GEOLOGY

of

MORTON COUNTY, NORTH DAKOTA

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

BULLETIN 72—PART I
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

COUNTY GROUNDWATER STUDIES 27—PART I
North Dakota State Water Commission
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Prepared by the North Dakota Geological Survey
in cooperation with the U.S. Geological Survey,
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CONTENTS

ILLUSTRATIONS

ABSTRACT

Morton County, located in west-central North Dakota, is on the southeast flank of the Williston Basin. The sedimentary section includes each of the geologic periods in the preserved section, and these strata have a gentle northwesterly dip. Surface elevations decrease eastward so the sedimentary section thickens westward from about 6,200 feet in the southeastern corner of the county to about 12,500 feet in the northwestern corner.

The near-surface sediment is of Recent, Pleistocene, Tertiary, or Cretaceous age. Recent sediment consists of alluvium, which is generally confined to lowland areas of current or Pleistocene drainages. Pleistocene sediments include scattered areas of till on upland areas in the eastern part of the county and water-sorted sediment in and along glacially diverted drainages. Soil horizons have developed on poorly consolidated sediment of Tertiary formations in most of the county except in the southeastern part where they are on Upper Cretaceous formations.

Sandstone beds within the Tertiary formations and the Hell Creek Formation are erratic in distribution, but where present they provide shallow aquifers. In some areas, lignite beds may also provide a shallow aquifer. Where shallow aquifers are inadequate, the Fox Hills Formation contains more or less continuous sandstones which provide a deeper aquifer in Morton County. The saline Dakota aquifer is present at depths of 2,600 to 4,900 feet from southeastern to northwestern Morton County.

Lignite beds are present in the Fort Union Group. In some areas they are thick enough and near enough to the surface to provide strippable reserves.

INTRODUCTION

Purpose of Study

This report describes the geology of Morton County, an area of about 1,944 square miles located in west-central North Dakota. It is one of a series of reports prepared by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission and the United States Geological Survey in the county groundwater study series.

The primary purposes of these studies are: a) provide geologic maps of the area, b) locate and define aquifers, and c) interpret the geologic history of the area. A general summary of natural resources of economic interest is also included.

Regional Setting

Morton County is bounded on the east by the Missouri River, on the south by Sioux and Grant Counties, on the west by Stark County, and on the north by Mercer and Oliver Counties. Physiographically it is in the Great Plains Province (fig. 1), an area characterized by generally low relief with gentle slopes interrupted by low buttes and ridges. The southwestern corner of the county is in the unglaciated Missouri Coteau Section. In most of the glaciated area the only evidence of glaciation is patchy areas of till on the upland divides and lag deposits of glacial boulders. For this reason, the landscape is similar in the two topographic sections.

Major drainages are the Missouri, Heart, and Cannonball Rivers and Square Butte Creek. Big Muddy Creek is located near the boundary between the two topographic sections and follows the course of a valley cut by glacially diverted drainage and glacial meltwaters. This valley crosses the Heart River extending southeastward past Flasher into Grant and Sioux Counties. Other glacial channels extend from the St. Anthony area northeastward to the Missouri River and southeastward through Northwest Chantapeta Creek.

The low buttes and ridges are held up by the more resistant rock types, which in western North Dakota are cemented sandstones, "scoria," or "pseudoquartzite." The most common type is cemented sandstone (fig. 2), which occurs in each of the Tertiary formations and is present in many areas. Scoria is a brick-like substance formed where lignite has burned and baked the overlying sediment. Scoria is present in many areas where lignite-bearing strata are present at the surface, but it is only in the Glen Ullin area that scoria is a prominent butte-former in Morton County (fig. 3). Pseudoquartzite, a finely crystalline silicate, is present at a few localities in Morton County, but it is not a prominent ridge-former here.

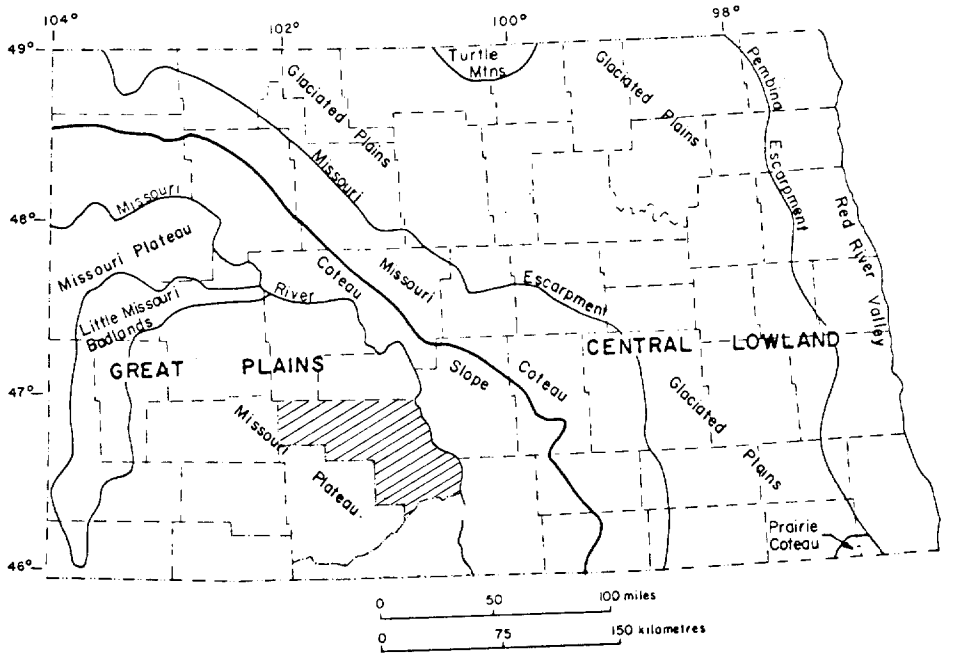

Figure 1. Location map showing area of study and physiographic subdivisions of North Dakota.

Morton County is located on the southeast flank of the Williston Basin, an intracratonic basin, the center of which is located near Watford City in McKenzie County. The most complete sedimentary record is in the western part of the county where rocks of each of the geologic periods have been preserved and as much as 12,500 feet of sedimentary section is present. The rocks have gentle northwesterly dips and generally thicken westward.

Surface elevations range from about 2,460 feet above sea level in the buttes north of Hebron to an elevation which fluctuates with the Oahe Reservoir level, but is around 1,600 feet in the southeastern corner of the county. The combination of regional dip to the northwest and topographic slope to the southeast results in rock units of younger age westward so that, north of Hebron, the Golden Valley Formation of Late Paleocene to Eocene age caps the hills. The oldest rocks exposed are the Fox Hills Formation of Upper Cretaceous age exposed along the Cannonball River in the southeastern area of the county. The near-surface materials are soils which have developed on the poorly consolidated sand, silt, and clay of the Upper Cretaceous and Tertiary formations, or on glacial till

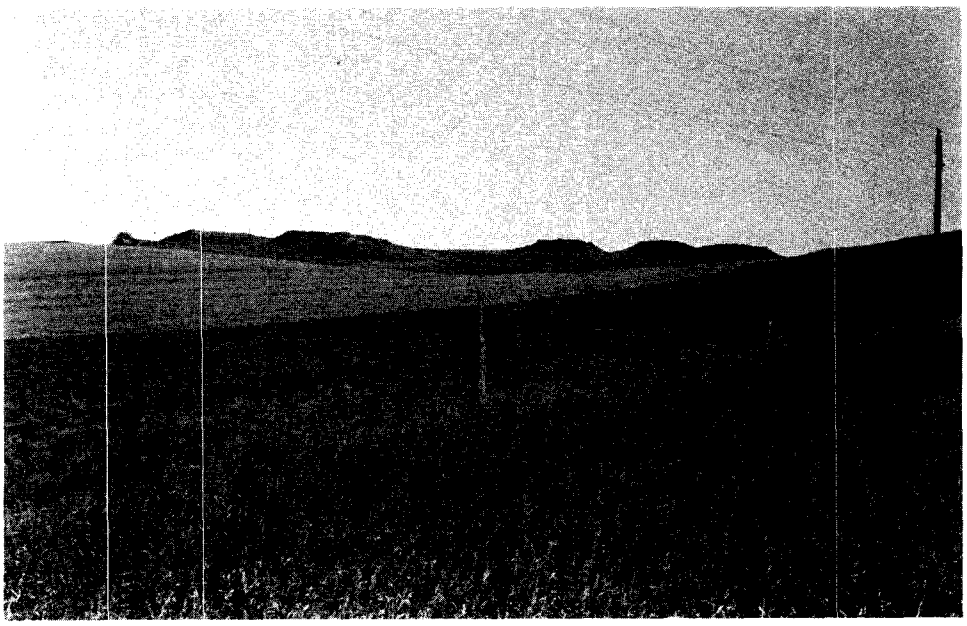

Figure 2. Sandstone capped buttes west of North Dakota Highway 49 north of Glen Ullin.

which is preserved on some upland surfaces, or on Recent alluvium in lowland areas.

Methods of Study

Fieldwork consisted of traversing all roads or trails by vehicle and traversing on foot to otherwise inaccessible areas of interest. The best geologic exposures are found along the major drainages and diversion channels which are incised 200 to 350 feet into the upland areas. Studies of the areas of good exposures were supplemented in upland areas (where exposures are generally poor) by road cuts, road ditch exposures or through the use of a 5-foot hand auger. Exposures were examined with special attention to formation contacts to provide a basis for extending contacts across areas of poor exposures and as an aid for subsurface interpretations. Stereoscopic pair photo coverage, scale 1:20,000, was available for the entire area. Topographic maps were also available for portions of the area. Geologic contacts were determined with the aid of aerial photos and plotted on county road maps, scale 1:63,360, obtained from the North Dakota Highway Department.

Subsurface information for the post-Pierre strata was provided by 60,000 feet of test-hole drilling by the North Dakota State Water Commission. The results of this drilling was published as groundwater basic data (Ackerman, 1977). A truck-

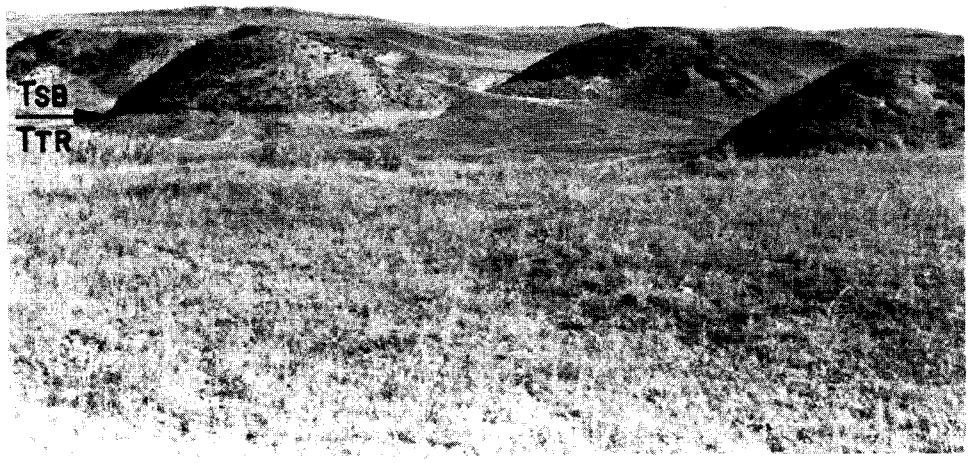

Figure 3. "Scoria" capped buttes east of Glen Ullin. "Scoria" formed from burning of the Richter bed. Sentinel Butte-Tongue River contact near middle of buttes.

mounted auger of the North Dakota Geological Survey was used to obtain information in a few areas and test-hole drilling for the Conservation Division of the U.S. Geological Survey provided some lignite information. The oil exploration files of the North Dakota Geological Survey provided information for the subsurface stratigraphy section. Recent oil exploratory activity has added much information for these interpretations.

Previous Work

A. G. Leonard spent the summer of 1909 mapping the Bismarck Quadrangle, which includes part of Morton County. The results of this work were published by the U.S. Geological Survey in 1912 as the Bismarck Folio (Leonard, 1912a). During the 1910 field season, Leonard extended his fieldwork westward and this was included as part of "The geology of south-central North Dakota" in the Sixth Biennial Report of the North Dakota Geological Survey (Leonard, 1912b). Hancock (1921) mapped the New Salem lignite field, about 16 townships. His report included township by township descriptions with emphasis on the lignite resources. Dove (1925) reviewed these reports and provided a description of the lignite beds of Morton County. Brant (1953)

estimated the lignite resources of Morton County as 15,251 million tons, but he did not provide an estimate of the amount recoverable by strip-mine methods. The Conservation Division of the U.S. Geological Survey, as part of a coal-land evaluation program, published detailed maps of the Heart Butte (Stephans, 1970a), Heart Butte NW (Stephans, 1970b), New Salem (Smith, 1973), Glen Ullin (Barclay, 1973), and Dengate (Barclay, 1974) Quadrangles. The stratigraphy was compiled using the classical approach of lignite beds as key beds and determining interburden thickness between key beds. Surface work was supplemented by 10 test holes in Morton County (Smith, 1970).

Thom and Dobbin (1924) presented a regional summary of the relationships of the post-Fox Hills strata. Their Fort Union Formation included the Lebo, Tongue River, and Sentinel Butte Members and their Lance Formation included the Hell Creek, Tullock, Ludlow, and Cannonball Members. Thom and Dobbin were uncertain whether some of the strata were Cretaceous or Tertiary in age. Studies by Brown (1939), Dorf (1940), and Fox and Ross (1942) clarified the age of these strata so that, when Laird and Mitchell (1942) mapped southern Morton County, they recognized the non-marine Cretaceous strata as the Hell Creek Formation and they assigned the non-marine Paleocene strata to the Fort Union Group.

Frye (1969) studied the Hell Creek Formation in the Missouri Valley area, which included part of Morton County. Feldmann's (1972) study of the Fox Hills Formation of the Missouri Valley area is concerned mostly with the better exposures in the adjacent counties. Cvancara (1976) included this area in his study of the Fox Hills Formation. Hall (1958) and Cvancara (1972, 1976) provided studies of the Cannonball Formation in this area. Fenner (1974) studied Cannonball Formation foraminifera from Morton County. Moore (1976) provided a general summary of the Ludlow and Hell Creek relationships in this area as well as a review of their usage in other areas. Glacial studies include those of Clayton (1966), Moran, and others (1976), and Clayton, Moran, and Bluemle (1980).

SUBSURFACE STRATIGRAPHY

Information obtained from oil exploration test holes provides the basis for interpretation of the early geologic history of the Morton County area. It shows that sedimentation began on a Precambrian surface of low relief about 550 million years ago. Each of the geologic periods are represented in the preserved section with Morton County having been alternately an area of marine deposition and emergence during which erosion of part of the sedimentary section occurred. Occasionally, non-marine deposition occurred. Episodes of emergence are marked by major

regional unconformities and the preserved sedimentary sections bounded by these unconformities have been defined as sequences. Sedimentary sequences recognized in the Morton County area are, in ascending order: Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas. Sediments of the Tejas Sequence and the upper part of the Zuni Sequence are present at the surface and will be treated in some detail. The sequences provide a convenient means for discussion of the geologic history.

The sedimentary section is further subdivided into units of similar lithology and origin which are defined as formations or groups. The stratigraphic column (fig. 4) provides the names of these units as well as the general lithology and thickness in Morton County. Generally, the thickness variations reflect a gradual downwarping of the central basin area so that the formations are slightly thicker northwestward. In some places, a rapid thinning eastward (e.g., Interlake Formation of Silurian age) is the result of erosion during episodes of emergence.

Precambrian

Five Precambrian tests have been drilled in Morton County. The deepest of these is 11,350 feet. It was drilled in sec 26, T140N, R88W. The first well to penetrate Precambrian rocks was the Phillips-Carter-Dakota No. 1 well, located in sec 29, T136N, R81W where Precambrian rocks were penetrated at a depth of 7,765 feet. Core from this well was described as horneblende schist (Maywald, 1957). The only other Precambrian samples yet received from Morton County are cuttings from the Amerada-Meyer No. 1 well located in sec 34, T135N, R83W. These cuttings have a granitic composition.

It has been projected that the boundary between the older Superior Province to the east and the younger Churchill Province to the west should lie in eastern Morton County. Age determinations for Precambrian samples from elsewhere in western North and South Dakota generally fall in a range about 1.7 billion years old. Ages for Precambrian samples from eastern areas of these states generally are in the range from 2.0 to 2.5 billion years old.

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. The Deadwood Formation was deposited during a marine transgression about 515 million years ago. The Texas-Pacific-Bachler No. 1 well, located in sec 14, T137N, R87W, lacks the

ERA	SYSTEM	SEQUENCE	FORMATION OR GROUP		THICKNESS	DOMINANT LITHOLOGY
CENOZOIC	QUATERNARY	TEJAS		ALLUVIUM	0- 30	Silt, Sand and Gravel
				COLEHARBOR	0- 300	Till, Gravel and Sand
	TERTIARY		FORT UNION GROUP	GOLDEN VALLEY	0- 60	Silt, Clay and Sandstone
				SENTINEL BUTTE	0- 420	Silt, Clay, Sand and Lignite
				TONGUE RIVER	0- 320	Silt, Clay, Sand and Lignite
				SLOPE	0- 60	Silt, Clay, Sand and Lignite
				CANNONBALL	0- 290	Mudstone and Sandstone
				LUDLOW	0- 200	Silt, Clay, Sand and Lignite
MESOZOIC	CRETACEOUS	ZUNI		HELL CREEK	0- 170	Clay, Sandstone and Shale
			MONTANA GROUP	FOX HILLS	230- 300	Sandstone and Shale
				PIERRE	1000-1500	Shale
			COLORADO GROUP	NIOBRARA	200- 220	Shale, Calcareous
				CARLILE	340- 360	Shale
				GREENHORN	160- 250	Shale, Calcareous
				BELLE FOURCHE	300- 325	Shale
			DAKOTA GROUP	MOWRY	70- 90	Shale
				NEWCASTLE	0- 58	Sandstone
				SKULL CREEK	200- 275	Shale
				INYAN KARA	150- 450	Sandstone and Shale
	JURASSIC			SWIFT	250- 350	Shale and Sandstone
				RIERDON	50- 70	Shale
				PIPER	285- 350	Limestone, Shale and Anhydrite
	TRIASSIC					
PALEOZOIC	PERMIAN	ABSAROKA		SPEARFISH	0- 100	Siltstone
				MINNEKAHTA	0- 45	Limestone
				OPECHE	0- 90	Shale and Siltstone
	PENNSYLVANIAN		MINNE-LUSA	BROOM CREEK	120- 300	Sandstone
				AMSDEN	250- 400	Dolomite, Sandstone and Shale
				TYLER	50- 150	Mudstone and Sandstone
	MISSISSIPPIAN	KASKASKIA		BIG SNOWY	50- 300	Shale, Sandstone and Limestone
				MADISON	1100-1600	Limestone, Anhydrite
	DEVONIAN			BAKKEN	0- 25	Shale and Siltstone
				THREE FORKS	0- 180	Shale, Siltstone and Dolomite
				BIRDBEAR	50- 80	Dolomite
				DUPEROW	130- 300	Interbedded Dolomite and Limestone
				SOURIS RIVER	50- 200	Interbedded Dolomite and Limestone
				DAWSON BAY	0- 120	Dolomite and Limestone
				PRAIRIE	0- 50	Limestone and Anhydrite
				WINNIPEGOSIS	0- 200	Limestone and Dolomite
	SILURIAN	TIPPECANOE		INTERLAKE	100- 600	Dolomite
				STONEWALL	60- 80	Dolomite
	ORDOVICIAN			STONY MOUNTAIN	135- 155	Argillaceous Limestone
				RED RIVER	600- 665	Limestone and Dolomite
			WINNIPEG GROUP	ROUGHLOCK	20- 65	Calcareous Shale and Siltstone
				ICEBOX	95- 115	Shale
				BLACK ISLAND	20- 60	Sandstone
	CAMBRIAN	SAUK		DEADWOOD	300- 650	Limestone, Shale and Sandstone
PRECAMBRIAN ROCKS						Igneous and Metamorphics

Figure 4. Stratigraphic column for Morton County.

basal sandstone and some other lower Deadwood strata indicating a location on a topographic high on the Precambrian surface when the Cambrian seas spread across the area. The thickness range of about 350 to 650 feet for the Deadwood Formation in Morton County reflects the variations due to non-deposition of lower beds over topographic highs as well as erosional thinning eastward of upper beds.

Tippecanoe Sequence

The Tippecanoe Sequence began with deposition of clastics of the Winnipeg Group as seas spread across Morton County about 470 million years ago. As the seas advanced, shallow-water carbonates with minor amounts of evaporites and shales were deposited. The thickness of this sequence ranges from about 1,100 feet in the southeast to 1,600 feet in the northwest parts of the county. The thinning is due almost entirely to erosional thinning eastward of the Silurian Interlake Formation prior to advance of the mid-Devonian seas.

Kaskaskia Sequence

The Kaskaskia Sequence began with deposition of shallow-water carbonates and thin shales as the Middle Devonian seas spread across the area from the northwest about 370 million years ago. The northwestern part of the county has nearly the entire depositional thickness of Devonian strata whereas minor erosional episodes thinned some of the units southeast. Erosional thinning is most pronounced in the mainly clastic Three Forks Formation. This occurred before Mississippian seas again spread over the entire area.

The initial deposits of Mississippian age are shaly carbonate of the lower Madison Group overlain by clean, shallow marine carbonates and then by alternating carbonates and evaporites of the upper Madison. Thinning of the Madison from 1,600 feet in the west to 1,100 feet in the southeastern corner of the county reflects some depositional thinning of the lower and middle units with most of the thinning resulting from erosion of the upper part. Thickness variations of the Big Snowy Group are mostly erosional below the regional unconformity.

Absaroka Sequence

The Absaroka Sequence is composed of clastics and carbonates that range in thickness from about 400 feet in the eastern part of Morton County to about 1,000 feet in the western part of the county. The preserved thickness reflects significant episodes of erosion within the sequence, which began about 315

million years ago, as well as erosion that resulted in the regional unconformity preceding Middle Jurassic deposition.

Zuni Sequence

The Zuni Sequence is primarily clastics. Redbeds, evaporites, and carbonates at the base were deposited when Middle Jurassic seas spread across the area from the west about 170 million years ago. A Late Jurassic-Early Cretaceous regressive phase occurred 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). Thick layers of marine shale accumulated before the fine-grained clastics of the Fox Hills Formation were deposited as the Late Cretaceous seas withdrew from the Morton County area about 70 million years ago. The regression of the Fox Hills sea 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 the Zuni Sequence are exposed in Morton County and will receive individual attention.

The Inyan Kara Formation in Morton County is an aquifer occurring at depths ranging from about 2,600 feet at the lowest elevations in southeastern Morton County to about 4,900 feet at the highest elevations in the northwestern part of the county. The Inyan Kara is quite variable in thickness (fig. 5). Its lithology seems to reflect the influence of drainage from the Sioux Arch area from Late Jurassic to Early Cretaceous time. The cross sections (pl. 2) show some of the variability of thickness and continuity of sandstone beds. The lower Inyan Kara appear to represent non-marine deposition whereas the uppermost beds appear to have been deposited during a marine phase of the advancing Lower Cretaceous seas; the contact with the overlying Skull Creek Formation shale is gradational. Areas of greatest thickness of the Inyan Kara (pl. 2, sec. A-A') generally are more sandy. This appears to represent, in part at least, a northwest-trending channel fill on an eroded Jurassic surface. Self-potential logs are generally reversed through the Inyan Kara sandstone beds indicating water fresher than the drilling fluids used for drilling these wells.

The Newcastle Formation sandstone is also an aquifer with an erratic distribution in Morton County (fig. 6). In the southeastern part of the county most wells have some sandstone at the Newcastle horizon with thicknesses ranging from 6 to 32 feet. These are inferred to be marine shoreline or offshore deposits. Only one well in the rest of the county has a sandstone developed at the Newcastle horizon, but it is 58 feet thick (pl. 2, well 7340) and, based on log characteristics, it appears to be a clean sandstone. Logs of the Newcastle show a normal

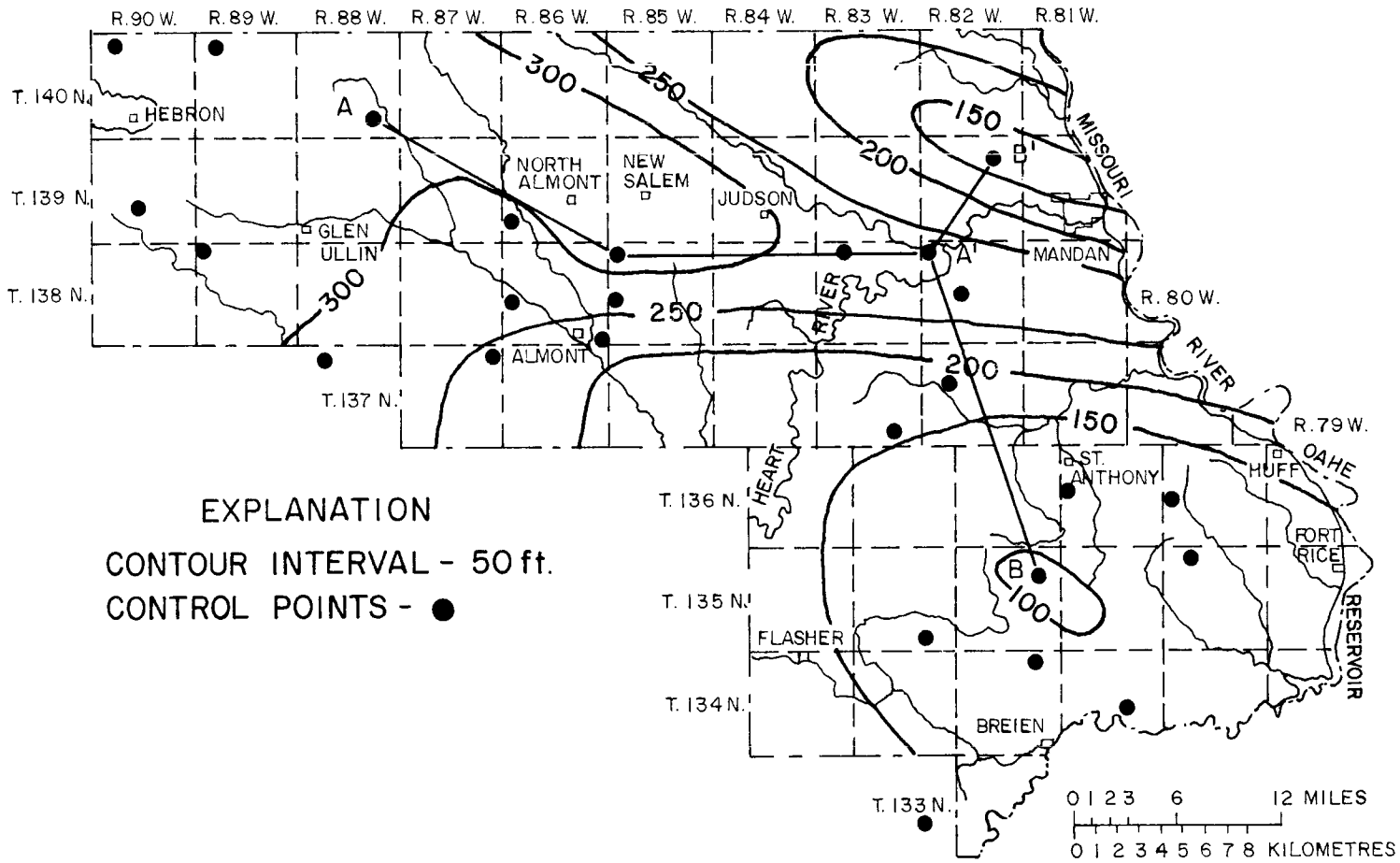

Figure 5. Isopachous map of the Inyan Kara Formation.

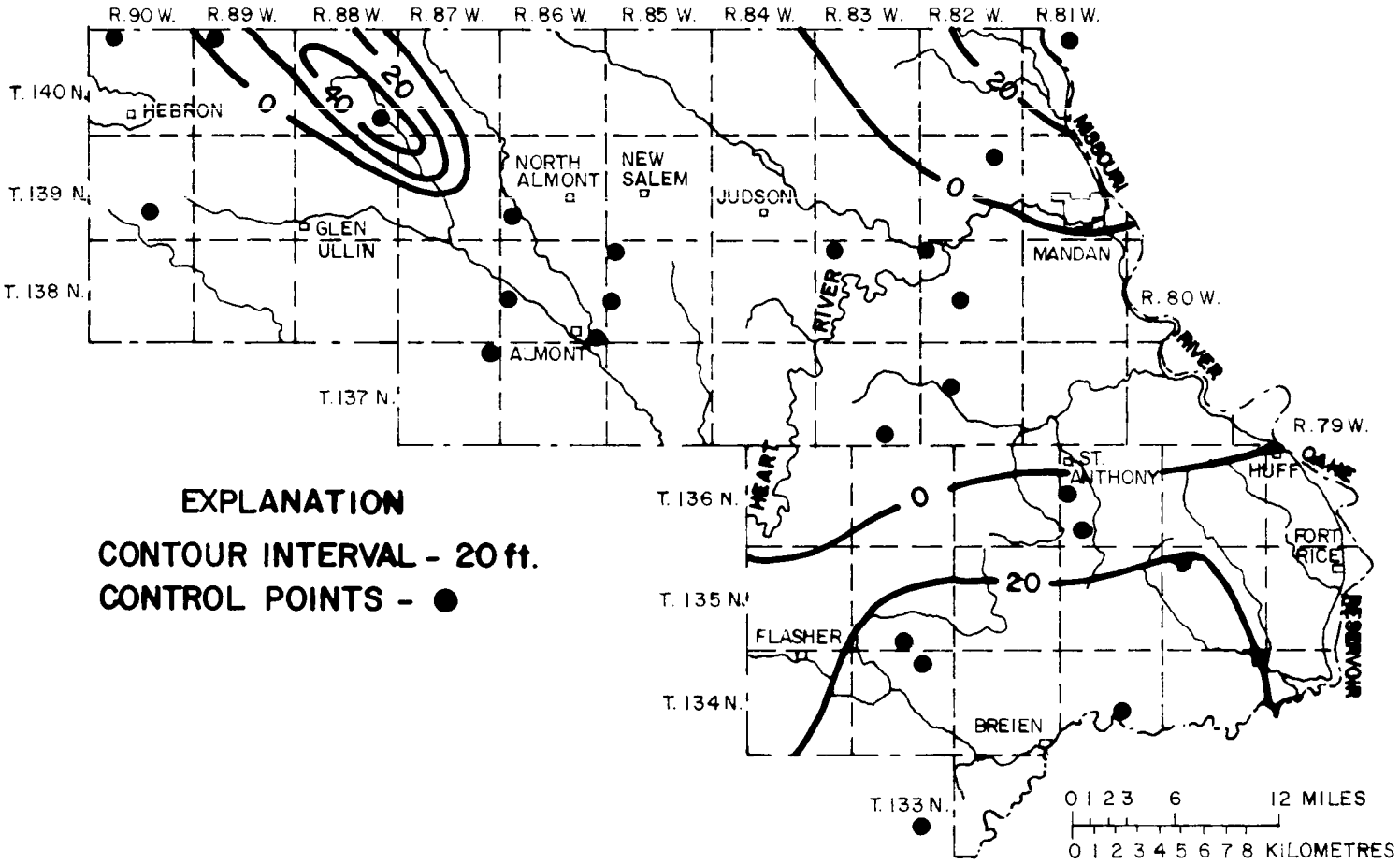

Figure 6. Isopachous map of the Newcastle Formation.

self-potential, which indicates water more saline than the drilling fluid and hence lower in quality than the Inyan Kara water.

SURFACE STRATIGRAPHY

Fox Hills Formation

The Fox Hills Formation is a marine- to brackish-water deposit of Late Cretaceous age. It outcrops along the Cannonball River in southeastern Morton County. Because it represents the regressive phase of the Late Cretaceous sea, lateral facies changes are common; these have led to various interpretations by different workers. Laird and Mitchell (1942, p. 9) recognized "three fairly distinct lithologic members" in southern Morton County: 1) a lower sand, 2) a banded sandstone and shale sequence, and 3) an upper sand, which they thought was probably equivalent to the Colgate Member of the Cedar Creek Anticline area. Fischer (1952) recognized a lower and upper series in the Fox Hills Formation in Emmons County. He used the terms Trail City and Timber Lake as members of his lower series. He also noted a resistant sandstone at the top of the Fox Hills, but he did not refer to it as Colgate. Waage (1968) studied the Fox Hills in outcrop areas of South Dakota extending into south-central North Dakota. He reviewed usage of the Fox Hills and proposed a reference area and subdivision into three members, all with type sections in South Dakota. In the lower Fox Hills Formation, he defined the Trail City Member as clayey silt and clayey sand overlain by sandstone of the Timber Lake Member. He showed the Trail City thinning northeastward while his Timber Lake Member thinned southwestward so that, in the western part of his study area, the Trail City Member is overlain by an upper Fox Hills unit. He designated this upper unit the Iron Lightning Member. Waage divided the Iron Lightning Member into a Bullhead lithofacies, which he described as thinly interbedded sand, silt, and clay, and a Colgate lithofacies, which he defined as sand beds occurring either at the top of or within the Iron Lightning Member. The sand beds at the top of the Fox Hills Formation were described by Waage as white, or grayish white and as much as 60 feet thick whereas those within the Bullhead lithofacies rarely exceed 20 feet. Feldmann (1972) recognized three members of the Fox Hills in south-central North Dakota using the terms Colgate, Bullhead, and Timber Lake Members. Klett and Ericson (1976) noted the cemented sandstone beds at the top of the Fox Hills Formation capping many of the buttes in Emmons and Sioux Counties. They interpret these as remnants of a channel sand of a south-flowing tidal river. Klett and Ericson accepted Waage's interpretation of the Colgate as a sand at various stratigraphic posi-

tions and introduced the term Linton Member for the channel sands at the top of the Fox Hills Formation.

Feldmann (1972, pl. 1) measured a section from the NW sec 21, T134N, R79W, just along the Cannonball River in Sioux County where the upper 180 feet of Fox Hills Formation is exposed. At that locality Feldmann measured about 5 feet of Colgate overlying about 5 feet of perlite ash, then about 80 feet of Bullhead Member and 90 feet of Timber Lake Member with the base of the Fox Hills below the flood plain. Fischer (1952) gives thicknesses of 285 to 325 feet for complete sections of the Fox Hills Formation in Emmons County.

Surface studies in areas adjacent to Morton County have documented facies changes and have suggested various nomenclatural practices to accommodate the interpretations. Subsurface studies add another dimension and introduce complexities that may either lead to ignoring subdivisions based on surface studies (Cvancara, 1976, Rice, 1977) or they might lead to further subdivision if the surface-study philosophy is extended to subsurface interpretations. Previous studies in adjacent counties by Carlson (1979, 1982) attempted to relate subsurface stratigraphy to nearby outcrop sections and to then extend the interpretations through the subsurface with a minimum of nomenclatural change. A similar approach, which is herein applied in Morton County, leads to an extension of the four-member subdivision. The upper three members, Colgate, Bullhead, and Timber Lake, are exposed in southeastern Morton County and can be correlated to the Anschutz-Gangl No. 1 well (11-135-82, pl. 3). The Trail City Member, although not exposed, may be traced through the subsurface.

The best Fox Hills Formation exposure in Morton County is located in SE sec 21, T134N, R80W (fig. 7). Measured upward from the river, the following section occurs: about 25 feet of slump-covered section; 75 feet of yellowish-brown, fine- to very fine grained sandstone of the Timber Lake Member; 16 feet of silt and silty clay; 10 feet of covered section; 42 feet of thinly banded sandstone, siltstone, and claystone of the Bullhead Member; 25 feet of light-brownish-gray to medium-light-gray, fine-grained sandstone of the Colgate Member. In most of the area mapped as Fox Hills Formation in Morton County, the weakly consolidated sediments have gentle slopes and a generally sandy soil with only a few small exposures scattered around the area.

Tracing the members of the Fox Hills Formation from the surface into the subsurface is difficult and Ackerman (1977) did not attempt to pick units within the Fox Hills for the test-hole drilling in Morton County. He did, however, consistently pick a sandstone unit as the top of the Fox Hills. This test-hole information, combined with oil exploration logs, provides a means for subsurface interpretations. The thickness of the

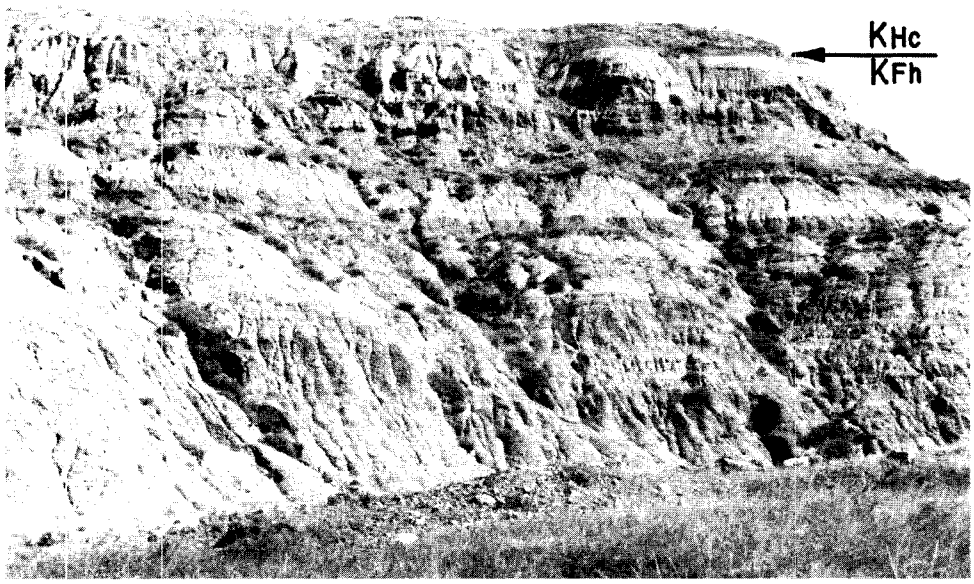

Figure 7. The Fox Hills Formation along the Cannonball River with Hell Creek capping the ridge. Location - SEsec 21, T134N, R80W.

formation ranges from about 280 to 300 feet in the southeastern part of the county to about 230 to 250 feet in the northwest.

The Trail City Member consists of silty to sandy shale that is only a few feet thick where it is exposed in Sioux County. It conformably overlies the Pierre Formation shale with a gradational contact; for this reason it is commonly referred to as a "transition zone." In southeastern Morton County, the Trail City Member is about 10 to 20 feet thick and the wedge of fine-grained sediment of the lower Fox Hills Formation thickens to 70 to 80 feet in western Morton County.

The Timber Lake Member is a predominantly sandstone unit that is about 175 feet thick where complete sections are exposed in Sioux County. In the Gangl well (pl. 3) it is about 150 feet thick. It thins westward to about 50 feet in a facies relationship to the Bullhead and Trail City Members with some claystone and siltstone beds included in the Timber Lake Member.

The Bullhead Member consists of alternating beds of sandstone, siltstone, and shale that have been referred to as the "banded beds." At the surface in southeastern Morton County, these beds were measured as 68 feet thick. In the Gangl well (pl. 3) about 90 feet of section is assigned to the Bullhead Member. The Bullhead Member is generally 80 to 100 feet thick in Morton County.

The Colgate Member generally consists of 10 to 25 feet of sandstone at the top of the Fox Hills Formation in exposures in

southeastern Morton and adjacent counties. In the subsurface, a sandstone unit 20 to 40 feet thick has been used to mark the top of the Fox Hills. This interpretation has the practical advantage of using a readily recognizable unit. It is also consistent with previous practice.

Hell Creek Formation

The Hell Creek Formation of Late Cretaceous age is well exposed in an area of badlands in southeastern Morton County along the Cannonball River and northward along the Missouri River to the Huff area. It consists of poorly consolidated sandstone, siltstone, claystone, and carbonaceous and bentonitic shales of a generally brown and brownish-gray hue. These beds, which have been referred to as the "somber beds," represent non-marine deposition in swamps and flood plains of streams near the margins of the Late Cretaceous seas. The fresh-water flora and fauna include dinosaur remains at some localities and the exposures show a general lack of lateral continuity of beds (fig. 8), typical of such depositional environments. A complete section is not exposed at any one locality in Morton County, but based on studies in adjacent areas, a complete section should be about 280 to 300 feet thick in southeastern Morton County.

Frye (1969) divided the Hell Creek Formation of this area into five members. In ascending order these are: Crowghost, Breien, Fort Rice, Huff, and Pretty Butte Members. The Breien Member, which was named by Laird and Mitchell (1942, p. 14), is a marine unit, the base of which is about 20 feet above the top of the Fox Hills Formation. Frye introduced the term Crowghost to apply to the non-marine strata between the top of the Fox Hills and the Breien. He designated a type section in the bluffs along the Cannonball River below the Crowghost cemetery in Sioux County. He also introduced the term Fort Rice Member for a section of lignitic shale, siltstone, and thin sandstone beds. These beds are generally 40 to 60 feet thick. They overlie the Breien Member and underlie thick sandstone bodies interpreted as channel deposits, which Frye named the Huff Member. Frye called the bentonitic beds at the top of the Hell Creek Formation the Pretty Butte Member. Type sections for the Fort Rice and Huff Members are located in Morton County.

Recognition of Frye's Hell Creek members is difficult in areas of good exposures and it becomes even more difficult in the subsurface. For this reason, the members are not used in this report. Frye (p. 36) noted some difficulties in recognizing his Fort Rice Member over more than limited geographic areas saying it "is recognizable only where it is underlain by the Breien Member." The Breien Member is recognizable only in a small area along the Cannonball River and probably does not

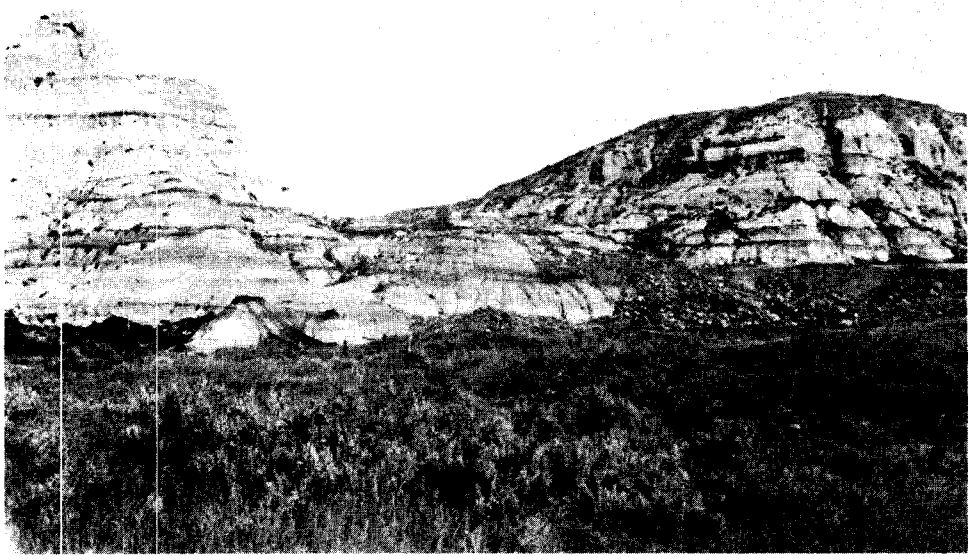

Figure 8. The Hell Creek Formation as exposed in NEsec 17, T133N, R82W near Cannonball River.

extend far into the subsurface. Sand is generally present in the upper part of the Hell Creek Formation, but a well-defined Huff sandstone member is not always present (e.g., Frye's section 5, p. 54). Frye states that the Huff Member interfingers with the underlying member and is gradational into the overlying Pretty Butte Member in central North Dakota. Generally, 15 to 30 feet of bentonitic and carbonaceous shale is present in surface sections as the uppermost (Pretty Butte) Member of the Hell Creek Formation. These carbonaceous and bentonitic shale beds are a useful marker for picking the top of the Hell Creek through the subsurface.

Ackerman (1977) did not subdivide the Hell Creek Formation into members in Morton County, but he included a section of sandstone, siltstone, and carbonaceous shale beds of variable thickness. Examination of the logs Ackerman used in his study indicate that individual sandstone units are generally less than 60 feet thick. Lithologies for the oil-exploration test holes are interpreted from the logs. The cross section (pl. 3) further indicates that individual beds are not traceable from well to well, verifying the same lack of continuity noted earlier in outcrops. Gamma-ray logs and density logs from test holes in adjacent areas indicate a thinning of the non-marine interval

between the Fox Hills Formation and the Fort Union Group northward from the outcrop areas. Consequently, about 170 feet of section is included in the Hell Creek Formation in northwestern Morton County.

Ludlow Formation

The term Ludlow was introduced by Lloyd and Hares (1915) to refer to non-marine, lignite-bearing strata between the Hell Creek and Cannonball Members of the Lance Formation in southwestern North Dakota and northwestern South Dakota. The type area is near Ludlow, South Dakota. When the Hell Creek was recognized as the uppermost Cretaceous strata, the Ludlow was transferred to the Fort Union Group. It is now recognized as the basal formation of the Fort Union Group.

The Ludlow is well exposed in southeastern Morton County where Laird and Mitchell report a thickness of 17 to 49 feet with a thickening westward. In this area it is characterized by drab-colored beds of clay, silt, sand, and lignite. Where they are well exposed (fig. 9), these beds show a continuity that contrasts with the underlying Hell Creek Formation. In most exposures, lignite beds are less than 3 feet thick and carbonaceous shale or shaly lignite is more common than lignite. The thickest lignite noted was in SE sec 15, T137N, R81W, in a bluff along the Little Heart River where a 7-foot bed consists of 2 feet of shaly lignite, 1 foot of carbonaceous shale, and a lower 4-foot bed of lignite.

Logs of test holes in Morton County generally do not include density logs, so the section of lignite-bearing beds must be based on samples or gamma-ray interpretations. Using this approach, the westward thickening noted at the surface is extended into the subsurface with about 175 to 200 feet interpreted as Ludlow in the westernmost part of the county. Part of the thickening appears to compensate for thinning of the Hell Creek Formation.

Cannonball Formation

Lloyd (1914, p. 247) introduced the term Cannonball to apply to about 250 to 300 feet of marine strata exposed along the Cannonball River in Grant County. The strata consist of alternating units of sandstone and siltstone or mudstone with mudstone the predominant lithology. The mudstone beds are generally gray or brownish gray and silty to sandy. The sandstone beds are generally yellowish brown in surface exposures and fine- to very fine grained. The sandstone is commonly partially cemented. As a result, it is resistant to erosion and forms benches along the major drainages.

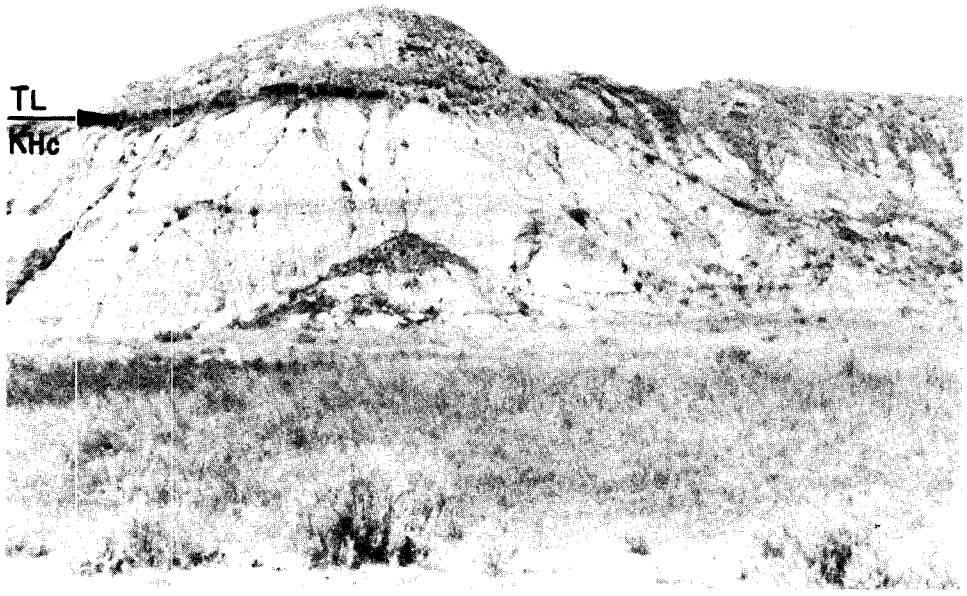

Figure 9. The Ludlow-Hell Creek contact exposed in sec 23, T134N, R83W.

Cvancara (1976) reviewed previous work on the Cannonball in this and adjacent areas (Laird and Mitchell, 1942; Hall, 1958; Cvancara, 1972; Fenner, 1974) and concluded that, while some sandstone beds are traceable laterally 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, but a nearly complete section is exposed along the north bank of the Heart River (fig. 10) in SE sec 10, T138N, R83W. About 290 feet of section is exposed at that locality with no lignite beds present. Cvancara (1976, fig. 3) shows the lower 70 feet as (?) Ludlow; however, in this report most of that section is included in the Cannonball Formation.

In the subsurface, about 230 to 290 feet of siltstone, mudstone, and sandstone are assigned to the Cannonball Formation. The fine-grained sediment is reflected by uniformly low resistivity on the electric logs interrupted only by higher resistivity of the sandstone beds. The higher resistivity readings contrast with the variable log responses in the overlying and underlying non-marine strata.

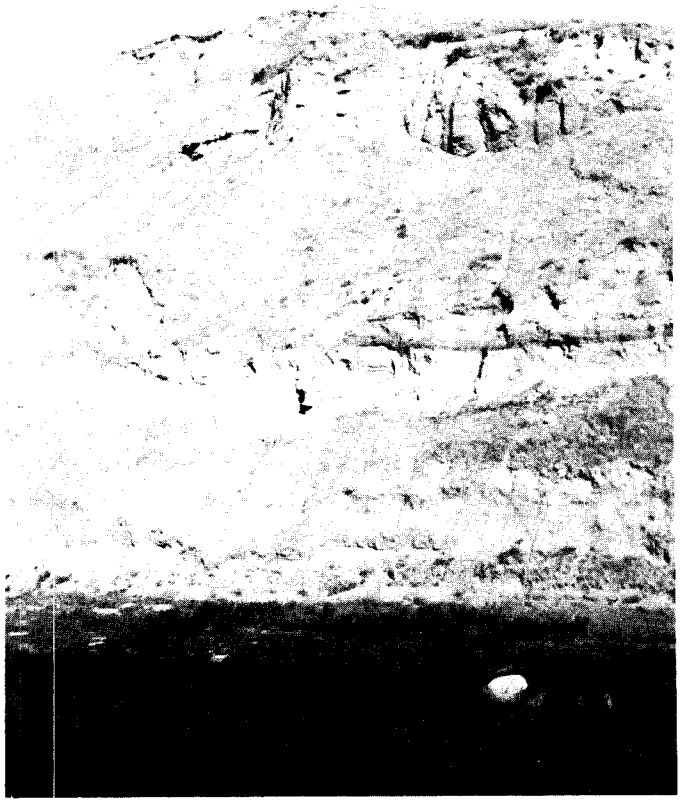

Figure 10. The Cannonball Formation exposed along north bank of the Heart River.

Slope Formation

The Slope Formation was introduced by Clayton and others (1977, p. 7) to resolve the problems of the intertonguing relationships of the Cannonball Formation within the Fort Union Group (fig. 11). The Cannonball Formation thins westward from Morton County with a compensating thickening wedge of nonmarine strata. In Morton County and adjacent areas the thickening wedge overlying the Cannonball Formation has previously been included in the Tongue River Formation. In Slope County equivalent strata were included in the Ludlow Formation (Hares, 1928; Moore, 1976). Moore (p. 35) recognized a "white siliceous bed," which he used as the uppermost bed of the Ludlow in his detailed studies along the Little Missouri River. He thought this bed might be associated with an unconformity and might have regional significance. Subsequent studies in Bowman, Adams, and Grant Counties have confirmed the eastward extension of this marker bed.

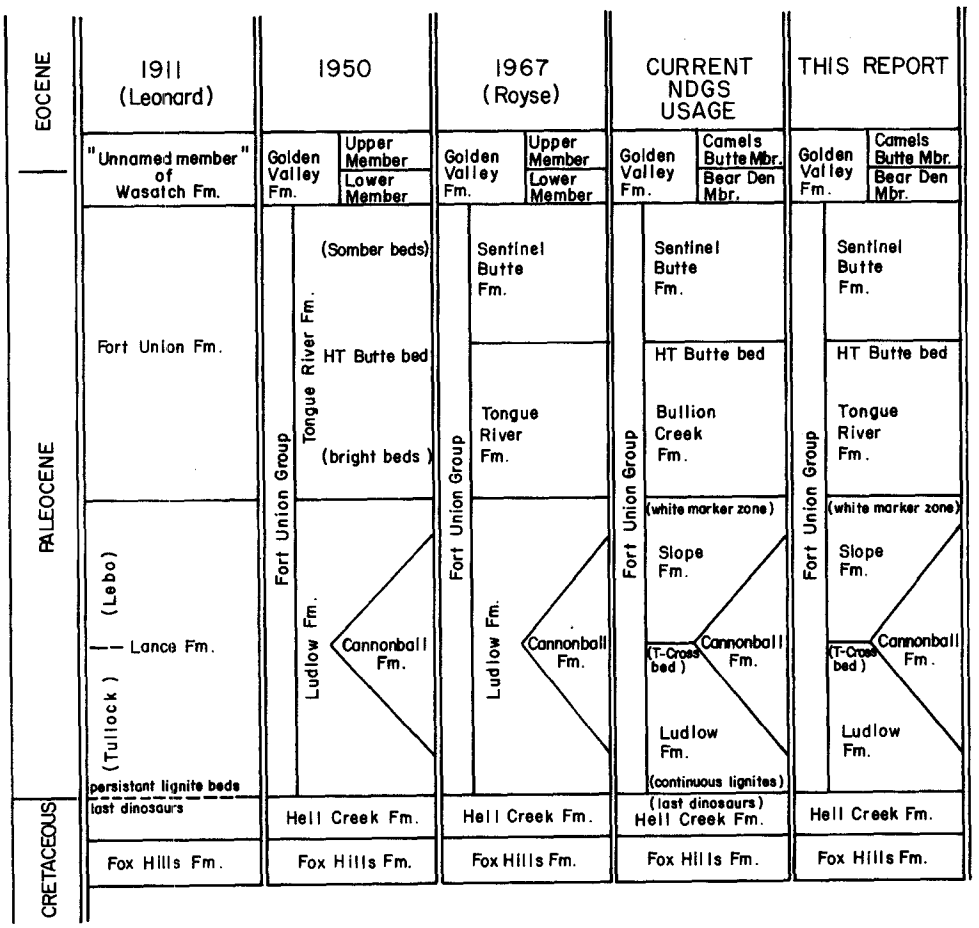

Figure 11. Relationship of Fort Union nomenclature of this report to previous usage in western North Dakota.

In Morton County, the "white siliceous marker zone" is exposed in the pastures in secs 21 and 22, T137N, R84W. A typical exposure is in a road cut in SW 15, T136N, R83W (fig. 12) and several other exposures occur in this area. The most northerly, good exposure is a road cut in SE SW sec 10, T139N, R83W where a few feet of white sediment is exposed beneath a thin layer of glacial sediment. In each of these areas the "white marker zone" is in relatively close proximity to exposures of the uppermost beds of the Cannonball Formation, indicating a thickness of about 60 to 80 feet for the Slope Formation in these areas.

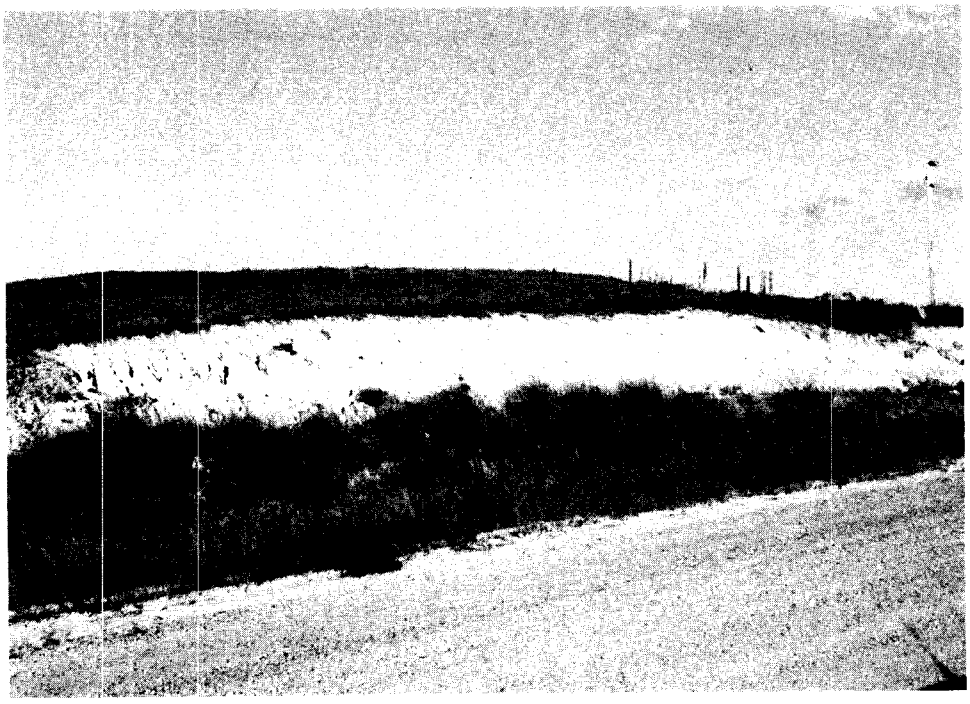

Figure 12. The "white marker zone" marking the top of the Slope Formation at SW corner sec 15, T136N, R83W.

Tracing the "white marker zone" through the subsurface is difficult because few control points are available and the quality of the logs is poor. The upper contact of the Slope Formation is defined by a relatively high resistivity on logs. The Slope Formation is about 100 feet in western Morton County.

Tongue River Formation*

The term "Bullion Creek Formation" was introduced by Clayton and others (1976, p. 10) to refer to strata between the "white marker zone" and the HT Butte lignite; this was done because uncertainties of correlation exist between the North Dakota and Wyoming exposures of Fort Union strata. Furthermore, the stratigraphic terminology differs among the various areas. As defined by Clayton, the Bullion Creek Formation is

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

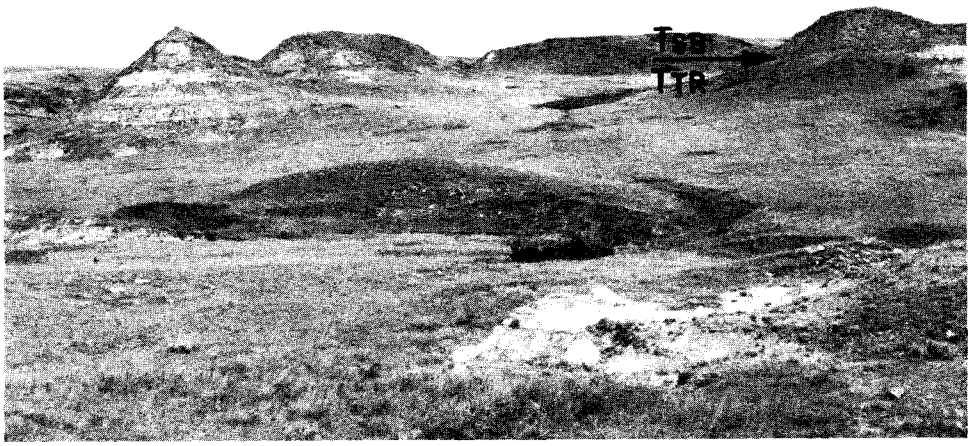

Figure 13. The Tongue River Formation near Big Muddy Creek.

approximately equivalent to Leonard's (1908) middle Fort Union. Leonard's R bed is considered to be equivalent to the HT Butte bed. In the badlands area along the Little Missouri River this readily recognizable unit has generally been called the Tongue River Formation or Member. Recent field reconnaissance indicates that the "bright colored" beds in the Williston and Powder River Basins are probably essentially equivalent, so extension of the term Tongue River to Leonard's middle Fort Union as originally proposed is satisfactory and this author sees no need for a new term (i.e., Bullion Creek).

The Tongue River strata are poorly exposed across the rolling prairie of Bowman, Adams, Slope, Hettinger, and Grant Counties, so the upper contact is difficult to trace in these areas. The lower contact is exposed in several places across Bowman and Adams Counties into western Grant County. Eastward, only scattered exposures of the "white marker zone" occur, so the contacts are not well defined at the county line; however, the Tongue River strata are present at the surface in a wide band through central Morton County (pl. 1). Only portions of the formation are exposed at any one locality so the thickness must be based on composite sections combined with subsurface information.

In Morton County fairly good exposures of the Fort Union strata are found near the valley of Big Muddy Creek (fig. 13).

Barclay (1972), noted a color change within these strata while mapping the Glen Ullin and Dengate Quadrangles (fig. 3). He used this color change as a key horizon for marking the stratigraphic position of the lignite beds. After a field conference of geologists from the Conservation Division of the U.S. Geological Survey and the North Dakota Geological Survey it was agreed that the color contact in the Glen Ullin area is probably equivalent to the one recognized by Leonard and later workers in the Little Missouri area. On this basis, Barclay (1970) used the terms Sentinel Butte and Tongue River as members of the Fort Union in his open-file report. This interpretation was used on subsequent Conservation Division quadrangle maps in adjacent areas in the coal study series and is accepted in this report. The upper contact of the Tongue River Formation (pl. 1) is based on Conservation Division quadrangle mapping wherever it was available. The contact was extended into adjacent areas by using topographic control, subsurface information, and interpretation of available exposures. The New Salem area has generally poor exposures, but in a nearby area of good exposures the Tongue River-Sentinel Butte contact was placed at the base of a bentonitic clay bed between the C and D lignite beds of Hancock (1921). This interpretation, based on lignite bed correlation supplemented by studies of petrified wood horizons, was used to extend the contact northeastward.

The Tongue River Formation consists of interbedded sand, silt, clay, lignite, and carbonaceous shales of non-marine origin deposited in swamps, lakes, streams, or flood plains of streams. Persistent lignite beds represent stable swamp environments. The thicker sand units, which in this area generally have thicknesses of 30 to 60 feet, are stream-channel deposits. The silts and clays are generally flood-plain or lacustrine deposits. There is a general lack of lateral continuity of lithology, so the stratigraphy has generally been based on study of the lignite beds and of the intervals between the lignite beds. Difficulty of correlation has led to problems in that new names have been introduced for each area of mapping.

The lower beds of the Tongue River Formation are best exposed in the area around Almont and southeastward where many exposures weather to buff and yellow colors typical of the Little Missouri area. The upper beds are best exposed in the Glen Ullin area and eastward to the New Salem area. Some of these beds, although lighter colored than the overlying beds, are not what has been generally recognized as "typical Tongue River" colors. Barclay (1972), for purposes of discussion, divided the Tongue River strata into two informal units, A and B. He estimated that his lower unit, A, had a thickness of at least 150 to 210 feet regionally and that his upper unit, B, was 95 to 160 feet thick in the Dengate Quadrangle. The only significant

lignite bed was the Tavis Creek bed, which was placed as generally 20 to 30 feet below the top of the formation.

Mowat (1980) used a thickness of about 310 feet for the Tongue River in the Clark Butte NE Quadrangle in southwestern Morton County. Mowat has six named coal beds. In ascending order they are: Schank, Shell, Koehler, Many Springs, Red Dog, and Beaver Creek. The same names were used earlier by Stephans (1970a, 1970b) with the Beaver Creek bed about 20 feet below the color contact (approximately equivalent to Tavis Creek bed of Barclay).

In the New Salem area, Hancock (1921) used letter designations A through E for the lignite beds. The approximate distances above the base of the Tongue River were given as follows: bed A, 45 feet; bed B, 100 feet; bed C, 155 feet; bed D, 230 feet; and bed E, 254 feet. No exposures of the contact of the Tongue River with the underlying Cannonball are found in Hancock's area of study. Smith (1973) mapped the New Salem Quadrangle and used names for Hancock's beds as follows: A, Sims; B, Crooked Creek; C, Cut Bank Creek; D, Kaleber; and E, Ramsland. Three local beds occur above the Ramsland. Marked color differences were not recognized in this area. Barclay (1972, p. 86) suggested that the Tavis Creek bed is equivalent to the Beaver Creek bed of Stephans and to the C bed of Hancock. This agrees with my own observations that the Kaleber bed is in about the position of the Richter bed, and the top of the Tongue River is between the C and D beds.

The surface studies suggest stratigraphic columns for the Tongue River based on intervals between lignite beds with thicknesses for the named beds based on outcrop measurements. Subsurface information indicates that, in most areas of Morton County, not more than one thick (more than 3 feet) lignite bed is present in the Tongue River Formation at any one locality and that thick beds are present at different horizons in different areas. In western Morton County, test-hole 4754 (140-88-16 abb) was logged to a depth of 715 feet with the top of the Tongue River at 338 feet. Only thin lignite beds were present except for a five-foot bed 226 feet below the top of the Tongue River (depth, 564 to 569). Test-hole 4753 (139-88-34 bcc) was drilled to a depth of 840 feet where it had penetrated about 30 feet of the Hell Creek Formation from an elevation of 2,070 feet. The Sentinel Butte-Tongue River contact is at an elevation of 2,140 feet in the southwestern part of section 34. Only thin lignite beds are present except for a bed at a depth of 85 to 90 feet (about 155 feet below the top of the Tongue River) in this test hole.

In the New Salem area, test-hole 4651 (139-85-30 aab) was drilled from a surface elevation of 2,065 feet. The only lignite bed more than 2 feet thick to a depth of 450 feet is a 12-foot bed (depth 117 to 129). This bed was at one time mined from a

nearby underground mine and probably extends northward to Oliver County (test-hole 3646, 141-85-27 ddd, depth 320 to 330 feet).

Sentinel Butte Formation

Leonard (1908, pl. XII) introduced the term Sentinel Butte for a sequence of lignite beds in the upper part of the Fort Union Formation. He also noted a color change at the lowest lignite bed in the sequence (bed R) and referred to the dark-gray shales and sandstones above bed R as the Upper Fort Union. Subsequent workers have recognized the same color contact and have applied the term Sentinel Butte to these strata either as a member of the Fort Union (Hares, 1928), or Tongue River (Hansen, 1955), or facies of the Tongue River (Fischer, 1954), or as a formation of the Fort Union Group (Royse, 1967). Recent North Dakota Geological Survey practice has favored its usage as a formation.

The Sentinel Butte Formation consists of interbedded sand, silt, clay, lignite, and carbonaceous shale representing depositional environments similar to those of the Tongue River Formation. The beds weather to browns and grays in contrast to the yellows and lighter grays of the underlying Tongue River strata. The lower beds of the Sentinel Butte Formation are best exposed in the Glen Ullin area (fig. 14). Clinker resulting from burning of the Richter bed caps many of the low buttes east and south of Glen Ullin. This lignite bed is about 40 to 60 feet above the color contact, with the intervening interval consisting of generally gray siltstone and mudstone beds. The base of the Sentinel Butte is placed at the base of a bentonitic mudstone. A petrified wood zone is another prominent marker horizon in the lower part of the Sentinel Butte in exposures in the Glen Ullin, Dengate, and north Almont areas.

South and west of Glen Ullin the contact is similar, but the lignite splits into two or more seams. Barclay (1970) referred to a Spring Valley-Richter zone. Subsequently, Stephans (1970) mapped an area to the southwest and used the term Richter for the lower split and Spring Valley for the upper split. Mowat (1980) extended the upper split to the southwestern corner of the county where no Richter bed is present. Stephans and Mowat both recognized a Heart Butte bed about 100 feet above the base and Mowat recognized a Discovery bed about 225 feet above the base of the Sentinel Butte in the Clark Butte NE Quadrangle.

The Sentinel Butte Formation is present at the surface in most of western and northwestern Morton County, so the only areas where the total thickness may be determined is in areas where the overlying Golden Valley Formation is present. Test-hole 4754 (140-88-16) was drilled at an elevation of 2,280 feet

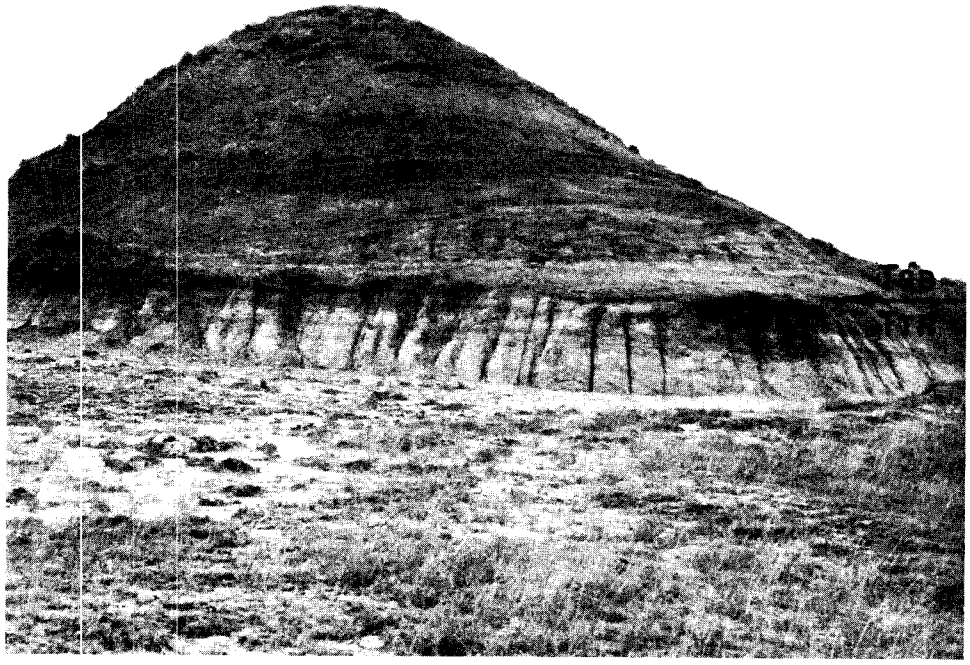

Figure 14. The Tongue River-Sentinel Butte contact as exposed in W½sec 11, T138N, R88W.

about one-half mile south of the Golden Valley-Sentinel Butte contact in section 9 where the contact is at an elevation of about 2,360 feet. In this test hole the Richter bed is about 10 feet thick at a depth of 285 to 295 feet, and the base of the Sentinel Butte is placed at the base of a clay bed at 338 feet. A complete section in western Morton County would, therefore, be about 420 feet thick.

The gamma-ray logs for test-hole 4754 indicate three lignite beds above the Richter bed. These are a split bed at a depth of 46 to 50 and 53 to 54 feet, a 5-foot bed at 104 to 109 feet, and a 3-foot bed from 133 to 136 feet. A lack of test-hole data prevents correlation of these beds to the area mapped by Stephans and Mowat.

Golden Valley Formation

The Golden Valley Formation was named by Benson and Laird (1947, p. 1116). It applies 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 the Golden Valley strata and divided them into lower and upper members. Hickey

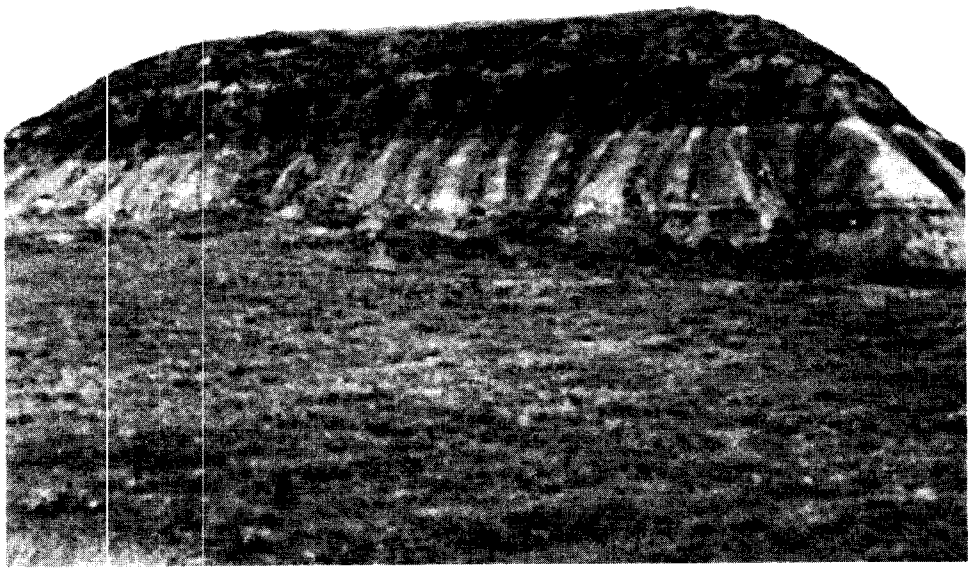

Figure 15. The Golden Valley Formation north of Hebron as exposed in SEsec 8, T140N, R90W.

(1976) reviewed previous usage and provided a detailed study of the lithology and distribution of the Golden Valley strata. He introduced the terms Camels Butte and Bear Den for the upper and lower members and designated a reference section in the type area.

Exposures of the Golden Valley Formation are limited to two areas in T140N, R90W in western Morton County. In each of these areas the light-colored, orange-weathering zone of the Bear Den Member is the most conspicuous exposure. Much of the area mapped as Golden Valley consists of grassed-over areas of Camels Butte and Bear Den Members. The areal extent of the Golden Valley is limited to the higher elevations on the drainage divide. One of the best exposures is in SE sec 8, T140N, R90W (fig. 15). At this locality, about equal amounts of the two members are exposed with the lower contact at the top of the Harnisch lignite bed. The Bear Den Member here has its typical three-unit subdivision. The lower part is light gray, silty clay, which locally may be quite sandy. The middle unit is very light gray, silty clay, which weathers to a bright orange. The upper unit is a purplish-gray, silty, carbonaceous clay capped by a thin lignite, which has been named the Alamo Bluff bed. The clays of this member are kaolinitic and are used to make the brick at the Hebron brick plant.

The Camels Butte Member generally consists of channel sandstone and interchannel deposits of siltstone, mudstone, and local lignite beds. Clay beds of the Camels Butte Member are illitic and montmorillonitic. Sandstone beds are generally micaceous. Plant remains are fairly common and have been identified as Eocene age, so the Paleocene-Eocene boundary is placed at the base of the Camels Butte Member.

Tejas Sequence

The only sediments found above the regional unconformity at the top of the Zuni Sequence in Morton County are the glacial and Recent sediments. Although the Tejas Sequence is considered to consist of Late Tertiary bedrock formations, it is useful to include these glacial and Recent sediments to complete the geologic history of this area.

Clayton (1966, fig. 1) applied the term Morton Drift, or Drift A, to the glacial deposits in Morton County. He placed this unit in the Early Wisconsinan (1966, fig. 2), but stated that the age was uncertain.

Clayton and others (1980, fig. 32) show three glacial advances, or outer margins, extending across Morton County. The outer Dunn margin, or Advance 1, coincides with the limit of Drift A and is now considered to be pre-Wisconsinan. The Verone margin, or Advance 2, is regarded as either Early Wisconsinan or pre-Wisconsinan. The only evidence of glaciation in the area between Advances 1 and 2 is scattered lag boulders in Morton County and an exposure of till and sorted sediment at one locality in nearby Grant County. The area covered by Advance 2 is characterized by thin, scattered remnants of till on upland divide areas, by abundant lag boulders in some areas, and by scattered lag boulders in other areas. The valley that enters the county near Hebron and extends southeastward past Glen Ullin and Flasher (the Killdeer-Shields channel) carried diverted drainage of the formerly northeastward-flowing drainage until the ice melted back far enough to allow a more easterly channel (Missouri River Valley) to carry the flow.

The Napoleon margin (Advance 3) may be pre-Wisconsinan, Early Wisconsinan, or Late Wisconsinan, with Early Wisconsinan considered most likely. Most of the areas of preserved till, mapped as Coleharbor (pl. 1) are within the limits of the Napoleon margin.

The ice margin positions are based largely on lag boulder interpretations (Clayton, 1980, p. 55). The outer margin is the southwestward limit of glacial boulders reinforced by the valley marking erosion by glacially diverted drainage. Advance 2 is marked by an increase from occasional to scattered glacial boulders. Advance 3 is marked by abundant glacial boulders.

Figure 16. View of St. Anthony "flats area."

Post-glacial deposition consists primarily of slope wash from the uplands which has exceeded the transport-capacity of the post-glacial streams. Post-glacial sediments are most evident in the broad valleys cut by diversion streams, but the pre-existing northeastward drainages are also adjusting their profiles to the post-glacial Missouri River. The Little Heart Flats area (fig. 16) is also an area of Recent deposition.

Coleharbor Group

The term Coleharbor Formation was introduced by Bluemle (1971, p. 16) to include all of the glacial sediments in North Dakota. He included three main facies: 1) "interlayered bouldery, cobbly, pebbly, sandy, silty clay (till, or unsorted drift); 2) sand and gravel; and 3) silt and clay." Each of these three facies are present in Morton County. Bluemle noted that future studies might lead to raising the rank to group and such has been the case.

The unsorted sediment of facies 1 (till) is present as erosional remnants on the upland areas in the eastern part of Morton County. Road ditch exposures show till on bedrock (fig. 17) and the thickness in many of these exposures is a few feet or less. No effort was made to determine glacial sediment thicknesses, but the general lack of constructional relief and information from a few test holes indicate that probably not more

Figure 17. An exposure of till on bedrock with lag boulders showing thin nature of remaining drift in many areas.

than 20 or 30 feet are preserved in most areas mapped as glacial till (pl. 1). The fine-grained sediment of facies 1 has been eroded from many areas, and the only evidence of the original extent in those areas is the lag boulders, or, as they are sometimes referred to, glacial erratics (fig. 18). Till may also be present in some of the glacial channels. No till was logged in test holes; however, some of the samples logged as silt and clay might actually be a washed till, or a partially sorted glacial sediment deposited when the ice was melting from the channels. This sediment might lack the cohesiveness of normal (unwashed) till and would be difficult to recognize in rotary cuttings.

The sorted glacial sediment of facies 2 and 3 is found in the diversion channels where they show some complex facies relationships, as well as some general patterns. The sand and gravel facies, facies 2, is generally present at the base of the deep channel in Big Muddy Creek and in branch channels extending northward into Mercer and northwestward into Dunn County (pl. 1). Thicknesses are variable and may in part reflect whether the test hole was located in the deepest parts of the channel where the fill is generally about 300 feet thick. In western Morton County a few feet to as much as 32 feet of

Figure 18. Concentration of lag boulders on slopes where finer grained sediment has been eroded.

gravel was noted in this channel. In the Flasher area as much as 76 feet of gravel was noted in one test hole (32-134-83). In some test holes no gravel was present at the base, but generally sand was present; and the gravels are commonly overlain by a thick sand section. Gravel is also present at the base of the fill in some of the minor drainages such as Sims Creek and Sweetbriar Creek.

The silt and clay, or facies 3, was probably deposited in two environments. The thick silt and clay units were probably deposited in ponds or lakes, which formed as advancing ice blocked the channels or else they were deposited during melting of the ice. The thin silt and clay units in the generally sandy sections may be flood-plain deposits of the diversion streams. Thick lacustrine deposits of Pleistocene age are present in the Little Heart Flats area.

Alluvium

In most areas mapped as alluvium the near-surface sediment is composed of dark-gray or brownish-gray silt and silty clay. It represents post-glacial deposition during the last 10,000 to 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. About 10 to 15 feet of alluvium lies on bedrock or glacial deposits in the minor drainage valleys. Thin, narrow bands of alluvium are also present in tributaries and minor drainages. This alluvium is of such limited extent that it was not included on the geologic map.

Alluvium on the lower terrace represents flood-plain deposits of the post-glacial Missouri River. Alluvium on the upper terrace represents flood-plain or slope-wash deposits, which lie on glacial gravels or bedrock.

ECONOMIC GEOLOGY

Lignite

Currently no lignite is being mined in Morton County, but there have been numerous mines in the past. The high point for licenses appears to have been 1935 when 47 licenses were issued for 29 strip mines and 18 underground mines. Most of the underground licenses were for slope or drift mines (tunnels into hillsides), but one was for a shaft mine near New Salem. Most of the mining was done prior to reclamation laws, which went into effect in 1969. Most of the mines were small operations that existed to supply domestic needs of nearby settlers; these would be difficult to locate today. However, some of the larger strip-mine operations have left abandoned open pits, which are present from south of New Salem to the Glen Ullin area.

Brant (1953) estimated lignite resources in Morton County as 15,251 million tons of which 334 million tons were in beds 10+ feet thick and 2,109 million tons were in beds 5 to 10 feet thick. The remainder was in beds 2½ to 5 feet thick. Most of the resources in beds greater than 5 feet thick were in the measured or indicated category. No attempt was made to estimate resources economically recoverable by strip-mine methods.

Recently, additional subsurface information has been obtained from gamma-ray logs of oil exploration tests, lignite drilling for the Conservation Division, U.S. Geological Survey (1970, 1977), county groundwater studies, and some coal exploration data. Density of control points is not yet sufficient to estimate strippable reserves in Morton County, but it is sufficient to indicate areas of interest. The Richter bed is generally 7 to 10 feet thick both north and south of Glen Ullin at depths that would provide significant reserves. The deep bed in the New Salem area may be present at depths shallow enough farther northeastward to provide strippable reserves. If development does occur in Morton County, it will likely be in those areas.

Petroleum

Thirty-three oil exploration tests had been drilled in Morton County as of January 1, 1981. Fifteen of these penetrated Ordovician rocks and five penetrated the complete sedimentary section. Although commercial quantities of oil have not been found, several wells have found traces. Since the western part of the county has a thick sedimentary section, which includes all the formations productive elsewhere in the basin, it will continue to be an area of interest for future exploration. Recent successes in the Black Island Formation in Stark County and the Red River Formation in Mercer County provide a basis for optimism that Morton County will one day be added to the oil- and gas-producing counties of North Dakota.

Sand and Gravel

Most of Morton County lies within the glaciated area and the best gravel deposits were deposited during melting of the glacial ice. Ice-contact or kame-terrace deposits in the former drainages or along the sides of drainages provide the best sources. Examples of these deposits are found in the lowland of the Flasher-Shields channel in T134N, and T135N, R83W and the northwest branch of the Chantapeta Creek in T135N, and T136N, R81W. Ponding and sorting of sediment near the junction of the valleys of the Little Heart and Heart Rivers with the Missouri River provide well-sorted gravels in those areas.

In the western parts of the county, beyond the limit of glaciation, "scoria" is used as a gravel substitute on roads. "Scoria" is the term used for the clinker, or baked sediment, where lignite beds have burned. The Richter bed has burned over a widespread area near Glen Ullin and provides most of the "scoria" in that area. In the New Salem area, the Kaleber, or D bed, is a common source.

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