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Stratigraphy and sedimentology of the Tongue River formation (Paleocene), southeast Golden Valley County, North Dakota

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STRATIGRAPHY AND SEDIMENTOLOGY OF THE TONGUE RIVER FORMATION (PALEOCENE), SOUTHEAST GOLDEN VALLEY COUNTY, NORTH DAKOTA

by

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This thesis submitted by Jack W. Crawford in partial fulfillment of the requirements for the Degree of Master of Science in the University of North Dakota is hereby approved by the Committee under whom the work has been done.

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ABSTRACT

The exposed Tertiary rock units in southeast Golden Valley County, North Dakota were measured and described with particular emphasis on the Tongue River Formation. Lithologic samples were collected and analyzed for total carbonate content, particle size, particle roundness, and mineral composition. In the area studied, the Tongue River Formation is 763 feet thick which is considerably thinner than in surrounding areas. The lower member of the Tongue River Formation is 313 feet thick and is composed of yellow-gray, very fine-grained sandstone, siltstone, claystone, shale, and lignite. The overlying Sentinel Butte Member is 450 feet thick and composed of yellow-brown, fine to medium-grained sandstone, siltstone, and lignite.

The lower member was found to be lighter colored, to have a higher total carbonate content, to be finer grained, and to have fewer dark minerals than the overlying Sentinel Butte Member. Particle characteristics of both members indicate little chemical weathering, a short distance of transportation, and little reworking. Heavy minerals are indicative of a metamorphic source area with associated granites.

The fauna and flora of plants, fish, reptiles, amphibians, gastropods, and pelecypods indicate a fairly warm, humid environment with sluggish rivers and swampy conditions prevailing.

INTRODUCTION

Location

The area studied is in the southeast corner of Golden Valley County and in the northern part of Slope County in southwest North Dakota. The exposures were measured in two separate, but stratigraphically overlapping sections (Fig. 1), which combine to form a composite section of the Tongue River Formation. The lower member of the Tongue River Formation was measured in the Red Hills Section which is in secs. 27, 28, 33, 34 of T. 137 N., R. 103 W. The Sentinel Butte Member of the Tongue River was measured in the Bullion Butte Section which is located in sec. 13, T. 137 N., R. 103 W.

Scope of Report

The purpose of this report is to: (1) provide a complete, detailed measured section of the Tongue River Formation for use in correlating with similar rocks of adjacent areas; (2) describe the major sedimentologic features of the Tongue River Formation; and (3) suggest methods of differentiating the lower Tongue River sediments from those of the overlying Sentinel Butte Shale Member.

Physiography

The area of study is an area of highly dissected badlands between the Little Missouri River and the top of Bullion Butte. The badlands occur between flat upland terraces and resistant "scoria"-capped ridges. This rugged topography has formed largely since

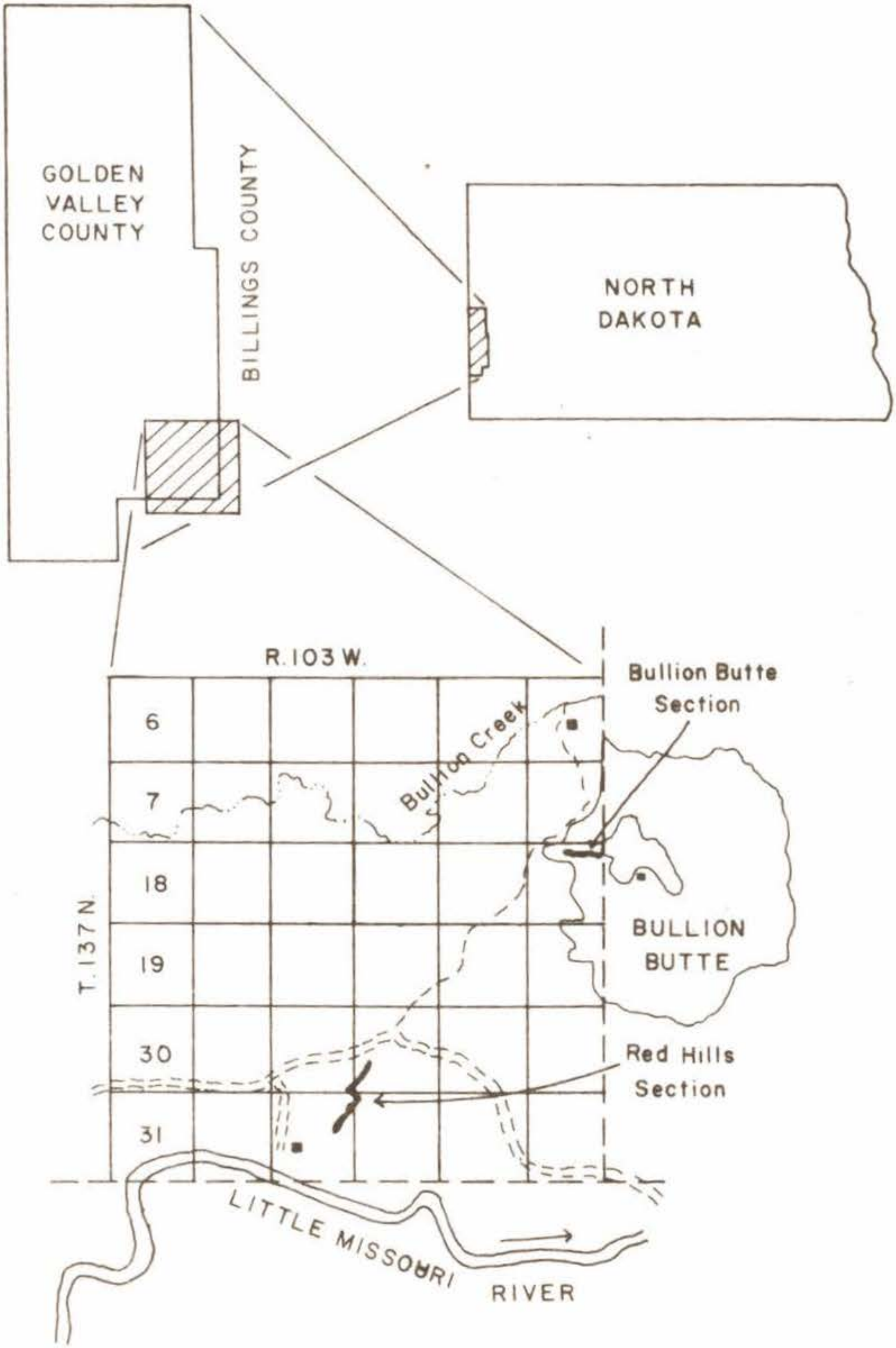

Fig. 1 - Index map to area studied, showing lines of measured sections.

Pleistocene time (Laird 1950, p. 9), and is still being actively eroded. The maximum relief in this area is approximately 1,000 feet with excellent exposures being furnished by the dissected topography.

Previous Work

The first geologic report on this area was by Meek and Hayden in 1862, in which they described and named the Fort Union Group from exposures near Fort Union (now Buford), North Dakota. In 1908 Leonard mapped the lignites of southwestern North Dakota and named the Sentinel Butte "coal group." Tisdale (1941) reported on the geology of the Heart Butte Quadrangle in northern Grant County which is 80 miles east of the area studied. Fisher (1953) described the geology of west central McKenzie County which is about 60 miles north of the area studied. Hanson (1955) reported on the geology of the Elkhorn Ranch area in northeastern Golden Valley County, which is 40 miles north of the area studied. Brown (1948, 1962) studied the Sentinel Butte Member and the Paleocene flora in southwestern North Dakota.

Field and Laboratory Work

Field studies were conducted during the summer of 1965 and for two weeks in the summer of 1966. A composite section was measured using a Keuffel and Esser hand level with a five-foot jacob's staff. All beds over six inches thick were measured and described, fossils were collected, and lithologic samples were collected at five-foot intervals for subsequent laboratory analysis.

The laboratory work consisted of size analysis, roundness determination, heavy mineral analysis, carbonate analysis, and determination of constituent minerals.

REGIONAL STRATIGRAPHY

Introduction

The rocks exposed in this area comprise the Paleocene Fort Union Group and the overlying Oligocene White River Formation. Of the Fort Union Group the upper part of the Ludlow Formation is exposed just above the Little Missouri River. The overlying Tongue River Formation (Fig. 2) is well exposed, except for the upper contact of the Sentinel Butte Shale Member with the White River Formation. Overlying the Sentinel Butte Member is found the sandstone of the White River Formation which forms the rim of Bullion Butte.

Paleocene Series

Fort Union Group

The name "Fort Union" was first used by Meek and Hayden (1862, p. 433) as applied to the lignite-bearing rocks near Fort Union (now Buford), North Dakota. The name has been redefined several times and is now used by the North Dakota Geological Survey as a "Group" containing the Ludlow, Cannonball and Tongue River formations (Fig. 2).

Ludlow Formation and Cannonball Formation

Name and definition.--The name "Ludlow" was first used by Lloyd and Hares (1915, p. 523, p. 528) for the sandstones and shales which crop out at Ludlow, South Dakota. The Cannonball was named by Lloyd (1914, p. 247) for exposures along the Cannonball River in Grant County, North Dakota.

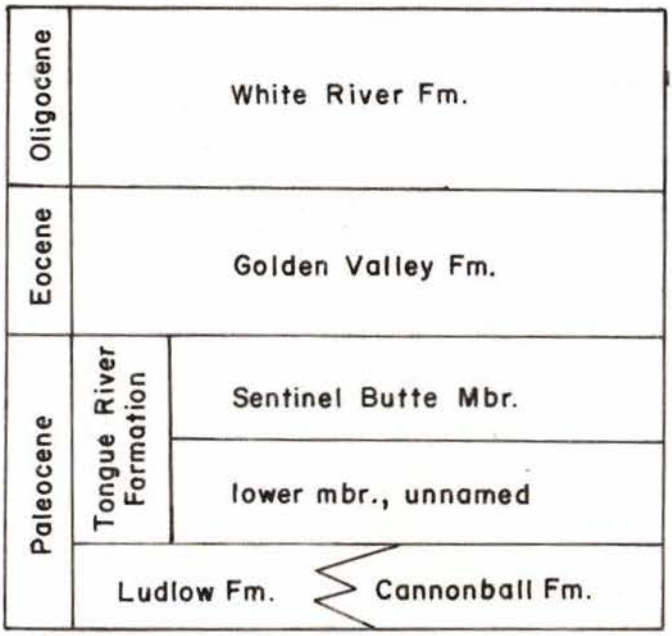

Fig. 2 - Tertiary rock units of western North Dakota.

Occurrence.--The Cannonball and Ludlow formations are essentially contemporaneous (Cvancara, 1965, p. 25-26). The Cannonball Formation is the eastward marine equivalent of the nonmarine Ludlow Formation.

The Cannonball Formation has been mapped in scattered exposures from the Turtle Mountains in the north central part of North Dakota, south to northern South Dakota, and westward to the outcrops near Yule, North Dakota. In the Yule area, thin marine tongues of the Cannonball Formation were observed by the writer interfingering with the Ludlow Formation.

The Ludlow Formation has been mapped in eastern Montana, southwest North Dakota, and northern South Dakota. The northern extent of the outcrop is in the area studied; however, only about 30 feet of the formation is exposed.

<u>Lithology</u>.--In southwest North Dakota the Ludlow Formation consists of poorly consolidated, gray and drab sandstones, shales and lignites (Hares, 1928, p. 25), which resemble the rocks of the Upper Cretaceous Hell Creek Formation. This dark gray appearance makes a striking color difference between the Ludlow and the overlying, yellowish gray Tongue River Formation, and greatly facilitates the placing of that contact.

The Cannonball Formation consists of two general types of lithologies, of poorly consolidated, light grayish green sandstone and medium gray to very dark gray mudstone (Cvancara, 1965, p. 25).

<u>Thickness</u>.--The Cannonball attains a thickness of about 300 feet (Cvancara, 1965, p. 34) to the east in southern Morton County. Three miles south of the area studied it is represented by very thin tongues of brackish water sediments.

The Ludlow Formation is about 350 feet thick in its type locality (Lloyd and Hares, 1915, p. 528), and thins northward to about 250 feet just south of Bullion Butte in the Yule area (Hares, 1928, p. 47). Only about 30 feet of the upper part of the Ludlow Formation is exposed in the southern part of the area studied.

Tongue River Formation

<u>Name and definition</u>.--The name "Tongue River" was first used by Taff in 1909 (p. 129-130) for the coal-bearing rocks of the Sheridan coal field of Wyoming. Taff placed the top of the "coal group" at the base of the Roland coal.

Thom and Dobbin (1924, p. 495) described the "member" as "yellow or light-colored strata containing massive sandstones and numerous thick coal beds." They placed the top of the "member" at the base of bed K of the Sidney field, the Roland coal of the Sheridan field, and bed F of the Sentinel Butte field.

Dorf (1940) reclassified the "member" as a formation of the Fort Union Group. This formational status was reversed by Seager, et al. (1942), when they applied the name "Tongue River member" to these rocks. This usage was continued until Fisher (1953) again used the formational designation. This status has been retained to the present by the North Dakota Geological Survey, but the United States Geological Survey considers the Tongue River as a member of the Fort Union Formation.

That part of the Tongue River Formation below the Sentinel Butte Member is as yet unnamed and in this paper will be referred to as the "lower member."

Occurrence.--The Tongue River Formation crops out in northeastern Wyoming, eastern Montana and western North Dakota. In North Dakota, excellent exposures of the lower member may be found near Buford, in the south unit of Theodore Roosevelt National Memorial Park, and south of the park in the badlands of the Little Missouri River south to the area of Bullion Butte.

Lithology.--The lithology within the Tongue River Formation is so variable that no single lithology is diagnostic. Nearly all possible gradations are found between sandstone, shale, claystone, limestone, and lignite. Most of the beds are not persistent and there is much thickening and thinning of the sandstone units. Several of the larger lignite beds are remarkably persistent with one bed, the Harmon, underlying at least 5,500 square miles (Hares, 1928, p. 50).

The lower member of the formation is generally a light yellow-gray, which is in marked contrast with the underlying dark gray Ludlow Formation and the overlying dark yellowish brown Sentinel Butte Member. This color difference has been used to separate the lower member from the Sentinel Butte Member by such authors as Leonard (1908), Hares (1928), Brown (1948, 1962), Fisher (1953), Hanson (1955), and the present writer.

Structure.--The area studied is on the northeast limb of the Cedar Creek anticline, a low, narrow uplift, the axis of which trends north 30° west (Hares, 1928, p. 44). The beds near Bullion Butte dip approximately 30 feet per mile to the northeast. This was found by measuring elevations at the base of the HT Butte lignite and the Meyer lignite over a distance of three miles and calculating the dip.

Thickness.--In the area studied, the lower member attains a thickness of 313 feet, which is considerably less than has been reported in surrounding areas. Stebinger (1912, p. 287) reported a thickness of 980 feet between Glendive and Sidney, Montana. Kepferle and Culbertson (1955, p. 134) measured a thickness of 400 to 600 feet in Slope and Bowman Counties, North Dakota. Hares (1928, p. 47) reported a thickness of 600 feet in the Marmarth lignite field. The Marmarth field includes the area studied and the writer cannot agree with the thickness reported by Hares.

The lower member apparently thins southward from its exposures in the area between Medora and Glendive. This thinning was observed by Brown (1948, p. 1270), for he stated that:

> Southward from Sentinel Butte toward Marmarth this lignitic unit [lower member of Tongue River Formation and Ludlow Formation] also thins to about 900 feet. Apparently most of the thickening and thinning is at the expense of the so-called light-colored Tongue River member.

Sentinel Butte Member

Name and definition.--Leonard (1908, p. 105) applied the name "Sentinel Butte" to a group of lignite beds south of the town of Sentinel Butte, North Dakota. He placed the contact of the lower member and the overlying Sentinel Butte Member between the light and dark colored beds. Leonard described the Sentinel Butte Member as resembling the Lance beds (Hell Creek Formation).

Thom and Dobbin (1924) correlated the Sentinel Butte Member with the "Intermediate Coal Group" (Stebinger, 1912) and the Kingsbury Conglomerate (of northern Wyoming), thus assigning it an Eocene Age.

Brown (1948), Benson (1952) and the United States Geological Survey have placed the Paleocene-Eocene boundary at the top of the Sentinel Butte Member (of the Fort Union Formation).

The base of the Sentinel Butte Member has been placed at the base of the R lignite (Leonard, 1925), the HT Butte lignite (Hares, 1928), and the L lignite (Fisher, 1953). The above designations are all equivalent and refer to the basal bed of the somber-colored member.

Occurrence.--The Sentinel Butte Member is conformable with the underlying lower member and crops out in essentially the same area of eastern Montana and western North Dakota. Excellent exposures can be seen in the North Unit of Theodore Roosevelt National Memorial Park (Clark, 1966), and in the higher buttes of the southwestern part of the state, such as Sentinel Butte, Bullion Butte, and Square Butte.

Lithology.--The sedimentary rocks of the Sentinel Butte Member are a repetitive sequence of dark gray and brown sandstone, siltstone, and lignite beds with many brown, limonitic, sandstone concretions. The beds are more massive, darker colored, and coarser grained than those of the underlying lower member. The sedimentary rocks of the Sentinel Butte Member closely resemble those of the Upper Cretaceous Hell Creek Formation. This fact has been recognized by many previous authors, such as Leonard (1908), Thom and Dobbin (1924), Hares (1928), and others.

Structure.--The structure of the Sentinel Butte Member is essentially the same as that of the previously discussed lower member, with the beds dipping gently to the northeast and being conformable with the underlying strata.

Thickness.--On the sides of Bullion Butte the Sentinel Butte Member is about 450 feet thick. The member is somewhat thicker to the north and west with 570 feet being found in McKenzie County (Clark, 1966, p. 24) and 500+ feet on the Crow Reservation of eastern Montana (Thom and Dobbin, 1924, p. 488).

Eocene Series

Golden Valley Formation

Name and definition.--The Golden Valley Formation was named by Benson and Laird (1947, p. 1166) for exposures near the town of Golden Valley, North Dakota. The formation is essentially conformable with the underlying Sentinel Butte Member, and disconformable with the overlying White River Formation (Benson, 1949).

Occurrence.--In the vicinity of Bullion Butte and Sentinel Butte, the Golden Valley Formation has been removed by pre-Oligocene erosion. The effect of this erosion apparently decreases northward away from the Black Hills (Benson, 1949, p. 1873) so that the nearest exposures are to the northeast of the area studied. The formation crops out in Mercer, Dunn, McKenzie, Stark and Mountrail counties, North Dakota.

Lithology.--The Golden Valley Formation elsewhere is a brightly colored sequence of kaolinitic and micaceous sands and clays. Generally the section is a lower gray clay overlain by an orange clay, a middle lavender clay, and an upper tan sand (Lee Clayton, University of North Dakota, oral communication, 1966). The beds may contain the fossil fern *Salvinia preauriculata*.

Thickness.--The formation ranges in thickness up to 200 feet (Bergstrom, 1956). It is 100 to 160 feet thick in the North Unit of Theodore Roosevelt National Memorial Park (Clark, 1966, p. 37), and about 175 feet thick at the type locality (North Dakota Geological Society, 1954).

Oligocene Series

White River Formation

Name and definition.--The White River Formation was named by Meek and Hayden in 1858 (p. 119, 133) for exposures near the mouth of the White River in South Dakota. They dated the deposits as Miocene but there have been subsequent fossil finds that demonstrate an Oligocene Age.

In a later paper, Meek (1876, p. LXIII) stated that the formation is an extensive fresh-water lacustrine deposit which reaches a thickness of 1,000 feet. It unconformably overlies the Fort Union Group and unconformably underlies Pliocene lake deposits in Nebraska.

In many areas such as South Dakota and Nebraska the unit is considered a group, but where it is not subdivided (as in North Dakota) it is called a formation.

Occurrence.--The White River Formation crops out on the higher buttes of the southwestern part of North Dakota and forms a small badlands area south of Dickinson. The formation is found over much of southern South Dakota, eastern Montana, Wyoming, Nebraska, and northeastern Colorado.

Lithology.--On Bullion Butte the formation is a massive, cliff-forming sandstone (Fig. 3). The basal part contains a conglomerate of pebble-sized, gray-green clay particles in a matrix of subangular, coarse-grained quartz particles with a calcareous cement. The clay particles weather very rapidly leaving a very rough irregular surface (Fig. 3). Above this conglomerate the formation becomes a very light gray, coarse-grained quartzite that weathers brown. From the top to six feet below the rim of Bullion Butte, is a very unusual purple siltstone which reaches three feet in thickness.

Thickness.--On the sides of Bullion Butte 79 feet of the White River Formation are exposed. Another 35 feet of the sandstone are inferred above the claystones of the upper Sentinel Butte Member.

Fig. 3 - Irregular weathering surface of the sandstone of the White River Formation on the west side of Bullion Butte. NW ¼ sec. 18, T. 137 N., R. 102 W.

SEDIMENTOLOGY

Texture

Particle Size

Field observations indicated that there was a definite size difference between the Sentinel Butte Member and the lower member. To substantiate this observation, sand, silt, and clay analyses were carried out on the samples collected in the field.

Procedure.--One hundred and thirty-six samples (63 from the lower member and 73 from the Sentinel Butte Member) were analyzed for particle size, using a method suggested by Dr. Frank Karner (written communication, 1966) of the University of North Dakota. The method entails primary crushing to aggregates ¼ inch or less in size, splitting out a 20 gram sample, dispersing in a "Calgon" solution by stirring for five minutes, allowing 24 hours to disperse and restirring. A 25 ml. pipette aliquot was taken at a depth of 4 cm. 76 minutes after the second stirring (Wadells' Law) to obtain the clay fraction. The sample was then wet sieved to obtain the sand-silt fractions.

Results.--The laboratory results substantiate field observations in showing that the Sentinel Butte Member is much coarser-grained than the lower member. Tables I and II give the percentages of sand, silt and clay obtained and show that the lower member contains only 9.7 per cent sand, whereas the Sentinel Butte Member contains 36.5 percent sand.

Table I. Size Analyses of lower member

southeast Golden Valley County

Unit	Percentage		
	Sand	Silt	Clay
2	79.4	15.6	5.0
	83.7	12.3	4.0
	27.1	68.9	4.0
	2.7	89.3	8.0
4	9.0	87.0	4.0
5	1.0	79.0	20.0
6	0.2	77.8	22.0
7	14.2	82.8	3.0
8	0	63.0	37.0
11	8.6	90.4	1.0
	11.1	75.9	13.0
12	0	13.0	87.0
14	0	31.0	69.0
15	0	59.0	41.0
16	42.4	52.6	5.0
	0	60.0	40.0
17	0	36.0	64.0
18	1.3	89.7	9.0
20	4.4	77.6	18.0
22	68.5	24.5	7.6
23	2.2	64.8	33.0
24	30.8	54.2	15.0
25	14.6	51.4	34.0
27	0	51.0	49.0
28	21.9	73.1	5.0
31	0	13.0	87.0
33	0.1	27.9	72.0
34	49.7	38.3	12.0
35	0	49.0	51.0
37	3.4	58.6	38.0
38	1.8	46.2	52.0
40	0	42.0	58.0
41	11.2	72.8	16.0
42	0	49.0	51.0
	0	15.0	85.0
43	4.1	74.9	21.0
44	25.9	66.1	8.0
45	0	20.0	80.0
47	0	47.0	53.0
48	0	16.0	84.0
51	18.7	70.3	11.0
52	0	15.0	85.0
	0	64.0	36.0
	0	44.0	56.0
	0.1	47.9	52.0
53	4.8	77.2	18.0
56	25.4	59.6	15.0
	1.0	80.0	19.0
57	0	22.0	78.0
58	2.5	85.5	12.0

Table I. (Continued)

Unit	Percentage Sand	Silt	Clay
61	0	38.0	62.0
	0	35.0	65.0
62	17.2	68.8	14.0
	0.5	57.5	42.0
63	0	35.0	65.0
66	11.3	77.7	11.0
67	0	50.0	50.0
69	0	37.0	63.0
	0	45.0	55.0
	5.4	71.6	23.0

Unit	Percentage Sand	Silt	Clay
70	5.9	79.1	15.0
	0	53.0	47.0
71	0	40.0	60.0
Lower Member Average (mean)			
	9.7	53.5	36.8

Table II. Size Analyses of Sentinel Butte Member

southeast Golden Valley County

	Percentage		
Unit	Sand	Silt	Clay
73	45.7	37.3	17.0
	41.9	38.1	20.0
	44.4	36.6	19.0
	54.3	31.7	14.0
	29.1	44.9	26.0
74	0	21.0	79.0
75	0	36.0	64.0
76	0.1	68.9	31.0
	2.3	71.7	26.0
78	0	32.5	67.5
79	0	99.5	0.5
80	29.9	49.1	21.0
	61.4	11.6	17.0
	46.0	37.0	17.0
81	17.9	54.1	28.0
82	0.7	62.3	37.0
83	2.2	58.8	39.0
84	0	39.0	61.0
	0	40.0	60.0
85	0	9.0	91.0
87	38.1	2.9	14.0
	81.4	1.6	17.0
	78.1	5.9	16.0
	73.8	8.2	18.0
	76.5	7.4	16.0
	70.6	9.4	20.0

	Percentage		
Unit	Sand	Silt	Clay
	82.1	1.9	16.0
	79.1	7.9	13.0
	76.4	8.6	15.0
	76.9	10.1	13.0
	77.6	6.4	16.0
	72.4	9.6	18.0
88	4.1	69.9	26.0
90	0	68.0	32.0
91	81.0	4.0	15.0
	29.8	51.2	19.0
	50.5	31.5	18.0
93	87.5	1.5	11.0
	87.1	5.9	7.0
	26.8	56.2	17.0
94	90.0	0	10.0
95	26.3	41.7	32.0
96	78.0	12.0	10.0
	88.6	3.4	8.0
	89.5	6.5	4.0
	88.9	6.1	5.0
	88.5	5.5	6.0
	15.8	71.2	13.0
	23.7	61.3	15.0
97	4.1	76.9	19.0
99	0	13.0	87.0
100	48.2	29.8	22.0

Table II. (Continued)

Unit	Percentage Sand	Silt	Clay
102	0.2	15.8	84.0
104	0	83.0	17.0
105	39.3	55.7	5.0
	82.3	11.7	6.0
	78.9	20.1	1.0
	77.8	15.2	7.0
	10.8	81.2	8.0
106	0.8	84.2	15.0
107	0	15.0	85.0
	0.9	76.1	23.0
108	7.8	79.2	13.0
	25.6	61.4	13.0
109	0.8	64.2	35.0
110	9.4	68.6	22.0
112	0	80.0	20.0
113	0	41.0	59.0
114	0	70.0	30.0
	3.3	67.7	29.0
	6.1	19.9	74.0
	4.9	69.1	26.0
	6.3	53.7	40.0
Sentinel Butte Average (mean)	36.5	37.4	26.1

The percentages were then plotted on triangular diagrams (Fig. 4), using sand, silt, and clay as the three end members. The sand of the lower member is nearly all very fine sand size, but most of the sand of the Sentinel Butte Member is fine to medium size.

This difference in particle size can be useful in field identification of isolated outcrops and has been observed in other areas by several authors (e.g., Bergstrom, 1956, stated, "...the Sentinel Butte shale member in this area [the Medora area] contains more sand than the lower portion of the Tongue River.").

Roundness

Particle roundness was determined on randomly picked sand samples to determine if any difference existed between the two members. This difference, if it existed, could indicate relative amounts of reworking or transportation.

Procedure.--Ten randomly picked sand samples of the lower member and ten from the Sentinel Butte Member were sieved to very fine sand size and examined with a Leitz petrographic microscope. Roundness was determined using the roundness chart of Pettijohn (1957, p. 59) and measuring 50 grains in each of the samples.

Results.--Very little difference in particle roundness was found between the sand grains of the two members. The sand grains of several sandstones of the Sentinel Butte Member are sub-rounded (edges and corners rounded off but original shape still distinct), but overall the particles from both members are sub-angular (particle faces still fresh, but some wear evident on the corners and edges).

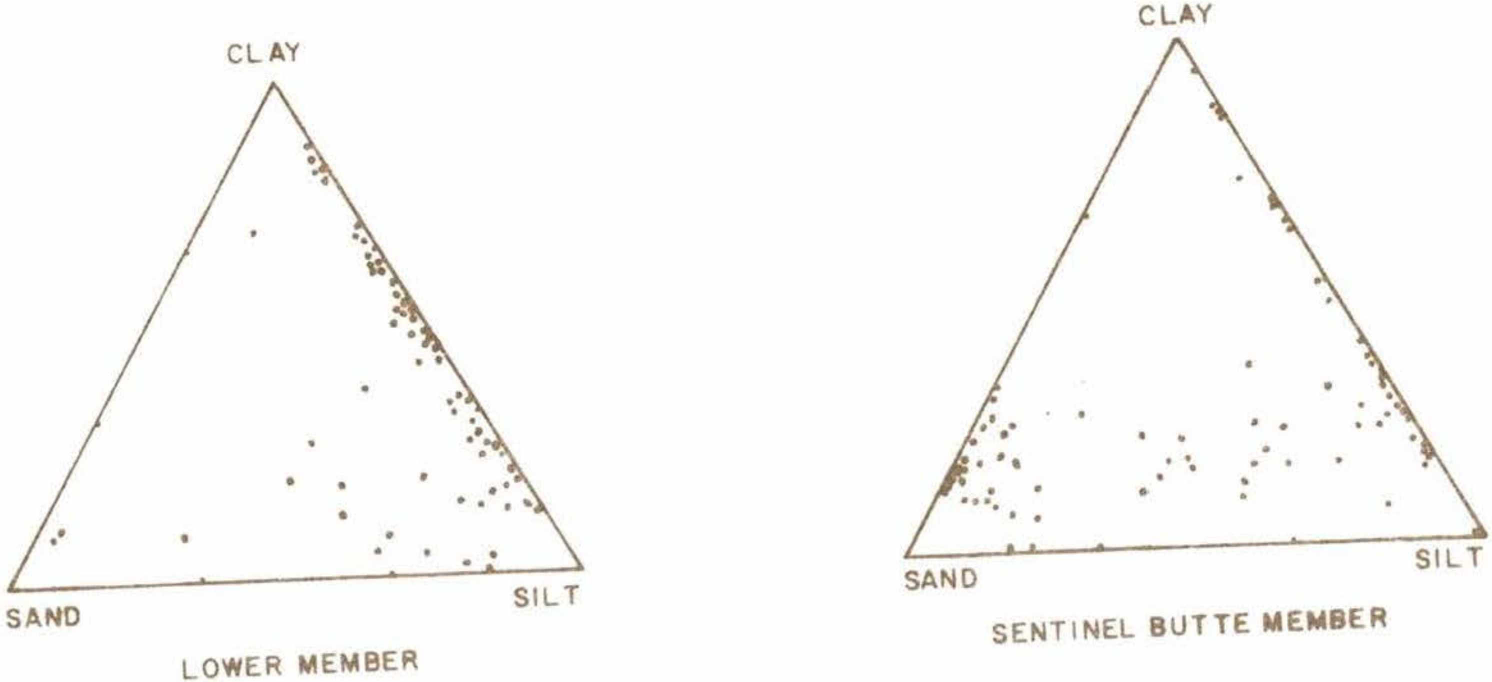

Fig. 4 - Triangular diagrams comparing particle size of the lower member with that of the Sentinel Butte Member, of the Tongue River Formation.

Total Carbonates

Field description of the sediments indicated more effervescence with HCl by carbonates in the lower member than in the Sentinel Butte Member. To check this observation, samples at ten-foot intervals throughout the measured section were analyzed for total carbonate content.

Procedure

The samples were ground to a size which would pass through a Tyler 115 mesh sieve, dried, weighed in one gram fractions and reacted with 0.4 normal H_2SO_4. The sample was then back-titrated with 0.45 normal NaOH using a phenolphthalein indicator (a procedure adapted from Herrin, Hicks, and Robertson, 1958).

Results

Results show that the lower member contains a greater percentage of total carbonates than the Sentinel Butte Member. The 33 samples from the lower member averaged 14.1 per cent total carbonate and the 38 samples from the Sentinel Butte Member averaged only 5.5 per cent carbonate. The percentages of total carbonates were then plotted against several size parameters to see if there was a correlation between particle size and total carbonate content (Plate III). Preliminary indications are that the amount of total carbonate varies directly with the amount of the silt-sized fraction. The coarser sandstone units and the claystone units have a lower total carbonate content.

Mineral Composition

Light Minerals

The sand-sized fraction of the lower member and the Sentinel Butte Member was examined with a binocular microscope to determine mineralogical composition. The samples were crushed and sieved to remove the silt and clay admixtures. Grains from each sand sample were then sprinkled on slides and examined with the microscope.

The most abundant minerals in the sandstones are quartz, feldspar, and dolomite. Two types of quartz were observed: (1) distinct grains of crystalline quartz; and (2) cryptocrystalline chert. The former is most abundant and the most common mineral in the sandstone. It is both colorless and, less commonly, rose colored. Many of the grains have "wavy" extinction when examined through a polarizer, due to a strained condition of the particles.

Feldspar is very common in most of the sandstone units. At least two varieties were observed. One variety is a plagioclase which shows twinning laminae and may be andesine. The other identified variety is orthoclase. The feldspar grains have been exposed to very little chemical weathering as is shown by their unaltered condition.

Mica is a very common constituent of Tongue River sandstones. Muscovite and phlogopite are diagnostic of the sandstones of the lower member and biotite is most abundant in the Sentinel Butte Member.

It should be noted that all of the particles are relatively fresh. The feldspar is essentially unaltered, the quartz grains are not frosted, and some of the biotite flakes still show pseudo-hexagonal outlines. These facts indicate a not-too-distant source and little exposure to chemical weathering.

Heavy Minerals

Ten randomly picked sands from the lower member and ten from the Sentinel Butte Member were examined for heavy minerals. This study was undertaken to determine if there is a difference between the heavy mineral suites which could be used to differentiate the members.

Procedure.--The sands were crushed and sieved; heavy minerals from the very fine sand fraction were separated with bromoform (specific gravity 2.8). The grains were sprinkled on a slide coated with Canada Balsam and covered with a cover glass. Each slide was then studied with a Leitz petrographic microscope, and individual species determined.

Results.--The minerals identified are listed below in approximate order of abundance:

carbonate - mostly dolomite	hornblende
muscovite	pyroxene - probably pigeonite
biotite	zircon
magnetite	apatite
garnet	staurolite
chlorite	tourmaline
epidote	kyanite

Several inconclusive generalizations can be made about the suites. The lower member was found to contain more carbonate, chlorite, hornblende and muscovite. The Sentinel Butte Member was more abundant in magnetite, zircon, biotite, and apatite. Coupled with the information on the light minerals, the heavy minerals indicate a metamorphic source area probably with associated granites. The strained quartz, the garnet, chlorite, staurolite, and kyanite are all indicative of metamorphic rocks. The character of the grains (roundness, composition, lack of chemical weathering) indicates a relatively close source area, which could have been a combination of the Black Hills and slightly reworked sediments. More detailed work would be useful in better differentiating the members and in more accurately determining source areas.

STRATIGRAPHY

Tongue River Formation

Lithology

Common sedimentary rock types found in the lower member are sandstone, siltstone, shale, claystone and lignite with nearly every possible gradational type. The lithology changes rapidly vertically in the section and it can also change rapidly horizontally. A sandstone may change laterally to a siltstone and that, in turn, into a claystone bed. The thicker lignite beds seemed persistent and could easily be traced within the area studied, but two thin (2-3 inch) lignitic shales were observed in the Bullion Butte section, between the Meyer lignite and the HT Butte lignite, which were not present in the Red Hills section.

The sandstone is usually light yellow gray, fine-grained, subangular, massive-bedded, case-hardened, concretionary, micaceous and calcareous. Cross-bedding is rare but was observed on a small scale (one-inch sets) in many of the sandstone concretions. Sandstone beds are confined to the lower one-fourth of the section and the basal sandstone is the only sandstone unit over five feet thick in the lower member (Fig. 5).

The sandstones tend to be lenticular, thickening and thinning within small areas. Much of the sandstone tends to be finely laminated

Fig. 5 - Basal sandstone of Tongue River Formation overlying Ludlow Formation, in the bluffs of the Little Missouri River, NE ¼ sec. 32, T. 137 N., R. 103 W.

(Fig. 6) but a peculiar "swirly" bedding was also observed in several beds (Fig. 7). All of the sandstone is case-hardened and more friable on the fresh surface. This has been attributed to evaporation of interstitial water leaving behind the dissolved salts (Bergstrom, 1956).

Lignite beds are found throughout the section but are more common in the basal one-third. They vary in composition from thin carbonaceous shales to hard, black, compact lignites. The beds commonly contain pyrite nodules, abundant selenite, yellow limonitic clay and interbedded shales. All of the lignites have a dark, bluish-gray underclay which contains vertical root molds indicating that the clay was the soil in which the lignite-making plants grew.

Shales are a common constituent of the lower member. They commonly contain abundant plant remains, limonitic concretions, and a high sulfate content. Much of the shale is medium gray or brown on the fresh surface but weathers nearly white due to a residual coating of some sodium sulfate compound. Most of the shales are finely laminated with thin interbedded silt layers.

Claystone beds are also found in the lower member. These are generally medium dark gray in color and weather medium light gray with a "popcorn" weathering surface due to abundant "swelling" clay or montmorillonite. The beds lack any distinct type of parting and have a blocky fracture. These beds seem very persistent and may be bentonites.

"Scoria" is found throughout the area studied, and occurs at the top of the Red Hills Section (Plate I). Four of the lignites (Harmon, Meyer, HT Butte, and the lignite below the Bullion Butte lignite)

Fig. 6 - Laminae in siltstone (unit 70 of lower member) in the NW ¼ sec. 34, T. 137 N., R. 103 W.

Fig. 7 - "Swirly" bedding in siltstone (unit 4 of lower member) in the NE ¼ sec. 33, T. 137 N., R. 103 W.

measured had locally burned and formed "scoria" and one, the HT Butte lignite, has formed a very extensive "scoria" between Medora and the area studied.

Limestone, which is a rather unusual rock type for continental sediments, is found in lenses or pods throughout the lower member (Fig. 8), but was not observed in the Sentinel Butte Member. The lenses range in size from less than a foot in diameter to twenty feet long by six feet high; they are almost always wider than high.

The limestone is dense, gray or brown when fresh, and weathers grayish orange. It has a conchoidal fracture and is generally structureless; however, horizontal slickensides were observed in the SE ¼ sec. 28, T. 137 N., R. 103 W. The same limestone also contained vertical root molds. Some of these limestones contain leaf fossils (locality 2) but they are generally devoid of fossils.

Thickness

The thickness of the lower member in the area studied is 313 feet. Of this about 217 feet, or 70 per cent, is clay and shale; 65 feet, or 20 per cent, is fine-grained silty sandstone; and the remainder of 31 feet, or 10 per cent, is lignite.

Sedimentary Structures

Concretions and nodules are the most common sedimentary structures found in the lower member. There are three common types of concretions; one type is a sandstone or siltstone with a calcareous cement which may be "log-like" (Fig. 9) or lens-shaped (Fig. 10) and is generally large (10 to 20 feet long). Another is a small (6 to 10 inches in

Fig. 8 - Lenticular limestones (unit 41 of lower member) in the SE ¼ sec. 28, T. 137 N., R. 103 W.

Fig. 9 - Log-like, calcareous sandstone concretion (unit 28 of lower member), SE ¼ sec. 27, T. 137 N., R. 103 W.

Fig. 10 - Platy bedding in a lens-like concretion in the basal sandstone of the Tongue River Formation (unit 2 of the lower member), NE ¼ sec. 33, T. 137 N., R. 103 W.

diameter), sub-spherical, limonitic, yellow or orange siltstone concretion which is very friable, with a lighter colored core. The third type is a brown limonitic clay concretion which is very resistant, generally small (1 to 6 inches in diameter) and has a light colored clay center.

The sandstone concretions have a calcareous cement and several also had a limonitic cement. Small sets (one-inch thick) of cross beds were observed in many of the concretions possibly indicating that the concretions have formed in places of high porosity in the sandstone. Water would accumulate in these places and as it evaporated, the dissolved salts would be left behind, thus cementing the sandstone.

The sub-spherical silty limonitic concretions formed around something which had caused precipitation of a few molecules of iron oxide. Once a few "seed" molecules were present, more were deposited from interstitial water until much of the iron from the surrounding host rock had migrated to this place of accumulation.

The brown limonitic clay concretions are formed upon weathering from a resistant clay. These concretions are confined to a given horizon (i.e. unit 39, Plate I), whereas the other two types are found randomly throughout the section.

Pyrite nodules are common in nearly all of the lignite beds. These nodules usually occur in the upper one-third of the bed, have a very irregular knobby surface, and may be elongate, tubular or sub-spherical.

An unusual structure observed in several beds was "convoluted bedding" (Fig. 11). This probably represents penecontemporaneous deformation of unconsolidated sediments.

Fig. 11 - Convoluted bedding in silt-
stone (unit 70 of lower member) in the
NW ¼ sec. 34, T. 137 N., R. 103 W.

Paleontology

Plants, gastropods, and pelecypods are the most abundant fossils in the lower member. Other types of fossils found include fish remains, turtle and crocodile scutes, amphibian teeth and mammal teeth. These fossils were found in varied lithologies and little generalization can be made relating fossils and lithology. The shales directly below or above lignite beds seemed to have more fossils than most beds, but this is an observation based on few occurrences.

The quality of the fossils seemed to increase with decreasing particle size with the best fossils being found in the shales. Most of the fossils in the shales were compressed, but external features were preserved. In the sandstones most of the external markings were highly worn, possibly indicating reworking, or a short distance of transportation after death.

The fossils were found at seven localities in the lower member and these are listed below with the corresponding stratigraphic unit number given on Plate I (in folder).

Locality

1. One-half mile northeast of Karnes Johnson ranch, 14 miles southeast of Golva, North Dakota, in the S ½ sec. 3, T. 136 N., R. 104 W.; lower part of unit 2.

   Fish remains

   Fish teeth - unidentified

   Ganoid fish scales

   Platacodon nanus Marsh

Amphibian teeth

Habrosaurus dilatus Gilmore

Miscellaneous reptiles

Crocodile teeth and scutes

Crocodile vertebrae, probably *Champsosaurus*

Turtle scutes and bones

Unidentified bones

Invertebrates

Campeloma nebrascensis (Meek and Hayden)

Unio stantoni White

Plants

Seed of *Cercidiphyllum arcticum* (Heer)

2. Fifty yards west of road in the SE ¼ sec. 32, T. 137 N., R. 103 W.: unit 4.

Leaf fossils

Ulmus rhamnifolia Ward

Cercidiphyllum arcticum (Heer)

Corylus insignis Heer

Platanus raynoldsi Newberry

Taxodium olriki (Heer)

3. Two hundred yards northeast of Fred Wojahn ranch in the NE ¼ sec. 33, T. 137 N., R. 103 W.: unit 22.

Pelecypods

Unio stantoni White

Rhabdotophorus senectus (White)

Plesielliptio priscus (Meek and Hayden)

4. Two hundred yards south of road in the SE ¼ sec. 28, T. 137 N., R. 103 W.: unit 25.

Pelecypods

Unio stantoni White

Unio wasatchensis ? Cockerell

Plesielliptio priscus (Meek and Hayden)

Gastropods

Campeloma nebrascensis (Meek and Hayden)

Lioplacodes tenuicarinata (Meek and Hayden)

Fish

Unidentified scale of the Order Clupeiformis

5. One hundred yards east of locality 4 in the SW ¼ sec. 27, T. 137 N., R. 103 W.: unit 33.

Pelecypods

Unio stantoni White

Sphaerium fowleri Russell

Bicorbula mactriformis (Meek and Hayden)

Gastropods

Campeloma nebrascensis (Meek and Hayden)

Viviparus sp.

6. Two hundred yards east of stream crossing in the SW ¼ sec. 13, T. 137 N., R. 103 W. Isolated outcrop, possibly unit 48.

Pelecypods

Plesielliptio priscus (Meek and Hayden)

Bicorbula mactriformis (Meek and Hayden)

Gastropods

Campeloma sp.

7. East side of steep hill in the SW ¼ sec. 24, T. 137 N., R. 103 W. Isolated outcrop, possibly unit 51.

Pelecypods

Plesielliptio priscus (Meek and Hayden)

Rhabdotophorus senectus (White)

Gastropods

Viviparus prudentis White

Campeloma nebrascensis (Meek and Hayden)

Miscellaneous

Reptile jaw fragments

Ganoid fish scale

Fish vertebra

The above named fossils represent an assemblage of fresh-water, brackish-water, and continental plants and animals. The plants represent a flora of a warm temperate environment with a medium amount of precipitation well distributed through the year (Brown, 1962, p. 96). The invertebrates, fish, reptiles and amphibians represent varied local environments.

The amphibian Habrosaurus dilatus is related to modern genera which live in swampy, sluggish rivers of the southern coastal plains (Estes, 1964, p. 162). The fish Platacodon nanus is related to fresh water river and lake species (Estes, 1964, p. 161). The gar fish remains would be indicative of river laid deposits. Crocodile and turtle fossils point to swampy lake and sluggish river conditions.

Modern species of Campeloma may be found in fresh-water lakes and rivers (Dr. A. M. Cvancara, University of North Dakota, oral communication, 1966). The relative paucity of species of mussels would seem to indicate lake or small river environments (Dr. A. M. Cvancara, University of North Dakota, oral communication, 1966). Viviparus is found in many brackish water faunas (Tozer, 1956, p. 7,9).

Environments of Deposition

The land upon which these sediments were deposited must have been strikingly different from that of the present. Nearly horizontal, thick lignite beds that cover hundreds of square miles point to a nearly flat, low-lying area with similar conditions of prolific plants in a swampy environment. The sand, silt and clay are of alluvial, fluviatile and lacustrine origins.

The land must have been a very wide, flat coastal plain which had several large rivers slowly anastomosing across the flat land. Minor fluctuations in water level would probably have inundated tremendous land areas. Upon this coastal plain were abundant plants of a mesophytic flora in a warm temperate environment (Brown, 1962, p. 96). Small lakes were also present on the coastal plain and it was in these that the limestone was deposited. The limestone was probably chemically precipitated under anerobic conditions. The term anerobic is used to indicate the lack of fossils except for several leaves which could have been blown into the ponds.

The sediments were probably derived from three main sources, the Rocky Mountains to the west, the Black Hills to the south, and from erosion of previously deposited sediments. The latter source is evident from lignite particles in some of the sandstones. The unaltered nature of the micas and feldspar and the angular nature of the particles, however, indicate very little weathering or reworking.

The bentonitic clays were probably derived from volcanic ash whose source was in the Rocky Mountains. This ash settled over the entire area and formed beds as thick as six feet. This ash must have formed a rich soil, for in several places lignite beds directly overlie these clays.

Sentinel Butte Member

Lithology.--The lithology of the Sentinel Butte Member differs from that of the lower member in being darker colored, coarser grained, having more massive beds and in being cyclic in nature.

The common rock types are sandstone, claystone, siltstone, lignite and minor shale and "scoria." The sediments seem to be cyclic in a sequence of a lignite overlain by sediment which becomes coarser grained upward to a concretionary sandstone which is overlain by an underclay and another lignite. This cycle is repeated six times, with minor variations as is shown on Plate II (in folder).

The sandstones tend to be moderate yellowish or brownish gray, fine to medium grained, friable on the fresh surface and case-hardened, concretionary, massive bedded, and steep (to 65°) slope formers. The sandstone contains abundant dark minerals (mainly biotite and magnetite), is essentially structureless, and is composed of sub-angular grains. Cross-bedding was observed in two of the sandstone units (Plate II) but this was the exception rather than the rule. The sandstones are essentially unfossiliferous with rare ganoid fish scales having been found by the writer.

The claystone beds apparently contain more montmorillonite and are possibly more volcanic in origin than the lower member. This is evident from the surface of the beds. Most of them have a very rough surface due to the swelling of the wet clays and where they are exposed on a steep surface the claystone has flowed down over the underlying strata as much as 20 feet, thus greatly exaggerating the apparent thickness of the bed. These claystone beds contain many plant fossils but they are not as abundant as in the lower member.

The siltstone is brownish gray and weathers yellowish gray; it is friable on the fresh surface, slightly case-hardened, and may contain small (less than six inches in thickness) limonitic concretions.

The lignite beds are very similar to those of the lower member. They contain abundant selenite crystals, some pyrite nodules and some yellow limonitic clay. Much of the coal has a blocky fracture and most is good quality lignite with few shale partings.

The Bullion Butte lignite and the lignite directly beneath it (Plate II) in one small area on the northwest side of Bullion Butte are the only lignites which have burned to form a "scoria." The "scoria" is not extensive and only a small part of the lignite has burned.

The 21-foot thick lignite in the upper part of the Sentinel Member (Fig. 12) has not been described previously. The bed is obscured by slumping on all parts of Bullion Butte except in the NE ¼ sec. 13, T. 137 N., R. 103 W., and has locally burned to form a small scoria outcrop. There are two thin (two and four inch) shale partings near the base, but the remainder is a well-developed lignite.

Fig. 12 - Newly discovered 21-foot lignite (unit 103 of Sentinel Butte Member) in the NE ¼ sec. 13, T. 137 N., R. 103 W.

Thickness.--The Sentinel Butte Member is about 450 feet thick at Bullion Butte. About 220 feet, or 49 per cent, is sandstone, 168 feet, or 37 per cent, is silt and clay, and the remainder of 62 feet, or 14 per cent, is lignite. The upper contact is covered due to slumping but its position can be placed fairly closely by a large number of springs below the White River Formation. The sandstone of the White River Formation is very permeable and an aquifer must develop at its base above the impermeable clays of the upper Sentinel Butte Member. Most of the springs occur at the same horizon and it is here that the inferred contact is drawn (Plate II).

Sedimentary Structures.--As in the lower member, concretions and nodules are the most common sedimentary structures. The "log-like" concretions are the most abundant type, and they are found in all the sandstone units. They have a higher concentration of limonite, however, than those did in the lower member, and are thus mostly colored moderate brown. These concretions weather resistantly and thus protrude from most of the sandstone units.

Smaller (six inches in diameter) limonitic concretions are found in the silty clays. Some are very friable, silty and limonitic, but others are very resistant to weathering and may resemble "cannonballs." These limonitic concretions are moderate brown on the weathered surface and lighter colored or yellowish brown on the fresh surface.

Paleontology.--Fossils are relatively rare in the Sentinel Butte Member. A few scattered pelecypods, gastropods, plant fossils, and ganoid fish scales were the only fossils found by the writer. There were no localities where more than a few specimens were found with the exception of the south side of a hill in the NE ¼ sec. 31, T. 135 N., R. 101 W., where a small collection of ganoid fish scales and vertebrae were found. The pelecypods were all of the family Unionidae; however, no identifiable species were collected. Broken fragments of the gastropod Campeloma were found in the lower half of the Sentinel Butte Member, but these were sporadic occurrences.

Most of the clay and shale units contained plant remains, but no identifiable leaves were found. The plant fossils have been studied extensively by Brown (1948, 1962) who said the flora is definitely a Paleocene mesophytic flora.

Environments of Deposition.--The sediments of the Sentinel Butte Member are much coarser than those of the lower member, but the writer believes the environment had not changed significantly. The writer tends to favor an environment of large sluggish rivers with a low energy, possibly depositing sediment in large, fresh water bodies of shallow, quiet water. This would account for the poor sorting (relatively high amounts of silt and clay) in the sandstones and the lack of many structures.

The rivers which deposited the Sentinel Butte Member would have had a lower energy than those which deposited the lower member. This is evident from the fact that fine and medium size sand is easier to move than the silt and clay sized material (Inman, 1949, p. 56). The higher energy rivers would be transporting silt and clay, whereas the lower energy rivers would transport the easier to move fine and medium sand. This is assuming that the sizes mentioned are available for deposition.

There were no limestones observed in the Sentinel Butte Member, and apparently none or very few are present north of Medora, North Dakota (Chester Royse, University of North Dakota, oral communication, 1966).

ECONOMIC GEOLOGY

Lignite is the major economic material in the area studied. There are five lignite beds of mineable thickness (six feet or greater) and only two of these (the Harmon and Meyer) have been mined in this area. Of the others, the HT Butte lignite has been naturally burned out of the area, the Bullion Butte lignite and the thick lignite below it are nearly inaccessible to transportation and only underlie small areas near the top of Bullion Butte. There is no mining of these lignites at the present time near the area studied.

"Scoria" has been mined by the ranchers for road metal, and there has been some interest in this material as a possible source of aluminum, but nothing conclusive has been reported as of the time of this writing.

Extensive geophysical work is currently being done in exploration for oil and gas; however, no producing wells exist in the area.

A flurry of interest in uranium, associated with the lignites of the Sentinel Butte Member in the late 1950's, has now abated somewhat. The lignites most promising were those with a thick (20 to 30 feet) sandstone directly overlying them (Dr. E. A. Noble, University of North Dakota, oral communication, 1966). This sandstone apparently would serve as an aquifer, and allow the soluble uranium to migrate to the lignite where it would concentrate because of its affinity for the carbonaceous material.

CONCLUSIONS

1. The lower member of the Tongue River Formation contains a much higher percentage of total carbonates, and a larger fauna than the Sentinel Butte Member. The lower member is generally a yellow gray color, with dominant lithologies of very fine-grained sandstone, siltstone, claystone and lignite.
2. The Sentinel Butte Member is coarser grained and darker colored than the lower member. The member contains a repetitive sequence of yellow brown, fine to medium grained sandstone, siltstone, and lignite.
3. The Tongue River Formation is thinner in the area studied than in the surrounding areas to the west, north and east. The lower member attains a thickness of 313 feet and the Sentinel Butte Member is 450 feet thick.
4. Particle analyses of size, roundness, and mineral composition indicate a nearby source area, little chemical weathering, and little reworking.
5. Mineral composition indicates a complex source area with metamorphic rocks and associated granites.
6. The fauna and flora indicate a fairly warm, humid environment with sluggish rivers, and swampy conditions, on a broad coastal plain.

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APPENDIX I

Included in this appendix are lithologic descriptions of the composite stratigraphic section measured in T. 137 N., R. 103 W. of Golden Valley County. The unit number corresponds to the number given on Plates I and II (in folder). The classification of McKee and Weir (1953) was used for describing stratification and splitting.

Bullion Butte Section

Measured on the west side of Bullion Butte in sec. 13, T. 137 N., R. 103 W., Golden Valley County, North Dakota. Section measured by J. W. Crawford, July, August 1965; elevation at top of section 3,366 feet. Plate II.

Description

Top of Section

White River Formation

Unit		Thickness in feet
115	QUARTZITE, medium grained, bluish white (5B 8/1), weathers yellowish gray (5Y 7/1), very resistant cliff former. Columnar jointing, massive bedded, clay galls in lower part which weather very rapidly. Lower forty ± feet not exposed. In upper part, a three foot bed of grayish red purple (5RP 4/2) siltstone.	79.0

Tongue River Formation (Sentinel Butte Member)

114	CLAYSTONE, silty, calcareous, yellow orange (10YR 7/6), weathers dark yellow orange (10YR 6/6). Variegated light and dark orange, very compact, concretionary, top of bed not exposed, upper part resembles an ash bed.	23.0
113	CLAYSTONE, silty, calcareous, medium light gray (N6), weathers light gray (N7) with dusky yellow	

Unit		Thickness in feet
	(limonitic stain) streaks throughout. Very compact, abundant leaf molds.	6.0
112	SILTSTONE, clayey, pale red (10R 5/1), weathers pale yellow brown (10YR 6/2), shaly partings, poorly consolidated, good plant stem and leaf fossils.	1.8
111	LIGNITE, Bullion Butte, good quality, hard, blocky and black. Locally burned to scoria. Highly slumped and poorly exposed.	11.1
110	SILTSTONE, clayey, sandy, yellowish brown (10YR 5/2), weathers pale yellowish brown (10YR 6/2). Very compact blocky fracture, plant fragments.	4.0
109	SILTSTONE, clayey, calcareous, olive gray (5Y 4/2), weathers light olive gray (5Y 6/1), compact with rough surface and sulfate stain. Irregular fracture, selenite, resistant limonitic concretions.	2.6
108	SILTSTONE, sandy, calcareous, pale yellow brown (10YR 7/1), weakly consolidated, weathers yellow gray (5Y 7/2) with a smooth surface. Finely laminated with several laminae of interbedded silt and clay.	11.1
107	SILTSTONE, clayey, medium grained, pale yellow brown (10YR 5/2), weathers yellow orange gray (5Y 7/2) with a smooth surface, and CLAYSTONE, silty, variegated olive gray (5Y 4/1), compact,	

Unit		Thickness in feet
	weathers very light gray (N7) with a sulfate stain and rough surface. Claystone is finely laminated.	9.0
106	SILTSTONE, coarse grained, variegated light olive gray (5Y 6/2), weathers yellow gray (5Y 6/4), poorly consolidated. Finely laminated with very light gray claystone. Small (three inches in diameter) limonitic concretions.	7.6
105	SANDSTONE, silty, calcareous, fine grained, light gray (N7), weathers yellow gray (5YR 6/3) with smooth surface. Several thin clay partings, massive bedded, concretions common but most abundant at top of bed. Case hardened.	30.0
104	SILTSTONE, clayey, calcareous, alternating medium light gray (N6) and very light gray (N8) in about one-inch beds. Weathers very light gray (N8), poorly consolidated, finely laminated and coarser grained downward.	3.0
103	LIGNITE, unnamed, good quality with two shale partings near base. One is 1.6 feet above base and 0.3 feet thick, the second is 0.5 feet above the first and 0.2 feet thick. Highly obscured due to slumping. Several springs occur at its base.	21.0
102	CLAYSTONE, medium gray (N5), weathers light gray (N7); compact, several shaly partings, smooth surface which is rounded from flowage.	5.8

Unit		Thickness in feet
101	LIGNITE, hard, blocky, black.	0.9
100	SANDSTONE, silty, clayey, calcareous, fine grained, moderate yellow brown (10YR 6/4), weathers grayish orange (10YR 7/4), very poorly consolidated with smooth surface. Yellow clay scattered throughout. Case hardened.	4.7
99	CLAYSTONE, medium gray (N5), weathers light gray (N7); very compact, with rough "popcorn" surface. Coarse shale partings with blocky fracture. Finely laminated, selenite, abundant plant fragments. Thin (two inches) lignitic shale at top.	5.5
98	LIGNITE, shaly, a good lignite (8 inches) at the base overlain by a lignitic shale (one foot thick) which is overlain by a hard, blocky black lignite (2.1 feet). Many plant stem, root and leaf fossils in shale.	3.6
97	SILT, clayey, pale yellow orange (10YR 8/5), weathers grayish yellow (5Y 8/2); compact, with a smooth surface.	7.5
96	SANDSTONE, silty (in upper part), fine grained, grayish yellow (5Y 8/2), weathers grayish yellow (5Y 7/1), poorly consolidated, abundant dark minerals, very friable on the fresh surface but a steep slope former and caps ridge. Becomes finer grained upward.	38.3

Unit		Thickness in feet
95	SILTSTONE, sandy, clayey, variegated grayish red (5Y 4/2) and light olive gray (5Y 5/2) on the fresh surface. Compact, plant stem imprints.	2.2
94	SANDSTONE, light brown (5YR 5/5), fine to medium grained, weathers light brown (5YR 6/4), poorly consolidated, abundant dark minerals, massive bedded, case hardened.	5.6
93	SANDSTONE, silty (in upper part), fine grained, grayish orange, weathers orange gray (10YR 7/4). Very friable on fresh surface. Very thick bedded. Resistant limonitic siltstone in upper three inches.	12.3
92	LIGNITE, well developed, hard, black, blocky, with two partings. One, a sandstone two inches thick a foot above the base, the second a shale three inches higher, also two inches thick. No under clay.	4.0
91	SANDSTONE, silty (more at top), calcareous, fine grained, medium grained, moderate yellowish orange (10YR 6/4), weathers yellow gray (5Y 7/1), poorly consolidated, many dark minerals, becomes finer grained, more grayish and more resistant upward. Case hardened.	17.2
90	SILTSTONE, clayey, variegated pale yellow orange (10YR 7/4) with minor thin beds of medium dark gray (N4), weathers yellow orange gray (5Y 7/3). Unctuous.	4.8

Unit		Thickness in feet
95	SILTSTONE, sandy, clayey, variegated grayish red (5Y 4/2) and light olive gray (5Y 5/2) on the fresh surface. Compact, plant stem imprints.	2.2
94	SANDSTONE, light brown (5YR 5/5), fine to medium grained, weathers light brown (5YR 6/4), poorly consolidated, abundant dark minerals, massive bedded, case hardened.	5.6
93	SANDSTONE, silty (in upper part), fine grained, grayish orange, weathers orange gray (10YR 7/4). Very friable on fresh surface. Very thick bedded. Resistant limonitic siltstone in upper three inches.	12.3
92	LIGNITE, well developed, hard, black, blocky, with two partings. One, a sandstone two inches thick a foot above the base, the second a shale three inches higher, also two inches thick. No under clay.	4.0
91	SANDSTONE, silty (more at top), calcareous, fine grained, medium grained, moderate yellowish orange (10YR 6/4), weathers yellow gray (5Y 7/1), poorly consolidated, many dark minerals, becomes finer grained, more grayish and more resistant upward. Case hardened.	17.2
90	SILTSTONE, clayey, variegated pale yellow orange (10YR 7/4) with minor thin beds of medium dark gray (N4), weathers yellow orange gray (5Y 7/3). Unctuous.	4.8

Unit		Thickness in feet
89	LIGNITE, minor amount of disseminated clay. Pyrite nodules in upper six inches.	3.2
88	SILTSTONE, clayey, calcareous, pale yellow orange brown (10YR 6/2), weathers yellow gray (5Y 7/2). Poorly consolidated, finely laminated with dark brown silty clay. Small (three inches in diameter), friable, limonitic concretions. Friable on fresh surface.	3.6
87	SANDSTONE, medium grained, moderate yellow (5Y 7/5), weathers moderate yellow brown (10YR 6/4). Poorly consolidated, very uniform, massive bedded, some cross bedding appears on weathered surface. Massive concretions with limonitic and calcareous cement 25 feet above the base. Steep (65°) slope former. Rare ganoid fish scales.	62.2
86	LIGNITE, many impurities, shale parting 1.5 feet above base, yellow clay, selenite.	4.3
85	SHALE, clay, slightly calcareous, olive gray (5Y 4/1), weathers light gray (N7) with weak slopes. Fissile, abundant selenite, plant fossils. More shaly and more plant remains under lignite.	8.2
84	CLAYSTONE, silty, calcareous, light olive gray (5Y 5/2), weathers yellow gray (5Y 7/1) with a smooth surface. Poorly consolidated, some shale partings, friable limonitic concretions.	11.8

Unit		Thickness in feet
83	SILTSTONE, clayey, calcareous, moderate yellow brown (10YR 6/4), weathers pale yellow brown (10YR 6/1) with a very rough surface. Poorly consolidated. Flows over underlying strata.	5.8
82	SILTSTONE, clayey, calcareous, light olive gray (5Y 5/2), weathers yellow gray (5Y 7/1) with weak slopes. Thin interbedded darker siltstone. Friable on fresh surface.	6.8
81	SILTSTONE, sandy, clayey, calcareous, brownish gray (5YR 5/1), weathers yellow gray (5Y 6/1) with a rough surface. Several thin (one to two inch) pale yellow orange beds at top and bottom. Friable on fresh surface. Small (three inches in diameter) limonitic concretions.	5.3
80	SANDSTONE, silty, clayey, calcareous, very fine grained, medium light gray (N6), weathers same. Upward mottled with pale yellow orange. Massive bedded, case hardened, steep (65°) slope former. Yellowish orange (10YR 7/6) concretions (six to ten inches in diameter).	16.9
79	SILTSTONE, calcareous, yellow gray (5Y 8/1) with thin beds of pale yellow orange (10YR 8/6), whole bed weathers yellow gray (5Y 8/2). Compact, very sharp upper contact, plant stem fossils.	7.5

Unit		Thickness in feet
78	SHALE, silty, grayish red (10R 4/2), weathers pale purple gray (5P 6/2) with several bands of light gray (N7). Papery splitting, weak slope former, plant fossils.	5.6
77	LIGNITE, good quality, black lignite with a blocky fracture. Minor limonitic clay.	2.2
76	SILTSTONE, clayey, calcareous, medium gray (N5), weathers light gray (N7) with a cracked polygonal surface. Poorly consolidated, structureless, few plant stem fragments.	9.0
75	CLAYSTONE, silty, calcareous, dark yellow orange (10YR 7/4). Very compact, blocky fracture, plant stem molds.	0.8
74	CLAYSTONE, silty, calcareous, dark gray (N3), weathers yellow gray (5Y 7/1) with a very rough surface. Compact, coarse shale partings. High amount of "swelling" clay.	9.8
73	SANDSTONE, silty, clayey, calcareous, fine grained, yellow gray (5Y 6/1) with thin interbedded dark yellow brown (10YR 5/2) clay. Bed weathers yellow gray (5Y 7/1) with a rough case hardened surface. Steep (70°) slopes, slumps and flows over underlying lignite.	26.5
72	LIGNITE, HT Butte, good quality, few impurities or shale partings. Burned to "scoria" in most localities.	12.3

lower member

Unit		Thickness in feet
71	CLAYSTONE, silty, typical underclay.	

Red Hills Section

Measured in secs. 27, 28, 33, 34, T. 137 N., R. 103 W. between the Little Missouri River and the top of the Red Hills. The base of the section is exposed in a southeast-facing butte in the NE ¼ sec. 33, T. 137 N., R. 103 W. Section measured by J. W. Crawford, June 1965, elevation at top of section 2,865 feet. Plate I.

Description

Top of Section

Sentinel Butte Member

Unit		Thickness in feet
72	"SCORIA," developed from burning of HT Butte Lignite. Contains three ash beds, the basal one is 1 inch thick, the second is 3 inches thick and 1 foot above the first, the third ash is 9 inches thick and 14 inches above the second.	7.0

lower member

Unit		Thickness in feet
71	CLAYSTONE, silty, calcareous, medium gray (N5), weathers yellowish gray (5Y 8/1) with some white sulfate on the surface. Very compact, a few friable limonitic concretions.	10.1
70	SILTSTONE, clayey, calcareous, finely laminated, light gray (N7), weathers a mottled gray, weakly consolidated shaly partings.	4.3

Unit		Thickness in feet
69	CLAYSTONE, silty, light olive gray (5Y 6/1) with thin bands of yellow orange (10YR 7/6), weathers very light gray (N8) with "popcorn" surface and sulfate coating. Very compact, blocky fracture, convoluted bedding (Fig. 11).	16.0
68	SILTSTONE, clayey, calcareous, yellow brown (10YR 6/4), weathers yellow gray (5Y 7/2) with smooth surface, weakly consolidated, case hardened.	4.1
67	CLAYSTONE, silty, calcareous, yellow gray (5Y 8/2), weathers same with "popcorn" surface. Very compact, coarse blocky fracture.	5.7
66	SILTSTONE, calcareous, yellow gray (5Y 6/2), weathers yellow gray (5Y 7/2), weakly consolidated, but case hardened, friable limonitic concretions.	1.0
65	CLAYSTONE, silty, yellow brown (10YR 4/2), weathers same. Compact, shaly partings, with lignite on partings, gypsum, friable limonitic concretions.	0.8
64	LIGNITE, Meyer, two four-inch shale partings. One starts six inches above base, the second four feet above the base. Slope former, abundant selenite.	9.3
63	CLAYSTONE, silty, medium dark gray (N6), weathers same; very compact, blocky fracture; abundant plant stem fragments and vertical root remains, selenite.	0.7
62	SILTSTONE, sandy, calcareous, yellow gray (5Y 6/2), weathers yellow gray (5Y 7/2), case hardened in beds	

Unit		Thickness in feet
	1 to 6 inches thick alternating with siltstone, clayey, calcareous, very fine grained, medium gray (N5), weathers same. Blocky fracture.	6.7
61	CLAYSTONE, silty, calcareous, light olive brown (5Y 4/6), weathers dusky yellow (5Y 6/4); compact, shale partings, lignitic plant material.	6.8
60	CLAYSTONE, silty, medium gray (N5), weathers yellow gray (5Y 7/2). Compact, very sharp upper and lower contacts.	0.5
59	CLAYSTONE, calcareous, grayish orange (7YR 6/4), weathers yellow gray (5Y 7/2) with sulfate staining. Very compact, blocky fracture, plant remains.	0.8
58	SILTSTONE, calcareous, light brown (5Y 5/6), weathers yellow gray (5Y 6/2). Poorly consolidated, finely laminated. Becomes more friable upward. "Log-like" concretions, and a few pyrite nodules.	6.0
57	CLAYSTONE, silty, medium dark gray (N4), weathers very light gray (N8) with mottled appearance. Weakly consolidated. Several thin lignite partings and shaly bedded.	5.1
56	SILTSTONE, sandy, calcareous, coarser grained at top, yellow brown (10YR 5/5), weathers yellow gray (5Y 7/3), weakly consolidated, small, limonitic concretions.	6.0

Unit		Thickness in feet
55	CLAYSTONE, alternating with siltstone, laminations of clay are dusky yellow (5Y 6/4) which weather very light gray. The siltstone is a calcareous light yellow brown (10YR 6/4), weathers yellow gray (5Y 7/2), compact. Claystone is blocky and siltstone is case hardened.	3.5
54	LIGNITE, sooty near top, contains yellow clay and limonite.	0.9
53	SILTSTONE, clayey, calcareous, light yellow brown (10YR 6/4), weathers yellow gray (5Y 7/2). Weakly consolidated. Plant stem, leaf, and root molds.	2.5
52	CLAYSTONE, silty, calcareous, light olive gray (5Y 6/1), weathers very light gray (N8) with several darker gray bands. Very compact, some shaly partings but mostly blocky; gradational lower contact, sharp upper contact.	16.3
51	SILTSTONE, calcareous, yellow gray (5Y 6/2), weathers yellow gray (5Y 7/1). Weakly consolidated. Laminated in lower two-thirds, gradational upper contact. Fossil locality 7 ?	5.0
50	CLAYSTONE, silty, olive gray (5Y 4/4), weathers very light gray (N8) but is reddish purple at the base with about two inches of sooty lignite. Compact. Abundant plant stem molds.	1.0

Unit		Thickness in feet
49	CLAYSTONE, silty, calcareous, grayish orange (10YR 7/4), weathers yellow gray (5Y 6/2) with a coarse "popcorn" surface, and white sulfate staining. Very compact. Slightly shaly.	3.3
48	CLAYSTONE, medium bluish gray (5B 5/1), weathers medium dark gray (N4) with polygonal weathering surface. Compact, shaly partings with lignitized plant material. Fossil locality 6 ?	6.3
47	SHALE, silty, calcareous, grayish red (10R 4/1), weathers same, weakly consolidated; more fissile at top. Slumps over underlying lignite.	1.2
46	LIGNITE, shaly, contains yellow and brown shales. Weakly consolidated, exposure slumped over and obscure.	0.9
45	CLAYSTONE, silty, alternating brown, reddish, and gray clay about 2 to 4 inches thick, thin (one inch) lignite partings. Beds thinly laminated.	4.0
44	SILTSTONE, sandy, calcareous, yellow gray (5Y 6/2), weathers yellow gray (5Y 7/2) with smooth weathering surface. Weakly consolidated, case hardened, caps ridge. Gradational upper contact.	6.0
43	SILTSTONE, clayey, calcareous, alternating brown silty clay and gray siltstone in one or two inch beds. Weakly consolidated, case hardened.	5.8

Unit		Thickness in feet
42	CLAYSTONE, silty, medium gray (N5), weathers light gray (N7). Very compact, basal three feet contains anastomosing brown claystone, upper part slightly darker.	9.0
41	SHALE, silty, calcareous, brownish gray (5YR 5/1), weathers light brownish gray (5YR 6/1). Weakly consolidated, very fissile, limestone lenses (which range up to six feet in diameter) occur at this horizon.	4.8
40	CLAYSTONE, silty, calcareous, alternating medium gray (N5) and brownish gray (5YR 4/1) claystone which weathers very light gray (N8) due to sulfate stain. Very compact, knobby surface.	4.3
39	CLAYSTONE, silty, medium gray (N5) and brownish gray (5YR 4/1) which weathers to medium gray (N5). Very compact; resistant limonitic pebbles.	2.8
38	CLAYSTONE, silty, pale brown (5YR 5/2), weathers very light gray (N8) due to sulfate stain. Very compact; breaks into small (one-half inch) angular blocks.	2.3
37	CLAYSTONE, silty, medium gray (N5), weathers same; with "popcorn" surface, very compact, bentonitic.	4.0
36	CLAYSTONE, silty, calcareous, medium gray (N5), with some yellowish brown (10YR 5/4) clay that weathers to resistant limonitic pebbles. Bed very compact and limestone lenses (which range up to	

Unit		Thickness in feet
	six feet in diameter) occur at this horizon.	2.8
35	CLAYSTONE, silty, calcareous, light gray (N7), weathers yellow gray (5Y 7/2) with resistant limonitic pebbles. Very compact, rough surface.	2.2
34	SANDSTONE, silty, calcareous, very fine grained, grayish orange (10YR 6/4), weathers yellowish gray (5Y 7/2) with smooth surface. Case hardened, small (four inches in diameter) limonitic concretions.	7.0
33	CLAYSTONE, silty, calcareous, dark yellow orange (10YR 5/6), weathers yellow gray (5Y 7/2), weakly consolidated, finely laminated with silty layers, plant stem fragments. Fossil locality 5.	4.5
32	LIGNITE, poor quality, abundant brownish shale with plant remains. Very weakly consolidated.	1.0
31	CLAYSTONE, moderate yellowish brown (10YR 5/4), weathers pale yellow brown (10YR 7/2), very compact, plant stem and leaf molds; root molds under lignite (30).	2.5
30	LIGNITE, blocky, good quality but becomes shaly near the top. Weakly consolidated.	4.5
29	SHALE, silty, calcareous, medium gray (N5), weathers yellow gray (5Y 7/2); weakly consolidated; selenite, concretions, root remains and darker colored under lignite.	2.5

Unit		Thickness in feet
28	SILTSTONE, sandy, calcareous, yellow gray (5Y 7/1), weathers grayish yellow (5Y 8/2); compact, very concretionary, some calcareous siltstones but mainly limonitic and pyrite nodules. Case hardened.	2.8
27	CLAYSTONE, silty, calcareous, dusky yellow (5Y 6/5), weathers grayish yellow (5Y 7/4). Very compact. Jointed, blocky fracture.	2.0
26	LIGNITE, hard, black, with some shale partings.	0.9
25	SILTSTONE, sandy, calcareous, yellow gray (5Y 7/2), and red under lignite. Weakly consolidated, bed thick-bedded but shaly under lignite, abundant plant remains, some of which are lignitized, and root imprints. Fossil locality 4.	3.5
24	SILTSTONE, sandy, calcareous, light olive gray (5Y 5/2), weathers yellow gray (5Y 7/2), weakly consolidated, thick-bedded, small calcareous concretions, plant fragments.	1.3
23	SILTSTONE, clayey, calcareous, light olive gray (5Y 5/2), weathers yellow gray (5Y 7/1); compact, with a knobby surface.	2.6
22	SANDSTONE, silty, calcareous, very fine grained, light gray (N7), but basal part is moderate yellow (5Y 7/5), weathers yellow gray (5Y 8/2). Weakly consolidated, thin clay laminations. Leaf fossils. Fossil locality 3.	1.2

Unit		Thickness in feet
21	LIGNITE, good quality, hard, black, blocky fracture. Slumped over.	4.0
20	SILTSTONE, calcareous, light gray (N7), weathers yellow gray (5Y 7/2). Contains several thin (one-half inch) beds of clay and becomes more clayey under the lignite with root and plant stem molds.	3.0
19	CLAYSTONE, silty, calcareous, dark yellow orange (10YR 6/4), weathers same. Compact, shaly in base with plant stem fossils.	0.5
18	SILTSTONE, clayey, calcareous, light gray (N7), weathers yellow gray (5Y 7/2); poorly consolidated, smooth weathering surface, case hardened.	1.9
17	CLAYSTONE, silty, calcareous, dusky yellow (5Y 6/4), weathers grayish orange (5Y 7/3), with sulfate stain. Very compact. Blocky fracture, plant fossils and gastropod fragments.	3.4
16	SILTSTONE, clayey, calcareous, light gray (N7), weathers yellow gray (5Y 7/1). Compact, thins and thickens laterally. Clay parting near center, pyrite nodules.	5.9
15	CLAYSTONE, silty, calcareous, light gray (N7), weathers very light gray (N8) with sulfate stain. Blocky fracture, reed stem molds throughout and rare gastropods.	6.4

Unit		Thickness in feet
21	LIGNITE, good quality, hard, black, blocky fracture. Slumped over.	4.0
20	SILTSTONE, calcareous, light gray (N7), weathers yellow gray (5Y 7/2). Contains several thin (one-half inch) beds of clay and becomes more clayey under the lignite with root and plant stem molds.	3.0
19	CLAYSTONE, silty, calcareous, dark yellow orange (10YR 6/4), weathers same. Compact, shaly in base with plant stem fossils.	0.5
18	SILTSTONE, clayey, calcareous, light gray (N7), weathers yellow gray (5Y 7/2); poorly consolidated, smooth weathering surface, case hardened.	1.9
17	CLAYSTONE, silty, calcareous, dusky yellow (5Y 6/4), weathers grayish orange (5Y 7/3), with sulfate stain. Very compact. Blocky fracture, plant fossils and gastropod fragments.	3.4
16	SILTSTONE, clayey, calcareous, light gray (N7), weathers yellow gray (5Y 7/1). Compact, thins and thickens laterally. Clay parting near center, pyrite nodules.	5.9
15	CLAYSTONE, silty, calcareous, light gray (N7), weathers very light gray (N8) with sulfate stain. Blocky fracture, reed stem molds throughout and rare gastropods.	6.4

Unit		Thickness in feet
14	CLAYSTONE, silty, calcareous, light gray (N7), weathers very light gray (N8), thin white laminae, very compact. Three-inch lignite at top of bed. Basal three inches is very thin bedded with lignite particles.	2.5
13	LIGNITE, good quality, black, hard, with blocky fracture. Slumped over. Mined locally.	6.0
12	CLAYSTONE, silty, grayish blue (5PB 5/2), weathers medium bluish gray (5B 5/1) with "popcorn" surface. Very compact, blocky fracture, plant stem molds; root remains under lignite.	6.3
11	SILTSTONE, calcareous, light gray (N7), weathers yellow gray (5YR 7/2); weakly consolidated with smooth, case-hardened surface. Laminated and "swirly" bedded (Fig. 7). Finer grained upward. Small (three inch) limonitic concretions.	8.1
10	SILTSTONE, clayey, calcareous, pale brown (5YR 5/2), weathers yellow gray (5Y 6/2); weakly consolidated, shaly partings, plant stem and leaf molds.	5.0
9	CLAYSTONE, silty, medium bluish gray (5B 5/1), weathers light brownish gray (5YR 6/1), compact, blocky fracture, plant fossils.	2.0
8	SHALE, lignitic, about 10 per cent lignite, reddish brown (10R 4/4), weathers pale brown (5YR 5/2), poorly consolidated, abundant selenite.	1.0

Unit		Thickness in feet
7	SILTSTONE, calcareous, dusky yellow (5Y 5/4), weathers yellowish gray (5Y 7/2); weakly consolidated, upper part shaly under lignitic shale with abundant plant remains. Rest is laminated with lighter and darker silts. Case hardened.	4.8
6	LIGNITE, poor quality, abundant clay, selenite, limonite. Shale parting six inches above base. Very weakly consolidated.	3.0
5	SILTSTONE, clayey, calcareous, grayish olive (10Y 4/2), weathers light olive gray (5Y 7/1) with sulfate stain. Compact, blocky fracture darker colored under lignite with root remains.	3.0
4	SILTSTONE, sandy, calcareous, light olive gray (5Y 5/1), weathers yellowish gray (5Y 7/2). "Swirly" bedded, case hardened, micaceous. Fossil locality 2. (Fig. 7).	5.5
3	CLAYSTONE, silty, calcareous, medium gray (N5), weathers medium light gray (N6) with rough surface. Compact, blocky fracture, sulfate stain.	4.5
2	SANDSTONE, silty, calcareous, very fine grained, light olive gray (5Y 7/1), weathers grayish orange (10YR 7/4). Weakly consolidated but case hardened. Medium grained at base, becomes finer upward to coarse siltstone at top. Locally clay stringers and fine laminations. Eighteen feet above base is a	

Unit		Thickness in feet
	concretionary zone with platy bedded calcareous concretions and "log-like" concretions. Base of sandstone fills channel scars, and has many small springs. Fossil locality 1.	22.5
Ludlow Formation		
1	CLAYSTONE, silty, medium gray (N5), weathers same, very compact, "popcorn" surface, blocky fracture, sulfate stain.	28.0

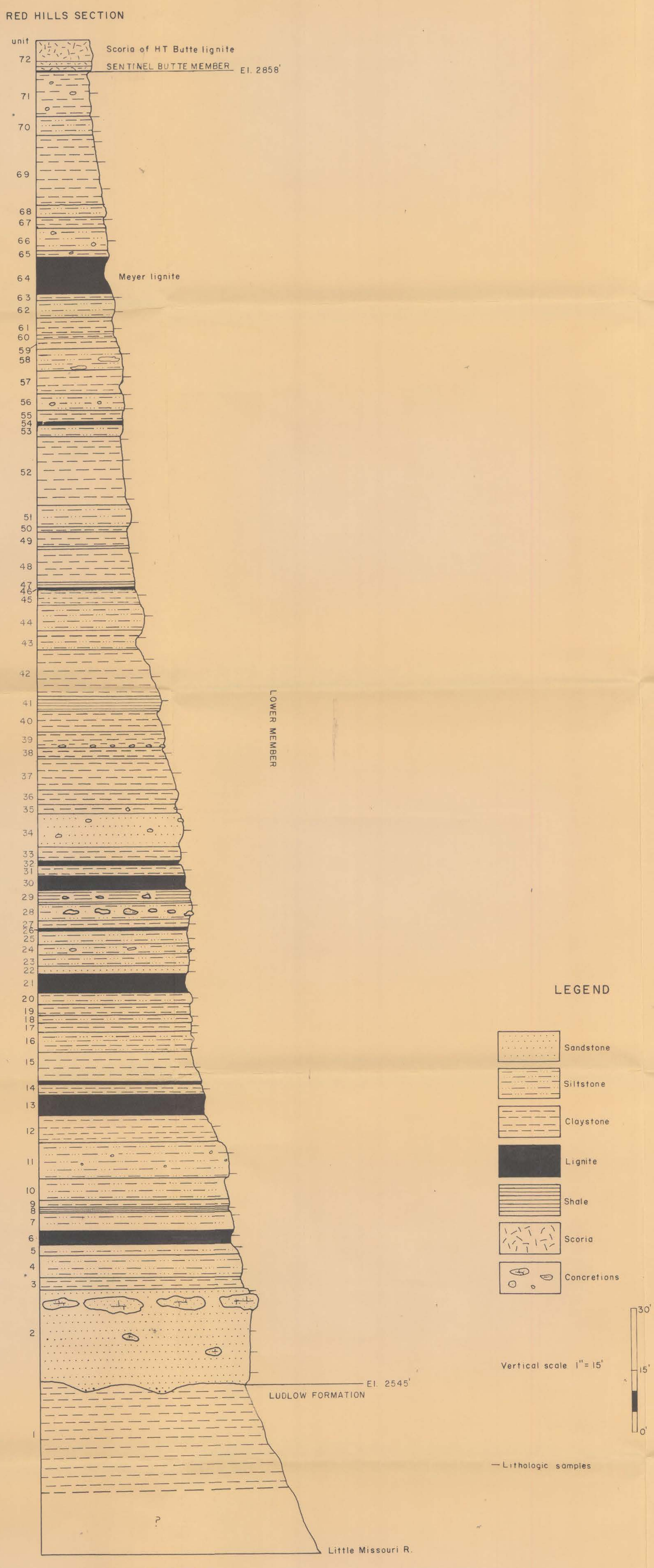

PLATE I

STRATIGRAPHIC SECTION OF THE LOWER MEMBER OF THE TONGUE RIVER FORMATION, SOUTHEAST GOLDEN VALLEY COUNTY, NORTH DAKOTA

PLATE II

STRATIGRAPHIC SECTION OF THE SENTINEL BUTTE MEMBER OF THE TONGUE RIVER FORMATION, SOUTHEAST GOLDEN VALLEY COUNTY, NORTH DAKOTA

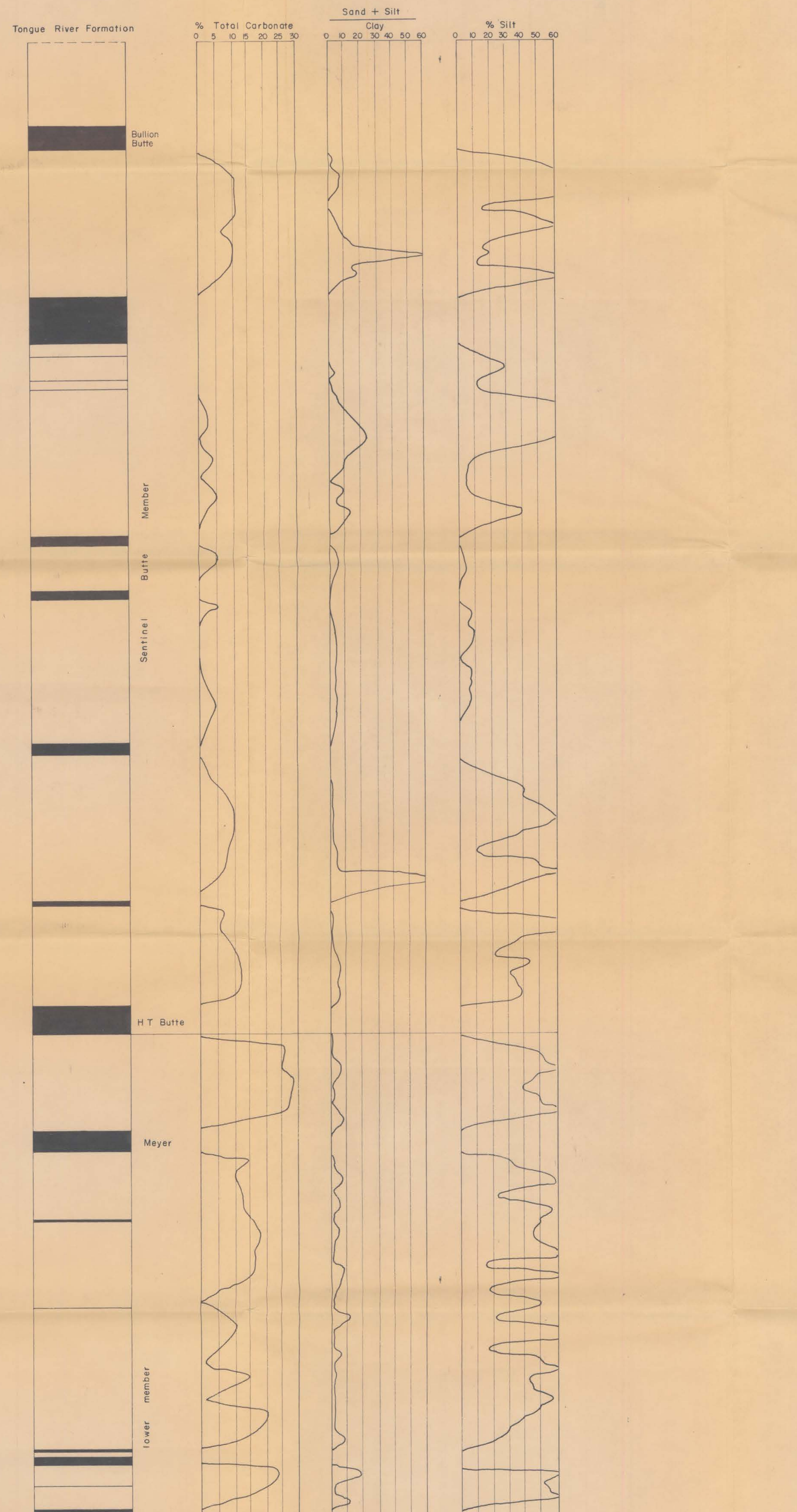

PLATE III

CARBONATE ANALYSES of the
TONGUE RIVER FORMATION