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Stratigraphy and history of the Sakakawea Sequence, south-central North Dakota

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STRATIGRAPHY AND HISTORY OF THE SAKAKAWEA SEQUENCE, SOUTH-CENTRAL NORTH DAKOTA

by
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This Dissertation submitted by William B. Bickley, Jr. 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: Stratigraphy and History of the Sakakawea Sequence South-central North Dakota

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William B. Bickley, Jr.

July 5, 1972

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ABSTRACT

The Sakakawea Sequence (Pleistocene) in North Dakota contains six formations that make up the Coleharbor Group (Pleistocene). The Braddock Formation (Wisconsinan) is mainly glacial sediment. The Emmons Formation (late Wisconsinan) is mainly glacial sediment. The Four Bears Formation (Wisconsinan) is mainly either fluvial or lacustrine sediment. The Coteau Formation (Holocene) is mostly fluvial, colluvial, or slough sediment. The Denbigh Formation (Holocene) is mostly eolian sediment. The Oahe Formation (late Wisconsinan and Holocene) is mostly eolian sediment (loess). The Oahe Formation is divided into three members: the Mallard Island (late Wisconsinan), Aggie Brown (latest Wisconsinan to earliest Holocene), and Riverdale (middle and late Holocene) Members. During preglacial time major rivers flowed toward Hudson Bay. With the initiation of glaciation, ice blocked the rivers and forced them to flow southward.

During the Pleistocene at least four major glaciations occurred. The Dunn Glaciation was pre-Wisconsinan, the Verone Glaciation was post-Dunn and pre-Napoleon, the Napoleon Glaciation was early Wisconsinan (?), and the Lostwood Glaciation was late Wisconsinan.

Three phases (Cattail Creek, Zeeland, and Long Lake) are recognized within the Lostwood Glaciation. The Cattail Creek was an early advance of the Lostwood Glaciation. The Zeeland and Long Lake Phases

were later advances; they may have been contemporaneous.

Numerous tundra polygons indicate permafrost conditions existed at the beginning of the Lostwood Glaciation. Polygons occur on all but the youngest glacial surfaces (Zeeland and Long Lake).

Lakes Standing Rock and McKenzie were formed when the Lostwood ice dammed the Missouri River. Lake McKenzie was formed when ice of the Cattail Creek Phase blocked the flow of the Missouri River in the Strasburg Channel. Lake Standing Rock probably formed when ice blocked the Missouri River in north-central South Dakota.

In postglacial time, more detailed evidence allows reconstruction of the history of hillslope stability. Variations in hillslope stability are largely controlled by vegetation and runoff, which are controlled by precipitation and temperature. In cool, moist areas, like North Dakota, stable conditions occur when the climate is cooler and moister. Soil formation occurs during these times.

The following series of stable and unstable episodes are interpreted to have occurred in south-central North Dakota during late Wisconsinan and Holocene time. The McCarny Unstable Episode began with the deposition of the yellow loess of the Mallard Island Member of the Oahe Formation and continued until after deglaciation when a spruce woodland migrated into the area. The Leonard Stable Episode began about 12,000 to 11,500 B.P. with the formation of a red brown forest soil (Aggie Brown Member of the Oahe Formation). This soil continued to form until the climate warmed slightly about 10,000 B.P. Spruce woodland was replaced by prairie grass, and a prairie soil formed on top of the forest soil. The Wolf Creek Unstable Episode began about 8500 B.P. when the climate warmed again. Tall-grass prairie was replaced by short-grass prairie and hillslope stability decreased. Deposition of the gray loess of the Riverdale Member of the Oahe Formation began and continued for about 4000 years. During this unstable time, barchans formed where there was an adequate sand supply. The Thompson Stable Episode began about 4500 B.P. when the climate cooled. The Thompson Paleosol formed during that time. The Garrison Unstable Episode began during the late Holocene when the climate warmed again. Deposition of the gray loess of the Riverdale Member of the Oahe Formation occurred again during this time. The Jules Stable Episode began when the climate cooled again. Deposition of the Jules Paleosol occurred during that time. The cool climatic conditions continued until about 1929 when the "Dirty Thirties" Unstable Episode began. It lasted for about 10 years, after which the Mandan Episode began.

INTRODUCTION

GENERAL

Much of the surficial geology of North Dakota has been mapped during the last fifteen years. In the eastern two-thirds of the state, the surficial material is mostly of Pleistocene age. With the exception of the Coleharbor Formation (Bluemle, 1971a), no formal lithostratigraphic nomenclature exists in North Dakota for material of this age. Even though the same lithologic units are present at the surface in the same stratigraphic position over much of the state, there has been no real agreement among maps done at different times because there were no formal lithostratigraphic units to standardize map units. Many of the maps were done by workers long since departed, so there was no chance for communication among the different workers involved in making the maps. Many times lithostratigraphic units were not used at all; instead, interpretive units were used, making the maps unusable for certain purposes.

PURPOSE

The primary purpose of this report is to formalize lithostratigraphic units for the Pleistocene of North Dakota and to test these units by mapping the geology of Emmons County, using them.

The secondary purpose of this report is to interpret the late Cenozoic history of south-central North Dakota, with emphasis on Emmons

County.

LOCATION OF WORK

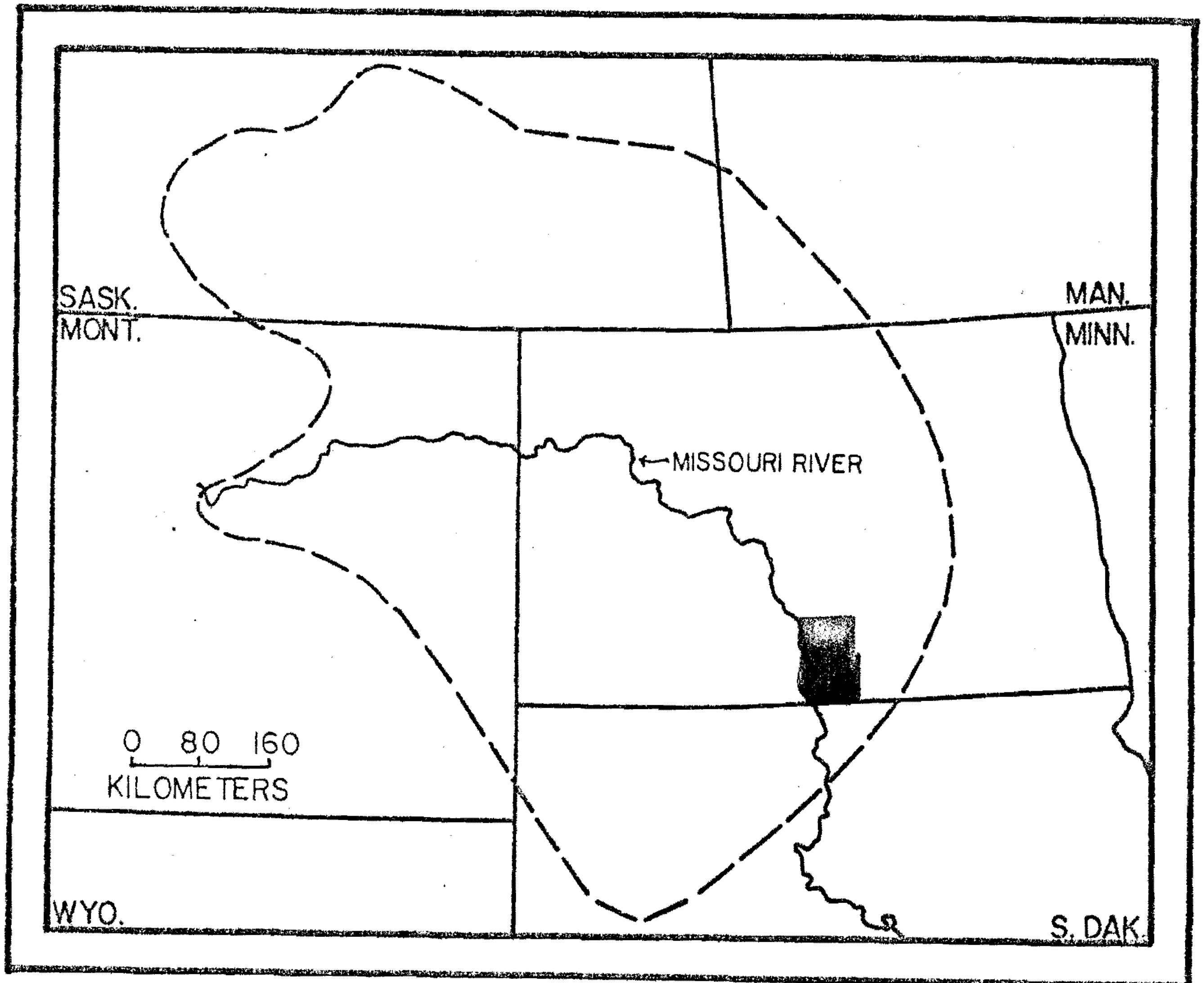
Most of the field work for this report was done in Emmons County, North Dakota. Emmons County contains about 1600 square miles (2650 square kilometers) in south-central North Dakota (Townships 129 to 136 North and Ranges 74 to 79 West). The county borders South Dakota, McIntosh, Logan, Kidder, Burleigh, Grant, and Sioux Counties. Emmons County lies on the southeastern flank of the Williston Basin (Figure 1), an intracratonic, structural, and sedimentary basin.

SEQUENCE APPROACH

Stratigraphic geology began in Europe in the eighteenth century. It was here that the relative time scale was established on the basis of sedimentation breaks in the rock record. As the time scale was used in North America, it became evident that the stratigraphic breaks in North America did not correspond to those of Europe. Major unconformities in North America generally did not occur at period boundaries; instead, more than one system generally occurred between the unconformities. If stratigraphic geology had begun in North America, these North American major unconformities would probably form the basis for the relative time scale.

These groups of rock bounded by interregional unconformities were called "sequences" by Sloss and others (1949). Sequences are defined as major lithostratigraphic units of rank high than megagroup. Each sequence contains rocks of diagnostic lithology or groups of lithologies and is bounded at the top and the bottom by a major intra-

Fig. 1.--Location of Emmons County (black area) within North Dakota and the Williston Basin.


SASK.
MONT.
MAN.
MINN.
MISSOURI RIVER
0 80 160
KILOMETERS
WYO.
S. DAK.

cratonic unconformity. Sloss (1963) recognized six sequences bounded by seven unconformities (the air-sediment interface being considered an unconformity). Wheeler (1965) defined two more sequences not recognized by Sloss. Wheeler split Sloss' Tippecanoe Sequence into the Tutelo and Creek Sequences, and he split the Kaskaskia Sequence into the Piankaska and Tamaroa Sequences. While Sloss' breakout is generally accepted and will be used in this report, there is evidence that Wheeler's sequences may have considerable validity, particularly the lower two, the Tutelo and Creek Sequences.

The sequence approach is a useful outline for any regional stratigraphic discussion involving the cratonic interior of North America. As the approach has become more widely known and its usefulness as a guide for regional stratigraphy has been recognized, its acceptance has begun to spread. An example of its increasingly widespread acceptance is the use of the sequence approach in the latest edition of Geologic Evolution of North America (Clark and Stearn, 1968). The reason for using this approach is that it ties large groups of similar lithologies together into more readily usable and practical, large, lithostratigraphic units. The sequence approach will form the stratigraphic basis for this report.

There are some problems involved with the sequence approach, particularly in the way a sequence is defined. Sloss (1966) says that it is implicit in the definition that each sequence represents a major cycle of marine transgression and regression. First, Article 4c of the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961) says that inferred geologic history plays no part in the definition of a lithostratigraphic unit. Secondly, the first problem ignored, the Tejas (?) Sequence does not represent a major cycle of marine transgression and regression on the craton, even though it does at the type area in the Gulf Coast of Texas.

Two problems exist with the Tejas (?) Sequence definition: (1) a major unconformity has been ignored and (2) two unrelated and contrasting lithologies occur above and below the unconformity. For these reasons the rocks of the Tejas (?) Sequence have been divided into two sequences; the upper one is defined in this report as the Sakakawea Sequence, while the lower one is retained at the Tejas (?) Sequence.

DESCRIPTIVE GEOLOGY

SUMMARY OF THE STRATIGRAPHY OF THE PRE-SAKAKAWEA SEQUENCES

Oil well records indicate that in Emmons County as much as 1880 meters of Phanerozoic sediment unconformity overlies the Precambrian igneous and metamorphic complex.

The stratigraphic column for Emmons County (Figure 2) and a subsurface cross section for Emmons County (Figure 3) serve as a guide for the following discussion.

Precambrian rocks

Three holes have been drilled into Precambrian rocks in Emmons County (Appendix II). Depth to the Precambrian in these holes ranges from 1785 to 1685 meters. The Precambrian rocks in one hole (North Dakota Geological Survey Well Number 23) have been identified as pink granite (Towse and Anderson, 1954).

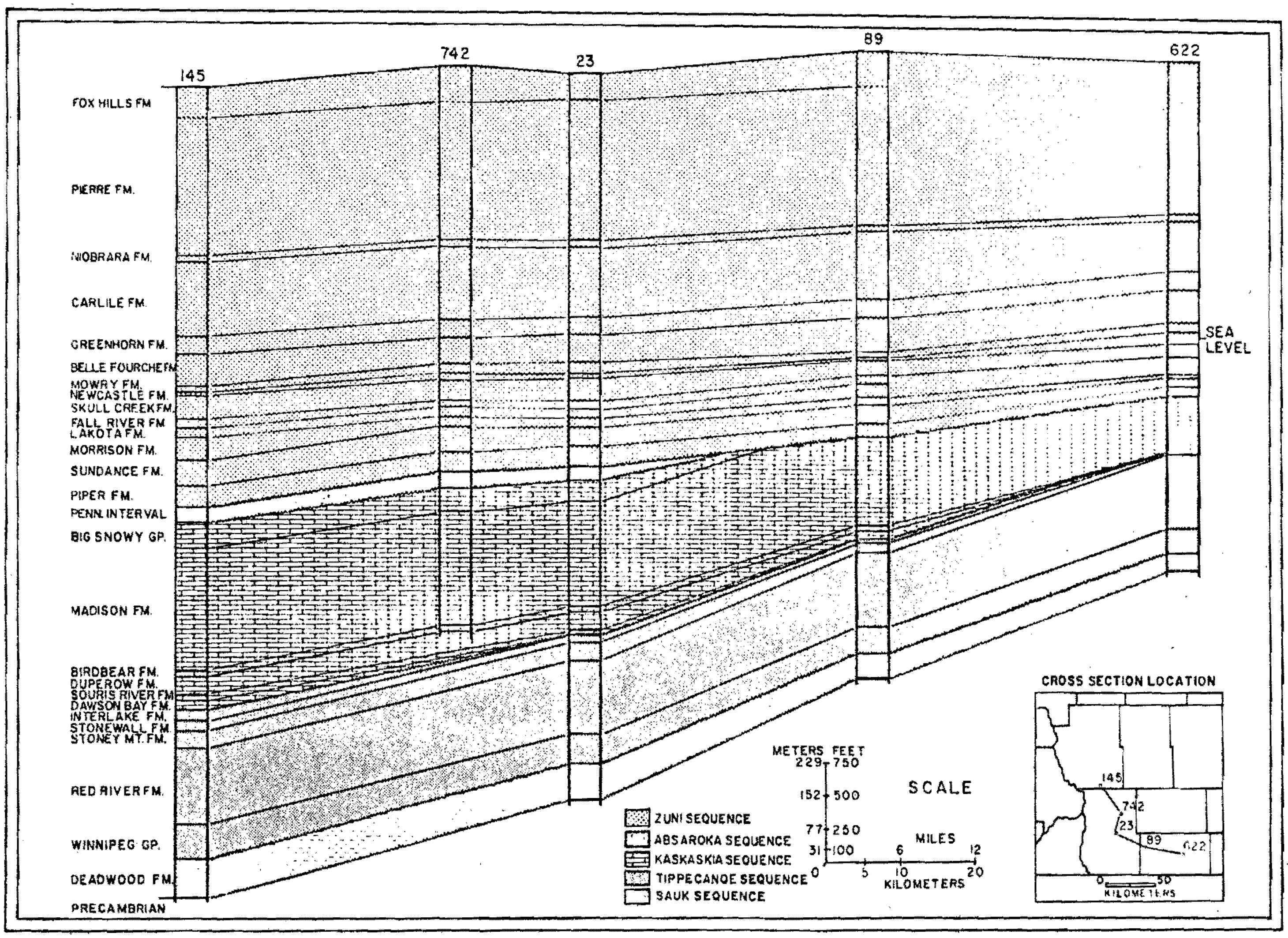
Sauk Sequence

The Sauk Sequence (Figures 2 and 3) in Emmons County consists of sandstone, shale, and limestone of the Deadwood Formation of Cambrian and Ordovician age. It rests unconformably on the Precambrian complex and is overlain unconformably by the Tippecanoe Sequence. Oil well records show the Deadwood Formation to be about 75 meters thick in central Emmons County. On an isopach map of the Deadwood Formation of the

Fig. 2.--Stratigraphic column for Emmons County, North Dakota.

AGE	UNIT NAME			DOMINATE LITHOLOGY
Pleistocene	Sakakawea Sequence	Coleharbor Group	Oahe Formation	Coarse silt
			Denbigh Formation	Well sorted, medium sand
			Coteau Formation	Organic, poorly sorted, gravelly, sandy, clayey silt
			Four Bears Formation	Non-organic sand and gravel and silt and clay
			Emmons Formation	Bouldery, pebbly, slightly sandy, silty clay
			Braddock Formation	Bouldery, pebbly, sandy, silty clay
Pliocene	Tejas ? Sequence	Flaxville Formation		Gravel containing cobbles of argillite and porphyry
Paleocene	Zuni Sequence	Cannonball Formation		Sandstone and shale
Cretaceous		Hell Creek Formation		Sandstone, siltstone, lignite
		Montana Group	Fox Hills Formation	Sandstone and shale
			Pierre Formation	Shale
			Niobrara Formation	Calcareous shale
		Colorado Group	Carlile Formation	Shale
			Greenhorn Formation	Calcareous shale
			Belle Fourche Formation	Shale
		Dakota Group	Mowry Formation	Shale
			Newcastle Formation	Sandstone
			Skull Creek Formation	Shale
			Fall River Formation	Sandstone and shale
			Lakota Formation	Sandstone and shale
Jurassic		Morrison Formation		Shale and clay
		Sundance Formation		Shale and sandstone
		Piper Formation		Shale and evaporite
Pennsylvanian	Absaroka Sequence	Alaska Bench Formation		Dolomite
		Tyler Formation		Sandstone and shale
		Amsden Formation		Limestone, shale, sandstone
Mississippian	Kaskaskia Sequence	Big Snowy Group	Undifferentiated	Limestone, shale, sandstone
		Madison Formation		Limestone and evaporite
Devonian		Birdbear Formation		Limestone
		Duperow Formation		Dolomite and limestone
		Souris River Formation		Dolomite and limestone
		Dawson Bay Formation		Dolomite and limestone
Silurian	Tippecanoe Sequence	Interlake Formation		Dolomite
Ordovician		Stonewall Formation		Dolomite and limestone
		Stony Mountain Formation		Limestone
		Red River Formation		Limestone and dolomite
		Winnipeg Group	Undifferentiated	Sandstone, shale, siltstone
Cambrian	Sauk Sequence	Deadwood Formation		Sandstone, shale, limestone
Precambrian				Granite

Fig. 3--Subsurface cross section across Emmons County, North Dakota.


145
742
23
89
622
FOX HILLS FM
PIERRE FM.
NIOBRARA FM.
CARLILE FM.
GREENHORN FM.
BELLE FOURCHE FM
MOWRY FM.
NEWCASTLE FM.
SKULL CREEK FM.
FALL RIVER FM
LAKOTA FM.
MORRISON FM.
SUNDANCE FM.
PIPER FM.
PENN. INTERVAL
BIG SNOWY GP.
MADISON FM.
BIRDBEAR FM.
DUPEROW FM.
SOURIS RIVER FM
DAWSON BAY FM.
INTERLAKE FM.
STONEWALL FM.
STONEY MT. FM.
RED RIVER FM.
WINNIPEG GP.
DEADWOOD FM.
PRECAMBRIAN
SEA LEVEL
ZUNI SEQUENCE
ABSAROKA SEQUENCE
KASKASKIA SEQUENCE
TIPPECANOE SEQUENCE
SAUK SEQUENCE
METERS FEET
229 750
152 500
77 250
31 100
0
SCALE
MILES
6 12
0 5 10 20
KILOMETERS
CROSS SECTION LOCATION
145
742
23
89
622
0 50
KILOMETERS

Williston Basin, Carlson and Anderson (1966) indicate that the formation is over 95 meters thick in the northwestern part of the county and less than 60 meters thick in the southeastern part of the county. At its thickest point in the Williston Basin, the Sauk Sequence is thicker than 290 meters.

Tippecanoe Sequence

The Tippecanoe Sequence (Figures 2 and 3) in Emmons County includes rock of Middle Ordovician and Silurian age. The Winnipeg Group is the lowest unit of the sequence. It consists mainly of sandstone, siltstone, and shale. The Winnipeg Group is about 75 meters thick in northern Emmons County and thins to less than 60 meters in the southern part of the county.

The Winnipeg Group is overlain by the Red River, Stony Mountain, Stonewall, and Interlake Formations. The predominant lithology of these units is limestone and dolomite. Red shales make up a minor part of the section. The Red River Formation is about 150 meters thick in Emmons County. The Stony Mountain Formation thins from 25 to 9 meters from northwestern to east-central Emmons County. The erosional limit of this formation is in western Logan and McIntosh Counties. The Stonewall Formation is present only in the northwestern half of the county. The thickest section is about 9 meters. The Interlake Formation is present only in the northwestern half of the county. The thickest section of Interlake Formation in the county is probably about 9 meters.

The combined thicknesses of these formations give the Tippecanoe Sequence a total thickness of from 270 to 365 meters from southeastern to northwestern Emmons County. At its thickest point in the Williston Basin, the Tippecanoe Sequence is over 666 meters thick. The Tippecanoe Sequence is unconformably overlain by the Kaskaskia Sequence.

Kaskaskia Sequence

The Kaskaskia Sequence (Figures 2 and 3) includes rock of early Devonian to late Mississippian age. Like the Tippecanoe Sequence, it is predominantly a limestone and carbonate sequence, but shale and evaporite commonly occur in the lower part of the Kaskaskia Sequence. The lowest unit of the sequence in Emmons County is probably the Dawson Bay Formation. Oil wells have not penetrated the unit in the county, but they have penetrated the unit in Burleigh County just north of the Emmons County line. Lithologically, the Dawson Bay Formation is mainly limestone and dolomitic limestone. The thickness of the unit is not known, but it is probably less than 12 meters.

The Souris River Formation rests on the Dawson Bay, Stonewall, and Stony Mountain Formations in Emmons County. The Souris River Formation consists of alternating limestone and shale beds. The unit thins from over 30 meters in the northwestern corner of the county (Carlson and Anderson, 1966) to about 10 meters in the east-central part of the county and to 0 meters in the southeastern corner of the county.

The Duperow Formation rests on the Souris River Formation in Emmons County. Like the Souris River Formation, it consists of alternating limestone and shale beds. The thickness of the Duperow Formation in central Emmons County is about 40 meters. Carlson and Anderson (1966) show the unit thinning to less than 30 meters in the southeastern part of the county and thickening to nearly 60 meters in the northwestern part of the county.

The Birdbear Formation overlies the Duperow Formation in Emmons County. The Birdbear Formation consists mainly of limestone. It is 9 to 10 meters thick in central Emmons County. This formation is probably the uppermost Devonian unit in the county. An unconformity occurs at the top of the Birdbear Formation, except possibly in the northwesternmost part of Emmons County where it may be overlain by the Three Forks Formation.

The Madison Formation, which overlies the Birdbear Formation, makes up a major part of the Kaskaskia Sequence. The Madison Formation is composed predominantly of limestone. The formation is between 230 and 255 meters thick in the central part of the county, and Carlson and Anderson (1966) suggest that it is greater than 335 meters thick in the northwestern part of the county.

The Madison Formation is conformably overlain by the Big Snowy Group in the northern half of the county and unconformably overlain by the Piper Formation (Jurassic) in the southern half of the county.

The Big Snowy Group is made up of three units, the Heath, Otter and Kibby Formations. These three units have not been separated in this report. Shale, sandstone, and limestone are the characteristic lithologies of the group. The Big Snowy Group is about 45 meters thick in the northern part of the county. This group is the uppermost unit of the Mississippian System and the Kaskaskia Sequence. The unconformity that marks the top of the Kaskaskia Sequence truncates the Big Snowy Group and the Madison Formation.

The Kaskaskia Sequence in Emmons County has a total thickness ranging from about 120 meters in the southeastern corner of the county to greater than 455 meters in the northwestern part of the county (Carlson and Anderson, 1966).

Absaroka Sequence

The Absaroka Sequence (Figures 2 and 3) in Emmons County consists of rock of Pennsylvanian age. The units that make up the Absaroka Sequence in Emmons County are the Tyler, Alaska Bench, and Amsden Formations. Carlson and Anderson (1966) indicate that the Absaroka Sequence is not present in the southeastern part of the county.

The Tyler Formation is the lowermost unit of the Absaroka Sequence. It is composed mainly of sandstone and shale. The thickness of the Tyler Formation in Emmons County thins southeastward from 5 to 0 meters. The unit is underlain unconformably by the Madison and Big Snowy Groups.

The Alaska Bench Formation conformably overlies the Tyler Formation. The characteristic lithology of the Alaska Bench Formation is dolomite. The thickest part of the unit in Emmons County is about 3 meters. Ziebarth (1972) places the erosional limit of the Alaska Bench Formation in the eastern third of Emmons County.

The Amsden Formation conformably overlies the Alaska Bench Formation in Emmons County. The characteristic lithology of the Amsden Formation is limestone, shale, and sandstone. The unit is about 7 to 10 meters thick in north-central Emmons County and thins to 0 meters in southeastern Emmons County. An unconformity truncates the top of the Amsden Formation.

The maximum thickness of the Absaroka Sequence in Emmons County is about 20 meters. In the middle of the Williston Basin, the sequence is thicker than 455 meters.

Zuni Sequence

The Zuni Sequence (Figures 2 and 3) in Emmons County includes rock of the Middle Jurassic through Paleocene age. The lowest unit of the Zuni Sequence is the Piper Formation. The characteristic lithology of the formation is red shale and evaporite. The Piper Formation rests unconformably on the Madison Formation, Big Snowy Group, and the Absaroka Sequence. In Emmons County the Piper Formation is about 45 meters thick.

The Piper Formation is overlain by the Sundance Formation. This unit consists mainly of siltstone and sandstone. The Sundance Formation is about 65 meters thick in Emmons County.

The Morrison Formation rests on the Sundance Formation. This unit is characterized by shale and clay. In Emmons County the unit is 20 meters thick. The Morrison Formation is thought to be the upper-most Jurassic lithostratigraphic unit in North Dakota.

The Fall River-Lakota Interval overlies the Morrison Formation in Emmons County. The predominant lithology of this unit is sandstone, but the Fuson Formation (shale) can locally be recognized. Where present, it separates the Fall River and Lakota Formations. These three units (Fall River, Fuson, and Lakota Formations) are about 65 meters thick in Emmons County.

The Skull Creek, Newcastle (Muddy), and Mowry Formations occur above the Fall River Formation. Skull Creek and Mowry Formations are typically shale and the Newcastle Formation is typically sandstone. These three units have a combined thickness of about 75 to 90 meters in Emmons County. When combined with the Fall River-Lakota Interval, the unit is called the Dakota Group. The upper three units are readily separable, but the lower units are hard to separate.

The Colorado Group overlies the Dakota Group. The Belle Fourche, Greenhorn, and Carlile Formations make up the Colorado Group. The characteristic lithology of this group is gray shale. The Greenhorn Formation differs from the other two formations by being more calcareous. The combined thickness of the Colorado Group in Emmons County is between 545 and 575 meters.

The Montana Group overlies the Colorado Group. The Niobrara, Pierre, and Fox Hills Formations make up the Montana Group.

The characteristic lithology of the Niobrara Formation is calcareous shale. The unit is about 30 meters thick.

The Pierre Formation rests on the Niobrara Formation. The characteristic lithology of the unit is gray shale. It also contains numerous bentonite beds. The Pierre Formation in Emmons County is at least 335 meters thick. This unit is the lowest lithostratigraphic unit to be recognized at the surface in Emmons County. It is exposed along Beaver Creek in the central and western part of the county, along the South Branch of Beaver Creek in the southeastern part of the county, along the South Dakota border in the southwestern part of the county, and along the Missouri River (Oahe Reservoir). The best exposure occurs in Seemen Park near Linton where more than 30 meters of Pierre Formation are exposed (Figure 4). The contact with the overlying Fox

Fig. 4.--Exposure of the Pierre and Fox Hills Formations in Seemen Park, Linton, Emmons County, North Dakota.

Hills Formation occurs near the top of the section. Plate 1 shows the surface distribution of Pierre Formation in Emmons County.

The Fox Hills Formation conformably overlies the Pierre Formation in Emmons County. The characteristic lithology of this unit is sandstone and shale. The total thickness of the Fox Hills Formation in Emmons County is about 120 meters. The Fox Hills Formation occurs at the surface over much of Emmons County. The best exposures of this unit occur just east of the Missouri River and on the buttes northeast of Linton. Plate 1 shows the surface distribution of Fox Hills Formation in Emmons County.

The Hell Creek Formation conformably overlies the Fox Hills Formation in Emmons County. The characteristic lithology of this formation is sandstone and mudstone. It also contains thin, discontinuous lignite beds. The Hell Creek Formation is about 75 meters thick in Emmons County. The best exposures occur on Coal Butte (sec. 32, T. 135 N., R. 78 W. and sec. 5, T. 134 N., R. 78 W.) and in sections 18, 28, and 33, T. 136 N., R. 78 W. The Hell Creek Formation occurs at the surface mainly in the northwestern quarter of the county. A few scattered erosional remnants occur elsewhere in the county. Figure 5 is a picture of the Hell Creek Formation in Emmons County. Plate 1 shows the surface distribution of Hell Creek Formation in Emmons County.

The Cannonball Formation is the uppermost unit of the Zuni Sequence in Emmons County. The characteristic lithology of the Cannonball Formation is sandstone and shale. The contact with the underlying Hell Creek Formation was not seen, but the unit is thought to be at least 15 meters thick in Emmons County. The unit occurs on a few

Fig. 5.--Exposures of Hell Creek Formation in sec. 33, T. 136 N., R. 78 W., Emmons County, North Dakota.

butte tops in the northwestern part of the county. The best exposure occurs at the top of the butte in sec. 28, T. 136 N., R. 78 W. Plate 1 shows the distribution of the Cannonball Formation in Emmons County.

Tejas (?) Sequence

Although the Tejas (?) Sequence is considered to be present in the midcontinent area on the craton, its type area is south of the craton in the Texas Gulf Coast.

The Tejas (?) Sequence, as originally defined by Sloss (1963), included all the rock-stratigraphy on the craton above the Zuni Sequence. However, two very different lithologic types are present within this body of material. The lithology of the lower part of the sequence consists mainly of gravel, sand, and silt, whereas the lithology of the upper part of the sequence consists mainly of massive, bouldery, cobbly, pebbly, sandy, silty clay (glacial sediment). Typical of the lower part of the sequence in central North America are the White River, Ogallalla, Wiota, Arikaree, and Flaxville Formations. Typical of the upper part of the sequence are the Wedron (Willman and Frye, 1970), Battleford and Floral Formations (Christiansen, 1967 and 1968), Coleharbor Formation (Bluemle, 1971a), and the Sutherlund Group (Christiansen, 1968). Even though gravel occurs in the upper part of the sequence, it is different from the gravel found in the lower part of the sequence. For example, gravel of the Flaxville, White River, and Wiota Formations is rich in porphyry, argillite, and quartzite pebbles and cobbles. Gravel in the upper part of the sequence contains mostly pebbles and cobbles of granite, basalt, and carbonate from the Canadian Shield. An interregional unconformity occurs between these different lithologies. In North Dakota this unconformity can be seen in sec. 28, T. 152 N., R. 102 W., McKenzie County, North Dakota.

Because the sequences are defined on the basis of (1) interregional unconformities and (2) the lithologic coherence of the unit, it seems logical to redefine the Tejas (?) Sequence to exclude the predominantly massive, bouldery, cobbly, pebbly, sandy, silty clay units that occur in the upper part of the Tejas (?) Sequence above the unconformity.

Redefinition of the Tejas (?) Sequence

It is recommended that the Tejas (?) Sequence be redefined to include the cratonic sequence that rests on the unconformity cut on the Zuni and older sequences and underlies the interregional unconformity at the base of the Sakakawea Sequence as proposed and defined in this report. The characteristic lithology of the Tejas (?) Sequence is generally poorly consolidated sand, silt, and clay and gravel composed mainly of cobbles and pebbles of porphyry, argillite, and quartzite. The Tejas (?) Sequence does not include the massive, bouldery, cobbly, pebbly, sandy, silty clay that is characteristic of the Sakakawea Sequence.

The type area of the Tejas (?) Sequence will remain the same. Sloss (1963) designated the type area of the Tejas (?) Sequence to be Texas (the American spelling of the Mexican word for the same area, Tejas) where there is a thick section of the Tejas lithology filling the Gulf Coast Basin. The Tejas (?) Sequence is composed of strata ranging in age from late Eocene to late Cenozoic, probably late Pliocene.

Stratigraphy of the Tejas (?) Sequence

The Flaxville Formation, thought to be late Pliocene to possibly early Pleistocene in age, is the only unit possibly belonging to the Tejas (?) Sequence in Emmons County. Lithologies typical of the Flaxville Formation (gravel composed of quartzite, argillite, and porphyry cobbles and pebbles) are found at the bottom of deep channels cut into the bedrock in Emmons County. The locations of drill holes where gravel similar to that of the Flaxville Formation is known to be present are shown in Figure 6. Even though its source is to the southwest, this gravel is commonly called "western gravel" to distinguish it from gravel of glacial origin. The thickness of the Flaxville Formation in Emmons County is unknown, but it is probably no more than a few meters. In Emmons County the Flaxville Formation probably everywhere rests unconformably on the Pierre Formation.

STRATIGRAPHY OF THE SAKAKAWEA SEQUENCE

Definition of the Sakakawea Sequence

Name

Sakakawea Sequence, new name

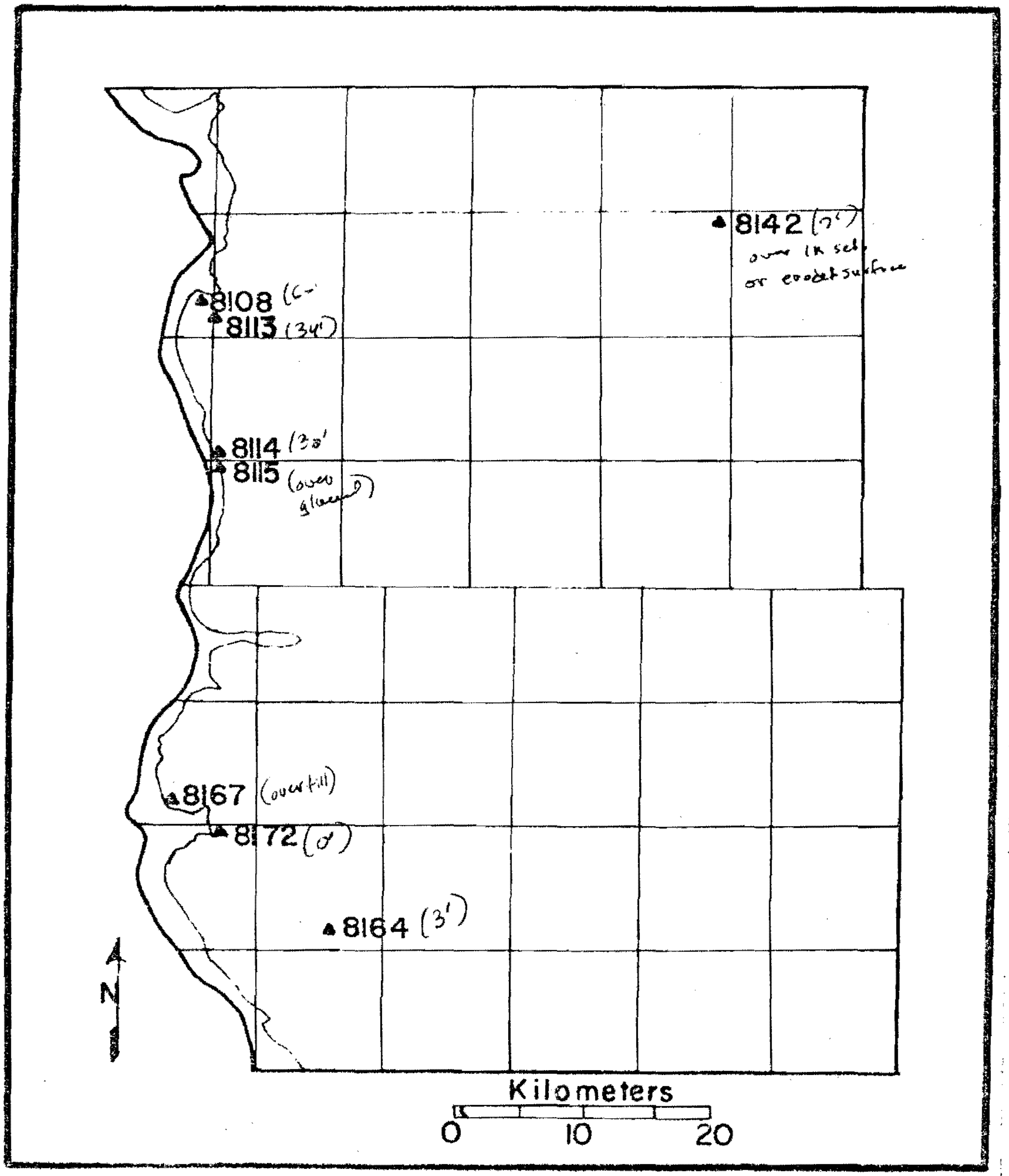
Source of the name

The Sakakawea Sequence is named for Lake Sakakawea (Garrison Reservoir), North Dakota.

Definition abstract

The Sakakawea Sequence is the major lithostratigraphic unit that rests on the interregional unconformity cut on the Tejas (?) Sequence

Fig. 6.--Locations of test holes in Emmons County, North Dakota, where Flaxville Formation type gravels have been found. Numbers are United States Geological Survey Test Holes.


8142
8108
8113
8114
8115
8167
8172
8164
N
Kilometers
0
10
20

and older sequences. It is characterized by massive, bouldery, cobbly, pebbly, sandy, silty clay containing pebbles and cobbles derived from the Canadian Shield; it also contains mixtures of gravel, sand, silt, clay, and some organics that are interbedded or overlie the bouldery, cobbly, pebbly, sandy, silty clay.

Type section

The type section is in the bluffs along Lake Sakakawea. It is located in the NW$\frac{1}{4}$ sec. 22, T. 147 N., R. 84 W., McLean County, North Dakota.

Description of the unit

At the type section, the Sakakawea Sequence in ascending order is as follows: (1) 4.5 meters covered; (2) 8.5 meters of gray to olive brown, slightly pebbly, sandy, silty clay, blocky and jointed with stain along the joints; (3) 3.5 meters of brown to gray, pebbly, slightly sandy, silty clay in subspherical to angular blocks; (4) 1.25 meters of gravel composed mainly of granite, basalt, and carbonate pebbles and cobbles; (5) 1.25 meters of gray, slightly pebbly, sandy, slightly silty clay containing no structure; (6) 6.6 meters of gray, slightly pebbly, sandy, silty clay, mostly massive but contains numerous vertical joints in the lower part of the unit with secondary carbonate and stain along the joints; (7) 1 meter of yellow to yellow brown, sandy silt; (8) 15 centimeters of dark brown to red brown, organic silt; (9) 1.7 meters of gray silt with a dark brown organic accumulation in the upper 15 centimeters; and (10) 1 meter of dark gray silt with a black organic accumulation in the upper 20 centimeters. See Appendix III for textural, carbonate, and dolomite analyses for the section. Data for the description of this section was supplied by S. R. Moran, North Dakota Geological Survey.

Figure 7 is a picture of the Sakakawea Sequence type section.

Nature of the contacts

The upper contact of the Sakakawea Sequence is the sediment-air interface. The Sakakawea Sequence rests unconformably on older units. Near the type section the contact of the Sakakawea Sequence with the Sentinel Butte Formation can be seen. It occurs where the gray to grayish brown sand and silt of the Sentinel Butte Formation is replaced by the overlying massive, bouldery, cobbly, pebbly, sandy, silty clay of the Sakakawea Sequence. In sec. 22, T. 152 N., R. 102 W. in McKenzie County, North Dakota, the contact of the Sakakawea Sequence with the Tejas (?) Sequence can be seen (Figure 8). The contact is unconformable and occurs where the gravel composed of argillite, quartzite, and porphyry cobbles and pebbles of the Tejas (?) Sequence is replaced by the bouldery, cobbly, pebbly, sandy, silty clay of the Sakakawea Sequence.

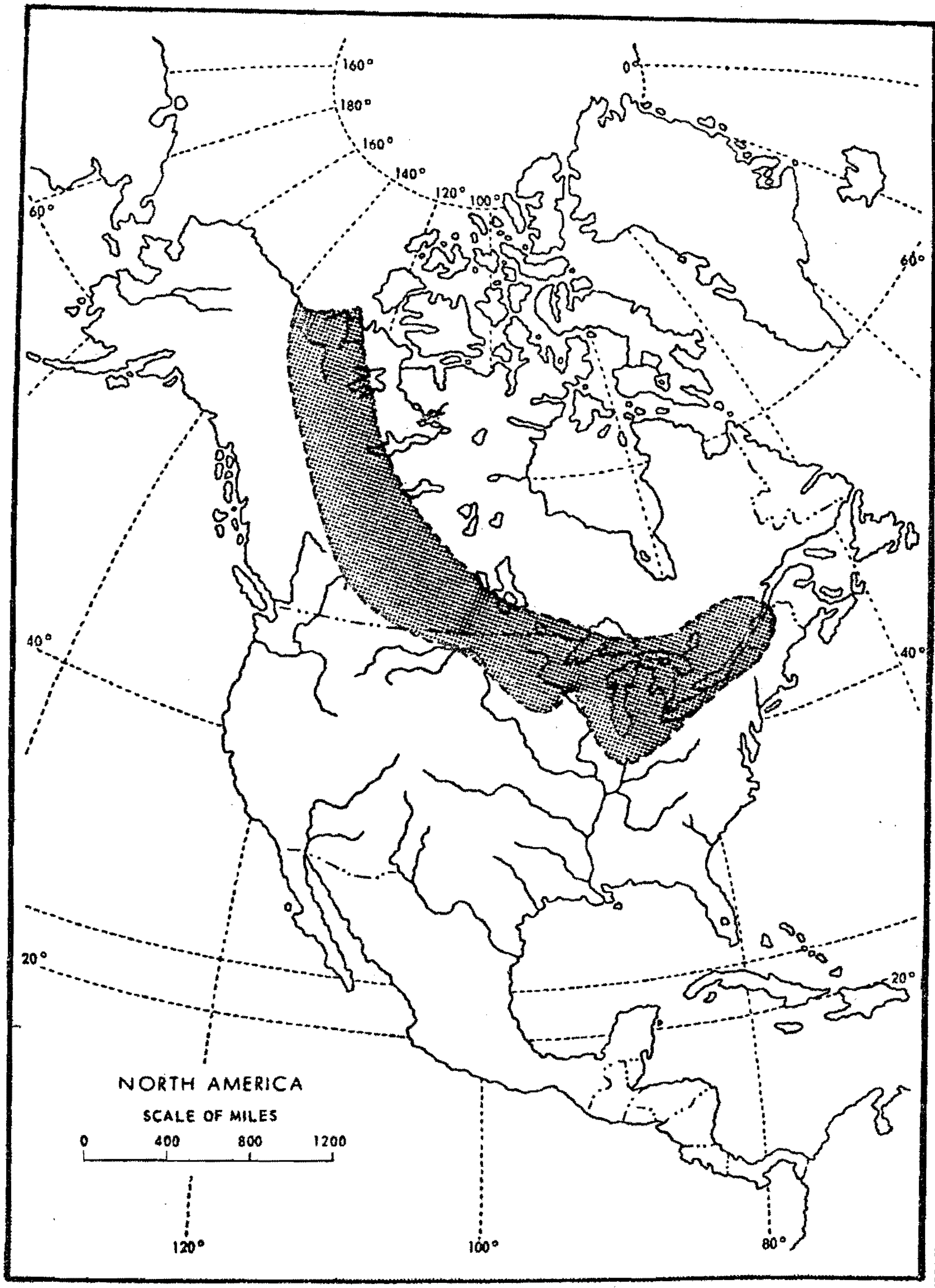
Regional stratigraphy, distribution, and thickness

Figure 9 shows the distribution of continuous Sakakawea Sequence where it is more than a few meters thick. The thickness of the Sakakawea Sequences ranges widely. In Illinois it is known to be as thick as 125 meters, but probably averages 35 to 50 meters (Piskin and Bergstrom, 1967). In Saskatchewan the thickness is known to be at least 310 meters

Fig. 7.--Picture of Sakakawea Sequence type section on Lake Sakakawea, McLean County, North Dakota. The contact with the Sentinel Butte Formation occurs at the base of the section.

Fig. 8.--Picture showing the contact of the Tejas (?) Sequence (Flaxville Formation) with the overlying Sakakawea Sequence (Braddock Formation of the Coleharbor Group) in sec. 28, T. 152 N., R. 102 W., McKenzie County, North Dakota.

Fig. 9.--Distribution of continuous Sakakawea Sequence more than a few meters thick.


NORTH AMERICA
SCALE OF MILES
0
400
800
1200
160°
180°
160°
140°
120°
100°
0°
60°
60°
40°
40°
20°
20°
120°
100°
80°

in one area, but probably averages 60 to 90 meters (Moran, 1972). In North Dakota it is known to be at least 180 meters in a few areas, but probably averages 35 to 50 meters (Bluemle, 1971b). The formations of the Coleharbor Group make up most, if not all, of the Sakakawea Sequence in North Dakota. In Saskatchewan the Sutherlund and Saskatoon Groups (Christiansen, 1967 and 1968) make up most of the Sakakawea Sequence.

Origin

The Sakakawea Sequence is predominantly of glacial origin. Fluvial, lacustrine, and eolian sediments make up a minor part of the sequence.

Age

The Sakakawea Sequence is late Cenozoic, probably largely Pleistocene in age.

Redefinition of the Coleharbor Formation

In North Dakota the Coleharbor Formation and the Walsh Formation make up what has been defined in this report as the Sakakawea Sequence. The Coleharbor Formation was defined (Bluemle, 1971a) as the lithostratigraphic unit that includes all the bouldery, cobbly, pebbly, sandy, silty clay, sand and gravel, and silt and clay at the type section and comparable sections. Bluemle (1971a, p. 21) also indicated that the formation should be restricted to bouldery, cobbly, pebbly, sandy, silty clay containing mainly montmorillonite clay. Moran and Clayton (1972) have modified this aspect of the definition. They substituted "conspicuous presence of soft gray or black Cretaceous shale" in place of "mainly montmorillonite clays." Shale pebbles are a field criterion, whereas the identification of montmorillonite requires laboratory information.

The Walsh Formation was defined (Bluemle, in press) as the lithostratigraphic unit that overlies the Coleharbor Formation and all other formations and includes a variety of clay, sand, silt, and gravel deposits. He also said (Bluemle, in press) that sediments of the Walsh Formation have a "dirty" appearance due to the presence of small (or large) amounts of organic material that commonly give them a dark, gray color.

Descriptive mapping in Emmons County has demonstrated that the Walsh Formation is not a useful lithostratigraphic unit. Because no type section was defined for the Walsh Formation, it is not possible to compare what has been defined as "type" Walsh Formation with what might be Walsh Formation elsewhere. The use of "dirtyness" (presence of disseminated organic material) as the lithologic criteria for major lithostratigraphic differentiation is not practical; two examples from Emmons County illustrate this.

(1) Coarse silt occurs on the uplands in Emmons County. Near the Missouri River (Oahe Reservoir) this silt is as much as 5 meters thick and can be differentiated into two lithologic units if the criteria for the Walsh Formation is used. The upper 2 to 2.5 meters of the unit are dirty gray because of the presence of organic material. The underlying silt is yellow and apparently lacking in organic material. There is not any other easily distinguishable break other than this color change. A more natural break occurs at the base of the section where the silt is

in contact with underlying units. If the Walsh Formation definition is used, the upper, gray silt is Walsh Formation and the lower, yellow silt is Coleharbor Formation; lithologically, they are essentially one unit.

(2) Bluemle (in press) stated that alluvium is included in the Walsh Formation (the inference being that all alluvium is "dirty"). However, the Missouri River alluvium in Emmons County and in most of the rest of North Dakota is clean sand and silt, making it Coleharbor Formation rather than Walsh Formation.

I believe that the confusion indicated by these two examples suggests that the Walsh Formation is not as practical a lithostratigraphic unit as the lithostratigraphic units defined in this report. For this reason, Walsh Formation will not be used and it is suggested that usage of Walsh Formation be discontinued. The Coleharbor Formation will be redefined to include material previously included in the Walsh Formation. I consider the Coleharbor Formation to be a group in most of North Dakota.

The Coleharbor Group is here redefined to include material that overlies it (previously called Walsh Formation). The Coleharbor Group thus includes all the massive, to jointed, bouldery, cobbly, pebbly, sandy, silty clay and the sand and gravel, silt and clay, and silt (whether or not it contains organic material) that overlies the bouldery, cobbly, pebbly, sandy, silty clay at the type sections and all comparable sections. The upper part of the Coleharbor Group does not occur at the type section.

Type section

The type section of the Coleharbor Group remains the same. It is located in the NW¼ NW¼ NE¼ sec. 22, T. 147 N., R. 84 W., McLean County, North Dakota.

Nature of the contacts

The upper contact of the Coleharbor Group is the sediment-air interface. The Coleharbor Group rests unconformably on older units. Near the type section the contact of the Coleharbor Group with the Sentinel Butte Formation can be seen. It occurs where the gray to grayish brown sand and silt of the Sentinel Butte Formation is replaced by the overlying massive to jointed, bouldery, cobbly, pebbly, sandy, silty clay of the Coleharbor Formation. In sec. 22, T. 152 N., R. 102 W. in McKenzie County, North Dakota, the contact of the Coleharbor Group with the Flaxville Formation can be seen (Figure 8). The contact is unconformable and occurs where gravel composed of argillite, quartzite, and porphyry cobbles and pebbles of the Flaxville Formation is replaced by the bouldery, cobbly, pebbly, sandy, silty clay of the Coleharbor Group.

Regional stratigraphy, distribution, and thickness

The exact regional distribution of the Coleharbor Group is not known. It is known that it covers most of the eastern two-thirds of North Dakota, extends into Saskatchewan, Manitoba, western and southern Minnesota, and South Dakota. The Coleharbor Group is probably equivalent to the Saskatoon Group (Christiansen, 1967) and part of the Sutherlund Group (Christiansen, 1968) in Saskatchewan.

In McLean County the unit is over 180 meters thick in one area and probably averages about 40 meters (Bluemle, 1971a). In Emmons County, the Coleharbor Group is more than 120 meters thick in one area and probably averages about 25 meters. In the rest of North Dakota, the Coleharbor Group averages 30 to 45 meters (Bluemle, 1971b).

Differentiation from other units

The Coleharbor Group can be distinguished from underlying units by the presence of the bouldery, cobbly, pebbly, sandy, silt clay. The gravel lithology within the Coleharbor Group may be hard to differentiate from gravels in other units. Gravel of the Coleharbor Group is composed of cobbles of granite, basalt, and carbonate derived from or near the Canadian Shield. Gravel of underlying units is composed predominantly of cobbles and pebbles of porphyry, argillite, and quartzite derived from a southwestern source.

Origin

The Coleharbor Group is glacial in origin. Minor amounts of it are fluvial, lacustrine, and eolian in origin.

Age

The Coleharbor Group is Pleistocene in age.

Remarks

In North Dakota the Braddock, Emmons, Four Bears, Coteau, Denbigh, and Oahe Formations comprise the Coleharbor Group.

Definition of the Braddock Formation

Name

Braddock Formation, new name

Source of the name

The Braddock Formation is named for Braddock, Emmons County, North Dakota.

Definition abstract

The Braddock Formation is massive to jointed, olive gray to yellowish brown, bouldery, cobbly, pebbly, sandy, silty clay. The texture of the unit consists of roughly equal amounts of sand, silt, and clay. Pebbles, cobbles, and boulders of igneous rocks, limestone, dolomite, and shale make up a few per cent of the unit. The Braddock Formation is probably the lowest unit of the Sakakawea Sequence in Emmons County and underlies the Emmons Formation.

Type section

The type section for the Braddock Formation is located 0.35 miles east of the southwest corner of sec. 31, T. 131 N., R. 69 W., McIntosh County, North Dakota.

Reference section

The reference section is located at the type section of the Sakakawea Sequence in sec. 22, T. 147 N., R. 87 W., McLean County, North Dakota. This section shows the relation of the Braddock Formation to other units in the Coleharbor Group.

Description of the unit

At the type section, the Braddock Formation consists of 3.7 meters of massive, yellow brown, bouldery, cobbly, pebbly, sandy, silty clay overlain by Emmons Formation 1.5 meters thick. The texture of samples of Braddock Formation at the type section is given in Appendix III.

The unit is unbedded and contains roughly equal amounts of sand, silt, and clay. Deviations from these average textures are as much as 10 per cent. Boulders, cobbles, and pebbles also make up a few per cent of the unit. The color of the unit varies widely from yellow brown to olive gray, and below the water table the colors are consistently grayer and bluer. At the type section the color of the unit is light yellowish brown (5Y 6.4). Mineralogically, the unit is composed of minerals derived both from the Canadian Shield and local sources. The clay-sized portion of the unit is composed largely of clay minerals (predominantly montmorillonite). The sand and silt-sized portions of the unit are composed mainly of quartz, feldspar, limestone, dolomite, shale, and a wide variety of small amounts of other minerals. The portion of the unit larger than sand size is composed of cobbles and pebbles of granite, basalt, limestone, dolomite, and shale. A pebble count, based on 188 pebbles greater than 4 millimeters in size collected at the type section, gave the following abundances for different lithologies: carbonate, 42 per cent; crystallines, 21 per cent; siliceous, 11 per cent; shale, 7 per cent; and miscellaneous, 19 per cent. Contained within the formation are clay and silt and sand and gravel lenses and layers that, except for stratigraphic position, are identical to the Four Bears Formation; these units each make up 5 to 10 per cent of the Braddock Formation.

Nature of the contacts

The contact of the Braddock Formation with the Emmons Formation is sharp (Figure 10). It can be seen at the type section and occurs where the yellower, more sandy Braddock Formation rests unconformably on older units. Near the type section of the Sakakawea Sequence, the contact with the Sentinel Butte Formation can be seen. It occurs where the gray to grayish brown sand and silt of the Sentinel Butte Formation is replaced by the overlying massive to jointed, bouldery, cobbly, pebbly, sandy, silty clay of the Braddock Formation. In sec. 28, T. 152 N., R. 102 N. in McKenzie County, North Dakota, the contact of the Braddock Formation with the Flaxville Formation can be seen (Figure 8). The contact is unconformable and occurs where gravel composed of argillite, quartzite, and porphyry cobbles and pebbles of the Flaxville Formation is replaced by the bouldery, cobbly, pebbly, sandy, silty clay of the Braddock Formation.

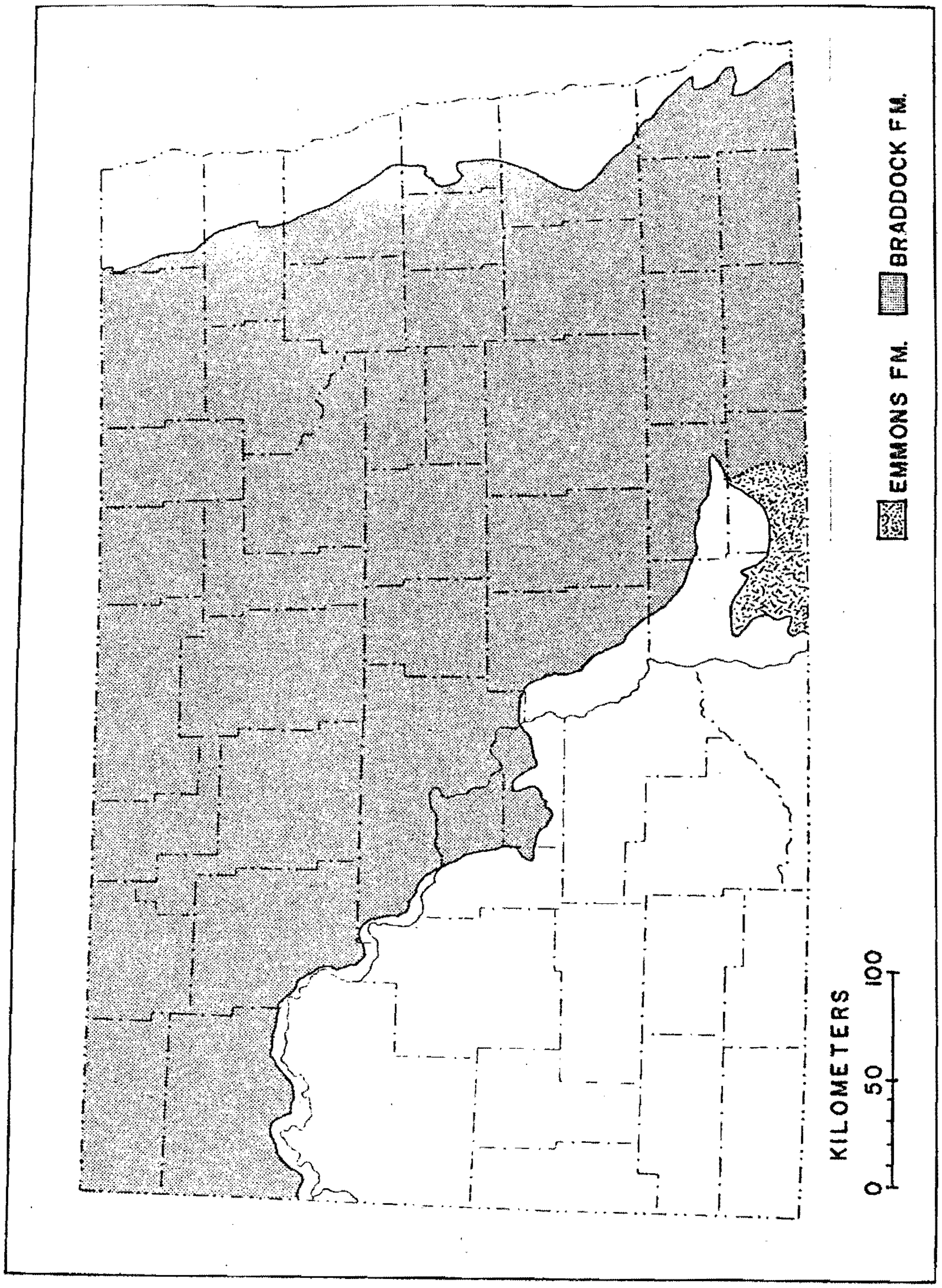
Regional stratigraphy, distribution, and thickness

The Braddock Formation is thought to occur over most of the state of North Dakota (Figure 11). In the Red River Valley it is thought to be equivalent to the Red Lake Falls and St. Hilaire Members of the Coleharbor Formation (Harris and others, in preparation). The unit probably extends into South Dakota, Minnesota, Manitoba, Saskatchewan, and Montana. In Saskatchewan, the unit is probably equivalent to the Saskatoon Group and at least part of the Sutherlund Group.

The thickness of the unit probably averages about 45 meters in most of North Dakota. It is known to be at least 150 meters thick in one area (Bluemle, 1971b).

Fig. 10.--Contact (dashed line) of the Braddock Formation with the overlying Emmons Formation, 0.35 miles east of southwest corner of sec. 31, T. 131 N., R. 69 W., McIntosh County, North Dakota.

Fig. 11.--Probable distribution of continuous Braddock Formation and known distribution of Emmons Formation in North Dakota.



KILOMETERS
0
50
100
EMMONS FM.
BRADDOCK FM.

Differentiation from other units

The Braddock Formation is not likely to be confused with any other unit of the Coleharbor Group in North Dakota except the Emmons Formation. The Braddock Formation can be distinguished from the Emmons Formation by the larger amounts of sand present in the Braddock Formation (approximately 33 per cent versus 17 per cent) and by the large number of shale pebbles in the Emmons Formation. Carbonate and igneous pebbles predominate in the Braddock Formation.

Origin

The Braddock is interpreted to be largely glacial sediment. Minor amounts of it are fluvial and lacustrine sediment.

Age

The Braddock Formation is probably Wisconsinan in age.

Remarks

At least two major event-stratigraphic boundaries (Napoleon and Lostwood Glaciations) are interpreted within the Braddock Formation.

<u>Definition of the Emmons Formation</u>

Name

Emmons Formation, new name

Source of the name

The Emmons Formation is named for the type area, Emmons County, North Dakota.

Definition abstract

The Emmons Formation is massive, olive gray to brown, bouldery, cobbly, pebbly, slightly sandy, silty clay. Shale typically composes a major part of the pebble lithologies in the unit. The texture of the unit averages 17 per cent sand, 36 per cent silt, and 47 per cent clay. The Emmons Formation lies above the Braddock Formation and below the Four Bears Formation.

Type section

The type section for the Emmons Formation is located 0.35 miles east of the southwest corner of sec. 31, T. 131 N., R. 69 W., McIntosh County, North Dakota.

Reference section

Reference sections for the Emmons Formation are located in the NW$\frac{1}{4}$ NW$\frac{1}{4}$ NW$\frac{1}{4}$ of sec. 21, T. 129 N., R. 74 W., Emmons County, North Dakota (United States Geological Survey Test Hole 8152), 0.5 miles east of the northwest corner of sec. 28, T. 129 N., R. 74 W. (auger hole DEM 1, see Appendix I), and in the SE$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ of sec. 23, T. 131 N., R. 75 W., Emmons County, North Dakota (a road cut showing 4.5 meters of Emmons Formation).

Description of the unit

At the type section, the Emmons Formation consists of 1.5 meters of olive gray (5Y 4.2), slightly sandy, silty clay with a few boulders and cobbles scattered throughout. The unit is underlain by 4 meters of Braddock Formation. The texture of the Emmons Formation at the type section is given in Appendix III.

The unit is composed of material derived from both Canadian Shield and local sources. The clay-sized portion of the unit is composed mostly of clay minerals (largely montmorillonite). The silt and sand-sized portions of the formation are mainly composed of quartz, feldspar, shale, limestone, and dolomite. Heavy minerals also make up a very small portion of this size material. The gravel-sized material in the Emmons Formation is composed largely of shale, limestone, dolomite, granites, and basalt cobbles and pebbles. Shale is the most common material in the gravel fraction of the unit. A pebble count, based on 146 pebbles of greater than 4 millimeters in size collected at the type section, gave the following abundances for different lithologies: shale, 34 per cent; crystallines, 27 per cent; carbonates, 27 per cent; siliceous, 4 per cent; and miscellaneous, 7 per cent. Small amounts of material similar to the Four Bears Formation make up as much as 10 per cent of the unit.

Nature of the contacts

The contact of the Emmons Formation with overlying and underlying units is sharp. The contact with the Four Bears Formation occurs where gravel composed of cobbles and pebbles of material derived from the Canadian Shield or silt and clay (generally rhythmic) replaces the underlying olive gray to brown, bouldery, cobbly, pebbly, slightly sandy, silty clay of the Emmons Formation. The contact with the underlying Braddock Formation (Figure 10) was discussed in this same section under the Braddock Formation.

Regional stratigraphy, distribution, and thickness

The Emmons Formation is overlain by the Four Bears Formation and underlain by the Braddock Formation.

The exact distribution of the Emmons Formation is not known, but it is thought to be related to the subcrop of the Pierre Shale under it. The unit is known to occur in southeastern Emmons and McIntosh Counties, North Dakota, and in northeastern Campbell and northwestern McPherson Counties, South Dakota. Figure 11 shows the known distribution of the Emmons Formation in North Dakota.

The unit may be chronologically equivalent to the Red Lake Falls Member of the Coleharbor Formation in northwestern Minnesota (Harris and others, in preparation). It may also be equivalent to the Battleford Formation in Saskatchewan (Christiansen, 1968). The unit is known to be at least 55 meters thick in southeastern Emmons County, North Dakota.

Differentiation from other units

The only other unit that the Emmons Formation might be confused with in the Coleharbor Group in North Dakota is the Braddock Formation. For comments on differentiating the two units, see this same section under Braddock Formation.

Origin

The Emmons Formation is largely glacial sediment. Small amounts of it are lacustrine and fluvial sediments.

Age

The Emmons Formation is late Wisconsinan in age.

Definition of the Four Bears Formation

Name

Four Bears Formation, new name

Source of the name

The Four Bears Formation is named for the Four Bears Bridge in Montrail County, North Dakota.

Definition abstract

The Four Bears Formation consists of two facies: a rhythmic silt and clay facies and a "clean" (free of disseminated organic matter) sand and gravel facies. Stratigraphically, the unit occurs between the Emmons Formation and the Coteau Formation.

Type section

The type section of the Four Bears Formation is in the NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 14, T. 152 N., R. 93 W. in the bluffs of Lake Sakakawea, 1 mile northeast of the Four Bears Bridge.

Reference section

Reference sections are located in the NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 14, T. 136 N., R. 74 W. (silt and clay facies) and the NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 24, T. 132 N., R. 77 W. (sand and gravel facies), Emmons County, North Dakota.

Description of the unit

At the type section, the Four Bears Formation consists of 15 meters of sand and gravel overlying more than 65 meters of laminated silt and clay (Figure 12). The sand and gravel facies (Figure 13) con-

Fig. 12.--Picture of the silt and clay facies of the Four Bears Formation at the type section in the NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 14, T. 152 N., R. 93 W. in the bluffs of Lake Sakakawea.

Fig. 13.--Picture of sand and gravel facies of the Fours Bears Formation. Picture was taken at the Dahlen Esker in Walsh County, North Dakota.

sists of lenses and beds of gravel and sand composed largely of gravel, sandy gravel, sand, and gravelly sand. The sediment is generally flat-bedded with small amounts of it being crossbedded; most of the facies is poorly sorted. The unit is generally unconsolidated, but iron-oxide and carbonate-cemented layers do occur (Bonneville, 1961). An example of this occurs at the type section of the Four Bears Formation. The sand and gravel facies is composed of gravel consisting of granite, basalt, carbonate, shale, and a wide variety of other less common lithologies. The sand-sized portion of the facies is composed largely of feldspar and quartz, but lesser amounts of other minerals such as calcite, dolomite, shale, igneous, and metamorphic minerals are also present. Maximum average grain size is about 25 centimeters, but larger boulders do occur. A white coating of carbonate is commonly found on the bottoms of individual cobbles and pebbles.

The silt and clay facies is for the most part free of pebbles and consists largely of clay, silty clay, clayey silt, silt, and some silty sand, but the sandy portion of the facies is not common. The facies is generally rhythmic (the individual layers vary greatly in thickness), but it may be unbedded and is generally gray to yellow in color. The facies is composed of clay (mostly montmorillonite), quartz, feldspar, calcite, and dolomite.

The bedding of both facies is usually flat lying, but it is not uncommon to find the sand and gravel facies slumped and faulted and the silt and clay facies slumped and contorted to the point of making individual beds hard to trace.

Mollusk shells and ostracod carapaces are common to both facies but are better preserved in the silt and clay facies.

Nature of the contacts

The contact of the Four Bears Formation with overlying and underlying formations is sharp. The contact with the overlying Coteau Formation can be seen at the type section of the Coteau Formation. There the contact occurs where gray, laminated silt and clay is replaced by green to brown, organic clay. The contact between the sand and gravel facies and the Coteau Formation has not been seen, but it is thought to be sharp. The contact with the underlying Emmons Formation was discussed in this same section under Emmons Formation.

Regional stratigraphy, distribution, and thickness

The Four Bears Formation occurs between the Emmons and the Coteau Formations. This unit is very common over much of the eastern two-thirds of North Dakota, Saskatchewan, Manitoba, Minnesota, and South Dakota. The limits of the unit are not known. The thickness of the unit ranges widely from a few centimeters to several hundred feet. At the type section, the unit is nearly 90 meters thick.

Differentiation from other units

The facies of the Four Bears Formation are identical to the silt and clay and the sand and gravel facies that occur within the Braddock and Emmons Formations. The presence of bouldery, cobbly, pebbly, sandy, silty clay above these latter facies differentiates them from the Four Bears Formation. The gravel facies of the Four Bears Formation is similar to the gravel of the Flaxville Formation of the Tejas (?)

Sequence. These two units can be differentiated by the presence of large amounts of porphyry, argillite, and quartzite particles in the Flaxville Formation and the predominance of granite, basalt, and carbonate in the gravel and sand facies of the Four Bears Formation.

The silt and clay facies of the Four Bears Formation is similar to the Oahe Formation. These units can be differentiated by the different stratigraphic positions of the units (the Denbigh and Coteau Formations occur between them), the lack of laminations in the Oahe Formation, and the difference in texture between the two units. Sand is much more common in the Oahe Formation, and clay is generally much more common in the Four Bears Formation.

Origin

The Four Bears Formation is mainly fluvial sediment (sand and gravel facies) and lacustrine sediment (silt and clay facies); lesser amounts may be eolian sediment.

Age

Most of the Four Bears Formation is Wisconsinan in age though some of it is Holocene in age.

Definition of the Coteau Formation

Name

Coteau Formation, new name

Source of the name

The Coteau Formation is named for the type area, the Missouri Coteau, North Dakota.

Definition abstract

The Coteau Formation consists of two facies. One facies, the black, organic, silty clay facies, is very common in the closed depressions of the Missouri Coteau (Figure 14). The other facies is found mainly in drainage bottoms and along the base of hillslopes. This facies is a "dirty" gray, organic, slightly pebbly, sandy silt and clay. The Coteau Formation occurs between the Four Bears and Denbigh Formations.

Type section

The type section of the Coteau Formation is in the Seibold Slough (Bickley, 1970; Cvancara and others, 1971). Specifically, the type section is in the SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 31, T. 141 N., R. 67 W., 16 kilometers south of Woodworth, Stutsman County, North Dakota.

Reference section

The first reference section is located in the Dockter-Sparrow Site in the NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 3, T. 146 N., R. 77 W., approximately 3 kilometers from the town of McClusky, Sheridan County, North Dakota (this section is similar to the type section). A second reference section is located in a cutbank on the Turtle River in the SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 32, T. 152 N., R. 54 W., Grand Forks County, North Dakota (this section shows the slightly pebbly, sandy silt and clay facies of the Coteau Formation not present at the type section).

Description of the unit

The type section (Figure 14) from bottom to top consists of the

Fig. 14.--Picture of the Coteau Formation type section. Numbers correspond to the different units discussed under the definition of the Coteau Formation.

following: (1) blue gray, laminated, slightly fossiliferous (ostracods, fish, and mollusks), silty clay; (2) 30 centimeters of green to brown, finely laminated, highly organic, extremely fossiliferous (more than 160 species of plants and animals) clay (trojenite); (3) 20 centimeters of brown, highly calcareous, very fossiliferous (mollusks, ostracods, and fish), silty clay (marl); (4) 75 centimeters of black, calcareous, fossiliferous (mollusks, ostracods, and fish), organic, silty clay; (5) 90 centimeters of black to brown, slightly calcareous, slightly fossiliferous (a few ostracods and mollusks), sandy silt and silty clay; and (6) 70 centimeters of black, slightly calcareous, fossiliferous (mollusks and ostracods), highly organic, silty clay. Unit one is not part of the Coteau Formation; it is the silt and clay facies of the Four Bears Formation.

In many areas, units two and three are not present. The other facies of the Coteau Formation is gray to brown, slightly pebbly, sandy silt and silty clay.

The Coteau Formation is composed of clay (mostly montmorillonite), quartz, feldspar, organics, and small amounts of a wide variety of other minerals.

Nature of the contacts

The contact of the Coteau Formation with the Denbigh Formation has not been seen. However, it is thought to be sharp because of the "dirty" appearance (due to the presence of disseminated organic material) of the Coteau Formation and the "clean" appearance (due to the lack of organic material) of the Denbigh Formation. The contact with the underlying Four Bears Formation was discussed in the same section under Four

Bears Formation.

Regional stratigraphy, distribution, and thickness

The black, organic, silty clay facies is very widespread over much of North Dakota, Saskatchewan, Manitoba, Minnesota, and South Dakota. The slightly pebbly, organic, sandy silt and silty clay facies is even more widespread, occuring in most valley bottoms. The limits of its distribution are not known.

The Coteau Formation lies below the Denbigh Formation and above the Four Bears Formation.

The black, silty clay facies averages about 4 meters thick. The thickness of the other facies ranges from a few centimeters to a few dozen meters.

Differentiation from other units

The topographic position and lithology of the Coteau Formation eliminate most possible confusion with other units. The only unit that the Coteau Formation might be confused with is the Riverdale Member of the Oahe Formation. The well-sorted nature and lack of pebbles (other than artifacts) in the Riverdale Member and the poorly-sorted nature and presence of pebbles in the Coteau Formation is a means of differentiation between the two units.

Origin

The Coteau Formation consists of alluvial, colluvial, and slough sediment. Small amounts of the unit are man-made deposits.

Age

Most of the Coteau Formation has been deposited during the last 10,000 years.

Remarks

The Coteau Formation is rather broadly defined. This is to allow the large number of similar, though not exactly identical, materials that exist to be defined as one lithologic unit. Defining the Coteau Formation in this way also eliminates the possibility that more narrowly defined lithostratigraphic units might be genetic rather than descriptive.

Definition of the Denbigh Formation

Name

Denbigh Formation, new name

Source of the name

The Denbigh Formation is named for the town of Denbigh, McHenry County, North Dakota.

Definition abstract

The Denbigh Formation consists mainly of loose, "clean" sand containing some large scale crossbedding. The unit is composed of quartz, feldspar, and other minerals. It occurs above the Coteau Formation and below the Oahe Formation.

Type section

The type section of the Denbigh Formation is located 0.12 miles south of the northwest corner of sec. 28, T. 156 N., R. 77 W., McHenry County, North Dakota.

Reference section

The reference section for the Denbigh Formation is located in the NW¼ NE¼ sec. 1, T. 132 N., R. 78 W., Emmons County, North Dakota.

Description of the unit

At the type section (Figure 15) the Denbigh Formation consists of 6 meters of well-sorted, unconsolidated sand containing some large-scale crossbedding. Pebbles, cobbles, or boulders are extremely uncommon, but may be present. When they do occur, they are artifacts. The unit is composed of quartz, feldspar, limestone, dolomite, shale, and small amounts of a wide variety of other minerals. At the type section, three dark organic horizons occur in the upper 1.5 meters (Figure 16).

Nature of the contacts

The contact of the Denbigh Formation with the overlying Oahe Formation has not been seen. It is thought to be sharp because of the difference in textures of the two units (Denbigh Formation is well-sorted sand, whereas the Oahe Formation is mainly coarse silt). The contact with the underlying Coteau Formation was discussed in this same section under Coteau Formation.

Regional stratigraphy, distribution, and thickness

In North Dakota the three largest occurrences of the Denbigh Formation are on the Sheyenne and Pembina Deltas and the Souris lake plain (Figure 17). Small local occurrences are present over much of North

Fig. 15.--Picture of the Denbigh Formation type section located 0.12 miles south of the northwest corner of sec. 28, T. 156 N., R. 77 W., McHenry County, North Dakota.

Fig. 16.--Closeup picture of the upper 1.5 meters of the Denbigh Formation. Three paleosols can be seen (dashed lines are placed at the top and the bottom of each).

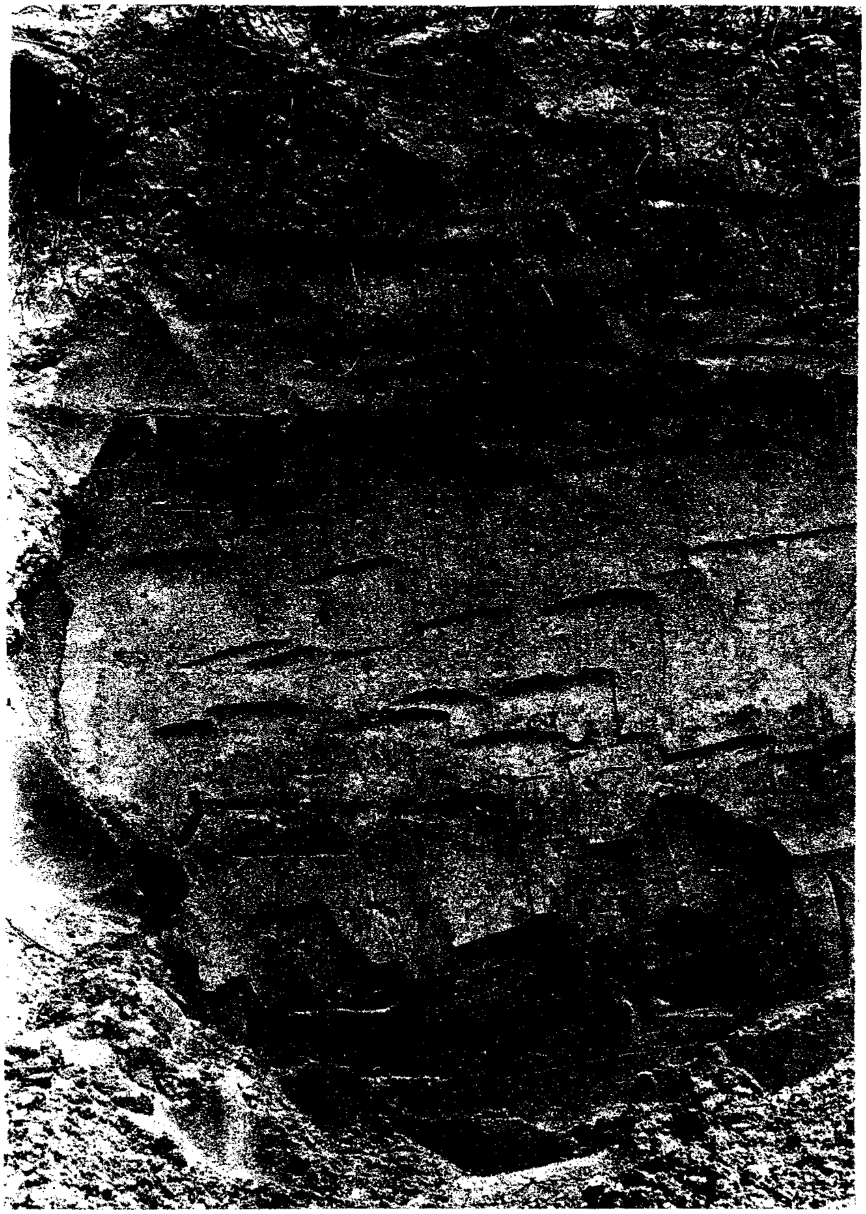
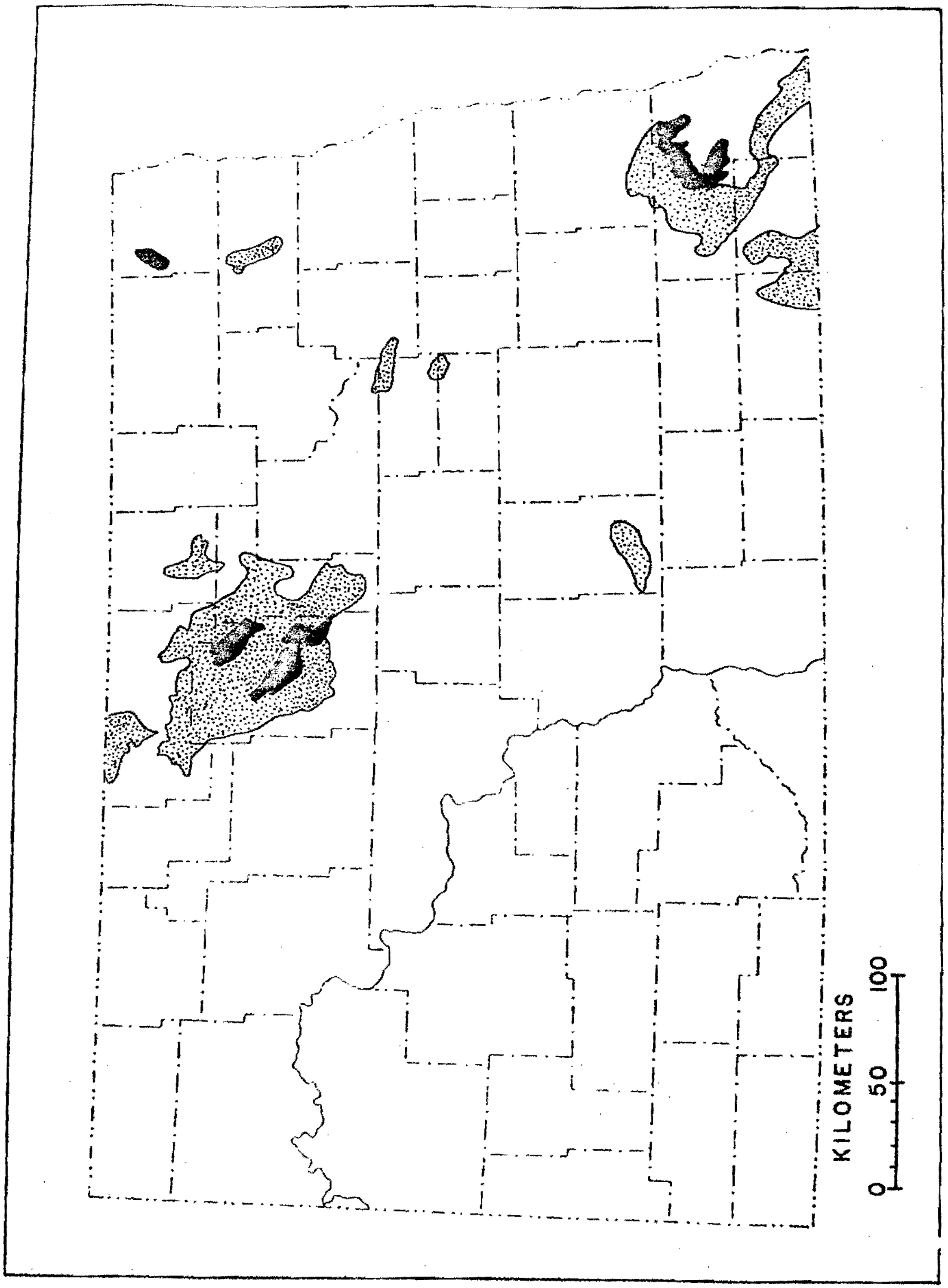


Fig. 17.--Distribution of continuous Denbigh Formation (black) and widespread discontinuous Denbigh Formation (speckled).


KILOMETERS
0
50
100

Dakota. Outside of North Dakota little is known of the distribution of the Denbigh Formation. A large deposit of this unit is known to occur on the Assiniboine Delta of Lake Agassiz, Manitoba (David, 1971). The thickness of the unit varies greatly.

Differentiation from other units

The only unit that the Denbigh Formation might be confused with is the Four Bears Formation. It is distinguished from the Four Bears Formation by the difference in sorting (the Four Bears Formation is very poorly-sorted while the Denbigh Formation is well-sorted) and the lack of gravel (except for occasional artifacts) in the Denbigh Formation.

Origin

The Denbigh Formation is mainly eolian sediment; minor amounts of the unit may be fluvial or lacustrine sediments. At the type section it is all eolian sediment.

Age

Most of the Denbigh Formation is probably Holocene in age.

<u>Definition of the Oahe Formation</u>

Name

Oahe Formation, new name

Source of the name

The Oahe Formation is named for the Oahe Reservoir, south-central North Dakota.

Definition abstract

The Oahe Formation is yellow, brown to red, or gray nonbedded, coarse silt and fine sand. It is found mainly on the flat to gently rolling uplands, but it may also be present in valley bottoms. It has the appearance of having been draped over the topography. It is the uppermost unit of the Sakakawea Sequence in North Dakota.

Type section

The type section of the Oahe Formation is 160 meters south and 30 meters west of the center of sec. 22, T. 147 N., R. 84 W., 5 kilometers north of Riverdale, North Dakota.

Reference section

The reference section for the Oahe Formation is the bluff in the SW$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 28, T. 136 N., R. 78 W., Emmons County, North Dakota.

Description of the unit

The type section (Figure 18) from bottom to top is as follows: (1) 116 centimeters of light yellow brown silt and sand moderately calcareous; (2) 15 centimeters of brown to red brown, moderately calcareous silt and fine sand; and (3) 72 centimeters of gray brown to gray, slightly calcareous, fine sand and coarse silt, containing several faintly visible and laterally traceable bands of dark organic silt. For a detailed description see Appendix III. All three units are composed mainly of quartz, feldspar, and carbonate minerals. The darker color in the upper two units appears to be due to an increased amount of disseminated organic material.

Fig. 18.--Picture of the Oahe Formation type section: Unit one is the Mallard Island Member of the Oahe Formation; unit two is the Aggie Brown Member of the Oahe Formation; and unit three is the Riverdale Member of the Oahe Formation.

Nature of the contacts

The upper contact of the Oahe Formation is the sediment air interface. The contact of the Oahe Formation with the underlying Denbigh Formation was discussed in this same section under Denbigh Formation.

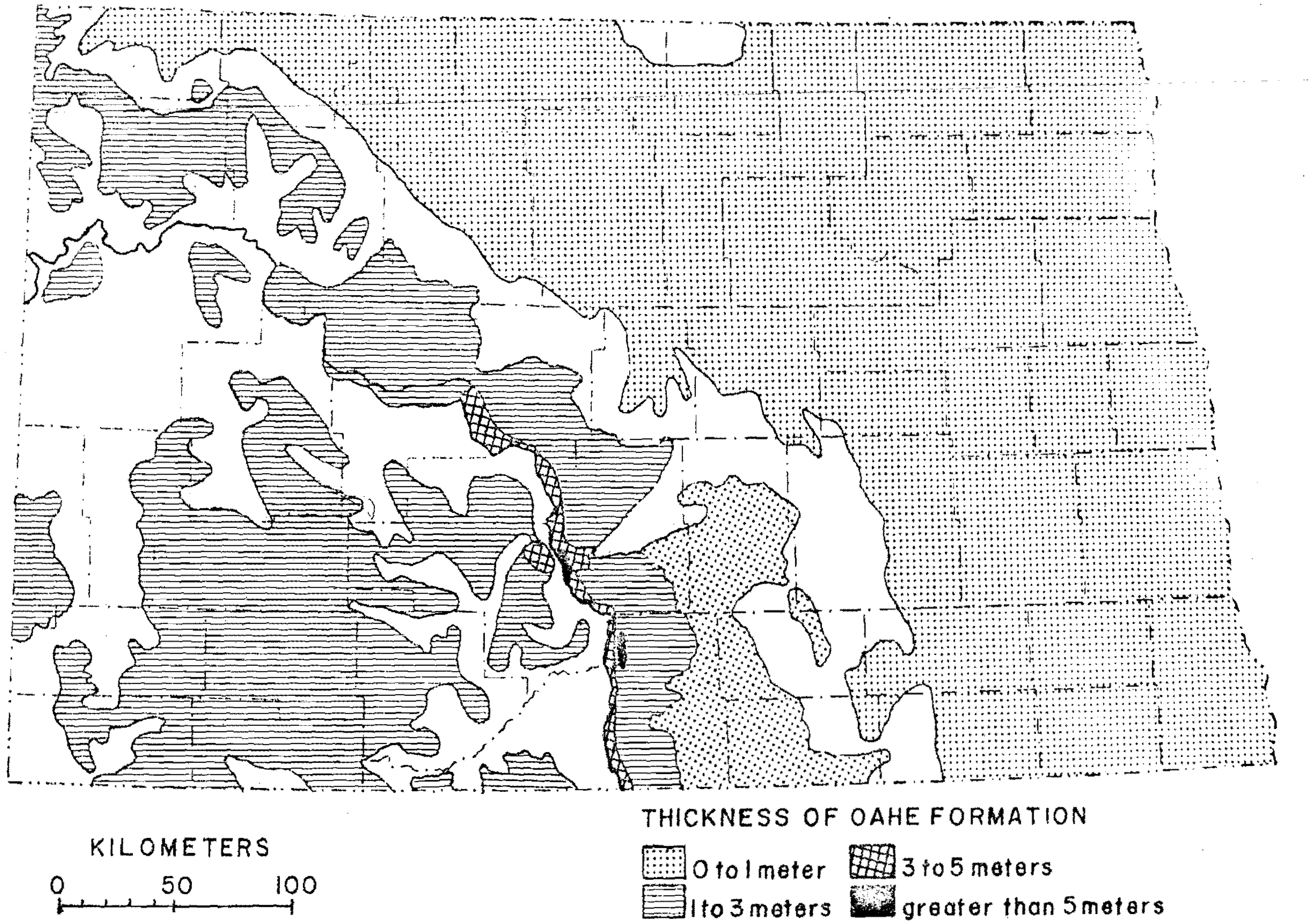
Regional stratigraphy, distribution, and thickness

The Oahe Formation occurs at the surface over much of North Dakota (Figure 19). Its thickness and distribution are controlled by the wind direction and strength. The unit occurs in deposits greater than 5 meters thick along the Missouri River, but rapidly thins away from the river. Figure 19 shows approximate thicknesses for the unit in North Dakota. When the unit is thin, it may not be recognizable if a very well developed soil has formed on it. Where the Oahe Formation approaches .6 meters in thickness, it is easily recognizable on air photos by a characteristic soft, mottled pattern. The extent of the Oahe Formation outside of North Dakota is not known, but it probably occurs along most major river drainages.

Differentiation from other units

The Coteau Formation and the silt and clay facies of the Four Bears Formation are probably the only units that the Oahe Formation can be confused with in the Sakakawea Sequence. Normally, topographic position is useful in differentiating between the two units. The Oahe Formation is normally found draped over the high topography between divides, and the Coteau Formation generally occurs only in valley bottoms, along the base of hillsides, and in closed depressions. However,

Fig. 19.--Distribution of the Oahe Formation. Areas without a pattern are areas where the formation is thought not to occur. Part of the information for the figure was obtained from Omodt and others (1961).



Bickley, 1972

when the Oahe Formation does occur in low areas as it does on the "30-foot" terrace of the Missouri River, it can be distinguished from the Coteau Formation by the lack of pebbles in the Oahe Formation and by the poorer sorting and presence of large amounts of organic material in the Coteau Formation. The Oahe Formation is generally much sandier than the silt and clay facies of the Four Bears Formation. The silt and clay facies of the Four Bears Formation is much clayier than the Oahe Formation. It is also commonly laminated while the Oahe Formation is never laminated.

Origin

The Oahe Formation is mainly of eolian origin, but minor amounts of the unit may be overbank and offshore sediment.

Age

The Oahe Formation is Pleistocene and Holocene in age.

Remarks

The Oahe Formation has been divided into three members: the Mallard Island, Aggie Brown, and Riverdale Members.

<u>Definition of the Mallard Island Member</u>

Name

Mallard Island Member, new name

Source of the name

The Mallard Island Member is named for the Mallard Island in Lake Sakakawea, McLean County, North Dakota.

Definition abstract

The Mallard Island Member is yellow to yellow brown, coarse silt and fine sand. It is unbedded and slightly calcareous. It occurs above the Denbigh Formation and below the Aggie Brown Member of the Oahe Formation.

Type section

The type section of the Mallard Island Member is the type section of the Oahe Formation.

Reference section

The reference section of the Mallard Island Member of the Oahe Formation is the same as that of the Oahe Formation.

Description of the unit

At the type section (Figure 18), Mallard Island Member is unit one of the Oahe Formation.

Regional stratigraphy, distribution, and thickness

See the same section under the Oahe Formation for comments on stratigraphy. The only areas where the Mallard Island Member does not occur are on the lowest terraces and floodplains of streams. The Mallard Island Member is 3 to 4 meters thick at the reference section.

Origin

The material in the type section is eolian in origin (loess). In other areas the unit may also include materials of lacustrine origin.

Age

The Age of the Mallard Island Member of the Oahe Formation is probably late Pleistocene to early Holocene.

Definition of the Aggie Brown Member

Name

Aggie Brown Member, new name

Source of the name

The Aggie Brown Member of the Oahe Formation is named for Aggie Brown Coulee that runs into Lake Sakakawea near the type section of the Oahe Formation.

Definition abstract

The Aggie Brown Member of the Oahe Formation is brown to red brown, coarse silt and fine sand (Figure 18) that occurs between the Mallard Island Member and the Riverdale Member of the Oahe Formation.

Type section

The type section of the Aggie Brown Member is the same as that of the Oahe Formation.

Reference section

The reference section for the Aggie Brown Member is the same as that of the Oahe Formation.

Description of the unit

The Aggie Brown Member is unit two in the type section description of the Oahe Formation.

Nature of the contacts

The contacts of the Aggie Brown Member with the members above and below it are diffuse. The contacts are placed at the position where the first noticeable change from yellow to brown (Mallard Island Member to Aggie Brown Member) and from brown to gray (Aggie Brown Member to Riverdale Member) is seen.

Regional stratigraphy, distribution, and thickness

The Aggie Brown Member of the Oahe Formation has been recognized in several places in North Dakota. Outside of the state the extent of the unit is not known. It is possible that the unit is the equivalent of the "Brady Soil" of the Great Plains. The Aggie Brown Member averages about 15 centimeters in thickness.

Differentiation from other units

Color and stratigraphic position eliminate the possibility that the Aggie Brown Member might be mistaken for any other unit.

Origin

The Aggie Brown Member of the Oahe Formation is eolian (loess) and slopewash sediment. A multiple paleosol is developed in it.

Age

The Aggie Brown Member is interpreted as being late Wisconsinan to early Holocene in age.

Remarks

In designating a soil as a lithostratigraphic unit, I may have violated an article of the Code of Stratigraphic Nomenclature (Article 18a). I am doing this because the separate category made for soils is an unneeded exception. The term "soil" is interpretative, whereas the unit that is interpreted to be a soil is purely descriptive. This descriptive unit has all the physical characteristics and the stratigraphic relationships that any lithostratigraphic unit has; it should be treated as such. The fact that a soil maintains a consistent stratigraphic relationship with other units suggests that the descriptive units that are interpreted to be soils are valid lithostratigraphic units. The Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961) assumes that soils are developed in a pre-existing material; it does not provide for "depositional soils," which the soil formed in the Aggie Brown Member probably are.

Definition of the Riverdale Member

Name

Riverdale Member, new name

Source of the name

The Riverdale Member is named for the town of Riverdale, North Dakota.

Definition abstract

The Riverdale Member is the uppermost unit of the Oahe Formation. The unit consists of unbedded, gray to dark gray silt occurring mainly on uplands but also recognizable in bottomlands. It occurs above the Aggie Brown Member of the Oahe Formation.

Type section

The type section of the Riverdale Member is the same as that of the Oahe Formation.

Reference section

The reference section of the Riverdale Member is the same as that of the Oahe Formation.

Description of the unit

The Riverdale Member (Figure 18) is unit three in the type section of the Oahe Formation.

Regional stratigraphy, distribution, and thickness

The major distribution difference between the occurrence of the Riverdale Member and the Mallard Island Member of the Oahe Formation is that the Riverdale Member occurs on the lowest-most terraces and floodplains of the Missouri and similar rivers; the Mallard Island Member does not. For comments on the regional stratigraphy, see the same section under the Oahe Formation. The Riverdale Member occurs in thickness of up to 2 meters.

Differentiation from other units

For differentiation from other units see the same section under the Oahe Formation.

Origin

At the type section, the Riverdale Member is thought to be completely eolian sediment. Elsewhere, the unit may also be at least partially overbank and offshore sediment.

Age

The Riverdale Member is Holocene in age.

TOPOGRAPHY AND SURFACE PATTERNS

Emmons County can be divided into three general topographic districts: the Missouri Coteau, the Coteau Slope, and the Missouri River Trench. The northeastern and southeastern corners of the county are in the Missouri Coteau. There the drainage is completely nonintegrated. Runoff collects in small closed depressions about 150 meters across. Along the western edge of the county is the Missouri River Trench. Oahe Reservoir (the Missouri River) occupies the bottom of the trench to an elevation of about 500 meters. The trench is several miles across at its widest spot. Between the Missouri Coteau and the Missouri River Trench is the Coteau Slope. The land slopes westward and is completely drained by tributaries of the Missouri River. The Coteau Slope can be divided into three areas: the northern, southern and Beaver Creek (which divides the northern and the southern areas) areas. Streams in the northern area drain directly westward or southwestward into the Missouri River. In the southern area, streams drain directly westward or north-westward into the Missouri River. In the Beaver Creek area, streams flow directly north or south into Beaver Creek and then west into the Missouri River.

Topography in the areas of integrated and nonintegrated regions can be subdivided into four types: flat (0 to 1° slopes), undulating to rolling (1 to 7° slopes), hilly (7 to 25° slopes), and badlands (greater than 25° slopes) topography in areas of integrated drainage; and flat (0 to 1° slopes), undulating to rolling (1 to 7° slopes), hilly (7 to 25° slopes), and steep (greater than 25° slopes) topography in areas of nonintegrated drainage.

At least three distinguishable surface patterns are present in Emmons County.

One pattern is confined to the northeastern corner of the county. It consists of a series of straight, parallel ridges and troughs that trend northnortheast-southsouthwest. Individual lineations are about 75 meters apart and as much as two kilometers long. They are underlain by sandstone of the Fox Hills Formation. Plate 1 shows the occurrence of the lineations within Emmons County.

A second pattern occurs in the southeastern and northeastern parts of the county where either the upper Braddock Formation or Emmons Formation is at the surface. The pattern consists of clusters of arcuate ridges and troughs. Individual ridges are about 2 meters high and as much as 1 kilometer long.

The third pattern is scattered throughout Emmons County. This pattern consists of polygonal-shaped areas delineated by darker-toned lines. Individual polygons are four, five, or six sided and about 15 meters across; a few are as large as 80 meters. Plate 1 shows the distribution of this pattern in Emmons County.

INTERPRETIVE GEOLOGY

GENERAL

Just as lithostratigraphic units are the basis for descriptive geology, the geologic-event and event-stratigraphic units are the basis for the interpretive geology.

Event-stratigraphic units are composed of material interpreted to be the result of a geologic event (Clayton and Moran, 1972). Geologic events are happenings or occurrences. Geologic-event and event-stratigraphic units are interpretive, genetic units. They often have time transgressive boundaries. Because they form the basis for the geologic history interpreted below, the following example may be useful to help clarify the difference between event-stratigraphic and geologic-event units and their relations to lithostratigraphic units.

All of the glacial sediment and associated fluvial and lacustrine sediment in northeastern Emmons County are included in the Braddock and Four Bears Formation (lithostratigraphic units). The Lostwood and Napoleon Glaciations (geologic events) have been interpreted from this sediment and other evidence. Even though they can not be told apart lithologically, the glacial sediment and the associated fluvial and lacustrine sediment of the upper part of the Braddock and Four Bears Formations make up the event-stratigraphic unit associated with the Lostwood Glaciation (a geologic-event unit), and the glacial sediment and the associated fluvial and lacustrine sediment of the lower part of the Braddock and Four Bears Formations make up the event-stratigraphic unit associated with the Napoleon Glaciation (a geologic-event unit). Since both glaciations began earlier in the north and east than they did in the south and west, the event-stratigraphic units have time-transgression boundaries.

Lithostratigraphic units (in this case the Braddock and Four Bears Formation) are descriptive. If they are defined well, they should change little with time. Geologic-event and event-stratigraphic units are interpretive and therefore subject to change as new evidence is uncovered. Instead of two major glaciations, evidence may be found that three or four glaciations occurred in northeastern Emmons County. If this happens, the geologic-event and event-stratigraphic units will change or be modified, but the Braddock and Four Bears Formations will remain the same.

HISTORY OF THE PRE-SAKAKAWEA SEQUENCES

Sauk time

After a period of erosion during the late Precambrian time, the sea advanced over the area depositing the sand, mud, and carbonate that make up the Deadwood Formation. The sea retreated during late Cambrian and early Ordovician time exposing the surface to erosion.

The Williston Basin may have become slightly tectonically negative during the deposition of the Sauk Sequence.

Tippecanoe time

The sea advanced again during the Middle Ordovician and deposited the predominantly clastic Winnipeg Group. By late-middle Ordovician time (deposition of the Red River Formation), carbonate was the predominant sediment being deposited. Except for brief times during which clastic and evaporite deposition predominated, carbonate deposition continued until late Silurian time, when the sea again retreated, exposing the surface to erosion.

The Williston Basin was relatively stable during the Tippecanoe time, but by late Tippecanoe time (deposition of the Stony Mountain and Stonewall Formations), the structure was becoming increasingly tectonically negative.

Kaskaskia time

Carbonate deposition continued during Kaskaskia (Devonian and Mississippian) time. As the basin became more tectonically negative, it also became closed to free circulation of water. When this occurred, evaporites replaced carbonates as the predominant sediment being deposited. At the end of Kaskaskia time (after the deposition of the Big Snowy Group) the sea retreated again exposing the surface to erosion.

Absaroka and Zuni time

For the next 150 to 200 million years during Absaroka and early Zuni time (Pennsylvanian through early Cretaceous time), the area was alternately covered by shallow sea and exposed to erosion.

During Cretaceous time a widespread sea covered the area, depositing first sand and then over 650 meters (2000 feet) of black mud. Near the end of Cretaceous time, the sea again shallowed, depositing the shore and nearshore sand of the Fox Hills Formation. At the end of

Cretaceous time, the coastal plain sediment of the Hell Creek Formation was deposited.

The sea advanced for the last time during early Paleocene time depositing the sand and mud of the Cannonball Formation.

Tejas time

In late Tertiary time, the gravel of the Flaxville Formation was deposited by rivers flowing eastward and northeastward toward what is now Hudson Bay.

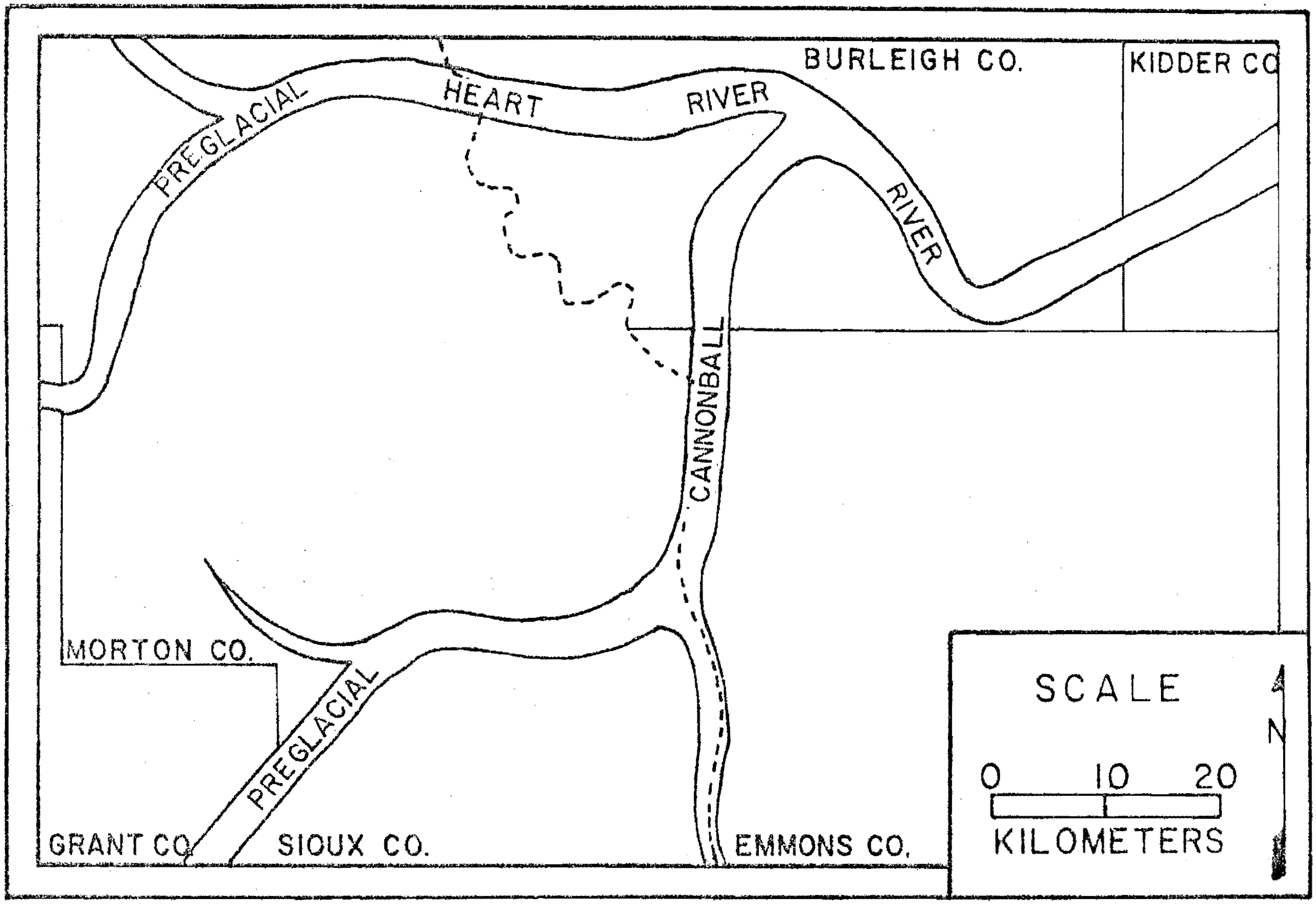
During Tejas time the pre-glacial Cannonball River probably drained much of south-central North Dakota. Figure 20 shows a postulated channel for the river in south-central North Dakota during Tejas time. The following reasons suggest that this channel was the pre-glacial Cannonball channel rather than the Badger Creek Sag as suggested by Kume and Hansen (1965). The channel in Figure 20 is much deeper than the Badger Creek Sag. Western gravel was found in United States Geological Survey Tests Holes drilled into the channel. None has been found in the bottom of the holes drilled into the Badger Creek Sag. The Missouri River Trench (north of the Badger Creek Sag) in the area of pre-glacial Cannonball River is the widest of any area in south-central North Dakota. This suggests that that part of the channel is probably older. If it had been used by the pre-glacial Cannonball River, this would be the case.

HISTORY OF THE SAKAKAWEA SEQUENCE

Dunn Glaciation

Evidence for the outer limit of glaciation in North Dakota is erratic boulders derived mainly from the Canadian Shield. Behind this

Fig. 20.--Diagram showing a possible position of the preglacial Cannonball River in south-central North Dakota.


BURLEIGH CO.
KIDDER CO
PREGLACIAL
HEART
RIVER
RIVER
CANNONBALL
MORTON CO.
PREGLACIAL
GRANT CO.
SIOUX CO.
EMMONS CO.
SCALE
N
0
10
20
KILOMETERS

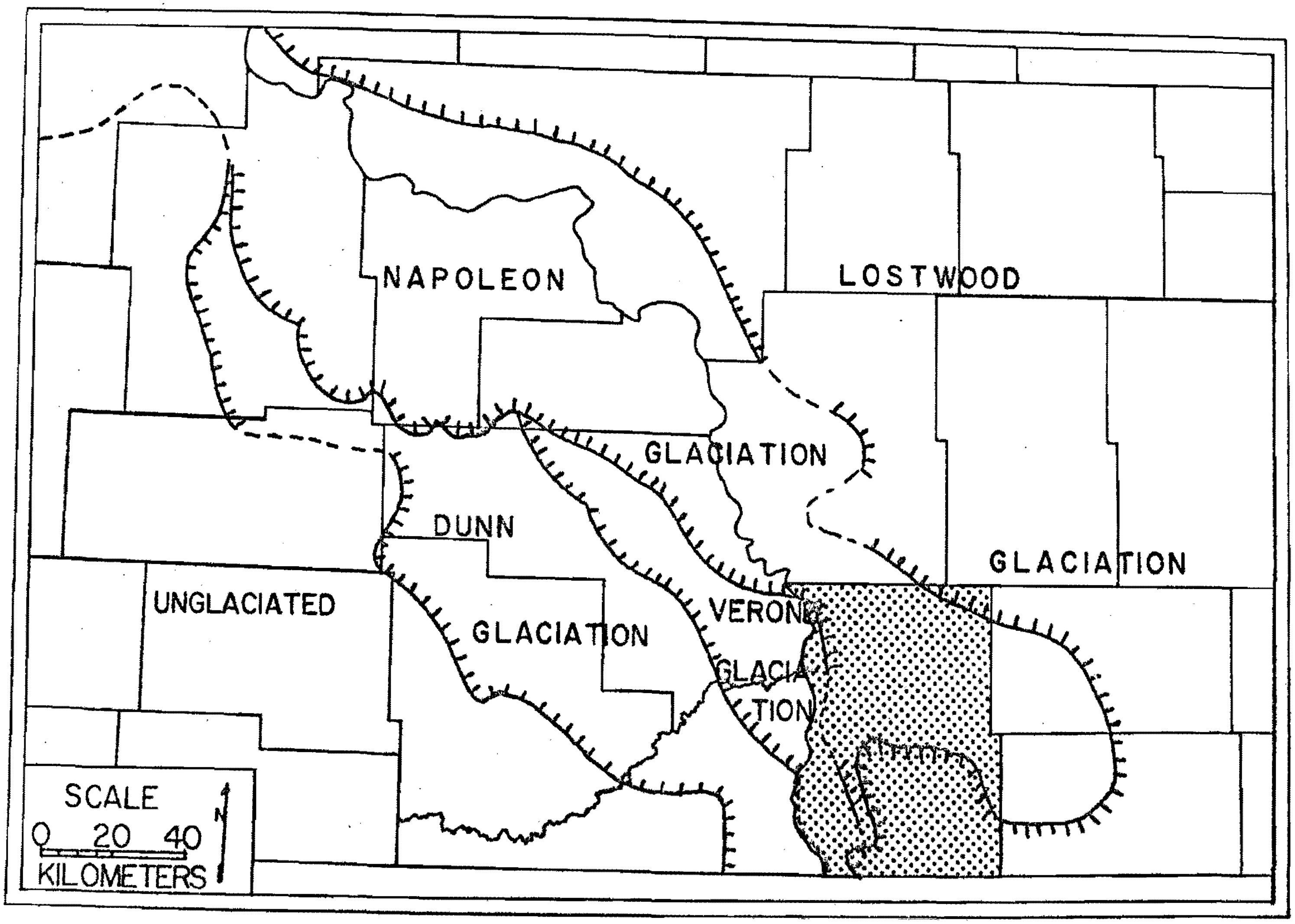
outer limit, the concentration of boulders is about one per linear mile back to the border of the next younger glaciation (Verone). It is probable that these boulders are the result of several glaciations, but until evidence for this is found, it seems reasonable to accept this uniform boulder concentration as being the result of one glaciation. At present, no other evidence of this glaciation exists.

Clayton (no date) called this initial glacial event the Dunn Glaciation after Dunn County, North Dakota. The Dunn Glaciation is pre-Wisconsinan in age; a more precise estimate of the age can not be given. However, the following reasons suggest that the Dunn Glaciation is very old. Clayton (no date) pointed out that an average of at least 60 meters of erosion has occurred since the Dunn Glaciation. This erosion destroyed any evidence of the ice-marginal channel that must have existed to carry water south around the ice. As the Dunn ice advanced, it blocked the northeastward drainage of the pre-glacial Cannonball and other northeastward flowing rivers forcing them to flow south around the ice. Because the rivers probably remained blocked for a long time, an ice-marginal channel formed. The large amount of erosion, indicated by lack of till and the presence of only scattered boulders, suggests that the Dunn Glaciation is very old.

The position of Emmons County (stipled pattern) in relation to the Dunn glacial limit is shown in Figure 21.

After the retreat of the Dunn Glacier, the regional drainage may have again shifted northeastward. If it did, it was subsequently forced southward by ice for which there is as yet no conclusive evidence. By the beginning of the next documented glaciation (Verone),

Fig. 21.--Diagram showing the approximate maximum positions of the four known major glaciations with respect to Emmons County, North Dakota (speckled area).


NAPOLEON
LOSTWOOD
GLACIATION
DUNN
GLACIATION
UNGLACIATED
GLACIATION
VERONA
GLACIA
TION
SCALE
0 20 40
KILOMETERS
N

there is evidence to suggest that the major drainage was southward.

Verone Glaciation

The Verone Glaciation (Bickley, 1972) advanced across North Dakota long after the Dunn Glaciation. Two lines of evidence suggest the existence of the Verone Glaciation. First, even though no till exists in the area of the Verone Glaciation, the boulder concentration behind the Verone glacial boundary is much greater than (approximately 10 to 20 per linear mile), and just as uniform as, that of the Dunn Glaciation. Second, an ice-marginal channel (the Glen Ulen, Flasher, Fort Yates channel) is present everywhere in front of the Verone ice border. Figure 21 shows the limit of the Verone Glaciation in North Dakota.

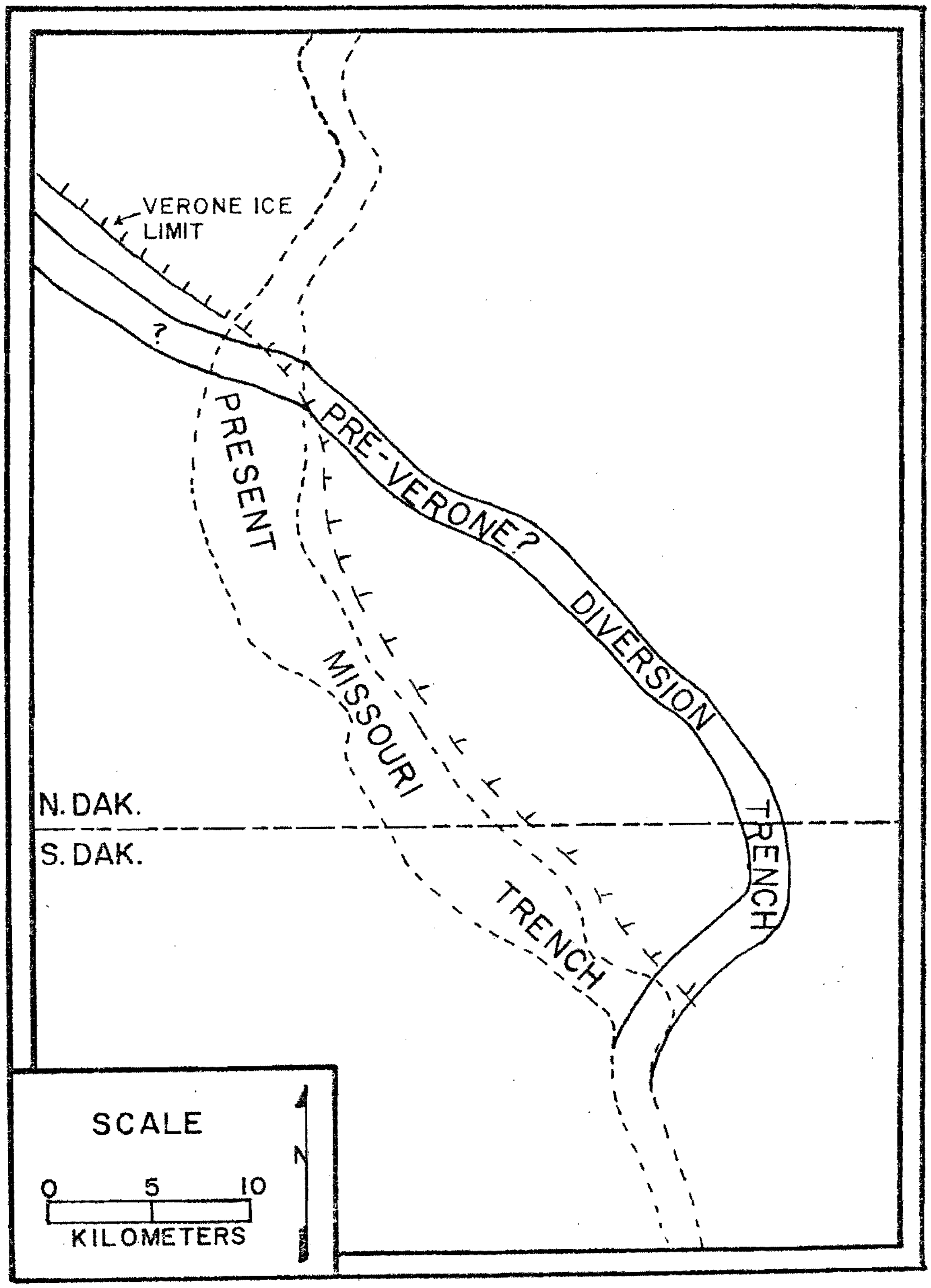
The Verone Glaciation is post-Dunn and pre-Napoleon in age. The preservation of the ice-marginal channel, due to much less erosion, in front of the Verone glacial boundary suggests that the Verone Glaciation is much younger than the Dunn Glaciation.

As the Verone ice advanced to the western part of Emmons County, it blocked the pre-Verone river that was flowing across southwestern Emmons County, Figure 22. The river was diverted along the front of the Verone glacial limit into or near what is now the Missouri River Trench. One of the widest spots in the Missouri River Trench in south-central North Dakota (over three miles wide) is in the area of the diversion suggesting that this part of the trench has been used for a longer period of time than areas to the north or south of the diversion.

Napoleon Glaciation

After an extensive period of erosion, during which most of the

Fig. 22.--Diagram showing the location of a pre-Verone Glaciation river thought to have been diverted by the advancing Verone ice.


VERONE ICE LIMIT
?
PRE-VERONE? DIVERSION TRENCH
PRESENT MISSOURI TRENCH
N. DAK.
S. DAK.
SCALE
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10
KILOMETERS
N

sediment related to the Verone Glaciation was removed, the Napoleon Glacier advanced across Emmons County. Figure 21 shows the limit of the Napoleon Glaciation.

The lower part of the Braddock Formation is interpreted to be the drift deposited by the Napoleon ice. Napoleon glacial sediment occurs as a continuous blanket on the uplands in eastern-most Emmons County. Here the drainage is still nonintegrated. West of the limit of continuous glacial sediment, the drainage is largely integrated and the glacial sediment occurs in scattered patches; a few areas of non-integrated drainage still remain in the area.

On the uplands in eastern Emmons and western Logan and McIntosh Counties where the topography is nonintegrated and essentially uneroded, the local relief is about 6 to 9 meters. This suggests that the glacial sediment here is about the same thickness (Clayton, 1967). West of the area of continuous glacial sediment, the glacial sediment averages less than 3 meters thick. In all but the northeastern corner of Emmons County, the yellower, more sandy Napoleon glacial sediment is easily distinguishable from the darker, brown to olive gray, clayey Lostwood glacial sediment.

The contact between the two glacial sediments can best be seen (Figure 10) in McIntosh County, at the type section of the Braddock and Emmons Formations. There, an irregular zone of carbonate accumulation occurs at the top of the Napoleon sediment. This zone of accumulation may be the Cca horizon of a truncated soil, or the carbonate concentration may be due to groundwater movement along the contact.

In the northeastern part of the county, the Napoleon glacial sediment is lithologically indistinguishable from the overlying Lostwood glacial sediment.

The direction of movement of the Napoleon ice can be obtained from two lines of evidence. Linear ridges (Plate 1 and Figure 23) occur in northeastern Emmons County. These ridges occur in or on sandstone and are confined to areas of the Napoleon Glaciation. They are interpreted to be subglacial scour marks made as the Napoleon ice advanced over the area. Their orientation indicates the Napoleon ice flowed southsouthwest. An alternative interpretation is that the ridges are exhumed beach ridges in the Fox Hills Formation. If they were exhumed by the Napoleon ice, the part of the ridge most likely to be preserved would be that part of the ridge parallel to the direction of flow of the ice. Thus they would still be an indicator of flow direction.

Napoleon glacial sediment is much sandier and contains fewer shale pebbles than the Lostwood glacial sediment (excepting that glacial sediment in the northeastern corner of the county). The high sand content and the low shale content in the Napoleon glacial sediment suggests that the Napoleon ice advanced from a northerly direction, rather than an easterly direction. The Fox Hills, Hell Creek, and Cannonball Formations (sources for the sand) outcrop and subcrop to the north, whereas the Pierre Formation (shale) occurs to the east.

The Napoleon glacial sediment is much thinner than the younger Lostwood glacial sediment. This indicates that it was deposited by a cleaner ice sheet that contained less debris than the ice that deposited the Lostwood glacial sediment. This in turn suggests that the flow regime of the ice was different from that of the Lostwood ice. The

Fig. 23.--Picture showing linear ridges and depressions that are thought to be subglacial scour features made by the ice of the Napoleon Glaciation. These features are on Fox Hills Formation located in sec. 18 and 19, T. 135 N., R. 74 W., Emmons County, North Dakota


1/2 Mile

Napoleon ice apparently did less scraping, grinding, abrading, and gouging as it advanced into Emmons County than the Lostwood ice did. This suggests that the flow direction of the Napoleon ice was from the north along the top of the Missouri Escarpment. In this situation, flow would be parallel or even possibly extending. When this type of flow occurs, little material is eroded from the surface over which the ice flows.

The flow direction suggested by the texture, mineralogy, and scour marks agrees generally with the flow direction suggested by the Napoleon glacial border (Figure 21).

As with the Dunn and Verone Glaciations, no conclusive evidence exists for the exact age of the Napoleon Glaciation. Three possible dates (two absolute and one relative) have been obtained from materials thought to be related to the Napoleon Glaciation. However, problems exist with each date. Kume and Hansen (1965) found a horse jaw, *Equus hatcheri* Hay, in Napoleon gravel in Burleigh County. The jaw is thought to be pre-Wisconsinan to early Wisconsinan in age. However, this fossil may have been eroded from older deposits. One radiocarbon date on mollusks was greater than 38,000 B.P. However, this date may have been contaminated by Tertiary mollusks (Kume and Hansen, 1965). Another radiocarbon date from organic material considered to be Napoleon was 28,700 B.P.; however, Clayton (1966) thinks that the material dated was Tertiary lignite contaminated by modern rootlets.

Thus there are no reliable dates on the Napoleon Glaciation. The degree of drainage integration suggests that it occurred much earlier than the Lostwood Glaciation. Soil development (the Williams and Zahl soil series are developed on both Lostwood and Napoleon glacial sediment) suggests that the Napoleon Glaciation is not extremely old.

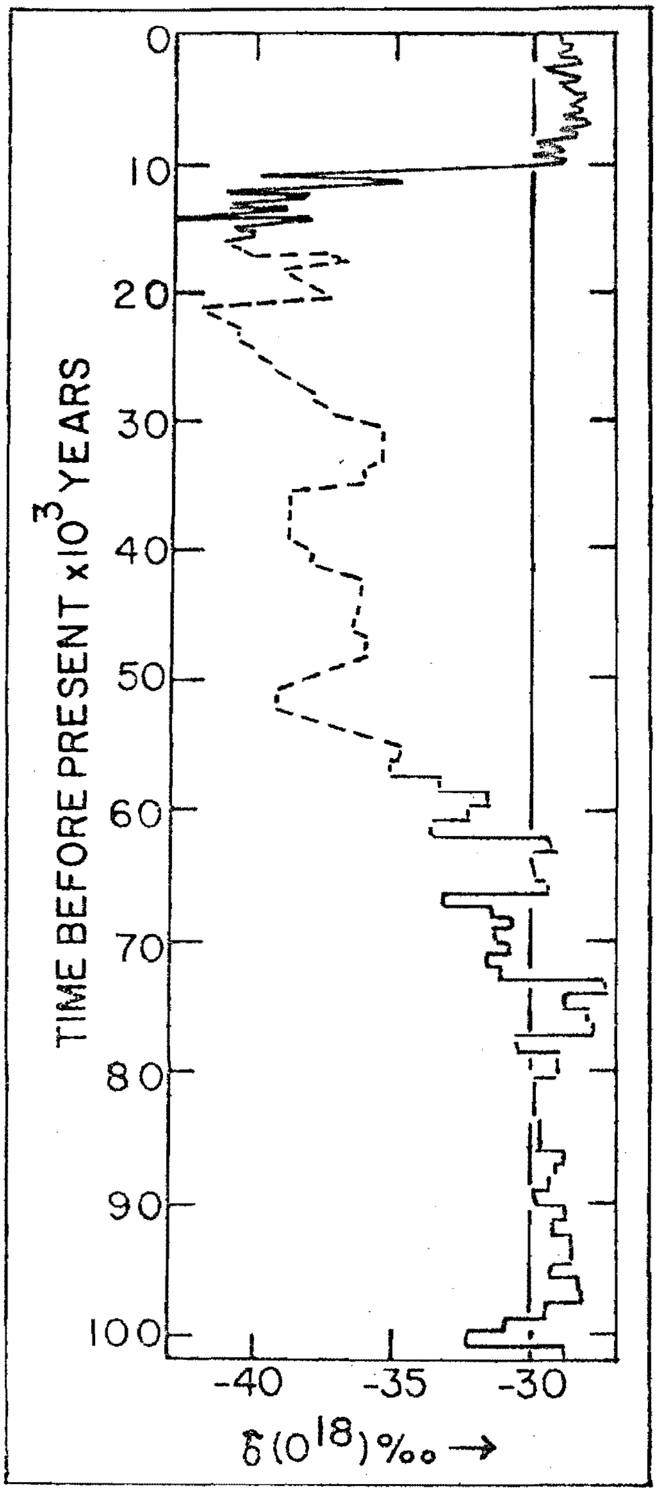
An age for the Napoleon Glaciation is suggested by oxygen isotope curves from Greenland (Figure 24; Dansgaard and others, 1969). The curve shows the climatic variations for the last 100,000 years based on oxygen isotope ratios. This curve agrees generally with the presently accepted worldwide climatic fluctuations.

The concentration of O_{18} in precipitation is controlled by the temperature. The lower the temperature, the less the amount of O_{18} in water, and thus the smaller O_{18}/O_{16} ratio.

The Napoleon glacial sediment is not strikingly more weathered than the Lostwood glacial sediment, suggesting that it is probably not pre-Wisconsinan. However, it probably is older than late Wisconsinan because of the more eroded topography. Thus, if the first cold period in Figure 24 (approximately 13,000 to 23,000 B.P.) is considered to represent the Lostwood Glaciation, then the Napoleon Glaciation may have occurred during either the second (approximately 35,000 to 42,000 B.P.) or third (48,000 to 55,000 B.P.) cold episode. This is purely speculative and until a post-Napoleon slough chronology, volcanic ash chronology, valid carbondating, or magnetic stratigraphy is obtained, any age suggested for the Napoleon Glaciation is open to question.

Aside from radiocarbon dating, magnetic stratigraphy offers perhaps the best promise for placing a minimum date on the Napoleon Glaciation, if refinements of the magnetic time scale continue at their present rate. It may be possible to use depositional remanent magnetism

Fig. 24.--Oxygen isotope curve taken from Dansgaard and others (1969). The horizontal axis is the isotope composition of snow and ice denoted by the relative deviation $\delta(O_{18})$ in per mille, of the O_{18}/O_{16} ratio from that of Standard Mean Ocean Water.


TIME BEFORE PRESENT x10^3 YEARS
0
10
20
30
40
50
60
70
80
90
100
-40
-35
-30
δ(O^{18})‰ →

to recognize such magnetic events as the Laschamp reversal in sloughs developed on the Napoleon surface.

Lostwood Glaciation

Ice of the Lostwood Glaciation was the last ice to advance across Emmons County. Figure 25 shows the maximum extent of the Lostwood Glaciation.

The Emmons Formation is interpreted to be glacial sediment and part of the Four Bears Formation is interpreted to be fluvial and lacustrine sediments in association with ice of the Lostwood Glaciation in southern Emmons County. Two phases, Cattail Creek and Zeeland, are recognized within the Lostwood Glaciation in southern Emmons County.

Cattail Creek Phase

Ice of the Cattail Creek Phase of the Lostwood Glaciation probably advanced to its maximum position (Figure 26) before 17,000 B.P. (Figure 24). Lack of "end moraine" type topography suggests the active ice-margin remained in this maximum position for only a short period of time before it retreated to a position behind the Zeeland Phase maximum position.

Zeeland Phase

Roughly 15,000 B.P. (Figure 24) the ice of the Zeeland Phase of the Lostwood Glaciation advanced to the position shown in Figure 26. The Zeeland End Moraine (Clayton, 1962) can be traced for a short distance (about 6 miles) into Emmons County.

Loess (Mallard Island Member of the Oahe Formation) is preserved on the glacial sediment deposited by the ice of the Cattail Creek Phase

Fig. 25.--Diagram showing the probable extent of the Lostwood Glaciation in Emmons County, North Dakota. Dots indicate location of fossil tundra polygons.

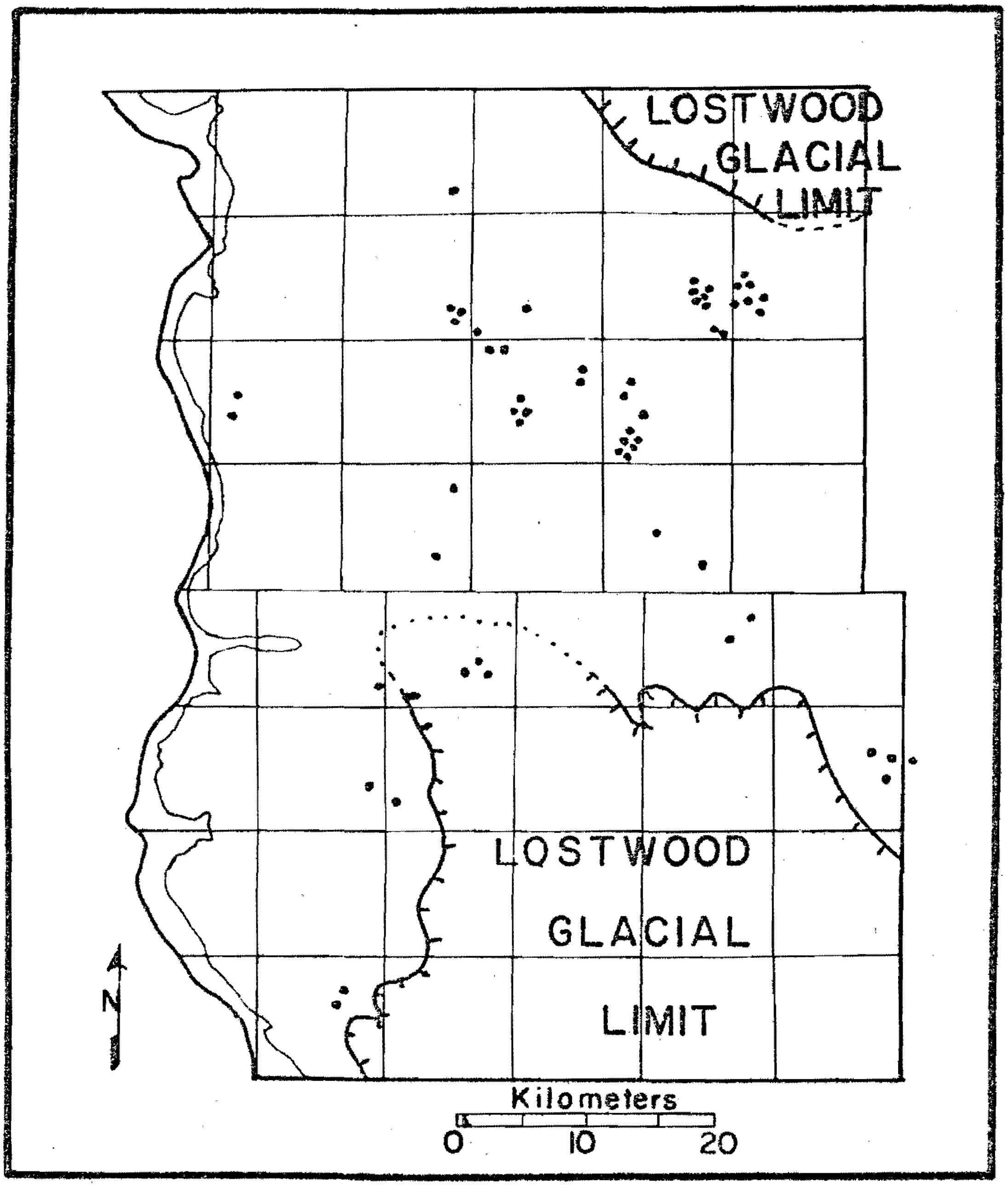
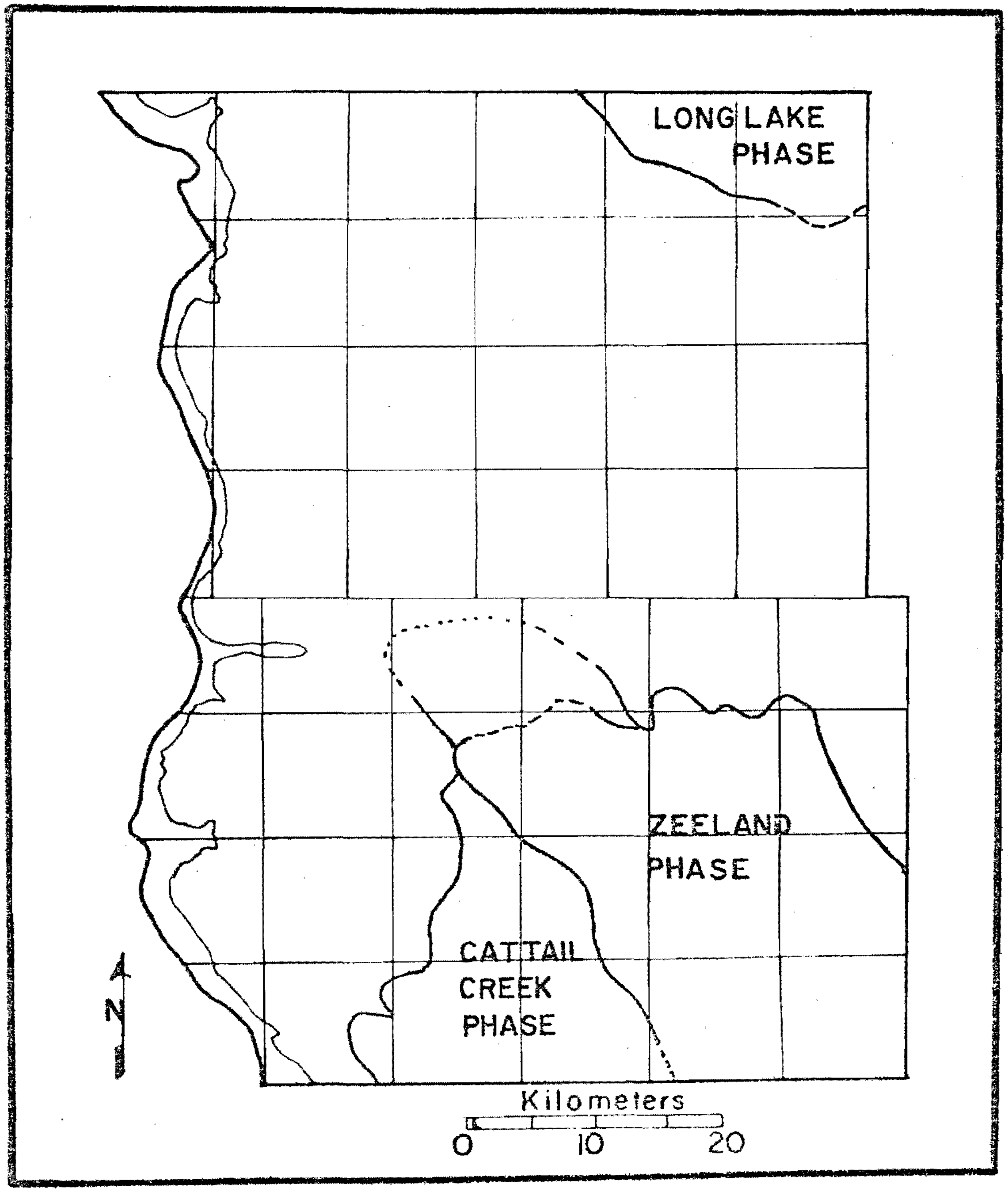

LOSTWOOD
GLACIAL
LIMIT
LOSTWOOD
GLACIAL
LIMIT
N
Kilometers
0
10
20

Fig. 26.--Diagram showing probable extent of the three phases of the Lostwood Glaciation, based on distribution of glacial sediment interpreted to be Lostwood in age.

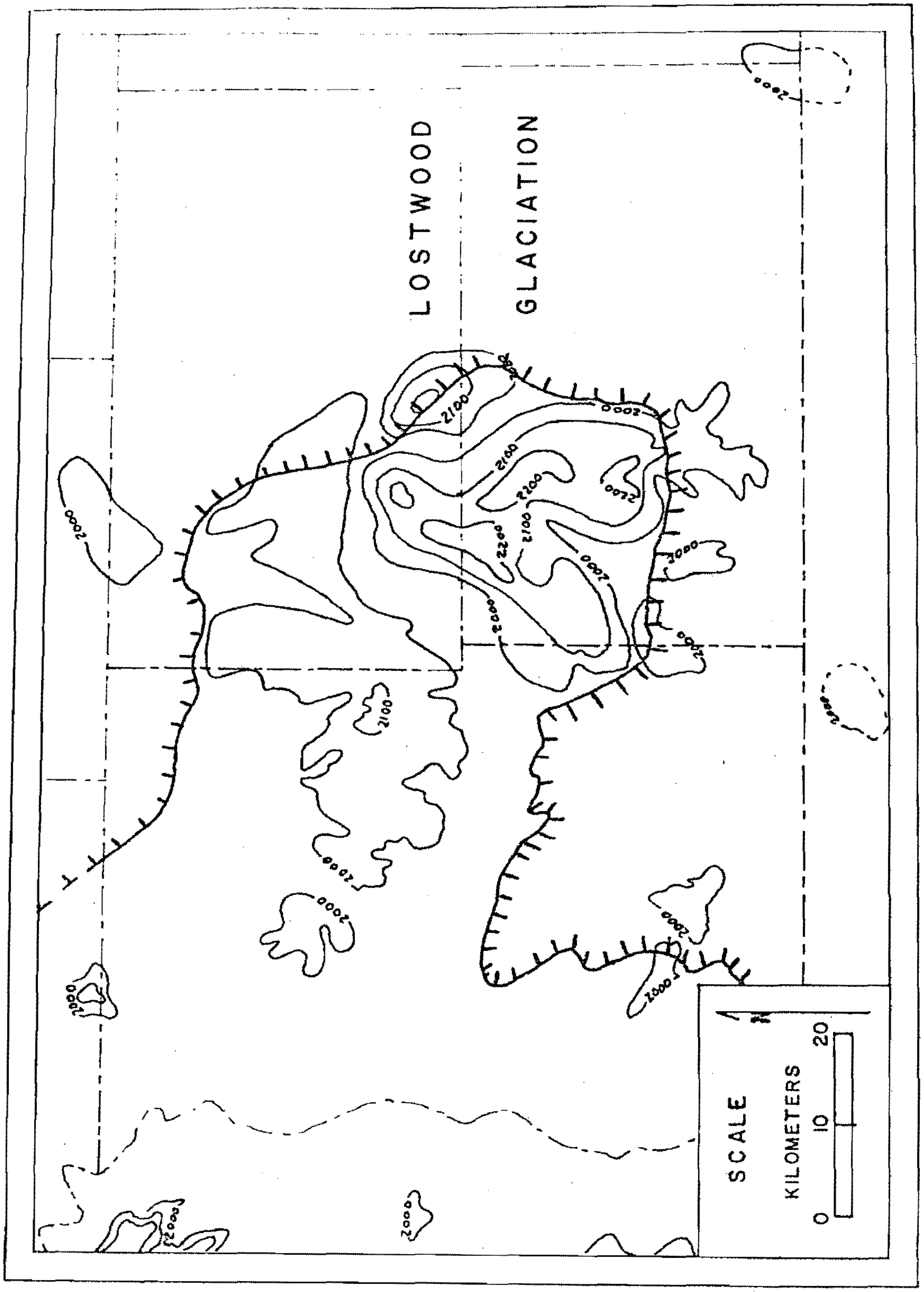

LONG LAKE
PHASE
ZEELAND
PHASE
CATTAIL
CREEK
PHASE
N
Kilometers
0
10
20

of the Lostwood Glaciation. The boundary between the Cattail Creek and Zeeland Phases is placed where the loess of the Mallard Island Member of the Oahe Formation is no longer present on Lostwood glacial sediment. Since the ice of the Zeeland Phase stagnated later than the of the Cattail Creek Phase, any loess of the Mallard Island Member of the Oahe Formation deposited in the Zeeland superglacial sediment was incorporated into the glacial sediment as the ice melted. The glacial sediment of the two phases of the Lostwood Glaciation in southern Emmons County are very similar and it is difficult to tell them apart. It may be impossible to do so, except where loess of the Mallard Island Member of the Oahe Formation is preserved between them.

The apparent shape of the Lostwood ice (Figures 21 and 25) and the orientation of the arcuate lineations interpreted to be washboard moraines in Emmons County, indicate the Lostwood ice advanced from the south and southeast. The topography was responsible for this. Figure 27 is a topographic map of the bedrock surface of south-central North Dakota and north-central South Dakota. The Lostwood Glacial limit is shown on it as a dashed line. The Lostwood ice followed the path of least resistance as it flowed across eastern Logan and McIntosh Counties. When it came in contact with high topography in the central part of the counties, it flowed southward into South Dakota around the topographic high and then back into Emmons County. This path of movement accounts for the high clay and shale content in the glacial sediment. While the ice was moving along this path, it was continuously on Pierre Formation.

Cattail Creek, Little Beaver Creek, Beaver Creek, and the South Branch of Beaver Creek drained water away from the Lostwood ice in

Fig. 27.--Diagram showing position of the Lostwood glacial limit with respect to the topographic high (2000 feet and above) in south-central North Dakota.


LOSTWOOD
GLACIATION
2000
2100
2200
SCALE
KILOMETERS
0
10
20
N

southern Emmons County. The South Branch of Beaver Creek may have been cut as a result of the advance of the Lostwood Ice. The Lostwood glacial advance into southern Emmons County blocked the generally westward drainage of the streams in that area. When this occurred, water was channeled around the margin of the ice sheet into Beaver Creek. As this happened, the valley for the South Branch of Beaver Creek was cut.

Long Lake Phase

Figure 26 shows the limit of Long Lake Phase of the Lostwood Glaciation.

The upper part of the Braddock Formation and most of the Four Bears Formation in northeastern Emmons County are interpreted to be glacial sediment and associated fluvial and lacustrine sediments deposited by the ice of the Long Lake Phase. The sediment deposited by the ice of the Long Lake Phase can generally be separated from the older sediment of the Napoleon Glaciation by its nonintegrated, uneroded appearance. Texturally, the composition of the sediment of these two glacial events is very similar.

The trench of the Long Lake Creek drained water away from the Long Lake ice margin in Emmons County north into glacial Lake McKenzie in central Burleigh County.

The age of the Long Lake Phase is unknown, but the lack of development of drainage on the Long Lake surface suggests that it is late Wisconsinan. Clayton (1962) and Kume and Hansen (1965) reported that the glacial sediment deposited by the ice of the Long Lake Phase appears to be overlapped by sediment of the Burnstad Phase in Logan and Burleigh Counties. If this is so, the Long Lake Phase is pre-Burnstad. No loess of the Mallard Island Member of the Oahe Formation occurs on the sediment of the Long Lake Phase indicating that it is younger than the Cattail Creek Phase. The Long Lake Phase may be the same age as the Zeeland Phase in Emmons County, but no evidence exists to prove or disprove that the two events were contemporaneous.

Stagnation of the Lostwood Glacier in Emmons County probably began about 13,000 to 12,000 B.P. As the ice melted, the glacial topography seen today began to form.

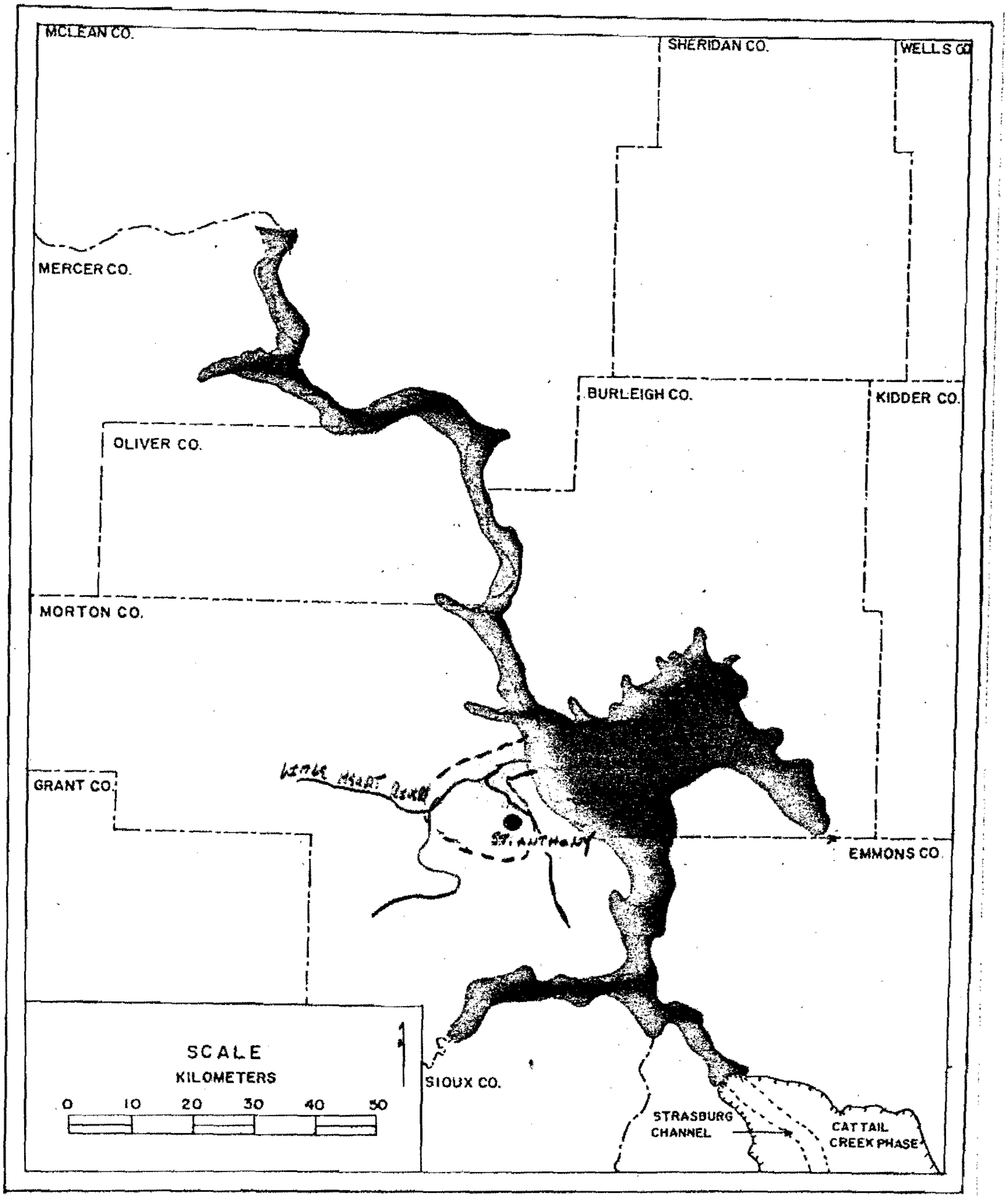
As the ice melted, englacial debris accumulated on top of the ice. As the debris thickened, it insulated the ice from melting; melting occurred more slowly. After the ice was insulated, vegetation migrated onto the debris-covered ice, lakes formed, and an environment very similar to present day north-central Minnesota developed (Bickley, 1970; Thompson, 1962; McAndrews, Stewart, and Bright, 1967; and McAndrews, 1967).

Lake McKenzie

Immediately before the Lostwood Glaciation, the Missouri River flowed across southern Emmons County in the Strasburg Channel. Kume and Hansen (1965) mapped the deposits of Lake McKenzie in Burleigh County; they suggested that the lake formed as a result of Lostwood ice blocking the Missouri River in the Strasburg Channel, although they gave no evidence for it. Evidence from Emmons County indicates that this in fact is the only likely explanation for the origin of Lake McKenzie.

Figure 28 shows the minimum extent of Lake McKenzie based on preservation of lake sediment in Burleigh County. The map shows that water backed up into the Strasburg Channel behind the ice until it

Fig. 28.--Diagram showing the maximum probable extent of Lake McKenzie based on the 1750 foot contour.


MCLEAN CO.
SHERIDAN CO.
WELLS CO
MERCER CO.
BURLEIGH CO.
KIDDER CO.
OLIVER CO.
MORTON CO.
GRANT CO.
ST. ANTHONY
EMMONS CO.
SCALE
KILOMETERS
0 10 20 30 40 50
SIOUX CO.
STRASBURG CHANNEL
CATTAIL CREEK PHASE

covered the area originally mapped as Lake McKenzie. More than 15 meters of lake silt and clay of the Four Bears Formation have been recovered from holes drilled into the Strasburg Channel. This lake sediment is post-Napoleon because it has no glacial sediment on top of it. No other place where the lake could have been dammed is known to exist. Lake McKenzie existed until after the lake rose to an elevation where it was able to flow over the drainage divide to the southwest into a much older part of the Missouri River Trench. The new section of channel cut through the drainage divide is the narrowest part of the Missouri River Trench in south-central North Dakota.

Lake Standing Rock

Lake Standing Rock formed when ice advanced across the Missouri River Trench in north-central South Dakota. The age of the lake is not known, but the occurrence of lake sediment below the "30-foot terrace" (thought to be late Lostwood in age) indicates the lake is at least early Lostwood in age. It may be much older. Lake sediment of Lake Standing Rock is known to occur at the following locations: SW$\frac{1}{4}$ sec. 31, T. 129 N., R. 79 W.; NE$\frac{1}{4}$ and SE$\frac{1}{4}$ sec. 13, T. 130 N., R. 80 W.; SE$\frac{1}{4}$ and NE$\frac{1}{4}$ sec. 29, T. 131 N., R. 79 W.; and sec. 28, T. 131 N., R. 80 W.

Lostwood Permafrost Episode

Permafrost is a characteristic feature of cold climates. While modern permafrost has been noted frequently in Alaska, Canada, Europe, and Asia, very little evidence for permafrost related to Pleistocene glaciation in central North America has been noted. Clayton and Bailey (1970) documented Pleistocene permafrost in western North Dakota.

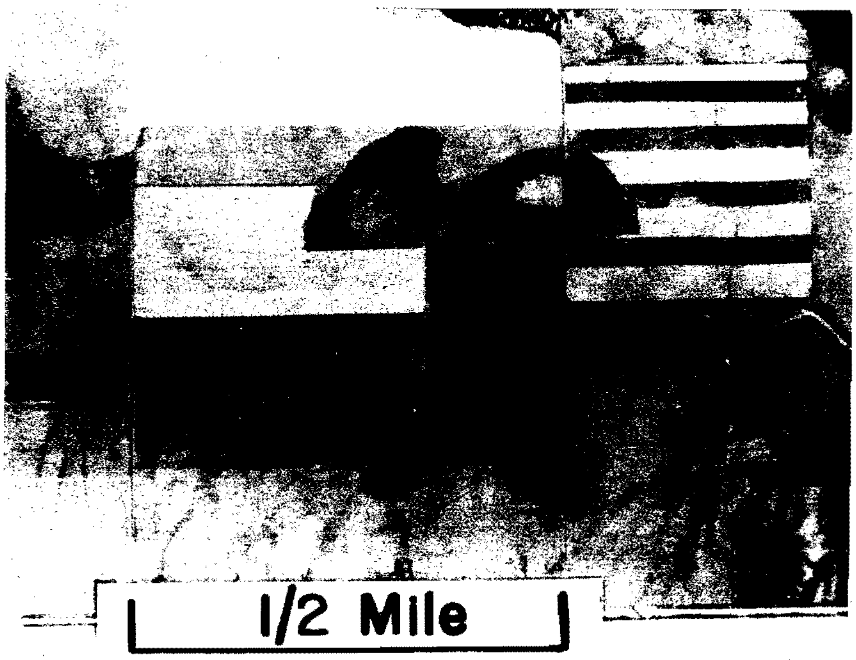
Others who have documented such features include Black (1969), Wayne (1967), Sharp (1942), and Morgan (1972). The fact that very few geologists have seen permafrost features (probably because they were overlooking them) has led to the misconception that there was no permafrost associated with the late Wisconsinan Glaciation. Figure 25 shows the location of permafrost polygons in Emmons County. Figure 29 shows one of the larger polygons in Emmons County, and Figure 30 shows the modern polygons in Alaska. Most of the polygons plotted on the map in Figure 25 are 15 to 34 meters across, but the largest one seen in Figure 29 is greater than 90 meters across. Almost all of the permafrost polygons seen in Emmons County occur on surfaces not covered by ice of the Lostwood Glaciation, probably because the polygons form only during glacial advance (a cold climate) and not during the retreat of the ice (a warm climate). The three polygons that occur on the Lostwood surface are on material deposited by the ice of the earlier Cattail Creek Phase. Work by Morgan (1972) appears to confirm the interpretation that permafrost conditions exist only during times of glacial advance.

Thirty-Foot Missouri River terrace

One of the prominent features along the Missouri River is the "30-foot" terrace. This terrace probably formed during the Lostwood Glaciation because the loess of the Mallard Island Member of the Oahe Formation that occurs on the Cattail Creek surface is not found on the terrace, whereas the loess of the Aggie Brown Member and the Riverdale Member, which are Holocene in age, (discussed in the following section)

Fig. 29.--Air photo picture of fossil tundra polygons in sec. 22, T. 132 N., R. 77 W., Emmons County, North Dakota.

Fig. 30.--Oblique aerial photograph of large-scale polygonal ground in the Donnelly Dome area, Alaska (from Pewe and others, 1969).


1/2 Mile

do occur on the terrace. The "30-foot" surface also appears to correlate (based on elevations from $7\frac{1}{2}$ minute topographic map sheets) with surfaces related to the Lostwood Glaciation, along Painted Woods Creek in Burleigh County and the Middle Branch of Douglas Creek in McLean County.

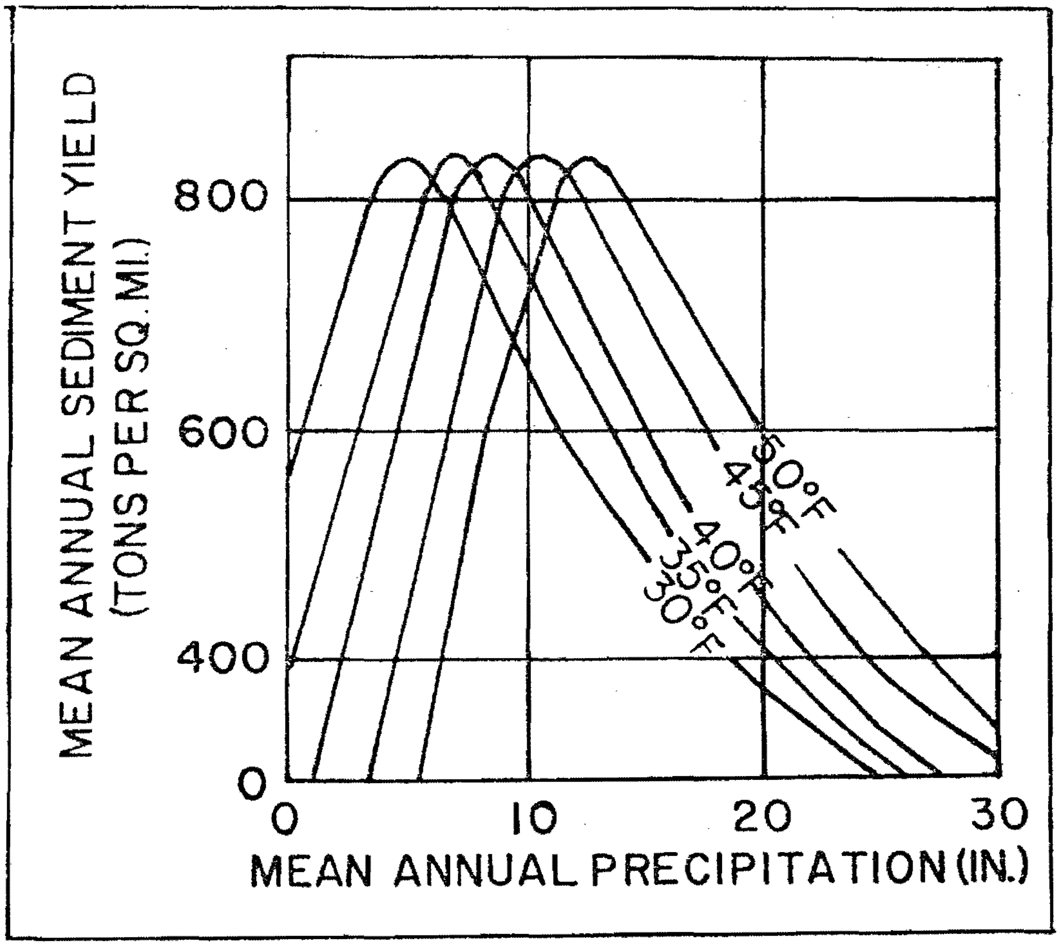
Hillslope stability during the late Pleistocene (last 12,000 years)

The history of the late Pleistocene of Emmons County and south-central North Dakota, as interpreted from sediment of the Coteau, Denbigh, and Oahe Formations, can best be discussed in terms of hillslope stability and instability.

According to Schumm (1965), hillslope stability is largely controlled by variations in overland flow and vegetation, which are in turn controlled by precipitation and temperature. Figure 31 shows that sediment yield from hillslopes increases rapidly as effective precipitation increases in warm areas, because of an increase in overland flow. The increased overland flow does not supply enough moisture to support a protective vegetation cover. Just the opposite situation occurs on the other side of the curve in Figure 31. In moist areas, increased effective precipitation causes a decreased sediment yield, even though overland flow is greater. Here the increased moisture is enough to support a protective vegetation cover. In general, moist climates are associated with cool conditions and dry climates are associated with warm conditions.

The peaks of the curves in Figure 31 correspond to the transition from desert shrubs to prairie grass. Thus a dry period would cause increased sediment yield in a cool, moist area like North Dakota and a decreased sediment yield in a warm, dry area like Arizona. In North

Fig. 31.--Curves illustrating the effect of the temperature on the relation between mean annual sediment yield and mean annual precipitation (modified from Schumm, 1965).


MEAN ANNUAL SEDIMENT YIELD
(TONS PER SQ. MI.)
800
600
400
0
0
10
20
30
MEAN ANNUAL PRECIPITATION (IN.)
50°F
45°F
40°F
35°F
30°F

Dakota, warmer, drier episodes should be accompanied by hillslope erosion, increased eolian activity, alluviation, and depositions of large amounts of coarse, nonorganic sediment in sloughs, whereas cooler, moister periods should be accompanied by soil formation, decreased eolian activity, and the deposition of smaller amounts of organic sediment in postglacial sloughs (Bickley, 1972; Bickley and Clayton, 1972; Clayton and Moran, 1971; and Hamilton, 1967).

Using this theory and the climatic chronology generally accepted for the last 15,000 years (Bryson, Baerris, and Wendland, 1970), the following sequence of events can be interpreted. Deposition of the loess of the Mallard Island Member of the Oahe Formation began, during what is here designated the McCarny Unstable Episode, with the initation of the Lostwood Glaciation and continued for as long as meltwater was flowing into the Missouri River. Most of the loess appears to have been derived from the Missouri River flood plain. About the time meltwater flow had ceased (13,000 to 12,000 B.P.) what is here designated as the Leonard Stable Episode began. Spruce woodland migrated into the area (McAndrews, 1967; Moir, 1958; and Bickley, 1972). Under the forested condition, the paleosol of the Aggie Brown Member of the Oahe Formation formed. Development of the forest soil continued until a warming climate caused the vegetation to change to grass about 10,000 B.P., then a prairie soil began to develop. As the climate became warmer and drier, hillslope stability decreased, and about 8500 B.P. what is here designated the Wolf Creek Unstable Episode began. At this time, deposition of the loess of the Riverdale Member of the Oahe Formation began. During this time, barchans formed on the flood plains, lake plains, and other areas where a source of sand existed. In Emmons County these areas include the Cattail Creek valley, Sand Creek valley, Beaver Creek valley, and the Strasburg Channel. About 4500 B.P. the climate became cooler and moister and what is here designated the Thompson Stable Episode began. The Thompson Soil (Figure 18) formed under tall grass vegetation. The increased sod cover also stabilized the sand dunes.

In the late Holocene, the climate again became warmer and drier. During what is here designated the Garrison Unstable Episode, deposition of gray loess (Riverdale Member of the Oahe Formation) began again. The Jules Paleosol (Figure 32) formed during the cool, moist Jules Stable Episode that followed (Hamilton, 1967). Development of the Jules Soil continued until about 1928 when the "Dirty Thirties" Unstable Episode began. During the "Dirty Thirties" sod cover thinned, hill-slopes became more unstable, and eolian activity increased. Barchans, formed during the Wolf Creek Unstable Episode (Middle Holocene), were modified into blow out dunes. Figure 33 is an air photo taken of the Sand Creek area in 1938, about the end of the "Dirty Thirties." Figure 34 is an air photo of the same area in 1961. About 1938, when the climate again became cooler and moister, what is here designated the Mandan Stable Episode began. Development of the modern soil began at this time.

This history discussed in the preceeding paragraphs agrees with the history developed from the study of postglacial sloughs (Coteau Formation) (Cvancara and others, 1971; Bickley, 1970; and Bickley and Clayton, 1972). The general stratigraphic sequence (Figure 35) in the sloughs from top to bottom is as follows: (1) boulder clay; (2) lam-

Fig. 32.--Picture showing Jules Paleosol (?) in Emmons County, North Dakota.

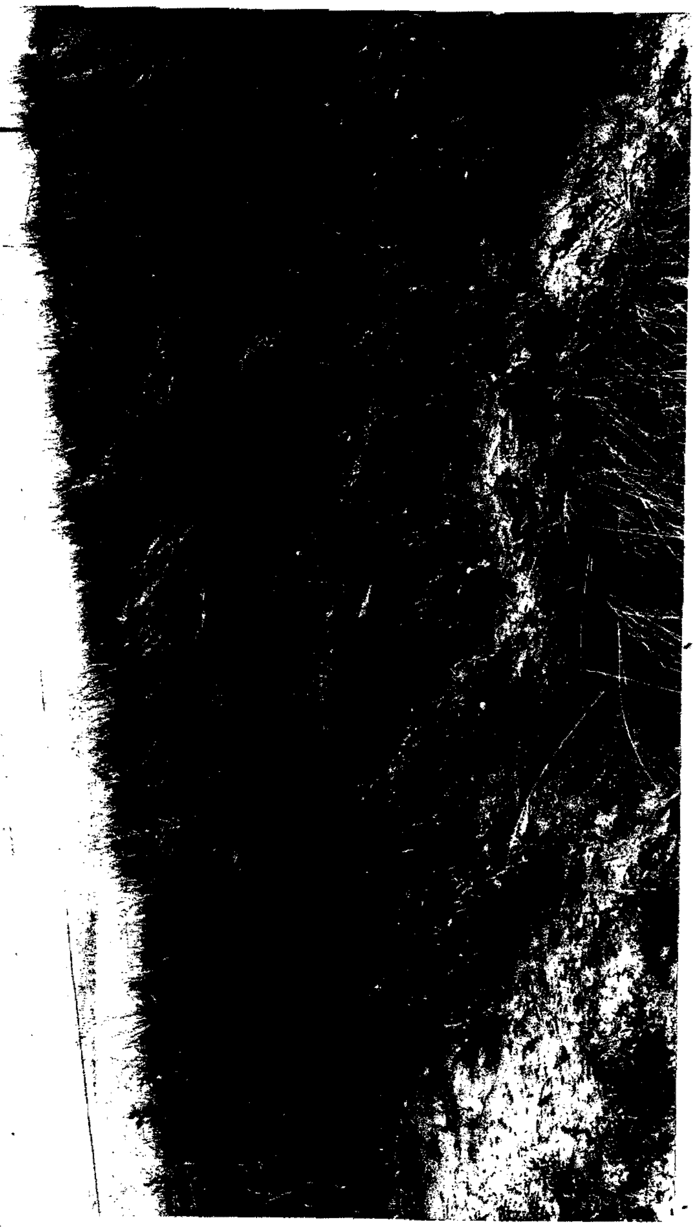
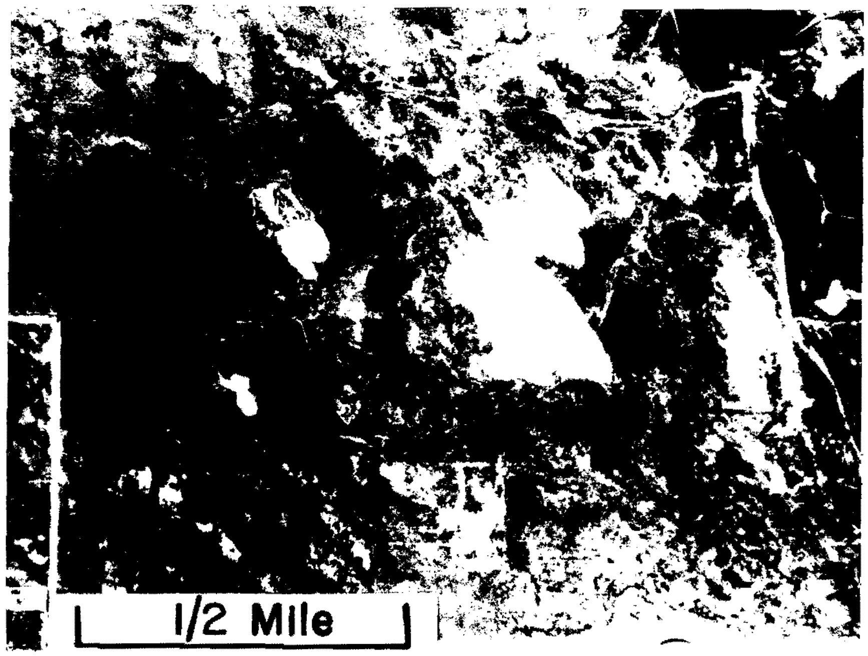


Fig. 33.--Air photo of sec. 32, T. 133 N., R. 77 W. along Sand Creek. The air photo was taken in 1938 at the end of the "Dirty-Thirties" Unstable Episode. The white areas are active eolian dunes.

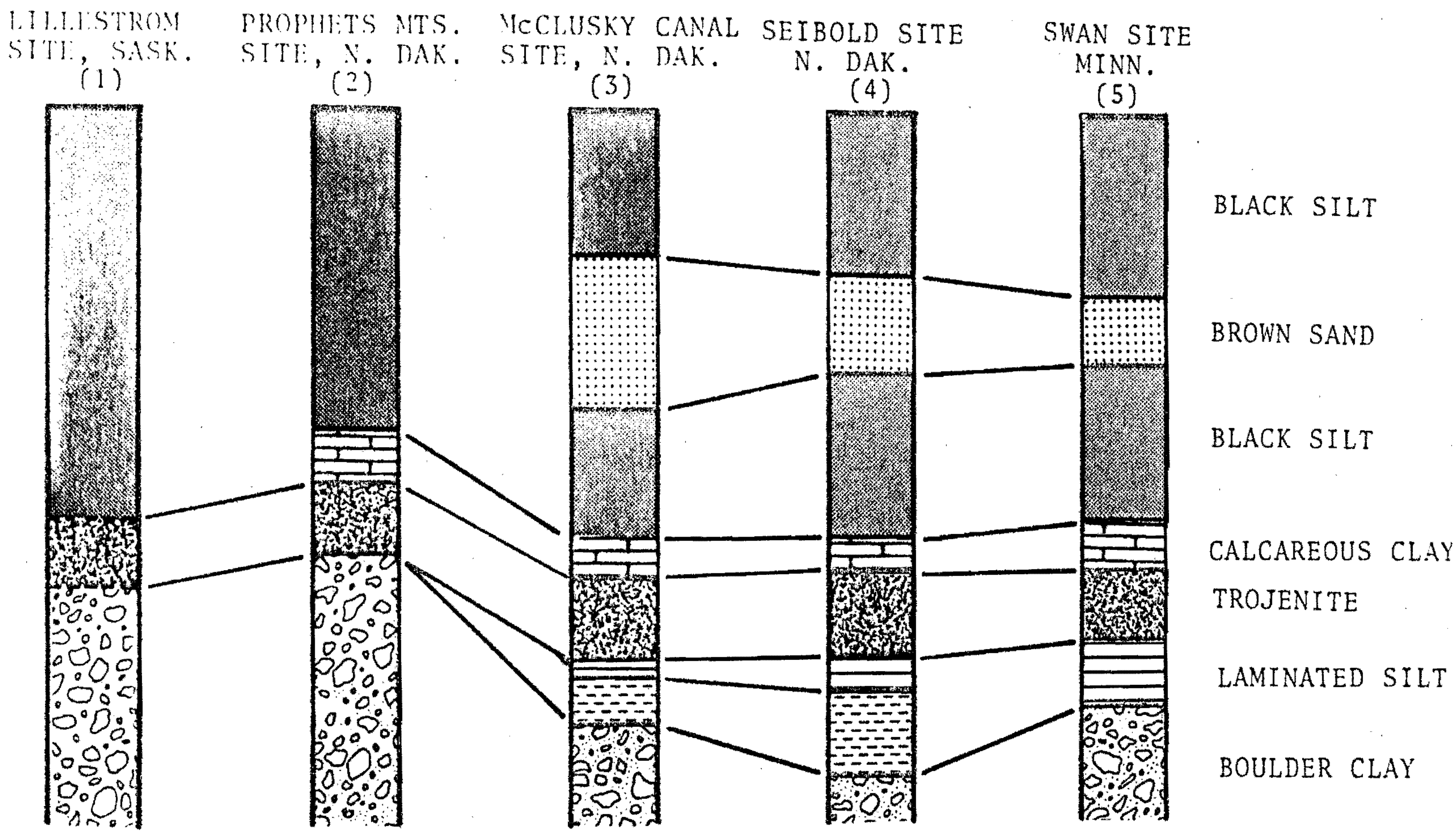
Fig. 34.--Air photo picture of the area shown in Figure 33. This picture was taken in 1961 during the Mandan Stable Episode. Vegetation has now moved onto the dunes and stabilized them.


1/2 Mile


1/2 Mile

Fig. 35.--Correlation of the stratigraphy of mid-continent postglacial slough sequences (modified from Bickley and Clayton, 1972).

MID-CONTINENT SLOUGH STRATIGRAPHY



inated silt and clay; (3) trojenite; (4) organic clay and silt; (5) sandy silt; and (6) organic silt and clay (similar to unit four).

The sedimentologic and paleontologic evidence from the sloughs is interpreted as follows. Unit one is glacial sediment deposited by the ice of the Lostwood Glaciation. Unit two is lake sediment deposited during the cool, moist postglacial climate immediately following glaciation, but before the hillslopes were stabilized by vegetation (the McCarny Unstable Episode). Unit three was deposited in a pond surrounded by spruce woodland. A radiocarbon date of 9750 ± 140 B.P., from the Seibold Slough (Bickley, 1970), was obtained on beaver-gnawed wood taken from this unit. This date and the fossils suggest that the Aggie Brown Member and the Seibold Bed (unit three) are different expressions of the same event, development of the spruce woodland and the environment related to it (Leonard Stable Episode). Unit four is interpreted to have been deposited during the time after prairie grass replaced spruce woodland as the predominant vegetation (Leonard Stable Episode). Unit five was deposited during the middle Holocene (Wolf Creek Unstable Episode). During this time, large amounts of coarse materials were eroded from the hillslopes into the sloughs due to the decreased sod cover caused by the warmer, drier climate. Unit six was deposited under the cooler, moister conditions of modern time (Thompson through Mandan Stable and Unstable Episodes).

Soils and their usefulness as a means of correlating Quaternary successions

The hypothesis that soil formation in the mid-continent occurs during cool, moist episodes disagrees with the generally accepted theory of soil formation (Morrison, 1968). It is generally theorized that soils form under stable conditions which occur during warm periods. Because warm conditions occur over large areas, it is believed that soils are useful interregional (even worldwide) time-stratigraphic markers and are the best means of correlating Quaternary successions.

Most work with soils has been in the warm, dry southwestern part of the United States. These areas are on the left side of the curves in Figure 31. So while within the warm, dry southwest, soil formation does occur during warm, stable episodes, the extension of this theory to other regions and even other parts of the world is probably invalid because the conditions that determine stability vary from region to region.

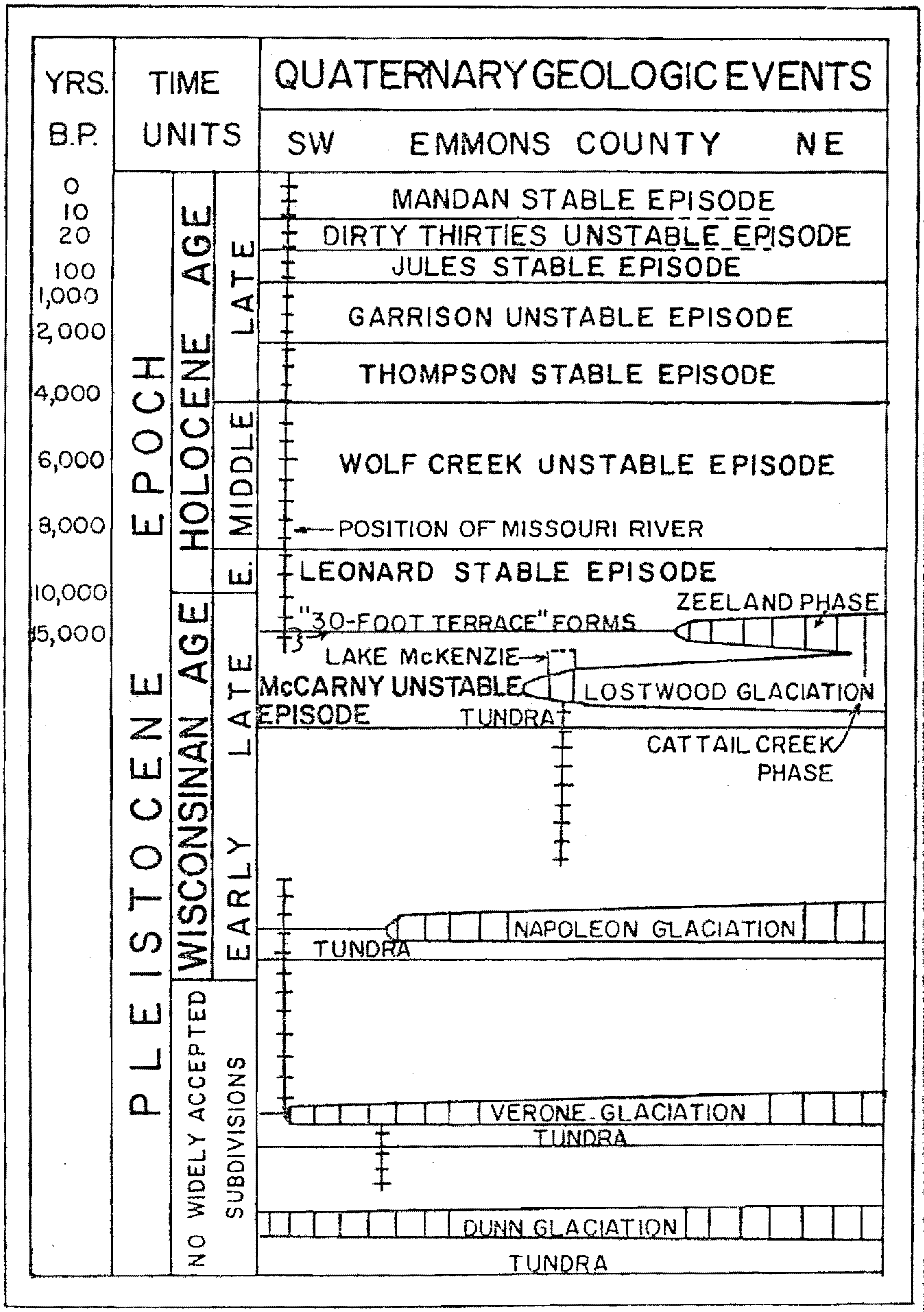
Soil forming episodes within warm, dry regions occur when the climate is warmer and drier. Soil forming episodes within cool, moist regions occur when the climate is cooler and wetter.

I think that soils can be useful regional time-stratigraphic markers. The soils formed during the Aggie Brown, Thompson, and Jules Stable Episodes appear to be, though radiocarbon dating is needed to verify this. Interregionally, however, these soils may not be useful as time-stratigraphic markers. Since stability occurs in response to different conditions in different areas, soil formation is probably out of phase in cool, moist and warm, dry areas.

SUMMARY

Figure 36 is a time-space diagram which summarizes the late Cenozoic history of south-central North Dakota.

Fig. 36.--Time-space diagram of the late Cenozoic history of south-central North Dakota.


YRS. B.P.
TIME UNITS
QUATERNARY GEOLOGIC EVENTS
SW EMMONS COUNTY NE
0
10
20
100
1,000
2,000
4,000
6,000
8,000
10,000
15,000
PLEISTOCENE EPOCH
HOLOCENE AGE
WISCONSINAN AGE
NO WIDELY ACCEPTED SUBDIVISIONS
LATE
MIDDLE
E.
LATE
EARLY
MANDAN STABLE EPISODE
DIRTY THIRTIES UNSTABLE EPISODE
JULES STABLE EPISODE
GARRISON UNSTABLE EPISODE
THOMPSON STABLE EPISODE
WOLF CREEK UNSTABLE EPISODE
POSITION OF MISSOURI RIVER
LEONARD STABLE EPISODE
ZEELAND PHASE
"30-FOOT TERRACE" FORMS
LAKE McKENZIE
McCARNY UNSTABLE EPISODE
LOSTWOOD GLACIATION
TUNDRA
CATTAIL CREEK PHASE
NAPOLEON GLACIATION
TUNDRA
VERONE GLACIATION
TUNDRA
DUNN GLACIATION
TUNDRA

CONCLUSIONS

(1) The sediment of the Tejas (?) Sequence should be divided into two sequences. The upper part, named for the Sakakawea Sequence (Pleistocene) in this report, is characterized by bouldery, cobbly, pebbly, sandy, silty clay. The lower part is retained as the Tejas (?) Sequence. On the North American craton, it is characterized by gravel composed of cobbles and pebbles of porphyry, quartzite, and argillite and by sand, silt, and clay containing scattered lignite fragments.

(2) The Coleharbor Group (Bluemle, 1971a) should be redefined to include material defined as Walsh Formation (Bluemle, in press). Descriptive mapping in Emmons County has demonstrated that the Walsh Formation is not a practical unit.

(3) Nine lithostratigraphic units are recognized within the Coleharbor Group.

The Braddock Formation (Wisconsinan) is composed mostly of yellow to olive brown, massive to jointed, bouldery, cobbly, pebbly, sandy, silty clay. Gravel and sand facies and silt and clay facies make up minor parts of it. The Braddock Formation is mostly glacial sediment. It is the lowest recognized lithostratigraphic unit of the Coleharbor Group.

The Emmons Formation (late Wisconsinan) overlies the Braddock Formation. It is brown to olive gray, massive, bouldery, cobbly, pebbly, slightly sandy, silty clay. Minor amounts of the formation are gravel and sand facies and silt and clay facies. The Emmons Formation is mostly glacial sediment.

The Four Bears Formation (Wisconsinan) overlies the Emmons Formation and older units. The unit consists of a sand and gravel facies and a silt and clay facies. The sand and gravel facies consists of poorly-sorted, flat-bedded, nonorganic sand and gravel derived locally and from the Canadian Shield. The silt and clay facies generally has rhythmic flat-bedding and is composed mostly of carbonate, montmorillonite, quartz, and feldspar.

The sand and gravel facies is mostly fluvial sediment, and the silt and clay facies is mostly lacustrine sediment.

The Coteau Formation (Holocene) overlies the Four Bears Formation. The unit consists of a brown to black, organic, poorly-sorted, slightly sandy, clayey silt facies and a brown to gray, poorly-sorted, organic, slightly pebbly, sandy silt and clay facies. The first facies is slough sediment, and the second facies is colluvial and alluvial sediment.

The Denbigh Formation (Holocene) overlies the Coteau Formation. The unit consists of buff brown, nonorganic, well-sorted sand with some large-scale crossbedding. The Denbigh Formation is mostly eolian sediment.

The Oahe Formation (late Wisconsinan and Holocene) overlies the Denbigh Formation. The Oahe Formation consists of yellow, red to red brown, or gray, coarse silt and fine sand. It is mostly eolian sediment (loess). The Oahe Formation has been divided into three members: the Mallard Island, Aggie Brown, and Riverdale Members. The Mallard

Island Member (late Wisconsinan) is the lowest member of the Oahe Formation. It consists of unbedded, yellow to yellow brown, coarse silt. The Mallard Island Member is mostly eolian sediment (loess). The Aggie Brown Member (late Wisconsinan to early Holocene) overlies the Mallard Island Member. This unit is brown to red brown, slightly clayey silt. The Aggie Brown Member contains at least one paleosol. It is mostly eolian sediment (loess). The Riverdale Member (middle and late Holocene) overlies the Aggie Brown Member. It is unbedded, light to dark gray, coarse silt. Several locally continuous organic horizons occur in the unit. The Riverdale Member is mostly eolian sediment (loess).

(4) Four major glaciations are recognized in Emmons County. They are the Dunn (pre-Wisconsinan), Verone (post-Dunn and pre-Napoleon), Napoleon (early Wisconsinan?), and Lostwood (late Wisconsinan) Glaciations.

(5) Three phases, Cattail Creek, Long Lake, and Zeeland, are recognized within the Lostwood Glaciations. The Long Lake Phase may be contemporaneous with the Zeeland Phase.

(6) Permafrost conditions existed during the advance of the Lostwood Glaciation. Permafrost polygons exist on all glaciated surfaces except the very youngest (the Zeeland and Long Lake) surfaces. Permafrost conditions do not exist when ice retreats (under a nonglacial climate), thus permafrost polygons did not form on the very youngest glacial surfaces.

(7) Lake McKenzie and Lake Standing Rock formed when ice dammed the Missouri River. Lake McKenzie formed when ice of the Cattail Creek Phase blocked the flow of the Missouri River in the Strasburg Channel.

Lake Standing Rock probably formed when ice dammed the Missouri River in north-central South Dakota. Its age is not known.

(8) The "30-foot" Missouri River terrace is tentatively correlated with the Lostwood Glaciation.

(9) The history of approximately the last 12,000 years has been one of cyclic stability and unstability. Stability is related to vegetation and runoff, which are controlled by precipitation and temperature. In warm, dry areas (like Arizona), stability occurs when the climate is warmer and drier. In cool, moist areas (like North Dakota), stability occurs when the climate is cooler and moister.

(10) Soil forms during stable episodes.

(11) Soils are not good interregional, chronologic markers. Stability occurs in response to different conditions in different climatic regions. Thus soil formation is probably out of phase between the different climatic regions.

APPENDIX I

DRILL-HOLE LOGS AND TEXTURAL ANALYSIS

A truck mounted auger was used to collect subsurface samples. All stratigraphic samples, except the first one in each hole, were taken at five foot intervals unless noted in the sample description. The first sample in each hole was taken at a depth of four feet. All subsurface sections are described from top to bottom. Where it is definitely known, the origin is given.

DEM 1: 0.5 miles east of northwest corner of sec. 28, T. 129 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 1.1	21.9 33.6 44.5	Fill?
DEM 1.2	19.0 35.5 45.5	Brown to dark brown, silty clay; slightly sandy; many shale fragments, igneous and carbonate pebbles; reddish brown iron stain on joints; till.
DEM 1.3	17.7 33.7 48.6	Brown to dark brown, silty clay; slightly sandy; many shale pebbles; one granitic cobble; brown stain along joints; till.
DEM 1.4	17.6 32.0 50.4	Dark brown, silty clay; slightly sandy; many shale fragments and carbonate pebbles; yellow brown to red brown stain along joints; more compact at 20 feet (drilling a little harder); till.
DEM 1.5	17.6 42.4 40.1	Brown to dark brown, silty clay;

		many shale, some carbonate, and igneous pebbles; 1 to 2 feet thick gravelly sand lens at about 22 feet; yellow brown stain along joints; till.
DEM 1.6	16.0 45.2 38.8	Brown to dark brown, silty clay; carbonate, igneous, and many shale pebbles; yellow brown stain along joints; many clay balls; some gypsum fragments; material seems to have more stones in it than above; till.
DEM 1.7	16.1 36.8 47.1	Brown, silty clay; shale, carbonate, and igneous pebbles; slightly sandy; very little stain; fewer stones than drill flight above; till.
DEM 1.8	13.7 41.2 45.1	Dark brown to brown, silty clay; numerous carbonate and shale pebbles; red brown iron stain along joints; till.
DEM 1.9	13.5 31.4 55.1	Dark brown, silty clay; red and yellow brown iron stain along joints; shale, carbonate, and igneous pebbles; sand lens near bottom of flight; till.
DEM 1.10	13.9 29.8 56.3	Brown to dark brown, silty clay; shale fragments and carbonate pebbles; some light colored lenses of clay; very little sand; red to yellow brown stain along joints; till.
DEM 1.11	12.9 30.7 56.4	Brown, silty clay; very little sand; fewer pebbles; only shale fragments seen; some brown stain along joints; hard and compact; till.
DEM 1.12	12.7 29.3 58.0	Dark brown, silty clay; very little sand; shale fragments; material looks slightly different at about 54 feet; more sand; brown to dark brown stain along joints; till.
DEM 1.13	13.9 37.0 49.1	Brown to dark brown, silty clay; shale fragments and a few carbonate pebbles; some red brown stain along joints; hard drilling at first (boulder present?), very stoney; till.

DEM 1.14	14.6 33.7 51.7	Blue gray, sandy, silty clay; pebbly (chert, carbonate, and igneous); some yellow brown stain along joints; breaks easier and appears to be more silty (easier drilling at 62 feet); till.
DEM 1.15	15.3 41.2 43.5	Blue gray, sandy, silty clay; pebbles (some shale, numerous carbonate and igneous); red to yellow brown stain along joints; some lenses of silt and fine sand; till.

DEM 2: 0.4 miles east of southwest corner of sec. 14, T. 129 N., R. 75 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 2.1	16.9 28.1 55.0	Brown, silty clay; contains shale and small carbonate concretions; red brown stain along joints; till.
DEM 2.2	16.4 29.9 53.7	Dark brown, silty clay; shale fragments and carbonate pebbles; red brown stain along joints; slightly more sandy than first sample; till.
DEM 2.3	16.6 30.3 53.0	Brown to dark brown, silty clay; shale and carbonate pebbles; carbonate stringers and red brown stain along joints; till.
DEM 2.4	18.4 36.6 45.0	Brown to dark brown, silty clay; contains some sand lenses; red brown stain along joints; contains shale, igneous, and a few carbonate pebbles; carbonate stringers seen throughout; till.
DEM 2.5	16.0 40.2 43.8	Brown to dark brown, silty clay; numerous shale, some carbonate and igneous pebbles; some brown stain along joints; few silt lenses scattered throughout; till.
DEM 2.6	24.1 31.8 44.1	Brown, silty clay; shale and a few carbonate pebbles; yellow brown stain along joints; sand lenses

		spread throughout the clay; (looks slightly different); till.
DEM 2.7	16.9 43.1 40.0	Dark brown, silty clay; red brown stain along joints; shale and carbonate pebbles; clay contains numerous scattered grains of coarse sand; compact; till.
DEM 2.8	13.6 36.0 50.5	Brown to dark brown, silty clay; (does not appear to be as silty as above); some shale, a few igneous, and carbonate pebbles (pebble abundance not as great as above); sandier; lacks apparent staining; different till (?).
DEM 2.9	13.8 45.1 41.0	Brown, silty clay; appears to be slightly sandier; few pebbles; real gumbo (sticky string stuck in hole); till.

DEM 3: 0.1 mile north of southeast corner of sec. 22, T. 130 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 3.1	17.1 37.7 45.2	Brown, silty clay; cobbles and pebbles (shale and igneous); carbonate stringers; material appears to be slightly sandy; brown stain; till.
DEM 3.2	17.6 43.3 37.0	Brown, silty clay; red brown stain along joints; shale, igneous, and carbonate pebbles; a few silt lenses; little sand seen; till.
DEM 3.3	17.6 38.1 44.3	Brown to dark brown, silty clay; contains shale, igneous, and carbonate pebbles; red and yellow brown stain along joints; very little sand and a few silt lenses scattered throughout; till.
DEM 3.4	16.3 41.2 42.5	Brown to dark brown, silty clay; many shale, some carbonate, and a few igneous pebbles; red brown stain

		along joints; few carbonate stringers; (easy drilling); till.
DEM 3.5	10.9 46.7 42.4	Brown to dark brown, slightly sandy, silty clay; contains shale and carbonate pebbles; brown stain along joints; material may be a slightly lighter color; a few carbonate stringers and silt lenses; till.
DEM 3.6	23.1 31.6 45.3	Brown, silty clay; contains carbonate and shale pebbles; brown stain along joints; a few carbonate stringers; wetter and more compact but easier drilling; till.
DEM 3.7	24.6 37.4 38.0	Brown to dark brown, silty clay; large shale and a few carbonate pebbles; brown stain along joints; a foot-thick sand lens at about 32 feet; clay very wet and compact; no carbonate stringers; till.
DEM 3.8	24.6 35.8 39.6	Brown, slightly sandy, silty clay; contains a few carbonate and shale pebbles; (maybe a second till?); flowing sand lens at about 36 to 38 feet; till.
DEM 3.9	32.6 29.5 38.0	Brown to dark brown, silty clay; slightly sandy; shale and carbonate pebbles; red brown stain along joints; till.
DEM 3.10	22.8 32.1 45.1	Blue gray sandy, silty clay; contains carbonate and a very few shale pebbles; till.

DEM 4: 0.2 miles west of southeast corner of sec. 16, T. 130 N., R. 75 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 4.1	57.0 17.8 15.3	Brown, silty clay; contains little sand; a few carbonate pebbles; a small amount of red brown oxidation; carbonate stringers present; sand lens at 4 to 5 feet; till.

DEM 4.2	18.5 35.2 46.3	Brown, silty clay; slightly sandy; shale and carbonate pebbles; carbonate stringers; red brown to yellow brown stain along joints; till.
DEM 4.3	14.8 40.0 45.2	Brown, silty clay; shale and carbonate pebbles; yellow brown stain along joints; contains silt lenses and carbonate stringers; some gypsum also present; till.
DEM 4.4	18.1 39.1 42.9	Dark brown to gray brown, silty clay; slightly sandy; contains shale and carbonate pebbles; clay is very compact and wet; red brown to yellow brown stain along joints; till.
DEM 4.5	20.5 34.4 45.1	Brown to dark brown, silty clay; slightly sandy; contains shale fragments and small carbonate pebbles; red to yellow brown stain along joints; some silt lenses present; clay very compact; till.
DEM 4.6	19.1 35.1 45.8	Brown to dark brown, silty clay; some grayer coloring; slightly sandy; clay contains shale and carbonate pebbles; yellow brown stain along joints; material not as compact as above; till.
DEM 4.7	19.8 38.5 41.8	Blue, gray, silty clay (at 29 feet); seems more silty and sandy; shale and carbonate pebbles; red brown stain along joints; some sand lenses and gypsum present; till.
DEM 4.8	18.0 32.4 49.6	Blue gray, sandy, silty clay; carbonate and a few shale pebbles present; little evidence of stain seen; till.
DEM 4.9	19.5 40.8 39.7	Blue gray, sandy clay; carbonate, igneous, and shale pebbles present; a little brown stain along joints; till.
DEM 4.10	15.9 38.9 45.2	Blue gray clay; slightly sandy; contains carbonate and shale (few) pebbles; some of the carbonate pebbles

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
		are cobble size (2 inches); till.
DEM 4.11	18.7 41.7 40.0	Blue gray, slightly pebbly, slightly sandy, silty clay; few carbonate pebbles (slightly more sandy and a little less pebbly than above); till.
DEM 4.12		Blue gray, silty clay; contains carbonate and shale pebbles; no stain noticed; this hole appears to have a sand content slightly higher than those before (?); till.
DEM 4.13	15.8 35.7 48.5	Blue gray clay; appears to be less sandier than above; carbonate and shale pebbles present, but not very abundant; till.

DEM 5: 0.1 mile north of southeast corner of sec. 23, T. 129 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
		Brown silt; $2\frac{1}{2}$ feet thick; (loess).
DEM 5.1	16.7 33.4 50.0	Brown, slightly sandy, silty clay; contains shale and carbonate pebbles; red brown stain along joints; carbonate stringers; sand lenses; till.
DEM 5.2	23.9 34.6 41.4	Brown, slightly sandy, silty clay; yellow brown to red brown stain along joints; contains shale and carbonate pebbles; appears slightly more silty; some sand lenses present; till.
DEM 5.3	21.7 35.5 42.8	Brown, sandy, silty clay; contains carbonate pebbles and a few shale fragments; there appears to be an oxidation zone at about 12 feet that may be the contact of another till (?); till.
DEM 5.4	2.7 53.8 43.5	Brown, silty clay with a few shale and carbonate pebbles; some red

		brown to yellow brown stain along joints; appears very silty; 2 samples taken; till (?).
DEM 5.5	1.2 57.4 41.4	Brown, silty clay; contains a few carbonate pebbles; slight amount of stain along joints (red to yellow brown in color); some silt balls; no shale fragments seen; till (?).
DEM 5.6	1.8 63.1 35.1	Blue gray, silty clay with very few pebbles (only carbonate); some carbonate stringers scattered throughout; little evidence of stain; till (?).

DEM 6: 0.2 miles north of southeast corner of sec. 27, T. 130 N., R. 77 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
		Brown silt; 3-feet thick; (loess).
DEM 6.1	28.0 35.0 37.0	Brown, slightly sandy, silty clay; contains very few pebbles (mostly shale, but some carbonate also present); clay contains carbonate stringers and has brown stain along fractures; till.
DEM 6.2	13.2 32.1 54.7	Brown to dark brown, slightly sandy, silty clay; contains shale and carbonate pebbles; red to yellow brown stain present along fractures; more pebbly at bottom of the flight at about 9 feet; till.
DEM 6.3	17.5 34.3 48.4	Brown to dark brown, silty clay; slightly sandy; shale, carbonate, and igneous (few) pebbles; clay appears to be stonier than above; very compact; yellow brown stain along joints; till.
DEM 6.4	18.7 34.0 47.2	Dark brown to brown, slightly sandy, silty clay; contains shale and carbonate pebbles; some large sand

		grains; carbonate stringers; brown stain along joints; till.
DEM 6.5	19.0 35.5 45.5	Brown, slightly sandy, silty clay; carbonate and shale pebbles; brown stain along joints; some cobbles 1 to 2 inches in diameter; till.
DEM 6.6	16.0 30.0 54.0	Brown, slightly sandy, silty clay; contains shale and carbonate pebbles; carbonate stringers; brown stain along joints; small amount of gypsum present; till.
DEM 6.7	17.1 29.7 53.3	Brown to dark brown, slightly sandy, silty clay; contains a few pebbles (shale and carbonate); carbonate stringers present; stain along joints and fractures; till.

DEM 7: 0.1 mile west of northeast corner of sec. 30, T. 131 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 7.1	16.5 33.9 50.0	Brown, silty clay with small amounts of sand; contains pebbles (carbonate and shale); yellow brown stain along joints and fractures; carbonate stringers; till.
DEM 7.2	22.0 34.6 43.5	Brown, silty clay with pebbles (shale and carbonate); yellow to red brown stain along joints; some carbonate and silty stringers scattered throughout; till.
DEM 7.3	19.3 39.8 40.9	Brown, silty clay with slightly more sand than above; shale and carbonate pebbles; red brown stain along joints; a few carbonate stringers; till.
DEM 7.4	18.7 42.3 39.1	Brown, slightly sandy, silty clay; contains shale and carbonate pebbles (few granite pebbles also seen);

		small amount of yellow brown weathering or stain along joints; there are a few silt lenses scattered throughout; till.
DEM 7.5	18.4 44.1 37.6	Brown, slightly sandy, silty clay; contains pebbles (carbonate and a few shale); brown stain along joints; some gypsum; clay appears to be less pebbly and more sandy; till.
DEM 7.6	15.5 40.9 43.7	Brown, silty clay; shale, carbonate, and a few igneous pebbles scattered throughout; slightly sandy; some stain seen along joints; clay very compact; till.
DEM 7.7	16.5 36.7 46.8	Brown, slightly sandy, silty clay; a few shale and carbonate pebbles; stony at 36 feet; possible boulder pavement (?); till.
DEM 7.8	15.6 36.7 47.7	Brown, silty clay; slightly sandy; contains only a few carbonate pebbles and even fewer shale fragments; till.
DEM 7.9	14.6 34.4 51.0	Blue gray, silty clay at about 40 feet; contains large interclasts of brown clay (from auger grinding?); material appears to be a lot stonier than clay drilled in previous holes; contains carbonate pebbles and cobbles and a few shale fragments; yellow brown stain along joints; till.
DEM 7.10	15.0 31.2 53.8	Blue gray, silty clay containing very little sand; contains shale and carbonate pebbles and cobbles; some secondary calcareous material present; till.
DEM 7.11	13.2 27.1 59.7	Blue gray, slightly sandy, silty clay; small number of small carbonate and shale pebbles; till.
DEM 7.12	11.8 30.3 57.9	Blue gray, slightly sandy, silty clay; contains a few shale and carbonate pebbles; some gypsum present; very little weathering or stain pre-

		sent; till.
DEM 7.13	22.4 39.0 38.6	Fox Hills Formation.

DEM 8: 0.1 mile west of southeast corner of sec. 33, T. 132 N., R. 75 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 8.1	10.3 58.9 30.9	Very dirty, sandy, silty clay; till (?).
DEM 8.2	2.8 61.5 35.7	Brown, slightly sandy, silty clay; contains very few pebbles of carbonate and shale variety; yellow brown stain along joints; till (?).
DEM 8.3	2.6 58.2 39.1	Brown, slightly sandy, silty clay; contains very few pebbles (shale and carbonate); yellow brown stain along joints; till (?).
DEM 8.4	4.7 58.7 36.6	Brown, slightly sandy, silty clay; a few shale pebbles; till (?).
DEM 8.5	17.6 46.1 36.3	Red brown to brown, slightly sandy, silty clay; pebbles mostly carbonate, but also contain a few shale fragments; appears to be highly weathered and stained along joints; clay balls coming up in lower part of flight; till.
DEM 8.6	15.8 41.9 42.3	Brown, slightly sandy, silty clay; contains a few carbonate pebbles; till.
DEM 8.7	17.3 38.0 44.8	Gray to blue gray, silty clay; contains no pebbles (hit at a depth of 29 feet); till.
DEM 8.8	22.9 40.8 36.3	Gray to blue gray, silty clay; contains a few red brown iron concretions; no pebbles seen; lake sediment.
DEM 8.9	13.4 46.6 40.0	Gray to blue gray, silty clay; unlam-

inated; contains some carbonate pieces; mollusk fragments (?); no pebbles; possible sand lens near bottom of flight; lake sediment.

DEM 9: 0.2 miles west of northeast corner of sec. 1, T. 131 N., R. 75 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 9.1	18.2 40.0 41.8	Brown, slightly sandy, silty clay; contains shale and carbonate pebbles; yellow brown stain and some carbonate stringers along joints; till.
DEM 9.2	19.3 38.7 42.0	Brown, slightly sandy, silty clay; contains shale and carbonate pebbles; red brown stain along joints; till.
DEM 9.3	20.1 40.4 39.6	Brown, slightly sandy, silty clay; contains shale and carbonate pebbles; yellow brown stain along joints; till.
DEM 9.4	18.5 36.8 44.8	Brown to dark brown, slightly sandy, silty clay; contains numerous shale, carbonate, and a few igneous pebbles; red brown to yellow brown stain along joints; carbonate stringers throughout; some lenses of silt; till.
DEM 9.5	18.3 30.7 51.1	Brown, slightly sandy, silty clay; contains a few pebbles of shale and carbonate variety; no stain noted; till.
DEM 9.6	3.9 35.7 60.4	Brown to dark brown clay; contains very few pebbles (shale fragments); brown stain noted along jointing; till (?).
DEM 9.7	3.6 24.8 71.7	Brown, slightly sandy clay; contains a few shale and carbonate pebbles; brown stain along joints; till (?).

DEM 10: 0.2 miles east of southwest corner of sec. 13, T. 131 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 10.1	17.9 35.5 46.7	Brown to dark brown, slightly sandy, silty clay; contains shale and carbonate pebbles; red brown to brown stain; carbonate stringers; till.
DEM 10.2	19.2 40.8 40.1	Brown to dark brown, slightly sandy, silty clay; contains shale and carbonate pebbles; brown to red brown stain along joints; some secondary carbonate; till.
DEM 10.3	21.3 47.2 31.5	Brown to dark brown, slightly sandy, silty clay; contains shale and carbonate pebbles; red brown stain present along jointing; clay appears to be stonier at the bottom of the flight; till.
DEM 10.4		Brown, slightly sandy, silty clay; contains shale and carbonate pebbles; red brown to yellow brown stain along jointing; more sand toward bottom of flight (hard layer at 18 to 20 feet); till.
DEM 10.5	3.0 35.8 61.2	Gray to gray brown, silty clay; less sand than above; very few shale pebbles and no carbonate pebbles; brown oxidation along jointing; till (?).
DEM 10.6	0.5 25.7 73.8	Brown to gray brown, slightly sandy, slickensided clay; no pebbles noted; big rock at bottom of hole prevented drilling deeper; till.

DEM 11: 0.1 mile north of southwest corner of sec. 14, T. 131 N., R. 77 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 11.1	16.3 32.3 51.5	Brown to dark brown, slightly sandy, silty clay; contains shale and carbonate pebbles; secondary carbonate common as stringers; brown stain along joints; till.
DEM 11.2	19.7 32.6 47.7	Brown to dark brown, slightly sandy, silty clay; contains pebbles and cobbles of shale and carbonate lithologies; secondary carbonate as stringers; red brown stain along joints; till.
DEM 11.3	17.0 35.6 47.5	Brown to dark brown, slightly sandy, silty clay; shale and carbonate pebbles; yellow to red brown stain along joints; some secondary carbonate present; till.
DEM 11.4	16.4 36.7 46.9	Brown to dark gray brown, slightly sandy, silty clay; shale and carbonate pebbles present; red brown stain along joints; till.
DEM 11.5	19.6 36.5 43.9	Brown to gray brown, sandy, silty clay; contains shale and carbonate pebbles; red brown stain along joints very common; till.
DEM 11.6	20.4 32.9 46.6	Brown to dark gray brown, pebbly, slightly sandy, silty clay; contains pebbles of shale, igneous (few), and carbonate variety; red to yellow brown stain along joints; some secondary gypsum; till.
DEM 11.7	19.2 37.6 43.3	Brown to gray brown, slightly sandy, silty clay; contains shale and carbonate pebbles; went through red brown, highly stained zone; material less stony than above; till.
DEM 11.8	20.2 39.7 40.1	Brown to dark brown, slightly sandy, silty clay; shale and carbonate pebbles; dark brown to red brown stain along joints; till.

DEM 12: 0.1 mile east of northwest corner of sec. 25, T. 133 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
		Brown silt; 2-feet thick (loess).
DEM 12.1	39.0 29.8 31.2	Brown, slightly sandy, silty clay; contains a few shale and carbonate pebbles; red brown to yellow brown stain along joints; till.
DEM 12.2	35.7 36.4 27.9	Brown, slightly sandy, silty clay; contains pebbles of shale and carbonate lithologies; red brown to yellow brown stain along joints; till.
DEM 12.3	35.5 35.4 29.0	Brown to dark brown, slightly sandy, silty clay; carbonate and shale pebbles scattered throughout; red brown to yellow brown stain along joints; till.
DEM 12.4	35.6 33.1 31.3	Brown, sandy, silty clay; carbonate and shale pebbles and cobbles; a little yellow brown stain along joints; till.
DEM 12.5	26.4 46.2 29.4	Bedrock (Fox Hills Formation at approximately 18 feet).

DEM 13: 0.3 miles west of southeast corner of sec. 36, T. 134 N., R. 75 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 13.1		Buff brown, fine to medium sand.
DEM 13.2		Buff brown, fine to medium sand.
DEM 13.3		Buff brown, fine to medium sand.
DEM 13.4		Buff brown, fine to medium sand.
DEM 13.5		Brown, fine to medium sand; red stain.

DEM 13.6		Brown, fine to medium sand; red stain.

DEM 14: 0.1 mile south of northwest corner of sec. 3, T. 133 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 14.1	35.4 27.5 37.2	Brown to yellow brown, sandy clay; contains shale and many carbonate pebbles; red brown stain along joints; some caliche; till.
DEM 14.2	39.5 29.6 31.0	Gray brown to yellow brown clay; many carbonate pebbles; yellow brown stain along joints; few small shale fragments toward bottom of flight; till.
DEM 14.3	50.2 27.1 22.7	Gray brown to yellow brown, sandy clay; shale and many carbonate pebbles; some secondary carbonate as stringers; till (?).
DEM 14.4	82.6 6.4 11.0	Gray, fine to medium sand at 16 feet; same texture as sand in hole 13; red brown iron concretions (small) at the top of bed; Fox Hills Formation (?).
DEM 14.5		Gray, medium to fine sand; red brown stain; Fox Hills Formation (?).
DEM 14.6		Bedrock (Fox Hills Formation).

DEM 15: 0.05 miles east of northwest corner of sec. 6, T. 134 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 15.1	29.3 54.1 16.7	Red brown, slightly sandy silt (fill?).
DEM 15.2		Buff brown sand at 4 to 5 feet.
DEM 15.3		Bedrock at 5 feet; gray to buff

brown sandstone; Fox Hills Formation.

DEM 16: 0.3 miles west of southeast corner of sec. 13, T. 134 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 16.1	36.7 28.2 35.1	Yellow to gray brown sand; slightly silty; yellow brown stain.
DEM 16.2		Yellow brown, fine to medium sand.
DEM 16.3		Fox Hills Formation at 6 feet.

DEM 17: 0.3 miles west of northeast corner of sec. 28, T. 135 N., R. 77 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 17.1	6.1 71.5 22.4	Yellow brown silt; slightly sandy (2 to 3 feet).
DEM 17.2	3.4 37.2 59.4	Gray brown to brown clay; some yellow brown stain; one very small pebble.
DEM 17.3	4.3 55.5 40.3	Brown to gray brown clay; red brown stain.
DEM 17.4	7.0 43.3 49.8	Brown to gray brown clay; red to yellow brown stain; no pebbles; some secondary carbonate.
DEM 17.5	15.3 50.0 34.9	Bedrock (Hell Creek Formation?).

DEM 18: 0.01 mile west of northeast corner of sec. 3, T. 135 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 18.1	28.2 35.4 36.4	Yellow brown, sandy silt (1 to 2 feet thick).

DEM 18.2	33.4 33.8 32.9	Gray brown, sandy clay; shale and carbonate pebbles; red brown oxidation; secondary caliche as stringers; till.
DEM 18.3		Brown to gray brown, sandy clay; carbonate pebbles and caliche (?); red brown stain; till.
DEM 18.4	25.8 42.7 31.5	Dark brown clay; slightly sandy; red brown stain and secondary carbonate; till (?).
DEM 18.5	27.3 37.1 35.6	Gray to brown, sandy, silty clay; red brown oxidation; secondary carbonate; small amount of gypsum; till (?).
DEM 18.6		Buff brown sand with some oxidation.
DEM 18.7		Brown to buff brown sand; some consolidated nodules; Fox Hills Formation.

DEM 19: 0.2 miles north of southeast corner of sec. 13, T. 135 N., R. 75 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 19.1	18.7 24.7 56.6	Gray brown, sandy, silty clay; contains a few carbonate pebbles; brown stain along joints; till.
DEM 19.2	15.7 15.4 68.9	Brown, sandy clay; contains carbonate pebbles; secondary carbonate; large rock; till.

DEM 20: 0.2 miles west of northeast corner of sec. 23, T. 135 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 20.1	52.0 40.6 7.4	Buff to red brown fine sand (stained).

DEM 20.2			Buff brown, fine to medium sand; Fox Hills Formation.
DEM 20.3			Buff to brown, fine to medium sand; Fox Hills Formation.
DEM 20.4			Buff to yellow brown to red brown, fine to medium sand; stained; Fox Hills Formation.
DEM 20.5			Buff to gray brown, fine to medium sand; Fox Hills Formation.

DEM 21: 0.15 miles west of northeast corner of sec. 31, T. 132 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 21.1		Buff brown, fine to medium sand.
DEM 21.2		Buff brown, medium sand.
DEM 21.3		Buff to brown, fine to medium sand.
DEM 21.4		Buff to buff brown, fine to medium sand; containing much silt.

DEM 22: 0.3 miles west of northeast corner of sec. 4, T. 129 N., R, 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 22.1	11.7 61.0 27.2	Tan to buff brown, sandy, silty clay; carbonate and shale pebbles; red brown stain along jointing; till.
DEM 22.2	25.9 51.0 23.1	Brown to gray brown, sandy, silty clay; shale and carbonate pebbles common; brown to yellow brown stain along joints; till.

DEM 22.3	7.2 67.3 25.5	Brown, silty clay; red brown stain at approximately 7 feet; till (?).
DEM 22.4	7.6 59.2 33.2	Brown, silty clay; red brown oxidation; sample taken at about 14 feet; till (?).
DEM 22.5	17.4 45.4 37.3	Gray to blue gray, silty clay; slightly sandy; contains carbonate pebbles and shale fragments; till (?).
DEM 22.6	25.9 40.5 33.7	Blue gray, slightly sandy clay; carbonate pebbles; till.

DEM 23: 0.5 miles north of southwest corner of sec. 23, T. 129 N., R. 77 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 23.1	19.8 37.7 42.5	Brown, silty clay; contains shale and igneous pebbles; slightly sandy; red brown stain along joints; small amount of secondary carbonate; till.
DEM 23.2	23.0 37.1 39.9	Brown to gray brown, slightly sandy, silty clay; shale and carbonate pebbles; red brown stain along joints; some secondary carbonate present; till.
DEM 23.3	22.7 35.5 41.9	Brown to gray brown, slightly sandy, silty clay; contains shale and carbonate pebbles; brown stain along jointing surfaces; small amount of secondary carbonate; till.
DEM 23.4	22.9 39.7 37.4	Brown to brown gray, slightly sandy, silty clay; contains shale and carbonate pebbles; brown to red brown stain along jointing; very stony in this interval; till.
DEM 23.5	22.4 37.2 40.4	Brown to brown gray, sandy, silty clay; contains carbonate, igneous and shale pebbles; brown along joint surfaces; till.

DEM 23.6	20.7 39.6 39.7	Blue gray, slightly sandy, silty clay; contains carbonate pebbles; little evidence of stain; till.

DEM 24: 0.3 miles west of northeast corner of sec. 30, T. 129 N., R. 77 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 24.1	7.0 70.5 22.5	Yellow to yellow brown, coarse to medium silt (7 feet thick); loess.

DEM 25: 0.2 miles west of northeast corner of sec. 29, T. 129 N., R. 78 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 25.1	24.0 41.3 34.7	Brown to gray brown silt; contains small carbonate nodules; some yellow brown stain (4 to 5 feet thick).
DEM 25.2	21.3 38.5 40.2	Gray to gray brown, silty clay; red brown stain; very little sand; some secondary oxidation.
DEM 25.3	22.9 43.0 34.1	Yellow brown, fine, sandy silt.
DEM 25.4	7.0 35.8 57.2	Brown to gray brown, slightly sandy clay; some secondary carbonate.
DEM 25.5	34.1 43.8 22.1	Gray brown, sandy silt.
DEM 25.6	51.6 42.3 6.2	Brown sand; coarse to slightly gravelly.
DEM 25.7	80.2 9.1 10.8	Brown sand to sandy gravel; lithologies of granite and carbonate.

DEM 26: 0.1 mile east of northwest corner of sec. 1, T. 130 N., R. 78 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 26.1	10.9 72.5 16.6	Yellow to yellow brown silt; contains secondary carbonate; loess.
DEM 26.2	36.7 50.5 12.8	Yellow brown, sandy silt; red brown stain (10 feet of silt); loess.
DEM 26.3	6.0 64.5 29.5	Brown, slightly sandy, clayey silt; red brown oxidation; loess.
DEM 26.4	32.1 48.3 19.6	Buff brown, sandy silt; red to red brown stain; loess.
DEM 26.5		Sandy clay at bottom of hole (probably Fox Hills Formation).

DEM 27: 0.1 mile west of northeast corner of sec. 32, T. 131 N., R. 79 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 27.1	60.6 32.5 7.0	Brownish gray, clayey, silty sand, grades down into very fine, gray brown sand.
DEM 27.2	94.4 7.1 1.4	Brown, slightly dirty, silty, fine sand; coarsens downward; loess.
DEM 27.3		Granite gravel from 11 to 15 feet.

DEM 28: 0.1 mile south of northeast corner of sec. 30, T. 133 N., R. 78 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 28.1	3.4 73.4 23.2	Brown, highly organic, silty clay; loess.
DEM 28.2	3.6 72.1 24.2	Yellow brown silt; boulder at 6 feet; loess.

DEM 28.3	3.2 57.3 39.5	Brown to brown gray, clayey silt; loess.
DEM 28.4		Brown to yellow brown clay; slightly sandy; very few pebbles (carbonate and sandstone); loess.
DEM 28.5	2.7 58.3 41.0	Gray brown silt; red brown oxidation; loess.
DEM 28.6	1.2 48.8 50.1	Gray to gray brown clay; bedded; bedrock.
DEM 28.7	2.0 50.3 47.7	Brown to gray brown clay; bedded; bedrock.

DEM 29: 0.1 mile west of northeast corner of sec. 23, T. 135 N., R. 79 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 29.1	5.9 82.5 11.7	Gray brown silt; loess.
DEM 29.2	2.5 57.5 40.0	Yellow brown, silty sand at 4 feet; loess.
DEM 29.3	74.8 18.1 7.1	Granitic type gravel at 7 to 9 feet.
DEM 29.4	1.8 54.9 43.3	Brown, fine, sandy silt; 9 to 10 feet.
DEM 29.5		Red brown, fine sandy silt at 11 feet.

DEM 30: 0.4 miles east of southwest corner of sec. 21, T. 134 N., R. 77 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 30.1	30.9 38.0 31.1	Gray, sandy clay; many carbonate pebbles; sample probably contaminated with road fill; till.
DEM 30.2	32.5 41.5 26.0	Brown, slightly sandy, silty clay;

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
		carbonate, shale, and igneous pebbles; till.
DEM 30.3	61.6 20.3 12.1	Buff to gray brown sand (fine to medium).
DEM 30.4		Buff to gray brown, fine sand; loess.
DEM 30.5		Buff to gray brown, fine to medium sand; loess.
DEM 30.6		Buff to gray brown, fine to medium sand (down to 25 feet).

DEM 31: 0.4 miles south of northeast corner of sec. 36, T. 136 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 31.1	31.1 27.2 41.7	Yellow silt; slightly sandy; 3 feet thick; brown, sandy, silty clay; contains few carbonate pebbles; red brown to yellow brown stain along joints; some silt lenses; till.
DEM 31.2	30.5 21.3 48.3	Brown to gray brown, silty clay; contains few carbonate pebbles; red brown to yellow brown stain along joints; till.
DEM 31.3	33.4 38.1 28.5	Brown to gray brown, silty clay; with carbonate and igneous pebbles; brown to yellow brown stain along joints; till.
DEM 31.4	33.8 31.0 35.2	Brown to gray brown, sandy, silty clay; carbonate and igneous pebbles; brown stain along fractures and joints; till.
DEM 31.5	32.4 33.4 34.2	Brown to yellow brown, sandy, silty clay; contains carbonate and igneous pebbles; brown stain along joints; till.
DEM 31.6	32.6 40.6 26.8	Brown to yellow brown, sandy, silty clay; brown stain along fractures and joints; carbonate and igneous

pebbles; slightly less pebbly than above; till.

DEM 32: 0.1 mile south of northwest corner of sec. 6, T. 136 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 32.1	23.9 43.8 32.3	Brown to gray brown, dirty, gravelly, sandy silt; some cobbles, 3 inches; 0 to 4 feet.
DEM 32.2		Brown, gravelly sand; 1 to 2 inch cobbles; 4 to 7 feet.
DEM 32.3		Fox Hills Formation at 7 feet.

DEM 33: 0.05 miles east of southwest corner of sec. 30, T. 136 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 33.1		Black to gray brown clay; sandy; carbonate pebbles; alluvium (?) or till (?).
DEM 33.2		Coarse, brown gravel (5 to 15 feet).
DEM 33.3		Blue gray sand; pebbles; clayey; flowing well.

DEM 34: 0.1 mile south of northwest corner of sec. 9, T. 136 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 34.1	31.2 40.5 28.3	Brown to gray brown, slightly sandy clay; contains carbonate pebbles; red brown stain along joints; till.
DEM 34.2	33.2 33.5 35.2	Brown, sandy clay; carbonate and

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
		shale pebbles; secondary carbonate; red brown stain along joints; till.
DEM 34.3	34.4 35.6 32.0	Brown, sandy clay; carbonate, igneous, and shale pebbles; a few silt lenses; red brown stain along joints and fractures; till.
DEM 34.4	34.6 39.6 25.8	Brown, sandy clay; carbonate and igneous pebbles; secondary carbonate; red brown stain along the joints and fractures; large rock at bottom of hole.

DEM 35: 0.2 miles east of northwest corner of sec. 24, T. 136 N., R. 74 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 35.1	29.0 36.2 34.9	Brown to brown gray, sandy clay; contains shale, igneous, and carbonate pebbles; some secondary carbonate; red brown stain along joints; till.
DEM 35.2	15.2 63.8 21.0	Brown to gray brown clay; slightly sandy; red brown stain along joints; igneous and carbonate pebbles; till.
DEM 35.3	17.8 56.4 25.7	Brown, slightly sandy clay; a few pebbles of carbonate lithology; red brown stain along joints; till.
DEM 35.4	7.1 68.3 24.6	Brown, slightly sandy clay; a few carbonate and shale pebbles; yellow brown stain along the joints and fractures.
DEM 35.5	9.3 54.5 36.2	Brown, very slightly sandy clay; contains a few carbonate and shale pebbles; little evidence of stain; some secondary carbonate; appears to be less sandier than above.

DEM 37: 0.1 mile west of southeast corner of sec. 32, T. 135 N., R. 73 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 37.1	28.3 28.0 43.7	Light gray brown to olive brown, sandy, pebbly clay; contains secondary carbonate; yellow brown stain along joints; contains carbonate and shale pebbles.
DEM 37. 2		Fox Hills Sandstone.

DEM 38: 0.1 mile west of southeast corner of sec. 16, T. 135 N., R. 73 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 38.1	27.2 53.2 19.6	Brown, sandy clay; shale and carbonate pebbles; tried 3 holes, hit a rock each time; possible boulder pavement.

DEM 39: 0.1 mile north of southwest corner of sec. 13, T. 130 N., R. 72 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 39.1	28.5 43.7 27.8	Brown clay with pebbles; till.
DEM 39.2	20.1 45.3 34.6	Yellow gray clay with pebbles at 3 feet; till.
DEM 39.3	23.5 36.3 40.1	Gray brown, sandy clay; pebbles; red brown stain along fractures; till.
DEM 39.4	27.8 42.4 27.9	Yellow brown clay; slightly grayer on the inside; many igneous and shale pebbles.
DEM 39.5	28.5 42.5 29.0	Sandy, yellow brown clay; contains igneous and carbonate pebbles; more

yellow gray on the inside.

DEM 40: 0.1 mile east of southwest corner of sec. 7, T. 130 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 40.1	20.1 35.2 44.8	Gray to olive brown, sandy, silty clay; contains carbonate, igneous, and shale pebbles; secondary carbonate; yellow brown stain along joints; till.
DEM 40.2	16.0 30.6 53.5	Brown to gray brown, silty clay; slightly sandy; contains shale and carbonate pebbles; yellow brown stain along fractures; till.
DEM 40.3	14.3 40.6 45.1	Brown, silty clay; shale and carbonate pebbles (fewer than above); brown stain and secondary carbonate in fractures; till.
DEM 40.4	16.1 41.8 42.2	Brown to tawny brown, silty clay; shale and carbonate pebbles (few); slightly sandy; red brown to yellow brown stain along joints; till.
DEM 40.5	34.8 2.0 63.2	Brown to gray brown, slightly sandy, silty clay; contains very few pebbles; till.
DEM 40.6	11.9 32.9 55.3	Brown, slightly sandy, silty clay; a few shale and carbonate pebbles; large boulder at 28 feet; till.
DEM 40.7	21.6 37.9 40.7	Bit sample; till.

DEM 41: 0.01 mile south of northwest corner of sec. 12, T. 130 N., R. 75 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
DEM 41.1	13.4 38.5 48.2	Dark brown, slightly sandy, silty clay; contains a few carbonate and shale pebbles; small amount of red brown stain; till.
DEM 41.2	12.9 42.1 42.2	Dark brown, slightly sandy, silty clay; contains few carbonate and shale pebbles; small amount of red brown stain; till.
DEM 41.3	14.7 38.9 46.3	Dark brown, slightly sandy, silty clay; contains carbonate and shale pebbles; red brown to brown stain; till.
DEM 41.4	15.6 46.7 37.7	Dark brown to brown, slightly sandy, silty clay; contains shale and carbonate pebbles; a little stain; till.
DEM 41.5	13.9 43.3 37.8	Dark brown, slightly sandy, silty clay; contains carbonate, shale, and igneous pebbles; little stain seen; till.
DEM 41.6	11.9 40.0 48.1	Gray brown to dark brown, slightly sandy, silty clay; contains igneous carbonate, and shale pebbles (mostly shale); no stain; till.
DEM 41.7	13.7 39.2 47.0	Brown to gray brown, slightly sandy, silty clay; contains very few pebbles, shale and one carbonate; no stain; till.
DEM 41.8	13.5 40.5 46.0	Brown to gray brown, slightly sandy, silty clay; shale, igneous, and carbonate pebbles; no stain; till.

DEM 42: 0.6 miles east of southwest corner of sec 21, T. 135 N., R. 76 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
		2 feet coarse yellow silt.

DEM 42.1	28.6 42.2 31.2	Light olive brown, sandy, silty clay; contains carbonate and igneous pebbles; some red brown stain; till.
DEM 42.2	57.4 21.0 21.6	Gray, medium to fine sand; some silt and clay.
DEM 42.3		Hell Creek Formation.
DEM 42.4		Hell Creek Formation.

DEM 43: 0.7 miles north of southwest corner of sec. 4, T. 136 N., R. 75 W.

Position	Texture (Sand-Silt-Clay Per cent)	Field Description
		Gray brown, slightly silty sand; changing to gravel in last 1½ feet; approximately 12 feet thick.
DEM 43.1	29.6 43.0 37.4	Olive brown to gray brown, sandy, silty clay; mottled; contains many carbonate pebbles and some igneous pebbles; sample at about 19 feet; till.
DEM 43.2		Olive brown to gray brown, sandy, silty clay; some patches of blue gray clay; contains mostly carbonate pebbles; till.
DEM 43.3	32.8 43.0 24.0	Blue to blue gray, sandy, silty clay; contains carbonate and igneous pebbles; no stain seen; till.
DEM 43.4	29.6 43.0 27.4	Blue gray, sandy, silty clay; contains carbonate and igneous pebbles; no stain; flowing sand at 32 feet; sample taken at about 39 feet; till.
DEM 43.5	28.3 44.2 27.5	Blue gray to gray, sandy, silty clay; contains carbonate, igneous, and one shale pebble; no stain; till.

APPENDIX II

OIL WELL RECORDS

Appendix II gives the lithostratigraphic units drilled into, location, and depth of all oil wells drilled in Emmons County.

NORTH DAKOTA GEOLOGICAL SURVEY WELL NUMBER	LOCATION OF WELL	TOTAL DEPTH IN FEET	STRATIGRAPHIC UNIT
16	Center of NW¼ SW¼ sec. 35, T. 133 N., R. 75 W.	5360	Precambrian
23	Center of NE¼ SW¼ sec. 35, T. 133 N., R. 76 W.	5556	Precambrian
43	Center of NE¼ SE¼ sec. 8, T. 132 N., R. 78 W.	5885	Precambrian
742	Center of SE¼ NW¼ sec. 30, T. 135 N., R. 75 W.	4346	Precambrian
4212	Center of SE¼ SE¼ sec. 17, T. 136 N., R. 76 W.	3780	Madison Formation
4600	Center of NE¼ NW¼ sec. 8, T. 131 N., R. 74 W.	2359	Fall River Formation
4601	Center of NW¼ SE¼ sec. 14, T. 131 N., R. 74 W.	2401	Fall River Formation
4602	Center of NW¼ NW¼ sec. 25, T. 132 N., R. 74 W.	2410	Fall River Formation

4629	Center of SE¼ SE¼ sec. 3, T. 130 N., R. 74 W.	2471	Fall River Formation
4681	Center of SE¼ NE¼ sec. 12, T. 132 N., R. 75 W.	2447	Fall River Formation
4843	Center of NE¼ NE¼ sec. 21, T. 131 N., R. 77 W.	2610	Fall River Formation
4850	Center of NE¼ NE¼ sec. 28, T. 130 N., R. 78 W.	2400	Skull Creek Formation

APPENDIX III

LABORATORY ANALYSES OF TYPE SECTION MATERIALS

This appendix consists of the textural and compositional (dolomite, calcite, and total carbonate) analyses of sediment collected from the type sections of the Oahe, Braddock, and Emmons Formations and the Sakakawea Sequence. For the location of these sections see the appropriate section under Descriptive Geology.

Sakakawea Sequence (Type Section) Coleharbor Group Oahe Formation (Type Section) Riverdale Member (Type Section)	TEXTURE Sand-Silt-Clay (Figures are percentages of the hole)	CALCITE (Per cent of total carbonate)	TOTAL CARBONATE (Per cent)	DESCRIPTION
	10-77-13	30	2	
	10-78-12	10	3	
	8-81-11	60	6	
	7-81-12	61	8	
	11-79-10	62	7	
0-1.7 meters	10-74-14	50	6.5	
	9-79-11	62	7	Gray to dark gray, slightly sandy silt containing several black organic bands
	10-78-12	55	11	
	9-75-16	51	10	
	7-78-15	51	13.5	
	8-76-16	43	13.5	
	10-70-20	42	12	
	10-80-10	38	11.5	
Aggie Brown Member (Type Section) 1.7-2 meters	10-73-17	55	10	
	10-70-20	62	9	Brown to red brown, organic silt
	8-80-12	56	12	
	13-75-12	42	16	
Mallard Island Member (Type Section)	11-69-20	48	17	
	15-71-14	28	17	
	16-72-12	37	16	
	20-68-12	35	15	Yellow to yellow brown, slightly sandy silt
2-3.1 meters	21-71- 8	34	13	
	16-74-10	31.5	14	
	11-79-10	32	11.5	
	15-74-11	30	14	
	14-71-15	17	12	

	TEXTURE Gravel-Sand-Silt-Clay (Values are precentages)	PERCENTAGES Calcite-Dolomite-Total Carbonate	DESCRIPTION
Braddock Formation 3.1-9.7 meters	6-30-45-25 3-31-49-25 4-28-43-29 2-28-40-32 3-29-42-29 4-30-38-32 5-29-39-32 4-30-36-34	8.1- 9.6-17.7 2.8-11.0-13.8 3.0-12.5-15.5 3.2-12.6-15.8 3.4-12.2-15.6 3.3-11.0-14.3 3.3-12.2-15.5 3.3- 9.8-13.1	Gray, pebbly, sandy, silty clay; massive, but has numerous vertical joints in lower part of unit; abundant secondary carbonate
9.7-10.95 meters			Gravel composed of cobbles of carbonate, granite, and basalt
10.95-12.2 meters	6-51-27-22 12-66-15-19	4.4- 9.6-14.0	Gray, pebbly, very sandy, silty clay; contains horizontal joints; locally separate from unit by gravel
12.2-15.7 meters	2-25-41-34 6-25-42-33 3-27-42-31 3-24-35-41 1-26-41-33 1-25-43-32 5-32-41-27 3-33-35-32 1-21-46-33 1-21-47-32 1-22-42-36	2.7-8.1-10.8 3.1-7.7-10.8 3.1-8.1-11.2 3.2-7.5-10.7 2.6-7.5-10.1 3.3-8.4-11.7 2.4-8.0-10.4 2.5-8.7-11.2 3.2-8.4-11.6 3.6-9.0-12.6	Brown to gray pebbly, sandy, silty clay; no visible structure, but material occurs in subspherical to angular blocks

15.7-24.2 meters	2-21-45-33 3-22-48-30 2-22-48-30 3-23-42-35 1-20-42-38	2.9-9.8-12.7 2.9-9.7-12.6 2.7-8.8-11.5	Gray to olive brown, slightly pebbly, sandy, silty clay; blocky and jointed with stain along joints
24.2-28.7 meters			Covered

	TEXTURE Gravel-Sand-Silt-Clay (Values are percentages)	DESCRIPTION
Coleharbor Group Emmons Formation (Type Section)		
0-1.5 meters	2.7-23.3-31.3-45.4 1.1-18.0-24.1-58.0 4.0-17.9-24.7-57.4	Olive gray, massive, slightly pebbly, slightly sandy, silty clay
Braddock Formation 1.5-3.6 meters	7.3-30.7-37.4-31.9 7.1-31.2-38.5-30.3 2.4-42.3-28.2-29.6 9.5-25.0-42.0-32.8 1.6-24.9-43.5-31.5	Light olive brown, massive, pebbly, sandy, silty clay

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