GEOLOGY

of

EMMONS COUNTY, NORTH DAKOTA

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

Emmons County, located on the southeastern side of the Williston Basin, is underlain by 4,500 to 7,000 feet of Paleozoic, Mesozoic, and Cenozoic rocks that dip to the northwest toward the center of the basin about 150 miles to the northwest. The Cretaceous Pierre, Fox Hills, and Hell Creek Formations, and the Tertiary Cannonball Formation are exposed in the county along with the Quaternary Coleharbor Group and Oahe Formation. Coleharbor Group till covers parts of eastern Emmons County and thick fluvial and lacustrine sequences fill preglacial valleys in several parts of the county. Wind-blown material of the Oahe Formation veneers the surface of much of the county.

Emmons County is located along the eastern edge of the Missouri River trench, mainly on the Coteau Slope, with northeastern and southeastern areas on the Missouri Coteau. Although all of the county was glaciated, only scattered glacial erratics remain of the early glacial advances. The topography over much of central Emmons County, especially along Beaver Creek, is entirely erosional. Buttes capped by the Fox Hills Linton Member sandstone are prominent features in the area of bedrock exposure. Late Wisconsinan glacial landforms are restricted to the northeastern and southeastern parts of the county.

INTRODUCTION

Purpose

This report is published by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the United States Geological Survey, and the Emmons County Board of Commissioners. It is one of a series of county reports on the geology and groundwater resources of North Dakota. The main purposes of these studies are: (1) to provide a geologic map of the area, (2) to locate and define aquifers, (3) to determine the location and extent of mineral resources in the counties, and (4) to interpret the geologic history of the area. This volume describes the geology of Emmons County. Readers interested in groundwater should refer to Part II of this bulletin, which includes detailed basic data on the groundwater, and Part III, which is a description and evaluation of the groundwater resources of Emmons County.

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

Previous Work

All or portions of Emmons County were included in several early reports. In 1896, Todd described the "Altamont" moraine of northeastern and southeastern Emmons County (Todd, 1896). Todd also discussed the history of the Missouri River (Todd, 1914, 1923), referring to the glacial till in the Emmons County area as "the Nebraskan or Kansan stage." Leonard (1912) described the geology of south-central North Dakota, referring to till of Kansan age in areas where most of the glacial deposits have been removed by erosion. Leonard also discussed Pleistocene drainage changes in the area (Leonard, 1916a) and he referred to pre-Wisconsin drift in the area (Leonard, 1916b). Stanton (1917) described the Cretaceous volcanic ash bed that occurs near Linton.

Much of the geologic study undertaken in the Emmons County area since the early studies just mentioned has dealt mainly with the stratigraphy of the Cretaceous Fox Hills Formation. In the early 1950s, Fisher (1952) mapped Emmons County, concentrating mainly on study of the Fox Hills Formation. His primary concern was structural interpretation of the formation. Fisher first applied the member terms "Timber Lake" and "Trail City" to the lower two members of the Fox Hills Formation in North Dakota. Morgan and Petsch (1945) had earlier coined these terms for rocks in Dewey and Corson Counties, near the type area of the Fox Hills Formation in South Dakota. Fisher (1952) provided a geologic map of Emmons County; however, he grouped most of the glacial deposits into a "Late Wisconsin outwash" unit, which he showed as veneering nearly everything.

Manz (1962) discussed the pozzolanic properties of the volcanic ash deposit near Linton. Erickson (1971) dealt with the various stratigraphic units contained within the Fox Hills Formation in Emmons County. Feldmann (1972) studied the stratigraphy and peleoecology of the Fox Hills Formation in North Dakota. His is the most comprehensive treatment of the Fox Hills Formation in North Dakota to date. Klett and Erickson (1976) described the Linton Member of the Fox Hills Formation in Emmons County.

Emmons County was mapped by William Bickley, a University of North Dakota geology student, as part of a study of the regional glacial stratigraphy. The resulting Ph.D. dissertation (Bickley, 1972) was not published, although it is available in the University of North Dakota library.

Several geologic reports of the present county series are now available for the area near Emmons County. They include Grant and Sioux Counties (Carlson, 1982), Morton County (Carlson, 1983), Burleigh County (Kume and Hansen, 1965), and Kidder County (Rau et al., 1962). Reports on groundwater basic data and hydrology are also available for each of these counties. A study of the glacial geology of McIntosh and Logan Counties was completed by Clayton (1962), although this report was not part of the county groundwater studies series. Reports on the groundwater resources of McIntosh and Logan Counties were completed recently (Klausing, 1981, 1983), and reports on the groundwater basic data are also available for these two counties. In addition, a geologic report is available for Campbell County, which lies adjacent to Emmons County in South Dakota (Hedges, 1972).

Methods of Study

Fieldwork for this study was completed during the 1983 field season. Fieldwork consisted of traversing most roads and trails by 4-wheel-drive vehicle and traversing on foot to otherwise inaccessible areas of interest. The best geologic exposures are found along the major drainages and diversion trenches. Studies of the areas of good exposures were supplemented in upland areas, where exposures are generally poor, by road cuts, road ditch exposures, or by use of a 5-foot hand auger. Exposures were examined with special attention to formation contacts to provide a basis for extending contacts across areas of poor exposures and as an aid for subsurface interpretations. Stereoscopic pair photo coverage flown in 1960, scale 1:20,000, was available for the entire area. Topographic maps, scale 1:20,000, were also available for the entire area. Geologic contacts were determined with the aid of the photos and topographic maps and plotted directly onto the topographic maps, then transferred to a county base map, scale 1:63,360 (½" = 1 mile).

Subsurface information for the post-Pierre strata was provided by 40,000 feet of test-hole drilling by the North Dakota State Water Commission. The results of this drilling were published as a groundwater basic data (Armstrong, 1975) report. The oil exploration files of the North Dakota Geological Survey provided information for the subsurface stratigraphic section.

Regional Topography and Geology

Emmons County, in south-central North Dakota, has an area of 1,499 square miles in Tps129 to 136N and Rs 74 to 79W. It is located between 45° 56' North Latitude on the south (the North Dakota-South Dakota state line), 46° 17' North Latitude on the north, 99° 52' 37" West Longitude on the east, and the Missouri River on the west (the westernmost point of Emmons County is at approximately 100° 40' West Longitude).

Emmons County lies within the Coteau Slope, an area of rolling to hilly plains east of the Missouri River, and the Missouri Coteau, an area of relatively fresh glacial topography with nonintegrated drainage (fig. 1). The Coteau Slope is characterized by both erosional and glacial landforms. Except for a dissected zone along the Oahe Reservoir known as the "breaks of the Missouri," and areas of buttes in the southwestern part of the county, the topography of the Coteau Slope is a rolling to hilly, mature plateau.

Through much of central Emmons County, especially in an area about 10 miles wide extending along the north side of Beaver Creek, the land is mainly an undulating to rolling (1° to 7° slopes) surface of Fox Hills Formation sand. Some wind-blown material mantles the surface, and patches of glacial sediment are found on some interfluve areas; but the Fox Hills bedrock sand is the main surface material. In the Linton area, Beaver Creek has eroded downward into the Pierre Formation (pl. 1), but the

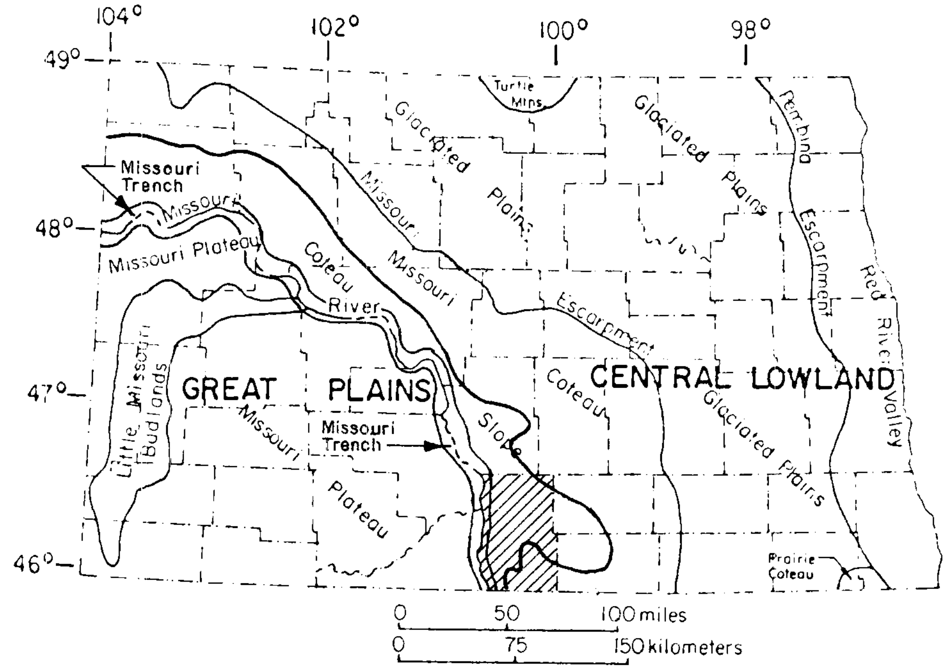


Figure 1. Physiographic map of North Dakota showing the location of Emmons County.

land surface there is little different than that developed on Fox Hills sands.

In western Emmons County, nearer the Missouri River Valley, the topography tends to be broken up by gullies. To the northwest, slightly more resistant materials of the Hell Creek Formation occur on top of the Fox Hills and the topography is more rugged, almost badlands (with slopes greater than 25°) in some places, although hilly topography (slopes ranging from 7° to 25°) predominates. To the southwest, the topography is also rugged, the result of erosion downward into the Pierre Formation.

The buttes of the northwest and southwest parts of Emmons County, and to a lesser extent the central part of the county, are easily the most prominent features in the county (fig. 2). Most of the buttes in Emmons County are capped by the Linton Member sandstone at the top of the Fox Hills Formation. On some of the buttes in southwestern Emmons County, the basal Hell Creek Formation beds are preserved. In the northwestern part of the county, many of the buttes are composed mainly of Hell Creek Formation material, and Cannonball Formation beds are preserved on the tops of some of these buttes.

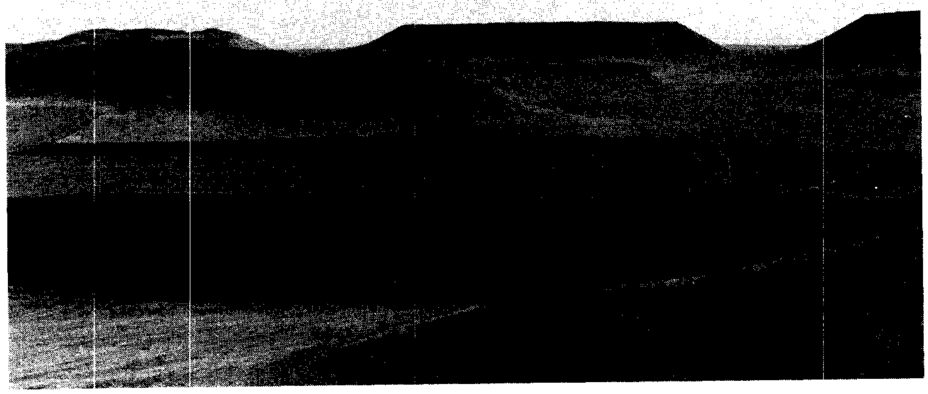


Figure 2. Two examples of typical sandstone-capped buttes in southwestern Emmons County. The resistant Linton Member of the Fox Hills Formation forms the caprock on most of the buttes in the area. Top view is of buttes located in sec 24, T130N, R78W (view to east). Lower view is of sandstone-capped butte in sec 15, T129N, R78W.

Drainage on the Missouri Coteau in northeastern and southeastern Emmons County is nonintegrated, but otherwise all the drainage in the county eventually reaches the Oahe Reservoir. Beaver Creek, with headwaters in Burnstad Lake in Logan County, is the major stream flowing westward through central Emmons County. Streams in the northeastern and southern parts of Emmons County flow out of the county before turning westward to the Missouri River Valley. In the southeastern part of the county, sizeable lake basins with interior drainage occur.

In northeasternmost Emmons County, north of Kintyre, and in the southeastern quarter of the county, southeast of Strasburg, the landscape is characterized by landforms resulting from glacial stagnation. In these areas, drainage is largely nonintegrated and the landforms are primarily constructional, consisting of materials that were built up by the glaciers. Through much of the remainder of the county glacial materials are common, but not generally responsible for the overall relief. In these areas, the landscape is an erosional one, veneered in most places with loess or wind-blown sand. Dunes (Qoed on pl. 1) are found in several places.

Southeastern Emmons County has a reasonably complete suite of fresh (Late Wisconsinan) glacial landforms, including a till plain (Qcti; Qctn), a few small eskers (Qce), elevated lake plains (Qcl), washboard moraines, numerous pothole sloughs (Qos), and an area of glacial outwash (Qcoc; Qcof) that extends northwestward to Beaver Creek. In places, the outwash gravels are collapsed with numerous potholes. A similar suite of glacial landforms occurs in the Braddock-Kintyre area, with collapsed and uncollapsed outwash near Goose Lake (Qcoc; Qcof), and a till plain (Qcti; Qctn) north of Kintyre. Drainage is nonintegrated in the area.

The soil in Emmons County is generally sandy to loamy, but heavier clay soils have developed over areas of glacial till in the eastern part of the county. Loams, clay loams, and sandy loams predominate.

At least three distinguishable surface patterns can be seen on airphotos of Emmons County. In the northeastern part of the county, a series of straight, parallel ridges and troughs trend north-northeast to south-southwest. Individual lineations are about 200 feet apart and as much as a mile long. They are underlain by beds of Fox Hills Formation sandstone. A second pattern can be seen in southeastern and northeastern Emmons County. Here are seen clusters of arcuate ridges and troughs. Individual ridges are about 5 feet high and a mile long. The third pattern, which is scattered throughout the county, consists of polygonal-shaped areas delineated by darker-toned lines. Individual polygons are four, five, or six-sided and about 50 feet across or even larger. These patterns are the result of permafrost action.

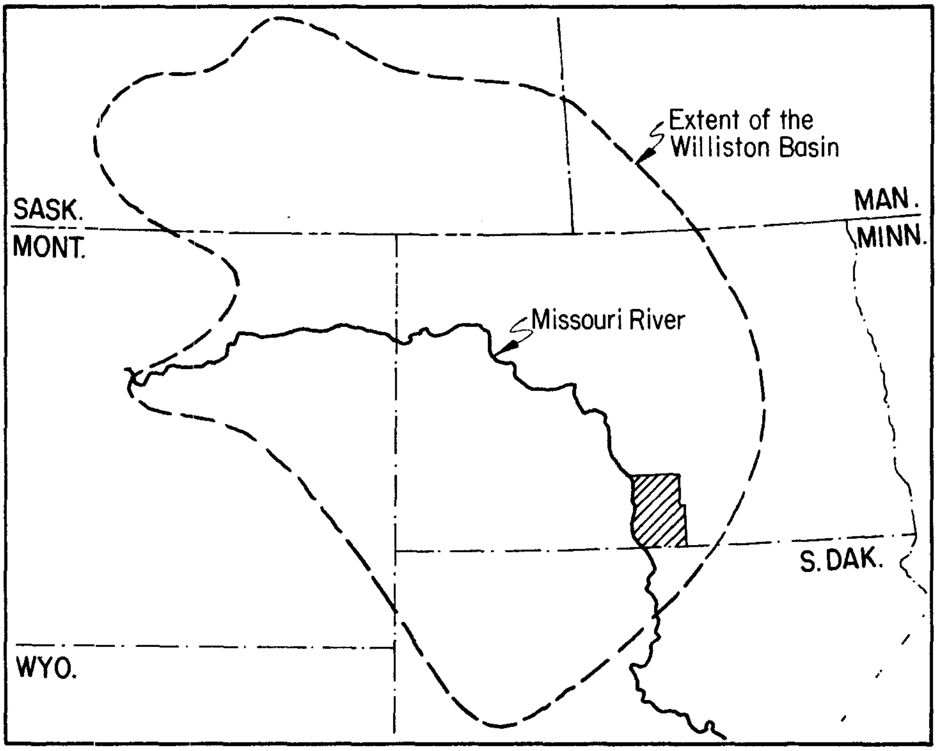


Figure 3. Map showing the location of Emmons County and the extent of the Williston Basin.

Elevations in Emmons County range from about 1,600 feet above sea level at the Oahe Reservoir water level to over 2,150 feet on some of the buttes capped by Fox Hills Formation sandstone in the southwestern part of the county (the top of Kiefer Butte is 2,170 feet above sea level). Most of Emmons County has elevations near 2,000 feet with slightly lower elevations near the valley of Beaver Creek. Away from the Missouri River trench, the lowest elevations, below 1,700 feet, occur in some of the low, linear sags, such as the valley of Cat Tail Creek, which mark preglacial or interglacial drainage channels. Local relief in some of the more rugged parts of southwestern Emmons County is between 150 and 200 feet. Elsewhere, local relief is mainly less than 100 feet. In the areas of continuous glacial cover, local relief is 20 feet or less.

Emmons County is located on the southeast flank of the Williston Basin (fig. 3), an intracratonic, structural basin containing a thick sequence of sedimentary rocks. Nearly all of the formations below the Coleharbor have a westerly to northwesterly regional dip and also thicken in the same direction.

STRATIGRAPHY

General Statement

A total of 28 oil exploration test holes had been drilled in Emmons County as of January 1, 1984. Of these, 13 bottomed in the Cretaceous and six reached the Precambrian basement. These exploratory holes, together with information from holes in adjacent areas, provide information concerning the geologic history of Emmons County. The discussion that follows is mainly a description of the composition, sequence, and correlation of the geologic units that lie at and immediately beneath the surface in the area. The description proceeds from the oldest known materials, which are discussed briefly, to the younger materials. The younger, more easily accessible geologic units are described in greater detail than are the older units.

The sedimentary rocks of Emmons County reveal a history of alternating episodes of deposition in marine seas and emergence with erosion of part of the sedimentary section. The preserved sedimentary section, bounded by the major regional unconformities associated with the emergence episodes, are called sequences (Sloss, 1963). Sequences present in Emmons County are the Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas (fig. 4). Rocks of the upper two sequences are present at the surface in Emmons County. The total preserved sedimentary section in Emmons County ranges from about 4,500 feet in the southeast to, perhaps, 7,000 feet in the northwest.

Subsurface Stratigraphy

Precambrian Rocks

Based on information obtained from the six wells that have been drilled to the Precambrian in Emmons County, and from Precambrian tests in nearby areas, it appears that the Precambrian surface slopes northwestward at about 40 to 50 feet in a mile. The Precambrian surface ranges from about 4,500 feet deep in southeastern Emmons County to about 7,000 feet deep in the northwest corner of the county.

E. G. Lidiak, in an unpublished manuscript, included descriptions of Precambrian rocks from three central Emmons County wells. He described the samples as (1) biotite-quartz-feldspar gneiss, (2) granite, and (3) biotite-hornblende-quartz-calcic-oligoclase gneiss. These rocks belong to the "McIntosh Granite Terrane" (Lidiak's term) which extends from Cass County, through McIntosh County, to Emmons County. According to Lidiak, the Emmons County basement rocks contain mainly gneissic rocks. One sample of Precambrian rock from Emmons County, an epidote-biotite gneiss, was dated by K-Ar

AGE	SEQUENCE	UNIT NAME	DESCRIPTION	THICKNESS (feet)
Holocene	Tejas	Oahe Formation	Sand, silt, and clay	0- 20
Quaternary	Tejas	Coleharbor Formation	Till, sand, gravel, silt, clay, and boulders	0- 550
Tertiary	Tejas	Flaxville Formation	Brownish gravels	0- 10
Tertiary	Zuni	Cannonball Formation	Marine sand and shale	0- 115
Cretaceous	Zuni	Hell Creek Formation	Sandstone, shale, lignite	0- 250
		Fox Hills Formation	Marine sandstone	0- 325
		Pierre Formation	Shale	800-1200
		Niobrara Formation	Calcareous shale	200- 250
		Carlile Formation	Shale	300- 400
		Greenhorn Formation	Calcareous shale	100- 175
		Belle Fourche Formation	Shale	150- 250
		Mowry Formation	Shale	30- 90
		Newcastle Formation	Sandstone	10- 100
		Skull Creek Formation	Shale	75- 200
		Inyan Kara Formation	Sandstone and shale	120- 250
Jurassic	Zuni	Swift Formation	Shale	100- 250
		Rierdon Formation	Shale and sandstone	40- 100
		Piper Formation	Limestone, shale, anhydrite	150- 300
Triassic	Absaroka		(Absent in Emmons County)	----
Permian	Absaroka			
Pennsylvanian	Absaroka	Amsden Formation	Dolomite, sandstone, shale	0- 275
		Tyler Formation	Sandstone, calcareous shale	0- 100
Mississippian	Kaskaskia	Big Snowy Group	Shale, sandstone, limestone	50- 250
		Madison Group	Carbonates and anhydrite	530-1120
Devonian	Kaskaskia	Birdbear Formation	Limestone	15- 60
		Duperow Formation	Dolomite, limestone, shale	60- 180
		Souris River Formation	Dolomite, limestone, shale	0- 90
		Dawson Bay Formation	Dolomite, limestone	0- 70
		Prairie Formation	Limestone, anhydrite	0- 15
		Winnipegosis Formation	Carbonates	0- 10
Silurian	Tippecanoe	Interlake Formation	Dolomite	0- 130
Ordovician	Tippecanoe	Stonewall Formation	Dolomite, limestone	0- 80
		Stony Mountain Formation	Dolomite, limestone, shale	75- 140
		Red River Formation	Limestone	550- 600
		Winnipeg Group	Siltstone, sandstone, shale	190- 225
Cambrian	Sauk	Deadwood Formation	Glauconitic sandstone, shale	250- 380
Precambrian basement rocks			Igneous granitic rocks	---

Figure 4. Stratigraphic column for Emmons County.

dating as Early Precambrian, approximately 2.5 billion years old (Burwash, et al., 1962).

Sauk Sequence

The Sauk Sequence is represented in North Dakota by the Deadwood Formation. The lower part of the formation, which is preserved in Emmons County, is of Upper Cambrian age. The Deadwood is an onlap depositional sequence consisting of a basal sandstone overlain by shale and carbonate, and then by another sandstone. The upper parts of the Deadwood Formation were probably removed by erosion in the Emmons County area. The Deadwood Formation in Emmons County consists of glauconitic sandstone with some greenish-gray shale. The formation ranges from about 250 feet thick in eastern Emmons County to about 380 feet thick in the northwest corner of the county.

Tippecanoe Sequence

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

In Emmons County, the Tippecanoe rocks range in thickness from about 840 feet in the southeast to about 1,170 feet in the northwest. Seven exploratory oil wells have been drilled as deep as the Silurian in Emmons County.

Kaskaskia Sequence

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

Devonian rocks that are probably present in Emmons County include, in ascending order, the Winnipegosis Formation (possible carbonates extending into northwesternmost Emmons County), the Prairie Formation (mainly salt with some limestone and anhydrite in the northwestern part of the county), the Dawson Bay Formation (limestone and dolomitic limestone in the northwestern quarter of the county), the Souris River Formation (alternating limestone and thin argillaceous beds over most of the county), the Duperow Formation (cyclical carbonates and shales throughout the county), and the Birdbear Formation (limestone over the entire county).

The overlying Mississippian rocks were deposited mainly during normal marine conditions after a period of late Devonian erosion. The Mississippian rocks include the fine-grained clastics of the Bakken Formation (these may exist in northwestern Emmons County, but their presence there has not been verified), the Madison Group (carbonates and evaporites), and the Big Snowy Group (shales, carbonates, and sandstones).

The Kaskaskia Sequence ranges from about 580 feet thick in the southeast corner of Emmons County to a maximum of about 1,400 feet in the northwest.

According to Ballard (1963), the top of the Madison in Emmons County, and in parts of adjoining Logan, McIntosh, and Kidder Counties, is characterized by a collapse breccia which resulted from evaporite and carbonate solution. This breccia is developed on the truncated Madison Group and consists of irregular fragments of limestone and dolomite in a matrix of calcareous silt and sand. The limestone fragments show evidence of solution. Part of the breccia is Late Mississippian in age as it is overlain by the Big Snowy Group in at least one well. However, much of the breccia may be post-Mississippian to pre-Piper (Jurassic) age.

Absaroka Sequence

Emmons County was flooded by a sea in early Pennsylvanian time and the Tyler beds of shale and limestone were deposited in the area. This was followed by the deposition of alternating carbonates and sandstones of the Amsden Formation. If additional Pennsylvanian sedimentary rocks were deposited in Emmons County, they were later removed during a period of erosion that lasted through late Pennsylvanian, Permian, and Triassic time. The Triassic Spearfish Formation apparently does not occur in Emmons County as the Amsden appears to be directly overlain by the Jurassic Piper Formation. The total thickness of the Absaroka sediments in Emmons County ranges from zero to as much as 350 feet in the northwest part of the county.

Zuni Sequence

Deposition of the Zuni Sequence sediments began with red shale, evaporites, and carbonates of the Middle Jurassic Piper Formation followed by normal marine shale and fine-grained sand of the Middle to Upper Jurassic Rierdon and Swift Formations.

Jurassic rocks range in thickness from about 400 to 600 feet, with the greatest thicknesses in the north. The Upper Jurassic fine-grained clastics are unconformably overlain by the well-developed basal Cretaceous sands of the Inyan Kara Formation. The Inyan Kara Formation consists of sandstone and shale with variable sandstone development. It is generally thickest, over 250 feet thick, in a northwest-southeast trending area of eastern Emmons County that extends from T135N, R76W, to T132N, R74W.

Except for the Newcastle ("Muddy") Formation, which is a muddy sand in Emmons County, the remainder of the Cretaceous sediments below the Fox Hills Formation are gray shales, some of which are calcareous and some of which contain bentonitic zones or beds. The marine Cretaceous section includes the Skull Creek, Mowry, Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre Formations.

The remaining units in the Zuni Sequence are all found in surface exposures in Emmons County. They include the Cretaceous Fox Hills Formation, a marine sandstone, the Cretaceous Hell Creek Formation, a continental sand and shale, and the Paleocene Cannonball Formation, a marine mudstone and sandstone. These units will be discussed more fully in the following pages.

Cretaceous rocks in Emmons County generally range in total thickness from about 2,500 feet in the southeast, to more than 3,000 feet in the northwestern part of the county where some buttes have a complete uppermost Cretaceous section including the Hell Creek Formation beds and the basal Tertiary Cannonball Formation deposits.

Surface Stratigraphy

Zuni Sequence

Pierre Formation

The Upper Cretaceous Pierre Formation is present mainly in the subsurface, reaching thicknesses of 800 to 1,200 feet. It subcrops directly beneath the glacial material in places where preglacial and interglacial (glacial diversion) valleys have been eroded through the overlying Fox Hills Formation. The Pierre Formation is exposed in several places near Linton and in parts of southwestern Emmons County (pl. 1). The exposures of the Pierre Formation seen in Emmons County probably belong to the Elk Butte Member (Searight, 1937), which is a medium- to dark-gray shale that weathers to lighter colored flakes and erodes to rounded, grass-covered knolls. The best exposures of Pierre Formation shale are along Beaver Creek and in several gullies at the south edge of the county (pl. 1). At Seeman Park (SE¼sec 17, T132N, R76W), about a mile southeast of Linton,

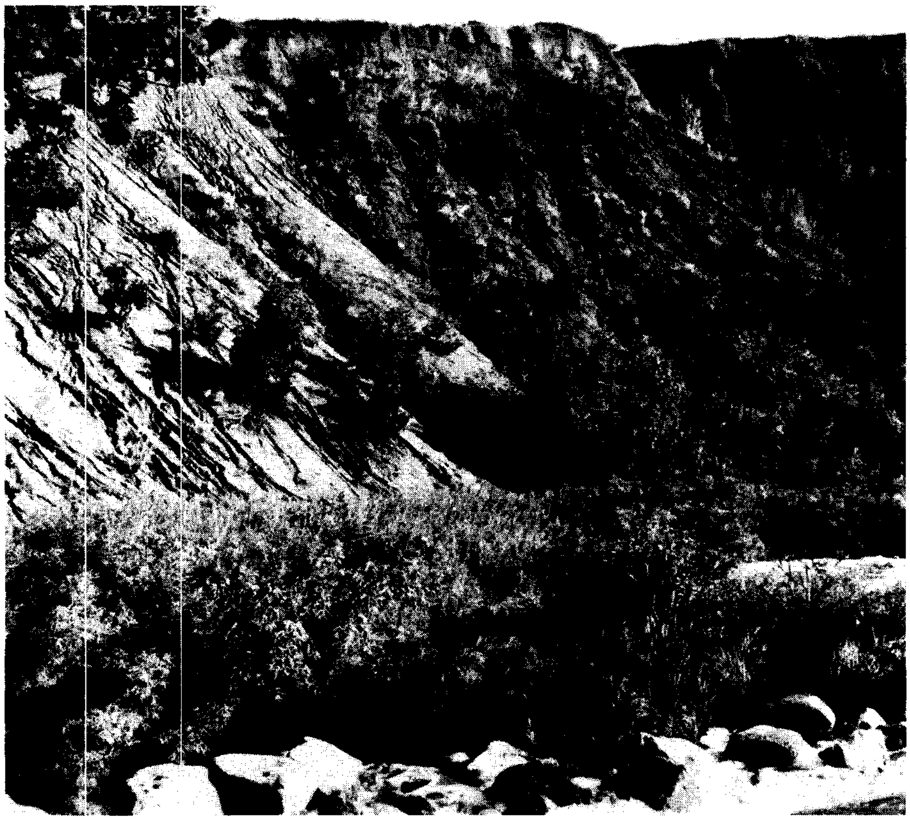


Figure 5. Exposure of Pierre Formation shale. The Pierre here is overlain by the Fox Hills Formation in a north-facing cutbank of Beaver Creek in Seeman Park, sec 17, T132N, R76W.

the Pierre Formation is represented, in a north-facing exposure, by 68 feet of dark bluish-black shale, which is gypsiferous and iron-stained throughout (Feldmann, 1972). This is also the best exposure in the county of the Pierre-Fox Hills formational contact (fig. 5).

In many places, especially in the valley of Beaver Creek, large blocks of Pierre Formation shale, along with overlying beds of Fox Hills sediments, have slid toward the river, commonly rotating as they did so. This makes it necessary to be especially cautious in measuring the Pierre-Fox Hills section as Fox Hills beds are sometimes found at elevations accordant with nearby Pierre stratigraphy.

Fox Hills Formation

The Fox Hills Formation conformably and gradationally overlies the Pierre Formation (figs. 5 and 6). It is a marine sandstone and shale sequence that outcrops throughout much of central Emmons County (pl. 1). Fox Hills beds are exposed on a structural high in T136N, R76W, and a narrow zone of Fox Hills sediments follows the Missouri River to within five miles of the Emmons-Burleigh County line. The Fox Hills Formation subcrops beneath the glacial sediment cover throughout much of the remainder of the county. It is absent in the central and southeastern parts of the county where it has been removed by preglacial and interglacial stream erosion.

According to Feldmann (1972) the Pierre Formation becomes somewhat siltier near its top and contains small blebs of fine-grained sand. The contact in Seeman Park can be identified by the occurrences of the first layers of jarosite in the Fox Hills Formation. At the general level of the jarosite stringers, fine-grained sand is more abundant than the silt and clay of the Pierre Formation. This level is about ten to twelve feet below the lowest fossiliferous concretion layer which would, therefore, be placed in the Fox Hills Formation (fig. 7). Above the appearance of the first jarosite, the sequence changes rapidly from silty, sandy shale to fine- to medium-grained buff sand with small pods of jarosite. This definition of the contact between the Pierre and Fox Hills Formations is consistent with the definition used by Morgan and Petsch (1945) and by Waage (1961, 1968).

The geology of the Fox Hills Formation has been studied by several workers (Feldmann, 1972; Waage, 1961, 1968; Cvancara, 1976; Klett and Erickson, 1976; Carlson, 1982; and others). Waage (1968) reviewed usage of the Fox Hills terminology. Based on his studies of outcrop areas in South Dakota, which extended into North Dakota, Waage proposed a reference area and subdivision into three members with type sections in South Dakota. In the lower Fox Hills, he used the Trail City and Timber Lake Members, defining the Trail City as a clayey silt and clayey sand member overlain by sandstone of the Timber Lake Member. In most parts of Emmons County where extensive exposures of Fox Hills Formation occur, the material is loose sand or poorly cemented sandstone, probably of the Timber Lake Member. Fossil *Ophiomorpha* are common in the Timber Lake Member (fig. 8). Waage showed the Trail City Member thinning northeastward, so that in south-central North Dakota it is so thin it is of doubtful use for correlation purposes. In the western part of Waage's study area, the Trail City Member was overlain by the upper Fox Hills, which Waage designated the Iron Lightning Member. He divided the Iron Lightning into the Bullhead and Colgate facies. The Bullhead facies was de-

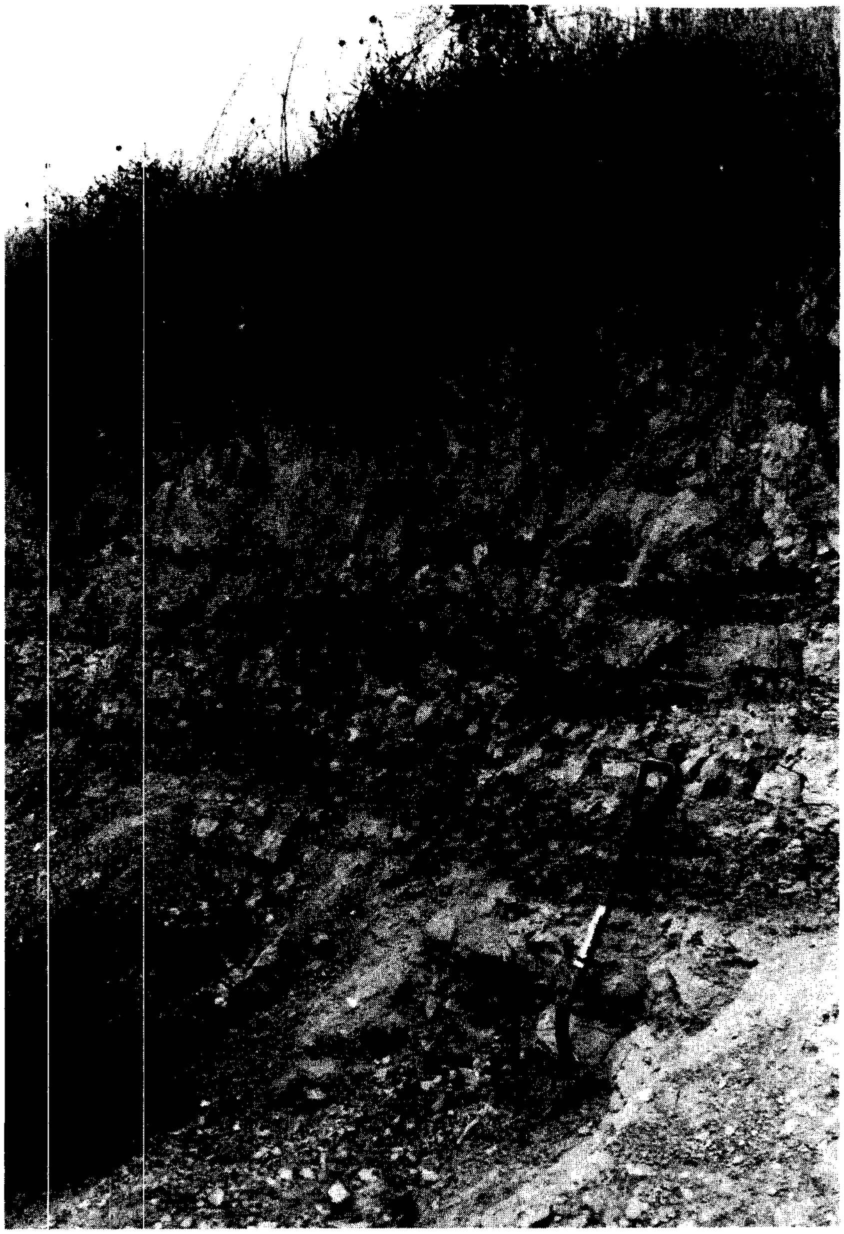


Figure 6. Gradational contact between the Cretaceous Pierre Formation (below) and the Fox Hills Formation (southeast corner of sec 31, T133N, R75W). Wind-blown material is at the top.

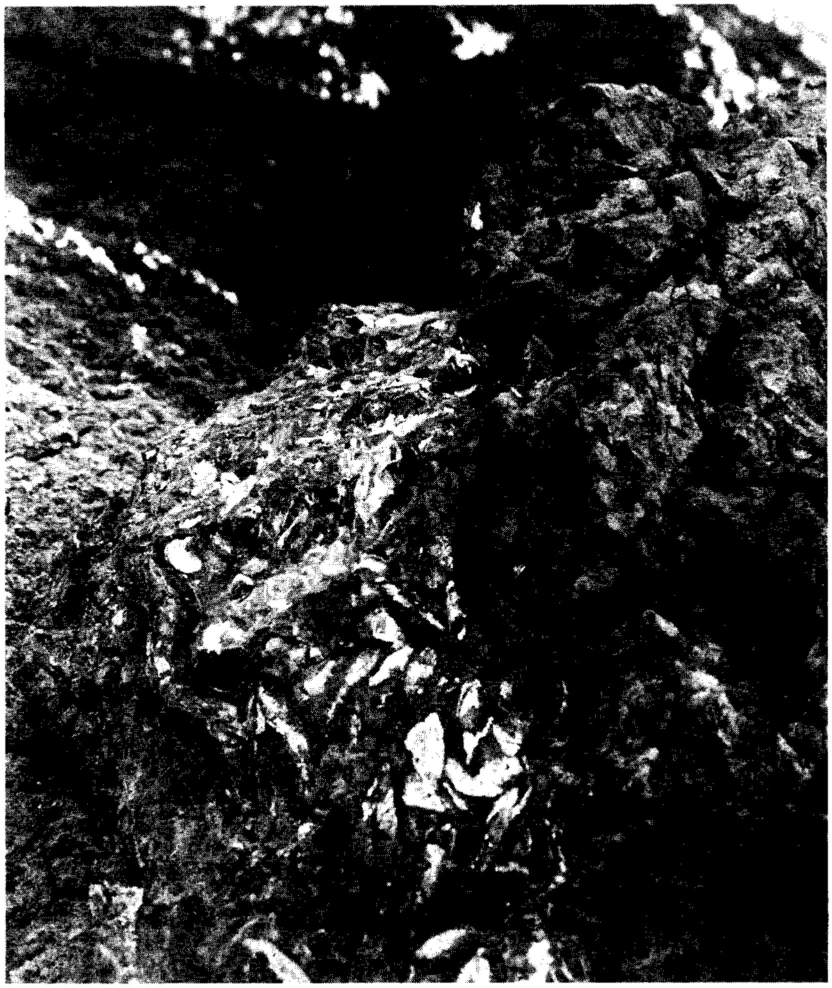


Figure 7. Fossiliferous concretion in the Fox Hills Formation, about 10 feet above the Pierre-Fox Hills contact. Seeman Park, sec 17, T132N, R76W.

Figure 8. Sandstone ledges in the Fox Hills Formation (Timber Lake Member) containing abundant fossil Ophiomorpha burrows. These branching structures are the preserved burrow linings and fillings of a decapod crustacean (shrimp). NW¼sec 36, T131N, R79W.

scribed as thinly interbedded sand, silt, and clay; this unit has been referred to as the "banded beds" (Laird and Mitchell, 1942) in North Dakota. The Colgate was described as sand beds either at the top or within the upper Fox Hills. Those beds at the top were described as white or grayish white, as much as 60 feet thick, while the sand beds within the Bullhead facies rarely exceed 20 feet. Most workers have considered Colgate to be restricted to sand at the top of the Fox Hills, but have, as Waage noted, left the impression that it is a continuous sand.

Feldmann (1972) reviewed usage of Fox Hills in North Dakota and, based on his outcrop studies, felt that a three-member subdivision was most useful for North Dakota. He noted the transitional beds, which might be assigned to the Trail City Member, but thought they should be included in the Timber

Lake Member. He preferred to divide the upper Fox Hills into Bullhead and Colgate Members with the Colgate at the top of the Fox Hills.

Erickson (1974) preferred Waage's interpretation, but added the Linton Member (Klett and Erickson, 1976) at the top of the Fox Hills. The Linton Member is described as a ridge-capping sandstone at the top of the Fox Hills exposed at a few localities in Emmons and Sioux Counties. Cvancara (1976) followed Erickson's usage in his discussion.

Carlson (1982) rejected the usage of the Linton Member as a formal unit. He said that, even though it may be recognizable in the outcrop area, it "seems more practical to include these exposures in the Colgate definition rather than to drop Colgate and erect a new member."

Because the indurated, siliceous sandstone beds of the Linton Member are so conspicuous in central and southwestern Emmons County and form resistant caprock layers up to 20 or 25 feet thick on most of the prominent buttes in the area (figs. 9 and 10) it seems appropriate to follow Klett and Erickson's (1976) usage. Thus, it seems practical to subdivide the Fox Hills Formation in Emmons County as follows (lowest to highest members): Trail City (tentatively identified only in southwesternmost Emmons County in sec 12, T129N, R79W), Timber Lake, Iron Lightning (with a Bullhead and a Colgate lithofacies), and Linton.

The Linton Member of the Fox Hills Formation in Emmons County consists of light-olive-gray to grayish-brown, very fine to fine-grained, subangular, moderately to poorly sorted, indurated, siliceous sandstone that weathers to varying shades of gray or to a distinctive copper brown with accompanying yellow stains. The unit is generally massive, but flat bedding and large-scale trough or planar crossbedding are present locally (fig. 9). Ripple marks and mud cracks are rare. Pellets about an eighth of an inch across are common. The sandstone is compositionally a subgraywacke to a feldspathic arenite, contains generally about 28 percent matrix and a substantial percentage of volcanic shards. The type section of the Linton Member is located about a mile east of the town of Linton (N½secs 8 and 9, T132N, R76W) (Klett and Erickson, 1976). The Linton Member merges into and forms the land surface in much of the northwestern quarter of the county.

Along the eastern Emmons County line, a few miles north of Beaver Creek, the Linton sandstone splits into two phases, which may alternate in position. One part retains the general characteristics of the Linton farther west but is darker gray and more quartzitic. The other part is a coarse, lenticular, crossbedded calcareous sandstone that weathers to buff color, often with some white, calcareous scale. Leaching of the cement gives it a spongy appearance (fig. 9). Either bed may be as

Figure 9. Linton Member sandstone exposed on a butte top in southwestern Emmons County (SW¼SW¼sec 15, T129N, R78W). The Linton Member here consists of about 23 feet of hard, fine-grained, flaggy, brownish-gray to brown sandstone.

Figure 10. Top of typical butte with pieces of sandstone of the Linton Member (Fox Hills Formation). All of the buttes in central and southwestern Emmons County have a caprock of Linton Member sandstone. The butte shown here is located in the SW¼ sec 30, T131N, R77W and the SE¼sec 25, T131N, R78W. The view here is to the northwest over Little Beaver Creek.

much as eight feet thick, and the zone within which alternation occurs is 10 to 14 feet thick. Farther north, only the calcareous sandstone phase is seen. The undersurface of the bed pinches and swells within short distances, and the bed apparently was deposited in depressions scoured into the poorly consolidated fine sands below.

From sec 18, T135N, R74W, southwestward to sec 18, T134N, R75W, the Linton Member shows a marked northeastward lineation on aerial photographs (fig. 11). These are especially prominent in secs 18, 19, and 30, T134N, R75W. The lineations are a series of straight, low swells, 150 to 200 feet wide, that resemble giant ripples. Fine sandstone beds, interbedded with loose gray sands, and totalling 30 to 38 feet thick occur at several points within this lineated area. According to Fisher (1952), the linear features probably result from the building of a low sandbar or bank. Currents acting on such a "high" removed the finer, calcareous muds, which occur between the harder sandstone ledges, and carried them outward to accumulate, along with some sands, in hollows at slightly greater depths. This transported material formed the irregular and crossbedded buff sandstone facies mentioned above. It is likely, too, that because the glacier advanced southwestward over the area of lineations, parallel to them, it helped to accentuate them by removing the softer materials between the ridges.

A conspicuous volcanic ash occurs near the base of the Fox Hills Formation in the Linton area (figs. 12, 13, 14, and 15). It consists of about 80 percent volcanic glass, 10 percent quartz, 7 percent feldspar, 1 percent hornblende, and 2 percent minor constituents. This 25- to 30-foot-thick ash bed apparently rises up section as it is traced from east to west (Feldmann, 1972). According to Cvancara (1976), the volcanic ash rises stratigraphically westward, occurring "very near the base of the Fox Hills Formation" in the Linton area to about 48 feet above the Fox Hills-Hell Creek contact in southeastern Morton County (Artzner, 1974). Presumably, the volcanic ash bed represents a single geologic event and was deposited everywhere at the same time. My own measurements place the base of the ash bed at 60 feet above the Pierre-Fox Hills contact in the Linton area. The westward-rising aspect of the ash bed is compatible with the generally accepted theory that, as the Fox Hills beds were being deposited in any given area, deeper water marine sediments of the Pierre Formation were being laid down generally to the east of that area and largely continental sediments of the Hell Creek Formation were being deposited generally to the west (Cvancara, 1976).

Hell Creek Formation

The Late Cretaceous Hell Creek Formation is a continental deposit that conformably and gradationally overlies the Fox Hills

Figure 11. Airphoto of a strongly lineated area in northeastern Emmons County. Parts of secs 18, 19, and 30, T134N, R74W and secs 13, 24, and 25, T134N, R75W are shown.

Figure 12. Highly fractured volcanic ash exposed in a pit three miles north of Linton (SE¼sec 21, T133N, R76W).

Formation in parts of northwestern and southwestern Emmons County (pl. 1) (figs. 16 and 17). The Hell Creek Formation is exposed throughout much of Tps134 to 136N, R78W (fig. 18). Small exposures of brownish shale of the Hell Creek Formation are also found on some butte tops, overlying the Linton Member of the Fox Hills Formation, in sec 30, T130N, R78W (figs. 16 and 17), and sec 12, T129N, R79W. Exposures generally consist of beds of sandstone, siltstone, mudstone, carbonaceous shale, and lignite, or some combination of these materials. The brownish shale beds contain abundant carbonaceous material and occasional thin lignite seams. Pieces of petrified wood are common (fig. 19). Hell Creek sandstones are generally friable, clayey, medium to fine grained, and contain many dark minerals which impart a "salt and pepper" appearance. Terrestrial dino-

Figure 13. Volcanic ash pit about a mile north of Linton (SE¼NE¼sec 33, T133N, R76W). Sandstone boulder surrounded by ash. Apparently a chunk of sandstone fell or rolled into the soft ash, sinking down and disturbing the original flat-lying structure. The contrast in this black and white photo is insufficient to show the edge of the boulder clearly so a dashed line has been drawn around the boulder.

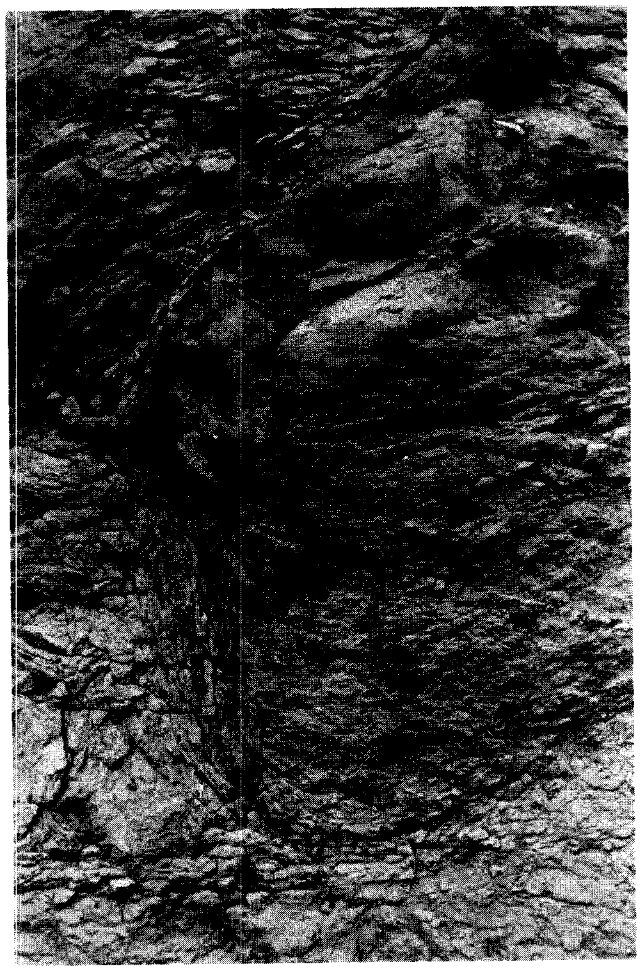


Figure 14. Detail of figure 13. Lower left portion of boulder in ash showing sandstone-ash contact.

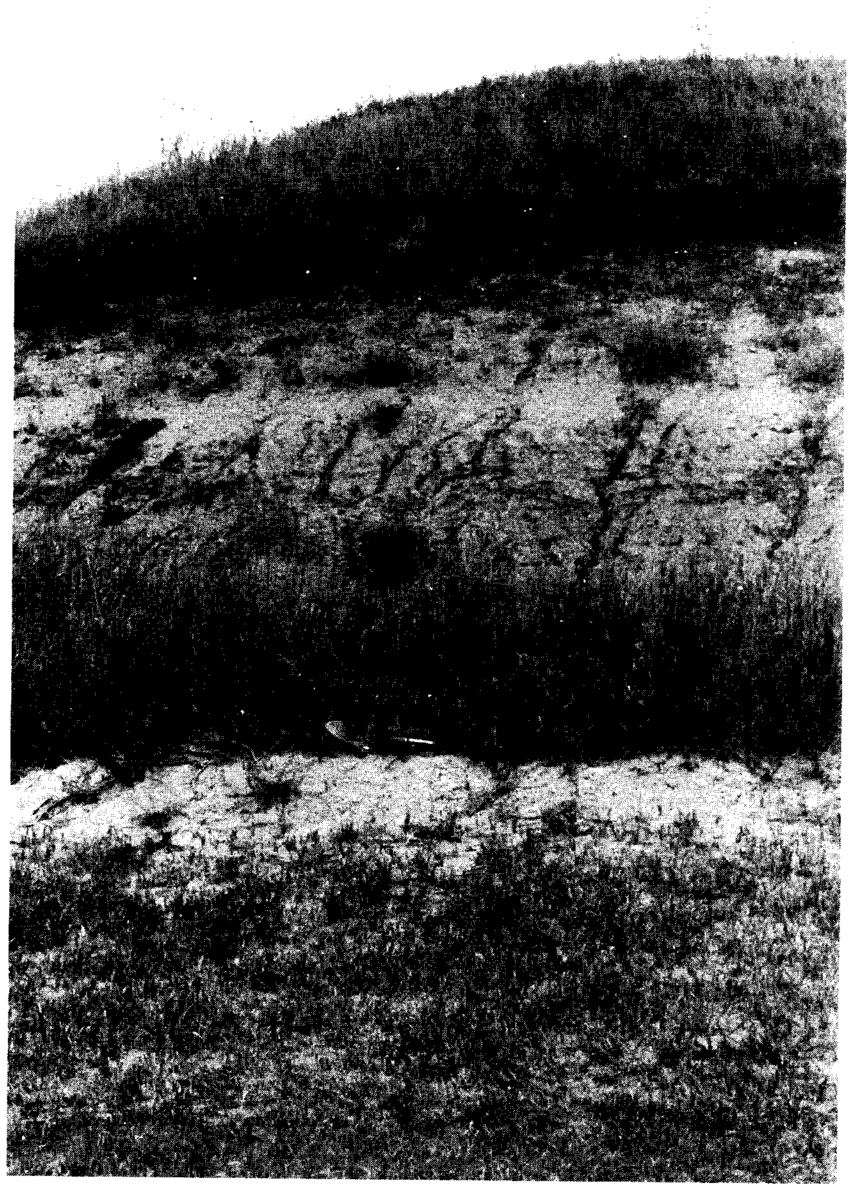


Figure 15. Marine shale of the Fox Hills Formation overlying volcanic ash (SW¼sec 33, T133N, R75W). Some thin stringers of ash appear in the overlying shale. Shovel marks top of ash.

Figure 16. Fox Hills-Hell Creek contact exposed in southwestern Emmons County (SW¼sec 30, T130N, R78W). Contact is shown by arrows. Here, the Linton Member sandstone is only about 4 to 6 inches thick and overlain by reddish-brown to brown, carbonaceous shale of the Hell Creek Formation. The Linton Member sandstone thickens rapidly to the east in this area.

Figure 17. Fox Hills-Hell Creek Formation contact. Same location as figure 16 (SW¼sec 30, T130N, R78W) showing the Fox Hills-Hell Creek formational contact.

saur fossils are found in the Hell Creek beds; these are the basis for assigning a Cretaceous age to the formation.

Frye (1969) subdivided the Hell Creek Formation in the Missouri Valley area into several members, but, because internal lateral continuity is poor and few beds can be traced for distances of a mile or more, Frye's members will not be discussed in detail here. The Hell Creek Formation is non-marine in western North Dakota, but it does contain a thin marine tongue in Sioux, Morton, and western Emmons Counties (Moore, 1976).

The Hell Creek Formation differs from the Fox Hills Formation in the variability of its lithologies and textures and from the overlying Cannonball Formation in its lack of persistence of beds and the absence of significant lignite content. The sands above the contact in secs 28 and 33, T136N, R78W are buff colored; the Hell Creek-Cannonball contact is placed at the highest lignitic shale bed, but no good exposures of the contact were seen in Emmons County.

Fine- to medium-grained, calcareous, gray sand beds are most common in the Hell Creek Formation exposures in Emmons County. The calcareous content of these sandy materials contributes to rapid erosion, and cavities a few feet in diameter

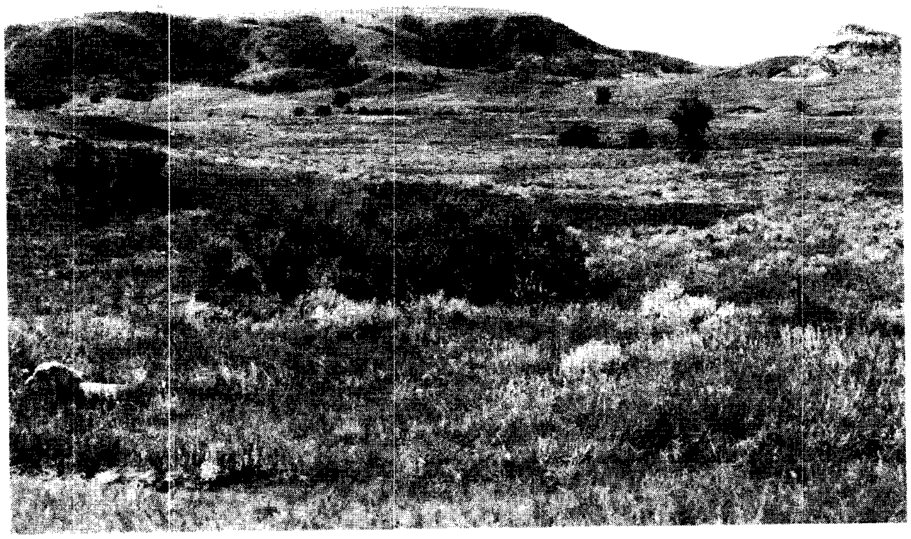


Figure 18. Badlands exposures of Rattlesnake Butte, Hell Creek Formation topography. View is to the south over sec 33, T136N, R78W.

are found in the sides of some buttes. The sands typically contain appreciable amounts of bentonitic clays which swell and form polygonal crack patterns. Thin partings of lignitic shale between the sand layers make the crossbedding conspicuous.

The lignitic shale beds are brownish and weather to reddish brown. They are thin-bedded, ranging in thickness from an inch or less to about three feet. Beds of black, carbonaceous shale or lignite, less than a foot thick, also occur.

Bentonitic clays are widespread in the Hell Creek Formation. When these are freshly exposed, and the clay is damp, the surfaces are sticky and plastic. The bentonitic clay absorbs moisture and swells considerably; on drying, the outcrop is marked by an intricate pattern of polygonal cracks. This dried zone may form a rather strong crust several inches thick over the wet clay beneath. The clay beds are commonly less than six feet thick, but they are quite resistant to erosion and form rilled terraces along the sides of buttes. These are easily

Figure 19. Petrified wood in the Hell Creek Formation. This exposure is located at the southeast corner of sec 7, T136N, R78W.

identified on airphotos and are an aid in mapping the Hell Creek Formation. Fisher (1952) reported observing an unaltered, three-foot-thick volcanic ash bed in the basal part of the cliffs in sec 34, T135N, R78W, but I did not see this exposure.

Several types of small concretions are found in the Hell Creek Formation sands. Ferruginous nodules, which occur as lenses or irregular masses, are most common. Their cores are either gray, sandy limestone or siliceous shale. Weathering results in a yellowish-brown, brown, or black shell, which is probably due to oxidation of iron impurities. The surfaces of the concretions are commonly varnished and show markings similar to septaria. Other types of concretions are clusters of gypsum crystals and small spheres of sand cemented by calcite.

Cylindrical and branching concretions, which resemble the fossil seaweed Halymenites, are common in the Hell Creek Formation in Emmons County. This fossil is composed of sand-sized materials and usually shows one color in cross section, whereas the concretions are commonly of finer materials and may show several color changes, each representing different weathering zones. If the rock is freshly broken, a carbonaceous film and small nodes may be seen on the surface of the fossil.

Laird and Mitchell (1942) pointed out that the Hell Creek Formation characteristically erodes to steep-sided buttes with a small flatland developed at the base. The poorly cemented sand and sandy clay beds are rapidly fluted to a maze of miniature gullies and spurs (miniature badlands topography) (fig. 20). In addition, leaching of calcareous cement creates small caverns. The caverns and gullies in and behind the face of the butte join together to isolate the columns and maintain erosion of the face at a relatively constant rate. Heavy rains tend to flush out and erode the embayments between columns to the general level of the surrounding flatlands.

The thickest section of Hell Creek Formation beds was noted in sec 33, T136N, R78W where nearly 200 feet occurs. The best exposures are on Coal Butte (sec 32, T135N, R78W, and sec 5, T134N, R78W). The total thickness of the formation in Emmons County is probably between 250 and 270 feet. This compares to the 300- to 350-foot thickness reported in the Selfridge area of Sioux County (Carlson, 1982).

Cannonball Formation

The Cannonball Formation sand and shale beds occur in northwesternmost Emmons County on buttes in secs 28 and 33, T136N, R78W. These consist of fine, buff marine sands and clayey shales which resemble the Fox Hills Formation sediments. Total thickness ranges up to about 113 feet in Emmons County; the upper parts of the buttes are poorly exposed and the contact with the underlying Hell Creek Formation was not seen.

Tejas Sequence

The Tejas Sequence is considered to be present in the midcontinent area of the craton even though its type section is located on the Texas coast. As defined by Sloss (1963), the Tejas Sequence includes all the rock-stratigraphy on the craton above the Zuni Sequence. In North Dakota, this does not include any marine sediments. Rather, it includes largely fluvial, lacustrine, and other continental deposits such as those of Oligocene age (White River Group sand, silt, and gravel deposits), Miocene (?) age (limestone, sandstone, and tuffaceous materials such as those on top of the Killdeer Mountains--"Arikaree" (?) or "Killdeer" (?) Formations), Pliocene (?) age (gravel deposits found on high-level erosion surfaces or buried beneath younger deposits in preglacial valleys), and Pleistocene age (glacial deposits of the Coleharbor Group). Certainly, most of the time span represented by the total Tejas Sequence sedimentary accumulation does not correspond to any preserved

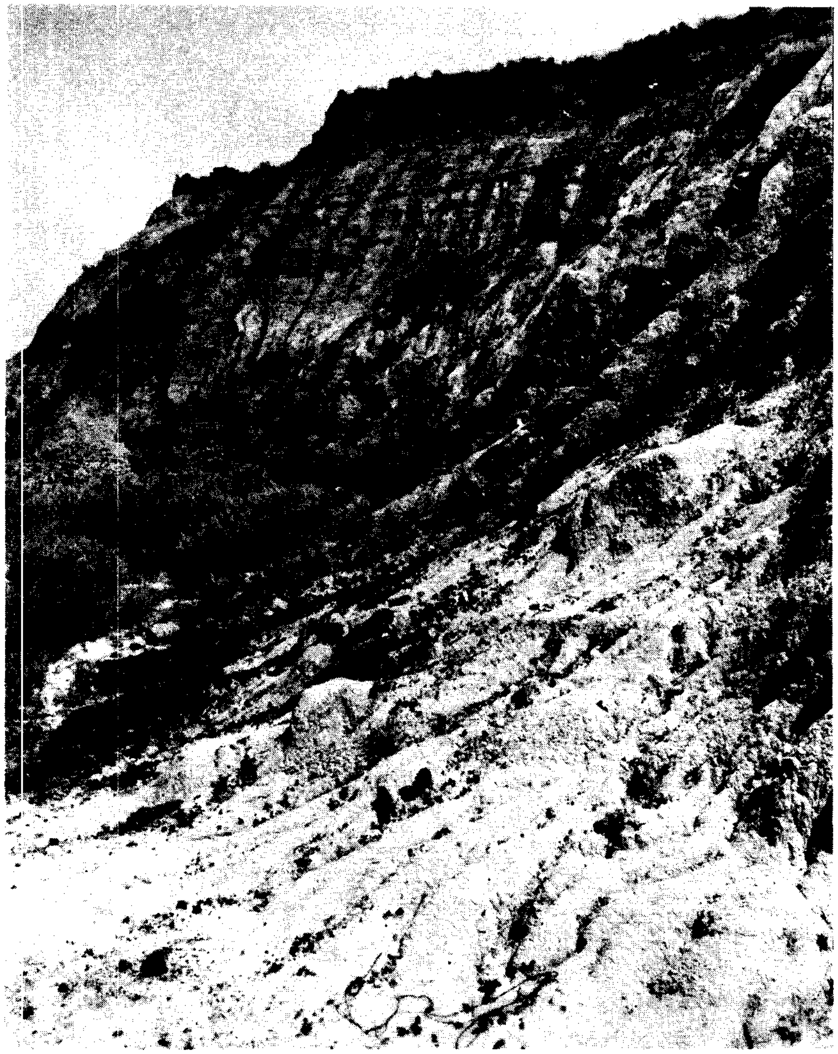


Figure 20. Hell Creek Formation badlands topography. Exposure in sec 33, T136N, R78W.

correlatable sedimentary section; the "Tejas Sequence" in North Dakota is primarily an unconformity represented by the residue from erosional events. Because Sloss's (1963) concept of sedimentary sequences presumes both interregional unconformities and lithologic coherence of the unit, a case could be made for excluding all post-Zuni North Dakota deposits from any subsequent sedimentary sequences.

Bickley (1972), in an unpublished doctoral dissertation, redefined the post-Zuni materials in North Dakota in terms of two sequences: the Tejas and Sakakawea Sequences. The Sakakawea Sequence was a new term Bickley introduced to include materials related to glaciation. According to Bickley, the Tejas Sequence should be restricted to the marine deposits found along the Texas Gulf Coast Basin and the Sakakawea Sequence should include the non-marine deposits of glacial-related origin found in the northern USA and southern Canada.

For purposes of this discussion, the concept of a "Sakakawea Sequence" is considered to be unnecessary. Rather, all the post-Zuni Sequence materials are here assigned to the Tejas Sequence.

Flaxville Formation

The only preglacial Tejas Sequence materials found in Emmons County are gravel deposits found at the bottoms of deep preglacial valleys. These materials are sometimes referred to as "Flaxville Formation," and they are generally considered to be either late Pliocene or early Pleistocene in age (Bluemle, Anderson, and Carlson, 1981). The source of this gravel is from the southwest, rather than from processes related to glaciation (Canadian Shield lithologies). Flaxville Formation gravel deposits, if they are undisturbed, generally lie directly on the Cretaceous bedrock surface. They were identified in at least three test holes in this situation where brownish cherts, sandstones, and other rock types not associated with glacial deposition lie on a deeply weathered surface of Pierre Formation (2 holes) and on a weathered Fox Hills Formation sandstone surface (1 hole). Although as much as 35 feet of gravel, which includes small fractions of western lithologies, does occur in some test holes along the Missouri River Valley, these thicknesses represent combined western and Canadian Shield types; the total part attributable to non-glacial sources is probably much less. Also, the thicker accumulations of gravel (which do contain some western gravels) occur on top of glacial till deposits, indicating either (1) re-establishment of drainage from the southwest after the early Pleistocene glacial events, and/or (2) reworking of existing western-derived gravels by glacial meltwater. The total thickness of Flaxville Formation (?) gravels is probably not greater than 10 feet anywhere in Emmons County.

Coleharbor Group

All the sediment related to glacial deposition in Emmons County, that is, all the materials that were deposited by the glacial ice as well as by flowing and ponded water associated with the ice, are collectively referred to as the Coleharbor Group (Bluemle, 1971). The Coleharbor Group has been subdivided into a large number of informal units and formally named formations by various geologists. Some of these units may be regionally correlatable, but others seem to have only local extent. Bickley (1972) recognized and named several formations within the Coleharbor Group that occur in the Emmons County area: Ulmer and Sackreiter (1973) and Clayton, Moran, and Bickley (1976) redefined and renamed Bickley's formations and named several other units as well.

Even though the various formations that have been named within the Coleharbor Group are probably valid in certain areas and, in many instances correlatable over reasonably wide areas, they are not nearly as well exposed in Emmons County as they are in some other parts of North Dakota. For this reason, all of the deposits that are the result of glacial processes and of processes directly related to glaciation, including deposits that resulted from deposition by running water, glacial ice, or in lakes during and immediately following the glacial event, are, for purposes of this report, considered to be part of the Coleharbor Group, undifferentiated. For purposes of the present discussion, however, I have informally referred to Bickley's (1972), and other researcher's, formal Quaternary formations when they help to clarify discussions of local areas within Emmons County. I have used the formally named Oahe Formation (Clayton, Moran, and Bickley, 1976) in the discussion of post-glacial materials.

Sediment of the Coleharbor Group is exposed throughout Emmons County, but the only areas where significant thicknesses occur are in the buried valleys of preglacial and interglacial origin and in parts of northeastern and southeastern Emmons County (pl. 3). The Coleharbor Group is generally thin or absent through much of central Emmons County for several miles on either side of Beaver Creek. It is thickest in the Strasburg area where over 500 feet of fluvial and lacustrine sediments fill a preglacial valley.

Those areas of Emmons County where glacial sediment (till) is found at and near the surface are shown on plate 1 as map units Qctn, Qcti, Qchv, Qcfv, and Qce. Bickley (1972) recognized upper and lower till units, the Braddock and Emmons Formations, respectively (fig. 21); and I will use his terms in this discussion, although I do not consider his till units to be formations. I recognize at least one more till unit in areas west of Bickley's two units, which I will refer to as the Temvik till.

Figure 21. Contact (dashed line) between the Braddock till and the overlying Emmons till. Located about 0.35 miles east of the southwest corner of sec 31, T131N, R69W in McIntosh County, North Dakota. Photo by William B. Bickley, Jr.

Bickley describes his Braddock (lower till) unit as an unbedded, massive to jointed, olive-gray to yellowish-brown, bouldery, cobbly, pebbly, sandy, silty clay. The texture of the Braddock consists of approximately equal parts of sand, silt, and clay with deviations from these average textures of as much as 10 percent. Pebbles, cobbles, and boulders of igneous rocks, limestone, dolomite, and shale make up a few percent of the Braddock. Mineralogically, the Braddock is composed of minerals derived both from the Canadian Shield and local sources. The clay-sized portion of the Braddock is composed largely of clay minerals (predominantly montmorillonite). The sand and silt-sized portions of the Braddock are composed mainly of quartz, feldspar, limestone, dolomite, shale, and a wide variety of small amounts of other minerals. The portion of the Braddock 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 southwest corner of sec 31, T131N, R69W in McIntosh County, gave the following abundances for different lithologies: carbonate, 42 percent; crystalline, 21 percent; siliceous, 11 percent; shale, 7 percent; and miscellaneous, 19 percent (Bickley, 1972). The Braddock also contains lenses of clay and silt, which make up between 5 and 10 percent of the total volume of the unit.

Bickley's Emmons (upper till) unit is similar to the Braddock, but olive gray to brown in color and typically contains a relatively high percentage of shale. The Emmons averages 17 percent sand, 36 percent silt, and 47 percent clay (Bickley, 1972). It is composed of material derived from both the Canadian Shield and local sources, as is the Braddock, but constituents derived from the west are uncommon. The clay-sized portion of the Emmons is composed mostly of clay minerals (largely montmorillonite). The silt- and sand-sized portions of the Emmons are composed mainly of quartz, feldspar, shale, limestone, and dolomite. Heavy minerals also make up a small fraction of the sand-sized material. The gravel-sized material in the Emmons till unit is composed largely of shale, limestone, dolomite, granite, and basalt cobbles and pebbles. Shale is the most common material in the gravel fraction of the Emmons. A pebble count, based on 146 pebbles greater than 4 millimeters in size collected at the southwest corner of sec 31, T131N, R69W in McIntosh County, gave the following abundances for different lithologies: shale, 34 percent; crystallines, 27 percent; carbonates, 27 percent; siliceous, 4 percent; and miscellaneous, 7 percent (Bickley, 1972). Small amounts of fluvial material make up about 10 percent of the Emmons till unit.

The land surface in western Emmons County is covered in places by a veneer of sandy till (pl. 1) which is informally referred to as the Temvik till. This material is invariably weathered through its total thickness, which is generally less than 5 feet where it was possible to auger through it or see its base. Commonly the Temvik till is associated with patches of glacial erratic boulders, or, in many places, only the boulders are present, sometimes in great abundance. In these areas, the finer fraction of the early till cover has been completely removed by weathering and erosion.

The approximate areal distribution of the Braddock, Emmons, and Temvik till units in Emmons County is shown on plate 4. The Braddock (lower unit) is found at the surface over much of northeastern Emmons County; many small patches are not shown on plate 4. The Emmons (upper unit) is present only in the southeastern quarter of the county. It is more continuous over its area of extent than is the Braddock. The Braddock likely underlies the Emmons in many parts of southeastern Emmons County. The area of the Temvik till is more problematical because, as was already pointed out, in many places the only evidence for it is scattered patches of glacial erratic boulders. Since boulders are present even in areas mapped as bedrock, it might be said that all of Emmons County not covered by Braddock or Emmons till is covered by the Temvik. However, I have attempted to restrict the areas of Temvik till on plate 4 to places where at least some of the other size fractions (besides boulders) do occur. Areas where any till unit is directly overlain by wind-blown or fluvial sediment are shown on plate 4 by either yellow stripes (wind-blown cover) or orange stripes (fluvial cover).

In addition to the surface till units described in the preceding discussion, several layers of older till lie deeply buried, interbedded with thick layers of gravel in the Cat Tail Creek, Winona, and Strasburg aquifers (Armstrong, 1978). Little is known of either the physical characteristics or ages of these till units, although it is likely they are older than Wisconsinan in age.

Several workers have speculated on the ages of the various surface till units recognized in Emmons County, McLean County, and elsewhere (Ulmer and Sackreiter, 1973; Salomon, 1974; Fulton, 1976; Clayton et al., 1980; and Clayton and Moran, 1982). However, no one has yet successfully correlated the till units to recognized ice-margin positions.

Sand and gravel of fluvial origin is found at and near the surface in several places in Emmons County (map units Qcoc, Qcof, Qce, and Qcot on pl. 1) (fig. 22). Such deposits are most extensive in the Goose Lake area near Kintyre, and in a northwest-southeast trending zone extending from west of Linton, past Strasburg, and past Hague into South Dakota. This area corresponds closely to the underlying Strasburg aquifer (Armstrong, 1978). Sand and gravel are also found on small, elevated terraces along Long Lake Creek and Beaver

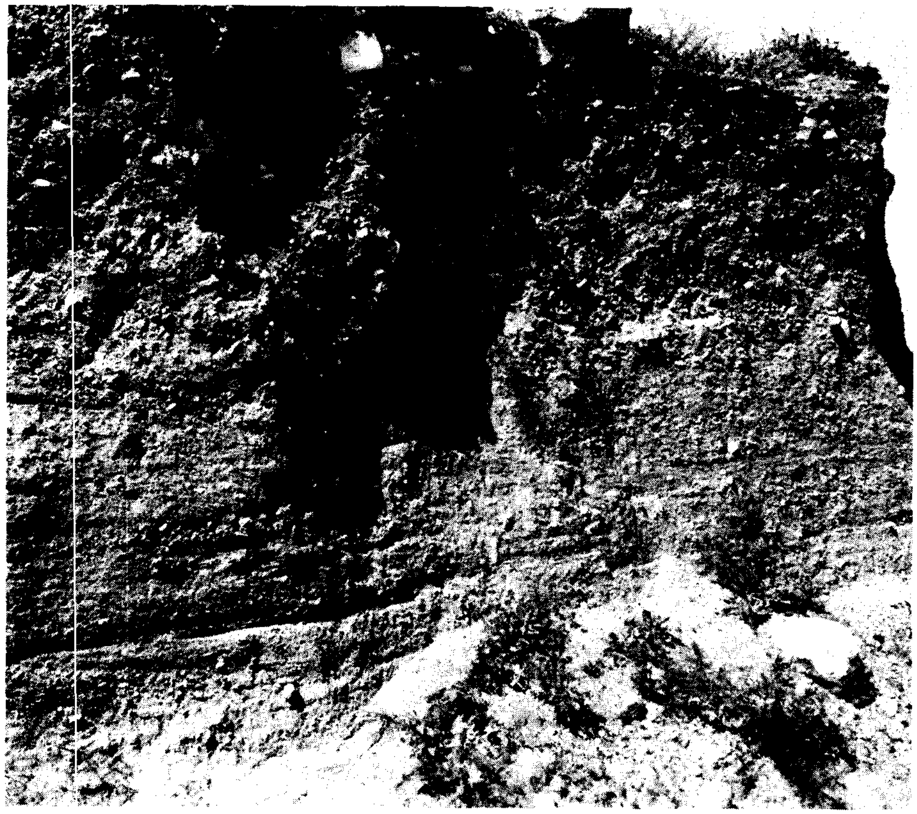


Figure 22. Flat-bedded gravel overlain by gravelly till in southeastern Emmons County, exposed in pit, sec 14, T130N, R74W. This is an ice-contact deposit.

Creek. The terraces are about 20 feet above present valley floors. Sand and gravel on the terraces is generally poorly sorted material containing cobbles, pebbles, and sand of the same lithologies as those described for the coarser fractions within the till units. This gravel has been used for most purposes in the area. Small areas of laminated, water-lain silt and clay are found in parts of eastern Emmons County (Qcl on pl. 1).

Thick layers of gravel and sand are also found buried in the Strasburg, Cat Tail Creek, and Long Lake aquifers (Armstrong, 1978). As much as 275 feet of gravel is reported at Strasburg and thicknesses of about 200 feet are common, although the average thickness of gravel in the major aquifers is probably closer to 60 feet.

Oahe Formation

The Oahe Formation was defined by Clayton, Moran, and Bickley (1976) to include all the well-sorted silt above the Coleharbor Group near Riverdale in McLean County. It was redefined by Clayton and Moran (1979) to include material of all grain sizes above the Coleharbor Group. The Oahe differs from the Coleharbor in lacking glacial sediment. In general, the non-glacial sediment at the top of the Coleharbor can be distinguished from sediment of the Oahe by its better sorting and lack of dispersed organic matter; the Oahe is typically shades of brown or black due to organic material that was probably derived from topsoil.

The Oahe Formation can in many places be subdivided into members (Clayton, Moran, and Bickley, 1976), but in Emmons County it is not so differentiated. It consists primarily of eolian material that is present on uplands, overlying all older units. Areas overlain by a veneer of wind-blown silt and sand of the Oahe Formation are designated on plates 1 and 4 by yellow stripes, with the major map color representing the underlying geologic unit. Thicker, more extensive areas of Oahe Formation sediment are present in several places (Qoed, Qoes on pl. 1) and in a few places dunal topography has developed (figs. 23 and 24).

For at least two reasons, the Oahe Formation is quite extensive in Emmons County, more so than in most other parts of North Dakota. The first reason is that the broad, sandy floodplain of the Missouri River (now submerged beneath the Oahe Reservoir) along the western boundary of Emmons County provided a ready source for wind-blown material. Secondly, extensive areas of loose Fox Hills Formation sandstone of the Timber Lake Member provided a local source of sand. In fact, much of the Oahe Formation material in Emmons County consists of wind-blown sand that is nearly identical in lithology, texture, and appearance to the underlying Fox Hills bedrock sandstone.

The Oahe Formation is also represented in Emmons County by areas of slough sediment (Qos on pl. 1), modern river alluvium (Qof), and landslide material (Qol). Areas of river sediment are as much as 20 feet thick except along the Missouri River where thicker accumulations occur. It consists of obscurely bedded clay and silt with some thin layers of sand. The underlying poorly exposed channel sediment in most places consists of crossbedded sand. Areas of slough sediment were not examined in detail in Emmons County and its thickness was not measured. It generally consists of black, organic, silty clay that may be slightly pebbly. The only area of landslide material identified in Emmons County is in the southwest corner of the county (secs 11, 12, and 13, T129N, R79W) along the Missouri River Valley (fig. 25). Here, blocks of Pierre and Fox Hills

Figure 23. Sand dunes north and south of Cat Tail Creek, western Emmons County (parts of secs 18 and 19, T130N, R78W, and secs 13 and 24, T130N, R79W).

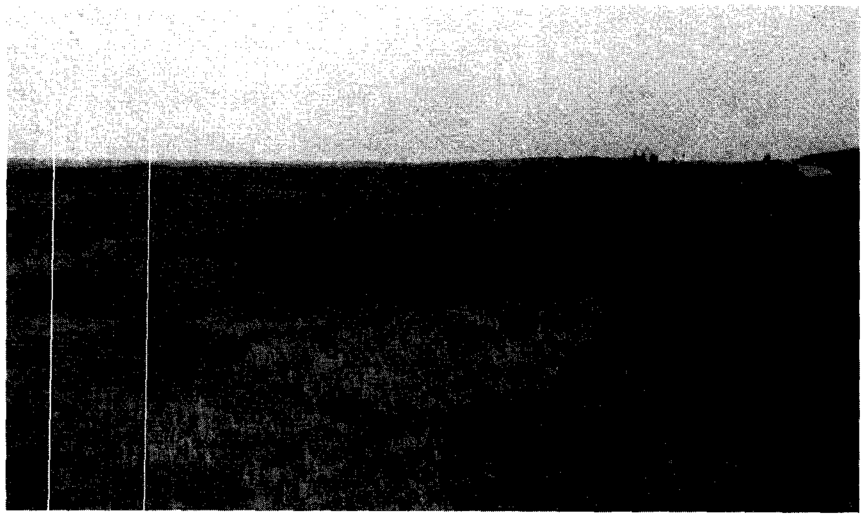


Figure 24. Two photos of wind-blown sand in eastern Emmons County. Exposed at the southeast corner of sec 15, T133N, R74W in northeastern Emmons County.

Figure 25. Landslide topography in the Cretaceous Pierre and Fox Hills Formations, southwestern Emmons County (secs 1, 2, 11, and 12, T129N, R79W). The Missouri River flood plain shown on this photo is now flooded by Lake Oahe.

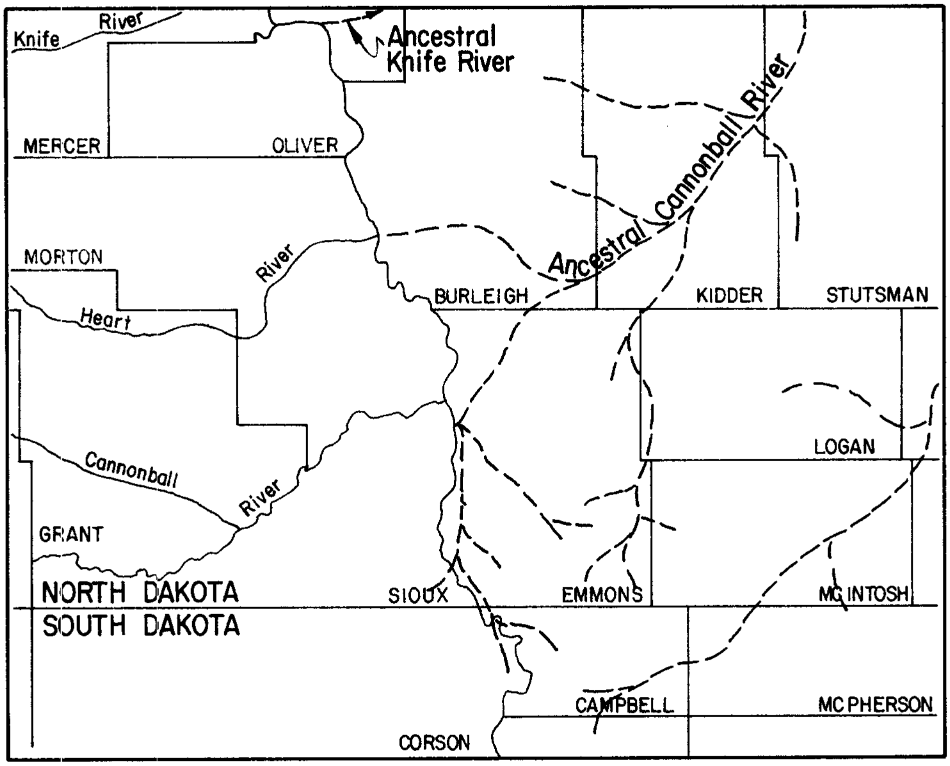


Figure 26. Preglacial drainage pattern in south-central North Dakota. Solid lines show the modern Knife, Heart, and Cannonball River routes. Dashed lines show the continuations of these and other rivers in areas where they are now buried beneath glacial sediment.

Formation bedrock have slid into a jumbled mass of material with extremely irregular topography. Perhaps an equally good case could be made for simply calling the landslide materials "jumbled Pierre and Fox Hills" or some such name, but since the original bedding and structure are disrupted or destroyed, it is here included as part of the Oahe Formation.

GEOMORPHIC HISTORY

Preglacial Events

Immediately prior to glaciation, south-central North Dakota was a gently rolling surface drained northeastward by several mature streams (fig. 26). Emmons County was drained by the ancestral Cannonball River. A north-flowing stream, located in the approximate position of the modern Missouri River along the western border of Emmons County, joined the Cannonball River in the northwestern part of the county. Beaver Creek and other modern streams did not yet exist. It is likely that much of northern and western Emmons County was covered by Hell Creek Formation sediments with a substantial amount of Cannonball Formation sediments on top of them. The Fox Hills Formation was at the surface in the remainder of the county.

Glacial Events

Earliest Glaciations

Evidence for the outer limit of glaciation in southwestern North Dakota is based on the presence of erratic boulders derived from the Canadian Shield and from carbonate occurrences north of Winnipeg. Behind (east and north of) this outer limit, which has been designated the Dunn Glaciation (Clayton, 1969), the concentration of boulders is about one or so along a linear mile of road back to the border of the next younger (Verone) glaciation (fig. 27). The limit of the Verone Glaciation is marked in places by a band of abundant boulders. In western Emmons County, the area of Verone Glaciation is marked by about ten boulders along a mile of road. It is possible that these boulders are the result of several glaciations, but evidence is not available to prove whether this is so.

The Dunn Glaciation is almost certainly pre-Wisconsinan in age because glacial landforms are totally absent ahead of the Verone margin and behind the Dunn ice margin (fig. 27). At least 200 feet of erosion has occurred in some areas behind the Dunn margin since the time of the Dunn Glaciation (Clayton and Moran, 1982). When the Dunn ice advanced (probably several glaciations were involved), it blocked the northeastward drainage of the preglacial Cannonball River and other northeastward-flowing streams, forcing them to flow south along the margin of the glacier. However, post-Dunn erosion in the area west of the modern Missouri River destroyed all evidence of the ice-marginal channel that would have been expected to have carried this diverted drainage. Along Lake Sakakawea in McLean County, thick deposits of till have been correlated with the Dunn Glaciation (Ulmer and Sackreiter, 1973), but this correlation is tenuous at best. It seems likely that physical differences in the various till units exposed in McLean County are related more to differences in the direction from which the units were deposited than to any significant differences in weathering due to age differences. For example, the lower till unit along the bluffs near Riverdale in McLean County contains lithologies suggesting a northwestern source, the result of glacial move-

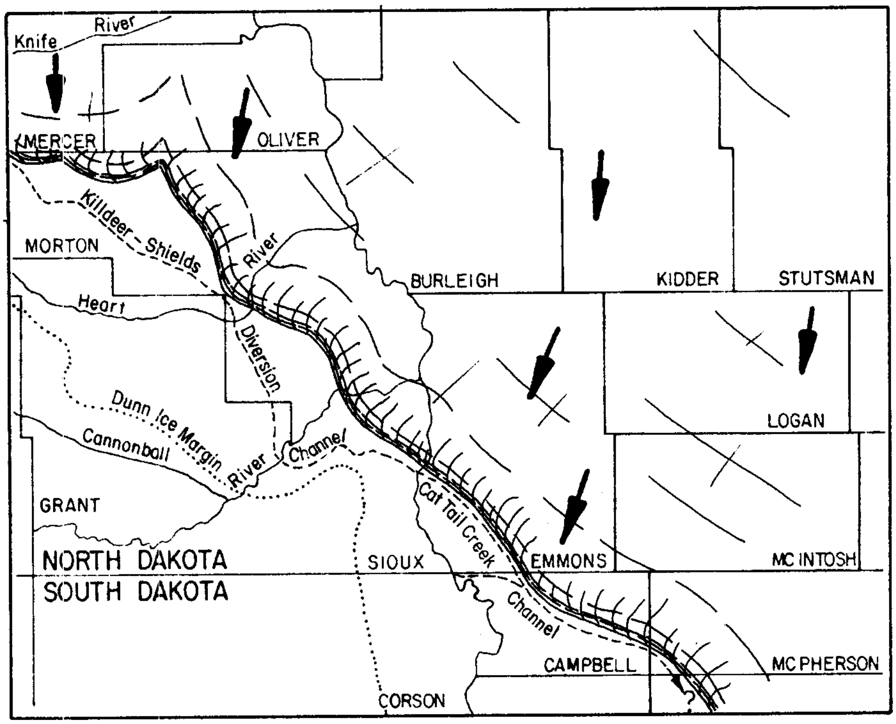


Figure 27. Verone Glaciation, late pre-Wisconsinan or Early Wisconsinan time. During this glaciation, the water diverted along the margin of the ice flowed through the Killdeer-Shields diversion channel. Water may have flowed southeastward through the Cat Tail Creek diversion channel in southwestern Emmons County and/or the Strasburg Channel (pl. 2) at some time during the Verone Glaciation (or during one or more of the several glacial pulses that constitute the "Verone Glaciation"). As the ice receded (and perhaps also while it advanced, earlier), proglacial lakes developed ahead of the glacier, flooding existing valleys. The dotted line through Sioux and Morton Counties shows the outer limit of glacial erratics, the limit of the Dunn Glaciation. Arrows on this and the following diagrams denote presumed directions of glacier flow.

ment over the Tertiary Bullion Creek and Sentinel Butte Formations sandstone and lignite beds, which are widely exposed in western North Dakota (Bluemle, 1971). The overlying unit contains lithologies suggesting a northeastern source, the result of glacial movement over the Cretaceous Pierre Formation and other shale units, which are present throughout eastern North Dakota.

All of Emmons County lies within the area affected by the second recognizable ice margin, the one left by the Verone Glaciation. The Verone margin coincides, in part, with the present routes of the Missouri River along the southwestern edge of Emmons County (fig. 27). No firm evidence is available to determine the age of the Verone Glaciation either. Clayton and Moran (1982) speculate it may be Early Wisconsinan in age. However, because of the lack of any significant thicknesses of till deposits behind the Verone margin (but ahead of younger ice margins), and because all exposures of till that were found there were thoroughly weathered, it seems at least as likely it is late pre-Wisconsinan (perhaps Illinoian) in age.

A major diversion trench coincides with the Verone ice-marginal position southwest of the Missouri River. This channel has undergone much more postglacial erosion than Late Wisconsinan channels, but it is still recognizable in most places. West of Emmons County, it carried water from most of Montana east of the continental divide and from northern Wyoming as well as southern Alberta and Saskatchewan through a series of ice-marginal channels (the same thing happened during the earlier Dunn Glaciation) (Bluemle, 1972). This diverted drainage flowed through south-central North Dakota by way of a large channel past Killdeer, Glen Ullen, and Shields, joining the Missouri River about 14 miles north of the South Dakota border, on the Emmons-Sioux County line, just north of Fort Yates. The diverted water may have flowed southward from there, forming the modern Missouri River trench at that time, or it may have continued southeastward through southwestern Emmons County into Campbell County, South Dakota beneath Winona Flats and what is now the Cat Tail Creek valley.

If the Verone Glaciation was actually a composite of several late pre-Wisconsinan or Early Wisconsinan glacial pulses, then it is likely that both the Cat Tail Creek trench and the Missouri River trench south of Fort Yates were formed (and possibly re-used) during one or more of these advances, although one or both of them may date to the Dunn Glaciation.

The ages of the Cat Tail Creek and Strasburg Channels cannot be determined at this time. Both are obviously ice-marginal diversion trenches through which large volumes of water flowed during one or several glacial advances. The Strasburg Channel is much the larger of the two with elevations about 200 feet lower than the Cat Tail Creek Channel. It may have served as the main drainage way for the Missouri River during mid-Wisconsinan time.

Both the Cat Tail Creek and Strasburg Channels contain thick sequences of alternating till, fluvial, and lake sediment (Armstrong, 1975, 1978). The amount of lake silt preserved in the channels is unusual. Some test holes penetrated as many as six layers of lake sediment separated by layers of fluvial material. Till is restricted mainly to the top part of the section as a covering over the fluvial and lake sediment and till is also common near the base of the section where it is typically quite hard, described as a "tillite" by Armstrong (1975).

The thick sequences of interbedded lake and fluvial sediment in the buried valleys indicates repeated damming by the glacier of the northward drainage and the formation of proglacial lakes ahead of the ice.

Early Wisconsinan Glaciation

Following the Verone Glaciation, south-central North Dakota was subjected to a prolonged period of erosion. During this period of time, the major drainage (the area east of the Rocky Mountains already referred to) was probably northeastward. Emmons County may have been drained by the ancestral Cannonball River to Canada and on to Hudson Bay or, more likely, by way of an undetermined route to the Red River Valley, then on to Hudson Bay. It is also possible that the major drainage was southward by way of a route such as the James River. After this long period of erosion, during which most of the sediment related to the Verone Glaciation was removed, the Napoleon Glaciation (Clayton et al., 1980; Clayton and Moran, 1982) advanced across the area, reaching a maximum extent in Emmons County generally coinciding with the Missouri River (fig. 28).

Deposits of the Napoleon Glaciation are preserved in several places in Emmons County. They consist primarily of the Temvik till (pl. 4) and great numbers of glacial erratic boulders throughout the western part of the county where drainage is largely integrated and the glacial sediment occurs as patches (fig. 29). Napoleon glacial sediment occurs as a continuous blanket on the uplands in easternmost Emmons County where drainage is still non-integrated. The lower several feet of the Braddock till in eastern Emmons County are considered to have been deposited by the Napoleon ice (Bickley, 1972). 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 post-Napoleon glacial sediment. Napoleon glacial sediment is much sandier and contains fewer shale pebbles than the younger glacial sediment to the east. The high sand content and the low shale content in the Napoleon glacial sediment suggest that the Napoleon ice advanced from a northerly direction, rather than from a more northeasterly 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.

Bickley (1972) suggested that, because the Napoleon glacial sediment is much thinner than the younger till layers, it was deposited by a cleaner ice sheet that contained less debris than the ice that deposited the younger deposits. He further suggested that the flow regime of the ice was different from that of

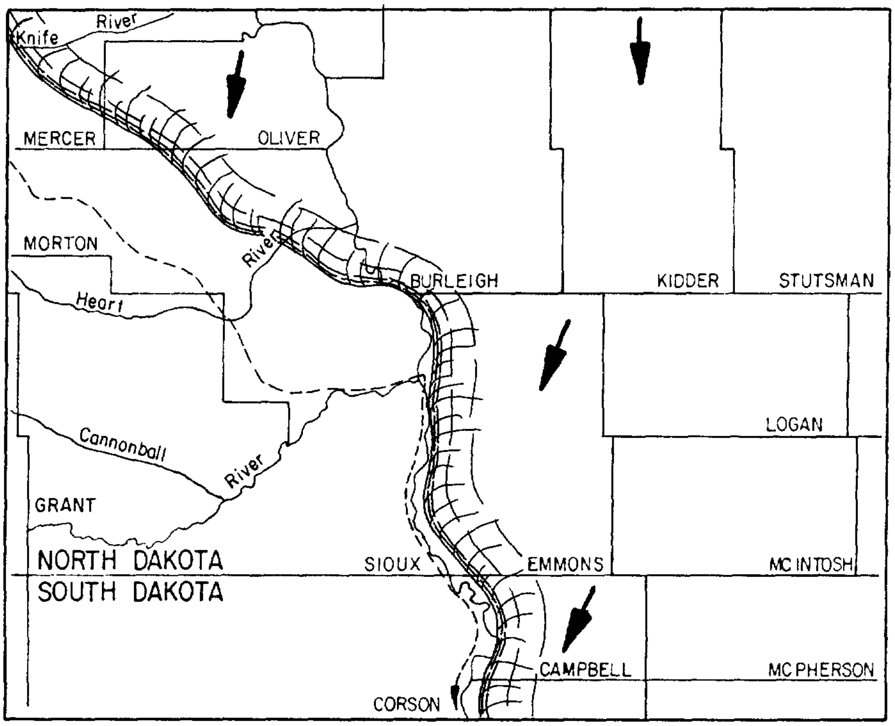
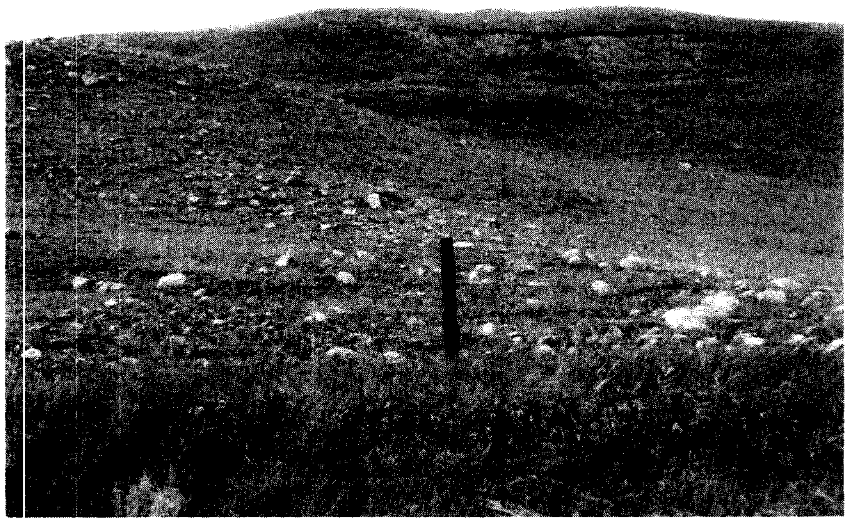


Figure 28. Maximum extent of the Early Wisconsinan glacier. The Early Wisconsinan Napoleon glacier advanced as far as the Missouri River, probably covering all of Emmons County. Diverted drainage flowed through the Killdeer Channel to the Missouri River at Cannonball, then southward, following the course of the modern Missouri River.

the later ice in that the Napoleon ice did less scraping, grinding, abrading, and gouging as it advanced into and over Emmons County than did the Late Wisconsinan glaciers. The flow direction of the Napoleon ice was probably from the north along the top of the Missouri Escarpment. In this situation, flow might be parallel or even extending. Given such flow conditions, little material is eroded from the surface over which the ice flows.

As with the Dunn and Verone Glaciations, no conclusive evidence exists to determine the exact age of the Napoleon Glaciation. No conclusive radiocarbon dates have been found to date the Napoleon sediment. 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. Clayton et al. (1980) suggest that the



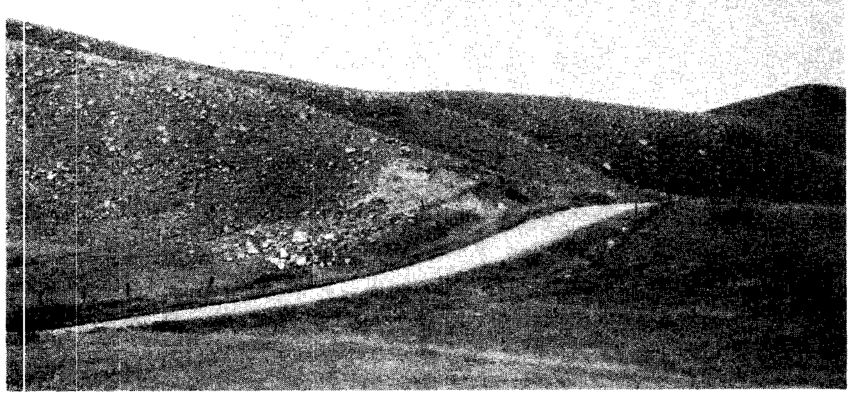


Figure 29. Two views of typical bouldery surface on the Fox Hills Formation. The boulder lag is all that remains of the till cover over much of western Emmons County. These scenes are in sec 29, T134N, R78W.

Napoleon Glaciation probably occurred in Early Wisconsinan time.

The modern drainage pattern in Emmons County is characterized by several generally west-flowing streams including Beaver Creek, Little Beaver Creek, Cat Tail Creek, Horsehead Creek, and Badger Creek (pl. 1). This drainage pattern probably dates to late pre-Wisconsinan or Early Wisconsinan time (Clayton, 1962), although it was greatly enhanced during Late Wisconsinan time when glaciers advanced into northeastern and southeastern Emmons County. During the intraglacial erosional period following the Napoleon Glaciation, much of the till and other glacier-related sediment that had been deposited in Emmons County by the Napoleon ice was stripped away, leaving a surface developed primarily on bedrock, especially adjacent to Beaver Creek. It is likely that, following the Napoleon Glaciation, the major Missouri River drainage was southeastward through the Strasburg Channel.

Late Wisconsinan Glaciation

The Late Wisconsinan glacier advanced across North Dakota between about 25,000 and 20,000 years ago (Clayton et al., 1980) with the glacier flowing into the northeast and southeast parts of Emmons County (fig. 30). The initial Late Wisconsinan advance into the county was likely the Long Lake advance in the northeast (A on fig. 30) in the Braddock and Kintyre area. At about the same time, a lobe of ice advanced northwestward into southeastern Emmons County (B on fig. 30). The seemingly anomalous flow directions of the initial Late Wisconsinan glacier have been attributed to the presence of an area of relatively high topography in western Logan and McIntosh Counties (Bickley, 1972). When the advancing glacier reached this high area, it split into two lobes, one flowing around the north side and the other around the south side of the high (fig. 30). This situation is most likely to occur when the glacier is in its wasting phase and relatively thin because, during its initial advance, a glacier is likely to be much thicker and its flow is less likely to be affected by relatively gentle obstructions (Bluemle, 1965). The path of glacier movement westward around the Logan-McIntosh topographic high area resulted in a glacial sediment relatively high in clay and shale because this flow path was continuously over shale of the Pierre Formation.

The glacial advance in southeastern Emmons County may be subdivided into the Cat Tail Creek and Zeeland phases (Bickley, 1972). The slightly earlier Cat Tail Creek ice covered a slightly larger area than did the Zeeland ice, which readvanced over part of the area that had been glaciated during the Cat Tail Creek phase (fig. 31). No recognizable ice-marginal deposits resulted from the Cat Tail Creek phase. This suggests that the

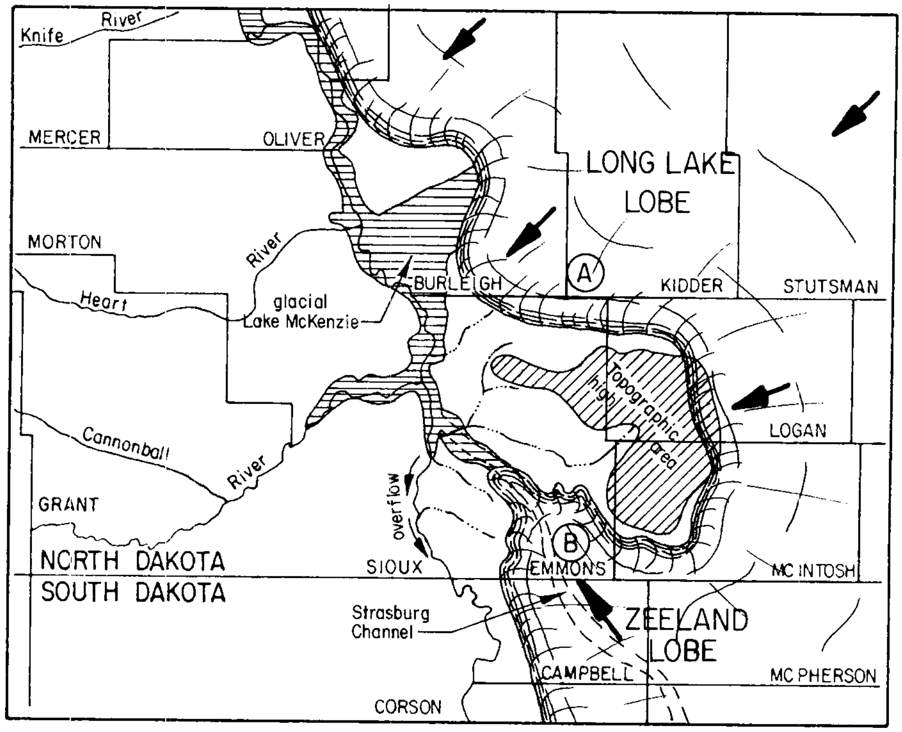


Figure 30. Late Wisconsinan glaciation. Ice advanced into the northeastern (A) and southeastern (B) parts of Emmons County, flowing around a topographic high area in western Logan and McIntosh Counties (stippled area). When the Late Wisconsinan glacier advanced, drainage that had been southeastward through the Strasburg Channel was dammed, forming glacial Lake McKenzie to the north and west. When this lake overflowed southward, it formed the modern Missouri River trench along the southwestern border of Emmons County.

glacier remained in the maximum Cat Tail Creek position for only a short time before retreating to a position behind the Zeeland phase maximum position (Bickley, 1972). The readvance of the glacier to the Zeeland maximum resulted in a small "end moraine" which can be traced a short distance into Emmons County.

Bickley (1972) was able to distinguish the Cat Tail Creek and Zeeland areas by studying the covering of loess on the glacial sediment deposited by ice of the Cat Tail Creek phase. He placed the boundary between the Cat Tail Creek and Zeeland phases (fig. 31) where the loess is no longer present on the Late Wisconsinan glacial sediment. The ice of the Zeeland phase

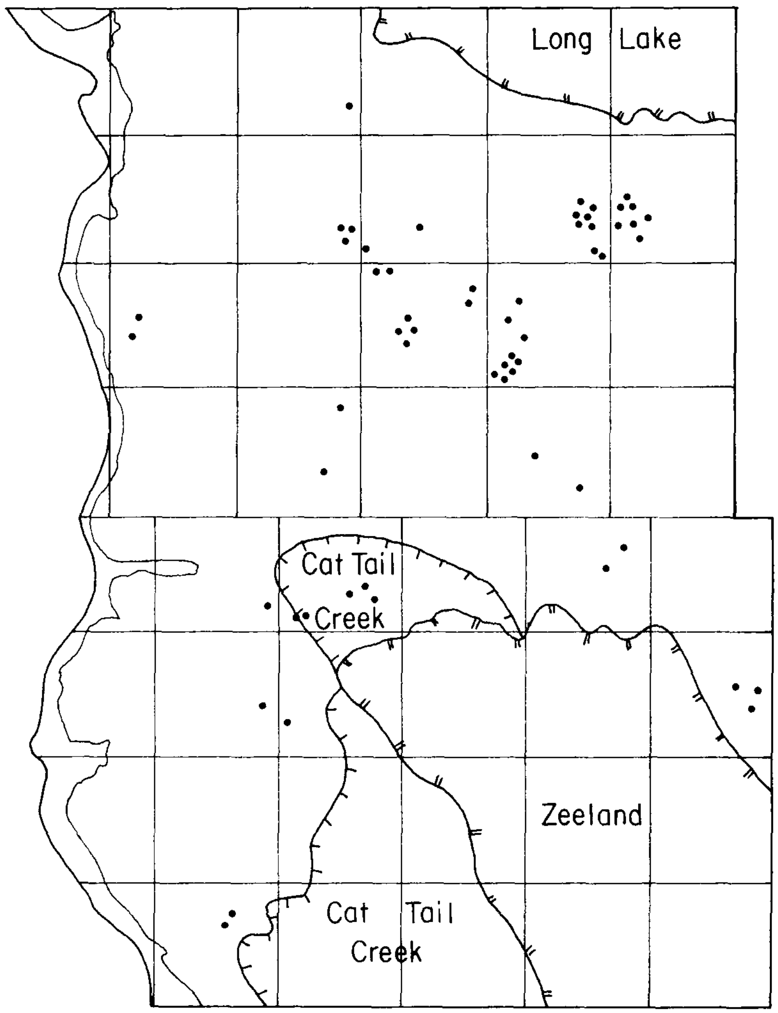


Figure 31. Areas of Emmons County covered by Late Wisconsinan glacial materials. These materials were deposited during the Long Lake, Cat Tail Creek, and Zeeland advances. The Cat Tail Creek area was glaciated slightly earlier than was the Zeeland area; the Zeeland ice partially covered the area that had earlier been glaciated by Cat Tail ice. The spots represent places where permafrost polygons were observed on airphotos; none of these were seen on the Late Wisconsinan glacial deposits.

Figure 32. View north over glaciated terrane in northeastern Emmons County (sec 10, T136N, R74W). The land surface is bouldery and characterized by numerous disintegration ridges similar to those shown here.

stagnated later than the ice of the Cat Tail Creek phase, so any loess deposited on the Zeeland superglacial sediment was incorporated into the glacial sediment as the ice melted. The glacial sediments of the two phases in southern Emmons County are otherwise so similar that it is difficult to tell them apart.

Cat Tail Creek, Little Beaver Creek, Beaver Creek, and the South Branch of Beaver Creek drained water away from the Late Wisconsinan ice in southern Emmons County. The South Branch of Beaver Creek may have been cut as a result of the advance of the Late Wisconsinan glacier. The ice in southern Emmons County blocked the generally westward drainage of the streams in that area, causing the water to channel around the margin of the ice sheet into Beaver Creek.

The surface glacial sediment in northeast Emmons County (fig. 32) was deposited by the Long Lake ice lobe. It is underlain by till of the earlier Napoleon advance in many places. The sediment deposited by the Long Lake ice can generally be distinguished from the older sediment of the Napoleon Glaciation by its non-integrated, uneroded appearance. Texturally, the composition of the sediment of these two glacial events is similar.

The trench of Long Lake Creek drained water away from the Long Lake ice margin in northeast Emmons County (pl. 1) into glacial Lake McKenzie in central Burleigh County.

The age of the Long Lake ice advance is probably Late Wisconsinan. Clayton (1962) and Kume and Hansen (1965) reported that the glacial sediment deposited by the Long Lake ice is overlapped by sediment of the Burnstad ice in Logan and Burleigh Counties so that the Long Lake ice was pre-Burnstad. No loess occurs on the Long Lake glacial sediment indicating that it is younger than the Cat Tail Creek glacial sediment. The Long Lake glacial sediment may be the same age as the Zeeland glacial sediment in Emmons County, but no evidence has been found to prove or disprove that the two were contemporaneous.

Stagnation of the Late Wisconsinan glacier in Emmons County probably began about 13,000 to 12,000 years ago. As the ice melted, the glacial topography seen there 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 so that melting occurred more slowly. After the ice became insulated, vegetation migrated onto the debris-covered ice, lakes formed, and an environment similar to present-day north-central Minnesota developed.

Glacial Lake McKenzie

Kume and Hansen (1965) and Bickley (1972) have postulated that, immediately prior to the Late Wisconsinan glaciation, the Missouri River flowed southeastward through the Strasburg Channel. When the Cat Tail/Zeeland ice advanced into southeastern Emmons County, it blocked this southeastward drainage, causing a proglacial lake to flood the area to the northwest (fig. 30). This lake, glacial Lake McKenzie, was extensive in Burleigh County and flooded parts of western Emmons County. As much as 250 feet of silt and clay occur in several places in the Strasburg Channel (Armstrong, 1975), but it is not known how many separate episodes of lake sediment deposition this thickness represents. The total thickness includes several layers of coarse fluvial sediment, but no glacial till occurs within or on top of the lake sediment so it must all have been deposited in post-Napoleon time. Lake McKenzie existed until the water level rose to an elevation sufficient to flow over the drainage divide to the southwest into an older segment of the Missouri River trench (Bluemle, 1972). The new section of channel cut through the drainage divide in T130N, R79W is one of the narrowest parts of the Missouri River trench in south-central North Dakota.

A second glacial lake formed when ice advanced across the Missouri River trench in north-central South Dakota. The age of glacial Lake Standing Rock (Bickley, 1972) is not known, but occurrences of lake sediment below the "30-foot terrace" (thought to be Late Wisconsinan in age) indicate that the lake probably existed during Late Wisconsinan time, although it may have formed earlier. Sediment of glacial Lake Standing Rock occurs at the following locations: SW¼sec 31, T129N, R79W; NE¼ and SE¼sec 13, T130N, R80W; SE¼ and NE¼sec 29, T131N, R79W; and sec 28, T131N, R80W.

Wisconsinan Permafrost Features

Permafrost polygons have been identified on airphotos in several places in Emmons County (fig. 31). Clayton and Bailey (1970) were the first to document the existence of Pleistocene permafrost features in western North Dakota. Additional documentation of about 200 permafrost locations and several ice-wedge locations in southwest North Dakota was presented by Bluemle and Clayton (1982a). Most of these occur on areas covered by gravel overlain by Late Wisconsinan loess.

Almost all of the permafrost polygons noted on the photos of Emmons County occur on surfaces not covered by Late Wisconsinan glacial sediment. This is because the polygons formed only during times of glacial advance (cold climates or tundra conditions) and not during times of ice wasting (a warmer climate). Those polygons that do occur on Late Wisconsinan glacial sediment are on material deposited by the Cat Tail Creek advance. The polygons are, therefore, Late Wisconsinan in age, formed during the advance of the Long Lake and Zeeland glacial lobes or slightly earlier. Polygons are commonly seen on the tops of some of the larger buttes such as Smith Butte (sec 10, T129N, R78W) and others throughout southwestern North Dakota (Bluemle and Clayton, 1982a).

Missouri River Terraces

A prominent feature along the Missouri River in Emmons County is the "30-foot terrace" (Bickley, 1972). This terrace probably formed during the Late Wisconsinan glaciation because Late Wisconsinan loess that occurs on the Cat Tail till surface in southern Emmons County is not found on the terrace, whereas younger Holocene loess does occur on the terrace. The terrace is found at about 1,650 feet elevation at the South Dakota border and in the Winona Flats area (T131N, R79W), at about 1,660 feet in the Horsehead Creek mouth area (T133N, R78W), 1,660 to 1,675 feet in the Badger Creek mouth area (T135N, Rs78 to 79W), and at about 1,670 feet in the Glencoe Creek mouth area (T136N, Rs78 to 79W), indicating a very gentle southerly gradient of about one foot in two to two and a half miles. The only place in Emmons County where good exposures were noted in association with the terraces was at the

South Dakota state line where a complex series of glacial and glaciofluvial sediments overlie crushed Pierre Formation shale (fig. 33).

Generally, the sequence exposed beneath the terrace in southwestern Emmons County consists of crushed shale that is weathered and oxidized in places. The shale is overlain by either a very stony till that is almost a breccia, or by a layer of silty lake sediment (fig. 34). The till is apparently the result of glacial movement over a muddy, fluvial deposit of loose cobbles and sand. It typically includes chunks of lake silt, crushed shale, and angular stones. All materials contained in the till are strongly iron stained. Whether till or lake silt overlies the shale base, either is overlain by an iron-stained, lignitic sand and gravel that has been cemented to a conglomerate in places. The conglomerate is overlain in places by a black soil, which is developed on silt, apparently of wind-blown derivation.

Overlying the soil zone is a sequence of fluvial material that is generally plane-bedded sand at the base overlain by cross-bedded, iron-stained gravelly sand, and a layer of coarse, gravelly sand on top. A modern soil developed on either silty alluvial material or on wind-blown silt overlies the entire area.

Postglacial Events

The Oahe Formation overlies material of the Coleharbor Group in Emmons County. It includes material of all grain sizes, but does not include glacial sediment (Clayton, Moran, and Bickley, 1976; Clayton and Moran, 1979). The Oahe Formation in many places can be subdivided into four members. The lowest, the Mallard Island Member, consists of coarse sediment with little organic material. In Emmons County, it consists mainly of loess that was deposited with the beginning of the Late Wisconsinan glaciation and continuing 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, although an undetermined portion of it consists of reworked, locally derived Fox Hills Formation sand, which is extensive over much of Emmons County.

About the time meltwater flow ceased, between about 13,000 and 12,000 years ago, the Mallard Island loess deposition ended and spruce woodland migrated into the area. This period of time has been designated the Leonard Stable Episode (Bickley, 1972; Bluemle and Clayton, 1982b) (fig. 35). Under the forested condition, a forest paleosol of the organic-rich Aggie Brown Member developed during the Leonard Stable Episode. Development of this forest soil profile continued until a warming climate caused the vegetation to change to grassland about 10,000 years ago. During this warmer period of time, which has been desig-

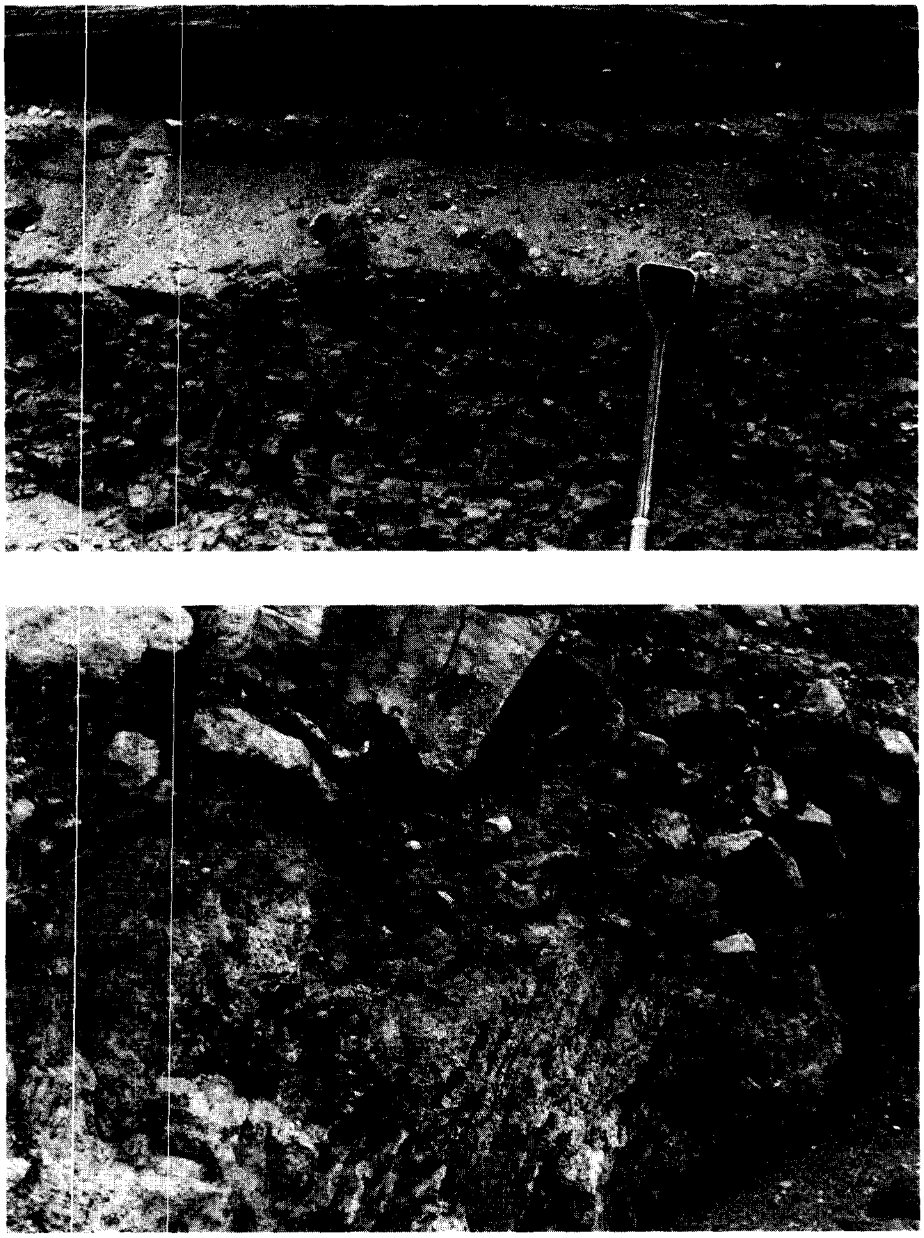


Figure 33. Exposure along Lake Oahe in southwestern Emmons County (SE corner, sec 30, T129N, R78W). Upper photo shows relatively undisturbed Pierre Formation shale overlain by crossbedded sand with plane-bedded sand on top. Lower photo shows crushed shale overlain by bouldery till.

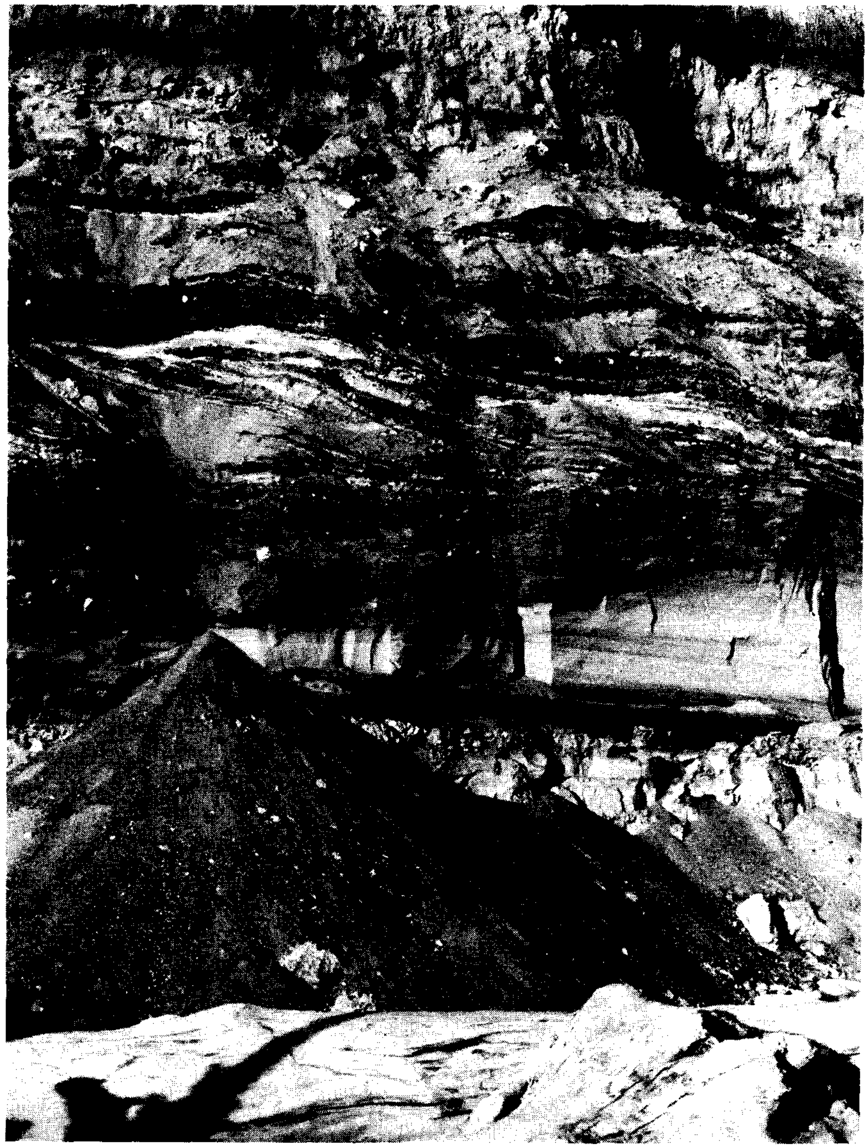


Figure 34. Exposure along Lake Oahe in southwestern Emmons County (SE corner of sec 30, T129N, R78W). This is a complex sequence that includes lake silt at the base of the exposure overlain by a conglomerate and then by more silt upon which a paleosol can be seen. The soil is overlain by plane-bedded sand, iron-stained, crossbedded sand, and then by coarse, gravelly sand without iron stains but with numerous streaks of carbon-rich silt (apparently soil-derived material). A modern soil is developed on wind-blown material at the top.

nated the Wolf Creek Unstable Episode, a prairie soil began to develop. With continued warming and drying during the Wolf Creek Unstable Episode, hillslope stability decreased (Bickley, 1972), and about 8,500 years ago loess of the Riverdale Member of the Oahe Formation began to be deposited. During this time, which is known also as "hypsithermal" or "altithermal" time, barchan dunes formed on the flood plains, lake plains, and other areas where a source of sand existed. In Emmons County, these areas include the Cat Tail Creek valley, Sand Creek valley, Beaver Creek valley, and the Strasburg Channel. About 4,500 years ago, the climate became cooler and moister and tall grass prairie covered the area, resulting in stabilization of sand dunes. This period of time has been designated the Thompson Stable Episode.

In late Holocene time, the climate again became warmer and drier during what has been referred to as the Garrison Unstable Episode. At this time, gray loess of the Riverdale Member of the Oahe Formation was deposited. The Jules Paleosol (Bickley, 1972) formed during the cool, moist period that followed (the Mandan Stable Episode). Except for frequent short-term fluctuations in the climate, the Mandan Stable Episode continues today.

In most places, the various members of the Oahe Formation are too thin to be mapped separately at the scale of the Emmons County geologic map (pl. 1). However, lithogenic subdivisions (river, pond, and wind-blown sediment) can be mapped in places. The various members can be recognized within these subdivisions.

ECONOMIC GEOLOGY

Petroleum

Only 29 oil exploration tests have been drilled in Emmons County. Of these, six penetrated the entire sedimentary section and 13 were drilled no deeper than the Cretaceous. Although results to date have not resulted in production, as much as 7,000 feet of sedimentary section is present in the county and many formations that are productive elsewhere in the state occur in Emmons County. Improved seismic techniques, which have aided exploration elsewhere in the state, may yet find reservoirs of oil or gas in Emmons County.

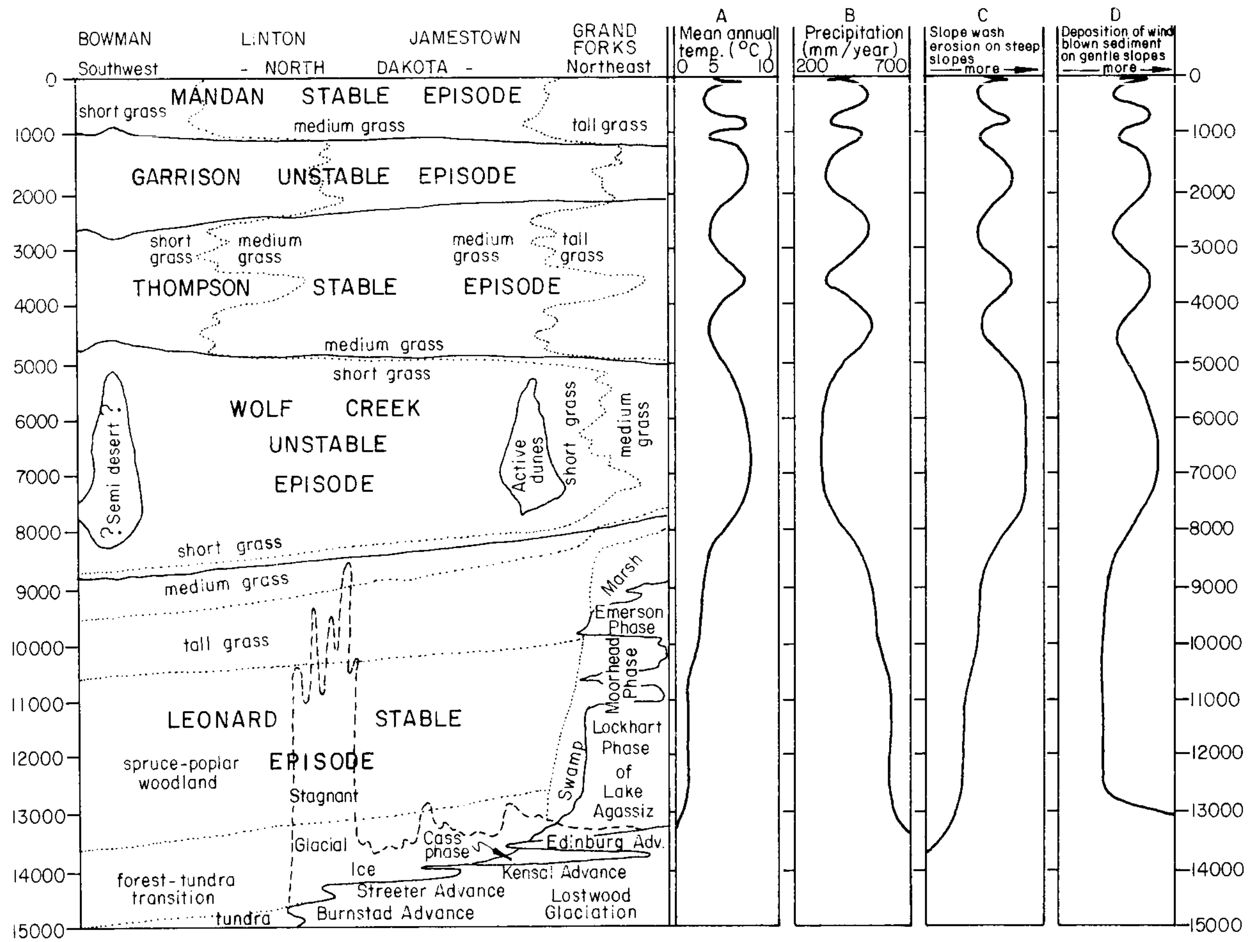
Sand and Gravel

Production of sand and gravel in Emmons County has been intermittent in recent years, with 36,000 cubic yards produced in 1977 in Emmons County, 124,000 cubic yards in 1978, and

Figure 35. North Dakota's climatic history for the last 15,000 years (adapted from Bluemle and Clayton, 1982b). This is a time-distance diagram, time represented in a vertical direction, and distance, from southwestern to northeastern North Dakota, shown from left to right. The diagram illustrates when certain climatic events occurred in various parts of the state. For example, as conditions dried about 9,000 years ago, short-grass prairie first covered southwestern North Dakota (about 8,700 years ago) and advanced northeastward, although not into the easternmost part of the state, before giving way to medium-grass prairie over most of the state about 5,000 years ago as the climate again became more moist.

The Lockhart, Moorhead, and Emerson Phases, shown in eastern North Dakota between about 13,000 and 9,500 years ago, portray the history of Lake Agassiz. The Burnstad advance, and other advances, represent glacial advances of the last glacier that affected North Dakota. The "stagnant glacial ice" occurred mainly on the Missouri Coteau between about 14,000 and 9,000 years ago (it also was widespread over the Turtle Mountains and Prairie Coteau in southeastern North Dakota).

The four columns on the right (A, B, C, and D) represent, in a general sort of way, how various specific conditions changed over the past 15,000 years. Column A shows how the mean annual temperature varied; B shows how precipitation varied; C shows the relative amount of slopewash erosion from the hillslopes; and D shows the amount of wind-blown sediment being deposited on gentle slopes and in low areas. In all four columns, the increasing amount is to the right, decreasing amount is to the left.


BOWMAN
LINTON
JAMESTOWN
GRAND FORKS
Southwest
- NORTH DAKOTA -
Northeast
A
Mean annual temp. (°C)
0 5 10
B
Precipitation (mm/year)
200 700
C
Slope wash erosion on steep slopes
more
D
Deposition of wind blown sediment on gentle slopes
more
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
MANDAN STABLE EPISODE
short grass
medium grass
tall grass
GARRISON UNSTABLE EPISODE
short grass
medium grass
medium grass
tall grass
THOMPSON STABLE EPISODE
medium grass
short grass
WOLF CREEK UNSTABLE EPISODE
?Semi desert?
Active dunes
short grass
medium grass
short grass
medium grass
tall grass
Marsh
Emerson Phase
Moorhead Phase
LEONARD STABLE EPISODE
spruce-poplar woodland
Stagnant
Glacial
Ice
Swamp
Lockhart Phase of Lake Agassiz
Cass phase
Edinburg Adv.
Kensal Advance
Streeter Advance
Burnstad Advance
forest-tundra transition
tundra
Lostwood Glaciation

70,000 cubic yards in 1979. No sand and gravel production were reported in 1980 and 1982. Most of the gravel has been produced from the terraces of Beaver Creek west of Linton (sec 6, T132N, R77W). Additional good quality gravel resources occur on terraces of Beaver Creek east of Linton and on terraces of Long Lake Creek in northern Emmons County. Large amounts of poorer quality gravel and sand can be found in areas shown as Qcoc and Qcof on plate 1.

Building Stone

Although it hasn't been used as a building material for many years, the Linton sandstone member of the Fox Hills Formation was used in the construction of several buildings in the Linton area (figs. 36 and 37) and for home construction in various parts of the county. By late 1902, a stone quarry was operating about a mile southeast of Linton. According to Woods and Wenzel (1976), the dark-gray building stone could be bought for 25 cents a wagonload and could be easily worked with stonemason tools.

Volcanic Ash

The volcanic ash bed that is prominent near the base of the Fox Hills Formation (see earlier discussion) was described as early as 1917 (Stanton, 1917). Manz (1962) studied the volcanic ash, investigating its potential for use as an admixture in Portland cement concrete. He determined that the Linton volcanic ash complies with ASTM specifications for raw natural pozzolan for use in Portland cement. He also concluded that, with the addition of lime, the ash stabilizes certain soils for use as base and subgrade materials capable of withstanding several freeze-thaw cycles. The volcanic ash certainly has potential as a mineral resource and it should be studied further.

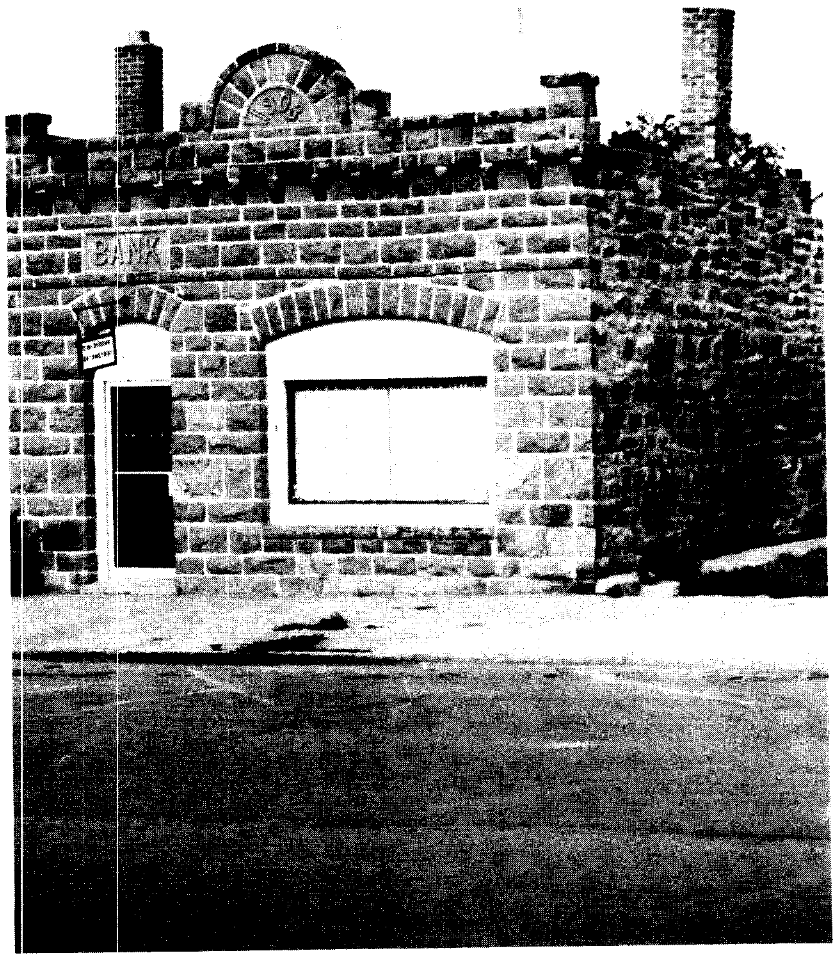


Figure 36. Old stone bank building in Linton. This is an example of sandstone construction used on several buildings in Linton at the turn of the century. The stone was quarried from the Linton Member of the Fox Hills Formation a short distance east of town.

Figure 37. Detail of stonework on building shown on figure 36.

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