rs 75-76W) are spaced about 1,200 to 1,500 feet apart. Relief between the edges of slabs and the intervening highs averages about 50 to 80 feet.

An area of smaller scale ice-thrust hills occurs in the area north of Souris, a few miles to the west of the large thrust features just described (fig. 16). These hills are relatively small features, 50 to 75 feet high, and typically about a tenth of a mile across at the base. Fox Hills Formation sandstone beds that are exposed in a few places dip in various directions at from 20° to 35°. In one exposure at the northwest corner of section 16, T163N, R77W, till appears to have been thrust over bedded sand. The thrust plane dips at about 30° to the southwest (fig. 17). Most of the hills appear to consist of materials that have been thrust northeastward short distances, less than a mile, from a narrow, trough-like area. Poorly defined depres-

Figure 13. Typical area of hilly collapsed glacial topography in the Turtle Mountains. This airphoto shows parts of secs 27, 28, 33, and 34, T163N, R75W about six miles northeast of Bottineau. Local relief here is as much as 130 feet in a mile. Wooded areas are mainly glacial sediment with large-scale disintegration features. Cultivated areas, especially in the lower, center portion of the area, are mainly thin deposits of lake sediment that was deposited in ice-walled lakes. These areas are now elevated lake plains. Scale is approximately 3.2 inches to a mile.

Figure 14. Typical high-relief collapsed glacial topography in the Turtle Mountains. View is to the west from the top of Butte St. Paul (sec13, T162N, R74W).

sions mark the source area of the ice-thrust hills. The depressions are largely filled with lake silt and clay.

Waterworn Glacial Topography

Extensive areas of Bottineau County have been washed by either running water or waves along the shore of glacial Lake Souris. Areas of glacial sediment that were washed by running water are located mainly in the western part of the county (Qces on pl. 1) and along the slopes of the Turtle Mountains (Qcer on pl. 1). Both of these units are covered by a lag of boulders in places. Areas of stream-eroded topography in western Bottineau County are flat to undulating, commonly with local relief of up to 10 feet in a mile. In places, as much as two or three feet of sand or gravel occurs sporadically on the surface on top of the till and, in other places, areas of continuous sand occur (Qcrf on pl. 1).

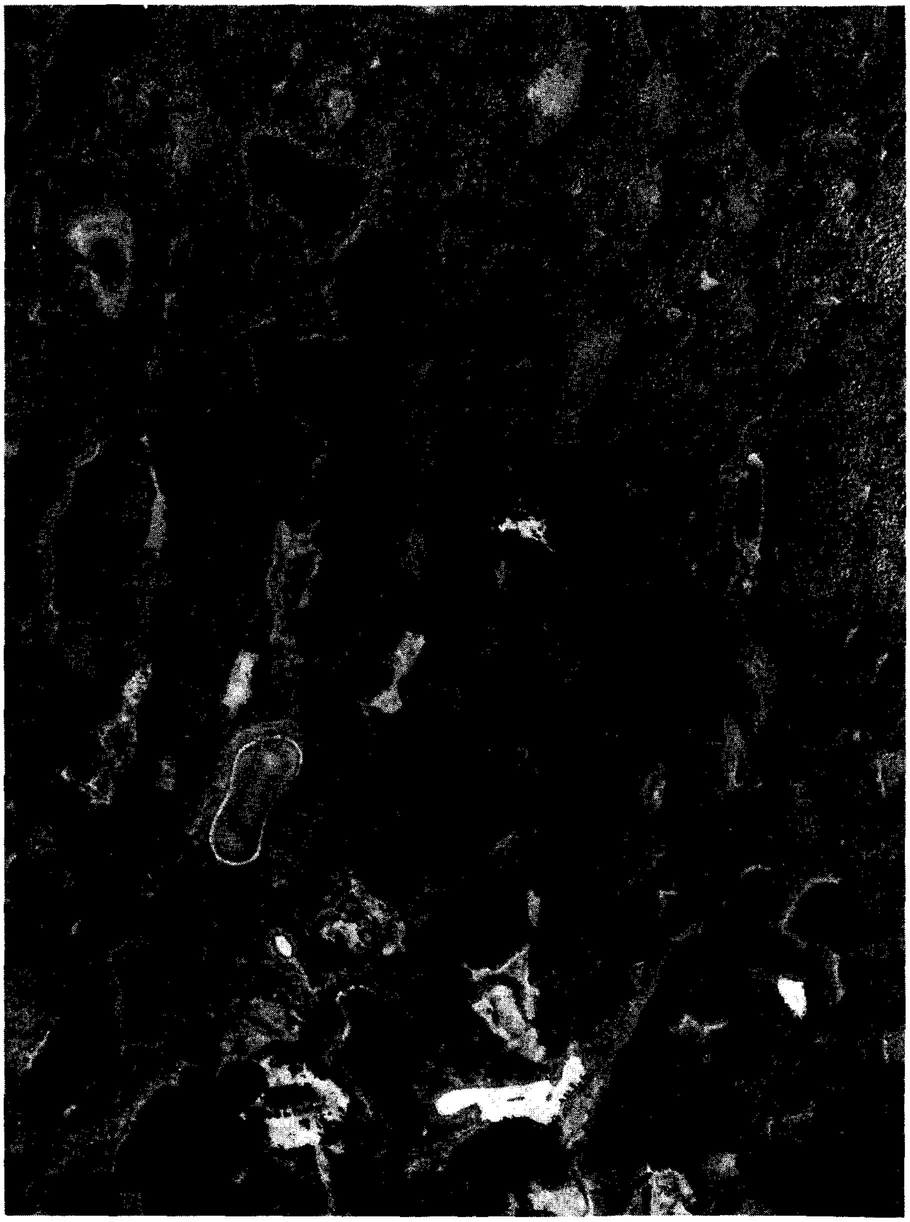

Figure 15. Area of large-scale ice thrusting in the western part of the Turtle Mountains. Individual thrust slabs trend mainly north-northeast to south-southwest. Long, narrow lakes and sloughs occur in the troughs between the thrust ridges. Parts of secs29, 30, 31, and 32, T164N, R75W are shown as well as a portion of southern Manitoba. The U.S.-Canadian boundary shows up as a straight, tree-cleared line through the mainly wooded areas. Scale is about 3.1 inches to a mile.

Figure 16. Small, ice-thrust hills at the northwest corner of sec16, T163N, R77W about three miles north of the town of Souris. View is to the north.

Along the slopes of the Turtle Mountains, areas of washed till (Qcer) occur too, but here, where the land slopes steeply to the west and southwest, the relief is much greater, as much as 300 to 400 feet in a mile. Bouldery slopes occur near the deep gullies that head upward into the Turtle Mountains. Patches of sand and coarse gravel occur in places and fans of gravel have developed in other places (fig. 11).

The third type of waterworn glacial topography covers a broad area in central Bottineau County where the land was worn by wave action along the shore of glacial Lake Souris (Qcew on pl. 1). Glacial sediment is the dominant surface material throughout this area, although patches of lake sediment--typically less than two feet of clay or fine silt--occur (Qclt). Relief is typically about three to five feet in a mile in most places in this waveworn topography.

Figure 17. Shear planes in a gravel pit excavation at the northwest corner of sec16, T163N, R77W. A deposit of unbedded gravel has been overthrust by a 3-foot-thick layer of bedded sand. The bedding in this sand layer is parallel to the underlying thrust plane. The bedded sand itself has been overthrust by a 6-foot-thick layer of till. The thrust planes here dip southwestward at about 30°.

In a few places, in the area shown on plate 1 as waveworn glacial sediment, small mounds that appear on the airphotos as light spots or "freckles" occur. Similar features have been noted in Rolette County (Deal, 1971) and Towner County (Bluemle, 1984), where they were attributed to the burrowing action of toads. The mounds are well developed in the vicinity of Roth, in north-central Bottineau County. In view of the fact that the mounds appear to be restricted to areas of fine sand in Rolette and Towner Counties, it is also likely that in the places where they are present in Bottineau County, the glacial sediment is covered by a veneer of sand.

Lacustrine Landforms

Nearly all of the central and southeastern part of Bottineau County was flooded by glacial Lake Souris (fig. 9). Throughout much of the area, little lake sediment was deposited, but instead the flooded areas of glacial sediment were washed by waves. Considerable fine sand occurs along the margins of the lake plain, most of it probably deposited by streams that flowed into the lake. A veneer of wind-blown sand is present over much of the lake plain and, in the southern part of Bottineau County, some dunes are present. Areas of offshore lake clay (Qclo) also have a veneer of sand and a northwest-southeast "grain" on airphotos.

Areas of Offshore Sediment

Several townships in the central part of the county are surfaced mainly by thin deposits of silt and clay that were probably deposited offshore in the deeper water of Lake Souris. This area (Qclo on pl. 1) generally has relief of less than two or three feet in a mile. The average elevation on the lake plain floor in central Bottineau County is about 1,470 to 1,475 feet. The lake deposits are probably generally less than 10 feet thick, filling in the lower areas in the underlying till plain, which rises above the lake plain in places. In areas where it was not feasible to distinguish whether till or lake sediment is the dominant material at the surface, a combined map unit (Qclt) was used. Here, patches of bedded clay or silt, presumably offshore sediments, overlie the till to a depth of no more than a few feet.

Areas of Nearshore Sediment

West of the area of offshore lake deposits in west-central Bottineau County, and southeast of it in the southeastern part of the county, deposits of bedded silt that are probably of nearshore origin cover the surface (Qcln on pl. 1). This silt grades into fine sand (Qcsl and Qcst) in many places (the designation Qcst on pl. 1 refers to areas where the sand is a discontinuous veneer on the underlying glacial sediment). Few well-defined beaches were noted in Bottineau County. A possible beach ridge occurs in sections 14, 23, 24, and 25, T162N, R77W a few miles southeast of Souris where several northwest-southeast trending ridges occur at elevations between 1,525 and 1,550 feet. These gravelly ridges, however, grade into obviously fluvial features and it was not possible to determine whether they might be related to a Lake Souris shoreline. In the area just north of Souris, a north-south trending, west-facing scarp extends for about six miles through the western part of T163N, R77W. The base of this 25-foot-high scarp is generally at about 1,525 feet. Lake deposits occur west of the scarp; a complex suite of fluvial, ice-contact, and ice-thrust features occurs to the east of it. Another beach ridge occurs south of Omemee in sections 16, 17, 21, 22, 26, and 27, T160N, R75W. This southeast trending 5-mile-long ridge is about 0.2 mile wide in most places and about 15 feet high. It occurs at elevations between 1,460 and 1,475 feet.

Lemke (1960, p. 115) mentioned two prominent levels of Lake Souris at approximately 1,550 and 1,510 feet above sea level. Bluemle (1982, p. 28) identified probable shoreline sediments at elevations between 1,510 and 1,515 feet in McHenry County and at elevations between 1,530 and 1,540. Moran and Deal (1970), identified strandline levels at 1,590, 1,570, 1,550, 1,540, 1,525, 1,510, 1,500, 1,475, and 1,460 feet in Rolette, Pierce, McHenry, and Bottineau Counties. They stated that the three most prominent strandlines are at 1,550, 1,510, and 1,475 feet.

Elevated Lake Plains

Sediment deposited in lakes that existed on stagnant glacial ice is designated Qcle on plate 1. It underwent collapse at least once, possibly several times, as the underlying ice melted. The sediment is mainly offshore silt and clay, but contains some nearshore and shoreline deposits of silt, sand, gravel, and mudflow sediment (till). These deposits rise above their surroundings as hills, and road cuts in their flanks commonly expose till. They often make good farmland in the Turtle Mountains as they are usually less hilly than surrounding areas and they are free of boulders.

Clayton and Cherry (1967) distinguished two types of ice-walled lake environments, stable and unstable (fig. 18). The ice-walled lakes that formed in the Turtle Mountains were stable-environment lakes that developed on top of well-insulated, buried stagnant ice. Most of the water in them 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. They probably contained fairly warm water and abundant aquatic life. They were surrounded by forest that was largely spruce.

The sediment in the unstable-environment lakes tends to be siltier and sandier than that in the stable-environment lakes. These lakes commonly have sandy or gravelly rims and the sediment in them is relatively thin.

Modern Ponds and Sloughs

Three types of standing water bodies occur in Bottineau County: perennial, intermittent, and temporary. The perennial

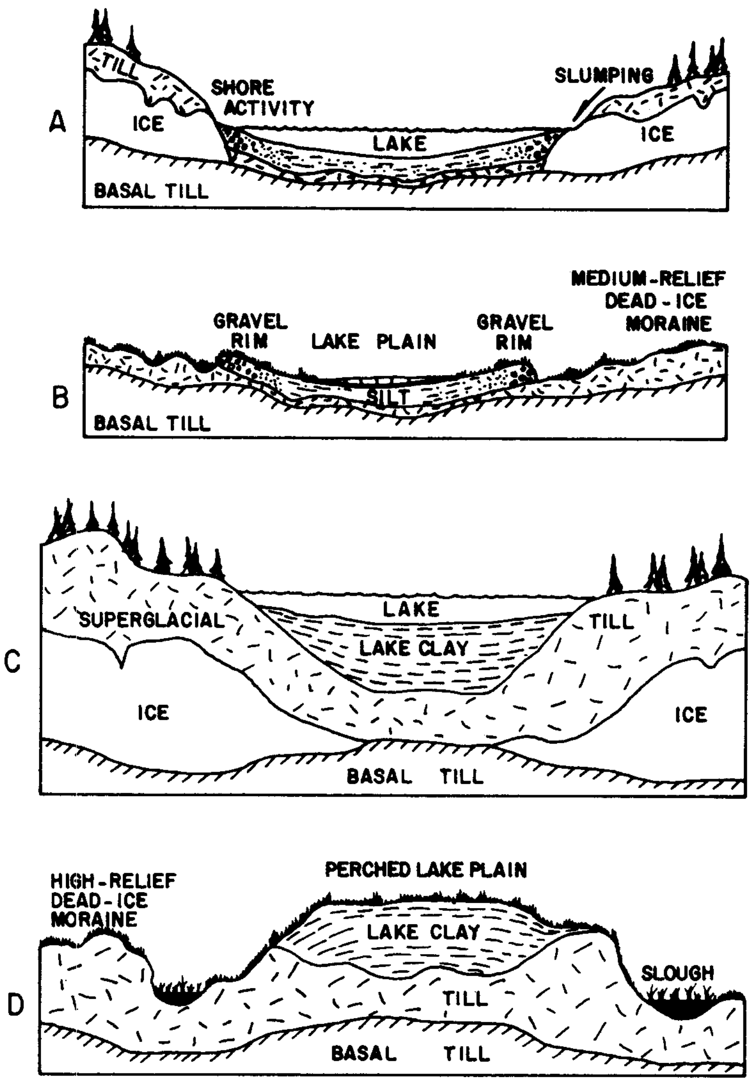

Figure 18. Generalized cross sections showing the type of modern landforms that resulted from lakes that existed in areas covered by stagnant, unstable glacial ice such as in the Turtle Mountains. Diagrams A and B show stages in the development of a gravel-rimmed, slightly elevated lake plain. C and D show stages in the development of a markedly elevated lake plain. Illustrations are from Clayton and Cherry (1967) and Deal (1971).

lakes are shown on plate 1 as white (uncolored) areas without any letter designation. Areas that are sometimes flooded are mapped as pond and slough sediment (Qos).

Perennial lakes and ponds always contain standing water. Such lakes occur in local groundwater discharge areas, especially in the Turtle Mountains. These lakes receive water from both the water table and from local runoff. Sediment deposited in these perennial lakes is mainly silt and clay derived from nearby soils and glacial sediment on adjacent hillsides. It is unoxidized and contains a few percent of organic material, lacustrine fossils such as fish, microcrustaceans, mollusks, and aquatic plants. Locally, some of the lakes along the Canadian boundary contain deposits of peat and bog deposits. These lakes typically have a central floating mat of sphagnum moss.

Intermittent lakes and ponds normally contain standing water, but they are dry during prolonged dry periods. They are also situated in local groundwater discharge areas and, even though they receive runoff from adjacent hillslopes during rains and during the spring thaw, they receive much of their water from the water table. The sediment in them is similar to that in permanent lakes, but it lacks fossils of plants and animals that require permanent standing water. The sediment also tends to be slightly oxidized and slightly tougher than that in perennial lakes and ponds.

Temporary ponds (sloughs) contain water only for a short time after rains and the spring thaw. These ponds are in groundwater recharge areas, that is, they lose water to the water table by seepage through the sediment in their bottoms. They contain a few feet of organic clay derived mostly from the uppermost soil horizon on surrounding hillslopes. The sediment is partially oxidized as it has been dry for part of the time. It is also typically quite tough as a result of this repeated drying.

Fluvial Landforms

Landforms resulting from the action of running water include deposits of both meltwater rivers and 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 outwash" of the Turtle Mountains 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 meltwater rivers is not really outwash. For example, much of the sand and gravel in western Bottineau County (Qcrf) was deposited by floods of water flowing from glacial Lake Regina to the northwest of the study area (Kehew, 1982). Much of the sand and gravel along the edge of glacial Lake Souris was delivered to the lake by small streams flowing into the lake (Qcrf and Qcrw on pl. 1). This material is, in a sense, "deltaic" sediment.

Meltwater Trenches

Numerous small valleys trend from northwest to southeast in western Bottineau County. Most of these probably served as short-lived spillways for periodic floods of water from the northwest (Kehew, 1982). The valley wall slopes are mainly till in most places and little sand and gravel is associated with the meltwater trenches. In some places, bouldery surfaces occur on the valley sides. Valleys such as Cut Bank Creek and its tributaries, East and West Cut Bank Creeks, Spring Coulee, and South Antler Creek are mainly shallow, incised only 10 to 20 feet below the surrounding glacial till plain (an exception is Cut Bank Creek, which has a valley that is as much as 50 to 60 feet deep in places). The valleys are quite diffuse in places, consisting only of a washed area where the markings usually associated with collapsed glacial topography ("doughnuts," etc.) have been removed.

The most extensive single area of fluvial sediment associated with any of the meltwater valleys just described occurs south of Maxbass where Cut Bank Creek flowed into glacial Lake Souris (area of Qcrf on pl. 1). The sand and gravel is not thick here, probably less than 10 feet in most places, but it covers about 15 square miles. Most of the small meltwater trenches of western Bottineau County carried streams that flowed into glacial Lake Souris. For this reason, they do not continue eastward much beyond the shoreline area of the lake plain, but rather, they simply die out on the lake plain. Modern streams do continue to the Souris River, but these flow in poorly defined valleys that never served as meltwater routes.

The largest meltwater trench is the Souris River valley in the central part of the county. This valley is as deep as 80 feet and ranges from three-quarters to a mile and a half wide at the Canadian boundary. It has gravel-covered terraces in places (Qcrf on pl. 1) and washed, till-surfaced terraces in other places. The Souris River flows through the center of the glacial Lake Souris plain and it is bordered, on both sides, by areas of washed till (Qcew), from which most of the lake sediment has been eroded away.

Eastern Bottineau County has numerous small meltwater trenches that trend mainly south and southwestward, away from the Turtle Mountains (areas designated Qor on pl. 1). No meltwater trenches occur in the Turtle Mountains themselves, with the possible exception of Oak Creek valley, which heads back a few miles as a discrete valley to near Duck Lake. Up-stream from Duck Lake, Oak Creek flows as a poorly defined stream without an identifiable valley.

Although several of the small valleys that head in the Turtle Mountains probably did carry some meltwater, they didn't serve as routes for large volumes of water, probably because the stagnant glacial ice in the Turtle Mountains melted over an extremely long period of time.

Modern fluvial overbank material (Qor on pl. 1) occurs on the Souris River flood plain and on some of the smaller stream flood plains. The modern river flood plains are flat and commonly underlain by up to 25 feet of flat-bedded organic silt and clay.

Areas of Collapsed Stream Sediment

In several places, especially in the Turtle Mountains, areas of gravel and sand that were deposited on top of stagnant glacial ice can be found (Qcrs on pl. 1). As the stagnant ice melted, flow was reduced to streams flowing in channels cut in the ice, and sediment accumulated and was gradually lowered down to the underlying solid ground. Gravity faulting displaced the sediment as it settled. Mudflows from the adjacent ice walls often covered the stream sediment with a veneer of till and, if the channel had been flushed of stream sediment before collapse, the mudflow material may have locally filled most of the channel. Most of the sand and gravel is well sorted and bedded, but some is poorly sorted and poorly bedded.

In the Hellick Lake-Grass Lake area (T163N, R74W), shaly gravel, interbedded with lake clay and till covers about three square miles. Relief in this area of collapsed stream sediment is from 10 to 70 feet locally and the area is somewhat elevated above the surrounding collapsed glacial topography. Some esker ridges also occur in the area.

A one- to two-mile-wide band of collapsed stream sediment borders the southern edge of the Turtle Mountains (pl. 1). Occurring at the slope to the upland, this gravelly area has high relief (up to 150 feet in a mile). It has been deeply gullied by stream erosion that took place after the time the stagnant glacial ice melted. In places, deposits of colluvial material (mainly inclusions of glacial sediment) occur in the gravel. This gravel unit grades southward in most places into an area of uncollapsed stream sediment (Qcrf on pl. 1); the boundary between the two units (Qcrs and Qcrf) is arbitrary in most places and based mainly on subjective appraisal of the amount of collapse that appears to have occurred.

Areas of Outwash and Valley Trains

Areas underlain by flat-lying beds of gravel (Qcrf on pl. 1) and sand have already been discussed to some extent in the discussions of meltwater trenches and collapsed stream sediment. Some of this fluvial material may be glacial outwash, but most of it was probably deposited by runoff from precipitation. In western Bottineau County, areas of flat-lying sand and gravel are usually associated with the many small stream valleys. This material may have been deposited, in part at least, by periodic floods of water released from glacial lakes to the northwest (Kehew, 1982).

Eskers

A few eskers and kames occur in the Turtle Mountains, but more of them are found around the periphery of the Turtle Mountains (Qcrz on pl. 1). Several ridges of gravel and sand that were apparently deposited in contact with the glacial ice are found in a 6-mile-wide zone between Carbury and Souris that extends southward from the Canadian boundary to near Highway 5 (Tps 162-164N, Rs 76 and 77W). These ridges, some of which are probably eskers, occur in what is an unusually complex area where several ice-thrust hills appear to be closely associated with the ice-contact features. The longest of the esker-like ridges is about a mile long (secs 9 and 10, T163N, R77W) and 40 to 50 feet high, but most of them are much smaller. Several small gravel pits are located in the ridges. Most of the gravel is well sorted and bedded, and it is commonly flat-lying. It contains inclusions of till that probably flowed into the streams as mudflows from the adjacent ice.

Eolian Landforms

Over parts of the glacial Lake Souris plain where fine sand predominates, especially where streams issued into the lake depositing "deltaic" sediments, the near-surface materials have been modified by eolian action (Qod on pl. 1). Near Eckman and Willow City, fairly well-developed dunes occur, although they are not nearly so large and spectacular as those found to the south in McHenry County (Bluemle, 1982). Local relief is only about 10 feet, but the dunes do show up on airphotos as strongly northwest-southeast lineated land. Over much of the remainder of the lake plain, in places where dunes are absent, a veneer of wind-blown sand is found in places. Because it is so thin and discontinuous, it was not shown on plate 1.

Colluvial Landforms

South and west of the Turtle Mountains, at the base of the slope to the upland and on the slope itself, much of the material at the surface is probably a combination of colluvial and fluvial sediment. The area south of the Turtle Mountains, east of Bottineau, is especially complex, and even though it is shown on plate 1 as a relatively few units (Qcrs, Qcer, Qcrt, and Qccu), it is difficult to be certain of the boundaries between the units. The land surface in this area along State Highway 5 is level and relatively free of boulders, except in a few places where washed glacial sediment (Qces on pl. 1) is exposed. The character of the area is further complicated by the presence of numerous springs, which result in a permanently mucky surface, almost a "quicksand" in places.

The rationale for referring to this complicated area as "colluvial landforms" is based on the idea that much of the material there has been derived from the nearby upland through mass-wasting processes. Much of the material is alluvial, but chunks of till, presumably mudflow material, gravel inclusions, and lake sediment also occur; at least some of this material may have slid downslope to be redistributed by gravity in the nearly always wet environment (due to the spring action).

SYNOPSIS OF GEOLOGIC HISTORY

Preglacial History

The Precambrian, Paleozoic, and Mesozoic history of Bottineau County is summarized earlier in this report in the section dealing with stratigraphy. During early Tertiary time, marine sediments were deposited in the Cannonball sea, probably over the entire county, but they are found today only in the Turtle Mountains and in the southwestern corner of the county. It is likely that the Paleocene Bullion Creek Formation, and perhaps the Sentinel Butte Formation, were also deposited over all or part of the area; but, if they were, they were removed during the long period of Tertiary erosion prior to glaciation. During this time of erosion, the area between the Turtle Mountains and the Missouri Coteau, which lies about 25 miles to the southwest of Bottineau County, was eroded down to the Paleocene Cannonball and Cretaceous Fox Hills and Pierre Formations, leaving the Turtle Mountains standing as an outlier capped by Cannonball Formation sandstone. If the Paleocene Cannonball Formation (and the Cretaceous Hell Creek Formation) ever extended over the area between the Turtle Mountains and the Missouri Coteau, the amount of erosion there during Tertiary time must have been more than 500 feet in most places. It is likely, too, that the Bullion Creek and possibly the Sentinel Butte Formation sediments were once present in part of the area, especially in western Bottineau County, and were removed by erosion during Tertiary time.

Erosion probably continued, intermittently, during much of Tertiary time in Bottineau County, through most of Pliocene time. By the end of the Pliocene Epoch, a gently rolling landscape had developed on the late Cretaceous and early Paleocene sands and shales of the Pierre, Fox Hills, Hell Creek, and Cannonball Formations. The land surface sloped gently northward and northwestward, except over the Turtle Mountains, which stood as a 400- to 500-foot-high mesa in the northeastern part of the area.

In spite of the relatively large amount of test-hole data available from Bottineau County, it was difficult to definitely identify many preglacial valleys. Some of the narrower valleys shown on the bedrock surface (fig. 19) appear to have resulted from glacial diversion of the drainage. The route of the preglacial "Bottineau River," shown on figure 19, is based largely on conjecture, although the route of the valley in Manitoba has been determined with reasonable accuracy (Klassen and others, 1970). The Bottineau River valley was a broad lowland, which today corresponds to the area containing the glacial Lake Souris plain. The central Bottineau County lowland is also an area of relatively thin Coleharbor Group sediments (glacial deposits), a fact that helps to accentuate the presence of the lowland. The Coleharbor Group sediments average less than 75 feet thick in the area between the Turtle Mountains and the Souris River, compared to over 200 feet thick in the southwestern part of the county and in the Turtle Mountains.

Glacial History

Pre-Wisconsinan History

The preglacial lowland between the Turtle Mountains and the Missouri Coteau directed and somewhat restricted the flow of the glacial lobes, channeling them southeastward through Bottineau County. This may have helped to cause some scouring of the preglacial surface in the area southwest of the Turtle Mountains. Certainly, the presence of the Turtle Mountains and Missouri Coteau uplands appreciably affected the directions of flow of the latest Wisconsinan glaciers.

The paths followed by early pre-Wisconsinan glaciers as they advanced southward and later receded cannot be determined. The Turtle Mountains upland probably had little effect on the advancing glaciers, but glacial ice stagnated there at the end of each glaciation, just as it did at the end of Late Wisconsinan time. The earliest glaciations may not have caused proglacial lakes comparable to the Late Wisconsinan glacial Lake Souris to form because drainage to the east probably carried meltwater away until the valleys became permanently blocked as a result of repeated glaciations; this is not definitely known though.

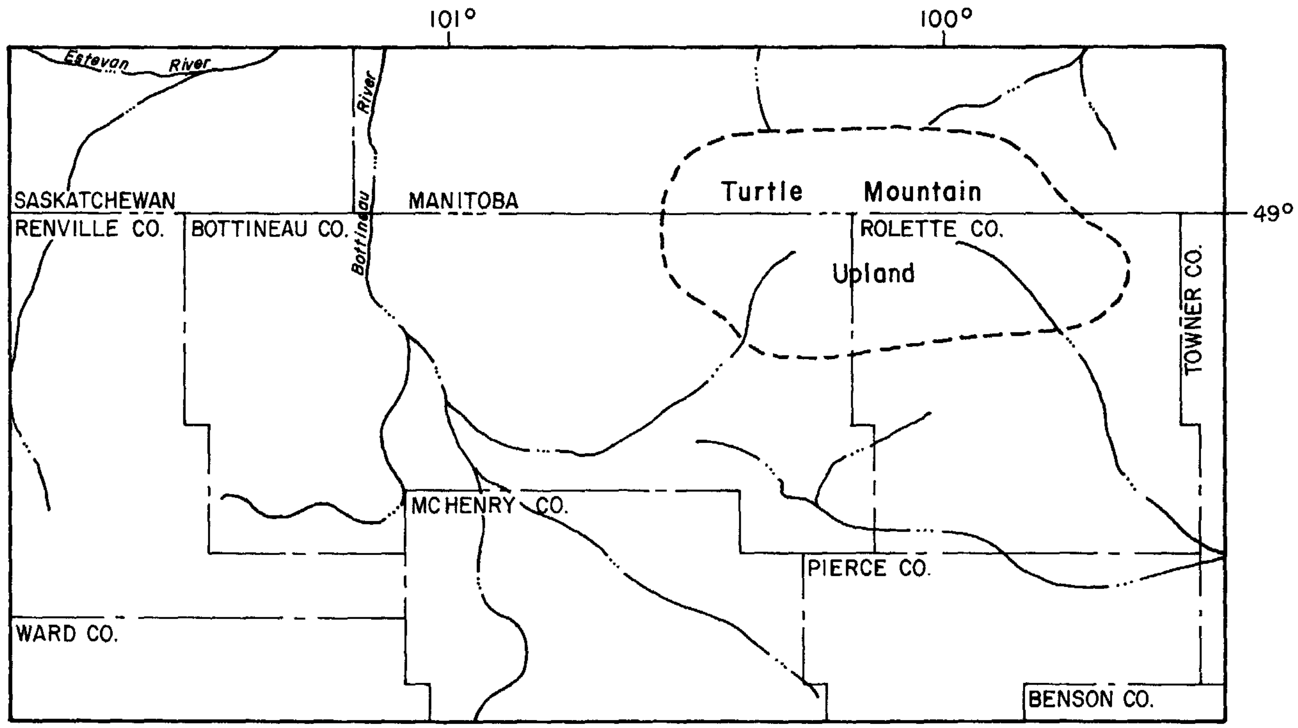

Figure 19. Preglacial drainage pattern. Prior to glaciation, Bottineau County and surrounding areas in north-central North Dakota and southernmost Saskatchewan and Manitoba drained northward by way of a river that followed a route similar to that shown for the "Bottineau River" on the above map.

Late Wisconsinan History

When the Late Wisconsinan glacier was receding from North Dakota, but at a time while it was still flowing southeastward over the Turtle Mountains, it stabilized long enough to deposit the Grace City end moraine in Foster, Eddy, and Stutsman Counties (Bluemle, 1965; Clayton, Moran, and Bluemle, 1980; Schnacke, 1982). Shortly thereafter, the receding glacier became so thin it could no longer flow over the Turtle Mountains and it stagnated there. The nearby glacier at lower elevations continued to flow, but the flow directions were changed around the Turtle Mountain upland area. This resulted in two discrete lobes of flowing glacial ice, the Leeds Lobe, which flowed south around the east side of the Turtle Mountains, and the Souris Lobe, which flowed southeastward, around the west side (fig. 20). The glacier probably stagnated over the Turtle Mountains slightly before 12,000 years ago (Clayton, Moran, and Bluemle, 1980). As a result of the lobation and redirection of the flow of the glacier, the eastern (Leeds) lobe of the receding glacier formed the Heimdal moraine (which is largely an accumulation of ice-thrust topography), while the margin of the western (Souris) lobe continued to recede to the northwest. It is not known how far the Souris Lobe receded, but, as it did so, the water from the melting glacier combined with other runoff to form a large proglacial lake in Pierce, McHenry, and possibly Bottineau Counties. This has been referred to as glacial Lake Souris I (Schnacke, 1982). Overflow from this lake was southeastward, but the exact route it took is not definitely known.

When the Souris Lobe readvanced to the Martin position (Clayton, Moran, and Bluemle, 1980), it overrode the deposits of Lake Souris I. A spectacular array of ice-thrust and streamlines features formed in the area south of Bottineau County during this glacial readvance (Bluemle and Clayton, 1984) (fig. 21). The Leeds Lobe also readvanced slightly at this time, to the North Viking position, and this readvance was also accompanied by intense thrusting; the North Viking moraine consists primarily of ice-thrust topography. The Souris Lobe apparently readvanced as far as western Towner County, over land that had been recently occupied by the Leeds Lobe (Bluemle, 1984). Following this short-lived, but important readvance of the Souris Lobe, the glacier again began to recede.

Glacial Lake Souris II first formed ahead of the receding Souris Lobe at an elevation of about 1,600 feet when it was restricted mainly to Rolette, Pierce, and McHenry Counties. The extent of the lake at successive stages, each one lower than the preceding one, is shown on figures 22 through 25. During the higher stages of the lake, much of the flooded area was probably still covered by stagnant glacial ice, so the lake-floor sediments, which were deposited on that ice, have collapsed

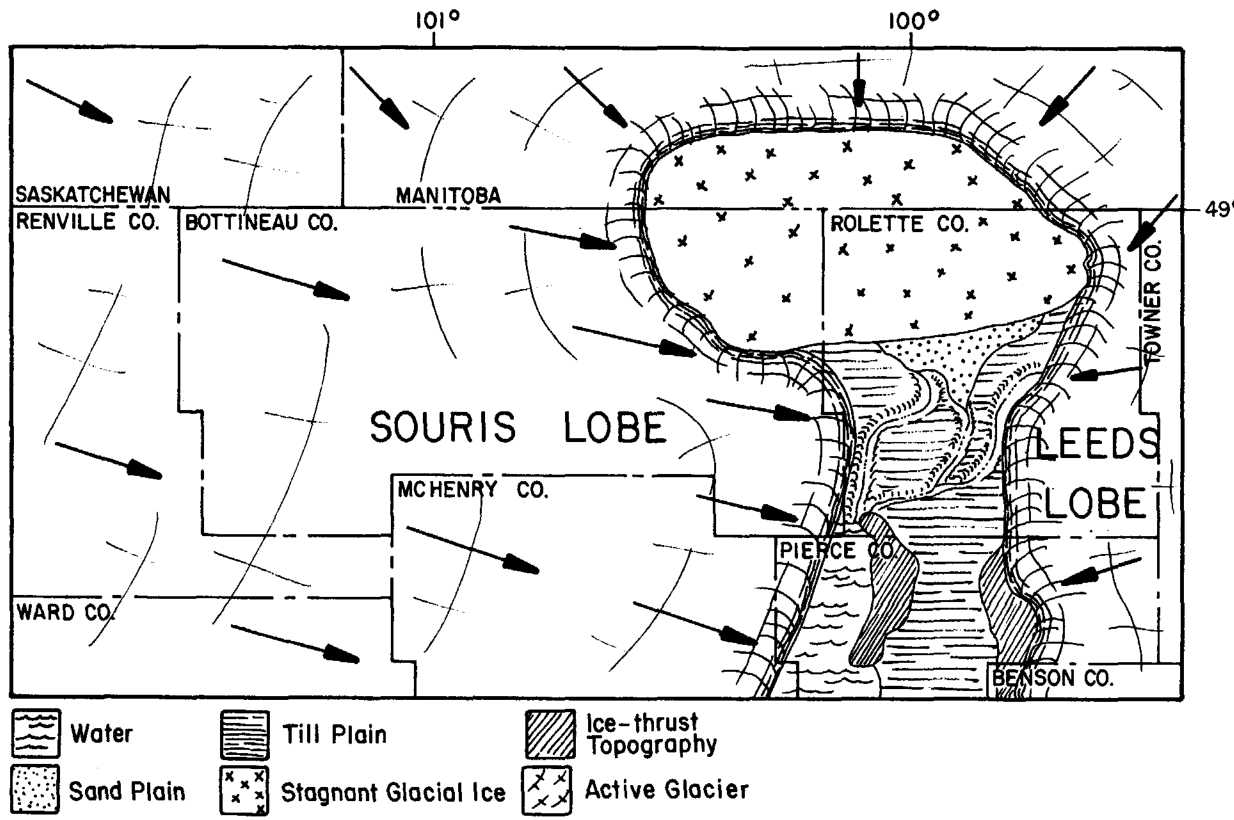

Figure 20. Formation of glacial Lake Souris I. The glacier split into two lobes as a result of stagnation over the Turtle Mountains, the Leeds Lobe on the east and the Souris Lobe on the west. The map above shows conditions shortly after the lobation of the glacier, approximately 12,000 to 12,500 years ago. The Heimdal and North Viking moraines formed in Eddy and Benson Counties along the margin of the Leeds Lobe at this time. At about the same time, glacial Lake Souris I flooded the deglaciated area east of the receding Souris Lobe. It drained southeastward, probably into the Heimdal Channel in Wells and Eddy Counties.

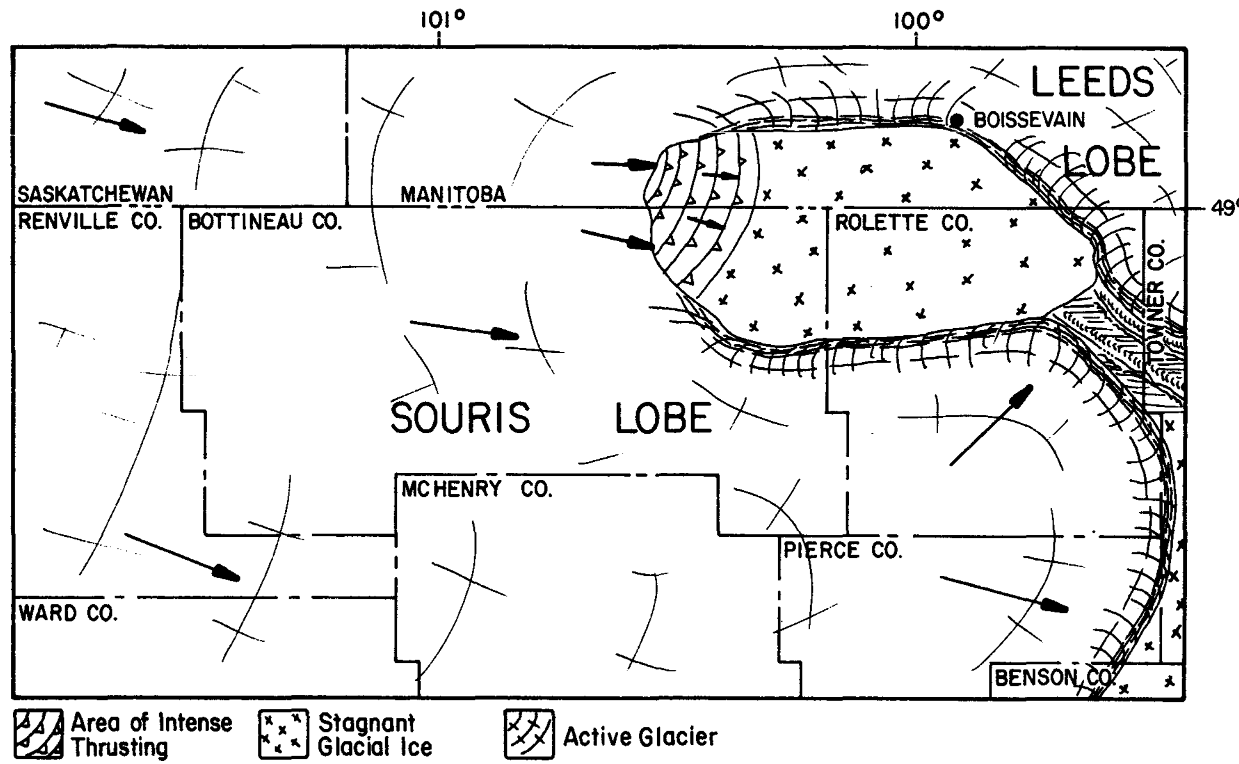

Figure 21. Maximum extent of the Souris Lobe after it readvanced over glacial Lake Souris I. The Souris Lobe ice reached as far east as western Towner County (Bluemle, 1984) before it began to recede again. It seems likely that massive thrusting at the western end of the Turtle Mountains may have happened during this readvance of the glacier.

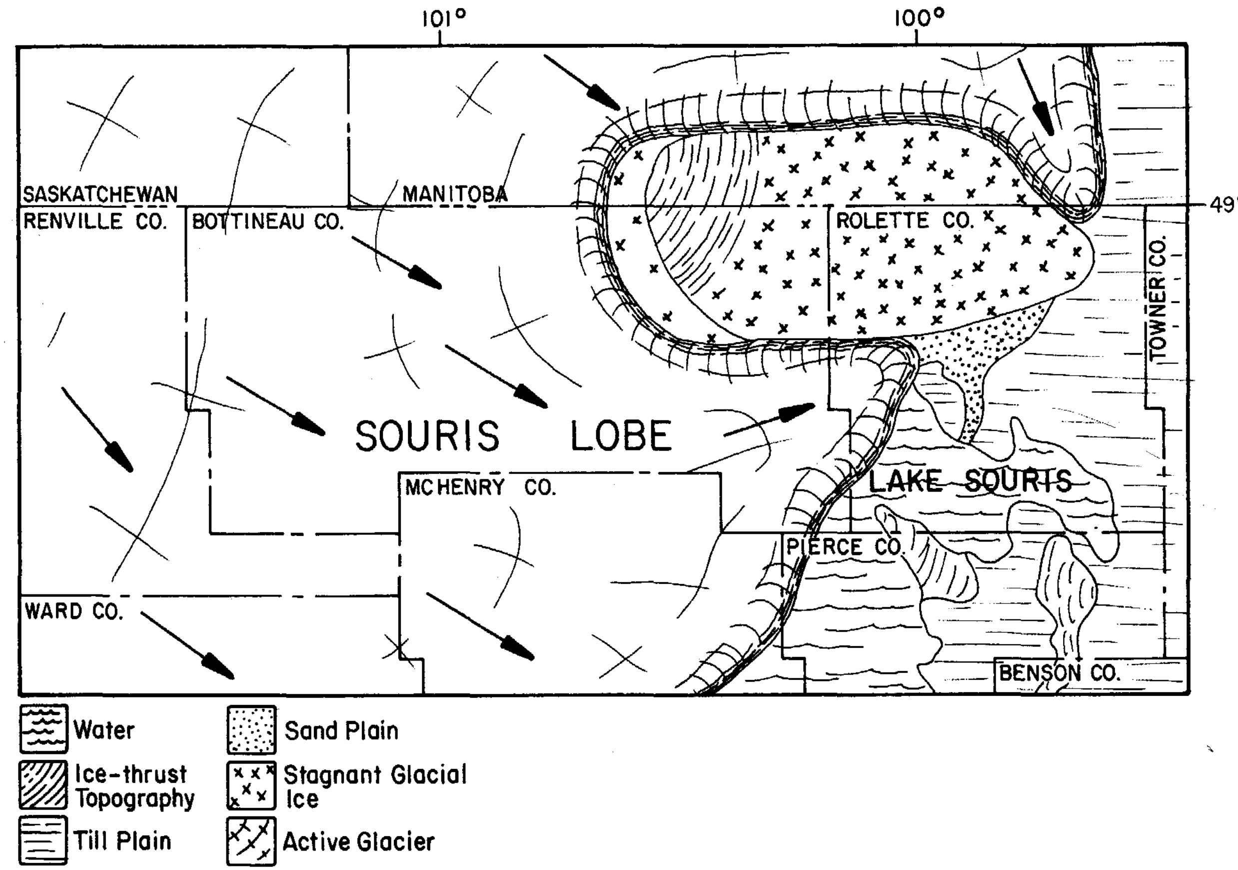

Figure 22. The formation of the second glacial Lake Souris (glacial Lake Souris II, which is referred to here simply as glacial Lake Souris) as the Souris Lobe receded from its maximum readvance position. The lake formed initially in Rolette, Pierce, and McHenry Counties at approximately 1,600 feet elevation.

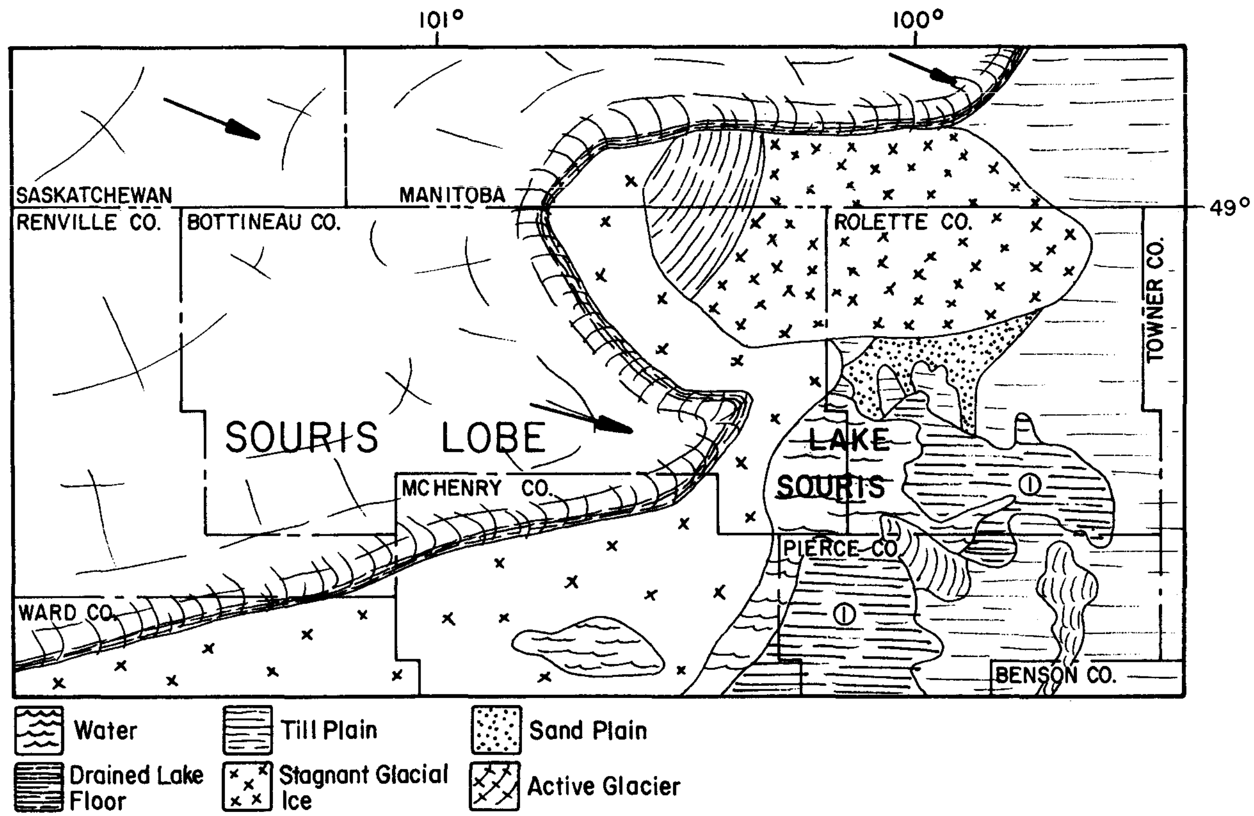

Figure 23. Lake Souris at an elevation of approximately 1,570 feet. In this and the following 2 figures, the areas covered by the lake at successively lower stages are shown by the numbered areas. The area labeled 1 on this diagram, for example, is the land that was flooded by the lake when it was at the 1,600-foot level (except, of course, part of area 1 was also flooded by the lake when it was at lower elevations). The extent of thin, discontinuous stagnant glacial ice (wide-spaced x pattern) is problematical as is the position of the active ice margin on this and the following diagram (fig. 24).

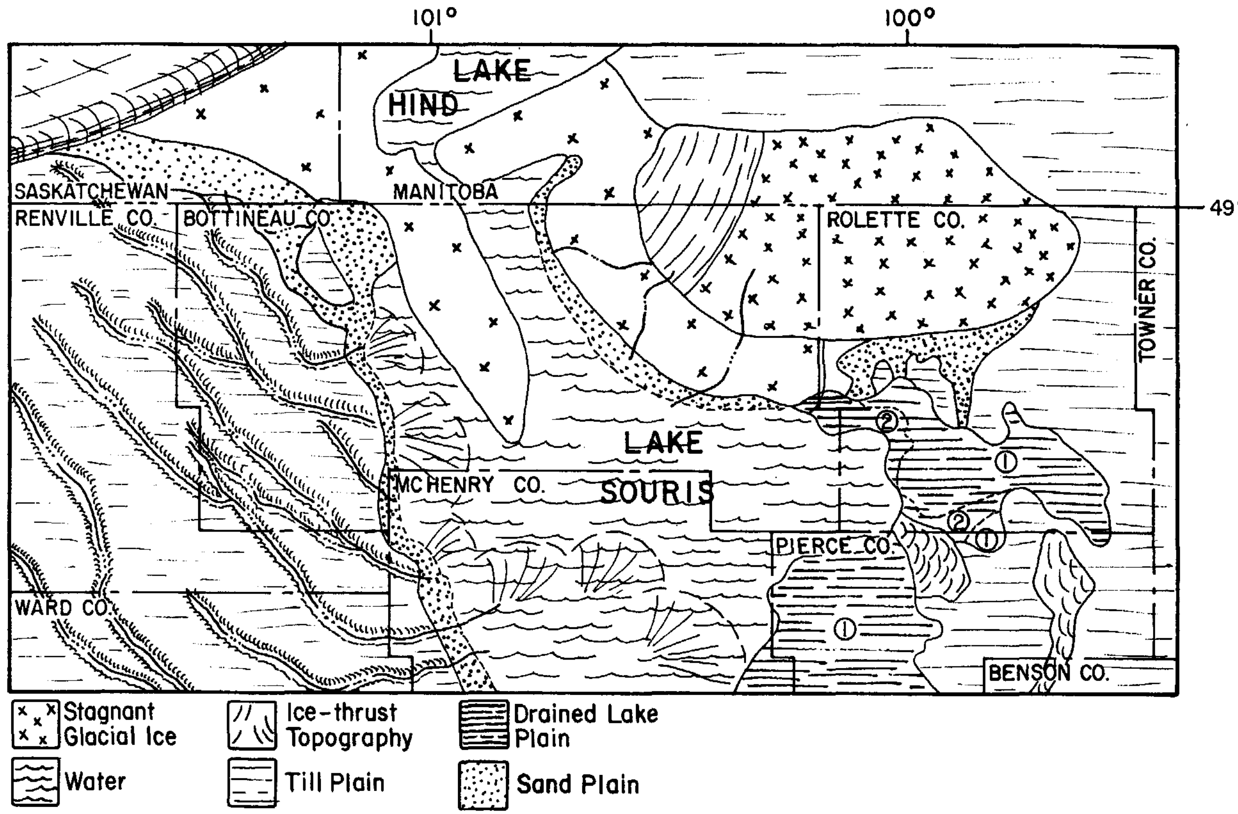

Figure 24. Lake Souris at an elevation of approximately 1,525-1,550 feet. At this level, Lake Souris was at its greatest extent in Bottineau County. The lake is shown draining northward to Lake Hind in Manitoba. Numerous small streams delivered a large sediment load of sand and silt to the lake while it stood at this level; this sediment spread out over the lake floor as a broad fan. The recently drained areas that had been flooded by the lake when it was at the 1,570-foot level are labeled 2.

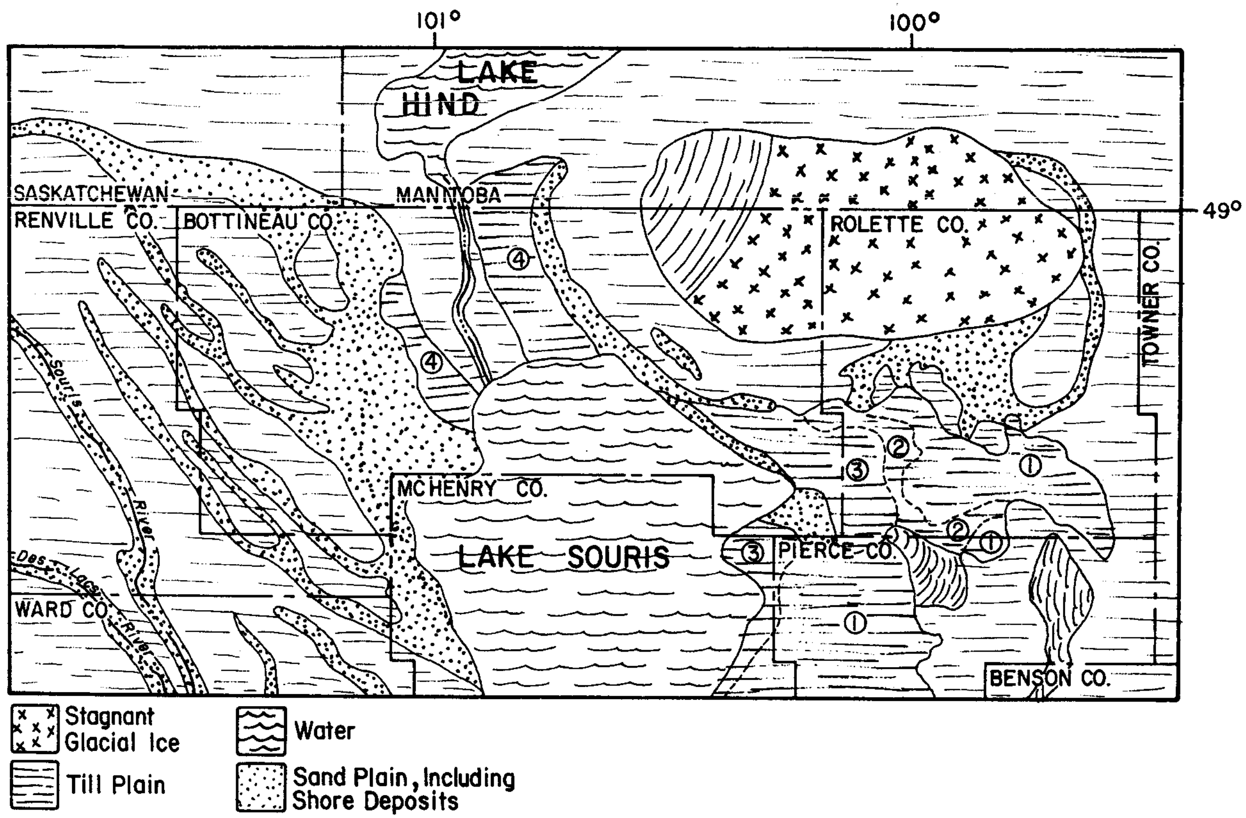

Figure 25. Lake Souris at the 1,470-foot level. This is the lowest level at which the lake could have drained southeastward through the Girard Lake spillway. While the lake was at this level, large floods of water, catastrophic overflow from glacial Lake Regina, emptied into Lake Souris with large volumes of water flowing southeastward resulting in the formation of the Sheyenne channel and large volumes of water flowing into Manitoba to glacial Lake Hind and on down the Pembina River valley.

bedding and are irregular in configuration. The lake apparently reached its maximum areal extent when it was at the 1,525-1,550-foot level. At that time it flooded much of central and southeastern Bottineau County.

Glacial Lake Souris drained southeastward by way of a number of outlets at all levels down to 1,470 feet. The earliest (and highest) of these outlets led to the Heimdal spillway in Wells and Eddy Counties and, from there, to the James River spillway and ultimately southward to the Missouri River drainage. The remainder of the outlets to the southeast were to the Sheyenne River spillway. Southeastern outlets include those now occupied by Pagel Lake, Antelope Lake, Long Lake, and Girard Lake (Schnacke, 1982). There may also have been a Cranberry-Filmore outlet. Except for the Girard Lake outlet, which is as low as 1,470 feet, all of these outlets range from 1,530 to 1,550 feet. Clayton, Moran, and Bluemle (1980) suggested that all the outlets, except for the Girard Lake spillway, were active for only a short period of time. When the glacier melted back from the Edinburg ice margin in northeastern North Dakota and southern Manitoba, the Girard Lake outlet was abandoned and the lake then drained through the Pembina River outlet.

Lake sediments are absent from a strip of land along the present route of the Souris River in central Bottineau County, and Lemke (1960) speculated that that land was covered by a small ice lobe at the time Lake Souris flooded it. He speculated that washboard moraines in the area east of the Souris River in northern Bottineau County indicate that the glacier there receded northeastward toward the Turtle Mountains. However, the present study suggests that Lemke's "washboard" moraines are actually a series of northwest-southeast-trending channel scars that may have formed as a result of flooding when glacial Lake Regina released large volumes of water (Kehew, 1982). Although it is certainly possible that a small lobe of glacial ice covered the area east of the Souris River where lake sediments are absent (fig. 24), it is equally possible that erosion after the lake drained removed any lake sediment that may have existed in that area.

When glacial Lake Souris was at the 1,525-1,550-foot level, numerous small streams flowing into the lake delivered large amounts of sand which was deposited nearshore as "deltaic" sediment. At that time, too, shoreline deposits apparently accumulated (fig. 24), but these were deposited mainly on stagnant ice and, as a result, few discrete beach elements can be identified in Bottineau County.

Sometime after most of the active glacial ice had melted from the Bottineau County area, between 12,000 and 11,000 years ago, glacial Lake Regina, in southeastern Saskatchewan, drained 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) (fig. 26). The dense, turbid floodwater flowing into Lake Souris flowed out across the bottom of the lake as an underflow current and deposited a characteristic sedimentary sequence. A fan-shaped deposit of coarse gravel and sand at the spillway mouth near Verendrye in McHenry County, grades lakeward into uniform, well-sorted sand and silt that covers the southern half of the lake basin floor.

The depth of the Souris spillway gradually decreases from about 100 feet near its mouth in McHenry County to about 15 feet near the center of the Lake Souris basin at the McHenry-Bottineau County line. The coarse sediment carried by the spillway flood was deposited at the spillway mouth and along this channel for some distance out into the basin. The decrease in channel capacity and gradient on the basin floor caused the underflow current to leave its channel and spread out across the lake floor. The fine sediment carried by the underflow current was well sorted, and it was deposited by progressively decreasing velocity lakeward from the spillway north.

The large discharge of water from Lake Souris during the flooding episode caused erosion of a northern outlet, and it cut a series of anastomosing channels to adjacent Lake Hind. The northward flood of water in north-central Bottineau County may have been responsible for eroding away any lake sediment in that area.

Holocene History

When glacial Lake Souris drained, the Souris River continued to flow northward through the channel that had been formed during the catastrophic flooding episode. With drying, the sand and silt of the density-current deposits of the glacial Lake Souris floor were subjected to intense wind erosion. Dunes are restricted to the southern part of Bottineau County, that is, the northern part of the density-current deposits described above. Much of the eolian activity probably occurred during the Holocene hypsithermal event, between approximately 8,500 and 4,500 years ago, when the regional climate was much more arid than it is today with less precipitation and warmer temperatures. Wind erosion continues today in the areas of dunes during prolonged periods of drought.

The warming of the climate at the end of the glacial epoch about 10,500 years ago ended the forest cover over most of North Dakota and, although the Turtle Mountains probably remained forested, they certainly had reduced forest cover during the driest part of the hypsithermal event. Many of the lakes and ponds in the Turtle Mountains were transformed to

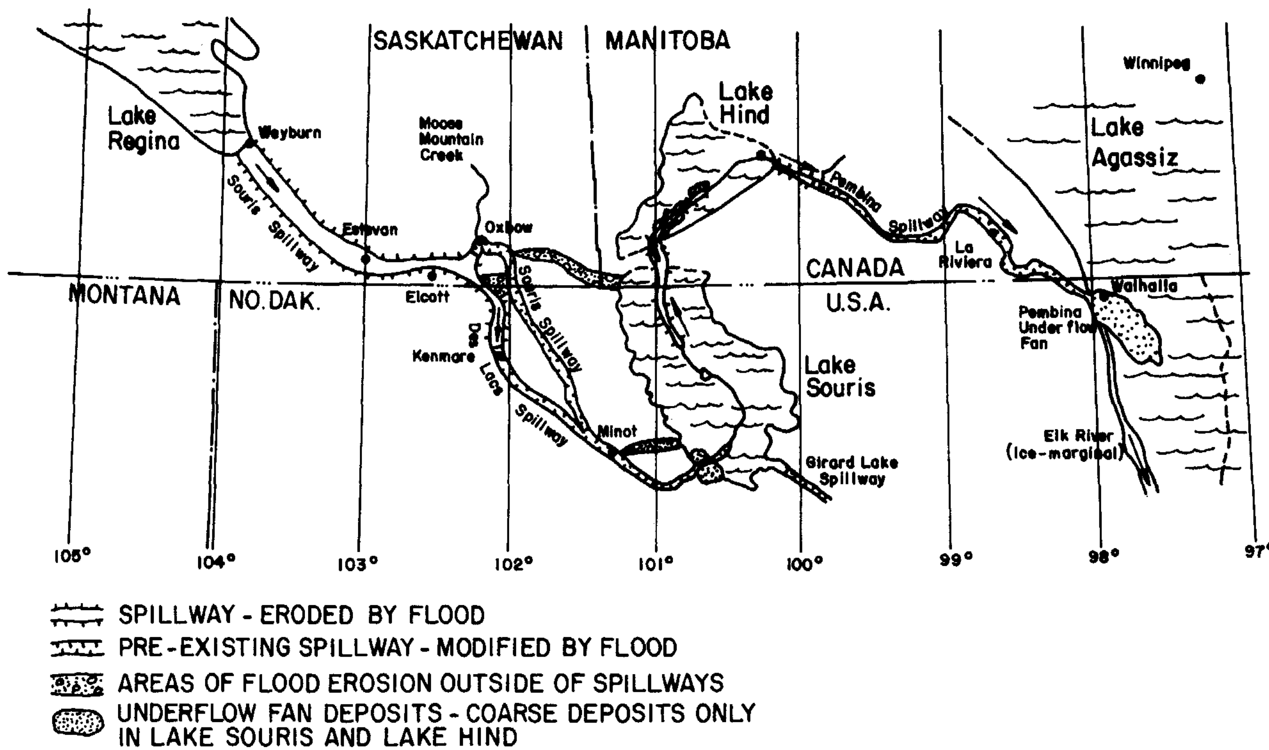

Figure 26. Area affected by catastrophic floods. Floods of water from Lake Regina and lakes north of there carved large channels including those of the Des Lacs, Souris, and Sheyenne Rivers. The erosion of the channels resulted in great amounts of fine-grained sediment, much of which settled into the various lakes along the path of the floods. Diagram is adapted from Kehew and Clayton, p. 189 (1983).

sloughs, and grass cover was reduced outside of the Turtle Mountains. As a result, hillslopes became less stable and more erosion took place even though there was less rainfall. The temporary ponds received coarser, less organic-rich sediment.

ECONOMIC GEOLOGY

Oil and Gas

Bottineau County became an oil-producing area in 1953. Oil is currently produced from about 50 fields with a total of between 550 and 600 wells. Production is from the Mississippian Madison Formation (40 fields) and Triassic Spearfish Formation (10 fields), although about 40 percent of the production is from Spearfish fields. Total production during 1984 was about 2.4 million barrels of oil. Production has been declining slightly in Bottineau County in recent years; in 1980 and 1981 it was 2.7 and 2.6 million barrels, respectively.

Sand and Gravel

Numerous deposits of sand and gravel occur in Bottineau County. In the western part of the county, many of the small coulees are lined with gravel or have terraces covered by gravel (Qcrf on pl. 1). Similarly, extensive deposits of gravel occur on the terraces of the Souris River valley in central Bottineau County. Some of the ice-contact deposits in the eastern part of the county also contain considerable amounts of sand and gravel. In the Turtle Mountains, numerous small pits have been developed in ice-contact deposits.

Small gravel pits operate as the need arises and dozens of these pits are found throughout Bottineau County. In 1982, the last year for which production was reported in Bottineau County (no operators reported any 1981 or 1983 production), a total of 65,000 yards of gravel was mined.

Peat

Some peat has been produced in Bottineau County at times. One plant that operated for a time about 10 miles north of Bottineau in the Turtle Mountains produced reed-sedge peat. Generally, the peat is produced from the shallow depressions where it accumulates in sloughs. Peat is prepared for production by first draining the deposit, then disking or harrowing it, and finally digging and piling by means of bulldozers. During the summer of 1984, the writer observed a peat-like material being harvested from Lake Metigoshe as a by-product when the lake was being cleared of excess vegetation. This process involved skimming the water plants from the lake and trucking them to a collecting area, then allowing them to dry for use as a soil conditioner.

Peat extraction operations are generally quite small and operated individually. No great development of the resource is expected in Bottineau County.

Other Minerals

Small accumulations of manganese are found in places in the Turtle Mountains. They occur in cold springs in the form of the mineral rancieite, a soft, fine, flaky, brownish-black, hydrous calcium-manganese oxide (Hansen, 1964). The mineral is found mixed with calcium carbonate in the form of calcareous tufa. The largest deposits so far identified are in Rolette County (sec 22, T162N, R73W and sec 30, T162N, R72W). Although no deposits of the mineral were noted in Bottineau County, the geologic situation here is similar to that in Rolette County, and it is possible that rancieite could be found in association with cold spring deposits.

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