GEOLOGY

of

GRANT AND SIOUX COUNTIES, NORTH DAKOTA

by
Clarence G. Carlson
North Dakota Geological Survey
Grand Forks, North Dakota
1982

BULLETIN 67—PART I
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

COUNTY GROUNDWATER STUDIES 24—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,
Grant County Water Management District,
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ABSTRACT

Grant and Sioux Counties are located in the Great Plains province in south-central to southwestern North Dakota. The outer limit of glaciation trends diagonally southeastward through these counties, but glacial deposits are limited to thin patches of drift in a few upland areas and channel deposits in valleys cut by glacially diverted drainages.

This area includes rocks of each of the geologic periods with the thickest accumulation of sedimentary rocks in northwestern Grant County where about 11,500 feet are present. The sedimentary section thins southeastward, reflecting the position of these counties on the southern flank of the Williston Basin. Thinning is due to more erosion toward the margin of the basin as well as depositional thickening toward the basin center, so in southeastern Sioux County the sedimentary record has thinned to about 5,600 feet.

Strata at the surface are limited to formations of Upper Cretaceous and Tertiary age. The Upper Cretaceous formations consist of poorly consolidated sand, silt, or clay and carbonaceous shale. Tertiary formations consist of poorly consolidated sand, silt, clay, and lignite. Upland areas have a gently rolling topography developed on these formations with a few scattered buttes held up by more resistant rock types, which in these counties are mostly the cemented sandstones. Major drainages are incised into the upland areas, and where the Hell Creek strata are exposed along these drainages some "badland" topography has developed.

Sandstone units within each of the exposed formations are potential sources of groundwater; however, the most reliable, or persistent, is the Timber Lake Member of the Fox Hills Formation. In some areas, in the absence of shallow sands, lignite beds provide a potential aquifer. In a few areas lignite beds of adequate thickness and appropriate depth provide an economically recoverable resource.

INTRODUCTION

Purpose of Study

This report describes the geology of Grant and Sioux Counties, an area of about 2,805 square miles located in south-central North Dakota (fig. 1). It is one of a series of reports prepared by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission and the U.S. Geological Survey in the county groundwater study series.

The primary purposes of the study are: (1) to provide a geologic map, (2) to locate and define aquifers, (3) to assess the extent of other mineral resources, and (4) to interpret the geologic history of the area.

Methods of Study

North Dakota Highway Department road maps, scale 1:63,000, were used as base maps. The general practice was to traverse all roads or trails by vehicle and to traverse on foot to otherwise inaccessible areas of interest. The exposures were studied with particular attention to formation contacts so as to provide a basis of extending contacts across areas of poor exposures.

The best exposures are along the major drainages, and in most areas the formation contacts may be traced with a fair degree of certainty. Determining thicknesses of the formations on surface studies alone is hazardous, however, as none of the formations are completely exposed at one locality. Thus, thicknesses must be based on composite sections and subsurface information. Subsurface information consists of test-hole drilling of the current study, test-hole drilling from a cooperative program with the Conservation Branch of the U.S. Geological Survey, and information in the files of the North Dakota Geological Survey from oil exploration test holes.

Previous Work

Early mapping in this area was primarily concerned with lignite resources. Lloyd (1914) provides information on the lignite resources together with township by township descriptions for much of Grant County. Calvert and others (1914) discuss the stratigraphy of Sioux County and provide a township by township analysis of lignite resources. Leonard (1925) provides a brief description of the lignite resources of Grant County. Brant (1953) summarized the available information and estimated total lignite resources of about 4.6 billion tons for Grant County of which about 1.4 billion tons were assigned to

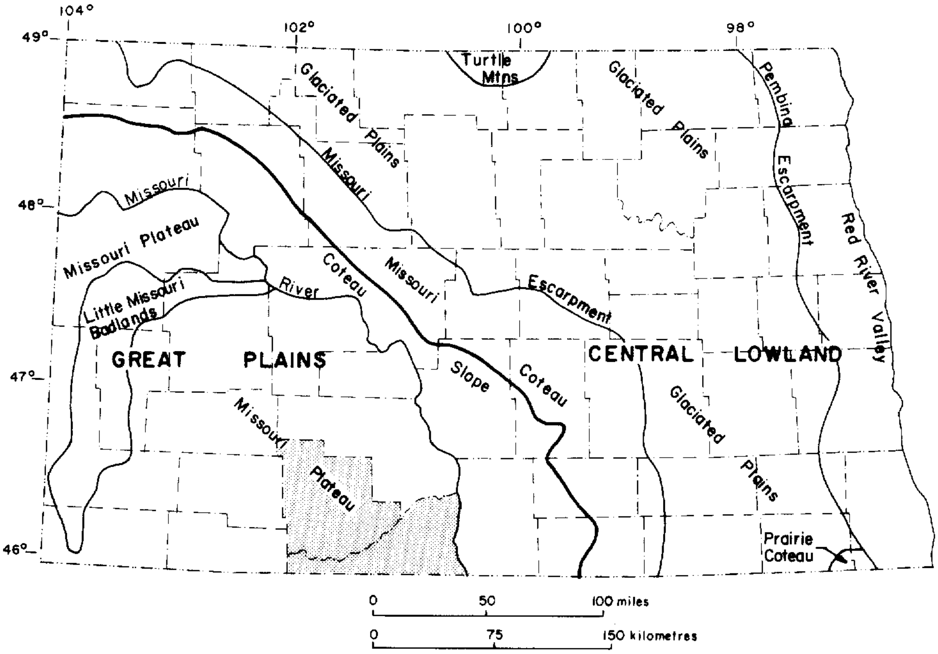

Figure 1. Location map showing area of study and physiographic subdivisions.

the Haynes bed. He made no estimate for Sioux County, since available data indicated no beds of economic interest.

These reports used the term Lance Formation, with a question as to its Cretaceous or Tertiary age, for the strata between the Cretaceous Fox Hills Formation and the Tertiary Fort Union Formation. Early reports dealing with this and other stratigraphic problems include those of Leonard (1911, 1912), Knowlton (1911), Lloyd and Hares (1915), and Dobbin and Reeside (1930). Thom and Dobbin (1924) presented a regional summary of the relationships of the post-Fox Hills strata. They used Fort Union Formation with Sentinel Butte, Tongue River, and Lebo Members and Lance Formation with Cannonball, Ludlow, Tullock, and Hell Creek Members. They were uncertain as to the Cretaceous or Tertiary age of these strata. Paleontological studies by Brown (1939), Dorf (1940), and Fox and Ross (1942) have established age relationships and now the nonmarine Cretaceous strata are assigned to the Hell Creek Formation with the overlying units all assigned to the Tertiary.

Tisdale (1941) mapped the Heart Butte Quadrangle. The Heart Butte and Heart Butte NW Quadrangles were mapped in detail by Stephens (1970). Frye (1969) divided the Hell Creek Formation into five members based on studies of the exposures in this area. His discussion provides useful concepts for the nature of the upper and lower contacts, but the member subdivision is not useful for either surface or subsurface studies.

The post-Pierre strata were reviewed for their uranium potential in a group of reports by Cvancara (1976a, 1976b), Jacob (1976), and Moore (1976). Glacial studies include Clayton (1966) and Clayton, Moran, and Bluemle (1980). An airphoto reconnaissance map of the area is provided by Clayton and others (1980).

Regional Setting

The area of study is bounded on the east by the Missouri River, on the south by South Dakota, on the west by Adams and Hettinger Counties, and on the north by Morton County. Physiographically this area lies in the Great Plains province, an area characterized by generally low relief with gentle slopes interrupted by low buttes or ridges. The limit of glaciation cuts diagonally southeastward across the two counties separating it into glaciated and unglaciated Missouri Coteau sections. Except for small patches of till in southeastern Grant County and in northeastern Sioux County, the only evidence of glaciation is scattered erratic boulders, patches of gravel, and a diversion channel; so in this area the sections are topographically similar.

Major drainages are the Missouri River, Heart River, Cannonball River, and Cedar Creek. Each of these streams are incised 200 to 300 feet into the gently rolling uplands. There are generally good exposures of the stratigraphic units along these drainages. In the upland areas, exposures are poor and scattered. The best exposures in these areas are where cemented sandstone holds up ridges or buttes.

A meltwater channel cut by diverted drainage and glacial meltwater follows the Heart River from Big Muddy Creek to the Morton County line. It re-enters Grant County near Freda, continues south to Shields, then flows eastward through Porcupine Creek to the Missouri River.

Where drainages cross the Hell Creek Formation badland or semi-badland, topography is common. Where they cross the Cannonball Formation, they commonly have a series of benches held up by sand units which alternate with the clay and silt units of that formation.

"Pseudoquartzite" is a finely crystalline siliceous rock that was probably deposited as a gel in ponds with an areal extent of a few square miles. These rocks are generally light gray, contain stem-like plant remains, and are present as a dense litter of boulders capping ridges and adjacent slopes (fig. 2). There are several such areas west and south of Elgin. The easternmost occurrence is in secs 16, 17, and 21, T130N, R83W, in Sioux County.

Figure 2. "Pseudoquartzite" littered ridge located in sec 22, T133N, R90W, southwest of New Leipzig looking west.

Cemented sandstone is present in each of the Tertiary formations. The most prominent of these ridge and butte formers are those near the base of the Slope or top of the Cannonball Formations in the area south and west of Lark (fig. 3).

These counties are located on the south to southeast flank of the Williston Basin, an intracratonic basin whose center is about 40 miles southeast of Williston. Sedimentary rocks of each of the geologic periods are present. They generally have gentle dips to the northwest with the thickest accumulation in northwestern Grant County.

SUBSURFACE STRATIGRAPHY

There have been 23 oil exploration test holes drilled in Grant County and 6 in Sioux County as of January 1, 1981. These holes, together with information from holes in adjacent areas, provide information concerning the geologic history of this area. The sedimentary rocks reveal a history of alternating episodes of deposition in marine seas and then emergence with erosion of part of the sedimentary section. The preserved

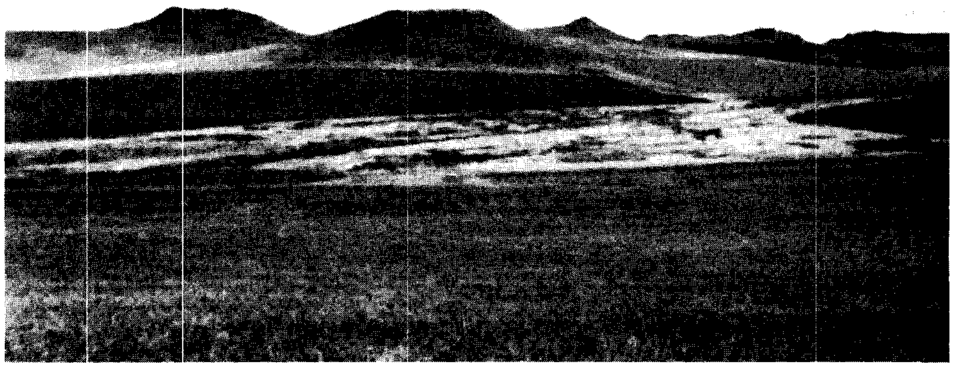

Figure 3. Cemented sandstone-capped buttes southwest of Lark sections.

sedimentary section, bounded by the major regional unconformities associated with the emergence episodes, are called sequences. Sequences present in this area are the Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas (fig. 4). Rocks of the upper two sequences are present at the surface in these counties.

The only Precambrian test that has been drilled in the two-county area is located in northernmost Grant County. There have been three Cambrian tests, one in Sioux and two in Grant, and a total of seven tests drilled into, but not deeper than, the Ordovician (two in Sioux, five in Grant). Based on these wells and wells in adjacent areas, depths to Precambrian rocks probably range from about 5,600 feet in southeastern Sioux County to about 11,500 feet in northwestern Grant County.

Sauk Sequence

The Sauk Sequence is represented in North Dakota by rocks referred to as the Deadwood Formation. Five test holes penetrate this sequence, penetrating 70 to 650 feet. The Deadwood Formation consists of glauconitic sandstone and dolomite in these wells. Based on these wells and wells in adjacent

ERA	SYSTEM	SEQUENCE	GROUP	FORMATION OR GROUP	THICKNESS	DOMINANT LITHOLOGY
CENOZOIC	QUATERNARY	TEJAS		ALLUVIUM	0- 30	Silt and Clay
				COLEHARBOR	0- 300	Clay, Silt, Sand, Gravel, and Till
	TERTIARY	ZUNI		GOLDEN VALLEY	0- 60	Silt, Clay, and Sand
			FORT UNION GROUP	SENTINEL BUTTE	0- 220	Silt, Clay, Sand, and Lignite
				TONGUE RIVER	0- 300	Silt, Clay, Sand, and Lignite
				SLOPE	0- 240	Silt, Clay, Sand, and Lignite
				CANNONBALL	0- 310	Mudstone and Sandstone
				LUDLOW	0- 150	Silt, Clay, Sand, and Lignite
MESOZOIC	CRETACEOUS			HELL CREEK	0- 400	Clay, Sandstone, and Shale
			MONTANA GROUP	FOX HILLS	0- 300	Sandstone and Shale
				PIERRE	1000-1300	Shale
			COLORADO GROUP	NIOBRARA	275- 385	Shale, Calcareous
				CARLILE	370- 435	Shale
				GREENHORN	140- 180	Shale, Calcareous
				BELLE FOURCHE	225- 250	Shale
			DAKOTA GROUP	MOWRY	75- 100	Shale
				NEWCASTLE	0- 60	Sandstone
				SKULL CREEK	200- 260	Shale
				INYAN KARA	150- 300	Sandstone and Shale
	JURASSIC			SWIFT	140- 400	Mudstone
				RIERDON	80- 100	Shale and Sandstone
				PIPER	120- 150	Limestone, Shale, and Anhydrite
	TRIASSIC	ABSAROKA		SPEARFISH	0- 150	Siltstone and Salt
PALEOZOIC	PERMIAN			MINNEKAHTA	0- 50	Limestone
			MINNELUSA GROUP	OPECHE	0- 130	Shale and Siltstone
				BROOM CREEK	0- 300	Sandstone and Dolomite
	PENNSYLVANIAN			AMSDEN	200- 320	Dolomite, Sandstone, and Shale
				TYLER	0- 65	Mudstone and Sandstone
	MISSISSIPPIAN	KASKASKIA		BIG SNOWY	200- 400	Shale, Sandstone, and Limestone
				MADISON	900-1500	Limestone and Anhydrite
				THREE FORKS	0- 185	Shale, Siltstone, and Dolomite
	DEVONIAN			BIRDBEAR	0- 70	Dolomite
				DUPEROW	100- 250	Interbedded Dolomite and Limestone
				SOURIS RIVER	20- 175	Interbedded Dolomite and Limestone
				DAWSON BAY	0- 90	Dolomite and Limestone
				PRAIRIE	0- 30	Limestone and Anhydrite
				WINNIPEGOSIS	0- 200	Limestone and Dolomite
	SILURIAN	TIPPECANOE		INTERLAKE	0- 500	Dolomite
				STONEWALL	55- 80	Dolomite
	ORDOVICIAN			STONY MOUNTAIN	130- 160	Argillaceous Limestone
				RED RIVER	570- 650	Limestone and Dolomite
			WINNIPEG GROUP	ROUGHLOCK	30- 60	Shale, Calcareous and Siltstone
				ICEBOX	100- 120	Shale
				BLACK ISLAND	10- 40	Sandstone
	CAMBRIAN	SAUK		DEADWOOD	300- 700	Limestone, Shale, and Sandstone
		PRECAMBRIAN ROCKS				

Figure 4. Stratigraphic column for Grant and Sioux Counties.

counties a complete section of Deadwood in eastern Sioux County would be about 300 feet thick and would thicken westward to about 700 feet in northwestern Grant County.

Tippecanoe Sequence

The Tippecanoe Sequence began with clastics of the Winnipeg Group (Middle Ordovician) followed by carbonates of the Red River (Middle to Upper Ordovician), Stony Mountain (Upper Ordovician), Stonewall (Upper Ordovician-Lower Silurian), and Interlake (Silurian) Formations. Depositional thicknesses show a slight thickening in the central basin area, but most of the units show only slight variations in these counties. The preserved section ranges in thickness from about 1,000 feet in southeastern Sioux County to about 1,500 feet in northwestern Grant County. The thinning is due mostly to erosion of the Interlake Formation which thins from about 500 feet in northwestern Grant County to being absent in southeastern Sioux County.

Kaskaskia Sequence

The Kaskaskia Sequence began with deposition of silty and argillaceous carbonates of the Winnipegosis, Prairie, and Dawson Bay Formations (Middle Devonian) as the Middle Devonian seas advanced southward over this area. The Souris River (Middle to Upper Devonian) and Duperow (Upper Devonian) Formations are predominantly carbonates with thin shales representing cyclical deposition in a shallow marine environment. This was followed by the Birdbear Formation (Upper Devonian), which is a clean carbonate, then fine-grained clastics with some carbonates of the Three Forks Formation (Upper Devonian). The Devonian Formations gradually thicken northwestward, reflecting a gradual sinking of the central basin area.

The Madison (Mississippian) Formation also thickens northwestward from about 900 feet in southeastern Sioux County to about 1,500 feet in northwestern Grant County, with the thickening due to deposition in a gradually subsiding basin. The lower part of this formation consists of fossiliferous, fragmental limestone with argillaceous and siliceous zones. The middle part consists of oolitic and granular, sometimes dolomitic, limestone; while the upper part consists of alternating shallow water carbonates and anhydrite. The Big Snowy Group (Upper Mississippian) marks a return to clastic deposition. These rocks thin from 300 feet in northwestern Grant County to an erosional edge across central Sioux County.

Absaroka Sequence

The Absaroka Sequence began with clastics of the Tyler Formation (Pennsylvanian) followed by alternating carbonates and sandstones of the Amsden and Minnelusa Formations (Pennsylvanian). In most of Grant County silt and shale of the Opeche Formation (Permian) and limestone of the Minnekahta Formation (Permian) are presently overlain in some areas by silt and shale redbeds of the Spearfish Formation (Triassic). Permian and Triassic Formations are absent in most of Sioux County. The preserved rocks of this sequence generally thicken westward across these counties from about 200 feet in southeastern Sioux County to about 1,000 feet in northwestern Grant County.

Zuni Sequence

The Zuni Sequence began with red shale, evaporites, and carbonates of the Piper Formation (Middle Jurassic) followed by normal marine shale and fine-grained sand of the Rierdon and Swift Formations (Middle to Upper Jurassic). Jurassic rocks range in thickness from about 250 feet in southeastern Sioux County to about 800 feet in northwestern Grant County. Late Jurassic and Early Cretaceous deposits include non-marine sandstone and mudstone of the Lakota Formation. These are overlain by shale of the Fuson Formation and sandstone and shale of the Fall River Formation (Black Hills surface terminology). Separation of these formations in the subsurface is not feasible so use of the term Inyan Kara seems preferable. The sands within the Inyan Kara interval are saline aquifers often referred to as the Dakota aquifer, which may be penetrated at depths of about 2,300 feet in southeastern Sioux County to about 4,500 feet in northwestern Grant County. The Newcastle Sandstone, where present, is about 200 to 250 feet above the Inyan Kara Formation.

The Inyan Kara Formation consists of sandstones and shales with variable sandstone development. In most areas of these counties sandstone is best developed in the lower part of the interval (pl. 2) with thicknesses usually in the range of 50 to 110 feet. The self-potential is usually reversed through this section indicating water quality less saline than the drilling fluid. Sandstone in the upper part is more variable, but water quality is similar.

Distribution of the Newcastle is erratic. It is absent in two wells, and, based on test holes in adjacent counties, is probably absent in Townships 136 and 137N. Where present, it ranges in thickness to as much as 60 feet in one well. All logs show a normal self-potential indicating water quality more saline than the drilling fluid and hence lower quality than the Inyan Kara.

The rest of the marine Cretaceous sediments through the Pierre Formation are marine shales or marlstones. Cretaceous rocks generally thicken westward from about 2,200 feet in eastern Sioux County to about 3,300 feet in northwestern Grant County. Most of the Pierre Formation is present only in the subsurface, but the upper part, consisting of dark-gray shale, is exposed at several localities in southeastern Sioux County.

SURFACE-SUBSURFACE STRATIGRAPHY

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

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

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

Erickson's usage in his discussion, but in his cross sections through the subsurface did not try to subdivide the Fox Hills into members.

The Linton Member is a relatively thin unit where present; it is a sandstone in the stratigraphic position of the Colgate Member of previous usage. Even though it may represent a recognizable variety in the outcrop area, it seems more practical to include these exposures in the Colgate definition rather than drop Colgate and erect a new member. Based on the surface and subsurface studies in these and adjacent counties, it seems that the most practicable Fox Hills terminology is to recognize four members, in ascending order: Trail City, Timber Lake, Bullhead, and Colgate.

The Fox Hills is not completely exposed at any one locality, but good exposures of the basal and upper contacts as well as appreciable sections at individual localities allow for a composite section thickness to be compiled. Feldmann (1972, pl. 1) shows a composite section for secs 27 and 36, T130N, R80W about 285 feet thick with no Hell Creek present. He recognized three members, which, in ascending order, were: Timber Lake Member, about 175 feet thick; Bullhead Member, about 100 feet thick; and Colgate Member, about 10 feet thick. Nearly 300 feet of Fox Hills is exposed in scattered roadcuts in the NE¼sec 21, T129N, R79W with the lower contact exposed. The transitional zone, or Trail City Member, is only a few feet thick. Exposures of the lower 200 feet are mostly sand of the Timber Lake Member, generally yellowish brown, fine to very fine grained with iron-cemented nodules and lenses. About 200 feet above the base about 27 feet of interbedded moderate brown shale and light-gray sandstone of the Bullhead Member are exposed. Oyster shells are common in these sand layers and oyster fragments are also common in higher exposures. The contact with the overlying Hell Creek is not exposed at this locality.

Portions of the Timber Lake Member are well exposed in numerous roadcuts along N.D. Highway 24 both north and southwest of Fort Yates. It consists of about 175 feet of buff colored, very fine to medium-grained sand with minor amounts of mudstone. The sand is commonly cross bedded, contains ferruginous and calcareous cemented nodules and concretions; Ophiomorpha is common in some horizons.

The Bullhead Member consists of about 100 feet of interbedded light-gray and buff sand and moderate brown shale. Exposures of portions of this member may be examined along N.D. Highway 24 in secs 28 and 33, T130N, R80W, as well as secs 4 and 9, T133N, R79W, and secs 26 and 27, T131N, R80W. Oyster fragments are common in this member at several localities.

The Colgate sand is best exposed near the Crowghost Cemetery near the center of sec 33, T134N, R81W, where about

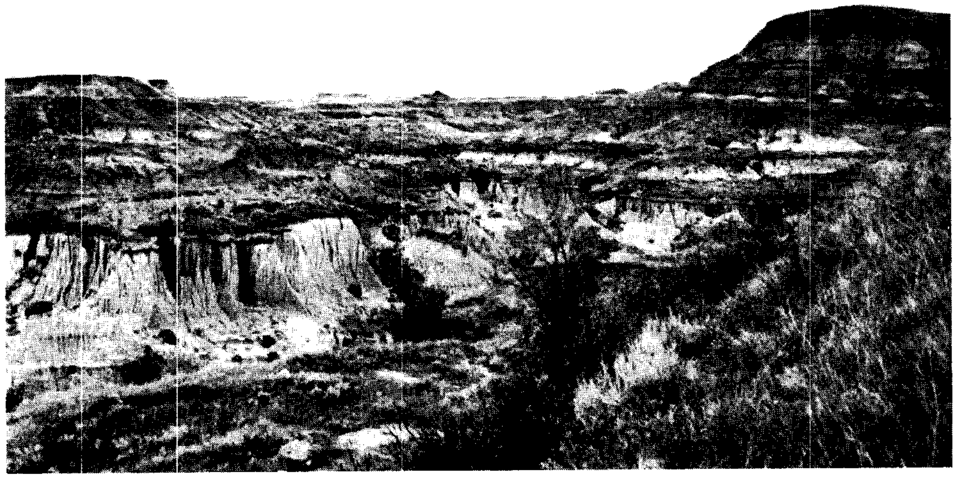

Figure 5. Contact between the Colgate Member of the Fox Hills and the lower part of the Hell Creek as exposed near the Crowghost cemetery.

30 feet of light-gray sandstone (fig. 5) underlies the Hell Creek Formation. In most areas of Sioux County the Colgate is not well developed or exposed, and Feldmann (1972, p. 31) says that generally "less than 10 feet of well indurated, white to cream colored, flaggy sandstone," which he referred to as Colgate, is present. Generally the map-contact between the Fox Hills and the overlying Hell Creek was based on poor exposures of carbonaceous shales. These shale beds are considered to be the Hell Creek Formation. The map-contact is an interpolation between these shale exposures and areas of good exposures of either lower Hell Creek or Bullhead strata.

Tracing the members into the subsurface is a difficult task, but an attempt is included on the cross sections (pls. 3, 4). The test holes near the exposures in southeastern Sioux County (e.g., NDSWC 4520) have a section similar to the outcrop so the Timber Lake and Trail City Members can be easily recognized in that test hole. Proceeding westward, the section overlying the Pierre Shale becomes less sandy, and this thickening wedge is assigned to the Trail City Member (e.g., NDSWC 4491). This interpretation agrees with Waage's surface observations in South Dakota where he noted a thickening westward of his Trail City Member. The thickening westward is accompanied by some thinning of the overlying predominantly sandy unit, which is herein included as the Timber Lake Member. However, the Timber Lake Member is traced westward as a significant portion of the Fox Hills, based on subsurface studies extending to the outcrops in western Bowman County (Carlson, 1979, pl. 3), rather than pinching out westward as Waage suggests.

The top of the Fox Hills is placed at the top of a sand unit which is generally 20 to 40 feet thick. The underlying predominantly shale or silt unit is referred to as the Bullhead Member. This interpretation preserves the practical advantage of having an identifiable log characteristic (a sandstone unit--Colgate) for the top of the Fox Hills in the subsurface. It also seems probable that, based on surface studies, this is usually the case.

In this area the Fox Hills is interpreted to be about 250 to 300 feet thick where complete sections are preserved. The thickest sections are to the south and east; the thinnest section would be in northwestern Grant County.

Hell Creek Formation

Frye (1969) divided the Hell Creek Formation into five members in this area which, in ascending order, were named: Crowghost, Breien, Fort Rice, Huff, and Pretty Butte Members. Type sections for the Crowghost and Breien Members were designated in Sioux County, the Fort Rice and Huff Members were designated in Morton County, and the Pretty Butte Member has its type section in Slope County in western North Dakota. A thin marine member, the Breien (Laird and Mitchell, 1942) had previously been recognized in southern Morton County, and the Crowghost was introduced to contain about 30 feet of nonmarine strata between the Fox Hills Formation and the Breien Member. The Breien is about 30 feet thick and is recognized by the presence of fossils of marine or brackish water species and a greenish-brown color. As Frye notes (p. 34), the Breien probably represents a westward "readvance of the Fox Hills Sea" and may not extend very far west of the area of exposures. The Fort Rice and Huff type sections are at different localities, and, as in the case of Frye's Hell Creek subdivisions in the Little Missouri valley, it is difficult to trace these units away from their type areas. The bentonitic and carbonaceous shales which Frye called the Pretty Butte Member are always present at the top of the Hell Creek in Grant and Sioux Counties, but a well-defined Huff sandstone is not usually found. In this area, as in the western North Dakota area, the Hell Creek is characterized by a general lack of continuity of beds and a heterogeneity so that subdivision into members is not very useful for either surface or subsurface interpretations.

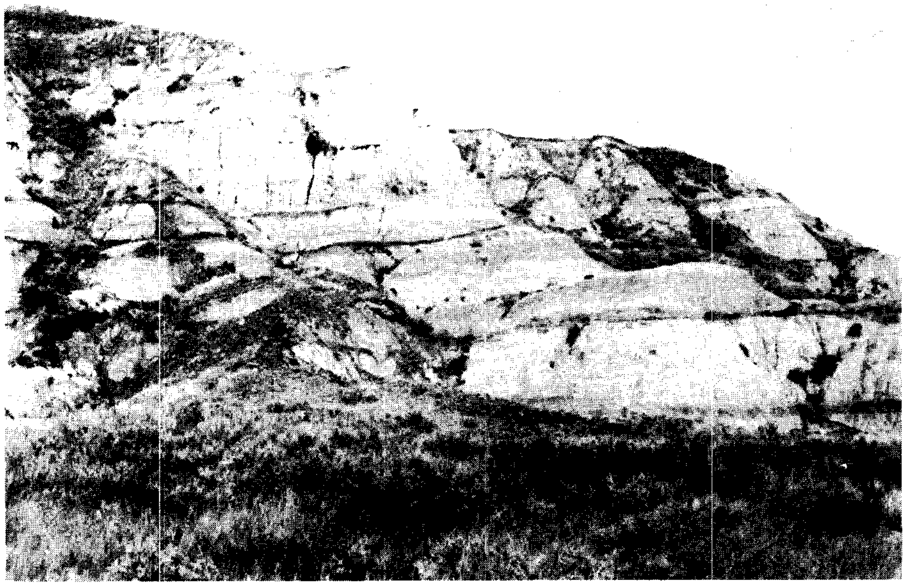

Figure 6. Hell Creek strata exposed north of the Cannonball River in NW¼sec 26, T131N, R85W.

The Hell Creek is well exposed in badland areas along the Cannonball River and Cedar Creek and their tributaries from R87W north and eastward to Solen. The entire formation is not exposed at any one locality, but, based on surface and subsurface data, a thickness of about 300 to 350 feet represents a complete section in the Selfridge area. The generally drab brown and gray strata (fig. 6) consist of poorly sorted, very fine to fine-grained sand, silt, and clay with some carbonaceous and bentonitic shales and occasional lignitic shales. Sands are generally less than 20 feet thick, but some beds 40 to 60 feet thick were noted. Generally the thicker sands are coarser grained and are commonly cross bedded with the cross bedding accentuated by carbonaceous lenses as well as iron-cemented nodules and concretions.

The heterogeneity noted at the surface extends into the subsurface as may be noted on the cross sections (pls. 3, 4). Sand generally accounts for a significant fraction of the total formation, but correlation of distinct units from one test hole to another is not evident. The top of the formation is placed on a thin shaly unit which is thought to represent the carbonaceous and bentonitic shales which are everywhere noted in exposures of the uppermost Hell Creek. In these interpretations the Hell

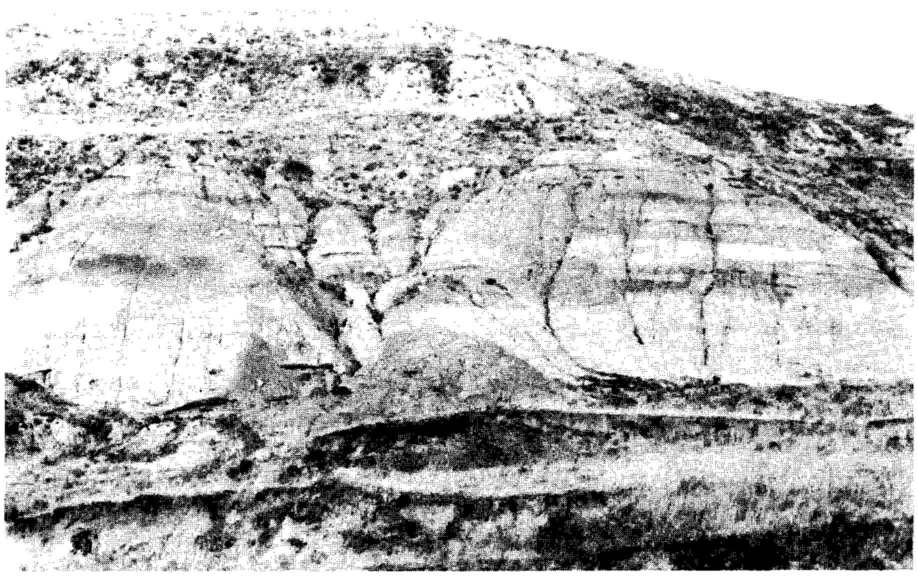

Figure 7. Contact of Ludlow and Hell Creek north of the Cannonball River in NE¼sec 29, T131N, R85W.

Creek ranges in thickness from about 300 to 400 feet with the thickest sections in western Grant County.

Ludlow Formation

Lloyd and Hares (1915) introduced the term Ludlow for the lignitic member between the Cannonball and Hell Creek Members of the Lance Formation in northwestern South Dakota and southwestern North Dakota. These terms have been raised to formations and are useful as originally defined in this area.

The Ludlow beds and the contact with the underlying Hell Creek are well exposed over much of the area. They generally consist of alternating beds of lignite or lignitic shale and carbonaceous shale, silt, clay, and sandstone of drab brown or gray color with some yellowish-brown or gray colors. The beds are laterally persistent, which is in marked contrast to the underlying Hell Creek (fig. 7). The contact with the overlying Cannonball is generally not well exposed. Since in much of the area the Ludlow is exposed in the bluffs along the drainages and occupies such a narrow band it is included with the Cannonball as a map unit (pl. 1).

The Hell Creek-Ludlow contact is exposed along the Cannonball River in NW¼sec 29, T132N, R86W where about 1½ feet of lignitic shale overlies the bentonitic and carbonaceous shales at the top of the Hell Creek Formation. The middle portion of the Ludlow is poorly exposed. There is a 4½-foot thick lignite with carbonaceous shale partings near the top of the Ludlow. The contact with the overlying Cannonball is exposed in the road ditch so the Ludlow is about 50 feet thick at this, the northwesternmost exposure in Grant County.

Another area of good exposures of most of the Ludlow Formation is in SE¼sec 20, T131N, R85W. At that locality the basal bed consists of 2½ feet of lignitic, carbonaceous shale, overlain by 12 feet of light-gray silty and sandy clay and then 7½ feet of lignite and carbonaceous shale.

In the subsurface, a section characterized by a thin alternation of lithologies, with the exception of an occasional 40- to 60-foot-thick sand bed interpreted as a channel sand, is herein referred to as the Ludlow Formation. The Ludlow is interpreted to be a non-marine wedge of sediment thickening north and westward, so in the cross sections (pl. 3) it is shown as 80 to 150 feet thick. A lack of density logs prevents positive identification of lignite beds, but the gamma-ray logs and some sample descriptions indicate that this is a lignite-bearing zone. The top of the Ludlow is picked at the base of a sand interpreted as a basal sand of the advancing Cannonball seas.

Cannonball Formation

Lloyd (1914) introduced the term Cannonball to apply to about 250 to 300 feet of marine strata exposed along the Cannonball River in Grant County. These strata are also well exposed along Cedar Creek and its tributaries, and the outcrop extends as a band northeastward along the Cannonball River and its tributaries and then to the Heart River in northeastern Grant County. The strata consist of alternating units of sandstone and siltstone or mudstone with the mudstones the predominant lithology. The mudstones are generally gray or brownish-gray and silty to sandy. The sandstones are generally yellowish-brown in surface exposures and fine- to very fine grained. The sandstones are commonly resistant and form benches along the drainages.

Cvancara (1976b) reviewed previous work on the Cannonball in this and adjacent areas (Laird and Mitchell, 1942; Hall, 1958; Cvancara, 1965; and Fenner, 1974) and concluded that, while some sandstone beds are laterally traceable for considerable distances, subdivision of the Cannonball into smaller units or members is not useful. A complete section is not exposed at any one locality so the thickness must be determined by composite measured sections or subsurface data. Hall (1958) has thicknesses of 265 and 280 feet for composite sections in the Grant County area (Hall, pl. V). Cvancara (1976, pl. 4) shows a thickness of 300 to 350 feet for the portion of Grant County where complete sections of Cannonball have been preserved.

Fenner (1974) obtained forams from samples of eight test holes in Grant County, obtaining most of the specimens from the mudstone facies. Based on his sampling of test-holes 4513 (136-88-13 AAA) and 4511 (137-89-9 ABA) he had thicknesses of about 300 to 310 feet for these areas.

The subsurface interpretations on the cross sections (pls. 3, 4) are an attempt to be consistent with previous lithologic interpretations of surface studies and the paleontological evidence of Fenner. Where complete sections of Cannonball are preserved in these counties, the thickness ranges from 260 to 310 feet with the thinnest section in southwestern Sioux County and thickening north and eastward. The top of the Cannonball is placed at the top of a sand which is interpreted as a regressive phase of the Cannonball seas.

Slope Formation

Recent studies of areas west and south of these counties has revealed a variable usage of "Tongue River" in North Dakota and adjacent areas. Strata previously called Tongue River in Grant County include strata which were called upper Ludlow in Slope County. To avoid the confusion of having different names applied to the same strata in different areas, Clayton and others (1977, p. 10) recommended discontinuing the use of Tongue River and redefining the Ludlow in North Dakota.

Clayton and others (1977) introduced the term "Slope Formation" to apply to non-marine strata overlying the Cannonball Formation (or, where Cannonball is absent, the T-Cross bed) and underlying a "white marker zone." The type area of the Slope Formation is in northwestern Slope County. Extension of the "white marker zone" to this area is difficult, but the exposures in the New Leipzig-Elgin area (fig. 8) are similar in appearance to those in Slope, Bowman, and Adams Counties. Because they are also in the correct stratigraphic position, they are herein regarded as correlative. Strata between the Cannonball and these "white marker zone" beds are therefore referred to as the Slope Formation (fig. 9). Because the mapping of Grant County was completed prior to redefinition of these strata, the map unit originally referred to as Tongue River has now been redefined. The redefinition is based on interpolations (on topographic maps) in the area of fairly con-

Figure 8. Siliceous bed at top of Slope Formation in sec 4, T133N, R89W.

tinuous exposures which were noted when the Elgin-New Leipzig area was mapped. Farther northeastward, in Morton County, exposures are too scattered to attempt interpolating the contact. The single-color unit (Tongue River plus Slope) represents the unit originally mapped as Tongue River. The area shown as Slope Formation is generally poorly exposed except for the siliceous zones on the "white beds" at scattered localities.

In the subsurface, the Slope Formation consists of alternating beds of lignite, sand, silt, and clay with the base placed at the top of a sandstone of the Cannonball Formation. In western Grant County another lower tongue is present as the Cannonball thins westward with an intertonguing relationship to the Slope Formation. Based on surface elevations of the "white marker zone" in sec 33, T133N, R89W and in test-hole 4484 located in sec 4, T132N, R89W, the Slope Formation in this area is about 240 feet thick.

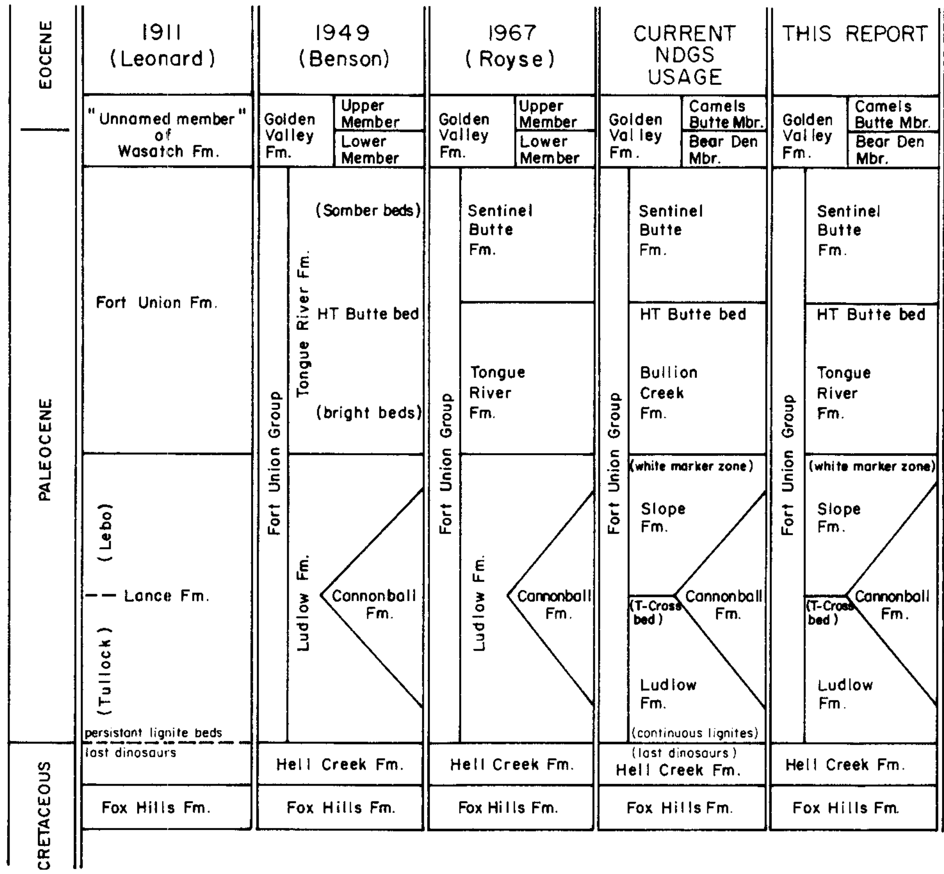

Figure 9. Comparison of early Tertiary stratigraphic nomenclature in western North Dakota at various points in time.

Tongue River Formation*

Thom and Dobbin (1924) extended the term Tongue River from Wyoming into North Dakota to refer to the generally bright-colored lignite-bearing strata which Leonard (1908) had referred to as middle Fort Union. They used Sentinel Butte as a member of the Fort Union and correlated it with the Wasatch (Eocene) of Wyoming. Since then, Tongue River has generally been accepted in North Dakota, but its boundaries have been

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*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.

placed at various horizons. When the strata which Leonard (1908) had referred to as upper Fort Union were recognized as being of Paleocene age, they were usually referred to as the Sentinel Butte Member (Hanson, 1955), or facies (Fischer, 1954), of the Tongue River Formation. When the Sentinel Butte was recognized as a mappable unit, it was referred to as a member (Stephens, 1970) or formation (Royse, 1967) of the Fort Union Formation or Group. The Tongue River was then restricted to the underlying brighter-colored strata which are approximately equivalent to Leonard's middle Fort Union strata.

The contact between the Sentinel Butte and the underlying strata is marked by a color change. In much of the area along the Little Missouri River it is also marked either by the HT Butte lignite bed or by a clinker zone where the lignite bed has burned. In Morton County, Barclay (1973, 1974) mapped a color contact and subsequently used it as his Sentinel Butte-Tongue River contact in the Glen Ullin and Dengate Quadrangles. Stephens (1970a, 1970b) extended that contact into the Heart Butte NW and Heart Butte Quadrangles. In these areas, a dark-gray, bentonitic clay is the lowermost bed in the darker-colored Sentinel Butte strata.

Clayton and others (1977, p. 10) introduced the term Bullion Creek to refer to the generally bright-colored strata between the "white marker zone" at the top of the Slope Formation and the drab-colored Sentinel Butte Formation because of uncertainties of correlation between North Dakota and Wyoming. These strata are essentially equivalent to Leonard's middle Fort Union (fig. 9), and although it cannot yet be demonstrated that these strata are equivalent to type Tongue River it now appears as though Thom and Dobbin's correlations were essentially correct. The slight redefinition of the lower contact does not necessitate introduction of a new name, and the term Tongue River should be retained with the Bullion Creek type section regarded as a reference section for definition of the Tongue River of North Dakota. Using this definition for Tongue River strata, the lower contact is readily recognized in the area south and west of Elgin. To the east, separation from the underlying Slope Formation is difficult. The upper contact is fairly well exposed in the area north of Lake Tschida, but it is only poorly exposed in other areas of Grant County.

Strata now included in the Tongue River Formation are the buff- or bright-weathering, alternating beds of silt, sand, clay, and lignite. The best exposures of these strata are along the Heart River and its tributaries in the Lake Tschida area (fig. 10). In that area, several fossiliferous localities occur among the yellowish beds and one zone is commonly associated with a lignite called the Shell bed. These strata form the upland area over much of the northwestern part of Grant County; however, in most of the area, only small portions of the forma-

Figure 10. Tongue River strata exposed south of Lake Tschida in sec 11, T136N, R89W.

tion are exposed at any one locality. The contact with the overlying Sentinel Butte Formation is poorly exposed in some of the drainages on the north side of Lake Tschida where it was mapped by Stephens (1970a, 1970b). His contact was extended westward to the Stark County line. The contact in the area south of Lake Tschida is the result of an attempt to trace the same contact across the Heart River in Stark County.

Stephens recognized five lignite beds in his Tongue River Formation in the Heart Butte and Heart Butte NW Quadrangles in exposures of the upper 200 feet of this unit. Beds recognized were in ascending order and in feet below the Sentinel Butte Formation contact: Shell bed, about 185 feet; Koehler, about 105 feet; Many Springs, about 85 feet; Red Dog, about 45 feet; and Beaver Creek, about 25 feet. The thickest bed is the Red Dog, which in this area is as much as 10 feet.

Test holes from the groundwater study and Conservation Division drilling programs in western Grant County provide subsurface information for interpretation of the Tongue River Formation (pls. 3,4,5). Test-hole 4511 is in Stephens (1970a) map area, and based on elevations and data from drill-hole 10 (Smith, 1970), the lignite bed from a depth of 116 to 125 is his

Red Dog bed and the lignite bed from 251 to 256 feet is his Shell bed. The other beds, if present, are not definitely recognizable on the gamma-ray log. Only the upper 200 feet of Tongue River is exposed north of Lake Tschida.

In the Elgin-New Leipzig area the lower contact is exposed, and drill-hole data, including density logs, provide accurate information for the Slope and lower Tongue River strata (pl. 5). Correlation to the area north of Lake Tschida is difficult, but a thickness of about 300 feet, based on test-hole 4511, seems appropriate for a complete section of Tongue River Formation. In most areas only the lower Tongue River has been preserved.

Sentinel Butte Formation

The somber weathering beds of the upper part of the Fort Union have long been referred to as Sentinel Butte and are herein referred to as a formation. These strata are limited in extent to small areas of northwestern Grant County where they are generally poorly exposed. The thickest section is at Heart Butte where the slopes are grassed over so the strata are not well exposed, but about 220 feet have been preserved. The Sentinel Butte Formation consists of gray or brownish-gray weathering, alternating beds of sand, silt, clay, and lignite. Petrified wood is fairly common. Stephens recognized four named and three local lignite beds in this unit in the Heart Butte and Heart Butte NW Quadrangles. In ascending order, above the base of the Sentinel Butte Formation, they are: the Haymarsh bed, about 15 feet; the Richter bed, about 25 feet; the Spring Valley bed, about 60 feet; and the Heart Butte bed, about 120 feet above the base of the Sentinel Butte. The only test hole penetrating the Sentinel Butte in this study was 4511 where only one bed was present in the lower 60 feet of the Sentinel Butte. Since the term Richter bed has been more frequently used for the lower coal in the Sentinel Butte of this area, it seems preferable to consider this bed the Richter bed.

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" (fig. 9). Benson (1949) further described these strata and divided them into lower and upper members. Hickey (1976) reviewed previous usage and provided a detailed study of the lithology and distribution of these strata. He introduced the terms Camels Butte and Bear Den for the upper and lower members and designated a reference section in the type area.

Hickey did not include Grant and Sioux Counties in the areal extent of the Golden Valley Formation, but he may not have examined the Pretty Rock Butte area. Near the top of these buttes in sec 27, T131N, R89W on the southwest face about 14 feet of the light-colored, "soapy," silty clay of the Bear Den Member is exposed. At this locality the silty clay is capped by a 2-foot-thick siliceous bed which is probably the source of many of the "pseudoquartzite" boulders which litter the slopes of the buttes. About 35 to 40 feet of the Camels Butte Member is poorly exposed at higher elevations where the surface also has a litter of "pseudoquartzite" boulders, so in this area there was more than one siliceous bed horizon.

The buttes north of Highway 21 between New Leipzig and Elgin are also capped by light-colored silt and clay beds with an associated siliceous bed. These beds might be referred to the Bear Den Member, but they are not exactly typical of the Bear Den, nor are they typical of the Fort Union strata. An alternative interpretation is that the light colors and siliceous bed represent a weathering profile on the Tongue River strata and the topography reflects the resistant siliceous zone.

Coleharbor Group

Glacial ice advanced over this area from the northeast as is evidenced by a few patches of glacial drift and scattered large erratic boulders. Clayton (1966) assigned the glacial drift of these counties to the Morton Drift (drift A) and said it may be pre-Wisconsinan (greater than 50,000 years old) although the lack of deep weathering suggests that it is Wisconsinan. Clayton and others (1980) now show two advances into this area. The oldest, or advance 1, is called the Dunn advance which is now believed to be pre-Wisconsinan (p. 65) based on the absence of glacial landforms and the amount of erosion which has occurred in that area. Advance 2 is called the Verone advance, and in the absence of any absolute dates is regarded as either pre-Wisconsinan or perhaps Early Wisconsinan. The Napoleon advance (more than 30,000 years ago), or advance 3, also extends southwest of the Missouri River but is not shown as extending into these counties. Its age is also uncertain, but Early Wisconsinan was given as most likely. On Clayton's time chart (fig. 35, p. 66) advances 2 and 3 are separated by a short interval. Advances 1, 2, and 3 are distinguished primarily by the relative abundance of boulders on the surface with progressively less boulders for the older advances. In these counties the surface till is all referred to the Verone advance. The only evidence of the Dunn advance are the scattered boulders of glacial origin.

Bluemle (1971, p. 16) introduced the term Coleharbor Formation to include all the glacial sediment in North Dakota.

He included three main facies: "1) interlayered bouldery, cobbly, pebbly, sandy, silty clay (unsorted drift; till); 2) sand and gravel; and 3) silt and clay." He noted that future studies might lead to raising the Coleharbor Formation to group rank and such has been the case.

In Grant and Sioux Counties each of the three facies are present. The unsorted sediment of facies 1 (till) is limited to small areas of the surface in northeastern Sioux County and a small portion of secs 19 and 30, T133N, R84W in Grant County. In these areas road cuts generally show 5 feet or less of yellowish-brown till on bedrock. The exposures in sec 30, T133N, R84W is adjacent to a gravel pit in the NW¼sec 30 where 10 to 12 feet of facies 2 is exposed. Here there are alternating beds of sandy gravel and coarse gravel with low-angle cross bedding and fair sorting within each bed. It probably represents an ice contact deposit laid down as the ice melted from the area. Other than this one exposure, areas mapped as Coleharbor are areas of till.

The Missouri River flows along the position of the Late Wisconsinan ice margin. Earlier advances caused a further westward diversion in what is sometimes called the Killdeer, Glen Ullin-Shields channel. This valley cut by ice-marginal drainage and glacial meltwaters enters Grant County in the valley of Big Muddy Creek. It continues in the Heart River Valley and then southeastward through Morton County reentering the county as two branches in the area east of Raleigh. Dog Tooth Creek then follows along the buried channel until the channel turns south to Shields, crosses the Cannonball River and joins the valley of Porcupine Creek and then continues to the Missouri River. This channel was cut near the margin of the Dunn advance by diversion of the pre-existing northeastward-flowing drainage and was probably deepened by meltwater flows as the ice melted back. During the Verone and Napoleon advances the channel was probably re-occupied and further diverted as evidenced by the divided channels in the Raleigh area.

Test holes in the channel reveal a variety of lithologies suggesting a complex history. Generally, the deeper tests have gravel, or sand and gravel at the base, but some tests have till at the base. Where till was logged it was at the base of the channel fill and was formed mostly in the area of Dog Tooth Creek and the divided channels. In some areas such as in the Porcupine Creek area in T133N, R83W a series of test holes have a 15- to 20-foot clay bed at similar elevations. Many test holes have thick clay or silt and clay units. Most test holes have a series of alternating beds of sand, or sand and gravel and beds of clay, or clay and silt.

The sand and gravel at the base of the fill probably represents deposition by the diverted drainage and some outwash from glacial meltwaters as the ice melted back. The till at the base probably represents a scouring of previous fill and redeposition by either the Verone or Napoleon advance. Some of the test holes may be located along the side of the preglacial valley where till may have been deposited along the side of the valley. The thin sand, silt, clay, and occasional gravels within the fill probably represent deposition by diverted drainage. The thicker silt and clay beds are probably lacustrine deposits formed in short-lived lakes as ice advanced into the area during the Verone and Napoleon glaciations. Some of the thicker sand might also have been deposited at these times as the diverted drainage and meltwaters flowed into the temporary lakes.

The Oahe reservoir has flooded the lower terrace of the Missouri River in most areas so the only subsurface information on valley fill is in the Fort Yates area. In that area the deeper tests all have significant sections of gravel, or sand and gravel, at the base of the fill. They also show the variety of lithologies reflecting the complex history of various depositional environments associated with repeated glaciations that were noted in the Killdeer, Glen Ullin-Shields channel.

Alluvium

In most areas mapped as alluvium the near-surface sediment is composed of silt or silty clay. It represents recent (postglacial) deposition during the last 20,000 years, and in some areas for 50,000 or more years (Clayton and others, 1980, fig. 35). Where this sediment lies on glacial deposits in the diversion channels the lower contact is not easily recognized but probably amounts to 10 or 15 to 30 feet in most areas. Test holes in the Cedar Creek and Cannonball River Valleys generally have less than 25 feet of alluvial fill. The thin fill in these old valleys reflects the post-glacial adjustment of these streams to a lower base level provided by the southward-flowing Missouri River. These streams are actively eroding back into the uplands with a resultant band of badlands extending away from the streams. Smaller streams are similarly adjusting to the Cedar and Cannonball Rivers and thin (5 to 10 feet), narrow bands of alluvium are present in those areas, but the extent was considered to be too insignificant to include on the geologic map. Similarly, in areas of significant topographic relief, heavy rainfall results in some erosion and redeposition at areas of change in slope, but they were not included on the map.

ECONOMIC GEOLOGY

Lignite

Lignite beds are present in the Fort Union Group, and the near-surface deposits have been a source of domestic supplies since the earliest settlements in these counties. Numerous small-scale strip, slope, or drift (tunnels into hillsides) mine operations were viable before modern means of transportation and cheap alternative fuels reduced the local markets. During the 1920s and 1930s, between 11 and 17 licenses were generally issued in Grant County with strip operations gradually dominating. One shaft mine, a mine near Leith, operated until the mid-1930s. The number of mines gradually declined, but modern stripping methods allowed increased production, so in most of the years through the 1950s production was around 25,000 tons per year. Declines in local markets then led to fewer mines and by 1972 only 2 mines were active, the Davenport and Sprecher mines, and they produced only about 5,500 tons. The Sprecher mine, located in sec 29, T134N, R90W, now operated by Knife River Coal Mining Company, is the only active mine in these counties. First quarter of 1981 production was 3,506 tons.

Brant (1953) regarded the lignite beds present in Sioux County as too thin to be of economic interest. Subsequent information confirms this assessment, as the only beds present are thin beds in the Ludlow Formation; and these are limited to small areas near Selfridge and in westernmost Sioux County.

Brant (1953, p. 55) estimated lignite resources of 4,657 million tons for Grant County of which only 32 million tons were in beds at least 10 feet thick. Most of the resources were in beds less than 5 feet thick (3,838 million tons) and were inferred (3,204 million tons), that is, they were based on projected areal extensions beyond existing data. Measured resources were limited to 21 million tons in beds at least 10 feet thick and 181 million tons in beds 5 to 10 feet thick. No attempt to estimate strippable reserves was made.

Test-hole drilling for the Conservation Division of the U.S. Geological Survey (1978) has provided additional information regarding possible areas of development in Grant County. Test holes were generally drilled into the Cannonball Formation and only a few holes had lignite beds as thick as 10 feet. In most holes the thickest bed was 5 to 9 feet. The investigation did not include the northwest corner of the county but does indicate three areas which may be of interest for small-scale operations. These might be called the Leith, Coffin Buttes, and New Leipzig areas.

A 7-foot lignite bed at 63 feet in test-hole H-16 (pl. 4) is the bed previously mined near Leith. It maintains a thickness of

7 feet in test-hole 17 located in SW¼sec 18, T133N, R87W where it is present at an elevation of 2,378 feet. It thins to 5 feet at an elevation of 2,318 feet in test-hole H-15 located in NE¼sec 2, T133N, R88W. Based on these test holes and topographic maps of the Leith Quadrangle about 33 million tons may be present at an economically strippable depth in the area outlined on plate 4.

In the Coffin Buttes area a lignite bed which ranges in thickness from 7 to 10 feet thick was penetrated in 4 test holes at elevations ranging from 2,493 feet in H-21 located in SW¼sec 2, T131N, R90W to 2,382 feet in H-23 located in NE¼sec 20, T132N, R90W. It thins north and eastward to 5 feet in H-25 (pl. 4) and H-19 located in NW¼sec 20, T132N, R89W. The area of greatest thickness is an area of considerable topographic relief, so the area which may be of interest for strip mining is to the north of the buttes where about 60 million tons may be present at economically recoverable depths (pl. 4).

Test-hole H-43 located in NW¼sec 26, T134N, R90W has a 10-foot-thick lignite at an elevation of 2,363 which is the bed that was mined at the Davenport mine and which Brant referred to as the Haynes bed. This bed is also the bed being mined at the Sprecher mine. It thins northeastward to 5 feet in test-hole 47 located in SE¼sec 2, T134N, R90W. It has thinned to 8 feet in test-hole H-37 where it is present at an elevation of 2,318 feet and a depth of 177 feet. Based on test holes and topography, the area outlined as economically recoverable by strip mining in the New Leipzig deposit may be about 76 million tons.

Petroleum

Thus far there have only been 29 oil exploration tests drilled in these counties of which only one penetrated the entire sedimentary section. That well was the Texas, Pacific-Steckler No. 1 located in SE¼NE¼sec 5, T137N, R88W, which was plugged after drilling to a depth of 11,027 feet. Fifteen other tests have penetrated Ordovician rocks; the others have been shallower tests. Although results to date have been discouraging, the thick sedimentary section present in these counties, including all of the formations productive elsewhere in North Dakota, indicate that this area will receive further exploration. Recent discoveries in the Red River in Hettinger County and the Winnipeg in eastern Stark County suggest that improved seismic techniques which have aided exploration elsewhere may yet find reservoirs of oil or gas in these counties.

Sand and Gravel

Sand and gravel deposits are scarce in most areas of these counties as parts of the counties were never glaciated, and in glaciated areas deposition was thin or erosion has removed most of any deposits which may have been present. Glacial gravels are present in the diversion channels and along the Missouri River; however, in the diversion channels much of the sand and gravel is not near the surface. Along the Missouri River there are some terrace gravels present near Cannonball. One of the best glacial gravel deposits is near the top of a hill in NW¼sec 30, T133N, R84W.

Fluvial gravels are present at scattered localities along the Cannonball and Heart Rivers and Cedar Creek. These deposits are usually only a few feet to as much as five feet thick and are composed of poorly sorted, dirty gravel usually capped by silt or sandy silt. In some areas small benches at higher elevations along these drainages mark earlier courses of these streams before the erosion to the present stream levels. The gravel benches are more resistant to erosion than the finer grained bedrock because of the percolation of water through the gravel. Similarly, small gravel deposits are present on some low ridges in upland areas marking the courses of earlier drainages. These deposits are generally poorly sorted and consist mainly of local rock types with an admixture of western or Black Hills types.

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