GEOLOGY

of

MERCER and OLIVER COUNTIES, NORTH DAKOTA

by
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GEOLOGY OF MERCER AND OLIVER COUNTIES

by Clarence G. Carlson

ABSTRACT

Mercer and Oliver Counties are areas of glacially modified bedrock topography. Glacial deposits include unsorted drift in the form of ground moraine and hummocky moraine and sorted drift which is present in the valleys of diversion channels, the present streams, and as ice contact deposits. Post-glacial events have added alluvium to the diversion channels and present stream valleys and in some areas wind action has produced sand dunes. The thickest glacial and recent deposits are in the diversion channels where as much as 280 feet of fill has been found.

Bedrock formations exposed in these counties are the Cannonball, Tongue River, Sentinel Butte, and Golden Valley Formations. Cannonball exposures are limited to southeastern and eastern Oliver County. Extensive exposures of the Tongue River Formation are present in the Square Butte drainage; discontinuous exposures are present in the short drainages along the Missouri River in Oliver and eastern Mercer County. The Sentinel Butte Formation is exposed in much of western Oliver and Mercer Counties and subcrops under the glacial drift in most of the rest of that area. Golden Valley exposures are limited to the higher elevations on some of the drainage divides in western Mercer and Oliver Counties. Maximum thicknesses for these formations (i.e., where erosion has not removed part or all of a formation) are about 350 feet for the Cannonball, 450 feet for the Tongue River, 550 feet for the Sentinel Butte and 160 feet for the Golden Valley. The Cannonball Formation is relatively uniform in thickness; the Tongue River and Sentinel Butte Formations thicken depositionally northwestward by about 200 to 250 feet; the Golden Valley Formation varies according to the amount of erosion at each locality.

Previous reports have named 24 lignite beds within the Tongue River and Sentinel Butte Formations in these two counties. Test hole drilling has shown that not that many beds occur at any one locality, but using key beds, measured sections, topographic control and subsurface information the previously named beds can be placed in their approximate stratigraphic positions. Two lignite beds are currently

being mined in these counties. They are the Hagel bed, which is about 275 feet above the base of the Tongue River Formation and is being mined near Center and Stanton; and the Beulah-Zap bed, which is about 140 feet above the base of the Sentinel Butte Formation and is mined in the Beulah-Zap area.

INTRODUCTION

Purpose of Study

This report describes the geology of Mercer and Oliver Counties, an area of 1,817 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 U. S. Geological Survey in their ground water study series.

The primary purposes of this study are: (1) to provide a geologic map of the area, (2) to interpret the geologic history of the area, (3) to locate and define aquifers, and (4) to determine the location and extent of other natural resources in these counties.

Area of Study

The area of this study includes all of the area of Townships 141 to 147 N., Ranges 83 to 90 W., which lies south or west of the Missouri River. Physiographically this area is in the Missouri Slope District of the Glaciated Missouri Plateau Section (Fig. 1) of the Central Lowland Province, with the exception of the lowland area bordering the Missouri River, which is in the Missouri River Trench District of the same section.

Methods of Study

Field work began in July, 1966, and continued through the 1967 and 1968 field seasons. The general practice was to traverse all roads and trails by vehicle and then to traverse on foot where necessary to

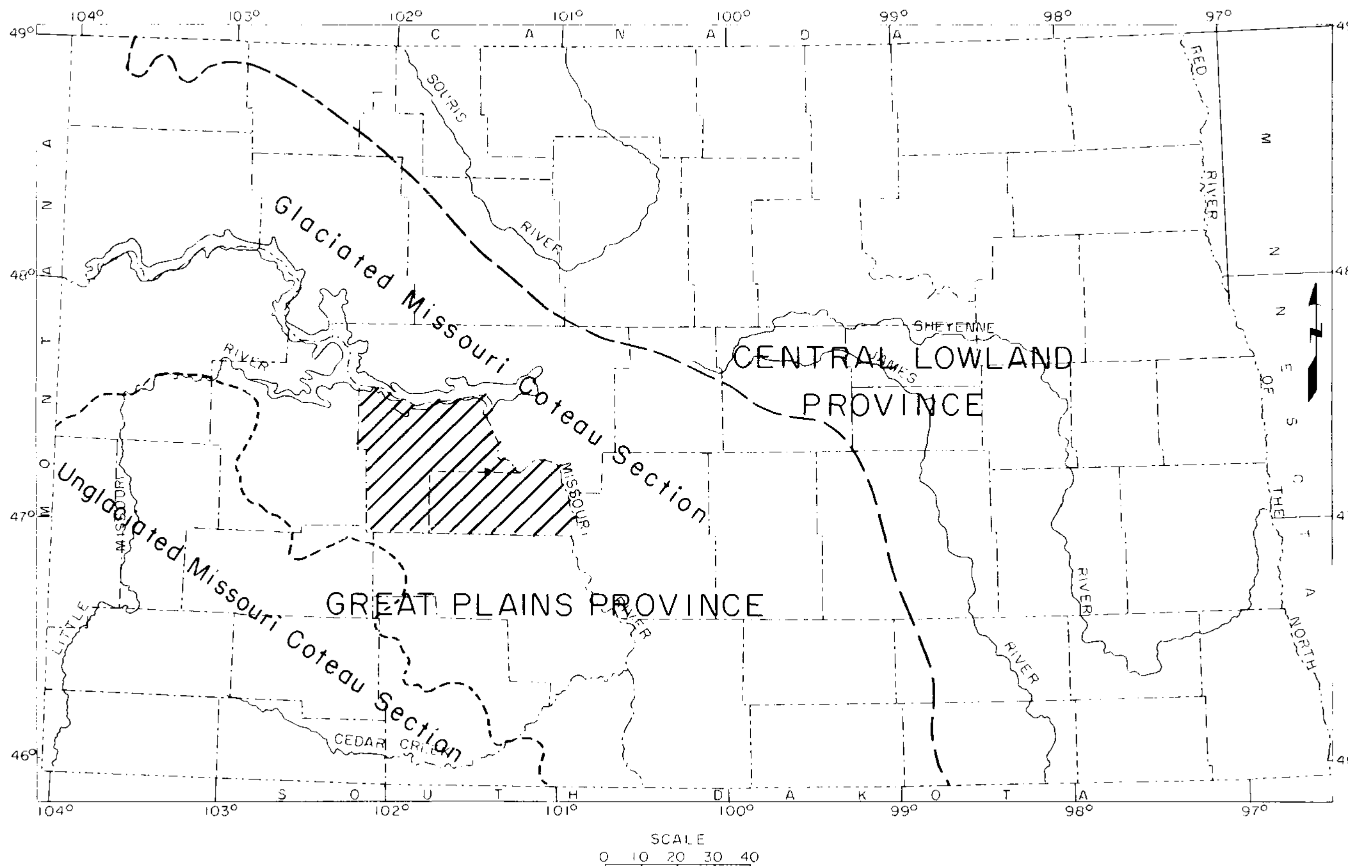

FIGURE 1. Location map showing area of study and physiographic divisions of North Dakota.

areas inaccessible by vehicle. Accessibility varies with section line roads located nearly every mile in northeastern Mercer County and other relatively flat lying areas. Only a few good roads are found in southwestern Mercer County and other areas of locally high relief. Exposures are generally good in the western one-third of the area and other areas of high relief. The good exposures, roadcuts, railroad cuts, and road ditches were examined. A 5-foot auger was used to supplement outcrop data in areas of poor exposures.

Topographic coverage of the area consists of the Army map service series, scale 1:250,000 for the entire area. Four quadrangles, the Garrison, Wilton, Stanton, and Bismarck sheets of the 15-minute series, scale 1:62,500 include part of the study area. During the summer of 1968, field copies of the 7½-minute series, scale 1:20,000 for the Seroco NE, Seroco NW, Stanton SW, Stanton E, Hannover NE, Hannover NW, Nisbet NE, Nisbet NW, Hazen SE, Hazen SW, Beulah SE, Medicine Butte NE, and Medicine Butte NW quadrangles became available.

Stereo pair photo coverage, scale 1:20,000 was obtained for the entire area. Aerial photo controlled mosaics, scale 1:63,360 were also available for the entire area.

North Dakota Highway Department county road maps, scale 1:63,360 were used for plotting field work. Contacts were plotted with the aid of photos and were rechecked in the field.

Subsurface information was obtained from files of the North Dakota Geological Survey for the oil exploration tests that have been drilled in Mercer and Oliver Counties and for some test holes in adjacent counties. Additional information was obtained through use of the North Dakota Geological Survey truck-mounted power auger and through test hole drilling by the North Dakota State Water Commission and the U. S. Geological Survey. Some information was also obtained from the Knife River Coal Mining Company and from the Minnkota Power Cooperative, Inc.

Acknowledgments

M. G. Croft of the United States Geological Survey and L. L. Froehlich of the North Dakota State Water Commission provided subsurface information from the test hole drilling program. Subsurface information was also provided by the Knife River Coal Mining Company and the Minnkota Power Cooperative, Inc.

Several members of the geological staff of the North Dakota Geological Survey and the United States Geological Survey made visitations in the field and discussed problems of interpretation. Their comments and views aided in arriving at some of the conclusions and even when not in agreement with my own, were appreciated. S. J. Tuthill identified a collection of mollusks from one test hole.

Access to the pits of current mining operations in these counties provided insights into the lateral variations of the lignite beds as well as the overburden materials. Such access as well as that of other property owners was appreciated.

Previous Studies

Early reports concerning lignite deposits in western North Dakota generally included some reference to lignite in Mercer and Oliver Counties (Wilder and Wood, 1903; Wilder, 1905; Smith, 1908; Leonard, 1909; Thom and Dobbin, 1924). Bauer and Herald (1921) mapped the lignite beds of the Ft. Berthold Indian Reservation, providing measured sections, and the stratigraphic sequence of the lignite deposits in northwestern Mercer County. A description of lignite mines in Mercer and Oliver Counties was provided by Leonard, Babcock, and Dove (1925). Andrews (1939) mapped and named some lignite beds in northeastern Mercer County. Benson (1952) mapped and named most of the lignite beds exposed in Mercer County; he also arranged them stratigraphically. Brant (1953) summarized the knowledge of the lignite beds in Mercer and Oliver Counties and made estimates of reserves. Johnson and Kunkel (1959) mapped the lignite beds of Oliver County and attempted to correlate them with previous lignite mapping in adjacent areas. Hickey (1966) studied the Golden Valley Formation, named the upper and lower members, and provided type areas and descriptions of these units.

Some of the early lignite reports mention the presence of glacial drift in the area, but only in a general way. Todd (1914) ascribed development of the Missouri River trench as related to events in the Pleistocene. Leonard (1916a) presented an alternate theory; suggesting that the Missouri River was developed in the Tertiary. Leonard (1916b) also ascribed a Kansan age to the drift west of the river. Todd (1923) criticized Leonard's interpretation and suggested that the present course of the Missouri was related to Wisconsinan glaciation; he also suggested that some of the drift west of the Missouri might be related to the glaciation that deposited the Altamont moraine (i.e., Late Wisconsinan). Alden (1932) in a regional study preferred the pre-Wisconsinan age assignment for the drift west of the Missouri River.

Benson (1952) mapped the glacial deposits in Mercer County and recognized three drifts; he thought the first two were Early Wisconsinan and the third Late Wisconsinan. Lemke and Colton (1958) in their summary of Pleistocene history of North Dakota generally accepted Benson's conclusions. Johnson and Kunkel (1959) mapped the glacial deposits in Oliver County and generally agreed with Benson's theory of three drift sheets as well as his age assignments; but they thought that the Missouri trench was probably Illinoian. Bradley and Jensen (1962) presented the results of test drilling in the Beulah area. Colton, Lemke, and Lindvall (1963) prepared a preliminary glacial map of North Dakota. Clayton (1966) summarized the Pleistocene history of North Dakota and suggested that the drift in Mercer and Oliver Counties is Early Wisconsinan. Bluemle (1968) advanced a multistage origin for the Missouri River trench.

STRATIGRAPHY

Subsurface Stratigraphy

PRECAMBRIAN ROCKS

Only one well has been drilled to the Precambrian in the two counties. It was the Carter Oil Company - E. L. Semling No. 1 well, located in SE sec. 18, T. 141 N., R. 81 W., Oliver County, which penetrated amphibolite at a depth of 8,850 feet. Depths to the Precambrian increase to the north and west so that in northwestern Mercer County a Precambrian test would have to penetrate about 12,500 to 13,000 feet of sedimentary rocks.

PALEOZOIC ROCKS

Paleozoic rocks range in thickness from about 4,500 feet in southeastern Oliver County to about 7,500 feet in northwestern Mercer County. For purposes of discussion, the Paleozoic rocks may be divided into four sequences; a sequence being the preserved sedimentary record bounded by major regional unconformities. Sequences recognized are, in ascending order: the Sauk, Tippecanoe, Kaskaskia, and Absaroka, with the Absaroka extending to include Triassic rocks of the Mesozoic era (Fig. 2).

Era	System	Sequence	Group or Formation		Dominant Lithology
Cenozoic	Tertiary	Tejas	Walsh		Silt, clay and sand
			Coleharbor		Sandy loam, sand and gravel
		Zuni	Golden Valley		Clay, sandstone and lignite
			Fort Union Group	Sentinel Butte	Shale, clay, sandstone and lignite
				Tongue River	Shale, sandstone and lignite
				Cannonball-Ludlow	Marine sandstone and shale
Mesozoic	Cretaceous		Hell Creek		Sandstone, shale and lignite
			Montana Group	Fox Hills	Marine sandstone
				Pierre	Shale
			Colorado Group	Niobrara	Shale, calcareous
				Carlile	Shale
				Greenhorn	Shale, calcareous
				Belle Fourche	Shale
			Dakota Group	Mowry	Shale
				Newcastle	Sandstone
				Skull Creek	Shale
				Fall River	Sandstone and shale
				Lakota	Sandstone and shale
	Jurassic		Morrison		Shale, clay
			Sundance		Shale and sandstone
			Piper		Limestone, anhydrite, salt and red shale
	Triassic	Absaroka	Spearfish		Siltstone, salt and sandstone
Paleozoic	Permian		Minnekahta		Limestone
			Opeche		Shale, siltstone and salt
	Pennsylvanian		Minnelusa		Sandstone and dolomite
			Amsden		Dolomite, limestone, shale and sandstone
			Tyler		Shale and sandstone
	Mississippian	Kaskaskia		Otter	Shale, sandstone and limestone
				Kibbey	
			Madison		Interbedded limestone and evaporites
					Limestone
			Bakken		Siltstone and shale
	Devonian		Three Forks		Shale, siltstone and dolomite
			Birdbear		Limestone
			Duperow		Interbedded dolomite and limestone
			Souris River		Interbedded dolomite and limestone
			Dawson Bay		Dolomite and limestone
			Prairie		Halite
			Winnipegosis		Limestone and dolomite
	Silurian	Tippecanoe	Interlake		Dolomite
	Ordovician		Stonewall		Dolomite and limestone
			Stony Mountain Formation	Gunton Member	Limestone and dolomite
				Stoughton Member	Argillaceous limestone
			Red River		Limestone and dolomite
			Winnipeg Group	Roughlock	Calcareous shale and siltstone
				Icebox	Shale
				Black Island	Sandstone
	Cambrian	Sauk	Deadwood		Limestone, shale and sandstone
	Precambrian				

FIGURE 2. Stratigraphic Column for Mercer and Oliver Counties.

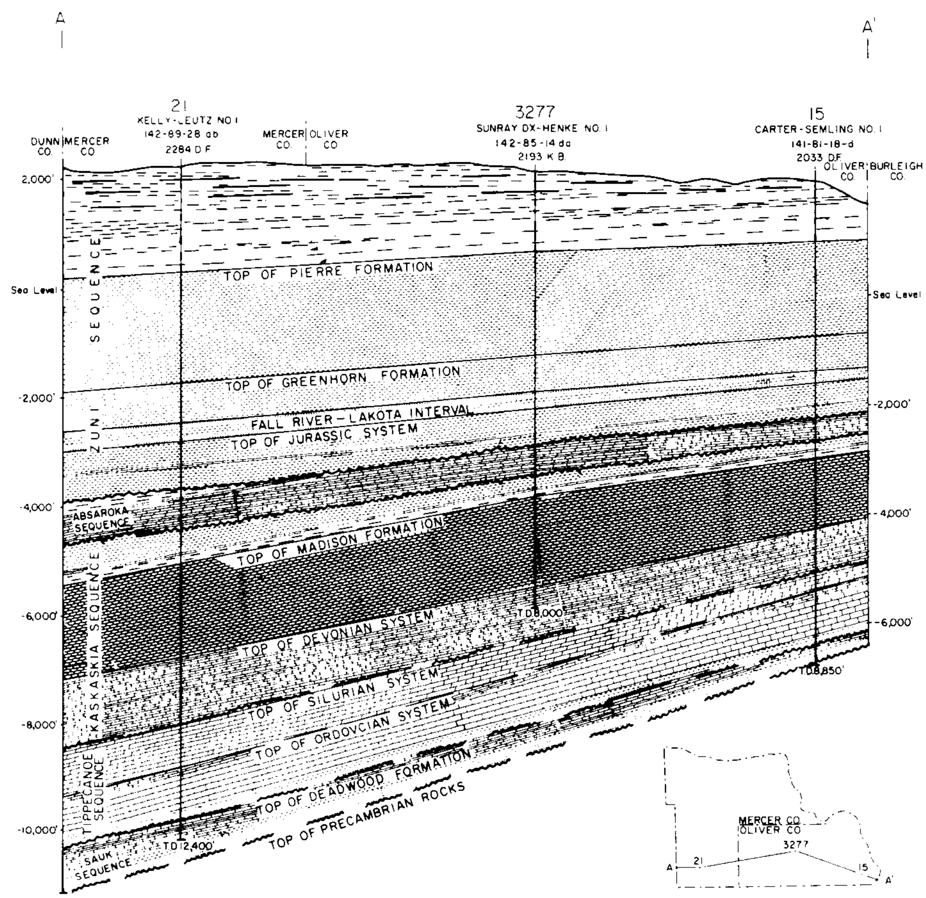

FIGURE 3. Cross sections of sedimentary rocks of Mercer and Oliver Counties.

Sauk Sequence

In the Carter - Semling No. 1 well, 295 feet of limestone, shale, and sandstone of the Deadwood Formation were present. The Deadwood thickens north and westward where in the Kelly, Plymouth - F. Leutz No. 1 well, located in NW NE sec. 28, T. 142 N., R. 89 W., 500 feet of Deadwood was penetrated without reaching Precambrian rocks.

Tippecanoe Sequence

Three wells in these counties, the two previously mentioned and the Youngblood and Youngblood - E. Wachter No. 1 well, located in SE SW sec. 3, T. 141 N., R. 81 W., have penetrated this sequence. Thicknesses range from about 1,360 feet in the Semling well to about 1,820 feet in the Leutz well. The initial deposits of this sequence were the clastics of the Winnipeg Group. These were followed by carbonates with minor amounts of evaporites of the Red River, Stony Mountain, Stonewall, and Interlake Formations.

Kaskaskia Sequence

Nine of the oil exploration tests drilled to date have penetrated this sequence with the three previously mentioned wells penetrating the complete Kaskaskia Sequence. In these wells, the thickness ranges from about 2,250 feet in the Semling well to about 3,400 feet in the Leutz well. These rocks are primarily limestones and dolomites with the exception of the Prairie, which is primarily evaporite and the Three Forks, Bakken, and Otter Formations, which are primarily fine-grained clastics.

Absaroka Sequence

Thicknesses of this sequence range from about 550 feet in the Semling well to about 1,130 feet in the Continental Oil Company - Schuh No. 1 well, located in SW SE sec. 25, T. 146 N., R. 90 W. Included in this sequence are rocks of the Pennsylvanian and Permian Systems and the Spearfish Formation, which ranges from Permian to Triassic in age. These rocks are primarily clastics except for the Amsden and Minnekahta Formations, which are mainly dolomite and limestone. The Opeche and Spearfish Formations include some salt beds but are mainly clastics of the redbed environment.

MESOZOIC ROCKS

General

Mesozoic rocks range in thickness from about 3,900 feet in southeastern Oliver County to about 4,600 feet in northwestern Mercer

County. All of these rocks are part of the Zuni Sequence, with the exception of the previously discussed Spearfish Formation. Since the Fox Hills and Hell Creek Formations are important aquifers, the general discussion of Mesozoic rocks will be limited to pre-Fox Hills rocks.

Thicknesses of Jurassic and pre-Fox Hills Cretaceous rocks range from 3,270 feet in the Semling well to 4,300 feet in the Schuh well. Jurassic rocks include sandstones, limestones, evaporites, and shales with shale the predominant lithology. Cretaceous rocks include well developed sandstones in the Fall River - Lakota interval and a poorly developed sandstone in the Newcastle; the rest of the pre-Fox Hills Cretaceous rocks are gray shales with some calcareous shales and some thin bentonites.

Fox Hills Formation

The Fox Hills Formation conformably overlies the Pierre Formation with the contact gradational. Therefore, it is rather difficult to pick consistently on mechanical logs, particularly the gamma ray laterologs, but an effort was made to do so. The contact with the overlying Hell Creek Formation also appears to be conformable, but there is a prominent sandstone unit in this area, the top of which was used as a marker for the top of the Fox Hills Formation.

The Fox Hills Formation has been shown to be about 300 feet thick in the subsurface of northwestern Burleigh County (Kume and Hansen, 1965, p. 44), just east of Oliver County, where they state that (p. 42), "The Fox Hills can be divided into four lithologic units of alternating shales and sandstones, which are somewhat similar to the units previously recognized in surface work to the south of this area." This was in reference to Fisher (1952) who in Emmons County recognized in ascending order: (1) Trail City Member, consisting of about 50 to 70 feet of sandy shales grading upward into sands; (2) Timber Lake Member, consisting of about 60 feet of fine-to-medium-grained sand; and (3) an upper Fox Hills consisting of 160 to 230 feet of sands and shales, which included the Colgate sandstone.

Lithologic logs of test holes drilled for this project combined with mechanical logs of oil exploratory wells (Plate 2) suggest a subdivision of the Fox Hills into 2 units: (1) a lower unit consisting of interbedded siltstone, claystone, and fine-grained sandstone, and (2) an upper unit consisting of fine-to-medium-grained sandstone. This upper unit is probably equivalent to the Colgate Member of the surface studies of the Fox Hills. Using this twofold subdivision, the lower unit ranges in thickness from about 180 to 225 feet, while the upper sandstone or Colgate Member ranges from about 20 to 100 feet; total thickness of the Fox Hills ranges from about 240 to 335 feet with areas of thin Colgate coinciding with areas of thin total thickness (Fig. 4).

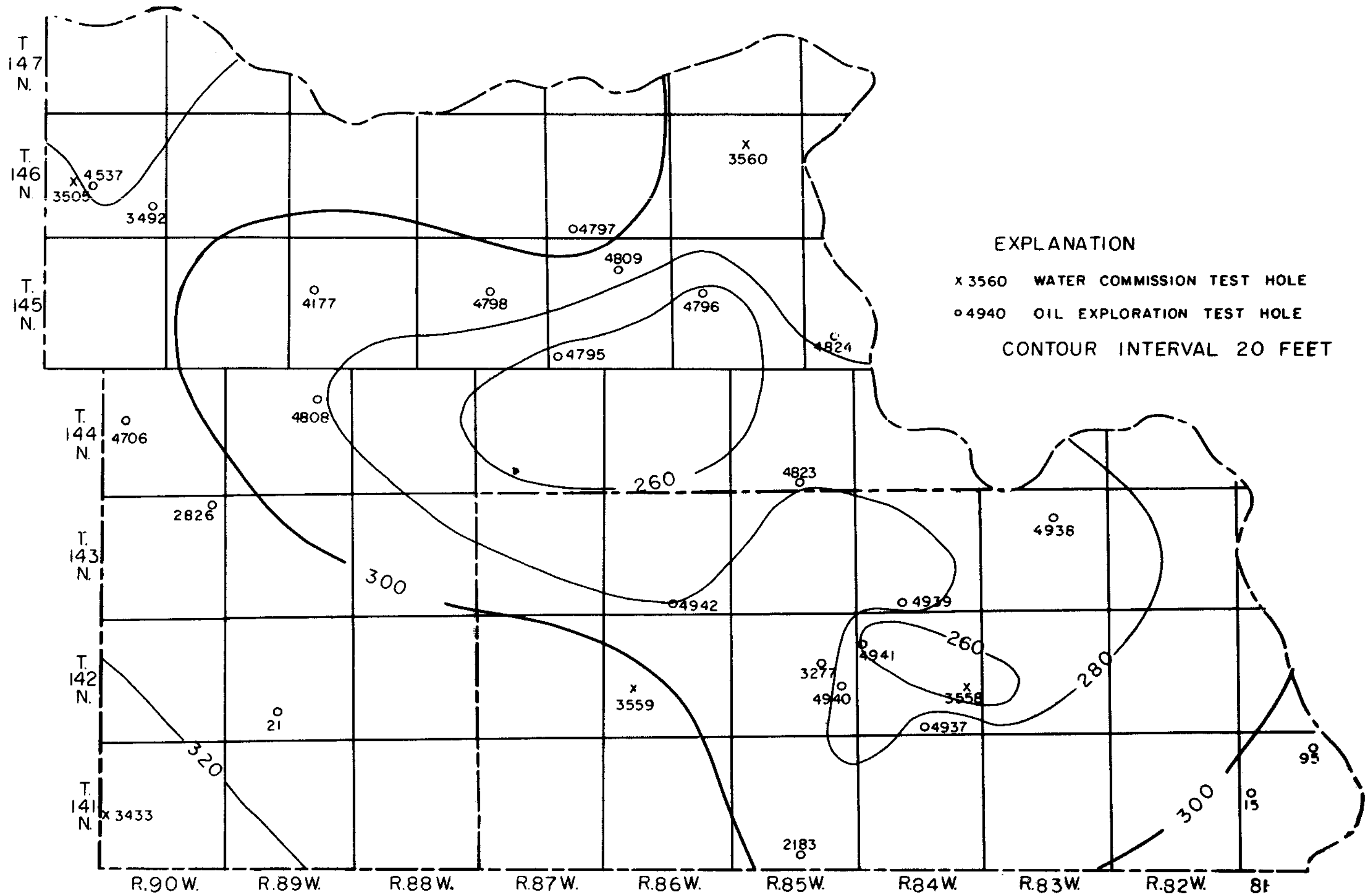

FIGURE 4. Isopachous map of Fox Hills Formation.

Hell Creek Formation

Kume and Hansen (1965, p. 44) described the Hell Creek Formation in the subsurface of northwestern Burleigh County as consisting of about 185 feet of "interbedded gray, greenish gray, and brown shales, siltstones, and sandstones." They noted a thickening southward to as much as 260 feet in southern Burleigh County. Fisher (1952, p. 19) reported a thickness of about 270 feet for the Hell Creek Formation in Emmons County where he described it as consisting of sands, lignitic shales, lignite, bentonitic shales and clays, but dominantly sand.

Frye (1968) divided the Hell Creek Formation of the outcrop areas into five members in south-central North Dakota and five members in southwestern North Dakota. In south-central North Dakota, he recognized two sandstone units, the Breien Member in the lower part and the Huff Member in the upper part of the Hell Creek. In southwestern North Dakota, he also recognized two sandstone units, the Marmarth Member in the lower part, and although he did not have subsurface information to trace these units between the areas of outcrop, he also recognized the Huff Member in that area. He described the Huff Member as "characterized by the presence of thick sandstone bodies believed to be channel deposits of large rivers." The Breien Member was described as marine, glauconitic sand. The Marmarth Member was described as consisting of two thick sandstone bodies, probably deposited in channels of large rivers, separated by a thin sequence of bentonites and bentonitic and lignitic shales. He showed the Hell Creek Formation as about 450 feet thick in southwestern North Dakota and about 260 feet thick in south-central North Dakota.

In the surface studies, the Hell Creek-Ludlow contact has been placed at "the lowest prominent lignite" above the Hell Creek lithology. This becomes difficult to recognize in the subsurface so the contact is somewhat arbitrary but is generally drawn at the base of a high resistivity "kick" on the electric or laterolog. Using this criteria the Hell Creek ranges from about 185 to 340 feet in thickness in these counties (Fig. 5). The lithology consists of grayish olive, dark greenish gray and olive gray siltstone, claystone and sandstone, lignitic in part. Mechanical logs suggest that these lithologies are generally thinly interbedded and that sandstone accounts for about 50 percent of the total thickness. Some sections are predominantly sand, but the lithologic units do not appear to have sufficient continuity to correlate them to the surface studies, nor is there any section that looks like an equivalent of the Breien (marine) Member.

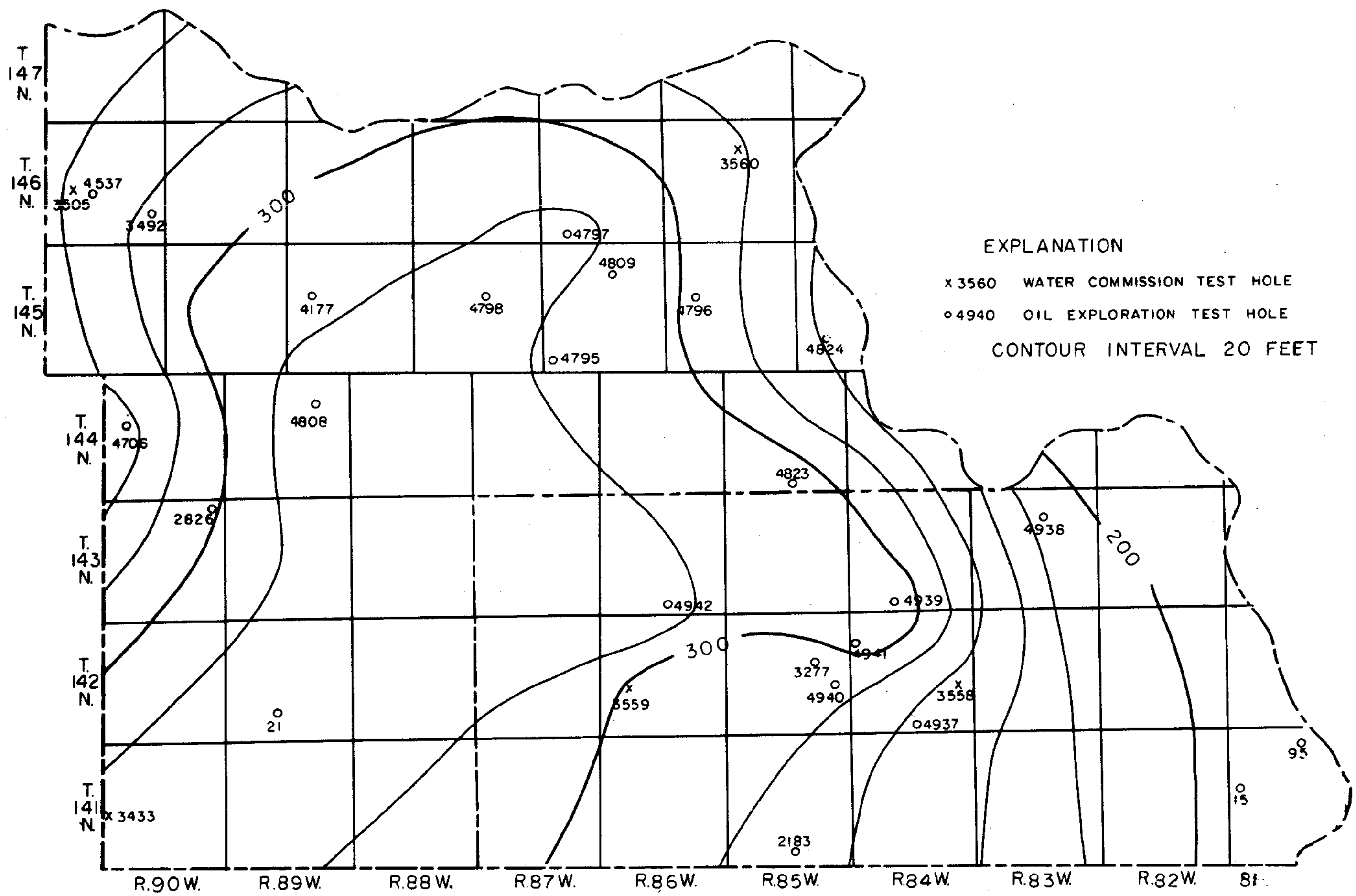

FIGURE 5. Isopachous map of Hell Creek Formation.

CENOZOIC ROCKS

The Cenozoic rocks of Mercer and Oliver Counties include in ascending order: the Ludlow, Cannonball, Tongue River, and Sentinel Butte Formations of the Fort Union Group, and the Golden Valley Formation. Since with the exception of the Ludlow Formation, these are present at the surface, discussions of these units has been deferred to a combined surface-subsurface treatment.

Surface - Subsurface Stratigraphy

CENOZOIC ROCKS

The Cenozoic rocks, which are all part of the Zuni Sequence, range in thickness from about 250 feet in southeastern Oliver County to about 1,350 feet in northwestern Mercer County. Thickness variations are due mainly to a combination of regional dip to the north and west, regional slope to the east, and processes of erosion that have carved the present topography largely from these rocks.

The terminology applied to the Cenozoic rocks has been developed in areas of western North Dakota where these rocks are well exposed. When the terminology is extended into areas of poor exposures or into the subsurface as in the present study, interpolation is necessary and this should be kept in mind in analysis of the ensuing presentation. Measured sections were made using a hand level; thicknesses of sand, silt, and clay were generally estimated within the eyeheight measurements; lignite and carbonaceous beds were measured with a tape. Because of the relatively rapid facies changes within the section this was deemed sufficient accuracy, since correlation based solely on lithology is not practical.

Previous studies have not differentiated the Tongue River and Sentinel Butte Formations in this area. Benson (1952, p. 45) referred to the strata between the Golden Valley and Cannonball Formations as the Tongue River Member of the Fort Union Formation, while Johnson and Kunkel (1959, p. 11) referred these strata to the Fort Union Formation. These writers felt that the basis for recognition of these formations (i.e., largely color) in western North Dakota was not feasible in this area. There is some validity to this approach since there appears to be a more gradual change vertically from typical Tongue River to typical Sentinel Butte colors in this area than in the Little Missouri area; also, the mantle of glacial drift and grassed over bedrock mask stratigraphic details in some critical areas. Thus, in the Square Butte Creek drainage typical Tongue River colors are prominent. Along the Missouri River from Hensler to Fort Clark, however, where the same stratigraphic interval is exposed in north flowing drainages, the colors are darker and some beds resemble typical Sentinel Butte colors. Nevertheless, there are recognizable differences within the section that seem to be sufficient for recognition of two formations in this area and subdivision is useful for placing the lignite beds in their proper stratigraphic position.

The best bedrock exposures are along the major drainages and scattered roadcuts. These generally expose only a small part of the formations at one locality. Therefore, the stratigraphic sequences must be pieced together based on measured sections, key beds, topographic control, and subsurface information. Since lignite beds are readily recognizable and are of such economic importance, these beds have generally been used for correlation of the Tongue River and Sentinel Butte strata. Terminology applied to these lignite beds has generally been one of applying local names in each area of study and then attempting general correlations to previous studies in nearby areas.

In the Knife River area Benson (1952) used the Beulah-Zap bed as his key bed in the area west of Hazen; to the east he used the Stanton bed as his key bed. He mapped and named numerous other lignite beds, relating them to the key beds by the stratigraphic interval above or below the key beds. He did not attempt to correlate between his eastern and western areas. A summary of his named lignite beds and their relationship to the key beds is shown in Table 1.

Johnson and Kunkel (1959) used a similar procedure for the Square Butte Creek study, using the Hagel bed as the key bed in the Square Butte Creek drainage and the Otter Creek bed in the Knife River drainage. They mapped and named other lignite beds, also relating them to the key beds by the stratigraphic interval above or below the key beds. They then attempted to correlate between different areas of the Square Butte Creek study and then to previous studies in adjacent areas. Table 2 is a summary of their Square Butte Creek relationships.

The variability in thicknesses of the lignite beds and the associated lithologic units creates difficulties in attempting to construct a stratigraphic column based on lignite beds and stratigraphic intervals between beds. Previous studies were also hampered by a lack of topographic control and subsurface information. Using the topographic control now available along with subsurface data from the current study, it appears that we can place the lignite beds more nearly in their correct stratigraphic positions.

A test hole was drilled about ten miles north of New Salem (3646, SE SE 27-141-85). Bedrock occurs at the surface at this location and the Tongue River-Cannonball contact was penetrated at a depth of 404 feet. A 3-foot lignite bed was present 270 feet above the base of the

TABLE 1.-Named lignite beds and their relationship to "key beds" according to Benson (1952).

WESTERN AREA

Golden Valley Formation

Shaffner bed
30 feet above Alamo Bluff bed
Alamo Bluff bed
at base of upper member

Fort Union Formation

Twin Buttes Bed
130 to 150 feet above Beulah-Zap bed
Schoolhouse bed
45 to 50 feet above Beulah-Zap bed;
increasing westward to 80 to 110 feet
Beulah-Zap bed
60 feet below Beulah-Zap bed
Spear bed
110 to 115 feet below Beulah-Zap bed
Hazen "B" bed

HAZEN AREA

Beulah-Zap bed
75 to 95 feet below Beulah-Zap bed
Star bed
25 to 40 feet below Star bed
Hazen "B" bed
155 to 160 feet below Beulah-Zap bed
Hazen "A" bed

GARRISON AREA

Kruckenberg bed
50 feet above Garrison Creek bed
Garrison Creek bed
(?) position
Wolf Creek bed

STANTON AREA

Local bed
50 feet above Stanton bed
Stanton bed
35 to 40 feet below Stanton bed
Coal Creek bed
85 to 95 feet below Stanton bed
Knoop bed
150 to 160 feet below Stanton bed
Hancock bed

BLACKWATER-EMMET AREA

Beulah-Zap bed
160 to 165 feet below Beulah-Zap bed
Garrison Creek bed

TABLE 2.-Named lignite beds and their relationship to "key beds" according to Johnson and Kunkel (1959).

NORTHWEST AREA

Byer bed
65 feet above Otter Creek bed
Otter Creek bed
135 to 145 feet above Beulah-Zap bed
Herman bed
25 to 30 feet above Buchman bed
Buckman bed
65 to 75 feet above Beulah-Zap bed
Schoolhouse bed
30 to 45 feet above Beulah-Zap bed
Beulah-Zap bed
45 feet below Beulah-Zap bed
Spear bed

CENTRAL AND NORTH-CENTRAL AREA

Red Butte bed
100 feet above Keuther bed
Keuther bed
35 to 45 feet above Hagel bed
Hagel bed
25 to 40 feet below Hagel bed
Yeagher bed
30 feet above Berg bed
Berg bed
40 feet above Stanton bed
Stanton bed
20 to 45 feet below Stanton bed
Brahzda bed

Tongue River and a 12-foot lignite bed was present 80 feet above the base of the Tongue River. No other lignite beds exceeding 2.5 feet in thickness were present in this test hole.

A test hole (3557, NE SE 3-143-85) was drilled about 3.5 miles west of the Glenharold mine south of Stanton where the Hagel lignite bed is being mined. Drift occurs at the surface here and overlies the lower 357 feet of the Tongue River Formation. This test hole penetrated a 5-foot lignite bed 170 feet above the base of the Tongue River, and a 6-foot lignite bed 245 feet above the base of the Tongue River. The base of the Hagel bed was 275 feet above the base of the Tongue River Formation at an elevation of 1,850 feet. Surface elevations of bedrock on the drainage divide about 3 miles south of this test hole are as high as 2,330 feet with no Golden Valley Formation present. Therefore, the total thickness of the Sentinel Butte and Tongue River Formations in this area is about 750 feet and the Hagel bed is at least 480 feet below an eroded top of the Sentinel Butte Formation.

A test hole south of Beulah (3651, SE SW 1-142-88) was drilled from a surface elevation of 2,075 feet. The base of the Golden Valley Formation is present at elevations of about 2,110 feet in Secs. 10 and 11, T. 142 N., R. 88 W. The Tongue River-Cannonball contact was placed at a depth of 610 feet, which if correct would thin the total thickness of Sentinel Butte and Tongue River Formations to about 650 feet in this area. It is difficult to determine the Tongue River-Cannonball contact when only a few feet are cut, so it seems probable that this contact was not penetrated in this test hole. A 10-foot-thick lignite bed present at a depth of 95 to 105 feet is the Beulah-Zap bed. Several thin lignite beds occur between depths of 100 to 200 feet. A 15- to 18-foot bed at a depth of 250 feet may be lignite but all other lignite beds are less than 5 feet thick. The base of the Beulah-Zap bed is about 500 feet above the base of the Tongue River Formation.

A test hole in northwestern Mercer County (3575, SW SW 20-146-90) started in sand of the Sentinel Butte Formation at a surface elevation of 2,120 feet. The Golden Valley Formation is exposed about one mile east of this site at a slightly higher elevation so a nearly complete Sentinel Butte-Tongue River section was penetrated in this test hole. The Cannonball Formation was penetrated at a depth of 960 feet. In this test hole a 10-foot-thick lignite bed was present 515 feet above the base of the Tongue River Formation; an 8-foot lignite bed was present 225 feet above the base of the Tongue River Formation; all other lignite beds were less than 5 feet thick.

Subsurface information collected during this study combined with surface studies provides a basis for revision of the stratigraphy based on intervals between lignite beds (Table 3). Johnson and Kunkel mapped and named the Herman bed in the northwestern part of the Square Butte study area. Based on thickness and elevation, the Herman bed is equivalent to the Beulah-Zap bed of Benson. Their Otter Creek bed then is equivalent to Benson's Schoolhouse bed and, as has been demonstrated earlier, this would place it about 275 feet above the Hagel bed rather than as an equivalent of that bed. This in turn revises the correlation of the other lignite beds mapped by Johnson and Kunkel in the Otter Creek drainage area. In the central and eastern areas their sequence of lignite beds should be elevated so that the Hagel bed is about 275 feet rather than 200 feet above the base of the Tongue River Formation. Other beds have been adjusted accordingly in Table 3.

Previous surface mapping studies are useful for providing measured sections of lignite beds at specific localities. One must be careful, however, to recognize the local nature of these lignite beds, and the fact that the same name has been applied to different lignite beds through miscorrelations. Although measured sections exist for 24 named lignite beds within the Tongue River and Sentinel Butte Formations in these two counties, any test hole penetrating the complete Fort Union stratigraphic section at any one locality will not have nearly that many recognizable beds. The safest use for the previously named lignite beds is to limit their use to their areas of outcrop except where subsurface information is available to extend them. The placement of the named lignite beds in Table 3 is not intended to infer that the Hazen "A" and Garrison Creek beds should be correlated as one and the same bed. Rather it is intended to show that these beds, present in different areas, are present at about the same stratigraphic horizon.

Ludlow Formation

The Ludlow Formation is known from areas of outcrop to the east and south. In Burleigh County, Kume and Hansen (1965, p. 45) report that it "generally is about 13 feet thick" and in Morton County, Laird and Mitchell (1942, p. 17) report a thickness ranging from 17 to 49 feet, generally thickening westward. In these areas the Ludlow has been described as brown lignitic shale, lignitic sand, and lignite similar lithologically to the Hell Creek except that lignites are better developed in the Ludlow.

In the subsurface of Mercer and Oliver Counties (Fig. 6) the Ludlow consists of about 45 to 115 feet of grayish-olive sandstone, siltstone, clay, and lignite. Both the upper and lower contacts are somewhat arbitrary when based on subsurface information. The Ludlow-Cannonball contact in fact is probably an intertonguing one with the Ludlow lithologies thickening westward as well as being present at progressively higher stratigraphic positions westward.

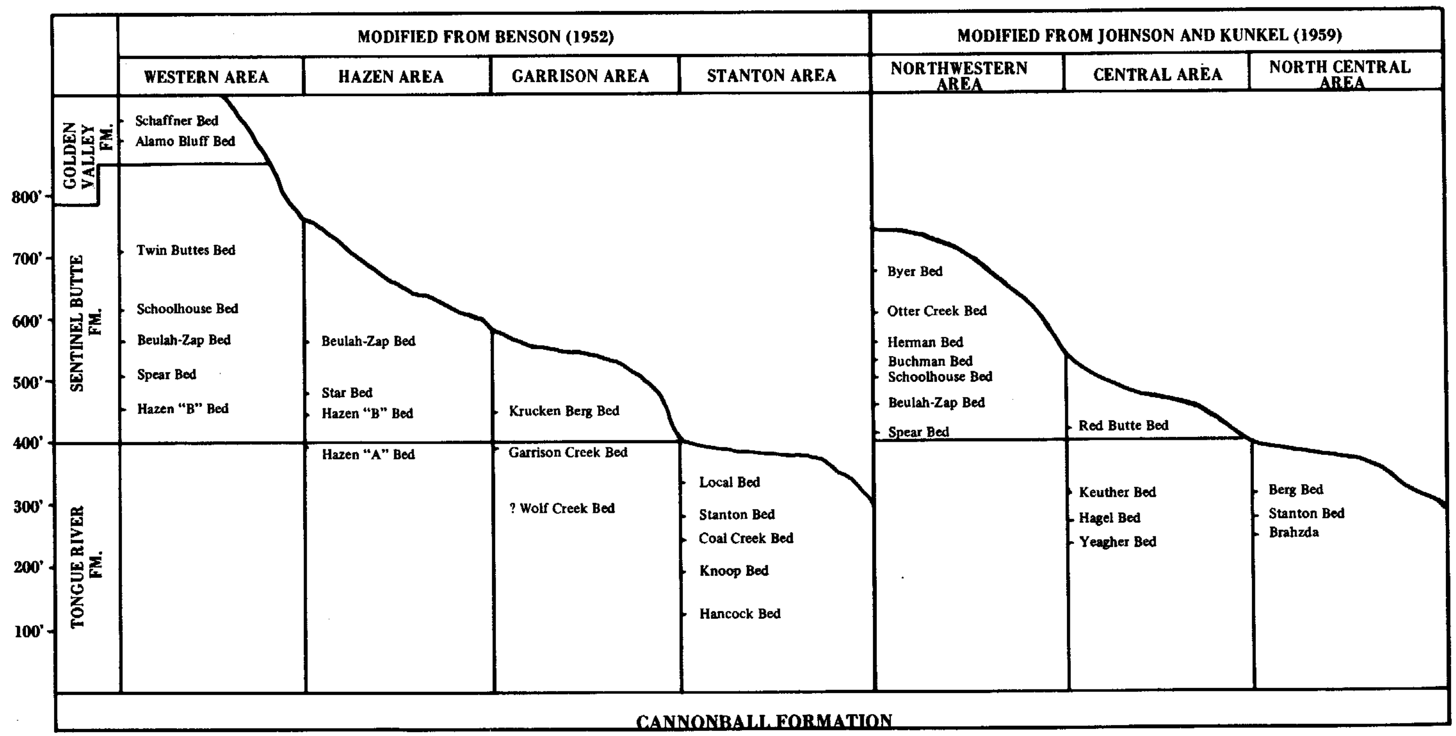

TABLE 3.-Approximate stratigraphic position of previously named lignite beds in Mercer and Oliver Counties.

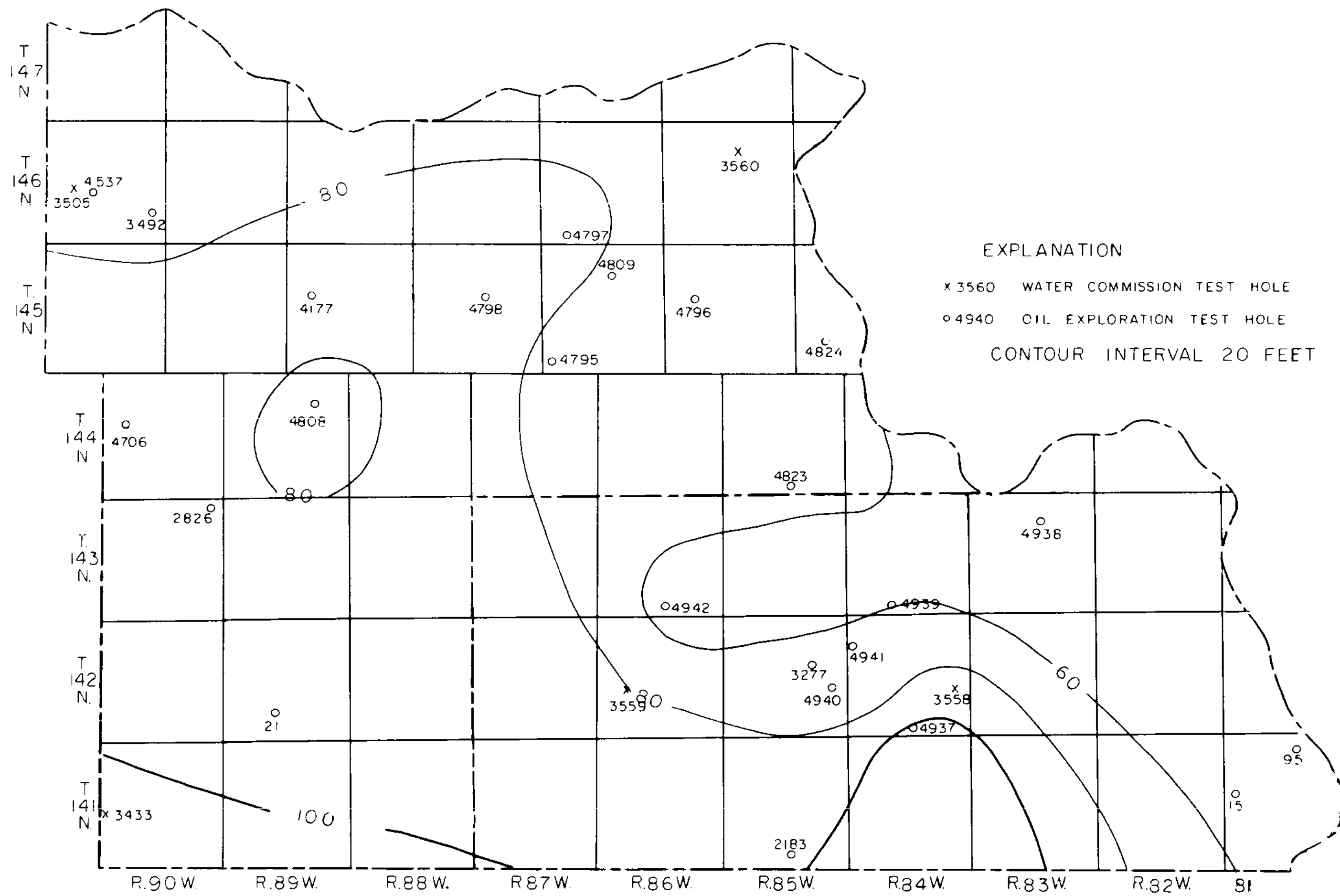

FIGURE 6. Isopachous map of Ludlow Formation.

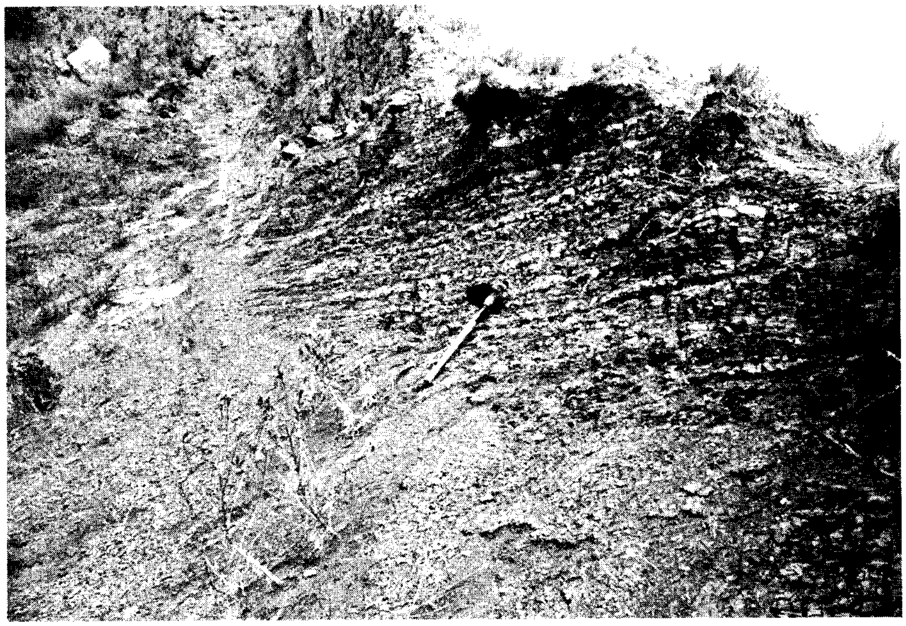

FIGURE 7. An exposure of thin bedded sands and clay-shales of the upper part of the Cannonball Formation in NW NE Sec. 27, T. 141 N., R. 82 W. Near measured section C-2 of Appendix A.

Cannonball Formation

The Cannonball Formation in northwestern Burleigh County has been described by Kume and Hansen (1965, p. 46) as consisting of "interbedded yellowish-brown, yellow gray, and olive gray sandstones, siltstones, shales, and lenticular limestones" in surface sections, changing colors to olive, greenish-black, and brownish-gray in the subsurface. They report a thickness of about 340 feet in that area. In Morton County, Laird and Mitchell (1942, p. 20) report an average thickness of about 300 feet and state that (p. 18) "the Cannonball Formation consists of two dominant types of lithologies, buff, fine-grained sand and grey, thin-bedded clay shales."

The upper part of the Cannonball Formation crops out in southeastern Oliver County (Pl. 1 and Fig. 7), where it is composed of thinly interbedded shale, silt, and sand; shale is predominant. In an exposure in NW NE Sec. 27, T. 141 N., R. 82 W., along Highway 25, the upper 38 feet 11 inches was measured with a 6-foot rule. It consists of 28 alternating beds of sand and clay-shales. Sand beds range from 3 to 39 inches thick and clay-shales range from 6 to 54 inches thick with a total sand thickness of 17 feet and a clay-shale thickness of 21 feet 11 inches. This section is capped by about 16 feet of the basal sandstone of the Tongue River Formation. An exposure of the upper Cannonball in NE SW Sec. 30, T. 143 N., R. 81 W. showed a thickness of 48.5 inches composed of 19 beds of sand and clay-shale with sand beds ranging from 0.5 to 3.5 inches, totaling 22.5 inches and clay-shales ranging from 0.5 to 7 inches, totaling 26 inches. Another exposure in SW SW Sec. 34, T. 142 N., R. 81 W. consists of, in ascending order, 13 feet of clay and silt, medium light gray; 7 feet of clay-shale, light brown and purplish gray, thinly bedded; 42 feet 8 inches of interbedded sand and clay-shale, thin bedded. The lower 28 feet of this last unit weathers medium gray to olive gray, the upper part weathers light brown to light gray and is capped by 24.5 feet of basal Tongue River sandstone.

In the subsurface the Cannonball Formation (Fig. 8) generally ranges in thickness from about 180 to 340 feet thick, thinning northeastward. This section was generally logged as claystone and siltstone with some fine grained sandstone.

Tongue River Formation

The Tongue River Formation consists of interbedded sand, silt, clay, shale, lignite, and limestone. The sand, silt, and clay generally weather to a light color, usually shades of yellow ranging from light yellow gray to light yellowish brown and very light to light gray in the Square Butte Creek drainage where the lower 200 to 300 feet of the formation is exposed (Fig. 9). Along the Missouri River the same stratigraphic section as that of the Square Butte drainage is exposed in the short, north flowing drainages in the area from Hensler west to Stanton, but the colors are generally more of the light gray to light brown hues and are often similar to typical Sentinel Butte colors of western Mercer County. The explanation seems to be that in these short drainages present day erosion is removing the surface materials before the weathering effects (i.e., the light colors) are produced and preserved.

The Tongue River Formation is about 375 to 450 feet thick where the entire formation is present, generally thickening to the west and northwest. A subdivision into members based on lithologic units is not feasible because of the facies changes present but there are some distinct lithologies which seem to be present at certain horizons. Some typical measured sections of the Tongue River Formation placed in their approximate stratigraphic position based on key beds, topographic control and/or subsurface information will provide a framework for

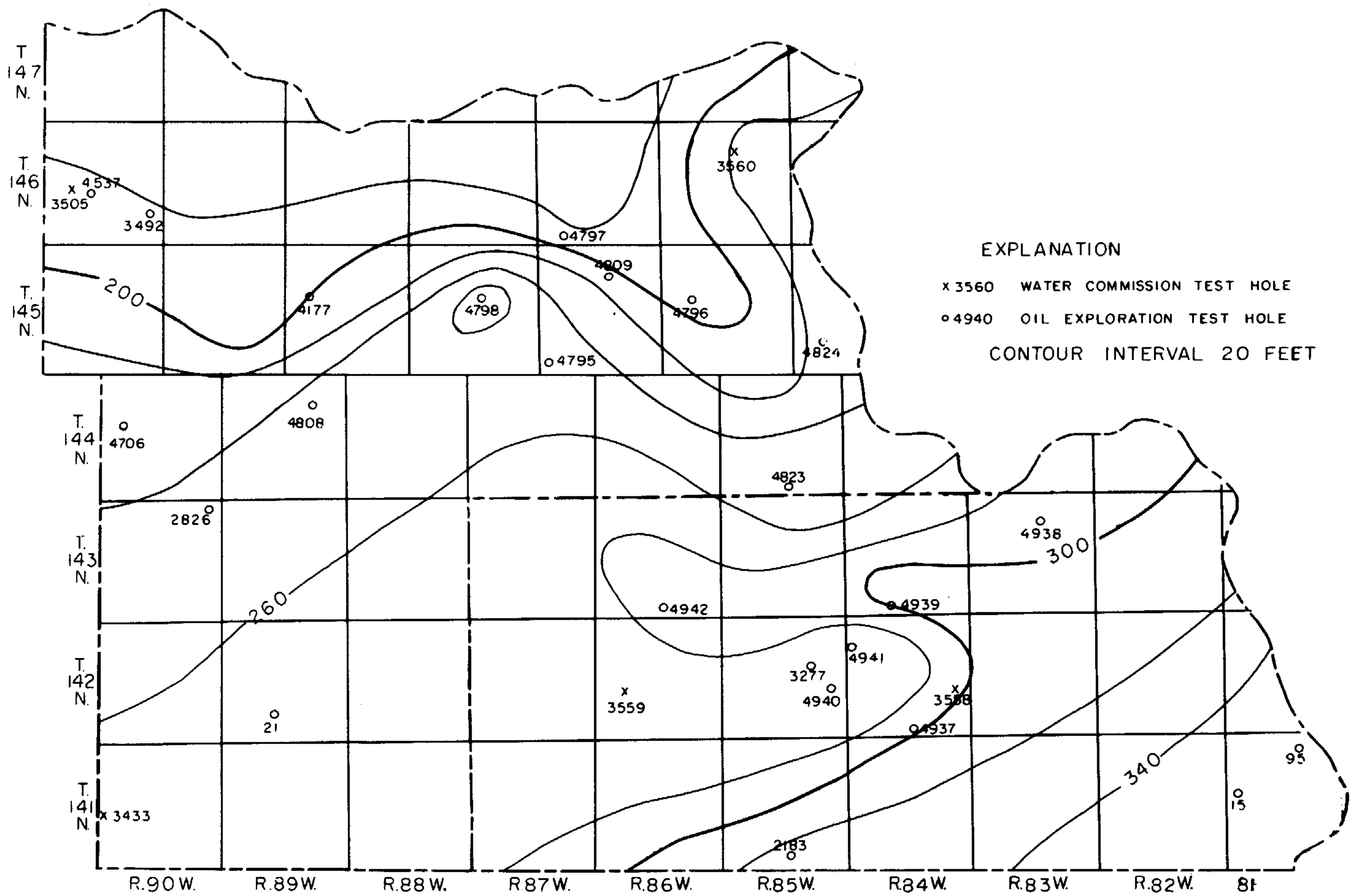

FIGURE 8. Isopachous map of Cannonball Formation.

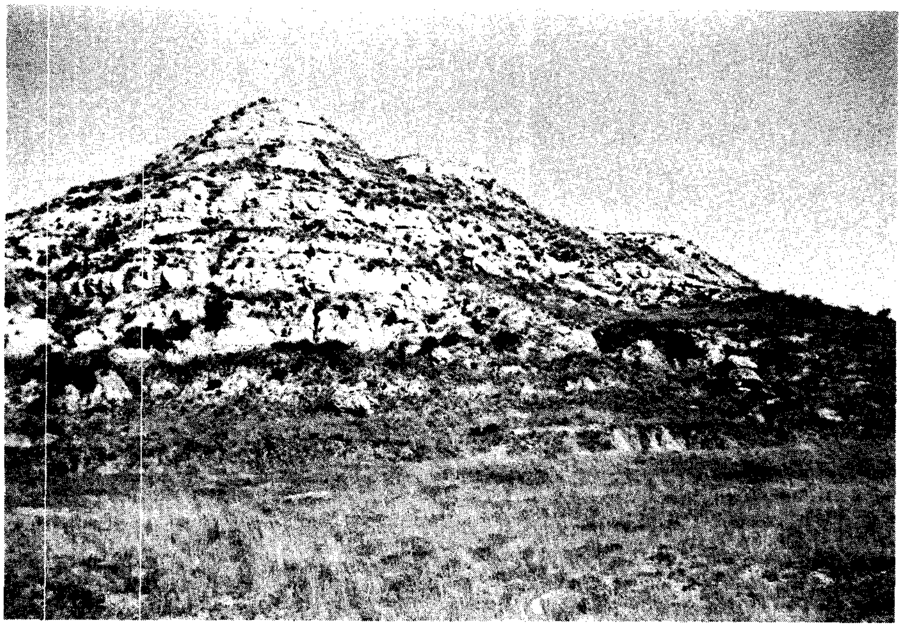

FIGURE 9. Exposure of Tongue River Formation in NW Sec. 32, T. 141 N., R. 82 W. showing light colored beds of the Square Butte drainage.

discussion (Pl. 3). Perhaps the most striking feature of these sections is the scarcity of thick lignite beds; most exposures of thick lignites are in mines or abandoned mines. This scarcity may be due in part to weathering of the lignite beds where they are exposed so that covered intervals may conceal some significant lignite beds, but subsurface information tends to verify that thick lignite beds are scarce in the Tongue River in this area.

Persistent sandstones occur at two stratigraphic horizons within the Tongue River Formation. The most persistent of these is a basal sandstone that is present wherever the Tongue River-Cannonball contact is exposed. However, nowhere could a complete section of the sand be measured because the lower and upper contacts of this sand were never exposed at the same locality. The thickest measured section was 39 feet in an exposure located in SE NW, Sec. 28, T. 141 N., R. 82 W. where the sand unit is generally unconsolidated and is composed of pale yellow brown, pale brown and light gray, very fine-to-medium grained sand, containing some large iron-stone concretions. It includes one 3-inch bed of carbonaceous shale and one 10-inch bed of light gray to purplish gray clay. Partial sections of this unit are exposed from south of Price north to Sanger. Good exposures of the sand are also present south of Hensler in SW SW Sec. 33, T. 144 N., R. 82 W. This unit extends into the subsurface where in many areas it is a good aquifer.

In eastern Oliver County, near Price, some sandstone beds are present about 200 feet above the base of the Tongue River Formation. Some of these beds have been fairly well cemented and they cap the high buttes and ridges of that area. At some localities, particularly at Square Butte (SW NW 10-141-81), this sandstone is very fossiliferous. As is shown on the typical sections (Pl. 3) sandstone is present at about the same stratigraphic position in other areas. At several other localities fossiliferous sands are present in the Tongue River Formation in Oliver County, but whether these are in the same stratigraphic position is questionable.

The rest of the formation generally consists of interbedded silt, clay, lignite, shale, sand, and limestone, predominantly silt and clay. Shales are generally brownish gray, carbonaceous, and usually are closely associated with lignite beds. Limestone is usually yellowish gray and occurs as large "pods" or lenses in silt and clay beds rather than as beds of limestone; because of their resistance to erosion they usually cap knobs, ridges, or benches. Some of the light colored clay beds are also fossiliferous, generally containing abundant, fragile gastropods. Silts and clays of the upper part of the formation are often of the light gray to light brown hues.

Table 3 lists the named lignite beds of the Tongue River Formation that crop out in the area of study placed in their approximate stratigraphic position. Previous studies (Benson, 1952, Johnson and Kunkel, 1959) provide measured sections and areas of exposure of these lignite beds. Some sections were measured in the present study and these sections together with other available information were used to place the lignite beds of the previous studies in their proper stratigraphic positions.

Sentinel Butte Formation

The Sentinel Butte Formation also consists of interbedded sand, silt, clay, shale, limestone, and lignite (Pl. 4). In Oliver County and eastern Mercer County about 350 feet of the Sentinel Butte Formation is preserved at the higher elevations of the drainage divides. In northwestern Mercer County, the formation thickens to slightly over 500 feet where a complete section is preserved. The weathered colors are grays and browns of a generally darker hue than those commonly found in the Tongue River Formation, although recognition based only on the color differences is not satisfactory for differentiation in the field. Therefore, a combination of lithology, key beds, subsurface information, and topographic control was used to place the Sentinel Butte-Tongue River contact in this area.

Along the Little Missouri River, where the contact is clear cut, Royse (1967, p. 3) used three criteria for definition of the contact: (1) color, (2) a lignitic horizon as the uppermost part of the Tongue River Formation, and (3) presence of a basal sandy unit of the Sentinel Butte Formation. In the absence of continuous outcrops to trace the contact and the absence of a distinct color difference, the third criteria of the Little Missouri area is the only one of practical use in this area.

In the roadcut along Highway 49 south of Beulah a sandstone unit occurs about 80 to 130 feet below the Beulah-Zap bed, which should be near the base of the Sentinel Butte Formation. Sandstone beds are present in Sec. 12, T. 144 N., R. 87 W., Secs. 11 and 12, T. 144 N., R. 85 W., and Sec. 33, T. 143 N., R. 84 W. at about the right stratigraphic positions to be basal beds of the Sentinel Butte Formation based on topography, key beds, and subsurface information so these sandstone beds were used to define the Tongue River-Sentinel Butte contact in these areas. Sand is also present in Townships 141 and 142 N., R. 85 W. and was the basis for defining the contact in those areas. Subsurface information indicates that sand is not always present at the contact (Pl. 4, sec. SB-5) but where present it is useful; where it is absent, topographic control, subsurface information and key beds provide a means for approximating the lower contact.

The thickness of the basal sand is variable and difficult to determine in outcrop sections because usually one or both contacts are obscured by glacial drift, erosion, slump or alluvium-colluvium. Perhaps the best exposure is along Highway 49, just south of Beulah (Pl. 4, sec. SB-5) where about 50 feet of light yellow brown to light gray, very fine-to-medium grained sand with numerous concretions is exposed. In most other areas exposures are on the order of 30 to 20 or less feet with one or both contacts obscured.

The increased thickness of the Sentinel Butte Formation in northwestern and southwestern Mercer County is due in part to a sand unit which is present in its uppermost part. This sand is generally yellowish brown, fine-to-medium grained and contains abundant ironstone nodules and concretions. In some areas where the sand is fairly well cemented, it caps ridges and buttes.

Except for the basal sand and the upper sand, the Sentinel Butte Formation is mostly interbedded silt, clay, and lignite. The interbedded silts and clays are often thinly bedded and weathering accents this to produce a thin banded appearance. Ironstone nodules are often concentrated along bedding planes further accentuating the banded appearance. Some bentonitic, medium gray clays, which weather to the "popcorn" type surface also occur.

Table 3 lists the named lignite beds of the Sentinel Butte Formation that crop out in the areas of study placed in their approximate stratigraphic position on the same basis as was used for the Tongue River Formation.

In other areas of the state a light gray "pod" horizon has been noted not far above the base of the Sentinel Butte Formation at several localities. In western Mercer County similar light gray, siltstone "pods" are present in the Sentinel Butte Formation (Fig. 10) at several localities, but their stratigraphic significance seems questionable since in these areas they are present in the vicinity of the Beulah-Zap bed.

Gastropods are relatively abundant in some light colored beds that are well exposed along the Knife River valley in T. 143 N., R. 90 W.; otherwise mollusks are rare in the Sentinel Butte Formation. Petrified wood is fairly common in some horizons, often being associated with the carbonaceous beds.

Golden Valley Formation

The Golden Valley Formation, named for the town of Golden Valley because of the good exposures near that town, is present as erosional remnants on some of the drainage divides in Mercer and Oliver Counties. The formation has generally been divided into two members, which have received informal names (Hickey, 1966) but which are herein referred to as lower and upper members (Figs. 11 and 12). The contact with the underlying Sentinel Butte Formation is generally covered so the thickness of the formation is difficult to measure but most of the lower member and the contact of the upper member are often well exposed around small buttes. The rest of the upper member is usually grassed over or obscured by glacial drift.

The lower member generally consists of clay and silty clay with minor carbonaceous beds; the clays are of distinctively different colors than the rest of the Tertiary beds. Generally the lower clay beds are very light gray to light purplish gray, the middle clay beds are very light gray, but weather to a yellowish or orangish gray and are called the "yellow marker" beds and the upper clay beds are light gray to purplish gray. In most of this area a thin lignite bed, termed the Alamo Bluff bed, is the uppermost bed of the lower member. This member is about 35 to 40 feet thick.

The upper member of the Golden Valley Formation which is generally poorly exposed, consists of interbedded silt, sand, clay, and lignite similar in color to beds in the Sentinel Butte Formation. The upper member is variable in thickness in this area depending entirely on

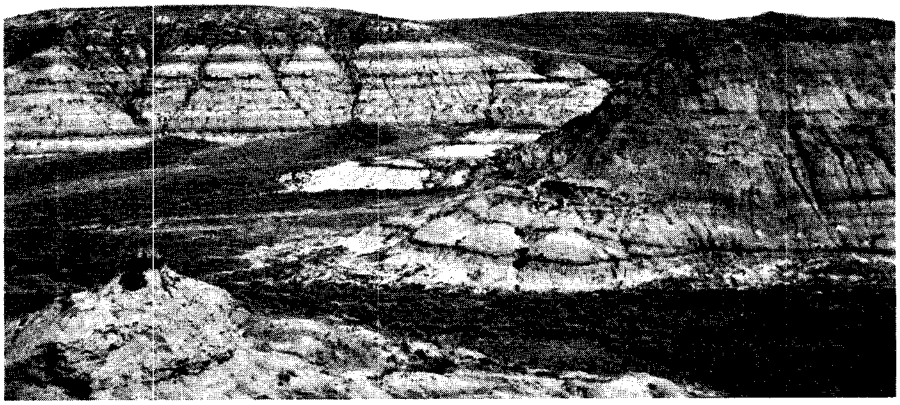

FIGURE 10. Exposure of the Sentinel Butte Formation in Sec. 5, T. 142 N., R. 89 W. Note light colored siltstone "pods" near base of exposure in right foreground.

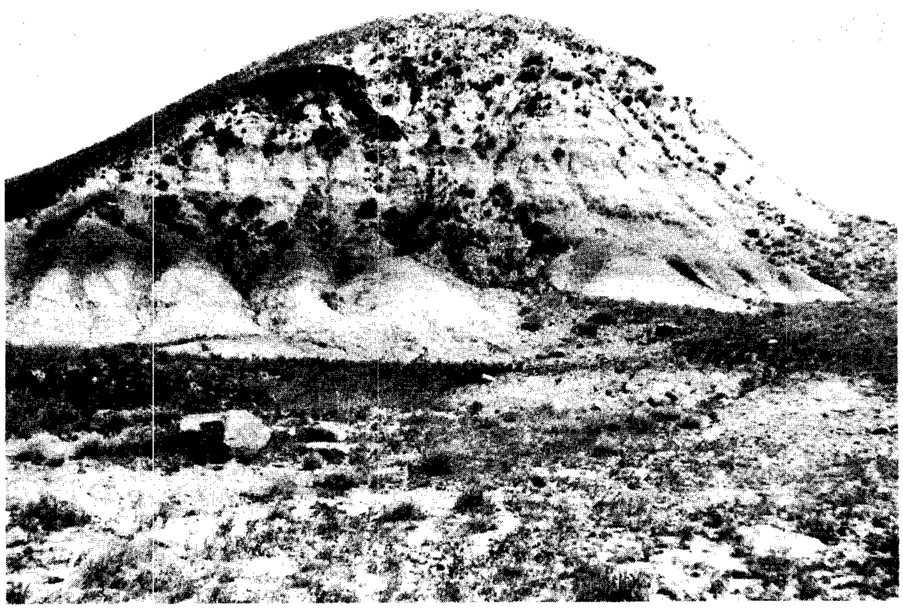

FIGURE 11. An exposure of Golden Valley Formation in SW SE Sec. 10, T. 142 N., R. 88 W. Section GV-2 in figure 12.

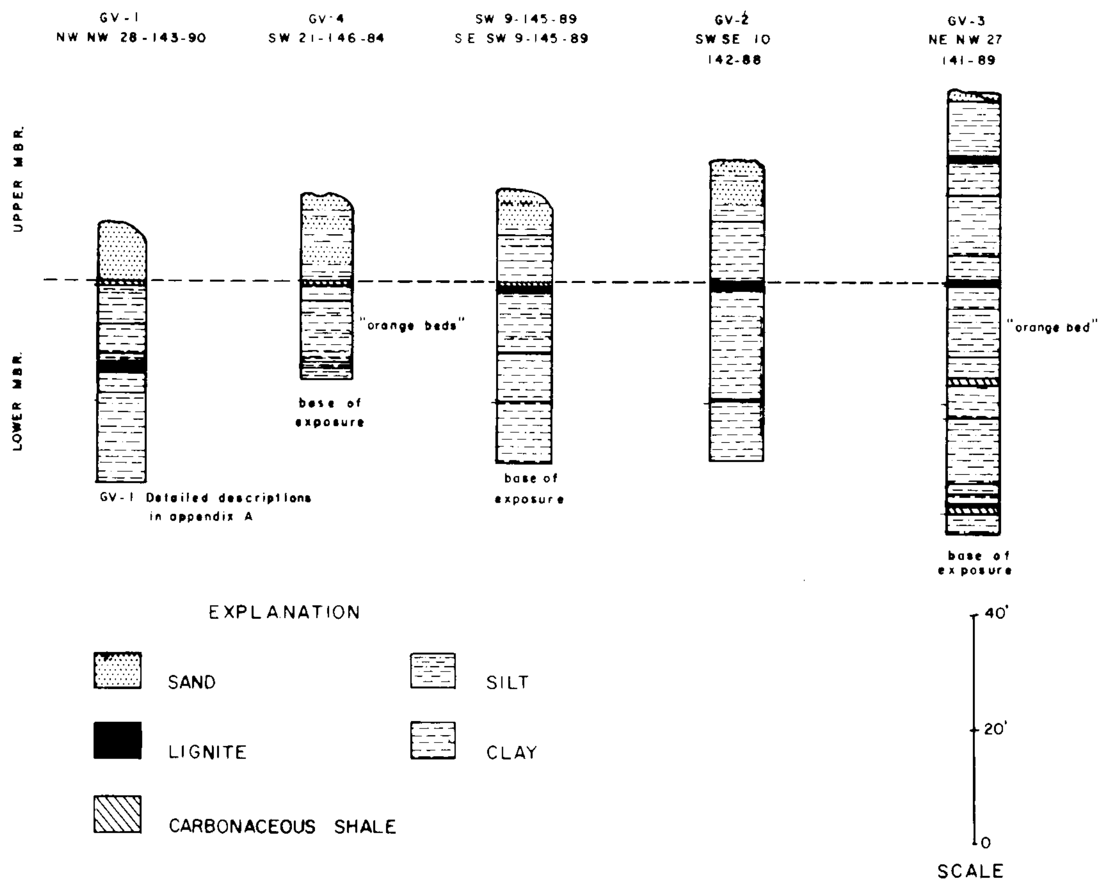

FIGURE 12. Typical measured sections of the Golden Valley Formation.

the amount that has been preserved from erosion. The thickest preserved section is at Medicine Butte where part of the lower member is exposed in a low butte just north of Medicine Butte at an elevation of about 2220 to 2230 feet. The top of Medicine Butte is at an elevation of 2356 feet, so about 125 feet of the upper member of the Golden Valley Formation is present at that locality. The butte is capped by about 35 feet of yellowish brown, fine-to-medium grained, micaceous sandstone, generally thin bedded, partly cross-bedded; generally calcareous and fairly well cemented. Because the slopes of the butte are grassed over and littered with blocks of the cemented sandstone, the lithology of the rest of upper member was hidden at this locality.

The Golden Valley Formation has generally been considered to be Eocene in age, but Hickey (1966) placed the lower member in the Paleocene and restricted the Eocene to the upper member based on his studies of the flora and fauna. No fossil collections were made in the present study so his age assignments are accepted, but plant fossils are relatively abundant in some of the carbonaceous beds in the upper part of the lower member and in clays in the lower part of the upper member. Fragile mollusks were also noted in silts of the upper member at two localities (SE Sec. 27, T. 142 N., R. 89 W., and NW Sec. 13, T. 145 N., R. 89 W.), but no identifications were attempted.

Pleistocene and Recent Deposits

DEPOSITION

Pleistocene and Recent deposits are the surface materials in most of the area north of the Knife River in Mercer County and north of Square Butte Creek in Oliver County. South of these areas glacial deposits are patchy or absent on the uplands, but they are relatively thick in the Knife River valley and in lowland areas that were used as diversion trenches. The diversion channel areas are characterized by relatively wide (.5 to 1.5 miles), flat floored valleys with small streams incapable of cutting such a valley. These areas have been previously named the Goodman Creek trench, Golden Valley trench, Beulah trench--Zap and Hazen branches, and Elm Creek trench. These "trenches" and the Knife River valley generally have 200 to 280 feet of Pleistocene to Recent fill. Square Butte Creek has lesser amounts of fill, only 80 to 160 feet. Tributaries of the Knife River and Square Butte Creek other than the diversion trenches have fill on the order of generally less than 50 feet, except for Otter Creek, which has at least as much as 133 feet of fill.

Deposition in the lowland areas, the valleys, and meltwater trenches, includes ice marginal stream deposits that were deposited as glacial ice advanced into the area, lake sediments that were deposited as streams were dammed by the advancing ice as well as by the receding ice margin, and outwash from meltwater as the ice melted. Since the glaciers left the area, Late Pleistocene to Recent slopewash from the valley walls has accumulated in the lowland areas. These surface materials of silt, clay, and fine grained sand have been mapped as alluvium with no attempt to separate Recent from Pleistocene deposition.

Mercer Till

Mercer till is exposed beneath younger till in cut banks along Lake Sakakawea at several localities. These are most easily accessible when the reservoir level is below the 1,840 foot level. Mercer till is mainly a very tough silty clay. Large blocks of the till that have fallen from reservoir cuts retain a hexagonal outline parallel to the jointing, which is a prominent characteristic of the exposures. Staining generally follows the joints. Stained portions are grayish orange (10YR 7/4), whereas unstained portions are medium light gray (N6) grading to pale yellow brown (10YR 6/2). The combined, or mixed, hue is yellowish gray (5Y 8/1). Locally lenses of sand and gravel as much as 2 to 3 feet thick separate the Mercer till from the younger till, but more typically the contact is marked only by a contrast in color (Fig. 13).

The Mercer till has been recognized only in exposures along the reservoir where it is present at elevations below 1,850 feet. The thickest exposures are about 10 feet with most exposures less than 10 feet thick.

Napoleon Till

The surface till, wherever drift is present in the two counties, is typically a silty clay, light olive gray (5Y 6/1) in color that may be locally sandy. This, the Napoleon till, is exposed along some banks of Lake Sakakawea and as isolated exposures elsewhere. Jointing is a prominent characteristic of the Napoleon till. The joints are nearly vertical and are accentuated by iron staining that follows the joint faces. The jointing does not extend to the surface; along the reservoir where the best exposures are located, jointing follows the present topography with the upper 2 to 4 feet unjointed. This suggests that the unjointing is probably a weathering effect, although it was first thought that the jointed till might be lodgment till and the unjointed till ablation till. The general lack of boulders at this contact, the close relationship of the unjointed till to present topography, and the transitional nature of the "unjointed-jointed" contact favor the weathering conclusion.

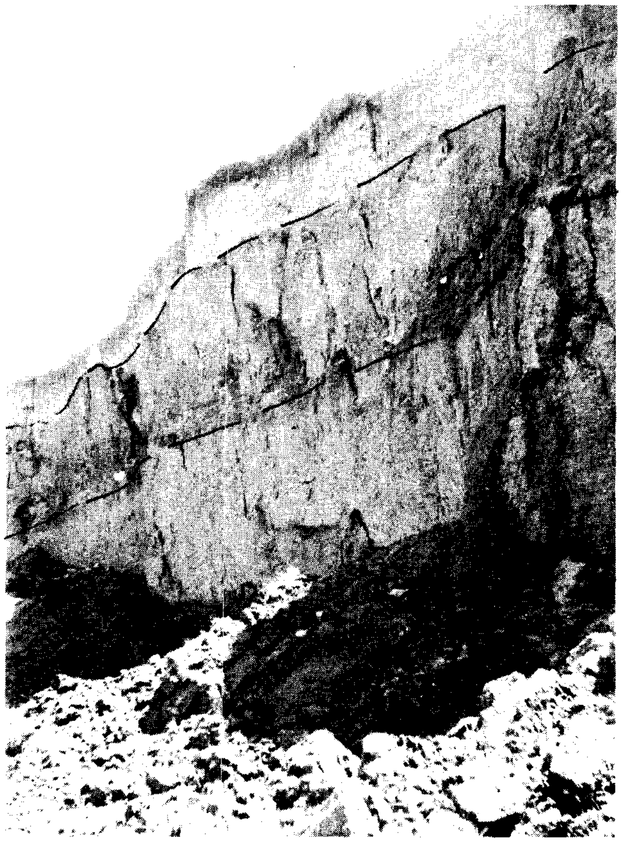

FIGURE 13. An exposure along Lake Sakakawea at SE NE Sec. 7, T. 146 N., R. 87 W. showing silt at surface on Napoleon till with underlying Mercer till.

Previous mapping in this area indicated that two tills were present in the Kineman Creek area. The flood of June 1966 provided good new exposures along this creek (Fig. 14), but the evidence is still inconclusive. Some concentrations of boulders occur near the top of the jointed zone, but they are not continuously present at this horizon. No distinct color difference exists between the jointed and unjointed tills. Therefore, it seems likely that the jointed-unjointed contact is a weathering effect and that the exposure is a single till.

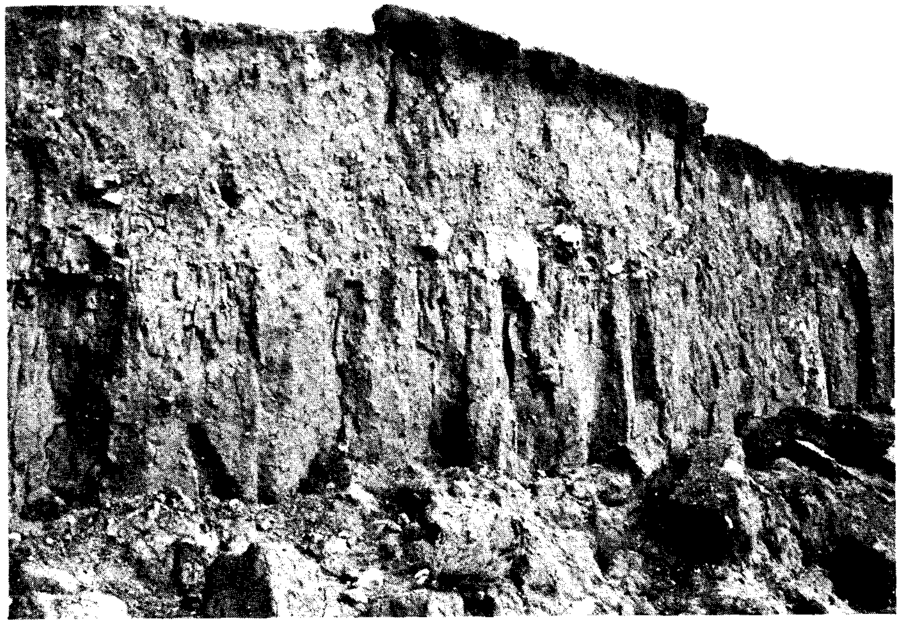

FIGURE 14. An exposure in SE SE Sec. 12, T. 144 N., R. 86 W. along east bank of Kineman Creek showing exposure of till. Note blocks of jointed till at base of exposure.

Sand and Gravel

Sand and gravel deposits are present at the surface as small patchy areas in the uplands (e.g., NW NW 29-147-90, NW NE 27-146-86) and along minor drainages (e.g., NW 26-146-87, NE 21-145-85) in the area north of the Knife River in Mercer County. These deposits are usually only a few feet thick and consist of generally clean, well sorted sand and gravel overlying till. There are also some sand and gravel deposits along major tributaries of the Knife River: Goodman Creek and Antelope Creek on the north side and Brush Creek and Coyote Creek on the south side. These also are usually only a few feet thick and generally overlie till. In the Beulah trench (Secs. 1, 2, 11, 12, 13 and 14-145-88) some gravel deposits occur near the present drainage divide and along the walls of the trench. Similar sand and gravel deposits are present along the Zap branch (secs. 8, 9 and 17-144-88) and Hazen branch (sec. 11-144-87) of the same trench.

Some patchy sand and gravel deposits occur along Spring Creek and the south side of the Knife River from Elm Creek to Brush Creek. East of here, sand deposits are nearly continuous to the Missouri trench in a band gradually widening eastward where the slopes are sand covered for 3 to 3.5 miles south of the Knife River floodplain. These sand deposits are generally fairly well sorted, fine to medium grained, clean sand. A couple of small patches of similar sand deposits occur on the north side of the Knife River.

In Oliver County patchy surface deposits of gravel are found along Square Butte Creek and in the short north and east flowing drainages in the northeastern part of the county. Similar patchy deposits occur along southeastward drainage in the central part of the county. These deposits are generally only a few feet thick. Some are gravel on till, some gravel on bedrock. Pebble counts generally are in the range of 55 to 65 percent carbonates, 20 to 30 percent igneous and metamorphics, 10 to 20 percent local rock types.

The best gravel deposits in terms of quantity are in the Missouri trench near Hensler and Sanger where extensive deposits of clean sand and gravel are found. These are gravels of glacial origin that may have been deposited by waters flowing from melting ice in Oliver and McLean Counties. The Missouri River trench in this area apparently carried a north flowing stream in pre-Wisconsinan time, and the gravels may have been deposited at the margin of the ice when it blocked this drainage.

"Scoria"

In many localities in these counties lignite beds have burned, baking the overlying sediments and producing a red or black baked sediment that has been called "scoria." Composition of "scoria" depends on the sediments overlying the lignite beds. In areas of bedrock these are usually silts, clays, and sand, and most "scoria" is composed of these materials. However, in the area north of the Knife River, there are numerous localities where till overlies lignite beds that have burned; there the "scoria" is composed of "baked" till. Since the till has been baked this dates the burning of much of the lignite in this area as post-glacial.

Alluvium

The most effective erosion in the present climate occurs during short periods of heavy rainfall. At these times silt and clay is washed down the slopes to the valley floors. When the runoff reaches the valley floors the gradient is reduced, some of the water seeps into the ground, and much of the sediment is deposited as alluvium. In many cases the steeper slopes are kept clean by slopewash. In other cases, the slopes may be covered by as much as 2 to 3 feet of colluvium and alluvium (Fig. 15). Since these sediments are limited to parts of the slope and generally cover small or patchy areas they were not separated as a map unit (Pl. 1). Colluvium and alluvium are common to slopes in the bedrock areas.

Slopewash is also effective in the glaciated areas. Many slopes are littered with concentrations of large glacial boulders that are lag deposits, the fine materials having been washed downslope (Fig. 16). In some areas slopewash from glaciated slopes has accumulated in narrow, low sloping troughs to thicknesses of 19 feet (auger hole, 0-68-10) and 35 to 46 feet (auger holes 0-68-22 and 0-68-23). More commonly this clay and silt is only a few feet thick in the steeper sloping draws.

Diversion Trenches and Knife River Valley Fill

In the diversion trench valleys and along part of the Knife River valley the gentle slopes and valley floors are covered by Pleistocene to Recent alluvium. Some auger holes were drilled to determine the nature and thickness of this alluvium. In the Beulah trench auger holes penetrated clay and silt with numerous "scoria" pebbles to depths of 15 to 30 feet before going into predominantly sand fill. Some test holes in the Beulah trench had 35 to 50 feet of silt and clay overlying sand. In the Goodman Creek trench the surface silts and clays are 20 to 30 feet thick. An auger hole on the north side of the Knife River (NE SE Sec. 11, T. 143 N., R. 89 W.) penetrated silt and clay with some "scoria" pebbles to a depth of 34 feet. It then penetrated 21 feet of sand before reaching bedrock at 54 feet. Wood fragments from alluvial fill at a depth of 25 feet in test hole 2677 (near Hazen) were radiocarbon dated as 5,700 ±300 years B.P. (W-2184). Therefore, the silt and clay (alluvium) is probably mostly post-glacial slopewash.

In Goodman Creek trench the pre-alluvial fill was logged as sand or sand and silt, generally coarser grained with depth, with 5 to 30 feet of gravel at the base. The fill in the Golden Valley trench was almost all sand, much of it fine grained with only a few feet of gravel at the base in one test hole. In Elm Creek trench the fill is generally finer grained with most of the fill logged as silt and clay. Gravels at the base were 3 to 26 feet thick. One test hole had a section logged as questionable till.

In the Beulah trench the fill is generally more variable than in the western trenches. There is more interbedding of the sands with silts and clays. Gravel beds were noted at various horizons within the fill, although the fill is mostly sand. Near the present drainage divide the surface deposits are till, sand, and gravel. The Hazen and Zap branches also have alternating sand, silt, and clay beds, predominantly sand. Samples from a depth of 55 to 60 feet in test hole 3656 (SE NW, Sec. 17, T. 144 N., R. 88 W.) in the Zap branch contained abundant mollusk

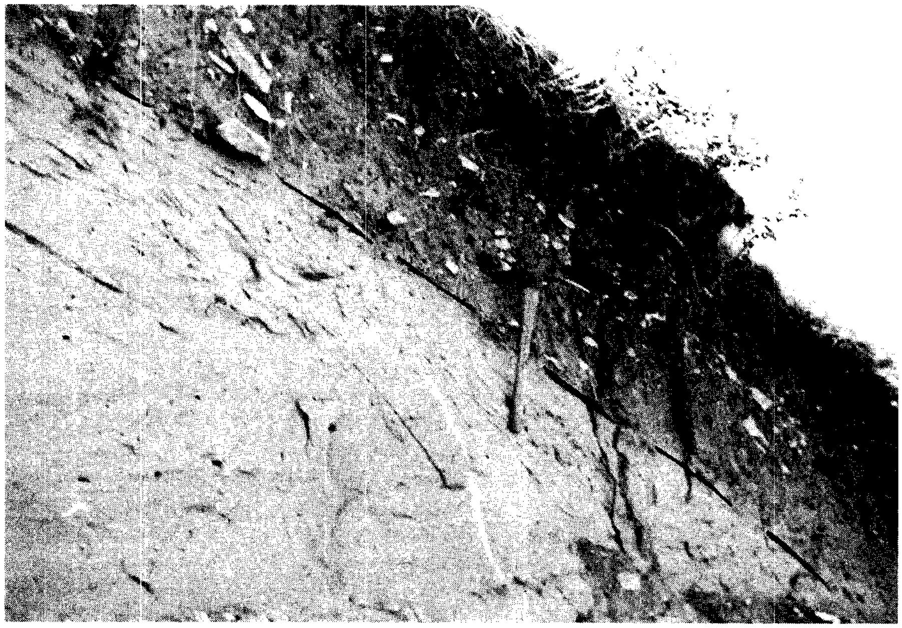

FIGURE 15. An exposure in SE NW Sec. 28, T. 141 N., R. 82 W. showing colluvium on a bedrock slope.

FIGURE 16. An exposure in SW Sec. 22, T. 141 N., R. 86 W. showing concentrations of lag boulders on till covered slopes due to slopewash of the fine grained material.

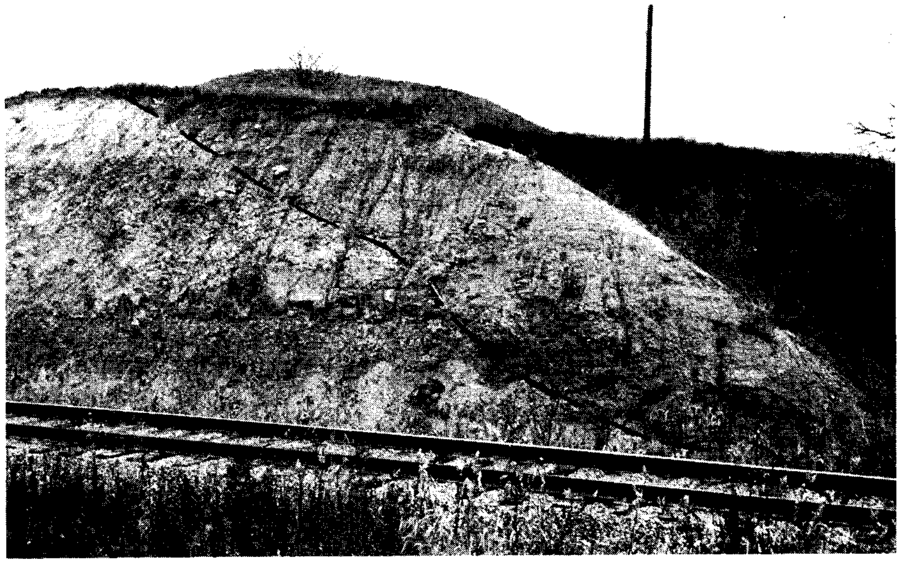

FIGURE 17. An exposure in NW Sec. 29, T. 144 N., R. 87 W. showing a till covered bedrock slope.

shells in a fine grained sand. This fauna was studied by S. J. Tuthill who stated (personal communication) that the fauna is dominated by *Valvata tricarinata* and that the entire assemblage suggests deposition in slow moving or standing water, perhaps even an oxbow lake in a river system.

The fill in the Knife River valley from Beulah east to North Dakota Highway 200 is sand, silt, clay, and some gravel; sand is predominant. Near Stanton a number of test holes penetrated one or more intervals of till within the fluvial fill, although the fill is mostly sand. Variable thicknesses of gravel are present at the base of the fill in the Knife River valley. More detailed descriptions of the fill are provided in Part II of this study.

LANDFORMS

The present topography of this area may be described as a glacially modified bedrock topography. The mantle of drift generally follows the pre-existing topography (Fig. 17), modifying it only slightly, although in some areas there is some glacial constructional relief. The general effect of the drift has been to lessen the local relief.

The major drainages and their main tributaries are pre-glacial bedrock valleys. The Knife River and Square Butte Creek are adjusting their profiles to the Missouri River base level, so they are currently aggrading streams with alluvial floored valleys.

Hummocky Moraine

Parts of the drainage divides between the Missouri and Knife Rivers in Mercer County and between Square Butte Creek and the Missouri River in Oliver County are marked by glacial constructional topography. In these areas there are numerous small undrained depressions, although only a few contain permanent sloughs. Surface material is till except for a few small patches of gravel; outwash is generally lacking. Auger holes in these areas penetrated bedrock at depths of 10, 30, and 36 feet (M 68-25, M 68-24, and M 67-9) demonstrating that the drainage divides are controlled by a pre-existing bedrock divide.

Ground Moraine

In Burleigh County, Kume and Hansen (1965, p. 15) used the term sheet moraine for "a landform composed of mappable, blanket-like, thin accumulations of drift deposited directly from glacial ice and having low constructional relief." They went on to state that sheet moraine is generally found in areas of moderate to high relief and reflects the underlying bedrock topography.

Many areas in Mercer and Oliver Counties show exposures of bedrock with a thin (a few feet or less) mantle of till; the till cover follows the pre-existing bedrock slope. These areas might have been mapped as sheet moraine; but without subsurface control the thickness of drift is unpredictable, and areas of exposure of thin drift have a similar surface appearance to nearby areas where 75 to 115 feet of till were penetrated in auger holes. Therefore, all the areas of till where constructional relief was lacking were mapped as ground moraine. Typically these are areas of gentle slopes.

Auger holes in relatively flat lying areas of ground moraine generally penetrated about 18 to 24 inches of dark brown silt and fine grained sand of the "A" soil horizon before penetrating the clay and silty clay till. On sloping areas much of this silt and sand has been eroded. Generally the ground moraine provides the best soil for agriculture in these counties.

Ice Contact Deposits

Ice contact deposits are usually thought of in terms of outwash, kames, and eskers where meltwater flowing away from the glacier margins has deposited sorted materials. Because of the bedrock topography over which the glacier moved in this area most of the ice-contact deposits were laid down in water ponded between the margin of the ice in the lowland areas and upland areas from which the ice had already melted. Because of the ponded water these outwash deposits are relatively clean interbedded sand and gravel. Since the water was not ponded for long periods of time at any one locality these deposits are not very thick and they are generally distributed as patchy deposits along the minor drainages. Examples of this type of deposit are located in Sec. 4 and 9, T. 143 N., R. 82 W., Sec. 13, T. 146 N., R. 87 W. and Sec. 23, T. 145 N., R. 89 W. Some drainages were ponded for relatively long periods of time, and, where this happened, rather continuous and more extensive deposits of sand and gravel occur. Examples of this type of deposit are found in northeastern Oliver County (Sec. 14, 15, 23, and 26, T. 143 N., R. 83 W.; Secs. 21, 22, 23, 26, 27, 28, and 33, T. 143 N., R. 82 W.). Similar rather continuous deposits are also present along parts of Kineman, Brady, and Otter Creeks.

The typical vertical sequence at exposures of these deposits is silt and sand at the surface, underlain by gravel and sand, then till, then bedrock (Fig. 18). At some localities the till may be missing and gravel may overlie bedrock (Fig. 19). The silt and sand is usually a few inches to 18 to 20 inches thick; in a few areas it thickens to 3 to 5 feet thick, but anything over 5 feet thick is unusual. Gravel is generally 1 to 3 feet thick. Till may be a few feet thick or indeterminable because bedrock is not exposed.

A sequence of depositon that would account for the above described succession calls for lodgment till emplacement as the ice advanced up the bedrock slopes followed by dumping of outwash materials near the ice margin as the ice melted. Since the slope gradients were toward the ice margin (Fig. 20), the outwash tended to be sorted in ponds of meltwater ahead of the ice. Melting of the ice in the valleys (ice may have been 600 to 900 feet thick in the Knife River valley, 500 feet thick in tributaries such as Otter Creek and Brush Creek) was a slow process, probably taking 2,000 to 3,000 years. During this period of melting there would have been erosion in the uplands areas that were free of ice. The material that could not be removed from the area because drainage was toward the ice blocked valleys was deposited on the sand and gravel mainly as "inwash" in the ponded meltwaters. Thicknesses of fluvial sediments at any one locality depends upon how long the meltwaters were ponded before they escaped to lower elevations along the side of the ice filled valleys.

Along the south side of the Knife River the nearly continuous sand on the slopes from Otter Creek east to the Missouri trench closely

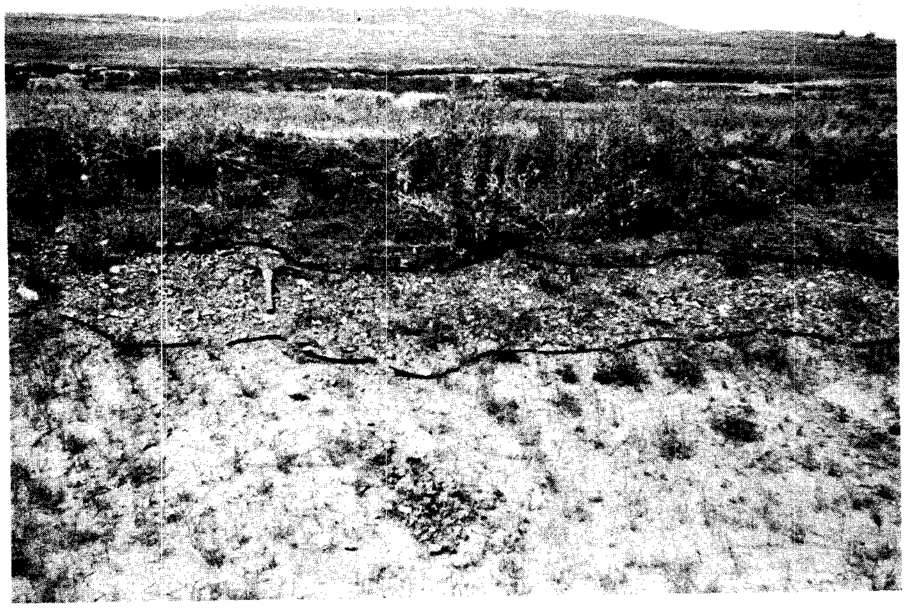

FIGURE 18. An exposure in SE SW Sec. 2, T. 141 N., R. 87 W. showing the sand on gravel on till sequence.

FIGURE 19. An exposure in SE Sec. 6, T. 141 N., R. 86 W. showing the sand on bedrock; sand on gravel on bedrock sequence.

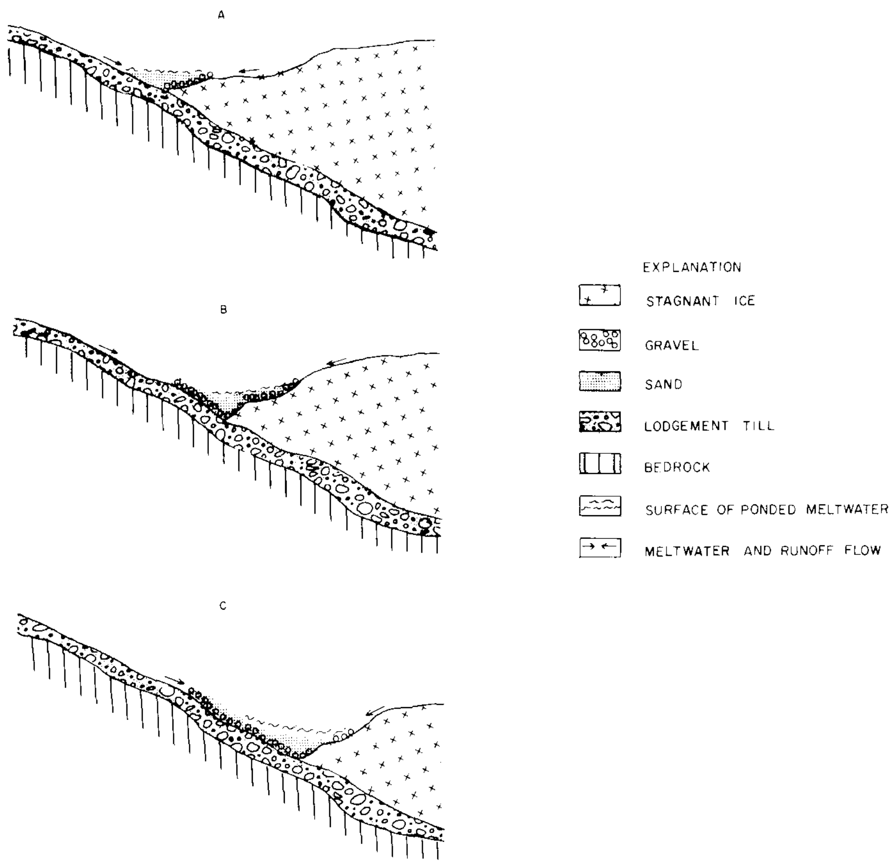

FIGURE 20. Diagram showing deposition of the sand on gravel on till sequence.

follows the 1,850-foot contour, except in the area just west of Kineman Creek where sand extends up to elevations of 1,900 to 1,950 feet and from Sand Creek east where it also extends up to 1,900 feet. Scattered exposures, auger holes, and test holes show that the vertical sequence here is usually sand, then till, then bedrock; or sand on bedrock (Fig. 21).

Deposition of this sand probably occurred when ice present in the Knife River valley had melted down to about 250 to 400 feet thick. At this time tributary waters from Otter Creek, Brady Creek, Kineman

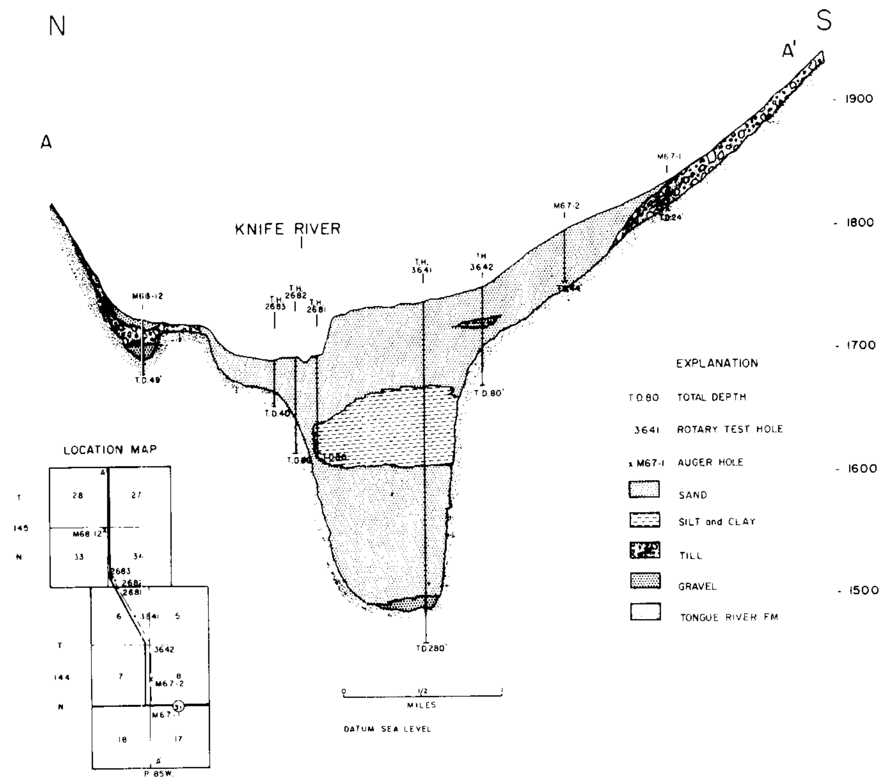

FIGURE 21. Cross section across the Knife River valley about 5 miles west of the Missouri River.

FIGURE 22. An exposure of fine grained, nearly horizontally bedded sediments in SE NW Sec. 34, T. 143 N., R. 87 W. near uppermost part of cut. Knife River valley in right background.

Creek, and Sand Creek, together with meltwaters from the ice in the Knife River valley, were ponded up between the valley wall and the ice in the valley. Evidence for this is best shown by exposures of fine grained, nearly horizontally bedded (Fig. 22) sediments near the Otter Creek-Knife River junction, where in SE NW Sec. 34, T. 143 N., R. 87 W. there is a nearly continuous exposure from the floodplain at an elevation of about 1,770 up to elevations of 1,840 feet. The slight dip of these beds toward the present Knife River valley indicates that they were deposited in an ice walled valley rather than as wall to wall fill of the Knife River. Further evidence was provided by a roadcut in NW NE Sec. 19,T. 144 N., R. 86 W. where a lens of till enclosed in sand was exposed in 1966 and 1967. Sand has slumped over the till now, but this must be an ice-contact deposit.

Sand deposits are not as continuous on the north side of the Knife River, but small areas near the Coal Creek-Knife River junction and the Knife River-Missouri River junction have exposures of sand on till. These are probably the result of temporary ponding in those areas.

Sand Dunes

In the area south of the Knife River from Brady Creek eastward to the Missouri River most of the sand deposits have been reworked by post-glacial winds. This resulted in a gently rolling sand dune topography with local relief of 10 to 15 feet except for a few areas where the sand dunes are better developed. Such areas are in Secs. 9 and 10, T. 144 N., R. 85 W. where the sand dunes are 25 to 35 feet above the general area and in Secs. 22, 23, 24, and 25, T. 144 N., R. 86 W. where there is 35 to 50 feet of local relief in the dune areas.

Terraces

Terraces are relatively flat areas bordering drainages. They mark distinct levels or periods of erosion and primarily represent a scouring or cutting into bedrock by a stream as it meanders across its valley floor and then deposits a valley fill of floodplain deposits. The valley fill includes channel deposits of the stream, natural levee deposits at the margin of the channel, and overbank deposits of the flood periods. The stream channel is an area of scouring during high flow periods and deposition during low flow periods, so these deposits are unstable. The main body of the preserved valley fill is the overbank flood stage deposits. During flood periods the stream may change the course of its channel, leaving its old channel as a meander scar on the floodplain surface; thus the floodplain profile is not one of a flat surface, but a relatively flat surface interrupted by old meander scars.

The best preserved terraces or terrace remnants in this area are along the Missouri River where Johnson and Kunkel recognized five terrace levels. Their terrace levels were 5 to 15, 20 to 25, 30 to 80, 60 to 135, and 120 to 180 feet above the present river level. They were not continuously present but were recognized as remnants where present. Across the river in Burleigh County, Kume and Hansen (1965, p. 8) recognized four terraces. The lowest two terraces were within 10 feet of each other and less than 20 feet above the river, terrace 3 was 20 to 40 feet above the river, and terrace 4 was 40 to 60 feet above the river.

In the present study only 2 terraces were recognized along the Missouri River. In the segment of the Missouri trench from Garrison Dam to the Knife River there is only one terrace present in Mercer County. It rises less than 20 feet above river level and represents the floodplain of the current stream before the dam was constructed. In the segment of the Missouri trench from the Knife River south to the Oliver County line two terrace levels were recognized. The lower terrace is equivalent to terraces 1 and 2 of the Burleigh study and represents the floodplain of the recent stream. The upper terrace is about 30 to 50 feet above the lower terrace, so it is equivalent to terraces 3 and 4 of the Burleigh study.

Twelve auger holes were drilled to put in observation wells on the lower terrace in the Hensler area, but none of these penetrated bedrock. Most of them stopped at 29 feet or less, but one hole (0-67, MK-13) penetrated 74 feet of generally coarse sand without reaching bedrock. A water well in SE NW Sec. 26, T. 144 N., R. 83 W. on this terrace penetrated 104 feet of mostly sand before penetrating claystone and siltstone of the Cannonball Formation. Test hole 3731 located on the lower terrace in SW NE Sec. 22, T. 144 N., R. 82 W. penetrated 211 feet of mostly sand before penetrating the Cannonball Formation.

The upper terrace is generally cut on the Cannonball Formation in the area of Oliver County east of Hensler. In the segment from Price to Sanger, outcrops in the minor drainages and auger holes generally found a few inches to a few feet of silt, then till as much as 23 feet thick, then bedrock. Near Sanger the channel of the Missouri abuts against the upper terrace, which is here composed of sand and gravel probably deposited by meltwaters of the short eastward flowing drainage as the ice melted. Auger holes in the segment from Sanger north to near Hensler penetrated silt and clay, then till, then bedrock; or silt and clay, then bedrock at depths of 19 to 42 feet. Auger holes in the Hensler area penetrated 4 to 13 feet of silt and clay, 1 to 12 feet of gravel and sand, then clay or till. Test hole 3638 was drilled near the margin of this terrace; it penetrated 15 feet of sand and gravel, 47 feet of till, then 64 feet of predominantly sand or sand and gravel before penetrating claystone of the Cannonball.

Auger holes on the upper terrace in Mercer County south of Stanton penetrated 34 feet of silt, clay, and sand without penetrating bedrock. One test hole (3639) penetrated sand, till, and sand to a depth of 150 feet without penetrating bedrock.

GEOLOGIC HISTORY

Pre-Glacial History

Mercer and Oliver Counties are located in the southeastern part of the central Williston basin, a structural basin whose center is south and east of Williston, North Dakota. During Paleozoic time, marine seas invaded this area at least four times during which carbonates, sandstones, shales, and evaporites were deposited. During times of emergence part of these deposits were removed by processes of erosion. Times of emergence were during the Early to Middle Ordovician, Middle Silurian to Middle Devonian, Late Mississippian to Early Pennsylvanian, and during the Triassic.

Mesozoic seas spread over the area during the Middle Jurassic, and marine deposition continued until the Late Jurassic when there was a time of emergence with non-marine deposition. Non-marine deposition continued into the Cretaceous until the Early Cretaceous seas again spread over this area and thick accumulations of fine grained clastics were deposited. The last phase of marine Cretaceous deposition is represented by fine grained clastics of the Fox Hills Formation.

A change to predominantly non-marine deposition began in the Late Cretaceous with deposition of the Hell Creek Formation and continued with the Ludlow Formation of Paleocene age. Then followed the last marine invasion of this area and the Cannonball Formation was deposited. This was followed by deposition of the non-marine Tongue River and Sentinel Butte Formations of Paleocene age and the Golden Valley Formation of Paleocene to Eocene age. The presence of the White River Formation in the Killdeer Mountains area of Dunn County suggests that Oligocene deposits may also have extended into Mercer County, but if they were ever present they were removed during the post-Oligocene erosional episode.

The post-Eocene Tertiary period was a time of development of an integrated drainage system. During this time the predominant process was erosion of the existing landscape. It was at this time that the present drainage with the exception of the Missouri River was established and the topography of the area in the early Pleistocene was probably similar to the present topography except for some of the channels (i.e., Golden Valley Trench, Beulah Trench), which were cut by ice-marginal diverted drainage and glacial meltwaters.

Glacial History

Glacial deposits are absent in many areas and generally thin where present, so the glacial history of these two counties must be pieced together from fragmentary evidence. It must be based partially on evidence from adjoining areas to the north and east of the Missouri River where detailed mapping has been done (Kume and Hansen, 1965, Bluemle, 1971), as well as other areas in North Dakota where detailed glacial mapping has been completed.

Benson (1952, p. 183) concluded from the evidence examined in Mercer County and from reconnaissance studies of glacial deposits elsewhere in North Dakota that three ages of drift were present in this area. He based his conclusions mainly on fills within the Knife River valley, and although only two fills were exposed at any one locality, he recognized three distinct fills. He thought that the first two (fills) drifts were early Wisconsinan (Iowan and Tazewell) and the third a late Wisconsinan (probably Mankato). Johnson and Kunkel (1959) accepted Benson's Wisconsinan correlations for the drift in Oliver County.

Clayton (1967, p. 3, Fig. 1) in summarizing the Pleistocene stratigraphy of North Dakota, recognized two surface drifts in Mercer and Oliver Counties, the Morton and Napoleon Drifts. The Morton Drift was referred to as the oldest glacial advance, probably early Wisconsinan, and its outer limit was south and west of these two counties. The outer margin of the Napoleon Drift, also early Wisconsinan, was shown as crossing Oliver County approximately along the north margin of the Square Butte Creek drainage, crossing the Knife River drainage in western Mercer County to follow the north flank of the Spring Creek drainage in Dunn County. Clayton also referred to "old, strongly-jointed tills" present under the surface drifts in scattered localities throughout the glaciated areas. The strongly-jointed tills were believed to be pre-Wisconsinan drift.

The age assignments of these previous studies were based mainly on physical evidence: the generally thin drift, the integrated drainage, and the general lack of glacial constructional relief. These were all used as arguments that the drift was old and processes of erosion had had time to modify the drift to its present form.

One radiocarbon date, W-402, has been reported from previous studies in Mercer County. It is from gastropods collected from a marl bed within till of hummocky moraine in northwestern Mercer County. Although, based on other physical evidence, the date seems to be anomalous, it would date this drift as late Wisconsinan (11,220 ±300). Lacking other absolute dates, the age of the glacial deposits must be determined by indirect means.

The first step in reconstructing the glacial history of the area is to construct a map of the pre-glacial surface over which the glacier advanced. The Square Butte Creek drainage had been established and flowed southeastward as a tributary of the Cannonball River, which at that time continued northeastward through Burleigh and Kidder Counties. Likewise, the Knife River flowed northeastward from its present outlet through McLean and Sheridan Counties on its way toward Hudson Bay. The segment of the Missouri in the area along the northern border of Mercer County as far west as Beaver Creek was probably a tributary of the Knife River system, probably joining the main stream in McLean County. The segment of the Missouri from Alderin Creek east to T. 144 N., R. 81 W. appears also to be an old valley, either a tributary of, or the course of, the Knife River.

When the first ice advanced into this area, when the diversion trenches were cut, and when the Missouri River became established in its present channel are key problem areas. Most previous workers have attributed the Missouri River diversion to Illinoian or older glaciations. Evidence from the present study combined with evidence from nearby studies suggests different ages for different segments of the present trench.

In the segment of the Missouri River from Garrison Dam westward, the bedrock surface slopes toward the present trench and is till covered. Therefore, this must be a pre-glacial valley, and presence of the Mercer Till means that it is probably a pre-Wisconsinan valley.

The uneroded upland area in the segment of the Missouri River from Garrison Dam to the Knife River has a slope away from the present trench. The river bed or the lower terrace of the present stream abuts against the valley wall in this segment and short, steep sided drainages are cutting into the uplands exposing the bedrock formations. The slopes of the upland and lack of drift in the short drainages indicate that this segment was not present prior to deposition of the Napoleon drift.

The history of the segments of the Missouri trench from the Knife River to Fort Clark and from Fort Clark to the southward bend east of Hensler are not so obvious. In these areas the lower and upper terraces are present except where the stream has removed them in its meandering course from valley wall to valley wall. The bedrock surface slopes toward the present trench in these segments, but the base level was higher than at present, so although the bedrock is till covered the present drainages are actively cutting back into the uplands and the topographic expression resembles the Garrison Dam-Knife River segment. Mercer till is also exposed on the McLean side of this segment. This suggests that this segment was present, probably as a tributary of the Knife River in pre-Wisconsinan time.

In the south flowing segment east of Hensler the bedrock surface also slopes toward the present trench and is till covered. Upper and lower terraces are present from Price northward and till is present on the upper terrace, thus dating the upper terrace as pre-last glaciation in this segment.

The test hole drilling in the Knife River valley revealed the presence of a deep channel in the Knife River valley with the slope of that channel in the direction of present flow (Fig. 23). The Goodman Creek-Golden Valley trenches, and the Beulah trench with its Zap and Hazen branches, also are part of the deep channel system with slopes

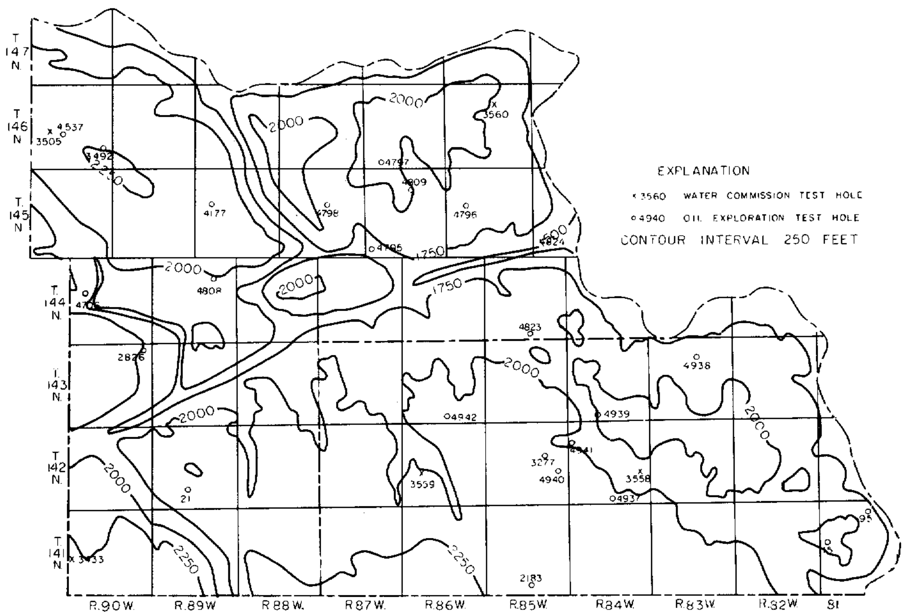

FIGURE 23. Bedrock topography.

toward the Knife River valley. The presence of the Mercer till as far west as the Beulah trench indicates that northeastward flowing drainage must have been diverted at least that far west at that time. The Beulah trench and the Knife River channel as far west as Beulah may have been cut by the diverted Missouri at that time. When the ice sheet that deposited the Mercer till was at its maximum it may have diverted the Missouri as far west as the Goodman Creek-Golden Valley trenches. Following the melting of that ice sheet the Missouri River returned to a more easterly channel. The present segment from Garrison Dam westward was probably part of that diverted Missouri. The Knife River drainage system was probably a tributary of that system. The segment of the present trench from south of Stanton east to Hensler may have been occupied by a diversion of the Knife River or else it was also a tributary of the diverted Missouri. The segment of the trench from near Price north toward Washburn was either part of the diverted Missouri or more likely a north flowing tributary of that stream. Elevations of the floor of the Goodman Creek-Golden Valley-Elm Creek trench suggest that at one time this may have been the ice marginal route of the Missouri; however, before it became firmly entrenched the Beulah trench-Knife River valley channel became available and was cut to a lower base level. As the ice melted further the Beulah trench segment was probably abandoned for a still more easterly course.

Another possibility is that the diversion trenches may be related to old, earlier (Pre-Mercer) glaciations for which no physical evidence was found in the area of study. Some of the diversion trenches may have been used by diverted drainage and meltwaters more often than others; the precise history is unclear. However, the physical evidence does indicate that the Beulah trench and the Goodman Creek-Golden Valley trenches were present prior to deposition of the Napoleon drift as Napoleon till is present along the valley slopes down to the present valley floors, and till is present in ice contact deposits at the drainage divide in the Beulah trench.

The outer limit of glaciation in North Dakota closely follows the 2,400-foot elevation from the Montana border east and south to Elgin, in Grant County, south and west of the area of study. Glacial drift is present at elevations exceeding 2,300 feet in Mercer County. Since the surface till, previously described as Napoleon till, is generally similar throughout its areal extent, it probably represents one glacial advance, rather than two or three separate advances as has previously been proposed. The area mapped as hummocky moraine, previously mapped as the "Krem end moraine" in Mercer County, is located on some of the highest ground in the area over which the ice moved. Because the hummocky moraine is on the drainage divide the constructional topography has been preserved. The outer margin of the ice sheet was to the west in Dunn and McKenzie Counties. Based on relationships to Late Wisconsinan drift borders to the north and east, this was probably an early Wisconsinan drift sheet.

Present areal distribution of the Napoleon till reflects the effects of the pre-existing topography on the melting of the ice and escape of the meltwaters during deglaciation. When the ice advanced into this area it probably moved up the pre-existing drainages with the thickest accumulations of ice in the valleys. When the ice began to melt the areas of thinnest ice (i.e., the divides) were freed of ice first. In the Square Butte drainage the southeastward flow was re-established in the early stages of melting, so much of the superglacial debris was carried away as outwash and ice-free areas began to be eroded. However, in the Knife River drainage the pre-existing northeastward escape was blocked by ice. Meltwaters were forced to escape to the southeast through diversions of the South Fork of the Knife River and Elm Creek. Meltwaters from tributaries of the Knife River flowed toward the valley of the Knife River and then escaped through the diversion channels until a lower escape through the Missouri trench became available. During part of this time the meltwaters were ponded between the ice in the Knife River valley and the valley walls on the south side of the valley. It was at this time that much of the sand present in this valley from Beulah to McLean County was deposited.

An area in northeastern Oliver County where drainage is to the north and east to the Missouri trench has drift deposition similar to the Knife River drainage. There is an area of hummocky moraine, flanked to the north and east by ground moraine with patchy gravel deposits along the drainages. Melting in this area was similar to that in the Knife River drainage.

Post-Glacial History

Since the melting of the ice the drainage has been adjusting its gradient to the Missouri River base level. The topography of the area has been modified by the forces of wind and water, with the main effect being to remove materials from the area, although in some areas they have merely been redistributed. Slope wash from the valley walls in the diversion trenches as well as many lesser drainages often exceeds the capacity of the runoff and results in deposition of alluvial fill in these areas. The sand dune areas on the south side of the Knife River valley are areas where glacial sands have been redeposited by post-glacial winds.

ECONOMIC GEOLOGY

Lignite

Mercer County has long been one of the leading areas of lignite production in North Dakota. Since systematic records have been kept (1932), with the exception of 1944 when Ward County was the leader, it has been the leading county each year. Present operations supplying power plants near Stanton and Mandan assure maintenance of this position for the near future.

Oliver County also has large lignite reserves, but it has not been a major producing area. However, this has changed with construction of the power plant near Center with its requirements of more than a million tons per year. Oliver County now ranks second in annual production in North Dakota and will until there are further developments elsewhere.

Brant (1953) estimated reserves for 13 lignite beds in Mercer County and 15 lignite beds in Oliver County, attempting to include all beds greater than 2.5 feet in thickness. He credited Mercer County with lignite reserves of 29,912.23 million tons of which 5,302.47 million tons were credited to the Beulah-Zap bed. He credited Oliver County with reserves of 17,838.80 million tons of which 2,035.34 million tons were credited to bed E. His estimates included reserves in three categories, measured, inferred, and indicated; the totals mentioned above include all three categories.

Mapping in this project was not done in sufficient detail to revise reserve figures, but test hole drilling provided some information regarding the number of lignite beds present. Test holes generally found not more than one ten-foot lignite bed and not more than five lignite beds exceeding 2.5 feet in thickness in the Tongue River Formation at any one locality. The only lignite bed exceeding 10 feet in thickness found in the Sentinel Butte Formation in this study was the Beulah-Zap bed. Other lignite beds in the Sentinel Butte Formation are best known from surface exposures, where the Twin Butte, Schoolhouse, and Spaer beds are exposed. Subsurface information for the Sentinel Butte Formation is sparse, but it seems unlikely that more than five beds exceeding 2.5 feet in thickness would be present at any one locality.

Brant did not present data on the number of beds present, nor thicknesses used in his reserve estimates, but he did break them down by townships. He credited T. 141 N., R. 85 W. with 1,286.25 million tons of which 120.96 million tons were credited to bed E. Test hole 3646 was located in this township. If we assume that the two lignite beds present in that test hole (the 3-foot lignite bed is in about the stratigraphic position of bed E) were present throughout the township and were uniform in thickness, they would represent a reserve of 604.8 million tons or about half the previous estimate. This should not be interpreted to say that the lignite reserve estimates should be cut in half, but the deep drilling did reveal that lignite beds do vary rapidly in thickness and, in fact, they are discontinuous. Therefore, reserve estimates made on the basis of projections through the subsurface, and, particularly if they are based on the presence of numerous beds, are hazardous.

All of the current commercial production of lignite in these counties is from two lignite beds. These are the Hagel bed, which is being mined in eastern Mercer County and central Oliver County, and the Beulah-Zap bed, which is mined in central and western Mercer

County. These are the only lignite beds in the area that meet the present economic conditions of both exceeding 10 feet in thickness and being within 100 feet of the surface. The Schoolhouse bed is expected to become commercial where it can be mined in connection with stripping operations to remove the Beulah-Zap bed. These three beds essentially provide the current economic lignite reserves of this area.

Surface Water

There are three major streams in the area; namely, Square Butte Creek, the Knife River, and the Missouri River. Dams have been constructed on each of these streams to utilize the surface waters. Nelson Dam, located on Square Butte Creek, provides a reservoir for use in cooling at a power plant and may also provide a recreation area. A low dam on the Knife River at Beulah provides a municipal water supply. Garrison dam on the Missouri River provides a large reservoir for use in generating electricity and is utilized as a recreational area. Discharges from Garrison dam are used for irrigation in Oliver County.

Ground Water

Ground water is obtained from both glacial drift and bedrock aquifers with most of the water obtained from bedrock. Part two of this report provides basic data on the wells and springs. Part three provides detailed information concerning quantity and quality of water that may be anticipated from various aquifers.

Lignite beds and sands in the Sentinel Butte and Tongue River Formations provide shallow bedrock aquifers in most areas. Sandstones near the base of the Tongue River Formation and within the Hell Creek and Fox Hills Formations provide deeper artesian aquifers in many areas.

Glacial drift is generally too thin or impermeable to provide good aquifers in the upland areas. However, in the valleys of the major streams and in the diversion channels, the glacial and alluvial fill may provide adequate supplies of ground water.

Clay

The Hebron Brick Company takes clay or silty clay from the lower member of the Golden Valley Formation from a clay pit in Morton County, just south of the Mercer County line, as a raw material for their brick plant in Hebron. This deposit extends northward into Mercer County where it would probably be of similar quality. The lower member is also present wherever Golden Valley has been mapped (Pl. 1), and since the lithology is relatively uniform it would probably provide a suitable clay for brick making in most of those areas if there were a future demand for more bricks.

Petroleum

There had been twenty oil exploration tests in the two counties as of January 1, 1970; three were drilled to the Madison Formation (Mississippian), three to Devonian rocks, one to Ordovician rocks, one to the Deadwood Formation, and one to Precambrian rocks. None of these wells found commercial oil production but oil shows were present in four wells. The Pel-Tex Petroleum Company, Conoco-Herrmann No. 1 well, located in NE SW Sec. 17, T. 145 N., R. 88 W., Mercer County, found oil stain in cores of the Madison but recovered only mud on a drill stem test. The Continental Oil Company - G. Schuh No. 1 well, located in SW SE Sec. 25, T. 146 N., R. 90 W., Mercer County, also found oil stain in cores of the Madison, but a drill stem test recovered only black, very salty sulphur water. Oil stain was also reported from cuttings of the Madison in the Fletcher Oil and Gas, Signal Drilling - Beuligen No. 1 well, located in NW NW Sec. 34, T. 141 N., R. 84 W., Oliver County, but a drill stem test recovered only salty sulphur water. Slight stain was also reported from cuttings of the Red River Formation in the Carter Oil Company - E. Semling No. 1 well, located in Sec. 18, T. 141 N., R. 81 W., Oliver County.

The presence of oil shows in so many of these wells is encouraging and suggests that oil exploration will continue in these counties. If favorable conditions of porosity and permeability associated with a suitable trapping mechanism can be found in the Madison it may some day be productive in this area. Deeper horizons, such as Devonian, Silurian, and Ordovician rocks are productive in other areas of the Williston basin and are potentially attractive horizons in this area that have not been adequately tested.

The Newcastle Sandstone of Cretaceous age shows interesting thickness variations in this area. The Pennsylvanian rocks are another prospective horizon. Therefore, although there is no commercial production as yet, the future prospects may be termed cautiously optimistic.

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APPENDIX A

Typical Measured Sections of Tertiary Formation Exposures

Typical Sections of Cannonball Formation

Section C-1 SW SW SW Sec. 34, T. 142 N., R. 81 W.; in pasture; northwest face

	Feet	Inches
Tongue River Formation		
Sand, light gray to pale brown, very fine to medium grained; some ironstone concretions	19	6
Sand, yellowish brown to pale brown and light gray, very fine to fine grained	5	
Total	26	6
Cannonball Formation		
Claystone, pale brown to moderate brown, thinly interbedded with sand, light gray to light brown, fine to very fine grained; weathers light brown	14	8
Claystone, pale brown, thinly interbedded with sand, light brown, very fine to fine grained, weather to medium gray and olive gray	28	
Clay, light brown and purplish gray, thin laminated, weathers to "popcorn surface"	7	
Clay and silt, medium light gray; weathers to "popcorn surface"	13	
Total	62	8

Section C-2 NW NE Sec. 27, T. 141 N., R. 82 W.; Exposure east of Highway 25

	Feet
Tongue River Formation	
Sand, pale brown to yellowish brown, fine to medium grained	10 to 12
Total	10 to 12

Cannonball Formation	Feet	Inches
Clay and silt, yellowish brown	0	8
Sand, light yellowish brown, very fine to fine grained, silty	4	
Clay and silt, pale to moderate brown, blocky	2	6
Sand, light gray to light yellowish brown, very fine to fine grained, silty	1	4
Claystone, moderate brown	0	10
Sand, light gray to light brown, very fine to fine grained	3	3
Claystone, moderate brown, thin bedded with some light brown silt lenses	2	6
Sand, light brown to light gray, very fine to fine grained	0	7
Clay, pale brown, blocky, with thin lenses of sand	2	6
Sand, as above	0	10
Clay, purplish gray	0	6
Sand, light gray to light brown, very fine to fine grained, silty	0	9
Clay, purplish gray	0	11
Sand, as above	2	2
Claystone, moderate brown, thin bedded with interbeds of sand	4	6
Sand, light gray, very fine grained, silty	1	6
Claystone, moderate brown	0	11
Sand, light brown, very fine to fine grained	0	7
Claystone, moderate brown	0	10
Sand, light gray, thin bedded	0	7
Claystone, moderate brown, with a few sand lenses	1	6
Sand, light gray to light brown, very fine to fine grained	0	3
Claystone, moderate brown	0	7
Sand, as above	0	7
Claystone, as above	0	7
Sand, as above	0	3.5
Claystone, as above	1	11
Sand, as above	0	3
Claystone, as above	0	6
Sand, as above	0	10
Claystone, as above	0	5
Total	40	1.5

Typical Sections of Tongue River Formation

Section TR-1 — SE NW Sec. 28, T. 141 N., R. 82 W.; east side of road to abandoned farm; base of section near draw.

	Feet	Inches
Sand, pale brown to yellowish brown, very fine to fine and medium grained, many small and some large ironstone concretions	15	
Clay, light gray to purplish gray; upper 3 to 4 inches carbonaceous	0	10
Sand, as above	7	
Shale, moderate brown, carbonaceous	0	3
Sand, light gray to pale yellowish brown, very fine to medium grained	16	
Total	39	1

Section TR-2 — NE NW Sec. 28, T. 141 N., R. 82 W.; west side of road, base of section-top of knoll; base of section about 10 feet above top of previous section.

Sand, light brown, very fine to fine grained; weakly cemented in part	16
Covered Interval	47
Clay and Silt, pale yellowish brown and light gray, thin bedded	16
Total Exposed Section	32
Total Section	79

Section TR-3 — NW NE Sec. 29 and SW NE Sec. 20, T. 141 N., R. 82 W.; exposures along northeast side of road.

Sand, fine grained - poorly exposed; continues up the hill

	Feet	Inches
Silt and very fine grained sand, light yellow to light yellowish brown; a few poorly preserved shells	4	
Clay, light brownish gray, carbonaceous	1	6
Shale, carbonaceous	0	3
Clay, very light gray	5	6
Covered Interval	11	
Sandstone, light brown, fine grained, thin bedded	5	
Silt and clay, light yellow gray, light yellow and light gray	6	
Sand, light gray to light brownish gray, fine grained	8	
Silt and clay, light brownish gray, carbonaceous	3	
Shale, carbonaceous, with powdery lignite	1	
Silt and sand, light brown, thin bedded	5	
Clay, light yellowish brown	6	
Clay, light gray and medium light gray; poorly exposed	22	
Clay, yellowish brown and light gray	2	6
Silt, very light gray-top 2 inches carbonaceous clay	5	
Lignite	1	9
Shale, carbonaceous	1	3
Sand, very light yellowish gray, very fine grained, silty	1	6
Clay, light yellow and very light gray, upper 2 to 3 inches carbonaceous	5	6
Total	95	9

Section TR-4 SE NW Sec. 6, T. 141 N., R. 82 W.; section along east bank of Square Butte Creek, base at Creek level.

	Feet	Inches
Silt and very fine grained sand, light yellowish brown to very light gray	6	
Limestone, light yellowish brown	1	3
Silt, yellowish brown	4	6
Silt and clay, light gray; many shells	3	
Sand and silt, yellowish brown	9	
Silt and clay, very light gray to light yellow	4	

	Feet	Inches
Clay, very light gray to light yellow gray	2	
Lignite and carbonaceous shale	1	6
Clay, very light gray to light brownish gray	1	8
Lignite and carbonaceous shale-mostly shale	6	
Clay, very light gray	5	
Silt, medium light gray	5	
Clay and shale, light brownish gray, carbonaceous	3	
Silt, light gray, carbonaceous	5	
Clay, light brownish gray to medium gray, slightly carbonaceous	1	8
Silt and very fine grained sand, light gray	2	6
Clay, medium gray	1	
Sand, very light gray to light brownish gray, very fine grained	5	8
Clay, light brown to light yellowish brown, thin bedded; some ironstone nodules	5	
Shale, carbonaceous	0	3
Clay, medium light gray, with ironstone nodules	2	6
Silt, very light gray	1	
Shale, carbonaceous	1	6
Clay medium to medium light gray	3	
Total	81	

Section TR-5 SW Sec. 6, T. 143 N., R. 83 W.;

Sand, light brown, very fine to fine grained	6	
Clay, olive gray and light brown to yellowish brown, thin bedded	5	
Silt, light brown	4	6
Clay and silt, light olive gray and light brown, thin bedded, ironstone nodules	6	
Lignite	1	6
Shale, carbonaceous	0	3
Covered Interval 5 to 10 feet		
Silt, very light yellowish gray	3	
Clay, light yellowish gray to very light gray	3	
Lignite	0	8
Silt and very fine grained sand	10	8

	Feet	Inches
Clay, medium light gray to light yellowish gray	1	
Clay, purplish gray, many shells	6	
Covered Interval	7	8
Sand, very light brownish gray, very fine to fine grained, ironstone nodules	3	
Clay and silt, light gray to medium light gray	3	6
Covered Interval	29	4
Sand, medium light gray, very fine to medium grained	12	
Silt and sand, medium light gray	2	
Clay and silt, light yellowish brown and light gray	3	
Clay, medium light gray, thin bedded	0	6
Lignite	1	2
Silt and clay, light yellowish gray to light gray, thin bedded	12	
Lignite and carbonaceous shale	1	6
Silt, light brown, thin bedded	5	9
Sand, very light brown, very fine to fine grained	1	9
Clay and silt, very light brown and light gray, thin bedded	5	
Clay, medium gray to light gray, carbonaceous	1	
Silt, light brown	0	8
Total	147	5

Section TR-6 SW NW, Sec. 7, T. 146 N., R. 84 W. and SE NE Sec. 12, T. 146 N., R. 85 W.; base at parking area west of river; section above covered interval west of road

	Feet
Top of Bluff-thin veneer of till	
Covered Interval	18
Clay, light brown, yellowish brown and light gray	10
Clay, light gray, thin bedded	3
Lignite	2

	Feet	Inches
Clay and silt, mostly silt, light brown to light yellowish brown	16	
Lignite	1	9
Silt and sand, very fine grained, light gray	11	
Clay, yellowish brown and olive gray	1	
Shale, carbonaceous	1	6
Clay, light to medium gray, "bentonitic"	9	
Silt and sand, very fine grained, light gray to olive gray	14	6
Clay, medium to light gray and olive gray, with ironstone nodules	5	
Shale, dark brown, carbonaceous	2	
Silt and sand, very fine grained, light gray	12	
Clay, light gray	2	6
Silt and clay, medium brown, thin bedded, carbonaceous	5	
Lignite	1	
Clay and silt, light gray	2	6
Silt, light olive gray and light gray	12	
Clay, yellowish brown, blocky	1	
Clay, medium gray, with carbonaceous streaks	1	3
Silt, very light to light gray	1	8
Clay, yellowish brown and light gray	0	10
Silt, medium light gray	5	
Covered Interval about 35'		
Silt, light gray, capped by limestone	3	
Clay, light gray and yellowish brown with ironstone nodules	0	6
Silt and sand, very fine grained, medium light gray; ironstone nodules	16	
Clay, yellowish brown, blocky	1	6
Shale, carbonaceous and lignite	2	6
Silt, light olive gray to light gray	6	
Total	169	3

Typical Sections of the Sentinel Butte Formation

Section SB-1 Sec. 14, T. 147 N., R. 90 W., SE NW

	Feet	Inches
Till, light olive gray	15	
Silt, light brown	3	
Silt and clay, poorly exposed	6	
Clay, yellowish brown, olive gray and medium gray, thin to medium bedded	16	
Shale, brownish gray, carbonaceous with 4 inches of lignite	1	3
Clay, medium gray to medium light gray	2	6
Silt, yellowish brown and medium light gray	8	
Clay, yellowish brown	2	6
Lignite	0	2
Clay, medium gray	1	2
Shale, brownish gray, carbonaceous	0	5
Clay, medium gray	3	
Lignite	2	
Clay, medium light gray, thin bedded	3	
Clay, medium gray to yellowish brown, silty, thin bedded	4	6
Limestone, yellowish brown		10
Clay and silt, medium gray and yellowish brown, medium bedded, mostly silt; some ironstone concretions	4	8
Silt and clay, light brown and medium light gray, thin bedded	10	6
Base of covered section about 45 feet above 1850 reservoir level.		
Total	84	6

Section SB-2 SE NW Sec. 24, T. 141 N., R. 89 W.; pasture west of abandoned farmyard

Sand, yellowish brown to light brown, fine to very fine grained, poorly exposed, upper part cemented	30' to 35'

	Feet	Inches
Silt and clay, yellowish brown and light gray, some ironstone nodules	5	
Clay, brownish gray, carbonaceous, thin bedded	5	6
Covered Interval	9	
Silt and clay, yellowish brown and light gray, mostly silt, poorly exposed	24	6
Lignite and carbonaceous shale	6	
Covered Interval	6	
Clay, olive gray, light brown and medium light gray with large, very light gray siltstone concretions	10	
Lignite	2	6
Clay, light gray	3	
Lignite; common petrified wood	1	6
Total	103 to 108	

Section SB-3 SW Sec. 4, T. 143 N., R. 89 W.; in pasture

	Feet	Inches
Clay, medium light gray to very light gray and yellowish brown	20	
Silt, clay and very fine grained sand, light yellowish brown and light gray, mostly silt	16	
Clay, medium light gray, thin bedded, carbonaceous	1	
Clay, light yellow brown and light gray with many ironstone concretions	12	6
Shale, brownish gray, carbonaceous	1	6
Silt, brownish gray, carbonaceous	1	
Silt, medium light gray, slightly carbonaceous with scattered ironstone concretions	15	6
Clay, light yellowish brown to light olive gray	11	
Clay, yellowish brown-poorly exposed with a few inches of lignite	6	
Clay, light bluish gray, "bentonitic"	5	
Clay, medium light gray and olive gray, thin bedded	10	6
Shale, brownish gray, carbonaceous	0	2

	Feet	Inches
Silt and sand, medium light gray; with some small ironstone concretions, some large concretions and a few thin clay lenses	16	
Total	116	2

Section SB-4 Sec. 5, T. 142 N., R. 89 W.; S½

	Feet	Inches
Sand, and silt, light brown to light gray	3	
Lignite	0	1
Sand, light brown, fine grained	1	
Clay, medium gray and brownish gray, thin bedded	16	
Silt, light gray	5	6
Clay, medium gray and brownish gray, capped by iron rich zone	6	6
Shale, carbonaceous, brownish gray	1	
Clay and silt, medium light gray to light brown	2	6
Shale, brownish gray, carbonaceous	0	2
Clay, light olive gray to light brown	2	6
Clay, medium light gray	2	6
Clay, light brown, thin bedded, iron rich zone	5	6
Lignite	1	6
Clay, yellowish brown and light gray, thin bedded	3	6
Lignite and carbonaceous shale	6	6
Clay, medium light gray	7	
Shale, carbonaceous, brownish gray	1	
Clay, medium gray	6	
Silt and clay, brownish gray and light brownish gray, thin bedded, scattered large concretions	7	
Clay, medium to light gray	1	6
Silt and clay, light gray to light brown, with iron rich zones	4	
Clay, light gray, with ironstone nodules	4	
Shale, purplish gray, carbonaceous	2	
Lignite	1	2
Clay, light to medium gray	3	
Clay, light to medium light gray and olive gray; silts, with ironstone nodules and large light gray siltstone concretions	16	

	Feet	Inches
Lignite	0	9
Clay, light to medium gray	2	3
Silt, very light to light brown, clayey, thin bedded	5	
Total	117	5

Section SB-5 SE SE Sec. 35, T. 144 N., R. 88 W.; road ditch east side of Highway 49

	Feet	Inches
Lignite, weathered-Beulah-Zap bed		
Clay, light brown and light gray	5	6
Shale, carbonaceous and lignite	3	
Clay, light gray and light brownish gray, thin bedded, slightly carbonaceous	5	
Clay, very light gray and light yellowish brown, silty; a few ironstone concretions	7	
Shale, carbonaceous and thin lignite	1	
Clay, light gray	2	
Silt, light gray and light yellow brown	7	6
Silt, light gray and light yellow brown, thin bedded, with a few concretions	7	6
Clay, light gray and light yellow brown, thin bedded, silty, a few small concretions	4	
Shale, brownish gray, carbonaceous	1	
Lignite	3	4
Shale, carbonaceous	2	
Lignite	2	8
Shale, carbonaceous and clay, light gray	1	6
Clay, very light to light gray, thin bedded, slightly carbonaceous	3	6
Clay, yellowish brown	3	
Covered Interval 20' to 25'		
Sand, very light gray, very fine to fine grained, a few concretions	5	4
Clay, light yellowish brown, silty	4	
Sand, very light gray, fine to very fine grained; with concretionary lenses	17	10
Sand, light gray and light yellowish brown, fine to very fine grained	5	8
Sand, light yellowish brown, fine to medium grained, finer upward; contains some iron cemented concretions	19	

	Feet	Inches
Till, light olive gray		
Total	111	4

Typical Exposure - Golden Valley Formation

Section GV-1 — Near NW corner of 28-143-90; Exposed in roadditch south side of road

	Feet	Inches
Golden Valley Formation		
Upper Member		
Sand, light yellowish gray, very fine grained, micaceous, some ironstone concretions	10	8
Lower Member		
Shale, brownish gray, carbonaceous		6
Silt and silty clay, yellowish gray	6	4
Clay, yellowish gray	5	4
Clay, purplish gray, carbonaceous	1	10
Lignite, soft, powdery	1	10
Clay, light gray and light brownish gray	3	6
Clay, purplish gray, yellow gray, and light gray, silty	16	9
Clay, purplish gray, carbonaceous	1	3
Total	36	4

Section GV-2 — SW SE Sec. 10, T. 142 N., R. 88 W.; Exposure at east end of low butte

	Feet	Inches
Golden Valley Formation		
Upper Member		
Silt, light yellow brown and sand, light yellowish brown, very fine grained	10	8
Clay, light yellowish brown and light gray	10	8
Total Upper Member	21	4

	Feet	Inches
Lower Member		
Lignite	1	8
Clay, light purplish gray and light gray, ironstone concretions zone 3 feet above base	12	8
Clay, yellowish gray, silty	5	5
Shale, brownish gray, carbonaceous		6
Clay, light purplish gray	10	8
Base of exposure		
Total Lower Member	31	11

Section GV-3 NE NW Sec. 27, T. 141 N., R. 86 W.; in pasture at west end of low butte

Golden Valley Formation

	Feet	Inches
Upper Member		
Sandstone, light brown, very fine to fine grained, fairly well cemented	1	6
Clay and silt, yellowish gray	9	6
Clay, light gray to light brownish gray	6	
Silt, light yellow brown	8	
Clay light gray to light yellow brown	5	6
Total Upper Member	30	6
Lower Member		
Lignite	1	2
Clay, brownish gray	4	4
Clay, very light gray, silty, "yellow marker"	8	
Lignite	1	
Clay, very light gray to light purplish gray	3	
Shale, brownish gray, carbonaceous	1	10
Clay, brownish gray	6	
Clay, very light gray, yellow stained	12	
Clay, light purplish gray to brownish gray with many plant fragments	2	
Clay, brownish gray, carbonaceous	0	6

	Feet	Inches
Clay, very light gray to light purplish gray, carbonaceous weathered section at base	2	6
Total Lower Member	41	4

Section GV-4 SW Sec. 21, T. 146 N., R. 90 W., in pasture

	Feet	Inches
Silt and clay, yellow brown to light yellow brown; and sand, light brown very fine grained	10 to 15	
Shale, brownish gray and purplish gray, carbonaceous	1	3
Clay, very light to light gray	2	6
Clay, light gray, silty, "yellow marker"	10	6
Clay, purplish gray	1	
Clay, very light gray, silty	2	
Total	27 to 32	3

APPENDIX B

Table of Formation Tops in Oil and Water Test Holes

NDGS Well No.	Elevation	Cannonball Fm.	Ludlow Fm.	Hell Creek Fm.	Fox Hills Fm.	Pierre Fm.
4537	2223	1064	1244	1320	1590	1913
4711	2100	923	1120	1215	1528	1816
4706	2043	895	1125	1220	1476	1785
4808	1968	730	978	1050	1385	1665
4798	1924	530	806	904	1245	1530
4795	1854	472	715	766	1080	1328
4797	2186	875	1055	1145	1380	1686
4809	2028	680	882	955	1155	1450
4796	1948	582	756	820	1116	1367
4824	1699			426(?)	685(?)	970
4823	1958	352	595	660	976	1246
4942	2216	620	920	968	1290	1570
4940	2252		830	893	1195	1467
4941	2138	492	744	810	1130	1375
4939	2138	446	740	800	1115	1400
4938	1951		565	610	815	1080
4937	2093	347	645	755	997	1280
2183	2173		748	842	1116	1403
NDSWC Well No.						
3433	2080	520	790	890	1230	1564
3557	1988	415	640	724	977	1260
3558	2006	310	595	696	945	1202
3559	2062	560	825	905	1205	1510
3560	2041	556	784	870	1150	1448
3575	2120	960	1144	1219	1460	1840