1971

Geology of McLean County, North Dakota

John P. Bluemle
University of North Dakota

GEOLOGY OF McLEAN COUNTY, NORTH DAKOTA

by

John P. Bluemle

Bachelor of Science in Geology, Iowa State University, 1960

Master of Science in Applied Science, Montana State University, 1962

A Dissertation

Submitted to the Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the Degree of

Doctor of Philosophy

Grand Forks, North Dakota

December
1971

This Dissertation submitted by John P. Bluemle in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

Dean of the Graduate School

Permission

Title Geology of McLean County, North Dakota

Department Geology

Degree Doctor of Philosophy

In presenting this dissertation in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my dissertation work or, in his absence, by the Chairman of the Department or the Dean of the Graduate School. It is understood that any copying or publication or other use of this dissertation or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of North Dakota in any scholarly use which may be made of any material in my dissertation.

Signature John P. Bluemle

Date December 9, 1971

ACKNOWLEDGMENTS

I am especially grateful to Dr. Wilson M. Laird, former State Geologist. He provided the opportunity for me to work toward the Ph. D. degree while continuing as an employee of the North Dakota Geological Survey. Dr. Edwin A. Noble, State Geologist, continued the arrangement, allowing me to complete work toward the degree. I also wish to thank Dr. Lee Clayton, chairman of my committee, for his suggestions and for reviewing the manuscript.

The help of the various individuals and agencies involved in this study is appreciated. Jack Kume, formerly of the North Dakota Geological Survey, mapped a large area of McLean County. Robert Klausing of the United States Geological Survey provided test hole data and other valuable information. Roy Staiger, who operated the North Dakota Geological Survey auger, provided valuable test hole data on glacial drift thicknesses. Finally, I extend my appreciation to the landowners of McLean County who were very cooperative in providing data on private wells and allowing access to their property.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

McLean County, in west-central North Dakota on the east side of the Williston Basin, is covered by 8,500 to 13,000 feet of Paleozoic, Mesozoic, and Cenozoic rocks, which dip to the west at low angles. The Tertiary Tongue River and Sentinel Butte Formations are widely exposed in McLean County, and the Tertiary Cannonball Formation is exposed in a few places. Glacial drift, assigned to a new formation, the Coleharbor Formation, occurs throughout the county and reaches a maximum thickness of at least 400 feet in certain preglacial valleys.

The eastern part of McLean County, part of the Missouri Coteau, is dominated by hilly topography on dead-ice moraine with associated lake sediments, ice-contact gravel deposits, and areas of collapsed outwash. Much of the remainder of the county is part of the Coteau Slope and is characterized by gently rolling topography on ground moraine. The Missouri Trench, with steep bedrock slopes, forms the western boundary of the county.

Glacial deposits of probable pre-Wisconsinan age were identified in McLean County, but little is known of either their exact age or the circumstances under which they were deposited. Glacial drift of probable Early Wisconsinan age covers most of the area of the Coteau Slope and Late Wisconsinan drift covers most of the Missouri Coteau. Both the Early and Late Wisconsinan glaciers stagnated as they thinned and receded from the area, resulting in hummocky areas of dead-ice moraine. The modern route of the Missouri River did not become firmly established

until the Late Wisconsinan glacier receded from the area. This modern route of the river is a composite of several valley segments that range in age from preglacial to Late Wisconsinan.

INTRODUCTION

Purpose

This report presents the results of an investigation of the geology of McLean County, North Dakota. The main objectives of the geological investigation were, 1) to map the glacial and associated deposits to locate and define aquifers, 2) to map the surficial bedrock geology, and 3) to arrive at an understanding of the geologic history. Parts of the report that are primarily descriptive include the discussions of the topography, rock, and sediment of the county. Parts of the report that are primarily interpretive include the discussions of the landforms and Quaternary history.

The descriptive material should be of value to anyone interested in the physical nature of the materials covering the county. Such people may be water-well drillers or hydrologists interested in the distribution of sediments that might produce usable ground water; civil engineers and contractors interested in the gross characteristics of possible sources of borrow material for concrete aggregate; industrial concerns looking for possible sources of economic minerals; residents interested in knowing more about their county, and geologists interested in the physical evidence for the geologic interpretations. The interpretive parts of the report are intended for those interested in the geologic processes and sequence of events during Pleistocene time.

The material in this report constitutes the first of a three-part North Dakota Geological Survey bulletin. The remaining two parts consist of a compilation of basic ground water data and a discussion of the ground water resources of the county.

Methods of Study

About three-fourths of McLean County was mapped during the 1966 and 1967 field seasons. The remaining one-fourth of the area was mapped during the 1966 field season by Jack Kume, formerly of the North Dakota Geological Survey.

Data were plotted on McLean County highway maps, scale 1:63,360, prepared by the North Dakota State Highway Department. In addition, topographic maps of the 7.5 minute series were available for much of the remainder of the area. Air photos, scale 1:20,000, taken in 1958, were used to accurately place geologic contacts. The surficial mapping was done by driving along all section line roads and trails and recording lithologies at all roadcuts or exposures. Less accessible areas were covered on foot. A shovel and soil auger were used to obtain lithologic information in areas of poor exposures. In addition, about 100 holes were bored using the North Dakota Geological Survey truck-mounted auger. This auger is capable of sampling to a maximum depth of 150 feet. The North Dakota State Water Commission provided rotary drilling equipment that was used during the 1967, 1969, and 1970 field seasons for about 40,000 feet of test drilling.

Surface Topography and Physiography

A topographic map of McLean County is shown on Figure 1. There are four distinct physiographic areas in the county.

1) The extreme northeast corner of the county is part of the relatively level Drift Prairie, which covers most of the northeast half

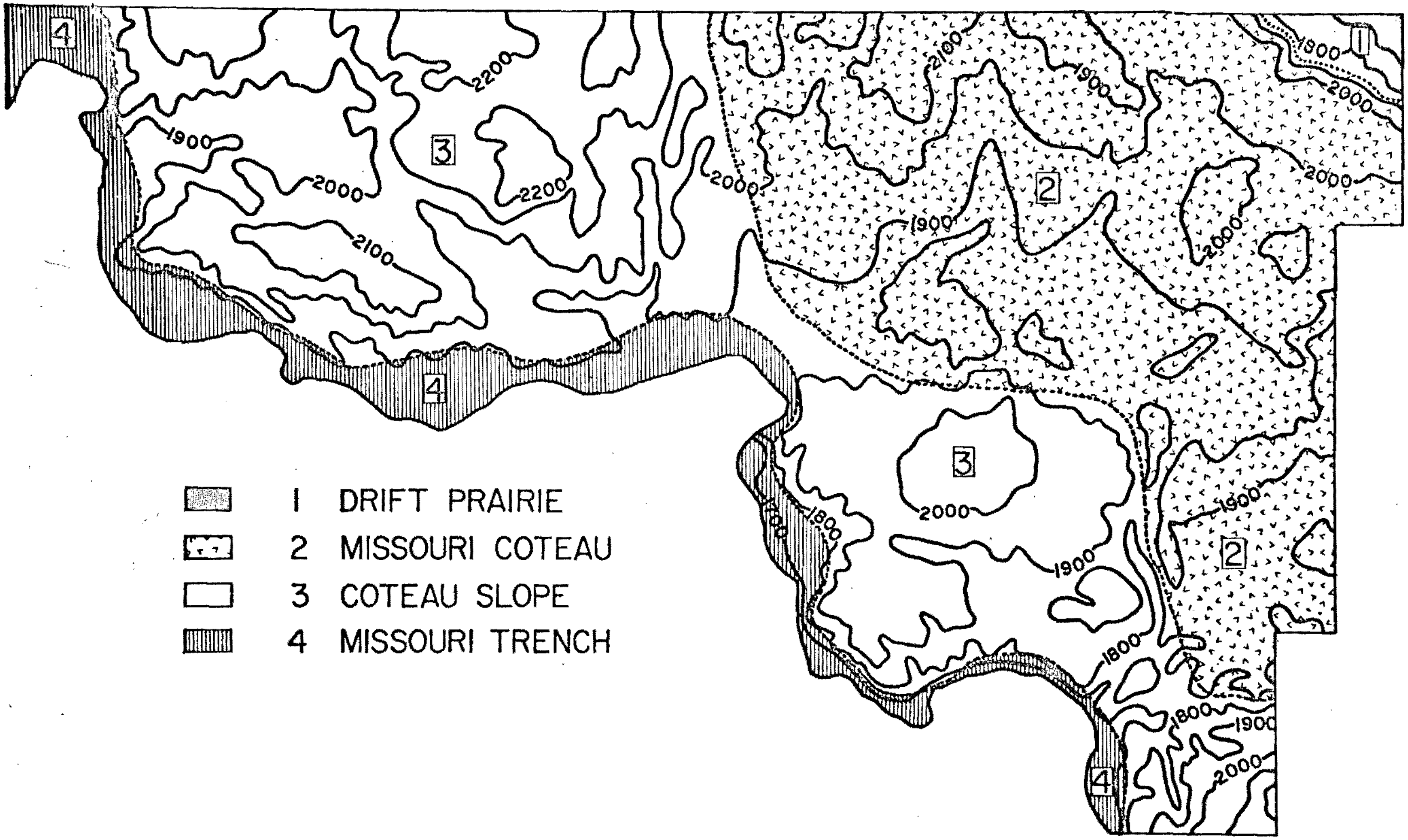


Figure 1. Topographic and physiographic map of McLean County.

of North Dakota. Drainage on this gently undulating glaciated plain is fair to good although many shallow depressions retain water after heavy rains. Streams of the Drift Prairie of McLean County and nearby areas flow into the Sheyenne River, a tributary of the Red River of the North, whose waters eventually reach Hudson Bay. Relief, which is generally less than 20 feet in a mile, is due almost entirely to irregularities on the surface of the ground moraine.

The edge of the Drift Prairie is marked by the Missouri Escarpment, a relatively smooth but stream-dissected slope that rises to the Missouri Coteau. Elevations rise from about 1,600 feet at the base of the escarpment to over 2,000 feet at the top, a change of about 400 feet in a distance of about 5 miles.

2) The Missouri Coteau, which lies west of the Missouri Escarpment, is an area with local relief averaging about 50 to 65 feet. This hilly area extends from east-central South Dakota northwestward into western Saskatchewan. The Missouri Coteau covers approximately the northeast half of McLean County and accounts for about 40 percent of the total area of the county. A few short streams occur in the area, but none transects it. The area is characterized by numerous sloughs, lakes, and closely-spaced hills. The Missouri Coteau is the continental divide between Gulf of Mexico and Hudson Bay drainage.

3) The Coteau Slope lies southwest of the Missouri Coteau. Relief is moderate, generally less than 25 feet locally, but is greater near some of the deeper valleys. Small intermittent streams flow south and westward through these valleys over the Coteau Slope to the Missouri River. Drainage is well developed and only a few lakes and sloughs occur in the area. The Coteau Slope is characterized mainly by stream-

dissected bedrock with a veneer of glacial deposits. Elevations range between about 2,000 feet near the Missouri River to over 2,400 feet in the western part of the county.

4) The southwest boundary of McLean County is the Missouri River, which flows in the Missouri Trench. Above Garrison Dam, in western McLean County, the trench is generally 3 to 5 miles from rim to rim and has a maximum relief of 200 to 250 feet (lake level to trench rim). Below the dam it is 1 to 2 miles wide with a maximum relief of about 350 feet. The wider segment of the trench is flooded by Lake Sakakawea and has sides consisting mainly of badlands on the Tertiary Sentinel Butte Formation. There discontinuous glacial drift occurs on the sides of the trench down to the level of the lake. Below the dam the floor of the trench is a broad floodplain. Some badlands occur on the sides of the trench but generally the sides of the trench are relatively smooth with terraces in some areas.

STRATIGRAPHY

General Statement

McLean County is on the east flank of the Williston Basin, an intracratonic, structural basin containing a thick sequence of sedimentary rocks (Fig. 2). The Williston Basin had its beginning in early Paleozoic time. Sedimentary rocks in western McLean County probably reach a total thickness greater than 13,000 feet, an estimate based on drill-hole data and projection of rock units from wells in adjacent areas. No test holes have yet been drilled that penetrate the entire sedimentary sequence. The rocks dip to the west at low angles in McLean County, from less than 25 feet in a mile in the Upper Cretaceous rocks to over 50 feet in a mile in the Paleozoic rocks.

Precambrian Rocks

Precambrian rocks range in depth from about 8,500 feet in northeastern McLean County to more than 13,000 feet in the western part of the county. No wells have penetrated Precambrian rocks in McLean County and their composition is unknown.

Paleozoic Rocks

Paleozoic rocks range in thickness from about 4,000 feet in northeastern McLean County to over 8,000 feet at the western edge of the county. The Paleozoic rocks can be subdivided into four sequences (Fig. 3). A sequence is defined as the preserved sedimentary rock bounded by major regional unconformities (Sloss, 1963). The Paleozoic

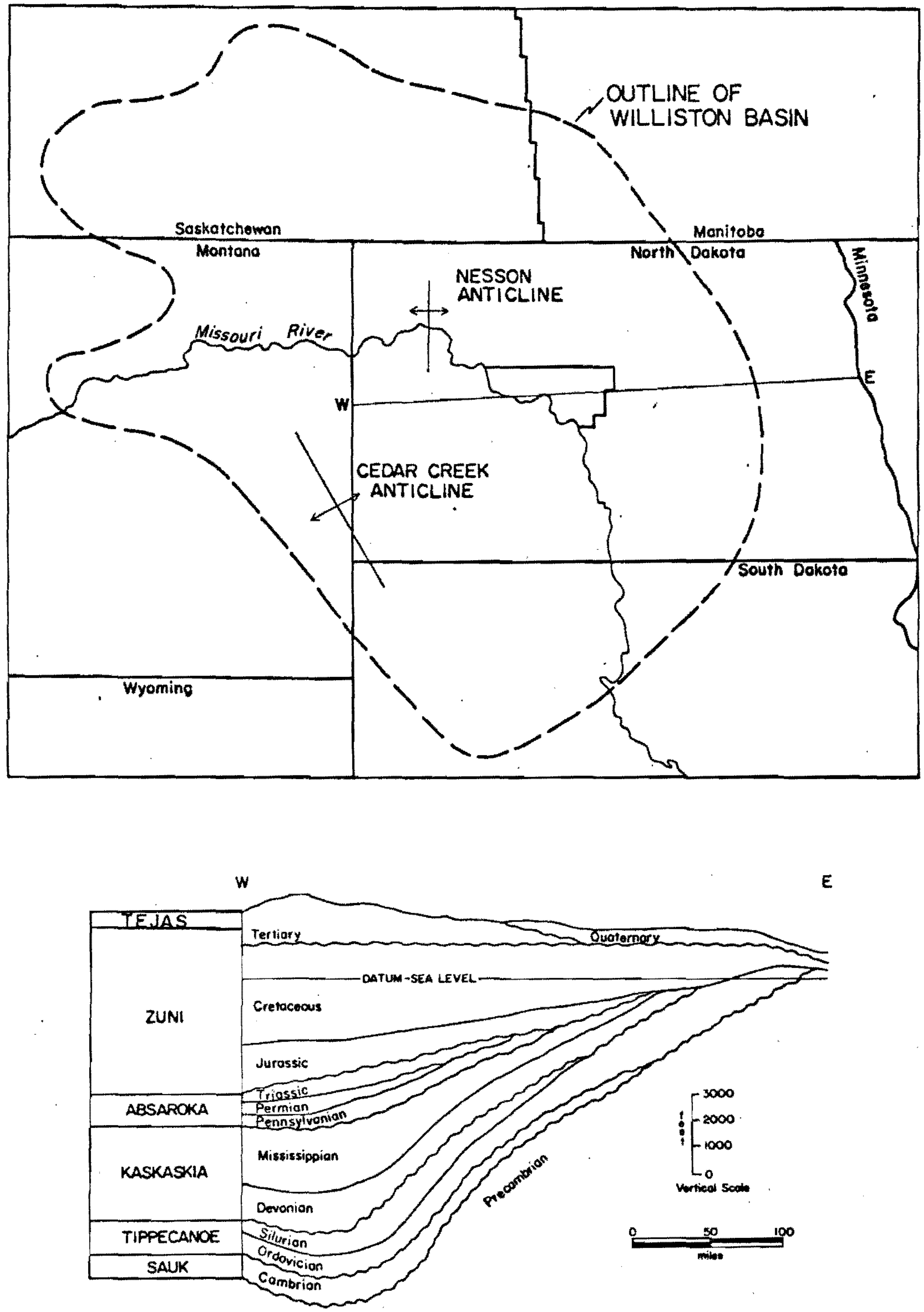


Figure 2. Regional map showing location of the Williston Basin and major structural features. Lower part of the illustration shows a generalized North Dakota stratigraphic column and cross section across the state. Modified from Carlson and Anderson, 1966, p. 1834.

SEQUENCE	SYSTEM	GROUP OR FORMATION		DOMINANT LITHOLOGY
TEJAS	QUATERNARY	Colcharbor		Glacial Drift
	TERTIARY	White River		Clay, Sand, Limestone
ZUNI		Golden Valley		Clay, Sand, Silt
		Fort Union Group	Sentinel Butte	Sandstone, Shale, Lignite
			Tongue River	Sandstone, Shale, Lignite
			Cannonball, Tullock, Ludlow	Marine Sandstone, Shale
	CRETACEOUS	Hell Creek		Sandstone, Shale and Lignite
		Montana Group	Fox Hills	Marine Sandstone
			Pierre	Shale
			Niobrara	Shale, calcareous
		Colorado Group	Carlile	Shale
			Greenhorn	Shale, calcareous
			Belle Fourche	Shale
		Dakota Group	Mowry	Shale
			Newcastle	Sandstone
			Skull Creek	Shale
			Fall River	Sandstone and Shale
			Lakota	Sandstone and Shale
	JURASSIC	Morrison		Shale and Clay
		Sundance		Shale, green & brown, Sandstone
		Piper		Limestone, Anhydrite, Salt and red shale
ABSAROKA	TRIASSIC	Spearfish		Siltstone, Salt and Sandstone
	PERMIAN	Minnekahta		Limestone
		Opeche		Shale, Siltstone and Salt
	PENNSYLVANIAN	Minnelusa		Sandstone and Dolomite
		Amsden		Limestone, dolomitic, Shale and Sandstone
KASKASKIA	MISSISSIPPIAN	Big Snowy Group	Heath	Shale
			Otter	Sandstone
			Kibbey	Limestone
		Madison		Limestones and Evaporites
		Bakken		Siltstone and Shale
	DEVONIAN	Three Forks		Shale, Siltstone and Dolomite
		Birdbear		Limestone
		Duperow		Dolomite and Limestone
		Souris River		Dolomite and Limestone
		Dawson Bay		Dolomite and Limestone
		Prairie		Halite
		Winnipegosis		Limestone and Dolomite
TIPPECANOE	SILURIAN	Interlake		Dolomite
	ORDOVICIAN	Stonewall		Dolomite and Limestone
		Stony Mountain Fm.	Gunton Mbr.	Dolomite and Limestone
			Stoughton Member	Argillaceous Limestone
		Red River		Limestone and Dolomite
		Winnipeg Group	Roughlock	Calcareous Shale & Siltstone
			Icebox	Shale
			Black Island	Sandstone
SAUK	CAMBRIAN	Deadwood		Limestone, Shale and Sandstone
	PRE-CAMBRIAN			

Figure 3. Stratigraphic column of North Dakota. Dashed lines represent major regional unconformities. Modified from Carlson and Anderson, 1966, p. 1835.

sequences recognized in McLean County are, in ascending order, the Sauk, Tippecanoe, Kaskaskia, and Absaroka, with the Absaroka Sequence extending to include Triassic rocks of the Mesozoic Era.

Sauk Sequence

The Sauk Sequence is represented in the Williston Basin by the Deadwood Formation of late Cambrian to early Ordovician age. The Deadwood is an onlap depositional sequence consisting primarily of a basal sandstone overlain by shale and carbonate and then by another sandstone. It thickens westward from a minimum of about 200 feet in northeast McLean County to a maximum of about 700 feet in the northwest part of the county. In the Vaughn-Hanson No. 1 well (Sec. 10, T. 146 N., R. 81 W.), 101 feet of limestone, shale, and sandstone of the Deadwood Formation were penetrated. Fifty-eight feet of the Deadwood were penetrated in the Stanolind-McLean No. 1 well (Sec. 28, T. 150 N., R. 80 W.).

Tippecanoe Sequence

The Williston Basin began to subside during deposition of the Tippecanoe Sequence. This sequence is the result of a transgressive event during which the seas invaded from the south and east, and the Williston Basin became part of a much more extensive epicontinental sea. The Tippecanoe Sequence is represented in the area by rocks of middle Ordovician to Silurian age. The initial deposits of the sequence were the clastics of the Winnipeg Group. These were followed by carbonates with minor amounts of evaporite of the Red River, Stony Mountain, Stonewall, and Interlake Formations. In McLean County the thickness of the Tippecanoe ranges from about 1,300 feet in the east to about 2,200 feet in the west. The two previously mentioned wells, the Vaughn-Hanson No. 1 and the Stanolind-McLean No. 1, are the only two that have penetrated the Tippecanoe Sequence in McLean County. In these wells the thicknesses are 1,442 feet and 1,437 feet, respectively.

Kaskaskia Sequence

During deposition of the Kaskaskia Sequence, the Williston Basin was slightly more tectonically negative than during deposition of the previous two sequences. The initial deposits of the Kaskaskia Sequence represent a transgressive sea that spread over the area from the north and west during Devonian time.

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

The Kaskaskia Sequence in McLean County ranges from about 2,000 feet thick in the southeast to about 4,100 feet thick in the northwest. In addition to the two previously mentioned wells, six others have penetrated the Kaskaskia Sequence to varying depths.

Absaroka Sequence

The Absaroka sea spread across the area from the west. Deposition began with nonmarine mudstone, followed by relatively thin marine deposits and then predominantly clastic and evaporite redbed units. Rocks of the Pennsylvanian and Permian Systems and the Spearfish Formation of Permian-Triassic age are included in the Absaroka Sequence. The formations include, in ascending order, the Amsden (dolomite and limestone), Minnelusa (clastics), Opeche (redbed clastics), Minnekahta (dolomite and limestone), and Spearfish (redbed clastics). The Absaroka Sequence in McLean County ranges from about 250 feet thick in the northeast to about 1,100 feet thick in the southwest. Eight of the ten oil exploration tests drilled to date in McLean County have penetrated the Absaroka Sequence.

Mesozoic and Tertiary Rocks

Mesozoic rocks range in thickness from about 3,900 feet in northeastern McLean County to about 5,000 feet at the western edge of the county. All of these rocks are part of the Zuni Sequence with the exception of the previously discussed Spearfish Formation. The Tertiary rocks of McLean County range in thickness from about 400 feet in the northeast to more than 1,100 feet in the western part of the county.

Zuni Sequence

Mesozoic rocks of the Zuni Sequence in the Williston Basin consist mainly of clastic rocks that were deposited in widespread Jurassic and Cretaceous seas. Jurassic strata range from about 600 to 1,000 feet thick in McLean County and consist of evaporite, red shale and carbonate of the Piper Formation and fine-grained clastics of the Sundance Group. Cretaceous rocks include a sandstone in the Fall River-Lakota Interval and a poorly developed sandstone in the Newcastle Formation. The rest of the Cretaceous rocks, below the Fox Hills Formation, consist of gray shale with some calcareous shale and some thin layers of bentonite; they include the Skull Creek, Mowry, Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre Formations.

The Fox Hills Formation conformably and gradationally overlies the Pierre Formation. It is a marine sandstone and shale sequence that ranges in thickness from about 350 to 450 feet in McLean County with the greatest thicknesses in the northeastern part of the county. The Hell Creek Formation, the youngest Cretaceous formation, conformably overlies the Fox Hills Formation in McLean County. It is of continental origin and consists of interbedded gray, greenish-gray and brown sandstone, mudstone, siltstone, carbonaceous shale, and thin lignite seams. It is overlain by interbedded sandstone, shale, and lignite beds of the Paleocene age Ludlow Formation. The Hell Creek and Ludlow Formations have a combined thickness that ranges from about 100 feet in eastern McLean County to about 500 feet in the western part of the county.

The Tertiary rocks of McLean County, in ascending order, are the Cannonball, Tongue River, and Sentinel Butte Formations. These sediments are all part of the Zuni Sequence and are late Paleocene in age. They are represented in the Williston Basin by predominantly nonmarine deposits derived from source areas to the west.

The Cannonball Formation, which laterally interfingers with the Ludlow Formation, is probably a marine equivalent of the Ludlow. It consists of olive black, carbonaceous and lignitic siltstone and shale, lignite, and friable, micaceous sandstone. These grade upward into similarly colored noncalcareous siltstone and claystone and friable, glauconitic, noncalcareous sandstone.

The Cannonball Formation in the western and southern part of McLean County is as much as 300 feet thick. It thins northeastward to less than 100 feet thick. Exposures of the uppermost Cannonball beds occur in Sections 22 and 23, T. 143 N., R. 81 W. in southern McLean County and along the Missouri River south of Washburn in Sections 14, 23 and 24, T. 144 N., R. 82 W. The contact of the highly weathered, brownish-black Cannonball shale with the overlying Tongue River sandstone occurs at an elevation of about 1,680 feet in this area, a figure that seems anomalously low in view of the fact that the contact is at about 1,700 feet across the river in Oliver County in a regionally downdip direction. It is probable that large blocks of material, including the Cannonball Formation shale, slid into the Missouri River valley.

The Tongue River and Sentinel Butte Formations are of continental origin and Paleocene in age. They directly underlie the glacial drift, except in a small part of extreme southern McLean County where they are absent and the Cannonball Formation underlies the drift, and in northwestern McLean County where preglacial Pleistocene sand lies between them and the overlying drift. Where the drift is absent they are exposed; the best and most extensive exposures occur in and near the Missouri River valley, where headward erosion has formed areas of badlands topography. Maximum thickness of the two formations is about 800 feet in western McLean County.

Exposures of rocks of the Tongue River Formation, which underlies the Sentinel Butte Formation, are confined to approximately the eastern third of the county; rocks of the Sentinel Butte Formation occur over the remainder of the county (Fig. 4). The contact between the two formations is difficult to recognize in McLean County. Based on tentative interpretations of several measured sections, the contact is exposed in the vicinity of Garrison Dam at an elevation of about 1,900 feet. The contact between the Tongue River and Cannonball Formations in this area is at about 1,500 feet, based on test-hole data to the southwest in Mercer County; therefore, the Tongue River Formation should be about 400 feet thick in the area. However, about 450 feet of composite section was measured in the area. This footage includes about 120 feet of section that was poorly exposed due to slumping, so the possibility for error is considerable.

The Tongue River Formation consists of buff to orange buff and gray sand, silt, and clay that ranges from poorly to fairly well cemented. The sand is commonly cross-bedded and in channels in places and has local horizons of sandstone concretions. Some of the more indurated sand horizons form prominent ledges that continue for several hundred yards. Fossils in the Tongue River Formation include gastropods, pelecypods, ostracods, and plants.

The clay and silt beds of the Tongue River Formation form good marker beds for correlative purposes. They are commonly light gray with orange bands due to iron oxide-rich beds. Commonly associated with the clay and silt beds are lignitic zones and lignite beds. Most of the lignite beds are less than a foot thick, and no commercially usable lignite was found in the Tongue River Formation of McLean County.

About 200 feet of Sentinel Butte Formation section was measured in western McLean County. The lowermost part of the formation is too poorly exposed in the area to allow for accurate correlation with bedrock

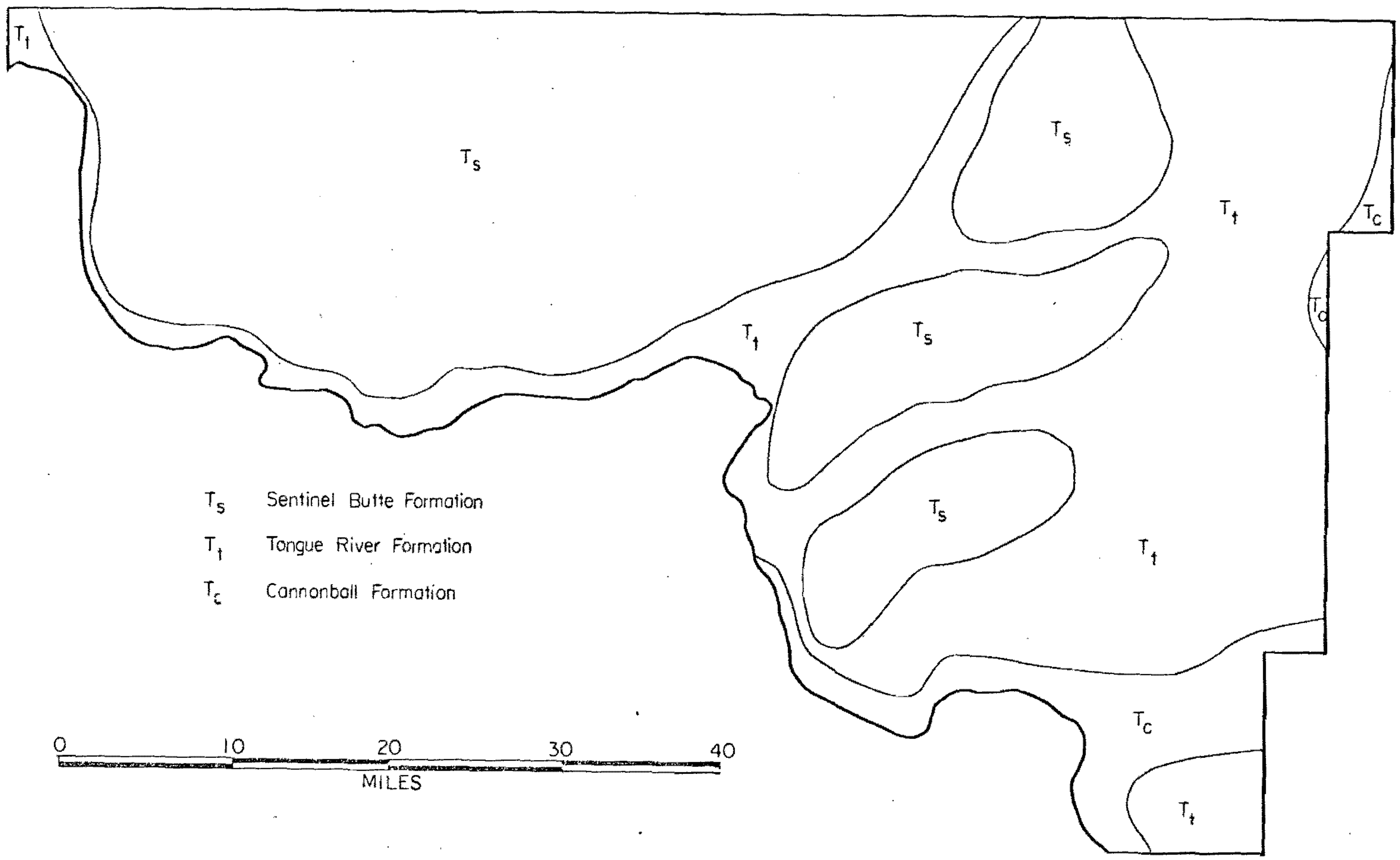


Figure 4. Subcrop map of Cannonball, Tongue River, and Sentinel Butte Formations in McLean County. These three bedrock formations lie directly beneath the glacial drift except in areas where glacial deposits are absent and in a small area of the northwestern corner of the county where preglacial Quaternary (?) river sediments occur between the bedrock and the drift.

exposures near Garrison Dam. In general, rocks of the Sentinel Butte Formation in McLean County consist of light gray to brownish gray sand and silt. Petrified wood, mainly Metasequoia, is common in the Sentinel Butte Formation, although it occurs also in the Tongue River as well. In some badland areas large stumps and logs occur, and small chips of petrified wood cover the surface. Reddish scoria beds, formed when burning lignite beds baked surrounding sediment, are common in both the Tongue River and Sentinel Butte Formations. Their lateral continuity is restricted to less than a few miles so they can be used only for local correlations. Large, solid, cylindrical concretions are common in the Sentinel Butte Formation. They are round to oval in cross-section and they commonly stand on pedestals. They consist of cross-bedded sand that is commonly coarser than the surrounding sediment.

Several beds of lignite averaging about 2 to 3 feet thick occur and a few thicker beds were observed. Two strip mines operate in the county. The Underwood Coal Company Mine, in Section 23, T. 146 N., R. 82 W., mines an 8- to 10-foot-thick bed of lignite. This lignite occurs at an elevation of 1,950 feet to 1,960 feet, about 25 feet above the presumed base of the Sentinel Butte Formation in that area. The other mine is the B and W Coal Mine (Sec. 16, T. 148 N., R. 86 W.), where two lignite beds are being mined. The lower 5-foot-thick bed is separated from the upper 2-foot-thick bed by a 4-inch clay seam. The lignite occurs at an elevation of about 1,915 to 1,925 feet, about 160 feet above the base of the Sentinel Butte Formation. Both of these mines are relatively small operations.

The single most important criterion for differentiating the Tongue River and Sentinel Butte Formations is color. In western North Dakota, weathered exposures of the Tongue River Formation have light, buff-yellow colors with considerable variations in texture and color between individual beds, and, particularly when viewed from a distance, they present a bright overall aspect. In contrast, the Sentinel Butte beds are more gray and somber in color and rather uniform in both texture and color.

Quaternary Sediments

Preglacial Sediments

Description--In several test holes in T. 150 N., R. 88 W. in extreme northwestern McLean County, fluvial sediment consisting of silt, sand, and gravel was found beneath glacial deposits. The direction from which the sediment was deposited could not be determined. The deposits do not appear to follow a valley as they are not particularly deep. The gravel and sand consists mainly of coarse, dark-brown chert, limestone, dolomite, and fragments of lignite. Granite and other rock types typical of the glacial drift are not present in the gravel. Silt and sand overlies the gravel, and it in turn is overlain by clay and silt.

Origin--The lithologies of the fluvial sediments described above, coupled with the lack of Canadian Shield rock types, suggest that they were derived mainly from the Rocky Mountains or Black Hills and that they were deposited by rivers flowing northeastward in late Tertiary or early Pleistocene time. If the sediments were deposited in a valley, that valley has been destroyed and may even be a topographic high today. Such a situation implies a long interval of time between deposition of the sediments and overriding by glaciers. During this interval, erosion completely changed drainage patterns so that no evidence for any buried valley now exists. For this reason, it seems likely the sediment is considerably older than fluvial sediment that is found in buried valleys, perhaps pre-Pleistocene in age. The presence of what are apparently lake deposits of Pleistocene age on top of the fluvial sediment suggests that a lake formed when early Pleistocene ice blocked the drainage.

Stratigraphic situations similar to the one described above occur elsewhere in McLean County, but these are mainly in northeast-trending preglacial valleys. Preglacial fluvial sediment may underlie the glacial deposits in many of the preglacial valleys.

Coleharbor Formation

General Statement--Several surface glacial drift units have been recognized and named in North Dakota. These are recognized on the basis of environmental analysis, geomorphology, interpretations of mineralogy, depositional structures and textures, and fossil faunas. In North Dakota most of the named drift units are thought to have been deposited during single phases of activity of the glacier, and they can be related to some event in the history of the glacier. Because the drift units are recognized mainly on the basis of inferred geologic history or origin, they are highly interpretive and subject to change as more knowledge becomes available.

The surface drifts that have been named in North Dakota are, for the most part, lithologically indistinguishable on a regional scale. For this reason, and because of their inferential nature, it is practical to include all of them in a single lithostratigraphic unit. Lithostratigraphic units, or rock units, are bodies of rock identified by objective lithologic criteria. They are delineated in vertical succession by surfaces representing changes in lithologic character or breaks in the depositional continuity (Krumbein and Sloss, 1963, p. 332).

Glacial sediment in North Dakota has been studied sufficiently to adequately characterize and formally designate the Coleharbor Formation entirely in lithostratigraphic terms without resort to inferred geologic history or origin. The Coleharbor Formation consists of thousands of alternating beds but only three main facies: 1) interlayered bouldery, cobbly, pebbly, sandy, silty clay; 2) sand and gravel; and 3) silt and clay. These three facies, taken as a whole, form as uniform and distinctive a unit as any of the previously named formations in North Dakota. The Coleharbor Formation ranges from 0 to 600 feet thick in North Dakota and it is one of the most widespread geologic units in the state.

The Coleharbor Formation is named for the town of Coleharbor in McLean County, North Dakota. It includes all bouldery, pebbly, sandy, silty clay, sand and gravel, and silt and clay exposed in the type section and in all comparable sections. The best exposures of the Coleharbor Formation in North Dakota are located about 6 miles west of Coleharbor along the shore of Lake Sakakawea in Secs. 14, 15, and 22, T. 147 N., R. 84 W. (101° 21' West Longitude, 47° 32' North Latitude); this has been designated the type area (Fig. 5). Rapid erosion of the lake shore by wave action has exposed as much as 85 feet of nearly vertical section. The type section of the Coleharbor Formation is located about 300 yards south of the mouth of Dead Man Coulee in the NW¼, NW¼, NE¼, Sec. 22, T. 147 N., R. 84 W., McLean County, North Dakota (Figs. 6 and 7). The following is a description of the type

Figure 5. View across bay of Dead Man Coulee showing the type area of the Coleharbor Formation. Cliffs in the distance are about 40 to 50 feet high.

Figure 6. Chunks of iron-cemented conglomerate lying on a till surface (the exhumed upper surface of the Dead Man till). Photo taken near the area of the type section of the Coleharbor Formation.

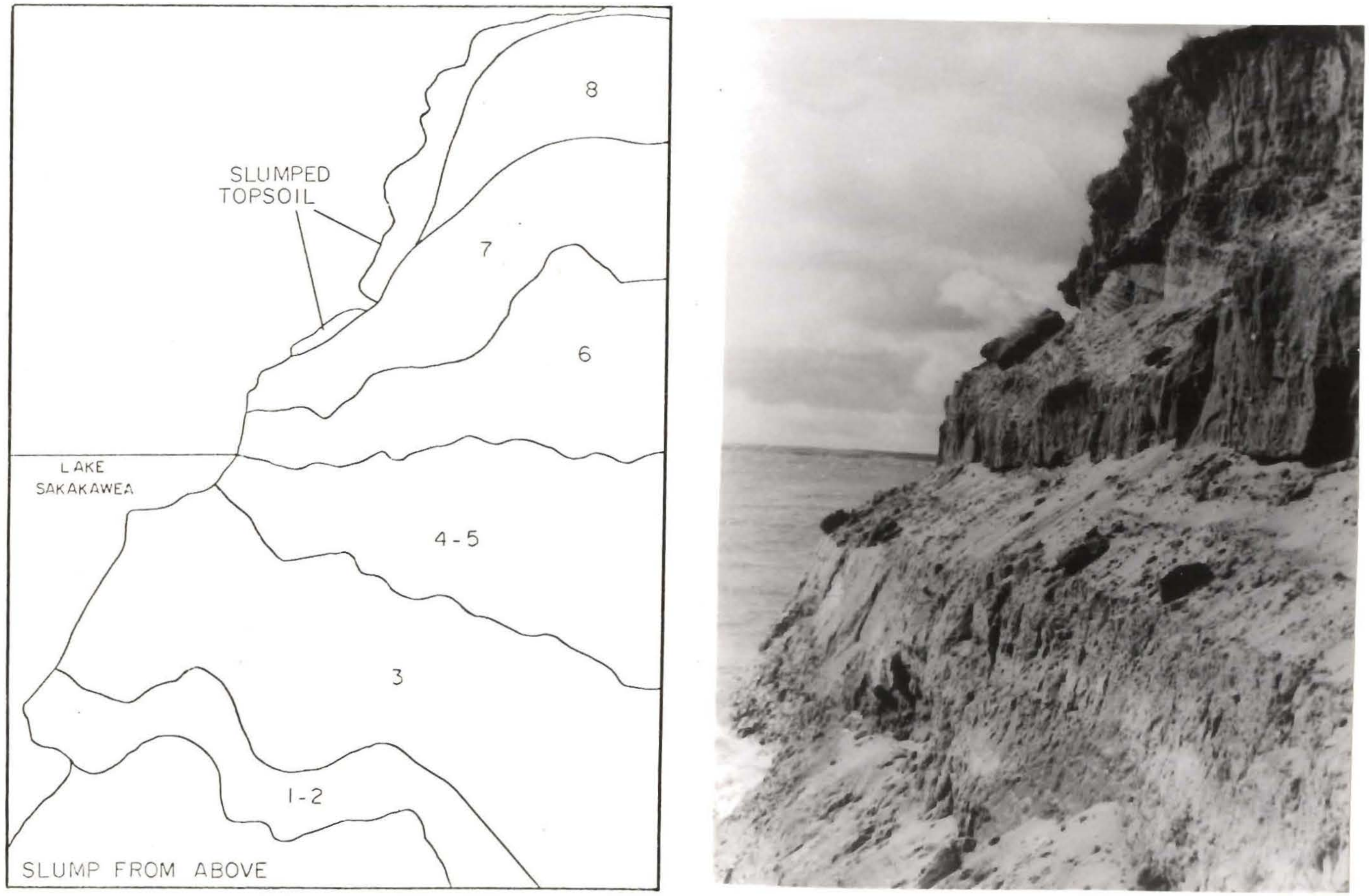


Figure 7. Photo of type section of Coleharbor Formation along Lake Sakakawea. Total exposed section shown here is about 40 feet. Numbers on the diagram identify the lithologic units shown on the photo and correspond to the numbers used in the section description.

section of the Coleharbor Formation (number 1 is the oldest unit, number 8 the youngest):

8. Clay; pebbly, sandy and silty; 15 to 20 feet thick; brownish buff to gray; pebbles are mainly granite and carbonate; chunky, unjointed and vaguely layered; calcareous. (Napoleon till of probable Early Wisconsinan age).

7. Gravel; 0 to 5 feet thick; medium-grained, sandy, cross-bedded in places; some iron oxide staining near base of unit; consists mainly of igneous and carbonate pebbles. (Stream channel deposit).

6. Clay; sandy and pebbly with a few lignite chips and pockets of silty, reddish brown, finely-divided limonite; 25 feet thick; strong vertical jointing results in almost vertical cliffs; appears to have good vertical permeability. (Mercer till of probable pre-Wisconsinan age).

5. Sand; 2 to 4 feet thick; fine to medium grained, cross-bedded and loose; consists mainly of quartz with much finely-divided lignite; lies above unit 4 in most places but appears to be laterally equivalent to unit 4 in a few places. (Glacial outwash deposit).

4. Gravel; 2 to 3 feet thick; coarse, sandy, highly iron oxide-cemented into a conglomerate (Fig. 6); chunks up to 10 feet long, but averaging 3 to 4 feet long, have fallen into the reservoir; consists mainly of pebbles and cobbles with lithologies typical of glacially-derived gravels from the northeast in Canada (igneous and carbonate rocks). (Glacial outwash deposit).

3. Silt; 15 to 20 feet thick; very pebbly with sand pockets up to 6 inches across; large inclusions of lignite and lake sediments; a few large boulders up to 15 feet in diameter; abundant lignite chips and charcoalized wood fragments; fine fraction is mottled gray and yellowish buff with lighter shades overall than found in overlying clay units (units 8 and 6); cliff surfaces are oxidized but in the freshest cuts the unit is unoxidized at 10 to 15 feet below its upper surface; contains relatively more carbonate pebbles than do the overlying clay units; irregularly jointed with selenite crystals and iron oxide and manganese dioxide staining common on joint faces; partially lithified (breaks across pebbles in places); massive; a few concretions; upper contact of this

unit with the overlying gravel is very sharp and, in places where gravel has been washed off by waves, a relatively flat erosion surface has been exhumed. (Dead Man till of probable pre-Wisconsinan age).

2. Silt; clayey; uniform texture; 3 feet thick; occurs at water level and is poorly exposed; brownish to yellowish-gray; has good horizontal banding that in places has been highly contorted; appears to be laterally equivalent to unit 1 in places. (Proglacial lake deposit).

1. Gravel; 2 to 3 feet thick (poorly exposed at water level); some iron oxide stains; mineralogy of pebbles and cobbles is typical glacially-derived assemblage (carbonate, granite, and metamorphic). (Glacial-outwash deposit).

By designating a formal stratigraphic unit, the Coleharbor Formation, it becomes possible to avoid the common practice of treating glacial deposits and bedrock in two entirely different ways. The formal designation should also facilitate more convenient study of comparable sediments over wide areas, not only in North Dakota, but in surrounding areas as well.

Christiansen (1967, 1968) has recognized several different units of glacial drift in the Saskatoon, Saskatchewan, area. He has divided the drift, first of all, into the Sutherland and Saskatoon Groups on the basis of carbonate content of tills, weathering zones, and inter-till stratified drift. He has further subdivided the upper group, the Saskatoon, into the Battleford and Floral Formations.

Subdividing the Coleharbor Formation in North Dakota on a lithostratigraphic basis is not yet practical. Preliminary field work with recognized drift units in North Dakota (see discussion of the Quaternary History later in this report) suggests that Christiansen's Battleford Formation may be equivalent to the Lostwood Drift and perhaps to the Napoleon Drift in North Dakota. His Floral Formation may be equivalent to the Mercer and Dead Man Drifts. Further study may make it possible to subdivide the Coleharbor Formation into members, or it may become necessary to elevate the Coleharbor Formation to group status. Possible members may be found to coincide with different glacial stages, or they may reflect predictable and mappable differences in till carbonate content, degree of weathering of feldspar particles, clay content, or some as yet unknown physical characteristics.

Distribution--The Coleharbor Formation covers most of the northeastern two-thirds of North Dakota, eastern South Dakota, Saskatchewan, Manitoba, northern Montana, and western and southern Minnesota. It unconformably overlies rock of all ages and is overlain in many areas by sediment of Holocene age.

The formation covers about 95 percent of McLean County (Pl. 1). It is more than 400 feet thick in at least one buried valley in western McLean County (Sec. 32, T. 149 N., R. 87 W.) but it averages about 100 feet thick throughout the county. Near the Missouri River Trench and over much of western McLean County, the formation averages less than 50 feet thick. The total volume of the Coleharbor Formation in McLean County is about 40 cubic miles.

Boulder-clay--The Coleharbor Formation of McLean County consists of about 70 percent bouldery, cobbly, pebbly, sandy, silty clay (boulder-clay for short) by volume. The terms "boulder-clay" and "till" are essentially synonymous but, as used in this report, "boulder-clay" refers only to the nonsorted, terrigenous sediment that contains a wide range of particle sizes. The term carries no genetic connotation in this report. Another strictly lithologic term that might have been used is "diamicton". In McLean County, all three terms (boulder-clay, till, and diamicton) refer to essentially the same sediment. The term "till," as used in this report, refers to glacial sediment and has a genetic connotation.

About 70 percent of the surface area of the county is covered by boulder-clay but much of this area has only a veneer. The boulder-clay facies of the Coleharbor Formation is a relatively uniform, unbedded mixture of approximately equal parts of sand, silt, and clay-sized sediment along with a small amount of pebbles, cobbles, and some boulders as much as a few feet in diameter.

The boulder-clay is generally dark gray below the water table, grayish brown above the water table. Colors commonly become darker downward from more to less highly weathered zones. Montmorillonite and other clay minerals along with small amounts of carbonate, quartz, and feldspar, are included in the clay-sized fraction of the boulder-clay. The silt and sand fraction consists largely of quartz and feldspar and some carbonate, shale, and lignite. Pebbles are varied and consist of limestone, dolomite, shale, lignite, and various hard metamorphic and igneous rock types. Most of the cobbles and boulders are igneous and metamorphic rock types; a few are carbonate.

Because of its low permeability, the boulder-clay is generally not a satisfactory source of ground water. Any permeability that the boulder-clay has is due to vertical fracturing so that the permeability is greater vertically than horizontally.

Sand and Gravel--In McLean County, the Coleharbor Formation consists of about 25 percent sand and gravel by volume. About 20 percent of the surface area of the county is sand and gravel. The deposits occur both as thin layers and lenses within the boulder-clay and as thick, continuous sequences independent of the boulder-clay. The sand and gravel facies is generally horizontally layered except in the hilly areas in the eastern part of the county where the layering is commonly tilted, faulted, or contorted. The sand and gravel ranges from sandy gravel and gravelly sand that is relatively free of finer materials to very dirty gravel with large amounts of silt and clay.

In general, the best sorted deposits cover the flat expanse of land northwest and east of Turtle Lake and east of Washburn. This gravel commonly has maximum grain sizes of less than 2 inches. Well-sorted sand and gravel occurs also on valley terraces south of Ruso in northeastern McLean County. Much of the sand and gravel that occurs in irregularly-shaped ridges and mounds in the hilly areas of eastern McLean County is poorly sorted and coarse-grained. It contains considerable amounts of boulder-clay and boulders of all sizes and is generally of little or no economic value.

The sand and gravel facies of the Coleharbor Formation has a mineralogic composition similar to the boulder-clay. The mineralogy indicates that it was ultimately derived from the northeast in Canada where igneous and metamorphic rocks of the Canadian Shield are widely exposed. The sand-sized fraction is largely quartz and feldspar with minor amounts of shale and carbonate. The gravel-sized fraction is composed largely of granite and metamorphic rock types, limestone, and dolomite. Some of the gravel has a high percentage of shale. Near the surface, caliche, $CaCO_3$, coats the undersides of pebbles and cobbles.

Generally, the sand and gravel is loose, but in some places it is cemented with iron oxide and forms a conglomerate. Exposures of iron oxide-cemented conglomerate are particularly common along the shore of

Lake Sakakawea at the mouths of Snake Creek and Dead Man Coulee (T. 147 N., R. 84 W.). In areas where the sand and gravel is loose and uncemented, it is also highly permeable. The sand and gravel is generally the largest and most dependable source of high-quality ground water in the county.

Silt and Clay-- Approximately 5 percent of the Coleharbor Formation in McLean County consists of layers and lenses of silt and clay. Only about 2 percent of the surface area is silt and clay, but considerable thicknesses of it occur in buried valleys throughout the county. It commonly has horizontal layering a fraction of an inch in thickness. Sand is uncommon in the silt and clay facies and pebbles are scarce. The silt and clay facies has the same mineralogy as the silt and clay fraction of the boulder-clay: montmorillonite and other clay minerals, carbonate, quartz, and feldspar. Its permeability is about the same as that of the boulder-clay.

Where the facies is exposed at the surface in McLean County, silt is commonly more abundant than clay, but there are exceptions. The same is true to a lesser extent of the subsurface deposits.

Age and Origin--The Coleharbor Formation was deposited during the Pleistocene Epoch from several hundred thousand to about 9,000 years ago. The boulder-clay facies of the formation is mainly glacial till consisting of sediment eroded by glaciers from areas north of McLean County as well as locally. Part of the boulder-clay was subsequently deposited directly from the moving ice, and the remainder slid, slumped, and flowed to its present position when the ice melted.

The sand and gravel of the Coleharbor Formation was deposited by rivers and streams during glacial times. Some of these rivers and streams must have been fed by meltwater from the glaciers but probably large amounts of sand and gravel were deposited by nonglacial rivers 12,000 to 9,000 years ago when precipitation amounts were high and runoff was much greater than it is today (Clayton, 1967, p. 33). Some of the sand and gravel was deposited on beaches of lakes.

The Coleharbor silt and clay exposed at the surface in eastern McLean County was deposited in lakes that were at least in part enclosed by glacial ice. Part of the surface silt and clay in western McLean County may have formed in the same way, but most of it was deposited in still-existing lake basins that contain lakes in years of above average precipitation. The subsurface silt and clay that is confined to buried valleys was probably deposited in large lakes that formed when easterly-flowing rivers were dammed by advancing ice.

Postglacial Sediment

Holocene sediment has been deposited since the Pleistocene Epoch throughout McLean County, especially as river and stream valley floodplains (Pl. 1), on slough floors, and in sporadic occurrences of sand dunes.

Fluvial Sediment--Fluvial sediment occurs along stream and river channels throughout McLean County. It ranges from a few feet thick along some of the smaller streams to over 100 feet thick in places beneath the Missouri River floodplain. It is sometimes difficult to distinguish modern fluvial deposits from the underlying fluvial and lacustrine sediments of glacial origin.

The fluvial sediment consists mainly of clay, silt, sand, and gravel. Silt and clay commonly make up about 90 percent of the sediment, sand and gravel the remaining 10 percent. Distinct and separate horizontal beds of dark brown sand, silt, and clay are common in the alluvium. The fluvial silt and clay differs from silt and clay of the Coleharbor Formation in that the fluvial materials are commonly sandy with a high organic content in places. The sand and gravel is similar to that in the Coleharbor Formation, but it is much less extensive and occurs as small lenses within the silt and clay.

Slough Sediment--The sediment in the bottoms of sloughs is a few tens of feet thick and consists of very dark brown and black clay with a high organic content. Most of the slough sediment is located in the hilly eastern and northeastern parts of McLean County. It consists of sediment washed into the lower areas from adjacent hillslopes by runoff water. Individual deposits are too small to map, and although many hundreds of sloughs containing clay exist, they are not all shown on Plate 1.

Eolian Sediment--Deposits of silt a few feet thick are common on and adjacent to sand and gravel deposits. These are loess deposits that accumulated during dry periods throughout the past 9,000 years. The silt is generally of uniform texture, massive, and blocky. Most exposures are buff colored. Windblown silt deposits occur in southern McLean County in Tps. 143 and 144 N., Rs. 80 and 81 W. and in Tps. 146 and 147 N., Rs. 83 and 84 W. near Garrison Dam. The deposits in southern McLean County were not mapped, because they are very discontinuous. The silt deposits near the Garrison Dam, which are about 15 to 20 feet thick, are well-exposed in the steep bluffs north of the dam. At least two paleosols occur in the loess in this area. The lower paleosol is persistent and is truncated by modern valleys so it must be older than the valleys. The upper paleosol, which becomes multiple in a few places, follows modern topography. The stratigraphy of this loess has been tentatively worked out by Clayton and Moran (1971).

Windblown-sand deposits occur throughout McLean County. Most of these deposits are small and insignificant but in Sec. 13, T. 145 N., R. 84 W., and Sec. 18, T. 145 N., R. 13 W. large sand dunes occur. These dune deposits average about 20 feet thick and consist mainly of brownish, fine-grained sand, mainly quartz. A few cobbles can be found in the area, but it seems likely they were carried there, probably by Indians, for anchoring tepees.

Glacial Landforms

Erosional Forms

Although erosional forms are common in some areas, only a few such landforms were recognized in McLean County. Small drumlin-like ridges that occur in extreme northeastern McLean County apparently formed during the last southeastward movement of ice northeast of the Missouri Coteau. The ridges are of erosional or depositional origin and were formed when ice moving over the fluvial deposits in the area reshaped the gravel into linear forms. The ridges are composed of the same gravel as the underlying fluvial deposits plus some clay and silt. Exposures through the ridges reveal a fabric that is superficially similar to till that contains a higher percentage of clay. Sand and gravel constitute the matrix material instead of silt or clay in these exposures.

Depositional Forms

Nearly all the landforms in McLean County that were formed as a direct result of glacial action are depositional. Included in this category are the various types of moraine. Fluvial and colluvial processes have played an important role in determining the final characteristics of the various depositional forms.

End Moraines--An end moraine is a linear deposit of glacial drift formed at or near the terminus of an ice sheet during a standstill of the glacier terminus. Most end moraines result from a process of dumping of superglacial till that has been brought into the ice by shearing at the edge of the glacier and then concentrated on the surface by ablation. A process of ice shove, similar to a bulldozing effect at the terminus, has been suggested as an important mechanism in the formation of some end moraines. Another type of end moraine, the shear moraine, is a special type of dump moraine. This is a smaller, isolated ridge of till that is seemingly unrelated to any major standstill of the glacier. It is produced by shearing either at the zone separating the active ice from the inactive ice, or at sites of bedrock highs. Many washboard moraines probably form in this way.

The glacial drift is commonly significantly thicker beneath an end moraine than it is beneath the adjacent ground moraine. This is not a necessary requirement if the end moraine marks an ice-marginal position that persisted for some time. The most important characteristic of an end moraine is its linearity, either an overall linearity of the end moraine as a unit, or linearity expressed by the alignment of depressions and ridges within the moraine. On the Missouri Coteau, end moraines are best distinguished from the surrounding dead-ice moraine by the presence of such lineations, which parallel the long axis of the end moraine. Commonly the boundaries between dead-ice moraine and end moraine are obscured by the collapse and obliteration of the linear ridges. In McLean County, no end moraines were recognized on the Missouri Coteau.

The Blue Mountain End Moraine occurs on the Coteau Slope of western McLean County. It has a maximum local relief of about 60 feet and elevations ranging between 2,000 and 2,200 feet. In addition to numerous small ridges that parallel the overall northeast-southwest trend of the feature, abundant small disintegration features more characteristic of dead-ice moraine occur over most of the Blue Mountain End Moraine. The glacial drift beneath the end moraine averages over 60 feet thick, based on about a dozen test holes. This compares with an average thickness of about 25 feet for the drift ahead of the end moraine and less than 20 feet for the drift behind it, although the ground moraine behind the end moraine becomes thicker farther northwest. Areas of high bedrock associated with the Blue Mountain End Moraine, particularly in front of it, appear to have been important in causing the deposition of the end moraine.

Ground Moraine and Sheet Moraine--Much of the western and southern part of McLean County is covered by ground moraine and sheet moraine (Pl. 1). Areas of sheet moraine are characterized by a thin, discontinuous layer of glacial drift, chiefly till, draped over nonglacial topography. Sheet moraine is a mappable, blanket-like, veneer of drift that was deposited directly from glacial ice (Kume, 1965, p. 164). It has low, constructional relief with few kettles. Its overall shape is the same as that of the landscape over which it is draped; it has inherited a pre-existing shape. Sheet moraine forms when the thin glacier drops its load as it loses the ability to carry it.

In McLean County, most of the sheet moraine consists of Napoleon

Drift of probable Early Wisconsinan age. It is discontinuous near the Missouri River Trench of western McLean County, where headward erosion is removing it, and near some of the larger streams.

Ground moraine is a landform composed of a drift accumulation, chiefly till, that was deposited from a moving glacier behind its margin. It has relatively low constructional relief and few disintegration markings. The ground moraine of McLean County occurs mainly northwest of the Blue Mountain End Moraine and was deposited by the same glacier that deposited the end moraine. It is characterized by irregular to gently rolling topography with relief that averages less than 20 feet in a mile except near streams where it is greater.

Dead-Ice Moraine--Most of the dead-ice moraine in McLean County is on the Missouri Coteau (Fig. 1). However, another band of relatively subdued dead-ice moraine occurs in the Underwood area to the west of the Coteau. The area of dead-ice moraine is characterized by knob and kettle topography, non-integrated drainage with numerous small ponds and sloughs, and a bouldery surface. The relief of the dead-ice moraine in eastern and northern McLean County ranges up to 100 feet locally, but it is only about 20 to 25 feet in a mile on dead-ice moraine in the Underwood area (Pl. 1). Relief may differ greatly within short distances, and boundaries of differing degrees of relief are difficult to delineate. Areas of high relief are differentiated from areas of low relief on Plate 1.

In the area east of Falkirk in southeastern McLean County (T. 145 N., R. 81 W.), it was possible to accurately map several small, east-west trending, drift-filled valleys in the bedrock by noting the presence or absence of dead-ice moraine of low relief. These valleys, which are too small to show on either Plates 1 or 3, have no surface expression, but they can be traced as strips of low relief dead-ice moraine on air photos. Augering in the strips of dead-ice moraine showed that the glacial drift is about 40 to 50 feet thick whereas the glacial drift adjacent to the dead-ice moraine is less than 15 feet thick. Apparently the development of disintegration features required a certain minimum thickness of glacial drift, somewhat greater than 15 feet.

Disintegration ridges are perhaps the most diagnostic characteristic of dead-ice moraine. They are rectilinear or circular ridges of glacial drift that were deposited between, around, or within depressions in blocks of glacial ice, through the process of mass movement from above or squeezing from below or both. Such features are abundant on the dead-ice moraine of eastern McLean County.

Closed disintegration ridges are the most common type of disintegration ridge found in McLean County. They are not easily seen in the field, but they are obvious on air photos. Closed disintegration ridges average about 500 feet in diameter, but they are as large as ½ mile across. They average about 15 feet in height and have circular to irregular shapes. Many of the closed disintegration ridges are breached at both ends, forming features that are easily recognized on air photos.

Kettle Chains--Kettle chains may be defined as linear areas with high concentrations of kettles or potholes. Most of the kettle chains in McLean County occur in areas of dead-ice moraine (Pl. 1). Many of the kettles contain sloughs or lakes. The kettles commonly follow a poorly defined valley or otherwise topographically low area. Some kettle chains overlie valleys that became filled with glacial ice and others may represent areas where particularly large pieces of ice became incorporated in the drift. The longer kettle chains are likely to overlie gravel-filled valleys, and test drilling for water might be useful in these areas.

Large Glacial Erratics--Dogden Butte in northeastern McLean County (T. 150 N., R. 79 W.) is apparently a large glacial erratic. North Dakota State Water Commission test hole 4079 shows a sequence of 100 feet of glacial till and fluvial deposits overlying 212 feet of bedrock (Tongue River Formation), which in turn overlies 44 feet of till and fluvial deposits. Similar large glacial erratics composed mainly of bedrock have been observed in Ransom and Nelson Counties, North Dakota. To the east in Sheridan County, several dozen similar abrupt and prominent hills were mapped in 1969 (Bluemle, 1970). In that area a depression is located up-ice from each hill. Although no obvious depression is associated with Dogden Butte, it seems likely the butte formed in the same way as did the Sheridan County hills and that any associated depression was subsequently filled with glacial drift by later glacial action.

In Sheridan County, which is also near the Missouri Escarpment, it was concluded that normal local ground water flow systems may have interacted with the regional ground water flow systems introduced by the glacier, resulting in greatly increased ground water discharge and accompanying high hydrodynamic pressures in the subsurface between the glacier and the Missouri Escarpment. These high pressures helped to force large blocks of material, including bedrock and glacial drift, upward into the advancing glacier. These materials were subsequently deposited by the glacier on top of the Missouri Coteau, resulting in high relief dead-ice moraine that developed when large-scale glacial stagnation occurred. When the glacier melted from the area, hydraulic conditions were essentially identical to those that had existed when the glacier advanced. Because the ice margin was fluctuating, but generally receding, newly formed blocks of material were moved only short distances and the adjacent depressions were left essentially undisturbed.

Glaciofluvial Landforms

Streams flowing on or from the melting glaciers were responsible for most of the landforms that have an indirect relationship to glacial action. Most of these forms are mainly constructional, but meltwater trenches and terraces are at least partly erosional landforms. All the landforms in this category indirectly require the presence of ice in or near the area, but ice was not necessarily the primary mechanism responsible for determining the location, extent, or shape of the features.

Depositional Forms

Alluvial Plains--Areas covered by gravel and sand are shown in yellow on Plate 1. Some of the gravel and sand is undoubtedly glacial outwash and some of the sediment was deposited by rivers and streams that were fed by the increased precipitation that occurred in early postglacial time (9,000 to 12,500 B. P.) (Clayton, 1967, p. 33). The relative percentages of glacial outwash sediment and postglacial alluvium are not known and, for purposes of discussion, the deposits will be referred to here simply as alluvial plains. The locations of these alluvial plains are shown on Plate 1.

The alluvial plains are relatively flat areas with local relief of

10 to 20 feet in a mile. Relief is greatest in areas where sand dunes have developed. Channel and meander scars, none of which continues for appreciable distances, are common. They are most easily seen on air photos. Boulders are rare on the surface.

The alluvial plains of western and southern McLean County are covered by sand and gravel that is generally less than 10 feet thick, but in the Turtle Lake area over 100 feet of gravel and sand covers the alluvial plain in places. It is unlikely, however, that the deeper sediments in these areas are related to the surficial alluvial plains; they probably were deposited during events that occurred prior to the deposition of the materials on the alluvial plains.

Collapsed Alluvial Sediment--Hilly areas of gravel and sand are collapsed alluvial sediment. Such areas consist of collapsed sediments of formerly flat alluvial plains that were deposited on stagnant glacial ice. When the stagnant ice melted, collapse of the overlying alluvium occurred. In general, these areas are characterized by hilly topography with abundant undrained depressions, faulted bedding and other collapse structures that can be observed in cuts. Maximum relief is about 75 feet in a square mile.

In McLean County, numerous small linear bodies of collapsed alluvium occur on the Missouri Coteau (Pl. 1). These are collapsed valley trains that were deposited in valleys on the stagnant glacier. A larger area of collapsed alluvium occurs in T. 147 N., Rs. 79 and 80 W. This area overlies a deep preglacial valley (Pl. 3) that apparently became filled with stagnant ice that was later covered by fluvial deposits.

Small, circular or semi-circular, isolated, elevated areas of collapsed alluvium are known as kames. Kames are "mounds composed of gravel or sand, whose form has resulted from original deposition modified by any slumping incident to later melting of glacial ice against or upon which the deposit accumulated" (Holmes, 1947, p. 248). In areas of dead-ice moraine, only conspicuous hills of sand and gravel that are more prominent than the surrounding hills should be considered to be kames. Numerous kames were mapped within the area of dead-ice moraine in McLean County, and a few were mapped in the area of ground moraine in the western part of the county (Pl. 1). The most prominent kames are in western McLean County, where local relief is generally low. A good example is Paint Hill (SW¼, Sec. 28, T. 149 N., R. 88 W.). This kame is about 50 feet high and about a quarter mile across at the base. It has few surface boulders, less than the surrounding area, and contains well sorted sand and gravel, some till, and a layer of silt.

Eskers are ridges of gravel or sand that were deposited by water flowing in tunnels or valleys on the stagnant glacial landscape. When the stagnant ice melted, the resulting glacial deposits remained as esker ridges. The largest esker in McLean County (Fig. 8) occurs in T. 150 N., R. 82 W. and extends from Section 7 to Section 35, a distance of about 6 miles. It has two branches on the north and grades into collapsed outwash on the south. The esker rises a maximum of about 50 feet above the surrounding dead-ice moraine. Notable esker ridges occur also in T. 147 N., R. 80 W. northeast of Turtle Lake and in T. 147 N., R. 79 W.

Flat Lake Topography--In western McLean County, a relatively flat area of about 10 square miles occurs in T. 150 N., R. 86 W. This area, along with a similar slightly smaller area about 4 miles to the southwest,

Figure 8. Esker between Benedict and Max in north-central McLean County (Sec. 21, T. 150 N., R. 82 W.). Relief on this esker is about 50 feet. Numerous small pits in the esker expose generally coarse, poorly sorted gravel and sand.

is covered by bedded silt and clay that is sandy in places. Relief in the two areas is generally less than 5 feet in a mile. These areas formed when the glacier that had deposited the Blue Mountain End Moraine melted back a short distance and meltwater from the glacier was dammed between the ice and the end moraine.

Undulating Lake Topography--Silt and silty sand that was deposited in lakes on stagnant ice later collapsed resulting in undulating lake topography. When the ice melted, the sediment became folded and contorted, and the surface, which had been flat, became undulating. Plate 1 shows several areas of collapsed lake deposits, all closely associated with dead-ice moraine. Some of the deposits are elevated slightly above the surrounding landscape and are rather flat. Apparently, the lakes in which this silt and fine sand accumulated were surrounded by, but were not on, stagnant ice so that when the ice melted, surrounding areas collapsed and the lake topography was left intact. A few of these flat deposits have till rims at the edge indicating that debris slid from the adjacent ice into the lakes. On air photos the areas of collapsed lake topography are easily recognized as cultivated patches of ground of relatively low relief surrounded by uncultivated dead-ice moraine of higher relief.

Erosional Forms

Meltwater Trenches--Meltwater trenches are channels that were cut by water flowing from melting ice sheets. Probably a significant amount of water that flowed through these channels was derived from local precipitation as well.

Many of the meltwater trenches on the Missouri Coteau of eastern McLean County are poorly defined because the stagnant ice over and through which they were cut later melted, obscuring their original courses. Some of the areas shown as collapsed alluvial topography on Plate 1 are confined in places to fairly well-defined valleys that are probably segments of meltwater trenches.

One of the largest meltwater trenches in the area of dead-ice moraine trends southward from the Ruso area into the alluvial plain in T. 147 N., R. 81 W. This trench has a gravel floor and a single terrace level that grades to an upper, partially collapsed level within the alluvial plain. Its floor grades to the lower, uncollapsed portion of the alluvial plain. Nearly paralleling this meltwater trench is another narrower, but equally deep trench in Tps. 148 and 149 N., R. 80 W. Strawberry Lake, Long Lake, and Crooked Lake all occur within the trench. This trench must have been cut while stagnant ice was still present. When the ice melted, the trench was blocked in places due to collapse as the original gradient was destroyed.

Another meltwater trench is the middle branch of Douglas Creek, which trends southward from the Ward County line to the Missouri River through T. 85 W. (Pl. 1). This trench is also parallel to the edge of the Late Wisconsinan dead-ice moraine and may have been initiated as an ice-marginal feature. The trench is about a mile wide where it nears the Missouri River Valley (Fig. 9) and about 150 feet deep. It is cut mainly in bedrock.

Turtle Creek flows through a deep, south-trending valley (Pl. 1). The position of this trench, parallel to the edge of the Late Wisconsinan dead-ice moraine, suggests that it was initiated as an ice-marginal feature. It begins near the town of Turtle Lake at the southern edge of the alluvial plain already referred to. The trench is cut mainly in

Figure 9. Middle branch of Douglas Creek meltwater trench in T. 148 N., R. 85 W. View is north from State Highway 37 in section 7.

Figure 10. Turtle Creek valley east of Washburn (T. 144 N., R. 81 W.). View is north over terraces along the meltwater trench.

bedrock and has highly dissected walls with badlands topography in places (Fig. 10).

The largest meltwater trench in the area is the valley of the Missouri River. The Missouri River Valley will be discussed in the part of this paper dealing with drainage development. Some segments of the Missouri River Valley are of preglacial origin, whereas others were cut by meltwater during glaciation, although the entire trench served as a meltwater route.

Erosion Surfaces--Relatively flat, pediment-like surfaces that cut across both Early Wisconsinan glacial drift and Tertiary bedrock occur in Tps. 144 to 145 N., Rs. 83 to 84 W. (Fig. 11). The surfaces occur at elevations that range from 1,800 to 2,000 feet and they slope southeastward. In a few places the erosion surfaces are covered by several feet of sandy gravel, but in most areas only a thin soil covers the bedrock or glacial drift. Boulders are common on the surfaces except in the gravel-covered areas. On air photos the erosion surfaces look smooth and lack the morainic markings typical of the surrounding areas.

The erosion surfaces apparently were cut by water that flowed southeastward from the Riverdale area when east-trending drainage was blocked and the south-trending segment of the Missouri River had not yet been cut. By projecting the slopes on the erosion surfaces southeastward to the center of the Missouri Trench in the area west of Washburn, a figure of about 1,740 feet is arrived at for the elevation of the base of the Missouri Trench at the time the surfaces were cut. The present floor of the trench is at about 1,670 feet, so the valley today is about 70 feet deeper than it was in Late Wisconsinan time.

Terraces--Many of the larger meltwater trenches have a single

Figure 11. View south over the flat profile of a remnant of an erosion surface (Secs. 25 and 26, T. 145 N., R. 84 W.). The low area in the foreground is the Missouri River floodplain.

terrace level developed on the valley walls. These terraces are cut on either bedrock or till and have a covering of gravel that is generally less than 5 feet thick.

Except for low, local terrace levels that are generally less than 15 feet above river level, and considered to belong to the modern floodplain, three terrace levels can be recognized within the Missouri Trench. The lowest of these is about 40 to 50 feet above the river level at elevations that range from about 1,730 feet near Riverdale to less than 1,700 feet at the Burleigh County line. Upstream from Riverdale any low terraces that may have been present are now flooded by Lake Sakakawea. The lowest terrace level is covered mainly by gravel and is a fill and cut terrace. It probably corresponds to terrace 4 in Burleigh County (Kume and Hansen, 1965, p. 8).

The middle terrace level is generally about 90 feet above the river level at elevations that range from about 1,790 feet in the Riverdale area down to about 1,735 feet near Washburn. This terrace level is cut across bedrock and till of probable Early Wisconsinan age and is covered by gravel that is commonly less than 10 feet thick. The middle terrace is fairly continuous all the way from Riverdale to the Burleigh County line. Because this terrace level was cut after the modern route of the river was established, the level of the river has been lowered at least 90 feet since the route was established, presumably when Late Wisconsinan glaciers reached their maximum extent.

The uppermost terrace level ranges from over 1,900 feet south of Garrison to about 1,770 feet near Washburn. This is a cut terrace with little alluvial material on the surface. It is apparently related to the cutting of the north-south segment of the trench south of Riverdale because pediments that were cut before the trench existed occur at about the same level.

Nonglacial Landforms

Nonglacial landforms include features that were shaped or are being shaped by nonglacial processes. In contrast to glacial and glaciofluvial landforms, which are mainly relict forms that have not changed significantly since they were formed, the nonglacial landforms are still being formed today. In McLean County only a few landforms are unrelated to glacial action and even these can be indirectly tied to glaciation. The Missouri River floodplain, for example, is a modern feature but its distribution is controlled by its position in the Missouri River Trench, which is, in part at least, of glacial origin. Similarly, the location of the McLean County badlands is controlled by the fact that they occur primarily in the Missouri River Trench.

Depositional Forms

River Floodplains--Most of the modern streams in McLean County have floodplains that are only a few hundred feet wide and covered by thin alluvium. The exception is the Missouri River floodplain, which is as much as 4 miles wide. It consists of channel bars and meander scars that are continually being modified by present river action. Topography on the floodplain is generally smooth and level. Oxbow lakes, such as Painted Woods Lake in Secs. 9 and 16, T. 143 N., R. 80 W., occur in some of the older meander scars. The Missouri River floodplain is characterized by thick woods. Cottonwood trees are particularly common.

Sloughs--Sloughs occur throughout McLean County, particularly in the areas of dead-ice moraine. Some of them become moderate-sized lakes during wet years, but normally they are areas of marshland. Most of the smaller sloughs occur in the bottoms of kettle depressions, but some, such as Weller Slough, (Secs. 1, 2, and 12, T. 145 N., R. 83 W.) and others in the Falkirk area, occur in broad depressions that may mark buried valleys.

Dunes--Sand dunes occur in Sec. 13, T. 145 N., R. 84 W. and Sec. 18, T. 145 N., R. 83 W. The source of the sand is the fluvial deposits on terraces of the Missouri River Trench to the northwest. The dunes cover an area of about 1 square mile. They have local relief of about 10 feet between dune crests and adjacent depressions. A few blowouts occur in the dune area, but for the most part, the dunes are stable with a grass and brush cover.

Erosional Forms

Eroded Topography--Areas of eroded topography occur along the larger stream valleys in the area of the Napoleon drift where they coincide, approximately, with the areas of bedrock exposures (Pl. 1). Little erosion has occurred on areas mantled by substantial thicknesses of glacial drift. The most extensive areas of eroded topography occur within the Missouri River Trench. In Rs. 87 to 90 W. and in Tps. 144 to 145 N., R. 84 W., the trench is characterized by badlands topography. These areas have slopes that range from 20° to 65° with locally high relief. Badlands are found on exposures of Tongue River and Sentinel Butte Formation rocks. A few buttes that are present in the badlands areas are capped by glacial drift overlying a resistant sandstone or siliceous bedrock layer. Erosion of the badlands topography has resulted in knife-like ridges with intervening arroyos and slopes that are almost devoid of vegetation.

GEOLOGIC HISTORY

Preglacial History

McLean County is located in the eastern part of the central Williston Basin, the center of which is located southeast of Williston, North Dakota. Seas invaded this part of the Williston Basin at least four times during Paleozoic time and deposited carbonate, sandstone, shale, and evaporite beds. During times the area was emergent, parts of these deposits were removed by erosion. The area was emergent during early to middle Ordovician, middle Silurian to middle Devonian, late Mississippian to early Pennsylvanian, and during Triassic time.

Marine deposition continued during the Mesozoic from middle to late Jurassic time when emergence with nonmarine deposition occurred. This nonmarine deposition continued into Cretaceous time until the early Cretaceous seas invaded the area and thick accumulations of fine grained clastics were deposited. The last phase of marine Cretaceous deposition is represented by fine grained clastics of the Fox Hills Formation.

A change to nonmarine deposition began in late Cretaceous time with the deposition of the Hell Creek Formation. This continued into the Paleocene with the deposition of the Ludlow Formation. The last marine invasion of the area resulted in the deposition of the Cannonball Formation. This was followed by deposition of the nonmarine Tongue River Formation and the Sentinel Butte Formation, both of Paleocene age. The Golden Valley Formation of Paleocene to Eocene age is present in

Mercer County directly south of McLean County, and the presence of the Oligocene White River Formation in the Killdeer Mountains of Dunn County suggests that these two formations may have extended into McLean County, but if they were ever present, they were removed from the area during the post-Oligocene erosional episode.

During post-Eocene Tertiary time, the predominant process was erosion of the then existing landscape. The topography of the area was probably similar to the present topography in areas of thin glacial drift.

Topography on the Preglacial Surface

The topography of the preglacial surface under the glacial drift in McLean County is shown on Plate 3. This generalized map is based largely on subsurface test-hole data and is therefore highly conjectural.

The preglacial surface, which was developed on the Tertiary Cannonball, Tongue River, and Sentinel Butte Formations, was a moderately rolling plain dominated by three northeast-trending valleys. The largest river valley trended eastward along the southern edge of McLean County through T. 147 N., Rs. 84 to 90 W. and continued eastward through T. 148 N., Rs. 79 to 83 W. (Pl. 3). The part of the valley in the western half of the county coincides with the modern Missouri River Valley, but the eastern part of the valley is buried beneath glacial drift.

The preglacial Knife River, which today joins the Missouri River about 10 miles south of Riverdale, continued northeastward to the valley described in the last paragraph in T. 148 N., R. 81 W. This northeast extension of the Knife River Valley is today buried beneath glacial drift.

The third major preglacial valley shown on Plate 3 coincides with the Missouri River Valley east of Washburn in T. 144 N., Rs. 82 to 84 W. and continues northeastward beneath the glacial drift to T. 148 N., R. 79 W., where it joins the first river valley.

In addition to the three preglacial valleys mentioned above, several rather narrow but deep meltwater trenches are shown on Plate 3. These trenches formed when drainage was diverted by the glaciers. In some places, the meltwater trenches may have been ice marginal.

Modern erosion has cut into the bedrock surface in some areas of thin glacial drift. This is particularly common along the edge of the Missouri River Trench in western McLean County where rather extensive areas of Sentinel Butte Formation sand and silt are exposed at the surface.

Development of Drainage During the Quaternary

The map of the bedrock surface in McLean County (Pl. 3) shows several rather deep valleys that cross the area. Some of these were in existence before the area was glaciated, and others were cut as glacial diversion trenches during the glacial epochs. In general, prior to glaciation, the area was relatively flat with elevations on the uplands ranging from about 1,900 feet in the northeast to about 2,200 feet in the southwest. Valleys that trended generally east and northeast were cut about 300 feet into the upland surface and were about 4 to 6 miles wide.

Preglacial Drainage

Figure 12 shows a probable drainage pattern shortly before glaciation. These generally northeast-trending valleys contain fluvial

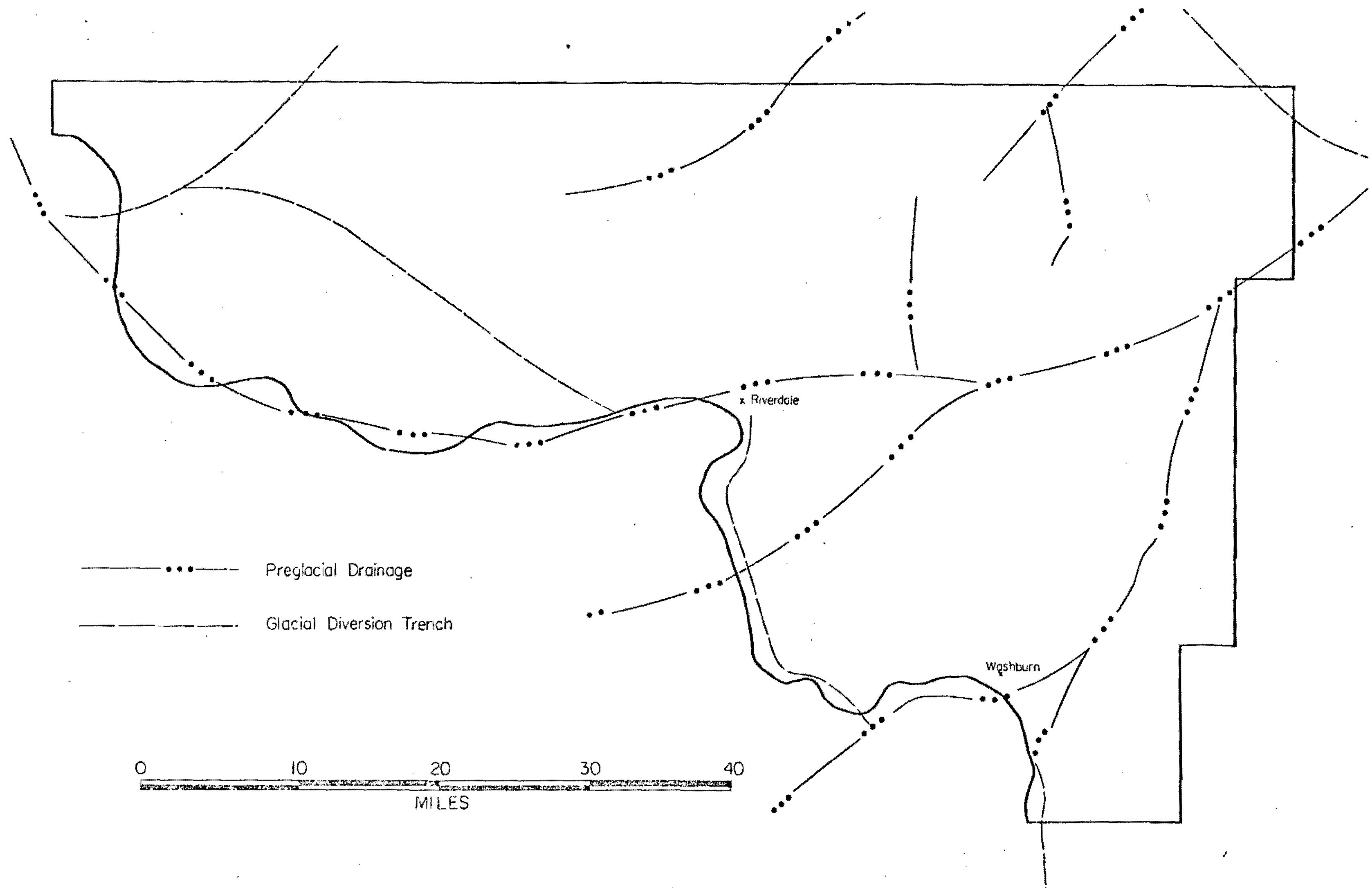


Figure 12. Map showing major preglacial drainages and glacial diversion trenches in McLean County.

sand and gravel of western derivation overlain by glacial deposits, which comprise most of the valley fill. The preglacial valleys were an important factor in establishing the modern course of the Missouri River, which marks the southwestern boundary of McLean County.

Drainage Development During Glaciation

Those parts of the east-trending preglacial valleys not completely filled with glacial deposits again carried rivers during glacial times. Due to increased precipitation during glacial times, these rivers were much larger than the original preglacial rivers and, as a result, narrow trenches were cut within the wide valleys. Parts of the original preglacial valleys became blocked by glacial deposits and, where this happened, narrow diversion trenches were cut without regard to the regional slope. The modern Missouri River Valley from Riverdale to a point about 12 miles south of Riverdale, is an example of such a diversion trench. This relatively young segment of the Missouri River Valley is much narrower than east-trending segments of the valley that apparently carried preglacial drainage.

Many diversion trenches, now deeply buried under glacial deposits in eastern and central North Dakota, were cut when northeast-flowing streams became blocked by advancing glaciers and were diverted southeastward. As later glaciers advanced, they overrode ice-marginal trenches that had formed earlier. Eastern and northern areas of North Dakota are characterized by a myriad of channels now deeply buried beneath the drift and traceable only through test drilling. Examples of such buried diversion trenches in McLean County include the one that trends southeastward from T. 149 N., R. 90 W. to T. 147 N., R. 85 W. This trench is as much as 300 feet deep and has no surface expression.

The vast array of buried valleys in McLean County as well as throughout eastern and northern North Dakota shows that drainage followed many routes during the various glaciations and the intervening interglacial stages. Because so many buried valleys have been found, it is difficult to pin down the drainage pattern that may have existed at any particular time prior to the present.

Some of the buried meltwater trenches in eastern North Dakota are both wide and deep, and it seems probable that they served as river valleys for long periods of time, perhaps for entire interglacial stages, carrying drainage from an area comparable in size to that drained by the modern upper Missouri River. Certainly during the pre-Wisconsinan glaciations drainage must have been southward around the ice sheets just as it was during Wisconsinan time. Some of the preglacial valleys were again used after each glaciation and some remained permanently blocked by glacial drift.

Regional evidence indicates that the modern Missouri River route did not exist in mid-Wisconsinan time downstream from a point near Riverdale. Instead, the main drainage flowed through the preglacial valley that trends eastward from Riverdale (Fig. 12). South of Washburn, terraces of till-covered bedrock occur within the relatively narrow Missouri River Valley. The till is Early Wisconsinan (?) in age so this segment of the valley must have been cut as a glacial diversion feature sometime prior to the Early Wisconsinan. Because the valley south of Washburn is relatively narrow, the river probably has not flowed in it for very long. It seems probable that this part of the trench was first cut during pre-Wisconsinan glaciations and then abandoned in favor of earlier, better established drainage farther east when the ice receded.

The present route of the Missouri River from Riverdale southward was established during Late Wisconsinan time. Large erosion surfaces were cut in the area southeast of Riverdale as the water flowed overland until a distinct trench was cut. When a trench was established it was rapidly cut to a depth of about 300 feet. In contrast to the 4- to 6-mile-wide, till-draped valley upstream from Riverdale, the trench south of Riverdale is only about 1½ miles wide in places and is free of glacial drift.

Somewhere east of Washburn the preglacial drainage was again blocked by ice in Late Wisconsinan time and was again diverted southward from near Washburn through the trench that had been cut earlier. The modern route of the Missouri River was thus finally established in Late Wisconsinan time.

Small valleys such as those of Douglas Creek and Turtle Creek also formed during this time, although some of them tend to follow older, drift-lined valleys. Modern drainage over McLean County is poorly developed, particularly in the areas covered by Late Wisconsinan drift.

Glacial Drift

On the preceding pages the Coleharbor Formation was described and the lithostratigraphic terminology necessary to characterize the formation was introduced. Each of the glacial drift units in McLean County is based on inferred geologic history or origin. For interpretive purposes, such inferential units are more useful than are lithostratigraphic untis, which are based on lithology.

Along the shore of Lake Sakakawea in McLean County, three glacial drifts are exposed in several places. The oldest of these, the Dead Man Drift, (named for Dead Man Coulee where it was first observed) was deposited by pre-Wisconsinan (?) ice. The till of the Dead Man Drift is similar to till found in eastern North Dakota in Minuteman Missile site excavations. The presence of well-developed erosion surfaces, buried oxidized zones, and buried soil profiles on top of these tills suggests that they are pre-Wisconsinan in age. Pre-Wisconsinan (?) drift has also been tentatively identified by Clayton (1970) in Dunn County and in an area to the southeast of there (Fig. 13). This, the Dunn Drift, consists mainly of surface boulders. The Dead Man Drift of McLean County is overlain by fluvial sediment and by a second drift, referred to here as the Mercer Drift because it is widely exposed in Mercer County to the southwest of McLean County. The Mercer Drift has many of the same characteristics as the Dead Man Drift and is also considered to be of probable pre-Wisconsinan age. Leonard (1916) discussed what he considered to be pre-Wisconsinan till in western North Dakota. He apparently dealt collectively with the two lower tills exposed along Lake Sakakawea and the boulders discussed by Clayton (1970).

Glacial drift with characteristics similar to the Napoleon Drift of Logan and McIntosh Counties (Clayton, 1962) overlies the Mercer Drift in the Lake Sakakawea exposures of McLean County. The Napoleon Drift was tentatively dated as Early Wisconsinan (?) by Clayton. It is exposed over a broad area of west central North Dakota (Fig. 13). The Lostwood Drift (named for Lostwood Lake in Mountrail County where it is well exposed) is the youngest glacial drift in McLean County. It covers much of eastern and northern North Dakota where it has been studied in considerable detail and broken down into minor components.

Pre-Wisconsinan (?) Drift

Dead Man Drift--The pre-Wisconsinan (?) Dead Man Drift is well

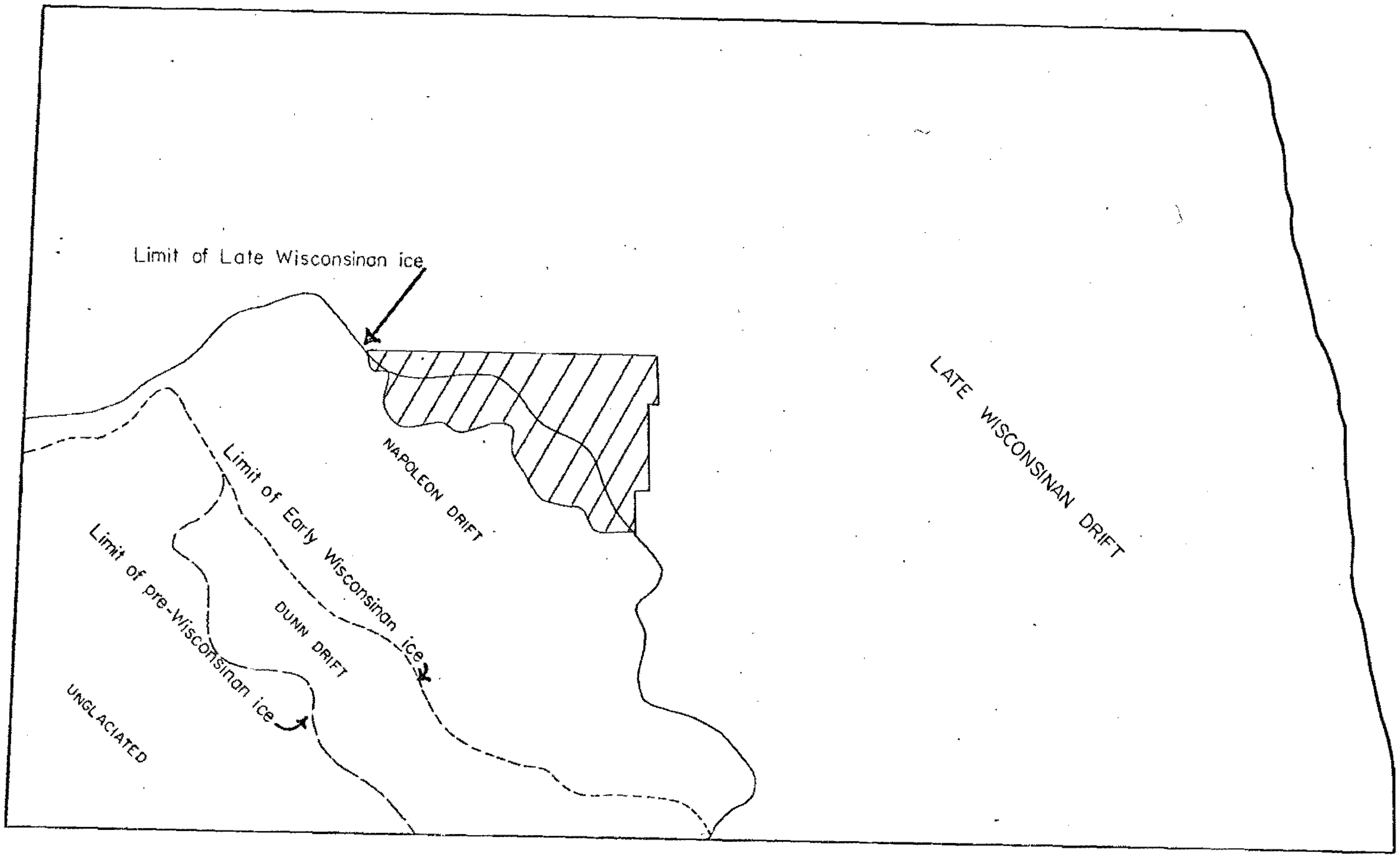


Figure 13. Map of North Dakota showing maximum extent of pre-Wisconsinan, Early Wisconsinan, and Late Wisconsinan glaciers. Areas covered by various aged drifts are shown. Shaded area is McLean County.

exposed along the shore of Lake Sakakawea in Secs. 14, 15, 22, 23, 24, and 27, T. 147 N., R. 84 W. It was also observed in the NE¼, SE¼, Sec. 21, T. 144 N., R. 83 W., on the north side of the Missouri River Trench. Its lower contact is submerged in most places, but it overlies bedrock in one exposure in Sec. 27, T. 147 N., R. 84 W.

The Dead Man Drift consists of at least two distinct facies. The lowermost of these consists of 5 to 10 feet of iron oxide-stained and poorly cemented gravel that grades to bedded silt in places and occurs in what appears to be a channel cut into the bedrock (Sec. 27, T. 147 N., R. 84 W.). It was not possible to determine the exact relationship between the silt deposit and the gravel. The gravel is a mixed assemblage of western lithologic types (quartz, chert, chalcedony, agate, and scoria) and glacially transported types (carbonate, granite, and varied metamorphic rock types).

The upper facies of the Dead Man Drift is mainly a silty to clayey till, 20 to 30 feet thick, that is weathered in most places to yellowish buff with irregular gray mottling. In a few deep wave cuts the till is unoxidized at 15 to 20 feet below its upper surface. The oxidized-unoxidized boundary is very irregular. The till has conspicuous straight and irregular joints that have closely associated heavy accumulations of iron and manganese oxides.

The till of the Dead Man Drift is harder and more compact than nearby overlying drifts. It is almost lithified in places; commonly fractures through the drift cut across and through the contained pebbles. Fresh fracture faces of till make single surfaces of a conglomerate. Most pebbles in the till are sound, but some of the igneous pebbles are rotted to shells. Vertical cliffs and horizontal ledges are common in exposures of the Dead Man till (Fig. 14). Overlying drifts have been washed away by waves leaving a clean surface either on the more resistant Dead Man till or the gravel conglomerate of the overlying lower facies of the Mercer Drift.

The Dead Man till contains some sandy lenses as much as 2 feet across, but generally it is a uniform, pebbly, silty clay. It contains abundant chips, grains, and chunks of lignite up to several inches in diameter. Large metamorphic and carbonate boulders, 15 feet or more in diameter, are common in the till. Many of them have grooves and striations. In places, large chunks of bedded silt occur within the till (Fig. 15). Without exception, the bedding is distorted. These silt masses were apparently picked up from a lake deposit and transported to their present location by the glacier that deposited the Dead Man Drift. It is possible the silt is the lowermost facies of the Dead Man Drift.

The upper surface of the Dead Man till is today being exhumed by wave action of Lake Sakakawea. In places, pieces of the till that have broken away from the cliffs are being worn to rounded cobbles (Fig. 16). In a few places, the upper few feet of the Dead Man till is a paleosol with caliche accumulations on ped surfaces (Figs. 17 and 18). The A horizon is absent and, if it ever existed, it was apparently eroded away before the overlying gravel was deposited.

Mercer Drift--The Mercer Drift overlies the till of the Dead Man Drift and consists of three facies, a lower fluvial deposit, a middle till deposit, and an upper fluvial deposit. The Mercer Drift is exposed in most of the same areas as the Dead Man Drift in McLean County, but it is widely exposed southwest of the Missouri River Trench in Mercer County.

Figure 14. Nearly vertical exposure of the Dead Man till showing wave-weathered joint faces.

Figure 15. Inclusion of banded silts (lake sediments) in the Dead Man till. Exposure is about 30 feet high.

Figure 16. Cobbles composed of the Dead Man till. In many places along Lake Sakakawea the beaches are covered by such rounded, water-worn pieces of till.

Figure 17. Caliche (?) accumulations near the top of the Dead Man till. This is apparently a paleosol.

Figure 18. Till (above shovel) of unit 3 in the description of the type section of the Coleharbor Formation. Black pieces are lignite and areas of white are fresh, carbonate-covered joint faces. Light area on the right below the shovel is silt (unit 2) and the area below and to the left of the shovel is a sandy gravel that was reworked when it was overridden by a glacier.

In all exposures in McLean County, it is separated from the overlying Early Wisconsinan drift by a sharp erosional contact. Its lower contact with the till of the Dead Man Drift is also sharp in most places (Fig. 6).

The lowermost facies of the Mercer Drift is a discontinuous sandy gravel that forms a sharp contact with the underlying till. It averages about 3 to 4 feet thick. The gravel is highly iron oxide-cemented in a few places and several chunks of the resulting conglomerate that have fallen into the reservoir are over 10 feet long. The iron oxide staining and cementation, such as is found in the gravel, is apparently a result of local ground water conditions. It has been suggested that iron staining and cementation are evidence of an unusually old deposit, but similar conditions have been observed in gravels of Late Wisconsinan age in Pembina County, North Dakota.

The iron oxide-cemented gravel is apparently equivalent to gravel that has been informally called the Four Bears Conglomerate (Clayton, in preparation). The Four Bears Conglomerate is best exposed in the Sakakawea shore bluffs 1 mile northwest of the Four Bears Bridge in Mountrail County, North Dakota.

The middle facies of the Mercer Drift is a brownish gray, sandy, pebbly till with a few chips of lignite and pockets of reddish brown, finely divided limonite. It has strong vertical jointing that results in almost vertical cliffs (Fig. 19). The Mercer till is about 25 feet thick, and, when viewed from a distance, it has a distinctive overall grayish aspect that makes it easy to distinguish from the underlying Dead Man Drift and the overlying Napoleon Drift. The till is partially oxidized throughout its thickness.

In some areas, the Mercer till contains abundant inclusions of sand

Figure 19. Contact between till and fluvial facies of the Mercer drift. Sand is loose and washes out easily leaving overhanging cliffs of Mercer till that tend to break off as large chunks and fall into the reservoir.

and gravel. As mentioned above, the underlying gravel is iron oxide-cemented in some locations where it is in place, but none of the inclusions that was found within the Mercer till was cemented. If the inclusions consist of the same sand and gravel as the underlying materials, it is likely that the cementing occurred after the gravel was buried beneath the Mercer till.

The gravel that overlies the Mercer till is up to 5 feet thick, sandy, cross-bedded in some areas, and has some iron oxide staining near the base. It is discontinuous and looks like stream sediment that was deposited in a channel that was eroded into the surface of the till. If this is so, the gravel could be as old as the Mercer till or as young as the overlying Napoleon till.

Early Wisconsinan Drift

Napoleon Drift--Napoleon Drift of probable Early Wisconsinan age, covers a wide area of southern and western McLean County (Fig. 20). It is bounded on the north and east by younger drift. The Napoleon Drift averages about 15 feet thick over western McLean County to about 25 feet thick in the southern part of the county. It is probably considerably thicker in some of the buried trenches, but it is not known whether the glacial sand and silt it overlies in these trenches is part of the Napoleon Drift or older drifts. Over most of western McLean County, the Napoleon Drift has little or no morainic topography, but rather it consists of a thin layer of till with almost completely integrated drainage. In the southern part of the county, subdued morainic topography is developed on the Napoleon Drift in places, and only partially integrated drainage exists. These areas are subdued dead-ice moraine and ground moraine.

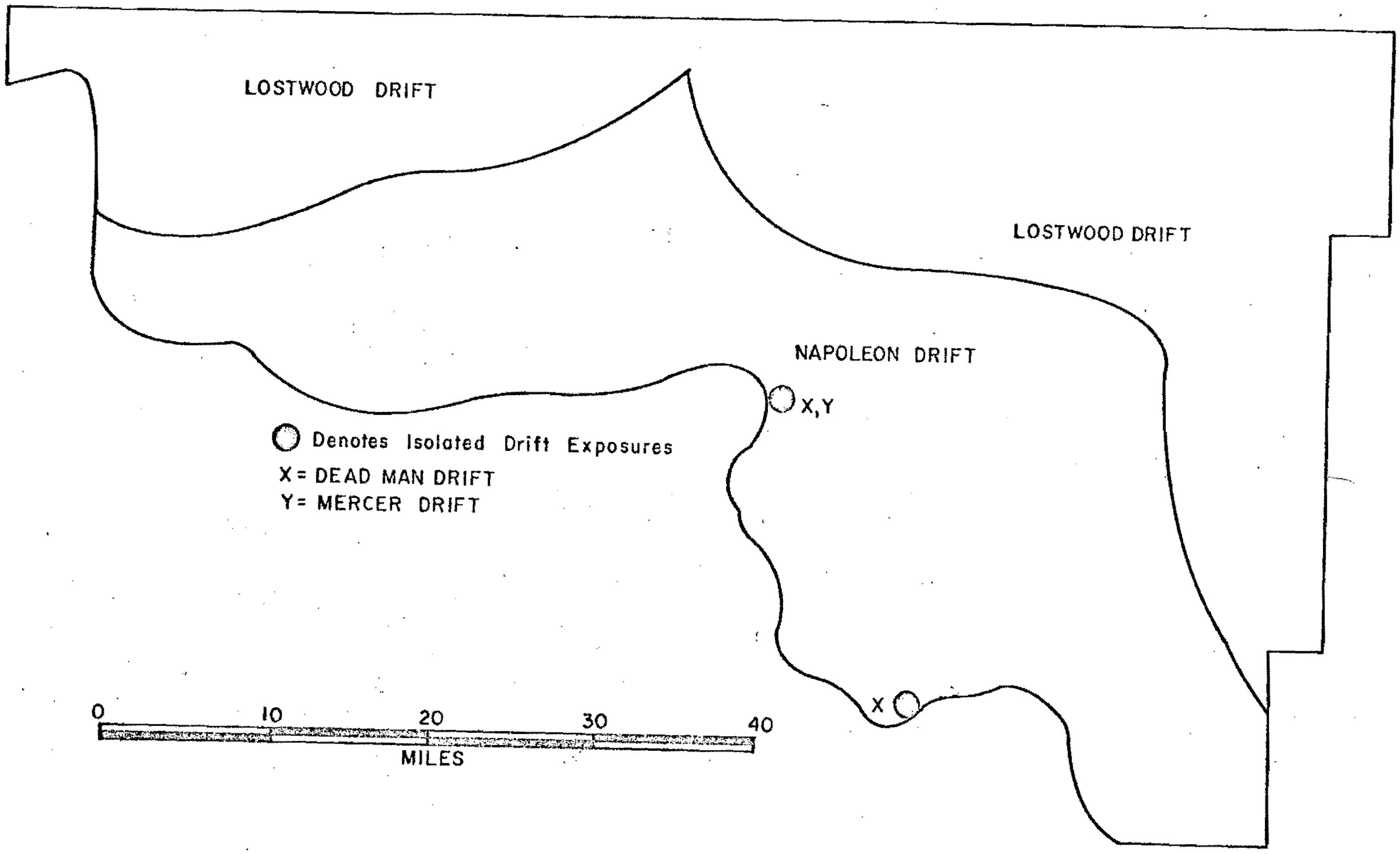


Figure 20. Map of McLean County showing areas of various drifts.

Till is the only sedimentary type in nearly all the surface exposures of Napoleon Drift in McLean County. Small lenses of sand and gravel were seen in the till, but they are of limited extent. In general, the till of the Napoleon Drift is silty to sandy but still rather cohesive. In all surface exposures, it is oxidized to shades of yellowish brown to dusky yellow. The till is lignitic, although lignite particles tend to be smaller than those of the Dead Man Drift. Particles of limestone, shale, and granite are common. These range from highly weathered shells to unweathered pebbles and cobbles. In general, the Napoleon till is not significantly different than most North Dakota till.

The thickness of weathered sediments penetrated in some test holes spudded in Napoleon till is unusual. As much as 136 feet of continuous oxidized section consisting of till, sand, and silty clays occurred in test hole 2834 (Sec. 29, T. 148 N., R. 85 W.). In other test holes, an interval of unoxidized sediment separates the surficial oxidized till from a second oxidized sediment, commonly till. It seems likely that one or more drifts of pre-Wisconsinan age were penetrated in these test holes.

The Napoleon Drift has not been distinguished lithologically in McLean County from the adjacent Lostwood Drift. It is, however, easily distinguished topographically because the end moraines and the edge of the dead-ice moraine of the Lostwood Drift overlie and truncate it. The resulting boundary on the Napoleon Drift is readily apparent on air photos and in the field.

Late Wisconsinan Drift

Lostwood Drift--Late Wisconsinan Lostwood Drift covers the northern and eastern parts of McLean County (Fig. 20) but it is generally difficult to determine its thickness, because it is lithologically indistinguishable from the underlying older drifts. Presumably it overlies Early Wisconsinan Napoleon Drift in most places, and in western McLean County the apparent contact is marked by a weathered zone on top of the Napoleon Drift in nine test holes. In these holes, the overlying Lostwood Drift averages 33 feet thick. In the eastern part of the county, very few test holes penetrate buried, weathered drift, so it was impossible to determine the thickness of the Lostwood Drift there.

The Lostwood Drift of McLean County can be subdivided into three areas with differing topographic expressions. In the western part of the county, the Blue Mountain End Moraine marks the southern edge of the Lostwood Drift. Dead-ice moraine features of rather low relief are apparent on air photos in the area north of the Blue Mountain End Moraine. Relief north of the end moraine is more subdued than over most of the area of Lostwood Drift in other parts of the county.

In eastern McLean County the Lostwood Drift is characterized by uneroded morainic topography with abundant dead-ice features. No prominent end moraines occur in eastern McLean County, but the boundary between Lostwood and Napoleon Drift is easily identified by the change from integrated drainage of Napoleon sheet moraine to nonintegrated drainage of Lostwood dead-ice moraine. In extreme northeastern McLean County, the Lostwood Drift is characterized by deeply eroded morainic topography on and adjacent to the Missouri Escarpment. This grades to relatively uneroded morainic topography on the Drift Prairie to the northeast.

In most places the lithology of the Lostwood Drift is essentially similar to that of the underlying Napoleon Drift. The till is generally silty to sandy and slightly cohesive with abundant lignite chips. It is commonly oxidized in exposures to shades of yellowish brown. Most of the surficial gravel and sand in McLean County (Pl. 1) is associated with the Lostwood Drift. It is commonly a poorly sorted mixture of sand and angular to subangular gravel composed mainly of carbonate and chips of shale and lignite. Lake silt and sand that occurs throughout the area is associated mainly with elevated lake plains formed only in areas of dead-ice moraine. In extreme northeastern McLean County, the Lostwood Drift is unusual in that the tills contain large amounts of sand and gravel. In exposure, it is easy to identify it as till, but samples taken by hand auger are commonly indistinguishable from outwash deposits. In Sheridan County to the east, lineations can be seen on a gravel outwash surface indicating that the outwash was overridden by a glacier. This probably occurred in northeastern McLean County also, resulting in a till that is composed almost entirely of reworked fluvial sediment.

The Late Wisconsinan age of the Lostwood Drift has been verified by numerous radiocarbon dates. Most of the Lostwood Drift in eastern McLean County was deposited from stagnant ice that may have taken 2,000 years to melt. Actively moving glaciers were probably present on the Missouri Coteau about 12,500 years ago (Clayton, 1967). Radiocarbon dates of materials from Lostwood Drift in North Dakota range from 9,000 B. P. (W-1019) to 11,070 B. P. (W-956) but these are from landforms deposited from stagnant ice. Materials taken from drift equivalent to Lostwood Drift that have been dated in South Dakota range from 12,050 B. P. (W-1189) to 12,760 B. P. (Y-595).

Pettyjohn (1967) considers the Lostwood Drift of western McLean and southwest Ward Counties (he refers to it as the Blue Mountain Drift) to be of Early Wisconsinan age. This is unlikely in view of the fact that stagnation features present on the Lostwood Drift form an interlocking pattern with similar stagnation features all the way to the Missouri Escarpment. An interlocking pattern could result only if a continuous sheet of stagnant ice covered the Missouri Coteau and melted everywhere over that area at about the same time. Pettyjohn states that the Blue Mountain Drift is oxidized to an average depth of 26 feet and that he has traced this oxidized zone nearly 40 miles north and more than 30 miles east of the Blue Mountain End Moraine in Ward County. However, it is likely that he was actually drilling into the weathered zone of the Napoleon Drift; certainly there is no reason to believe it is necessarily on the Blue Mountain Drift. The unusually thick oxidized zone (44 feet) on the Blue Mountain Drift of southwestern Ward County is probably a composite of weathered Blue Mountain Drift lying on weathered Napoleon Drift.

The total oxidized zone in areas covered by Lostwood Drift in western McLean County averages about 35 feet thick. In view of the fact that where it could be identified with reasonable certainty the Lostwood Drift itself averages only 33 feet thick in this area (based on 9 test holes), part of this oxidized interval must be in Napoleon Drift. The two drifts are lithologically indistinguishable, so it is impossible to determine how much of the weathering has occurred since the Lostwood Drift was deposited. In eastern McLean County the oxidized zone on the Lostwood Drift averages about 21 feet thick.

Glacial History

Pre-Wisconsinan (?) Glacial History

Glaciers apparently advanced into McLean County at least twice prior to the Wisconsinan, depositing the Dead Man and Mercer Drifts. Stratigraphic relationships of the various facies of the Dead Man Drift suggest that an advancing glacier caused a proglacial lake to form in the Riverdale area in an east-trending river valley. As the glacier continued to advance, probably southwestward, it overrode the silt that had been deposited in the lake and deposited the silty Dead Man till. It is not known how far the ice that deposited the Dead Man Drift advanced. The boulders found at the surface beyond the limit of the Napoleon Drift in Dunn County may also be part of the Dead Man Drift.

The Dead Man Drift is unevenly oxidized, and its upper surface is an erosion surface that appears to have been cut into a well-developed soil zone. The paleosol on top of the till of the Dead Man Drift (Fig. 17) suggests a significant interglacial interval and, since the overlying Mercer Drift is also probably pre-Wisconsinan, the Dead Man Drift may be relatively old.

The gravel that rests on the Dead Man till is probably only slightly older than the underlying Mercer till. It may be proglacial outwash sediment laid down in front of an advancing glacier. The absence of lake sediment suggests that no proglacial lake formed when the gravel was deposited, perhaps indicating that the ice advanced from a northerly or northwesterly direction. However, this cannot be determined, as it is also possible that the east-trending preglacial drainage had been filled to such an extent with drift during the first advance that a basin for a lake no longer existed. Continued advance of the second glacier resulted in deposition of the Mercer till on the gravel. Again, it is now known how far this glacier advanced.

Early Wisconsinan (?) Glacial History

In Early Wisconsinan (?) time, perhaps 50,000 years ago, the Napoleon glacier advanced across North Dakota, until it covered all but the southwest corner of the state (Fig. 13). While the Napoleon glacier was at its maximum extent, a deep diversion trench was cut at the edge of the ice through Dunn, Mercer, and Morton Counties by runoff from an area that was comparable in size to that now drained by the upper Missouri River.

In McLean County, the Napoleon Drift, where it is not covered by younger Late Wisconsinan drift, consists of only a few tens of feet of till. In southwestern McLean County, the Napoleon Drift was deposited on a rolling surface that was mainly bedrock with only an occasional patch of pre-Wisconsinan Drift in low areas. Most of the pre-Wisconsinan drift had been eroded away by the time Napoleon ice advanced over the area. In the eastern and northern parts of the county, however, considerable pre-Wisconsinan drift probably remained when the Napoleon Drift was deposited. Numerous test holes in this area penetrated complex drift sections with several tills. Although it is impossible to correlate these buried tills with tills that are exposed farther southwest, it is likely some of them are pre-Wisconsinan in age.

Figure 21 is necessarily generalized because the actual position of the Napoleon ice margin at any given time, as it receded from the area, is unknown. End moraines may have existed in the area, but they have since been overridden by Late Wisconsinan ice and their positions are not known. It seems likely that by the time an approximation of the conditions portrayed in Figure 21 was reached, numerous meltwater diversion trenches, mainly in Mercer County, had been cut and, for the

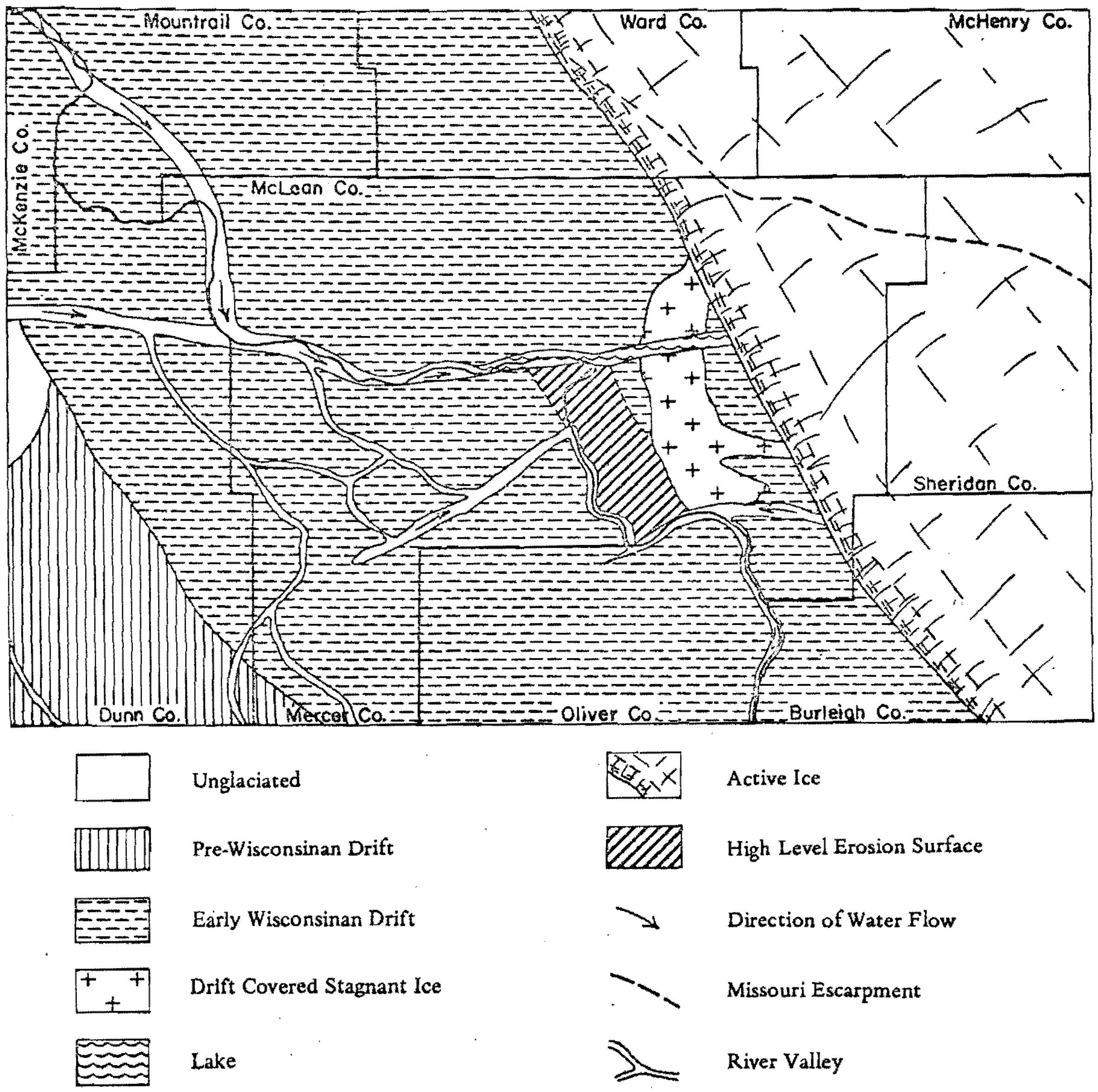


Figure 21. Receding Early Wisconsinan Napoleon ice.

most part, abandoned. A proglacial lake formed about this time in the preglacial valley that trended eastward through the Riverdale area, and water overflowed southward, cutting an erosion surface in the area southeast of Riverdale. A rather thick layer of Napoleon Drift was probably deposited on the Missouri Coteau. In fact, whenever glaciers advanced over the Missouri Escarpment, they probably picked up large volumes of material and subsequently deposited it on the Coteau. As the Napoleon glacier receded, it stagnated in places (Fig. 21) leaving areas of drift-covered ice that later melted, resulting in dead-ice moraine.

Late Wisconsinan Glacial History

In Late Wisconsinan time a glacier advanced across a large area of northern and eastern North Dakota. While it was at its maximum extent, two lobes of the glacier crossed McLean County. The westernmost of these (Fig. 22) deposited the Blue Mountain End Moraine (Pl. 1). This lobe apparently reached its maximum extent slightly earlier than did the lobe in eastern McLean County because it is overlapped by the eastern lobe. The Blue Mountain End Moraine was deposited against a bedrock high and the local slope was toward the ice, so little outwash was deposited ahead of the end moraine. Instead, relatively narrow valleys were formed that carried meltwater southward to a broad, east-trending valley that was later to carry the Missouri River. Figure 12 shows that much of the major pre-Late Wisconsinan drainage in the McLean County area coincided with what is the modern Missouri River Trench. During that part of Late Wisconsinan time portrayed on Figure 22, the glacier diverted the major drainage southwestward in Mountrail County. The resulting diversion trench now carries the Missouri River, and the

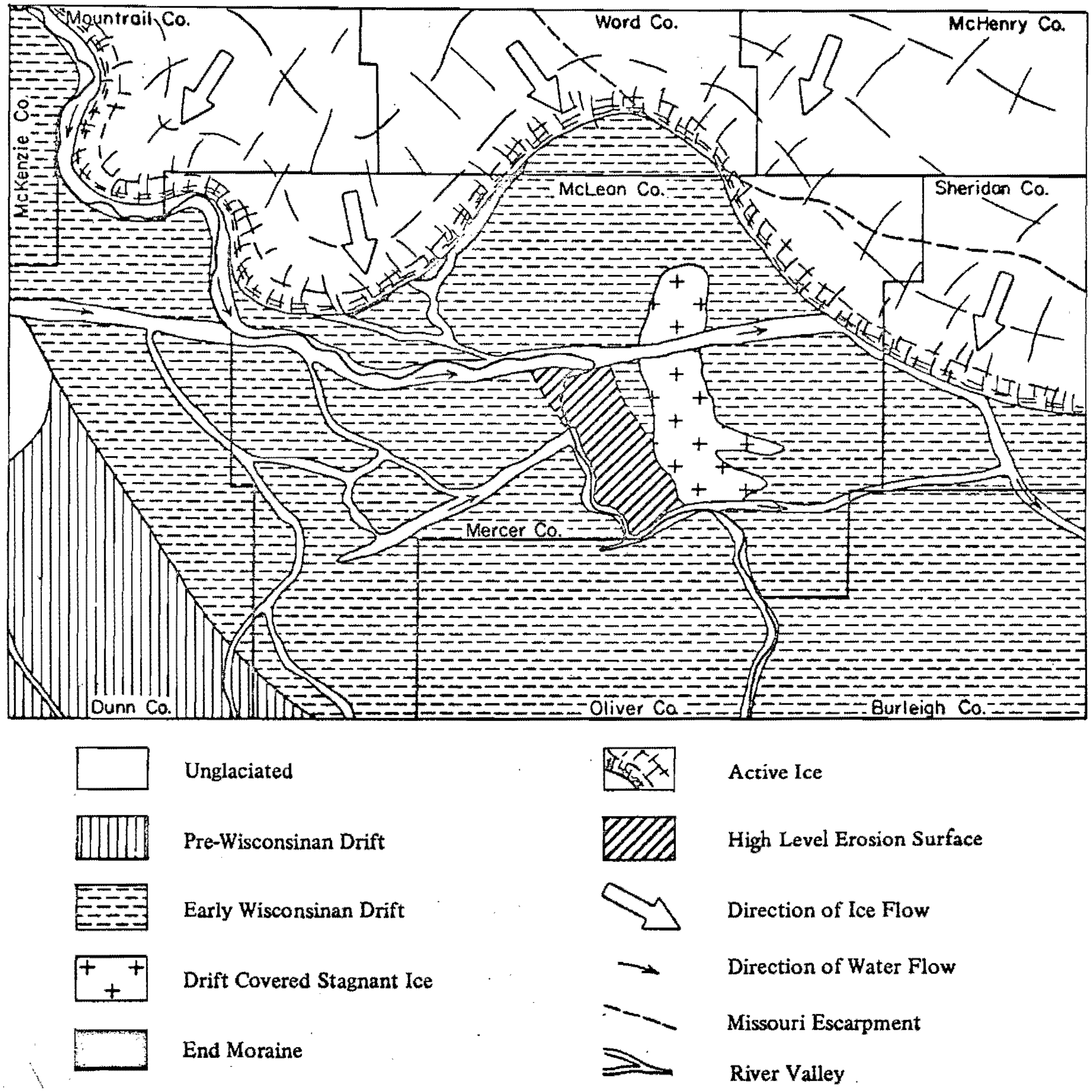


Figure 22. Deposition of the Blue Mountain End Moraine.

abandoned valley has become the Van Hook arm of Lake Sakakawea.

The glacier margin continued to advance in eastern McLean County until it reached the position shown on Figure 23. At the same time the ice margin was receding from the Blue Mountain position to the west. The west-flowing part of the glacier overrode the Blue Mountain End Moraine, but it seems unlikely that the resulting dead-ice moraine that truncates the end moraine is appreciably younger than is the end moraine. It has already been pointed out that disintegration features that are present on both ground moraine and low relief dead-ice moraine behind the Blue Mountain End Moraine in Ward County form continuous chains with similar disintegration features to the northeast in high relief dead-ice moraine. This high relief dead-ice moraine was deposited from the northeast. Therefore, a continuous area of stagnant ice must have existed throughout the area on both sides of the line of truncation. If there had been a significant time lapse between the deposition of the materials on either side of the line of truncation, the stagnant ice to the southwest would have melted, and no interfingering of disintegration features would have been possible.

When the ice margin receded from the position shown on figure 23, large areas of drift-covered stagnant ice were left behind. The active ice margin tended to become lobate as the glacier thinned and receded, and several small loop-shaped segments of recessional moraine were deposited, particularly in Sheridan County. Meltwater flowing from the glacier deposited thick sequences of gravel in eastern McLean County and southern Sheridan County. Much of this gravel was deposited on top of stagnant ice and later collapsed when the underlying ice melted. In the Turtle Lake area, broad areas of glacial outwash occur. The gravel

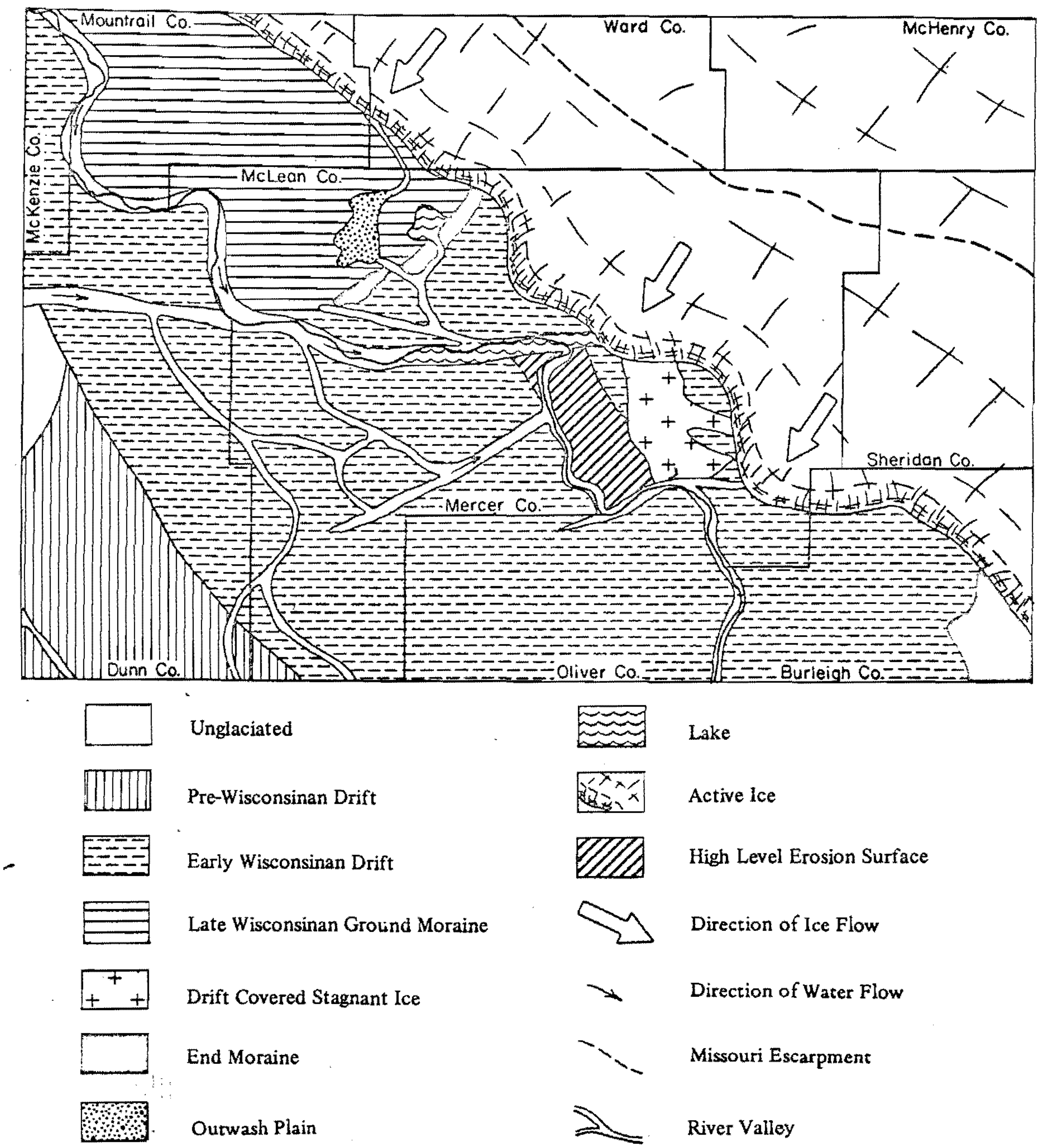


Figure 23. Maximum extent of the Late Wisconsinan ice in eastern McLean County.

occurs at two levels, the upper of which is slightly collapsed and the lower of which is flat. Apparently, stagnant ice was thin in the area. The first episode of gravel deposition was on the thin stagnant ice, but the second apparently occurred after the stagnant ice had melted as evidenced by the well defined scarp separating the lower, flat gravel deposits from the upper pitted deposits.

By the time the ice margin had receded to the position shown on Figure 24, the modern course of the Missouri River was firmly established along the McLean County border. The diversion trenches southwest of the river were all abandoned and probably already partly filled with slopewash sediment.

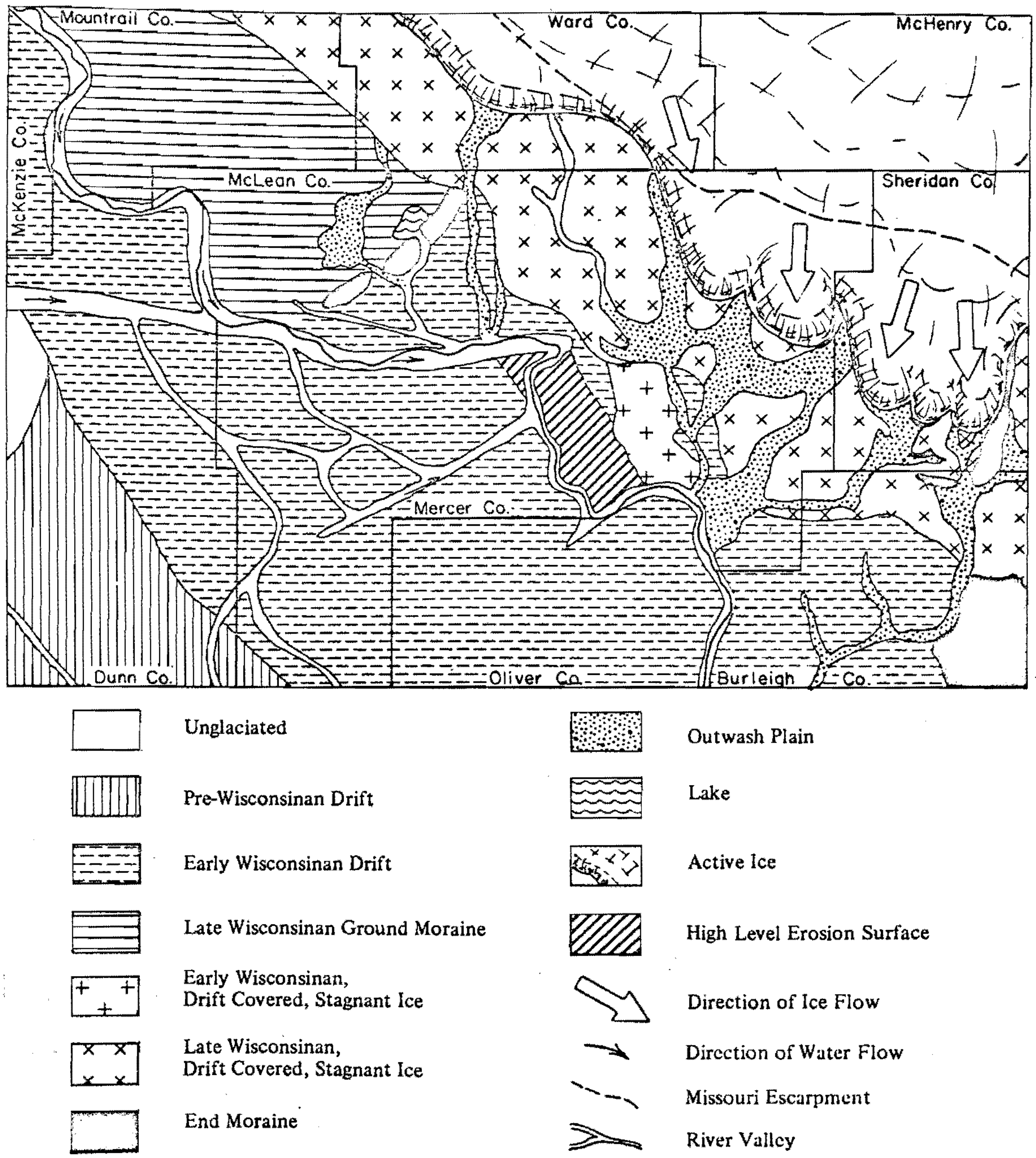


Figure 24. Withdrawal of the active ice margin from McLean County.

ECONOMIC GEOLOGY

The total value of mineral production in McLean County in 1967, the last year for which figures are available, was about $700,000. Sand and gravel accounted for most of this amount.

Sand and Gravel

Sand and gravel occurs on terraces of the Missouri River Trench downstream from Garrison Dam, in outwash deposits in the Turtle Lake area, on valley terraces in the Ruso area, and in numerous ice contact deposits throughout the county.

Lignite

Lignite occurs in the Tongue River and Sentinel Butte Formations of McLean County. Brant (1953) lists seven major lignite beds in the county. He estimates a total reserve of over 16 billion tons, but this figure is probably high because some of Brant's lignite beds probably correlate with one another. The total recoverable reserves are much lower than this, as strip mining techniques that are used to mine lignite are limited to areas where overburden is less than about 100 feet thick. Stripping rations should not exceed about 7 to 1 (for example, seventy feet of overburden for a 10-foot-thick coal seam).

Production of lignite in McLean County was 18,384 short tons from July 1, 1969 to June 30, 1970 from mines of the Underwood Coal Corporation, Inc., Underwood, and the B & W Coal, Inc., Garrison. The total value of lignite production during the same period was $28,606.

Clinker

McLean County has a minor amount of clinker ("scoria"), a material formed when burning lignite beds bake the overlying sediments. Clinker is used locally for road surfacing material.

Riprap and Building Stone

Abundant glacial boulders found throughout McLean County may be used as riprap. Riprap and building stone can also be obtained from the Tongue River and Sentinel Butte Formations, which contain resistant beds of sandstone.

Hydrocarbons

Sixteen exploratory petroleum tests had been drilled in McLean County as of January 1, 1971, but no production has yet resulted. Interest continues in the area because of the presence of the Newcastle and other Cretaceous sands that underlie the area. The Paleozoic formations that produce oil elsewhere in North Dakota have high porosity in McLean County. The many possibilities for stratigraphic and structural traps should do much to promote exploration in the area.

REFERENCES CITED

American Commission on Stratigraphic Nomenclature, 1961, Code of stratigraphic nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 645-665.

Bluemle, J. P., 1967, Geology and ground water resources of Traill County, North Dakota, pt. 1, geology: North Dakota Geol. Survey Bull. 49, 34 p.

Brant, R. A., 1953, Lignite resources of North Dakota: U. S. Geol. Survey Circ. 226, 78 p.

Carlson, C. G., and Anderson, S. B., 1965, Sedimentary and tectonic history of North Dakota part of Williston Basin: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 1833-1846.

Chamberlain, T. C., 1883, Terminal moraines of the second glacial epoch: U. S. Geol. Survey, 3rd. Ann. Rept., p. 291-402.

Christiansen, E. A., 1967, A thin till in west-central Saskatchewan, Canada: Can. Jour. of Earth Science, v. 5, p. 329-336.

______, 1968, Pleistocene stratigraphy of the Saskatoon area, Saskatchewan, Canada: Can. Jour. of Earth Science, v. 5, p. 1167-1173.

Clayton, Lee, 1962, Glacial geology of Logan and McIntosh Counties, North Dakota: North Dakota Geol. Survey Bull. 37, 84 p.

______, 1966, Notes on Pleistocene stratigraphy of North Dakota: North Dakota Geol. Survey Rept. of Inv. 44, 25 p.

______, 1967, Stagnant-glacier features of the Missouri Coteau in North Dakota: North Dakota Geol. Survey Misc. Series 30, p. 25-46.

______, 1970, Geologic map of Dunn County, North Dakota: North Dakota Geol. Survey Misc. Map 11.

______, and Moran, S. R., 1971, Late Quaternary loess in central North Dakota: Geol. Soc. America (abstract), Program, Fifth annual meeting, North-Central Section, p. 256.

Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U. S. Geol. Survey Misc. Geol. Inv. Map I-331.

Easton, G. B., 1966, Annual Report, July 1, 1964-June 30, 1966: North Dakota Coal Mine Inspection Department, 19 p.

Holmes, C. D., 1947, Kames, Am. Jour. Sci., v. 245, p. 248.

Krumbein, W. C., and Sloss, L. L., 1963, Stratigraphy and sedimentation: San Francisco, W. H. Freeman and Company, 660 p.

Kume, Jack, 1964, Sheet moraine in Burleigh County, North Dakota: North Dakota Acad. Sci., v. 18, p. 162-166.

______, and Hansen, D. E., 1965, Geology and ground water resources of Burleigh County, North Dakota, pt. 1, geology: North Dakota Geol. Survey Bull. 42, 111 p.

Lemke, R. W., 1960, Geology of the Souris River area, North Dakota: U. S. Geol. Survey Prof. Paper 325, 138 p.

______, and Colton, R. B., 1958, Summary of Pleistocene geology of North Dakota, in Mid-Western Friends of the Pleistocene Guidebook, 9th. Ann. Field Conf.: North Dakota Geol. Survey Misc. Ser. 10, p. 41-57.

______, Laird, W. M., Tipton, M. J., and Lindvall, R. M., 1965, Quaternary geology of northern Great Plains, in Wright, H. H., Jr., and Frey, D. G., The Quaternary of the United States: Princeton, Princeton University Press, p. 15-27.

Leonard, A. G., 1916, The pre-Wisconsin drift of North Dakota: Jour. of Geology, v. 24, p. 521-532.

Pettyjohn, W. A., 1967, Multiple drift sheets in southwestern Ward County, North Dakota, in Glacial geology of the Missouri Coteau and adjacent areas: North Dakota Geol. Survey Misc. Series 30, p. 123-129.

Rau, J. L., Bakken, W. E., Chmelik, J. C., and Williams, B. J., 1962, Geology and ground water resources of Kidder County, North Dakota, pt. 1, geology: North Dakota Geol. Survey Bull. 36, 70 p.

Sloss, L. L., 1963, Sequences in the cratonic interior of North America: Geol. Soc. America Bull., v. 74, p. 93-114.

Todd, J. E., 1896, The moraines of the Missouri Coteau and their attendant deposits: U. S. Geol. Survey Bull. 144, 71 p.

Townsend, R. C., and Jenke, A. L., 1951, The problem of the origin of the Max moraine of North Dakota and Canada: Am. Jour. Sci., v. 249, p. 842-858.

PLATE I

Geologic Map of McLean County, North Dakota

John P. Bluemle

This map shows both lithology and geomorphology. The various geologic formations are indicated by colors. Landforms are represented by red patterns. Deposits shown on this sheet are mapped where they reach three feet or more in thickness. Thinner deposits are not shown.

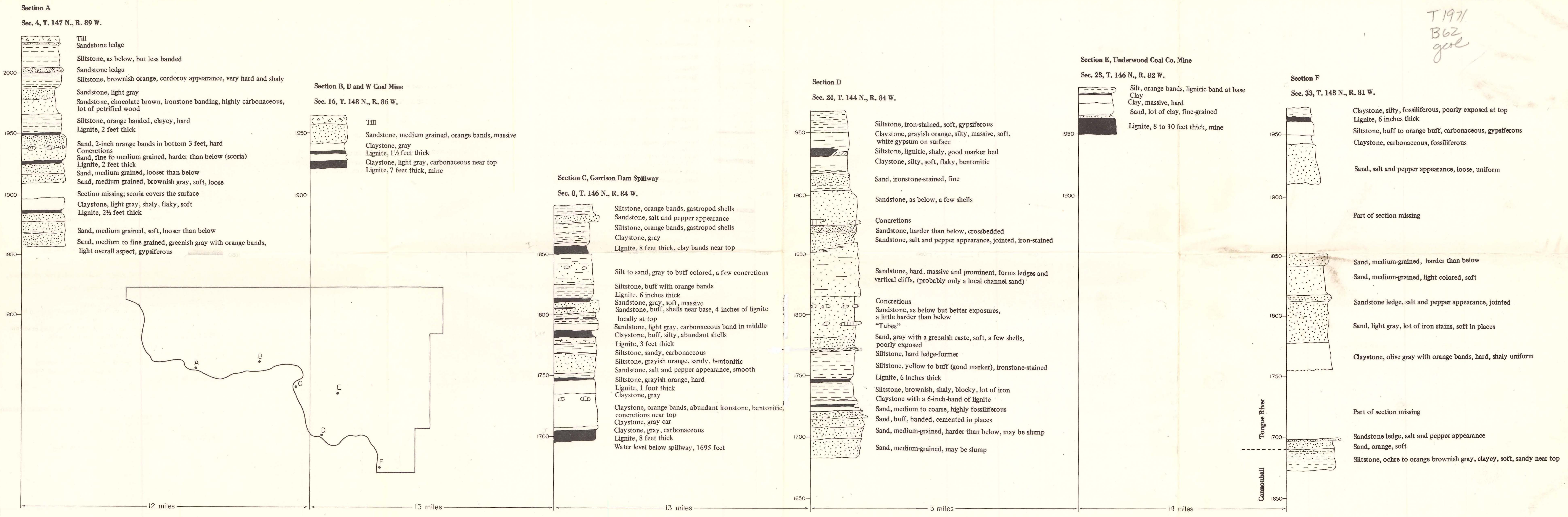
EXPLANATION

LITHOSTRATIGRAPHY

- **A — UNNAMED FORMATION**: Alluvial deposits of dark brown, gray or black silty clay, clayey silt, clay or sandy silt and some gravel; vague horizontal bedding; oxidized; bones, shells, and wood common. Also includes some slough deposits of soft, organic clay; bluish or greenish hues; vaguely bedded.
- **E — UNNAMED FORMATION**: Well-sorted eolian sands.
- **COLEHARBOR FORMATION**: Glacial deposits consisting of three main facies:
  - **Cb — Boulder-clay facies**: A relatively uniform nonbedded mixture of approximately equal parts sand, silt, and clay-sized materials along with small percentages of pebbles, cobbles, and boulders. Largely glacial till.
  - **Cg — Sand and gravel facies**: Sand, gravelly sand, sandy gravel, and some silty sand. Some cross-bedding; poor to medium sorting; rude horizontal bedding. A small fraction is material that was deposited by glacial meltwater (outwash) and most of the remainder is stream sediment deposited by water derived from local precipitation during and immediately following glaciation.
  - **Cc — Silt and clay facies**: Silty clay, clay, clayey silt; horizontal bedding; oxidized; shells common. Lake sediments.
- **S — SENTINEL BUTTE FORMATION**: Shale and sandstone, lignitic, calcareous, petrified wood common.
- **T — TONGUE RIVER FORMATION**: Shale and sandstone, lignitic, calcareous.
- **CB — CANNONBALL FORMATION**: Marine sands, sandstone, clays, and shale.

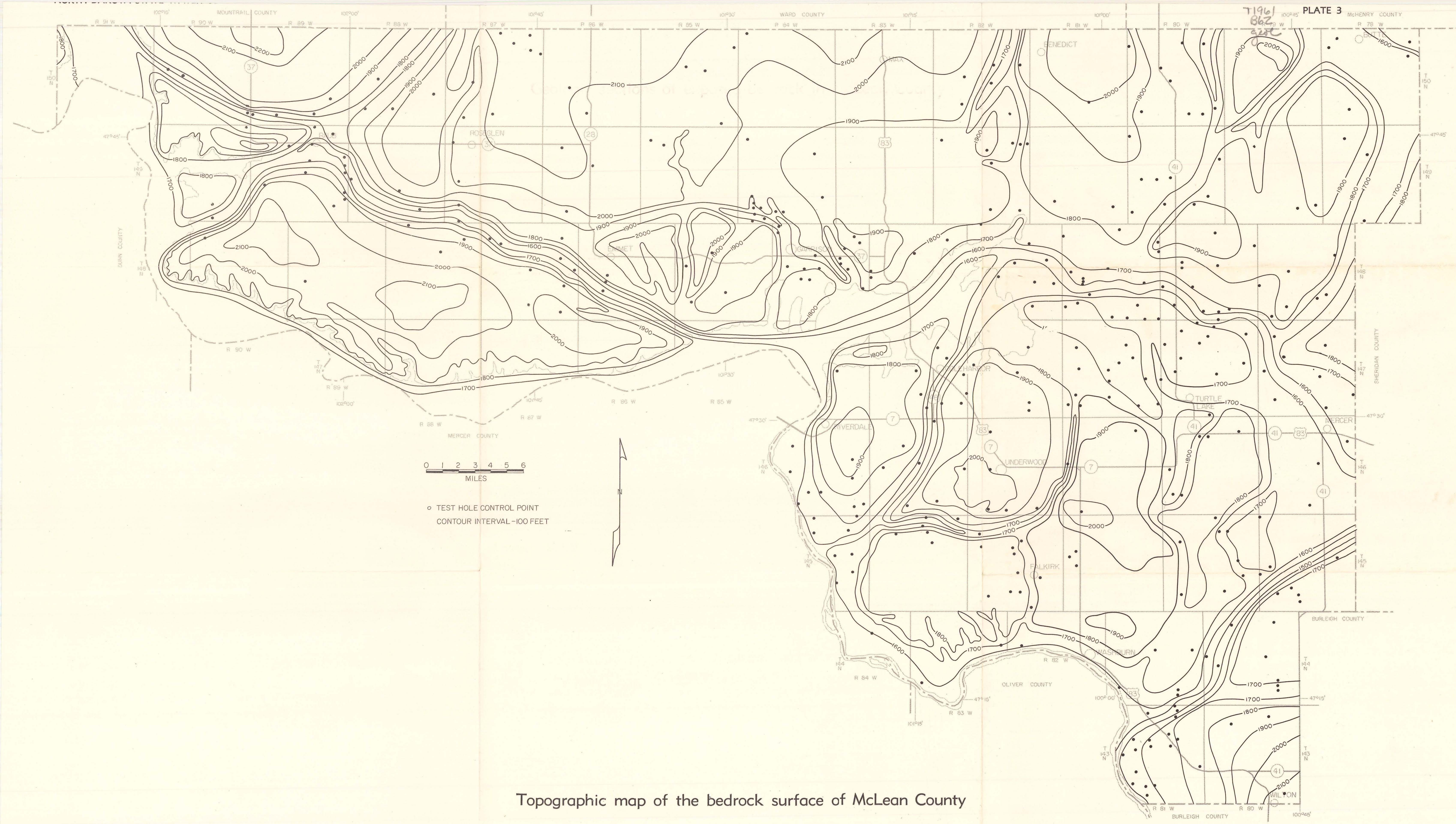
GEOMORPHOLOGY

- **DEAD-ICE MORAINE, High Relief**: Hummocky accumulation of glacial drift, chiefly boulder-clay lacking linear trends, with high constructional relief, numerous kettles, nonintegrated drainage, and ice-disintegration features.
- **Low relief**
- **END MORAINE**: A ridge-like accumulation of glacial drift, chiefly boulder-clay, with moderate local constructional relief and with an overall internal linear pattern.
- **GROUND MORAINE**: A gently undulating accumulation of glacial drift, chiefly boulder-clay, with low, local constructional relief.
- **SHEET MORAINE**: A veneer of glacial drift, chiefly boulder-clay, on bedrock; very low local constructional relief.
- **ALLUVIAL PLAIN**: Gently undulating to nearly flat accumulation of sand and gravel with some associated outwash; generally stratified.
- **COLLAPSED ALLUVIAL PLAIN**: Hummocky accumulation of sand and gravel with moderate to high local relief and numerous kettles. Bedding is commonly slumped and faulted.
- **LAKE PLAIN**: A level or gently undulating accumulation of lake sediments, chiefly silt and clay, generally stratified. Commonly elevated and rimmed in areas of dead-ice moraine.
- **STREAM-ERODED BEDROCK TOPOGRAPHY**: Areas of high local relief along the larger streams, particularly along the side of the Missouri River Trench, underlain by bedrock with scattered small areas of Coleharbor Formation. Postglacial stream erosion in these areas has resulted in rugged topography with badlands in places.
- **ALLUVIAL FLOODPLAIN**: Areas of relatively smooth land adjacent to streams, built chiefly of modern alluvium, and covered by water during times of flood.
- **SAND DUNES**: Eolian sand deposits characterized by dune topography. Includes sand blowouts.
- **ICE-CONTACT FEATURES** (E, K): Includes eskers, crevasse fillings and kames of widely differing size, shape, and extent. Composed of poorly sorted gravel and gravelly sand with lesser amounts of boulder-clay. Red K designates kame. Red E designates esker or crevasse filling.
- **PARTLY BURIED VALLEYS**: Sags that may reflect the presence of buried glacial meltwater trenches, preglacial valleys or pluvial trenches.
- **MELTWATER TRENCHES**: Trenches that carried glacial meltwater or runoff from pluvial precipitation. Modern stream erosion has modified these trenches in many instances.
- **TERRACES**: Terraces along the margins of meltwater trenches.
- **PEDIMENTS**: Flat surfaces with veneers of fluvial sediments that slope generally southeastward toward the Missouri River Trench; an erosional surface that lies on both bedrock and glacial drift.



Geologic sections of exposed bedrock in McLean County

PLATE 3



Topographic map of the bedrock surface of McLean County