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Pelecypoda from the lower Fox Hills Formation (Upper Cretaceous) of Emmons County, North Dakota

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PELECYPODA FROM THE LOWER FOX HILLS FORMATION (UPPER CRETACEOUS) OF EMMONS COUNTY, NORTH DAKOTA

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

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ABSTRACT

PELECYPODA FROM THE LOWER FOX HILLS FORMATION (UPPER CRETACEOUS) OF EMMONS COUNTY, NORTH DAKOTA

Rodney Feldmann

The thesis here abstracted was written under the direction of Dr. F. D. Holland, Jr., committee chairman, and approved by Drs. Holland, W. M. Moore, and O. C. Wheeler who served as members of the examination committee.

The Fox Hills Formation in Emmons County, North Dakota, consists of 250-350 feet of medium to fine grained sand and sandstone with some shale interbeds. In Emmons County, the four members, Trail City, Timber Lake, Bullhead, and Colgate are not as distinct lithologically as they are in the areas from which they were described; thus, the unit has been subdivided into a lower part consisting of crossbedded sand and sandstone with calcareous, fossiliferous concretions and an upper part consisting of interbeds of buff sand and chocolate shale.

The gradational change from Pierre Shale lithology to the sands of the overlying Fox Hills Formation have resulted in several different definitions of the contact. The most consistent criterion for defining the contact in Emmons County is a zone of jarosite below the lowest fossiliferous concretion layer. The base of the jarosite zone has been arbitrarily selected as the division between the two formations.

Twenty-two species of pelecypods were identified from the concretions of the lower part of the formation. The concretions were probably formed

as clay boulders along the strand line of the Fox Hills Sea and were later transported to their site of deposition farther offshore. The entire formation represents the shoreline and nearshore facies of the regressive Upper Cretaceous seaway.

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INTRODUCTION

Purpose.—The Fox Hills Formation in North Dakota and adjacent areas contains an abundant molluscan fauna which has received little study since the classic work on the Cenozoic and Cretaceous Systems of the Mid-continent in the mid-nineteenth century. During the summer of 1962, while employed by the North Dakota Geological Survey, I made extensive collections of fossils from the Fox Hills Formation in Emmons County, North Dakota. This material will form the framework of a study of the paleontology of the Fox Hills Formation in North Dakota of which the present work on the Pelecypoda is a part. The primary purpose of this work is to present a modern study of the Pelecypoda from the lower part of the formation in Emmons County. Secondly, the occurrence of the majority of the fossils in concretions will be discussed with regard to the ecology of the formation.

Location and physiography.—Emmons County is located in the south-central part of North Dakota; it is bounded on the west by the Missouri River, on the north by Burleigh County, on the east by Logan and McIntosh Counties, and on the south by South Dakota (Fig. 1). Physiographically, it lies in the Coteau Slope district of the glaciated Missouri Plateau section of the Great Plains province (Clayton, 1962 1963 , p. 14). Approximately 70% of the area of the county is covered by Pleistocene deposits; the remainder has Cretaceous and Paleocene bedrock either exposed at the surface or beneath very thin soil cover. In gross aspect, the county is a mature plateau which has only recently been secondarily dissected along its western border by the Missouri River

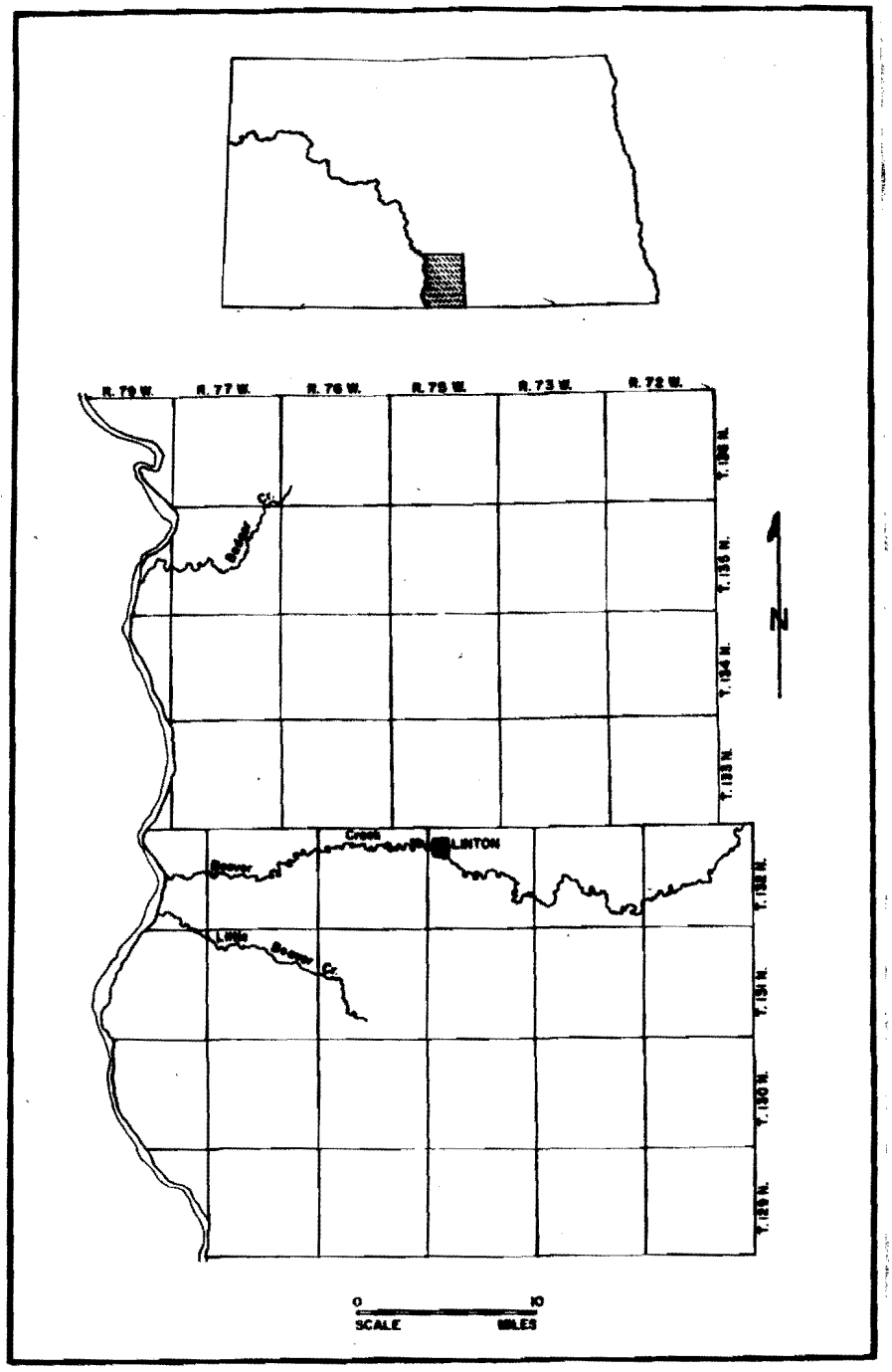

Fig. 1. Index map of Emmons County, North Dakota.

and its tributaries. The result is a gently rolling prairie, seldom with relief in excess of 100 feet, except where dissected by the three major tributaries to the Missouri River. These tributaries--Badger Creek, Beaver Creek, and Little Beaver Creek--provide the only natural outcrops of bedrock in the county. Other outcrops are mostly the result of highway development.

The climate of the area is semi-arid with rainfall averaging approximately fifteen inches per year. The economy is entirely agrarian. Several petroleum prospects have been drilled on the southeast flank of the Williston Basin in Emmons County but no production has been established. A possible future source of income might result in exploitation of extensive volcanic ash deposits that occur in the Fox Hills Formation in eastern Emmons County. Full details of this deposit have been published by Manta (1962).

Previous work.--The earliest work on the Upper Cretaceous in the Mid-continent is summarized by Meek (1876). Prior to this time the Cretaceous and Cenozoic formations in the area had been subdivided into five units, of which the Fox Hills sandstone was unit number five. Meek's work, primarily paleontological, is a compendium of material collected during several studies prior to that time. Type specimens of several species collected by Hayden and described in this work are recorded from the vicinity of Long Lake. The location of this type area is still unknown, although I am confident that, if the present Long Lake in Burleigh County is the locality cited, the name was used in only a very general sense. No exposures are present in the area of Long Lake, Burleigh County, that could have yielded the fauna described

from Meek's "Long Lake". This is, however, the only evidence available that any of the material collected by the early workers was taken from Emmons County. In 1912, Leonard published a geologic map of the south-central portion of North Dakota in which the extent of the Pierre, Fox Hills, and Lance Formations are shown in Emmons County. Even allowing for more modern interpretations of the formational boundaries, Leonard was far too conservative in portraying the extent of the Fox Hills in the county. Following Leonard's work, Stanton (1917) noted the presence of volcanic ash in the area surrounding Linton. Nothing more was done in the area until Fisher (1932) mapped Emmons County. This was essentially an extension of work previously done by Calvert and others (1914) in Sioux County, and Laird and Mitchell (1942) in southern Morton County. Fisher not only drew a geologic map of the county but also constructed a structural contour map of the same area. Although the geologic map has proved to be reliable with regard to areal extent of the bedrock, the structure as mapped cannot be demonstrated in the field.

Following this work, Evanoara (1956) studied the Gastropoda of the Pierre Formation in Beeman Park, 3/4 of a mile southeast of Linton, North Dakota. This outcrop, located in SE¼, Sec. 17, T. 136 N., R. 72 W., is a steep cutbank on the south side of Beaver Creek. As it is the best locality in central North Dakota to see the Pierre-Fox Hills contact, the outcrop has been much studied. The gradational nature of this contact has resulted in almost constant conflict with regard to placement of the contact. A more complete review of this problem is given below. Suffice it to say here that I believe the

gastropod fauna described by Cvancara (1956) should be placed in the Fox Hills Formation. This would be more consistent with the modern definition of the lower limit of the Fox Hills.

STRATIGRAPHY

General.--The pre-Pleistocene surficial bedrock in Emmons County is made up of the Pierre, Fox Hills, and Hell Creek Formations in the Cretaceous System and the Ludlow and Cannonball Formations in the Cenozoic System. In response to regional structure, the units have a general dip of 20 feet per mile to the northwest (Fisher, 1952, pl. 2). The stratigraphic column showing rocks cropping out at the surface is shown in Fig. 2.

As the structure in the area is minimal, the topography in the western half of the county is controlled almost exclusively by the lithology of the units exposed. From T. 134 N. to the southern border of the county the dominant element of topography is the upper part of the lower Fox Hills Formation (Fig. 3). Several thick, calcareous ledges crop out at this stratigraphic level and form the present general land surface. Above the general land surface, buttes and small hills are formed in the upper Fox Hills while the lower part of the section is exposed along valley walls. North of T. 134 N. the Fox Hills Formation crops out less frequently and the topography is controlled by the Hell Creek Formation. The lithology of the Hell Creek is such that it normally supports minimal vegetation with the result that buttes and bare slopes are far more common in this part of the county than farther south (Fig. 4).

East of R. 76 W. the dominant topographic features are glacial in origin and the effect is a more subdued topography than in the western part of the county.

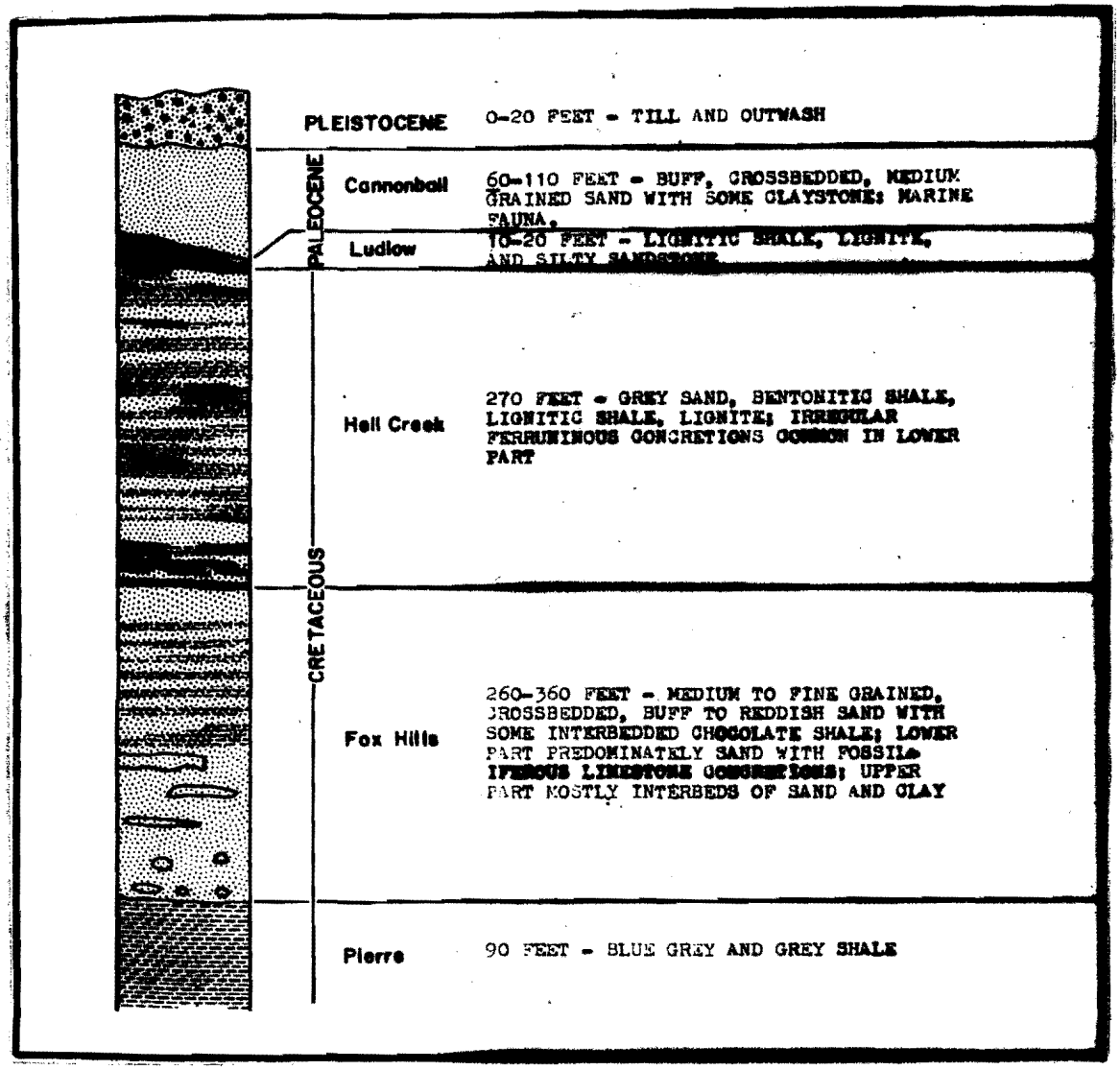

Fig. 2. Stratigraphic column of rocks cropping out in Emmons County. Thicknesses, with the exception of that of the Fox Hills, are taken from Fisher (1952).

Fig. 3. View of the topography developed on the lower part of the Fox Hills Formation in Emmons County, North Dakota. The picture was taken from T. 134 N., looking southeast.

Fig. 4. View of the topography developed on the Hell Creek Formation in Northern Emmons County, North Dakota. The picture was taken in Section 20, T. 136 N., R. 78 W.

Pierre Formation.--The Pierre Formation was named by Meek and Hayden (1862, p. 419, 428) for exposures near old Ft. Pierre in either Stanley or Hughes County, South Dakota. (The precise location is apparently unknown). Subsequently the unit has been subdivided into eight members (Crandall, 1950) of which only the Elk Butte Member is exposed in Emmons County. Fisher (1952, p. 8) indicated that the Mobridge Member may be present at the surface in the extreme southwestern part of the county but this has not been demonstrated. The Elk Butte Member is a blue-grey, non-calcareous, fissile shale that may be locally gypsiferous. In South Dakota, where it has been more thoroughly studied, the member rarely produces fossils (Wange, 1961, p. 232); Baculites sp. is the only species commonly encountered (Gries, 1942, p. 32).

Following Fisher's placement (1952, p. 9) of the Pierre-Fox Hills contact, Evanoura (1956) considered the concretion layers in Seeman Park, Linton, North Dakota, part of the Elk Butte Member and thus listed a rather large suite of gastropods and mentioned other molluscs from the member. As will be discussed below, I believe the contact was placed higher in the section by both Fisher (1952) and Evanoura (1956) than modern interpretation allows. Although the Pierre Formation is present at the surface in many places in Emmons County, the only exposures that are not obscured by vegetation are in the vicinity of Linton. Detailed examination of these exposures yielded only a few unidentifiable pelecypod fragments. At Seeman Park, Fisher (1952, p. 3) reported 135 feet of Elk Butte sediments; however, if the contact is placed below the above mentioned concretion

layers, the result is a reduction in thickness of exposed Pierre formation to 90 feet and a corresponding increase in thickness of exposed Fox Hills.

Pierre-Fox Hills contact.--The change from the dark clay shales of the Pierre Formation to the buff sandstones of the Fox Hills Formation has been recognized as gradational since the early work was done on the units. Meek (1876, p. xxxv-xxxvi) summarized the problem by saying that

> It the Fox Hills Formation is not separated by any strongly-defined line of demarkation from the Fort Pierre group below. . . indeed, it has sometimes been thought that we might, with almost equal propriety, on palaeontological grounds carry the line separating these two groups down so as to include in the Fox Hills group the upper fossiliferous beds of the Fort Pierre group. Most of the known facts, however, especially when we take into consideration the change of sediments at or near where we have always placed the line between these two rocks, seem to mark this as about the horizon where we find evidences of the most marked change of physical conditions.

At that time no definite statement was made with regard to the criterion used to determine the exact contact and it was simply placed above the lowest concretion layer. They did, however, suggest another possible placement of the contact below this layer. Fisher (1952, p. 9) defined the contact in Hanson County in relation to the lower concretion layers saying, "Where concretions are present the contact was placed at the top of that zone. These concretions are about two feet below the highest bentonite." This interpretation is not in accord with that of a committee of the Rocky Mountain Association of Petroleum Geologists (1932, p. 702-703) which concluded that the contact should be drawn at the ". . . horizon below which the section is predominately gray marine clay shales and sandy shales of Pierre

age, and above which the section changes rapidly to a buff to brown sandstone containing numerous gray to brown hard sandy concretions." Using the same general definition, Morgan and Petsch (1945, p. 10) noted that

> The interval between the top bentonite and the lowest concretionary layer varies from 3 to 25 feet. . . . When a decided lithological or color change appeared in this interval (usually an upward change from predominantly gray shale to more sandy material of yellow or buff tone) the Pierre Fox Hills contact was placed at this point. Where no apparent lithological change occurred in this interval the contact was assumed to be about intermediate between the topmost bentonite and the overlying concretionary layer.

They were unable to pick an exact contact and resorted to the base of the "bentonite" for structural mapping purposes. The "bentonite" discussed by Morgan and Petsch has since been shown (Waage, 1961, p. 233) to be jarosite, a hydrous iron sulfate which is dull yellow to yellow brown in color. It normally occurs as drusos of minute crystals which, combined with the dull lustre give the mineral an earthy appearance. Waage (1961, p. 232) solves this problem by designating the contact at the base of the jarosite (bentonite of Morgan and Petsch) in the same area. In Beaman Park the first occurrence of jarosite is ten feet below the lowest concretion layer. It then becomes more common until it forms persistent beds two to three inches thick above the lowest concretion layer.

The gradational nature of this contact by definition makes designation of an exact line of demarkation impossible. It is, however, advantageous to be able to select some arbitrary criterion, or set of criteria, which allow the field geologist to locate himself stratigraphically.

With this in mind, I have used the base of the first occurrence of jarosite to mark the base of the Fox Hills Formation in Emmons County. Not only is this consistent with the work presently being done in South Dakota, it is also extremely valuable in Emmons County where one can anticipate proximity to the contact, even in areas of poor exposures, merely by the presence of jarosite pods at the surface. Further, it restricts the occurrence of concretions to the Fox Hills Formation and leaves the Elk Butte Member as described--a sparsely fossiliferous unit.

Fox Hills Formation.--The Fox Hills Formation was named by Meek and Hayden (1862, p. 419, 427) for exposures in the Fox Hills in South Dakota. The location of the Fox Hills is the divide between the Cheyenne and Moreau Rivers, South Dakota (Meek and Hayden, 1862, p. 127). As the area named by Meek and Hayden does not provide a complete section of the formation, Waage (1961, p. 230) has redefined the type locality to include parts of Dewey, Corson, and Ziebach Counties, South Dakota. A composite section of the unit can be pieced together in this area. Since the naming of the formation, four members have been recognized, three of which are typically exposed in this area.

Trail City Member.--The lowermost member of the formation, the Trail City Member, was named by Morgan and Petsch (1945, p. 13) for exposures at Trail City, Corson County, South Dakota. They describe the unit as ". . . usually a sandy brown or buff clay near its base, becoming more sandy in its upper parts near the contact with the overlying Timber Lake sandstone member." Also mentioned are several layers of dense, blue limestone concretions with sandy "jackets".

These concretions are being studied in the type area by K. M. Waage (1962, oral communication) who has thus far been able to trace six concretion layers over a considerable part of the type area. The individual layers are identified not on lithology but on fossil content and have been so named. The term "zone" has been used (Waage, 1961) in reference to these layers but this is not in keeping with either the definition of d'Orbigny (1842) or that of Oppel (1856-1858). The more general term, layer, is used by the writer herein. The following concretion "zones" have been recognized by Waage (1961, p. 233-234):

1. The Discoasterbilina micelioti "zone" occurs 1-8 feet above the base of the formation and is characterized by an abundance of the ammonite D. micelioti. This layer, and the overlying Limopsis-Cervillia layer, have definitely been identified in North Dakota in Sneman Park near Linton.

2. The Limopsis-Cervillia "zone" crops out about 18 feet above the base of the unit and is distinguished on the presence of abundant Limopsis minuta-cumulatus and Cervillia recta.

3. The Protocardia "zone", 35-40 feet above the lower contact, contains abundant Protocardia subquadrata and Placenticeras meeki.

4. Two barren concretion "zones" occur above the Protocardia "zone". They are separated from each other by 10 feet; the lower of the two units lies 35-40 feet above the Protocardia layer. Lithologically, although they contain no fossils, the concretions of this layer appear to be composed of the same brittle, blue limestone as the concretions below.

5. The Discoscaphites gulosus "zone", containing D. gulosus, occurs near the top of the Trail City Member. This is the most discontinuous layer in the type area.

This, unfortunately, is not the entire picture. Waage (1961, p. 234) points out that the character of the concretions as well as their enclosing matrix changes laterally; therefore, correlation by any means other than direct tracing is difficult. Some of the fossiliferous concretion layers become barren as they are traced laterally while the enclosing matrix may change from sandy silt to sand. Further, the layers are not identified strictly on the basis of the fossils mentioned above. The names applied to the layers are merely taken from fossils in their zone. Occurrence of species of Discoscaphites, a genus presently being revised (Waage, 1962, oral communication), is important in making exact distinctions between layers. The contact of the Trail City Member with the overlying Timber Lake Member is designated (Waage, 1961, p. 234) as a thin bed of highly glauconitic sand.

Timber Lake Member.--The Timber Lake Member was named for exposures in and around Timber Lake, Dewey County, South Dakota (Morgan and Petsch, 1945, p. 15). The lower part of the unit consists of greenish-yellow, medium grained, friable or unconsented sandstone while the upper part is characterized by thin beds or stringers of orange to brown, well cemented, limonitic claystone in a matrix of buff sand. The presence of discontinuous, brown-weathering ledges of calcareously cemented sandstone makes at least the upper part of the unit readily distinguishable from the adjacent members. The Timber Lake becomes

finer grained as it is traced westward in the type area (Waage, 1961, p. 236). The fauna, characterized by an abundance of Placia linguaeformis and Echmocardiopsis lenticularis, occurs for the most part in punky, red-weathering, limestone concretions in the lower part of the member. Fossils in the upper Timber Lake are rarer than in the lower part of the member; species are generally restricted to the clam Inoceramus americanus and the supposed decapod crustacean burrow Halymenites major.

Notable in the upper Timber Lake Member are a number of calcareously cemented, sandstone ledges. In isolated outcrops the impression is gained that these harder sandstone layers would be easily traceable, but Morgan and Petsch (1945, p. 17) point out that "sandstones are often lenticular and change rapidly on strike, both as to thickness and lithologic character." This fact restricts their use as stratigraphic markers to very local areas.

Bullhead Member.--Overlying the Timber Lake Member is a sequence of interbedded olive-drab shales and thin sands named the Bullhead Member by Stevenson (1956) for exposures in the Bullhead Quadrangle, Corson County, South Dakota. The sequence had previously been referred to as the "Banded Beds" (Morgan and Petsch, 1945; Fisher, 1952).

Although paleontologic evidence indicates a definite marine origin for the two underlying members, proof of the environment of deposition of Bullhead sediments is scanty. Near the top of the member, sandstone becomes more prominent; and marine, or at least brackish water, fossils are found, including (Morgan and Petsch, 1945, p. 18) the oyster Ostrea glabra.

Colgate Member.--Capping the Fox Hills sequence in the type area is a fine to medium grained, dirty sandstone that has been correlated (Waage, 1961, p. 237) with the Colgate Member named by W. R. Calvert (1912) for exposures near Colgate Station, Dawson County, Montana. Although in its type area the Colgate is a readily traceable unit, its distribution becomes more patchy in Corson County, South Dakota.

Fox Hills in Ramona County.--In Ramona County, all four members described from the type area have been recognized in local outcrops. The lithology of the lowermost member is, however, different enough from that in the type area that differentiation between the Trail City and Timber Lake Members is often impractical. Wherever the Trail City Member can be recognized on the presence of limestone concretions, the matrix material is medium grained sand resembling lower Timber Lake lithology so that Fisher (1952, p. 10) suggested that the formation could more readily be subdivided in Ramona County into a ". . . lower series of green-gray and brown sands and sandstone, and an upper sequence consisting chiefly of thin gray and brown shales and sands, with several thicker sandstones." This type of subdivision places the Trail City and Timber Lake Members in a lower part of the Fox Hills and the Bullhead and Colgate Members in an upper part. Although the Trail City and Timber Lake Members can be identified in local outcrops on the basis of presence or absence of limestone concretions and claystone stringers, lack of topographic control or extensive outcrops in the area makes lateral tracing of beds or concretion layers impossible. Pleistocene deposits and intense farming make it impractical to identify member lithologies except where actual

exposures are available and, even then, such identification is difficult as stated above.

The factor that most strongly speaks for a twofold division of the Fox Hills in Emmons County is the lithologic change from the type area to Emmons County. Although Fisher (1952, p. 12) stated that "no recognizable beds of these members Trail City and Timber Lake were found east of Range 78 West . . .", the finest outcrop of the lower Fox Hills is in Seeman Park, in Range 76 West. At this locality both the _D. nicolleti_ and _Limopsis-Gervillia_ concretion layers crop out. Their relation to the Pierre-Fox Hills contact is similar to that described for the type area. The lowest occurrence of jarosite is 7-10 feet below the _D. nicolleti_ concretion layer and is separated from it by brownish, jarosite rich, silty shale. Above the _D. nicolleti_ layer, however, the shale is rapidly replaced by buff, medium grained sand that has the same appearance as the sand of the lower Timber Lake Member in the type area.

This can be interpreted in one of two ways. Either the Trail City Member retains its approximate thickness but becomes coarser grained north of the type area, or the Trail City Member thins to about 12 feet at Linton and the _Limopsis-Gervillia_ concretion layer at Seeman Park, North Dakota, is in the Timber Lake Member. Considering the variable lithology of the Fox Hills Formation throughout its area of outcrop (Waage, 1961, p. 229) it seems more reasonable to conclude that the Trail City Member becomes coarser north of the area in which it was originally described, and that the _Limopsis-Gervillia_ layer is in the Trail City. This uncertainty, however, further strongly suggests

that the lower two members of the type area in South Dakota should be treated as a single unit in North Dakota.

Concretion layers have been found in several localities in Emmons County but, at present, their stratigraphic position in the formation is unknown. Neither lithology nor fauna have served to place these higher concretion layers in the section. The lithology of all the concretions above the D. nicolletti layer is fairly uniform; and, at almost every locality collected, the fauna is different so that concretions will have to be found in vertical sequence before their relationships can be deciphered.

Thickness of the Fox Hills in Emmons County is questionable. Fisher (1952, p. 16) reports a thickness of 325 feet in the southwest corner of the county, an area in which the formation has been eroded away above the lower Fox Hills, and 196 feet in the vicinity of Linton, where the Fox Hills-Hell Creek contact is not exposed within a radius of 10 miles. Hence, both of these thicknesses, although called "measured sections" by Fisher, should probably be considered estimates. In T. 131 N., R. 78 W. both the Fox Hills-Hell Creek contact and a concretion layer in what appears to be lowermost Fox Hills are exposed. The upper contact, exposed at two localities with a horizontal separation of 1½ miles, shows vertical relief of 120 feet, probably due to pre-Hell Creek erosion. Total thickness of the formation, in this township may be as little as 268 feet or as much as 388 feet. These figures, obtained with a Paulin altimeter, have not been adjusted for structure as no reliable structural datum exists in the area.

The contact between the Fox Hills Formation and the overlying Hell Creek Formation is one of disconformity in Ramsey County. This contact is exposed in only a few places; the best exposures are in the NW¼, Sec. 8, T. 134 N., R. 78 W. and NE¼, Sec. 19, T. 131 N., R. 78 W. As is conventionally done (Waage, 1961, p. 237), the contact is picked at the base of the lowest conspicuous lignite or lignitic shale. In the exposures available in Ramsey County, Colgate lithology everywhere underlies this lignite. The accompanying vertical section (Fig. 5) represents as complete a section of the Fox Hills Formation in Ramsey County as it is possible to compile at this time.

Correlation.--The classic correlation (Stephenson and Reeside, 1938) of the Fox Hills Formation is with the Lennep Sandstone in central Montana and the upper part of the Navarro Group in Texas. Further correlation (Gabbun and Reeside, 1952) with the Lance, Pierre, and Medicine Bow Formations in Wyoming and the Laramie Formation and Mesaverde Group in Colorado has been made. However, recent work, summarized by Jeletzky (1962), indicates that the Fox Hills varies in age from lowermost Maestrichtian in eastern Wyoming to the lower part of the upper Maestrichtian in North Dakota and South Dakota. This makes the Fox Hills Formation in Wyoming a time equivalent of the upper Pierre Formation of North Dakota. The cephalopod fauna in Ramsey County is composed almost entirely of Discoscaphites sp. and Scheonditeuthis sp.; Baculites sp. is not present, nor is the clam Inoceramus sp. This indicates that the formation in Ramsey County is at least as young as the upper part of the lower Maestrichtian and is probably upper Maestrichtian for the most part. Further work on the taxonomy of the Cephalopods in Ramsey County must be done before more accurate correlations than these mentioned above can be made.

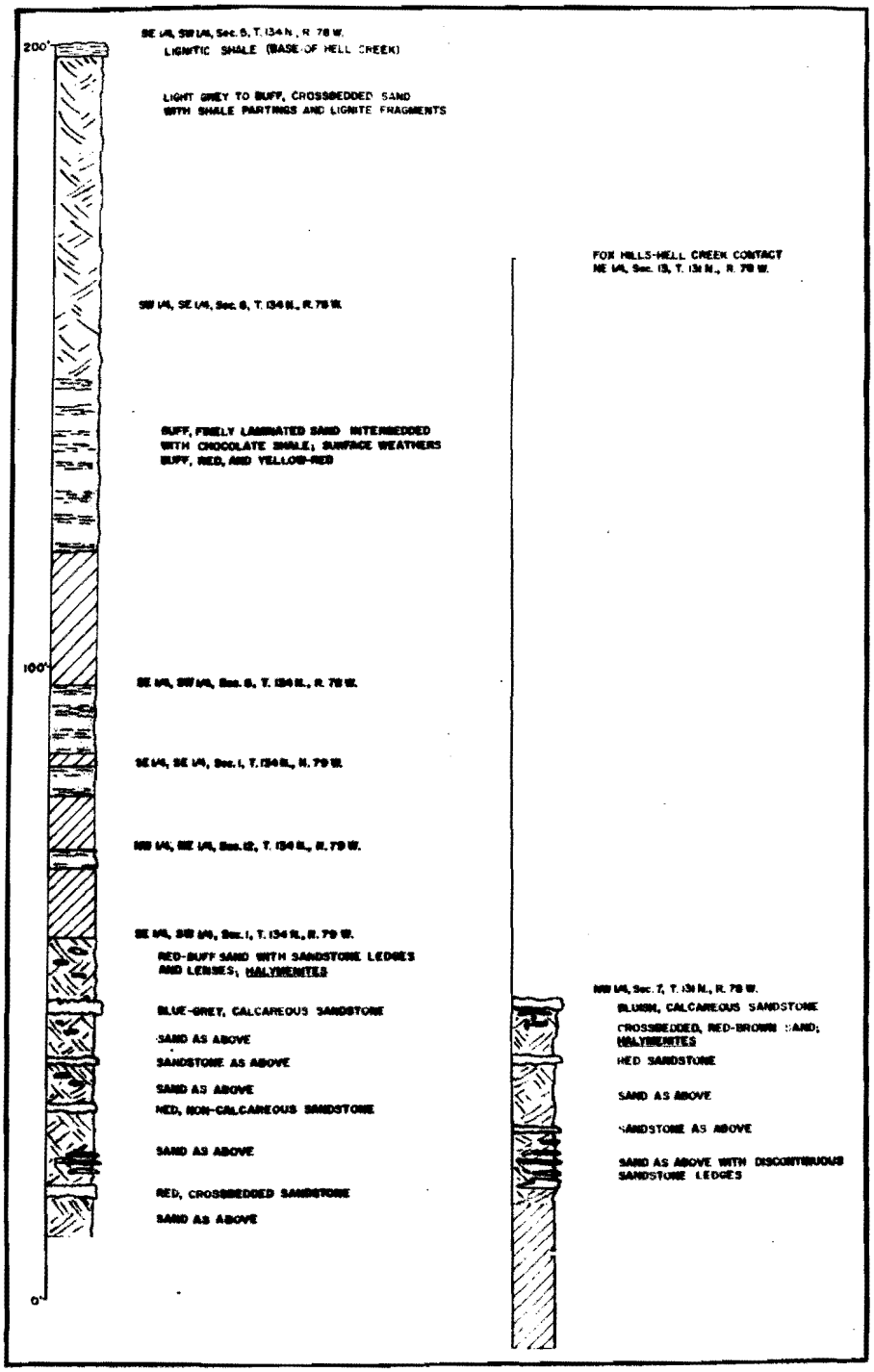

Fig. 5. Stratigraphic section of the Fox Hills Formation in Emmons County. The data was obtained from measured sections and represents as complete a section as can be pieced together in the county.

Occurrence.--As discussed above, fossils in the lower Fox Hills in Lemmons County are restricted almost exclusively to concretions. Fifteen localities were discovered in which pelecypod bearing concretions occurred in place. The only pelecypod that was commonly encountered free in the matrix was Inoceramus americanus. Fragments of this animal were collected at numerous localities throughout the county.

The most difficult feature of fossil occurrence is the presence of highly fossiliferous concretions, predominately calcareous, in a sparsely fossiliferous, non-calcareous matrix. Several alternative explanations are possible. High concentrations of animals could have, upon death, acted as centers about which more calcium carbonate was deposited. This does not, however, explain those concretions in which no trace of fossil material is found. Another possibility is that the only animals that were preserved were those about which limestone was deposited. In other words, those animal masses that, for one reason or another, did not act as centers of carbonate deposition were subsequently leached out of the matrix. This theory is weakened by the presence of unfossiliferous concretions as well as the presence of excellently preserved fragments of Inoceramus americanus which show no evidence of leaching.

A third, and much more plausible, explanation is that the masses formed in a manner similar to that described by Graham (1960, p. 711-712) for the origin of "clay boulders." Graham describes this process in action in the modern day along the coast of Scotland where fragments of glacial clay are broken from cliffs, rolled about by waves, and

finally deposited in a more stable environment. During the process, pebbles of foreign material are incorporated into the rolling mass. Walther (1894, p. 847) and Frass (1872, p. 277) describe a similar process in which fine grained material deposited along the Red Sea during high tide was dried, fragmented and later rolled about. The resulting structure was similar to that described by Grabau in Scotland.

This description adequately explains the nature of Fox Hills concretions. Lithologically, they are composed of a dense, structureless limestone core that may or may not contain fossils. Surrounding the core is a "jacket" of partially cemented medium sand with a composition similar to that of the matrix. Occasionally the fossils in the concretions show evidence of having been transported while in the concretion. Edges of shells near the periphery of the structure are often worn and broken while those in the interior show no signs of attrition.

It is probable, then, that these concretions formed at, or very near, the strand line of the Fox Hills sea by wave agitation. As they were rolled about, some of them incorporated animals. Eventually they rolled out of the area of formation into an environment of low enough energy that they could come to rest.

Whether the site of deposition was near or far from the area of formation cannot be demonstrated at this time. It is also difficult to state conclusively that the original mud forming the concretion was as highly calcareous as the masses are at present; although, if the carbonate was secondary, limestone deposition as cement in the matrix material might be expected. If the limestone was primary, the term

concretion (in the strict sense) is perhaps inappropriate; however, before they are referred to as accretions a thorough petrographic study should be made.

Collection and processing.--Bulk collections of concretions were made only after field work had progressed to the point that some evaluation of stratigraphic position could be made. Prior to making the collections I visited the type area of the Fox Hills formation where, under the leadership of Dr. K. N. Waage, the layers as noted by Morgan and Petsch (1945) and described by Waage (1961) were examined. Lack of Pleistocene cover made tracing the layers in the type area easier. The fossil fauna in the type area is apparently much like that noted in Emmons County.

Collections were made in Emmons County and notes on lithology of the concretions and matrix were taken; they have so far yielded no clue as to the exact stratigraphic position of the various layers. Some of the masses were broken in the field; however, it was noted that many specimens were destroyed in the process. Most of the material was brought back as bulk samples to be processed in the laboratory.

Several techniques were tested to extract the fossils from the enclosing stone without destroying specimens. None was wholly successful. Having tried an acid bath, dental drill, and ultrasonic cleaner, it was concluded that patient work with a small hammer and chisel was most efficient although many specimens were lost in the process. Once the specimens were removed from the concretions a dental drill and an ultrasonic bath were used to further clean the specimens in preparation for study and photography. Specimens to be photographed were whitened with ammonium chloride vapor.

Localities.--Fifteen localities provided specimens for the present study, each of which represents only one stratigraphic horizon. To reduce repetition in the systematic descriptions, the localities are listed below, with an index number that will be repeated in the description of each species.

3-0-1. Trail City (?) lithology in a road cut, east side of road, SE¼, Sec. 7, T. 129 N., R. 78 W., Emmons County, North Dakota.

3-0-4. Trail City (?) lithology on top of hill overlooking new road, NE¼, Sec. 18, T. 129 N., R. 78 W., Emmons County, North Dakota.

3-0-2. Trail City (?) lithology in stream cut on east side of road, NW¼, Sec. 33, T. 130 N., R. 78 W., Emmons County, North Dakota.

3-0-7. Trail City lithology at base of road cut, SW¼, NW¼, Sec. 3, T. 130 N., R. 78 W., Emmons County, North Dakota. This locality is about 20-25 feet higher stratigraphically than locality 3-0-2.

3-0-7A. Trail City (?) lithology at same locality as described for 3-0-7. The concretions at this locality occur about five feet higher than those described from locality 3-0-7.

3-1-2. Trail City (?) lithology in road cut, east side of road, NE¼, Sec. 12, T. 131 N., R. 78 W., Emmons County, North Dakota.

3-1-3. Timber Lake (?) lithology at top of small stream valley, tributary to Little Beaver Creek, NW¼, Sec. 7, T. 131 N., R. 78 W., Emmons County, North Dakota. At this locality the concretions were ferruginous rather than calcareous.

7-3-7. Trail City (?) lithology in ditch, north side of road at corner where road turns north, SE Cor., Sec. 27, T. 133 N., R. 77 W., Emmons County, North Dakota.

7-4-2. Timber Lake (?) lithology in ditch, north side of road, SE¼, SW¼, Sec. 35, T. 134 N., R. 77 W., Emmons County, North Dakota.

6-9-1. Trail City (?) lithology, SW¼, Sec. 2, T. 129 N., R. 76 W., Emmons County, North Dakota.

6-2-3. Lower concretion layer at base of Fox Hills, Trail City (?) lithology, SW¼, Sec. 17, T. 132 N., R. 76 W., Seeman Park, SE of Linton, Emmons County, North Dakota.

6-2-9. Trail City (?) lithology about 10-15 feet above base of Fox Hills Formation, at top of hill at east edge of dump grounds NW of Linton, SW¼, Sec. 6, T. 132 N., R. 76 W., Emmons County, North Dakota.

6-2-14. Second concretion layer, approximately 15 feet above base of Fox Hills Formation, Trail City (?) lithology, SW¼, Sec. 17, T. 132 N., R. 76 W., Seeman Park, SE of Linton, Emmons County, North Dakota.

6-3-6. Timber Lake (?) lithology in road cut, east side of road, SW¼, Sec. 27, T. 133 N., R. 76 W., Emmons County, North Dakota.

Measurements.--Each of the species descriptions is followed by a series of measurements which, where applicable, include length, height, thickness, and hinge length. All dimensions are taken to be maximum along the given axis. Length is herein defined as the greatest length measured parallel to the hinge line or the hinge extremities if the hinge is curved. Height is the greatest height measured in the plane of commissure, perpendicular to the hinge line. Thickness is the greatest thickness measured perpendicular to the other two axes. Measurements of thickness are, except where otherwise stated, measured across both valves. Hinge length is a straight line distance between the extremities of the hinge. The only other measurement used herein is

[redacted] height which is the distance from the beak to the furthest point of the posterior border.

Paleoecology.--The fossils from the Fox Hills Formation indicate that at the time of burial the area in question was the site of a cool, shallow sea. The strand line probably lay a short distance east of [redacted] County.

That the environment was marine is readily demonstrated by the abundance of cephalopods and scaphopods in the fauna. Water depth and temperature are a bit more vague. If the Navarro Group is time correlative with the Fox Hills Formation, a comparison of faunas can be made that indicates cool water. Two general lines of evidence are available. Bergman's Rule (Allee, et al., 1949, p. 119) states that shelled invertebrates tend to be larger in warmer water. Although this is an empirical rule it is probably true generally. Visual, non-quantitative inspection of the fauna of the Navarro Group as illustrated by Stephenson (1941) indicates that the pelecypods and gastropods from his study are generally larger than those in the Fox Hills Formation. Secondly, it has been observed (Lochman, 1957, p. 134) that larger numbers of genera and species inhabit warm temperate and tropical water than cooler water. The Nacatoch Sand, a unit in the Navarro Group which is similar, lithologically, to the Fox Hills, contains 136 species of Pelecypods while only 25 species were noted by the writer from the Fox Hills Formation. These two bits of evidence are further fortified by the observation (Kriesland, 1962, oral communication) that the scaphite fauna of the Fox Hills is quite similar to that of Greenland while it is distinct from that of the Gulf Coast.

Water depth may be deduced from the type of sediments as well as one member of the fauna, Halymenites major. When Halymenites was named by Lesquereux, it was considered an algae, an interpretation that has persisted until work by Hayasaka (1935) pointed out their similarity to Recent neritic decapod crustacean burrows. H. major occurs in the form of anastomosing tubes composed of medium to coarse grained sand grains cemented by limonite. They are more resistant to erosion than the matrix material and are often found nearly covering an outcrop. Their surface is knobby suggesting that they were formed as a number of discrete spheroidal masses. As discussed in the section on Fox Hills stratigraphy, the formation is composed primarily of cross-bedded sand and sandstone. This type of sedimentation would not be expected if the sediments were deposited below wave base. The presence of Halymenites is even more restrictive. Recent decapod burrows have been observed (Hayasaka, 1935) that open at the surface as much as 40 cm. above sea level. If this was the case in the Cretaceous forms, they offer an excellent index to the position of the strand line at the time of their formation. As indicated above, concretions were probably being deposited a short distance offshore.

The gross structural picture of the Fox Hills Formation has not been thoroughly worked out; however, it appears to represent the shoreline and nearshore facies of the retreating Cretaceous seaway. Further work with the Pierre, Fox Hills, Bell Creek, and Cannonball Formations and their stratigraphic relationships is necessary before a final statement can be made in this regard.

CONCLUSIONS

On the basis of the work thus far completed on the Fox Hills Formation, several conclusions can be drawn:

1. To maintain a consistent usage of the definition of the contact between the Pierre and Fox Hills Formations from the type area in South Dakota to Emmons County, North Dakota, the contact should be placed at the first occurrence of jarosite below the lowest concretion layer.

2. The concretion layers, as defined by Waage (1961) in the type area, cannot definitely be placed in stratigraphic sequence in Emmons County at this time due to difficulties in tracing stratigraphic horizons.

3. Thickness of the Fox Hills Formation in Emmons County is 250-350 feet, where measureable.

4. Lower Fox Hills concretions were probably formed as "mud balls" in a relatively high energy environment and were transported to their site of deposition, a lower energy environment.

5. The Fox Hills Formation probably represents the shoreline and nearshore facies of the retreating Midcontinent Cretaceous seaway.

6. Due to northward coarsening of the lower Fox Hills sediments, it is impossible in many cases to distinguish between the Trail City and Timber Lake Member lithologies in Emmons County. At this time, therefore, it seems best to divide the formation in Emmons County into upper and lower parts and to avoid using member terminology in the strict sense.

7. Twenty-two species of pelecypods were collected and described from the Fox Hills Formation in Emmons County. Gastropods, cephalopods, and scaphopods were also collected but were not described.

3. Future work on the Fox Hills Formation in North Dakota should include tracing the formation into adjacent areas, attempting to trace the members from the type area in South Dakota into North Dakota, and identifying and studying the remainder of the rich molluscan fauna. Such work would shed considerable light on the history of deposition and on the paleoecology of the unit.

SYSTEMATIC PALEONTOLOGY

The pelecypods described herein were identified using Meek (1876) as a basic reference. Stephenson (1923, 1941) and Richards (1958, 1962) were also frequently consulted. Names of taxa above the family level are those of Thiele (1935) while family assignments are those of Stephenson (1941) and Richards (1958). No new names are proposed in this work.

In general, the descriptions of species in Meek (1876) are quoted. Many of the animals covered in this work have not been considered from a taxonomic standpoint since that time; in all cases his descriptions are both modern and succinct. Additional information concerning description and occurrence of the specimens collected in Emmons County is given in the discussion following each description.

Phylum MOLLUSCA

Class PELECYPODA

Order TAXODONTA

Superfamily NUCULACEA

Family NUCULIDAE

Genus Nucula Lamarck 1799

Nucula planimarginata Meek and Hayden 1856

Plate 1 Figures 4-5

Nucula planimarginata Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 85.

Nucula planimarginata Meek and Hayden, Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 101, pl. 15, fig. 8.

Nucula planimarginata Meek and Hayden, Stanton, 1920, U. S. Geol. Survey, Prof. Paper 128, p. 19, pl. 1, figs. 2-3.

Nucula planimarginata Meek and Worthen, Shimer and Shrock, 1944, p. 375, pl. 145, fig. 35.

Meek (1876, p. 101) described the species thus:

> Shell transversely subovate or subelliptic, compressed; posterior or shorter side obliquely truncated above, and abruptly rounded or subangular below the middle; anterior or longer side cuneate and rather narrowly rounded; base forming a regular semi-elliptical curve, not crenate within; dorsum declining gently with a gradual convex curve, from near the beaks to the anterior extremity; beaks small, incurved, nearly contiguous, and located about half way between the middle and the posterior side; surface marked by very fine, irregular, radiating, and minute concentric striae; hinge forming at the beaks an angle of about 110°, having in the adult some twenty-six or twenty-seven dentiles on the longer or anterior side of the beaks, and about ten behind, in each valve; lunule-like area behind the beaks lanceovate, flattened along each side, and a little convex in the middle.

Discussion.--Individuals of this species were found at only one locality. One of the three specimens collected was found free in the matrix

while the other two were extracted from a concretion. Shell material was present only on the isolated specimen; however, both shell and mold of the interior displayed the characteristic features of the species including smooth ventral margin. Near the anterior margin, where the outer layer of shell material has been eroded away, concentric striae are visible on one of the inner laminae. These striations are not expressed on the inner or the outer surface of the valve.

Measurements.--The figured specimen, right valve only, had the following measurements:

USD Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9202	20.0	16.9	9.2

Repository.--Univ. of S. Dak. Cat. Nos. 9202 (right valve), 9261 (unfigured specimen).

Locality.--S-1-2; Trail City (?) lithology in the lower Fox Hills Formation.

Nucula cancellata Meek and Hayden 1856

Plate 1 Figures 31-33

Nucula cancellata Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 85.

Nucula cancellata Meek and Hayden, 1876, U. S. Geol. Survey Terr., v. 9, p. 102, pl. 28, fig. 13.

Nucula (Leptonucula) cancellata Meek and Hayden, Ehlmer and Sprock, 1904, p. 375, pl. 145, fig. 30.

Meek (1876, p. 102) described the species thus:

> Shell transversely ovate-subtrigonal, rather gibbous; posterior or shorter side obliquely truncated above, and subangular below, the middle; anterior or longer side a little

more rounded at the extremity; basal margin semi-elliptical or semi-oval in outline, neatly crenulate within; dorsum declining with a gently convex outline in front of the beaks, and sloping more abruptly behind; lunule-like area behind the beaks obovate, flattened, or a little concave, and bounded on each side by a very slight ridge; escutcheon-like area in front of the beaks lance-ovate and moderately well defined; beaks rather gibbous, incurved, nearly touching, and located a little nearer the middle than the posterior side; surface marked by numerous small, regular, simple, radiating striae, which are broader than the linear depressions between, near the lower border, and crossed on all parts of the valves by smaller, more irregular, concentric costae, so as to form a neat sub-cancellate style of sculpturing; hinge thick, forming an angle of near 120° at the beaks, and provided with about seventeen to nineteen teeth in front, and about twelve behind the beaks, in each valve of an adult.

Discussion.—This species is readily distinguished from N. glandmarginata in that the former has a finely serrate ventral margin and tends to be more elongate. It is most closely related (Meek, 1876, p. 103) to N. pectinata which has larger costae and a deeper lunule than N. cancellata. This similarity with N. pectinata probably explains the assignment by Stiner and Burock (1943, p. 375) of N. cancellata to the subgenus Pectinucula Cuenstedt 1930 (Geol. Pal. Abh., N.F. , v. 18, no. 1, p. 112, non vise).

Measurements.—The figured specimen, a mold of the interior, has the following measurements:

UND Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9203	17.3	12.3	10.2

Repository.—Univ. of N. Dak. Cat. Nos. 9203 and 9204 (figured hypotypes), 9262-9263 (4 unfigured specimens).

Localities.—S-1-2 and S-9-4. Trail City (?) lithology in the lower Fox Hills Formation.

Family NUCULANIDAE

Genus Yoldia Moeller 1842

Yoldia scitula (Meek and Hayden) 1856

Plate 1 Figures 6-11

Nucula scitula Meek and Hayden, 1856, Acad. Nat. Sci., Philadelphia, Proc., v. 8, p. 84.

Leda scitula (Meek and Hayden), Meek and Hayden, 1860, Acad. Nat. Sci. Philadelphia, Proc., v. 12, p. 135 fide Meek, 1876, p. 110 .

Leda (Yoldia) scitula (Meek and Hayden), Meek and Hayden, 1860, Acad. Nat. Sci. Philadelphia, Proc., v. 12, p. 428 fide Meek, 1876, p. 110 .

Yoldia scitula (Meek and Hayden), Meek, 1876, U. S. Geol. Survey Terr., p. 110, pl. 26, fig. 9.

Yoldia scitula (Meek and Hayden), Stanton, 1920, U. S. Geol. Survey, Prof. Paper 128, p. 21, pl. 1, fig. 9-10.

Yoldia scitula (Meek and Hayden), Shimer and Shrock, 1944, p. 379, pl. 146, fig. 42.

Meek (1876, p. 110) described the species thus:

> Shell transversely subovate, gibbous in the central and umbonal regions; anterior extremity rather narrowly rounded; posterior side narrower and more compressed, subangular or very narrowly rounded in outline, the most prominent part being above the middle; base forming a semiovate curve, sometimes very slightly sinuous near the middle; dorsum declining from the beaks; cardinal border of each valve having a distinct marginal groove behind the beads, which forms, when the valves are united, a lanceolate, escutcheon-like depression; beads rather obtuse, not oblique, placed a little in advance of the middle; surface marked by regular, fine, distinct, concentric lines, which are nearly equal to the grooves between, and more strongly defined on the middle than toward the extremities of the valves.

Discussion.--The specimens collected in the present study resemble those described by Meek that there is no doubt that they are members of the same species. At locality 8-9-4, several small concretions were collected that contained vast numbers of this species, almost to the exclusion of other species. Their preservation in the limestone masses made extraction difficult; but, several excellent specimens of articulated valves and molds of the interior were obtained. In other localities in the county they occur as minor constituents of the fauna.

Measurements.--The figured specimens have the following measurements:

USNM Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9205	8.4	4.6	4.0
9206	7.5	5.0	3.9
9207	8.7	4.7	4.0

Hypotypes.--Univ. of N. Dak. Cat. Nos. 9205-9207 (figured hypotypes), 9264-9267 (unfigured specimens).

Localities.--8-9-4, 8-1-3, 7-3-7, and 8-1-2. Timber Lake (?) and Trail City (?) lithology in the lower Fox Hills Formation.

Genus Nuculana Link 1807

Nuculana bimulcata (Meek and Hayden) 1861

Plate 1 Figure 12

Leda bimulcata Meek and Hayden, 1861, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 440.

Nuculana bimulcata (Meek and Hayden), Meek, 1864, Smithsonian checklist Cretaceous Foss. N. Am., 3 [fide Meek, 1876, p. 104] .

Nuculana bimulcata (Meek and Hayden), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 104, pl. 15, fig. 4.

(1876, p. 104) described the species as follows:

> Shell small, transversely subovate, rather gibbous in the central region; anterior side narrowly rounded or subangular above the middle; base nearly semi-elliptic, with a very slight sinuosity near the posterior extremity; posterior end compressed, narrow, and subangular in outline above the middle; obtuse, placed slightly in advance of the middle; posterior umbonal slopes distinctly angular, the angles extending from the beaks along very near the dorsal margin, to the upper part of the subangular extremity, where they terminate in a small fold bordered below by an obscure, oblique sulcus; escutcheon lanceolate, concave along the middle, and strongly defined by the umbonal angles, just within which there is, on each side, a narrow, well-defined sulcus, extending from the beaks to the posterior extremity of the shell; lunule not defined; surface ornamented by small, rather distinctly-elevated, regularly-arranged, concentric striae.

Discussion.--During dissection of concretions from locality S-1-2, three fragmentary interior molds were discovered which, on casual observation, appeared to be members of the genus Yoldia. Subsequent study of the specimens revealed no evidence of a pallial sinus, a characteristic of the genus Nuculana. Meek (1876, p. 103) suggests that the best means of distinction are the nature of the resilifer and the configuration of the pallial line and points out the similarity in shape between Yoldia and Nuculana. His specimens of Nuculana bisulcata were restricted to exteriors of shells while molds of the interior are all that is available in the present study. Nevertheless, the general outline of the shell and the simplicity of the pallial line on the specimens in question readily typify them as N. bisulcata.

Measurements.--The figured specimen has the following dimensions:

UMD Cat. No.	Length (mm)	Height (mm)
9212	6.4	4.2

All other specimens of this species are broken, some to the point that their generic assignment is in question. They were not measured.

Repository.--Univ. of N. Dak. Cat. No. 9212 (figured hypotype), 9268-9269 (unfigured specimens).

Locality.--3-1-2. Trail City (?) lithology in the lower Fox Hills Formation.

Superfamily ARCACEA

Family CUCULLAEIDAE

Genus Cucullaea Lamarck 1801

Cucullaea shumardi Meek and Hayden 1856

Plate 1 Figures 24-30

Arca (Cucullaea) shumardi Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 96.

Cucullaea shumardi (Meek and Hayden), Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia Proc., v. 8, p. 295.

Cucullaea fibrosa (Meek and Hayden), Meek and Hayden, 1860, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 428.

Cucullaea (Idonearca) shumardi (Meek and Hayden), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 96, pl. 28, fig. 15, pl. 29, fig. 4.

Cucullaea shumardi (Meek and Hayden), Stanton, 1920, U. S. Geol. Survey, Prof. Paper 128, p. 22, pl. 2, fig. 1.

Cucullaea shumardi (Meek and Hayden), Morgan and Petch, 1945, S. Dak. Geol. Survey, Bept. Invest. 49, pl. 5, fig. 4, no. 1.

Cucullaea shumardi (Meek and Hayden), Fisher, 1952, S. Dak. Geol. Survey, Bull. 26, pl. 6, fig. 5.

Meek (1876, p. 86) gives the following description of the species:

> Shell transversely rhombic-oval, very slightly inequivalve, entirely closed, rather thin; anterior margin rounded, sometimes intersecting the hinge above so as to form an obtuse angle, rounding more or less obliquely into the base below; basal margin semi-ovate in outline, the most prominent part being behind the middle, not crenulate within; posterior side obliquely truncated above, and narrowly rounded below; hinge less than three-fourths the entire length of the shell; cardinal area rather narrow, marked by very fine longitudinal striae, and about four strong, oblique, divaricating grooves; beaks gibbous, moderately elevated, incurved nearly at right angles to the cardinal line, and located slightly in advance of the middle. Surface marked by concentric striae, which are crossed on young shells by small, obscure, radiating costae, which become nearly or quite obsolete on adult specimens.

Discussion.--Considerable difficulty was encountered in distinguishing between C. shumardi and the related species C. nebrascensis Owen. Meek (1876, p. 89) points out that the latter can be "readily distinguished on its longer hinge area, thicker shell, and more oblique form." Making separations on the three characters independently, however, invariably led to different groupings. Hinge characteristics were most carefully studied and in none of the specimens were as few as four divaricating grooves, mentioned by Meek as typical of C. shumardi, found. Nor were any specimens found which had eight or more divaricators, typical of C. nebrascensis.

Length, thickness, slant length, and hinge length were measured on all 24 specimens of the genus collected from locality S-O-2 to test shape. To minimize the effect of size, ratios of length versus hinge length and length versus slant length were computed and coefficients of variability were calculated for the two ratios. A value of V = 29.4 was obtained for the ratio of length to hinge length while the ratio of length to slant length resulted in a V of 4.21. The latter value is an

expectable variability for a homogeneous group, indicating that if there were two species present the character analyzed would not distinguish between them. The value obtained from the ratio of length to hinge length indicates either that the character analyzed is too variable to be of taxonomic value or that the sample is not homogeneous. A frequency histogram of the ratios showed no natural break; therefore, I conclude that if there is a significant shape difference between the two species in question more than twenty-four specimens would be required to test it. As the shape of the hinge and the general outline more closely approximate C. shumardi than C. nebrascensis the specimens are referred to the former species.

Measurements.--Mean values of the length and thickness of the specimens collected at locality S-O-2 were computed. Mean length of twenty-six specimens was 40.4 millimeters while mean thickness of twenty-one specimens was 31.3 millimeters. Height could not be measured in most cases as a result of breakage, especially in the area of the beaks. The figured specimens have the following measurements:

UND Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9208 mold of the interior	46.2	39.5	35.6
9209 mold of the interior	43.9	39.4	35.9
9210	45.0	38.0	
9211	39.6	34.9	34.3

Hypotypes.--Univ. of N. Dak. Cat. Nos. 9208-9211 (figured hypotypes) 9270 (measured series), 9271-9274 (unfigured specimens).

Localities.--3-0-2, 3-1-2, and 3-0-7. Trail City (?) lithology in the lower Fox Hills Formation.

Family GRAMMATODONTIDAE

Genus Nemodon Conrad 1869

Nemodon sulcatinus (Evans and Shumard) 1857

Plate 1 Figures 1-3

Area sulcatina Evans and Shumard, 1857, Acad. Sci. St. Louis, Trans., v. 1, p. 39.

Nemodon sulcatinus (Evans and Shumard), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 82, pl. 15, fig. 6.

Nemodon sulcatinus (Evans and Shumard), Shimer and Shrock, 1944, p. 379, pl. 136, fig. 44.

Meek (1876, p. 82-83) described the species as follows:

> Shell small, transversely rhombic-trapezoidal, about half as high as long; beaks rather depressed, and placed a little in advance of the middle, incurved and somewhat distant; posterior umbonal slopes oblique, prominent or sub-angular; cardinal margin straight, equaling about five-sixths the length of the valves; basal margin parallel to the dorsal, nearly straight, or more or less sinuous near the middle; anterior margin rounding up a little obliquely, so as to intersect the hinge above at slightly less than a right angle; posterior margin truncated from the abruptly-rounded or subangular posterior basal extremity, a little obliquely forward and upward, with a slightly sinuous outline, so as to connect with the end of the hinge at rather more than a right angle; cardinal area unknown; free margins finely crenate within; internal casts showing a broad, deep sulcus starting from each beak, and descending, with a slight backward obliquity to the most sinuous part of the base. Surface with radiating striae.

Discussion.--The description and the illustration in Meek well characterize the specimens collected in this study, as does a description

by Julia Gardner (Wade, 1926, p. 42) in a discussion of Meekopsis sufaulensis (Gabb) 1860, a name that has been widely applied to specimens from the Gulf Coast and the Eastern Seaboard (Stephenson, 1941, p. 83; Richards, 1958, p. 79). The specimens collected in this study are molds of the interior and on only one specimen is any shell material preserved. This is unfortunate because Evans and Shumard (Meek, 1876, p. 83) describe the prosopon of M. subglobosa as consisting of " . . . 18 to 20 radiating striae, with accessory ones in the intervals." while M. sufaulensis has prosopon of 40-50 radial threadlets (Wade, 1926, p. 42). Not enough shell material is present on any of the specimens to make a definite distinction between the two types, but if the density of striae seen on the fragment was to persist across the shell, the number of striae would greatly exceed 20. Until good shell material is discovered the specimens might well be assigned either to M. subglobosa or M. sufaulensis with equal propriety. They are here assigned to the former species on geographic, not biologic grounds.

Measurements.—The figured specimens have the following measurements:

USD Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9200	12.3	7.9	5.2
9201	11.0	6.5	5.0

Thickness measured on specimen No. 9201 includes the shell material attached to the mold. With this exception, all measurements are of molds of the interior.

Specimens.—Univ. of N. Dak. Cat. Nos. 9200 and 9201 (figured specimens), 9275 (2 unfigured specimens).

Locality.--6-2-3. Trail City (?) lithology in the lower Fox Hills Formation.

Family LIMOPSIDAE

Genus Limopsis Sassi 1827

Limopsis parvula (Meek and Hayden) 1856

Plate 2 Figures 38-39

Pectunculina parvula Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 86.

Limopsis parvula (Meek and Hayden), Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 285.

Limopsis parvula (Meek and Hayden), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 97, pl. 23, fig. 17.

Meek (1876, p. 97) gave the following description of the species.

> Shell very small, obliquely rhombic-subovel, moderately compressed; anterior side rounded, usually a little more prominent above than below; base forming a rather broad curve, sometimes nearly straight in the middle; posterior side obliquely truncated above, and more or less narrowly rounded below; pallial margin faintly crenulate within; hinge somewhat arched on the inside, generally equalling nearly half the length of the shell, and provided with three or four teeth on each side of the small triangular pit for the reception of the ligament; cardinal area small but well defined; beaks moderately elevated, pointed, and incurved at right angles to the hinge, located slightly in advance of the middle. Surface marked by fine lines and occasional stronger marks of growth, crossed by exceedingly obscure, fine radiating, subpunctate striae, which are usually nearly or quite obsolete on the anterior part of the shell.

Discussion.--Although this species is extremely common in the type area of the Fox Hills (Mapes, oral communication), Beaman Park was the only locality in Emmons County from which specimens were collected. At this locality they did not comprise a large part of the fauna as they do

in the type area, but were vastly outnumbered by another small pelecypod, Protocardia subundata which is distinguished from L. parvula on the presence of a crenulate posterior margin. The specimens identified as L. parvula diverge from Meek's description only in regard to size. Meek (1876, p. 97) stated that typical specimens are about .25 inches long while those found at Beaman Park range in size one-third to two-thirds inch long.

Measurements.—The specimen illustrated has the following dimensions:

USD Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9213	9.9	8.4	5.8

Repository.—Univ. of N. Dak. Cat. No. 9213 (figured specimen), 9276 (17 unfigured specimens).

Locality.—6-2-14. Trail City (?) lithology in the lower Fox Hills Formation.

Order ANISOMYARIA

Superfamily MYTILACEA

Family MYTILIDAE

Genus Volsella Scopoli 1777

Volsella calvinianus (Evans and Shumard) 1854

Plate 1 Figures 14-16

Mytilus calvinianus Evans and Shumard, 1854, Acad. Nat. Sci. Philadelphia, Proc., v. 7, p. 184.

Mytilus calvinianus Evans and Shumard, Meek and Hayden, 1860, Acad. Nat. Sci. Philadelphia, Proc., v. 12, p. 427.

Volsella calviniana (Evans and Shumard), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 73, pl. 23, fig. 7.

Evans and Shumard (1854, p. 164) described the species thus:

> Shell sub-ovate, arcuate, inflated, surface smooth, or marked only by five indistinct concentric lines of growth; umbones prominent, rounded, anterior side short; beaks nearly terminal, muscular impression small, placed near the anterior extremity; posterior side broad, extremity rounded.

Meek (1876, p. 72) added further to this description.

> Shell transversely arcuate-subovate, gibbous along the umbonal slopes, and cuneate posteriorly; surface marked only with fine concentric striae; anterior end very short; beaks very oblique, placed over the anterior margin, and somewhat compressed; hinge-margin a little straightened for near half the length of the valves, and rounding off imperceptibly into the posterior margin, which curves obliquely to the narrowly-rounded posterior basal extremity; basal margin strongly arcuate along the middle, near which the flanks are compressed and contracted below the umbonal ridge; anterior muscular impression distinct.

Discussion.--Members of this species were found at three localities; however, they are always a minor constituent of the fauna. Three of the four specimens collected conform nicely to the general outline described by Meek. The fourth specimen is more abruptly terminated posteriorly resulting in foreshortened version of the more normal individuals. In two of the specimens the posterior muscle scar is visible, though quite indistinct. It is arcuate in shape and occupies a position in the postero-dorsal part of the valve. The anterior end of the scar narrows rapidly and terminates just posterior to the hinge.

Measurements.--The specimens illustrated have the following dimensions:

UND Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9214	33.4	22.6	9.2
9215	20.7	16.1	8.4

Holotypes.—Univ. of S. Dak. Cat. Nos. 9214-9215 (figured hypotypes), 9277 (unfigured specimen).

Localities.—6-9-1, 8-0-2, and 8-1-3. Trail City (?) and Timber Lake (?) lithologies in the lower Fox Hills Formation.

Genus Cremella Brown 1827

Cremella elegantula Meek and Hayden 1861

Plate 2 Figures 1-6

Cremella elegantula Meek and Hayden, 1861, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 441.

Cremella elegantula Meek and Hayden, Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 75, pl. 28, fig. 6.

Cremella elegantula Meek and Hayden, Weller, 1907, New Jersey Geol. Survey Paleont. Ser., v. 4, p. 511, pl. 56, fig. 6.

Cremella elegantula Meek and Hayden, Gardner, 1916, Md. Geol. Survey, p. 625, pl. 36, fig. 19.

Cremella elegantula Meek and Hayden, Wade, 1926, U. S. Geol. Survey, Prof. Paper 137, p. 71.

Cremella elegantula Meek and Hayden, Shimer and Shrock, 1944, p. 413, pl. 164, figs. 20-21.

Cremella elegantula Meek and Hayden, Groot, Organist and Richards, 1954, Delaware Geol. Survey Bull., v. 3, p. 45 [fide Richards, 1958, p. 156].

Cremella elegantula Meek and Hayden, Richards, 1958, p. 156, pl. 25, fig. 10.

Meek's description of the species (1876, p. 75-76) was as follows:

> Shell nearly vertically ovate-cordate, very thin, ventricose; postero-basal and basal margins rounded; dorsal sloping abruptly behind, with a convex outline above, and rounding into the base below; anterior margin sinuous just under the beaks; moderately prominent near the middle, and rounding

into the base below; umbonal region of both valves very gibbous; beaks prominent, anterior, or subterminal, pointed and incurved, with a forward obliquity at their extremities; hinge-margin thin and apparently smooth, or only very minutely crenate; surface marked by extremely fine regular, closely-arranged, radiating striae, which appear to increase chiefly by bifurcation, and continue of uniform size on all parts of the shell; crossing these, there are less regular, more distant, small, concentric marks of growth.

Discussion.--Specimens of this species were collected at only two localities, both in the vicinity of Linton. Stratigraphically they are found less than ten feet above the Pierre-Fox Hills contact. Those specimens found at locality 6-2-9 by Dr. F. N. Holland, Jr. occurred in an argillaceous lens in a shaley matrix while the single specimen collected from locality 6-2-14 was found in a concretion. The specimen from locality 6-2-14 had shell material preserved which shows the delicate nature of the prosopon while the remainder of the specimens are molds of the interior.

Measurements.--The specimens measured are intended to represent the widest range of shape variation noted in the individuals assigned to this species.

UND. Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9216	20.4	17.9	
9217	14.3	16.0	12.3
9218	17.2	16.4	12.9
9219	15.4	16.1	10.5
9220	13.3	12.5	10.6

Repository.--Univ. of N. Dak. Nos. 9216-9220 (figured specimens), 9278 (13 unfigured specimens).

Localities.--6-2-9 and 6-2-14. Near the base of the Fox Hills Formation in Trail City (?) lithology.

Superfamily PTERIACEA

Family PTERIIDAE

Genus Pteria Scopoli 1777

Pteria linguaeformis (Evans and Shumard) 1854

Plate 1 Figures 17-20

Avicula linguaeformis Evans and Shumard, 1854, Acad. Nat. Sci. Philadelphia, Proc., v. 7, p. 163.

Pteria linguiformis (Evans and Shumard), Meek, 1864, Smithsonian check-list N. Am. Cretaceous fossils, p. 9 [fide Meek, 1876, p. 32].

Pteria linguiformis (Evans and Shumard), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 32, pl. 15, fig. 1.

Pteria linguiformis (Evans and Shumard), Whitfield, in Newton and Jenny, 1880, Geology and resources of the Black Hills of Dakota, p. 384, pl. 7, figs. 2-3 [fide Stanton, 1920, p. 24].

Pteria linguiformis (Evans and Shumard), Whiteaves, 1895, Cont. Canadian Paleontology, v. 1, p. 31 [fide Stanton, 1920, p. 24].

Pteria petrosa (Conrad), Weller, 1907, New Jersey Geol. Survey, Paleontology, v. 4., p. 429 [fide Stanton, 1920, p. 24].

Pteria linguaeformis (Evans and Shumard), Stanton, 1920, U. S. Geol. Survey, Prof. Paper 128, p. 24, pl. 3.

Pteria? linguaeformis (Evans and Shumard)?, Stephenson, 1941, U. of Texas, Pub. 4101, p. 102, pl. 12, figs. 7-8.

Pteria linguaeformis (Evans and Shumard), Shimer and Shrock, 1944, p. 391, pl. 152, fig. 6.

Pteria linguiformis (Evans and Shumard), Morgan and Petch, 1945, S. Dak. Geol. Survey, Rept. of Invest. 49, pl. 5, fig. 4, nos. 3 and 6, pl. 6, fig. 3, no. 3.

Evans and Shumard (1854, p. 163) described the species thus:

> Shell very oblique, elongated, linguaeform, moderately convex; surface smooth; cardinal line straight, about equal to the greatest width of the shell; posterior wing triangular, acute, anterior wing triangular, separated from the body of the shell, by the continuation of a shallow groove which surrounds its most gibbous portion; posterior edge sigmoid, forming an obtuse angle with the cardinal line from the anterior extremity. The mould of the shell exhibits a line of small tubercles, commencing at the point of the beak and extending in a curve to the base of the posterior muscular impression; the latter is very large and somewhat reniform.

Discussion.--This is perhaps the most widespread and abundant fossil in the Fox Hills Formation in Emmons County. Although it varies considerably in outline, it is easily recognized even when fragmentary. The shell material tends to exfoliate readily so that most specimens consist of a mold of the interior with fragments of shell material attached. Meek (1876, p. 32) misspelled the name of the species which has led to some confusion subsequently. There is considerable question as to whether P. linguaeformis is a junior synonym of P. petrosa (Conrad). Stanton (1920, p. 25) considered the problem and concluded that the type material of P. petrosa was so imperfectly preserved that it is best to say that the two species are closely related but not synonymous. Richards (1953, p. 100) considered the two synonymous but, until comparison of the types is made, the common midwestern name will be maintained.

Measurements.--The specimens illustrated have the following dimensions:

UND Cat. No.	Length (mm)	Hinge Length (mm)	Height (mm)
9221	25.3	21.0	22.3
9222	15.5	14.5	13.7
9223 left valve	24.2	24.2+	21.3
right valve	30.8	24.9+	24.7

Syntypes.--Univ. of N. Dak. Cat. Nos. 9221-9223 (figured hypotypes), 9279-9288 (unfigured specimens).

Localities.--3-1-3, 3-9-3, 5-1-2, 5-8-7, 5-8-2, and 6-2-14. The lower Fox Hills Formation in both Trail City (?) and Timber Lake (?) lithologies.

Pteria (Oxytoma) nebrascana (Evans and Shumard) 1857

Plate 1 Figure 23

Avicula nebrascana Evans and Shumard, 1857, St. Louis Acad. Sci., Trans., v. 1, p. 38.

Pteria nebrascana (Evans and Shumard), Meek, 1864, Smithsonian check-list Cretaceous fossils N. Am., p. 9 [fide Meek, 1876, p. 34].

Pteria (Oxytoma) nebrascana (Evans and Shumard), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 34, pl. 29, fig. 11.

Pteria (Oxytoma) nebrascana (Evans and Shumard), Shimer and Shrock, 1944, p. 391, pl. 152, fig. 5.

Meek (1876, p. 34) defined the species thus:

> Shell small, rather compressed, obliquely oval exclusive of the wings, distinctly inequivalve, the left valve being more convex, with its ventral margin and posterior wing projecting apparently beyond those of the other; hinge generally, if not

always, less than the length of the valves. Left valve with anterior wing small, triangular, compressed, generally about rectangular or sometimes a little more obtusely angular, not defined by a marginal sinus, and apparently never quite as long as the margin below; posterior margin, decidedly longer than the other, but not as long as the posterior margin, compressed, acutely angular at the extremity, and defined by a rather deep, broadly-rounded sinus; posterior basal margin rather narrowly rounded; basal margin forming a broad semiovate curve, being more prominent posteriorly, and rounding up obliquely anteriorly into the regularly-rounded front; beak moderately oblique, scarcely rising above the hinge-margin, and placed about half-way between the middle and the anterior end of the same; surface ornamented by numerous small, threadlike, radiating lines, less at and near the free margins, than the breadth of the spaces between, in some of which latter a smaller line is often intercalated; very minute concentric striae are also to be seen on well-preserved specimens by the aid of a magnifier. Right valve with a broad compressed alation behind, that seems not to extend into a defined wing; posterior margin truncated and nearly or quite straight; anterior wing very small, and defined by the usual deep, sharply-cut byssal sinus of the subgenus Oxytoma; surface appearing nearly smooth, but when examined under a good magnifier, showing obscure traces of small, radiating costae, crossed by extremely fine, regular, crowded, concentric striae; beak more compressed than that of the other valve, and a little less prominent.

Discussion.--Although this is a widespread and common species, it is seldom well preserved. It commonly occurs as molds of the interior in ferruginous concretions from Timber Lake (?) lithology; their extraction is nearly impossible. The general outline of P. nebrascana is far less variable than that of P. linguaeformis and is distinguished from it by the radial striae and less oblique outline.

Measurements.--The figured specimen has the following dimensions:

UND Cat. No.	Length (mm)	Hinge Length (mm)	Height (mm)
9224	14.0	11.6	11.1

Hypotype.--Univ. of N. Dak. Cat. No. 9224 (figured hypotype) 9289-9293 (unfigured specimens).

Localities.--3-1-3, 6-1-2, 6-2-14, and 7-3-7. Timber Lake (?) and Trail City (?) lithologies in the lower Fox Hills Formation.

Family PECTINIDAE

Genus Gervillia Defrance 1820

Gervillia subtortuosa Meek and Hayden 1856

Plate 2 Figures 31-34

Gervillia subtortuosa Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 276.

Gervillia subtortuosa Meek and Hayden, Meek, 1876, U. S. Geol. Survey Terr. v. 9, p. 65, pl. 16, fig. 7.

Gervillia subtortuosa Meek and Hayden, Shimer and Shrock, 1944, p. 389, pl. 150, fig. 20.

Gervillia subtortuosa Meek and Hayden, Fisher, 1952, N. Dak. Geol. Survey, Bull. 26, p. 16, pl. 6, fig. 4.

Meek (1876, p. 65) gave the following description of the species:

> Shell thick, obliquely sublanceolate, tortuous, and laterally curved; right valve distinctly convex, left nearly flat; posterior side elongate, narrow, widest at its junction with the posterior extremity of the hinge; cardinal border straight, rather long, and forming an angle of about 20° with the longitudinal axis of the shell; cardinal area rather broad; cartilage-pits about six, nearly as wide as the intervals between; hinge-teeth nearly obsolete; scar of the adductor and posterior pedal muscles large, obliquely elongate, and placed nearly centrally above the middle of each valve; anterior scar small, very deep, and located close under the anterior extremity of the hinge. Surface unknown.

Discussion.--Meek included two species, Gervillia subtortuosa and G. recta in the genus Gervillia as represented in the Midcontinent. They are distinguished on size, shell thickness, convexity and general outline. The individuals of the genus collected from the Limenavis-Gervillia

layer in Seaman Park conform to the description of Q. subcrassus in all respects except convexity. The specimens in the present study possess a nearly flat right valve and a convex left valve, characteristic of Q. regia. However, the entire configuration of the shell is so irregular that it is probable that convexity as well as the other factors of shell shape are a function of environmental crowding. The specimens show no signs of deformation. This being the case, characters of the hinge and musculature are probably more accurate criteria of species recognition than shape. Meek's material was poorly preserved and no description of the exterior of the shell was possible. Shell exterior is preserved in specimen 9226 of the present study. The surface is generally smooth and is traversed only by slightly irregular, concentric growth lines, more crowded anterio-ventrally than posteriorly which indicates that most of the growth of the animal tended toward posterior elongation.

Measurements.--None of the elements of the shells in the specimens illustrated is complete so that total measurements are impossible. As an indication of general size, however, specimen 9226 has a segment of hinge preserved that is approximately 53 mm long, while the preserved hinge on specimen 9227 is 47.5 mm long. If an extrapolation of shell outline is made similar to that of Meek (1876, pl. 16) total length would be in excess of 100 mm.

Repository.--Univ. of N. Dak. Cat. Nos. 9226 and 9227 (figured).

Locality.--6-2-14. Trail City (?) lithology in the lower Fox Hills Formation.

Superfamily OSTREACEA

Family OSTREIDAE

Genus Ostrea Linnaeus 1758

Ostrea sp.

Plate 1 Figure 13

Meek (1876, p. 10) gives the following generic description:

> Shell irregular, laminated, subaxcreous, attached by the left or under valve; surface sometimes nearly smooth, but more frequently provided with more or less prominent imbricating laminae and smaller marks of growth, or plicated, and very rarely armed with projecting root-like processes. Upper valve flat or concave, and often plane; lower valve convex, and having a prominent beak. Ligament occupying a medial longitudinal furrow, extending to the beaks in a kind of cardinal area marked by transverse striae. Muscular impression subcentral.

Discussion.--Oysters are apparently very rare in the lower Fox Hills of Emmons County. Two specimens were discovered at locality S-1-3 in a ferruginous concretion. Both were small but had the same general outline as that of the larger O. glabra of the upper Fox Hills. As the hinge and muscle impression on both specimens is obscured I can only refer them to the genus Ostrea.

Measurements.--The specimens illustrated are so irregular and incomplete that only the length of the long axis was measured. Specimen 9225A is 25.0 mm. long and specimen 9225B is 23.9 mm. long.

Repository.--Univ. of N. Dak. Cat. No. 9225.

Locality.--S-1-3. Timber Lake (?) lithology in the lower Fox Hills Formation.

Order EULAMELLIBRANCHIA

Superfamily LUCINACEA

Family TANCREDIDAE

Genus Tancredia Lycett 1850

Tancredia americana (Meek and Hayden) 1856

Plate 2 Figures 23-30

Astarnella americana Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 274.

Astarnella americana Meek and Hayden, Meek and Hayden, 1860, Acad. Nat. Sci. Philadelphia, Proc., v. 12, p. 133 [fide Meek, 1876, p. 142].

Tancredia americana (Meek and Hayden), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 142, pl. 38, fig. 1.

Tancredia americana (Meek and Hayden), Shimer and Shrock, 1944, p. 423, pl. 168, fig. 20.

Meek (1876, p. 142-143) gave the following description of the species:

> Shell thick, ovate-subtrigonal, moderately gibbous in the umbonal region; posterior end broader than the other, obliquely truncated and gaping above, rather narrowly rounded or subangular below; anterior half narrow, compressed and presenting a more or less restrated aspect, subangular, or very narrowly rounded at the extremity; basal margin forming a broad semicurve, being more prominent posteriorly and in the middle, than toward the front; dorsal border elevated in the region of the beaks, from which it slopes forward with a slightly concave outline, while it is convex just behind the beaks, thence declining abruptly; beaks small, rather approximate, located a little behind the middle of the shell. Surface marked by fine lines of growth, and sometimes a few, faint, irregular, stronger, concentric furrows.

Discussion.--The specimens found in this study and referred to this species fit the description above. They do not, however, have the same appearance as the specimen illustrated by Meek (1876, pl. 38, fig. 1) or Shimer and Shrock (1944, pl. 168, fig. 20), who repeated Meek's figure.

None of the figures shows the posterior gape as well developed as it is described or as it is seen on the specimen here discussed. To my knowledge the species has not been illustrated elsewhere.

This is one of only two species of pelecypod that was found free in the Timber Lake (?) matrix. At no time was a complete, unbroken specimen found; the figured specimen is the only complete specimen found in Dewey County. It was pieced together from several fragments.

Measurements.--The figured specimen, left valve only, has the following measurements:

USD Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9228	49.0	35.0	12.9

Structure.--Univ. of S. Dak. Cat. No. 9228.

Locality.--6-3-6. Timber Lake (?) lithology in the lower Fox Hills Formation.

Superfamily CARDIACEA

Family CARDIIDAE

Genus Protocardia Meyrich 1895

Protocardia (Leptocardia) subquadrata (Evans and Shumard) 1857

Plate 2 Figures 7-10

Cardium subquadratum Evans and Shumard 1857, Acad. Sci. St. Louis, Trans., v. 1, p. 39.

Cardium (Protocardia?) subquadratum Evans and Shumard, Meek, 1864, Smithsonian check-list Cretaceous fossils, p. 13.

Protocardia (Leptocardia) subquadrata (Evans and Shumard), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 175, pl. 29, fig. 8.

Protocardia subquadrata (Evans and Shumard), Shimer and Shrock, 1944, p. 425, pl. 169, figs. 14-15.

Protocardia subquadrata (Evans and Shumard), Fisher, 1952, N. Dak. Geol. Survey, Bull. 26, p. 16, pl. 5, fig. 3.

Evans and Shumard (1857, p. 39) gave the following description of the species:

> Shell small, subquadrate, length greater than the height, gibbous; anterior margin rounded, posterior margin truncated, very slightly arched; umbones prominent, large, obtusely subangulated; beaks nearly medial, rather obtuse, and extending but little beyond the cardinal margin; substance of the shell thin; surface with fine concentric striae of growth, waved and dentate posteriorly, where they are crossed by obscure longitudinal ribs.

Discussion.--Meek (1876, p. 175-176) described two species of Protocardia, P. subquadrata and P. rara, which occur in the Fox Hills. They are distinguished on external shell characteristics including lustre, thickness and costation. As all of the specimens in the present study are molds of the interior, only the characteristics of the costae are applicable. The vast majority of specimens studied are more or less heavily costate on the posterior half of the animal. This is reflected in a crenulate postero-ventral margin which makes them readily distinguishable from Limopsis parvula another small pelecypod in the fauna. The specimens collected were subjected to biometric analysis to determine any possible shape groupings. None were noted.

Measurements.--The figured specimens have the following dimensions:

USNM Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9829	13.3	12.1	9.0
9830	16.5	14.6	9.7

Specimens.--Univ. of N. Dak. Cat. Nos. 9229 and 9230 (figured specimens), 9294-9295 (measured specimens), 9296-9303 (unfigured specimens).

Localities.--8-9-4, 7-3-7, 8-0-74, 6-2-14, 8-0-7, 8-0-2, and 8-1-3. Timber Lake (?) and Trail City (?) lithologies of the lower Fox Hills Formation.

Superfamily VENERACEA

Family VENERIDAE

Genus Trigonecallista Conrad 1930

Trigonecallista dowayi (Meek and Hayden) 1856

Plate 1 Figures 21-22

Cytherea dowayi Meek and Hayden, 1856, Proceed. Acad. Nat. Sci. Philadelphia, v. 8 p. 83.

Meretrix dowayi (Meek and Hayden), Meek and Hayden, 1860, Acad. Nat. Sci. Philadelphia, Proc., v. 12, p. 135 [Cite Meek, 1876, p. 182] .

Callista dowayi (Meek and Hayden), Meek and Hayden, 1861, Acad. Nat. Sci. Philadelphia, Proc., v. 13, p. 443.

Dione dowayi (Meek and Hayden), Meek, 1864, Smithsonian check-list N. Am. Cretaceous fossils, p. 13.

Callista (Dosiniopsis?) dowayi (Meek and Hayden), Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 182, pl. 17, fig.

Callista (Dosiniopsis) dowayi (Meek and Hayden), Stanton, 1920, U. S. Geol. Survey, Prof. Paper 128, p. 31, pl. 5, figs. 11-12.

Trigonecallista dowayi (Meek and Hayden), Shimer and Shrock, 1944, p. 427 pl. 170, figs. 6-7

...k, (1876, p. 182) gave the following description of the species:

> Shell subcircular, or very broad-suboval, rather thin, moderately convex; lateral margins rounded, the posterior side being a little broader than the other; dorsum sloping gradually with a slightly convex outline behind the beaks, and concave and more abrupt in front; base semi-oval; escutcheon lanceolate; beaks not very prominent, somewhat gibbous, incurved, nearly touching, and placed a little in advance of the middle; muscular impressions shallow, anterior one narrow-oval, posterior one broad-ovale; sinus of the pallial impression broad, triangular, its sides converging at an angle of about 35°, extending obliquely forward and upward nearly to the middle of the valves, very slightly obtuse at the immediate extremity. Surface marked by fine, regular, prominent lines of growth.

Discussion.—Only one specimen of this species was found. Since it is poorly preserved the only characteristics that could be used for identification were general shape, shell thickness, and prosopon. In these characteristics, it conforms strictly to the above description. The Cretaceous forms of the genus (or subgenus) Dosiniopsis have been referred to the genus Trigonocallista Hennes. They have a more trigonal outline, slightly different dentition, and a more pronounced pallial sinus than the Cenozoic forms that are retained in the genus Dosiniopsis. As no internal material is available, only outline can be used in making the assignment to Trigonocallista.

Measurements.—The figured specimen has the following dimensions:

UND Cat. No.	Length (mm)	Height (mm)
9231	19.2	16.9

Hypotype.—Univ. of N. Dak. Cat. No. 9231.

Locality.—8-0-7A. Trail City (?) lithology in the lower part of the Fox Hills Formation.

Superfamily MACTRACEA

Family MACTRIDAE

Genus Cymbophora Gabb 1868

Cymbophora warrenana (Meek and Hayden) 1856

Plate 2 Figures 35-37

Mactra warrenana Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 271.

Mactra (Cymbophora?) warrenana Meek and Hayden, Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 205, pl. 30, fig. 7.

Cymbophora warrenana (Meek and Hayden), Shimer and Shrock, 1944, p. 431, pl. 171, Figs. 21-22.

Cymbophora warrenana (Meek and Hayden), Fisher, N. Dak. Geol. Survey, 1952, Bull. 16, pl. 6, figs. 1-3.

Meek gave the following description of the species:

> Shell rather thin, subtrigonal, moderately gibbous; cardinal border sloping from the beaks in front and rear, at an angle of about 110°; posterior slope slightly more convex than the anterior; extremities subangular, the anal end being a little more obtuse than the other; base forming a broad, regular curve; beaks moderately elevated, incurved, and approximate, rather gibbous and nearly central; lunule lance-oval, large, faintly impressed at the margins, and extending from the beaks nearly or quite to the anterior extremity; escutcheon having the same form, but still larger, and bounded on each side by a faint ridge, which passes from the beaks to the lower part of each side by a faint ridge, which passes from the beaks to the lower part of the anal border, to the outline of which it imparts a very slight angularity. Surface marked by faint, irregular lines of growth, which become more regular and distinct on the lunule and escutcheon. Muscular impressions not very deep, the anterior one narrow-ovate, pointed above, and a little sinuate, the other ovate; sinus of the pallial impression moderate, and rounded at the extremity.

Discussion.--Specimens of this species were found at seven localities so that they are one of the dominant pelecypods in the Fox Hills

fauna. Preservation varied from fair in the Trail City (?) lithology to poor in Timber Lake (?) lithology. In most cases, only molds of the interior were preserved in the Timber Lake (?) lithology.

In general, the specimens showed very little variation in shape, but shell thickness was less constant. As described above, the shell was thin in all cases. It varied from a fraction of a millimeter thick to one millimeter. A complete series of intergrades are also present which indicates that shell thickness should not be used taxonomically except to say that it is generally thin.

Measurements.--The figured specimens have the following dimensions:

UND Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9232	37.3	29.5	Broken
9233	34.7	29.0	20.2
9234	36.1	29.1	19.7

Specimens.--Univ. of N. Dak. Cat. Nos. 9232 (mold of interior), 9233 (mold of interior), (Both valves), 9235-9243 (51 unfigured specimens).

Localities.--8-9-1, 8-9-4, 8-10-2, 8-10-7, 8-11-2, 8-11-3, and 6-9-1. Trail City (?) and Timber Lake (?) lithologies in the lower Fox Hills Formation.

Superfamily TELLINACEA

Family TELLINIDAE

Genus Tellina Linnaeus 1758

Tellina subtilis Meek and Hayden 1856

Plate 2 Figures 15-17

Tellina subtilis Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 82.

Tellina (Peronaea?) subtilis Meek and Hayden, Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 197, pl. 30, fig. 1.

Tellina subtilis Meek and Hayden, Fisher, 1952, N. Dak. Geol. Survey, Bull. 16, pl. 5, fig. 2.

Meek (1876, p. 197) described the species thus:

> Shell subelliptical, compressed, thin, a little curved laterally so as to make the left valve slightly more convex than the right; anterior side somewhat broader than the other, but rather narrowly rounded; base nearly straight, or forming a broad semi-elliptical curve; posterior side very obliquely subtruncate above, subangular at the extremity below, and with a moderately defined umbonal ridge in the right valve; dorsum declining almost equally before and behind, from the beaks, which are small, compressed, and generally located slightly behind the middle; surface ornamented by fine, regular, equidistant, concentric striae; anterior muscular impression narrow-ovate, posterior broader; pallial line distinct, and provided with a nearly horizontal sinus, which extends beyond the middle of the valves, and is rounded at the extremity.

Discussion.--Several specimens of this common species were found; however, none were well preserved. The extreme thinness of the shell results in rapid destruction or crushing, of the shell material at most localities. Pallial markings and muscle impressions are indistinct, and cannot be seen at all in most specimens. With one exception, the fossils ranged in size from 13 mm to 24 mm long. This is in agreement with

the size reported by Meek (1876, p. 196). A single specimen has a length of 34.3 mm. This specimen, a mold of the interior, conforms to the description of the species except that it is somewhat more inflated and has slightly more prominent beak. Although this might be enough difference to consider it a new species, it might simply be a factor of age. Meek questionably assigned T. solitula to the subgenus Pterotrigonia on the basis of shell outline. Pterotrigonia is distinguished by having a more elliptical shell, shorter, rounded anterior border, subacuminate posterior, and obsolete lateral teeth. Meek's material as well as that of the present study did not show characters of the hinge so that subgeneric assignment was questionable. In the large specimen mentioned above, the elements of the hinge are preserved on the mold and weak lateral teeth are present. The significance of this cannot be known unti better preserved material similar to the large specimen is collected.

Measurements.--The figured specimen has the following dimensions:

UND Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9284	23.0	14.8	5.1

Occurrence.--Univ. of N. Dak. Cat. Nos. 9284 (mold of interior with some shell material on right valve), 9245-9253 (24 unfigured specimens).

Localities.--3-1-2, 3-1-3, 3-0-2, 3-9-4, and 7-3-7. Trail City (?) and Timber Lake (?) lithology in the lower part of the Fox Hills Formation.

Tellina cheyennensis Meek and Hayden 1856

Plate 2 Figures 11-14

Tellina? cheyenninsis Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 82.

Tellina (Arcomella?) cheyennensis Meek and Hayden, Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 607, pl. 17, fig. 16.

Meek (1876, p. 607) described the species as follows:

> Shell transversely ovate, compressed, very thin; anterior margin rounded; posterior margin faintly subtruncated, or rounding from above to the very narrowly rounded or subangular posterior basal extremity; basal outline semiovate; beaks rather prominent, placed a little in advance of the middle; umbonal slopes prominently rounded from the umbones to the posterior basal extremity; surface ornamented with fine lines of growth, and somewhat stronger little ridges and furrows near the lower margins.

Discussion.--Meek (1876, p. 607) was hesitant about placing this species in the genus Tellina because characters of the hinge were not available on his material. Although this is also the case with the specimen found in this study, I have no doubt that the generic assignment is correct. There is, however, some question on the species assignment in that the above description does not perfectly describe the external shape. No subsequent descriptions have been published. In profile, the present specimen conforms to the description; but, if viewed in ventral position, it is quite distinctive. The line of juncture of the two valves, rather than being straight, is a very gentle sigmoid curve. That portion of the left valve which is anterior to the beak is slightly concave while the same area on the right valve is the area of greatest anterior-posterior convexity. There is no sign of deformation of the specimen. The specimen illustrated by Meek (1876, pl. 17, fig. 16) shows

the right valve with the rest of the fossil still imbedded in the matrix. If this was the only specimen available to him it is probable that this curvature would not have been apparent.

Measurements.--The specimen illustrated has the following dimensions:

UND Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9254	23.4	18.7	17.4

Structure.--Univ. of N. Dak. Cat. No. 9254.

Locality.--3-9-4. This specimen was found in Trail City (?) lithology in the lower Fox Hills Formation.

Tellina sp.

Plate 2 Figures 18-19

Discussion.--One specimen of pelecypod, definitely of the genus Tellina but unassignable to species, was found in an isolated outcrop in Timber Lake (?) lithology. In most respects it resembles T. scitula; however, the beaks are located anterior of the midline of the shell. The shell is moderately prosocline. Preservation of the specimen is very poor so that details of prosopon are limited to faint suggestions of growth lines.

Measurements.--The specimen illustrated has the following dimensions:

UND Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9255	23.3	16.2	5.6

Structure.--Univ. of N. Dak. Cat. No. 9255.

Locality.--7-4-2. Timber Lake (?) lithology in the lower Fox Hills Formation.

Superfamily MYACEA

Family CORBULIDAE

Genus Corbula Bruguiere 1792

Corbula inornata Meek and Hayden 1856

Plate 2 Figures 20-25

Corbula inornata Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 52.

Corbula inornata Meek and Hayden, Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 245, pl. 30, fig. 4.

Meek described the species thus:

> Shell small, oval-subtrigonal, very gibbous, distinctly inequivalve; anterior side of right or larger valve irregularly rounded or obliquely truncated above, and subangular below; anterior side of smaller valve more narrowly rounded; posterior side of both obliquely truncated above, and more or less distinctly angular below; basal margins of each nearly straight, or but slightly convex in outline, a little warped laterally, and not crenulated within; beaks subcentral, that of right valve considerably elevated above the other, flattened or depressed on top, incurved, and sometimes truncated at the point by pressure against that of the other valve. Surface nearly smooth, or only marked by very obscure lines of growth, and a few indistinct, irregular undulations.

Discussion.--Seven specimens of this species were collected at three localities. All of them conform to the above description except that weathering of the shell material has made the growth lines more distinct than those described by Meek.

Measurements.--The figured specimens have the following dimensions:

USNM Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9256	5.7	5.4	4.3
9257	6.4	6.0	4.5

Syntypes.--Univ. of N. Dak. Cat. No. 9256 (mold of the interior), 9257 (both valves with shell material), 9259-9260 (5 unfigured specimens).

Superfamily ANATINACEA

Family PHOLADOMYIDAE

Genus Goniomya Agassiz 1839

Goniomya americana Meek and Hayden 1856

Plate 2 Figures 26-27

Goniomya americana Meek and Hayden, 1856, Acad. Nat. Sci. Philadelphia, Proc., v. 8, p. 81.

Pholadomya americana (Meek and Hayden), Gabb, 1861, Synop. Mollusca Cretaceous fm., p. 164.

Goniomya americana Meek and Hayden, Meek, 1876, U. S. Geol. Survey Terr., v. 9, p. 221, pl. 30, fig. 12.

Goniomya americana Meek and Hayden, Morgan and Petsch, 1945, S. Dak. Geol. Survey, Rept. of Invest. 59, pl. 5, fig. 4, no. 2.

Meek (1876, p. 221) described the species thus:

> . . . the curve of its lines of growth indicate a transversely oblong or narrow-oval outline, with a narrowly-round anterior, and a subtruncated posterior margin. Laterally, the valves appear to be rather compressed. The beaks are small, depressed, and placed in advance of the middle. The costae are moderately distinct, though not very prominent, and at the deflection along the flanks form angles of from 20° to 30°. Those near the two extremities, although converging and passing down parallel to the others, do not meet to form angles along the flanks before they intersect the base. The surface shows obscure concentric markings of growth, which are crossed by the usual regular, equidistant, radiating rows of extremely minute granules, which appear, as seen under a magnifier, like minute drops of amber. The substance of the shell is very thin.

Discussion.--The chevron-like prosopon of Goniomya makes this one of the most easily identified paleocypods in the Fox Hills fauna. This species is rare in Emmons County; only one broken specimen was found. In the type area of the Fox Hills Formation they are more common (Waage, 1962, oral communication). On the basis of the specimen at hand, little can be added to Meek's description except that the beak is located in the anterior quarter of the shell. The specimen illustrated by Morgan and Petsch (1945, pl. 5, fig. 4, no. 2) is nearly rectilinear in outline.

Measurements.--The figured specimen has the following dimensions:

UND Cat. No.	Length (mm)	Height (mm)	Thickness (mm)
9304	45.4 (broken)	27.9	12.4

Syntypes.--Univ. of N. Dak. Cat. No. 9304.

Locality.--8-1-2. The only specimen found during this study was collected in Trail City (?) lithology in the lower Fox Hills Formation.

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Plate 1

PLATE I

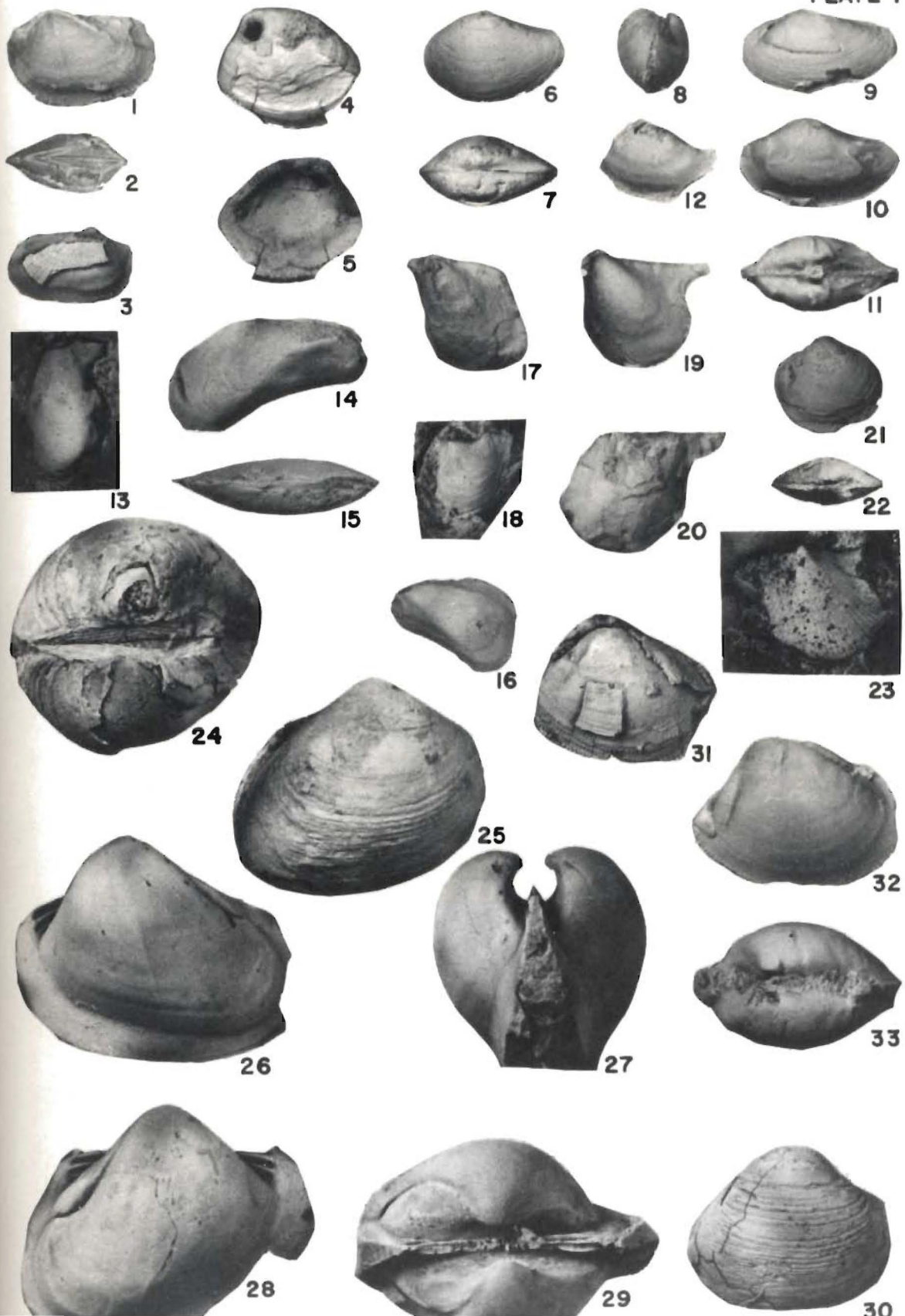
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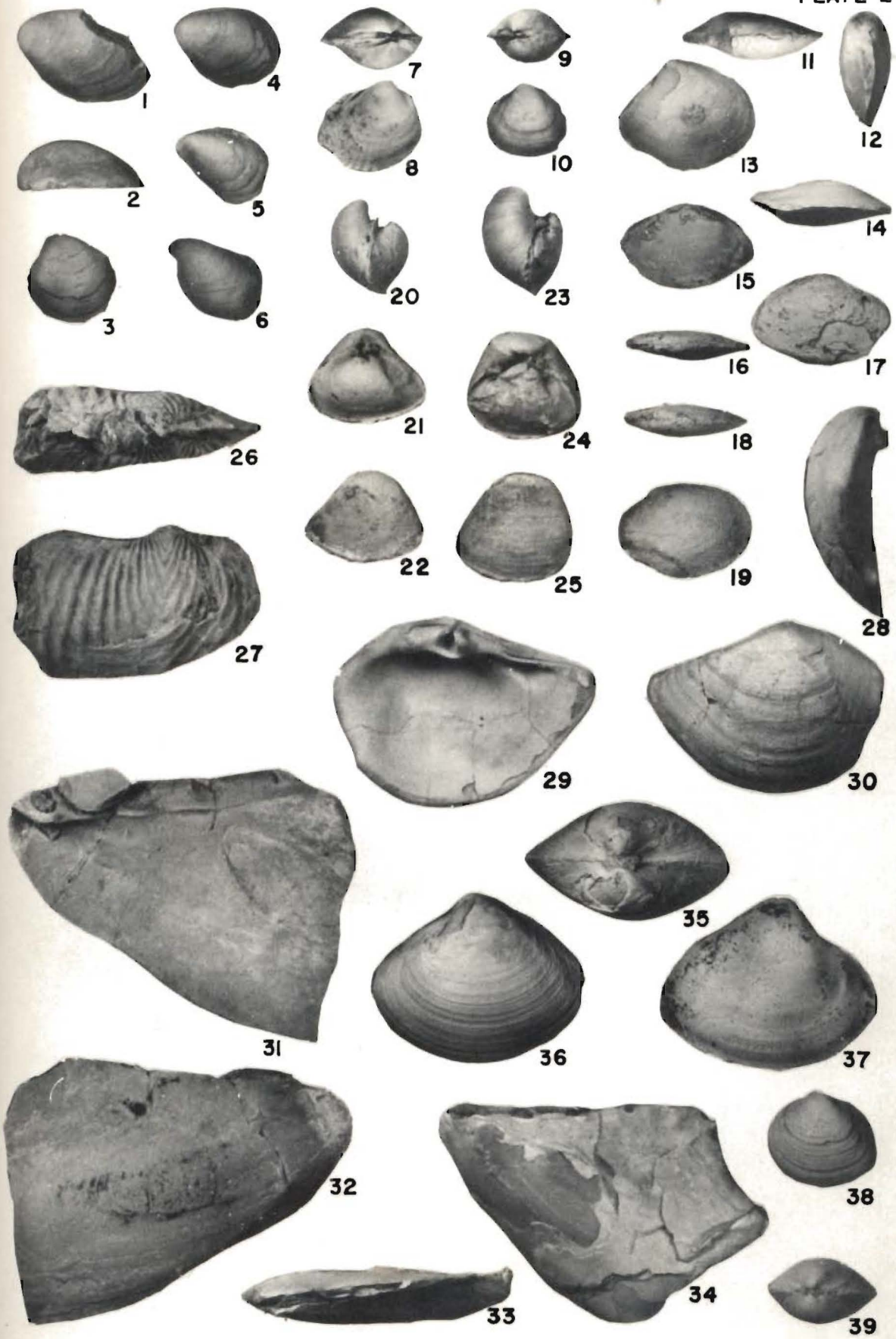
Plate 2

PLATE 2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