GEOLOGY

of

DUNN COUNTY

by
Edward C. Murphy
North Dakota Geological Survey
Bismarck, North Dakota
2001

BULLETIN 68—PART I
North Dakota Geological Survey
John P. Bluemle, State Geologist

COUNTY GROUNDWATER STUDIES 25—PART I
North Dakota State Water Commission
Dale Frink, Acting State Engineer

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ABSTRACT

Dunn County, located in west-central North Dakota near the center of the Williston Basin, is underlain by 13,000 to 16,000 feet of Paleozoic, Mesozoic, and Cenozoic rocks. These beds dip slightly to the north-northwest into the center of the basin. The Sentinel Butte Formation is present at the surface of approximately 90% of the county and is the oldest strata exposed in the county. The Golden Valley Formation is present on topographically high, isolated ridges and hill tops in the county. Tuffaceous siltstones and carbonates of the Arikaree Formation cap the Killdeer Mountains.

Scattered erratics mark the southern limit of glaciation in southern Dunn County. Most of the glacial deposits in the north and central portion of the county have been eroded resulting in isolated, thin to moderately thick till deposits in upland areas. A system of proglacial channels is present in the central and southern parts of the county. These channels may contain several hundred feet of channel-fill deposits.

Approximately 600,000 years ago glaciers diverted the north-flowing ancestral Little Missouri River to the east through northern Dunn County. The Little Missouri and its tributaries rapidly incised into the soft strata creating rugged badlands topography in this portion of the county. The strata exposed in steep, badlands topography are very susceptible to slope failure.

Although thick beds of coal are present in the county, no large-scale mining has ever taken place. Oil and gas have been produced from the county since 1959. Clinker and the caprock in the Killdeer Mountains have been used for road metal in the county.

ACKNOWLEDGEMENTS

Jim Cron, Eric Graney, and Dave Lechner assisted with the drilling of the testholes in the county. Special thanks to Don Rufeldt and the Dickinson Office of the U.S. Bureau of Land Management for loan of their set of color aerial photographs of the county.

INTRODUCTION

Purpose of Study

This report describes the surface and the shallow subsurface geology for the 2,081-square-mile area of Dunn County, North Dakota. The report is one of a series on geology and groundwater prepared by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission and the United States Geological Survey. The primary purpose of these studies is: 1) to provide a geologic map of the county, 2) to locate and define aquifers, and 3) to interpret the geologic history of the area. A general assessment of the county's natural resources is also included.

Regional Setting

Dunn County is situated in the west-central portion of North Dakota and is bounded by the following counties: Mountrail on the north, McKenzie on the north and west, Billings on the west, Stark on the south, and Mercer and McLean on the east (Figure 1). Dunn County was organized between 1904 and 1906 and incorporated areas previously part of Stark and Mercer counties. Approximately 440 square miles of land in the northeastern corner of the county is included within the Fort Berthold Indian Reservation.

Dunn County is situated on the Missouri Slope Uplands of the Great Plains Province. The eastern portion of Dunn County shows evidence of glaciation; the western third does not. The Missouri Slope Uplands are characterized by gently rolling topography interrupted by isolated buttes. In the northern part of the county the Missouri Slope is interrupted by the Little Missouri River Badlands (Figures 1 and 2). These rugged badlands began forming in this area approximately 600,000 years ago when a glacier diverted the north-flowing Little Missouri River to the east near the west edge of the North Unit of Theodore Roosevelt National Park. This new route was shorter and steeper than the old one which caused the river to erode easily downward through the soft layers of sedimentary rock. Erosion has averaged approximately one inch per 100 years (Murphy et al., 1994). Since its diversion, the Little Missouri River has eroded 500 to 600 feet below the level of the surrounding Missouri Plateau, creating a 3-to 5-mile wide stretch of badlands on either side of the river.

Dunn County is drained by several creeks and rivers: the Missouri and Little Missouri rivers drain the northern part of the county; Spring Creek drains the central part; and the Little Knife, Knife and Green rivers form the major drainage systems in the southern part of the county.

The Killdeer Mountains (composed of two large mesas) are a major geographic feature within the county. The mesas rise approximately 700 feet above the surrounding topography and the highest point in the county is located on South Killdeer Mountain (3,281 feet at T.146N., R.96W., nenw sec. 29). The Killdeer Mountains are visible on the skyline from nearly every part of Dunn County. The lowest point in the county, approximately 1,838 feet (dependent upon water levels in Lake Sakakawea), occurs along the valley of the Missouri River in northeastern Dunn County.

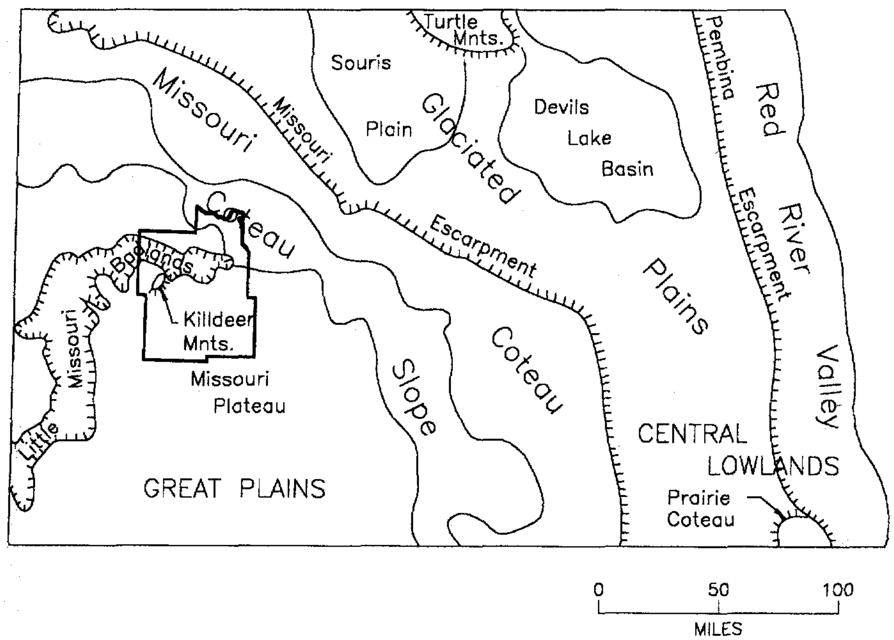

Figure 1. Location map showing area of study and physiographic subdivisions (Bluemle, 1991).

The Russian Springs Escarpment is a northeast-facing feature situated in the southwest corner of Dunn County. The southeast-trending escarpment is approximately 100 feet high and marks the southern edge of erosion within the Knife River basin. State Highway 22 crosses the escarpment approximately 14 miles north of Dickinson (T.142N., R.96W., north line of sec. 36).

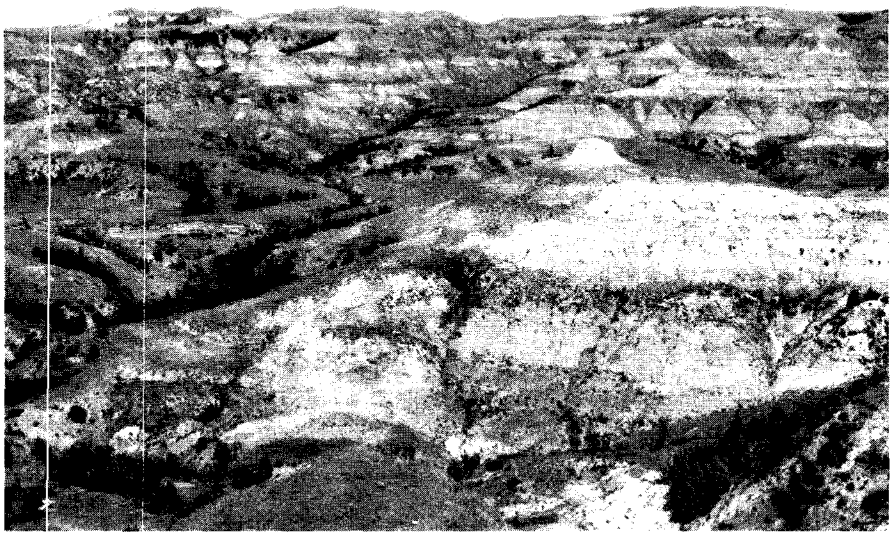

Figure 2. Badlands topography developed in the Sentinel Butte and Golden Valley formations (the latter at the top of the ridge in the background). Photograph taken near Slater Bay in north-central Dunn County (T.146N., R.93W., sec. 2).

Method of Study

I initially conducted a field reconnaissance of the county to determine outcrop accessibility. During the course of mapping, I traversed all county roads, as well as all passable section line roads and farm trails. I visited all areas of extensive or important outcrops in the field. I visually traced stratigraphic contacts both in the field and on black and white and color infrared aerial photographs of the county. Transects were also flown across the county in a small plane to obtain oblique photographs of specific features. I used changes in relief, vegetation, and other variations in surface expression to trace stratigraphic contacts buried beneath the surface. A hand auger and entrenching tool were routinely used to excavate below the soil horizon to determine the local geology in areas of limited outcrop. In addition, 113 testholes, ranging in depth from 10 to 80 feet, were augered throughout all but the northern portion of the county. Most of the field mapping was done during the 1983, 1985, and 1986 field seasons.

Previous Work

Wood (1904) provided a detailed description of many of the topographic features in Dunn County and also included a description of the position and thickness of many of the lignite beds in the area. The first geologic map of the Dunn County surface was Clapp and Babcock's (1906) map of the "high grade Tertiary clays." Clapp and Babcock analyzed these deposits for their suitability in ceramic production. Several additional studies involving the suitability of claystones in and around Dunn County for ceramic production and alumina content were undertaken over the course of the next 60 years (Budge, 1932; Manz, 1953, 1968). In the 1940s, Clapp and Babcock's "high grade Tertiary clays" were placed in the "unnamed member of the Wasatch Formation" (Seager et al., 1942; Laird, 1944). Later, these clays were formally recognized as the lower part of a separate stratigraphic unit named the Golden Valley Formation (Benson and Laird, 1947; Benson, 1949). Benson and Laird determined that the Golden Valley Formation was Eocene in age. Hickey (1977) conducted a comprehensive study of the stratigraphy and paleobotany of the Golden Valley Formation in an area that included Dunn County. Hickey (1977) proposed two members for the Golden Valley; the Bear Den Member and the overlying Camels Butte Member. The Bear Den Member is the same stratigraphic unit referred to as the "high grade Tertiary clays" by Clapp and Babcock (1906). Additional studies of the mineralogy and origin of the Bear Den Member were done by Freas (1962), Karner and others (1978), and Prichard (1980).

A.G. Leonard, North Dakota State Geologist, spent portions of several field seasons from 1911-1916 in Dunn County noting the lignite resources. In the early 1900s, several studies were undertaken by the United States Geological Survey to determine the lignite resources within the Fort Berthold Indian Reservation (Smith, 1909; Pishel, 1912; and Bauer and Herald, 1921). In the 1950s and 1960s, emphasis was also placed on the identification of uraniferous sandstones and lignites in western North Dakota (Denson and Gill, 1965).

T.T. Quirke (1913, 1918), a graduate student and field assistant to Leonard, was the first to do a comprehensive geologic study of the Killdeer Mountains. Quirke placed the caprock of the mountains in the White River Group. Subsequent workers identified the caprock as either White River or Arikaree strata (Leonard, 1922; Powers, 1945; Clayton, 1970; Denson and Gill, 1965; Stone, 1973; Delimata, 1975; and Murphy et al., 1993).

Only a few detailed geologic maps of Dunn County or parts of the county have been done. Dingman and Gordon (1954) mapped the surface geology of the Fort Berthold Indian Reservation at a scale of 1:100,000. Clayton (1970) produced a countywide geologic map at a scale of 1:125,000. Clayton's map was titled "preliminary" because he was not able to spend an adequate amount of time in the field and relied heavily on interpretations of aerial photographs to map the geology. In spite of the title, this map has proven to be very accurate. The geology of Dunn County is also accurately portrayed on Clayton and others (1980) 1:500,000-scale geologic map of the state.

Two coal-correlation studies were undertaken in portions of Dunn County by the North Dakota Geological Survey in the late 1970s (Moran et al., 1978; Groenewold et al., 1979). Both studies contain detailed cross-sections through east-central Dunn County.

SUBSURFACE STRATIGRAPHY

Precambrian

Only one well, the Wolberg No. 1 (T.141N., R.95W., sec. 18), penetrated Precambrian rocks in Dunn County. The total depth of the Wolberg well was 14,300 feet. Another Precambrian well was drilled just over the county line in the northeastern corner of Billings County. Heck (1988) estimated the top of the Precambrian crystalline rocks is between 11,000 and 13,400 feet below sea level in Dunn County.

Paleozoic

The Paleozoic rocks in North Dakota are predominantly carbonates, although rocks at both the beginning and end of this time period are primarily clastics. Approximately 7,500 feet of Paleozoic rocks underlie Dunn County. Most of the county's oil production comes from the Madison Group (Mississippian) and Red River Formation (Ordovician) (Figure 3).

The Deadwood Formation and the overlying Winnipeg Group represent the basal clastics of the Paleozoic rocks (Figure 3). These Upper Cambrian to Upper Ordovician sandstones and shales lie on the irregular surface of the Precambrian crystalline rocks. The Deadwood, the base of which is Cambrian in age, and Winnipeg (Ordovician) strata are 900 to 1,250 feet thick in Dunn County (Carlson and Thompson, 1987).

ERA	SYSTEM	FORMATION OR GROUP		THICKNESS (feet)	DOMINANT LITHOLOGY
CENOZOIC	QUATERNARY	alluvium, colluvium, and lacustrine		0- 40	Sand, Silt, Clay and Gravel
		COLEHARBOR		0- 250	Sand, Silt, Clay, Till and Gravel
	TERTIARY		ARIKAREE	0- 330	Tuffaceous Siltstone and Carbonate
			WHITE RIVER	0- 90	Conglomerate, Sand, Silt and Clay
			GOLDEN VALLEY	0- 300	Silt, Clay, Sand and Lignite
		FORT UNION GROUP	SENTINEL BUTTE	0- 550	Silt, Clay, Sand and Lignite
			TONGUE RIVER	0- 520	Silt, Clay, Sand and Lignite
			SLOPE	100	Silt Clay, Sand and Lignite
			CANNONBALL	100- 200	Mudstone and Sandstone
			LUDLOW	100	Silt, Clay, Sand and Lignite
MESOZOIC	CRETACEOUS	MONTANA GROUP	HELL CREEK	300	Clay, Sandstone and Shale
			FOX HILLS	200	Sandstone and Shale
			PIERRE	2,000-2,200	Shale
		COLORADO GROUP	NIOBRARA	170- 200	Shale, Calcareous
			CARLILE	350- 500	Shale
			GREENHORN	200- 250	Shale, Calcareous
			BELLE FOURCHE	240- 320	Shale
		DAKOTA GROUP	MOWRY	115- 200	Shale
			NEWCASTLE	0- 110	Sandstone
			SKULL CREEK	190- 325	Shale
			INYAN KARA	350- 420	Sandstone and Shale
	JURASSIC		SWIFT	400- 500	Mudstone
			RIERDON	50- 120	Shale and Sandstone
			PIPER	280- 370	Limestone, Shale and Anhydrite
	TRIASSIC		SPEARFISH	400- 550	Siltstone and Salt
PALEOZOIC	PERMIAN		MINNEKAHTA	35- 50	Limestone
			OPECHE	95- 350	Shale and Siltstone
	PENNSYLVANIAN	MINNE-LUSA GROUP	BROOM CREEK	110- 180	Sandstone and Dolomite
			AMSDEN	210- 400	Dolomite, Sandstone and Shale
			TYLER		Mudstone and Sandstone
	MISSISSIPPIAN		BIG SNOWY	200- 500	Shale, Sandstone and Limestone
			MADISON	1 350-2 000	Limestone and Anhydrite
			BAKKEN	0- 65	Shale and Siltstone
	DEVONIAN		THREE FORKS	0- 245	Shale , Siltstone and Dolomite
			BIRDBEAR	0- 90	Dolomite
			DUPEROW	190- 340	Interbedded Dolomite and Limestone
			SOURIS RIVER	50- 270	Interbedded Dolomite and Limestone
			DAWSON BAY	0- 80	Dolomite and Limestone
			PRAIRIE	0- 80	Limestone and Anhydrite
			WINNIPEGOSIS	0- 230	Limestone and Dolomite
	SILURIAN		INTERLAKE	250- 920	Dolomite
	ORDOVICIAN		STONEWALL	75- 115	Dolomite
			STONY MOUNTAIN	110- 155	Argillaceous Limestone
			RED RIVER	510- 660	Limestone and Dolomite
		WINNIPEG GROUP	ROUGHLOCK	35- 50	Calcareous Shale and Siltstone
			ICEBOX	65- 95	Shale
			BLACK ISLAND	25- 115	Sandstone
	CAMBRIAN		DEADWOOD	420- 950	Limestone, Shale and Sandstone
	PRECAMBRIAN ROCKS				

Figure 3. Stratigraphic column for Dunn County (modified from Carlson, 1983b).

Mesozoic

The rocks of Mesozoic age in North Dakota are primarily marine shales, but nonmarine rocks are present at the base (Inyan Kara Formation) and at the top (Hell Creek Formation) of this interval (Figure 3). In Dunn County, the Mesozoic rocks are approximately 5,400 feet thick (Carlson and Anderson, 1966). In North Dakota, the Cretaceous rocks are split into three stratigraphic groups: Dakota, Colorado, and Montana. The Dakota Group is likely the best known of the three because it is the horizon into which most of the water produced with oil-and-gas is injected/disposed into the subsurface and it is an important aquifer in other areas of the upper midwest.

Pierre Formation

The Pierre Formation consists of shales, siltstones and, to a lesser degree, sandstones that were deposited offshore in a large inland sea that covered the midcontinent during the late Cretaceous (Figure 3). The Pierre Formation was named by Meek and Hayden (1862) for exposures of thick Cretaceous shales near the site of old Fort Pierre in what is now South Dakota. The Pierre Formation is extensive and covers the following states: North and South Dakota, eastern Montana, eastern Wyoming, eastern Colorado, Nebraska, and Kansas. The Pierre Formation is approximately 2,000 feet thick in Dunn County and the top of the formation ranges from 200 to 500 feet above sea level (Carlson, 1982). The top of the Pierre Formation varies in depth from 2,900 feet below the surface in the Killdeer Mountains to 1,500 feet deep near the mouth of the Little Missouri River, in the northeast corner of Dunn County.

Fox Hills Formation

The Fox Hills Formation consists primarily of mudstones, siltstones, and sandstones that were deposited in a shore and nearshore environment of the Pierre sea (Figure 3). The Fox Hills Formation was named by Meek and Hayden (1862) for exposures along Fox Ridge in northern South Dakota. The Fox Hills contains four recognizable members in North Dakota. Three of the members consist primarily of interbedded siltstone and mudstone, but the upper member, the Colgate, is primarily sandstone and is an important aquifer throughout western North Dakota. The Fox Hills Formation is approximately 200 feet thick in Dunn County and the Colgate Member is generally 20 to 30 feet thick. The contact with the underlying Pierre Formation is gradational in outcrop in the southwestern corner of the state and appears on electric logs to be gradational in the subsurface in Dunn County. The contact between the Fox Hills and Pierre formations is one of the stratigraphically highest contacts that is easily discernable on electric logs.

Hell Creek Formation

The Hell Creek Formation consists of alternating beds of sandstone, siltstone, mudstone, claystone, and occasional lignite (Figure 3). The Hell Creek is the basal portion of a nonmarine clastic wedge that extends from the Rocky Mountains to central North Dakota. Hell Creek strata were deposited during late Cretaceous on or near a deltaic front adjacent to the Pierre sea. The Hell Creek Formation is famous in North Dakota for its dinosaur fossils. In outcrop, the Hell Creek reaches a maximum thickness of 400 feet in Bowman County and thins to less than 200 feet in Emmons County. Beneath the surface in Dunn County, the Hell Creek is approximately 300 feet thick.

In the subsurface, the base of the Hell Creek Formation is commonly placed at the top of the first sandstone above the Pierre Formation, assumed to be the Colgate Member of the Fox Hills Formation. This stratigraphic pick becomes more difficult when channel sandstones are present at the base of the Hell Creek Formation.

Cenozoic

Ludlow Formation

The Ludlow Formation (Paleocene) is the basal unit of the Fort Union Group (Figure 3). The type section of the Ludlow Formation is in northwestern South Dakota, near the town of Ludlow. The Ludlow Formation is characterized by alternating beds of sandstone, siltstone, claystone, mudstone, and lignite. It is distinguished in outcrop from the underlying Hell Creek Formation by its brown tones, in contrast to the generally gray-colored Hell Creek strata, and by the presence of laterally persistent lignite beds.

In the Little Missouri River Valley, the Ludlow Formation is overlain by the Slope Formation, formerly Moore's (1976) upper part of the Ludlow Formation, and the contact is placed at the base of the T Cross lignite (Clayton et al., 1977). It is also generally distinguishable from the overlying darker colored Slope Formation. In the Missouri River Valley, the nonmarine Ludlow Formation is often overlain by the marine Cannonball Formation. In outcrop, the Ludlow Formation reaches a maximum thickness of 300 feet at Pretty Butte in Slope County and thins to 20 feet, or less, in Burleigh and Emmons counties. In Dunn County, the Ludlow Formation is approximately 100 feet thick.

In the subsurface, the first lignite above the Fox Hills-Hell Creek interval is generally chosen as the contact between the Hell Creek and Ludlow formations. This contact is suspect in light of recent studies of the Hell Creek and Ludlow formations in North Dakota that demonstrated lignite was present at this stratigraphic contact at less than half of the study localities (Murphy et al., 1995).

Slope Formation

The Slope Formation (Paleocene) was proposed by Clayton and others (1977) to formalize the stratigraphic split of the Ludlow Formation made by Moore (1976). The Slope Formation consists of alternating beds of sandstone, siltstone, mudstone, claystone, and lignite. The top of the Slope Formation is placed at the top of a white siliceous unit known as the Rhame Bed (Wehrfritz, 1978; Clayton et al., 1977). The Rhame Bed is thought to represent a weathering horizon and is characterized by a 20- to 40-foot-thick dazzling white (bleached) zone overlain by a 1- to 3-foot-thick layer of silcrete.

At its type section, near the abandoned Yule Post Office in Slope County, the Slope Formation is approximately 270 feet thick and thins to zero near the Missouri River. In the Little Missouri River Basin, the Slope Formation is characterized by numerous channel sandstones and lignites. The Slope Formation is approximately 100 to 150 feet thick in Dunn County.

It is extremely difficult to differentiate between the Ludlow and Slope formations in the subsurface except where the T Cross lignite is present and can be traced into the area. The Rhame Bed was recognizable in cuttings from Slope County, but it is difficult to differentiate between the silicrete and the many concretionary zones that occur in the Fort Union Group.

Cannonball Formation

The Cannonball Formation (Paleocene) is the only marine stratigraphic unit in the Fort Union Group (Figure 3). Lloyd (1914) applied the name Cannonball Formation to strata exposed along the Cannonball River in southern Grant County. The Cannonball Formation is characterized by alternating beds of sandstone and mudstone. It reaches a maximum thickness in outcrop of 275 feet in eastern Morton County and is present as two or three thin brackish water tongues at its western-most locality in western Slope County.

The Cannonball Formation is differentiated from the other Fort Union strata by the absence of lignite. Sandstones in the Cannonball Formation tend to be cleaner than those in the nonmarine strata of the Fort Union Group, a distinction that is often discernable on electric logs. Fenner (1976) used the occurrences of marine foraminifera in well cuttings to differentiate the Cannonball Formation in the subsurface throughout western North Dakota. Fenner (1976) detected foraminifera in only one of the three wells he tested in Dunn County (T.142N., R.92W., sec. 9) from which he determined that the Cannonball Formation was present between the elevations of 960 and 1,290 feet. Moran and others (1978) placed the top of the Cannonball Formation in central Dunn County at an elevation of 1,135 to 1,265 feet and determined it ranged in thickness from 200 to 300 feet.

Bullion Creek Formation

The Bullion Creek Formation was named by Clayton and others (1977) for the brightly colored (yellow) alternating beds of sandstone, siltstone, mudstone, claystone, and lignite exposed between Bullion Butte and the Little Missouri River. The Bullion Creek Formation was proposed essentially as a name change, although it does contain a lower boundary change. The authors felt this change was needed because these strata were not correlative with the Tongue River Formation of Wyoming and Montana. Carlson (1982, 1983a, 1983b) believed the rock interval in question is correlative with the upper portion of the Tongue River Formation in Wyoming and Montana. He abandoned the name Bullion Creek and instead reapplied the term Tongue River retaining the basal contact suggested by Clayton and others (1977).

The Bullion Creek Formation reaches a maximum thickness of 650 feet in western North Dakota, but is about 500 feet thick in Dunn County. Both the upper and lower contacts of the Bullion Creek Formation are difficult to pick in the subsurface due to the absence of control on both the Rhame Bed and the HT Butte lignites (the upper and lower contacts) in this area. To the west in McKenzie County, the HT Butte bed is very thin (less than a foot in many places) and does not always correspond with the same stratigraphic horizon as the color change.

SURFACE STRATIGRAPHY

Sentinel Butte Formation

A.G. Leonard (1908) introduced the term Sentinel Butte group to include a series of lignite beds in his upper Fort Union strata along the Little Missouri River. Leonard and subsequent workers found it generally easy to separate the brightly colored strata (Bullion Creek Formation) from the overlying more somber (grays and blues) colored beds of the Sentinel Butte Formation. The Sentinel Butte Formation consists of alternating beds of sandstone, siltstone, mudstone, claystone, and lignite.

The Sentinel Butte Formation is present at the surface throughout approximately seventy-five percent of Dunn County. Near the mouth of Charlie Bob Creek in eastern McKenzie County, a thick channel sandstone that may represent the base of the Sentinel Butte Formation (T.148N., R.97W.) is exposed at river level. The elevation of this sandstone coincides with the elevation of the basal Sentinel Butte contact chosen by Carlson (1985) in the subsurface three miles to the southwest. As noted by both Royse (1967) and the author, a thick fluvial channel sandstone is commonly present at the base of the Sentinel Butte Formation in northern Billings and southern McKenzie counties. The thickest, most complete sections of the Sentinel Butte Formation in Dunn County occur along the valley of the Little Missouri River near Lost Bridge and Slater Bay (Figure 4). In excess of 500 feet of Sentinel Butte strata are exposed in this area.

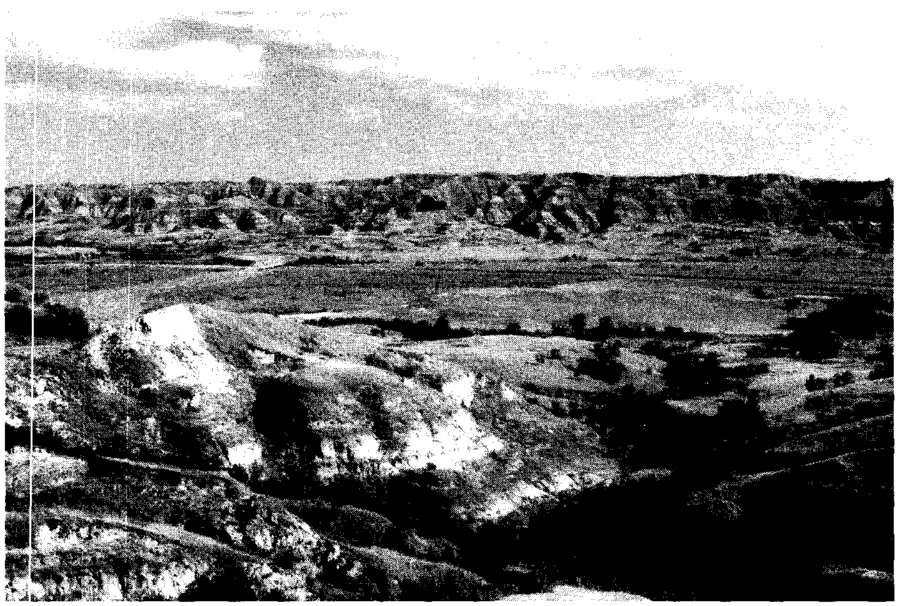

Figure 4. The thickest, most complete section of Sentinel Butte strata exposed in Dunn County occurs in badlands topography along the Little Missouri River Valley near Lost Bridge (southeast quarter of T.148N., R.95W.).

An upper and lower "yellow bed" can be traced throughout the Little Missouri River Valley from the North Unit of the Theodore Roosevelt National Park to the mouth of this river. The Sentinel Butte Formation tuff (the "big blue bed" of Laird, 1956), which is well exposed in the North Unit of the park, could not be traced by the author into Dunn County, although both Stancel (1974) and Nesemeier (1981) thought that it could be. Several thick coal beds are present in the Sentinel Butte Formation in Dunn County. At least one of these coals, the Dunn Center bed, has been seriously investigated for mining.

Although the Sentinel Butte Formation is generally easily separable from the underlying and overlying strata by its dull colors compared to other strata, in some places brightly colored beds within the Sentinel Butte make it difficult to identify the contacts. Locally (as in the south half of T.142N., R.95W. and the north half of T.141N., R.95W.), brightly colored beds within the Sentinel Butte Formation can be used as stratigraphic markers (Figure 5). At first glance, these beds may be confused with the overlying Bear Den Member of the Golden Valley Formation.

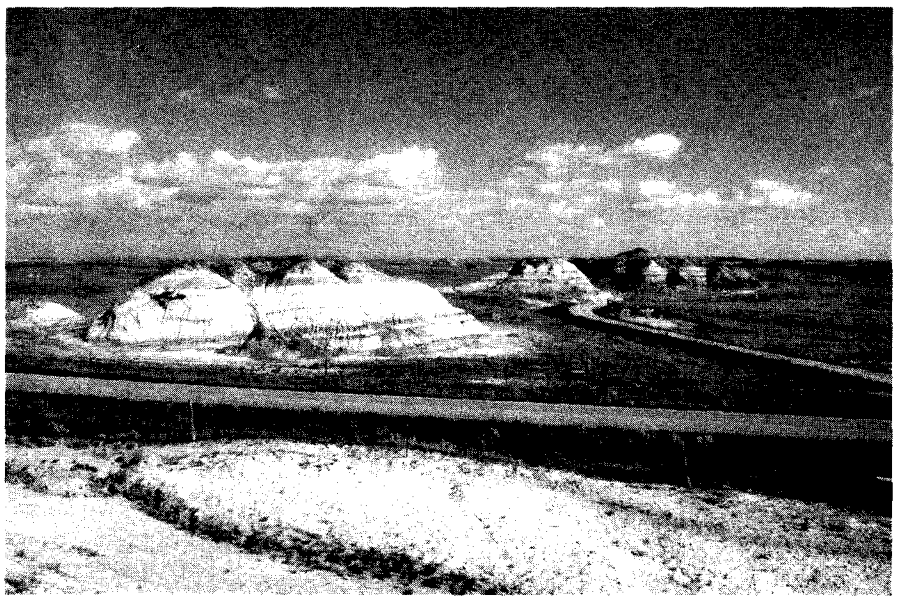

Figure 5. Bright white bed in the Sentinel Butte Formation (T.142N., R.95W., sec. 21).

Golden Valley Formation

The Golden Valley Formation (Paleocene-Eocene) was named by Benson and Laird (1947) for exposures near the town of Golden Valley in Mercer County. Prior to that time, these beds had been included in the "unnamed member of the Wasatch Formation" (Laird, 1944). The Golden Valley Formation was subsequently divided into two members, first informally by Benson (1949 and 1952) and then formally by Hickey (1977) into the Bear Den Member and the overlying Camels Butte Member.

Although the Golden Valley Formation was initially assigned an Eocene age, Hickey determined that the Bear Den Member is latest Paleocene in age.

The Bear Den Member (Paleocene) consists of 20 to 40 feet of white to orange/gray, kaolinitic sandstone, siltstone, mudstone, and claystone (Figure 6). As early as 1906 (when Babcock and Clapp mapped the "white clays") geologists recognized that the Bear Den Member could be separated from the rest of the strata in this area. The Bear Den Member often contains iron staining displayed in polygonal patterns (Figure 7). These gypsum-filled polygons may have formed during desiccation. In addition, small iron spheres (up to 1 mm in diameter) are common in this member. Benson (1952) noted that the Bear Den Member can often be subdivided into three distinctly colored zones, from bottom to top: the gray, orange, and carbonaceous zones. These zones are apparent along the Crooked Creek escarpment north of New Hradec (T.142N., R.96W., sec. 27). The Bear Den Member rests conformably on the Sentinel Butte Formation and is unconformably overlain by the Camels Butte Member of the Golden Valley Formation.

The Bear Den Member is unique in comparison to the surrounding units because of its bright color and kaolinite content (the clay mineralogy of this strata averages 66% kaolinite compared to only 10%-20% for the overlying and underlying strata) (Freas, 1962; Hickey, 1977; Karner et al., 1978; Prichard, 1980). Information collected by these workers indicates the Bear Den Member is a paleosol that developed on pre-existing Sentinel Butte strata. This member is a bleached zone that formed after a period of prolonged and/or intense weathering at the end of the Paleocene. This scenario explains why the percentage of kaolinite decreases with depth through the member. Where the paleosol developed on a Sentinel Butte sandstone, the leached zone is not as obvious as it is where developed on fine grained sedimentary rocks (T.146N., R.92W., sec. 17).

In the southern part of Dunn County, the top of the Bear Den Member is capped by a 1-to 3-foot-thick silicious layer termed the Taylor Bed (Hickey, 1977), named for occurrences near the town of Taylor in northwestern Morton County (T.141N., R.95W., sec. 26 and T.143N., R.93W., sec. 31 swsene). The Taylor Bed is generally grayish brown, iron stained, and contains numerous stem molds. It has a dull-earthy appearance in fresh outcrop and a polished surface where it has been exposed to the elements. The Taylor Bed is highly resistant to erosion and, as a result, pieces of it can be found lying as float on older strata throughout western North Dakota. In other areas of the county (T.145N., R.96W., sec. 2; T.142N., R.96W., sec. 27; T.147N., R.91W., sec. 28 sesesw; and T.143N., R.91W., sec. 32 nesese) a thin, less than 3-foot-thick, lignite or carbonaceous mudstone, named the Alamo Bluff Lignite by Benson (1952), is correlative to the Taylor Bed at the top of the Bear Den Member.

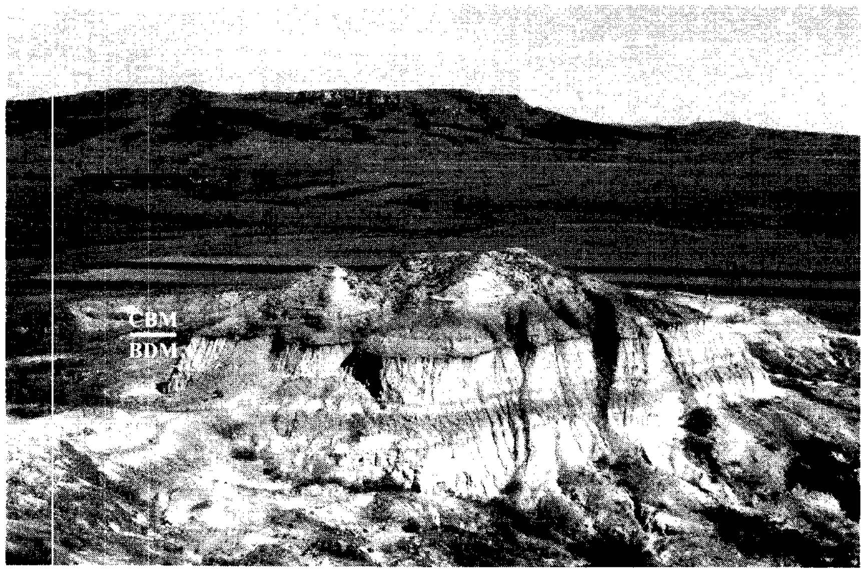

Figure 6. A typical outcrop of the Golden Valley Formation south of the Killdeer Mountains (T.145N., R.96W., sec. 2). Approximately 30 feet of Bear Den (BDM) and 15 feet of Camels Butte (CBM) strata is exposed at this locality.

Figure 7. Characteristic iron staining along joints in the Bear Den Member of the Golden Valley Formation (T.148N., R.95W., sec. 3).

Although the Golden Valley Formation was initially assigned an Eocene age, Hickey determined that the Bear Den Member is latest Paleocene in age.

The Bear Den Member (Paleocene) consists of 20 to 40 feet of white to orange/gray, kaolinitic sandstone, siltstone, mudstone, and claystone (Figure 6). As early as 1906 (when Babcock and Clapp mapped the "white clays") geologists recognized that the Bear Den Member could be separated from the rest of the strata in this area. The Bear Den Member often contains iron staining displayed in polygonal patterns (Figure 7). These gypsum-filled polygons may have formed during desiccation. In addition, small iron spheres (up to 1 mm in diameter) are common in this member. Benson (1952) noted that the Bear Den Member can often be subdivided into three distinctly colored zones, from bottom to top: the gray, orange, and carbonaceous zones. These zones are apparent along the Crooked Creek escarpment north of New Hradec (T.142N., R.96W., sec. 27). The Bear Den Member rests conformably on the Sentinel Butte Formation and is unconformably overlain by the Camels Butte Member of the Golden Valley Formation.

The Bear Den Member is unique in comparison to the surrounding units because of its bright color and kaolinite content (the clay mineralogy of this strata averages 66% kaolinite compared to only 10%-20% for the overlying and underlying strata) (Freas, 1962; Hickey, 1977; Karner et al., 1978; Prichard, 1980). Information collected by these workers indicates the Bear Den Member is a paleosol that developed on pre-existing Sentinel Butte strata. This member is a bleached zone that formed after a period of prolonged and/or intense weathering at the end of the Paleocene. This scenario explains why the percentage of kaolinite decreases with depth through the member. Where the paleosol developed on a Sentinel Butte sandstone, the leached zone is not as obvious as it is where developed on fine grained sedimentary rocks (T.146N., R.92W., sec. 17).

In the southern part of Dunn County, the top of the Bear Den Member is capped by a 1-to 3-foot-thick silicious layer termed the Taylor Bed (Hickey, 1977), named for occurrences near the town of Taylor in northwestern Morton County (T.141N., R.95W., sec. 26 and T.143N., R.93W., sec. 31 swsene). The Taylor Bed is generally grayish brown, iron stained, and contains numerous stem molds. It has a dull-earthy appearance in fresh outcrop and a polished surface where it has been exposed to the elements. The Taylor Bed is highly resistant to erosion and, as a result, pieces of it can be found lying as float on older strata throughout western North Dakota. In other areas of the county (T.145N., R.96W., sec. 2; T.142N., R.96W., sec. 27; T.147N., R.91W., sec. 28 sesesw; and T.143N., R.91W., sec. 32 nesese) a thin, less than 3-foot-thick, lignite or carbonaceous mudstone, named the Alamo Bluff Lignite by Benson (1952), is correlative to the Taylor Bed at the top of the Bear Den Member.

Camels Butte Member

The Camels Butte Member (Eocene) of the Golden Valley Formation consists of alternating beds of yellowish brown to brown sandstone, siltstone, mudstone, claystone, and thin lignites (Figure 8). Due to the similarity of lithology and appearance between Camels Butte and Sentinel Butte strata, it is difficult to distinguish between these units if the intervening Bear Den Member is covered. One criteria that can be used to differentiate between the two is the visible presence of mica grains in the Camels Butte Member. This criteria must be applied cautiously however, because upper portions of Sentinel Butte strata are often micaceous. The middle and upper portions of the Camels Butte Member contain a high proportion of channel sandstones, some of which contain intraformational conglomerates. One of the best examples of these can be seen in Camels Butte in southwestern Dunn County (Figure 9).

The Camels Butte Member is typically well exposed only at the top of small buttes where erosion has generally reduced the member to less than 50 feet (Figure 10). The only place in Dunn County where the Camels Butte Member is overlain by Tertiary bedrock is in the Killdeer Mountains where approximately 300 to 400 feet of

Figure 8. Cross-bedded sandstone in the Camels Butte Member of the Golden Valley Formation (T.147N., R.97W., sec. 13).

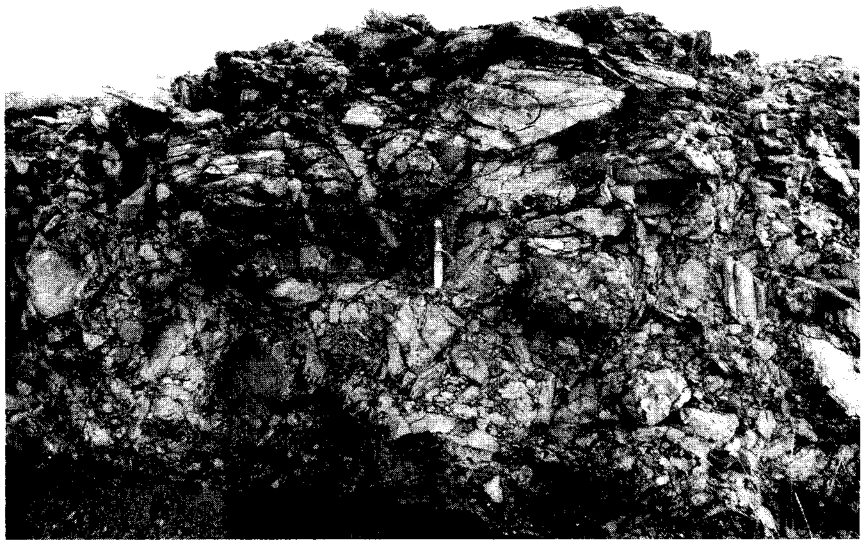

Figure 9. Intraformational conglomerate in the Camels Butte Member of the Golden Valley Formation at Camels Butte (T.141N., R.96W., sec. 27).

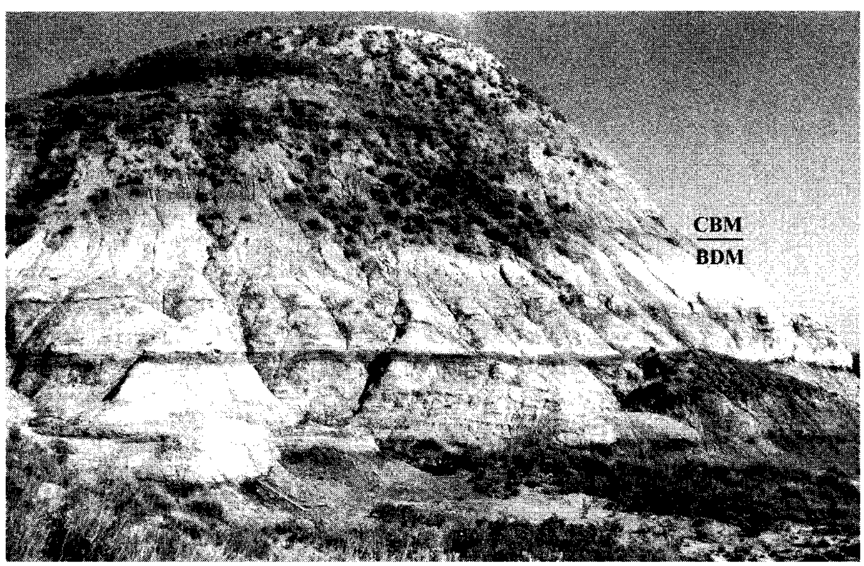

Figure 10. Typical, thin outcrop of the Camels Butte Member (CBM) at the top of a small hill southwest of the Killdeer Mountains (T.145N., R.97W., sec. 16).

strata have been preserved. The upper contact of the Camels Butte Member is an unconformity and the Camels Butte Member was likely much thicker at the time of deposition. Because the Bear Den Member appears to be a paleosol, the contact between the members in the Golden Valley Formation is an unconformity, although few, if any, obvious features of an unconformity can be seen in the field (T.147N., R.92W., sec. 26 sesese).

The Camels Butte Member is early Eocene in age as determined from sparse vertebrate fossils and the presence of an Eocene index fossil, the floating fern *Salvinia preauriculata* (Benson and Laird, 1947).

Chadron Formation

The caprock of the Killdeer Mountains consists of White River and Arikaree strata. The Chadron Formation is not well exposed anywhere in the Killdeer Mountains, but consists of 30 to 90 feet of yellowish green sandy to pebbly mudstone and clayey sandstone. This lithology is consistent with the Chalky Buttes Member of the Chadron Formation exposed in Stark and Slope counties (Murphy et al., 1993). The Chadron Formation is Eocene in age.

Brule Formation

The Brule Formation does not appear to be present in the Killdeer Mountains. Therefore, these rocks are absent in Dunn County.

Arikaree Formation

The caprock of the Killdeer Mountains consists of 330 feet of gray, tuffaceous siltstones, sandstones, and carbonates of the Arikaree Formation. A 15- to 30-foot-ledge-forming, heavily burrowed, interbedded sandstone and siltstone is present in the lower third of the Arikaree Formation. This bed, the "wormy marker bed" of Delimata (1975) and the "burrowed marker unit" of Forsman (1986), is well exposed along the southeast edge of South Killdeer Mountain and can be traced laterally throughout much of the area. Sparse vertebrate fossils and geochemical dating of the Arikaree caprock in the Killdeer Mountains have determined that these strata span the time from late Oligocene to early Miocene (Murphy et al., 1993).

The Arikaree strata are best exposed near Medicine Hole Plateau along the southeast end of South Mountain (Figure 11). A walking trail leads from a park near the old village of Oakdale up to Medicine Hole, which is a 90-foot-deep fissure that developed when a portion of the caprock broke away. A rock-crushing operation on the southeast end of North Mountain created a large pit which provides continuous

Figure 11. Arikaree caprock consisting of tuffaceous sandstone, siltstone, and carbonates near Medicine Hole Plateau in the Killldeer Mountains.

outcrops of Arikaree strata. Despite several extended trips to the quarry and investigations of the crushed rock piles, no additional fossils were discovered.

Quaternary

Coleharbor Group

At least the eastern two thirds of Dunn County has been glaciated as evidenced by the presence of glacial erratics at the surface in this portion of the county (Figure 12). Clayton and others (1980) noted that at least three glacial advances took place in Dunn County; the Dunn, Verone and Napoleon glaciations. Post-depositional erosion has removed most of the till, often leaving only glacial boulders (erratics) at the surface. These erratics have been used to map the different glacial advances. The area covered by the Dunn Glaciation has only a few boulders per mile whereas the area of the Verone Glaciation has up to a hundred or more boulders per mile (Moran et al., 1976). Lag boulders are even more abundant from the Napoleon Glaciation and till is widely preserved from this episode (Clayton et al., 1980). Clayton (1970) and Moran and others (1976) determined that the Dunn Glaciation was pre-Wisconsinan in age, the Verone either pre-Wisconsinan or Early

Wisconsinan and the Napoleon Glaciation likely Early Wisconsinan, the latter occurring approximately 40,000 years ago.

As a result of erosion, till is generally preserved only along drainage divides, commonly in patches less than a few square miles in area. Till thicknesses are extremely variable in these deposits, but seldom are more than 30 feet. Outcrops of till in Dunn County are generally poor and usually restricted to road ditches (T.142N., R.91W., sec. 35 nwnene; T.143N., R.91W., sec. 26 nwnwne; and T.144N., R.91W., sec. 34 swsesw). Clayton (1970) determined that this till was likely from the Napoleon Glaciation because it was not as highly weathered as till from the older glaciations that have been preserved in other parts of the state and it resembles Napoleon drift from the south-central part of the state.

Figure 12. Erratics in northern Dunn County.

Killdeer Mountain Pediments

On the east, west, and south sides of the Killdeer Mountains large pediment surfaces extend out from the mesa sides for several miles. These pediment surfaces are covered by up to 10 feet of gravel derived primarily from the Arikaree caprock ie., gray to white siltstone, sandstone, and carbonate. Occasionally, pieces of green chert, visible in outcrop in the Killdeer Mountains, and brown to black flint (Knife River Flint) are also present. The pediments once formed a continuous ring around the Killdeer Mountains, but they have been dissected and eroded to the point that only about 25% of the pediments are still intact. Clayton (1970) believed that base level lowered while the pediments were forming noting that some were formed at lower levels than others. He also noted that the pediment appeared to grade into the level of the Killdeer-Shields channels, which formed during the Verone Glaciation and therefore should be pre-Wisconsinan or Early Wisconsinan in age.

Gravel

In the valleys of Crooked Creek, Little Knife, Knife, and Green rivers are scattered deposits of coarse gravel (Figure 13). These gravels consist primarily of locally derived Taylor Bed silcrete, chert, flint, agate, petrified wood, mudstone, and concretions derived from the Golden Valley and Sentinel Butte formations (T.141N., R.96W., sec. 32; T.145N., R.94W., sec. 1 se). In addition, gravels along the Green River also contain quartzite and porphyries that Clayton (1970) attributed to the Rocky Mountains. These gravels appear to be Late Tertiary (probably Pleistocene) in age.

The hills within a mile of the Knife River often contain thin, generally less than 5 feet thick, lenses of sand and gravel alluvium that was deposited when the river was flowing at higher elevations. These gravels are readily mappable where they are present in well-developed terrace deposits. The flat surfaces of these terrace deposits are easily discernible on aerial photographs and are often identifiable on topographic maps. However, thin lenses (typically less than 6 feet) of sand and gravel also occur on the surface of gently sloping hillsides within a half mile of the Knife River and Spring Creek. These gravels, which may have been deposited at the same time that the Killdeer-Shields channels were forming, only slightly drape the pre-existing topography and are difficult to identify on aerial photographs. These deposits were typically too thin to be mapped.

Landslide Deposits

Sentinel Butte and Golden Valley strata are very susceptible to slope failure due to the poorly cemented, poorly consolidated nature of the beds. Landslide deposits, primarily the result of slumping of Sentinel Butte strata, are prevalent in the Little Missouri River Valley. Slumps are easily recognized on aerial photographs due to the ponding of water in depressions above the heads of the slumps, benches formed at the heads of scarps, the presence of steep scarp faces, and the numerous concentric scarps (generally accentuated by vegetation) that have developed on the toes of the major slump blocks, demonstrating that these units are not connected, but consist of numerous "slivers" of bedrock. Some slumps are also recognized because their toes have diverted stream drainages. These slumps developed primarily as a

Figure 13. Terrace gravel along the Knife River near the town of Marshall.

result of the oversteepening of the outcrop due to incision by the Little Missouri River and associated tributaries.

Knife River Flint

Knife River Flint was used extensively by Native Americans for projectile points and therefore is of much interest to archaeologists (Root et al., 1986). Shallow pits or quarries dug by Native Americans into Pleistocene sediments are readily visible along Spring Creek between Dunn Center and Halliday. Both geologists and archaeologists have been interested in the origin of the Knife River Flint since it has been found only in secondary deposits. The mixing of Killdeer Mountain caprock with the flint in the pediments and ancient fluvial gravels around the mountains suggest that they were both being eroded at the same time. In the Dunn Center area, most of the Golden Valley Formation has been removed by erosion except for the area around the Killdeer Mountains. It seems likely that the Knife River Flint formed in either Golden Valley, White River, or Arikaree strata. One possible scenario is that the flint was deposited in a swamp that ringed the lacustrine system in which the Arikaree caprock of the Killdeer Mountains formed. This would explain why many of the gravels observed were primarily carbonate caprock and flint with little or no other bedrock gravel. The large pieces of flint (up to 2 feet in diameter) found near Killdeer suggest that the original source was not far away. Clayton and others (1970) have suggested that the likely source of the Knife River Flint is Jepsen's (1963) HS bed in the Camels Butte Member of the Golden Valley Formation in Stark County. They also argue for a pre-Chadron source for the Knife River Flint because of the presence of flint pieces in the Chalky Buttes Member (Chadron) in the Chalky Buttes, Slope County.

TOPOGRAPHIC FEATURES

Killdeer Mountains

The Killdeer Mountains are the dominate topographic feature in Dunn County (Figure 14). The mountains, more correctly defined as mesas, rise 600 to 700 feet above the surrounding countryside and can be seen from 50 miles away. The lithology (fresh-water carbonates) and bedding characteristics of the Killdeer Mountain caprock indicate that it was deposited in a lacustrine basin. The mesas formed because the resistant carbonate caprock protects the underlying strata, which are typically poorly cemented and poorly indurated.

Medicine Hole, a 70-foot deep, 2-foot wide fissure, is located on the southeast corner of South Killdeer Mountain. Medicine Hole, which plays an important role in local Native American folklore, was created when a block of tuffaceous sandstone and carbonate broke off and moved slightly away from the main body of caprock. Numerous photographs and detailed measured sections are presented in Murphy and others (1993).

Glacier Margin (Proglacial) Channels

The surface and near-surface geology of southern (especially southeastern) Dunn County is dominated by anastomosing channels. These proglacial meltwater channels developed along the margin of the Verone glacier and carried water that entered the state from northern Wyoming and that portion of Montana east of the Rocky Mountains (Clayton et al., 1980). The westernmost of these

Figure 14. Oblique aerial photograph of the southeast edge of south Killdeer Mountain. Photo taken looking northeast.

channels has been called the Killdeer-Glen Ullin Channel (Clayton, 1970) or Killdeer-Shields Channel (Figure 15). It lies everywhere west of the Verone glacier margin indicating that it formed along the western limit of the Verone ice. The channels to the east formed either as the ice was advancing and were later overridden by the glacier, as evidenced by till at the surface of the channel floors, or they may have formed along the ice margin as the glacier was retreating. As noted by Clayton (1970), the more easterly channels formed as the ice retreated. These channels are filled with up to 200 feet of fluvial sediment and are easily identified due to their low-relief surfaces in contrast to the high to moderate relief of the surrounding bedrock topography (Klausing, 1979).

Clayton (1970) theorized that, because the glacier advanced up the gradient of the regional slope in this area, the advancing ice would have dammed any valleys in the area thereby creating lakes. Clayton believed that the sudden release of water from these lakes, likely due to failure of an ice wall, caused catastrophic flooding that quickly eroded the channels. No lacustrine sediments have been found in boreholes from the ice- margin area to support this theory. However, it is possible that any silt and clay deposits were removed by subsequent upgradient catastrophic floods or by erosion in the time since such deposits accumulated.

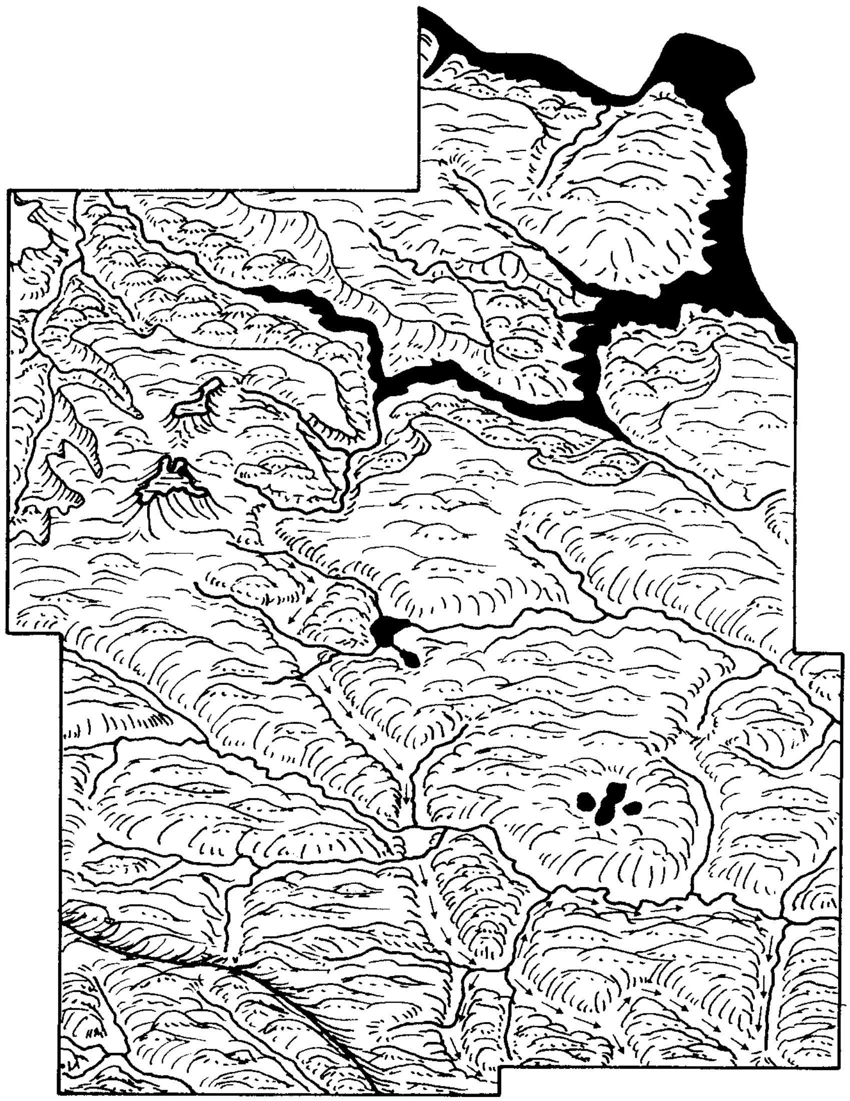

Figure 15. Physiographic map of Dunn County. Arrows indicate the direction that water flowed through the northern terminus of the proglacial Killdeer-Shields channel. This proglacial channel extends through six counties in western and south-central North Dakota.

The position of erratics relative to the Killdeer-Shields channels may support a theory that they were formed, at least in part, by catastrophic flooding. Erratics are scattered throughout the eastern two thirds of Dunn County with the frequency varying from rare to numerous. In some areas erratics are concentrated along the sides of the glacial margin channels (T.143N., R.93W., secs. 13 swsese and 7 nwnene; T.144N., R.93W., secs. 20 sese and 29 sese) similar to what Kehew and Lord (1986) found near meltwater channels in Ward County. They believed that these erratics were boulder-lags and used their frequency and position to support the hypothesis that many of the glacial meltwater channels in that area had been formed by catastrophic flooding. In addition to that evidence, several channels (T.144N., R.93W., secs. 26 and 27) bend sharply or abandon former channels as if done under relatively short-lived, but high flow conditions. On the other hand, Clayton (1970) believed that the relatively narrow width of these channels was evidence that they formed in a glacial climate when the ice was melting relatively slowly.

Inverted Topography

Throughout parts of Dunn County, ridges of gravel represent inverted topography, areas that were topographically low when the fluvial sediments were being deposited (T.141N., R.95W., secs. 5, 8, 17, 20, and 23). The gravel deposits are generally more resistant to erosion than the surrounding strata and this results in sinuous, ridge-capped gravels. The examples cited all contain eroded Arikaree strata from the Killdeer Mountains.

Russian Springs Escarpment

The Russian Springs Escarpment (Spring Creek Escarpment) rises approximately 200 feet above the lowlands to the north (Figure 16). Clayton (1970) and Moran and others (1976) postulated that, following the Dunn and possibly the Verone glaciations, 100 to 200 feet of strata along the Missouri Slope were eroded to the approximate position of the present surface between the Little Missouri River badlands and the Russian Springs Escarpment. Following this erosion event, there was a period of eolian activity on and to the south of the escarpment followed by renewed erosion of the area north of the escarpment. The present surface of this area was formed largely at that time although more recent erosion has further sculpted the area.

Badlands Topography

The badlands topography in northern Dunn County began forming approximately 600,000 years ago when advancing glaciers diverted the north-flowing Little Missouri River to the east at a point near the North Unit of Theodore Roosevelt

Figure 16. Oblique aerial photograph of the Russian Springs Escarpment (T.142N., R.97W., sec. 24). Photo taken looking east. The Golden Valley Formation rims the escarpment.

National Park (Bluemle, 1991). The ancient Little Missouri River cut quickly down through the layers of soft sedimentary rock as it flowed down this shorter, steeper path (Figure 17). Numerous landslides have occurred in the badlands topography. Badlands topography has also developed in the area north of the Russian Springs Escarpment.

Landslides

Landslides are a major geologic hazard in Dunn County. They occur primarily along the slopes of the Killdeer Mountains and within badlands topography adjacent to the Little Missouri and Missouri Rivers and Crosby Creek. Landslides range from small individual slides that occupy a few acres up to large complexes which extend for several miles and occupy more than one thousand acres. Over 700 landslides were mapped. The actual number of individual slides may be several thousand because slide complexes were generally mapped as one occurrence. The total area of landslides exceeds 28,000 acres, which is approximately 2% of the entire county or 10% of the badlands area. Most landslides are vegetated with mature trees indicating that the slides occurred a few decades to a few centuries ago, and have been relatively stable since (Figure 17).

Figure 17. Oblique aerial photo of the former flood plain of the meandering Little Missouri River east of Lost Bridge in north-central Dunn County. This is the point where the Little Missouri River enters Lake Sakakawea. Badlands topography extends for three to six miles along either side of the river. Ancient landslide deposits are present in the foreground.

ECONOMIC GEOLOGY

Lignite

No large-scale coal mining operations have ever taken place in Dunn County. However, coal was mined in the county from the face of outcrops and dumped directly into farm wagons. In the mid-1970s, the Natural Gas Pipeline Company of America drilled hundreds of shallow investigation holes in north-central Dunn County to determine the extent and quality of the 10- to 20-foot-thick Dunn Center lignite bed (Moran et al., 1978; Menge, 1977 and 1978). This drilling was done in preparation for the establishment of a mine to supply a coal gasification plant that was to be constructed in the area. Plans for the gasification plant were abandoned in the early 1980s due to the discovery of abundant natural gas reserves in the United States and the failure of gas prices to rise to projected levels.

The Dunn Center bed was traced over a 144-square-mile area centered midway between Dunn Center and Werner (Moran et al., 1978). According to Stancel

(1974) the Dunn Center bed extends north from this area to at least the Little Missouri River Valley in northern Dunn County. Murphy and Goven (1998a and 1998b) were able to trace the Dunn Center Bed in the subsurface only as far north as T.146N., R.92W., sec. 20. Several additional reports contain information on the coal resources of Dunn County (Leonard et al., 1925; Law, 1977; Harch and Affolter, 1978; Woodward-Clyde, 1978; Menge, 1980; Kirschbaum and Schneider, 1981).

Oil and Gas

Oil and gas have been produced in Dunn County since 1959. Currently there are 18 oil fields in the county. The largest of these is the Little Knife Field, with production primarily from the Mission Canyon Formation. Over 49 million barrels of oil have been produced through the end of 1999 in Dunn County.

Carbonate

The carbonate caprock (Arikaree Formation) of the Killdeer Mountains was used by homesteaders for building stone. In more recent years, the caprock has been mined and crushed for use as road metal on local roads.

Clinker

Clinker, known locally as scoria, is brightly colored rock (commonly reddish orange), that has been baked and fused by the heat from burning lignite. Clinker can be found throughout Dunn County and is especially common along the valley of the Little Missouri River, where badlands topography has exposed numerous lignite beds. Clinker is generally more resistant to erosion than other Tertiary strata and is commonly found as the caprock on buttes (T.143N., R.93W., secs. 17 and 20; T.143N., R.95W., sec. 12). Locally it is used as road metal. Small mine pits are scattered throughout the county.

Sand and Gravel

Sand and gravel are present in thin alluvial deposits along the Little Missouri, Knife, and Green rivers and numerous creeks such as Spring Creek and Crooked Creek. Sand and gravel are present in three types of deposits in Dunn County; Pleistocene alluvium, glaciofluvial deposits, and Recent alluvium. The older fluvial gravels are found on terraces located above the modern flood plains. These gravels are typically mixtures of quartzite, iron stone, flint, and fossil wood. Glaciofluvial deposits, scattered across the eastern half of the county, are generally less than 30 feet thick except within the Killdeer-Shields, Goodman Creek, and Little Knife channels where as much as 200 feet of sand and occasional lenses of gravel may occur. Gravel from both of these sources has been mined on a small to moderate scale throughout the county.

Recent alluvium is typically much finer grained than the older gravels and generally consists of sand and silt. Recent alluvium is restricted to the modern flood plains along rivers, creeks, and their tributaries. These deposits are generally less than 20 feet thick.

Uranium

In the 1950s and 1960s numerous investigations for uranium took place in North Dakota (Denson et al., 1960; Moore and others, 1960; Denson, 1965; Denson and Gill, 1965). The earliest of these studies concluded that tuffaceous rocks of White River and Arikaree strata were the source of uranium in western North Dakota. Denson and Gill evaluated the uranium potential of the Killdeer Mountains. Slightly radioactive rocks were detected by two oil-well gamma logs in the Killdeer Mountains (T.146N., R.96W., secs. 29 and 31). These logs indicate a concentration of radioactive minerals in the upper part of the Golden Valley Formation in this area.

Volcanic Glass

Volcanic glass is present in the tuffs in the Killdeer Mountain caprock (Forsman, 1986; Murphy et al., 1993). At the present time it does not appear that it would be economical to mine and separate glass from the tuffs given that much purer volcanic ash deposits in the state have not proven to be economic. Zeolites, which are also present in the caprock, may warrant further assessment.

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