CARLSON, C. G.–GEOLOGY OF BILLINGS, GOLDEN VALLEY, AND SLOPE COUNTIES–N.D.G.S. Bulletin 76, N.D.S.W.C. County Groundwater Studies 29, Pt. I

GEOLOGY

of

BILLINGS, GOLDEN VALLEY, AND SLOPE COUNTIES, NORTH DAKOTA

by
Clarence G. Carlson
North Dakota Geological Survey
Grand Forks, North Dakota
1983

BULLETIN 76–PART I
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

COUNTY GROUNDWATER STUDIES 29–PART I
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

Prepared by the North Dakota Geological Survey
in cooperation with the U.S. Geological Survey,
North Dakota State Water Commission,
Billings County Water Management District,
Golden Valley County Water Management District,
and the Slope County Water Management District.

GEOLOGY

of

BILLINGS, GOLDEN VALLEY, AND SLOPE COUNTIES, NORTH DAKOTA

by
Clarence G. Carlson
North Dakota Geological Survey
Grand Forks, North Dakota
1983

BULLETIN 76–PART I
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

COUNTY GROUNDWATER STUDIES 29–PART I
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

Prepared by the North Dakota Geological Survey in cooperation with the U.S. Geological Survey, North Dakota State Water Commission, Billings County Water Management District, Golden Valley County Water Management District, and the Slope County Water Management District.

Printed by Dakota Printing Company, Bismarck, ND 58501 1983

CONTENTS

ILLUSTRATIONS

ABSTRACT

Billings, Golden Valley, and Slope Counties are located in westernmost North Dakota in the Unglaciated Missouri Plateau Section of the Great Plains Province. The area contains rocks of each of the geologic periods with the thickest accumulations of sedimentary rocks in northeastern Billings County, where 15,340 feet were present in a Precambrian test. The sedimentary section thins to about 10,600 feet in southwestern Slope County. This reflects the effects of the Cedar Creek Anticline and the position of this area on the southwest flank of the Williston Basin.

Strata at the surface are limited to formations of Upper Cretaceous and Tertiary age. The Upper Cretaceous Fox Hills and Hell Creek Formations, consisting of poorly consolidated sand, silt, clay, and carbonaceous shale, are exposed in southwestern Slope County. The rest of the area has Tertiary formations at the surface. These strata are well exposed in badlands areas along the Little Missouri River and slopes of the high buttes. They generally consist of poorly consolidated sand, silt, clay, and lignite.

Sandstones within each of the exposed formations are potential sources of groundwater. Lignites of the Fort Union Group are alternate sources of supply.

The lignite beds are of sufficient thickness and shallow enough to provide strippable reserves in some areas. There are also low-grade uranium concentrations in some of the sandstones, lignites, and carbonaceous shales in the upper part of the Sentinel Butte Formation in some areas.

Gravel is limited to terrace deposits of present or former drainages. "Scoria," the clinker-like material, which is readily available in most areas, is commonly used as a gravel substitute.

INTRODUCTION

Purpose of Study

This report describes the geology of Billings, Golden Valley, and Slope Counties, an area of about 3,380 square miles, located in southwestern North Dakota. It is one of a series of reports in the groundwater study series 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 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

North Dakota Highway Department road maps, scale 1:63,000 were used as base maps. Topographic maps of the 7.5-minute series were available for portions of the area, and since the fieldwork was completed, topographic maps have become available for most of the rest of the area. Fieldwork consisted of traversing all roads or trails by vehicle and traversing on foot to otherwise inaccessible areas of interest. Characteristics of the formations and contacts between formations were determined in the areas of good exposures in the badlands areas along the Little Missouri River and slopes of the high buttes. These contacts were then traced through the area of good exposures and extended across other areas. Most of the contacts are in areas of good exposures, but the Sentinel Butte-Tongue River contact is less certain in the area south and east of the Chalky Buttes area of Slope County.

Subsurface information consisted of samples and/or logs from test-hole drilling of the current study, test-hole drilling from a cooperative lignite investigation with the Conservation Branch of the United States Geological Survey, and information from oil exploration test holes in the files of the North Dakota Geological Survey. Thicknesses of the formations were determined by measuring sections in areas of good exposures combined with available subsurface information. The study was done on a reconnaissance basis with fieldwork completed in one field season.

Regional Setting

These counties are bounded on the south by Bowman County, on the east by Hettinger, Stark, and Dunn Counties, on the north by McKenzie County, and on the west by Montana. Physiographically they are in the Unglaciated Missouri Plateau

Section of the Great Plains Province (fig. 1). This section is generally characterized by gently rolling uplands interrupted by buttes and ridges capped by resistant rock types. However, in these counties, the northward-flowing Little Missouri River has been incised about 200 to 500 feet into that upland surface with the relief increasing northward. This is the result of capture of the preglacial Little Missouri by the ice-marginal Missouri River and subsequent adjustment to that lower base level. Adjustment continues as tributaries are cutting back into the uplands creating a northward-widening band of badlands about 6 to 18 miles wide through these counties. Remnants of the pre-diversion surface are the upland flat areas (high terraces) bordering the Little Missouri (pl. 1). Generally the area from Range 100 West and eastward, and an area bordering Montana has topography typical of the section in other areas of the region.

The Chalky Buttes area (fig. 2), located on the drainage divide between the Little Missouri and Missouri Rivers, includes the highest elevation of 3,506 feet in North Dakota at White Butte. The lowest elevation is in the Little Missouri valley in northern Billings County where the elevation is about 2,080 feet. The isolated buttes rising above the general upland area (Bullion, Black, Sentinel, Flat Top, and Rainy Buttes) are held up by resistant sandstones or limestones of the White River Group. Clinker, or "scoria" formed by the baking of sediment where lignite has burned also caps some low buttes and is a prominent ridge-former in the badlands area of these counties.

These counties are located on the south and southwest flanks of the Williston Basin, an intracratonic basin, whose center is near Watford City in McKenzie County. Generally the near-surface strata are relatively flat lying, but they have gentle dips to the north or northeast. In western Slope County a major structure, the Cedar Creek Anticline, has a northwest-southeast trend with its axis just southwest of Slope County. In that area the beds have a greater dip, and the northwest trend of the formation contacts reflects the effects of that structure. Other structural elements not readily apparent from surface studies have been delineated by seismic methods. These lesser structures are responsible for recent oil development in these counties.

Previous Work

Wilder (1902) provided the first general description of the coal resources of various areas within these counties and first noted a 40-foot bed in sec 31, T135N, R101W. Wood (1904) investigated lignite beds near the major streams of western North Dakota including the Little Missouri area. Leonard spent the field season of 1907 mapping the North Dakota portion of

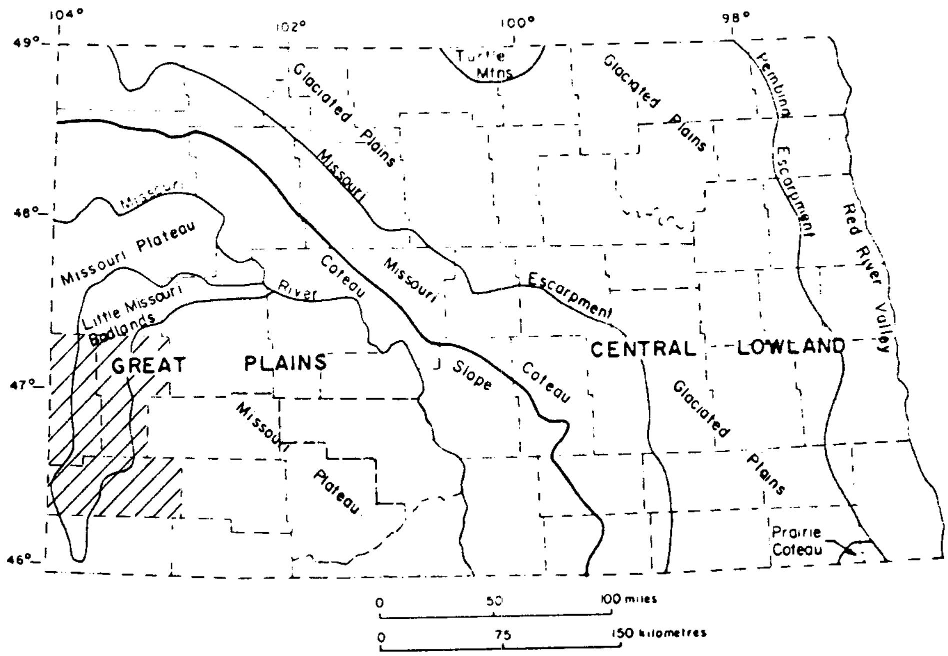


Figure 1. Location map showing area of study and physiographic subdivisions.

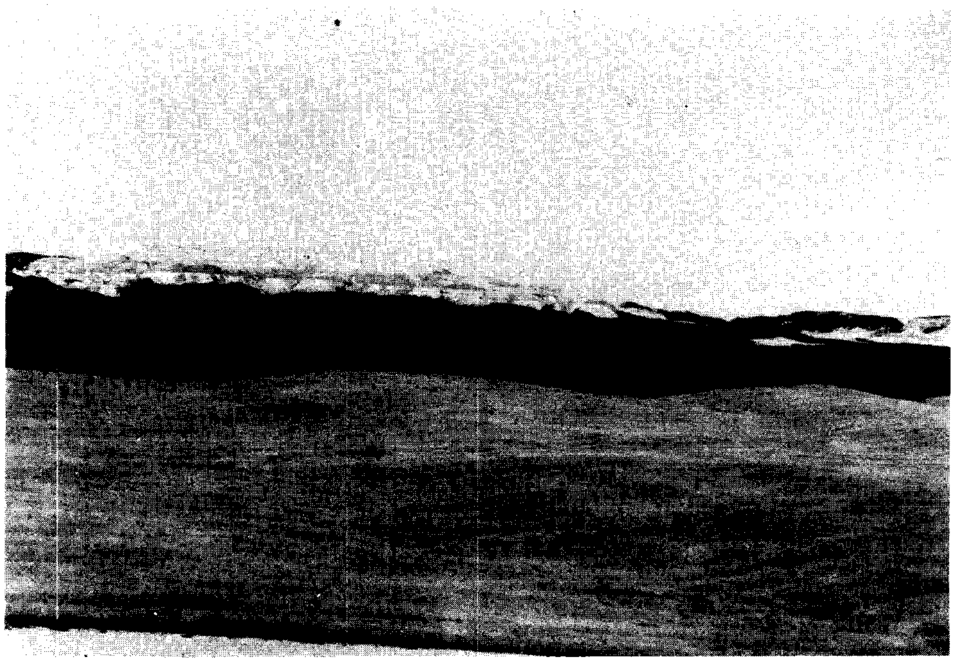


Figure 2. View looking north to Chalky Butte area, sec 6, T133N, and sec 31, T134N, R100W, Slope County.

the Sentinel Butte lignite field (Leonard and Smith, 1909) for the U.S. Geological Survey and then extended his studies southward along the Little Missouri River. The 1908 field season further extended these studies and provided the basis for the report, "Geology of southwestern North Dakota, with special reference to coal" (Leonard, 1908). In that report, Leonard used letter designations for the coal beds (pl. XII) and in ascending order named the Yule, Great Bend, Medora, Beaver Creek, and Sentinel Butte Groups of coal beds. He also noted color changes within the coal-bearing strata and referred to an Upper dark-gray unit, a Middle buff and light-gray unit, and a Lower dinosaur-bearing somber unit.

Leonard (1925a) provided many measured sections from the good exposures in the badlands areas of these counties in his summary of the lignite deposits of North Dakota. He continued use of letter designations and group terms with the Yule and lower part of the Great Bend Group in the Ludlow lignitic member of the Lance and the rest of the lignites in the Fort Union Formation.

Hares (1928) mapped the Marmarth coal field, which included the area from the Montana line eastward through R102W and from T138N southward in these counties. He provided a township by township description of the lignite resources and named some of the significant beds. He provided a general discussion of the stratigraphy of the exposed section.

Further studies of the lignite strata include: Brant (1953) who estimated the resources available in these counties; May (1954) who mapped part of Golden Valley County; Fischer (1954) and Hanson (1955) who used lignite beds for mapping structures in northern Billings and Golden Valley Counties; and Royse (1967) who reviewed usage of the term Sentinel Butte and recommended its acceptance as a formation.

Recent test-hole drilling by the Conservation Division of the U.S. Geological Survey has provided significant basic data for lignite resource evaluation (U.S. Geological Survey, North Dakota Geological Survey, 1976, 1977, 1978, 1979). Owen (1979), Lewis (1977, 1979), Menge (1977), and Banet (1980) have mapped portions of these counties and provide some interpretation of the test-hole data.

Studies of the uranium potential in western North Dakota include portions of these counties (Kepferle and Culbertson, 1955; Denson and others, 1955; Bergstrom, 1956; Cvancara, 1976a, 1976b; Jacob, 1976; Moore, 1976).

The age and terminology to be applied to the Late Cretaceous and Early Tertiary non-marine strata overlying the Fox Hills Formation of this area has been a long-term problem. In the early reports, the strata below the Fort Union Formation were generally referred to as the Lance Formation (Knowlton, 1911, 1922; Stanton, 1914, Dobbin and Reeside, 1930; as well as previously cited works) and the age assigned was Cretaceous, Tertiary, or both. Thom and Dobbin (1924) presented a regional summary of the relationships of the post-Fox Hills strata. They divided the Fort Union into Sentinel Butte, Tongue River, and Lebo Members and the Lance into Cannonball, Ludlow, Tullock, and Hell Creek Members. They were undecided as to the Cretaceous or Eocene age of these formations. Hares (1928) used the term Lance with Hell Creek, Ludlow, and Cannonball Members for the strata between the Fox Hills and Fort Union for the Marmarth area, retaining the Tertiary (?) age for the Lance.

Paleontological studies by Brown (1938, 1962), Dorf (1940), and Jeletsky (1962) established age relationships of these strata that are presently accepted, and they defined the Cretaceous-Tertiary boundary as the top of the Hell Creek Formation. This led to discontinuance of use of the term Lance in North Dakota and inclusion of the Ludlow and Cannonball in the Fort Union.

Frye (1969) made a detailed study of the Hell Creek Formation in the outcrop areas along the Little Missouri River, which including the area in southwestern Slope County. Feldmann (1972) studied the Fox Hills Formation in North Dakota and included a detailed section in an adjacent area in Bowman

County. Jacob (1973, 1975) studied depositional environments in the Tongue River Formation and mineralogy and petrology of the Tongue River and Sentinel Butte Formations. Moore (1976) provided detailed descriptions of the lower Fort Union strata in these counties and a general summary of Hell Creek and Ludlow strata between these counties and the surrounding areas. Cvancara (1976a, 1976b) and Jacob (1976) provide general stratigraphic studies of Upper Cretaceous and Tertiary strata in these counties. Clayton and others (1977) reviewed stratigraphic nomenclature problems of some of the Tertiary strata.

SUBSURFACE STRATIGRAPHY

General

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. These sequences provide a convenient means for discussion of the geologic history of this area. Sediment of the Tejas and upper part of the Zuni Sequences are present at the surface and will be treated in some detail.

The sedimentary section is further subdivided into units of similar lithology and origin which are defined as formations or groups. The stratigraphic column (fig. 3) provides the names of these units as well as the general lithology and thickness in these counties. Generally the thickness variations reflect a gradual downwarping of the central basin area so the formations generally thicken northeastward. In some cases (e.g., Interlake, Big Snowy) a rapid thinning southward is a result of erosion during episodes of emergence.

The most complete sedimentary record is found in northeastern Billings County where 15,340 feet of sedimentary rocks were penetrated in the Gulf-Zabolotny 1-3-4A well (NWSWsec 3, T144N, R98W). The sedimentary section thins southwestward, so in southwestern Slope County, where the deepest penetrations are the Red River Formation, a complete sedimentary section would be about 10,600 feet thick.

ERA	SYSTEM	SEQUENCE	FORMATION OR GROUP		THICKNESS (feet)	DOMINANT LITHOLOGY
CENOZOIC	QUATERNARY	TEJAS		ALLUVIUM	0- 40	Silt, Sand and Gravel
	TERTIARY			WHITE RIVER	0- 400	Conglomerate, Sand, Silt and Clay
		ZUNI		GOLDEN VALLEY	0- 50	Silt, Clay and Sand
			FORT UNION GROUP	SENTINEL BUTTE	0- 520	Silt, Clay, Sand and Lignite
				TONGUE RIVER	0- 520	Silt, Clay, Sand and Lignite
				SLOPE	0	Silt, Clay, Sand and Lignite
				CANNONBALL	0- 200	Mudstone and Sandstone
				LUDLOW	0	Silt, Clay, Sand and Lignite
MESOZOIC	CRETACEOUS		MONTANA GROUP	HELL CREEK	0- 450	Clay, Sandstone and Shale
				FOX HILLS	0- 220	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	ABSAROKA		SPEARFISH	400- 550	Siltstone and Salt
PALEOZOIC	PERMIAN			MINNEKAHTA	35- 50	Limestone
				OPECHE	95- 350	Shale and Siltstone
	PENNSYLVANIAN		MINNELUSA GROUP	BROOM CREEK	110- 180	Sandstone and Dolomite
				AMSDEN	210- 400	Dolomite, Sandstone and Shale
				TYLER		Mudstone and Sandstone
	MISSISSIPPIAN	KASKASKIA		BIG SNOWY	200- 500	Shale, Sandstone and Limestone
				MADISON	1,350-2,000	Limestone, 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	TIPPECANOE		INTERLAKE	250- 920	Dolomite
				STONEWALL	75- 115	Dolomite
	ORDOVICIAN			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	SAUK		DEADWOOD	420- 950	Limestone, Shale and Sandstone
	PRECAMBRIAN ROCKS					

Figure 3. Stratigraphic column for Billings, Golden Valley, and Slope Counties.

Precambrian

As of January 1, 1983, four test holes had penetrated Precambrian rocks in these counties. Cuttings from the Gulf-Zabolotny 1-3-4A well, the Shell-Kremers No. 21X-22 well (NWSEsec 22, T137N, R106W), and the Amerada-Scoria No. 8 well (NESWsec 10, T139N, R101W) are either igneous or metamorphic rocks composed of quartz, feldspar, biotite, and hornblende. Goldich and others (1966) refer to the Scoria No. 8 cuttings as Quartz Monzonite (?) and report a Rb-Sr age as 1,550 million years old and a K-Ar age as 1,740 million years old. These age determinations are considered as Middle Precambrian and the area is referred to as part of the Churchill Province.

Sauk Sequence

The Sauk Sequence is represented by the Deadwood Formation of Upper Cambrian to Lower Ordovician age. It consists of variable thicknesses of glauconitic sandstone, carbonate, and minor amounts of shale with a clean, quartzose sandstone at its base. It was deposited as shallow seas spread across the area from the west about 515 million years ago. Thicknesses vary from about 425 to 950 feet in the four wells. Two of the wells, the Shell-Kremers No. 21X-22 and the Tenneco-Burlington Northern No. 1-29 (NESWsec 29, T143N, R100W), have anomalously thin sections of Deadwood. Comparisons of logs for these wells with the other wells indicate that lower parts of the Deadwood are missing, suggesting deposition over topographic highs on the Precambrian surface.

Tippecanoe Sequence

The Tippecanoe Sequence began with deposition of clastics of the Winnipeg Group as seas spread across this area about 470 million years ago. Shallow water carbonates with minor evaporites were deposited as these seas advanced over the area. The thickness of this sequence ranges from about 1,100 feet in southwestern Slope County to about 2,100 feet in northeastern Billings County. There is some depositional thickening of the Winnipeg Group and the Red River Formation northward, but the thinning southward is due mainly to erosional thinning of the Interlake Formation.

Kaskaskia Sequence

The Kaskaskia Sequence began with deposition of shallow-water carbonates and thin shales as Middle Devonian seas spread across the area from the northwest about 370 million years ago. The northern part of these counties has nearly continuous depositional thicknesses of Devonian and Mississippian strata. Thicknesses range from about 1,850 feet in southwestern Slope County to 3,800 feet in northeastern Billings County. The Devonian formations thin southward reflecting depositional thinning of the lower units as well as minor erosional episodes within Devonian strata. A Late Devonian-Early Mississippian erosional episode removed Three Forks and Bakken strata along the Cedar Creek Anticline and thinned these strata in other areas. The Bakken Formation is limited to northeastern parts of Golden Valley and Billings Counties. Mississippian deposition began with carbonates and then shallow water carbonates and evaporites of the Madison Formation. The Madison thickens northward from about 1,350 feet to about 2,000 feet reflecting basinward depositional thickening including salt beds in the upper Madison. Mississippian deposition closed with clastics of the Big Snowy Group.

Absaroka Sequence

The Absaroka Sequence, which began with deposition about 315 million years ago, is composed of clastics, carbonates, and evaporites ranging in thickness from about 1,100 feet in southwestern Slope County to about 1,500 feet in northern Billings County. Nearly continuous depositional thicknesses of the formations of this sequence have been preserved. Variations in thickness of the evaporite beds of the Opeche and Spearfish Formations account for most of the thickness variations within this sequence.

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 Fox Hills and overlying formations of this sequence are exposed in these counties and will receive individual attention.

The Inyan Kara Formation is an aquifer which is present at depths ranging from about 4,000 feet in southwestern Slope County to about 5,600 feet in the northeastern part of Billings County. It is quite variable in lithology reflecting its depositional environment. The lower Inyan Kara represents non-marine deposition while the uppermost beds seem to represent a marine phase of the advancing Lower Cretaceous seas and the contact with the overlying Skull Creek Shale is gradational. Sandstone units within the Inyan Kara are variable in thickness and are present at various horizons (pl. 2).

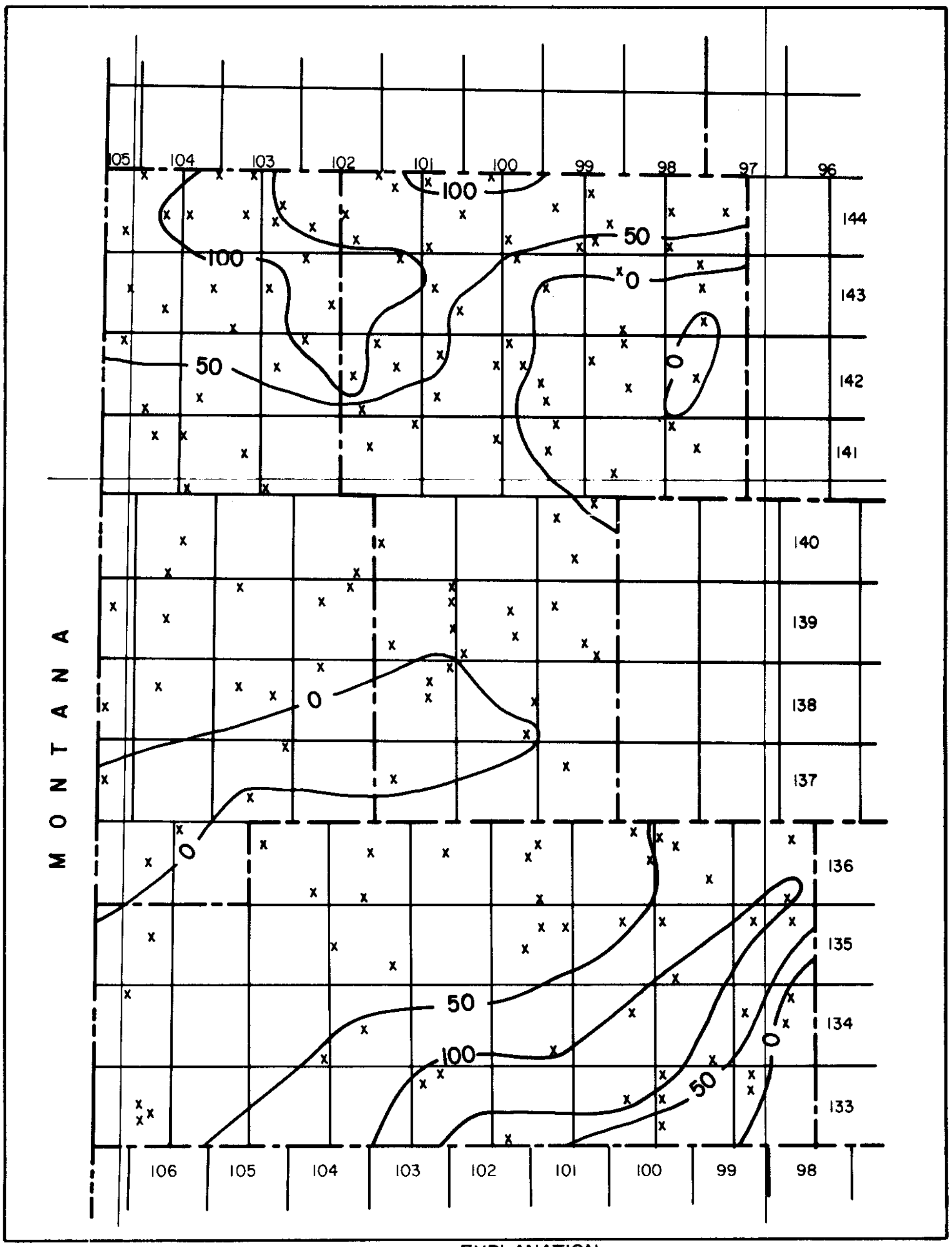
The Newcastle Formation is extremely variable in thickness and distribution (fig. 4). In areas of greatest thickness there is usually a well-developed sandstone at the base (e.g., NDF 7216, pl. 2) with gamma-ray characteristics which indicate a general fining upward. Electric logs usually have a normal self-potential through the Newcastle Formation, whereas the self-potential may be reversed through the Inyan Kara Formation. This indicates that the water in the Newcastle is generally more saline than that in the Inyan Kara.

SURFACE - SUBSURFACE

Fox Hills Formation

Waage (1968) reviewed usage of Fox Hills. Based on his studies of outcrop areas in South Dakota, which extended into North Dakota, he proposed a reference area and subdivision into three members with type sections in South Dakota. In the lower Fox Hills he used the Trail City and Timber Lake Members, defining the Trail City as a clayey silt and clayey sand member overlain by sandstone of the Timber Lake Member. He showed the Trail City thinning northeastward, so that it is of doubtful use. His Timber Lake Member thinned southwestward, so that in the western part of his study area the Trail City Member was overlain by upper Fox Hills, which he designated as the Iron Lightning Member. He divided the Iron Lightning Member into Bullhead and Colgate lithofacies, but these have generally been treated as members of the Fox Hills (Feldmann, 1972) and a four-member subdivision of the Fox Hills seems to be useful in south-central North Dakota (Carlson, 1979, 1982, 1983, Bluemle et al., 1980).

The Fox Hills Formation is exposed in the southwesternmost corner of Slope County, but is better exposed in Bowman County. In that area Hares (1928) divided the Fox Hills into an upper, light-gray, massive crossbedded sandstone (Colgate Member) and a lower, brown, fine-grained, calcareous sandstone member separated by a thin shale. He (p. 17) provided a measured section (sec 18, T132N, R106W) where a complete section is given as 60 feet, 2 inches. Feldmann (1972) also



EXPLANATION
Contour Interval - 50 feet
Control Point - x

Figure 4. Isopachous map of Newcastle Formation.

recognized two members in this area, the Colgate and Timber Lake Members. He (pl. 1) showed a thickness of about 80 to 90 feet for surface sections in Bowman County and notes that the contact with the underlying Pierre is gradational through a ten-foot section of shale and siltstone. Carlson (1979) referred to this transition zone as the Trail City Member of the Fox Hills Formation. He then used a three-member subdivision for the outcrop sections and a four-member subdivision through the subsurface of Bowman, Adams, Grant, and Sioux Counties (Carlson, 1979, 1982).

In southeastern Slope County the Fox Hills may be divided into four lithologic units which, in ascending order, are the Trail City, Timber Lake, Bullhead, and Colgate Members (pl. 3). The Trail City Member is a silty shale transition zone, which ranges from a few feet to about 30 feet in these counties. The Timber Lake Member consists of a predominantly sandstone unit, which thickens northwestward in a facies relationship with the overlying Bullhead Member. The Bullhead Member consists of interbedded sandstone, siltstone, and mudstone, which thins northwestward, pinching out northward in Golden Valley County. The Colgate Member of variable thickness is a sandstone unit at the top of the Fox Hills Formation. It represents the regressive shoreline facies of the Late Cretaceous sea.

The contact between the Fox Hills and Hell Creek Formations is poorly exposed in Slope County, so interpretations are based on the good exposures nearby in Bowman County. In that area (Carlson, 1979, fig. 7) the lower part of the Hell Creek consists of carbonaceous sandstone interbedded with carbonaceous and bentonitic mudstones lying on light-gray sandstone of the Colgate Member. In the subsurface a unit of interbedded sandstone and mudstone overlying sandstone has been used to define the Fox Hills-Hell Creek contact (pls. 3, 4). The Fox Hills gradually thickens into the subsurface to 120 to 150 feet in southern Slope County and attains a maximum thickness of about 180 to 220 feet in eastern Billings and northeastern Slope County.

Hell Creek Formation

The Hell Creek Formation is exposed in southwesternmost Slope County with good exposures of most of the formation; however, the complete formation is not exposed at any one locality so the thickness must be based on composite sections. Hares (1928) used Hell Creek as a member of the Lance Formation which he characterized as dark-gray and brown, variable, non-persistent sandstones and shales with a thickness of about 575 feet in the Marmarth area. Frye (1969) thought that he could recognize units within these strata and proposed a five-member subdivision for the Little Missouri area with type sections for three of the members in Slope County. In ascending order he named these members: Little Beaver Creek, Marmarth, Bacon Creek, Huff, and Pretty Butte. He described the Little Beaver Creek as mostly thin lignitic sandstones and shales. The Marmarth was described as two thick channel sandstone bodies separated by a thin sequence of bentonitic and lignitic shales. The Bacon Creek was described as bentonitic and lignitic shales with occasional sandstone channels. The Huff was described as variable lithologies but characterized by channel sandstones. The Pretty Butte was described as bentonitic beds that are usually about 25 to 35 feet thick. Frye (p. 22) estimated a thickness of 450 feet for the Hell Creek in southwestern Slope County.

Exposures of the Hell Creek Formation consist of sandstone, siltstone, mudstone, and carbonaceous and bentonitic shales which are characterized by a lack of lateral persistence of beds. Colors are generally drab shades of brown and gray so these strata have been referred to as the "somber beds." The thicker sandstones generally consist of fine-grained crossbedded sandstone with carbonaceous material and large clasts suggesting relatively rapid deposition and poor sorting by large streams.

The upper contact of the Hell Creek in outcrop sections has been placed at the base of the first persistent lignite which has also been used as the base of the Tertiary system. Dinosaur fragments are common in the carbonaceous and bentonitic beds in the uppermost portion of the Hell Creek Formation, but have not been found above the first persistent lignite. A lack of density logs makes recognition of this horizon difficult in the subsurface, but a combination of gamma-ray characteristics suggestive of lignite on a mudstone section have been used to extend this contact through the subsurface in these counties. Using these criteria, the Hell Creek thins northward from around 450 feet in southern Slope County to about 275 feet in northern Golden Valley and Billings Counties.

The Hell Creek Formation represents fluvial or deltaic deposition near the margin of the Late Cretaceous seas. There are rapid lateral facies changes so the members proposed by Frye are difficult to trace away from their type sections even in areas of good exposures. Subsurface sections (pls. 3, 4) show the same lack of continuity of beds noted in surface sections (fig. 5). Thick sandstone units, which are probably channel sandstones, are present at various horizons within the overall sections rather than as correlatable Marmarth and Huff Members so the member designations have not been used in this report.

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 south-

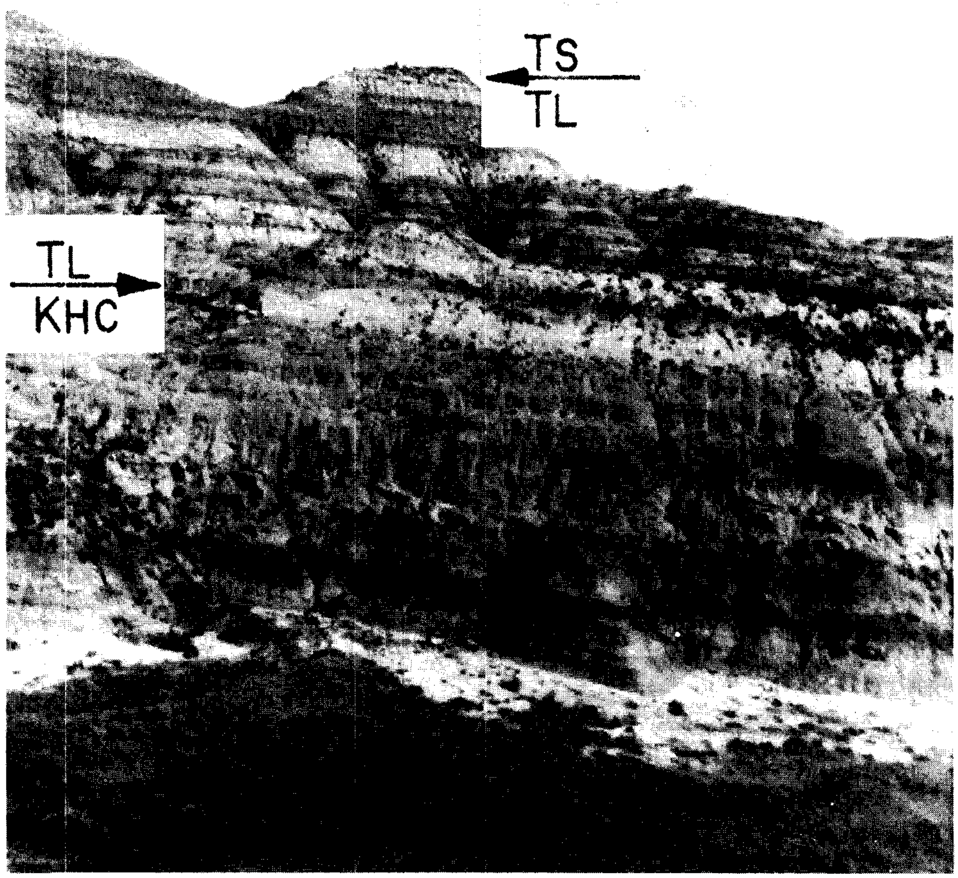


Figure 5. View looking northwest at Pretty Butte in NEsec 16, T134N, R106W, Slope County. T-Cross clinker caps butte. Ludlow Formation and upper part of Hell Creek are present.

western North Dakota and northwestern South Dakota. As the Cannonball thins westward it is replaced by a thickening wedge of non-marine strata and the facies equivalency has been generally accepted, although the details have not been entirely clear.

Leonard (1908) referred to the Lower Fort Union as dinosaur-bearing somber beds, which he also called the "Yule group" of coal beds, in his studies along the Little Missouri River. The "Yule group" includes coal beds A through F. Leonard (1925, pl. 4) used the term Ludlow lignitic member of the Lance for strata extending upward through coal bed H of his overlying "Great Bend group" of lignite beds.

Hares (1928) used the Ludlow lignitic member of the Lance in his Marmarth field study to include the coal beds up to a massive sand which was about 60 feet below Leonard's H bed. He recognized the lateral equivalency to the Cannonball and noted some brackish water beds about 100 feet above the T Cross bed, which he considered to be the marginal phase of a sea to the east. He also noted that the Ludlow along the Little Missouri is more somber than at its type area in South Dakota and suggested that this might explain the placing of the Lance-Fort Union contact at different horizons by different geologists.

Moore (1976) made a detailed study of the Ludlow strata in the Slope County area. He noted a variety of color within the "somber beds" and stated that placing an upper contact based solely on color was difficult. He noted a widespread white "siliceous zone" at the horizon of the base of Leonard's H bed which he thought was more useful than the massive sandstone, and he used this bed as the uppermost bed of his Ludlow Formation (fig. 6). This white "siliceous zone" has been traced southeastward through Bowman and Adams Counties (Carlson, 1979). Eastward scattered exposures of the same marker bed have been used to extend this contact through Grant and Morton Counties (Carlson, 1982, 1983).

Moore (1976) divided the Ludlow of the Little Missouri area into lower and upper units. The lower unit contains only thin coals and numerous sandstones and is generally somber-toned with some yellow beds. The upper unit has the T Cross bed at the base and several thicker coals as well as more buff and yellow beds. The brackish water "oyster beds" are about 150 feet above the T Cross bed which marks the base of this upper unit. Frye (1969) referred to the strata of Moore's lower unit as the Tullock Formation and used Ludlow Formation for Moore's upper unit.

Clayton and others (1977) noted problems with previous usage of the terms Ludlow and Tongue River in western North Dakota and adjacent states and suggested a revision of usage of these terms (fig. 6). They recommended that Ludlow be used for the strata between the Hell Creek Formation and the top of the T Cross bed. Since the T Cross bed is overlain by a brackish water clay the Ludlow of this area is then restricted to an eastward thinning wedge of lignite-bearing strata between the Cannonball and Hell Creek Formations. This is consistent with the original concept of Ludlow and is herein accepted for this report with the exception of placement of the T Cross bed. Retaining T Cross in the upper unit as Moore did has the advantage of placing the thicker lignites in the same unit, and avoids problems where splits occur in the bed. Since mapping often involves the base of the associated clinker zone, using the base of the T Cross as the top of the Ludlow is a more satisfactory mapping horizon.

The Ludlow Formation, as thus defined, is well exposed in the badlands areas along the Little Missouri River in south-western Slope and southern Golden Valley Counties. A complete section is exposed at Pretty Butte (fig. 5) where Frye measured

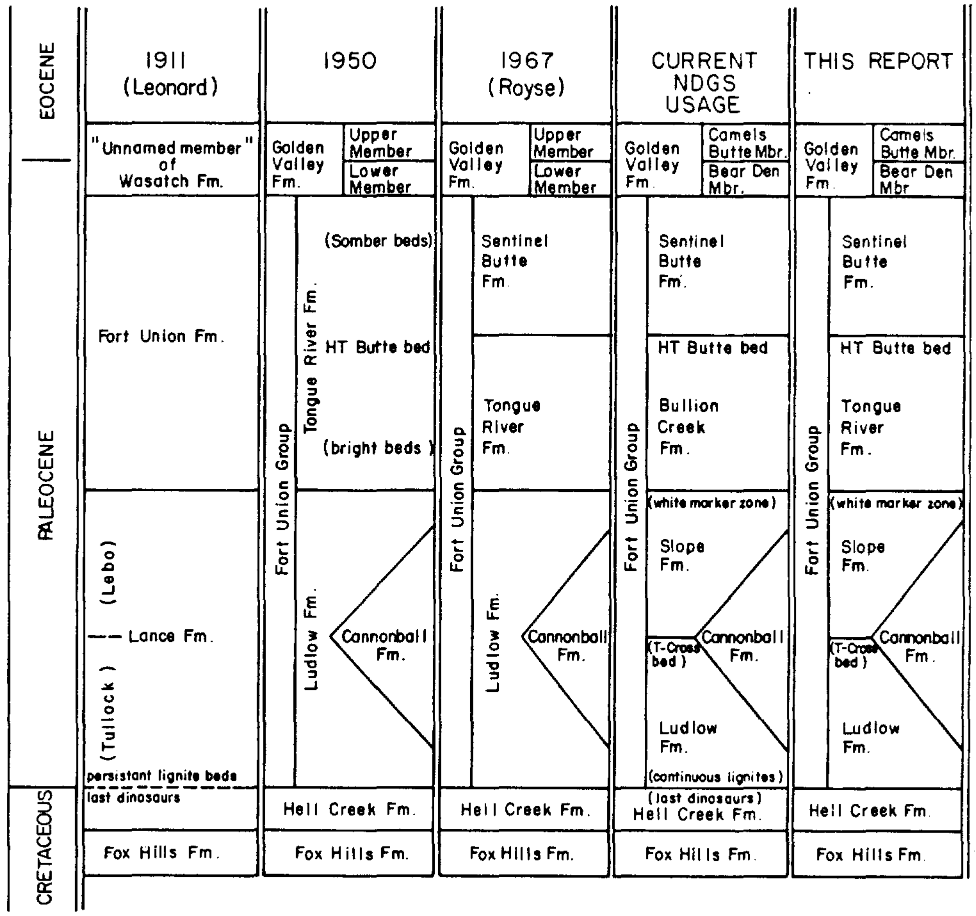


Figure 6. Historical summary of nomenclature applied to Paleocene strata in western North Dakota.

a thickness of 160 feet (p. 50-52) for his Tullock Formation. Moore (1976, fig. 2) lists a thickness of about 240 feet for his lower unit or Ludlow of this report. Although this formation was deposited in fluvial and swamp environments, individual units have lateral persistence over considerable areas which contrasts sharply with the underlying Hell Creek Formation. In the present study area, the Ludlow Formation is generally from 200 to 280 feet thick.

At the surface, the Ludlow consists of thin lignites alternating with layers of generally gray- or brownish-hued silt, clay, and sand. Similar lithologies are noted in the subsurface except that, based on the log of one well, one thick lignite bed is present to the north. The thicker sandstone units, noted at various horizons within the Ludlow (pls. 3, 4), are channel sandstones. These sandstone units were deposited by streams of lesser capacity than the sandstone units of the Hell Creek Formation.

Cannonball Formation

The term Cannonball Formation was introduced by Lloyd (1914) to apply to about 250 to 300 feet of marine strata exposed along the Cannonball River in Grant County. These marine or brackish-water strata intertongue westward with non-marine strata of the Ludlow and Slope Formations. Consequently, only a few feet of brackish-water strata are present in exposures along the Little Missouri River. These are recognized as Cannonball Formation in outcrop areas in the three counties. One tongue of brackish-water clay is present just above the T Cross bed and a second tongue is an oyster-bearing clay about 150 feet above the T Cross bed. The lower tongue is only a few feet thick whereas the upper tongue is about 5 to 20 feet thick. To the east, in the subsurface in eastern Slope and Billings Counties, the Cannonball Formation strata are about 150 to 200 feet thick.

Slope Formation

The problems of previous usage of Ludlow led Clayton and others (1977) to restrict the Ludlow of this area to the strata from the T Cross bed to the Hell Creek Formation. This left the section from the T Cross bed to the H bed, previously called upper Ludlow (Moore, 1976), or included in the Ludlow (Hares, 1928), as an unnamed interval. Therefore, they (p. 7) introduced the term Slope Formation to apply to these strata. The term Slope Formation is herein accepted for this report, but the base is placed at the base of the T Cross bed rather than the top of that bed.

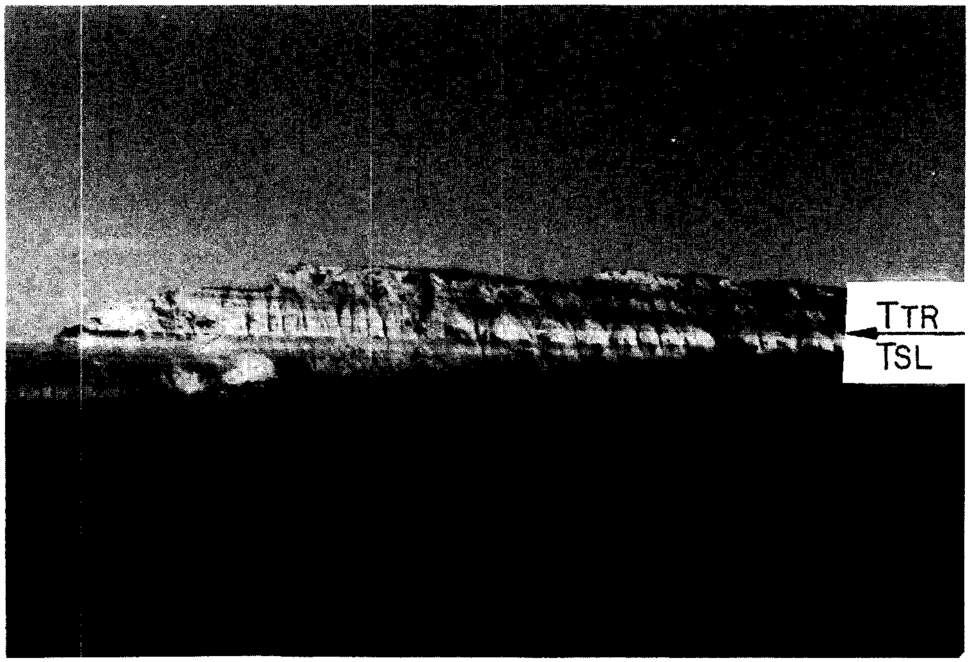


Figure 7. View looking east at white "siliceous zone" in sec 29, T135N, R102W, Slope County.

The Slope Formation, as thus defined, is exposed east of the Little Missouri River in western Slope County (fig. 7) and across the river through southern Golden Valley County. A complete section is not exposed at any one locality, so the thickness must be based on composite sections. Moore (1976, fig. 2) has a composite section of about 335 feet for the Slope (his upper Ludlow) in western Slope County where the tongues of Cannonball are included in the composite section. Traced into the subsurface the interval from the white "siliceous zone" to the base of the T Cross bed is as much as 350 feet thick. The white "siliceous zone" present at the surface is noted on electric logs as a high resistivity zone on the cross sections (pl. 5).

The Slope Formation consists of interbedded sand, silt, clay, and lignite of generally somber hues with some buff and yellow colors. Generally the sandstones are the brighter colored beds. Lignites which are present at strippable depths and thicknesses are the T Cross bed at the base and the Yule bed in the upper part of the formation. There are other lignites present which Moore (1976, fig. 2) referred to as, in ascending order: the lower pair, upper pair, and oyster lignites. Subsurface information (pls. 3, 4) indicates that these lignites might be recognized in test hole 4813 but correlation northward is not apparent. However, the observation of thicker lignites in the interval from the T Cross to the white "siliceous zone" appears to extend through the subsurface.

Tongue River Formation*

Leonard (1908, pl. XII) used the term Middle Fort Union to refer to buff and light-gray shales and sandstones of the Great Bend, Medora, and Beaver Creek groups of coal beds along the Little Missouri River. The upper contact was placed at the base of bed R, and, except for the minor differences previously noted regarding the contact with the underlying Slope (Ludlow), subsequent workers have found his unit useful as originally defined. Thom and Dobbin (1924) in their regional study of Tertiary strata extended the term Tongue River (type area, northeastern Wyoming) to refer to these brighter colored strata in North Dakota. Hares (1928, fig. 1) then used the term Tongue River Member of the Fort Union Formation in the Marmarth area and introduced the term HT Butte lignite (= bed R) as the lignite bed at the color contact. Subsequent workers have generally recognized these strata as a mappable unit and have used Tongue River for these strata in North Dakota (Hanson, 1955; Royse, 1967; and Jacob, 1976). Clayton and others (1976, p. 10) introduced the term Bullion Creek to refer to these strata because of uncertainties of correlation between the North Dakota and Wyoming exposures of Fort Union strata and perceived differences of usage in different areas. Recent field reconnaissance indicates that the bright-colored beds of the Williston Basin are essentially equivalent to those in the Powder River Basin. Extension of the term "Tongue River" to Leonard's Middle Fort Union as originally proposed and commonly used is satisfactory. There is no need for a new term so the term Tongue River is herein retained for this report.

As thus defined, the Tongue River Formation consists of light-colored beds of sand, silt, clay, and lignite between the "white siliceous" bed and the HT Butte lignite. These strata are present at the surface in most of Golden Valley County and through central Slope County. They are well exposed in the badlands areas adjacent to the Little Missouri River (fig. 8), but a complete section is not exposed at any one locality so the thickness must be based on composite surface sections and subsurface interpretations. Surface studies have generally consisted of using lignite beds as markers and then constructing a stratigraphic column based on lignite beds and the inter-

---

* 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.

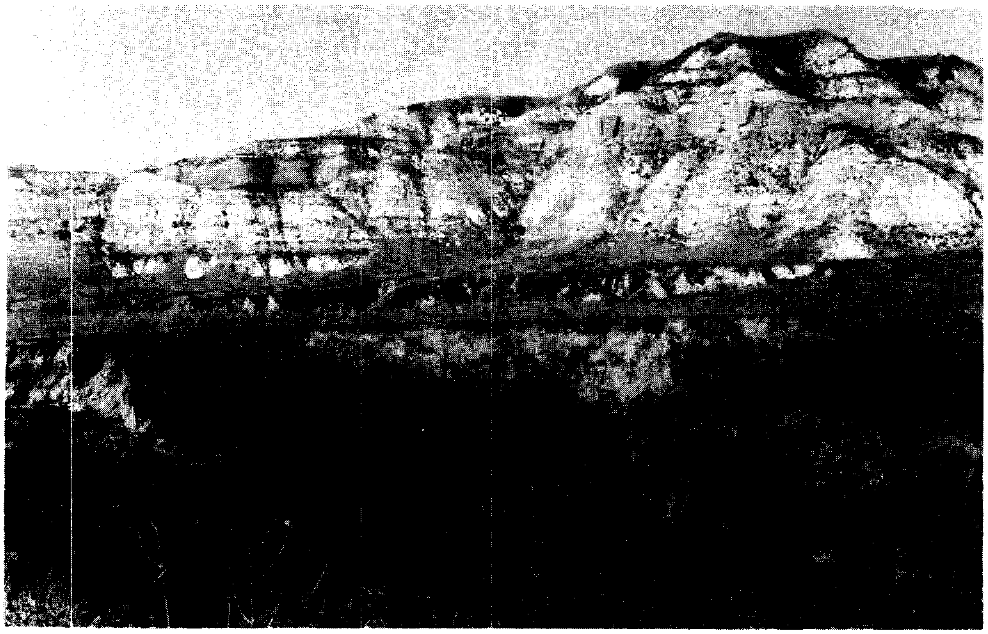


Figure 8. View looking north at Tongue River Formation in sec 1, T139N, R102W, Billings County. HT clinker caps ridge. Sully Creek is cutting into alluvial fill in foreground.

vals between these beds. Leonard (1908, pl. XII) includes 11 lignite beds, which he referred to as beds G through Q, within his bright-colored, or Middle Fort Union (= Tongue River) strata. Based on measured sections and correlations between sections he estimated a thickness of about 500 feet (p. 61) for these strata.

Hares (1928, p. 47) listed a thickness of about 600 feet for the Tongue River on his generalized stratigraphic column based on his studies of the area from T138N and southward. He placed his lower contact at the base of a sand about 60 feet lower than Leonard's H bed. He noted five lignite beds within these strata which he referred to as, in ascending order: H, Hansen, Harmon, Garner Creek, and Meyer beds. In a measured section (sec 24, T137N, R103W, p. 33) he listed a thickness of about 346 feet for the interval from the HT Butte bed through the Harmon bed. This would indicate that Tongue River strata are not more than about 500 feet thick in this area. He referred to a 3-foot 2-inch lignite bed 175 feet above the Harmon bed as the Garner Creek bed. There were no other lignite beds noted in that section.

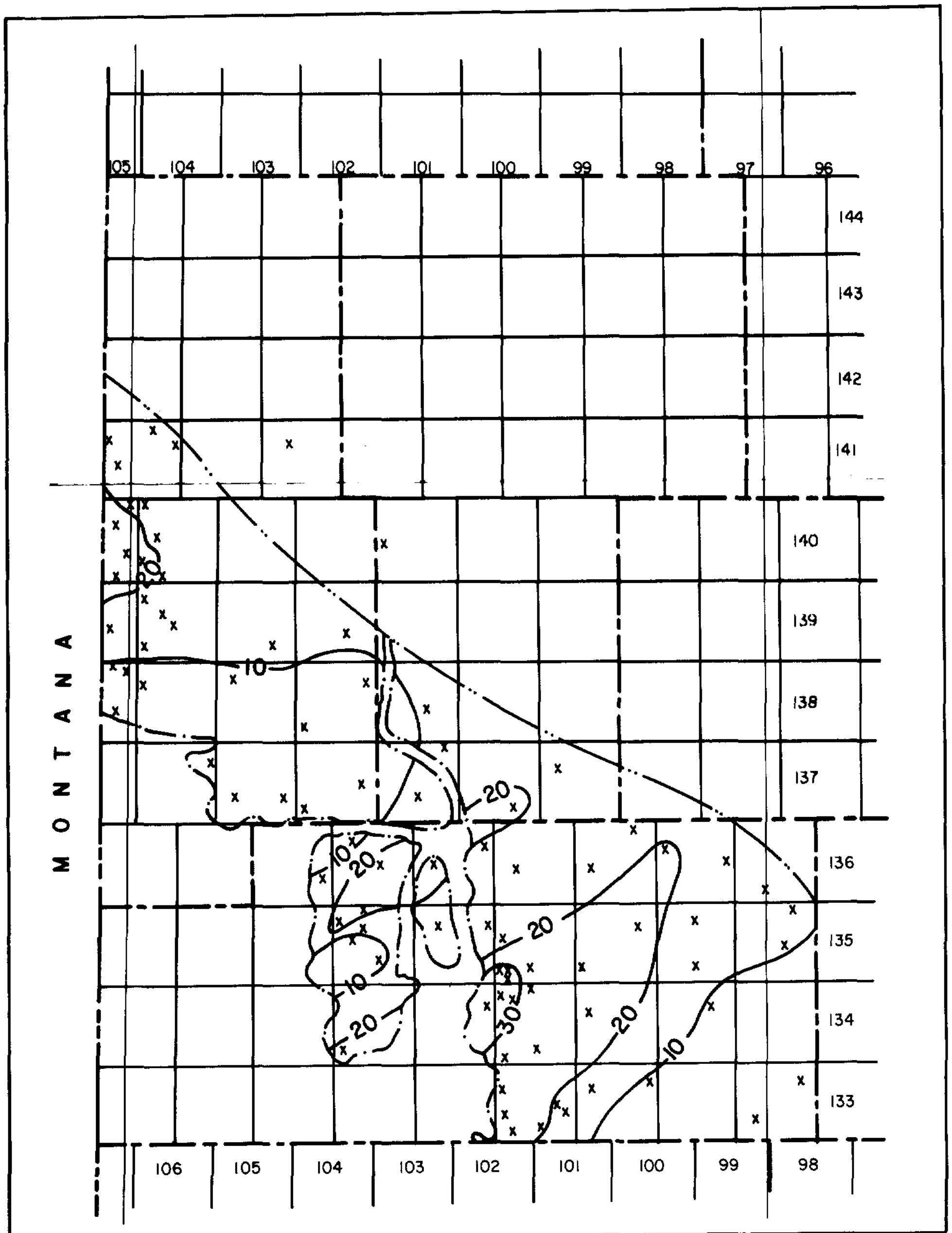
Subsequent studies of these strata in this area have either used letter designations or have used the names Hares introduced to refer to the lignite beds. Subsurface information obtained from the groundwater study supplemented by gamma-ray and density logs of oil or lignite exploration test holes now provide a better understanding of these strata. They show that a thickness of about 500 to 520 feet in areas along the Little Missouri River are in close agreement with the estimates based on early field studies. However, the number of lignite beds present is generally fewer than might be expected from stratigraphic columns based on surface studies. Subsurface information also shows wide variations in numbers and thickness of lignite beds in different areas as well as problems of correlation across the area. In general, test holes which contain thick sandstone units have fewer and thinner lignites while wells lacking sandstones have thicker and more numerous lignite beds. This is best illustrated by test holes 4915 and 4921 (pl. 5) where there are numerous and few lignite beds, respectively. Tongue River strata thin southeastward to less than 400 feet in southeastern Slope County.

The key bed in the lower Tongue River is the Harmon bed which varies from about 80 to 150 feet above the base. The variation reflects the lithology of the intervening strata with the thicker sections being those with prominent sandstone beds. The Harmon bed is readily correlatable along the subcrop (fig. 9) with thick areas where it is one bed separated by areas where it thins and splits with clay partings. The maximum thickness is about 36 feet in the area (secs 5, 6, 7, and 8, T134N, R101W). It is also more than 30 feet thick in the area near Beach. In both of those areas it is near enough to the surface to be of economic interest by strip mine methods. The thicker area that extends from Slope County into southwestern Billings County is an area of considerable topographic variation, so it is not as attractive. Northward the correlation is not so firm but a thicker bed at depth has been interpreted as the Harmon bed.

A well-developed lignite bed, which Hares referred to as the Hansen bed, occurs in the outcrop areas along the Little Missouri River and extends into the subsurface in western Slope County. In some areas it splits into a zone of thin beds, and in some areas there are no lignite beds between the Harmon and the base of the Tongue River.

Gamma-ray logs in the Flat Top Butte area (pl. 4) indicate that the interval from the Harmon to the HT Butte bed is about 430 feet. Three lignite beds in the 3- to 5-foot-thick range occur in this interval. The thickest is a 5-foot bed about 160 feet above the Harmon, or in the approximate position of the Garner Creek bed of Hares.

In the Tracy Mountain area, test hole 98 (pl. 5) begins in clinker of the HT Butte bed. The 20-foot lignite at a depth of about 380 feet is correlated as the Harmon bed. Three beds greater than 4 feet occur in the intervening 360-foot interval, a 5-foot bed 125 feet above the Harmon, a 4-foot bed about 165



EXPLANATION
Contour Interval - 10 feet
Control Point - x
Erosional Limit
Limit of Close Control

Figure 9. Isopachous map of Harmon bed.

feet above the Harmon, and a 5-foot bed about 200 feet above the Harmon.

In the Franks Creek area, test hole 73 (pl. 5) has the HT Butte bed present at a depth of 86 feet. A 19-foot-thick lignite at a depth of 420 feet may be correlated as the Harmon bed with no lignite beds thicker than 2.5 feet in the intervening 315 feet, or more probably is a lignite bed higher stratigraphically that has thickened in this area.

In northern Billings County only thin lignite beds are present in the upper 300 feet of Tongue River strata.

Sentinel Butte Formation

Leonard (1908, pl. XII) used the term "Sentinel Butte group" for coal beds R through U in his Upper Fort Union of the Little Missouri area. He characterized the intervening beds as dark-gray shales and sandstones. Thom and Dobbin (1924) used Sentinel Butte shale as a member of the Fort Union (?) when referring to equivalent strata and considered these strata as equivalent to the Intermediate coal group of northern Wyoming and part of the Wasatch Formation of that area. Hares (1928, p. 39) used Sentinel Butte shale as a member of the Fort Union (?) Formation for these same strata in the Marmarth area. Subsequent workers have recognized these darker colored beds as a mappable unit as originally defined in this area and have either referred to them as the Sentinel Butte facies (Fisher, 1954) or member (Hanson, 1955) of the Tongue River Formation, or as a formation (Royse, 1967) of the Fort Union Group (fig. 10). Recent North Dakota Geological Survey usage has favored usage as a formation (Jacob, 1975, 1976; Clayton and others, 1977; Carlson, 1979). Royse (1967, p. 7) refers to a basal sand unit of the Sentinel Butte. However, in most areas where the lignite has not burned it is overlain by silt or clay except where a channel sand is present. Even where thick clinker is present it may be determined to be baked clay or silt. In Golden Valley County a channel sand has cut through the thin HT Butte bed at at least one locality in T143N, R103W and is present in section 17, T142N, R102W (fig. 11). Along the Blacktail Creek road and along Sullys Creek are other areas where a channel sand is present at the base of the Sentinel Butte.

These strata are well exposed in the badlands areas along the Little Missouri River in Billings County. They are present at the surface in most of the upland areas in Billings County and eastern Slope County. In Golden Valley County complete sections are present in the high buttes, but elsewhere only remnants of the lower part of the formation are found. The remnants in the northeastern part of the county provide a

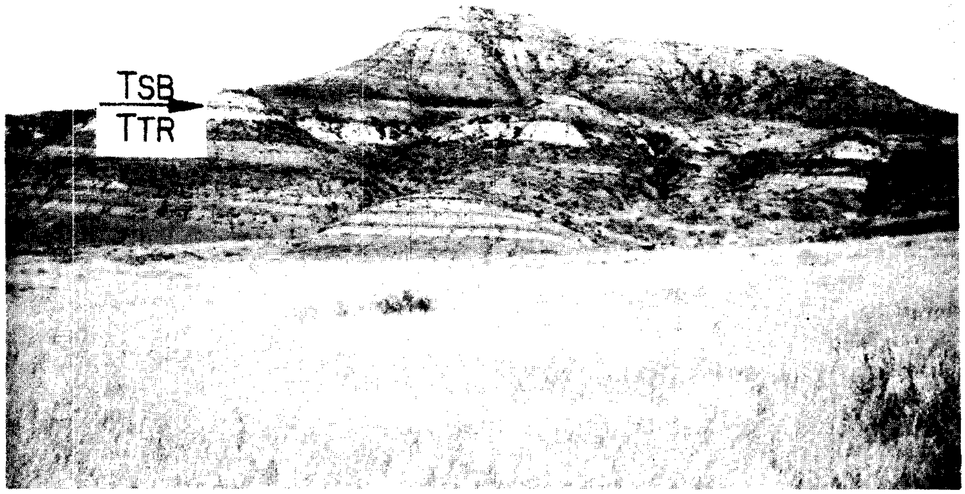


Figure 10. View looking southwest toward Camels Hump Butte, sec 10, T140N, R104W, Golden Valley County. Sentinel Butte-Tongue River contact on lower slope.

unique opportunity for detailed study of the lower contact of the Sentinel Butte.

The lignite bed at the color contact has variously been referred to as the R (Leonard, 1908, 1925), HT Butte (Hares, 1928; Royse, 1967), or L (Fischer, 1954; Hanson, 1955) bed in this area and placed either at the top of the Tongue River Formation or at the base of the Sentinel Butte Formation. Since this bed was originally included in the "Sentinel Butte group" of coal beds and mapping is often done on the basis of the base of the clinker, I prefer to include the HT Butte bed in the Sentinel Butte Formation. The HT Butte bed, or the clinker where it has burned, can be traced continuously from the northern border of Billings County, where it is just a few inches thick, to the area northwest of Amidon. The maximum thickness is about 25 feet (fig. 12). The thick clinker at the contact on both sides of the river and subsurface control indicate that the central part of the swamp was in areas now eroded. The HT Butte bed thins rapidly northwestward and then may be traced for long distances as a thin bed in surface sections. Extension through the subsurface of northeastern Billings County is tenuous (pl. 5).

Complete sections of the Sentinel Butte are present in the Fairfield area in northern Billings County where the Sentinel Butte is conformably overlain by the Golden Valley Formation.

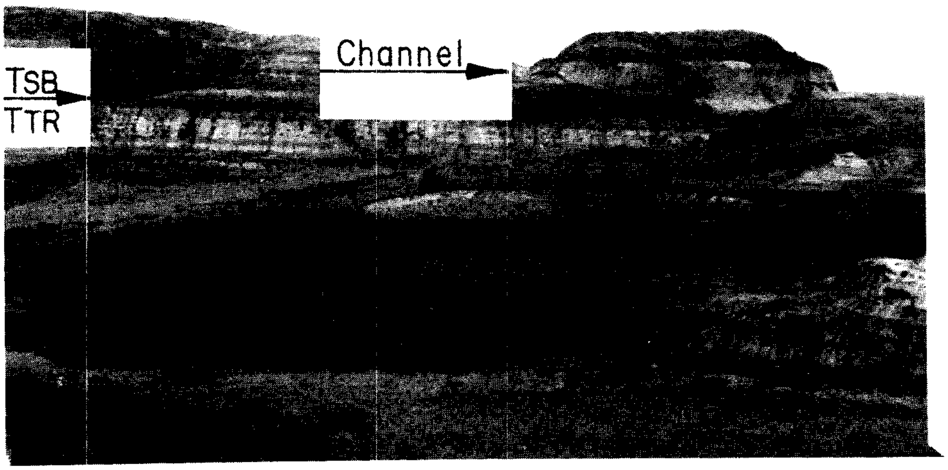
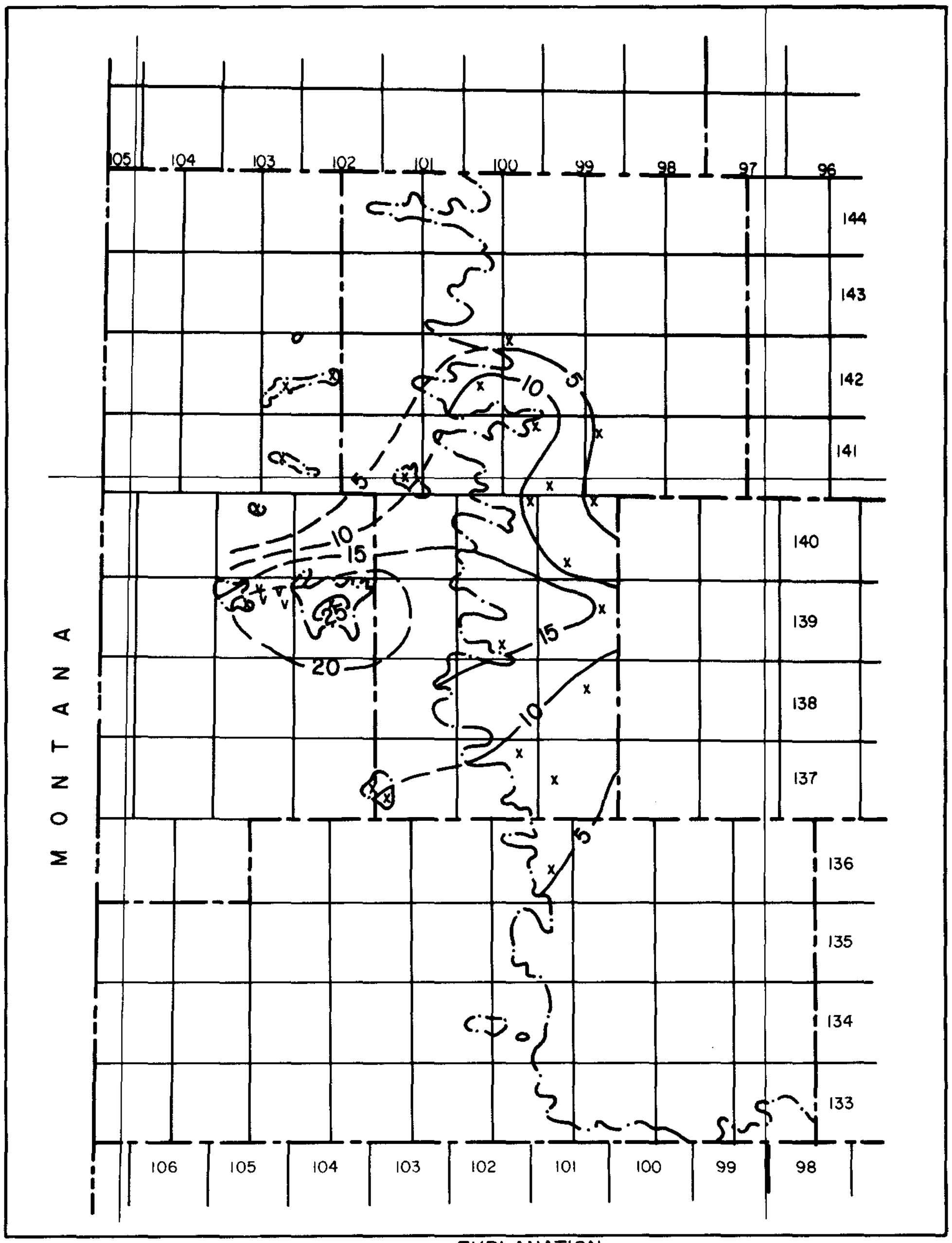


Figure 11. View looking northeast in SWsec 17, T142N, R102W, Billings County. Sentinel Butte-Tongue River contact in foreground. Channel sand cutting through lower strata of Sentinel Butte Formation on right.

The contact with the underlying Tongue River is exposed about 10 to 12 miles west of this area, so subsurface correlations are necessary to determine the thickness in this area. The HT Butte bed appears as a split bed in USGS-33 (pl. 5) with the split beds thickening eastward to USGS-36. Based on these correlations and the elevation of the Golden Valley-Sentinel Butte contact in T144N, R99W, a complete section is about 500 to 520 feet thick in northern Billings County. In that area most of the lignite beds are thin (less than 3 feet) and are not easily traced through the subsurface.

Good exposures of the Sentinel Butte Formation occur on the flanks of Sentinel and Bullion Buttes where the White River Group lies unconformably on the Sentinel Butte Formation. The Sentinel Butte Formation is poorly exposed around Flat Top Butte, but logs from an oil exploration test (pl. 4, NDF 8085) penetrate the complete section and show a thickness of about 410 feet. A 7-foot-thick lignite bed lies about 215 feet above the base of the formation. Otherwise there are only thin (less than 3 feet) lignites are present in this well.

A complete section of the Sentinel Butte Formation is exposed on the southwest side of Bullion Butte in the SENWsec 13, T137N, R103W. At that locality the Sentinel Butte is about



EXPLANATION
Contour Interval - 5feet Contours - Original Extent ———
Erosional Limit —·—·— Current Extent ———

Figure 12. Isopachous map of HT Butte bed.

425 feet thick and the HT Butte bed is about 13 feet thick. A 22-foot-thick lignite bed is found about 310 feet above the HT Butte bed which Hares referred to as the Bullion Butte bed. There is also a 6-foot-thick lignite about 60 feet above the Bullion Butte bed. Otherwise lignite beds are less than 3 feet thick. Three sandstone units, which are each about 60 feet thick, and another which is about 30 feet thick, are found at this locality.

In the Sully Springs area (T139N, R101W), nearly 300 feet of the Sentinel Butte are exposed between the HT Butte bed and the surface of the upland areas to the east. A 5-foot-thick lignite is present about 200 feet above the HT Butte bed; otherwise only thin lignites (less than 3 feet) are present in this area. Large petrified stumps are present about 60 feet above the HT Butte bed. The same zone is present in Theodore Roosevelt Park in T141N, R102W and is referred to as the petrified forest.

Petrified wood is common at various horizons within the Sentinel Butte Formation, whereas it is rarely found in the Tongue River Formation. Mollusk fossils, which are common to various horizons of the Tongue River, are rarely found in the Sentinel Butte except for one horizon. In northeastern Golden Valley County and extending into southern McKenzie County is a zone about 30 feet above the HT Butte bed which commonly contains gastropods and pelecypods. The Twin Buttes area is a good collecting locality.

In southern Billings County some thicker lignite beds are found in the lower part of the Sentinel Butte Formation. The terms Fryburg, Heart River, and Lehigh have been applied to these beds (Leonard, 1925). The Fryburg bed is about 60 feet, the Heart River bed about 130 feet, and the Lehigh bed about 200 feet above the HT Butte bed.

The Sentinel Butte Formation has been thinned by erosion to about 270 feet in the Chalky Buttes area where it is unconformably overlain by the White River Group. In this area, a paleosol of the pre-Oligocene surface has been preserved and is well exposed near Amidon (fig. 13).

Golden Valley Formation

The Golden Valley Formation was named by Benson and Laird (1947, p. 1166) to apply to strata well exposed 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 usage and provided a detailed study of the lithology and distribution of these strata. He introduced the terms Camels

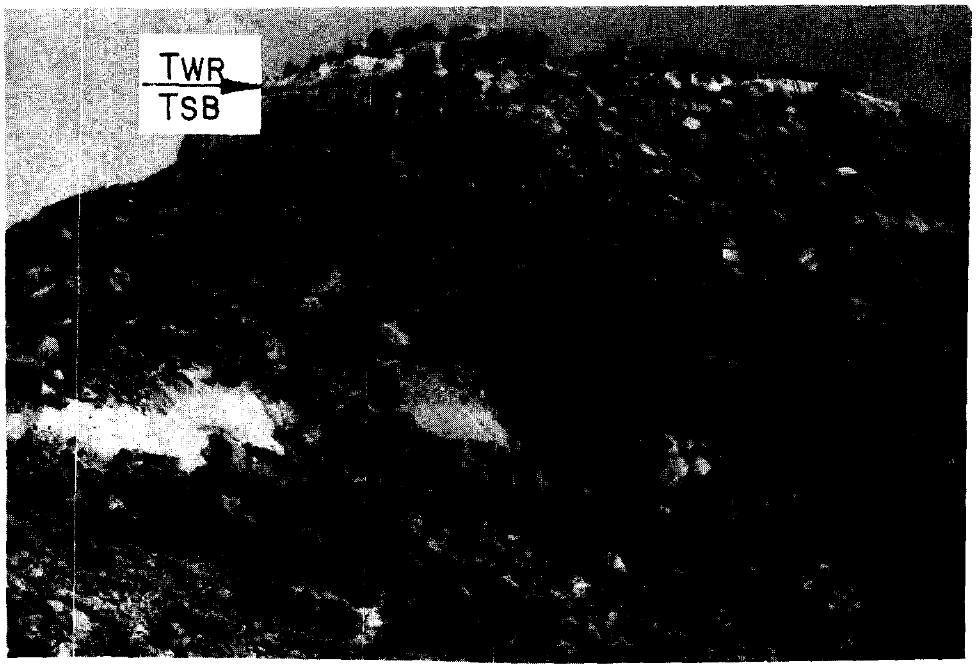


Figure 13. View looking northeast in SWsec 2, T134N, R101W, Slope County. Paleosol developed on Sentinel Butte Formation capped by White River Group.

Butte and Bear Den for the upper and lower members and designated a reference section in the type area.

In these counties exposures of the Golden Valley Formation are limited to the northeastern part of Billings County where the Golden Valley Formation has been preserved on the drainage divide in the Fairfield area (fig. 14). The best exposures are in the "breaks" at the heads of the Knife River and Little Missouri drainages. The contact with the underlying Sentinel Butte is conformable and gradational where exposed, but is generally poorly exposed in this area.

The Bear Den Member has its typical three-unit subdivision. The lower unit is light-gray, silty clay in some areas, but in the area southwest of Fairfield also includes purplish-gray, carbonaceous sand. The middle unit consists of very light gray, silty, "soapy" clay which weathers to a bright orange. The upper unit consists of purplish-gray, silty clay which in the Fairfield area is capped by a yellowish-gray siliceous bed which Hickey (1976) termed the Taylor bed. Because of its resistance to erosion it caps broad flat areas near Fairfield and is present as lag deposits on slightly lower elevations in nearby areas.

The Camels Butte Member is limited to just a few remnants on the highest part of the divide in the area northeast of

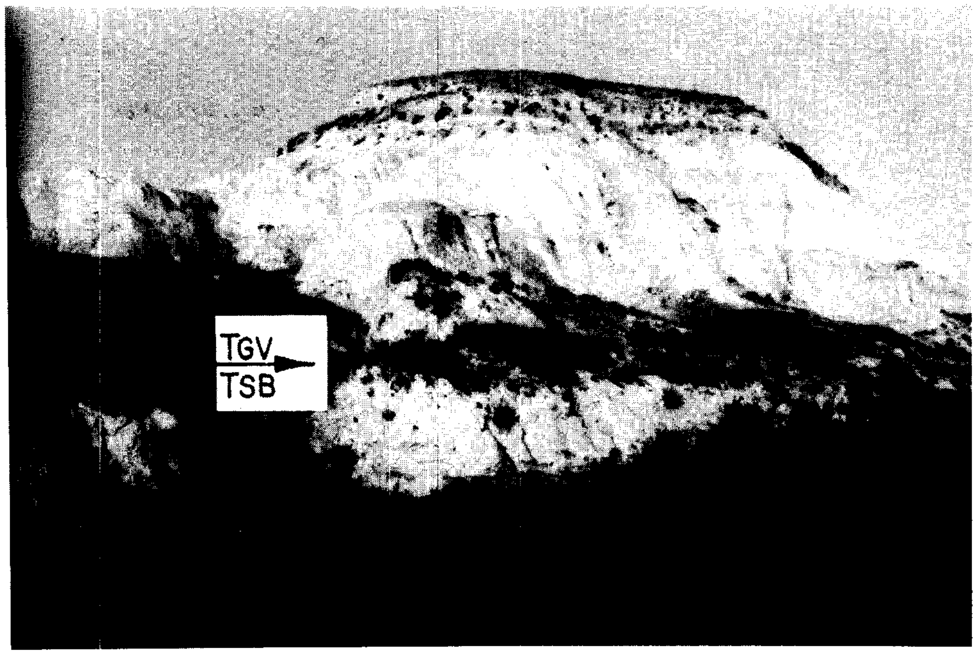


Figure 14. View looking west in SWsec 2, T143N, R99W, Billings County. Golden Valley Formation exposed in butte. Upper Sentinel Butte in lower foreground.

Fairfield. At these localities it consists of thin alternating beds of silt and silty clay which represent interchannel deposits. In some areas of western North Dakota micaceous sandstones interpreted as channel deposits are a prominent element of this member. Studies of plant remains from this member have determined that the Eocene-Paleocene boundary should be at the base of the Camels Butte Member.

White River Group

Strata of the White River Group are exposed in the Chalky Buttes area (fig. 2) and as the caprock of the high buttes (Black, Bullion, Rainy, Sentinel, and Square) in these counties. These strata generally consist of poorly sorted clastics. Where the sandstones are cemented they are resistant to erosion and hold up the high buttes. The Chalky Buttes area is on the drainage divide. These strata are poorly consolidated and easily erodable in that area, so on the east side of Chalky Buttes there is an apron of alluvium on the underlying Sentinel Butte Formation.

The White River Group lies unconformably on the Sentinel Butte Formation except in the Rainy Buttes where some Golden

Valley Formation is present between the White River and Sentinel Butte Formations. The thickness of these strata is variable depending upon the amount of erosion in the various areas. In the Square Butte area they are about 270 feet thick. At Bullion Butte they are about 160 feet thick and at Sentinel Butte they are about 200 feet thick. In the Chalky Buttes area, about 400 feet are present at the highest point. In that area, Stone (1972) recognized the Chadron and Brule Formations and then proposed member subdivisions for these formations. The members were never formally published and are not recognized on the high buttes so they will not be used for this report.

The Chadron, or lower, Formation consists of light-colored, bentonitic and silty clay and light-colored, fine- to coarse-grained, cobbly arkose, which has been referred to as the "dazzling white" beds. The overlying Brule Formation is slightly darker in color, but generally consists of poorly sorted, poorly consolidated clastics ranging from mudstones to sandstones. These strata represent terrestrial deposits derived from uplift in the Rocky Mountain area. Volcanic activity was occurring during the Oligocene epoch and this activity accounts for the bentonitic clays and uranium mineralization noted in some of the White River strata.

Alluvium

Alluvium is present along the Little Missouri River and the tributary streams as well as smaller deposits in other areas. Generally this is the result of rapid erosion of steep slopes of the poorly consolidated strata during periods of intense precipitation. This sediment is then redeposited in the valleys of the Little Missouri River and its tributaries. The intermittent tributary streams are incised into the alluvial fill as they adjust to the current Little Missouri base level (fig. 8). The high flat areas along the Little Missouri mapped as high terraces have alluvium which has a similar origin, but was deposited when that level represented the flood plain of the river.

An area of colluvium occurs in the Chalky Buttes area where the White River Group is being washed out as a thin apron overlying the Sentinel Butte strata on the east side of the buttes.

ECONOMIC GEOLOGY

Lignite

A complete section of the lignite-bearing strata are present in parts of these counties, so lignite resources are significant, although no current production exists and previous development has been minimal. In Golden Valley and Slope Counties the only lignite mining has been small mines to supply local heating needs. The peak production was 8,862 tons in 1943 in Golden Valley County and 3,053 tons in 1938 in Slope County. The licensed mines peaked at 7 in 1937 in Golden Valley County and 11 in 1938 in Slope County. Mines near Medora were used to supply the Northern Pacific until about 1925 so production was then about 40,000 tons per year in Billings County. Subsequently, when mining was only for local needs, peak production was 2,837 tons in 1937. The last mining was in 1948 in Slope County, 1951 in Billings County, and 1968 in Golden Valley County.

The lignite resources for these counties in beds greater than 5-foot thicknesses has been estimated as about 26.3 billion tons (Brant, 1953). Slope County was credited with 13.9 billion tons in beds greater than 10 feet thick and 2.7 billion tons in 5- to 10-foot beds. Billings County was credited with 3.9 billion tons in beds greater than 10 feet thick and 3.8 billion tons in 5- to 10-foot beds. Golden Valley was credited with 2.0 billion tons in 5- to 10-foot beds.

The economically recoverable resources will be the strippable reserves until such time as in situ methods have been developed. These have generally been defined as a 10-to-1 stripping ratio with a maximum of 120 feet of overburden; however, the thicker beds in these counties might justify increasing the overburden limit to as much as 200 feet.

Strippable reserves have now been outlined in several areas of these counties (fig. 15). The most extensive deposits are in the Harmon bed, which is present at strippable depths in two general areas. The Beach area consists of deposits north and south of town and extending westward into Montana. Pollard and others (1972) estimate about 450 million tons of strippable reserves for the area south of Beach. The west Amidon area is another attractive area for development of the Harmon bed. Lewis (1979, p. 7) has estimated a reserve of about 650 million tons with less than 150 feet of overburden in that area. The Hansen bed may be a strippable reserve in an adjacent area (Kepferle and Culbertson, 1955), and the T Cross bed may be of economic interest in T133N, R104W.

Banet (1980) calculated lignite resources for T137 and 138N, R100W for 8 lignite beds greater than 5 feet thick in that area as 2.9 billion tons. He calculated strippable reserves in the Heart River and Fryburg beds, using 150 feet of overburden as a cutoff, as about 736,000 tons in these townships. Based on topography these deposits should extend into adjacent townships.

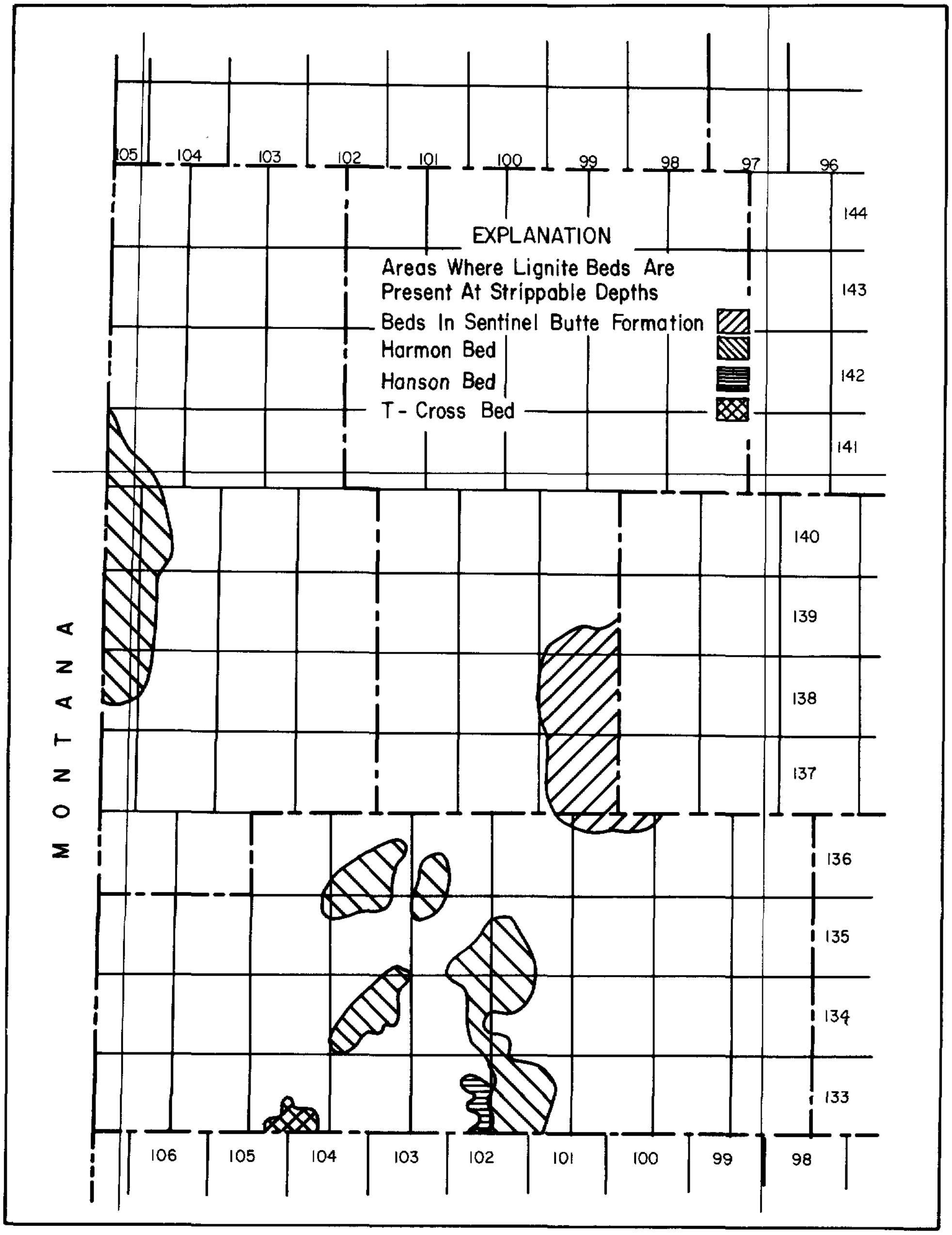


Figure 15. General areas of strippable lignite deposits.

Petroleum

Billings County became an oil producing area in 1953, Slope County in 1966, and Golden Valley County in 1969. Slope and Golden Valley Counties have been minor producing areas, and Billings County was also a minor producing area until the Little Knife and "Billings Nose" development began in 1977. Development in those areas propelled Billings County into the leading producing county in 1980 and it has remained there through 1982. The presence of a thick sedimentary section of Paleozoic rocks and known structures in the area promise further development in these counties.

Uranium

The uranium potential of this area was investigated during the mid-fifties (Bergstrom, 1956) and there was some development in this area in the early- to mid-sixties. The deposits are generally low grade, but they were economic at the time because of government incentives. There are no current developments, but when the price of uranium soared in the seventies, further exploration occurred.

The generally accepted theory is that volcanic ash in the White River strata is the source for the uranium. Subsequently uranium has been transported by water percolating through the strata downward to the lignites, carbonaceous shales, and sandstones of the underlying Golden Valley and Sentinel Butte Formations. This seems likely because uranium has an affinity for carbon, and the known deposits have been found in the lignites in closest proximity to either the surface or overlying White River strata where White River strata are present.

Previous development was limited to near-surface deposits which were developed by strip-mine methods. The lignite and carbonaceous shales were burned to reduce the bulk and then transported to processing facilities. If the sandstone deposits were to be developed they might be amenable to in situ solution mining processes, but none have as yet been attempted in North Dakota.

Sand and Gravel

Only limited quantities of sand and gravel are found in these counties, so in many areas "scoria" is used as a gravel substitute. "Scoria" is the term used for the clinker-like material where lignite has burned and baked the overlying sediment. "Scoria" is present near the surface in most areas of these counties where Fort Union strata are present at the surface.

Sand and gravel deposits are limited to terrace deposits of present or former drainages. The better gravel deposits in these counties are the high terrace deposits along the Little Missouri River. These were deposited when the river was flowing at that level prior to lowering of the base level associated with Pleistocene glaciation.

REFERENCES

Anna, L. O., 1980, Ground-Water data for Billings, Golden Valley and Slope Counties, North Dakota: North Dakota State Water Commission County Ground-water Studies 29 and North Dakota Geological Survey Bulletin 76, Part II, 241 p.

________, 1981, Ground-Water resources of Billings, Golden Valley, and Slope Counties, North Dakota: North Dakota State Water Commission County Ground Water Studies 29 and North Dakota Geological Survey Bulletin 76, Part III, 56 p.

Banet, A. C., Jr., 1980, Coal geology and resource calculations of the south Belfield area, Billings and Stark Counties, North Dakota: U.S. Geological Survey Open File Report 80-870, 18 p.

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

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

Bergstrom, J. R., 1956, The general geology of uranium in southwestern North Dakota: North Dakota Geological Survey Report of Investigation 23.

Bluemle, J. P., and others, 1980, North Dakota Stratigraphic Column: North Dakota Geological Survey.

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

Brown, R. W., 1938, The Cretaceous-Eocene boundary in Montana and North Dakota (abstract): Washington Academy of Science Journal, v. 28, p. 421-422.

________, 1962, Paleocene flora of the Rocky Mountains and Great Plains: U.S. Geological Survey Professional Paper 375, 119 p.

Carlson, C. G., 1979, Geology of Adams and Bowman Counties, North Dakota: North Dakota Geological Survey Bulletin 65 and North Dakota State 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 State Water Commission County Ground-Water Studies 24, Part I, 32 p.

________, 1983, Geology of Morton County, North Dakota: North Dakota Geological Survey Bulletin 72 and North Dakota State Water Commission County Ground-Water Studies 27, Part I, 40 p.

Carlson, C. G., and Anderson, S. B., 1965, Sedimentary and tectonic history of North Dakota part of Williston Basin: American Association of Petroleum Geologists Bulletin, v. 49, p. 1833-1846; reprinted North Dakota Geological Survey Miscellaneous Series 28.

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.

Crawford, J. W., 1967, Stratigraphy and Sedimentology of the Tongue River Formation (Paleocene), southeast Golden Valley County, North Dakota: University of North Dakota M.S. thesis, 73 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.

________, 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.

Denson, N. M., and others, 1955, Uraniferous coal beds in parts of North Dakota, South Dakota, and Montana: U.S. Geological Survey Coal Investigations Map C-33.

________, 1959, Uranium in coal in the western United States: U.S. Geological Survey Bulletin 1055, 315 p.

Dobbin, C. E., and Reeside, J. B., Jr., 1930, The contact of the Fox Hills and Lance Formations: U.S. Geological Survey Professional Paper 158-B, p. 9-25.

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

Erickson, B. R., 1982, The Wannagan Creek Quarry and its reptilian fauna [Bullion Creek Formation, Paleocene] in Billings County, North Dakota: North Dakota Geological Survey Report of Investigation 72, 17 p.

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

Fischer, S. P., Jr., 1954, Structural geology of the Skaar-Trotters area, McKenzie and Golden Valley Counties, North Dakota: North Dakota Geological Survey Report of Investigations 15.

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

Gill, J. R., and Denson, N. M., 1956, Regional synthesis, eastern Montana and the Dakotas, in Geologic investigations of radioactive deposits, semiannual progress report for June 1 to November 30, 1956: U.S. Geological Survey Report TEI-700, p. 160-171.

Goldich, S. S., and others, 1966, Geochronology of the mid-continent region, United States, pt. 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 Investigations 18.

Hares, C. J., 1928, Geology and lignite resources of the Marmarth Field, southwestern North Dakota: U.S. Geological Survey Bulletin 775, 110 p.

Hickey, L. J., 1976, Stratigraphy and paleobotany of the Golden Valley Formation (early Tertiary) of western North Dakota: Geological Society of America Memoir 156, 183 p.

Jacob, A. F., 1973, Depositional environments of the Paleocene Tongue River Formation, western North Dakota: American Association of Petroleum Geologists, v. 57, p. 1038-1052.

________, 1975, Criteria for differentiating the Tongue River and Sentinel Butte Formations (Paleocene), North Dakota: North Dakota Geological Survey Report of Investigations 53, 55 p.

________, 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.

Jeletsky, J. A., 1962, The allegedly Danian dinosaur-bearing rocks of the globe and the problem of the Mesozoic-Cenozoic boundary, Journal of Paleontology, v. 36, p. 1005-1018.

Kepferle, R. C., and Culbertson, W. C., 1955, Strippable lignite deposits, Slope and Bowman Counties, North Dakota: U.S. Geological Survey Bulletin 1015-E, p. 173-182.

Knowlton, F. H., 1911, Further data on the stratigraphic position of the Lance Formation ("Ceratops beds"): Journal of Geology, v. 19, p. 358-376.

________, 1922, The Laramie flora of the Denver basin with a review of the Laramie problem: U.S. Geological Survey Professional Paper 130, 175 p.

Leonard, A. G., 1908, The geology of southwestern North Dakota with special reference to coal: North Dakota Geological Survey 5th Biennial Report, p. 22-114.

________, 1911, The Cretaceous and Tertiary formations in western North Dakota and eastern Montana: Journal of Geology, v. 19, p. 507-547.

________, 1925a, Billings and Golden Valley Counties, in Leonard, A. G., Babcock, E. J., and Dove, L. P., The lignite deposits of North Dakota: North Dakota Geological Survey Bulletin 4, p. 58-77.

________, 1925b, Bowman and Slope Counties, in Leonard, A. G., Babcock, E. J., and Dove, L. P., the lignite deposits of North Dakota: North Dakota Geological Survey Bulletin 4, p. 88-95.

Leonard, A. G., and Smith, C. D., 1909, The Sentinel Butte lignite field, North Dakota and Montana: U.S. Geological Survey Bulletin 341, p. 15-35.

Lewis, R. C., 1977, Preliminary report of the geology of the Harmon and Hansen lignite beds in the southern half of the Bowman-Gascoyne area, Slope, Bowman and Adams Counties, North Dakota: U.S. Geological Survey Open-File Report 77-377, 4 p.

________, 1979, Coal geology of the Bowman-Gascoyne area, Adams, Billings, Bowman, Golden Valley, and Slope Counties, North Dakota: U.S. Geological Survey Open-File Report 79-1698, 38 p.

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

May, P. R., 1954, Strippable lignite deposits, Wibeaux area, Montana and North Dakota: U.S. Geological Survey Bulletin 995-G, p. 255-292.

Menge, M. L., 1977, Preliminary report on the coal resources of the Dickinson area, Billings, Dunn and Stark Counties, North Dakota: U.S. Geological Survey Open-File Report 77-482, 11 p.

Moore, G. W., Mellin, R. E., and Kepferle, R. C., 1959, Uranium bearing lignite in southwestern North Dakota: U.S. Geological Survey Bulletin 1055-E, p. 147-166.

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

Owen, H. E., 1979, Coal geology of the New England-Mott area, Billings, Stark, Slope, Hettinger and Adams Counties, North Dakota: U.S. Geological Survey Open-File Report 79-569, 77 p.

Pollard, B. C., Smith, J. B., and Knox, C. C., 1972, Strippable lignite reserves of North Dakota: location, tonnage and characteristics of lignite and overburden: U.S. Bureau of Mines Information Circular 8537, 37 p.

Rehbein, E. A., 1977, Preliminary report on stratigraphy, depositional environments, and lignite resources in the Fort Union Formation, west-central North Dakota: U.S. Geological Survey Open-File Report 77-69, 23 p.

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

Stanton, T. W., 1914, Boundary between Cretaceous and Tertiary in North America as indicated by stratigraphy and invertebrate faunas: Geological Society of America Bulletin, v. 25, p. 341-354.

Stone, W. J., 1972, Middle Cenozoic stratigraphy of North Dakota, in Depositional environments of the lignite-bearing strata in western North Dakota: North Dakota Geological Survey Miscellaneous Series No. 50, p. 123-132.

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

U.S. Geological Survey and North Dakota Geological Survey, 1976, Preliminary report on 1975 drilling of lignite in western North Dakota: Adams, Bowman, Dunn, Hettinger, McLean, Mercer, Oliver, Slope and Williams Counties: U.S. Geological Survey Open-File Report 76-869, 144 p.

________, 1977, Preliminary report on 1976 lignite drilling in western North Dakota: Adams, Billings, Dunn, Hettinger, McKenzie, Mercer, Morton, Oliver and Stark Counties: U.S. Geological Survey Open-File Report 77-857, 336 p.

________, 1978, Lignite drilling during 1977 in western North Dakota: Adams, Billings, Bowman, Dunn, Golden Valley, Grant, Hettinger, Mercer, Oliver, Slope, Stark and Williams Counties: U.S. Geological Survey Open-File Report 78-888, 541 p.

________, 1979, Lignite drilling during 1978 in western North Dakota: Adams, Billings, Bowman, Burke, Golden Valley, Hettinger, McKenzie, McLean, and Slope Counties: U.S. Geological Survey Open-File Report 79-1051, 519 p.

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

Wilder, F. A., 1902, Lignite deposits of Billings County: North Dakota Geological Survey 2nd Biennial Report, p. 63-74.

Wood, L. H., 1904, Report on the region between the Northern Pacific Railroad and Missouri River: Its topography, climate, vegetation, irrigation possibilities and coal deposits: North Dakota Geological Survey 3rd Biennial Report, p. 41-125.