University of North Dakota
UND Scholarly Commons

Theses and Dissertations | Theses, Dissertations, and Senior Projects

1974

The foraminiferids of the Cannonball Formation (Paleocene, Danian) and their paleoenvironmental significance : Grant, Morton and Oliver counties, North Dakota

William E. Fenner
University of North Dakota

Follow this and additional works at: https://commons.und.edu/theses

Part of the Geology Commons

Recommended Citation
Fenner, William E., "The foraminiferids of the Cannonball Formation (Paleocene, Danian) and their paleoenvironmental significance : Grant, Morton and Oliver counties, North Dakota" (1974). *Theses and Dissertations*. 92.
https://commons.und.edu/theses/92

This Thesis is brought to you for free and open access by the Theses, Dissertations, and Senior Projects at UND Scholarly Commons. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of UND Scholarly Commons. For more information, please contact zeineb.yousif@library.und.edu.

THE FORAMINIFERIDS OF THE CANNONBALL FORMATION (PALEOCENE, DANIAN) AND THEIR PALEOENVIRONMENTAL SIGNIFICANCE: GRANT, MORTON AND OLIVER COUNTIES, NORTH DAKOTA

by

William E. Fenner

Bachelor of Science, University of Wisconsin, 1968

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

May
1974

This thesis submitted by William E. Fenner 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.

(Chairman)

Dean of the Graduate School

379880

Permission

Title THE FORAMINIFERIDS OF THE CANNONBALL FORMATION (PALEOCENE, DANIAN) AND THEIR PALEOENVIRONMENTAL SIGNIFICANCE: GRANT, MORTON AND OLIVER COUNTIES, NORTH DAKOTA

Department Geology

Degree Master of Science

In presenting this thesis in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my thesis work or, in his absence, by the Chairman of the Department or the Dean of the Graduate School. It is understood that any copying or publication or other use of this thesis or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of North Dakota in any scholarly use which may be made of any material in my thesis.

Signature William E. Fenner

Date 4/26/74

ACKNOWLEDGMENTS

I am grateful to Dr. Alan M. Cvancara, chairman of my graduate committee for acquainting me with this problem and for his patient guidance and helpful supervision. I am also indebted to Drs. Walter L. Moore and Arthur F. Jacob for critically reviewing the manuscript.

Several other persons were extremely helpful in various aspects of this project. They include Mr. Clarence Carlson of the North Dakota Geological Survey, who gave me much information on the regional geology; Mr. James Van Alstine and Mr. Ron Richardson of the Geology Department, University of North Dakota, who helped me in my field work, and Mr. Miles Baska of the University of North Dakota Computer Science Department who prepared the invaluable computer programs.

I am especially thankful to Dr. Frank N. Low of the University of North Dakota Anatomy Department for taking the photographs on the scanning electron microscope purchased with National Institute of Health Grant NS09363 from the Institute of Neurological Diseases and Stroke.

I am grateful to the North Dakota Geological Survey for funding part of my field expenses and the Geology Department, University of North Dakota for making laboratory facilities available to me.

I am especially indebted to my wife, Sandy, for her patience and help in preparing the manuscript.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Two hundred-forty samples (of which fifty-five contained microfossils) were collected from six measured sections in the Cannonball Formation (Paleocene, Danian) in Grant, Morton and Oliver Counties, North Dakota. Twenty-six species of benthonic foraminiferids were identified from these samples: 6 textulariines, 2 miliolines and 18 rotaliines. No planktonic foraminiferids were found. The fauna is characterized by a predominance of individuals of textulariines, especially the lituolids. Although the Cannonball Formation is characterized by an alternating sequence of sandstones and mudstones, the foraminiferid fauna was restricted to the mudstone facies in the upper and upper-middle part of the formation. Two characteristic assemblages based on dominant families and genera are recognized, the lituolid (dominantly arenaceous) and nodosariid (dominantly calcareous) assemblage. R-mode cluster analysis shows three distinct clusters of species: one corresponds to the lituolid assemblages, another corresponds to the nodosariid assemblage, and the third is composed of species that are represented only rarely in the foraminiferid fauna. The Q-mode cluster analysis shows a high level of correlation between two lithologic units in two widely separated stratigraphic sections; other foraminiferid correlations were not possible because of the sparse occurrence of foraminiferids in other stratigraphic sections.

The two assemblages, the dominance of arenaceous forms, the absence of planktonic forms and the occurrence of the microfauna

in the mudstone facies, suggests nearshore, shallow (less than 100 m), possibly cooler, protected environments such as shallow bays behind barrier islands. The dominance of textulariines in the sediments is indicative of lower than normal marine salinity.

INTRODUCTION

The primary purpose of this study is to reconstruct the paleoenvironments of a part of the Cannonball Formation by using foraminiferids. Secondary purposes are to determine possible foraminiferid assemblages and biostratigraphic relationships using Q- and R-mode cluster analyses.

Previous Work

Stratigraphy.--Early workers, such as Meek and Hayden (1856) and Hayden (1857), generally confused the yet-to-be-named Cannonball Formation with the Late Cretaceous Fox Hills Formation. In their terminology, the Fox Hills Formation was known as "Formation No. 5" and was erroneously correlated with rocks now known to be in the Cannonball. Ludlow (1875) considered a section measured in the Cannonball as part of the Cretaceous "Fox Hills Group."

Leonard (1908) concluded that all rocks above the Cretaceous Pierre and Fox Hills Formations belong to the Fort Union Formation; however, he did not distinguish any members. In 1914, he said that the Fort Union Formation was underlain by the fresh-water sediments of the Lance Formation, which, in turn, was underlain by the Montana Group.

Lloyd (1914) first recognized the "Cannonball marine member of the Lance Formation" as a distinct stratigraphic entity. He considered the "Cannonball marine member" as the upper 250-300 ft of the Lance Formation. The name was derived from the Cannonball River along which the bulk of the exposures occur in the type area.

Lloyd and Hares (1915) enlarged upon Lloyd's (1914) discussion of the Cannonball; designated the lignitic, nonmarine beds below the Cannonball the "Ludlow lignitic member of the Lance Formation," and suggested that the Ludlow was the nonmarine, stratigraphic equivalent of the Cannonball. The Hell Creek Formation, although at that time included in the Lance Formation, remained an unnamed member.

Thom and Dobbin (1924a, 1924b) assigned the Cannonball to the Fort Union Formation because of the equivalency of the Upper Cannonball and Ludlow with the Lebo Member of the Fort Union of eastern Montana.

Fox and Ross (1942), using the foraminiferid fauna, suggested the elevation of the Cannonball to formational status. Also in 1942, the formational status of the Cannonball was adopted by the North Dakota Geological Survey (Laird and Mitchell, 1942). (For a more complete discussion of the history of the stratigraphic study of the Cannonball Formation, see Cvancara, 1965.)

Paleontology.--Stanton (1920), in his study of the Cannonball mollusks, reported two species of foraminiferids from the Cannonball. The Cannonball microfauna was first studied in detail by Fox and Ross (1942), who identified sixty-four species of foraminiferids. Because of the similarity in the foraminiferid fauna in the Cannonball and the Paleocene Midway of Texas, Fox and Ross concluded that the Cannonball was also Paleocene in age. Of the sixty-four species of foraminiferids from the Cannonball, thirty-eight were previously reported from the Midway.

Swain (1949) identified five species of ostracodes from the Cannonball. He reported that all five species also occur in the Paleocene Midway Group of Texas, and agreed with Fox and Ross (1942) that the age of the Cannonball was Paleocene.

Based on thirty species of foraminiferids and five species of ostracodes, Lemke (1960) enlarged the previously recognized areal extent of the Cannonball by 60 miles to the north into the Souris River area. In addition to the foraminiferids and ostracodes, he reported ten species of mollusks, one worm and one shark.

Fox and Olsson (1969) reported seven species of plantonic foraminiferids from the Cannonball and concluded that this assemblage belonged either to the Globigerina edita zone of Hillebrandt or the Globorotalia pseudobulloides zone of Bolli. In either case, both zones are indicators of the Danian Stage of the Paleocene. Furthermore, it was suggested that the relative scarcity of plantonic foraminiferids and the presence of a shallow-water, benthic, foraminiferid assemblage indicated deposition in "shallow neritic depths." The small size of the planktonic foraminiferids and their sparse occurrence, were thought by Fox and Olsson to be indicators of shallow water.

Other invertebrate groups reported from the Cannonball include six species of corals (Vaughan, 1920), five species of corals (Wilson, 1957); bryozoans (Cvancara, 1965); sixty-three species of scaphopods, gastropods and bivalves (Stanton, 1920); thirty species of bivalves, including one species of boring bivalve (Cvancara, 1966, 1970a); one species of nautiloid cephalopod (Feldman, 1972); two species of crabs (Holland and Cvancara, 1958), lobsters (Feldman and Holland, 1971), and Halymenites (=Ophiomorpha), the presumed burrows of a decapod crustacean (Cvancara, 1965).

Vertebrate fossils include sharks (Stanton, 1920; Leriche, 1942; and Cvancara, 1965) and skates, rays, turtles and crocodiles or alligators (Cvancara, 1965).

The Cannonball flora includes dinoflagellates, hystrichosphaerids, spores and pollen (Stanley, 1965), and two or three species of driftwood (Cvancara, 1970b).

METHODS OF STUDY

Six stratigraphic sections (Figures 3-8) were measured and sampled in June and July, 1972. The sections are generally in two areas, along the Missouri and Heart River drainages, and along the Cannonball River in the type area of the Cannonball Formation (Figure 1).

Sampling Method

A stratified random sampling method was used in the collection of samples for textural and microfaunal analysis. Samples were selected randomly from each lithologic unit within a given measured section, the number of samples depending upon the thickness of the unit; one sample was collected per meter. For determining the number of samples, measurements involving fractions were rounded to the nearest whole number; one sample was selected for units less than one meter thick. After each lithologic unit was measured, a table of random numbers was utilized to determine the sample locations within the unit. The random numbers were rounded off to three digits, converted to percentages and multiplied times the unit thickness, the result of which was a distance that was measured from either the upper or lower contact, depending upon which was most expedient.

Three types of subsamples were separated from the two hundred-forty, 1-liter samples. A 400-ml subsample was separated from each of the two hundred-forty samples for microfaunal analysis, thirty-eight subsamples (12-35 g) were separated for grain-size analysis, and five subsamples (80-100 g) were separated for X-ray analysis of the clay mineralogy.

Sample Preparation for Microfossils

The 400-ml subsample for microfaunal analysis was placed in a container to which was added a 5% Calgon (sodium hexa-meta-phosphate) solution. The samples were allowed to stand for 2-3 days to allow the Calgon solution time to deflocculate the clays. The solutions were not agitated because of the danger of damaging or destroying the microfossils. While the samples were soaking in Calgon solution, the pH of the solution was monitored to avoid the possibility of the solution becoming acidic and consequently dissolving the calcareous microfossils. After soaking, the samples were wet sieved through a 62 μ sieve. All material coarser than silt- and clay-sized material, which remained in the sieve, was saved for further preparation. If all of the silt and clay had not deflocculated and large aggregates remained, the material in the sieve was soaked in 5% Calgon solution for an additional 2-3 days. After the additional soaking, the samples were wet sieved again and, in most cases, the additional soaking was sufficient to deflocculate most of the remaining clay aggregates.

After wet sieving, the samples were dried at either room temperature or in an oven at 40°C. After drying, the samples were dry sieved through Tyler sieves 20, 50, 60, 80 and 120.

The size fractions of prepared samples were scanned under a microscope (36 and 72 power) and all microfossils were picked. In most cases the entire sample was scanned; however, in the coarser-grained sediments, where there was little silt and clay and consequently a large amount of sample to deal with, either ½, ¼ or 1/8 of each size fraction was scanned, the percentage of the cut being dependent upon the size of the prepared sample, the largest of which was 400 ml. The amount of prepared sample that was picked was usually about 50 ml.

Sample Preparation for X-ray

Five samples were prepared for X-ray analysis of the clay mineralogy. The samples were prepared without the use of any chemical deflocculants. Approximately 80-100 g of sample was added to deionized water in a 50-ml beaker that was placed into a sonic bath, which caused sufficient deflocculation after approximately one hour. After deflocculation, the samples were placed into 1-liter graduated cylinders and filled with deionized water and agitated. After two or more hours, a portion of the supernatant liquid above the silt-clay interface was pipetted off and placed on standard petrographic slides. Two slides were prepared for each sample; after drying, one of the slides was glycolated for forty-eight hours and the other slide was left untreated. After preparation, each of the slides was X-rayed from 2° to 32° 2Θ on a Phillips high-angle diffractometer using a Nickel filter and Copper k-alpha radiation. The resulting defractograms were compared to standard defractograms for clay mineral identification. Relative percentages were estimated from peak areas.

Grain-Size Analysis

Two samples were randomly selected from each lithologic unit of each measured section for grain-size analysis. Two methods were used:

sieve analysis (with sieves at quarter Φ intervals) for the coarser, sand-sized sediments (Folk, 1968, p. 34-36), and pipette analysis for the finer-grained sediments (Folk, 1968, p. 37-40). The main purpose of grain-size analysis was to approximate the mean grain-size of each lithologic unit and to determine if any relationships existed between the microfauna and grain-size. The mean grain sizes of the two samples were averaged to determine an average for the entire lithologic unit.

Statistical Methods

For the purpose of analysis of the Cannonball microfauna, Q- and R-mode cluster analyses were performed. The Q-mode correlation matrix plotted sample against sample and a Jaccard's correlation coefficient was calculated for each possible pair of samples in a measured section. Jaccard's correlation coefficient (Cheatham and Hazel, 1969, Table 1) is:

$$\frac{C}{N_2+N_1-C}$$

where N_1 is the number of species in sample one, N_2 is the number of species in sample two and C is the number of species common to both samples. All of the samples were compared and clustered for the purpose of biostratigraphic correlation. The other type of correlation matrix, the R mode, plotted species against species and Jaccard's correlation coefficient was calculated based upon the percentage of mutual occurrences of each possible pair of species. Although the mathematical representation remains the same as in the Q mode, the variables have different meaning. In the R mode, N_1 is the number of samples in which species one occur, N_2 is the number of samples in which species two occurs and C is the number of samples in which both species occur.

The correlation coefficients for both Q and R mode cluster analyses were computed, clustered and the denograms were constructed by an NTSYS computer program presently on file at the University of North Dakota computer center.

Photographic Methods

Photographs of the microfossils are either photographs utilizing normal light optics or scanning electron photomicrographs. Where there was only one specimen or where color contrast was important, normal light optics were used because the coating required for use with the scanning electron microscope essentially destroys specimens for further use, and color contrast is not visible on the scanning electron photomicrograph. Where color contrast was important, specimens photographed conventionally were left uncoated; otherwise, they were coated with magnesium oxide.

The equipment that was used for the normal light photographs was a Leitz "Aristophot" apparatus consisting of a Leitz 4in X 5in camera, bellows and Sumar 24 mm lens. During photography all specimens were magnified 20X and all microfossils were photographed on Kodak Plus-X film. During printing the photographs were enlarged an additional 2X to give a total magnification of 40X on the finished photograph.

The scanning electron photomicrographs were made on polaroid film using a Cambridge Stereoscan S-4 scanning electron microscope at a magnification of 100X or 200X. The specimens were coated with an undercoating of carbon and an overcoating of gold-palladium.

GEOLOGIC SETTING

Structural Setting

The Cretaceous and Tertiary rocks in North Dakota generally dip gently toward the center of the Williston Basin. Other structures superimposed upon the basin account for local variations in the amount and direction of dip. Ballard's (1942, fig. 2) structure-contour map, utilizing the top of the lower Cretaceous "Dakota Sandstone" as a datum, showed the center of the basin about 60 miles southeast of Williston, North Dakota. Benson (1952, p. 228), however, suggested that structure contours drawn on top of the Tertiary beds would indicate a center east of the one proposed by Ballard. Electronic well log information (Carlson, 1973) would agree with Benson's suggestion that the Paleocene center of the Williston Basin is farther east than the one suggested by Ballard.

Regional Stratigraphy

Late Cretaceous and early Tertiary rocks in North Dakota crop out predominantly in southwestern and southern North Dakota around the margin of the Williston Basin. In addition, late Cretaceous and early Tertiary rocks also crop out in north-central North Dakota in the Souris River and Turtle Mountain areas (Figure 1).

The Cannonball Formation intertongues with and overlies the nonmarine Ludlow Formation (Brown, 1948, p. 1271) (Figure 2). The

Fig. 1. Geologic sketch map of North Dakota showing Cannonb and adjacent formations and detailed geologic map of Grant, Morton a Oliver Counties showing measured section localities. Locality numbe correspond to those on Figures 3-8 and in Appendix A (both geologic maps modified from Carlson, 1969).

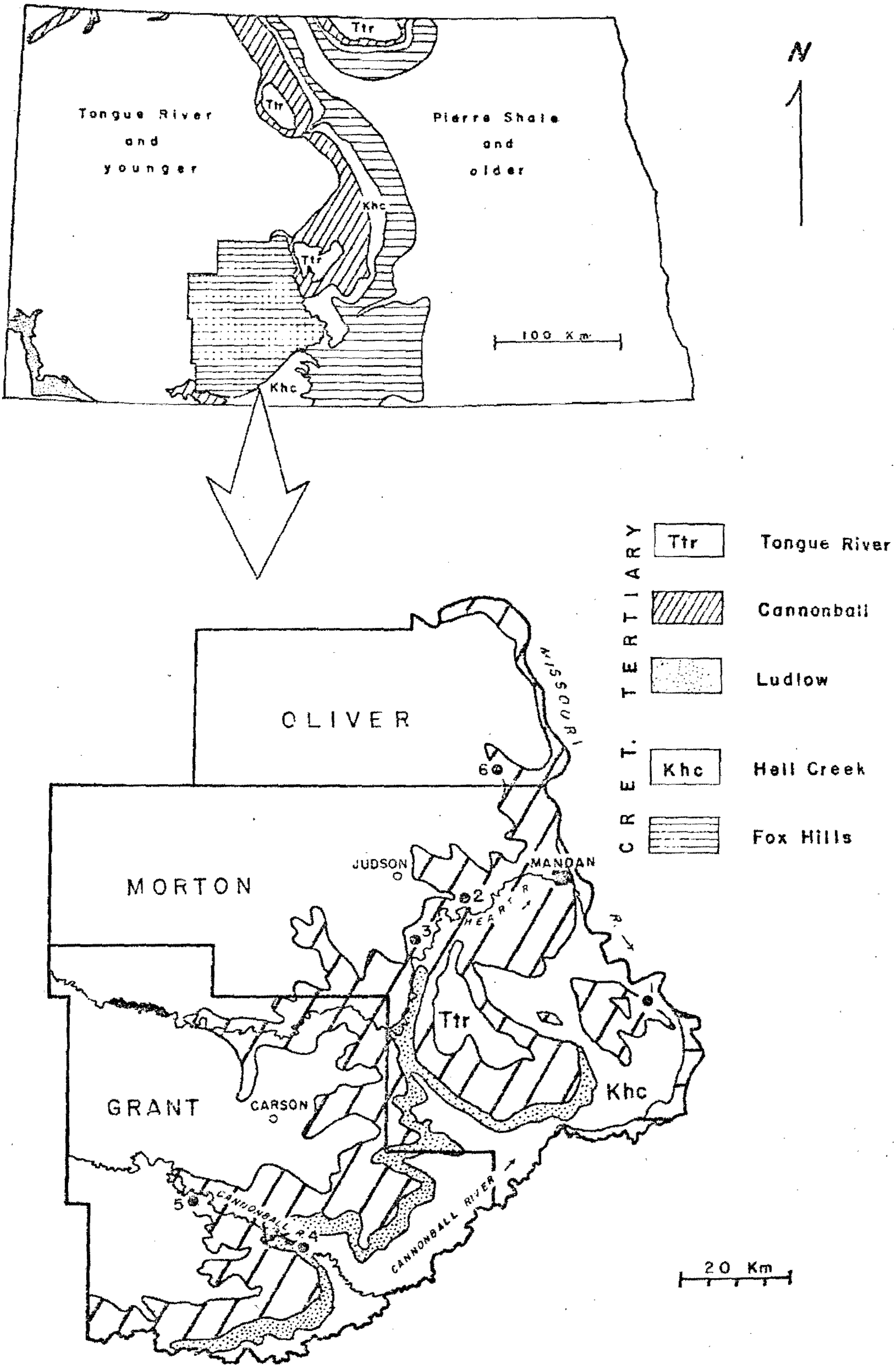
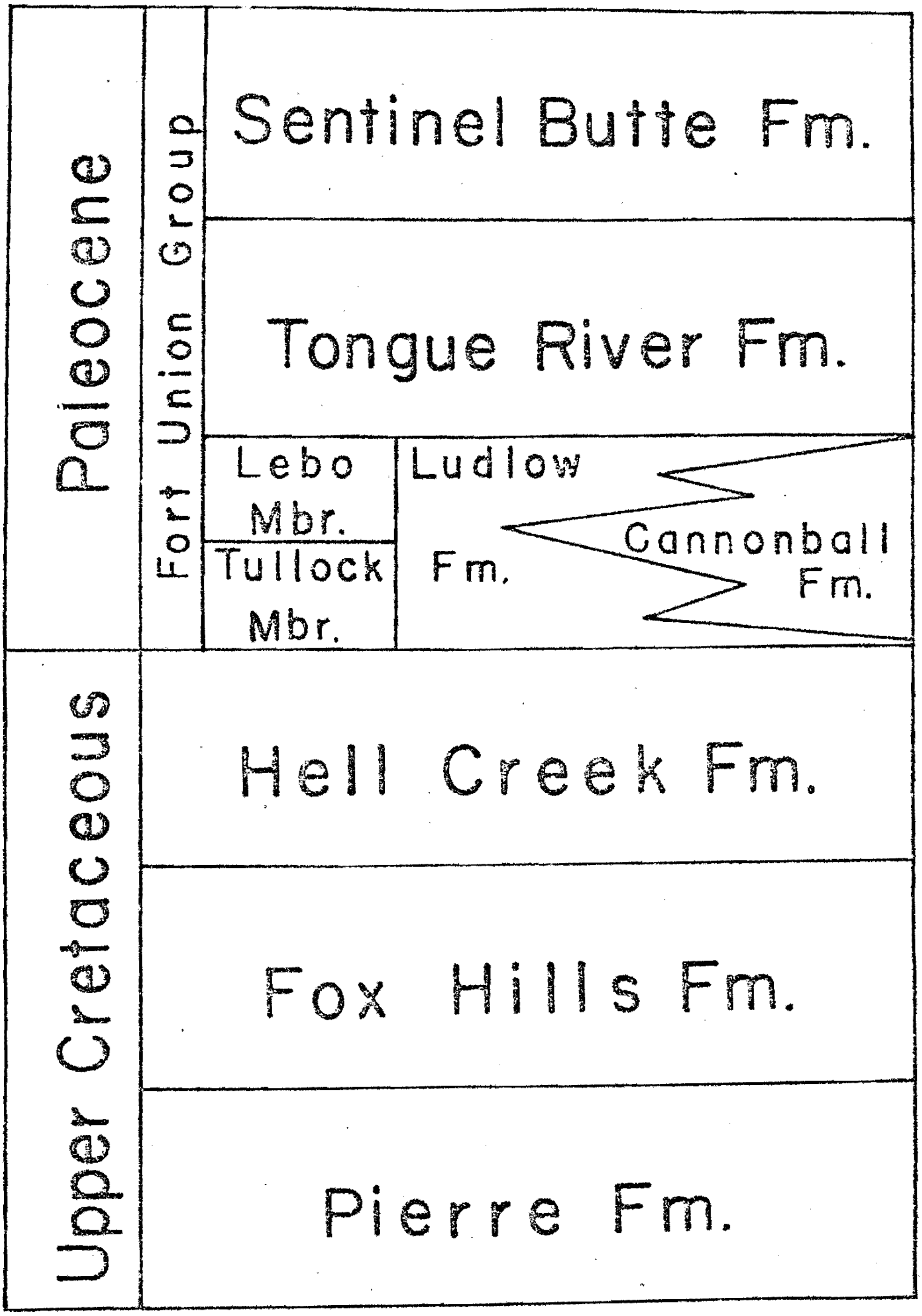

Ttr
Tongue River
and
younger
Pierre Shale
and
older
Khc
100 Km
N
TERTIARY
CRET.
Ttr Tongue River
Cannonball
Ludlow
Khc Hell Creek
Fox Hills
OLIVER
MORTON
GRANT
MISSOURI
JUDSON
MANDAN
HEART R.
CARSON
CANNONBALL R.
CANNONBALL RIVER
Ttr
Khc
1
2
3
4
5
6
20 Km

Fig. 2. Generalized stratigraphic column for the Upper Cretaceous and Paleocene in North Dakota (modified from Clayton, 1972, p. 4).


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

Ludlow is composed mainly of sand, lignite and lignitic shale. The mainly fluvial Tongue River Formation, which consists of calcareous sand, silt, shale and lignite, overlies the Cannonball Formation both conformably and disconformably (Cvancara, 1972, p. 71). Above the Tongue River Formation is the Sentinel Butte Formation, which is also mainly fluvial and consists mostly of calcareous sand, silt, shale and lignite. The Ludlow-Sentinel Butte interval is known as the Fort Union Group, which consists of the bulk of the Paleocene sequence in North Dakota. The classification used here has been adopted by the North Dakota Geological Survey and differs from that of the United States Geological Survey, which recognizes the Ludlow-Sentinel Butte sequence as the Fort Union Formation rather than as the Fort Union Group. Below the Fort Union Group, in descending order, are the nonmarine and marine sand, silt, shale and bentonitic claystone of the Hell Creek Formation; the sands of the marine Fox Hills Formation and the marine Pierre Shale, all of which are late Cretaceous. Overlying the Fort Union Group is the Golden Valley Formation which is continental in origin and Paleocene and Eocene in age (Hickey, 1972, p. 107).

STRATIGRAPHY OF CANNONBALL FORMATION

Lithostratigraphy

General thickness, lithology, and sedimentary structures.--The thickest, reported Cannonball occurs on the eastern flank of the Williston Basin in the subsurface, 120 m at Garrison dam (Fox and Olsson, 1969). The thickest known surface exposure is measured section 2 (figs. 1, 4) on the Heart River west of Mandan, and is 98 m thick. The Cannonball thins to the west where it is represented by two, brackish-water tongues (Brown, 1962, fig. 1). According to Van Alstine (1973), the combined thickness of both brackish-water tongues is about 17 m.

The Cannonball Formation is composed of an alternating sequence of sandstones, averaging 7 m thick, and mudstones, averaging 12 m thick. Concretions of varying composition, morphology and size appear throughout the section (figs. 4-7).

The Cannonball sandstones are fine- to very fine-grained with angular particles. They are variable in composition, but constituents common to all Cannonball sandstones are quartz, mica and varying amounts of clay. Small lignitic particles and glauconite are usually present. The percentage of lignitic particles increases and the percentages of glauconite usually decreases as the percentage of clay increases. Secondary components include gypsum aggregates and crystals and marcasite nodules. The color of the sandstones varies from yellowish gray to light greenish gray when fresh, but both generally appear brownish yellow when weathered.

The clay fraction of the Cannonball mudstones are predominantly of montmorillonite and illite with traces of kaolinite and possibly chlorite. The mudstones are often sandy, the coarser-grained material mainly consisting of quartz, biotite and muscovite, lignitic particles, gypsum aggregates and crystals. Marcasite nodules and glauconite pellets are sometimes present. The Cannonball mudstones are very dark gray to grayish brown where fresh and weather to light brownish gray or light gray. In most cases, the mudstones are blocky rather than fissile.

Concretions in the Cannonball are of mudstone, sandstone and limestone (Cvancara, 1965, p. 36-37). The mudstone concretions are most commonly calcareous, occur only in the mudstone lithofacies and are lenticular and elongate in the direction of the bedding. They are light or medium gray to bluish gray on fresh surfaces and light gray to brownish yellow on weathered surfaces.

The concretions in the sandstones are of two types (Figures 4, 7). One type is smaller (mean diameter 6.4 cm), subspherical to elongate to fusiform and phosphatic; the fresh surfaces are medium grayish brown and weathered surfaces are light yellowish gray to light grayish brownish yellow. The other type is larger (mean diameter, 0.7 m), medium gray to medium blue-greenish gray on fresh surfaces and light grayish, brownish yellow where weathered. The larger concretions occur as distinct linear zones that trend parallel to the bedding and occasionally grade into more massive, continuous, lenticular, sandstone beds.

The limestone concretions occur exclusively in the mudstone lithofacies, are dark bluish gray to black on fresh surfaces and weather to very light or medium brownish yellow. They are about 0.15 m to 0.7 m thick.

Fossils occur in all types of concretions, but are most common in those of limestone.

In addition to the concretions, other sedimentary structures include ripple marks, cross-stratification (Figures 3, 4, 8), nodules, cone-in-cone structure and questionable clastic dikes and sills (Cvancara, 1965, p. 35).

Measured sections.--Locations of the measured sections are given on Figure 1 and illustrations of the measured sections and the general mean grain-size distributions are given in Figures 3-8. Detailed section descriptions are given in Appendix A.

Grain-size distributions.--The mean grain size of the samples collected for this report ranges from approximately 2.4 Φ for the sandstones to 8.4 Φ for the mudstones. The Cannonball sandstones are consistently fine- to very fine-grained, ranging from about 2.4 Φ to 3.0 Φ. The mudstones are much more variable in grain-size distribution, the percentages of silt varying significantly from mudstone to mudstone. Individual grain-size determinations are given in Figures 3-8 and the mean grain-sizes and standard deviations are summarized in Figure 9.

Clay mineralogy.--The major clay minerals in the Cannonball samples that were X-rayed are montmorillonite, illite and kaolinite/chlorite. Kaolinite and chlorite were not differentiated because

Fig. 3. Measured section 1, including sample locations. La
black dots to the right of the measured section are mean grain-size
determinations. Blank spaces indicate concealed intervals. The
location of the section is shown in Figure 1; a detailed locality
and section description is given in Appendix A.

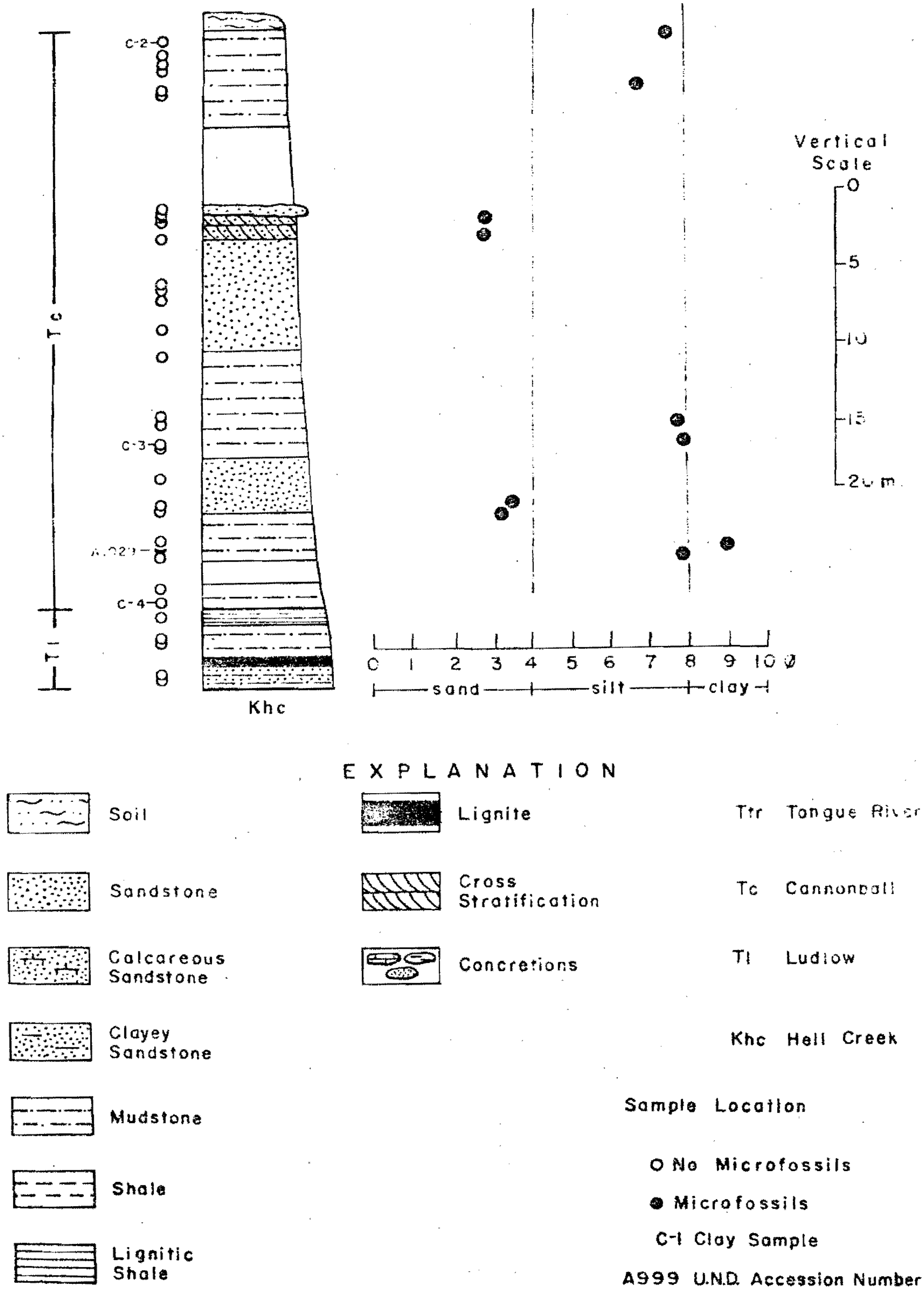

C-2
C-3
C-4
Tc
Tl
Khc
Vertical Scale
0
5
10
15
20 m.
0 1 2 3 4 5 6 7 8 9 10 Ø
sand
silt
clay
EXPLANATION
Soil
Sandstone
Calcareous Sandstone
Clayey Sandstone
Mudstone
Shale
Lignitic Shale
Lignite
Cross Stratification
Concretions
Ttr Tongue River
Tc Cannonball
Tl Ludlow
Khc Hell Creek
Sample Location
No Microfossils
Microfossils
C-1 Clay Sample
A999 U.N.D. Accession Number

Fig. 4. Measured section 2, including sample locations. Larger black dots to the right of the measured section are mean grain-size determinations. Explanation of the symbols is given on Figure 3. The location of the section is shown on Figure 1; a detailed locality and section description is given in Appendix A.

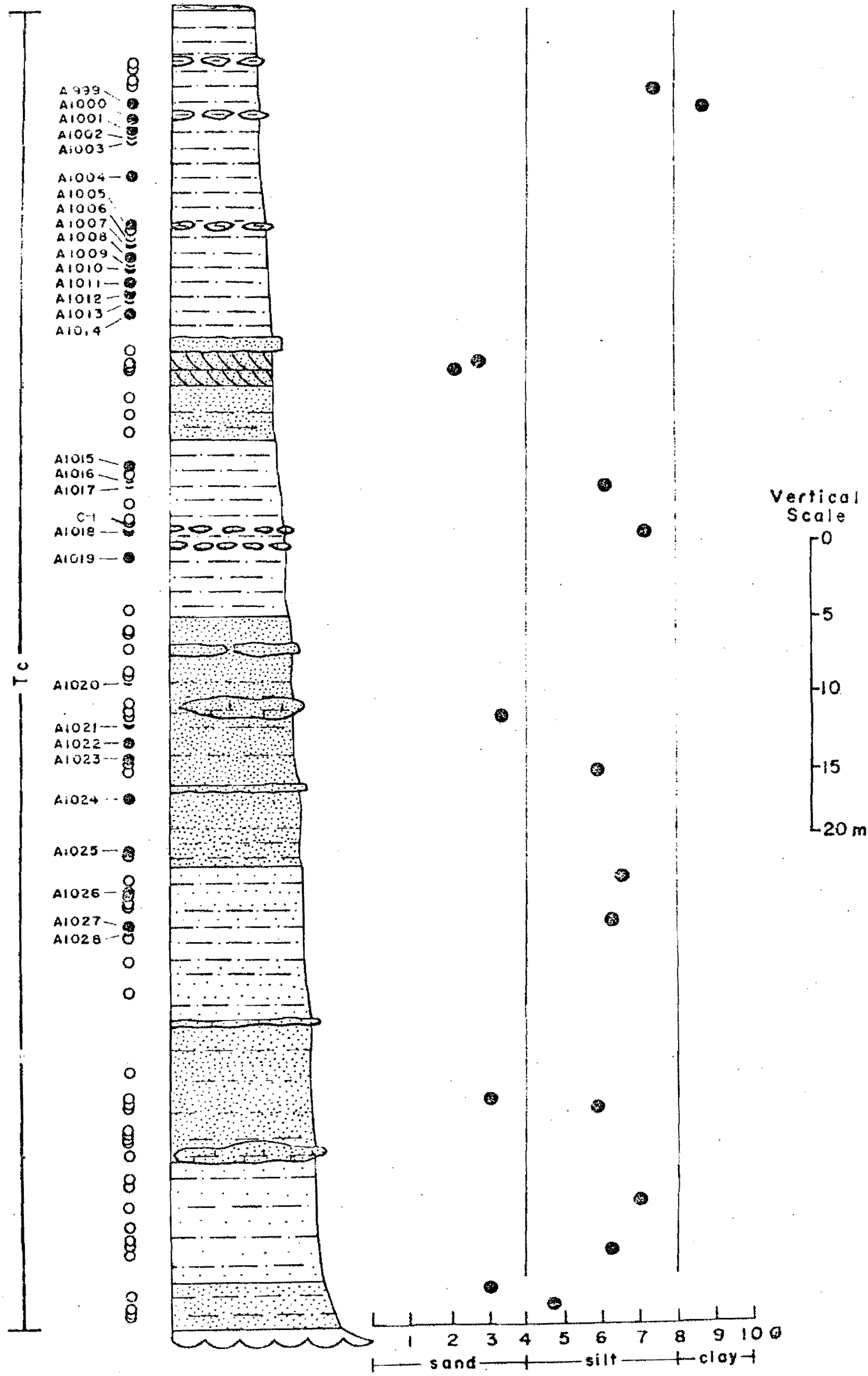

Tc
A999
A1000
A1001
A1002
A1003
A1004
A1005
A1006
A1007
A1008
A1009
A1010
A1011
A1012
A1013
A1014
A1015
A1016
A1017
C-1
A1018
A1019
A1020
A1021
A1022
A1023
A1024
A1025
A1026
A1027
A1028
Vertical Scale
0
5
10
15
20 m
1 2 3 4 5 6 7 8 9 10 Ø
sand
silt
clay

Fig. 5. Measured section 3, including sample locations. Larger black dots to the right of the measured section are mean grain-size determinations. Blank spaces are concealed intervals. Explanation of the symbols is given on Figure 3. The location of the section is shown in Figure 1; a detailed locality and section description is given in Appendix A.

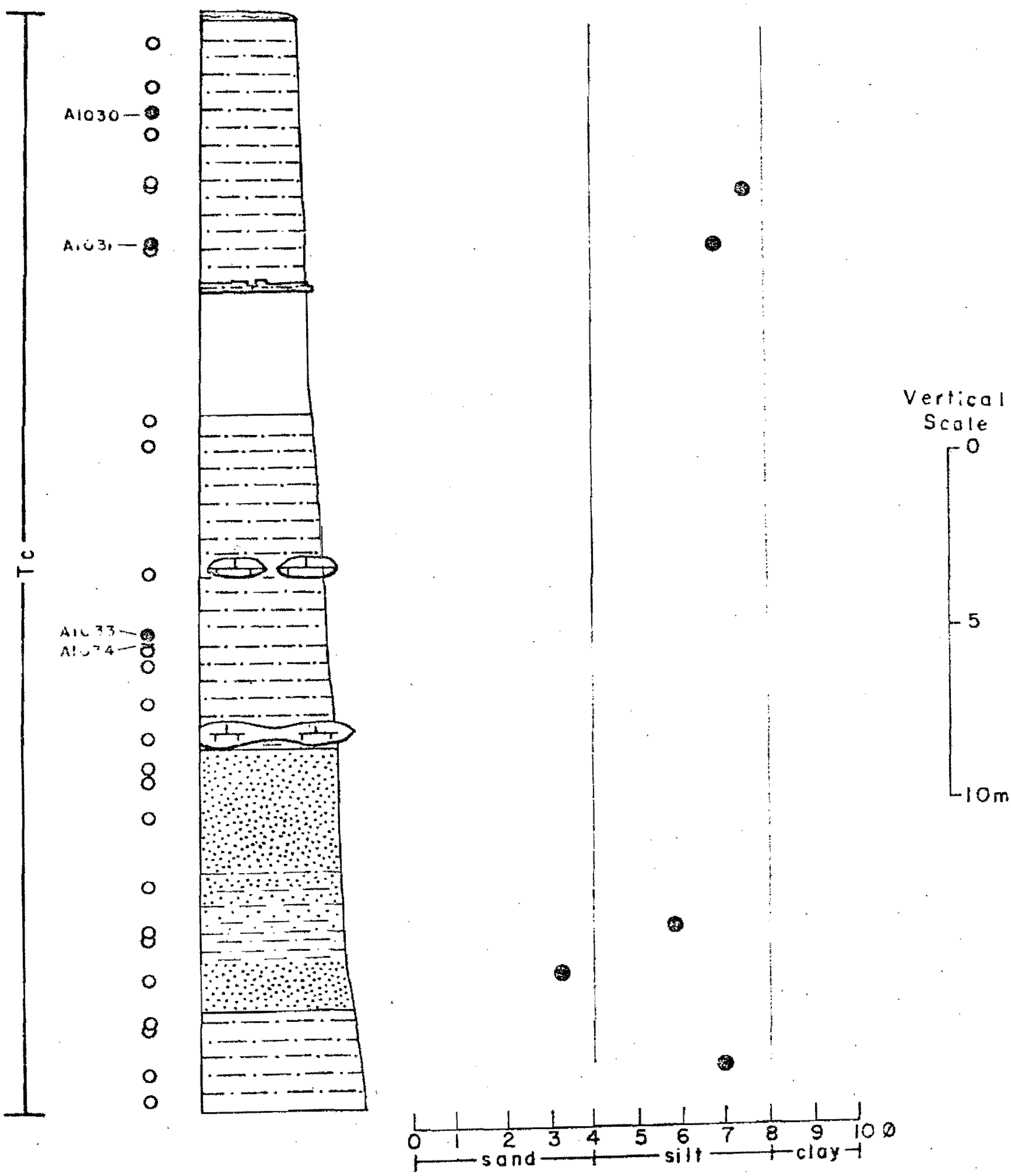

A1030
Tc
Vertical Scale
0
5
10m
0 1 2 3 4 5 6 7 8 9 10 Ø
sand
silt
clay

Fig. 6. Measured section 4, including sample locations. Larger black dots to the right of the measured section are mean grain-size determinations. Explanation of the symbols is given on Figure 3. The location of the section is shown on Figure 1; a detailed locality and section description is given in Appendix A.

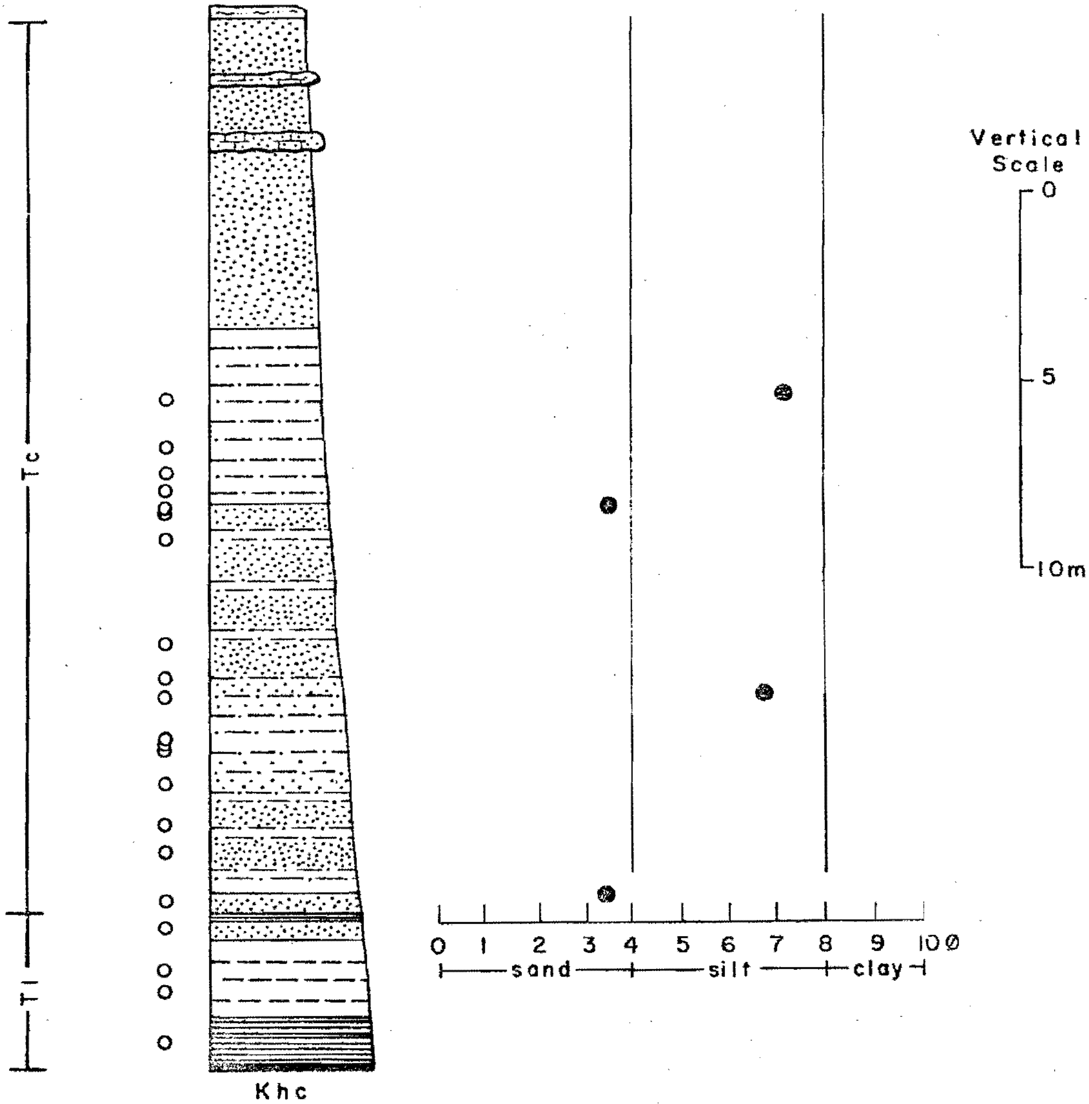
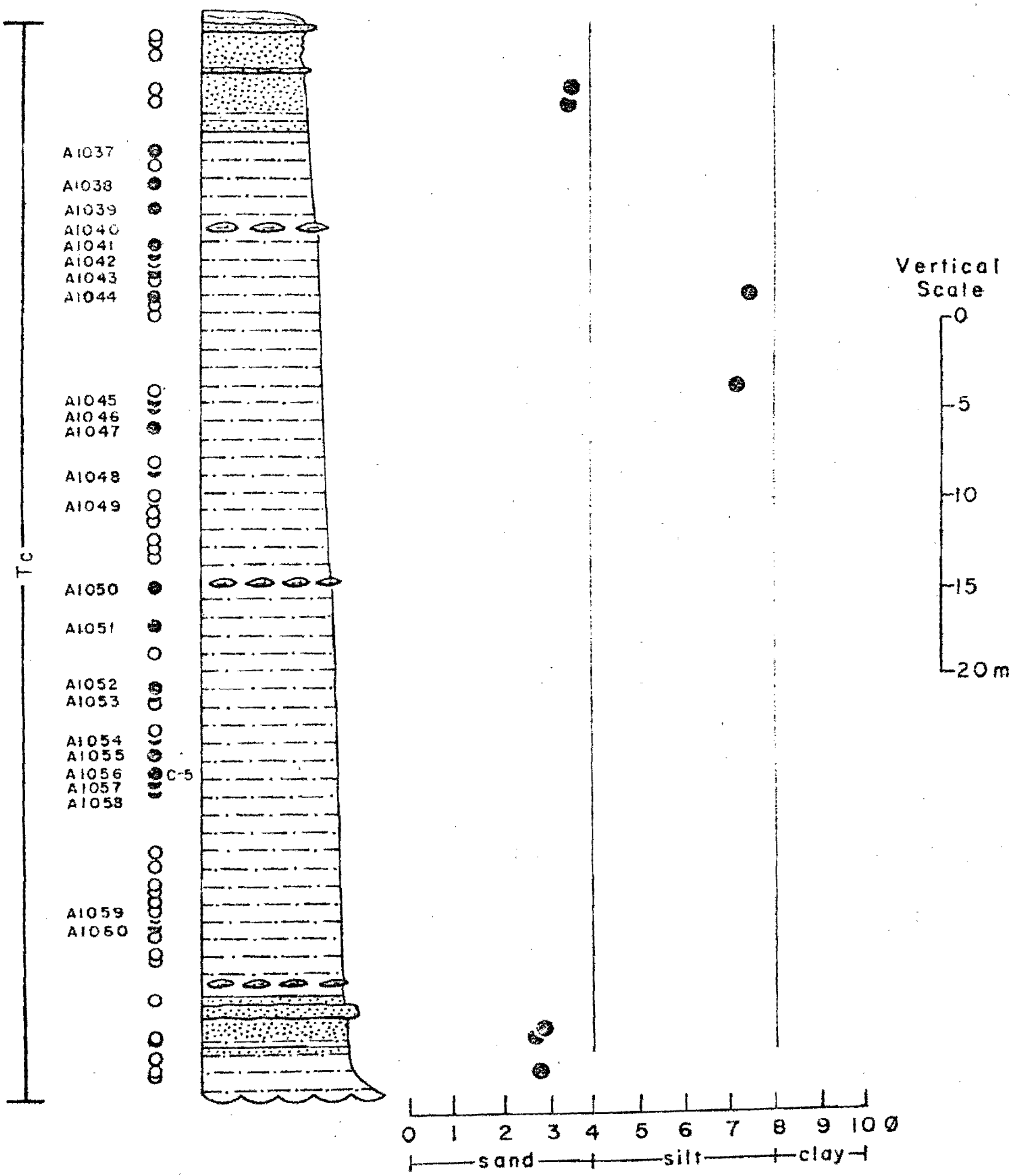

Tc
Tl
Khc
0 1 2 3 4 5 6 7 8 9 10Ø
sand
silt
clay
Vertical Scale
0
5
10m

Fig. 7. Measured section 5, including sample locations. Larger black dots to the right of the measured section are mean grain-size determinations. Explanation of the symbols is given on Figure 3. The location of the section is shown on Figure 1; a detailed locality and section description is given in Appendix A.



Tc
A1037
A1038
A1039
A1040
A1041
A1042
A1043
A1044
A1045
A1046
A1047
A1048
A1049
A1050
A1051
A1052
A1053
A1054
A1055
A1056
C-5
A1057
A1058
A1059
A1060
Vertical Scale
0
5
10
15
20m
0 1 2 3 4 5 6 7 8 9 10 Ø
sand
silt
clay

Fig. 8. Measured section 6, including sample locations. Larger black dots to the right of the measured section are mean grain-size determinations. Explanation of the symbols is given on Figure 3. The location of the section is shown on Figure 1; a detailed locality and section description is given in Appendix A.

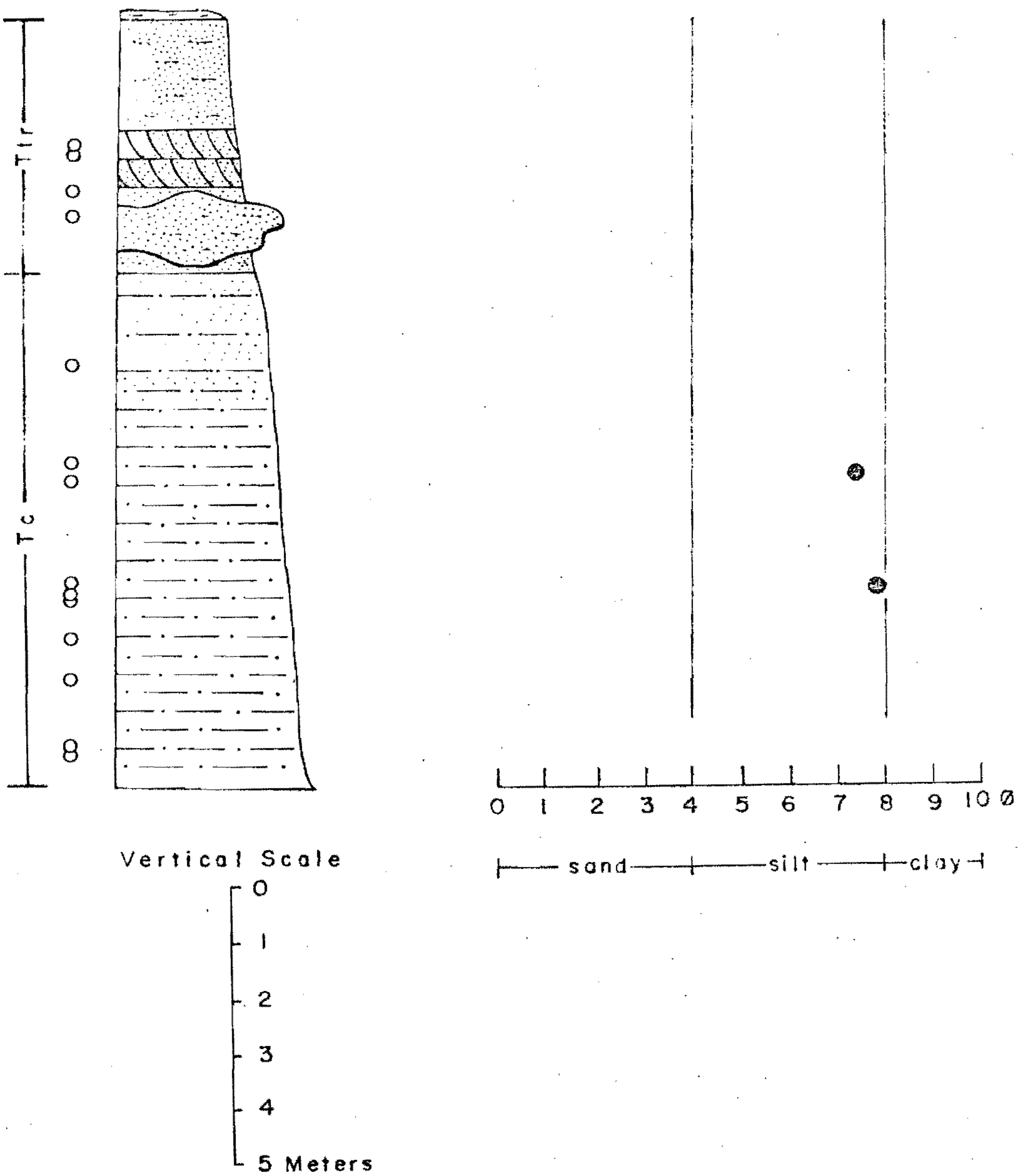
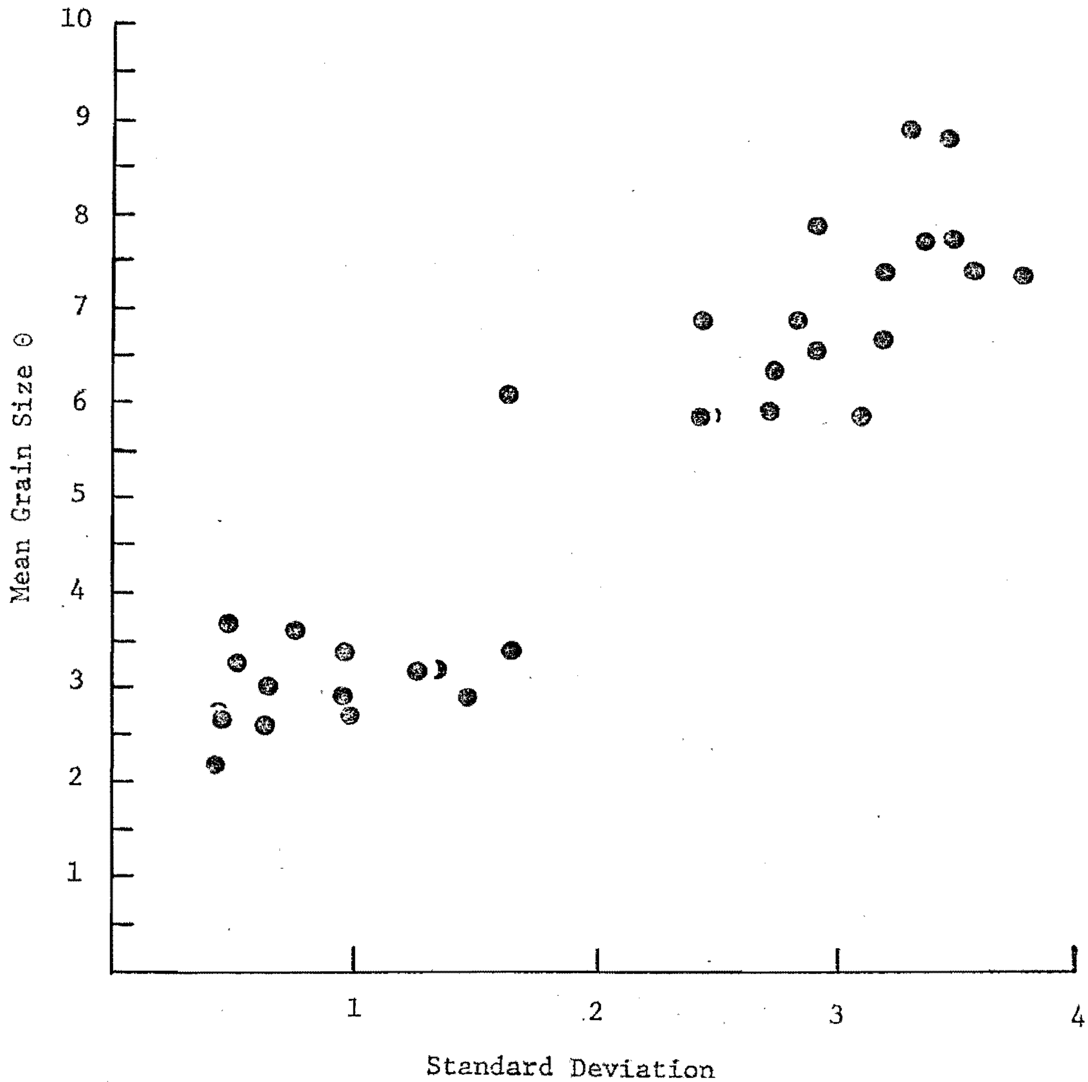

Ttr
Tc
Vertical Scale
0
1
2
3
4
5 Meters
0
1
2
3
4
5
6
7
8
9
10 Ø
sand
silt
clay

Fig. 9. Scatter plot of mean grain size against standard deviation.


10
9
8
7
6
5
4
3
2
1
Mean Grain Size Θ
1
.2
3
4
Standard Deviation

the processes involved are time consuming and kaolinite and chlorite are minor constituents. Peak areas were determined and the adjustments made as suggested by Johns, Grim and Bradley (1954). It is clear that montmorillonite is the predominant mineral in all of the samples. Illite is the second most abundant, in all cases followed by kaolinite/chlorite (both fairly minor constituents) (Table 1). Defractograms for each sample are given on Figure 10.

TABLE 1

PERCENTAGES OF CLAY MINERALS IN CANNONBALL FORMATION

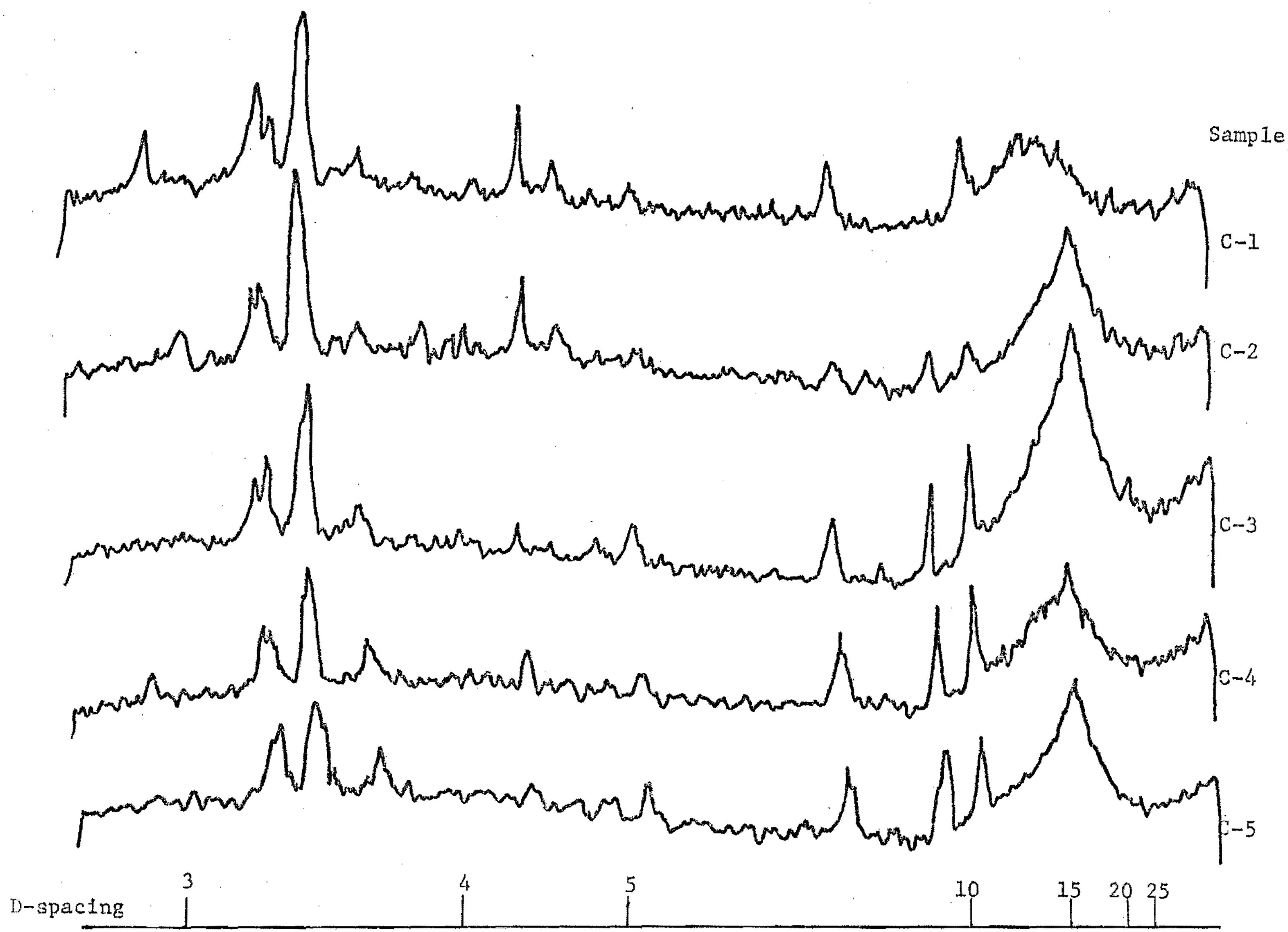
Sample	Percentage Montmorillonite	Percentage Illite	Percentage Kaolinite/Chlorite
C-1	75	18	7
C-2	85	13	2
C-3	79	16	5
C-4	55	34	11
C-5	65	23	12

Note:
Sample numbers correspond to those on Figures 3, 4 and 5.

Biostratigraphy

Although Cannonball microfossils may be locally abundant, their occurrence throughout the Cannonball is spotty and generally rare. In samples collected for this report, those from the lower Cannonball are almost devoid of microfossils, with the exception of two questionable foraminiferids found 3.4 m above the lower contact at measured section 1 (Figure 3, A1029). Fox and Ross (1942, p. 667) likewise reported

Fig. 10. Diffractograms of clay samples (unglycolated), from Cannonball mudstone; copper k-alpha radiation, 2° to 32° 2Θ. Sample locations given in Figures 3, 4 and 7.


Sample
C-1
C-2
C-3
C-4
C-5
D-spacing
3
4
5
10
15
20
25

the absence of foraminiferids from the lower Cannonball, and Cvancara (1965, fig. 4, appendices B, C) reported no fossils other than trace fossils from the lower Cannonball. Despite the apparent scarcity of body fossils in the lower Cannonball, small burrows as well as the larger Ophiomorpha burrows are commonly present in the sandstones.

The majority of microfaunal occurrences in this report are in the upper and upper-middle Cannonball. Cvancara (1965, p. 81) noted a generalized bivalve and crab zonation consisting of two main zones, one occurring in the lower-middle and the other in the upper-middle Cannonball.

Foraminiferids were collected from the upper Cannonball at measured section 3 where the exact placement of the upper contact was uncertain. The Tongue River Formation is exposed in the area and crops out within a vertical distance of 20 m above the highest exposed Cannonball; however, the Cannonball-Tingue River contact is not locally exposed. This is the only occurrence of foraminiferids in the upper Cannonball in this report. Fox and Ross (1942, p. 667) collected foraminiferids at four localities presumed to be in the upper Cannonball. One locality was along the Cannonball River and three were along the Heart River. Cvancara (1965, fig. 6) did not consider Fox and Ross's locality along the Cannonball River (locality 15 = Cvancara's measured section 6) upper Cannonball, but more likely middle Cannonball. In the absence of detailed locality data, it is not possible to discuss the placement of Fox and Ross's (1942) other "upper" Cannonball localities, all of which occur along the Heart River. The Heart River localities of Fox and Ross could include a portion of the middle Cannonball if any of their samples were collected near river level. No microfossils were found at measured sections 4 and 6 (figs. 6, 8) where the lower and upper contacts are exposed. A single "grab" sample collected 0.5 m below the Cannonball-Tongue River contact in Burleigh County, North Dakota (southwest corner NE¼ Sec. 13, T. 140 N., R. 81 W., 14 km north-northwest of the intersection of Interstate 94 and US 83) likewise yielded no microfossils. Considering the proximity of foraminiferid occurrences in measured section 3 with the overlying Tongue River, the absence of microfossils in measured section 6 and the "grab" sample is most likely due to incomplete sampling.

The Cannonball foraminiferid fauna occurs exclusively in the mudstone lithofacies. The Cannonball macrofauna, however, occurs mainly in "poorly consolidated, dark grayish green to greenish gray, clayey, glauconitic sandstone" (Cvancara, 1965, p. 80). The reason for this discrepancy is not clear but it may be related to fossil size. The smaller foraminiferids could easily be removed from the higher energy environments represented by the sandstones and transported to and deposited in lower energy environments represented by the mudstones or a deeper-water facies.

Two assemblages based on dominant families and genera were recognized, the lituolid and the nodosariid assemblages. The assemblages often occur together where foraminiferids are abundant in the upper and upper-middle Cannonball. Occurrences are primarily in two lithologic units in sections 2 and 5 (Figures 4, 7).

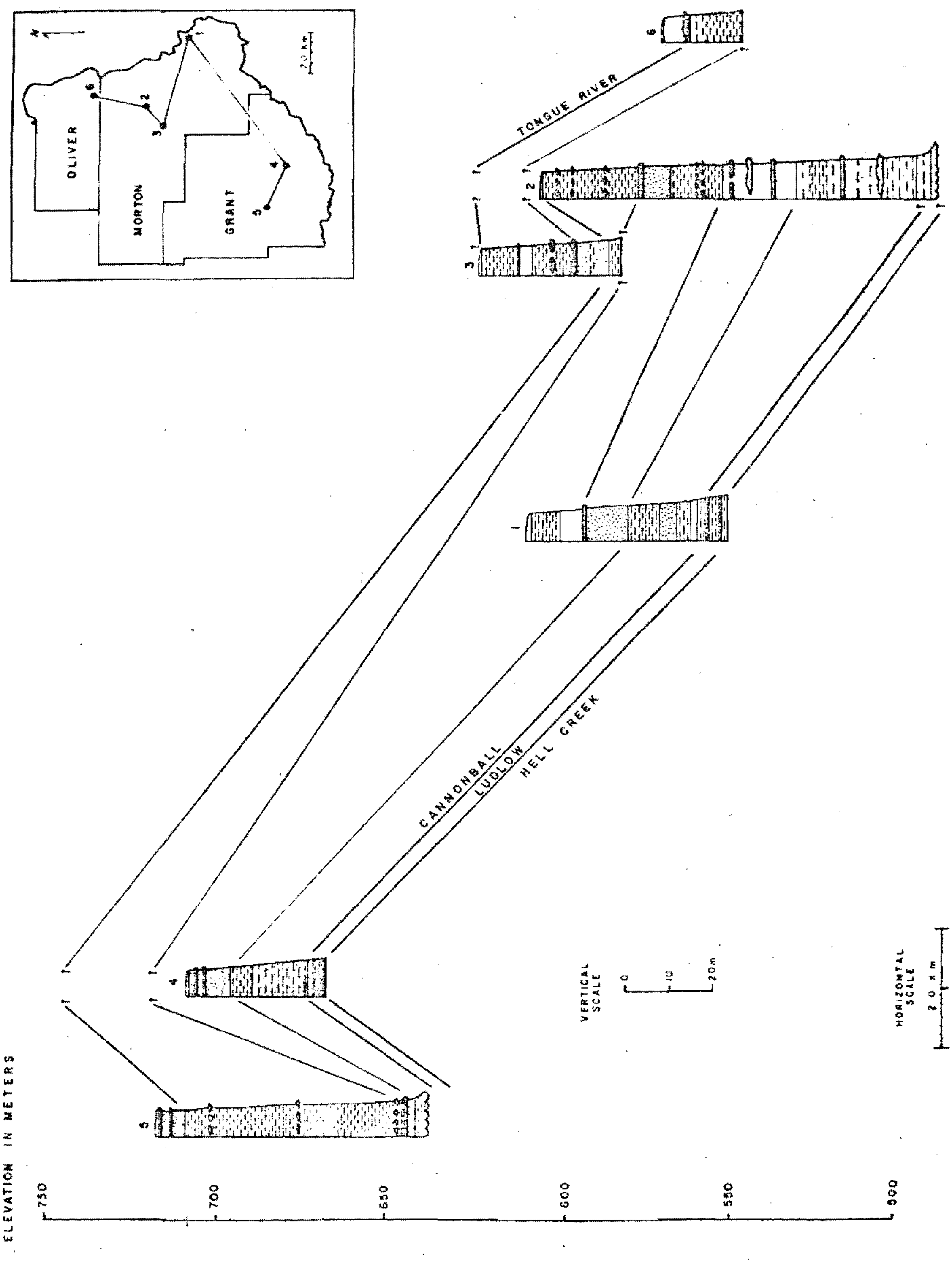
The dendogram (Appendix C, R-mode) shows three main groupings of species. The first consists of Haplophragmoides excavata,

H. glabra, Cyclogyra involvens, and Ammodiscus incertus and corresponds to the lituolid assemblages. The other two are both dominated by the nodosariids with Valvulineria wilcoxensis and rare Globulina. The lowermost of the two nodosariid groupings is misleading because many of the species in this group are represented by single or few (less than 10) specimens.

Correlations

Tentative faunal correlations for the six measured sections are given in Figure 11. These correlations are based upon microfaunal similarity (Jaccard's correlation coefficient) and macrofaunal similarity (Cvancara, 1965, figs. 6, 7). It was impossible to correlate on the basis of microfaunal similarity alone because the microfossil occurrences were concentrated primarily in two lithologic units in two sections (measured sections 2 and 5). The correlations are largely incomplete because the faunal occurrences are, for the most part, sparse. Only the two lithologic units mentioned above can be correlated based on the microfauna alone. Comparison of the Jaccard's correlation coefficient for each possible pair of samples between these two units shows wide variation, but for the majority of samples it is above 0.5 with the highest correlation between samples being 1.0. Fourteen samples, seven from each section, show a perfect correlation of 1.0 (Appendix C, Q-mode dendogram). Lumping all samples together in the two units and comparing them yields a correlation coefficient of 0.6. The correlation between the two units is perfect (1.0) when all of the foraminiferids that are represented by only one individual are eliminated. The remaining units that were correlated were based

Fig. 11. NE-SW cross section with sections arranged according to elevation above sea level. Numbers of sections correspond to those on the enclosed index map, those on Figure 1, and those on Figures 3-8. Blank areas indicate concealed intervals. Explanation of the symbols is given on Figure 3.


OLIVER
MORTON
GRANT
20 km
TONGUE RIVER
CANNONBALL
LUDLOW
HELL CREEK
VERTICAL SCALE
0
10
20m
HORIZONTAL SCALE
20 km
ELEVATION IN METERS
750
700
650
600
550
500

on the macrofaunal correlations of Cvancara (1964, figs. 6, 7). Lithologic similarity was not used because the number of exposures was limited and distances between sections were fairly large (10-75 km). As a result, possible lithofacies changes might not have been recognized.

Age

Lloyd (1914, p. 248) questionably assigned the Cannonball to the Tertiary. Stanton (1920), using mollusks, assigned a late Cretaceous age to the Cannonball. Stanton's Cretaceous age assignment was sidely accepted until Dorf (1940) offered indirect evidence with plants in the interfingering Ludlow Formation that the Cannonball was Paleocene. Fox and Ross (1942) based their Paleocene age assignment to the Cannonball on strong foraminiferid affinities between the Cannonball foraminiferid fauna and that of the Paleocene Midway. In 1949, Swain, using the ostracodes, said that the Cannonball Formation was Paleocene in age. Stanley's (1965) study of plant microfossils indicated a Paleocene age for the Cannonball and Cvancara's (1966) revision of the Cannonball bivalves indicated a Thanetian Stage (middle Paleocene). Utilizing seven species of planktonic foraminiferids, Fox and Olsson (1969) were able to specifically assign the Cannonball to the Danian Stage (earliest Paleocene). Sloan (1970, p. 441), utilizing mammalian remains in the overlying Tongue River Formation, suggested that the Cannonball Formation encompassed the Puercan and Torrejonian (early to middle Paleocene) mammalian stages. This age determination is partly in conflict with the Danian Stage suggested for the Cannonball by Fox and Olsson (1969). Sloan's evidence,

MICROFAUNAL ANALYSIS

Samples collected for this report yielded 26 species of benthonic foraminiferids representing 18 genera and 13 families. Also, two fragmental ostracodes were found. By suborder, the foraminiferid fauna consisted of 6 textulariines, 2 miliolines and 16 rotaliines. Although the textulariines comprised only about 23 percent of the species, they accounted for almost 75 percent of the individuals. The miliolines accounted for about 8 percent of the species and 2 percent of the individuals, and the rotaliines comprised about 69 percent of the species and only 23 percent of the individuals. No planktonic foraminiferids were found. Textulariine individuals predominated in all measured sections where microfossils were collected. They were also abundant in places where the other groups were absent. Measured section 1 (Figure 3) had 100 percent textulariines; measured section 2 (Figure 4) had 64.3 percent textulariines, 6.4 percent miliolines and 29.3 percent rotaliines; measured section 3 (Figure 5) had 54.5 percent textulariines and 45.5 percent rotaliinas; and measured section 5 (Figure 7) had 78.1 percent textulariines, 12.9 percent miliolines and 9.0 percent rotaliines. No microfossils occurred in measured sections 4 and 6 (Figures 6, 8). The predominance of agglutinated individuals is further illustrated by the agglutinated/calcareous (textulariines/miliolines+rotaliines) ratios of individuals. Measured section 1 had 100 percent textulariines and only two however, was derived from a unit that overlies the Cannonball Formation. Fox and Olsson's age determination is direct and is more applicable than Sloan's age based on indirect evidence. They, however, neglected to mention the stratigraphic occurrence of their foraminiferids. If the bulk of their occurrences of planktonic foraminiferids were in the middle or upper middle Cannonball, with no occurrences in the upper part of the formation, their age determination could be based upon incomplete data for the upper Cannonball. The Cannonball, therefore, could extend into the middle Paleocene as Sloan and Cvancara suggested. My report can lend little to the resolution of this conflict, since no planktonic foraminiferids were collected, and the foraminiferid stages of the Paleocene are based upon planktonic foraminiferid assemblages; however, a few of the benthic forms are characteristic of the lower Tertiary. According to Fox and Ross (1942, p. 669-670), Valvulineria midwayensis, Ceratobulimina perplexa and Allomorphina sp. do not occur in rocks older than early Tertiary. Cushman (1951, p. 24) stated that Nodosaria latejugata does not occur in rocks older than Tertiary. All species collected for this report, other than these four diagnostic species, appear to be long ranging species. Only a general age assignment of early Tertiary can be made from my material.

questionable individuals so no ratio could be computed. For measured sections 2, 3 and 5, the ratios were 1.80, 1.20 and 3.57.

Two assemblages based on dominant families and genera were recognized in the Cannonball samples, the lituolid and nodosariid assemblages. The lituolid assemblage was characterized by large numbers of Haplophragmoides with abundant Ammodiscus and Cyclogyra in places. The nodosariid assemblage was dominated by Nodosaria and Lenticulina with occasionally rare dentalines and globulines. In four samples Valvulineria was abundant. The nodosariid assemblage always occurred with the lituolid assemblage; however, the lituolid assemblage occurred independently of the nodosariid assemblage.

Although Fox and Ross (1942) collected sixty-four species of foraminiferids, they used only forty-three species that occur in the Gulf Coast for the purpose of their study. Because a complete species list was not included, valid comparisons cannot be made; however, one obvious discrepancy is the lack of the genus Haplophragmoides in their material. Two species of Haplophragmoides (Haplophragmoides excavata and H. glabra) were collected in abundance in this study. Also, they reported two species of planktonic foraminiferids whereas none were collected in this study. Fox and Ross also included no actual or estimated numbers of individuals in their study. The absence of plates also prohibits a visual comparison with their material. Because Fox and Ross based their study on only about 67 percent of the species collected, their conclusions are questionable.

Of the forty-three species reported by Fox and Ross (1942), three (about 7.0 percent) were textulariines, one (about 2.3 percent) was a milioline and thirty-nine (about 90.7 percent) were rotaliines.

The material collected for this report yielded a higher number and significantly higher percentage of textulariines; however, the rotaliines were also the dominant group in terms of numbers of species.

There is a large discrepancy between the species collected for this study and those listed by Fox and Ross. The following are the species (32) reported by Fox and Ross that I did not collect:

Eggerella? sp.
Guttlina cf. *G. wilcoxensis*
Dentalina gardnerae
D. pauperata
D. plummerae
Globigerina triloculinoides
G. pseudo-bulloides
Virgulina cf. *V. wilcoxensis*
Lenticulina cf. *L. orbicularis*
L. degolyeri
L. pseudo-mamilligera
Vaginulina midwayana
V. plumoides?
Palmula budensis
Bulimina quadrata
Valvulineria aff. *V. allomorphinoides*
V. midwayensis
Alabamina exigua
Cibicides alleni
Nodogenerina plummerae
Byroidina aequilateralis

Siphonina prima

Nonionella cf. *N. robusta*

Marginulina aff. *M. tumido*

Epistomina elegans

Spiroplectammina laevis

Nodosaria radicula

N. longiscata

Lagena apiculata

L. substriata

Globulina cf. *G. communis*

G. ovata

The following are the species (16) that I collected but were not listed by Fox and Ross (1942):

Bathysiphon eocenicus

Haplophragmoides excavata

H. glabra

Spiroplectammina sp (not *S. laevis*)

Trochammina sp.

Peneroplis sp.

Nodosaria latejugata

Dentalina colei

Dentalina sp. (not similar to any of Fox and Ross' species of *Dentalina*)

Marginulina sp. (not *M. tumido*)

Globulina sp. A (not similar to any of Fox and Ross' species of *Globulina*)

Lenticulina sp. A.

Lenticulina sp. B (neither L. sp. A nor L. sp. B is similar to any of Fox and Ross' species of *Lenticulina*)

Lagena sp. (not similar to any of Fox and Ross' species of *Lagena*)

Valvulineria wilcoxensis?

Cibicides sp. (not *C. alleni*)

The following species (7) were in common between the two studies:

Ammodiscus incertus

Ceratobulimina perplexa

Cyclogyra involvens (=*Cornuspira involvens*)

Dentalina mucronata

Lenticulina rotulata

Nodosaria affinis

Globulina gibba

The following species may be in common between the two studies, but uncertain identifications and the lack of plates in Fox and Ross' paper make comparisons difficult (Fox and Ross' (1942) name is listed first):

Allomorphina n. sp. = *Allomorphina* sp.?

Chrysalogonium granti = *Chrysalogonium* sp.?

Globulina lactea = *Globulina* sp. B?

MICROFAUNAL PALEOECOLOGY

Two characteristic foraminiferid assemblages occur in my samples, the lituolid and nodosariid assemblages. The lituolid assemblage, the most widespread, is dominated by Haplophragmoides with abundant individuals of Ammodiscus and Cyclogyra in places. The nodosariid assemblage is dominated by Nodosaria and Lenticulina and, in four instances, large numbers of Valvulineria are associated with this assemblage. These assemblages are comparable in part with those of Albritton and others (1954) who recognized two microfaunal "facies" in the Grayson Marl (Cretaceous). One facies was characterized by "a predominance in numbers of agglutinated tests" (p. 334), and Haplophragmoides and Ammobaculites were the predominant genera. This corresponds to the lituolid assemblage although Ammobaculites is absent in my Cannonball samples. This facies was thought to represent a nearshore zone and Haplophragmoides was found in the epineritic zone (5-20 fathoms deep) of Scott (1940, p. 1168). Ammobaculites, on the other hand, presumably occurred "in weakly brackish waters inside the shoreline" (p. 335). The other microfaunal facies mentioned by Albritton and others was characterized by a predominance of calcareous tests, and two subfacies were recognized. One subfacies was characterized by the Lagenidae, Rotaliidae and Anomalinidae, the other by the Buliminidae. The first subfacies is recognized in the Cannonball, although two of the familial names differ because a different classification is used here. The subfacies characterized by the Buliminidae, not present in the Cannonball, was thought to represent water about 50 fm deep and the subfacies characterized by the Lagenidae, Rotaliidae and Anomalinidae (=Nodosariidae, Discorbidae and Anomalinidae (Loeblich and Tappan, 1964) was intermediate between the shallow-water agglutinated facies and the deeper-water Buliminidae subfacies. The general correspondence of the microfaunal facies of Albritton and others (1954) and the foraminiferid assemblages of the Cannonball suggests that my Cannonball material is mainly shallow water, representing a depth range of 5 to less than 50 fm.

Lowman (1949, figs. 13-15) prepared distribution charts for the depth distribution and relative abundance of foraminiferid genera in the Gulf Coast. Of the genera in common with the Cannonball, Haplophragmoides and Trochammina extended from about 8 ft to more than 8000 ft; however, at depths greater than 900 ft, there was a large percentage of planktonic foraminiferids, and none occurred in depths less than 80 ft. Cibicides, Marginulina, various Peneroplidae and Miliolidae, and Cristellaria = Lenticulina (in part) also occurred in Lowman's distributions. Little comparison can be made with two genera in the Cannonball, Peneroplis and Marginulina, because each is represented by only a single specimen. Cibicides extends from less than 100 ft to greater than 1700 ft of water and Cristellaria = Lenticulina (in part) from 100-150 ft to 300-350 ft. Throughout much of these depth ranges there was a large percentage of planktonic foraminiferids, which were insignificant at depths of less than 200 ft and absent at depths less than 80 ft.

Todd and Bronnimann (1957) collected recent foraminiferids from the eastern Gulf of Paria, Trinidad, including five species of Haplophragmoides, one species of Spiroplectammina, one species of Cyclogyra, three species of Trochammina, one species of Lenticulina (=Robulus), one species of Dentalina, twelve species of Lagena and five species of Cibicides, in addition to representatives of several other genera not in common with those of the Cannonball. In their study, they recognized three distinct environments, the tidal zone, the nearshore zone and the offshore zone. The tidal zone was subdivided into Mangrove I and Mangrove II. Mangrove I was said to be transitional between the Mangrove II and the nearshore zone. The nearshore zone was 0-2 fm deep and the offshore zone 2-18 fm deep. Applying the depth data of Todd and Bronnimann (1957) to the genera in common between their study and the Cannonball, a generally nearshore environment is indicated for the Cannonball. The generalized depth associations are given in Table 2.

Murray (1968) collected 50 species of foraminiferids from Buzzards Bay, Massachusetts. Of the groups that he collected, six genera including one species are in common with my Cannonball material. The common genera and the depths at which they were collected are: Ammodiscus (18-24 m), Cibicides (18 m), Cyclogyra involvens (24 m), Lagena (14-24 m), Nodosaria (17 m) and Trochammina (12-24 m).

The absence or scarcity of planktonic foraminiferids in my Cannonball samples is significant. It is unlikely that the planktonic forms were selectively destroyed because excellently preserved calcareous individuals of benthonic forms are locally abundant. Sampling error may be a factor in the absence of planktonic foraminiferids in my material; however, Fox and Ross (1942, p. 668) noted that their two species of planktonic foraminiferids were rare and

TABLE 2

DISTRIBUTION OF TODD AND BRONNIMAN'S (1957) GENERA OF FORAMINIFERIDS IN COMMON WITH THOSE OF THE CANNONBALL

	Tidal (Intertidal)	Nearshore	Offshore
Haplophragmoides	A	C	
Cyclogyra (=Cornuspira)	R	C	R
Trochammina	C-A	C	R
Lenticulina (=Robulus)		R	R
Dentalina		R	
Nodosaria			R
Lagena		R	R-C-A
Cibicides		R	

A=Abundant

C=Common

R=Rare

and thought that the rarity of planktonic foraminiferids indicated "shallow inner neritic depths."

According to Phleger (1960, p. 259) planktonic foraminiferids would begin appearing in appreciable numbers (10-15%) in the depth range of 60-100 m ± (the outer continental shelf). According to

Lowman (1949, p. 1958, fig. 15), the planktonic foraminiferids comprise about 10% of the fauna at 200 m. Ingle (1967, p. JI-A-4) stated that, "Planktonic abundance generally increases offshore with a major increase at depths greater than 100 m or approximately the shelf edge." Bandy and Arnal (1960, p. 1927) noted the same phenomenon.

The predominance of agglutinated individuals in the Cannonball is of paleoecologic importance. Brooks (1973), Greiner (1970) and Murray (1969) have discussed the significance of the predominance of agglutinated individuals. Brooks (1973, p. 400) noted that "arenaceous species are common in the coastal lagoons of British Honduras" where they are adapted to "low salinity coastal waters with restricted marine communication." According to Greiner (1970, p. 83), agglutinated foraminiferids dominate in terms of numbers of individuals where there is a low availability of $CaCO_3$ such as environments of low salinities and low temperatures. Murray (1969, p. 409) stated that cool water and lower salinities account for an abundance of agglutinated foraminiferids.

Heckel (1972, p. 233-236) indicated that in the transitional restricted marine environment (salinity of 20-30 ppt), either the calcareous or agglutinated forms can predominate in terms of numbers of species. The calcareous forms are more diverse at the upper limit of the salinity range and the agglutinated forms are more diverse at the lower limit of the salinity range. Heckel (1972) also indicated that the overall biotic diversity decreased from normal marine to marginal marine conditions.

Lowman (1949, p. 1956) stated that abundant Haplophragmoides, Trochammina and Ammoastuta were noted in the salt marshes of the Gulf

Coast. Although *Ammoastuta* was not collected in the Cannonball, *Haplophragmoides* was found in abundance and *Trochammina* only rarely. *Haplophragmoides* and *Trochammina* also occurred in water of more marine salinity and low oxygen content (p. 1156-1157). This indicates that these two genera are tolerant of brackish water conditions but can also live in normal marine waters. Lowman pointed out, however, that *Haplophragmoides* and *Trochammina* are probably most characteristic of a stagnant (quiet, poorly oxygenated) environment (p. 1956, table II).

Parker and Athearn (1959) reported on species of *Haplophragmoides* and two species of *Trochammina* from marsh habitats. They stated that *Haplophragmoides* and one species of *Trochammina* (*T. macrescens*) decrease toward more marine waters, suggesting salinity as an important factor in their distribution.

The occurrence of foraminiferids exclusively in the mudstone lithofacies suggests that sedimentary facies may have exercised some control over the distribution of the Cannonball foraminiferids. Phleger (1960, p. 117) stated:

> From the information available it appears that bottom sediment type is not a limiting factor in distribution of most benthonic Foraminifera, except where certain forms are attached to a hard bottom and in the coral reef assemblage. It is quite probable that sediment type does have some ecologic effect, either directly or indirectly, on the distribution of benthonic Foraminifera. Fine-grained sediments contain a larger amount of organic material and thus more potential food, than coarse-grained sediments.

In connection with the exclusive occurrence of foraminiferids in my samples in the Cannonball mudstones and the absence of foraminiferids in the sandstones, Phleger (1960, p. 118) stated, "In addition, the sands often support very small living populations."

Although the ecological conditions under which most Cannonball foraminiferid genera today are living vary widely, the assemblage in general indicates a shallow-water, near-shore environment, probably much less than 100 m deep. The indicator genera vary so widely in distribution that a more precise determination cannot be made on the foraminiferids alone. However, other criteria indicate a somewhat shallower maximum depth than that indicated by the foraminiferids. The predominance of agglutinated foraminiferids suggests a lower-than-normal marine salinity, possibly brackish water; no true brackish-water macrofossils, however, have been found. The predominance of agglutinated individuals and brackish water-tolerant genera suggests a shallow water-shore environment, probably somewhat protected and brackish. An occasional influx of more marine waters such as in a storm or a slight marine transgression could account for the presence of the more characteristically normal-marine, shallow-water, calcareous fauna (the nodosariid assemblage).

PALEOENVIRONMENTS OF THE CANNONBALL

The foraminiferids occur exclusively in the mudstone lithofacies associated with large amounts of lignitic plant fragments. The presence of the lignitic plant fragments suggests that the mudstones were deposited in relatively shallow, low-oxygenated water. The lignitic plant material appears to be lignitized, woody particles. The lignitic particles could have come from three sources, aquatic plants that were lignitized in place, deposited peaty material that was lignitized later, or driftwood that was lignitized after becoming water logged and incorporated in the sediment. Of these explanations, the first two seem to be most reasonable because of the occurrence of the lignite as minute particles. Were water-logged driftwood the source, one would expect to find larger pieces of lignite, similar in size to those of teredinid-bored driftwood that occur commonly in many of the Cannonball sandstones. Lowman (1949, p. 1956) also reported abundant carbonized plant remains associated with shallow-water foraminiferids, and Fox and Olsson (1969, p. 1400) noted the presence of lignitized plant material and indicated that it suggested deposition in "shallow inner neritic depths."

The presence of the trace fossil _Ophiomorpha_ in many of the Cannonball sandstones has been noted previously. According to Howard (1972), the present day equivalent to the organism that produced _Ophiomorpha_ is the "deep burrowing large crustacean _Callianassa_ major," which is a cosmopolitan shoreface inhabitant. As a result, he assumed that the fossil Ophiomorpha was the burrow of a shoreface inhabitant. According to Howard, the organism responsible for Ophiomorpha was not the most abundant shoreface inhabitant but it was the main inhabitant that left a preservable trace. It seems likely that many of the Cannonball sandstones likewise represent shoreface environments. According to Phleger (1960, p. 159), only the larger foraminiferids could live in the beach environment and the smaller forms would either be transported away from the beach and nearshore zone or destroyed. According to Lowman (1949, p. 1962-1963), an abundant, indigenous fauna inhabits the lower part of the beach at the strand line and seaward from it. Possibly, this was the case in the Cannonball sea as well and the microfossils were selectively destroyed after burial or were removed after death and transported elsewhere as Phleger suggested. Cvancara (1973) also noted that sandstones that contained Ophiomorpha rarely contained other macrofossils. It seems likely, therefore, that the microfauna that was associated with the sandstones was either destroyed or was transported to a nearby quiet-water environment after death. Since few fossils of any kind occur in the Ophiomorpha sandstones, it is suggested that the macrofossils were, for the most part destroyed in the highly agitated environment represented by these lithologies and that the microfossils were either destroyed or transported to quieter water.

The paleoenvironmental utility of clay mineralogy is questionable. Several workers, most notably Pryor and Glass (1961) and Weaver (1969), have attempted to use clay mineralogy as a paleoenvironmental indicator; however, it is probable that the local effects are more important in determining the clay mineralogy than environmental influences. Also, paleoenvironments as determined from the clay mineralogy are so general as to be of little or no use.

The limited sedimentological data gathered for the Cannonball sandstones in this study are generally useful. The Cannonball sandstones consist mainly of fine- to very fine-grained particles that are angular and well sorted (Figure 9). The good sorting suggests a nearshore, shallow-water environment such as a beach environment or an environment near the beach. The angular particles in a beach or near-beach environment can be accounted for by the fine to very fine grain size. Particles of this small size do not become well rounded as do particles of large size that are associated with highly agitated beach environments because hydraulic cushioning becomes more effective as the grain size decreases (Twenhofel, 1932, p. 221-222). The fine to very fine grain size is indicative of a lowland source area for the sediments (Twenhofel, 1932, p. 119).

The Cannonball sandstones are predominantly quartzitic with abundant mica and common glauconite. The presence of common glauconite in most of the sandstones suggests a slightly reducing environment (Hendricks and Ross, 1941). According to Grim (1968, p. 542) the present-day depth limits for the common occurrence of glauconite is between 5 and 1000 fathoms.

It is concluded that the Cannonball sea was locally shallow and poorly agitated. Locally, foraminiferids lived in nearshore, somewhat protected, possibly brackish-water environments. There are, however, no exclusively brackish-water species of macrofossils that have been reported on the eastern side of the Williston Basin. The presence of Ophiomorpha indicates that many of the sandstones represent a shoreface environment. Quiet bays or lagoons behind barrier islands are envisioned as possible local environments for the Cannonball. Gradual marine transgressions possibly accounted for the presence of more characteristically marine calcareous foraminiferids in the fauna. Cvancara (1972, p. 73) suggested that the Cannonball sea was similar in setting to "that of the coastal area of the Netherlands and part of northern Germany adjacent to the southeastern part of the North Sea. Here a lagoon (Wadden Sea) separates a chain of barrier islands (Frisian Islands) from the mainland." Unfortunately the foraminiferid fauna of this area has not been studied recently, but, with the foraminiferid information available from the Cannonball, such a setting would be a reasonable analog.

CONCLUSIONS

Twenty-six species of benthonic foraminiferids, representing eighteen genera and thirteen families, were collected from six measured sections in the Cannonball Formation (Paleocene, Danian) in Grant, Morton and Oliver Counties, North Dakota. The foraminiferid fauna includes 6 textulariines, 2 miliolines and 18 rotaliines. No plankonic foraminiferids were found and the fauna is dominated by individuals of textulariines, especially the lituolids. The fauna was found only in the upper and upper-middle part of the formation. Two characteristic assemblages based on dominant families and genera were recognized, the lituolid and nodosariid assemblages. R-mode cluster analysis shows three distinct clusters of species: one corresponds to the lituolid assemblage, another to the nodosariid assemblage and the third is composed of species that occur only rarely (less than 10 individuals) in the Cannonball foraminiferid fauna. The Q-mode cluster analysis shows high levels of association between two lithologic units in two widely separated stratigraphic sections: other microfaunal correlations were not possible because too few foraminiferids occurred elsewhere.

The two assemblages and the exclusive occurrence of the foraminiferids in the mudstone lithofacies suggests nearshore, shallow (less than about 100 m), protected environments such as shallow bays behind barrier islands. The dominance of textulariines is indicative of lower than normal marine salinity. A possible modern analog might be along the northern coast of Germany and the Netherlands where the Frisian islands form a barrier separating the North Sea from the Wadden Sea (Cvancara, 1972, p. 73).

SYSTEMATIC PALEONTOLOGY

The classification for the foraminiferids used here is that of Loeblich and Tappan (1964). This classification is not only the most recent, but is also the most inclusive classification for the Foraminiferida. It is based on the most complete data available including:

> . . . complete morphological data (e.g. characters of the test, protoplasm, inclusions in the protoplasm, nucleus), obtained by all known suitable techniques, as well as on information concerning reproductive processes (e.g., modifications of the alternation of generations, gametes), life habits and habitat, geologic ranges, and ontogenetic changes (Loeblich and Tappan, 1964, p. C153).

The following generic diagnoses are adapted from Leoblich and Tappan (1964) and are, in many cases, rearranged into a more logical order. The species diagnoses are based upon the most complete diagnoses available. In many cases, the species diagnoses had to be considerably edited in order to remove generic characters.

Generic synonymies are not included. Only the original reference for that genus is included. Species synonymies are abbreviated. Rather than giving every citation of a particular name, only the earliest citation is given. In cases where the earliest citation of a presently accepted name is reasonably old, a more recent citation or illustrated citations are included as well.

Included in the occurrences is a locality number that corresponds to the numbers of the measured sections and accession numbers (which are also indicated on the graphic representations of the measured sections (Figures 3-8) and in Appendix B). The general stratigraphic occurrences within the Cannonball Formation are given as well as the type of lithology in which the microfossils were collected.

The discussions include any pertinent information concerning the taxonomy of the foraminiferids. Also included are the numbers of specimens collected and their state of preservation.

Phylum PROTOZOA

Subphylum SARCODINA

Order FORAMINIFERIDA

Suborder TEXTULARIINA

Family ASTRORHIZIDAE Brady, 1881

Genus BATHYSIPHON M. Sars, 1872

Original reference.--M. Sars, in G. O. Sars, 1872, p. 251.

Type species.--*Bathysiphon filiformis* M. Sars, in G. O. Sars, 1872, p. 251 (by original designation).

Diagnosis.--Test free, elongate (to 50 mm long), may have annular constrictions; aperture at either of open ends of tube; aboral end may be secondarily closed by a secreted disc; wall agglutinated, of siliceous sponge spicules and fine sand or other mineral matter in calcareous cement (adapted from Loeblith and Tappan, 1964, p. C186).

Bathysiphon eocenicus Cushman and Hanna, 1927

Plate 1, figure 1

Bathysiphon eocenica Cushman and Hanna, 1927, p. 210, pl. 13, figs. 2, 3.

Bathysiphon eocenicus Cushman and Hanna. Cushman, 1951, p. 3, pl. 1, figs. 1, 2.

Diagnosis.--Wall composed of very fine-grained sand.

Measurements.--Length of figured specimen, 0.4 mm; width of figured specimen, 0.3 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13768.

Occurrence.--This species was collected at locality 2 (A1013). Stratigraphically, this species occurs in the upper middle Cannonball and is restricted to the mudstone facies.

Discussion.--The three well-preserved specimens from the Cannonball all occur as short segments, a phenomenon which Cushman and Hanna (1927, p. 210) discussed in their description of the holotype. This phenomenon was attributed to constrictions at intervals along the length of the test that caused lines of weakness, resulting in specimens being broken into short pieces when washed from a sample. The Cannonball form is closely comparable to the specimen of *B. eocenicus* described and illustrated by Cushman (1951, p. 3, pl. 1, figs. 1, 2); however, since only three fragmental individuals are available, only tentative assignment can be made to *B. eocenicus*. Fox and Ross (1942) did not report this species from the Cannonball.

Family AMMODISCIDAE Reuss, 1862

Genus AMMODISCUS Reuss, 1862

Original reference.--Reuss, 1862, p. 365.

Type species.--*Ammodiscus infimus* Borneman, 1874, p. 725 (by original designation).

Diagnosis.--Test free, discoidal, proloculus followed by undivided planispirally enrolled tubular chamber, which may show transverse growth constrictions but no internal partitions;

aperture at open end of tubular chamber; wall agglutinated (adapted from Loeblich and Tappan, 1964, p. C210).

Ammodiscus incertus Brady, 1884

Plate 1, figure 10

Operculina incertus d'Orbigny, 1839, p. 71, pl. 6, figs. 16, 17.

Spirillina arenacea Williamson, 1858, p. 93, pl. 7, fig. 203.

Trochammina incerta Brady, 1876, p. 71, pl. 2, figs. 10-14.

Ammodiscus incertus Brady, 1884, p. 330, pl. 38, figs. 1-3. Plummer, 1926, p. 63-65, pl. 13, figs. la-d.

Diagnosis.--Test finely arenaceous; slightly biconcave, consisting of 4 to 5 whorls (adapted from Plummer, 1926, p. 63-65).

Measurements.--Diameter of figured specimen, 0.5 mm; thickness of figured specimen, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13769.

Occurrence.--This species was collected at localities 1 (A1029), 2 (A999, A1001, A1002, A1003, A1004, A1005, A1006, A1008, A1015, A1018, A1019, A1021, A1023, A1024), 3 (A1034) and 5 (A1037, A1039, A1042, A1045, A1046, A1047, A1048, A1049, A1050, A1054, A1055, A1056, A1057, A1058, A1060); it occurs throughout the stratigraphic section but is restricted to the mudstone facies.

Discussion.--The 242 well-preserved individuals that I collected are closely comparable to the individuals of Ammodiscus incertus described and illustrated by Plummer (1927, p. 63-65, pl. 13, figs. la-d). This species is locally abundant, and although found in the lower Cannonball, it is most abundant in the middle and upper-middle

Cannonball. Fox and Ross (1942) reported this species from the Cannonball.

Family LITUOLIDAE de Blainville, 1825

Genus HAPLOPHRAGMOIDES Cushman, 1910

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

Type species.--Haplophragmoides canariense (d'Orbigny)=Nonionina canariense d'Orbigny, 1839, p. 128 (by original designation).

Diagnosis.--Test planispirally coiled, involute; aperture an equatorial intermarginal slit; wall agglutinated (adapted from Loeblich and Tappan, 1964, p. C225).

Haplophragmoides excavata Cushman and Waters, 1927

Plate 1, figure 2

Haplophragmoides excavata Cushman and Waters, 1927, p. 82, pl. 10, figs. 3a, 3b.

Diagnosis.--Test laterally compressed; individual chamber walls depressed laterally; sutures thickened and raised, outer periphery thickened and lobate (adapted from Cushman and Waters, 1927, p. 82).

Measurements.--Diameter of figured specimen, 0.3 mm; thickness of figured specimen, 0.03 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13770.

Occurrence.--This species was collected at localities 2 (A999, A1001, A1002, A1003, A1004, A1005), 3 (A1031, A1033, A1034) and 5 (A1037, A1038, A1039, A1042, A1047, A1048, A1051), and occurs only in the upper half of the Cannonball in the mudstone facies.

Discussion.--The sixty-eight moderately well preserved individuals of this species from the Cannonball Formation are closely comparable to the individuals of Haplophragmoides excavata described and figured by Cushman and Waters (1927, p. 82), and Cushman (1946, pl. 4, figs. 14a, b, 15a, b). Cushman (1951, p. 4) mentioned the possibility that this species may occur in the Midway of Arkansas and Texas. Madenwald (1962, p. 36) noted the occurrence of this species in the Niobrara Shale of North Dakota. A possibility exists that this form may not be a distinct species, but is the result of flattening by compression leaving the outer chamber walls concave with the sutures standing out in relief. Nauss (1947, p. 337) mentioned this possibility for H. collyra. Martin (1964, pl. 2, figs. 6a, 7a) illustrated deformed individuals of H. incognatus that appear very similar to H. excavata. Fox and Ross (1942) did not report this species from the Cannonball.

Haplophragmoides glabra Cushman and Waters, 1927

Plate 1, figure 3

Haplophragmoides glabra Cushman and Waters, 1927, p. 83, pl. 10, figs. 6a, 6b.

Diagnosis.--Test closely coiled, umbilicate; sutures depressed and distinct; chambers slightly inflated (adapted from Cushman and Waters, 1927, p. 83).

Measurements.--Diameter of figured specimen, 0.4 mm; thickness of figured specimen, 0.05 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13771.

Occurrence.--This species was collected at localities 1 (A1029), 2 (A999, A1000, A1001, A1002, A1003, A1004, A1005, A1007, A1010, A1011, A1024, A1025), 3 (A1031, A1033) and 5 (A1037, A1039, A1040, A1041, A1042, A1043, A1044, A1045, A1046, A1047, A1048, A1049, A1050, A1051, A1052, A1054, A1055, A1056, A1058, A1059, A1060); it is found throughout the Cannonball, but is lithologically restricted to the mudstone facies.

Discussion.--The Cannonball form is comparable to *Haplophragmoides glabra* as illustrated by Cushman and Waters (1927, p. 83, figs. 6a, 6b) and Cushman (1946, pl. 2, figs. 16a, 16b, 17a, 17b). Often individuals appear to be somewhat more compressed than the previously figured specimens, but this is likely the result of post-mortem alterations. This species is the most abundant foraminiferid in the Cannonball and is represented by 739 poorly to moderately preserved individuals. No individuals of this species were collected by Fox and Ross (1942, p. 668) in their study of the Cannonball foraminiferids.

Family TEXTULARIIDAE Ehrenberg, 1838

Genus SPIROPLECTAMMINA Cushman, 1927

Original reference.--Cushman, 1927, p. 23.

Type species.--*Spiroplectammina biformis* (Parker and Jones) = *Textularia agglutinans* d'Orbigny var. *biformis* Parker and Jones, 1865, p. 370 (by original designation).

Diagnosis.--Test free, elongate, early portion in planispiral coil of few chambers, later chambers biserially arranged; aperture low arch at inner margin of final chamber; wall agglutinated (adapted from Loeblich and Tappan, 1964, p. C251).

?*Spiroplectammina* sp.

Plate 1, figure 4

Description of material.--Sides of test nearly parallel, sutures indistinct; wall of medium-grained sand; color reddish brown; aperture indistinct.

Measurements.--Length of figured specimen, 1.0 mm; width of figured specimen, 0.3 mm maximum, 0.2 mm minimum.

Hypotype.--Univ. of N. Dak. Cat. No. 13772.

Occurrence.--This species was collected at locality 2 (A1008), in the upper middle Cannonball, from the mudstone facies.

Discussion.--Because my material consists of only three specimens and the relatively coarse particles of the tests result in a masking of morphologic characteristics, these specimens can only questionably be assigned to the genus *Spiroplectammina*. Fox and Ross (1942) reported *Spiroplectammina laevis* from the Cannonball. This species is not *Spiroplectammina laevis*.

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 gradually in size; aperture low interiomarginal extra-umbilical-umbilical arch which may have narrow bordering lip; wall agglutinated (adapted from Loeblich and Tappan, 1964, p. C259).

Trochammina sp.

Description of material.--Test compressed; sutures on dorsal surface indistinct; ventral surface with four chambers of nearly equal size, sutures depressed; umbilicate; wall of extremely fine-grained quartz with much cement, dark brown.

Measurements.--Diameter of figured specimen, 0.3 mm; height of figured specimen, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13773.

Occurrence.--This form was collected at locality 5 (A1039), from the mudstone facies in the upper Cannonball.

Discussion.--This form is represented by a single well-preserved specimen that appears similar to *Trochammina claibornensis* Howe (1939, p. 40); however, the periphery of *T. claibornensis* is obviously segmented by the four sutures on the last whorl. The Cannonball form is almost circular with no obvious depression of the sutures on the periphery. The chamber arrangement on the dorsal side of this individual is indistinct, which makes any assignment of species questionable. Fox and Ross (1942) did not report this genus from the Cannonball.

Suborder MILIOLINA

Family FISCHERINIDAE Millet, 1898

Genus CYCLOGYRA Wood, 1842

Original reference.--Wood, 1842, p. 458.

Type species.--*Cyclogyra multiplex* Wood, 1842, p. 458 (by original designation).

Diagnosis.--Test free, discoidal, consisting of globular proloculus and long undivided planispirally wound second chamber, partly or wholly evolute; aperture at open end of the tube; wall, calcareous, imperforate, porcellaneous (adapted from Loeblich and Tappan, 1964, p. C438).

Remarks.--According to Loeblich and Tappan (1964, p. C438), the genus Cornuspira should be combined with the genus Cyclogyra.

Cyclogyra involvens (Reuss), 1850

Plate 1, figure 9

Operculina involvens Reuss, 1850, p. 370, fig. 30.

Cornuspira involvens (Reuss). Reuss, 1863, p. 39, pl. 1, fig. 2.

Diagnosis.--Tubular, second chamber partly evolute, occasionally becoming angular in cross section in later growth stages from an initial, circular, cross section (adapted from Cushman, 1922, p. 140 and Cushman and Cahill, 1933, p. 12).

Measurements.--Diameter of figured specimen, 0.8 mm; thickness of figured specimen, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13774.

Occurrence.--This species was collected at localities 2 (A1001, A1002, A1003, A1004, A1006, A1008, A1009, A1012, A1013) and 5 (A1047, A1051, A1054, A1055, A1056, A1057, A1058, A1060), in the upper middle Cannonball from the mudstone facies.

Discussion.--The 119 well-preserved individuals of this species are closely conformable to the description and figures of Cornuspira involvens of Cushman (1922, pl. 25, fig. 1). This species shows some morphological variation; however, it is apparent that most variation is due to post-mortem alterations. Fox and Ross reported Cyclogyra involvens (=Cornuspira involvens) from the Cannonball.

Family SORITIDAE Ehrenberg, 1839

Genus PENEROPLIS Montfort, 1808

Original reference.--Montfort, 1808, p. 258.

Type species.--Peneroplis planatus (Fichtel and Moll) = Nautilus planatus Fichtel and Moll, 1798, p. 91 (by original designation).

Diagnosis.--Test compressed, planispirally enrolled at least in early stages, later may be uncoiled and flaring, external form variable; chambers broad, low, not subdivided; aperture terminal, row of slits in slight depression along the apertural face; well porcelaneous, surface smooth, pitted, or more commonly longitudinally straite (adapted from Loeblich and Tappan, 1964, p. C482).

Peneroplis sp.

Plate 1, figure 7

Description of material.--Test flabelliform, early planispirally coiled portion partially evolute; sutures indistinct on early portion of test, becoming wide, depressed and prominent on last chambers.

Measurements.--Diameter of figured specimen, 0.5 mm; thickness of figured specimen, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13775.

Occurrence.--This form was collected at locality 5 (A1047), from the mudstone facies in the upper middle Cannonball.

Discussion.--This form is represented by one poorly preserved fragmental specimen that is badly pitted and with no aperture; as a result, a species assignment cannot be made. The planispiral-flabelliform test and porcellaneous wall suggests an assignment to the genus Peneroplis. Fox and Ross (1942) did not report this genus from the Cannonball.

Suborder ROTALIINA

Family NODOSARIIDAE Ehrenberg, 1838

Genus NODOSARIA Lamarck, 1812

Original reference.--Lamarck, 1812, p. 121.

Type species.--Nodosaria radicula (Linné) = Nautilus radicula Linné, 1758 (by subsequent designation of Children, 1823, p. 117).

Diagnosis.--Test free, multilocular, rectilinear rounded in section; sutures distinct and commonly perpendicular to axis of test; surface smooth, costate, straite, hispid or tuberculate; aperture terminal, central basically radiate, may be produced on neck (adapted from Loeblich and Tappan, 1964, p. C512).

Nodosaria affinis Reuss, 1845

Plate 1, figure 11

Nodosaria affinis Reuss, 1845, p. 26, pl. 13, fig. 16. Plummer, 1926, p. 89-91, pl. XIV, figs. 2a-d.

Diagnosis.--Test with chambers of uniform diameter throughout; 9 to 11 continuous, longitudinal costae along length of test beginning as distinct projections on aboral extremity; sutures appear as slight constrictions in the test (adapted from Plummer, 1926, p. 88).

Measurements.--Length of figured specimen, 0.9 mm; width of figured specimen, 0.4 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13776.

Occurrence.--This species was collected at localities 2 (A1000, A1001, A1002, A1004, A1012, A1017), 3 (A1034) and 5 (A1047) from the mudstone facies in the upper middle and upper Cannonball.

Discussion.--The forty-seven well preserved individuals from the Cannonball are comparable to those of Nodosaria affinis Reuss as figured by Cushman (1946, pl. 25, figs. 8-23). Some intraspecific variation exists as a result of microspheric and megalospheric test differences (Cushman, 1946, p. 70-71). A continuous range of variation appears to exist between N. affinis and N. latejugata Gümbel which results in considerable difficulty in assigning intermediate forms to one species or the other (Cushman, 1951, p. 24). Fox and Ross (1942) reported this species from the Cannonball.

Nodosaria latejugata Gümbel, 1868

Plate 1, figure 12

Nodosaria latejugata Gümbel, 1868, p. 619, pl. 1, fig. 32. Cushman, 1951, p. 23-24, pl. 7, figs. 1, 2.

Diagnosis.--Chambers distinct, highly inflated, ornamented by distinct costae, either longitudinal or helical; sutures are distinct and depressed, marked by strong constrications in the test; distinct spine occurs on aboral end of test where costae merge (adopted from Cushman, 1951, p. 24).

Measurements.--Length of figured specimen, 1.2 mm; width of figured specimen, 0.5 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13777.

Occurrence.--This species was collected at localities 2 (A1017), 3 (a1034) and 5 (A1057), from the mudstone facies in the upper middle Cannonball.

Discussion.--The four moderately well preserved, fragmental individuals of this species are very similar to N. affinis; however, the two species differ mainly in the greater inflation of the chambers and the less prominent costae in *N. latejugata*. According to Cushman (1951, p. 24), *N. affinis* and *N. latejugata* are probably closely related; however, although *N. affinis* is found throughout the upper Cretaceous, the lowest known occurrence of *N. latejugata* is lower Paleocene. Fox and Ross (1942) did not report this species from the Cannonball.

Genus CHRYSALOGONIUM Schubert, 1907

Original reference.--Schubert, 1907, p. 243.

Type species.--*Chrysalogonium polystoma* (Schwager) = *Nodosaria polystoma* Schwager, 1866, p. 217 (by original designation).

Diagnosis.--"Test similar to Nodosaria but with a series of pores taking place of radial apertural slits of Nodosaria (Loeblich and Tappan, 1964, p. C514)."

?*Chrysalogonium* sp.

Plate 1, figure 6

Description of material.--Test uniserial, very slender and elongate, highly tapered toward aboral end; sutures marked by constrictions between chambers, width of chamber about one-half chamber length.

Measurements.--Length of figured specimen, 0.4 mm; width of figured specimen, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13778.

Occurrence.--This form was collected at localities 2 (A1011), 3 (A1034) and 5 (A1046), from the mudstone facies in the upper middle Cannonball.

Discussion.--Four fragmental, poorly preserved specimens were collected, and only a small portion of a test was available in each case, resulting in a questionable assignment to Chrysalogonium. These fragments appear similar to C. texanum Cushman (1936, p. 55, pl. 9, fig. 25a) and C. Granti (Plummer) (Kline, 1943, p. 29, pl. 2, fig. 9); however, in both cases the Cannonball form presumably increases more abruptly in diameter. The only species of Chrysalogonium previously reported from the Cannonball Formation is C. granti (Fox and Ross, 1942, p. 670).

Genus DENTALINA Risso, 1826

Original reference.--Risso, 1826, p. 16.

Type species.--Dentalina cuvieri (d'Orbigny) = Nodosaria (Dentaline) cuveri d'Orbigny, 1826, p. 255 (monotypic in Risso, 1826).

Dentalina communis (d'Orbigny) = Nodosaria (Dentaline) communis d'Orbigny, 1826 (designated by Jones, 1883).

Dentalina obliqua (d'Orbigny) = Nodosaria (Dentaline) obliqua d'Orbigny, 1826 (designated by Galloway and Wissler, 1927).

Diagnosis.--Test elongate, arcuate, uniserial; sutures commonly oblique; aperture radiate, terminal, may be eccentric or nearly central. (Differs from Nodosaria in being Asymmetrical.) (Loeblich and Tappan, 1964, p. C516).

Dentalina colei Cushman and Dusenbury, 1934

Plate 2, figure 13

Vaginulina legumen (Linne) var. elegans Cole (not d'Orbigny), 1927, p. 21, pl. 3, figs. 10, 11.

Dentalina colei Cushman and Dusenbury, 1934, p. 54, pl. 7, figs. 10-12.

Diagnosis.--Test tapers slightly toward aboral end; sutures slightly elevated; chambers uninflated, earliest ones compressed, later ones circular in transverse section; end of test with no initial spine and fairly blunt; early sutures oblique, later sutures transverse (adapted from Cushman, 1951, p. 19).

Measurements.--Length of figured specimen, 1.0 mm; maximum width of figured specimen, 0.3 mm; minimum width of figured specimen, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13779.

Occurrence.--This species was collected at locality 2 (A1004) from the mudstone facies in the upper middle Cannonball.

Discussion.--The single, poorly preserved fragment of this species that is available, closely resembles the description and figures of *Dentalina colei* of Cushman and Dusenbury (1934, p. 54, pl. 7, figs. 10-12). *Dentalina colei* and *D. gardnerae* (Plummer) appear closely related; however, *D. colei* does not taper as rapidly toward the aboral end of the test and appears to be more blunt than *D. gardnerae*. Cushman (1951, pl. 6, figs. 4-10) illustrates *D. gardnerae* and *D. colei* together. From Cushman's illustration the differences in taper and the difference in the "bluntness" between the two species is apparent. As a result of the fragmental specimen available, this form is only tentatively assigned to *D. colei*. Fox and Ross (1942) did not report this genus from the Cannonball.

Dentalina mucronata Neugeboren, 1856

Plate 2, figure 20

Dentalina mucronata Neugeboren, 1856, p. 83, pl. 3, figs. 8-10.

Dentalina cf. D. mucronata Neugeboren. Cushman, 1951, p. 22, pl. 6, figs. 34, 35.

Diagnosis.--Chambers increase gradually in size; initial chamber with distinct axial spine; walls on early chambers straight, walls on later chambers inflated; sutures oblique and faintly depressed in early growth stages becoming transverse and more prominently depressed in later growth stages (adapted from Neugeboren, 1856, p. 83 and Cushman, 1951, p. 22).

Measurements.--Length of figured specimen, 1.1 mm; maximum width of figured specimen, 0.2 mm; minimum width of figured specimen, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13780.

Occurrence.--Of the eighteen well preserved specimens available, all are fragmental; therefore, only a tentative identification is possible. The fragments strongly resemble Dentalina cf. D. mucronata illustrated by Cushman (1951, pl. 6, figs. 34, 35). This form is also similar to D. pauperata d'Orbigny as illustrated by d'Orbigny (1846, pl. 1, fig. 57); however, on d'Orbigny's illustration, the initial spine is centrally located and on the Cannonball forms, the initial spines are off-center as they are in D. mucronata. Fox and Ross (1942) reported this genus from the Cannonball.

Dentalina sp.

Plate 1, figure 8

Description of material.--Test tapers gently toward aboral end; chambers slightly inflated; sutures moderately constricted, 15 longitudinal costae along length of test.

Measurements.--Length of figured specimen, 1.0 mm; maximum width of figured specimen, 0.2 mm; minimum width of figured specimen, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13781.

Occurrence.--A single, well preserved individual was collected at locality 2 (A1003) from the mudstone facies in the upper middle Cannonball.

Discussion.--This form is represented by a single fragment that appears to be similar to *Dentalina pseudo-obliquestriata* (Plummer) as figured by Cushman (1951, pl. 6, figs. 1-3) and *Nodosaria pseudo-obliquestriata* Plummer as figured by Plummer (1927, pl. 4, fig. 18); however, the Cannonball specimen is not as highly arcuate nor are its chambers as highly inflated as those on those on the specimens illustrated by Plummer and Cushman.

Genus LAGENA Walker and Jacob, 1798

Original reference.--Walker and Jacob, *in* Kanmacher, 1798, p. 634.

Type species.--*Lagena sulcata* (Walker and Jacob) = *Serpula (Lagena) sulcata* Walker and Jacob, 1798 = *Serpula (Lagena) striata sulcata rotunda* Walker and Boys, 1794 (by subsequent designation of Parker and Jones, 1859, p. 337).

> Diagnosis.--Test unilocular, rarely 2 or more chambers; surface variously ornamented; aperture on elongate neck which may have phialine lip, not radiate (Loeblich and Tappan, 1964, p. C518).

?*Lagena* sp.

Plate 1, figure 5

Description of material.--Test pyriform, consisting of two attached spherical bodies, one being much larger than the other, Measurements.--Length of figured specimen, 0.3 mm; width of figured specimen, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13782.

Occurrence.--This form was collected at locality 5 (A1058) from the mudstone facies in the upper middle Cannonball.

Discussion.--This form is represented by one broken, poorly preserved individual that appears superficially similar to the genus *Nodosaria*, although the lack of an apertural opening on the larger spherical body would preclude this possibility. The smaller portion of the test is broken such that if an apertural opening were there it is now absent; as a result, this form can only questionably be assigned to the genus *Lagena*.

Genus LENTICULINA Lamarck, 1804

Original reference.--Lamarck, 1804, p. 186.

Type species.--*Lenticulina rotulata* (Lamarck) = *Lenticulites rotulata* Lamarck, 1804, p. 187 (by subsequent designation of Children, 1823, p. 153.

> Diagnosis.--Test free, planispiral or rarely slightly trochoid, lenticular, biumbonate, periphery angled or keeled; chambers increasing gradually in size, in general of greater breadth than height; sutures radial, straight or curved and depressed, flush or elevated; surface may be variously ornamented with thickened, elevated sutures, bosses or sutural nodes; aperture radial at peripheral angle (Loeblich and Tappan, 1964, p. C520).

Remarks.--According to Loeblich and Tappan (1964, p. C520), the genus *Lenticulina* now also includes all species formerly included in the genus *Robulus*.

Lenticulina rotulata (Lamarck) Plummer, 1931

Plate 2, figure 17

Lenticulites rotulata Lamarck, 1804, p. 187.

Cristellaria rotulata (Lamarck). Carsey, 1926, p. 39, pl. 6, fig. 2.

Lenticulina rotulata (Lamarck). Plummer, 1931, p. 142, pl. 11, fig. 20.

Diagnosis.--Test planispiral, involute, subcircular, slightly elongate, biconvex, with distinct umbo; peripheral margin very sharp but no keel is present; sutures curve slightly, are sometimes elevated; aperture peripheral; irregularly developed umbonal boss is present (adapted from Frizzell, 1943, p. 341 and Kline, 1943, p. 21-22).

Measurements.--Diameter of figured specimen, 0.8 mm; thickness of figured specimen at umbonal boss, 0.3 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13783.

Occurrence.--This species was collected at localities 2 (A1003, A1004, A1005), 3 (A1034) and 5 (A1046, A1048, A1050) from the mudstone facies in the upper middle and upper Cannonball.

Discussion.--Lenticulina rotulata is represented by twenty-eight well preserved specimens that closely resemble Lenticulina cultratus ((Montfort), 1808, p. 215). The absence of a distinct keel and the slight curvature of the sutures serve to distinguish L. rotulata from L. cultratus, which is strongly keeled and has sharply curved sutures.

Lenticulina sp. A

Plate 2, figures 18, 19

Description of material.--Test almost circular, not elongate, biconvex, with distinct umbo and regularly developed umbonal boss; peripheral margin acute but not keeled; sutures elevated and slightly curved; 7 to 9 chambers in last whorl; aperture peripheral and sometimes slightly extended.

Measurements.--Diameter of figured specimen, 0.4 mm; thickness of figured specimen at umbonal boss, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13784.

Occurrence.--This form was collected at localities 2 (A1003, A1004, A1005) and 5 (A1046, A1048, A1050) from the mudstone facies in the upper middle and upper Cannonball.

Discussion.--This form is represented by twenty-nine well preserved specimens which appear to be similar to L. rotulata except that it is more circular, the aperture is extended, and the umbonal boss is more regularly developed than on L. rotulata. In all cases the sutures and umbonal boss are distinctly raised on this form; however, the sutures and umbonal boss on L. rotulata are rarely raised and are not as prominent.

Lenticulina sp. B

Plate 2, figure 16

Description of material.--Test elongate, lenticular, with distinct, well developed umbo; umbonal boss slightly elevated; peripheral margin acute but not keeled; sutures curved, raised slightly on early growth stages, becoming depressed on last few chambers; chambers significantly larger in last whorl, possibly showing a tendency to become uncoiled, last few chambers are inflated; aperture at apex of last septal face.

Measurements.--Maximum diameter of figured specimen, 0.4 mm; thickness of figured specimen at umbonal boss, 0.1 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13785.

Occurrence.--This form was collected at localities 2 (A1004) and 5 (A1046, A1048, A1050) from the mudstone facies in the upper middle Cannonball.

Discussion.--This form is represented by six well preserved specimens that appear similar to Cushman's (1951, p. 15) description of *Robulus wilcoxensis* Cushman and Ponton (1932, p. 210). Nogan (1964, p. 22), however, stated that *R. wilcoxensis* is probably just a variety of *R. midwayensis* (Plummer). The Cannonball forms appear to be mainly immature and as a result they show only the beginnings of the development of the inflated last chambers. With no mature forms available for comparison with the published figures of *R. midwayensis* a precise specific assignment cannot be made.

Genus MARGINULINA d'Orbigny, 1826

Original reference.--d'Orbigny, 1826, p. 258.

Type species.--*Marginulina raphanus* (Linné) = *Nautilus raphanus* Linné, 1758, p. 711 (by subsequent designation of Deshayes, 1830, p. 416).

> Diagnosis.--Early portion slightly coiled but not completely enrolled, as in *Marginulinopsis*, later rectilinear; sutures oblique, especially in early portion; aperture of dorsal angle somewhat produced (Loeblich and Tappan, 1964, p. C520).

Marginulina sp.

Plate 2, figure 6

Description of material.--Test elongate, consisting of 5 chambers that gradually increase in height and width; aboral extremity blunt; sutures distinct, flush with test surface; aperture radiate, somewhat extended.

Measurements.--Length of figured specimen, 0.7 mm; maximum width of figured specimen, 0.4 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13786.

Occurrence.--This form was collected at locality 2 (A1004) from the mudstone facies in the upper middle Cannonball.

Discussion.--One fragmental, well preserved specimen was collected on which parts of the last-formed chamber are broken but the typical, produced Marginulina-type septum of the last-formed chamber is visible with the previous aperture still intact. This form is similar to those illustrated by Cushman (1951, pl. 5, figs. 30, 31) that were designated Marginulina sp. A. The Cannonball form, unlike Cushman's, does not have depressed sutures, or inflated chambers, and it also has a more extended apertural neck. Since only one fragmental specimen is available, only a generic assignment is made. Fox and Ross (1942) reported this genus from the Cannonball.

Family POLYMORPHINIDAE d'Orbigny, 1839

Genus GLOBULINA d'Orbigny, 1839

Original reference.--d'Orbigny in de la Sagra, 1839, p. 134.

Type species.--Globulina gibba (d'Orbigny) = Polymorphina (globuline) gibba d'Orbigny, 1826, p. 266 (by subsequent designation of Cushman, 1927b, p. 189).

Diagnosis.--Test globular to ovate, chambers strongly overlapping, added in planes of approximately 144° apart; sutures flush, not depressed, aperture radiate, but commonly obscured by fistulose growth (Loeblich and Tappan, 1964, p. C531).

Globulina gibba (d'Orbigny), 1826

Plate 2, figure 1

Polymorphina (Globuline) gibba d'Orbigny, 1826, p. 266.

Polymorphina gibba d'Orbigny. Plummer, 1927, p. 122, pl. 6, fig. 8.

Globulina gibba (d'Orbigny). Cushman, 1927b, p. 189.

Diagnosis.--Test highly inflated, globular, circular in transverse section; sutures indistinct (adapted from Cushman and Cahill, 1933, p. 18).

Measurements.--Length of figured specimen, 0.3 mm; width of figured specimen, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13787.

Occurrence.--This species was collected at localities 2 (A1003, A1004, A1019) and 5 (A1046) from the mudstone facies in the upper middle Cannonball.

Discussion.--The four, well preserved individuals of this species are closely conformable with the descriptions and figures of G. gibba var. globosa (Von Munster) by Cushman (1935, p. 26, pl. 9, fig. 9) and Cushman and Applin (1945, pl. 9, fig. 9). Fox and Ross (1942) reported this species from the Cannonball.

Globulina sp. A

Plate 2, figure 4

Description of material.--Test elongate, globular, with greatest diameter toward aboral end; test tapers slightly toward oral end; aboral end gently rounded; test circular in transverse section; no accessory apertural growth; sutures indistinct.

Measurements.--Length of figured specimen, 0.4 mm; maximum width of figured specimen, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13788.

Occurrence.--This form was collected at locality 2 (A1004) from the mudstone facies in the upper middle Cannonball.

Discussion.--One well preserved individual of this form was collected and it appears to be narrower in respect to height than most species of *Globulina*. The Cannonball specimen slightly resembles *Globulina prisca* Reuss as illustrated by Cushman (1946, pl. 40, fig. 15), with the exception that the Cannonball form is proportionally not as wide and its greatest test width is closer to the aboral end. The occurrence of only a single individual and the lack of types preclude a species assignment.

Globulina sp. B

Plate 2, figure 5

Description of material.--Test globose, initial extremity slightly pointed; somewhat flattened in transverse section; apertural end fistulose.

Measurements.--Length of figured specimen, 0.6 mm; maximum width of figured specimen, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13789.

Occurrence.--This form was collected at locality 5 (A1045) from the mudstone facies in the upper middle Cannonball.

Discussion.--This form is represented by one poorly preserved, internal mold, and therefore no specific assignment is attempted. This form appears generally similar to G. fistulosa (Bullard (1953) in that it has a fistulose aperture, and its initial extremity is somewhat pointed, which is a diagnostic character of G. fistulosa (Bullard, 1953, p. 342). This form also appears somewhat similar to G. lactea var. navangliae as figured by Cushman (1923, pl. 23, fig. 8), with the exception that the Cannonball form is not as elongate.

Family DISCORBIDAE Ehrenberg, 1838

Genus VALVULINERIA Cushman, 1926

Original reference.--Cushman, 1926, p. 59.

Type species.--Valvulineria californica Cushman, 1926, p. 59 (by original designation).

Diagnosis.--Test free, trochospiral, umbilicate, periphery rounded; chambers increasing gradually in size; sutures radial, thickened; aperture interiomarginal, extraumbilical-umbilical, with broad, thin, apertural flap projecting over umbilicus; wall calcareous, finely perforate, radial in structure, monolamellid, surface smooth (adapted from Loeblich and Tappan, 1964, p. C587).

Valvulineria wilcoxensis Cushman and Ponton, 1932?

Plate 2, figures 7, 8, 9

Valvulineria wilcoxensis Cushman and Ponton, 1932, p. 70, pl. 9, fig. 6.

Diagnosis.--Test subcircular; chambers distinct, inflated; sutures distinct, depressed in later portion, slightly curved; periphery lobate through last formed chambers (adapted from Cushman, 1951, p. 50).

Measurements.--Maximum diameter of figured specimen, 0.4 mm; minimum diameter of figured specimen, 0.3 mm; height of figured specimen, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13790.

Occurrence.--This species was collected at localities 2 (A1003, A1004, A1005) and 5 (A1046) from the mudstone facies in the upper middle Cannonball.

Discussion.--This species is represented by twenty-eight well preserved individuals that are closely comparable to *Valvulineria wilcoxensis* Cushman and Ponton as figured by Cushman (1951, pl. 14, figs. 10-13). Superficially similar to *Cibicides alleni* Plummer, this species lacks the angularity of the periphery in transverse section that is common in *C. alleni*. This species is only tentatively assigned to the species *V. wilcoxensis* because Cushman's figures do not show pertinent morphologic details. Fox and Ross (1952) reported another species of this genus from the Cannonball.

Family CIBICIDIDAE Cushman, 1927

Genus CIBICIDES Montfort, 1808

Original reference.--Montfort, 1808, p. 122.

Type species.--*Cibicides reflugens* Montfort, 1808, p. 130 (by original designation.

Diagnosis.--Test attached; plano-convex, trochospiral, spiral side flat to excavated, evolute, umbilical side strongly convex, involute, apertural face sharply angled, nonporus, distinct from umbilical side, periphery angular, with nonporous, keel; aperture a low interiomarginal opening with narrow lip, may extend along spiral suture on spiral side; wall calcareous, radial in microstructure, bilamellar, coarsely perforate on spiral side, large pores of earlier chambers may be closed by lamellar thickening of wall, finely perforate on umbilical side (adapted from Loeblich and Tappan, 1964, p. C688).

Cibicides sp.

Plate 2, figures 10, 11, 12

Description of material.--Test compressed, unequally biconvex; sutures slightly curved, somewhat depressed, appearing as lighter colored areas in contrast to the remainder of the test; periphery somewhat lobate in later growth stages.

Measurements.--Maximum diameter of figured specimen, 0.4 mm; minimum diameter of figured specimen, 0.3 mm; height of figured specimen, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13791.

Occurrence.--This form was collected at localities 2 (A1003, A1004, A1005), 3 (A1034) and 5 (A1046) from the mudstone facies in the upper middle and upper Cannonball.

Discussion.--This form is represented by thirty-five well preserved specimens that appear similar to Cibicides subcarinatus Cushman and Deaderick as illustrated by Cushman (1946, pl. 65, fig. 8), however, the Cannonball specimens are ventrally more convex than those figured by Cushman. Although it is apparent that this form belongs to Cibicides, a specific assignment is not possible because of the lack of reliable types for the purpose of comparison. Fox and Ross (1942) reported Cibicides alleni from the Cannonball. This species is not Cibicides alleni.

Family NONIONIDAE Schulze, 1854

Genus ALLOMORPHINA Reuss, 1849

Original reference.--Reuss in Czjzek, 1849, p. 50.

Type species.--*Allomorphina trigona* Reuss, 1850, p. 30 (by subsequent designation).

Diagnosis.--Test trochospiral, commonly 3 chambers to whorl, involute, only final whorl visible externally; aperture an elongate slit, paralleling suture and bordered with slight lip; wall calcareous, perforate, granular in structure (adapted from Loeblich and Tappan, 1964, p. C743).

Allomorphina sp.

Plate 2, figures 14, 15

Description of material.--Test subtriangular in outline, compressed dorso-ventrally; sutures weakly expressed as slight indentations; three recognizable chambers in the adult whorl, each showing large size increase over its predecessor; aperture an elongate slit at base of last-formed chamber; large, prominent, overhanging apertural lip; test discolored, dark reddish brown to black.

Measurements.--Maximum diameter of figured specimen, 0.4 mm; minimum diameter of figured specimen, 0.3 mm; height of figured specimen, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13792.

Occurrence.--This form was collected at locality 2 (A1010) from the mudstone facies in the upper middle Cannonball.

Discussion.--This form is represented by one well preserved individual that is basically similar to the form Cushman identified as Allomorphina paleocenica Cushman (1948, p. 45, pl. 8, fig. 10a, 10b); however, the Cannonball form is more triangular in outline and the apex of the last chamber is more acute; also, it appears that the overhanging apertural lip is more prominent on the Cannonball form. Since this form is represented by a single specimen that is not comparable to any of the illustrated types, no species assignment can be made. Fox and Ross (1942) reported this genus from the Cannonball.

Family CERATOBULIMINIDAE Cushman, 1927

Genus CERATOBULIMINA Toula, 1915

Original reference.--Toula, 1915, p. 654.

Type species.--Ceratobulimina contraria (Reuss) = Rotalina contraria Reuss, 1851, p. 76 (by original designation).

Diagnosis.--Test trochospiral, deeply umbilicate, chambers enlarging rapidly, whorls few, coiling dextral; aperture umbilical, consisting of elongate slit extending in groove up face of final chamber on umbilical side; internally incomplete, marginally serrate partition attached to posterior side of vertical apertural slit at interior of umbilical side, bends around aperture and extends across to be attached to spiral wall for short distance; wall laminated, surface smooth, polished (adapted from Loeblich and Tappan, 1964, p. C766).

Ceratobulimina perplexa (Plummer), 1927

Plate 2, figures 2, 3

Rotalia perplexa Plummer, 1927, p. 156, pl. 12, fig. 2.

Ceratobulimina perplexa (Plummer). Cushman and Harris, 1927, p. 173, pl. 29, fig. 2.

Diagnosis.--Test elongate, biconvex, trochoid, somewhat flattened on ventral side; periphery lobate; sutures prominent, depressed on ventral side (adapted from Nogan, 1964, p. 36-37).

Measurements.--Diameter of figured specimen, 0.3 mm; height of figured specimen, 0.2 mm.

Hypotype.--Univ. of N. Dak. Cat. No. 13793.

Occurrence.--This species was collected at locality 2 (A1020) from the mudstone facies in the upper middle Cannonball.

Discussion.--Despite the fact that the single specimen of this species is poorly preserved, fragmental and slightly distorted, it seems the critical morphologic details remain intact. This form is comparable in overall shape and in the shape of the aperture to *C. perplexa* as figured in detail by Plummer (1936, fig. 1). Although the Cannonball specimen is compressed dorso-ventrally, the umbilical notch and the closed ventral lobe of the final chamber are present although not prominent. The lobate and prominent final chamber is also diagnostic. Fox and Ross (1942) reported this species from the Cannonball.

PLATES

Accession numbers correspond to those on Figures 3-8 and those in Appendix B. All figures are X40 unless otherwise indicated.

Explanation of Plate 1

Figure

1. Bathysiphon eocenicus Cushman and Hanna, side view. Accession number A1013, Univ. of N. Dak. Cat. No. 13768.
2. Haplophragmoides excavata Cushman and Waters, side view. Accession number A1037, Univ. of N. Dak. Cat. No. 13770.
3. Haplophragmoides glabra Cushman and Waters, side view. Accession number A1037, Univ. of N. Dak. Cat. No. 13771.
4. Spiroplectammina sp., side view. Accession number A1008, Univ. of N. Dak. Cat. No. 13772.
5. Lagena sp., side view. Accession number A1058, Univ. of N. Dak. Cat. No. 13782.
6. ?Chrysalogonium sp., side view. Accession number A1011, Univ. of N. Dak. Cat. No. 13778.
7. Peneroplis sp., ventral view showing flabelliform test. Accession number A1047, Univ. of N. Dak. Cat. No. 13775.
8. Dentalina sp., side view showing longitudinal costae. Accession number A1003, Univ. of N. Dak. Cat. No. 13781.
9. Cyclogyra involvens (Reuss), side view. Accession number A1047, Univ. of N. Dak. Cat. No. 13774.
10. Ammodiscus incertus Brady, X100, SEM photo, side view. Accession number A1037, Univ. of N. Dak. Cat. No. 13769.
11. Nodosaria affinis Reuss, X200, SEM photo, side view showing longitudinal costae and initial spine. Accession number A1002, Univ. of N. Dak. Cat. No. 13776.
12. Nodosaria latejugata Gumbel, side view showing helical costae and highly constricted sutures. Accession number A1034, Univ. of N. Dak. Cat. No. 13777.


1


2


3


4


5


6


7


8


9


10


11


12

Explanation of Plate 2

Figure

1. Globulina gibba (d'Orbigny), side view showing almost cir cular shape. Accession number A1003, Univ. of N. Dak. Ca No. 13787.

2, 3. Ceratobulimina perplexa (Plummer), dorsal (2) and ventral (3) views. Accession number A1020, Univ. of N. Dak. Cat. No. 13793.

4. Globulina sp. A, side view. Accession number A1004, Univ of N. Dak. Cat. No. 13788.

5. Globulina sp. B, side view showing fistulose apertual growth. Accession number A1045, Univ. of N. Dak. Cat. No. 13789.

6. Marginulina sp., side view showing broken last chamber an last septum with an earlier aperture. Accession number A1004, Univ. of N. Dak. Cat. No. 13786.

7, 8, 9. Valvulineria wilcoxensis Cushman and Ponton? dorsal view, peripheral view showing rounded periphery, ventral view. Accession number A1046, Univ. of N. Dak. Cat. No. 13790.

10, 11, 12. Cibicides sp., dorsal view, peripheral view showing interiomarginal aperture with apertural lip, plano-convex shape and angular periphery, ventral view. Accession num- ber A1046, Univ. of N. Dak. Cat. No. 13791.

13. Dentalina colei Cushman and Dusenbury, side view. Access number A1004, Univ. of N. Dak. Cat. No. 13774.

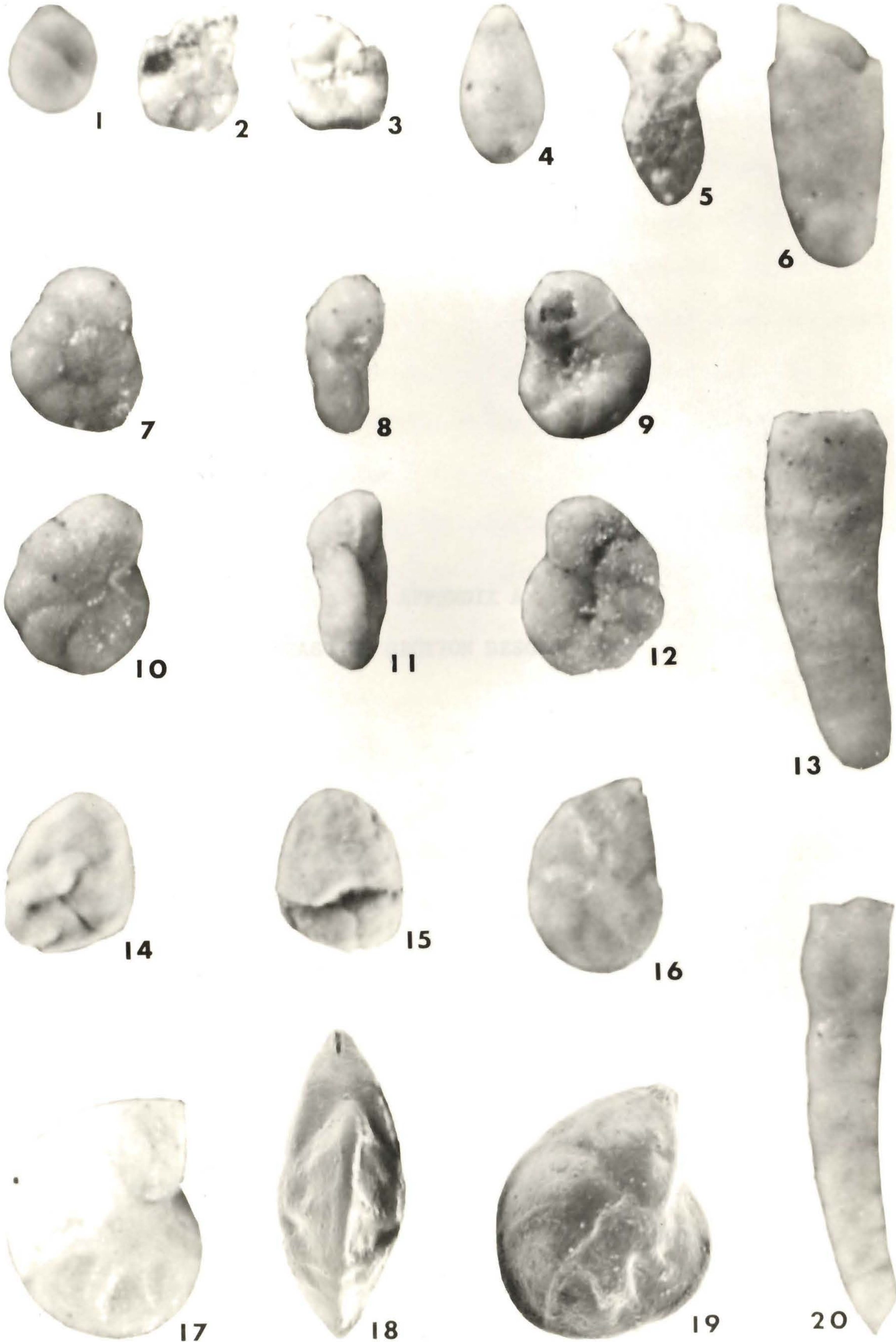
14, 15. Allomorphina sp., dorsal and ventral views showing apertur and overhanging lip. Accession number A1016, Univ. of N. Dak. Cat. No. 13792.

16. Lenticulina sp. B, dorsal view showing inflated final chamber with aperture at peripheral angle and lighter colored, raised sutures and umbonal boss. Accession number A1048, Univ. of N. Dak. Cat. No. 13785.

17. Lenticulina rotulata (Lamarck) Plummer, dorsal view showing aperture at peripheral angle and slightly raised sutures. Accession number A1050, Univ. of N. Dak. Cat. No. 13783.

18, 19. Lenticulina sp. A, X200, SEM photos, apertural view showing aperture at peripheral angle and acute periphery, dorsal view showing raised aperture at peripheral angle, raised sutures, umbonal boss. Accession number A1005, Univ. of N. Dak. Cat. No. 13784.

20. Dentalina mucronata Neugeboren, side view showing inflated last chambers, darker sutures, axial spine. Accession number A1001, Univ. of N. Dak. Cat. No. 13780.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

APPENDIX A

MEASURED SECTION DESCRIPTIONS

MEASURED SECTION DESCRIPTIONS

The measured sections are arranged numerically, the numbers corresponding to those on Figure 2, which shows the section locations; the detailed columnar sections are shown on Figures 3-8. Accession numbers (A999) (Department of Geology, University of North Dakota), which represent samples from which fossils were collected, are also given for each section. The accession numbers also appear on Figures 3-8 at the level from which each sample was collected and in Appendix B. All descriptions are arranged in descending order. The words "indurated and consolidated" are frequently used in describing lithologies. Indurated is a condition in which the rock is held together by a mineral cement, and consolidated relates to the cohesiveness of the rock as the result of compaction.

Measured section 1

NW¼SW¼ sec. 8, T. 136 N., R. 79 W., approximately 1.6 km southwest of Huff, Morton County, North Dakota. Exposures are along an unimproved earth road trending northeast. This section was measured by W. E. Fenner on June 22, 1972; accession number A1029; Figure 3 (detailed columnar section). This section was measured by Cvancara (1965, p. 327), section 28, Huff Section.

Description

Top of section Meters

Cannonball Formation

Mudstone; poorly consolidated; grayish brown where fresh, grayish brown where weathered, becoming lighter gradually downward; thin (2.0-3.0 cm), sporadically occurring, fissile, shale beds

Cannonball Formation | Meters

2.6 to 3.8 m below top of section grade downward into a very clayey sandstone bed 4.3 m below top of section; sandstone is dark yellowish brown where fresh, grayish brown where weathered; fine-grained 6.3

Concealed interval 5.0

Sandstone; poorly consolidated; light olive gray where fresh, pale yellow where weathered; fine-grained; well sorted; cross stratification in upper 2.0 m; Ophiomorpha and other burrows abundant in upper 4.0-5.0 m; well indurated in upper 0.5-0.7 m 9.5

Mudstone; poorly consolidated; very dark gray where fresh, very pale brown where weathered becomes darker gradually downward; thin (2.0-3.0 cm), sporadically occurring, black, mudstone beds most abundant in lower 5.0 m 7.0

Sandstone; poorly consolidated; olive to pale olive where fresh, pale olive where weathered; fine to very fine-grained; moderately well sorted; heavily burrowed 3.8

Mudstone; poorly consolidated; very dark gray to black where fresh, medium gray where weathered; very silty and sandy 3.0

Concealed interval 1.1

Mudstone; poorly consolidated; very dark gray to black where fresh, medium gray where weathered; very silty and sandy;

Cannonball Formation — Meters

concretions of fine to very fine-grained well indurated, clayey sandstone at top (0.2-0.3 m thick) 1.5

Ludlow Formation

Shale; moderately consolidated; black where fresh, very dark reddish brown where weathered, becoming darker downward; plant fragments common 1.0

Mudstone; poorly consolidated; reddish brown where fresh, light brown where weathered becoming lighter downward, plant fragments common 2.0

Lignite 0.5

Sandstone; poorly consolidated; gray where fresh, grayish brownish yellow where weathered; fine-grained; clayey on top and bottom with little clay in middle of unit (0.8 m below top) 1.5

Hell Creek Formation No Hell Creek was measured.

Total 39.2

Total exposed Cannonball 28.1

(Bottom of Cannonball at top of first lignitic shale, bottom of Ludlow at top of first bentonitic clay)

Measured section 2

South-facing cutbank on north side of Heart River, SE¼ sec. 10, T. 138 N., R. 83 W., approximately 5.4 km south of Sweet Briar or about 1411 km southeast of the Sweet Briar Dam. Section measured by W. E. Fenner, June 14, 1972; accession numbers A999-A1028; Figure 4 (detailed columnar section). This section was measured by Cvancara (1965, p. 335), section 30, Heart River Section (Sweet Briar).

Description

Top of section Meters

Cannonball Formation

Mudstone; poorly consolidated; gray to grayish brown where fresh; light yellowish brown where weathered; 3.08 m below top are concretions of well indurated, silty mudstone approximately 0.5 m thick; concretions are light gray where fresh, light brownish yellow where weathered and lenticular. Mudstone becomes gradually more sandy and silty downward from about 5.6 m below top of section, where color is gray to brownish where fresh, light yellowish brown where weathered. Approximately 6.6 m below top are concretions of well indurated, calcareous mudstone approximately 0.5 m thick; concretions light gray where fresh, brownish yellow where weathered. About 13.9 m below top of section are highly calcareous mudstone concretions; well indurated; dark gray where fresh, yellowish brown where weathered 21.6

Sandstone; poorly consolidated; light grayish green where fresh, reddish yellow where weathered; well sorted, fine-grained; particles angular; at top is lenticular, well indurated, bench-forming sandstone approximately 0.5 m thick; cross stratification common; clay content increases downward with distinct reddish-brown (weathered) clay beds 4 to 10 cm thick, becoming

Cannonball Formation	Meters
more frequent downward; burrows of Ophiomorpha abundant at base of well indurated sandstone	6.8
Mudstone; poorly consolidated; very dark gray to grayish brown where fresh, gray where weathered. Concretions of well indurated, clayey limestone 5.9 m below upper contact; concretions gray to dark gray where fresh, reddish yellow where weathered; about 0.2 m thick; 6.6 m below top of unit are concretions of well indurated, clayey limestone; very dark gray where fresh, pale yellow where weathered, variable in thickness (0.2-0.4 m)	11.7
Sandstone; poorly consolidated; greenish gray where fresh, light yellowish brown where weathered; clayey at top; medium to well sorted; fine-to medium-grained, angular. Concretions of well-indurated, clayey sandstone 1.8 m below upper contact; gray where fresh, light yellowish brown where weathered; fine-to medium-grained; lenticular; variable in thickness (0.5-0.7 m). Sandstone just above concretions very clayey; olive gray where fresh, light yellowish brown where weathered; sandstone below concretions is light greenish brown where fresh, light yellowish brown where weathered; clayey; fine to very fine-grained. Below upper contact 6.0-7.0 m is a thin (15 cm), lenticular, clayey sandstone bed, very dark grayish green where fresh, light gray where weathered (contains numerous, friable macrofossils). Concretions of well indurated, clayey sandstone 7.02 m below top of unit; light gray where fresh, light yellowish

Cannonball Formation | Meters

brown where weathered; fine-to very fine-grained; variable in thickness (0.5-1.5 m). Concretionary bed 11.0 m below upper contact; of well indurated sandstone; light gray where fresh, pale olive where weathered; fine-to very fine-grained; approximately 0.5 m thick. Directly below concretions is 5.0-1.5 cm of black clay; sandstone increases in clay content downward gradually grading into the underlying mudstone 16.5

Mudstone; poorly consolidated; very dark gray, almost black where fresh, light brownish gray where weathered; very sandy near upper and lower contacts; little sand near middle of unit 10.1

Sandstone; poorly consolidated; light grayish green where fresh, pale olive to yellowish brown where weathered; fine-to very fine-grained; upper 0.7 m with sandstone and clay interbedded; clay dark brown to black where fresh, light gray where weathered, with gypsum on weathered surface of clay. Thin (0.3 m) concretions at upper contact; concretionary bed of well indurated sandstone; light gray where fresh, pale olive where weathered; fine-to very fine-grained. At base of unit are concretions of well indurated, calcareous sandstone; light gray where fresh, greenish yellow where weathered; fine-to very fine-grained; thickness variable (0.4-1.6 m) 9.8

Cannonball Formation	Meters
Mudstone with interbedded sandstone; mudstone poorly consolidated; very dark brown to black where fresh, light brownish gray where weathered; sandstone poorly consolidated; olive gray where fresh, light brownish gray where weathered; fine to very fine-grained. Mudstone beds at top of unit are thick (15-20 cm) and widely spaced; mudstone beds thin downward, becoming more closely spaced	8.1
Sandstone; poorly consolidated; light olive gray where fresh, light brownish gray where weathered; few, very dark brown to black mudstone beds approximately 1 cm thick; small-scale cross stratification approximately 2.9 m below upper contact occurs in a 0.1 m zone with individual beds up to approximately 3 cm thick	3.9
Concealed (to river level)	1.4
Total thickness	89.9
(Total exposed Cannonball 88.5 m)	

Measured section 3

Earth road leading to North Dakota State Fish and Game Commission earth dam on Fish Creek, NW¼ sec. 36, T. 138 N., R. 84 W.; and northeast and north-facing bluffs overlooking dam and reservoir, NE¼SW¼ sec. 36, T. 138 N., R. 84 W.; approximately 13 km south-southeast of Judson, Morton County, North Dakota. Section measured by W. E. Fenner, June 22, 1972; accession numbers A1031, A1033 and A1034; Figure 5 (detailed columnar section).

Description

Top of Section	Meters
<u>Cannonball Formation</u>	
Mudstone; poorly consolidated; very dark grayish brown where fresh, light yellowish brown where weathered; interbedded, very dark brown to black to gray (fresh) claystone beds approximately 1 mm thick. Concretionary bed of well indurated, slightly calcareous mudstone; brownish yellow where fresh, grayish brown where weathered; concretionary bed 7.5 m below top of section, approximately 0.3 m thick	7.8
Concealed	3.5
Mudstone; poorly consolidated; dark grayish brown where fresh, light yellowish brown where weathered. Concretions (0.5 m thick) of well indurated limestone 4.2 m below concealed interval; concretions gray where gypsum-filled fractures abundant; below concretions the mudstone becomes siltier. Concretions at bottom contact of well indurated, calcareous, fine- to very fine-grained sandstone at top of unit; concretions 0.4 m thick; light gray where fresh, pale yellow where weathered	9.2
Sandstone; unconsolidated; olive where fresh, very pale olive where weathered; interbedded with thin (2 cm) beds of dark grayish brown mudstone; mudstone beds become more frequent and thicker downward to 5.85 m below upper unit contact where mudstone beds become 10 cm thick	7.45

Cannonball Formation	Meters
Mudstone; unconsolidated; very dark brown where fresh, brownish yellow where weathered; very silty	2.9
Total	30.85

(Total exposed Cannonball 27.35 m, lowest exposed Cannonball at top of dam)

Measured section 4

West-facing cutbank exposure, east side of Cannonball River, NE¼SW¼ sec. 36, T. 132 N., R. 87 W., about 15.3 km south of Brisbane, Grant County, North Dakota. This section is located about 200 m south of a section measured by Cvancara (1965, p. 260), section 3, Cannonball River Section (Leith). Section measured by W. E. Fenner, July 15, 1972; Figure 6 (detailed columnar section).

Description

Top of Section	Meters
?Cannonball Formation	
Sandstone; unconsolidated; light olive brown where fresh, light brownish gray where weathered; fine-to very fine-grained. Concretionary beds 1.5 and 3.2 m below top of section, 0.4 and 0.5 m thick; both of well indurated, calcareous sandstone; light olive brown where fresh, light brownish gray where weathered; fine- to very fine-grained . . .	8.3
Mudstone; unconsolidated; very dark gray where fresh, light gray where weathered; reddish-brown, mudstone beds throughout unit	4.7

Cannonball Formation	Meters
Sandstone; unconsolidated; brown where fresh, light brownish yellow where weathered; very fine-grained and very silty; with much interbedded silt and clay; gradually grading downward into brownish gray mudstone that weathers light gray; mudstone sandy at top and becomes sandy toward bottom with little sand in middle, grades into interbedded sandstone and mudstone 7.8 m below upper contact. Mudstone dark grayish brown where fresh, gray where weathered; sandstone light greenish yellow where fresh, gray where weathered; fine to very fine-grained; lignitic particles common	10.3
Sandstone; unconsolidated; yellow gray where fresh, light gray where weathered; fine-to very fine-grained	0.6
Ludlow Formation	
Shale; very dark to black where fresh, gray where weathered; highly lignitic	0.2
Sandstone; unconsolidated; yellowish gray where fresh, light gray where weathered; fine-to very fine-grained; abundant lignitic particles and plant fragments	0.5
Shale; very dark brown to black where fresh, very dark grayish brown where weathered; very silty; lignitic, becoming more lignitic downward; at base is a 15-cm-thick lignite	3.4

Hell Creek Formation No Hell Creek was measured.

	Meters
Total	28.0
Total exposed Cannonball	23.9

(Bottom of Cannonball at top of first lignitic shale, bottom of Ludlow at top of first bentonitic? (swelling) clay)

Measured section 5

NE¼NW¼ sec. 32, T. 133 N., R. 88 W., about 18.3 km southeast of New Leipzig, southern Grant County, North Dakota. Section is a composite section of two sections, the upper part is a north-facing bluff on the south side of the Cannonball River approximately 200 m south of the river; the lower part is a west-facing cutbank on the east side of the Cannonball River. Section measured by W. E. Fenner, July 14, 1972; accession numbers A1037-A1060; Figure 7 (detailed columnar section). This section was measured by Cvancara (1965, p. 285) section 12, Cannonball River Section (Leith).

Description

Top of section Meters

Cannonball Formation

Sandstone; poorly consolidated; light olive brown where fresh, light yellowish brown where weathered; fine-to very fine-grained. Two concretionary beds are present, one at the top of the section, the other 2.5 m below the top. The upper concretions are of well indurated, calcareous sandstone, fine to very fine-grained, approximately 0.5 m thick; lower concretions are of similar composition and approximately 0.2 m thick. Between concretions are thinner (approximately 15 cm) beds

Cannonball Formation | Meters

of well indurated sandstone similar in composition to the concretions, and irregular, well indurated, light reddish-brown (weathered), mudstone beds; sandstone beds grade into underlying mudstone; interbedded with mudstone at bottom 5.9

Mudstone; poorly consolidated; dark brown to gray where fresh, light gray to light brown where weathered; upper 2.0 m interbedded with overlying sand. Three zones of concretions, 4.0, 24.6 and 47.8 m below upper contact. The upper concretions are of lenticular, well indurated, calcareous mudstone approximately 0.5 m thick; the lower concretions are of similar composition and are approximately 0.2 m thick 48.1

Sandstone; poorly consolidated; brownish to grayish green where fresh, reddish brown at top, progressively grayer toward bottom where weathered; amount of clay increases downward; fine-grained. Concretionary bed of well indurated sandstone 1.0 m below contact, 0.5 to 1.0 m thick; abundant macrofossils (gastropods and bivalves) present near lower part of concretions. Interbedded with a dark gray mudstone at bottom 2.9

Mudstone; poorly consolidated; very dark gray to dark brownish gray where fresh, brownish gray where weathered; interbedded with overlying sand throughout uppermost 0.7 m 2.6

Meters

Base of section at river level.

Total 59.5

Measured section 6

West-facing bluff, approximately 200 m east of North Dakota Highway 25, 50-100 m east of Square Butte Creek, NW¼NE¼ sec. 27, T. 141 N., R. 32 W., approximately 12.5 km southwest of Price, Oliver County, North Dakota. Section measured by W. E. Fenner, June 14, 1973; Figure 8 (detailed columnar section).

Description

Top of section Meters

?Tongue River Formation

Sandstone; poorly consolidated; yellowish brown where fresh, light brownish yellow where weathered; fine-grained; clayey with common cross stratification. Concretions of well indurated, clayey sandstone; 2.5-3.5 m below top of section; yellowish brown where fresh, light brownish yellow where weathered; fine-grained; top and bottom of concretions very irregular, thickness varies from 0.5 to 1.5 m 4.5

Cannonball Formation

Mudstone with interbedded sandstone; poorly consolidated; mudstone dark grayish brown where fresh, medium brownish gray where weathered; sandstone yellowish brown where fresh, light brownish yellow where weathered; fine-to very fine-grained; sandstone beds thicker (15-20 cm) at top, becoming thinner (5-6 cm) and less frequent toward bottom 9.25

	Meters
Total	13.75
Total exposed Cannonball	9.25

(Base of section near road level)

APPENDIX B

DISTRIBUTION OF CANNONBALL FORAMINIFERIDS

Accession numbers (e.g. A999) correspond to those shown on the detailed columnar sections (Figures 3-8). Numbers for each species are numbers of individuals collected from each 400-ml. subsample. Accession numbers corresponding to each measured section are: A1029, measured section 1 A999-A1028, measured section 2, A1030-A1034, measured section 3, A1037-A1060, measured section 5, A1037-A1060.

	A999	A1000
Phylum Protozoa		
Order Foraminiferida		
Suborder Textulariina		
1. *Bathysiphon eocenicus*		
2. *Ammodiscus incertus*	6	
3. *Haplophragmoides excavata*	13	
4. *Haplophragmoides glabra*	19	2
5. ?*Spiroplectammina* sp.		
6. *Trochammina* sp.		
Suborder Miliolina		
7. *Cyclogyra involvens*		
8. *Peneroplis* sp.		
Suborder Rotaliina		
9. *Nodosaria affinis*		1
10. *Nodosaria latejugata*		
11. *Chrysalogonium* sp.		
12. *Dentalina colei*		
13. *Dentalina mucronata*		
14. *Dentalina* sp.		
15. ?*Lagena* sp.		
16. *Lenticulina rotulata*		
17. *Lenticulina* sp. A		
18. *Lenticulina* sp. B		
19. *Marginulina* sp.		
20. *Globulina gibba*		
21. *Globulina* sp. A		
22. *Globulina* sp. B		
23. *Valvulineria wilcoxensis*		
24. *Cibicides* sp.		
25. *Allomorphina* sp.		
26. *Ceratobulimina perplexa*		

	A1001	A1002	A1003	A1004	A1005	A1006	A1007	A1008
1.								
2.	10	23	23	43	3	1		27
3.	4	16	3	2	4		2	
4.	4	42	17	37	14		3	3
5.								4
6.								1
								18
7.		2	6	1		4		
8.								
			17					
9.	2	1		17				
10.	3							
11.								
12.				1				
13.		2	1	4				
14.			3					
15.								
16.	1	3	1	8	1			
17.			6	17	1			
18.				2				
19.				1				
20.			1	1				
21.				1				
22.								
23.				30				
24.			1	15	1			
25.								
26.								

	A1009	A1010	A1011	A1012	A1013	A1014	A1015	A1016
1.					3			
2.							2	
3.								
4.		1	1					2
5.								
6.								
7.	1			1	1			
8.								
9.				1				
10.			1					
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								
26.								

	A1017	A1018	A1019	A1020	A1021	A1023	A1024	A1025
1.								
2.		1	1		2	1	5	
3.								
4.							2	4
5.								
6.								
7.								
8.								
9.	1							
10.	2							
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.			1					
21.								
22.								
23.								
24.								
25.								
26.				1				

	A1026	A1027	A1028	A1029	A1031	A1033	A1034	A1037
1.								
2.				1			1	2
3.				1	1	1	5	2
4.								11
5.								
6.								
7.								
8.								
9.							4	
10.							1	
11.							1	
12.								
13.								
14.								
15.							4	
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								
26.								

	A1038	A1039	A1040	A1041	A1042	A1043	A1044	A1045
1.								
2.		5			7			12
3.	1	14	1	10	2			
4.		91			44	2	4	30
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								1
19.								
20.								
21.								
22.								
23.								
24.								
25.								
26.								

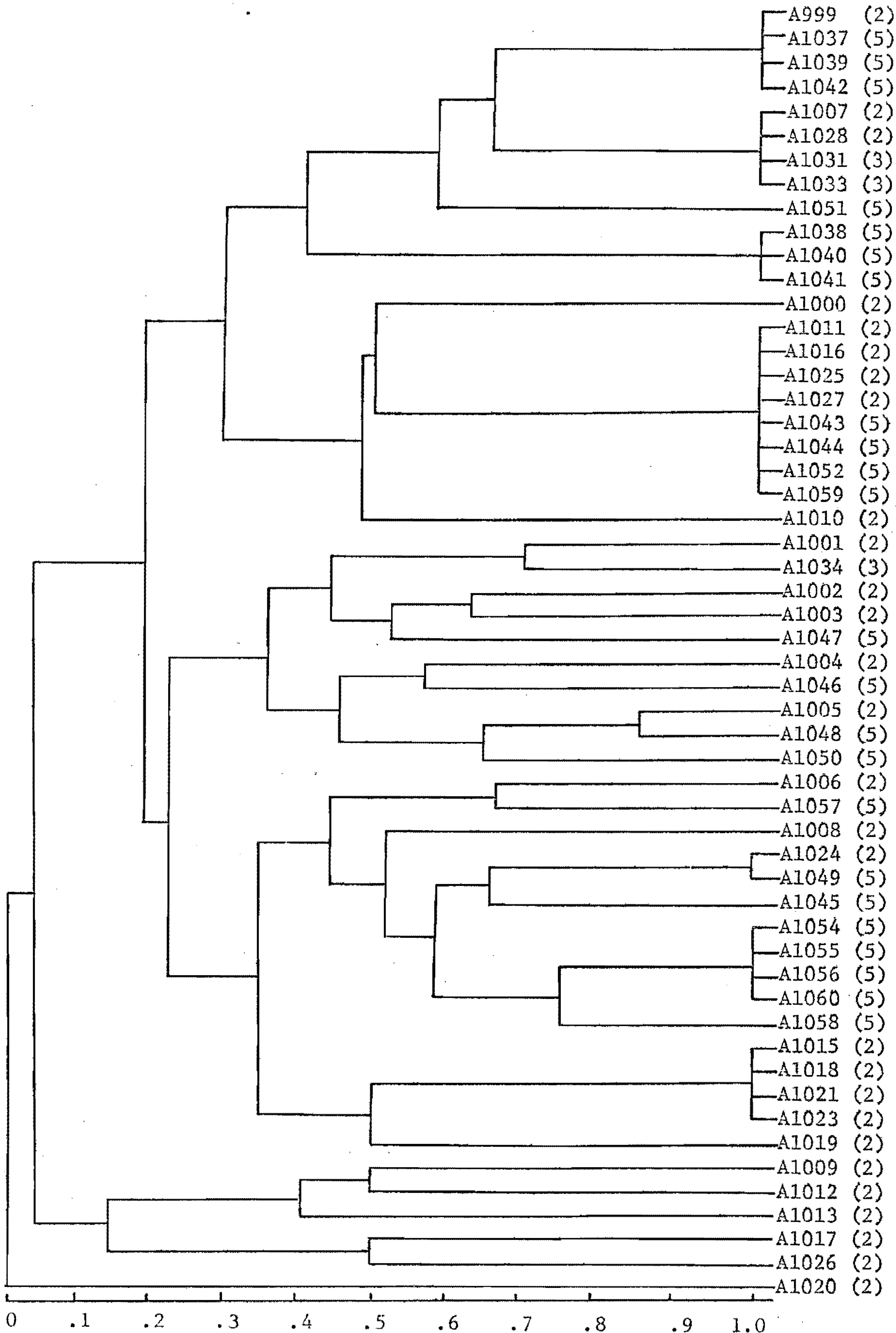
	A1046	A1047	A1048	A1049	A1050	A1051	A1052	A1054
1.								
2.	10	44	1	2	2			1
3.		3	2			3		
4.	9	156	11	2	1	11	6	4
5.								
6.								
7.		2				11		8
8.		1						
9.		1						
10.								
11.	1							
12.								
13.	2							
14.								
15.								
16.	4		2		2			
17.	1		1		2			
18.	1		1		1			
19.								
20.	1							
21.								
22.								
23.								
24.	15		1					
25.	22							
26.								

	A1055	A1056	A1057	A1058	A1059	A1060
1.						
2.	1	2	1	1		1
3.						
4.	6	3		1	4	1
5.						
6.						
7.	32	1	20	11		1
8.						
9.						
10.			1			
11.						
12.						
13.						
14.						
15.				1		
16.						
17.						
18.						
19.						
20.						
21.						
22.						
23.						
24.						
25.						
26.						

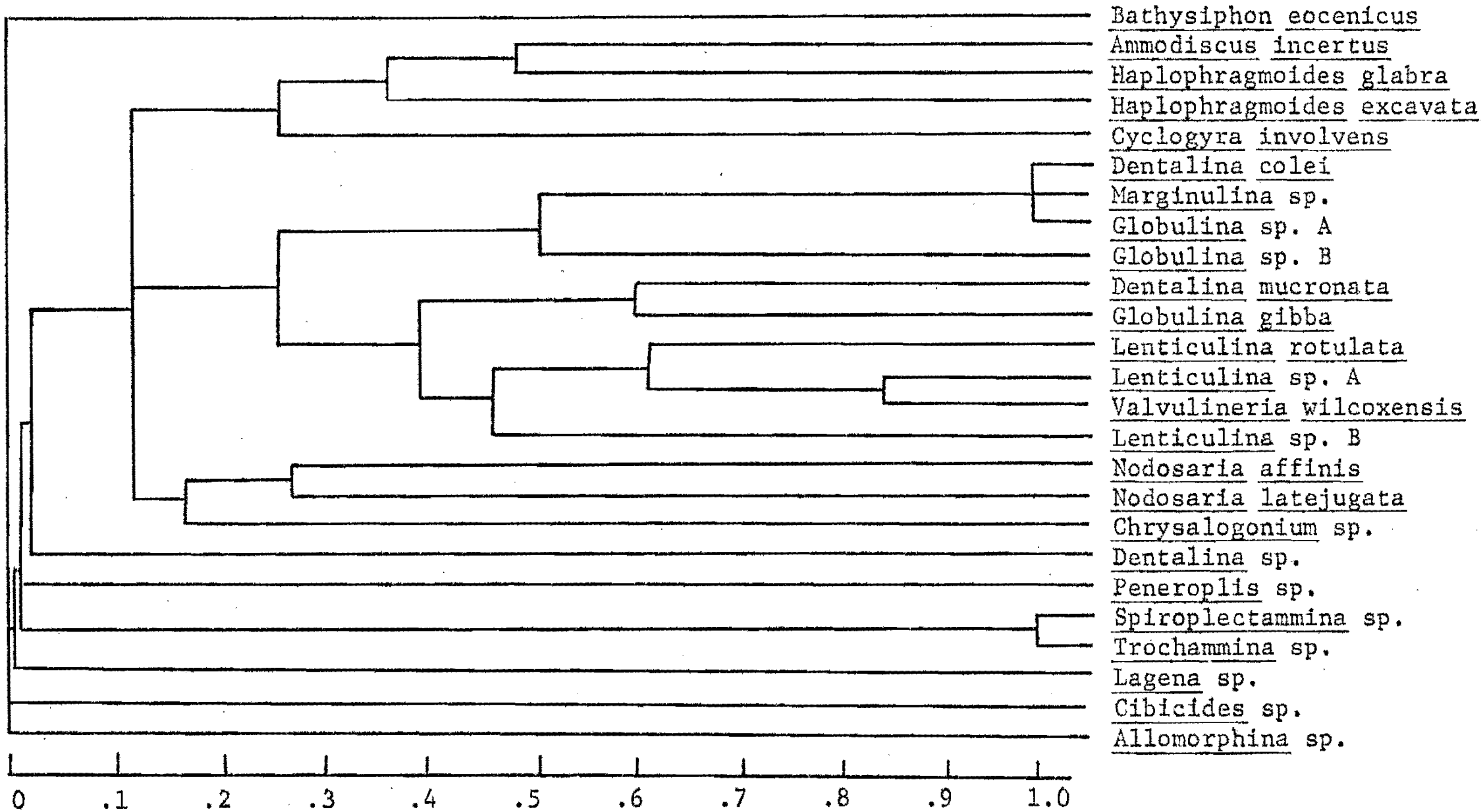
APPENDIX C

Q-AND R-MODE DENDOGRAMS

Q-mode Dendogram. Accession numbers correspond to those on Figures 3-8 and Appendix B. Numbers in parenthesis following accession numbers correspond to measured section numbers. Scale along bottom corresponds to levels of association between sample pairs using Jaccard's correlation coefficient.


A999 (2)
A1037 (5)
A1039 (5)
A1042 (5)
A1007 (2)
A1028 (2)
A1031 (3)
A1033 (3)
A1051 (5)
A1038 (5)
A1040 (5)
A1041 (5)
A1000 (2)
A1011 (2)
A1016 (2)
A1025 (2)
A1027 (2)
A1043 (5)
A1044 (5)
A1052 (5)
A1059 (5)
A1010 (2)
A1001 (2)
A1034 (3)
A1002 (2)
A1003 (2)
A1047 (5)
A1004 (2)
A1046 (5)
A1005 (2)
A1048 (5)
A1050 (5)
A1006 (2)
A1057 (5)
A1008 (2)
A1024 (2)
A1049 (5)
A1045 (5)
A1054 (5)
A1055 (5)
A1056 (5)
A1060 (5)
A1058 (5)
A1015 (2)
A1018 (2)
A1021 (2)
A1023 (2)
A1019 (2)
A1009 (2)
A1012 (2)
A1013 (2)
A1017 (2)
A1026 (2)
A1020 (2)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

R-mode Denogram. Scale along bottom corresponds to levels of association between species pairs using Jaccard's correlation coefficient.


Bathysiphon eocenicus
Ammodiscus incertus
Haplophragmoides glabra
Haplophragmoides excavata
Cyclogyra involvens
Dentalina colei
Marginulina sp.
Globulina sp. A
Globulina sp. B
Dentalina mucronata
Globulina gibba
Lenticulina rotulata
Lenticulina sp. A
Valvulineria wilcoxensis
Lenticulina sp. B
Nodosaria affinis
Nodosaria latejugata
Chrysalogonium sp.
Dentalina sp.
Peneroplis sp.
Spiroplectammina sp.
Trochammina sp.
Lagena sp.
Cibicides sp.
Allomorphina sp.
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

REFERENCES

REFERENCES

Albritton, C. C., W. W. Schell, C. S. Hill, and J. R. Puryear. 1954. Foraminiferal populations in the Grayson Marl. Geol. Soc. America Bull. 65:327-336.

Ballard, N. 1942. Regional geology of Dakota Basin. American Assoc. Petroleum Geologists Bull. 26:1557-1584.

Bandy, O. L. and R. E. Arnal. 1960. Concepts of foraminiferal paleoecology. American Assoc. Petroleum Geologists Bull. 44(12): 1921-1932.

Benson, W. E. 1952. The geology of the Knife River area, North Dakota. U. S. Geol. Survey Open-file Report. 323 p.

Bornemann, L. G. 1874. Ueber die Foraminiferengattung Involuta. Deutsche Geol. Gesell. Zeitschr. 26:702-749.

Brady, H. B. 1876. A monograph of the Carboniferous and Permian Foraminifera (the genus Fusulina excepted). Palaeontograph. Soc. London. p. 1-166.

_______. 1884. Report on the Foraminifera dredged by H.M.S. Challenger during the years 1873-1876. Rept. Scientific Results Explor. Voyage H.M.S. Challenger, Zoology. 9:1-814.

Brooks, W. W. 1973. Distribution of recent foraminifera from the southern coast of Puerto Rico. Micropaleontology. 19(4): 385-416.

Brown, R. W. 1948. Correlation of Sentinel Butte Shale in western North Dakota. American Assoc. Petroleum Geologists Bull. 32(7):1265-1274.

_______. 1962. Paleocene Flora of the Rocky Mountains and Great Plains. U. S. Geol. Survey Prof. Paper. 375:1-119.

Bullard, F. J. 1953. Polymorphinidae of the Cretaceous (Cenomanian) Del Rio Shale. Jour. Paleont. 27(3):342.

Carlson, C. G. 1969. Bedrock geologic map of North Dakota. North Dakota Survey Misc. Map No. 10.

_______. 1973. Oral communication.

Carsey, D. O. 1926. Foraminifera of the Cretaceous of central Texas. Univ. Texas Bull. 2612:1-56.

Cheatham, A. H. and J. E. Hazel. 1969. Binary (presence-absence) similarity coefficients. Jour. Paleont. 43:1130-1136.

Children, J. G. 1823. Lamarck's genera of shells, translated from the French by J. G. Children with plates from original drawings by Miss Anna Children. The Author (London). 177 p.

Clayton, L. C. 1972. Roadlog. p. 2-30. In F. T. C. Ting (ed.), Depositional environments of the lignite-bearing strata in western North Dakota. N. D. Geol. Survey Misc. Series 50.

Cole, W. S. 1927. A foraminiferal fauna from the Guayabal Formation in Mexico. American Paleontology Bull. 14:1-46.

Cushman, J. A. 1910. A monograph of the Foraminifera of the North Pacific Ocean. Astrorhizidae and Lituolidae. U. S. Nat. Museum Bull. 71(1). 134 p.

________. 1922. The Foraminifera of the Mint Spring Marl member of the Marianna Limestone. U. S. Geol. Survey Prof. Paper 129-F:123-143.

________. 1923. The Foraminifera of the Atlantic Ocean. Part 4. Lagenidae. U. S. Nat. Museum Bull. 104:146.

________. 1926. Foraminifera of the typical Monterey of California. Cushman Lab. Foram. Research Contr. 2(3):53-69.

________. 1927a. An outline of a reclassification of the Foraminifera. Cushman Lab. Foram. Research Contr. 3(1):1-105.

________. 1927b. The designation of some genotypes in the Foraminifera. Cushman Lab. Foram. Research Contr. 3(4):188-190.

________. 1935. Upper Eocene Foraminifera of the southeastern United States. U. S. Geol. Survey Prof. Paper. 181:1-88.

________. 1936. Some American Cretaceous species of Ellipsonodosaria and Chrysalogonium. Cushman Lab. Foram. Research Contr. 12(3):55.

________. 1945. A Foraminiferal fauna from the Twiggs Clay of Georgia. Cushman Lab. Foram. Research Contr. 21(1):1-11.

________. 1946. Upper Cretaceous Foraminifera of the Gulf Coastal Region of the United States and adjacent areas. U. S. Geol. Survey Prof. Paper. 206:1-241.

________. 1948. Additional new Foraminifera from the American Paleocene. Cushman Lab. Foram. Research Contr. 24(2):45.

Cushman, J. A. 1951. Paleocene Foraminifera of the Gulf Coastal region. U. S. Geol. Survey Prof. Paper. 232:1-75.

________ and E. R. Applin. 1943. The Foraminifera of the type locality of the Yegua Formation of Texas. Cushman Lab. Foram. Research Contr. 19(2):28-46.

________ and E. D. Cahill. 1933. Miocene Foraminifera of the coastal plain of the eastern United States. U. S. Geol. Survey Prof. Paper. 175-A:1-50.

________ and A. N. Dusenbury, Jr. 1934. Eocene Foraminifera of the Poway conglomerate of California. Cushman Lab. Foram. Research Contr. 10(3):54.

________ and G. D. Hanna. 1927. Foraminifera from the Eocene near Coalinga, California. Proc. California Acad. Sci. ser. 4. 16(8):210.

________ and R. W. Harris. 1927. Some notes on the genus Ceratobulimana. Cushman Lab. Foram. Research Contr. 3(4):171-179.

________ and G. M. Ponton. 1932. An Eocene Foraminiferal fauna of Wilcox age from Alabama. Cushman Lab. Foram. Research Contr. 8(3):51-72.

________ and J. A. Waters. 1927. Arenaceous Paleozoic Foraminifera from Texas. Cushman Lab. Foram. Research Contr. 3(3):146-153.

Cvancara, A. M. 1965. Bivalves and biostratigraphy of the Cannonball Formation (Paleocene) in North Dakota. Ph. D. dissertation, Univ. of Michigan. 470 p.

________. 1966. Revision of the fauna of the Cannonball Formation (Paleocene) of North and South Dakota, Part I, Bivalvia. Contr. Univ. Michigan Mus. Paleontology. 20(10):277-374.

________. 1970a. North Dakota's state fossil. North Dakota Quarterly. 32(2):31-35.

________. 1970b. Teredinid (Bivalvia) pallets from the Palaeocene of North America. Palaeontology. 13(4):619-622.

________. 1972. Summary of the Cannonball Formation (Paleocene) in North Dakota. p. 69-73. In F. T. C. Ting (ed.), Depositional environments of the lignite-bearing strata in western North Dakota. N. D. Geol. Survey Misc. Series 50.

________. 1973. Oral communication.

Czjzek, J. 1849. Über zwei neue Arten von Foraminiferen aus dem Tegel von Baden and Mollersdorf. Freunde Naturwiss. Wien, Ber. Mitteil. 5(6):50-51.

Deshayes, G. P. 1830. Encyclopedie methodique. Histoire Naturelle des Vers. 2:1-594.

d'Orbigny, A. D. 1826. Tableau methodique de la classe des Cephalopodes. Ann. Sci. Nat. Paris. Ser. 1. 7:245-314.

_______. 1839a. Foraminiferes des Iles Canaries. In Hist. Nat. des Iles Canaries par. MM. P. Barker-Webb et Sabin Berthelot. Bethune, Paris. 2(2):128.

_______. 1839b. Foraminiferes. In R. De La Sagra (ed.) Histoire physique, politique et. naturelle de lile de Cuba. 224 p.

_______. 1846. Foraminiferes fossiles du bassin tertiare de Vienne (Autriche) (Die fossilen Foraminiferen des Tertiaren Bekens von Wien). Gide et. Comp., Paris. p. 46.

Dorf, E. 1940. Relationship between floras of type Lance and Fort Union Formations. Geol. Soc. America Bull. 51:213-236.

Feldman, R. M. 1972. First report of Hercoglossa ulrichi (White, 1882) (Cephalopoda: Nautilida) from the Cannonball Formation (Paleocene) of North Dakota, U.S.A. Malacologia. 11(2): 407-413.

_______ and F. D. Holland, Jr. 1971. A new species of lobster from the Cannonball Formation (Paleocene) of North Dakota. Jour. Paleont. 45(5):838-843.

Fichtel, L. von and J. P. C. von Moll. 1798. Testacea microscopica, aliague minuta ex generibus Argonauta et Nautilus, ad naturam picta et descripta (Microscopische und andere klein Schalthiere aus den Geschlectern Argonaute und Schiffer). Camesina (Wien). 123 p.

Folk, R. L. 1968. Petrology of sedimentary rocks. The University of Texas, Austin, Texas. 170 p.

Fox, S. K., Jr. and R. J. Ross, Jr. 1942. Foraminiferal evidence for the Midway (Paleocene) age of the Cannonball Formation in North Dakota. Jour. Paleont. 16:660-673.

_______ and R. K. Olsson. 1969. Danian planktonic Foraminifera from the Cannonball Formation in North Dakota. Jour. Paleont. 43(6):1397-1404.

Frizzell, D. L. 1943. Upper Cretaceous Forminifera from northwestern Peru. Jour. Paleont. 17(4):331-353.

_______. 1954. Handbook of Cretaceous Foraminifera of Texas. Texas Univ. Bur. Econ. Geol. Rept. Inv. 22:1-232.

Galloway, J. J. and S. G. Wissler. 1927. Correction of names of Foraminifera. Jour. Paleont. 1:193.

Greiner, G. O. G. 1970. Distribution of major bethonic foraminiferal groups on the Gulf of Mexico continental shelf. Micropaleontology. 16(1):83-101.

Grim, R. E. 1968. Clay mineralogy. McGraw-Hill Co., New York. 596 p.

Gümbel, C. W. 1868 [1870]. Beitrage zur Foraminiferenfauna der nordalpinen Eocangebilde. K. Bayer. Akad. Wiss. Abhandl. Cl. II. 10(2):581-730.

Hayden, F. V. 1857. Notes explanitory of a map of the country bordering on the Missouri River, from the mouth of the Platte River to Fort Benton, in lat. 47°30' N., long. 110°30' W. Phila Acad. Nat. Sci. Proc. 9:109-116.

Heckel, P. H. 1972. Recognition of ancient shallow marine environments. p. 226-286. In J. K. Rigby and W. K. Hamblin (eds.), Recognition of ancient sedimentary environments. Society of Economic Paleontologists and Mineralogists Special Pub. 16. *

Hendricks, S. B. and C. S. Ross. 1941. Chemical composition and genesis of glauconite and celadonite. Am. Mineralogists. 26:683-708.

Hickey, L. J. 1972. Stratigraphic summary of the Golden Valley Formation (Paleocene-Eocene) of western North Dakota. p. 105-122. In F. T. C. Ting (ed.), Depositional environments of the lignite-bearing strat in western North Dakota. N. D. Geol. Survey Misc. Series 50.

Holland, F. D., Jr. and A. M. Cvancara. 1958. Crabs from the Cannonball Formation (Paleocene) of North Dakota. Jour. Paleont. 32(3):495-505.

Howard, J. D. 1971. Comparison of the beach-to-offshare sequence in modern and ancient sediments. p. 148-183. In J. D. Howard, J. W. Valentine and J. E. Warme (eds.), Recent advances in paleoecology and ichnology. A.G.I. Short Course Lecture Notes, American Geological Institute, Washington, D. C.

Howe, H. V. 1939. Louisiana Cook Mountain Eocene Foraminifera. Louisiana Dept. Conservation, Geol. Survey Geol. Bull. 14:40.

Ingle, J. C. 1967. Biofacies and lithofacies as empirical geological models. p. JI-A-1 - JI-A-21. In O. L. Bandy, J. C. Ingle, R. L. Lankford and H. A. Lowenstam (eds.), Paleoecology. A.G.I. Short Course Lecture Notes, American Geological Institute, Washington, D. C.

Johns, W. D., R. E. Grim, and W. F. Bradley. 1954. Quantitative estimations of clay minerals by diffraction methods. Jour. Sed. Petrology. 24(4):242-251.

Kanmacher, F. 1798. Adam's essays on the microscope; the second edition, with considerable additions and improvements. Dillon and Keating (London).

Kline, V. H. 1943. Clay County fossils (Midway Foraminifera and Ostracoda). Miss. Geol. Survey Bull. 53:1-98.

Laird, W. M. and R. H. Mitchell. 1942. The geology of the southern part of Morton County, North Dakota. North Dakota Geol. Survey Bull. 14. 42 p.

Lamarck. 1804. Suite des memoires sur les fossiles des environs de Paris. Museum Natl. Histoire Nat. Paris, Ann. 5:179-188.

_______. 1812. Extrait du cours de zoologie du museum d'Histoire naturelle sur les animaux invertebres. Dentu (Paris). 127 p.

Lemke, R. W. 1960. Geology of the Souris River area, North Dakota. U. S. Geol. Survey Prof. Paper. 325:1-138.

Leonard, A. G. 1908. The geology of southwestern North Dakota with special reference to coal. State Geol. Survey N. Dak. 5th Bienn. Rept. p. 27-114.

Leriche, M. 1942. Contribution a l'etude faunes ichthyologiques marine des terrains Tertiares de la Plaine Cotiere Atlantique et du contre des Etats Unis. Soc. Geol. France Mem. 45, N. S. 20(2-4): 1-110.

Lloyd, E. R. 1914. The Cannonball River lignite field, Morton, Adams and Hettinger Counties, North Dakota. U. S. Geol. Survey Bull. 541:243-291.

_______ and C. J. Hares. 1915. The Cannonball marine member of the Lance Formation of North and South Dakota and its bearing on the Lance-Laramie problem. Jour. Geol. 23(6):523-547.

Loeblich, A. R. and H. Tappan. 1961. Suprageneric classification of the Rhizopodea. Jour. Paleont. 35:245-330.

_______ and _______. 1964. Treatise on invertebrate paleontology, Part C. Protista 2, Sarcodina (Foraminiferida). Geol. Soc. America and U. of Kansas Press. 900p.

Lowman, S. W. 1949. Sedimentary facies in Gulf Coast. American Assoc. Petroleum Geologists Bull. 33:1939-1997.

Linné, C. 1758. Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synoymis, licis. G. Engelman, (Lipsiae). 1:1-824.

Ludlow, W. 1875. Report of a reconnaissance of the Black Hills of Dakota made in the summer of 1874. Washington Government Printing Office, U. S. Engineer Dept., U. S. Army War Dept. 121 p.

Martin, L. 1964. Upper Cretaceous and Lower Tertiary Foraminifera from Fresno County, California. Austria, Geol. Bundesanst., Jahrb., Sonderb. 9:49.

Madenwald, K. A. 1962. Foraminiferida from outcrops of the Niobrara Shale (Upper Cretaceous) of North Dakota. M. S. Thesis, University of North Dakota. 154 p.

Meek, F. B. and F. V. Hayden. 1856. Descriptions of new species of Gastropoda from the Cretaceous Formation of Nebraska Territory. Proc. Phila. Acad. Nat. Sci. 8:63-69.

Montagu, G. 1808. Testacea britannica, supplement. S. Woolmer (Exeter, England). 183 p.

Montfort, D. de. 1808. Conchyliologie systematique et classification methodique des coquilles. 1:1-409.

Murray, J. W. 1968. Living foraminifers of lagoons and estauries. Micropaleontology. 14(4):435-455.

_______. 1969. Recent foraminifers from the Atlantic continental shelf of the United States. Micropaleontology. 15(4):401-419.

Nauss, A. W. 1947. Cretaceous microfossils of the Vermillion area, Alberta. Jour. Paleont. 21:337.

Neugeboren. 1856. Die Foraminiferen aus der Ordnung der Stichosteger von Ober Lapugy in Siebenburgen. K. Akad. Wiss. Wien, Math.-Naturwiss. Cl., Denkschr., 12(2):65-108.

Nogan, D. S. 1964. Foraminifera, stratigraphy and paleoecology of the Aquia Formation of Maryland and Virginia. Cushman Found. Foram. Research Spec. Pub. 7:1-50.

Parker and Jones. 1859. On the nomenclature of the Foraminifera; Pt. 2, On the species enumerated by Walker and Montagu. Ann. and Mag. Nat. History, Ser. 3. 4:333-351.

_______ and _______. 1865. On some Foraminifera from the north Atlantic and Arctic Oceans, including Davis Straits and Baffins Bay. Philos. Trans. 155:325-441.

Parker, F. L. and W. D. Athearn. 1959. Ecology of marsh Foraminifera in Poponesset Bay, Massachusetts. Jour. Paleont. 33(2):333-343.

Phleger, F. B. 1960. Ecology and distribution of recent Foraminifera. The Johns Hopkins Press, Baltimore. 297 p.

Plummer, H. J. 1926. Foraminifera of the Midway Formation in Texas. Univ. Texas Bull. 2644:1-206.

Plummer, H. J. 1931. Some Cretaceous Foraminifera in Texas. Univ. Texas Bull. 3101:109-203.

_______. 1936. Structure of Ceratobulimina. American Midland Naturalist. 17(2):460-463.

Pryor, W. A. and H. D. Glass. 1961. Cretaceous-Tertiary clay mineralogy of the upper Mississippi Embayment. Jour. Sed. Petrology. 31:38-51.

Reuss, A. E. 1845. Die Versteinerungen der böhmischen Kreideformation. E. Schweizerbart, Stuttgart, Deutschland Abt. 1, p. 26.

_______. 1850. Neues Foraminiferen aus der Schichten des österreichischen Tertiärbeckens. K. Akad. Wiss. Wien, Math.-Naturwiss. Cl., Denkschr. 1:365-390.

_______. 1851. Ueber die fossilen Foraminiferen und Entomostraceen der Septarienthone der Umgegend von Berlin. Deutsch. geol. Gesel., Zeitschr. 3:49-91.

_______. 1862. Entwurf einer systematischen Zusammenstellung der Foraminiferen. K. Akad. Wiss. Wien, Math.-Naturwiss. Cl., Sitzungsber. 44:365.

_______. 1863. Beträge zur Kentniss der tertiären Foraminiferen-Fauna (Zweite Folge). K. Akad. Wiss. Wien, Math.-Naturwiss. Cl., Sitzungsber. 48(1):36-71.

Risso, A. 1826. Histoire naturelle des principales productions de l'Europe meridionale et particulièrement de celles des environs de Nice et des Alpes maritimes. F. G. Levrault (Paris and Strassburg). 4:1-439.

Sars, M. 1872. Undersogelser over Hardangerfjordens fauna. In G. O. Sars. (ed.) Vidensk.-Selsk. Christiana, Fordhandl. 1871: 246-255.

Schubert, R. J. 1908. Beiträge zur einer natürlichen Systematik der Foraminiferen. Neues Jahrb. Mineral. Geol. und Palaont. Beil.-Bd. 25:232-260.

Scott, G. 1940. Paleoecological factors controlling distribution of Cretaceous ammonoids in Texas area. American Assoc. Petroleum Geologists Bull. 24:1164-1203.

Sloan, R. E. 1970. Cretaceous and Paleocene terrestrial communities of western North America. North American Paleont. Convention, Chicago, 1969, Proc., E. 427-453.

Stanton, T. W. 1920. The fauna of the Cannonball marine member of the Lance Formation. U. S. Geol. Survey Prof. Paper. 128-A: 1-66.

Swain, F. M. 1949. Early Tertiary Ostracoda from the western interior United States. Jour. Paleont. 23(2):172-181.

Thom, W. T., Jr. and C. E. Dobbin. 1924a. Stratigraphy of the Cretaceous-Eocene transition beds in eastern Montana and the Dakotas. Geol. Soc. America Bull. 35:481-506.

_______ and _______. 1924b. Correlation of the Lebo member of the Fort Union with Cannonball member of the Lance. Jour. Wash. Acad. Sci. 14(7):165.

Todd, R. and P. Brönnimann. 1957. Recent Foraminifera and Thecamoeba from the eastern Gulf of Paria. Cushman Found. Foram. Research Spec. Pub. 3:1-43.

Toula, F. 1915. Über den marinen Tegel von Neudorf an der March (Deveny Ujfalu) in Ungarn und seina Mikrofauna. K. K. Geol. Reichsanst. Jahrb. 64(4):635-674.

Twenhofel, W. H. 1932. Treatise on sedimentation. 2nd ed. Williams and Wilkins Co., Baltimore. (Republished in 1961 by Dover Publications. 926 p.)

Van Alstine, J. B. 1973. Oral communication.

Vaughan, T. W. 1920. Corals from the Cannonball marine member of the Lance Formation. U. S. Geol. Survey Prof. Paper. 128-A:61-66.

Weaver, C. E. 1961. Clay mineralogy of the late Cretaceous rocks of the Washakie Basin. Wyoming Geol. Assoc. Guidebook 16th Ann. Field Conf. 148-154.

Williamson. 1858. On the recent Foraminifera of Great Britain. Roy. Soc. Publs. 107 p.

Wilson, E. E. 1957. An investigation of the corals from the Cannonball Formation (Paleocene) of North Dakota. North Dakota Acad. Sci. Proc. (abs.). 11:15-16.

Wood, S. V. 1842. A catalogue of shells from the Crag. Ann. and Mag. Nat. History. Ser. 1. 9:455-462.