GEOLOGY

of

MCKENZIE COUNTY, NORTH DAKOTA

by
Clarence G. Carlson

BULLETIN 80–PART I
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

COUNTY GROUNDWATER STUDIES 37–PART I
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

Prepared by the North Dakota Geological Survey
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ABSTRACT

McKenzie County is located in northwestern North Dakota in the Missouri Plateau Section of the Great Plains Province. The southern and southwestern parts of the county lie outside the limit of glaciation which generally follows the course of Bennie Pierre Creek and then eastward along the Little Missouri River. Upland areas within the glaciated area have patchy areas of till near the limit of glaciation and nearly continuous thin till in the northern areas.

The area includes rocks of each of the geologic periods with the thickest accumulations of sedimentary rocks at about 16,000 feet in the area of T153N, Rs97, 98W which is near the center of the Williston Basin. The near-surface sediment is of Recent, Pleistocene, or Tertiary age. Recent sediment consists of alluvium or colluvium which is generally confined to lowland areas of current or Pleistocene drainage. Pleistocene sediments consist of till on the upland areas and water-sorted sediment in and along glacial drainages. Soil horizons have developed on the poorly consolidated Tertiary formations in the unglaciated areas.

INTRODUCTION

Purpose of Study

This report describes the geology of McKenzie County, an area of about 2,842 square miles, located in northwestern North Dakota. It is one of a series of reports prepared by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission and the United States Geological Survey in the groundwater study series.

The primary purposes of these studies are: (1) to provide a geologic map of the area, (2) to locate and define aquifers, and (3) to interpret the geologic history of the area. A general assessment of natural resources of the area is also provided.

Methods of Study

Fieldwork consisted of traversing all roads or trails by vehicle and traversing on foot to otherwise inaccessible areas of interest. The best exposures are along the major drainages and diversion channels which are incised 200 to 500 feet into the upland areas. These areas of good exposures were supplemented in upland areas by road cuts, road ditch exposures, or through use of a 5-foot hand auger. Exposures were examined with special attention to formation contacts so as to provide a basis for extending contacts across areas of poor exposures and as an aid for subsurface interpretations. Stereoscopic pair photo coverage, scale 1:20,000, was available for the entire area. Topographic maps were available for most of the area. Contacts were determined with the aid of aerial photos and plotted on county road maps, scale 1:63,360 obtained from the North Dakota Highway Department. The study was done on a reconnaissance basis with fieldwork accomplished in portions of two field seasons.

Subsurface information for the post-Pierre strata was provided by about 60,000 feet of test-hole drilling by the North Dakota State Water Commission published as Ground Water Basic Data (Croft, 1985) supplemented by other available information. About 1,600 oil exploration wells have been drilled in this county and information in the files of the Oil and Gas Division of the North Dakota Industrial Commission provided information for the subsurface stratigraphy section. A truck-mounted auger of the North Dakota Geological Survey was used to obtain information in a few areas and test-hole drilling for the Conservation Division of the U.S. Geological Survey provided some lignite information.

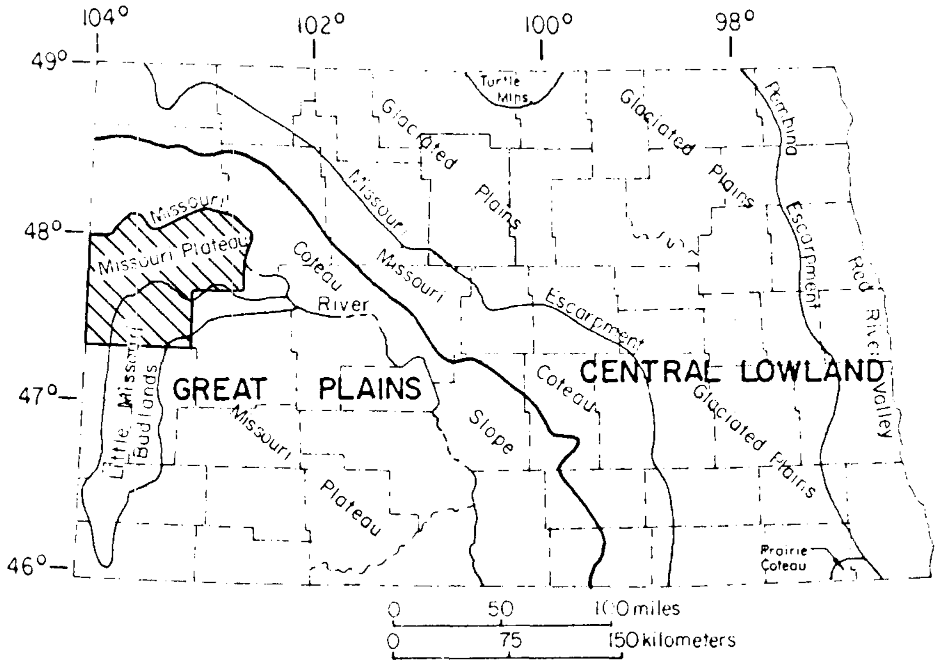


Figure 1. Location map showing area of study and physiographic subdivisions of North Dakota.

Regional Setting

McKenzie County is bounded on the west by Montana, on the north and east by the Missouri River and on the south by Golden Valley, Billings, and Dunn Counties. Physiographically most of the county is in the Glaciated Missouri Plateau Section of the Great Plains Province (fig. 1) with the southwestern part in the Unglaciated Missouri Plateau Section. These sections are generally characterized by low relief and gentle slopes interrupted by buttes and ridges. In the glaciated section the drift is generally thin except for valley fill so the topography reflects the pre-glacial topography (fig. 2). Major drainages are the Missouri, Yellowstone, and Little Missouri Rivers. The Missouri River formed when glaciers blocked the northeastward flowing drainages and the diverted drainage flowing southeastward along the margin of the glacier was entrenched in that course after the ice melted. The Little Missouri River flowed northward in the valleys now occupied by Red Wing Creek and Tobacco Garden Creek prior to glaciation. Subsequently it was diverted eastward from Red Wing Creek. Similarly the Yellowstone River flowed through the Charbonneau Creek-Timber

Figure 2. View looking north at till-capped exposures of Sentinel Butte Formation in railroac cut in NWsec 22, T150N, R99W.

Creek Valley prior to glaciation. The process of adjustment to the lowered base level of the Missouri River is developing a band of badlands along these drainages.

This county is situated near the center of the Williston Basin, an intracratonic basin whose center is near Williston. The thickest sedimentary section is in Ts153-154N, Rs97-98W where the sedimentary section is 16,000 ± feet based on structure maps on the Red River Formation. The deepest well yet drilled in this county is the Patrick Petroleum-Enderud No. 1-17 (SWNEsec 17, T152N, R98W) which had penetrated about 80 feet of the Deadwood Formation at a total depth of 15,300 feet. Rocks of each of the geologic periods have been preserved with the most complete section in the Blue Buttes area. These buttes are capped by cemented sandstones of the Golden Valley Formation at elevations as high as 2,820 feet (fig. 3). Sites on the highest buttes might also penetrate nearly 16,000 feet of sedimentary section. Scattered glacial boulders on the upper slopes indicate that these buttes were ice covered during the Pleistocene. The lowest elevations are along the Missouri River where

Figure 3. Cemented sandstone of the Golden Valley Formation capping one of Blue Buttes in NW;sec 31, T151N, R95W.

pool elevations of Lake Sakakawea fluctuate seasonally in the 1,825- to 1,854-foot range.

The sedimentary strata generally have gentle dips to the north or northeast towards the center of the basin. The Nesson Anticline is the major structure with the Blue Buttes located on the north-south axis of that structure in northeastern McKenzie County. The oldest formation exposed is the Tongue River Formation which is at the surface in the western and southwestern part of the county. The Sentinel Butte Formation is at the surface in most other areas except where glacial drift is present in the northern or northeastern parts of the county or Recent sediment is present along current drainages.

Previous Work

The lignite beds have been an object of study since Wilder (1904) made a reconnaissance study of the strata exposed along the Missouri River. The only area mapped for lignite resources is the western part of the Fort Berthold Indian Reservation

(Bauer and Herald, 1921) which includes a portion of eastern McKenzie County. Leonard (1925) divided the county into five districts for purposes of discussion of the lignite beds, but did not attempt correlations between districts. Brant (1953) reviewed previous lignite studies and estimated the lignite resources of McKenzie County at about 32,183 million tons. Fisher (1953, 1954) prepared structure maps of portions of southwestern McKenzie County utilizing the lignite beds as marker horizons. Meldahl (1956) mapped the Grassy Butte area. Subsurface information for lignite resource evaluation has been aided by drilling for the Conservation Division of the U.S. Geological Survey (Spencer, 1978; U.S.G.S., 1979).

Oil exploration has provided a wealth of information on the subsurface strata and there have been numerous publications dealing with the Paleozoic strata of this county. Nevin (1946) mapped the Keene Dome portion of the Nesson Anticline. Carlson and Anderson (1966) provide a summary of the history of the Williston Basin and a series of isopachous maps which show the areal distribution of most of the Paleozoic formations.

Drainage changes as a result of glaciation have been addressed by Leonard (1916), Alden (1932), Howard (1960), Bluemle (1972), and Clayton, Moran, and Bluemle (1980). Colton, Lemke, and Lindvall (1963) provided a reconnaissance glacial map of this area. Fulton (1976) mapped the glacial and post-glacial sediments in McKenzie County. Brostuen (1977) provided an interpretation of the suitability of the near-surface materials for different land uses. Clayton with others (1980) provided a more detailed geologic map of the area.

SUBSURFACE STRATIGRAPHY

General Statement

Information obtained from oil exploration provides the basis for interpretation of the early geologic history of this area. It shows that sedimentation began on a Precambrian surface of low relief about 515 million years ago. Each of the geologic periods are represented in the preserved section with this area having been alternately an area of marine deposition and then emergence with erosion of part of the sedimentary section or occasionally an area of non-marine deposition. Episodes of emergence are marked by major regional unconformities and the preserved sedimentary section bounded by these unconformities has been defined as a sequence. Sedimentary sequences recognized in this area are in ascending order: Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas. The sequences provide a convenient means for discussion of the geologic history.

The sedimentary section is further subdivided into units of similar lithology and origin which are defined as formations or groups. The stratigraphic column (fig. 4) provides the names of these units as well as the general lithology and thickness in McKenzie County. Generally the thickness variations reflect a gradual downwarping of the central basin area so the thickest sections are on the west flank of the Nesson Anticline in northern McKenzie County.

Precambrian

There have been three Precambrian tests in McKenzie County and one test near the southeast corner in Billings County. The Amerada Hess-Antelope Unit "A" No. 1 (NESEsec 1, T152N, R95W) was the first of these and was the deepest test in the state at 15,130 feet until the Gulf-Zabolotny No. 1-3-4A (NWSEsec 3, T144N, R98W) well in Billings County was drilled to a depth of 15,380 feet. Subsequently Shell has drilled two Precambrian tests in the western part of the county, the USA 42-8 (SENEsec 8, T147N, R103W) and the USA 34X-6 (NESEsec 6, T148N, R104W) each of which were drilled to depths of more than 14,000 feet.

The Antelope Unit "A" No. 1 cored the Precambrian rocks, and samples of the gneiss have been dated as 1,700 ± million years old by the Rb-Sr method and 2,200 ± million years old by the K-Ar method (Goldich, 1966). These ages are considered Middle Precambrian and are inferred as probably associated with events related to the Black Hills orogeny. Cuttings from the other wells consist of quartz, feldspar, biotite, and amphiboles so they are also either granite or granite gneiss.

Sauk Sequence

The Sauk Sequence is represented by the Deadwood Formation of Upper Cambrian to Lower Ordovician age deposited as Upper Cambrian seas spread across this area from the west about 515 million years ago. It consists of variable thicknesses of glauconitic carbonate, sandstone, and minor amounts of shale with a clean, quartzose sandstone at the base. Thicknesses of about 750 to 900 feet are present in the wells which have penetrated these strata. The thinning appears to be due mainly to pre-Middle Ordovician erosion, although topography on the Precambrian surface may have had some influence.

Tippecanoe Sequence

The Tippecanoe Sequence began with deposition of clastics of the Winnipeg Group as mid-continent seas spread across this area from the south and east about 470 million years ago. As the seas advanced, shallow-water carbonates with minor amounts of evaporites and shales were deposited through the Upper

ERA	SYSTEM	SEQUENCE	GROUP	FORMATION OR GROUP	THICKNESS	DOMINANT LITHOLOGY
CENOZOIC	TERTIARY	TEJAS		ALLUVIUM-COLLUVIUM	0- 60	Silt, Sand and Gravel
				COLEHARBOR	0- 300	Till, Sand, Gravel, Silt, and Clay
				WIOTA	0- 30	Sand and Gravel
		ZUNI		GOLDEN VALLEY	0- 180	Silt, Clay and Sand
			FORT UNION GROUP	SENTINEL BUTTE	0- 620	Silt, Clay, Sand and Lignite
				TONGUE RIVER	250- 600	Silt, Clay, Sand and Lignite
				SLOPE	600- 650	Silt, Clay, Sand and Lignite
				CANNONBALL		Mudstone and Sandstone
				LUDLOW		Silt, Clay, Sand and Lignite
MESOZOIC	CRETACEOUS			HELL CREEK	200- 250	Clay, Sandstone and Mudstone
			MONTANA GROUP	FOX HILLS	200- 250	Sandstone and Shale
				PIERRE	2000-2300	Shale
			COLORADO GROUP	NIOBRARA	200- 230	Shale, Calcareous
				CARLILE	300- 350	Shale
				GREENHORN	200- 230	Shale, Calcareous
				BELLE FOURCHE	220- 250	Shale
			DAKOTA GROUP	MOWRY	90- 130	Shale
				NEWCASTLE	0- 150	Sandstone
				SKULL CREEK	180- 270	Shale
				INYAN KARA	400- 525	Sandstone and Mudstone
	JURASSIC			SWIFT	440- 570	Mudstone and Sandstone
				RIERDON	90- 140	Shale and Sandstone
				PIPER	380- 450	Limestone, Shale and Anhydrite
	TRIASSIC	ABSAROKA		SPEARFISH	380- 450	Siltstone and Salt
PALEOZOIC	PERMIAN			MINNEKAHTA	25- 40	Limestone
				OPECHE	200- 420	Shale, Siltstone and Salt
			MINNELUSA	BROOM CREEK	200- 220	Sandstone and Dolomite
	PENNSYLVANIAN			AMSDEN	300- 350	Dolomite, Sandstone and Shale
				TYLER	80- 180	Mudstone and Sandstone
	MISSISSIPPIAN	KASKASKIA		BIG SNOWY	400- 550	Shale, Sandstone and Limestone
				MADISON	1900-2300	Limestone, Anhydrite and Salt
				BAKKEN	20- 100	Shale and Siltstone
	DEVONIAN			THREE FORKS	85- 240	Shale, Siltstone and Dolomite
				BIRDBEAR	75- 105	Dolomite
				DUPEROW	300- 490	Interbedded Dolomite and Limestone
				SOURIS RIVER	190- 280	Interbedded Dolomite and Limestone
				DAWSON BAY	60- 125	Dolomite and Limestone
				PRAIRIE	70- 225	Salt
				WINNIPEGOSIS	160- 435	Limestone and Dolomite
	SILURIAN	TIPPECANOE		INTERLAKE	600-1200	Dolomite
	ORDOVICIAN			STONEWALL	75- 110	Dolomite
				STONY MOUNTAIN FM.	125- 170	Argillaceous Limestone
				RED RIVER	475- 660	Limestone and Dolomite
			WINNIPEG GROUP	ROUGHLOCK	20- 50	Calcareous Shale and Siltstone
				ICEBOX	100- 130	Shale
				BLACK ISLAND	40- 260	Sandstone
	CAMBRIAN	SAUK		DEADWOOD	750- 950	Limestone, Shale and Sandstone
PRECAMBRIAN ROCKS						

Figure 4. Stratigraphic column for McKenzie County.

Ordovician to Middle Silurian Series. The thickness of this sequence ranges from about 1,400 feet in the southwest to 2,200 feet in the northeast parts of the county. The thinning is due mostly to erosional thinning of the Interlake Formation prior to advance of the mid-Devonian seas and partially to depositional thinning of the other strata.

Kaskaskia Sequence

The Kaskaskia Sequence began with deposition of shallow-water carbonates and thin shales as the Middle Devonian seas spread across the area from the northwest about 370 million years ago. The variations of thickness of Devonian strata are primarily depositional with thicker accumulations in the basin center while minor erosional episodes have thinned some of the units southwestward. Erosional thinning is most pronounced in the mainly clastic Three Forks Formation before Mississippian seas again spread over the entire area.

The initial Mississippian deposition was shale and silt of the Bakken Formation followed by shaly carbonates of the lower Madison followed by clean, shallow marine carbonates and then alternating carbonates and evaporites of the Upper Madison. Thinning of the Madison from 2,300 feet in the east to 1,900 feet in the southwestern corner of the county reflects depositional thinning with most of the thinning in the evaporites.

Absaroka Sequence

The Absaroka Sequence, which began with deposition about 315 million years ago, is composed of clastics, carbonates, and evaporites which range in thickness from about 1,150 feet in the northern part of the county to about 1,550 feet in the south. The thickness variations reflect primarily depositional variations of salt beds in the Spearfish and Opeche Formations and some erosional thinning at the regional unconformity preceding Middle Jurassic deposition.

Zuni Sequence

The Zuni Sequence is primarily a clastic sequence beginning with redbeds, evaporites, and carbonates as Middle Jurassic seas spread across the area from the west about 170 million years ago. There was a Late Jurassic-Early Cretaceous regressive phase before Early Cretaceous seas again spread across the area. The initial Cretaceous deposits are the non-marine to marine Inyan Kara Formation (Fall River-Lakota interval; or Dakota aquifer of previous usage). Subsequently, thick deposits of marine shale were deposited before the fine-grained clastics of the Fox Hills Formation were deposited as the Late Cretaceous seas withdrew from the area about 70 million years ago. This was followed by deposition of the non-marine, dinosaur-bearing beds of the Hell Creek Formation and the lignite-bearing strata of the Fort Union Group.

The Inyan Kara Formation is a saline aquifer which in this county is present at depths ranging from about 4,100 feet at the lower elevations along the crest of the Nesson Anticline in northeastern McKenzie County to about 5,700 feet in the west-central part of the county. It is generally about 400 to 500 feet thick consisting of alternating sandstone and mudstone units with a general lack of continuity of beds.

The cross section (pl. 2) shows some of the variability of thickness and continuity of sandstone beds. The lower Inyan Kara seems to represent non-marine deposition, while the uppermost beds seem to represent a marine phase of the advancing Lower Cretaceous seas. The contact with the overlying Skull Creek Shale is gradational.

The Newcastle Sandstone is also a saline aquifer with an erratic distribution in this county (fig. 5). Except for the eastern part of the county, most wells have some sandstone at this horizon with thicknesses of as much as 110 feet in some wells.

Log analysis combined with a few chemical analyses indicate that total dissolved solids exceed 10,000 ppm in both formations throughout this county. Basin-wide analyses show the Newcastle to have generally higher total dissolved solids than sandstones in the Inyan Kara.

UPPER CRETACEOUS STRATIGRAPHY

Fox Hills Formation

The Fox Hills Formation is a marine- to brackish-water deposit representing the nearshore deposits of the receding Late Cretaceous seas. In the outcrop areas in southwestern and south-central North Dakota it may be divided into four members (Waage, 1968; Feldmann, 1972) and these were extended into the subsurface near the areas of good exposures (Carlson 1979, 1981). Northward these members lose their identity, as the upper part of the Fox Hills is composed primarily of fine- to very fine grained sandstone with minor amounts of mudstones or shale. The lower contact is gradational from the shale of the Pierre Formation into silty shale, shaly silt, and sand. This transitional zone, which is generally 30 to 60 feet thick in McKenzie County, is probably equivalent to the Trail City Member of south-central North Dakota. The sandstones are laterally continuous and consistently provide an aquifer in this county. The upper contact is difficult to determine as the sandston

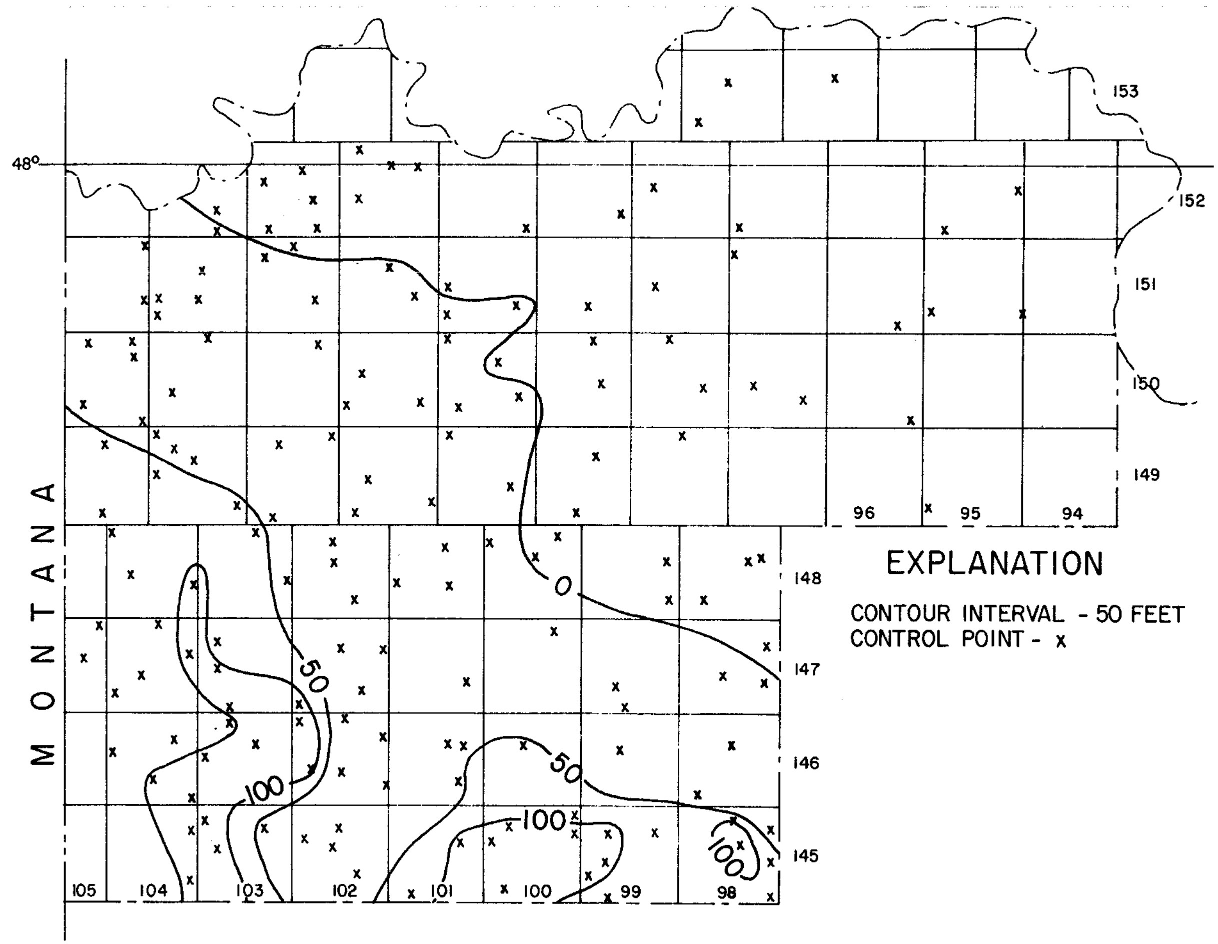


Figure 5. Isopachous map of the Newcastle Formation.

units in the overlying Hell Creek are quite similar in texture to those in the Fox Hills. The contact is herein placed at the top of the sandstones, which are as much as 200 feet thick in some parts of the county (pls. 3, 4), but other interpretations may be more correct.

Hell Creek Formation

The Hell Creek Formation was deposited in flood-plain and swamp environments near the shore of the receding Late Cretaceous seas. The nearest exposures are along the Missouri River near Wolf Point in Eastern Montana and along the Little Missouri River in southwestern North Dakota where Frye (1969, p. 22) reported thicknesses of 420 to 450 feet. In outcrop areas these strata are composed of "somber colored," sandstone, siltstone, mudstone, and bentonitic and carbonaceous shales which generally show a lack of lateral continuity of beds. These same characteristics have been noted as the Hell Creek is traced through the subsurface as well as a thinning eastward to south-central North Dakota (Carlson, 1979, 1981). A similar thinning northward was noted in Billings and Golden Valley Counties (Carlson, 1983).

In outcrop areas, the top of the Hell Creek Formation is placed at the base of the lowest lignite and the upper beds of the Hell Creek consist of bentonitic and carbonaceous shales. In the subsurface the upper contact is placed at a gamma-ray marker which is interpreted as representing a lignite bed. This interpretation results in a unit consisting of variable thicknesses of sandstone, siltstone, mudstone, and shale about 250 feet thick. This represents the Hell Creek Formation in McKenzie County (pls. 3, 4).

TERTIARY STRATIGRAPHY

Fort Union Group

The term Fort Union Group was introduced by Meek and Hayden (1862, p. 433) to refer to the lignite-bearing strata between the Fox Hills beds and the overlying Wind River (=White River of North Dakota) deposits in the northern Great Plains. Thom and Dobbin (1924) presented a regional summary of the post-Fox Hills strata using Fort Union and Lance Formations for the same strata they considered to be of Tertiary and Cretaceous age. As the controversy involving the boundary between Cretaceous and Tertiary strata was resolved, all of the lignite-bearing Paleocene strata were included in the Fort Union, the term Lance was dropped, and Cretaceous strata between the Fox Hills and Fort Union were assigned to the Hell Creek Formation.

Logs of oil exploration test holes combined with test-hole drilling for the groundwater study and lignite evaluation work now provide considerable subsurface information for the lignite-bearing strata. Density logs for the groundwater test holes were used to determine the base of the lignites; gamma-ray correlations of oil exploration test holes were then used to extend the interpretations across the county (pls. 3, 4, and 5). The Fort Union Group is about 1,860 feet thick at the test hole in sec 11, T145N, R99W (NDGS 5422). This well was drilled at a point near the contact between the Golden Valley and Sentinel Butte Formations where the base of the lignite-bearing strata was at a depth of 1,859 feet. The gamma-ray log indicates only thin lignites below 1,090-foot depth and some fairly thick sections between lignite beds, which might represent tongues of marine strata. The high resistivity at a depth of 1,214 to 1,218 feet is tentatively correlated as the siliceous white marker bed used as the top of the Slope Formation in southwestern North Dakota. Consequently, the thickness of the Slope-Cannonball-Ludlow section in this well is about 650 feet and the Tongue River and Sentinel Butte Formations are about 1,220 feet thick.

Various names have been applied to Fort Union strata in North Dakota and there still are conflicting views so a historical summary of some of the changes is provided (fig. 6). It shows some of the previous usage and usage of this report. Correlations of the lower units are based entirely on subsurface log interpretations through adjacent counties. The Sentinel Butte Formation and upper portions of the Tongue River Formation are exposed in this county so a combination of surface and subsurface information was available for studying these formations.

Ludlow Formation

The term Ludlow was introduced by Lloyd and Hares (1915) to refer to non-marine, lignite-bearing strata between the Hell Creek and Cannonball Members of the Lance Formation in southwestern North Dakota and northwestern South Dakota with a type area near Ludlow, South Dakota. Subsequently the relationship was determined to be an intertonguing one with an eastward thinning Ludlow facies and a westward thinning Cannonball facies. When the Hell Creek was recognized as the uppermost Cretaceous strata, the term Lance was dropped and the Ludlow and Cannonball were transferred to the Fort Union.

The nearest exposures of Ludlow sediments are along the Little Missouri River in Slope County where the complete section is exposed at Pretty Rock Butte. The base of the formation was placed at the lowest persistent lignite and the upper contact was placed at the base of the T Cross bed. Carlson (1983)

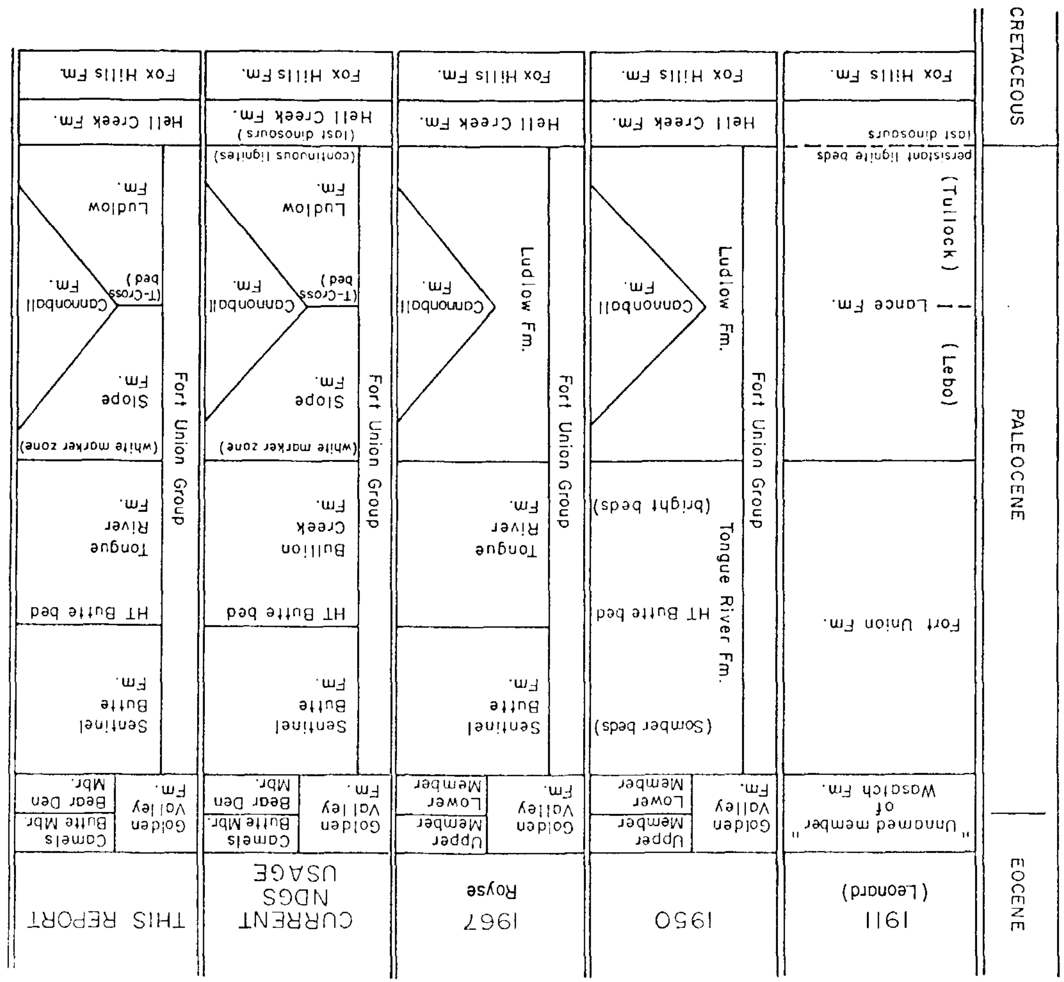


Figure 6. Relationship of Fort Union nomenclature of this report to previous usage in western North Dakota.

traced these strata northward through the subsurface of Billings and Golden Valley Counties; however, the T Cross bed thins, or pinches out, northward so the correlation to southern McKenzie County is only tenuous. The intertonguing relationship of the Cannonball Formation is also difficult to interpret from log characteristics so no effort was made to differentiate these formations on the cross sections (pls. 3, 4).

The Ludlow Formation consists of interbedded sand, silt, clay, and lignite. The lignite beds are generally thin, with most beds less than 3 feet thick, but a few beds attain thicknesses of 4 to 7 feet in some areas. The only thicker bed noted in the lower Ludlow is in the area of T149N, Rs100 to 102W where one bed is generally 8 to 10 feet thick and is 13 feet thick in a well in sec 23, T149N, R100W.

Cannonball Formation

Lloyd (1914, p. 247) introduced the term Cannonball to apply to about 250 to 300 feet of marine strata exposed along the Cannonball River in Grant County. The strata there consist of alternating units of sandstone, siltstone, or mudstone with mudstone the predominant lithology. These strata thin westward in a facies relationship with the non-marine strata of the lower part of the Fort Union Group so that in exposures along the Little Missouri River in Slope County (Moore, 1976, p. 33) only two thin tongues are present. Northwestward, a non-lignite-bearing interval has been traced through Mercer (Carlson, 1973), Morton (Carlson, 1983), and into Dunn Counties. Although this unit is probably present, at least in eastern McKenzie County, precise delineation was not attempted.

Slope Formation

Recent studies of areas to the west and south of McKenzie County have revealed a variable usage of Tongue River in North Dakota and adjacent areas. Strata previously called Tongue River in western North Dakota include strata that were called Upper Ludlow in Slope County. To avoid the confusion of having different names applied to the same strata in different areas, Clayton and others (1977, p. 10) recommended discontinuance of the use of Tongue River and redefinition of the Ludlow in North Dakota.

They introduced the term "Slope Formation" to apply to non-marine strata overlying the Cannonball Formation (or where Cannonball is absent, the T-Cross bed) and underlying a "white marker zone" with its type area in northwestern Slope County. This approach is practical in the outcrop area and can be extended into the subsurface with confidence in areas near the outcrop (Carlson, 1983). However, as noted earlier, the base is not readily recognized in this area nor are the intertonguing relationships with the Cannonball easily interpreted.

Lithologically this unit is similar to the Ludlow Formation as well as the overlying Tongue River Formation so subsurface delineation is difficult. Nevertheless, strata equivalent to what is elsewhere recognized as Slope Formation are present in this county and the section is referred to as Slope-Cannonball-Ludlow undifferentiated on the cross sections (pls. 3, 4).

Tongue River Formation*

Thom and Dobbin (1924) extended the term Tongue River from Wyoming into North Dakota to refer to the generally bright-colored, lignite-bearing strata which Leonard (1908) had referred to as Middle Fort Union. They used Sentinel Butte as a member of the Fort Union and correlated it with the Wasatch (Eocene) of Wyoming. Since then, Tongue River has generally been accepted in North Dakota, but its boundaries have been placed at various horizons. When the strata which Leonard (1908) had referred to as Upper Fort Union were recognized as being of Paleocene age, they were usually referred to as the Sentinel Butte Member (Hanson, 1955), or facies (Fisher, 1954) of the Tongue River Formation. When the Sentinel Butte was recognized as a mappable unit, it was referred to as a member (Stephens, 1970) or formation (Royse, 1967) of the Fort Union Formation or Group. The Tongue River was then restricted to the underlying, brighter colored strata and considered to be approximately equivalent to Leonard's Middle Fort Union strata.

The term Bullion Creek Formation was introduced by Clayton and others (1976, p. 10) to refer to strata between the "white marker zone" and the HT Butte lignite because of uncertainties of correlation between the North Dakota and Wyoming exposures of Fort Union strata and perceived differences of usage in different areas. As thus defined, it is approximately equivalent to Leonard's (1908) Middle Fort Union with Leonard's R bed equivalent to the HT Butte bed. Recent field reconnaissance indicates that the bright-colored beds in the Williston and Powder River Basins are probably essentially equivalent; so, extension of the term Tongue River to Leonard's Middle Fort Union, as originally proposed, is satisfactory and there is no need for a new term.

The contact between the Sentinel Butte and the underlying strata is marked by a color change and in the area along the Little Missouri River in Billings and Golden Valley Counties it is

* The stratigraphic nomenclature used in this report (e.g., Tongue River Formation) is that of the author and does not conform to terminology currently in use by the North Dakota Geological Survey.

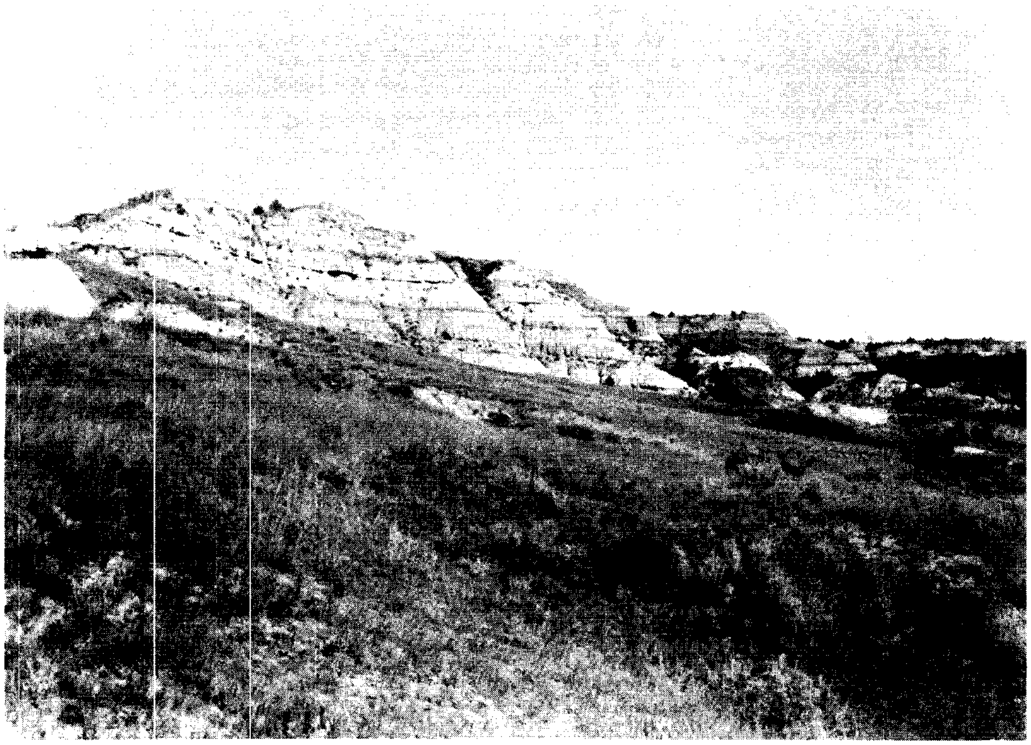


Figure 7. View looking north at Tongue River Formation along Magpie Creek in NEsec 30, T145N, R101W.

also marked by the HT Butte lignite bed or a clinker zone where that bed has burned. The HT Butte bed thins to nothing in southern McKenzie County; northward the contact is simply a color change from the "bright" or buff colors of the Tongue River Formation to the "somber" colors of the Sentinel Butte Formation.

The upper 350 feet of Tongue River sediments are exposed in the southwestern part of the county with good exposures of the upper contact present in many areas of the badlands. The most accessible areas on the east side of the Little Missouri River are along Magpie, Beicegal, and Bennett Creeks (figs. 7, 8). West of the Little Missouri River the contact may be traced nearly continuously northward to the Cartwright area (fig. 9). The contact is then obscured by glacial drift in some areas before dipping into the subsurface. Eastward the contact is again exposed along the Nesson Anticline where the color change is present above bentonitic clay beds (fig. 10).

Exposures in the southwestern portion of the county weather to buff, light-yellow, and light-gray colors. They

Figure 8. View looking northeast at Sentinel Butte-Tongue River contact on north side of Bennett Creek in SWsec 29, T147N, R100W.

consist of interbedded sand, silt, clay, carbonaceous shale, and lignite with silt and clay the predominant lithologies. Fresh-water snails and clams are common at some horizons and lime-stone pods are common in some of the silt beds.

Generally several lignite beds are found ranging from 4 to 8 feet thick in western McKenzie County, and one lignite bed is as much as 50 feet thick in sec 13, T147N, R102W. The top of this bed is about 500 feet below the top of the Tongue River Formation (pl. 5). It maintains a thickness of more than 40 feet

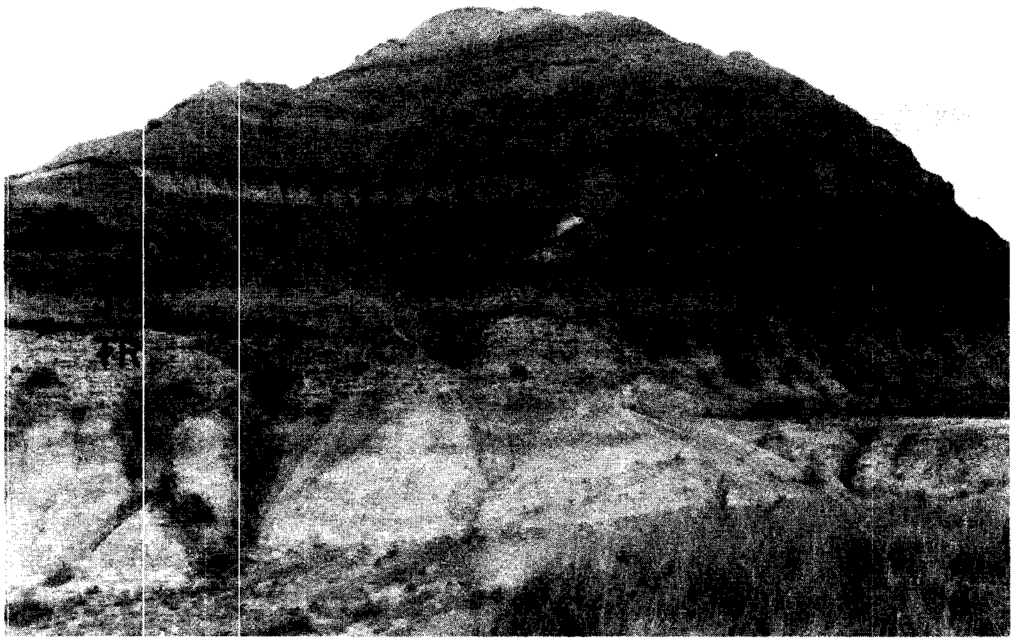


Figure 9. View looking northwest at Sentinel Butte-Tongue River contact in Cartwright area in NWsec 25, T150 N, R104W.

with only a thin clay parting over an area of about 65 square miles. It thins rapidly and splits to the north and west whereas the upper split maintains a thickness of more than 20 feet over a 150-square-mile area to the south and east (fig. 11). Its depth ranges from depths of about 300 feet under the Little Missouri River to more than 800 feet at the higher elevations in the area. This bed is in the approximate stratigraphic position of the Harmon bed in southwestern North Dakota.

The lignite bed that thickens to as much as 24 feet thick in the lower part of the Tongue River Formation in northwestern McKenzie County, appears to be in approximately the same stratigraphic position as the lower split of the thick bed in the southern part of the county. In the eastern part of the county the thickest lignites are in the middle to upper part of the Tongue River Formation with beds as much as 20 to 25 feet thick present at different horizons in different areas.

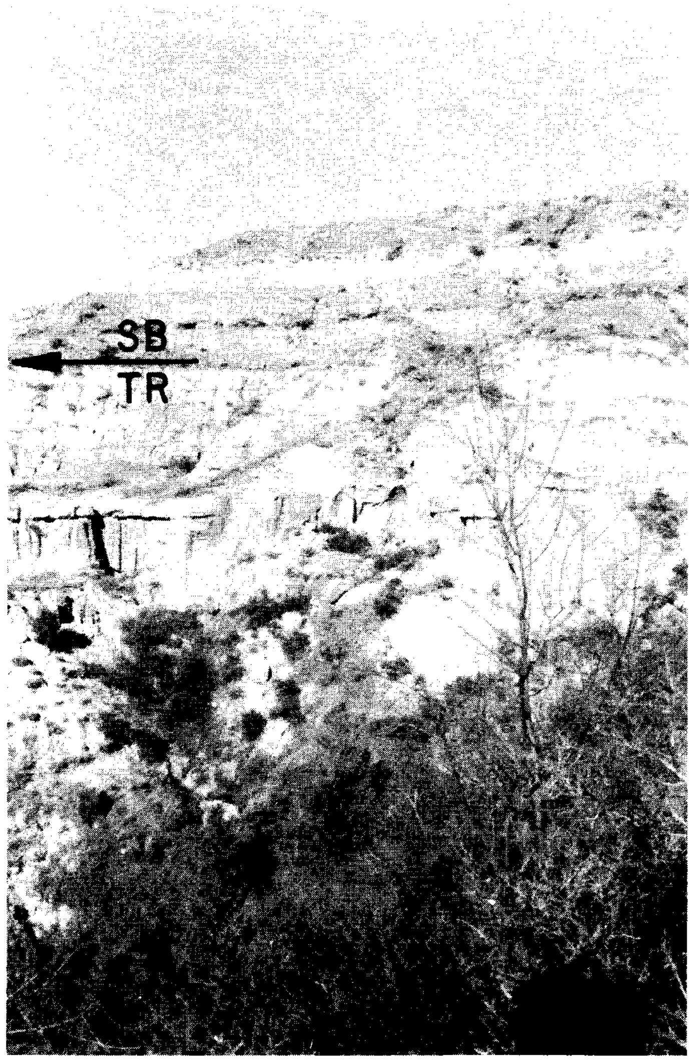


Figure 10. View looking north at contact of Sentinel Butte-Tongue River contact in Charlson area in NWsec 3, T154N, R95W.

Sentinel Butte Formation

Leonard (1908, pl. XII) introduced the term Sentinel Butte Group for a sequence of lignite beds in the upper part of the Fort Union Formation. He also noted a color change at the lowest lignite bed in the group (bed R) and referred to the dark-gray shales and sandstones above bed R as the Upper Fort Union. Subsequent workers have recognized the same color contact and mappability of this unit over wide areas, and the term Sentinel Butte Formation is the current favored usage of the North Dakota Geological Survey.

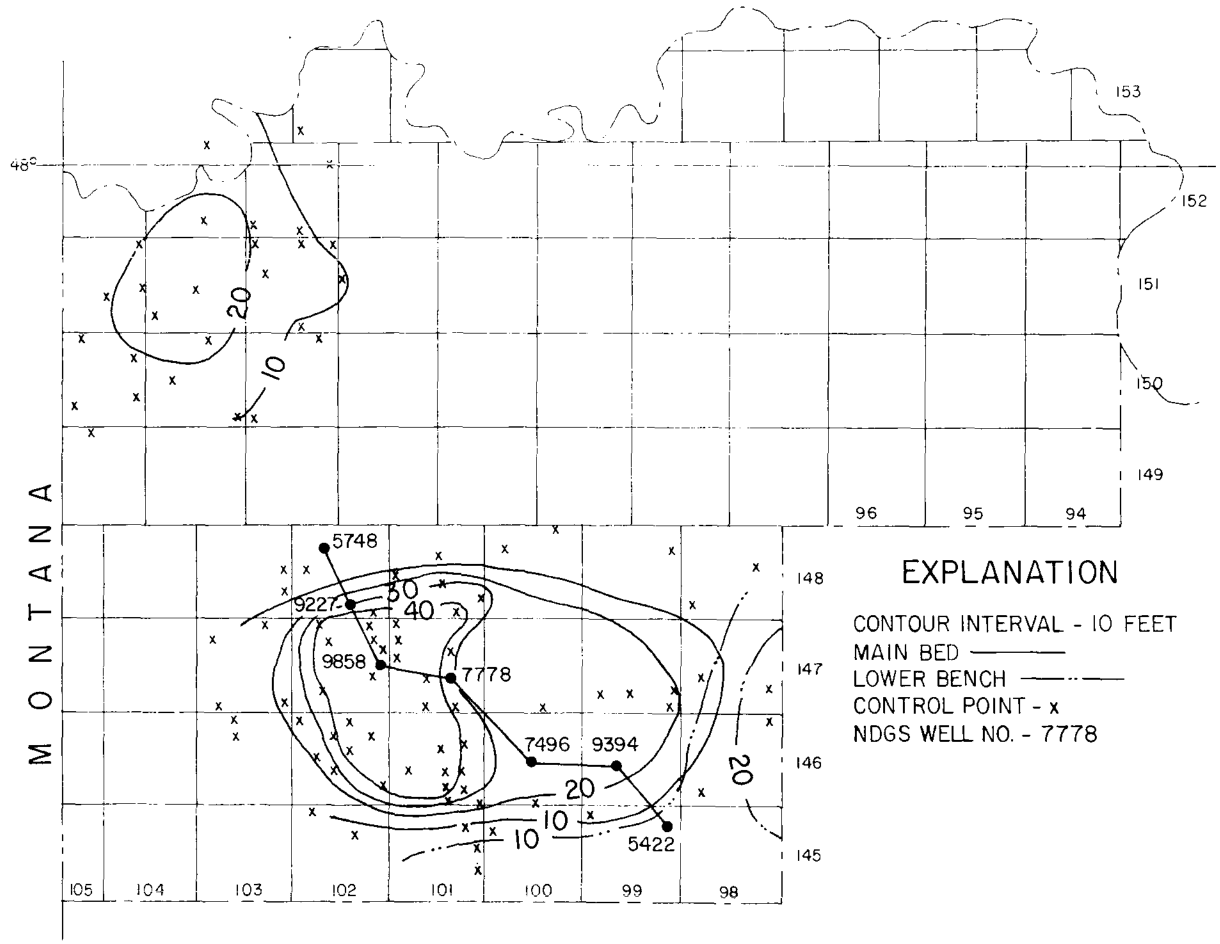


Figure 11. Isopachous map of lignite beds in the lower part of the Tongue River Formation.

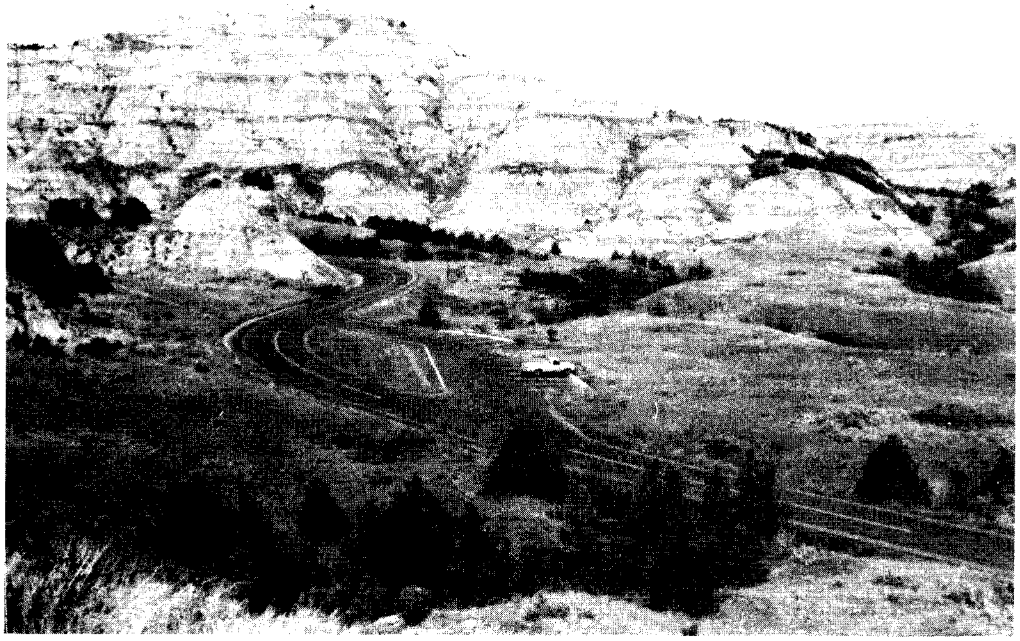


Figure 12. View looking northwest at Sentinel Butte Formation in Theodore Roosevelt National Memorial Park in N½sec 25, T148N. R99W.

The most accessible exposures of the Sentinel Butte Formation are the nearly complete sections along the Little Missouri River in the Theodore Roosevelt National Memorial Park area (fig. 12), where nearly 600 feet of vertical section is continuously exposed. The lower contact is not exposed there, but the nature of the contact may be determined by continuous exposures east of the Little Missouri River along Magpie, Beicegal, and Bennett Creeks. The HT Butte bed thins from a few inches in secs 28-35 to nothing in sec 6, T145N, R101W and is absent northward. In the area east of the Little Missouri River about 10 to 15 feet of brownish-gray and medium-gray, bentonitic mudstone and silt is overlain by a 2- to 3-foot-thick lignite at the base of the Sentinel Butte. This unit thickens northward to about 25 feet along Bennett Creek where petrified wood is commonly associated with the lignite bed. A similar sequence is present west of the Little Missouri River along Bowline Creek. The lignite thickens and the interval between the lignite and the color contact thins westward along Hay Creek to the Squaw Gap area. The lignite is extensively burned to form a prominent "clinker zone" in that area and Fisher (1953) used this "clinker zone" as his L bed at the base of his

Figure 13. View looking northeast at petrified stump zone of Sentinel Butte Formation in SWsec 13, T147N, R102W.

Sentinel Butte Formation. Northward to the Cartwright area somber beds also occur between the lowest lignite of the Sentinel Butte Formation and the top of the Tongue River Formation.

The Sentinel Butte Formation consists of interbedded sand, silt, mudstone, carbonaceous shale, and lignite. Ironstone nodule zones in the silt and mudstone and petrified wood in the lignite and carbonaceous shale are characteristic of this formation. A petrified stump zone with the stumps preserved in growth positions is associated with bentonitic beds about 50 feet above the base of the Sentinel Butte in the Bowline-Hay Creek area (fig. 13). The beds have a general lack of lateral continuity, but in the area of good exposures some useful marker horizons are found. These strata generally weather to shades of gray and brown of a "somber" tone; however, two zones, each about 15 to 30 feet thick, weather to buff and yellow tones similar to typical Tongue River strata. These horizons have been referred to as the low and high yellow markers. These zones may be traced for considerable distances in the good exposures along the Little Missouri River. The lower yellow marker is about 220 feet above the base of the Sentinel Butte Formation in the Bennett Creek area. The interval between the upper and lower yellow marker is about 120 feet in this area. A prominent bentonitic clay bed, which has been referred to as the "blue bed," is present just below the low yellow marker bed in the Roosevelt Park area. The "blue" bentonitic bed is also a prominent marker in exposures south of Arnegaard and westward in western McKenzie County.

The Sentinel Butte Formation is characterized by numerous 1- to 3-foot-thick lignite beds with only a few localities where any beds are as much as 10 feet thick. In the western and northwestern part of the county, wells penetrating the complete formation generally have no more than 1 or 2 lignite beds exceeding 3 feet in thickness. In the eastern and northeastern part of the county wells more commonly have several beds in the 5- to 10-foot-thick range. Generally, the thicker beds are in the upper part of the Sentinel Butte Formation.

Golden Valley Formation

The Golden Valley Formation was named by Benson and Laird (1947, p. 1166) to apply to well-exposed strata in the area near Golden Valley in Mercer County. These strata had previously been called the "unnamed member of the Wasatch Formation." Benson (1949) further described these strata and divided them into lower and upper members. Hickey (1976) reviewed previous usage and provided a detailed study of the lithology and distribution of these strata. He introduced the terms Camels Butte and Bear Den for the upper and lower members and designated a reference section in the type area.

Exposures of the Golden Valley strata are limited to a small area near Grassy Butte in the southeastern part of the County and the Blue Buttes area of northeastern McKenzie County. The nature of the lower contact is best understood where it is exposed in NEsec 10, T145N, R99W where it is conformable with the underlying Sentinel Butte Formation (fig. 14). In the Grassy Butte area, the Bear Den Member has its typical three-unit subdivision, a lower gray zone, a middle orange weathering zone, and an upper purplish, carbonaceous zone. The lower member is also well exposed southeast of the Blue Buttes at NWsec 33, SEsec 32, and SEsec 29, T151N, R94W (fig. 15), where it has a similar lithology.

The Camels Butte Member consists of yellowish-brown, fine-grained, micaceous sandstone with cemented zones forming the caprock of the Blue Buttes. Portions of this member are exposed at various localities, but in most places the slopes are covered with vegetation or a litter of blocks of cemented sandstone.

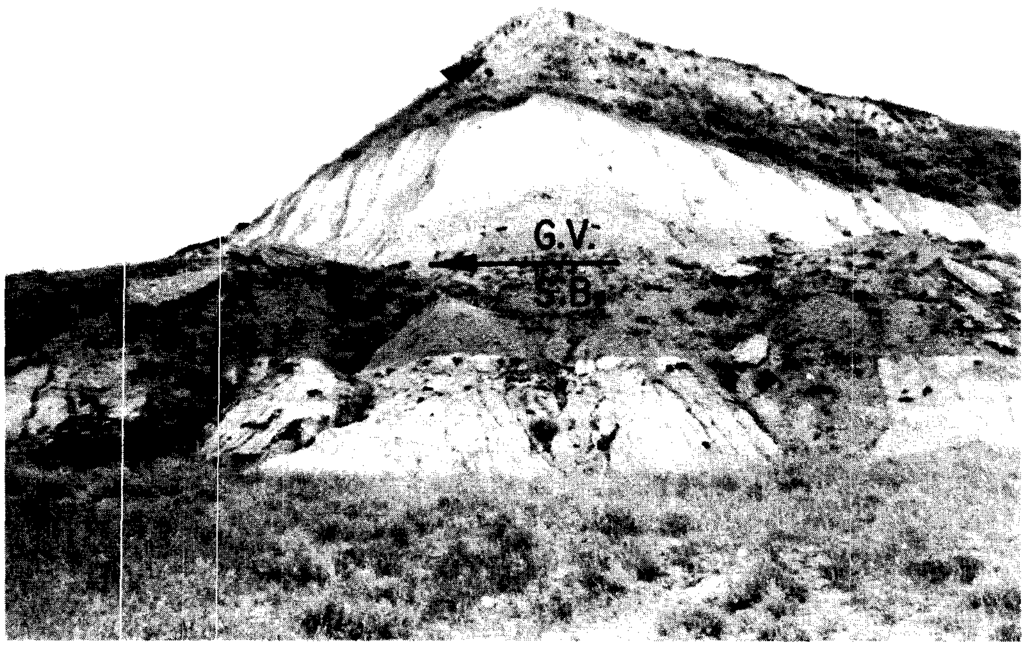


Figure 14. View looking northeast at Golden Valley Formation and uppermost Sentinel Butte Formation in Grassy Butte area in NEsec 10, T145N, R99W.

A few feet of reddish-green and yellowish, silty clay are overlain by a few feet of greenish-gray, fine-grained sandstone capping the highest butte in sec 21, T151N, R95W. These are not typical Upper Golden Valley lithologies, but probably represent weathering effects on the pre-Oligocene surface rather than an outlier of White River strata.

Wiota Gravel

Some well-sorted, well-rounded, brown gravels derived from western sources are found along the pre-diversion courses of the Yellowstone and Little Missouri Rivers. Howard (1960) referred to these as Cartwright and Crane Creek gravels to emphasize differing terrace levels. Freers (1970), in his Williams County report, preferred to use Wiota and emphasize similar lithologic characteristics without implying precise correlations. I prefer the latter approach and these high level gravels are herein referred to as Wiota Gravel.

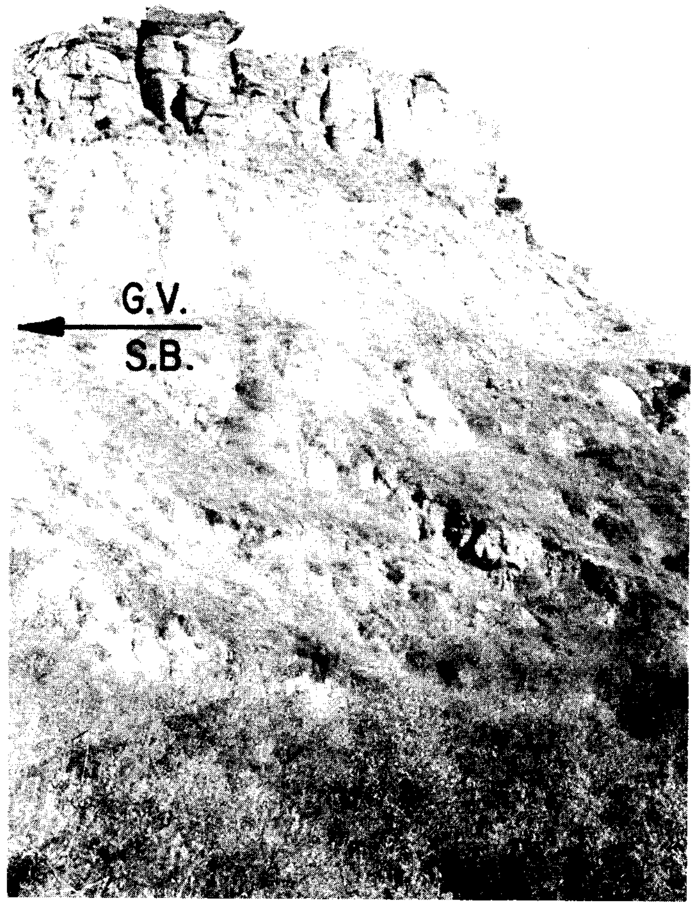


Figure 15. View looking northeast at Golden Valley Formation in Blue Buttes area in SEsec 29, T151N, R94W.

The most extensive of these gravel deposits are present on the east side of the Yellowstone River in northwestern McKenzie County (pl. 1). The gravels are as much as 25 to 30 feet thick (fig. 16) and are well-sorted with alternating layers of coarse gravel and sand. Gravels of similar composition and character occur along Redwing Creek and isolated areas along other old drainages. Subsequent deposition of a few feet of colluvium has masked these deposits in most areas except where pits have been developed (e.g., NEsec 3, T148N, R100W) so they have not been delineated as map units (pl. 1) except along the Yellowstone River.

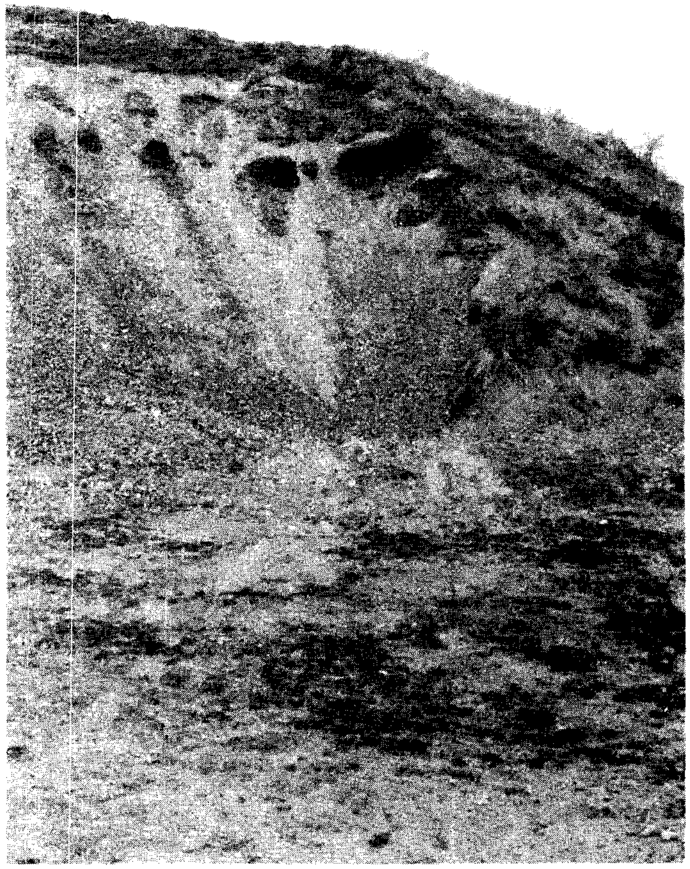


Figure 16. View looking north at exposure of Wiota gravel in NWsec 27, T152N, R103W.

QUATERNARY STRATIGRAPHY

Historical Review

The Missouri River was recognized as an ice-marginal stream by Warren as early as 1869 (Warren, 1869), but there have been various interpretations of when the diversion occurred. Alden (1932, p. 58) thought that it occurred during the Kansan glaciation at a level about 200 feet above its present level. Howard (1960) thought it formed marginal to either the Illinoian or Kansan glaciation, but thought the Early Wisconsinan ice sheet was the most widespread and had extended to the limit of glaciation in northwestern North Dakota. Bluemle (1972), and later Clayton and others (1980, p. 68) suggest different ages for different segments of the current trench with the latest changes resulting from Late Wisconsinan glaciation.

The consensus has generally been to consider the outer margin of glaciation as the oldest advance with later advances progressively less extensive. Clayton and others (1980, figs. 33, 35) refer to margin 1 (or Dunn) as a pre-Wisconsinan advance and margin 2 (or Verone) as pre-Wisconsinan or Early Wisconsinan. Margin 3 (or Napoleon) was considered as most likely Early Wisconsinan, but possibly older.

The area between margins 1 and 2 is marked by only occasional boulders in other areas of southwestern North Dakota. The area between margins 2 and 3 is marked by more numerous boulders, but also generally lacks till. The area northeast of margin 3 is generally marked by a greater abundance of boulders and Napoleon till has been preserved on upland areas. The olive-brown Napoleon till is relatively thin and lies on bedrock in most areas. Along the Missouri Trench in Mercer (Carlson, 1973, fig. 13) and McLean (Bluemle, 1971, fig. 20) Counties there are exposures of multiple tills with Napoleon till on light-gray, jointed till that has been called the Medicine Hill Formation (Ulmer and Sackreiter, 1973). Similar multiple till sequences were noted in the subsurface of these counties as well as in Williams County during lignite evaluation drilling in 1975.

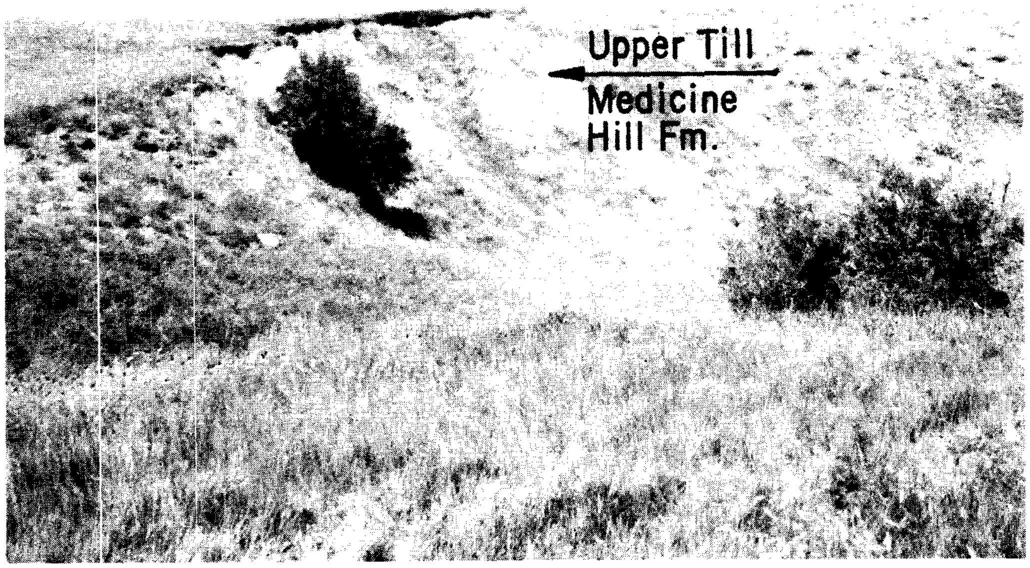
Fulton (1976) recognized four glacial advances across McKenzie County. He designated these advances glaciations A, B, C, and D. Advance A extended to the limit of glaciation and the younger glaciations were progressively less extensive. He analyzed till samples and recognized four units, three of which he correlated with previously named units. He referred to his units as follows: Medicine Hill Formation-glaciation A; Horseshoe Valley Formation-glaciation B; Snow School Formation-glaciation C; and Dimmick Lake Formation-glaciation D. The till analyses show wide variations of composition within each unit, so differentiation based solely on these analyses is not readily apparent. The samples which he referred to as Medicine Hill Formation were all collected from the southeastern area where thin till overlies bedrock and the analyses are similar to the Horseshoe Valley analyses. Clayton and others (1980, p. 57) suggest that, "the Snow School and Horseshoe Valley Formations, which are similar in lithology, may both be sediment of the Napoleon glaciation."

Only a few localities in McKenzie County can be found where multiple tills with obvious differences are exposed in a single exposure. In most areas a relatively thin olive-brown till lies on bedrock with no noticeable differences within the till. In a few places in old drainages light-gray, jointed till has been preserved below the olive-brown surface drift (figs. 17, 18). It seems likely that the thin surface drift on most upland areas was deposited by the same ice sheet and most likely was the Napoleon or an Early Wisconsinan advance. The light-gray, jointed till was probably deposited by the Verone advance. Pre-Napoleon erosion removed most of the glacial sediment from that and any earlier advances with only isolated remnants preserved, so the margins of earlier advances cannot be determined in this area. Fulton's glaciation D, or advance 5 of Clayton and others (fig. 32) is regarded as a Late Wisconsinan event that generally did not reach the Missouri River Trench, but is projected to have crossed the trench into northeastern McKenzie County. In that area, some undrained depressions are found as well as a small lake plain on the upland area. Clayton and others (1980, p. 68) credit this advance with diverting the Missouri River from its previous course through the Van Hook arm in Mountrail County to its southerly course from the Four Bears bridge. It also caused ice-marginal lakes to form in the pre-existing valleys as the ice melted back.

Fisher (1953) reviewed the preglacial, interglacial, and present drainage courses in McKenzie County. He recognized the Redwing Creek-Cherry Creek-Tobacco Garden Creek valleys as the preglacial route of the Little Missouri River. He thought that the Yellowstone River followed its present course with the Charbonneau Creek-Timber Creek segment as an interglacial diversion channel. It seems more likely, based on test-hole drilling, that this segment was a preglacial course of the Yellowstone River (fig. 19). Southeastward-trending narrow valleys floored by colluvium may have served as outlets for ice-marginal ponded meltwaters as the glacier melted back. The lower reaches are now tributaries for current drainages, whereas upper portions are sites of deposition of colluvium from adjacent uplands.

Coleharbor Group

Bluemle (1971, p. 16) introduced the term Coleharbor Formation to include all the glacial sediment in North Dakota. He noted that future studies might lead to raising the rank to group status and such has been the case. He included three main facies: "1) interlayered bouldery, cobbly, pebbly, sandy, silty clay (unsorted drift, till); 2) sand and gravel; and 3) silt and clay." Each of the three facies are present, but the main map unit represents the unsorted facies. Sand and gravel facies and silt and clay facies are present at the surface in only a few localities and are exposed below till or alluvium-colluvium in the banks along Lake Sakakawea. They are the dominant facies in the lowland areas where till is either absent or is a minor element in most test holes.



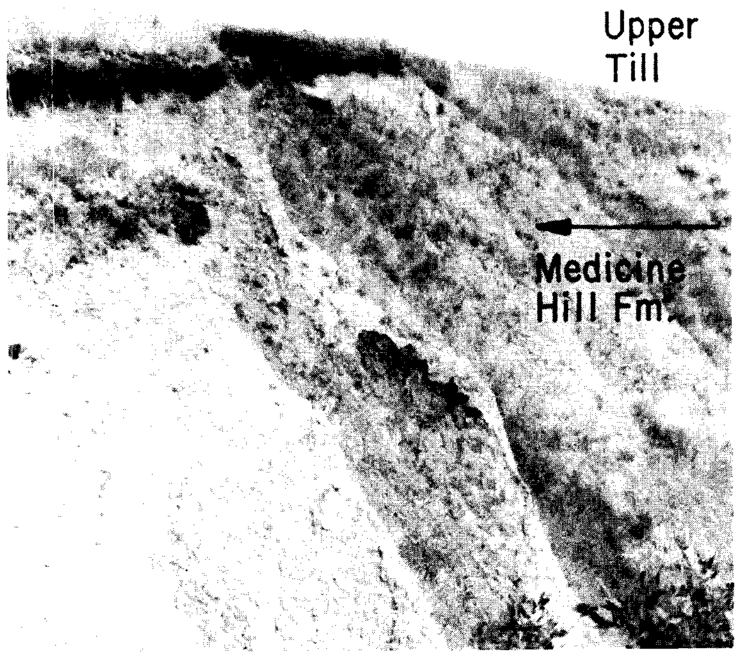


Figure 17. View looking north at multiple tills in pasture in NEsec 3, T151N, R100W.

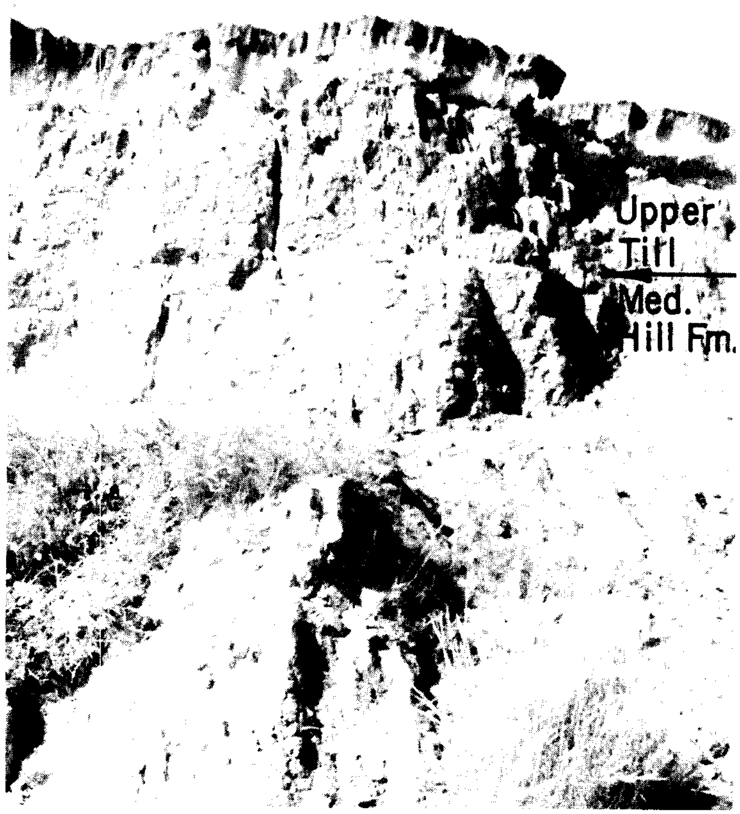


Figure 18. View looking west at multiple tills in sec 33, T153N, R96W.

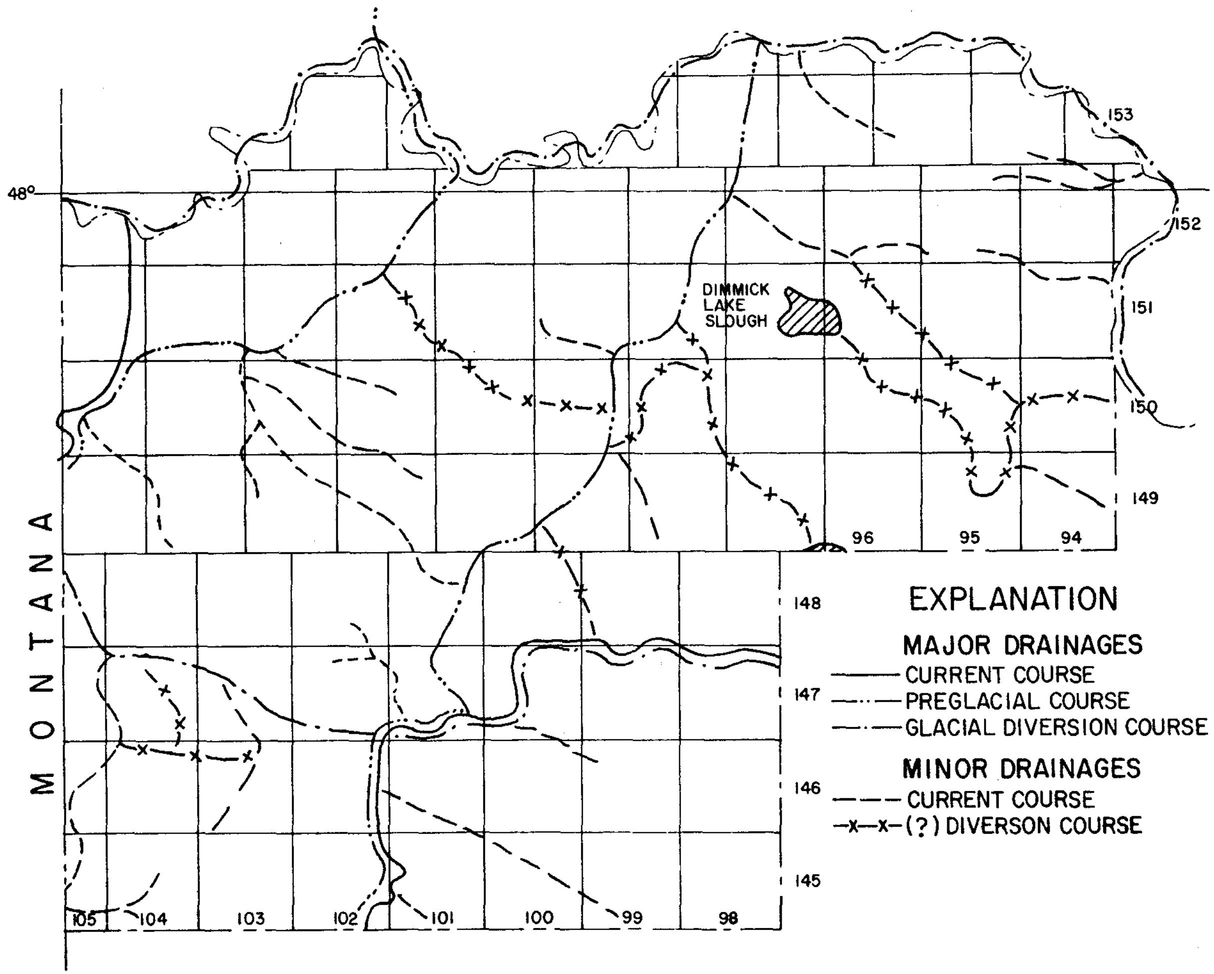


Figure 19. Current drainage and drainage changes in McKenzie County.

The near-surface till is an olive-gray or yellowish-brown, sandy, silty clay with pebbles, cobbles, and boulders in all areas. The thickness (where it has been determined) is generally less than 25 feet. No noticeable differences were noted within the till in auger holes or road cuts, so it has been mapped as one unit although it may represent different advances of glacial ice. Since the relationship to previously named tills is in doubt, no name has been attached to this map unit.

One auger hole (McK-15A; 152-96-7 aa) penetrated two tills. A yellowish-brown till was present to a depth of 14 feet, below which occurred a saturated zone (presumably sand) to a depth of 18 feet. A hard zone was penetrated at 18 feet, but samples were not retrieved until the augers were pulled after drilling to 34 feet. The lower augers were coated with medium-dark-gray till that is similar in color and drilling characteristics to buried tills in McLean and Williams Counties. Exposures of light-gray to olive-brownish-gray, jointed till below yellowish-brown surface till are present at two localities. One is poorly exposed along the north bank of a draw in a pasture in NEsec 3, T151N, R100W (fig. 17). The other locality is a bank along Lake Sakakawea in sec 33, T153N, R96W (fig. 18). This lower till is probably equivalent to the light-gray, jointed till of the Medicine Hill Formation of Mercer County.

Sand and gravel are most common in the subsurface of preglacial or diversion channel valleys. Some ice-contact deposits also occur along these valleys. This facies has a mantle of colluvium so it is not a prominent map unit (pl. 1). The segment of the Little Missouri River channel from the Hay Creek junction eastward has as much as 175 feet of fill, which is primarily sand and gravel except for near-surface colluvial silt and clay along the flood plain. The Bennie Pierre Creek, Hay Creek, and adjacent southwestern channels (fig. 19) generally have about 30 to 70 feet of sand and gravel at the base of the fill in most test holes. Test holes in the preglacial channel in the Timber Creek area have as much as 225 feet of predominantly sand and gravel fill. Test holes in the Tobacco Garden Creek valley show variable thicknesses of sand and gravel at the base of the fill with thicker sections to the north.

The preglacial valleys were sites of meltwater lakes when the ice began to melt back from this area. Where these lakes were present for some time and subsequent erosion has not removed the sediment, some exposures of silt, sand, and gravel are found. The best exposures are in the bluffs along Lake Sakakawea. Silt and sand beds exposed in sec 36, T152N, R94W and secs 30, 31, T152N, R93W were deposited in what has been referred to as Lake Crow Flies High (Clayton and others, 1980, p. 25). Extensive sand in the bluffs west of Tobacco Garden Creek in secs 33, 34, T154N, R97W were probably deposited at about the same time in a proglacial lake extending into the

Tobacco Garden Creek valley. These proglacial lake deposits have a mantle of colluvial silt and clay so they are not shown as map units (pl. 1).

The silt and clay facies of the Coleharbor Group is most common as subsurface valley fill. Thick accumulations of lake clays are found in the southwestern diversion channels as well as thinner accumulations in other areas of this county. Thickness variations are difficult to determine since the contact with the overlying colluvial silt and clay is obscure unless some intervening beds of sand are present.

A small flat area in secs 4, 5, 8, and 9, T152N, R96W has silt and clay deposited in a temporary lake as the last ice melted in that area. An auger hole (McK-14, SWSW 4-152-96) was drilled to a depth of 27 feet in this area. It penetrated clay with some silt and sand grains to a depth of 21 feet and the lower augers had gravelly clay on them when they were pulled from the hole.

Alluvium-Colluvium

This map unit consists of recent sediment along current drainages. The Yellowstone and Little Missouri Rivers have alluvial silt, sand, and gravel terrace deposits along their flood plains. Similar deposits along the Missouri River are now submerged beneath Lake Sakakawea except for a few narrow remnants in some areas (fig. 20). Current streams flowing in preglacial valleys, Redwing, Tobacco Garden, Timber, and Charbonneau Creeks, are underfit streams, which cannot transport the slope wash from adjacent uplands, so these areas have colluvial silt and clay at the surface. Bennie Pierre Creek and Hay Creek are also flowing in valleys cut by glacially diverted drainage and currently are sites of deposition of colluvial silt and clay. There are also some smaller southeastward-trending valleys which may have served as meltwater channels which contain intermittent streams and are sites of deposition of slope wash. The short tributary streams in the badlands are also sites of deposition as erosion of the badlands slopes exceeds the capacity of these intermittent streams.

ECONOMIC GEOLOGY

Petroleum

Oil was discovered in McKenzie County shortly after the initial discovery in North Dakota. Development along the Nesson Anticline in the northeastern part of the county propelled McKenzie County into second place behind Williams County as the leading producing county. Subsequent development led to

Figure 20. View looking west at terraces of Missouri River in sec 29, T154N, R98W.

short periods as the leading producing county, and currently it has recently overtaken Billings County to become the leading county once again. McKenzie County has also taken the lead in cumulative production. McKenzie County has accounted for about 25 percent of the total oil production to date in the state. The position of the county in the deepest part of the basin with its greater thickness of sedimentary strata leads to the conclusion that this county will retain its rank as the leading oil producing county.

Lignite

Currently no lignite is being mined in McKenzie County and only small-scale operations were present in the past. The last active mine closed in 1968 after producing 312 tons that year. The peak year for production was 1943 when reported production was 8,560 tons. The peak year for coal mine licenses was 1939 when 14 mines reported production of 7,561 tons.

Brant (1953, table 1) estimated lignite resources of McKenzie County in beds at least 2½ feet thick as about 32.2 billion tons. This estimate was based on information available from surface studies and projections through the subsurface. Beds less than 5 feet thick accounted for 26.3 billion tons, while only 350 million tons was credited to beds exceeding a thickness of 10 feet.

Subsurface information now available from test holes for lignite evaluation and gamma-ray logs of oil exploration test holes provides a means for revision of the resource assessment. Test holes penetrating the complete Fort Union section generally have 3 to 6 individual lignite beds or splits with a thickness of 3 or more feet. The aggregate thickness and number of beds present at each locality (fig. 21) gives an average thickness of 30 feet with a range of 5 to 75 feet of lignite across the county. This represents a resource of about 90 billion tons in beds at least 3 feet thick in McKenzie County.

There are 5- to 6-foot-thick lignite beds present near the surface in portions of the northeastern part of the county, and a 10-foot-thick bed was noted at one locality near Johnson Corner (Spencer, 1978). These beds are present at considerable depth in the Blue Buttes area, but in other areas they are present at less than a 10 to 1 stripping ratio. They represent strippable deposits and were utilized for small-scale operations when there were local markets. They are not very attractive for large-scale development, however, since the topography of the area limits the areal extent of each deposit to relatively small quantities of strippable reserves.

The south and western parts of the county also have lignite beds which are 5 to 14 feet thick and at strippable depths in some areas (Spencer, 1978). The topography also limits the areal extent of these deposits, and the lack of water supplies is a further deterrent to development in those areas. The northwestern part of the county generally lacks lignite beds exceeding 5 feet thick near the surface. Since thicker beds are present under more favorable mining conditions elsewhere in North Dakota, and those resources far exceed current markets, it is not likely that this county will see major lignite mining in the near future.

The thick lignite bed in the lower part of the Tongue River Formation is a major resource (fig. 11). It will not be of economic interest, because of its depth of 300 to more than 800 feet, until in situ methods of development are feasible. However, in the area where this bed is more than 40 feet thick, it represents a deposit of about 3.2 billion tons; and at least an additional 7 billion tons are present in the area where the split beds have a thickness of 20 or more feet. The bed, which exceeds 20 feet in thickness in northwestern McKenzie County, is also present at depths of 500 to 800 feet. In the area where it exceeds 20 feet it represents an additional resource of about 1 billion tons.

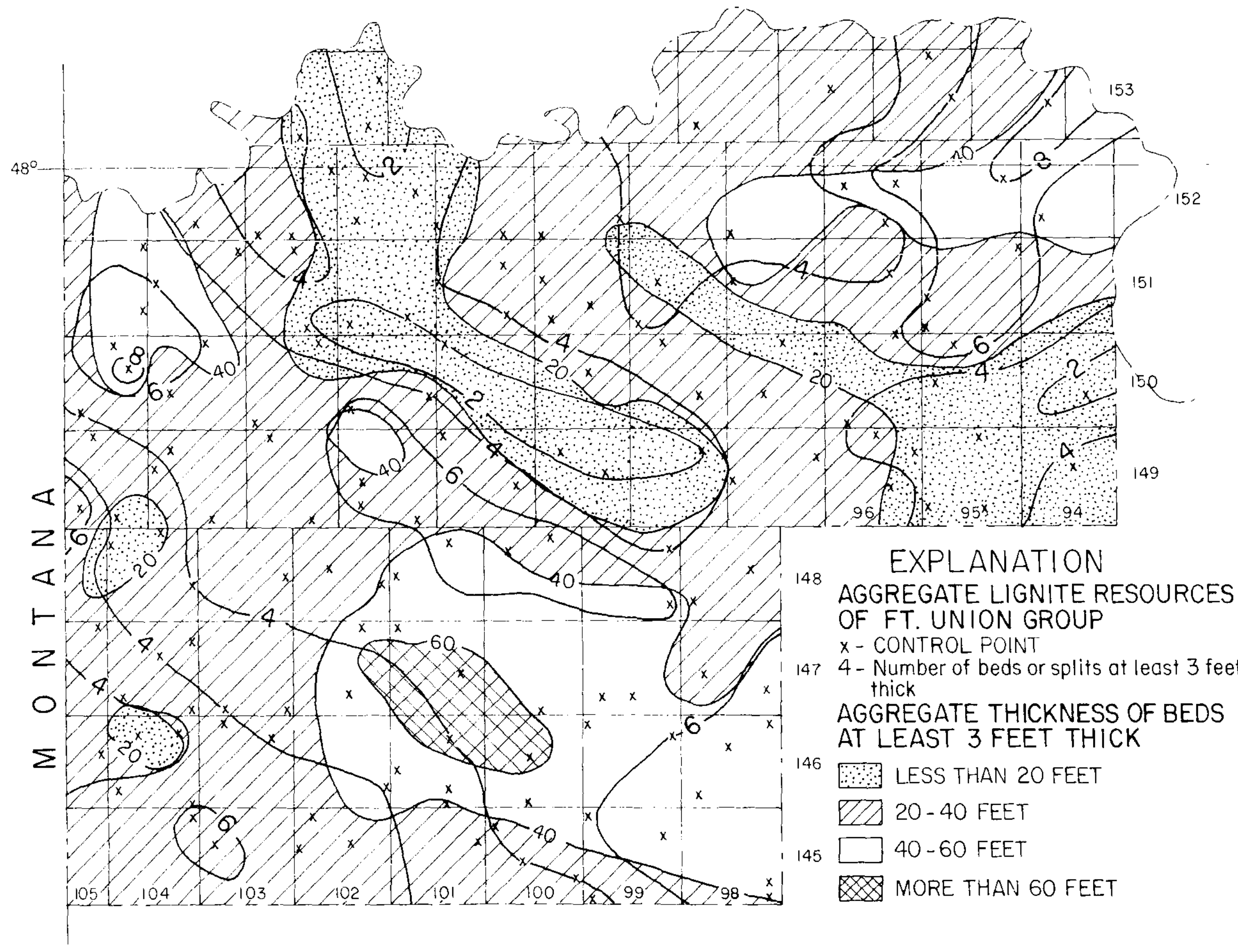


Figure 21. Aggregate lignite resources of Fort Union Group in McKenzie County.

Sand and Gravel

The sand and gravel deposits of McKenzie County consist of the Wiota, or western gravels, and the glacial deposits. The most widespread and utilized are the western gravels, which are present along preglacial drainages where they are present on upland surfaces. Glacial sand and gravel is present near the surface in a few places where glacial ice occupied pre-existing valleys. "Scoria," the reddish-colored baked sediment formed where lignite beds have burned, is abundant in areas where Fort Union strata are present near the surface. "Scoria" is extensively used as a gravel substitute for road maintenance in areas where glacial gravels are absent and western gravels scarce.

Nitrogen

The Broom Creek Formation contains nitrogen gas in some areas of the state including areas along the Nesson Anticline in northeastern McKenzie County. It is present at pressures which have caused drilling problems in oil exploration in that area. Its primary value lies as a source of gas for oil field secondary recovery operations. Injection of nitrogen from 1967 through 1976 increased the ultimate recovery from the Clear Creek Madison reservoir.

Salt

Salt beds in the form of halite are present as 10 separate beds in the Spearfish, Opeche, Madison, and Prairie Formations. These beds account for as much as 750 feet of cumulative thicknesses with the thickest beds in the Prairie and Madison "A" and "F" beds. These beds are relatively deep. Since salt is such a common mineral, these beds have little value as salt, but they might be utilized as underground storage sites through solution-mining processes. Potassium salts also occur within the Prairie Formation. These potash beds may have some economic interest, but they are at greater depth and appear to be of lesser quality than potash beds in other areas of the basin.

REFERENCES

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geological Survey Professional Paper 174, 133 p.

Bauer, C. M., and Herald, F. A., 1921, Lignite in the western part of the Fort Berthold Indian Reservation, south of the Missouri River, North Dakota: U.S. Geological Survey Bulletin 726-D, p. 109-172.

Benson, W. E., 1949, Golden Valley Formation of North Dakota (abstract): Geological Society of America Bulletin, v. 60, p. 1873-1874.

Benson, W. E., and Laird, W. M., 1947, Eocene of North Dakota (abstract): Geological Society of America Bulletin, v. 58, p. 1166-1167.

Bluemle, J. P., 1971, Geology of McLean County, North Dakota: North Dakota Geological Survey Bulletin 60, North Dakota Water Commission County Studies 19, Part I, 65 p.

Bluemle, J. P., 1972, Pleistocene drainage development in North Dakota: Geological Society of America Bulletin, v. 83, p. 2189-2194.

Brant, Russell, 1953, Lignite resources of North Dakota: U.S. Geological Survey Circular 226, p. 2, 54-57.

Brostuen, E. A., 1977, Physical data for land-use planning, Divide, McKenzie, and Williams Counties, North Dakota: North Dakota Geological Survey Report of Investigation 62, 17 p.

Brown, Roland W., 1939, Fossil plants from the Colgate Member of the Fox Hills Sandstone and adjacent strata: U.S. Geological Survey Professional Papers 189-I, p. 239-275.

Carlson, C. G., 1973, Geology of Mercer and Oliver Counties, North Dakota: North Dakota Geological Survey Bulletin 56 and North Dakota Water Commission County Ground Water Studies 15, Part I, 72 p.

________, 1979, Geology of Adams and Bowman Counties, North Dakota: North Dakota Geological Survey Bulletin 65 and North Dakota Water Commission County Ground Water Studies 22, Part I, 29 p.

________, 1982, Geology of Grant and Sioux Counties, North Dakota: North Dakota Geological Survey Bulletin 67 and North Dakota Water Commission County Groundwater Studies 24, Part I, 32 p.

________, 1983, Geology of Morton County, North Dakota: North Dakota Geological Survey Bulletin 72 and North Dakota Water Commission County Groundwater Studies 27, Part I, 37 p.

________, 1983, Geology of Billings, Golden Valley and Slope Counties, North Dakota: North Dakota Geological Survey Bulletin 76 and North Dakota Water Commission County Groundwater Studies 29, Part I, 40 p.

Carlson, C. G., and Anderson, S. B., 1966, Sedimentary and tectonic history of North Dakota part of Williston basin: North Dakota Geological Survey Miscellaneous Series 28 (reprint from American Association of Petroleum Geologists Bulletin, v. 49), p. 1833-1846.

Clayton, Lee, 1966, Notes on Pleistocene stratigraphy of North Dakota: North Dakota Geological Survey Report of Investigation 44, 25 p.

Clayton, Lee, and others, 1977, The Slope (Paleocene) and Bullion Creek (Paleocene) Formations of North Dakota: North Dakota Geological Survey Report of Investigation 59, 14 p.

Clayton, Lee, with assistance of others, 1980, Geologic Map of North Dakota: U.S. Geological Survey, Denver, Colorado.

Clayton, Lee, Moran, S. R., and Bluemle, J. P., 1980, Explanatory text to accompany the geologic map of North Dakota: North Dakota Geological Survey Report of Investigation 69, 93 p.

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

Croft, M. G., 1985, Groundwater data for McKenzie County, North Dakota: North Dakota Geological Survey Bulletin 80 and North Dakota Water Commission County Groundwater Studies 37, Part II, 455 p.

Cvancara, A. M., 1976a, Geology of the Fox Hills Formation (Late Cretaceous) in the Williston basin of North Dakota, with reference to uranium potential: North Dakota Geological Survey Report of Investigation 55, 16 p.

Cvancara, A. M., 1976b, Geology of the Cannonball Formation (Paleocene) in the Williston basin, with reference to uranium potential: North Dakota Geological Survey Report of Investigation 57, 22 p.

Dingman, R. J., and Gordon, E. D., 1954, Geology and ground-water resources of Fort Berthold Indian Reservation, North Dakota: U.S. Geological Survey Water-Supply Paper 1259, 115 p.

Dorf, Erling, 1940, Relationship between floras of the type Lance and Fort Union Formations: Geological Society of America Bulletin, v. 51, p. 213-236.

Feldmann, Rodney M., 1972, Stratigraphy and paleoecology of the Fox Hills Formation (Upper Cretaceous) of North Dakota: North Dakota Geological Survey Bulletin 61, 65 p.

Fisher, S. P., Jr., 1953, Geology of west-central McKenzie County, North Dakota: North Dakota Geological Survey Report of Investigation 11, 2 sheets.

________, 1954, Structural geology of the Skaar-Trotters area, McKenzie and Golden Valley Counties, North Dakota: North Dakota Geological Survey Report of Investigation 15.

Freers, T. F., 1970, Geology and ground water resources of Williams County, North Dakota: North Dakota Geological Survey Bulletin 48 and North Dakota Water Commission County Groundwater Studies 9, Part I, 55 p.

Frye, Charles I., 1969, Stratigraphy of the Hell Creek Formation in North Dakota: North Dakota Geological Survey Bulletin 54, 65 p.

Fulton, C. S., 1976, The glacial geology of McKenzie County, North Dakota: University of North Dakota M.S. thesis, 100 p.

Goldich, S. S., and others, 1966, Geochronology of the midcontinent region, United States - Part 2, northern area: Journal of Geophysical Research, v. 71, p. 5389-5408.

Hanson, B. M., 1955, Geology of the Elkhorn ranch area, Billings and Golden Valley Counties, North Dakota: North Dakota Geological Survey Report of Investigation 18.

Hickey, L. J., 1977, Stratigraphy and Paleobotany of the Golden Valley Formation (Early Tertiary) of western North Dakota: Geological Society of America Memoir 150, 181 p., 55 pls.

Howard, A. D., 1960, Cenozoic history of northeastern Montana and northwestern North Dakota: U.S. Geological Survey Professional Paper 326, 107 p.

Jacob, Arthur F., 1976, Geology of the upper part of the Fort Union Group (Paleocene) Williston basin, with reference to uranium: North Dakota Geological Survey Report of Investigation 58, 49 p.

Leonard, A. G., 1908, The geology of southwestern North Dakota, with special reference to the coal. North Dakota Geological Survey Fifth Biennial Report, p. 27-114.

Leonard, Arthur G., 1911, The Cretaceous and Tertiary Formations of western North Dakota and eastern Montana: Journal of Geology, v. 19, p. 507-547.

________, 1916a, The Pleistocene drainage changes in western North Dakota: Geological Society of America Bulletin, v. 27, p. 295-304.

________, 1916b, The pre-Wisconsinan drift of North Dakota: Journal of Geology, v. 24, p. 521-532.

Leonard, Arthur G., 1925, McKenzie County, in Leonard, Arthur G., Babcock, E. J., and Dove, L. P., The lignite deposits of North Dakota: North Dakota Geological Survey Bulletin 4, p. 95-111.

Lloyd, E. R., 1914, The Cannonball River Lignite Field, North Dakota: U.S. Geological Survey Bulletin 541-G, p. 243-291.

Lloyd, E. R., and Hares, C. J., 1915, The Cannonball marine member of the Lance Formation of North Dakota and South Dakota and its bearing on the Lance-Laramie problem: Journal of Geology, v. 23, p. 523-547.

Meek, F. B., and Hayden, F. V., 1862, Description of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska by the Exploring Expedition under the command of Capt. Wm. F. Reynolds, U.S. Top. Engrs: Philadelphia Academy of Natural Science Proceedings, v. 13, p. 415-447.

Meldahl, E. G., 1956, The geology of the Grassy Butte area, McKenzie County, North Dakota: North Dakota Geological Survey Report of Investigation 26, 1 sheet.

Moore, Walter L., 1976, The stratigraphy and environment of deposition of the Cretaceous Hell Creek Formation (reconnaissance) and Paleocene Ludlow Formation (detailed), southwestern North Dakota: North Dakota Geological Survey Report of Investigation 56, 40 p.

Moran, S. R., and others, 1976, Quaternary stratigraphy and history of North Dakota, southern Manitoba, and northwestern Minnesota, in Mahaney, W. C. (editor), Quaternary Stratigraphy of North America: Stroudsberg, Pennsylvania, Dowden, Hutchinson and Ross, Inc., p. 133-158.

Nevin, Charles, 1946, The Keene Dome, northeast McKenzie County, North Dakota: North Dakota Geological Survey Bulletin 21, Part I, p. 1-10.

North Dakota Coal Mine Inspectors Reports, 1923-1969.

Rice, Dudley D., 1977, Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains, North Dakota and South Dakota: U.S. Geological Survey Oil and Gas Investigations Chart OC-72, sheet 3.

Royse, C. F., Jr., 1967, Tongue River-Sentinel Butte contact in western North Dakota: North Dakota Geological Survey Report of Investigation 45, 53 p.

Spencer, J. M., 1978, Geophysical and lithologic logs for 1977 coal drilling in McKenzie County, North Dakota: U.S. Geological Survey Open-File Report 78-451.

Stephens, E. V., 1970, Geologic map of the Heart Butte NW quadrangle, Morton and Grant Counties, North Dakota: U.S. Geological Survey Coal Investigations Map C-52.

Thom, William T., Jr., and Dobbin, C. E., 1924, The stratigraphy of Cretaceous-Eocene beds in eastern Montana and the Dakotas: Geological Society of America Bulletin, v. 35, p. 481-506.

Ulmer, J. H., and Sackreiter, D. K., 1973, Late Cenozoic stratigraphy of the Lake Sakakawea bluffs north and west of Riverdale, North Dakota: North Dakota Geological Survey Report of Investigation 51.

U.S. Geological Survey, North Dakota Geological Survey, 1979, Lignite drilling during 1978 in western North Dakota: Adams, Billings, Bowman, Burke, Golden Valley, Hettinger, McKenzie and Slope Counties: Open-File Report 79-1051, 41{ p.

Waage, K. M., 1968, The type Fox Hills Formation, Cretaceous (Maestrichtian), South Dakota: Peabody Museum of Natura History Bulletin 27, 175 p.

Warren, G. K., 1869, A report of activities during the fisca year beginning July 1, 1867, and ending June 30, 1868 App. G, Annual Report, Chief of Engineers, U.S. Army for 1868, p. 299-385.

Wilder, Frank A., 1904, The lignite on the Missouri, Heart an(Cannonball Rivers and its relation to irrigation: Nortl Dakota Geological Survey Third Biennial Report, p. 9-40

APPENDIX A

AUGER HOLE DATA

McK-1 NWNEsec 14, T150N, R98W

Lithology	Depth
Silt, grayish-brown	0- 5
Clay, dark-brown, silty	5- 7
Clay, medium-gray, silty, saturated	7-12
Clay, medium-gray to medium-dark-gray, silty, poor returns	12-22
Sand, gray, poor returns	22-27
Clay, medium-dark-gray, silty, with pebbles	27-32
Sand, greenish-gray, poor returns	32-42
Clay, medium-dark-gray	42-47

McK-2 SENEsec 23, T151N, R97W

Lithology	Depth
Clay, medium-gray, silty, scoria pebbles	0- 2
Clay, brownish-gray, silty, very moist	2- 7
Clay, brownish-gray, saturated	7-27
Clay, medium-gray to brownish-gray, saturated	27-37
No returns	37-47

McK-3 SWNWNWsec 29, T151N, R96W

Lithology	Depth
Clay, brownish-gray to medium-gray, silty	0- 2
Clay, brownish-gray, silty, scoria pebbles and other pebbles	2-12
Clay, brownish-gray, saturated	12-17
Poor returns of clay to total depth	17-47

McK-4 SWSEsec 5, T151N, R96W

Lithology	Depth
Clay, brownish-gray, silty, pebbly	0- 7
Clay, brownish-gray, saturated	7-22
Poor returns; drilled harder at 22; no samples on augers when we pulled out	22-37

McK-5 NESEsec 24, T151N, R96W

Lithology	Depth
Clay, brownish-gray, silty	0- 7

Clay, brownish-gray, silty; some pebbles	7-12
Clay, brownish-gray, silty	12-27
Clay, as above, very moist	27-32
No returns	32-42
Clay, yellowish-brown	42-52
No returns	52-72
Sand, blue on 1 foot of lignite on medium-gray clay on lower 2 augers when we pulled out - bedrock at about 47	

McK-6 SESESWsec 18, T150N, R95W

Lithology	Depth
Silt, yellowish-brown to brownish-gray; a few pebbles	0- 7
Clay, brownish-gray, silty, moist	7-32
No returns; drilled harder at 42	32-47

McK-7 NWNWsec 10, T152N, R96W

Lithology	Depth
Till, yellowish-brown, sandy	0- 7
Till, olive-gray	7-14
Silt, yellowish-brown, clayey	14-16
Sand, yellowish-brown	16-20
Bedrock at 14	

McK-8 SESWsec 36, T153N, R96W

Lithology	Depth
Till, light-yellowish-brown to yellowish-brown, silty, pebbly; boulder at 12	0-12
8A-60' east of McK-8	
Till, yellowish-brown, as above	0-12
Till, yellowish-brown to olive-brown, silty, pebbly; boulder at 20	12-20

McK-9 NENWsec 4, T152N, R95W

Lithology	Depth
Till, yellowish-brown	0- 3
Lignite	3- 5
Clay, light-yellowish-brown	5- 7
Bedrock at 3	

McK-10 SWSWsec 21, T153N, R94W

Lithology	Depth
Till, light-yellowish-brown, powdery	0- 2
Till, yellowish-brown, silty, pebbly; many carbonate pebbles 12-17	2-22
Silt, light-gray	22-27
Bedrock at 22	

McK-11 NENEsec 36, T153N, R96W

Lithology	Depth
Till, yellowish-brown, powdery	0- 4
Till, yellowish-brown, silty, pebbly, boulder at 10	4-10

McK-14 SESEsec 5, T152N, R96W

Lithology	Depth
Clay, dark-gray, silty	0- 5
Clay, olive-gray	5- 7
Clay, olive-gray and yellowish-brown with a few sand grains	7-14
Clay, yellowish-brown, silty	14-21
Poor returns; yellowish-brown gravelly clays on augers	21-27

McK-15 NENEsec 7, T152N, R96W

Lithology	Depth
Till, yellowish-brown to olive-gray, many carbonate pebbles	0-14
No returns; drilled hard at 18; till, medium-dark-gray on augers when we pulled out	14-34

McK-17 NWSWsec 22, T151N, R97W

Lithology	Depth
Sand, yellowish-brown	0- 4
Gravel and sand	4- 8
Clay, yellowish-brown, silty, carbonate and scoria pebbles	8-16
Clay, medium-gray, silty, scattered carbonate and scoria pebbles	16-24
Lignite, weathered	24-26
Clay, greenish-gray	26-30
Silt, bluish-gray, sandy	30-34
Clay, medium-gray	34-36
Bedrock at 24	

McK-19 NWNWsec 5, T151N, R96W

Lithology	Depth
Silt and clay, silty, yellowish-brown	0- 5
Gravel and gravelly sand, yellowish-brown	5- 9
Clay, medium-gray, scattered pebbles and sand	9-19
Clay, medium-gray	19-24
Clay, medium-gray, gravelly	24-29

McK-20 NENWsec 22, T150N, R97W

Lithology	Depth
Clay, brownish-gray, silty	0- 4
Clay, yellowish-brown, a few pebbles	4- 9
Clay, yellowish-brown	9-14
No returns; drilled harder at 31	14-38

McK-21 SESWsec 17, T150N, R97W

Lithology	Depth
Clay, light-brownish-gray, silty	0- 4
Clay, light-olive-gray; a few pebbles	4- 9
Clay, olive-gray to brownish-gray, silty	9-21
Gravel and gravelly sand, saturated	21-29
Clay, dark- to medium-gray, a few pebbles	29-34
No returns; drilled easy to 39; drilled hard at 49	34-49

McK-22 SESWsec 32, T151N, R100W

Lithology	Depth
Sand, light-brown, silty	0- 7
Clay, light-brown, silty, sandy, very moist	7-10
Gravelly, sandy clay, yellowish-brown, scoria and other pebbles	10-14
Poor returns; gravel	14-19
No returns	19-24
Clay, dark-gray, gravelly	24-29
No returns; clay and silt, medium-light-gray on augers when we pulled out; bedrock at 29(?)	29-44

McK-23 NWNWsec 19, T151N, R101W

Lithology	Depth
Silt, medium-brown to light-gray with a few pebbles	0- 4
Till, brownish-gray, sandy, slightly cohesive, some lignite and scoria pebbles	4-14

Sand, yellowish-brown	14-19
Bedrock at 14	

McK-24 SWSEsec 9, T151N, R102W

Lithology	Depth
Till, olive-gray	0- 4
Till, brownish-gray	4-16
Lignite, weathered	16-17
Clay, yellowish-brown	17-19
Silt and clay, yellowish-brown and light-brownish-gray	19-24
Bedrock at 16	

McK-25 SESEsec 32, T152N, R102W

Lithology	Depth
Till, light-yellowish-brown, silty	0- 4
Till, yellowish-brown	4- 7
Clay, yellowish-brown	7- 9
Bedrock at 7	

McK-26 SESEsec 22, T152N, R102W

Lithology	Depth
Till, light-brownish-gray, silty	0- 4
Till, brownish-gray, sandy	4- 8
Sand, yellowish-brown, fine-grained	8-14
Silt and clay, yellowish-brown	14-19
Bedrock at 8	