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Paleontology of brackish-water faunas in two tongues of the Cannonball Formation (Paleocene, Danian), Slope and Golden Valley counties, southwestern North Dakota

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ERRATA

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Pl. 1, fig. 5, page 60, should read "Cat. No. 13798)."

Pl. 2, fig. 4, page 62, should read "Cat. No. 13484)."

Pl. 2, fig. 5, page 62, should include "(Univ. of N. Dak. Cat. No. 13802)."

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Page 52, should read "Hypotypes. -- Univ. of N. Dak. Cat. Nos. 13485, and 13802."

PALEONTOLOGY OF BRACKISH-WATER FAUNAS IN TWO TONGUES OF THE CANNONBALL FORMATION (PALEOCENE, DANIAN), SLOPE AND GOLDEN VALLEY COUNTIES, SOUTHWESTERN NORTH DAKOTA

by

James B. Van Alstine

Bachelor of Arts, Winona State College, 1971

A Thesis

Submitted to the Graduate Faculty

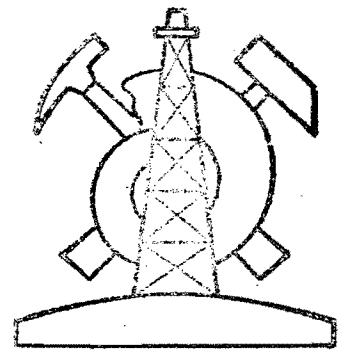
of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science



Grand Forks, North Dakota

December
1974

This Thesis submitted by James B. Van Alstine in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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ABSTRACT

In June and July, 1972, four stratigraphic sections were measured and described in Slope and Golden Valley Counties, southwestern North Dakota. Within the sections, the Cannonball and Ludlow Formations are recognized. The Cannonball consists of two tongues in the upper part of the Ludlow (perhaps equivalent to the Lebo Member), separated stratigraphically by about 30 m of Ludlow. The U tongue (upper tongue in the study area) is up to 11.7 m thick. The L tongue (lower tongue in the study area) is up to 3.8 m thick. The Cannonball is composed mostly of mudstones and the Ludlow consists of sandstones, mudstones, and lignite. The sections were sampled systematically for microfossils and macroinvertebrates, and 13 species in 12 genera were identified. Both formations can be distinguished by their contained fossils. The fauna of the U tongue of the Cannonball consists of three bivalves (Corbicula berthoudi?, Corbula (Bicorbula) subtrigonalis, and Crassostrea glabra) and the trace fossil Ophiomorpha. The fauna of the L tongue of the Cannonball consists of two foraminiferids (Trochammina sp. and ?Haplophragmoides sp.) and three bivalves (Corbicula berthoudi?, Corbula (Bicorbula) subtrigonalis, and ?Ostrea sp.). The Ludlow biota consists of 3 gastropods (Viviparus sp., Goniobasis cf. G. tenuicarinata, and ?Goniobasis sp.), 2 ostracods (Candona sp. and Ilyocypris sp.), and 1 charophyte (Sphaerochara sp.). No species are in common with the two formations and only two species are in common with the two Cannonball tongues (Corbicula berthoudi? and Corbula (Bicorbula) subtrigonalis).

The ostracods and the charophyte in the Ludlow and the foraminiferids, ?Ostrea sp., and Ophiomorpha in the Cannonball tongues are here newly reported. The foraminiferids and Ophiomorpha have been reported from the marine Cannonball to the east of the study area, whereas ?Ostrea sp. is newly reported for the formation. The fauna of the tongues is characteristically brackish, but three species of the L tongue (Trochammina sp., ?Haplophragmoides sp. and ?Ostrea sp.) suggest conditions of slightly higher salinity than those in which the U tongue was deposited. The two tongues are interpreted to have been deposited on tidal flats and in lagoons in an interdeltaic region behind a barrier island.

INTRODUCTION

The primary purpose of this thesis is to establish the paleontology of faunas of tongues of the Cannonball Formation, within the stratigraphic interval between the T Cross and Yule lignite beds, in Slope and Golden Valley Counties, southwestern North Dakota. This was accomplished by differentiating tongues of the Cannonball, defining their stratigraphic limigs, and identifying the contained faunas. Secondary purposes of this study are to determine the extent of interfingering of the Cannonball and Ludlow Formations within the study interval, and attempt to establish the environment of deposition of the tongues.

Based on the contained faunas, two brackish-water, stratigraphic units were defined. For purposes of clarification, the upper tongue (essentially that of Leonard, 1908) is referred to informally as the U tongue, and the lower tongue (essentially that of Brown, 1948) is referred to informally as the L tongue.

PREVIOUS WORK

General

Because of the interfingering of the Cannonball and Ludlow Formations, and the three distinct facies (marine, brackish, and fresh-water) in the study area and in the area to the east and west of it, all three are considered in this section. The previous work in stratigraphy and paleontology of the Cannonball and Ludlow Formations is covered briefly, with a more detailed historical account presented of the Cannonball tongues.

Cannonball Formation

Stratigraphy.--The Cannonball was first named by Lloyd (1914) as the Cannonball marine member of the Lance Formation, and designated as the upper 250-300 feet of the formation.

Earlier workers (notably Meek and Hayden, 1856 and Hayden, 1857), who explored and mapped the lignite-bearing strata of the western Dakota Territory, did not differentiate the Cannonball, generally confusing it with the late Cretaceous Fox Hills Formation ("Formation number 5"). Leonard (1908, p. 44) considered everything above the Cretaceous Fox Hills and Pierre Formations of the Fort Union Formation, and did not differentiate members. Lloyd and Hares (1915) elaborated on Lloyd's 1914 work and differentiated the Ludlow lignitic member of the Lance Formation. This member was suggested to be the non-marine equivalent of the Cannonball member of the Lance Formation.

Fox and Ross (1942) elevated the Cannonball to formational status within the Fort Union Group and, based on foraminiferal assemblages, suggested a Paleocene age. Laird and Mitchell (1942) adopted the formational status and Paleocene age of Fox and Ross (1942) for the Cannonball. (For a more detailed discussion of the history of the stratigraphy of the Cannonball Formation, see Cvancara, 1965, p. 1-13.)

Paleontology.--The Cannonball biota consists of foraminifers (Fox and Ross, 1942; Fox and Olsson, 1969; Fenner, 1974), corals (Vaughan, 1920; Wilson, 1957), bryozoans (Cvancara, 1965), mollusks (Stanton, 1920; Cvancara, 1966, 1970a; Feldman, 1972), ostracods (Swain, 1949), crabs (Holland and Cvancara, 1958), lobsters (Feldman and Holland, 1971), Ophiomorpha (Cvancara, 1965), sharks (Stanton, 1920; Leriche, 1942), skates, rays, turtles, and crocodiles or alligators (Cvancara, 1965), dinoflagellates and hystrichospharids (Stanley, 1965), spores and pollen (Stanley, 1965) and driftwood (Cvancara, 1970b) (adapted from Cvancara, 1972). For a more detailed discussion of the history of Cannonball paleontology, see Cvancara (1965, p. 13-19).

Ludlow Formation

Stratigraphy.--In 1854, F. V. Hayden explored the coal-bearing strata of the Great Plains area of Montana and the Dakotas. He called the strata the "Great Lignite Group" without differentiating any subunits (Hayden, 1862). Meek and Hayden (1862, p. 433) substituted the name "Fort Union Group" for strata along the Missouri River between Snowden, Montana and Buford, North Dakota. King (1876) introduced the term "Laramie" for lignite beds on the Laramie plains of Wyoming, complicating the nomenclature (Great Lignite Group = Fort Union Group =

Laramie Group). Addition of other informal names in the literature such as "Ceratops beds," "Lower Fort Union," and "Somber beds" complicated the already confused nomenclature. The present subdivisions of the "Great Lignite Group," accomplished by many workers over many years, is as follows (in ascending order): Upper Cretaceous Lance (Stanton, 1910, p. 181) and Hell Creek (Brown, 1907, p. 829-835) Formations; Paleocene Tongue River (Taff, 1909, p. 129-131), Sentinel Butte (Leonard, 1908, p. 57), Cannonball (Lloyd, 1914, p. 248-249) Formations and the Tullock (Rogers and Wallace, 1923, p. 29) and Lebo (Stone and Calvert, 1910, p. 746) Members of the Ludlow (Lloyd and Hares, 1915, p. 523-547) Formation.

The use of the terms "Tullock," "Lebo" and "Ludlow" is still uncertain in North Dakota. (More complete discussions of the evolution of the "Great Lignite" nomenclature are given by Brown (1962) and Frye (1969).

Paleontology.--Early workers in the "Great Lignite Group" reported a diverse fauna and flora from the lignite-bearing strata. The Ludlow was not differentiated, however, so an early list of the biota for it alone is not available. Delimata (1969, p. 9) characterized the Ludlow as essentially unfossiliferous except for poorly preserved plant fragments. Brown (1962), in his extensive study of the diverse Paleocene flora, did not differentiate the Fort Union Formation. Frye (1967) reported several species of plants, vertebrates, and invertebrates, from the Ludlow formation, but he had few illustrations, and did not include species descriptions. To date, there is no list of the biota for the Ludlow formation.

Cannonball Tongues

Stratigraphy.--Leonard, in 1907, first discovered oysters along the banks of the Little Missouri River near Yule, North Dakota in sec. 16, T. 135 N., R. 105 W. The oysters were approximately 152 m (500 feet) above the base of the Lance Formation (Leonard, 1908, p. 49). Lloyd and Hares (1915, p. 540) stated that the oysters of Leonard (1908) occurred about 212 m (700 feet) above the base of the Lance Formation, and 36.5 m (120 feet) below the base of the Fort Union Formation. Hares (1928, p. 24-30) reported that the oysters of Leonard (1908) were about 21 m (70 feet) above the T Cross lignite bed. According to Hares, the closest occurrence of the marine Cannonball Formation was 48 km (30 miles) to the east, about 30 m (100 feet) above the T Cross lignite bed. He used this stratigraphic relationship to equate the tongues to the marine Cannonball. In the same paper, Hares listed two additional sites for the occurrence of oysters; sec. 10, T. 135 N., R. 105 W., and sec. 13, T. 134 N., R. 105 W., Slope County, North Dakota. Brown (1948, p. 1271 and 1962, p. 10) discovered a second tongue of the Cannonball Formation on the east bank of the Little Missouri River, in sec. 14, T. 135 N., R. 105 W., about 45 m (150 feet) below the oyster bed of Leonard (1908). Moore (1972) discovered a small patch of oysters at Brown's locality but about 33 m above the lower tongue. The patch is believed to be part of the same upper tongue of Leonard (1908). Moore (1972) also mentioned several other localities of oysters at the stratigraphic position of Leonard's upper tongue.

Paleontology.--Stanton identified the oysters found by Leonard (1908) as Ostrea subtrigonalis Evans and Shumard. In 1910 (p. 183) Stanton added another oyster species, Ostrea glabra Meek and Hayden.

Brown (1948, p. 1271) reported a species of Corbicula and Corbula (1962, p. 10) from a second tongue of the Cannonball Formation 45 m (150 feet) below the oysters of Leonard (1908, p. 49). Cvancara (1965) reported Corbicula cf. C. berthoudi White from the upper tongue of Leonard (1908) associated with the oyster Crassostrea glabra (Meek and Hayden). Cvancara also identified the Corbula of Brown (1962) as Bicorbula subtrigonalis (Meek and Hayden). Moore (1972) reported the occurrence of the trace fossil Ophiomorpha from the upper tongue of Leonard (1908).

MATERIALS AND METHODS

Field Work

Field work was carried out during the summer of 1972. Four detailed stratigraphic sections were measured (Figures 1 and 3) and sampled systematically for microfossils. Each section was measured where macrofossils were observed, and where the most complete sequence could be obtained. Positions of measured sections and fossil localities were established by using county road maps and air photos. A Craftsman hand level and a 2-m Jacob staff were used in measuring the thickness of the units. All distinct beds were measured and described (Appendix II). The Geological Society of America Rock Color Chart (Goddard et al., 1963) was used in describing the colors of the units. A Wentworth scale, sand gauge was used to describe the particle size of the sands.

Macrofossils were collected wherever they were observed within and adjacent to the measured sections. Locations of macrofossils, whether observed or collected, are given in Appendix I. A bulk sediment sample (approximately 1 liter for microfossils) was collected from the center of each 1-m interval in a unit, or from the center of each unit, if less than 1-m thick. Lignite beds were measured, but not sampled. A systematic sampling method was employed rather than a random method, because the tongues are relatively thin compared to the total thickness of a section. With totally random sampling, it is

conceivable that a complete tongue (undefined by macrofossils) could be missed.

Preparation of Macrofossils

All macrofossils were cleaned as much as possible with a dental pick (under a binocular dissecting microscope) and a white Air Abrasive Unit. Friable specimens were sprayed with clear lacquer to prevent breakage.

Preparation of Microfossils

The entire 1-liter bulk sample was crushed in a jaw crusher, with a 500-ml subsample for microfossil analysis split out randomly. The entire 500-ml subsample was soaked in a 5% Calgon (Sodium hexametaphosphate) solution to deflocculate the clays. A very slight agitation was applied to insure a complete disaggregation of the sediment. After soaking, the samples were wet sieved through a 250 mesh sieve to remove the silt and clay size fraction. All material remaining on the sieve was dryed at room temperature and saved for further analysis. If the bulk sample was not disaggregated, a second (and rarely a third) soaking in 5% Calgon solution was attempted. The remaining dry samples were split randomly into workable subunits (about 50 ml), usually 1/2, 1/4, or 1/8 of the dry sample. This subsample was dry sieved through Tyler hand sieves of 20, 50, 60, 80, and 120 mesh. The size fractions of each prepared sample were scanned under a binocular microscope (9, 27, and 54 power) and all microfossils were picked.

Photographic Methods

Photographs of the macrofossils were made with normal light optics with a Leitz "Aristophot" apparatus consisting of a Leitz 4 inch X 5 inch camera, bellows, and Summer 12 cm lens. Magnification varied, depending on size of specimens from 3/4X to 4X. All macrofossils were photographed on Kodak Panatomic-X film. All macrofossils were coated with ammonium chloride to help bring out detail.

All microfossils were photographed with a scanning electron microscope. Magnification of all microfossils is 100X, except for the detailed photograph of Ilyocypris (500X).

GEOLOGIC SETTING

Structure

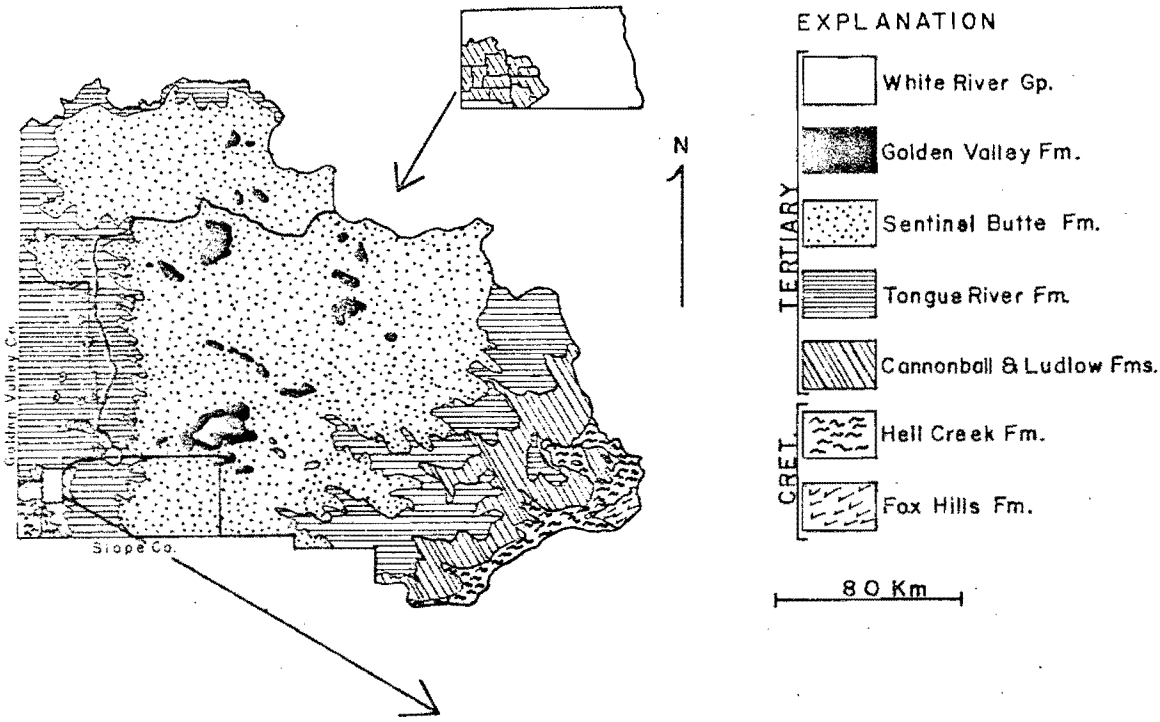
The major structural feature affecting the Cretaceous and Tertiary strata in North Dakota is the Williston Basin, with dips toward the center of the basin of less than 1°. On the southwest edge of the Williston Basin is the Cedar Creek anticline with dips of 5°-20° on the west limb and 3° on the east limb. Ballard (1942) placed the center of the Williston Basin about 80 km southeast of Williston, North Dakota (using the top of the Cretaceous "Dakota Sandstone" as datum). Benson (1952) suggested that the center of the basin was farther to the east during the Paleocene, using structure contours drawn on the top of the Tertiary beds. Electric well-log information (Carlson, 1973) agrees with Benson's suggestions of a more eastward position of the Paleocene center of the Williston Basin. Hares (1928) used the lignite beds in the Ludlow and Tongue River Formations to study the structure in southwestern North Dakota (on the eastern flank of the Cedar Creek anticline). He arrived at an average strike of N. 30° W., and an average dip of 20 feet per mile to the northeast.

Stratigraphy

The late Cretaceous and early Tertiary rocks in North Dakota are generally of two types: largely nonmarine strata (Hell Creek, Ludlow, Tongue River, and Sentinel Butte Formations) forming a wedge of sediment

thickening to the west, and marine strata (Pierre, Fox Hills, and Cannonball Formations) forming a wedge of sediment thickening to the east (fig. 2). Interfingering of marine and nonmarine strata occurs between the Fox Hills and Hell Creek Formations (Frye, 1967) in the Missouri River Valley and its tributaries, and in the southwestern most part of the state. The Paleocene Cannonball Formation in the study area interfingers with, and is underlain and overlain by, its nonmarine stratigraphic equivalent, the Ludlow Formation. In descending order, the Ludlow Formation is underlain by the late Cretaceous nonmarine and brackish Hell Creek Formation, the marine Fox Hills Formation, and the marine Pierre Formation. The Ludlow Formation is overlain, in ascending order, by the Paleocene nonmarine Tongue River and Sentinel Butte Formations. The Paleocene strata, collectively called the Fort Union Group in North Dakota, are overlain by the nonmarine Paleocene and Eocene Golden Valley Formation and the Oligocene White River Group.

Fig. 1. Geologic map of southwestern North Dakota showing Cannonball and adjacent formations (adapted from Carlson, 1960) and detailed map of northwestern Slope and southeastern Golden Valley Counties, showing fossil localities (l) and measured section localities (sl). Measured sections are shown graphically in Figs. 3-4, and described in detail in Appendix II. All locality descriptions are given in Appendix I.


EXPLANATION
White River Gp.
Golden Valley Fm.
Sentinal Butte Fm.
Tongue River Fm.
Cannonball & Ludlow Fms.
Hell Creek Fm.
Fox Hills Fm.
TERTIARY
CRET.
N
80 Km
Golden Valley Co.
Slope Co.

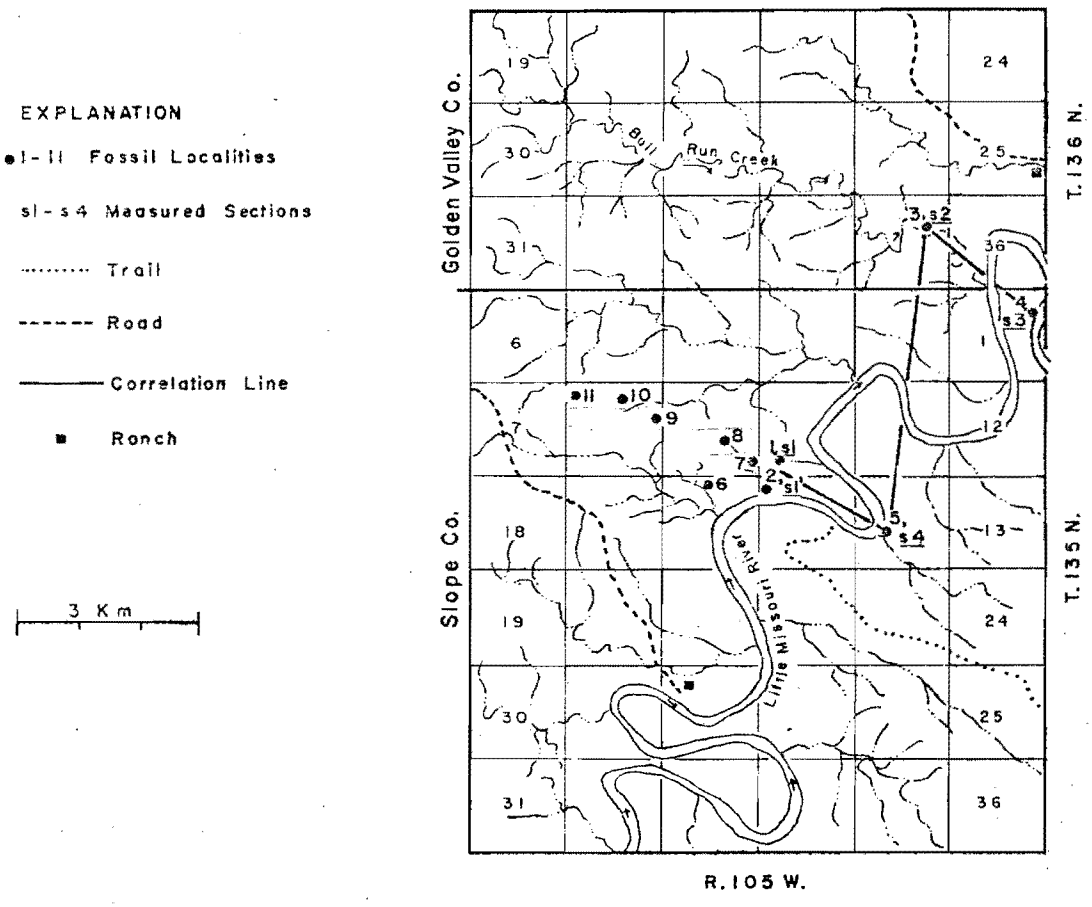
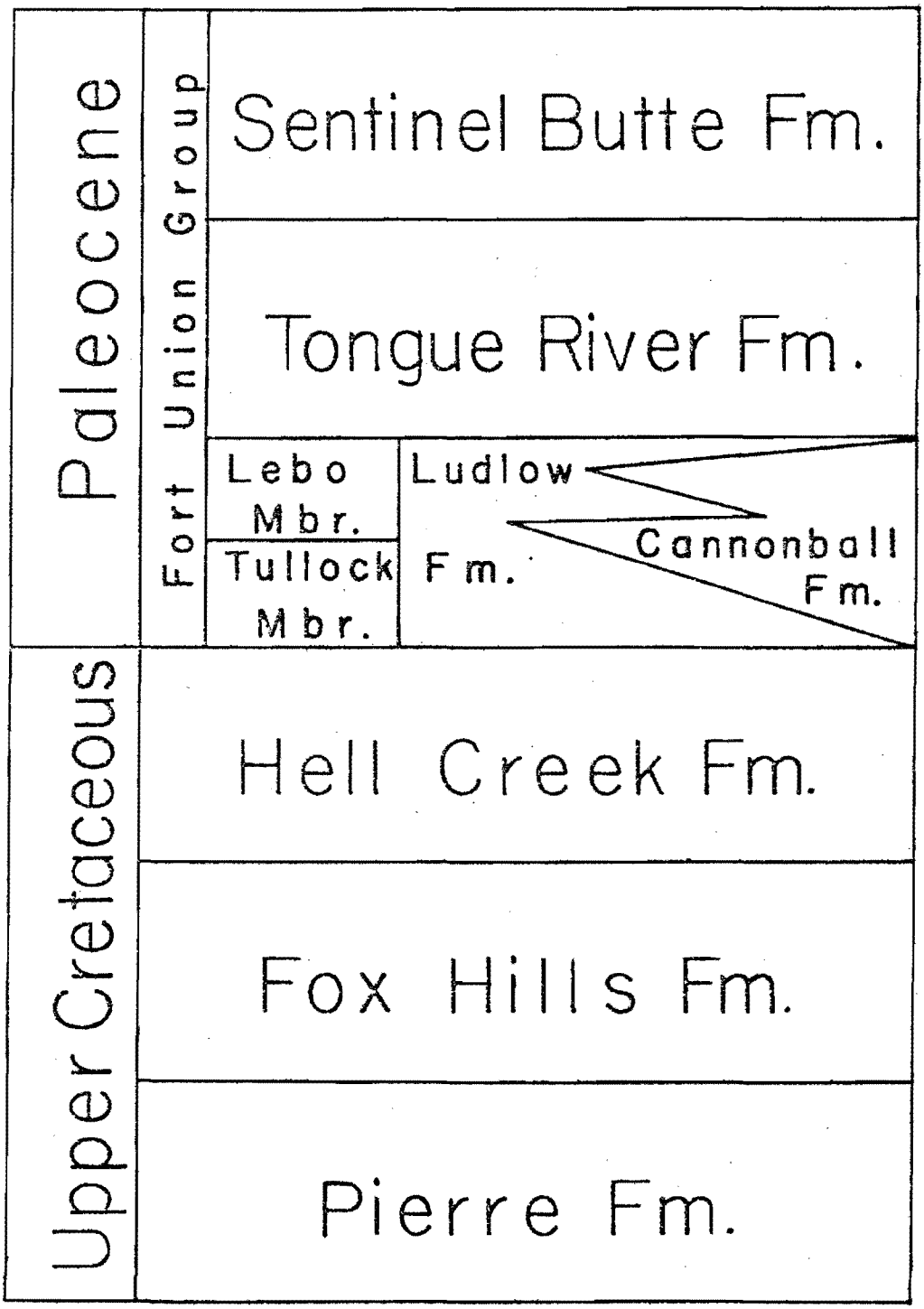

EXPLANATION
●I-II Fossil Localities
sl-s4 Measured Sections
Trail
Road
Correlation Line
Ranch
3 Km
Golden Valley Co.
Slope Co.
Ball Run Creek
Little Missouri River
T.136 N.
T.135 N.
R.105 W.

Fig. 2. Generalized stratigraphic column for the Upper Cretaceous and Paleocene strata in North Dakota.


Paleocene
Upper Cretaceous
Fort Union Group
Sentinel Butte Fm.
Tongue River Fm.
Lebo Mbr.
Tullock Mbr.
Ludlow Fm.
Cannonball Fm.
Hell Creek Fm.
Fox Hills Fm.
Pierre Fm.

LITHOLOGY

Cannonball Formation

The Cannonball Formation is composed of an alternating sequence of sandstones and mudstones thickest (120 m) in the subsurface at Garrison Dam (Fox and Olsson, 1969). At the farthest known westward extent of the Cannonball in North Dakota (measured section 1, fig. 3) it thins to two tongues that have a total thickness of 10.95 m.

The Cannonball tongues are composed typically of poorly consolidated mudstones and sandstones. Well indurated concretions of either fine-grained sandstone or mudstone are present within the units. The mudstones of the Cannonball tongues, by far the most common lithology, are often sandy (mostly of very fine-grained quartz and mica), and contain lignitized plant particles and abundant selenite. The mudstones are generally blocky and are typically dark yellow brown on fresh surfaces. Weathered surfaces are generally light gray brown, with common selenite crystals. The Cannonball sandstones are typically very fine- to fine-grained, thinly bedded (beds less than 2 cm thick), and often interbedded with mudstones. Mica and small lignitized particles are common constituents, but quartz is the most common mineral. Marcasite nodules are present in places, but not common. The sandstones are generally poorly consolidated, with scattered, well indurated, lenticular concretions. The fresh surface is generally medium yellowish brown and the weathered surface is typically light yellowish gray. Uncommon

planar bedding and cross bedding occurs in the sandstones of the Cannonball tongues.

Ludlow Formation

The Ludlow Formation is about 76 m thick in the vicinity of Wibaux, Montana (May, 1954), and thins eastward. Laird and Mitchell (1942) measured only 5.2-15 m in southern Morton County, North Dakota.

The Ludlow Formation in the study area is typically composed of alternating mudstones, sandstones, lignite beds, and common sandstone and mudstone concretions. A typical sequence in the sections is a lignite bed (0.5-1 m thick) overlain by sandstone or sandy mudstone, which, in turn, is overlain by mudstone, and finally overlain by another lignite bed. The Ludlow mudstones, more common than sandstones, are generally poorly consolidated, often sandy or interbedded with fine sandstone and commonly bentonitic. Lignitized plant fragments and selenite are common in all Ludlow mudstones. The mudstones are more often blocky on fresh surfaces than fissile, and typically very dark brown to gray brown when moist. The weathered (dry) surface is generally light yellowish gray-brown. A swelling "popcorn"-like surface is present if the mudstone is bentonitic. The Ludlow sandstones are typically fine- to medium-grained, poorly consolidated and often interbedded with mudstone. Mica and lignite particles are common constituents, but quartz is the most common mineral. Well indurated, lenticular and tabular sandstone bodies, as well as smaller concretions, are common throughout the sections. The sandstones are typically yellowish gray on fresh (moist) surfaces, and light yellowish gray on weathered surfaces (dry). There is little evidence of sedimentary structures other than uncommon,

faint cross bedding within the study interval. The lignite beds in the Ludlow Formation are less than 0.10 m thick to about 3.5 m thick. The average thickness within the study area is about 1 m.

ANALYSIS OF FAUNA

Cannonball Fauna

The Cannonball fauna consists of foraminiferids, bivalves, and the trace fossil Ophiomorpha. The bivalves are the most abundant in numbers of specimens and species.

Foraminiferids.--Two genera of foraminiferids are newly reported for the Cannonball tongues. They occurred only at locality 5(A1072) (Appendix I and fig. 1). Both genera (Trochammina and ?Haplophragmoides) have been reported from the marine Cannonball to the east of the study area by Fenner (1974).

Bivalves.--Four species of bivalves, in four genera occur in the tongues of the Cannonball Formation. Corbicula berthoudi? and Corbula (Bicorbula) subtrigonalis occurred at localities 1(A1070), 5(A1072), 7, 8, 9, 10, and 11 (Appendix I and fig. 1). Crassostrea glabra occurred at localities 1(A1069), 3(a1078), 4(A1080), 5, 7, 8, 9, and 10 (Appendix I and fig. 1). ?Ostrea sp., newly reported for the Cannonball, occurred only at locality 5(A1072) (Appendix I and fig. 1). Other unidentified bivalve fragments and impressions occurred at localities 2(A1066) and 6(A1082) (Appendix I and fig. 1). Corbicula is the only bivalve in common with the Cannonball tongues and the marine Cannonball, having been reported by Stanton (1920) and Cvancara (1965).

Ophiomorpha.--The trace fossil Ophiomorpha is newly reported for the Cannonball tongues, at locality 4(A1081) (Appendix I and fig. 1). Ophiomorpha also occurs in the marine Cannonball (Cvancara, 1965).

Ludlow Fauna

The Ludlow fauna, collected within the measured sections, consists of charophytes, gastropods, and ostracods. The gastropods are the most abundant in species, but the ostracods are the most abundant in numbers of specimens.

Charophytes.--Sphaerochara is newly reported for the Ludlow Formation. It occurred only at locality 5(A1079) (Appendix I and fig. 1). Other unidentified plant remains (seed pods ?) were collected throughout the section.

Gastropods.--Three species (two genera) of gastropods are reported from the Ludlow Formation. Other unidentified fragments and immature specimens also were collected. Goniobasis cf. G. tenuicarinata and ?Goniobasis sp. occurred just above the L tongue at locality 5(A1075 and A1074) (Appendix I and fig. 1). Viviparus sp. was collected at the same locality, but about 9 m stratigraphically above the species of Goniobasis. Numerous, unidentified unionid bivalve fragments were also collected throughout the Ludlow Formation.

Ostracods.--Two genera of ostracods are newly reported for the Ludlow Formation. The most common, Candona, was found in localities 3(A1077), 4(A1079), and 5(A1076). It was always found in a mudstone, between the two tongues of the Cannonball. Ilyocypris is represented by two unmatched valves. It was found only at locality 4(A1079), again in a mudstone, between the two tongues.

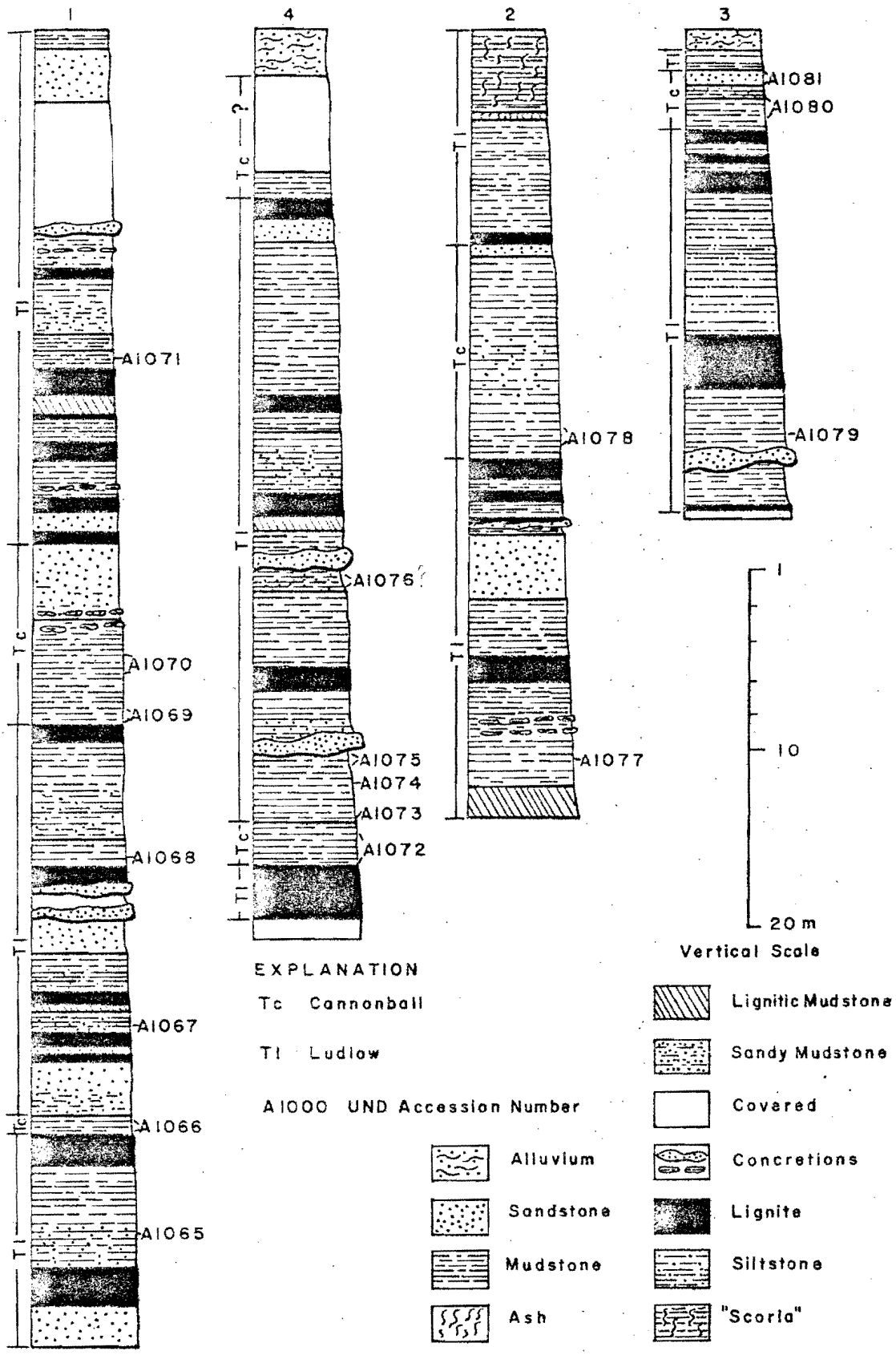
BIOSTRATIGRAPHY

Macrofossils were collected or noted from eleven localities in southwestern North Dakota (Appendix I and fig. 1). Fossils are generally uncommon within the study interval, although locally they occur in great numbers as do the oysters. The Cannonball tongues are readily defined on the basis of macrofossils and microfossils, even though the stratigraphic limits of the tongues were drawn on the basis of lithology in all but one case (the presence of lignite beds was used as an indicator of the Ludlow Formation). At locality 5(A1072 and A1073) the upper limit of the L tongue was drawn with certainty on the basis of macrofossils and microfossils (a unionid bivalve and the two species of Goniobasis directly overlying ?Ostrea, Corbula, Corbicula, Trochammina, and ?Haplophragmoides.

The species in the U tongue consists of: Corbicula berthoudi?, Corbula (Bicorbula) subtrigonalis, Crassostrea glabra and the trace fossil Ophiomorpha (generally considered sublittoral). The species in the L tongue consists of: Trochammina sp., ?Haplophragmoides sp., Corbicula berthoudi?, Corbula (Bicorbula) subtrigonalis and ?Ostrea sp. The apparent faunal differences between the two tongues (only two species in common) may be significant, in that the two units are readily distinguished on the basis of their contained fauna, and that the fauna in the L tongue appears to represent conditions of higher salinity. Three of the genera, Corbicula, Trochammina, and Haplophragmoides have been reported from the marine Cannonball (Stanton, 1920; Cvancara, 1965; Fenner, 1974).

The U tongue is readily traceable on the basis of the macrofossils. Crassostrea is the most noticeable, simply because of its mode of occurrence (large numbers in patches or lenses). Corbicula and Corbula are the only macrofossils found to the west of locality 10, allowing the U tongue to be traced about 1 km farther to the west (fig. 1). The other brackish and fresh-water genera and species within the measured sections are useful to limit and define the tongues stratigraphically, but are not useful in correlation because of their limited occurrences. In the Cannonball tongues and the Ludlow Formation, the fossils generally occur in the mudstones, the only except being Ophiomorpha, which occurs in a sandstone.

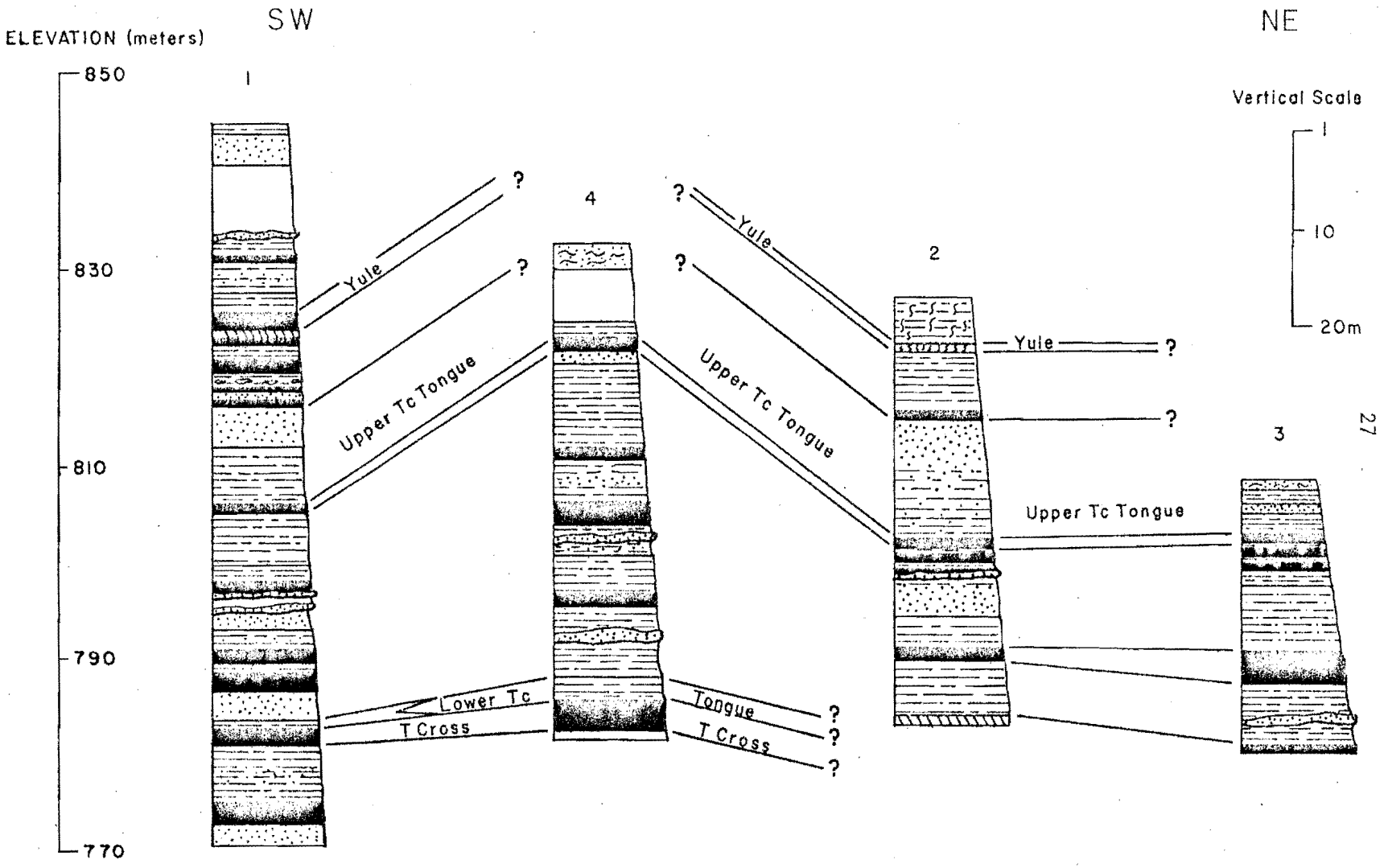
Fig. 3. Measured sections 1, 2, 3, and 4. Accession numbers (corresponding to those in Appendix III) to right of sections indicate stratigraphic positions of fossils collected. Measured section numbers correspond to those on Fig. 1, Fig. 4, and to Appendix II. Blank spaces indicate concealed parts of section. Ash symbols indicate a burned lignite bed.


1
4
2
3
Tl
Tc
?
A1071
A1070
A1069
A1068
A1067
A1066
A1065
A1076
A1075
A1074
A1073
A1072
A1078
A1077
A1081
A1080
A1079
1
10
20 m
Vertical Scale
EXPLANATION
Tc Cannonball
Tl Ludlow
A1000 UND Accession Number
Alluvium
Sandstone
Mudstone
Ash
Lignitic Mudstone
Sandy Mudstone
Covered
Concretions
Lignite
Siltstone
"Scoria"

CORRELATION

Correlation for the four measured sections (fig. 4) is based on faunal similarity and traceable lithologic units. The oyster Crassostrea glabra, which was first used to recognize the U tongue of the Cannonball Formation (Leonard 1908, p. 49), is still the most useful and important "correlation tool." This species was found in all four sections and only in the U tongue, providing the only means of correlation between all four sections. The Yule lignite bed, overlying the U tongue appears only in sections 1 and 2. The L tongue of Brown (1948 and 1962) as defined by brackish macrofossils and microfossils, appears only in measured section 4 (figures 3 and 4). The T Cross lignite bed, underlying the L tongue, is traceable to the west and occurs in measured section 1. The mudstone containing the brackish fauna in the L tongue in section 4, is also traceable to the west (Moore, 1972) but in measured section 1, what appears to be fresh-water mollusk impressions occur (A1082). A tentative correlation, based on Candona sp., fresh-water mollusk fragments, lithology, and stratigraphic position, is made in the Ludlow Formation, between measured sections 2, 3, and 4. An attempt to correlate the thickest lignite beds between measured sections 1 and 4, and between 2 and 3, is also made. The other lithologic units are not readily traceable because of the limited number of exposures, and the distance between the sections.

Fig. 4. Cross section with sections arranged according to elevation. Section numbers correspond to those on Fig. 1, and those on Fig. 3. Blank areas indicate concealed intervals. Symbols are explained on Fig. 3. Correlation is generally that of Moore (1972).


ELEVATION (meters)
SW
NE
850
830
810
790
770
1
4
2
3
Vertical Scale
1
10
20m
Yule
Upper Tc Tongue
Lower Tc
T Cross
Tongue
?
27

The Cannonball in the study area is thought to interfinger with the Lebo Member of the Ludlow Formation (the upper part of the formation).

AGE

A Paleocene age for the Cannonball formation has been accepted since Dorf (1940, p. 231) indicated a Paleocene age for its nonmarine stratigraphic equivalent, the Ludlow Formation, based on plants. Previously, the Cannonball had been considered Tertiary, by Lloyd (1914, p. 248) and late Cretaceous by Stanton (1920). Fox and Ross (1942) substantiated a Paleocene age for the Cannonball based on a comparison of the Cannonball foraminiferid fauna with that of the Paleocene (Midway) of the United States Gulf Coast. Swain (1949), using ostracods, indicated a Paleocene age for the Cannonball formation. Stanley (1965), using plant microfossils, also indicated a Paleocene age. Cvancara (1966), in a revision of the Cannonball bivalves, indicated a Thanetian stage (late Paleocene) for the Cannonball, and Fox and Olsson (1969) specifically assigned the Cannonball to the Danian stage of the Paleocene. Sloan (1970) gave an early to middle Paleocene age for the Cannonball, based on mammal remains in the overlying Tongue River Formation. The species identified in my study are not useful for further refinement of the Paleocene (Danian) age.

PALEOECOLOGY

Microfaunal Paleoecology

The foraminiferid fauna in my samples (Trochammina and ?Haplophragmoides) are considered to be shallow, brackish-water forms, although able to withstand more marine conditions.

Todd and Bronnimann (1957) reported common to abundant Trochammina and abundant Haplophragmoides in a tidal flat marsh in 2- 18 fathoms of water. Murray (1968) also reported common Trochammina from Buzzards May Massachusetts at depths of 12- 24 m. Fenner (1974) stated, on the basis of foraminiferid assemblages containing Trochammina and Haplophragmoides, that the marine Cannonball was probably deposited in a shallow sea from 5-50 fathoms deep.

Both Trochammina and ?Haplophragmoides are agglutinated forms. Greiner (1970, p. 83) stated that agglutinated foraminiferids predominate in areas of low salinities. Lowman (1949, p. 1956) reported Haplophragmoides and Trochammina from salt marshes of the United States Gulf Coast, and considered these genera most characteristic of a stagnant (poorly oxygenated) environment. Remane and Schlieper (1971, p. 89, fig. 32) indicated that Trochammina is characteristic of brackish to brackish-marine conditions. Parker and Athearn (1959) also reported Trochammina and Haplophragmoides from salt marshes and indicated a decrease in abundance toward more marine waters.

Macrofaunal Paleoecology

The macrofauna of the Cannonball tongues consists of the bivalves Corbula (Bicorbula) subtrigonalis, Corbicula berthoudi?, Crassostrea glabra, and ?Ostrea, and the trace fossil Ophiomorpha. All the bivalves are considered brackish-water genera, with Crassostrea being especially diagnostic of brackish, shallow water.

Korringa (1956) and Hedgpeth (1953) both stated that Crassostrea can be cosmopolitan, but reaches its maximum occurrence in bays, lagoons, and estuaries, where a reduced salt content occurs. Korringa (1956) also reported that even though Crassostrea is found in many coastal areas, it only forms banks (reefs) in lagoons. A partial explanation for the increase in numbers of individuals under these conditions is the abundance of nutrients and escape from parasites and predators, not able to tolerate reduced salinity.

Ostrea is also considered a brackish to marine form but it can not tolerate brackish conditions to the extent as Crassostrea (Cox et al., 1971). Dahl (1948, 1956) stated that Crassostrea can penetrate much farther into water of low salinity than Ostrea, and can settle more easily on soft substrates. This may possibly explain the absence of Ostrea and the abundance of Crassostrea in the U tongue. If the upper unit is indeed more brackish (less marine), as is interpreted, there should be a lack of forms, such as Trochammina, ?Haplophragmoides, and ?Ostrea, that require higher salinity, and an abundance of forms that can tolerate conditions of reduced salinity such as Crassostrea.

The other bivalve genera, Corbula and Corbicula, are not as useful as strict brackish-water indicators. Both living genera can exist

in marine, brackish, or fresh waters (Cox et al., 1971). Sinclair (1971) reported that an introduced species of Corbicula is invading rivers of the Pacific and Gulf of Mexico coasts, and is apparently thriving. The suggestion that both genera seem relatively tolerant to salinity changes, might explain their presence in both tongues of the Cannonball (the only two species in common), even though the L tongue appears to represent conditions of higher salinity, as well as their presence in the farthest westward extention of the U tongue (fig. 1, locality 11). Locality 11 is interpreted to be the closest locality to the paleo-shore line. Corbicula is an infaunal form (Sinclair, 1971), which might have allowed it to tolerate sudden salinity changes (the interstitial water in the substrate acts as a buffer) from floods or heavy rains that would be experienced in the shore side of an estuary or lagoon.

The trace fossil Ophiomorpha, present at the top of the U tongue, is indicative of wave-agitated, littoral or shallow sublittoral conditions (Howard, 1972). According to Howard, the present-day equivalent to the organism that produced Ophiomorpha is the crustacean Callianassa major, a shore face inhabitant.

The fauna in the Ludlow Formation, which overlies and underlies the Cannonball tongues in the study area, is considerably different from the fauna of the tongues (no species or genera in common), and it is considered to be a fresh-water fauna. The specific paleoecology of the genera in the Ludlow will not be considered here.

PALEOENVIRONMENTS OF THE CANNONBALL TONGUES

The tongues of the Cannonball Formation studied here are interpreted to have been deposited in lagoons and tidal flats in an interdeltaic region behind a barrier island, because the fauna in both tongues is diagnostic of shallow, brackish water, associated with a tidal flat or lagoon. The salinity in a lagoon is variable, depending on the nearness to a tidal channel or a river mouth (Reineck and Singh, 1973, p. 350). The possibility that the L tongue was deposited in water of a higher salinity than the U tongue indicates that the L tongue may have been deposited farther from a river mouth or tidal channel than the U tongue, at least in the study area. Lateral migration of the channel or lagoon could result in the vertical change observed (a fauna indicating a lower salinity overlying a fauna indicating a higher salinity).

Ophiomorpha is indicative of littoral or shallow sublittoral conditions (Howard, 1972). In the study area this trace fossil is found in a clean, well sorted sandstone, on top of the oyster-bearing mudstone in the U tongue (fig. 3, sec. 3). This sequence can be explained by the transgression of the barrier sand body over the top of the lagoonal deposits.

The sediments in the tongues are predominantly mudstones. According to Reineck and Singh (1973), lagoon-bottom deposits are primarily dark black-brown mudstones. Primary structures are not evident because of destruction due to bioturbation.

The sediment source would most likely have been a low coastal plain. The sediment would have been silt and clay, carried in suspension, and dispersed laterally along the coast (LeBlanc, 1972). Sand would have had to have been available in enough quantity to form the barrier complex (Reineck and Singh, 1973). A low-land source area (low coastal plain) is indicated by the fine grain size of the sediments (Twenhofel, 1932, p. 119).

The Ludlow fauna is composed of fresh-water forms found exclusively in mudstones, indicating that the mudstones were deposited in fresh-water swamps, marshes, or lakes. The abundance of lignite beds in the Ludlow is also an indication of a low, swampy, coastal plain (Fisher, 1968).

Fenner (1974) indicated a shallow, near-shore environment of deposition for the marine Cannonball, with limited access to the open sea. The proposed environments of the Cannonball tongues fits well with Fenner's model, possibly representing that area immediately adjacent to the coast.

A modern analog, mentioned by Cvancara (1972, p. 73) might be the area along the northern coast of the Netherlands, where the Frisian islands form a barrier separating the North Sea from the Wadden Sea. The Wadden Sea has been an area in which considerable research has been conducted on estuarine and tidal-flat sedimentation.

CONCLUSIONS

The following conclusions are based on field relationships, as well as laboratory analyses of the microfossils and macrofossils collected from four stratigraphic sections in the study area.

1. Two formations, the Cannonball and Ludlow, are recognized in the study area. The Cannonball consists of two tongues, in the upper part of the Ludlow (perhaps equivalent to the Lebo member). The Cannonball tongues are separated stratigraphically by about 30 m of Ludlow Formation. The U tongue (upper tongue in the study area) is up to 11.7 m thick (at section 3). The L tongue (lower tongue in the study area) is up to 3.8 m thick (section 4).

2. The Cannonball lithology is mostly of mudstone, differing from the Ludlow which consists of sandstones, mudstones, and lignite.

3. The fauna of the U Cannonball tongue consists of three bivalves (Corbicula berthoudi?, Corbula (Bicorbula) subtrigonalis, and Crassostrea glabra) and the trace fossil Ophiomorpha.

4. The U tongue appears to extend the farthest to the west, as defined by Corbula and Corbicula.

5. The fauna of the L Cannonball tongue consists of two foraminiferids (Trochammina sp. and ?Haplophragmoides sp.) and three bivalves (Corbicula berthoudi?, Corbula (Bicorbula) subtrigonalis, and ?Ostrea sp.).

6. The Ludlow fauna consists of three gastropods (Viviparus sp., Goniobasis cf. G. tenuicarinata, and ?Goniobasis sp.), two ostracods (Candona sp., and Ilyocypris sp.), and one charophyte (Sphaerochara sp.). All species are generally considered fresh-water.

7. The ostracods and the charophyte in the Ludlow formation, and the foraminiferids, ?Ostrea sp., and Ophiomorpha, in the Cannonball tongues are newly reported here. The foraminiferids and Ophiomorpha have been reported in the marine Cannonball, whereas ?Ostrea sp. is newly reported for the formation.

8. The fauna of the Cannonball tongues is considered to be brackish-water.

9. Three species of the L tongue (Trochammina sp., ?Haplophragmoides sp., and ?Ostrea sp.) suggest that the L tongue was deposited in water of slightly higher salinity than the U tongue.

10. The Cannonball tongues are interpreted to have been deposited on tidal flats or in lagoons, in an interdeltaic region, behind a barrier island.

SYSTEMATIC PALEONTOLOGY

The classifications for the fauna used here are as follows: Charophytes, Peck (1957); Foraminiferids, Loeblich and Tappan (1964); Ostracods, Van Morkhoven (1963); Bivalves, Cox et al. (1969, 1971), Gastropods, Wenz (1938), with the descriptions and diagnoses adapted from Meek (1876); and Ophiomorpha, Hass et al. (1962).

The generic diagnoses are adapted from the above sources and are rearranged where necessary to follow a more consistent, logical order. The species descriptions were edited to attempt to remove generic characters. Generic synonymies are not included, and only the original reference for each genus is included. Locality numbers correspond to those in Appendix I and III, and fig. 3 and accession numbers correspond to those in Appendix I and III, and figs. 1 and 3.

All specimens are stored in the University of North Dakota geology department, Grand Forks, North Dakota.

Order Foraminiferida

Suborder Textulariina

Family Trochamminidae Schwager, 1877

Genus Trochammina Parker and Jones, 1859

Original reference.--Parker and Jones, 1859, p. 347.

Type species.--Trochammina inflatus (Montagu) = Nautilus inflatus Montagu, 1808, p. 81 (by original designation.

Diagnosis.--Test free, trochospiral; globular to ovate; chambers increasing in size gradually; aperture a low, interio-marginal,

extra umbilical-umbilical arch which may have a narrow bordering lip; wall agglutinated (adapted from Loeblich and Tappan, 1964, p. C259).

Remarks.--The geologic range of Trochammina is Carboniferous to Holocene (Loeblich and Tappan, 1964, p. C259).

Trochammina sp.

Pl. 1 Figs. 1, 3

Description of Cannonball material.--Test compressed in all but eight specimens; sutures on compressed specimens appear as raised, radial ribs, whereas sutures on inflated specimens are impressed; septa simple; five to seven chambers of about the same size; slighlly umbilicate; wall of very fine-grained particles (appear to be predominantly quartz) with much cement; light tan to brown.

Measurements.--Diameter of figured specimen, 0.5 mm (fig. 3).

Hypotype.--Univ. of N. Dak. Cat. No. 13797.

Occurrence.--Cannonball Formation, locality 5(A1072).

Material.--218 poorly preserved specimens (210 compressed, 8 inflated).

Discussion.--This form appears quite similar to Trochammina inflata (Montagu). The position of the aperture could not be determined with certainty, and would have to be known before a specific name can be assigned.

Most of the specimens (96.3%) have compressed chambers. This is common in species of Trochammina, which characteristically have thin-walled chambers.

Coiling direction of the test appears to have no significance. Orienting the specimens with dorsal side up, 47.2% are dextrally coiled, and 52.8% are sinistrally coiled.

The presence of foraminiferids from the Cannonball tongues is newly reported here. The association of Trochammina sp. with Corbicula berthoudi?, Corbula (Bicorbula) subtrigonalis, ?Ostrea sp., and ?Haplophragmoides sp. is a positive indication of a brackish-water environment.

Family Lituolidae de Blainville, 1825

Genus Haplophragmoides Cushman, 1910

Original reference.--Cushman, 1910, p. 99.

Type species.--Nonionina canariensis D'Orbigny, 1839, p. 128 (by original designation).

Diagnosis.--Test free, planispiral; involute; aperture an equatorial, interio-marginal slit (adapted from Loeblich and Tappan, 1964, p. C225).

Remarks.--The geologic range of Haplophragmoides is Carboniferous to Holocene (Loeblich and Tappan, 1964, p. C255).

?Haplophragmoides sp.

Pl. 1 Fig. 5

Description of Cannonball Material.--Specimen very small, poorly preserved; sutures and aperture not visible; wall of very fine-grained sand (predominantly quartz), with much cement; light tan.

Measurements.--Diameter of figured specimen, 0.55 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13798.

Occurrence.--Cannonball Formation, locality 5(A1072).

Material.--One poorly preserved specimen.

Discussion.--The poor preservation of the single specimen makes it impossible to determine the position of the aperture. The position,

as well as the shape, of the aperture would have to be known before a positive generic, much less specific name, can be assigned.

This genus was collected in association with Trochammina sp., Corbicula berthoudi, and Corbula (Bicorbula) subtrigonalis.

Haplophragmoides was reported by Fenner (1974) from the marine Cannonball to the east.

Class Gastropoda

Subclass Prosobranchia

Order Mesogastropoda

Family Viviparidae

Genus Viviparus Montfort, 1810

Original reference.--Montfort, 1810.

Type species.--Viviparus fluviorum Montfort, 1810 = (Helix vivipora Linnaeus).

Diagnosis.--Shell ovate or conoid-subovate, thin, usually with small, umbilical perforation; whorls rounded or more or less flattened; surface smooth, or with revolving lines or carinae; aperture more or less regularly oval; outer lip thin, straight in outline; operculm corneous (adapted from Meek, 1876, p. 576).

Remarks.--The geologic range of Viviparus is ?Carboniferous to Holocene (Wenz, 1938, p. 490).

Viviparus sp.

Pl. 2 Fig. 1

Description of Ludlow material.--Specimen poorly preserved, very small, with only apex and one other whorl present; smooth, with no obvious ornamentation (probably most of exterior of shell missing).

Measurements.--Because of the incompleteness of the specimen, no measurements were attempted.

Hypotype.--Univ. of N. Dak. Cat. No. 13803.

Occurrence.--Ludlow Formation, locality 5(A1076).

Material.--One poorly preserved, incomplete specimen.

Discussion.--Viviparus (=Paludina) was first reported from the Dakota Territory by Meek and Hayden (1856) near Fort Union, in the Judith River lignitic beds. My specimen was collected from the Ludlow Formation, lower Fort Union Group (Paleocene) above the L tongue of the Cannonball Formation. It was collected in association with other fresh-water mollusk fragments, and the ostracod ?Candona sp. The poor preservation, incompleteness of the specimen, and lack of any other material, makes it impossible to identify it as anything more than Viviparus sp., this being done primarily on shape of the apical whorls and occurrence.

Class Gastropoda

Subclass Prosobranchia

Order Mesogastropoda

Family Thiaridae Guillaume, 1924

Genus Goniobasis Lea, 1862

Original reference.--Lea, 1862, p. 262-271.

Type species.--Goniobasis osculata Lea (Hannibal, 1912, p. 112-211).

Diagnosis.--Shell subovate to elongate-conoidal, or subfusiform; apex often eroded; whorls flattened, more or less convex or sometimes angular; aperture usually ovate-rhomboidal and generally angular, but

without a canal below; outer lip without ridge or sinus, columella rarely slightly thickened toward apex; surface smooth, or variously ornamented with revolving lines, ridges, or vertical costae that are sometimes tubercular (Meek, 1876, p. 560).

Remarks.--The geologic range of Goniobasis is ?Upper Cretaceous to Holocene (Wenz, 1938, p. 699).

Goniobasis cf. G. tenuicarinata (Meek and Hayden)

Pl. 2 Fig. 2

Melania tenuicarinata Meek and Hayden 1857, p. 137.

Goniobasis tenuicarinata (Meek and Hayden(Meek, 1876, p. 566 Pl. 43, fig. 14.

For a more complete synonymy see Henderson, 1935, p. 228-229.

Diagnosis.--Shell narrow-subovate; spire conical, of medium height, pointed and not eroded at apex; whorls six, very convex, obliquely flattened abapically and angular around the mid-length; sutures well defined; surface ornamented by fine obscure growth lines, which are crossed in the middle of the whorls by 3 to 5 prominent, revolving lines, or narrow carinae, and on all parts of the shell excepting near the apex of the spire, by traces of very fine, indistinct, revolving striae; aperture ovate, angular adapically, narrowly rounded and very faintly sinuous abapically; lip slightly prominent below midline of aperture; columella gently arcuate (adapted from Meek,1876, p. 566).

Description of Ludlow material.--Specimen moderately well preserved but incomplete (apex and body whorl missing); ornamentation consists of three, well-defined carinae at regular intervals on whorl, and growth lines; whorls very convex, sutures well defined.

Measurements.--Height of incomplete, figured specimen 8.9 mm, maximum diameter of figured specimen, 7.7 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13804.

Occurrence.--Ludlow Formation, locality 5(A1075).

Material.--One moderately well preserved, incomplete specimen.

Discussion.--Goniobasis tenuicarinata (=Melania tenuicarinata) was first reported from the Tertiary rocks of the Dakota Territory by Meek and Hayden (1857) near Fort Union in the Tertiary "Lignite Formation." My specimen was collected from the Ludlow Formation, lower Fort Union Group (Paleocene) just above the L tongue of the Cannonball Formation. It was collected in association with other fresh-water mollusk fragments and in the same unit (2 m stratigraphically above) another species of Goniobasis sp.

Comparison is made with G. tenuicarinata based on the shape of whorls, spiral ornamentation, and general shape of the shell, even though the specimen is incomplete.

?Goniobasis sp.

Pl. 2 Fig. 3

Description of Ludlow material.--Shell elongate, spire conical, large; whorls slightly convex; sutures well defined; surface ornamented by prominent spiral and axial tubercular ridges or costae, as well as fine growth lines; specimen very poorly preserved, protoconch and aperture missing.

Measurements.--Because of the poor preservation of the specimen, no measurements were attempted.

Hypotype.--Univ. of N. Dak. Cat. No. 13805.

Occurrence.--Ludlow Formation, locality 5(A1074).

Material.--One poorly preserved, crushed, incomplete specimen.

Discussion.--Goniobasis (=Melania) was first reported from the Dakota "Tertiary Formations" of Nebraska Territory by Meek and Hayden (1856) near Fort Union. Meek (1876) reported and illustrated several species of Goniobasis from the "Judith River Fresh and Brackish water Lignite Beds at the mouth of the Judith River, Montana, probably belonging to the last division of the Cretaceous (Meek, 1876, p. 563)." My specimen was collected from the Ludlow Formation, lower Fort Union Group (Paleocene) just above the L tongue of the Cannonball Formation. The stratigraphic position is probably close to that of Meek (1876). The poor preservation of the studied specimen makes it impossible to identify it as anything more than ?Goniobasis sp., this being done primarily on shape, ornamentation, and occurrence.

Superfamily Corbiculacea

Family Corbiculidae Gray, 1847

Genus Corbicula Mergele von Mühlfeld, 1811

Original reference.--Mergele von Mühlfeld, 1811, p. 56.

Type species.--Tellina fluminalis Müller, 1774, p. 205 (designated ICZN, 1955).

Diagnosis.--Rounded-trigonal; concentric sculpture present; lateral teeth mostly serrate (Cox, L. R. et al., 1969, p. N666).

Remarks.--The geologic range of Corbicula is late Cretaceous to Holocene (Cox, L. R. et al., 1969).

Corbicula berthoudi White ?

Pl. 2 Figs. 13, 14, 15, 17, 18

Corbicula berthoudi White, 1882, p. 94, Pl. 4, figs. 1-3; 1883b, p. 438, Pl. 21, figs. 1-3. Stanton, 1920, p. 29-30, Pl. 5, figs. 1a-1b, 2, 3.

Corbicula cf. C. berthoudi White. Cvancara, 1966, p. 328-329, Pl. 6, figs. 7-12.

Diagnosis.--Shell large from genus, subtrigonal; beaks rather highly elevated; concave immediately in front of beaks; anterior margin regularly rounded, basal margin broadly rounded, posterior margin abruptly rounded; hinge strong; all teeth well developed, the laterals especially long; muscular and pallial impressions having usual characteristics; surface marked with concentric growth lines (adapted from White, 1882, p. 94-95).

Description of Cannonball Material.--All specimens are weathered, poorly preserved (incomplete and distorted); characteristically light brownish, and heavily encrusted with selenite.

Measurements.--Because of distortion and incompleteness of material, no measurements were attempted. An approximate idea of size can be gained from the illustrations.

Hypotype.--Univ. of N. Dak. Cat. Nos. 13799, 13428-13491.

Occurrence.--Cannonball Formation, localities 1 (A1070), 5(1072), 7, 8, 9, 10, and 11.

Material.--Seven compressed or incomplete specimens with both valves present, seven incomplete right valves (six with discernible dentition), ten incomplete left valves (nine with discernible dentition) and numerous, undetermined, incomplete valves.

Discussion.--Corbicula berthoudi White was first discovered from the Cannonball tongues by Brown in 1931 (Brown, 1962, p. 8) on the east

side of the Little Missouri River at locality 5(A1072). Cvancara (1966, p. 328-329), reported Corbicula cf. C. berthoudi from the west bank of the Little Missouri River at locality 1(A1070).

In the present study, specimens of Corbicula berthoudi? were collected in association with Corbula (Bicorbula) subtrigonalis on both the east and west bank of the Little Missouri River (localities 1(A1072), 7, 8, 9, 10, and 11).

Comparison of the size, general shape, cardinal and lateral dentition, and external growth ornamentation of the specimens in this study with the descriptions of White (1882 and 1883 b), Stanton (1920), and Cvancara (1966) allowed me to place, with only slight reservation, the studied specimens in the species Corbicula berthoudi White. A complete, well-preserved interior, showing the entire lateral teeth and muscle scars is required for a positive identification.

The occurrence of Corbicula berthoudi? in the U tongue in close proximity to the oyster Crassostrea glabra (two meters stratigraphically above) on the west side of the river, and in association with the foraminiferids Trochammina sp., ?Haplophragmoides sp., and ?Ostrea sp. on the east side of the river, in the lower tongue, indicate the brackish-water affinities of this species.

Superfamily Myacea

Family Corbulidae Lamarck, 1818

Genus Corbula Bruguiére, 1797

Subgenus Bicorbula Fisher, 1887

Original reference.--Fisher, 1887, p. 1123.

Type species.--Corbula gallica Lamarck, 1801 (by monotypy).

Diagnosis.--Shell large for family, inequivalved, keel obsolescent; sculpture weak; pallial sinus broad and shallow. (Cox et al., 1969, p. N692).

Remarks.--The geologic range of Corbula (Bicorbula) is Paleocene to Holocene (Cox et al., 1969).

Corbula (Bicorbula) subtrigonalis Meek and Hayden

Pl. 2 Figs. 10, 11 and 12

Corbula subtrigonalis Meek and Hayden, 1856, p. 116.

Corbula (Potamomya) subtrigonalis Meek and Hayden. Meek and Hayden, 1860b, p. 432.

Corbula (Pachydon) subtrigonalis Meek and Hayden. Meek, 1876, p. 529-530, Pl. 40, figs. 3a-b.

Corbula subtrigonalis Meek and Hayden. White, 1883a, p. 80, Pl. 25, fig. 6a-f; 1883b, p. 442, Pl. 19, figs. 10-17. Stanton, 1893, p. 123-124, Pl. 27, figs. 7-8.

Bicorbula subtrigonalis (Meek and Hayden). Cvancara, 1966, p. 343-345, Pl. 8, figs. 4, 5, 10 and 11.

Diagnosis.--Shell subtrigonal, very convex, obliquely truncate from the beaks to the extremities, the two slopes diverging at an angle of 95°; basal margin rounding up abruptly in front and converging towards the posterior slope at an angle of about 48°; beaks elevated, located ahead of the midline; hinge strong; right valve with strong, triangular, cardinal tooth, and long resilial pit; left valve with long, triangular socket; surface marked by faint growth lines and concentric winkles, becoming stronger toward the extremities (mainly from Meek and Hayden, 1856, with reference to Cvancara, 1966, p. 343-345, Pl. 8, figs. 4, 5, 10 and 11).

Description of Cannonball Material.--All specimens poorly preserved, interior and exterior heavily encrusted with selenite and characteristically light brown (preservation is similar to that of C. berthoudi?).

Remarks.--Although the studied specimens are poorly preserved, comparison with figured specimens of previous workers allowed the writer to place them in the species Corbula (Bicorbula) subtrigonalis.

Measurements.--Because of distortion and incompleteness of material, no measurements were attempted. An approximate idea of size can be gained from the illustrations.

Hypotype.--Univ. of N. Dak. Cat. No. 13800 and 13486.

Occurrence.--Cannonball Formation, localities 1(A1070) and 5(A1072), 7, 8, 9, 10 and 11.

Material.--Fourteen broken or crushed specimens with both valves present, five left valves with discernible dentition, five right valves with discernible dentition, and numerous, undetermined, incomplete valves.

Discussion.--Brown (1962, p. 8), reported the occurrence of species of Corbula and Corbicula from what was interpreted as a second tongue of the Cannonball Formation (34 m below the original tongue of Leonard 1908, p. 49) on the east bank of the Little Missouri River at locality 5(A1072). The Corbula was newly reported for the Cannonball Formation, whereas the Corbicula (Corbicula berthoudi) had been previously reported by Stanton (1920, p. 29-30). Cvancara (1966) studied the specimens of Corbula collected by Brown in 1931 and assigned them to Bicorbula subtrigonalis (=Corbula (Bicorbula) subtrigonalis), but did not report the species from elsewhere in the Cannonball Formation. The present studied specimens were collected from Brown's original

locality (locality 5(A1072)) in association with Corbicula berthoudi, ?Ostrea sp. and the foraminiferids Trochammina sp. and ?Haplophragmoides sp. Corbula (Bicorbula) subtrigonalis is here newly reported from the west bank of the Little Missouri River (locality 1(A1070), 7, 8, 9, 10 and 11) in association with Corbicula berthoudi? and in close proximity to (about 2 m stratigraphically above) the oyster Crassostrea glabra. This occurrence is about 34 m stratigraphically above Brown's locality, at the same horizon of Leonard (1908, p. 49).

Family Ostreidae Rafinesque, 1815

Genus Crassostrea Sacco, 1897

Original reference.--Sacco, 1897, p. 15.

Type species.--Ostrea virginica (Gmelin) 1791, p. 3336 (designated by ICZN opinion 338).

Diagnosis.--Shell small to very large (to 60 cm high), outline very variable among individuals but very high, slender, spatulate forms with subparallel anterior and posterior margins seeming to predominate; surface rough, with many non-appressed, irregularly spaced growth squamae, simple or frilled along free ends; steep-sided radial ribs on some individuals, more common on left valve than on right valve, such ribs tending to project beyond general outline of margins; chambers common and left valve with well-developed umbonal cavity; no chomata; adductor muscle scar close to posterior valve margin and closer to ventral margin than to hinge, its outline with two fairly sharp corners, dorsal margin nearly straight; slender, spatulate forms with left valve ligamental area higher than long and subparallel anterior and posterior boundaries, both flanked by many growth

foliations; such forms possess strongly convex resilifer and convex ligamental area on right valve (adapted from Cox, L. R., et al., 1971, p. N1128-N1129).

Remarks.--The geologic range of Crassostrea is late Cretaceous to Holocene (Cox et al., 1971, p. 1129).

Crassostrea glabra (Meek and Hayden)

Pl. 2 Figs. 6, 7, and 9

Ostrea glabra Meek and Hayden, 1857, p. 146-147. Meek, 1876, p. 509-510, Pl. 40, figs. 2a-d. White, 1883b, p. 412, Pl. 9, figs. 1-4; Pl. 10, figs. 1-5; Pl. 11, figs. 1-4; Pl. 59, figs. 1-5; Pl. 60, figs. 1-4; Pl. 61, figs. 1-3. Stanton, 1917, p. 311, Pl. 79, figs. 1-3.

?Ostrea glabra Meek and Hayden. Böse, 1906, p. 41-42. Pl. 2, fig. 5. Böse, 1913, p. 43-45, Pl. 5, figs. 5-14; Pl. 6, figs. 1-10, and Pl. 7, figs. 1-5.

Crassostrea glabra (Meek and Hayden). Cvancara, 1966, p. 320-323, Pl. 4, figs. 3-6; Pl. 5, figs. 10-12.

Diagnosis.--Shell usually subovate, slightly arcuate laterally, narrowing toward the beaks, and rounded at the other extremity; left valve deep and provided with a small, rather short ligamental area; upper valve flat or a little concave and truncated at the extremity of the beak (adapted from Meek, 1876, p. 509-510).

Description of Cannonball Material.--All specimens are poorly preserved, with much of the exterior missing and heavily encrusted with selenite.

Measurements.--Because of incompleteness and poor preservation of the material, no measurements were attempted. An approximate idea of size can be gained from the illustrations.

Hypotype.--Univ. of N. Dak. Cat. No. 13801 and 13811.

Occurrence.--Cannonball Formation, localities 1(A1069), 3(A1078), 4(A1080), 5, 7, 8, 9, and 10.

Material.--One specimen with both valves present, 31 incomplete left valves (3 with discernible muscle scars), 9 left valves showing some form of attachment, 16 right valves (3 with discernible muscle scars), and numerous shell fragments.

Discussion.--Oysters were first discovered in what is now considered to be a tongue of the Cannonball Formation by Leonard (1908, p. 49). Stanton first referred (Leonard, 1908, p. 49; and Stanton, 1909, p. 249) the oysters to Ostrea subtrigonalis Evans and Shumard. In 1910, Stanton said (p. 183) the oysters were referrable to two species, O. subtrigonalis, and O. glabra. Cvancara (1966, p. 320-323, Pl. 4, figs. 3-6; Pl. 5, figs. 10-12) placed the oysters in Crassostrea glabra (Meek and Hayden), based on the general shape of the shell, the relatively deep left valve, the recess under the hinge, and the laterally and distally positioned adductor muscle scars.

The tremendous amount of interspecific variety in Crassostrea glabra seems to account for the variation in form of the studied specimens. Hence I concur with Cvancara, and have placed the specimens in this species.

Family Ostreidae

Genus Ostrea Linne' 1758

Original reference.--Linne', 1758, p. 696.

Type species.--Ostrea edulus Linne', 1758, p. 696. (designated by ICZN opinions 94 and 356).

Diagnosis.--Shell medium-sized to large, outline variable, but average shape tends to be roughly circular with inconspicuous umbones, width about 0.25 of height resulting in rather flat shell; right valve flat to gently convex, covered by many fragile, flattish conchiolinous growth squamae, concentric undulations absent or present, never conspicuous; left valve slightly convex, hardly ever deeply cupped, covered by many, long, unequally rounded radial ribs interrupted by free-standing, frilled, delicate, growth squamae; radial rib patterns variable; chomata always present, but differ in prominence; adductor-muscle imprint reniform, both ends well rounded, centrally located; left valve without umbonal cavity (adapted from Cox et al., 1971, p. N1138-N1139).

Remarks.--The geologic range of Ostrea is Cretaceous to Holocene (Cox et al., 1971, p. N1139).

?Ostrea sp.

Pl. 2 Figs. 4, 5, 8

Description of Cannonball material.--All specimens poorly preserved, compressed and broken, and heavily encrusted or replaced with selenite; small (maximum height 1.69 cm, maximum length 1.18 cm; mean height/length ratio 1.36 cm), tear-drop shaped; no external ornamentation on either valve, except for growth lines. Muscle scars not present, umbonal cavity shallow, but not filled with shell material; resilifer not present, but one specimen shows definite chomata on both sides of beak; shell thin, no indication of attachment.

Measurements.--Height of figured specimen 1.69 cm. Length of figured specimen 1.18 cm (fig. 5).

Hypotype.--Univ. of N. Dak. Cat. Nos. ~~13802~~. 13484, 13458, and 13800

Occurrence.--Cannonball Formation, locality 5(Al072).

Material.--46 complete specimens (both valves), of which 20 are crushed or fragmented, 44 separate valves (34 crushed or fragmented).

Discussion.--This form is newly reported for the Cannonball tongues, and presents a perplexing problem. It is quite unlike anything reported from the Late Cretaceous or Paleocene rocks in North Dakota or Montana. It was found at locality 5(al072) in the L tongue of the Cannonball in association with Corbula (Bicorbula) subtrigonalis, Corbicula berthoudi?, Trochammina sp. and ?Haplophragmoides sp.

Questionable assignment to Ostrea is made on the basis of shape, shallowness of the umbonal cavity and the presence of chomata. The position and shape of the adductor-muscle scar, as well as evidence of external ornamentation would have to be known before a positive generic, much less a specific assignment could be made. There is no indication of attachment on any of the specimens. This would indicate that this oyster is either an adult small form, with an unattached mode of existence, or that it represents a juvenile stage of an oyster, possibly introduced into a hostile environment.

White (1895) reported a new species of small oyster (less than 50 mm high), Ostrea haydenii, from the Cretaceous Bear River Formation. He gave no description of the oyster, other than a comparison to "certain specimens of the young of the living oyster Ostrea virginica." Without seeing the type specimens, it is impossible to compare the Cannonball form to that species. Frye (1967) also reported Ostrea cf. O. haydenii from the Hell Creek Formation in North Dakota. Again, no description was given of the species and only poor molds are present for comparison. Until further comparisons of these specimens to

Ostrea haydenii or other similar forms can be made, I have no choice but to designate the form ?Ostrea sp.

Order Ostracoda

Suborder Podocopa

Family Cyprididae Baird, 1850

Genus Candona Baird, 1845

Original reference.--Baird, 1845, p. 152.

Type species.--Cypris candida Mueller, 1776, p. 199 (designated ICZN, 1958).

Diagnosis.--Shape variable, bean shaped, triangular or elongate-ovate, valves moderately inflated; thin shelled; hinge adont; muscle scars as for all Candoninae with occasionally slight variations even within a species (adapted from Van Morkhoven, 1963, p. 58-61.

Remarks.--The geologic range of Candona is Tertiary to Holocene (Benson et al., 1961, p. Q233).

Candona sp.

Pl. 1 Fig. 7

Description of Ludlow material.--All specimens extremely thin shelled and fragile (all but three valves broken or fragmented); characteristically translucent white; muscle scars often not visible; bean shaped, longer than high.

Measurements.--Length of figured specimen 0.63 mm, height of figured specimen 0.29 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13806.

Occurrence.--Upper Ludlow Formation, localities 3(A1077), 4(A1079), and 5(A1076).

Material.--Three complete single valves, 67 fragmented valves.

Discussion.--Candona is reported to be a fresh-water genus (Van Morkhoven, 1963, p. 58-59), and in the study area was associated with the fresh-water ostracod Ilyocypris, fresh-water mollusks, and charophytes. Candona sp. was found always in a mudstone, and always below the U tongue of the Cannonball Formation. The genus is newly reported for the Ludlow Formation.

Family Cyprididae Baird, 1850

Subfamily Ilyocypridinae, Kaufmann, 1900

Genus Ilyocypris Brady and Norman, 1889

Original reference.--Brady and Norman, 1889, p. 106.

Type species.--Cypris gibba Ramdohr, 1808, p. 91, fig. 13-17.

Diagnosis.--Subquadrate; anterior and broadly rounded, posterior end truncate, dorsal margin straight, ventral margin concave; two prominent sulci in antero-dorsal part of shell; valves clearly punctate, occasionally spinose, anterior and posterior denticulatations common; thin shelled; hinge adont; muscle scars basically that of the Cyprididae (adapted from Van Morkhoven, 1963, p. 91).

Remarks.--The geologic range of Ilyocypris is ?Triassic to Holocene (Benson et al., 1961, p. Q240).

Ilyocypris sp.

Pl. 1 Figs. 2, 4, 6

Description of Ludlow material.--Specimens fairly well preserved, with most of the generic characters present; characteristically translucent, light yellowish-white; muscle scars undeterminable.

Measurements.--Length of figured specimen 0.82 mm, height of figured specimen 0.47 mm (fig. 2).

Hypotype.--Univ. of N. Dak. Cat. No. 13807.

Occurrence.--Ludlow Formation, locality 4(A1079).

Material.--Two complete, moderately well preserved, unmatched single valves.

Discussion.--Ilyocypris is a fresh-water genus (Van Morkhoven, 1963, p. 91) and in the study area was associated with the fresh-water ostracod Candona sp., fresh-water mollusks, and charophytes. Ilyocypris sp. was found in a mudstone below the U Cannonball tongue. The genus is newly reported for the Ludlow Formation.

Genus Ophiomorpha Lundgren, 1891

Original reference.--Nilsson, 1836.

Type species.--Ophiomorpha nodosa Nilsson, 1836.

Diagnosis.--Tunnel trails with tubercle-like or wart-like ornamentation of outer wall but smooth inside; width 1 to 2 cm; may be branched with place of ramification widened in blistered or pear-shaped way (Hass et al., 1962, p. W205-206).

Remarks.--The geologic range of Ophiomorpha is upper Cretaceous to Quaternary? (Hass et al., 1962, p. W205).

Description of Cannonball material.--All specimens observed were friable and poorly preserved; tube diameter up to 1.5 cm; borings generally vertical, up to 12 cm long; characteristically yellowish orange on weathered surface.

Measurements.--Diameter of figured specimen, 1.5 cm.

Hypotype.--Univ. of N. Dak. Cat. No. 13808.

Occurrence.--Cannonball Formation, locality 4(A1081).

Material.--One poorly preserved (very friable) specimen collected.

Discussion.--The trace fossil Ophiomorpha (=Halymenites) was newly reported for the Cannonball tongues by Moore (1972). Weimer and Hoyt (1964) proposed that the decapod Callianassa, because of similarity of form and the nearly identical environmental distribution, is the most likely group of organisms to have produced the Ophiomorpha structures. Ophiomorpha, in the study area, occurs about 2 m above the oyster Crassostrea glabra, in a fine-grained, well-sorted, planer-bedded sandstone. According to Weimer and Hoyt (1964), burrows found in massive-bedded, well-sorted sandstone indicates wave-agitated, littoral or shallow, sublittoral conditions.

Division Chlorophyta

Class Charophyta

Order Charales

Family Characeae

Subfamily Chareae v. Leonhardi, 1863

Genus Sphaerochara Mädler, 1952, p. 6

Original reference.--Mädler, 1952, p. 6.

Type species.--Sphaerochara himeri (Rasky); by original designation.

Diagnosis.--Oogonia with the summit structure of Chareae (spirals coming together to form a closed summit) and of more or less spherical form without decoration (adapted from Peck, 1957, p. 36; translated from Mädler, 1952, p. 6).

Remarks.--Sphaerochara contains those species with summit characters of Chara and a spherical shape that prevents their assignment to

Chara. The geologic range of Sphaerochara is Jurassic to ?Holocene (Peck, 1957, p. 36, from Mädler, 1952, p. 6).

Sphaerochara sp.

Pl. 1 Fig. 8

Description of Ludlow material.--All but one specimen crushed, but a spherical shape is obvious: five sinistral spirals readily visible, maintaining a constant thickness, not tapering toward the summit; summit closed, with no clear indication of orunula cells; characteristically light yellowish white.

Measurements.--Length of figured specimen 0.78 mm, width of figured specimen 0.7 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13796.

Occurrence.--Ludlow Formation, locality 4(A1079).

Material.--Twelve specimens; 10 broken or crushed, 1 complete but partially covered with matrix, and 1 complete, totally free from matrix.

Discussion.--Charophytes were reported from the Fort Union Group by Brown (1962, p. 38-40) but not specifically from the Ludlow Formation.

They have been reported from fresh-water and slightly brackish stream and lake deposits, but have been never considered as marine. All specimens were collected from the Ludlow Formation in a mudstone, in association with the fresh-water ostracods Ilyocypris sp. and Candona sp. and fresh-water gastropod and bivalve fragments.

PLATES

Accession numbers correspond to those on fig. 3 and in Appendices I, II, and III.

Explanation of Plate 1

Figure

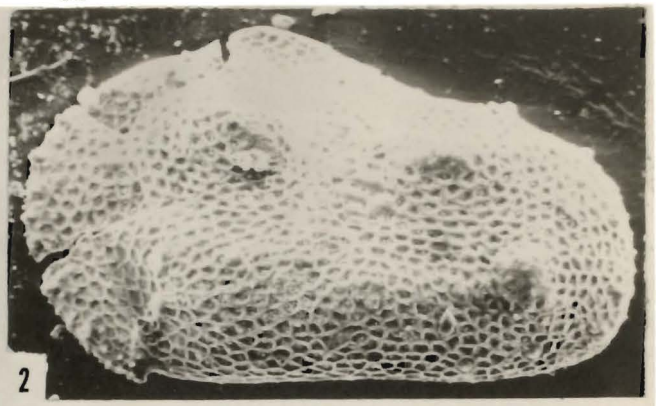
1,3. Trochammina sp. 1, ventral view of hypotype (Univ. of N. Dak. Cat. No. 13809). 3, dorsal view of hypotype (Univ. of N. Dak. Cat. No. 13797). UND Acc. A1072. SEM photos, X100.

2,4,6. Ilyocypris sp. 2, side view. 4, side view rotated 45° showing sulci. 6, side view showing punctae. Hypotype (Univ. of N. Dak. Cat. No. 13807). UND Acc. A1079. SEM photos, 2, 4, X100, 6, X500.

5. ?Haplophragmoides sp. Dorsal view of hypotype (Univ. of N. Dak. Cat. No. 1379). UND Acc. A1072. SEM photo X100.

7. Candona sp. Side view of hypotype (Univ. of N. Dak. Cat. No. 13806). UND Acc. A1076. SEM photo, X100.

8. Sphaerochara sp. Ventral view of hypotype (Univ. of N. Dak. Cat. No. 13796). UND Acc. A1079. SEM photo, X100.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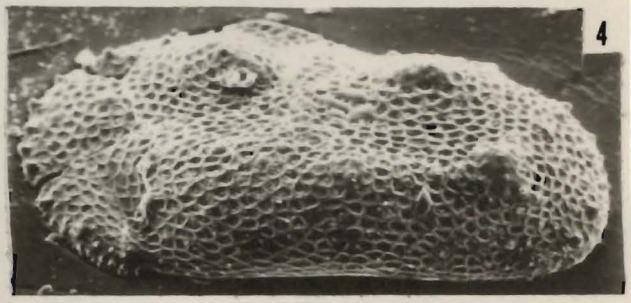
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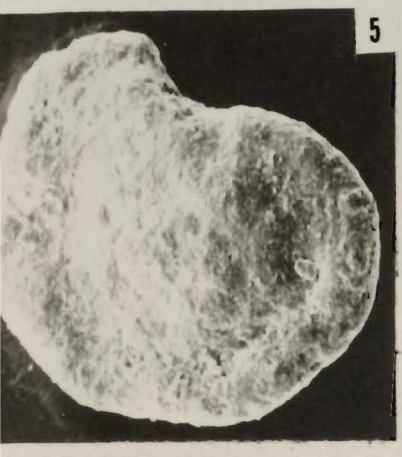
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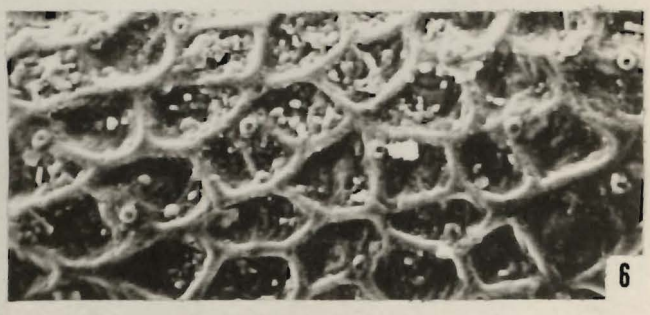
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Explanation of Plate 2

Figure

1. Viviparus sp. Apertural view of hypotype (Univ. of N. Dak. Cat. No. 13803). UND Acc. A1076. X4.

2. Goniobasis cf. G. tenuicarinata (Meek and Hayden). Apertural view of hypotype (Univ. of N. Dak. Cat. No. 13804). UND Acc. A1074. X1.5.

3. ?Goniobasis sp. Apertural view of hypotype (Univ. of N. Dak. Cat. No. 13805). UND Acc. A1074. X1.5.

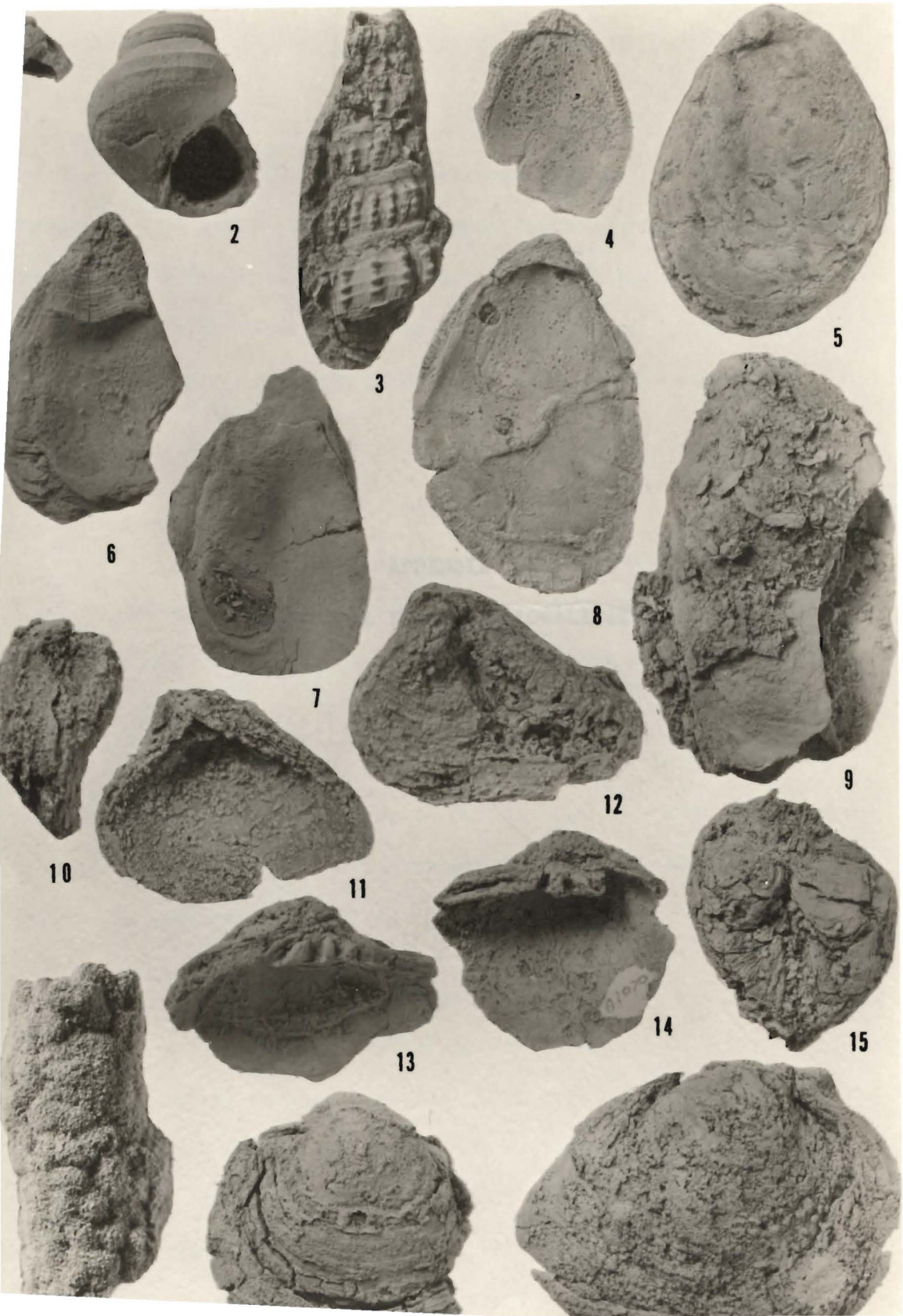
4,5,8. ?Ostrea sp. 4, interior of right valve showing chomata of hypotype (Univ. of N. Dak. Cat. No. 13810). 5, exterior of left valve showing growth lines. 8, interior of left valve showing shallow umbonal cavity. Hypotype (Univ. of N. Dak. Cat. No. 13802). UND Acc. A1072. X4.

6,7,9. Crassostrea glabra (Meek and Hayden). 6, interior of left valve showing resilifer. 7, interior of left valve showing adductor muscle scar. 9, exterior encrusted with selenite. Hypotype (Univ. of N. Dak. Cat. No. 13811). UND Acc. A1078. 6, 7, X1. 9, X3/4.

10,11,12. Corbula (Bicorbula) subtrigonalis Meek and Hayden. 10, anterior view of right valve. 12, exterior of left valve. Hypotype (Univ. of N. Dak. Cat. No. 13800). 11, interior of right valve of hypotype (Univ. of N. Dak. Cat. No. 13812). UND Acc. A1070. X1.5.

13,14,15,17,18. Corbicula berthoudi White?. 13, interior of right valve showing dentition. 14, interior of left valve showing dentition. 15, dorsal view. 17, exterior of left valve showing growth lines. Hypotype (Univ. of N. Dak. Cat. No. 13813). 18, exterior of right valve encrusted with selenite. Hypotype (Univ. of N. Dak. Cat. No. 13799). UND Acc. A1070. 15, 17, 18, X3/4. 13, 14, X1.

16. Ophiomorpha sp. Exterior side view of hypotype (Univ. of N. Dak. Cat. No. 13808). UND Acc. A1081. X1.5.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APPENDIX I

CANNONBALL FORMATION LOCALITIES

CANNONBALL FORMATION LOCALITIES

All localities in this appendix are numbered on figure 1. Localities 1 through 5 are the measured sections sampled for microfossils (Appendix II and figure 3 and 4). Localities are given where brackish water fossils were noted or collected. Where collections were made, a University of North Dakota accession number is given. The occurrence of specific macrofossils and microfossils at each locality is given in Appendix III.

Locality 1

(upper one-half of measured section 1)

Southwest-facing hillside exposure, west side of Little Missouri River (about 0.8 km west of river) on east side of small auto trail, SW¼SW¼ sec. 10, T. 135 N., R. 105 W., approximately 24.8 km north-northeast of Marmarth, Slope County, North Dakota. Univ. of N. Dak. accession numbers A1068-A1071, J. B. Van Alstine, 25 July, 1972. Fossils collected from Ludlow Formation and U tongue of the Cannonball Formation (Appendices II and III).

Locality 2

(lower one-half of measured section 1)

South-facing cutbank exposure, west side of Little Missouri River, NW¼NW¼ sec. 15, T. 135 N., R. 105 W., approximately 23.2 km north-northeast of Marmarth, Slope County, North Dakota. Univ. N. Dak. accession numbers A1065-A1067: J. B. Van Alstine 25 July, 1972. Fossils collected from Ludlow Formation and L tongue of the Cannonball Formation (Appendices II and III).

Locality 3

(measured section 2)

South-facing cutbank exposure, north side of Bull Run Creek (about 1.2 km northwest of Little Missouri River) on north side of small auto trail, SW¼NE¼ sec. 35, T. 136 N., R. 105 W., approximately 29.6 km north-northeast of Marmarth, Golden Valley county, North Dakota. Univ. N. Dak. accession numbers A1077-A1078; J. B. Van Alstine, 26 July, 1972. Fossils collected from Ludlow Formation and U tongue of the Cannonball Formation (Appendices II and III).

Locality 4

(measured section 3)

East-facing cutbank exposure, east side of Little Missouri River, SE¼NE¼ sec. 1, T. 135 N., R. 105 W., approximately 28.8 km north-northeast of Marmarth, Slope County, North Dakota. Univ. N. Dak. accession numbers A1079-A1081; J. B. Van Alstine, 27 July, 1972. Fossils collected from Ludlow Formation and U tongue of the Cannonball Formation (Appendices II and III).

Locality 5

(measured section 4)

Northwest-facing cutbank exposure, east side of Little Missouri River, NE¼SW¼ sec. 14, T. 135 N., R. 105 W., approximately 23.2 km north-northeast of Marmarth, Slope County, North Dakota. Univ. N. Dak. accession numbers A1072-A1076; J. B. Van Alstine, 28 July, 1972. Fossils collected from Ludlow Formation and L tongue of the Cannonball Formation (Appendices II and III).

Locality 6

Southwest-facing hillside exposure on west side of Little Missouri River (about 0.4 km northwest of river) on northeast side of dry wash, NE¼NW¼ sec. 16, T. 135 N., R. 105 W., approximately 24 km north-northeast of Marmarth, Slope County, North Dakota. Univ. N. Dak. accession number A1082, J. B. Van Alstine, 25 July, 1972. Fossils collected from well indurated "scoria" near top of exposure (L tongue of the Cannonball Formation).

Locality 7

South-facing Hillside exposure on west side of Little Missouri River (about 0.8 km north of river) on south-west side of small auto trail, SE¼SE¼ sec. 9, T. 135 N., R. 105 W., approximately 24 km north-northeast of Marmarth, Slope County, North Dakota; J. B. Van Alstine, 25 July, 1972. Fossils noted in dark brownish mudstone, directly above 0.85 m-thick lignite, and also 3 m above same lignite (U tongue of the Cannonball Formation).

Locality 8

South-facing hillside exposure on west side of Little Missouri River (about 1.6 km north-northwest of river) on south side of small auto trail, NE¼SE¼ sec. 9, T. 135 N., R. 105 W., approximately 24.8 km north-northeast of Marmarth, Slope County, North Dakota; J. B. Van Alstine, 25 July, 1972. Fossils noted in dark brownish mudstone, directly above 0.85 m-thick lignite, and also about 3 m above same lignite (U tongue of the Cannonball Formation).

Locality 9

South-facing hillside exposure, on west side of Little Missouri River (about 2 km northwest of river), on south side of small auto trail (just over hill from trail), SE¼NE¼ sec. 8, T. 135 N., R. 105 W., approximately 24.8 km north-northeast of Marmarth, Slope County, North Dakota; J. B. Van Alstine, 26 July, 1972. Fossils noted in dark brownish mudstone, directly above 0.85 m-thick lignite, also from about 3 m above same lignite (U tongue of the Cannonball Formation).

Locality 10

South-southwest-facing hillside exposure, on west side of Little Missouri River (about 3.2 km northwest of river) on southwest side of small auto trail (just over hill from trail) NW¼NE¼ sec. 8, T. 135 N., R. 105 W., approximately 25.6 km north of Marmarth, Slope County, North Dakota; J. B. Van Alstine, 26 July, 1972. Fossils noted in dark yellowish brown, mudstone concretion, and in dark brownish mudstone about 3 m above 0.85 m-thick lignite (U tongue of the Cannonball Formation).

Locality 11

South-southwest-facing hillside exposure, on west side of Little Missouri River (about 3.2 km northwest of river) on south west side of small auto trail (just over hill from trail, and about 200 m west of locality 10) NW¼NW¼ sec. 8, T. 135 N., R. 105 W., approximately 25.6 km north of Marmarth, Slope County, North Dakota. J. B. Van Alstine, 26 July, 1972. Fossils noted in dark mudstone, about 3 m above 0.85 m-thick lignite (U tongue of the Cannonball Formation).

APPENDIX II

MEASURED SECTIONS

MEASURED SECTIONS

Descriptions of measured sections are arranged consecutively, with section numbers corresponding to those in Appendices I and III, figure 1, 3, and 4. The columnar sections shown on Figs. 3-4 are generalized from these descriptions. Accession numbers (A1060, Department of Geology University of North Dakota), refer to stratigraphic positions within the sections where fossils were collected, and are given for each section. The accession numbers also appear in Appendix III, and in figure 3. The descriptions are arranged in descending stratigraphic order.

The terms used in describing the lithology are defined as follows:

Blocky: condition on a fresh surface of a rock, where breakage is in small irregular pieces.

Consolidated: cohesiveness of a rock as a result of compaction.

Fissile: condition on a fresh surface of a rock where breakage is parallel to thin bedding planes.

Indurated: condition in which a rock is held together by a mineral cement.

Massive: condition on a fresh surface of a rock, where no bedding planes are evident.

Thinly bedded: condition on a fresh surface of a rock where beds less than 2-cm thick are evident.

Thickly bedded: condition on fresh surface of a rock where beds greater than 2-cm thick are evident.

Measured section 1

Composite section; upper one half measured on southwest-facing hillside exposure, west side of Little Missouri River (about 0.8 km west of river) on east side of small auto trail, SW¼SW¼ sec. 10, T. 135 N., R. 105 W., approximately 24.8 km north-northeast of Marmarth, Slope County, North Dakota; lower one-half of section measured on south-facing cutbank exposure, west side of Little Missouri River, NW¼NW¼ sec. 15, T. 135 N., R. 105 W., approximately 23.2 km north-northeast of Marmarth, Slope County, North Dakota. Section measured by J. B. Van Alstine, July 25, 1972: the upper one half of the section is similar to the section given by Cvancara (1965, p. 250-257); accession numbers A1065-A1071; figure 3 (detailed columnar section).

Description

Top of section Meters

Ludlow Formation:

MUDSTONE; poorly consolidated; dusky yellow where fresh (moist), yellowish gray where weathered (dry); blocky on fresh surface, swelling on weathered surface; gradationally interbedded with sand..... 1.04

SANDSTONE; poorly consolidated; dusky yellow where fresh (moist), yellowish gray where weathered (dry); fine to medium grained, poorly sorted and rounded, faint cross bedding; gradationally interbedded with dark shaley lenses (1-cm thick); 2.8 m below

top of unit is a thin (0.3 m), dark brown, almost lignitic shale; unidentified insect fragments (probably contamination) common in lower portion of unit..... 3.10

CONCEALED (sandy slope wash and vegetation);..... 7.00

SANDSTONE; well indurated; dusky yellow brown; concretionary; fine-grained muddy sand; common plant fragments; lenticular bench former..... 0.30

MUDSTONE; poorly consolidated; dusky yellow where moist, yellowish gray where weathered (dry); grades into muddy fine- to very fine-grained sandstone toward bottom; scattered lenticular muddy sandstone concretions in middle of unit..... 1.80

LIGNITE;..... 0.30

MUDSTONE; poorly consolidated; dusky yellowish brown where moist, pale yellowish brown where weathered (dry); blocky on fresh surface, with abundant plant fragments; gradational interbedding into a muddy sand, down into predominantly sand; yellowish brown where moist, pale yellowish brown where weathered (dry)..... 2.90

MUDSTONE; well consolidated; dark yellowish brown where moist, pale yellowish brown where weathered (dry); blocky on fresh surface; plant fragments common..... 0.83

SILTSTONE; well consolidated; grayish brown where moist, pale yellowish brown where weathered (dry); massive; plant fragments abundant (seed pods?, A1071)..... 1.06

LIGNITE (quite possibly Yule Lignite of Hare (1928, p. 26);..... 1.37

LIGNITIC MUDSTONE; poorly consolidated; dark grayish brown where moist, light grayish brown where weathered (dry); bentonitic; lignite particles abundant..... 1.00

LIGNITE; 0.04

MUDSTONE; poorly consolidated; dusky yellow where moist, yellowish gray where weathered (dry); massive, grading into muddy sand thiny bedding in places; lignitized plant particles and marcasite nodules abundant at base of unit..... 1.20

LIGNITE; 0.95

MUDSTONE; poorly consolidated; dark yellowish brown where moist, grayish brown where weathered (dry); blocky on fresh surfaces; thinly bedded; lenticular mudstone concretions (0.05 m thick) present 1.5 m below top of unit; below this zone unit grades into interbedded mud and sand; plant fragments abundant..... 2.18

LIGNITE; 0.70

SANDSTONE; poorly consolidated; dusky yellow where moist, yellowish gray where weathered (dry); very fine- to fine-grained; interbedded with lenses (0.1 cm thick) of mudstone at top, becoming massive toward bottom; lignite particles and lignitized plant fragments abundant throughout unit..... 1.15

LIGNITE; 0.59

Cannonball Formation:

SANDSTONE; poorly consolidated; moderate yellowish brown where moist, yellowish gray where weathered (dry); very fine- to fine-grained; thinly bedded, grading into interbedded sandstone and mudstone toward the bottom of unit; marcasite nodules and thin (0.03 m) tabular concretions at base of unit..... 4.20

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light grayish brown where weathered (dry); thinly bedded with some sand at the top, becoming blockier and almost a lignitic mudstone at bottom of unit; thin (0.03 m) concretions about 0.4 m below the top of the unit, and poorly indurated, thin (0.03 m), blocky, dark mudstone "marker bed" approximately 3.5 m below top of unit; fossiliferous, common to abundant Corbicula berthoudi White ? and Corbula (Bicorbula) subtrigonalis Meek and Hayden (A1070) from 0.52-0.80 m above dark mudstone marker bed and abundant oysters Crassostrea glabra (Meek and Hayden) (A1069) as lenticular patches (up to 0.1 m thick) in lower 1-1.5 m of unit (1.9 m below dark marker bed); abundant selenite throughout unit (particularly encrusting the fossils) and sulfur (particularly abundant in thin zone at the base of unit)..... 5.75

Ludlow Formation:

LIGNITE; 0.85

MUDSTONE; poorly consolidated; olive gray where moist, light gray where weathered (dry); bentonitic, with "popcorn"-like weathered surface in upper portion of unit, grading into interbedded sand

and mudstone about 4.5 m below top of unit; unidentified insect parts (probably contamination) and plant fragments present throughout unit..... 5.50

MUDSTONE; poorly consolidated; very dark brown (almost lignitic) where moist, light yellow brown where weathered (dry); bentonitic, with a "popcorn"-like weathering surface; thinly bedded throughout unit; plant fragments (seed pods? A1068) present..... 1.50

LIGNITE; 1.00

SANDSTONE; well indurated; dusky yellow brown when weathered, fine-grained muddy sandstone..... 0.30

CONCEALED; (sandy slope wash and vegetation). Includes the lateral distance from the bottom of the first half of the composite section, west 0.8 km to the top of the Little Missouri River cutbank where the second half of the composite section was measured..... 1.00

SANDSTONE; moderately consolidated; dusky yellow brown where moist, light yellowish brown where weathered (dry); fine- to medium-grained; massive, forming an almost vertical face; capped by a 0.5 m, well indurated, tabular, sandstone concretion..... 2.50

MUDSTONE; poorly consolidated; yellowish brown where moist, light yellowish brown where weathered (dry); predominantly mudstone at top of unit, grading into interbedded mudstone and sandy mud toward bottom; thin (0.01 m), lenticular mudstone concretions form the top of the unit..... 2.30

LIGNITE AND LIGNITIC MUDSTONE; 1.15

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light yellowish brown where weathered (dry); blocky on fresh surfaces; plant fragments abundant (seed pods? A1067)..... 0.59

SANDSTONE; poorly consolidated; dusky yellowish brown where moist, light yellowish brown where weathered (dry); fine- to medium-grained; poorly sorted..... 0.40

LIGNITE; 0.67

SANDSTONE; poorly consolidated; dusky yellowish brown where moist, light yellowish brown where weathered (dry); fine- to medium-grained; lignite particles abundant..... 0.40

LIGNITE; 0.40

SANDSTONE; poorly consolidated; dark yellowish brown where moist, yellowish gray where weathered (dry); fine- to medium-grained; interbedded with mudstone in middle of unit, grading into mudstone at bottom of the unit; unidentified insect parts (probably contamination) present near bottom of unit..... 3.15

Cannonball Formation ?:

MUDSTONE; moderately consolidated; dark yellowish brown where moist, light grayish brown where weathered (dry); thinly bedded, but blocky on fresh surfaces; carbonaceous; abundant plant fragments present; fossiliferous, common to abundant fresh water gastropod and bivalve impressions (A1066); unit is interpreted

to be the farthest westward extension of the lowest tongue of the Cannonball Formation in the study area..... 1.00

Ludlow Formation:

LIGNITE (T cross lignite of Hares 1928); To west, burning lignite has baked overyling mudstone; bivalve and gastropod impressions common in "scoria" (A1082)..... 1.76

MUDSTONE; poorly consolidated; dark reddish brown where fresh (moist), light yellowish brown where weathered (dry); blocky on fresh surface; interbedded with less sand; insect parts (probably contamination) and a single immature gastropod found (A1065)..... 5.90

LIGNITE: 1.87

SANDSTONE; poorly consolidated; yellowish gray where moist, light yellowish gray where weathered (dry); fine grained; interbedded with mudstone in places..... 2.90

CONCEALED (sandy slope wash and vegetation); 2.00

Base of section at level of Little Missouri River.

Total..... 74.60

Thickness of exposed Cannonball Formation..... 10.95

Measured section 2

Section measured on south-facing cutbank exposure, north side of Bull Run Creek (about 1.2 km northwest of Little Missouri), north side of small auto trail, SW¼NE¼ sec. 35, T. 136 N., R. 105 W., approximately 29.6 km north-northeast of Marmarth, Golden Valley County, North Dakota. Section measured by J. B. Van Alstine, July 26, 1972; Accession numbers A1077-A1078; figure 3 (detailed columnar section).

Description

Top of section — Meters

Ludlow Formation:

"SCORIA"; well indurated; yellowish red at top of unit, darker orange red at bottom; abundant plant fragments and leaf impressions..... 4.60

ASH; (result of a burned lignite which baked the overlying mudstone to "scoria." Quite possibly the Yule Lignite of Hares, 1928, p. 26)..... 0.40

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light yellowish gray where weathered (dry); blocky on fresh surface; interbedded with fine-grained sand from about 0.9 m from the top of the unit; plant fragments and unidentified insect fragments (probably contamination)common throughout unit..... 6.25

LIGNITE (interbedded with fine sand); 0.25

LIGNITE; 0.25

Cannonball Formation:

SANDSTONE; poorly consolidated; brownish yellow where moist, grayish yellow where weathered (dry); fine- to medium-grained; interbedded with some mudstone; possible faint cross-bedding observed..... 0.20

MUDSTONE; moderately consolidated; dark yellowish brown where moist, light yellowish gray where weathered (dry); blocky on fresh surface; interbedded with sand near top, grading into predominantly sand about 3 m from top of unit, and into mudstone toward bottom of unit; moderately indurated, thin (0.03 m), dark mudstone "marker bed" present about 8.5 m below top of unit; plant fragments present; fossiliferous, with oyster Crassostrea glabra (Meek and Hayden) (A1078) in lenticular patches and stringers, about 11 m below top of unit; abundant selenite (particularly encrusting fossils), and sulfur throughout unit..... 11.70

Ludlow Formation:

LIGNITE; 1.00

MUDSTONE; poorly consolidated; grayish brown where moist, light grayish brown where weathered (dry); blocky on fresh surfaces; bentonitic, with a "popcorn"-like weathering surface..... 0.60

LIGNITE; 0.40

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light grayish brown where weathered (dry); blocky on fresh surface; interbedded with silt lenses (less than 1 cm thick) in middle of unit; plant fragments and lignite particles common..... 0.97

LIGNITE; 0.20

SANDSTONE; indurated in upper portion; dusky yellowish gray where moist, light yellowish gray where weathered (dry); upper 0.26-0.5 m forms a tabular concretion, remaining portion poorly consolidated; fine-grained; slight interbedding with mudstone.... 0.74

MUDSTONE; poorly consolidated; dark grayish brown where moist, light grayish brown where weathered (dry); plant fragments present throughout unit..... 0.30

SANDSTONE; poorly consolidated; dusky yellowish brown where moist, light yellowish gray where weathered (dry); fine- to medium-grained; grades into mottled sand and mudstone in middle of unit, and predominantly sand at bottom..... 3.60

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light yellowish gray where weathered (dry); blocky on fresh surface..... 3.20

LIGNITE; 1.40

MUDSTONE; moderately consolidated to well indurated in places; dark yellowish brown where moist, light yellowish gray where weathered (dry); blocky on fresh surface; interbedded with grayish brown silt lenses (less than 1-cm thick) in bottom two thirds of unit; two thin (0.03-0.05 m), lenticular, mudstone concretions are present 3.2 and 3.8 m below the top of unit; fossiliferous, fresh water bivalves, gastropods, and ostrocods present in lower one half of unit..... 5.75

A1077

LIGNITIC MUDSTONE; 2.50

CONCEALED (slope wash and vegetation); 1.00

Base of section at level of Bull Run Creek.

Total..... 45.31

Thickness of exposed Cannonball Formation..... 11.7

Measured section 3

Section measured on east-facing cutbank exposure, east side of Little Missouri River, SE¼NE¼ sec. 1, T. 135 N., R. 105 W., approximately 28.8 km north-northeast of Marmarth, Slope County, North Dakota (section is about 3.6 km southeast of measured section 2). Section measured by J. B. Van Alstine, July 27, 1972; accession numbers A1079-A1081; figure 3 (detailed columnar section).

Description

Top of section — Meters

SOIL; 0.60

GRAVEL AND COBBLE ALLUVIUM; 0.50

Ludlow Formation?: (upper contact uncertain).
MUDSTONE; poorly consolidated; dark reddish brown where moist, light yellowish brown where weathered (dry); blocky on fresh surface; interbedded with some sand toward middle of unit..... 1.00

Cannonball Formation:
SANDSTONE; poorly consolidated; dark brownish yellow where moist, light grayish yellow where weathered (dry); very fine- to fine-grained; very obvious thin planer (less than 2 cm thick) stratification; clean, well sorted; where measured, about 0.2 m thick, unit thickens to north to about 2m; fossiliferous, with abundant Ophiomorpha borings (up to 0.01 m in diameter) (A1081) in center of thickest part of unit..... 0.20

MUDSTONE; poorly consolidated; dark reddish brown where moist, light yellowish brown where weathered (dry); blocky on fresh surface; interbedded with lenses of fine sand throughout unit.... 0.80

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light yellowish brown where weathered (dry); blocky on fresh surface; carbonaceous; plant fragments abundant; fossiliferous, with abundant oysters Crassostrea glabra (Meek and Hayden) (A1080) in lenticular patches (up to 0.55 m thick), about 0.2 m below the top of unit; abundant selenite (particularly encrusting the fossils) and sulfur throughout unit..... 1.80

Ludlow Formation:

LIGNITE; 0.79

MUDSTONE; poorly consolidated; dusky yellowish brown where moist, light yellowish gray where weathered (dry); blocky on fresh surfaces at top of unit, becoming almost fissile toward middle of unit, and almost lignitic toward the bottom of unit..... 0.56

LIGNITE; 0.39

MUDSTONE; poorly consolidated; reddish brown where moist, light grayish brown where weathered (dry); blocky on fresh surface; interbedded with lenses of gray silt in middle of unit; sulfur present throughout the mudstone..... 0.39

LIGNITE; 1.05

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light yellowish gray where weathered (dry); blocky on fresh surface; little sand present..... 0.90

SILTSTONE; poorly consolidated; dusky yellowish gray where moist, light yellowish gray where weathered (dry); blocky on fresh surface at top of unit; interbedded silt and clay in the middle of unit grading into sandy silt toward bottom of unit; plant material and unidentified insect parts (probably contamination) common at bottom of unit..... 6.93

LIGNITE; 2.90

MUDSTONE; poorly consolidated at top to moderately indurated at bottom of unit; dark reddish brown when moist, light grayish brown when weathered (dry); fissile on fresh surfaces at top of unit becoming blocky toward the bottom of unit; plant fragments abundant; fossiliferous, with fresh water charophytes, gastropods, bivalves and ostracods present (A1079) at the bottom 1.5 m of unit..... 3.50

SANDSTONE; well indurated (concretionary); dusky yellowish brown when fresh, light yellowish brown when weathered; bench forming tabular body..... 1.00

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light grayish brown where weathered (dry); thinly bedded, with interbedded sand in places..... 2.00

LIGNITE; 0.30

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light yellowish brown where weathered (dry); blocky on fresh surface; very little sand present; sulfur abundant throughout unit..... 0.30

CONCEALED (slope wash and vegetation)..... 0.50

Bottom of section at level of Little Missouri River.

Total..... 26.41

Thickness of exposed Cannonball Formation..... 3.80

Measured section 4

Section measured on northwest-facing cutbank exposure, east side of the Little Missouri River NE¼SW¼ sec. 14, T. 135 N., R. 105 W., approximately 23.2 km north-northeast of Marmarth, Slope County, North Dakota (section is about 2 km east-southeast of measured section 1). Section measured by J. B. Van Alstine, July 28, 1972; Accession numbers A1072-A1076; figure 3 (detailed columnar section).

Description

Top of section	Meters
SOIL;	1.00
SAND AND GRAVEL;	1.50
CONCEALED (sandy gravely slope wash, soil and vegetation); ...	5.35
Cannonball Formation:	
MUDSTONE; moderately consolidated; dark yellowish brown where moist, light grayish brown where weathered (dry); blocky on fresh surface; fossiliferous, with small patch of oyster Crassostrea glabra (Meek and Hayden) present near top of unit. Oysters photographed, but not collected because of small number of specimens present; abundant sulfur and selenite throughout unit.....	1.50
Ludlow Formation:	
LIGNITE;	0.90

SANDSTONE; poorly consolidated; dusky yellowish gray where moist, light yellowish gray where weathered (dry); fine to medium grained; interbedded with thin lenses of mudstone in places..... 1.35

MUDSTONE; poorly consolidated; dark yellowish brown where moist, light grayish brown where weathered (dry); blocky on fresh surface; little sand; becomes very dark brown, almost lignitic toward the bottom of unit; plant fragments common..... 8.50

LIGNITE; 0.80

MUDSTONE; poorly consolidated; dark gray brown where moist, light gray brown where weathered (dry); blocky on fresh surface; little sand..... 1.15

MUDSTONE; poorly consolidated; dark yellowish gray where moist, light yellowish gray where weathered (dry); thinly bedded, interbedded with fine-grained, yellowish brown sand throughout unit; plant material common..... 3.32

LIGNITE; 1.20

LIGNITIC SHALE; moderately consolidated; dark yellowish brown where moist, dark grayish brown where weathered (dry); rather fissile with thin lenses of lignite..... 0.80

MUDSTONE; poorly consolidated; dark grayish brown where moist, light grayish brown where weathered (dry); blocky on fresh surface; lenses of yellowish brown fine-grained sand present; 2.1 m below top of unit is zone of lenticular concretions (about 1 m

thick) of sandstone and mudstone below concretions is mudstone with interbedded sand; unidentified shell fragments at base of unit..... 3.50

MUDSTONE; poorly consolidated; dark grayish brown where moist, light grayish brown where weathered (dry); blocky on fresh surface; becomes almost lignitic toward middle of unit; plant material abundant; fossiliferous, fresh water ostracods, gastropods, and bivalves, (A1076) common especially at top of unit..... 4.10

LIGNITE;..... 1.40

MUDSTONE; moderately consolidated; dark grayish brown where moist, light grayish brown where weathered (dry); blocky on fresh surface; grades into interbedded sand and mudstone, down into clean, well consolidated to moderately indurated, tabular (1 m thick), yellowish gray, fine-grained sandstone body (about 2.3 m below top of unit), back into dark gray mudstone; abundant plant fragments; fossiliferous, fresh water gastropods and bivalves (A1075), about 0.5 m below tabular sandstone, a fresh water gastropod (A1074) was found about 2.5 m below tabular sand, and a unionid bivalve (A1073) was found at very bottom of unit, in living position..... 7.25

Cannonball Formation:

MUDSTONE; moderately consolidated; dark yellowish brown where moist, light yellowish brown where weathered (dry); blocky on fresh surface, almost lignitic in places; abundant plant fragments; fossiliferous, with uncommon bivalves Corbicula

berthoudi White?, Corbula (Bicorbula) subtrigonalis Meek and Hayden, ?Ostrea (new oyster), and common foraminiferids Trochammina sp. and rare ?Haplophragmoides sp. near top of unit (A1072)..... 2.30

Ludlow Formation:

LIGNITE; (T Cross lignite of Hares, 1928)..... 3.50

LIGNITIC MUDSTONE; poorly consolidated; very dark brown where moist, dark brown where weathered (dry); fissile; abundant plant fragments (seed pods?)..... 1.50

Base of section at level of Little Missouri River

Total..... 50.92

Thickness of exposed Cannonball Formation..... 3.80

APPENDIX III

FOSSIL OCCURRENCES

Locality numbers correspond to localities described in detail in Appendix I, and the measured section descriptions in Appendix II. An asterisk (*) indicates that the genus or species was noted but not collected, and a University of North Dakota accession number (A1060) indicates that the genus or species was collected.

Fossil Occurrences

Organism	Locality 1	2	3	4	5	6	7	8	9	10	11
Foraminiferids											
Trochammina sp.					A1072						
?Haplophragmoides sp.					A1072						
Gastropods											
Goniobasis cf. G. tenuicarinata					A1075						
?Goniobasis sp.					A1074						
Viviparus sp.					A1076						
Bivalves											
Corbula (Bicorbula) subtrigonalis	A1070				A1072		*	*	*	*	*
Corbicula berthoudi?	A1070				A1072		*	*	*	*	*
?Ostrea sp.					A1072						
Crassostrea glabra	A1069		A1078	A1080	*		*	*	*	*	
Ostracods											
Candona sp.			A1077	A1079	A1076						
Ilyocypris sp.				A1079							
Other											
Ophiomorpha sp.				A1081							
Sphaerochara sp.				A1079							

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